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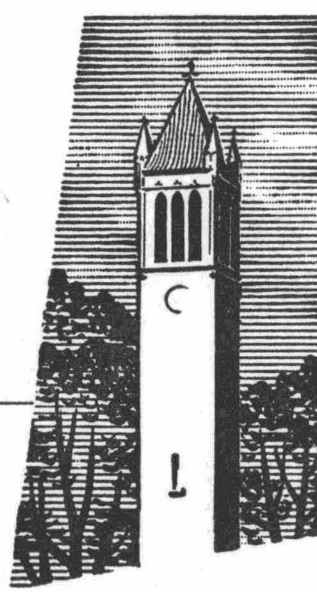
BITUMINOUS MIXES PREPARED WITH UNGRADED LOCAL AGGREGATES

by
L. H. Csanyi

IOWA ENGINEERING EXPERIMENT STATION



Iowa State University
Ames, Iowa

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INTRODUCTION

Granular materials suitable under present construction practices for building all-weather roads are not uniformly distributed throughout the state of Iowa. For this reason the Iowa Highway Research Board has sponsored an intensive research program for the purpose of developing new and effective methods for making use of whatever materials are locally available.

This bulletin is a report on the development of bituminous paving mixtures containing various local materials and asphaltic binders. The laboratory investigations described in this bulletin were performed as part of Iowa Highway Research Board project HR-20, "Treating Loess, Fine Sands, and Limestone Dusts With Liquid Binders". This project was awarded to the Iowa Engineering Experiment Station of Iowa State University in 1952, and continued to June, 1958.

When the laboratory work had progressed to the proper point, the Research Board cooperated with several counties in building full scale experimental roads using the techniques developed in the laboratory. This report also includes a description of these experimental construction projects.

Approach to the Problem

The methods now used in designing and preparing bituminous paving mixtures in the United States are not suited to much of the local materials available in Iowa for the construction of bituminous roads. Some modification of these practices, or even an entirely new concept of design or mixing, or both were needed if these plentiful materials are to be used in bituminous pavements.

To toughen and strengthen the binder is one solution already used in Germany. The product produced by this method is called Gussasphalt[4, 28]. A large quantity of mineral dust can be incorporated into the bituminous binder in colloidal suspension, resulting in the hardening and toughening of the binder. Natural Trinidad asphalt, although the asphalt itself is very soft, contains much dust, and as a binder is very tough. Large quantities of loess or any other fine mineral matter can be incorporated by the Gussasphalt method into a soft asphalt thus producing a tough binder to give strength and density. But the method is much too cumbersome and time-consuming for American production demands; and it requires mixing at over 410°F, which is contrary to American practices.

Another solution was the development of a method for coating every particle of mineral dust with a thin film of binder. A mastic of mineral dust and bituminous binder could then be produced. A mastic with body, strength, and cementing properties could be used in cementing ungraded sands, gravels, and coarse aggregates together into a bituminous pavement (figure 1). The strength of this mastic, increased by the interlock of the ungraded aggregate particles, would control the stability of the mix. If the strength of the mastic, or a sand and mastic mortar were sufficient, coarse aggregate particles need not interlock and could be used mainly to provide bulk to the mixture.

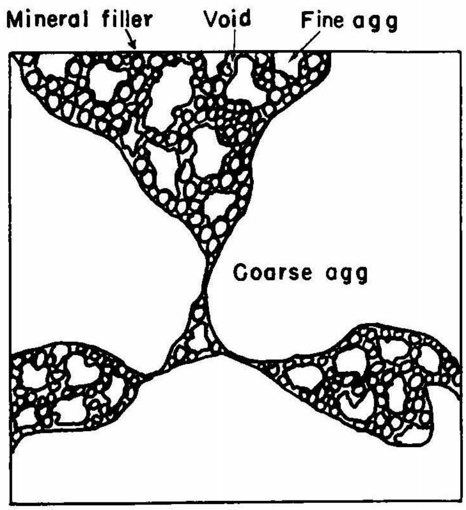

Fig. 1. Cross section of mat designed by mastic principle.

Preliminary Investigations

Some preliminary studies were needed before the major research work could be undertaken. Among these were the determination

(1) of the manner in which binder films are formed on aggregates;

(2) of the thickness of bituminous binder films on aggregates and of the effect of variations of film thickness on bituminous mixes;

(3) of methods of producing thin films of bituminous or other binders on aggregates; and

(4) of procedures for producing various mineral dusts.

The generally accepted method of designing a bituminous paving mixture is to blend suitable coarse and fine aggregates with a small quantity of mineral dust or filler and to add enough bituminous binder to coat all aggregate particles and to fill a certain portion of the voids in the aggregates. When tested, the mixture must prove to be dense, stable, and durable.

Density in a compacted paving mixture is attained mainly by blending the graded aggregates, including the mineral dust, by using enough binder to fill void spaces, and by adequate compaction. Density may be increased by using more mineral dust as a void filler. This procedure, however, is not desirable. Conventional mixing methods cannot coat dust particles with binder uniformly, and consequently the durability of such a mixture would probably be lessened.

The soundness and hardness of the aggregates and the interlock of the aggregate particles determine the stability of the compacted mixture. The bituminous binder acts primarily to hold the aggregate particles in place. Excessive binder, as thick films which coat aggregate particles or overfill the voids, acts to reduce friction between aggregate particles and lower stability.

Durability of a mixture in a pavement depends on such details as the toughness of the aggregates, the affinity between the aggregates and the binder, the weathering and aging characteristics of the binder, the basic design of the mixture, and the manner of mixing and laying the mixture.

Most of the aggregates available locally throughout Iowa fail to meet the traditional requirements for hardness, toughness, and durability of materials suitable for conventional bituminous paving mixtures. This, however, does not mean that these aggregates cannot be used with different mixing methods.

Soft limestones, although properly graded, do not meet the usual requirements of strength and toughness. If the strength needed in a mix could be transferred to another aggregate, the soft limestones could be used, as in stone-filled sheet asphalts, to give bulk to the mix.

Natural sands, which have the strength, fail to meet gradation requirements. To attain the required density the voids in ungraded sands or gravels could be filled with either mineral dust or binder or with both. Filling of voids with binder alone would reduce stability. Use of large quantities of a mineral dust is not practical because the usual mixing cannot coat the individual particles of the dust, and the dust tends to ball up and affect the durability adversely. If individual dust particles are coated with thin films of binder, they could probably be used with ungraded sand in suitable mixes.

If loess and clayey soils could be pulverized economically, they could be used as mineral fillers, and could be used with blends of ungraded sands and aggregates to make suitable paving mixes for lightly traveled roads.

Factors Affecting the Formation of Films on Mineral Aggregates

The factors affecting the formation of bituminous films on mineral aggregates are many, varied, and involve complicated physical and surface chemistry. Viscosity, surface tension, and internal cohesion of a bituminous binder are probably most important in the formation of thin films. Generally these factors are interrelated. When the viscosity increases the others increase, and as the viscosity decreases the others decrease. Because the viscosity of a bituminous binder is related to temperature, the temperature of both the binder and the aggregate are significant in forming a thin film. A binder with a low viscosity will flow and spread rapidly over the surface of a hot aggregate and form a comparatively thin film. The same binder used with a cold aggregate has increased viscosity, its spread over the aggregate is retarded, and a thicker film results. When asphalt cements or heavy cut-backs, which must be heated to the desired viscosity, are used, this behavior becomes of special importance. Measurements of the viscosity and the surface tension of asphalt cements indicate that regardless of penetration they have about the same surface tension and viscosity when heated to 325°F or slightly higher (figures 2 and 3). Heating of a binder or aggregate to more than 325°F is useless and may be harmful, and temperatures much below 325°F may retard the formation of thin films. Emulsified asphalts and light

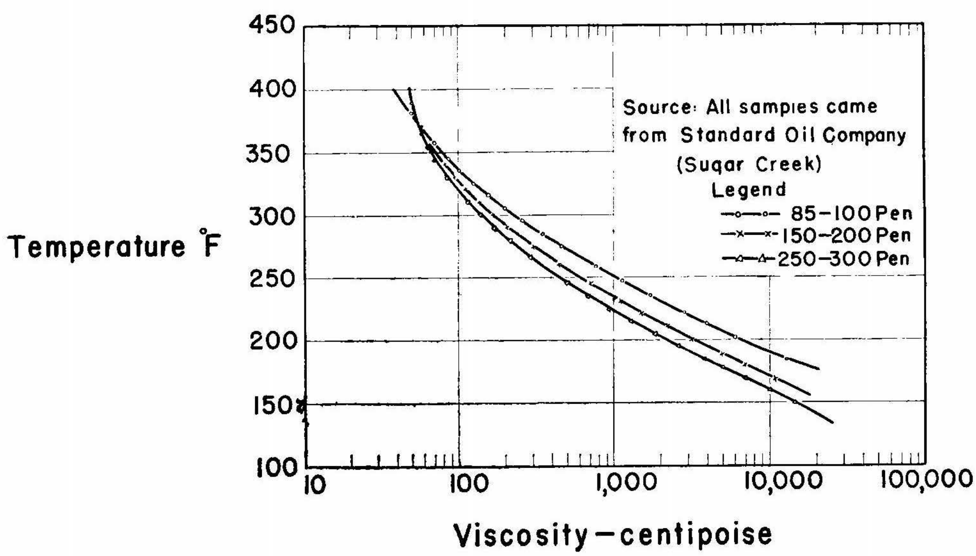

Fig. 2. Viscosity-temperature of asphalts.

cut-back asphalts, with comparatively low viscosities and not so susceptible to temperature, form a thin film at lower temperatures.

The thickness of films is also affected by the quantity of binder. At high temperatures the amount of binder is of little importance because the thickness of the film is controlled by other forces. As the mixture cools, however, excess binder causes the film to thicken quickly. For thin films the quantity of binder in a mix should be adjusted to high temperatures rather than to low.

Aggregates of rough surface texture sometimes tend to acquire thicker films than smooth surfaced aggregates. The crevices of the rough surface apparently fill up as the binder cools and films of varied thickness develop. Thinner films seem to form on aggregates when the binder is more widely and uniformly distributed into the mixture during mixing[6]. The interfacial tension between the binder and the aggregate and the

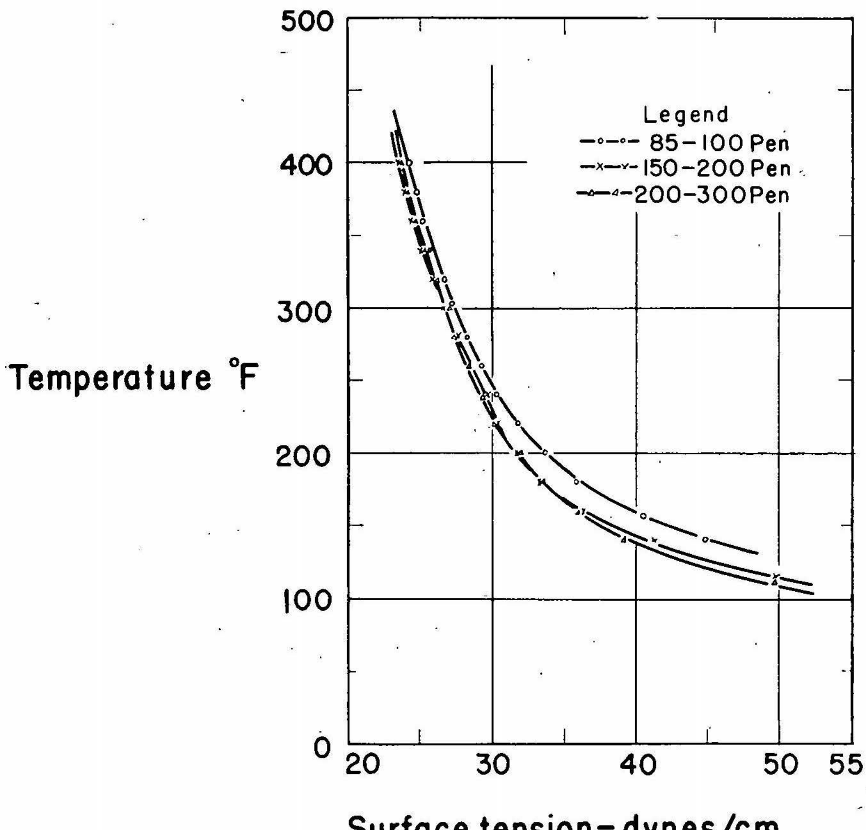

Fig. 3. Surface tension-temperature of asphalts.

surface tension of the binder will also cause thick films to form. Thinner films seem to have greater adhesion than thicker films.

The temperature inside the mixer, the mixing action, time of mixing, quantity of material in the mixer, and mixing speed also affect the thickness of the binder film on an aggregate particle.

Measurement of the Thickness of Bituminous Films on Aggregates. The average film thickness is determined by calculations from the average surface area of the aggregate and the quantity of binder. Average film thickness in bituminous hot mixes seems to vary between 10 and 25 microns. Since no method of measuring film thickness on an aggregate could be found, a method was developed.

In fact, three methods of measurement were devised; one for coarse aggregates, one for fine aggregates, and one for dusts passing the No. 100 sieve. The methods are satisfactory for approximations of film thicknesses, but they are not completely accurate because the thickness of the film on an individual particle varies, and thickness of films on different particles may also vary.

To measure film thickness on coarse aggregates, take several aggregate particles coated with a binder from a mixture immediately after mixing and place in a freezer set at —30°F for 1 hour. Then split the particle in a knife edge hydraulic jack splitter. Place the two halves of the particle in a bed of fine grain sand with split surfaces leveled. Return the specimens to the freezer. When frozen again to —30°F, remove from the freezer, and measure the film thickness on the particle with a microscope having a calibrated scale eyepiece. Readings of film thickness are made around the periphery of the split edges of the particle and averaged for average film thickness. This method of measurement also indicates the depth to which binder has penetrated into the aggregate.

To measure film thickness on fine aggregate particles passing the No. 10 sieve and retained on the No. 80, place the particles for the test in a freezer at —30° for 1 hour. After cooling, cut a groove in the film with a weighed razor blade that has also been cooled. Then set the specimens in a wax specimen holder and return to the freezer. When frozen again to —30°F, measure the width of the groove with a microscope and calculate the thickness of the film. The thickness of the film may also be measured by a depth measuring microscope.

The thickness of films on dust particles passing the No. 100 sieve can only be approximated. Asphalt films less than 5 microns thick are brown in color. If the asphalt film on a particle of dust under a microscope is brown in color, the thickness may be assumed as less than 5 microns. If the film is almost transparent, a direct measurement may be made with a depth measuring microscope.

METHODS OF PRODUCING THIN FILMS OF BINDER ON AGGREGATES

When this investigation was undertaken, three known methods could produce bituminous films on aggregates that were usually thinner than those created in the conventional mixing operation. One method uses emulsified asphalt in the mixture. Another is the Steam Mix, and the third is the Atomized Asphalt Process. All can be adapted to the twin shaft pug mills used in conventional mixing operations.

Selection of the Method of Forming Thin Films

Since local aggregates vary greatly in particle size and gradation, any method that utilizes such aggregates in bituminous paving mixtures must produce thin films of binder on all particles ranging from very small soil particles to relatively coarse sand and gravel particles. Loess or local soils may then be used not only as a single aggregate but also as a mastic to bond coarser aggregate particles together.

Several tests were made to find which of the methods of producing thin films was best. The emulsified asphalt method was checked first. The low viscosity and surface tension of the emulsified asphalt permit rapid spreading of the binder over the surfaces of aggregate particles in very thin layers. If there is no excess of binder, thin films will form as the binder sets and hardens. Excellent thin films were produced on both fine and coarse particles. But mineral dusts tended to break the emulsion prematurely and destroyed its low viscosity. The water in the emulsion transferred to the clayey particles causing them to ball and agglomerate. This prevented the coating of the individual particles. These problems were solved, and thin films were deposited on mineral dusts by using specific emulsifiers in the asphalt which diluted the emulsion so that clayey lumps softened and could be permeated with binder. The mix, however, became so plastic that it was difficult to handle and required aeration before it set enough for compaction. Although the emulsified asphalts will function, they are not practical.

The Steam Mix Method is used in the North Atlantic States. In this patented process the viscosity of the asphalt is lowered by the introduction of steam in a pressure vessel to create a temporary asphalt emulsion. By forcing the emulsion into the mixer through fine spray nozzles thin films of binder are formed on the aggregates. But if large quantities of mineral dust are used in the mix, the dust tends to agglomerate and ball.

The Impact Process is also patented and is used extensively in Europe and to a lesser degree in the North Atlantic States. In this process the asphalt cement is heated to 320°F and pumped at high pressure, usually around 300 pounds, through special atomizing nozzles to form a cloud of minute droplets of asphalt in the top of the enclosed twin pug mill mixer. The operating speed of the mixer is increased to fluff the aggregate and throw its particles up into the top of the mixer. The impact between the aggregate particles and the minute droplets of asphalt causes the asphalt to splash on the aggregate surface. This coupled with the temperature of the aggregate causes the asphalt to spread over the surface rapidly and form a thin film. By limiting the quantity of asphalt introduced, thin persistent films are formed. Mastics of limestone dust, fly ash, pulverized loess and soil were successfully produced by this process, and it was selected for further study.

Pulverization of Loess and Soils

The mineral dust used in the atomized asphalt process must be dry, hot, discrete particles. Loess and other clayey soils must be processed to make them suitable for use.

Loess is composed of silt and clay, with the clay content varying from very small amounts to as much as 50 percent. Its moisture content, in the natural state, varies from zero to 30 percent [14, 15]. Very wet loess is quite liquid. As the moisture is removed the loess turns plastic, then it becomes very hard and brittle. When very little or no moisture remains, it is dusty and friable. Loess may be separated into its primary particles either wet or dry. Since the mineral dust used in the atomized asphalt process must be dry, the wet method could not be used.

Some interesting changes in the loess took place during its drying. Loess with 25 to 30 percent moisture, when put through a drier and heated to 350°F, gave up some of its moisture rapidly. In the drying process it changed from a plastic to a hard, dusty and lumpy material containing about 12 percent moisture. The fragments of the broken lumps appeared dry inside.

When the dried loess was passed through an eight inch laboratory hammermill pulverizer, it pulverized readily into a fine mineral dust, all of which passed the No. 200 sieve and had a moisture content of less than one percent. It appears that pulverization reduced the moisture content from 12 percent to less than one percent.

Loess and clayey soils were similarly processed by the dry method with regular commercial driers and hammermills. A mineral dust containing 30 percent passing the 200 mesh was processed at the rate of about 10 tons per hour. In a companion full-scale test road project, HR-44, loess was processed through a feed grinder at the rate of 25 tons per hour. Loess and clayey soils can be processed in sufficient quantities to be used with the atomized asphalt or with any other process which can utilize them in the preparation of paving mixtures.

ATOMIZED ASPHALT PROCESS

The atomized asphalt process, generally referred to as the Impact Process, was patented by Dr. Albert Sommer of Switzerland. Basically, the principle of this process involves the passing of hot aggregate through a cloud of atomized binder. The hot aggregate particle from the mixer and the minute droplet of binder from the atomizing nozzle meet with an impact which causes the binder to splash on the aggregate particle and to flow over its hot surface thus forming a thin film of binder on the aggregate. Since the droplets of the binder are minute, each of the particles of the mineral dust may be coated by a thin film as it goes through the cloud of atomized binder, and no kneading action of the mixer is necessary.

In practice the atomized cloud of asphalt is created by pumping an asphalt cement at about 300°F through special atomizing nozzles at pressures from 150 to 400 pounds. A properly placed spray bar fitted with a number of atomizing nozzles distributes the binder uniformly within an enclosed pug mill. Usual twin shaft pug mill mixers with slight modifications may be used in this process. The top of the mixer is enclosed to contain the dust cloud, the speed of mixer is increased, the paddle tips are adjusted to throw the aggregate particles up through the atomized asphalt, and the kneading action of the mixer is reduced to a minimum.

Asphalt Cement and Atomization

When hot asphalt cement is exposed to air, the material oxidizes, and its physical and chemical properties are changed. Since atomization exposes the asphalt cement to air, a series of tests was conducted to determine what effect, if any, atomization had on the asphalt cement.

The tests included penetration, softening point, loss on heating, viscosity measurements by both the Koppers and Brookfield Viscometer over a range of 150°F to 400°F, and surface tension measurements by the De Nouye surface tensiometer over a range of 180°F to 400°F. Analyses were also made of the asphalt cement both before and after atomization. These tests showed no significant changes due to atomization in either the physical properties or the asphaltene content.

The atomizing nozzle and the asphalt cement as it came from the nozzle were investigated under high speed motion picture photography at 5000 frames per second. These pictures showed that the asphalt cement at 325°F and 300 psi pressure was ejected by the nozzle as a conical film for a distance of about ½ inch below its tip. At this point the conical film disintegrated at comparatively high speed into minute droplets. The temperature of the asphalt cement in the conical film and in the droplets could not be determined; however, droplets of asphalt cement striking the skin of the operator did not burn. The atomization seemed to be helped by the rapid cooling of the asphalt cement at the outer fringe of the conical film ejected by the nozzle. It was cold enough that the air did not cause oxidation. Since the coated material was discharged from the mixer as soon as the asphalt cement was introduced, mixing oxidation was reduced to a minimum.

FORMATION OF BITUMINOUS MASTICS WITH MINERAL FILLERS

The word *mastic,* as used throughout this discussion, denotes a combination of mineral dust and asphalt cement. In this combination the individual particles, or minute agglomerations of the particles of dust are coated with thin films of asphalt.

In the course of the study it was found that the atomization process could make such a mastic. The thickness of the film on any particle is determined by the temperature of the particle, the size of the atomized droplet of asphalt, and the quantity of asphalt. By proper design and controls, a mastic can be made which has high strength and stability. A mastic of this type with adequate strength and stability may be used to fill the voids between coarser aggregate particles and to bond such particles into dense, strong paving mixtures.

The mastic may be produced alone or mixed with coarser aggregates in one operation by the atomization process. When the mineral dust is used with coarser aggregates, the coarser aggregates only are heated to about 350°F. The mineral dust that is added cold attains its temperature from the coarse aggregate during the dry mix period of the mixing cycle. As the atomized asphalt is added, the mineral dust is covered with a thin coating of asphalt and forms the mastic that is distributed through the mix uniformly by the mixing action. By proper mix design and control of the quantity of asphalt added, all particles in the mix are coated with thin films of asphalt, and when compacted are bonded together.

Mastic Theory

The atomization process led to a new method for the design of hot asphaltic mixes. A mastic with the strength to carry traffic loadings can be used to fill the voids between aggregates and to bond them together in a pavement. The gradation of the coarse aggregate is not then important, and coarse aggregates of one size, or skip graded aggregate can be used in mixes. This permits the use of local ungraded aggregates in asphaltic mixes.

If this concept is valid, the design of such hot asphaltic mixes should be relatively simple. The correct combination of a suitable mineral dust and asphalt to make a strong and durable mastic can readily be determined by test. The voids in the aggregate, regardless of gradation, also can be determined by test. The amount of mastic required to fill the voids of the aggregate to the desired degree then can be determined by calculation. Further calculation is needed for the quantities of asphalt, mineral dust, and aggregate required for the mix. A few test mixes readily establish the job formula for the mix to be used in a pavement.

A number of tests were conducted in the laboratory and in the field with various mineral dusts, asphalts, and local ungraded aggregates. The results of these tests fully substantiated the basic concept of the Mastic Theory for the design of asphaltic mixes produced by the atomization process.

LABORATORY TESTS OF ATOMIZED ASPHALT MIXES

When the laboratory mixer was adapted to the atomization process (figure 31), bituminous mastic mixes composed of pulverized loess, limestone dusts, fly ash and various grades of asphalt cement were prepared and tested.

These investigations included preliminary tests of the physical properities of a wide range of asphalts, mineral dusts, sands, locally available crushed limestones and gravels. Tests were later made to determine the stability, strength, and durability of asphalt and mineral dust mixtures, and of sheet asphalt and asphaltic concrete mixes produced by the atomization process using the mastic theory.

Materials Tested

Asphalt Cements: In the laboratory tests, softer asphalt cements of 150-200 penetration and 200 plus penetration were used. In pilot and full scale commercial field tests, asphalt cements of 85-100 penetration were also used. Softer asphalt cements were used in the laboratory because their lower viscosity at normal plant temperatures permitted the operation of the atomization process system on the laboratory pug mill at 150 pounds pressure. This was safer than the 300 pounds pressure used by this process commercially (table I).

Mineral Dusts: Limestone Dust (table II).

Fly Ash: Tests on fly ash were made only to determine whether or not this material would form an asphaltic mastic. It was found to form such a mastic quite satisfactorily.

TABLE. I. Characteristics of Asphalt Cements.

Code Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	A.S.T.M.
Specific Gravity 77°F.	1.004	1.013	1.013	1.013	—	1.011	—	—	1.007	0.993	1.015	0.997	1.012	0.993	D70-27
Loss on Heat at 325°F. %	0.04	0.02	0.01	0.002	—	—	—	—	0.007	0.02	0.005	0.04	0.03	0.004	D6-39T
Penetration 77°F.	210	177	207	257	101	99	110	229	155	191	215	214	213	182	D5-47T
Softening Point R&B °C.	40.0	43.5	40.5	37.0	—	46.0	—	—	42.5	41.0	40.2	41.2	39.0	41.0	D36-26
Total Bitumen C Cl_4 %	99.3	99.5	99.9	99.9	—	—	—	99.9	99.4	99.8	99.8	99.9	99.7	99.9	D165-42
Vis- Brook- cosity field															
c.p. 280°F.	276	248	540	470	460	360	—	350	190	420	200	130	130	210	
c.p. 180°F.	8000	8400	53,000	33,000	13,500	3560	—	10,000	3600	17,000	5000	2200	2500	3300	
Surface* 300°F.	28.0	—	—	—	—	—	—	—	28.4	28.3	27.8	27.6	27.7	27.2	
Tension 200°F.	33.0	—	—	—	—	—	—	—	34.9	34.0	33.1	33.8	33.4	33.2	
Dynes/cm 160°F.	—	—	—	—	—	—	—	—	55.0	48.0	41.0	39.8	37.7	40.6	
Flash Point °F.	590	600	549	580	—	559	—	545	605	619	581	637	593	651	D96-46
Fire Point °F.	660	680	613	640	—	655	—	624	685	696	656	715	662	724	D96-46
Asphaltenes %†	16.6	15.2	17.5	14.0	13.2	18.4	17.8	19.4	15.1	13.0	16.6	13.8	13.0	11.0	

*De Nouye Surface Tensiometer.
†For Code No. Identification, See Table V.

TABLE II. Characteristics of Mineral Dusts.

Code No.	1	2	3	7	8	8	10	10	11	12	13
Gradation	*	*	*		†	*	*	‡	*	‡	*
% Passing											
No. 4	100.0	100.0	100.0	100.0	100.0	100.0	98.1	100.0	100.0	100.0	100.0
No. 10	100.0	100.0	100.0	100.0	100.0	100.0	94.4	100.0	100.0	100.0	100.0
No. 40	100.0	100.0	100.0	100.0	99.4	100.0	81.4	84.8	100.0	94.0	100.0
No. 80	100.0	100.0	100.0	92.8	96.7	100.0	——	50.8	100.0	73.9	100.0
No. 200	98.9	99.5	99.5	64.9	91.6	99.2	45.2	27.0	99.3	47.9	98.9
% Clay 5 micron and less	28.1	19.8	39.6		37.8	38.5	23.8	18.7*	29.1	34.3	29.2
Specific Gravity	2.50	2.75	2.53	2.72	2.70	2.70	2.70	2 70	2.67	2.69	2.70

*Particle-Size distribution by hydrometer method.
†Gradation of laboratory pulverized material.
‡Graduation of commercially pulverized material in pilot plant.
For Code No. Identification, See Table V.

Loess: Loess found in Iowa is predominantly silt and clay, with the clay fraction varying from zero to as much as 50 percent. The natural moisture content varies from zero to 30 percent. Since wide variations in composition are observed in various locations, a number of samples from different locations were included in the study (table II).

Dirt: Dirt as termed in this study is any material underlying the rich top soil. It may contain some organic matter, clay, silt, and very fine sand in various combinations. The dirt used in this study was secured from the upper portion of the B horizon and contained about 19 percent moisture (table II). When processed in the same manner as loess, a satisfactory mineral dust containing less than one half percent of moisture was secured.

Fine Aggregates

Sands: Natural sands varying widely in gradation were tested to determine their use in the preparation of asphaltic mixtures by the atomization process. These sands ranged from fine blow sand to coarse concrete sand. The sands were used as dug from the pits, and no adjustments in gradations were made (table III and figure 4).

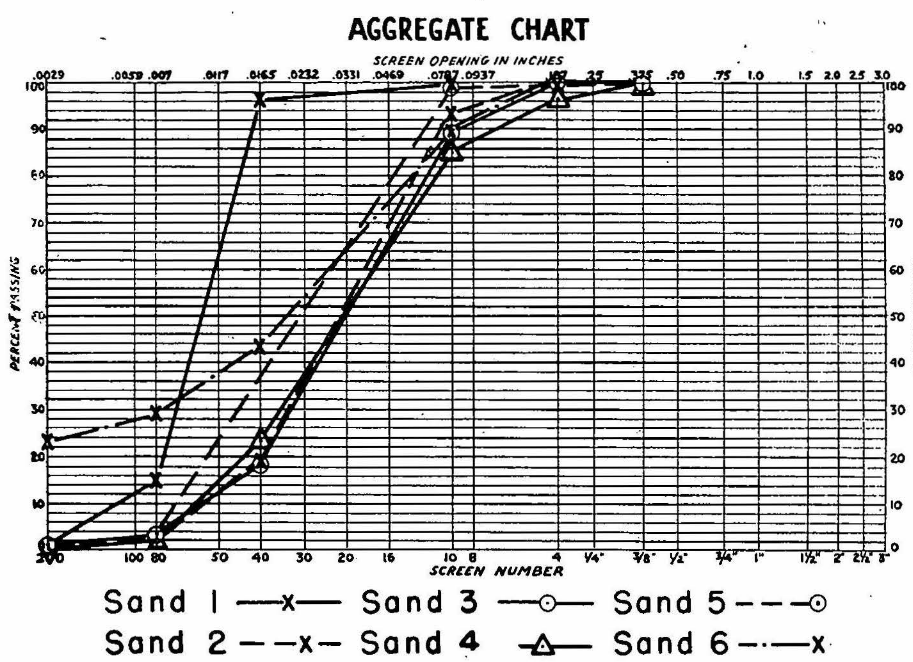

Fig. 4. Sand gradation curves.

Agricultural Limestone: Limestone quarries in Iowa and elsewhere produce as a by-product large quantities of a material commonly known as agricultural limestone. This *ag lime* is used as a blending material for asphaltic concrete mixes and by the farmers to sweeten the soil. Since this material is abundant, it was included in these tests (table III).

TABLE III. Characteristics of Fine Aggregates.

Code No.	1	2	3	4	5	6	14	3	6
Gradation							*	*	*
% Passing									
Sieve No. 4	100.0	99.4	100.0	97.7	99.9	99.9	100.0	99.8	100.0
No. 10	100.0	94.0	88.8	84.9	99.4	90.0	100.0	72.9	73.0
No. 40	96.3	19.8	18.4	23.6	36.7	43.2	96.2	13.7	35.1
No. 80	14.7	2.6	3.0	2.0	3.6	28.7	21.2	3.0	20.7
No. 200	0.5	0.6	0.8	0.4	0.5	22.8	3.0	1.2	14.6
Specific Gravity	2.63	2.70	2.62	2.65	2.65	2.65	1.56	2.63	2.62
% Voids by Chapman Flask	39.4	34.7	39.0	38.5	40.0	—	46.0	39.1	—

*Material used in test road.

Coarse Aggregates

Gravel: A relatively fine pit run gravel available in many places and not deemed suitable for regular asphaltic paving mixes was included in these tests. This material is identified as Class B, Pit Run Gravel [20] (table IV).

Soft Crushed Limestone: Although soft crushed limestones of various gradations were not tested in the laboratory, limestone having a ¾ to ¼ inch gradation was used in a test road mix (table IV).

TABLE IV. Characteristics of Coarse Aggregates.

Code No.	7	8
Gradation		
% Passing		
Sieve ¾ inch	100.0	99.1
½ inch	98.5	72.9
⅜ inch	95.7	37.4
No. 4	85.5	6.9
10	68.5	—
40	27.2	—
80	5.4	—
200	2.1	—
Specific Gravity	2.64	2.50
% Voids in Aggregate		45.6*
By Chapman Flask	33.0	52.1†
% Loss by Los Angeles Abrasion Test	—	54

*Rodded
†Loose

Code Designation of Materials and Their Combination in Mixes

Since many combinations and proportions of materials in asphaltic mastics and mastic paving mixtures were tested, a simple code was adopted for identifying the materials in the various mixes (table V). The materials and their proportions in a mastic paving mixture are designated by the code number of the material followed by its proportion in the following order: mineral dust, fine aggregate, coarse aggregate and asphaltic binder. The proportions of the mineral dust, of fine and of coarse aggregates are given as percentage by weight of total aggregate, and the asphaltic binder is given as percentage by weight of the total mixture.

Table V. Code Designation of Materials.

Mineral Dust

Code No.	Description
1.	Loess, Dunlap, Iowa
2.	Loess, Mo. Valley, Iowa
3.	Loess, Shenandoah, Iowa
7.	Limestone Dust, Buffalo, Iowa
8.	Loess, Page County, Iowa
9.	Fly Ash, Cedar Rapids, Iowa
10.	Dirt, Ames, Iowa
11.	Loess, Pottawattamie County, Iowa
12.	Commercial Loess Mixture of No. 8, 11, 13
13.	Loess, Montgomery County, Iowa

Fine Aggregate

Code No.	Description
1.	Blow Sand, Muscatine County, Iowa
2.	Fine Sand, Muscatine County
3.	Concrete Sand, Hallett, Boone, Iowa
4.	Concrete Sand, Roberson, Ames, Iowa
5.	Plaster Sand Roberson, Ames, Iowa
6.	Agricultural Limestone, Cook, Ames, Iowa
14.	Blow Sand, Hallett (Fine), Boone, Iowa

Asphalt Cement

Code No.	Description
1.	250-300 Pen. Standard Oil Co. of Indiana Sugar Creek, Mo.
2.	150-200 Pen. Same as 1
3.	150-200 Pen. Texaco, Pt. Neches, Texas
4.	200-300 Pen. Same as 3
9.	150-200 Pen. Same as 1
10.	150-200 Pen. Socony Vacuum, Augusta, Kansas
11.	150-200 Pen. Same as 2
12.	150-200 Pen. Skelly Oil, Kansas City, Mo.
13.	150-200 Pen. Same as 1
14.	150-200 Pen. Phillips Oil, Bartlesville, Okla.

Coarse Aggregate

Code No.	Description
7.	Class B—Pit Run Gravel—Hallett, Boone, Iowa
8.	Crushed Stone—¾"-¼"—Cook, Ames, Iowa

As an example, suppose a mastic paving mixture contains 94 percent of mineral aggregate and 6 percent of No. 9 binder, and that the mineral aggregate is composed of 20 percent of No. 8 mineral dust, 45 percent of No. 1 fine aggregate and 35 percent of No. 8 coarse aggregate. This mixture would be designated as 8.20; 1.45; 8.35; 9.6. If a class of aggregate is not used in a mixture, its designation in the code sequence is 0.0. Thus a sand mastic mix that contains no coarse aggregate might be designated as 8.30; 5.70; 0.0; 9.8. A mastic, which contains only mineral dust and binder, might be termed a loess mastic and is designated as 8.100; 9.20. Since two types of atomizing nozzles were tested, a standard American nozzle and a German Wibau nozzle, the letters *S* for the standard and *W* for the Wibau are added at the end of the sequence to indicate the nozzle used in preparing the mix. If no nozzle designation is indicated, the *W* nozzle was used.

TESTS OF MASTICS AND MASTIC MIXTURES

The asphaltic mastics and mastic paving mixtures prepared in the laboratory and the field were tested to determine their physical properties and characteristics. Included were stability tests conducted under differing temperature and moisture conditions, a variety of tests to determine specific gravity and void content of compacted specimens, tests to ascertain resistance to freezing and thawing and moisture absorption, and other tests to discover changes in the binder during atomization and mixing. Mixes were also examined in loose and compacted condition both visually and microscopically, to determine the uniformity of the mix and the uniformity of formation and distribution of the binder and the films of binder on the aggregates.

The stability of the mastic and the sand mastic mixes was determined by the Hubbard-Field Stability test[33]. This test was selected because the results could best be correlated to service behavior. Specimens two inches in diameter and about one inch in height were prepared and tested in accordance with the standard procedure recommended for this test.

Twenty-five such specimens of each mastic and sand mastic mix were prepared for testing. The specimens were cured for three days in air at a room temperature of about 75°F before testing. Five specimens were tested for stability at 77°F, five were tested after heating in an oven at 140°F for one hour, and five more after one hour of immersion in a constant temperature water bath at 140°F. Specimens after being subjected to the stability test were examined and measured for type and character of the extruded portion (figure 5). This examination provided excellent comparative data concerning the cohesive character of the mixes.

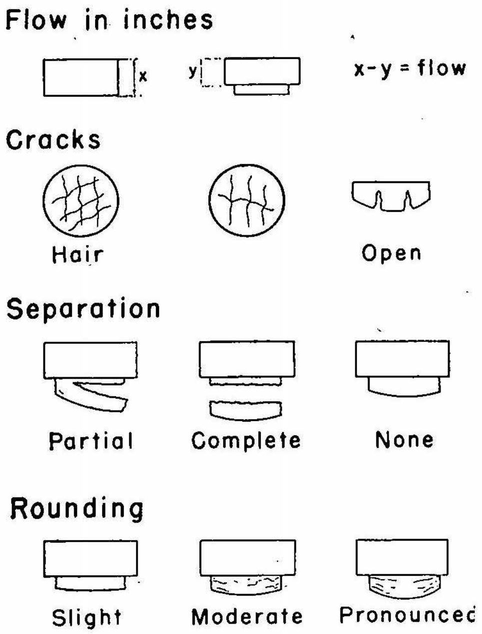

Fig. 5. Characteristics of extruded portion of specimens from Hubbard-Field Stability Test.

Five laboratory compacted specimens were tested to determine specific gravity and voids in accordance with prescribed procedure for the Hubbard-Field Test[33]. The specific gravity of each was also checked by the Serafin Method[32].

Four of the remaining five were subjected initially to the Freezing and Thawing Test, ASTM D560-44. After experience had indicated uniformity of results, only one specimen from each mix was subjected to this test, which was limited to twelve cycles of freezing and thawing because it was noted that mixes subject to failure usually failed before twelve cycles. In this test volume change and moisture absorption measurements were also made.

The remaining specimens were examined visually and microscopically and stored for future test or examination. If found necessary, they were also used for check tests.

Loose material from each test batch was examined microscopically to check the uniformity of the mix and the characteristics of the binder films. The asphalt cement was also extracted from samples of the mixes and checked for alterations in physical and chemical composition.

Mixtures containing coarse aggregates were similarly tested, except that the Marshall Test[18] was used to determine stability. Nine specimens from each batch of this type of mixture were prepared according to the Marshall test procedure. Five of these specimens were tested for stability after immersion for one hour in a constant temperature water bath at 140°F. Three specimens were tested for voids, voids filled with asphalt, and unit weights, as required by the test. Maximum theoretical specific gravity was determined by the solvent immersion method[32]. The last specimen was subjected to a freeze and thaw test. Visual and microscopic examinations and test of extracted binder were also made.

RESULTS AND EVALUATION OF TESTS

A mastic made of mineral dust and asphalt is not necessarily suitable for highway purposes. Each of the mastics was therefore tested to determine the proportions of dust and asphalt that would provide the properties needed to bond ungraded aggregates together satisfactorily for highway pavements and would give the mastic sufficient strength to carry highway traffic loads.

Tests were made on different mastics under various conditions to determine their behavior during mixing, the limiting proportions of materials, and the effect of clay on mixing procedure. The information gained from these tests was used for selecting combinations and proportion of materials for further detailed tests.

The materials selected for detailed test were Page County loess (No. 8) pulverized in the laboratory; a mixture (No. 12) of Page (No. 8), Pottawattomie (No. 11) and Montgomery (No. 13) loesses pulverized commercially in a pilot plant; limestone dust (No. 7) and dirt (No. 10), each pulverized in a pilot plant. Asphalt cements maving a penetration of 150-200 (No. 9 and 14) were selected for use as the binder (tables I and II).

Included in the tests to determine the optimum binder content of loess, limestone dust and dirt mastics were those for stability, resistance to freeze and thaw, moisture absorption and void content. Other tests were made to find the effect of mixing time, since the Wibau nozzle has a much higher capacity than the standard nozzle. Since mixing in the atomization method is considered complete as soon as the asphalt has been introduced, the Wibau nozzle required a shorter mixing time than the standard nozzle.

Complete tests were made on the following mastics and mastic paving mixtures:

Loess Mastics, 8:100; 9.20-25 (figures 6, 7, 8)
Loess Mastics, 12:100; 14.10-20 (figure 9)
Limestone Dust Mastic; 7:100; 1.10-15 (figures 10, 11, 12)
Dirt Mastic, 10:100; 14.8-14 (figure 13)
Agricultural Limestone Mastic Paving Mixes (figures 14, 15)
Sand-Limestone Dust Mastic Paving Mixes (figures 16, 17, 18, 19, 20)

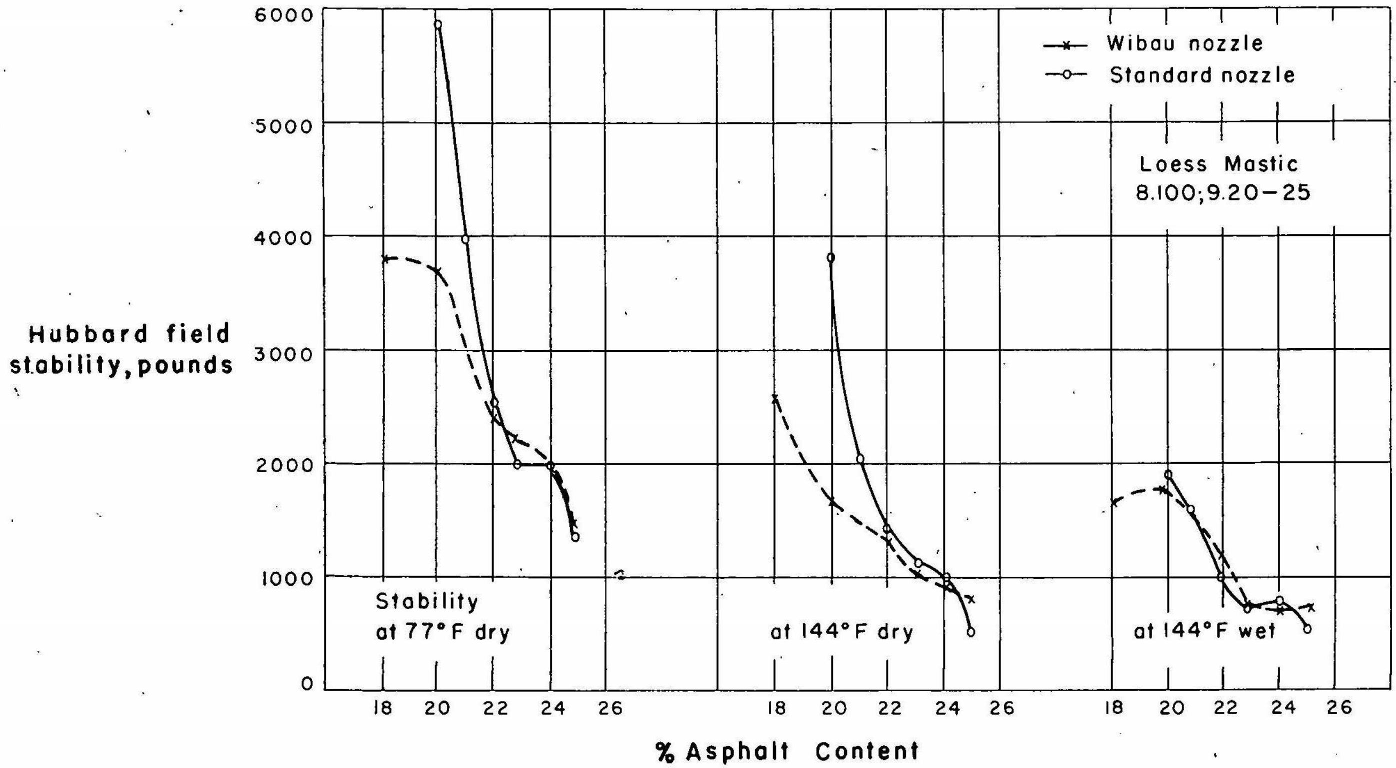

Fig. 6. Stability, loess mastic.

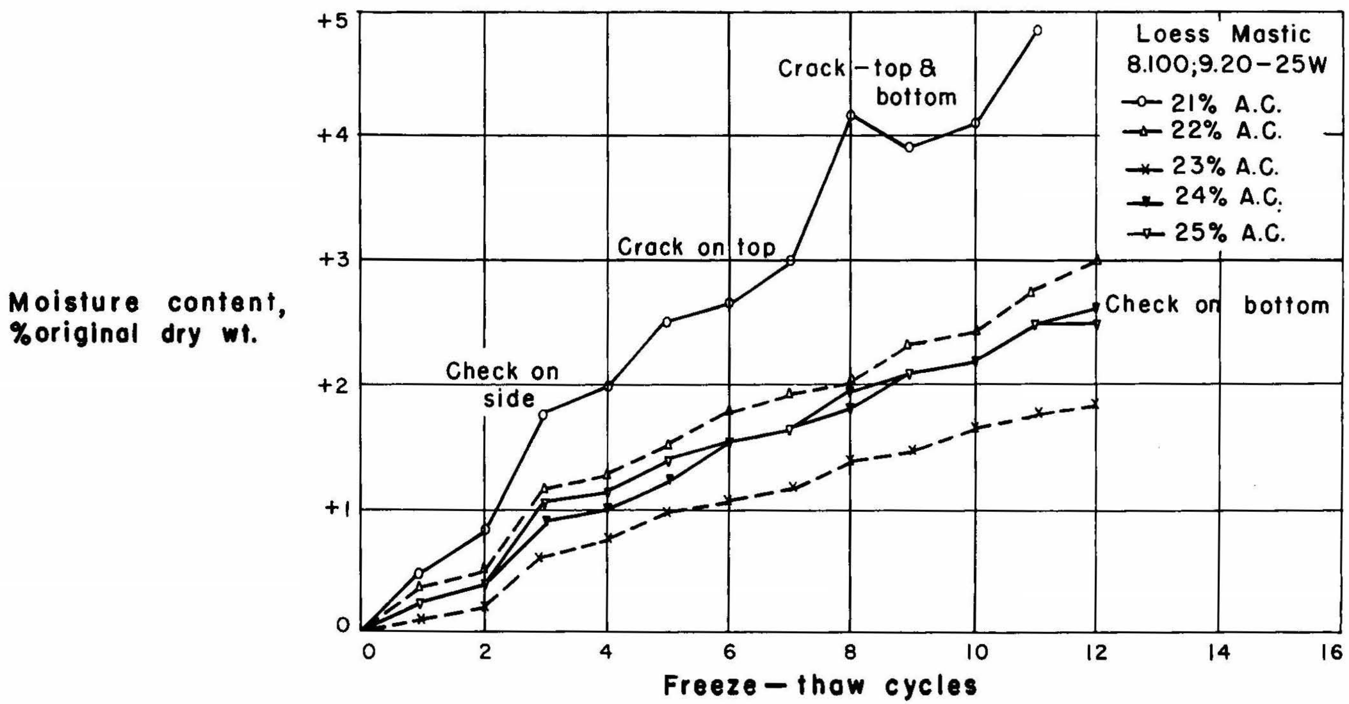

Fig. 7. Freeze-thaw, loess mastic.

TABLE VI. Hubbard-Field Stability and Voids in Laboratory Compacted Specimens. Loess Mastic 8.100; 9.20-25.

	Asphalt Cement Content					
	20%	21%	22%	23%	24%	25%
Voids %	5.5	2.1	3.8	2.3	2.2	1.3
Stability 77°F. Dry lbs.	5800	4000	2500	2000	2000	1400
Flow in.	¼	5/16	5/16	11/32	13/32	13/32
Cracks	none	few hair	few hair	few hair	open & hair	open & hair
Separation	none	none	none	none	none	none
Swelling	none	none	none	none	none	none
Rounding	none	moderate	moderate	pronounced	pronounced	pronounced
Stability 140°F. Dry lbs.	3800	2050	1450	1100	970	540
Flow in.	¼	¼	¼	5/16	11/32	⅜
Cracks	none	none	open	few hair	open & hair	open
Separation	complete	complete	complete	partial	partial	partial
Swelling	none	none	none	none	none	none
Rounding	slight	slight	slight	slight	moderate	moderate
Stability at 140°F. Wet	1900	1550	1050	780	750	500
Flow in.	5/32	7/32	7/32	9/32	9/32	5/16
Cracks	none	none	none	none	none	few open
Separation	complete	partial	complete	partial	partial	none
Swelling	slight	none	none	none	none	none
Rounding	slight	slight	slight	moderate	moderate	pronounced

TABLE VII. Hubbard-Field Stability and Voids in Laboratory Compacted Specimens. Loess Mastic 8.100; 9.19-25W

	Asphalt Cement Content							
	18%	20%	21%	22%	23%	24%	25%	23%*
Voids%	7.7	8.5	5.8	2.2	2.2	4.7	1.9	2.2
Stability 77°F. Dry	3800	3700	2500	2400	2200	2000	1500	2500
Flow in.	9/32	5/16	5/16	11/32	7/16	5/16	13/32	5/16
Cracks	few hair	few hair	few hair	none	hair & open	few open	open	open
Separation	none	none	none	none	none	none	none	none
Swelling	none	none	none	none	none	none	none	none
Rounding	slight	moderate	moderate	moderate	pronounced	moderate	pronounced	moderate
Stability 140°F. Dry	2600	1700	1300	1400	1000	950	750	1250
Flow in.	7/32	7/32	¼	¼	9/32	9/32	5/16	9/32
Cracks	hair	hair	hair	few open	hair & open	hair & open	open	open
Separation	partial	partial	complete	partial	partial	partial	partial	partial
Swelling	none	none	none	none	none	none	none	none
Rounding	slight	slight	moderate	slight	moderate	slight	slight	moderate
Stability 140°F. Wet	1600	1750	1000	1200	800	750	650	900
Flow in.	5/32	3/16	3/16	7/32	9/32	¼	11/32	9/32
Cracks	none	none	none	none	open	few open	open	none
Separation	partial	partial	complete	partial	partial	none	none	partial
Swelling	slight	none	none	none	none	none	none	none
Rounding	slight	slight	slight	slight	moderate	moderate	slight	slight

*Cured for 28 days at room temperature.

Sand-loess Mastic Paving Mixes (figures 21, 22, 23, 24)
Sand-Dirt Mastic Paving Mixes (figures 25, 26)
Gravel-Loess Mastic Paving Mixes (figure 27)
Gravel-Dirt Mastic Paving Mix (figure 28)
Detailed results are shown in tables VIII to XXIII, inclusive.

Although all of the mastics and mastic paving mixes prepared by the atomization process were given the same sequence of tests, some of the tests are more critical than others. The results of each test must therefore be studied separately in evaluating a mix.

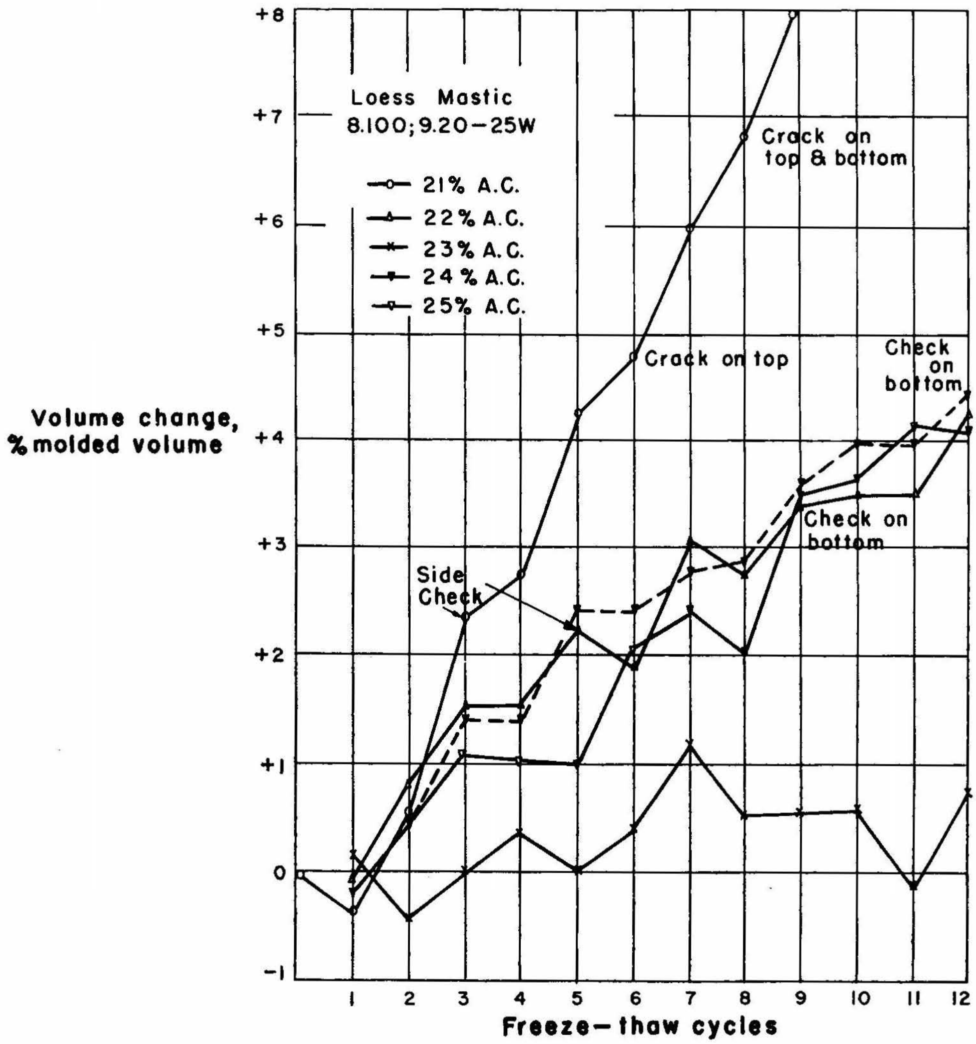

Fig. 8. Freeze-thaw, loess mastic.

TABLE VIII. Freezing and Thawing Test. Loess Mastic; 8.100; 9.18-25W.

Volume Change—Percent of Molded Volume

Asphalt content %	18		21		22		23		24		25	
Frozen or thawed	F	T	F	T	F	T	F	T	F	T	F	T
Cycle 1	0.7	1.4	—0.8	—0.4	—0.4	0.0	0.8	0.0	0.0	0.4	0.0	0.0
2	1.4	1.6	—0.4	0.4	0.0	0.8	0.0	—0.4	0.4	0.4	0.0	0.4
3	2.0*	2.3	2.0*	2.8	1.6	1.6	0.4	0.0	1.2	1.6	0.8	1.6
4	2.3	2.3	2.0	3.2	1.6	1.6	0.0	0.4	2.4	1.6	1.6	1.6
5	2.3	4.3	3.2	4.4	1.6*	2.3	0.4	0.0	1.2	2.4	1.2	1.6
6	4.3	4.7	4.8	4.8	1.9	1.9	0.0	0.4	2.4	2.4	2.0	2.0
7	5.1	5.9	5.2°	6.0	2.3	3.1	0.4	1.2	2.4	2.8	2.0	2.4
8	5.5	6.3	6.0†	6.7	2.7	2.7	—0.4	0.4	2.8	2.8	2.0	2.0
9	5.9°	6.7	6.8	8.8	3.5	3.5°	0.4	0.4	2.8	3.6	2.4	3.3
10	7.5	6.7	8.0	8.8	3.5	3.5	0.4	0.4	3.7	4.0	2.9	3.3
11	6.3	8.3	8.4	9.6	3.5	3.5	—0.1	—0.1	3.2	4.0	2.9	4.1
12	8.3	8.8	9.6	10.5	3.5	4.3	0.4	0.7	4.0°	4.4	3.7*	4.1

*Checked on side
°Crack on bottom
†Crack on top and bottom

TABLE IX. Freezing and Thawing Test. Loess Mastic 8.100;9.18-25W.

Moisture Content — Percent of Original Dry Weight

Asphalt content %	18		21		22		23		24		25	
Frozen or thawed	F	T	F	T	F	T	F	T	F	T	F	T
Cycle 1	0.0	0.5	0.5	0.5	0.0	0.4	0.0	0.2	0.0	0.3	0.0	0.3
2	0.5	0.8	0.6	0.9	0.4	0.6	0.2	0.3	0.3	0.5	0.3	0.5
3	1.5*	1.7	1.6*	1.8	1.0	1.2	0.6	0.7	0.9	1.0	0.9	1.1
4	1.6	1.8	1.7	2.0	1.2	1.3	0.7	0.8	1.0	1.1	1.0	1.2
5	1.9	2.3	1.9	2.5	1.3*	1.6	0.8	1.0	1.1	1.4	1.2	1.5
6	2.3	2.5	2.5	2.7	1.6	1.8	1.0	1.1	1.4	1.6	1.4	1.6
7	2.6	2.8	2.8°	3.0	1.8	1.9	1.1	1.2	1.6	1.7	1.6	1.7
8	2.8	2.8	3.0†	4.2	1.9	2.0	1.2	1.4	1.7	2.0	1.7	1.9
9	3.3°	3.6	3.6	3.9	2.2	2.4°	1.4	1.5	2.0	2.1	1.9	2.1
10	3.6	3.8	3.9	4.1	2.3	2.5	1.5	1.6	2.1	2.2	2.1	2.2
11	4.0	4.4	4.2	4.7	2.5	2.8	1.5	1.7	2.2	2.5	2.2	2.5
12	4.5	4.8	4.8	5.0	2.9	3.1	1.7	1.8	2.5*	2.7	2.5*	2.6

Loess Mastics

As far as stability is concerned, it appears that a loess mastic can be produced with sufficient strength to serve alone as a pavement carrying moderate traffic[33] (figures 6, 9) and also to serve as a bond in mastic paving mixes suitable for pavements carrying moderate traffic (figures 21, 22, 23, 24, 27).

The measure of voids in compacted specimens shows that mastic made of either No. 8 or No. 12 loess have densities within the desired limits (figure 9).

If two percent is taken as the maximum allowable limit for moisture absorption or volume change in a mastic suitable for paving purposes, the results of the freeze-thaw test reveal several important characteristics of the mastic. Preliminary freeze-thaw tests were made on mastics containing loess No. 1, loess No. 2, or loess No. 3 with each having the gradation of loess No. 8 (table II), except for clay content. The results of these tests indicate that the quantity of asphalt required for results within the allowable limits depend largely on the clay content of the loess. A loess of lower clay content requires less asphalt to remain within the limits of moisture absorption and volume change than does a loess of higher clay content. From this it may be deducted that the freeze-thaw test may be used to indicate whether or not the clay particles in the loess are adequately coated with asphalt to prevent the adverse effect of water upon the clay, and the minimum quantity of asphalt required to adequately coat the clay particles may thus be ascertained.

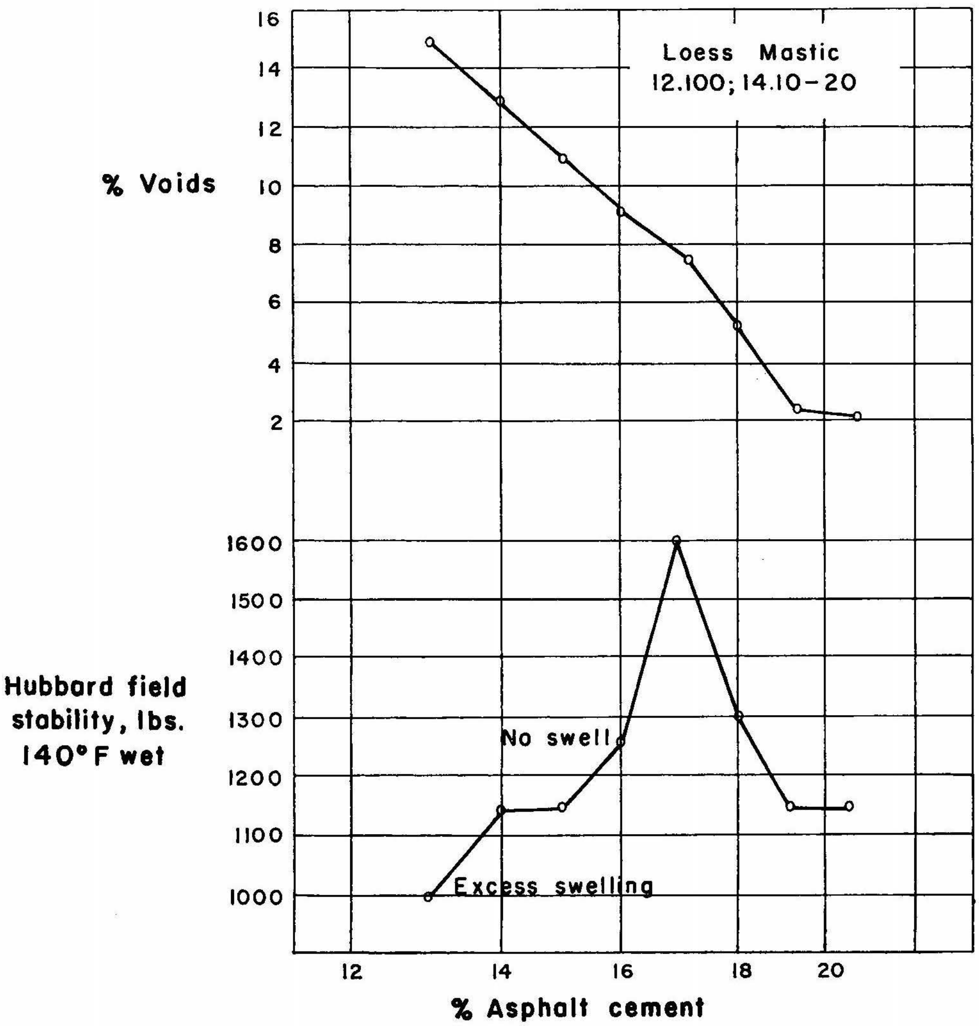

Fig. 9. Stability, voids, loess mastic.

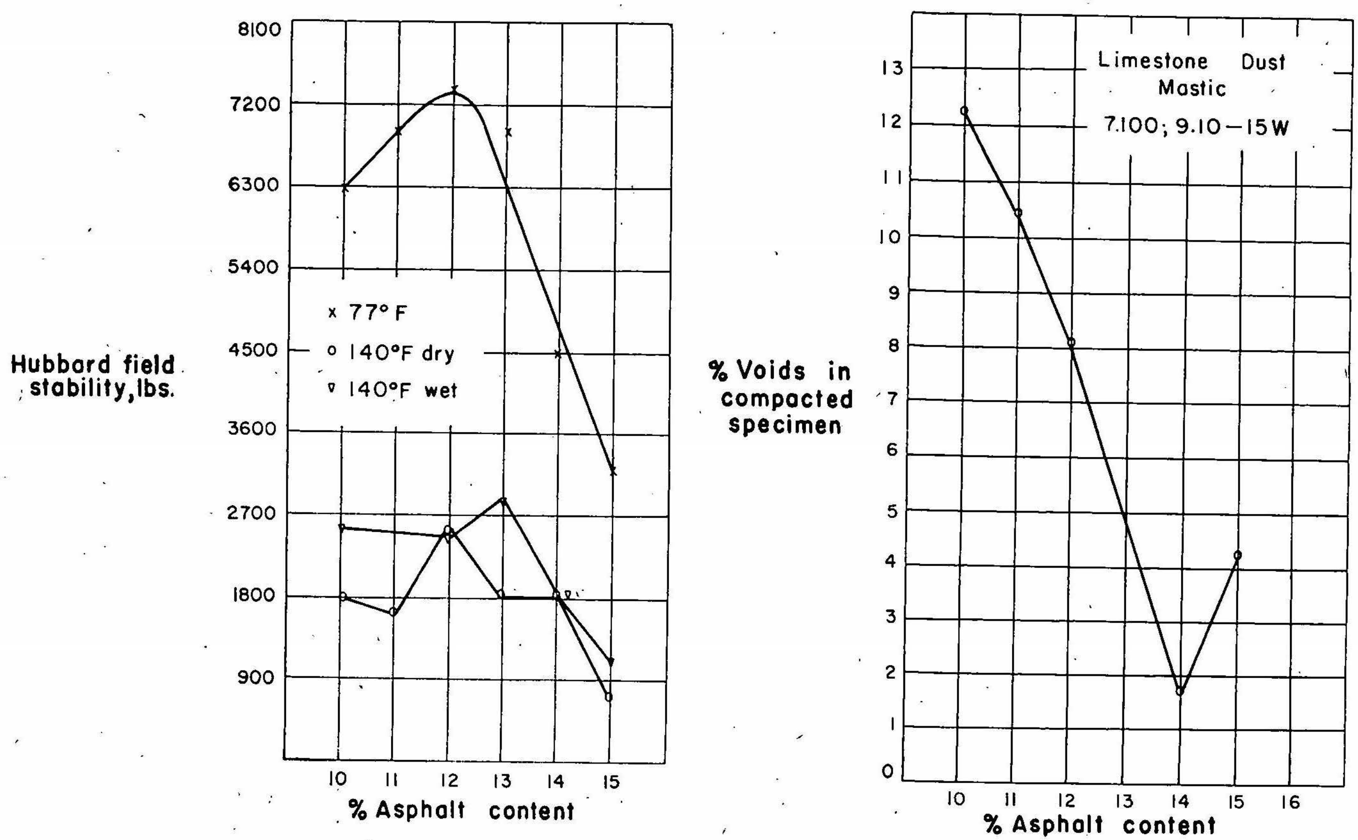

Fig. 10. Stability, voids, limestone dust mastic.

TABLE X. Hubbard-Field Stability and Voids in Laboratory Compacted Specimens. Limestone Dust Mastic 7.100; 9.10-15W.

	Asphalt Cement Content					
	10%	11%	12%	13%	14%	15%
Voids%	12.3	10.5	8.2		1.6	4.4
Stability 77°F. Dry	6200	6800	7400	6900	4550	3100
Flow in.	——	9/32	9/32	¼	9/32	5/16
Cracks	none	none	none	hair	few hair	hair
Separation	none	complete	complete	partial	none	none
Swelling	none	none	none	none	none	none
Rounding	slight	slight	slight	slight	slight	moderate
Stability 140°F. Dry	1820	1600	2550	1850	1750	720
Flow in.	3/16	3/16	7/32	7/32	¼	9/32
Cracks	open	——	open	none	few open	many open
Separation	complete	——	complete	complete	partial	partial
Swelling	none	——	none	none	none	none
Rounding	slight	——	slight	slight	slight	slight
Stability 140°F. Wet	2500	——	2400	2850	1750	1100
Flow in.	3/16	——	7/32	7/32	¼	¼
Cracks	open	——	few open	none	few open	open
Separation	complete	——	complete	partial	partial	none
Swelling	slight	——	none	none	none	none
Rounding	slight	——	slight	slight	slight	moderate

TABLE XI. Freezing and Thawing Test. Limestone Dust Mastic 7.100; 9.10-15W. Volume Change—% of Molded Volume.

Asphalt content %	10		11		12		13		14		15	
Frozen or thawed	F	T	F	T	F	T	F	T	F	T	F	T
Cycle 1	—0.4	—0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.8	0.8	0.8	0.0
2	—0.4	—0.4	0.0	0.0	0.0	0.0	0.0	—0.4	0.8	0.8	0.4	—0.4
3	—0.8	—0.4	0.0	0.1	0.0	0.0	0.0	—0.4	0.8	0.0	0.0	0.4
4	—0.0	—0.8	0.4	—0.4	0.0	0.0	0.0	—0.4	—0.2	0.0	0.4	0.4
5	—0.8	—0.8	—0.4	—0.4	—0.4	—0.4	—0.8	—0.8	—0.4	—0.4	0.4	—0.4
6	—0.4	—0.8	—0.4	—0.4	—0.4	—0.4	—0.8	0.0	—0.4	—0.2	0.0	—0.8
7	—0.8	—0.8	—0.4	—0.4	—0.4	—0.4	—0.8	—0.8	—0.4	—0.4	—0.4	0.4
8	—0.4	—0.8	—0.8	—0.4	—0.4	—0.4	—0.8	—0.8	0.0	—0.4	0.4	0.4
9	—0.8	—0.8	—0.4	0.0	—0.4	—0.4	—0.8	—0.4	—0.4	—0.4	0.4	0.8
10	—0.8	—1.2	1.2	—0.8	0.0	—0.4	—0.4	0.0	—0.2	—0.4	0.4	—0.8
11	—0.8	—0.8	0.0	—0.4	—0.4	—0.4	—0.8	—1.2	—0.8	—0.4	0.4	—0.8
12	—0.8	—0.4	0.0	—0.8	—0.8	—0.8	—0.8	—1.2	—0.4	—0.8	0.8	0.8

This test for moisture absorption and volume change also showed by a comparison of mastics prepared with loess No. 8 and loess No. 12 that the gradation of the loess had a bearing on asphalt content. The difference in clay content between the two materials is relatively small, 3.5 percent, but the gradation of loess No. 12 is much coarser than that of loess No. 8 (table II). Freeze-thaw test results indicate that loess No. 8 mastic requires 23 percent binder, while loess No. 12 mastic requires only 16 to 17 percent asphalt to meet the allowable limits set. Based upon clay content alone, this difference is too large; it may therefore be assumed that the difference is due primarily to gradation. The freeze-thaw test indicates not only the resistance of the mastic to the effects of freezing and thawing, but also shows the amount of asphalt needed to coat the particles of dust properly and the amount of asphalt needed to prevent the action of water on the clay. In evaluating a mastic, this test is therefore quite critical.

The results of the various tests upon mastics containing loess of various clay contents clearly indicate that loess mastics suitable for use in highways can be produced by the atomization process.

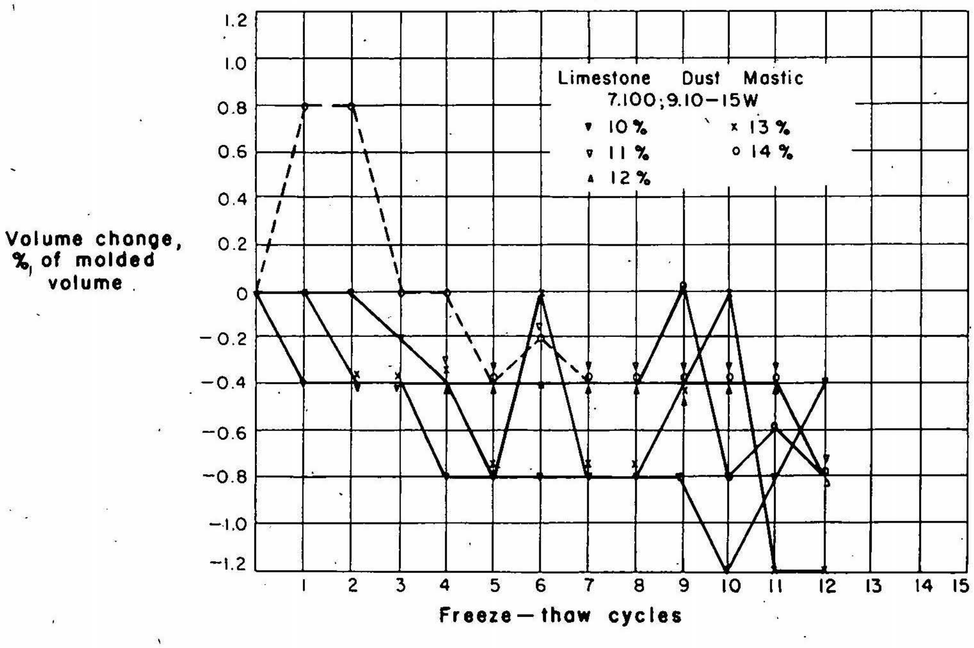

Fig. 11. Freeze-thaw, limestone dust mastic.

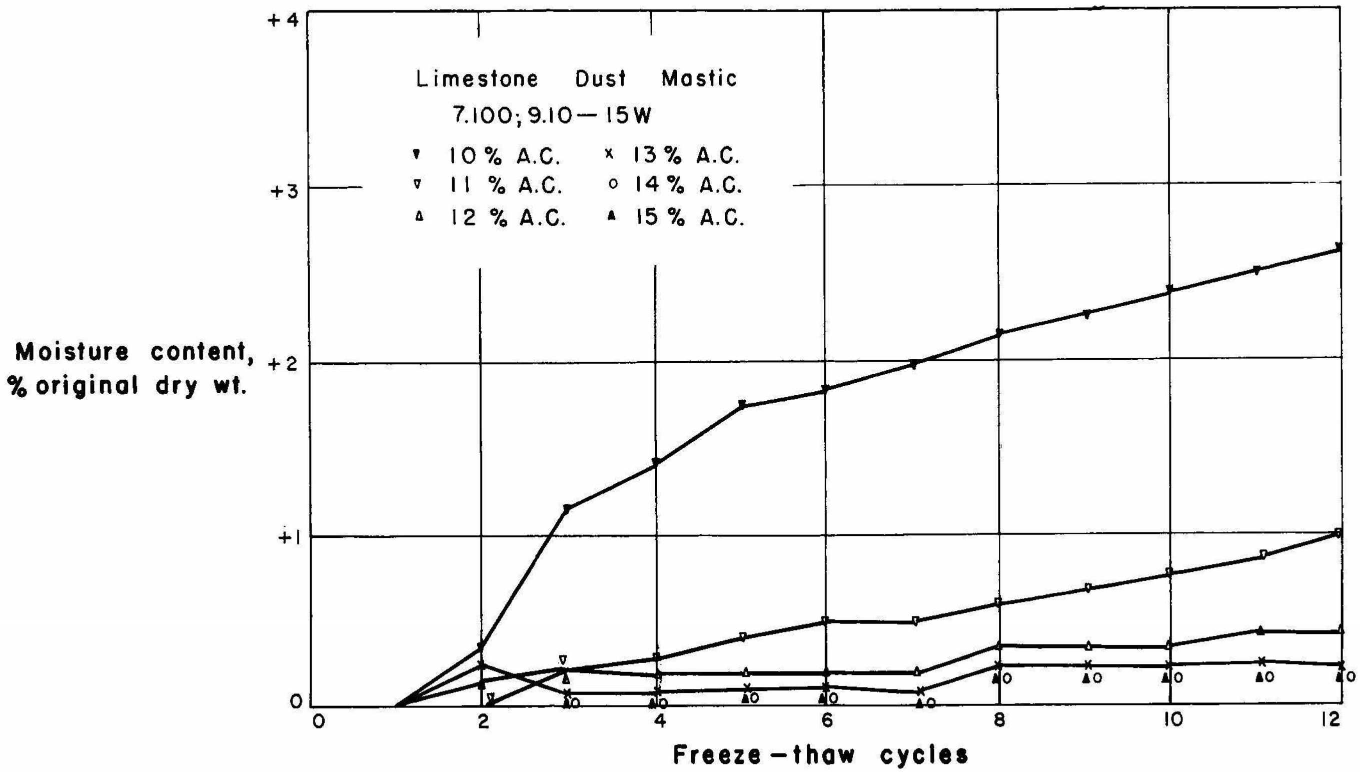

Fig. 12. Freeze-thaw, limestone dust mastic.

TABLE XII. Freezing and Thawing Test, Limestone Dust Mastic 7.100; 9.10-15W.

Moisture Content—Percent of Original Dry Weight

Asphalt content %	10		11		12		13		14		15	
Frozen or thawed	F	T	F	T	F	T	F	T	F	T	F	T
Cycle 1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.3	0.0	0.0	0.0	0.1	0.1	0.2	0.0	0.0	0.0	0.0
3	0.9	1.1	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.0	0.0
4	1.1	1.3	0.2	0.3	0.1	0.2	0.1	0.1	0.1	0.1	0.0	0.0
5	1.4	1.7	0.2	0.4	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1
6	1.7	1.8	0.4	0.5	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1
7	1.9	2.0	0.5	0.5	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1
8	1.9	2.2	0.5	0.6	0.2	0.3	0.1	0.2	0.1	0.1	0.1	0.1
9	2.2	2.3	0.6	0.7	0.2	0.3	0.1	0.2	0.1	0.1	0.1	0.1
10	2.2	2.4	0.7	0.8	0.3	0.3	0.2	0.2	0.1	0.1	0.1	0.1
11	2.2	2.5	0.7	0.9	0.2	0.4	0.1	0.2	0.1	0.2	0.1	0.1
12	2.5	2.6	0.9	1.0	0.3	0.4	0.2	0.2	0.2	0.2	0.1	0.1

TABLE XIII. Ag Lime and Asphalt 0.0,6.100; 3.5-11.

Asphalt Cement %	6	6½	7	8½	9½	10	13
Voids %	14.8	14.3	10.9	7.9	5.4	4.0	1.2
Stability at 77°F. Dry	5600	5400	5000	5100	4750	4600	3800
Stability at 140°F. Dry		1100	1050	1450	1900	1450	1350

Limestone Dust Mastics

Analysis of the results (figures 10, 11, 12) discloses that limestone dust mastics suitable for highway purposes can be produced by the atomization method. It is interesting to note that these mastics, unlike the loess mastics, are subject to shrinkage (figure 11) rather than swelling. If shrinkage is to be avoided, sufficient asphalt, about 14 percent, must be present to coat all of the dust particles. These mastics are very sensitive to excess binder.

Dirt Mastics

Analysis of the results (figure 13) indicate that dirt mastics suitable for highway purposes can be prepared by the atomization method. Since the material called "dirt" in these tests contained 18 to 23 percent clay, the freeze-thaw test was the critical test. This test shows at least 12 percent of asphalt is required to control the results within allowable limits.

TABLE XIV. Freezing and Thawing Test, Ag Lime-Asphalt Mix.

Mix	Volume Change Max %	Volume Change Range %	Moisture Content Max %	Moisture Content Range %	
0.0; 6.100; 3.5	—7.5	7.5	8.3	8.3	Complete Failure 4 Cycle
0.0; 6.100; 3.6	0.8	1.6	8.4	5.4	Edge Loose 7 Cy. Spalling 8 Cy. Edge
0.0; 6.100; 3.7	1.1	1.1	6.1	5.7	Spalling 9 Cy.
0.0; 6.100; 3.8	—7.8	7.8	4.5	3.4	No Failure
0.0; 6.100; 3.9	—1.5	2.3	1.4	1.1	Spalling 3 Cy.
0.0; 6.100; 3.10	5.2	2.0	2.1	1.9	No Failure
0.0; 6.100; 3.11	—2.8	2.6	0.6	0.5	" "

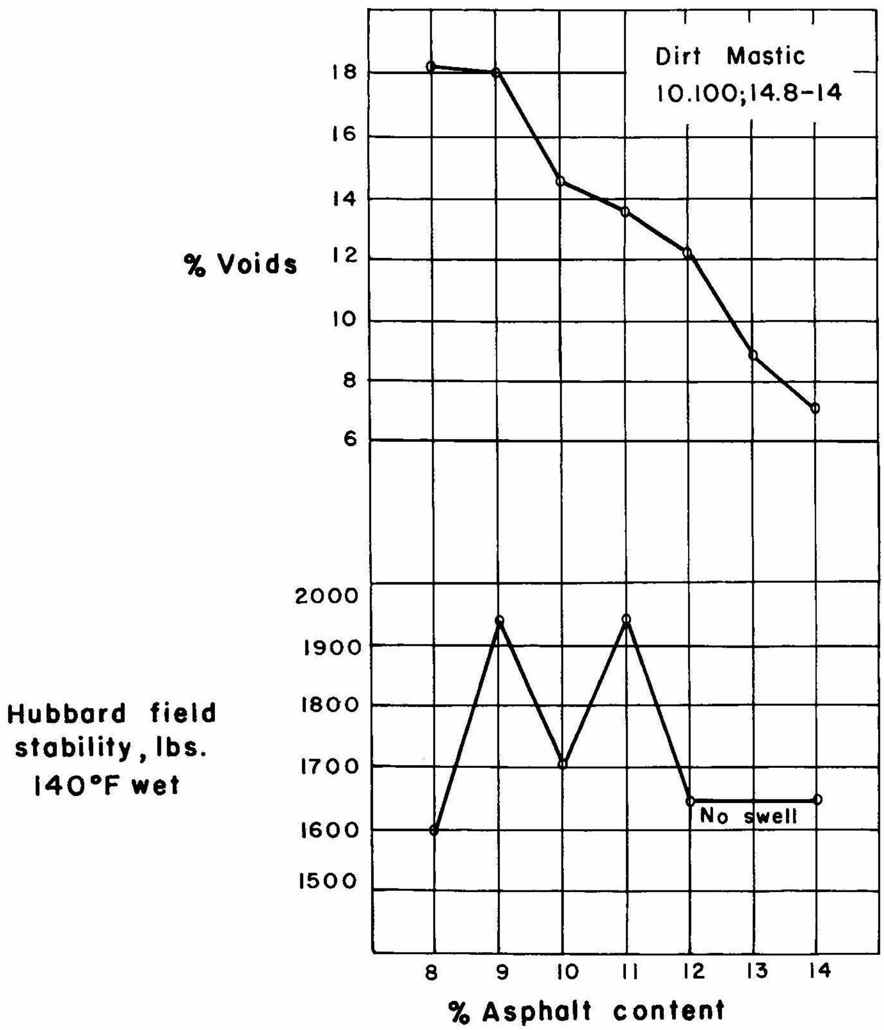

Fig. 13. Stability, voids, dirt mastic.

Agricultural Limestone Mastic Mixes

The material known as agricultural limestone is generally a by-product of a rock crushing plant producing coarse aggregate for use in Portland cement concrete and asphaltic concrete mixes. Ag-lime is a fine material, nearly all of which passes the No. 4 sieve, and up to 25 percent passing the 200 mesh sieve (table III, code No. 6). It was tested as a single aggregate in the preparation of an asphaltic mastic mixture. The tests conducted on the agricultural limestone mastic mixes were the same as those made on other mastics discussed (tables XV and XVI, and figure 14).

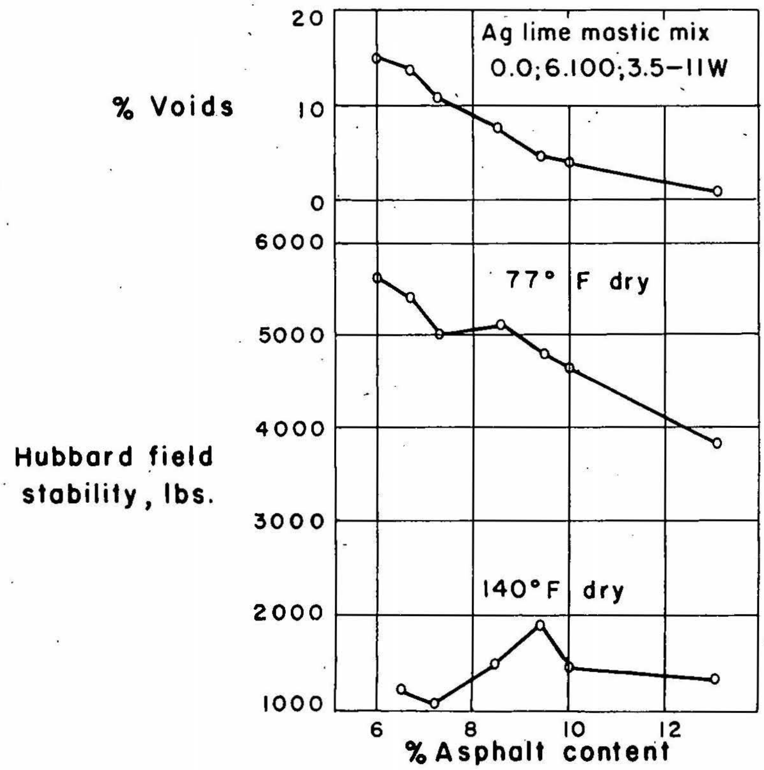

Fig. 14. Stability, voids, ag lime mix.

Stability and freeze-thaw tests indicate that the optimum binder content for this ag-lime mastic is about 9 percent. The freeze-thaw test is not critical. The Hubbard-Field stability tests showed that stabilities at 140°F wet were higher than the stabilities at 140°F oven dry, contrary to usual results. For this reason 140°F dry test results only are shown (figure 14). Agricultural limestone may be used as a unit aggregate in the preparation of a mastic mix by the atomization method for use as a pavement carrying intensive mixed traffic. This was confirmed by large scale test roads.

Agricultural limestone stockpiled in quarries generally contains moisture in excess of 6 percent, and the drying of this material is a difficult and dusty process. The addition of about 15 percent sand expedited drying and reduced dusting during drying. The sand also increased the stability of the material to a point where the mastic mix could be used for moderately heavy traffic.

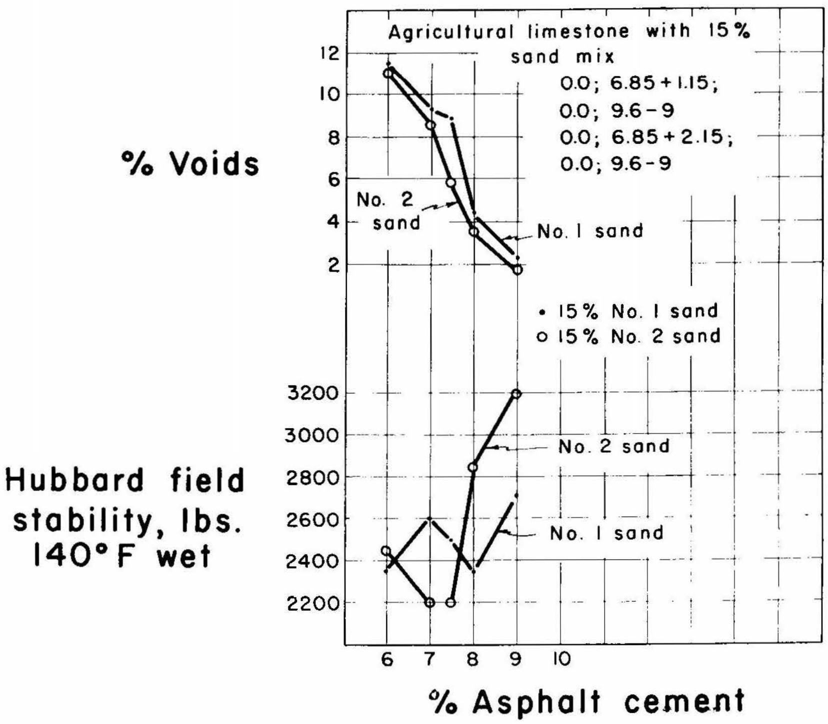

Fig. 15. Stability, voids, ag lime plus 15% sand mix.

Sand Mastic Mixtures

Mastic mixes of mineral dust and asphalt having sufficient strength for use as paving for moderate traffic can be produced by the atomization method. However, since the asphalt content of these mastics is quite high, their use as pavements would be quite expensive. Tests were conductd with various ungraded sands combined with mineral dusts to form sand mastic mixes in which the sand would serve as a bulk material bonded together by the mastic. This combination would lower the amount of asphalt required in the mix, and provide an inexpensive pavement using local ungraded aggregates.

Tests were made to find the sands, mineral fillers and asphalt which in combination would make sand mastic mixes suitable for highway purposes. Used in the tests were five sands, Nos. 1, 2, 3, 4, 5, (table II), four mineral dusts, limestone dust No. 7, laboratory pulverized loess No. 8, commercially pulverized loess No. 12 and commercially pulverized dirt No. 10, (table II). The asphalt cements used were Nos. 2, 3, 9, and 14 (table I).

TABLE XV. Sand and Limestone Dust Mastic Mix.

Mix	Voids %	Hubbard-Field Stability lbs. 77°F. Dry	140°F. Wet	
7.10; 1.90; 2.6	20.0	1900	380	360-140° Dry
7.20; 1.80; 2.6	16.6	2350	580	520- " "
7.30; 1.70; 2.6	16.2	2950	460	790- " "
7.10; 1.90; 2.7	16.1	1800	500	
7.20; 1.80; 2.7	12.0	2500	860	
7.30; 1.70; 2.7	7.2	3000	1200	
7.10; 1.90; 2.8	14.3	1600	400	
7.20; 1.80; 2.8	8.2	2200	600	
7.30; 1.70; 2.8	4.6	3050	1700	
7.40; 1.70; 2.8	4.4	3600	1550	
7.20; 1.80; 2.9	8.7	3000	600	700-140°F. Dry
7.30; 1.70; 2.9	4.2	3600	1100	
7.40; 1.60; 2.9	3.7	3400	1250	1350- " " "
7.10; 2.90; 3.5	12.7	1650	520	
7.20; 2.80; 3.5	5.4	2600	1100	
7.30; 2.70; 3.5	8.1	3000	1150	
7.10; 2.90; 3.6	11.9	1650	380	
7.20; 2.80; 3.6	5.6	2450	1000	
7.30; 2.70; 3.6	3.3	3200	1350	
7.40; 2.60; 3.6	7.2	3150	1150	
7.10; 2.90; 3.7	8.8	1800	400	
7.20; 2.80; 3.7	4.0	2000	620	
7.30; 2.70; 3.7	3.0	1650	620	High Flow Character
7.10; 2.90; 3.8	6.8	1650	54	
7.20; 2.80; 3.8	—			
7.30; 2.70; 3.8	—			Mix too fat.

TABLE XVI. Sand and Limestone Dust Mastic Mix.

Mix	Voids %	Hubbard-Field Stability lbs. 77°F. Dry	140°F. Wet	
7.10; 3.90; 3.5	10.7	3400	1350	
7.20; 3.89; 3.5	8.7	4200	1650	
7.10; 3.90; 3.6	5.7	3550	1300	
7.20; 3.80; 3.6	4.8	4100	1700	
7.30; 3.70; 3.6	4.8	4300	1800	
7.10; 3.90; 3.7	6.2	3450	1350	
7.20; 3.80; 3.7	2.1	3250	1300	
7.30; 3.70; 3.7	1.3	3250	1200	
7.40; 3.60; 3.7	3.7	3850	1550	
7.10; 4.90; 3.5	6.8	3850	1400	Brittle
7.20; 4.80; 3.5	5.5	4150	1800	Brittle
7.30; 4.70; 3.5	—	——	——	Too dry to compact
7.10; 4.90; 3.6	10.7	4000	1600	
7.20; 4.80; 3.6	7.9	4700	1750	
7.30; 4.70; 3.6	3.9	4900	2100	
7.40; 4.60; 3.6	6.5	5000	2150	
7.10; 4.90; 3.7	6.1	4100	1250	
7.20; 4.80; 3.7	2.0	3550	1550	
7.30; 4.70; 3.7	2.3	3000	1200	
7.40; 4.60; 3.7	3.4	4500	1600	

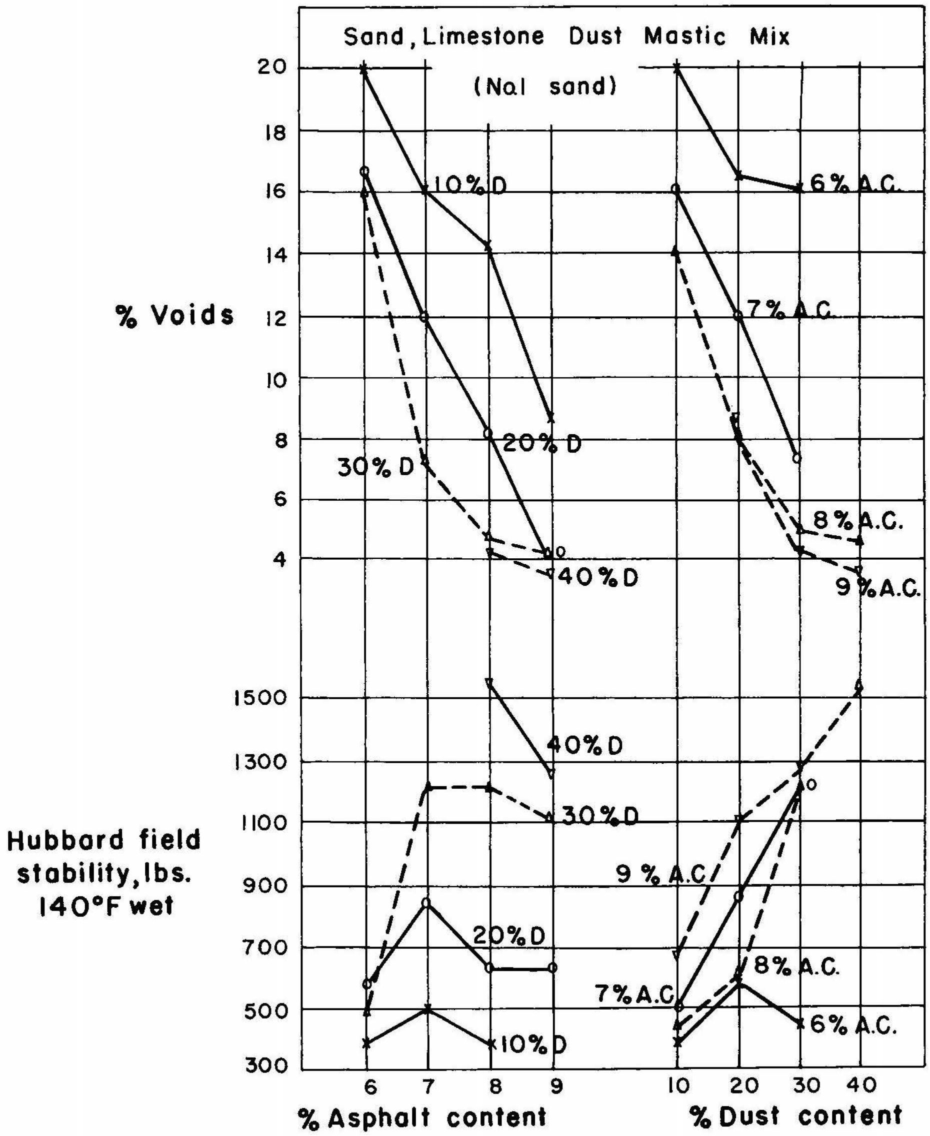

Fig. 16. Stability, voids, sand No. 1, limestone dust mix.

Sand-Limestone Dust Mastic Mixes

Limestone dust was the mineral dust used with each of the five sands as fine aggregate and No. 2 and No. 3 asphalt cement was the binder. With each sand the quantity of dust was varied from 10 to 40 percent, at 10 percent intervals. The asphalt content was varied from 5 to 9 percent at one percent intervals. Hubbard-Field stability tests at 77°F, 140°F

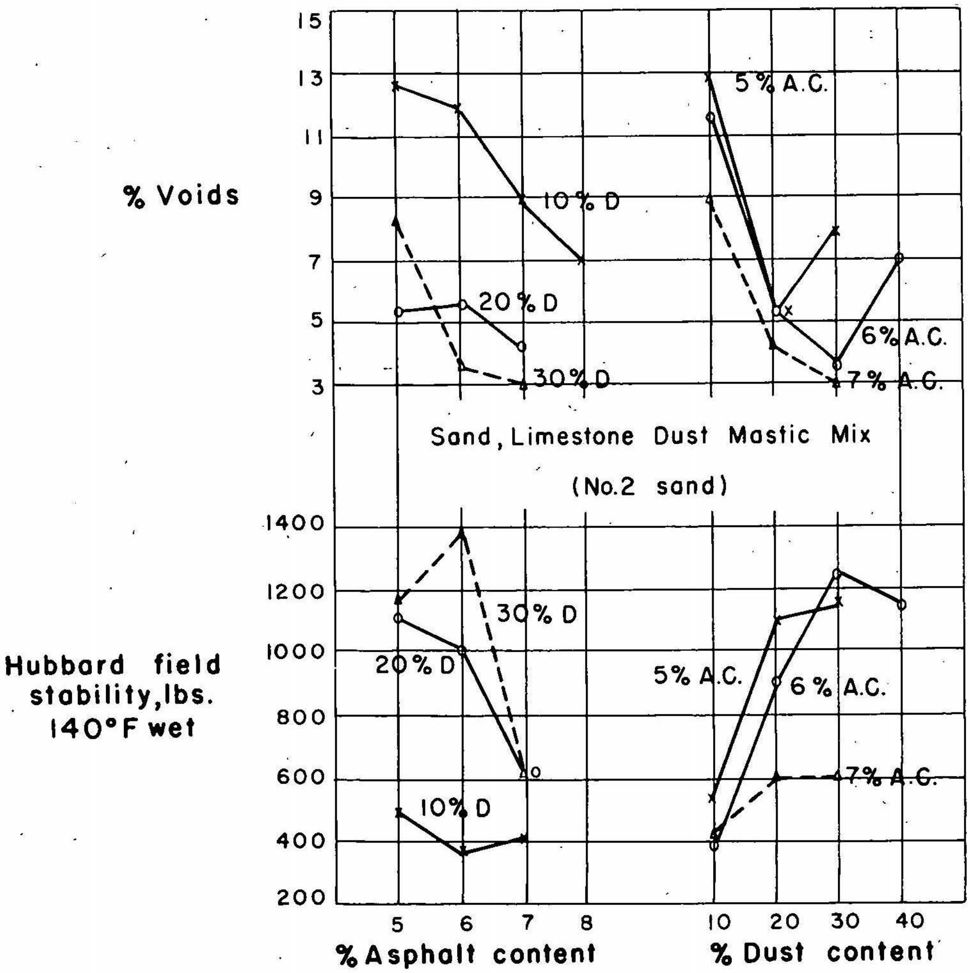

Fig. 17. Stability, voids, sand No. 2, limestone dust mix.

TABLE XVII. Sand and Limestone Dust Mastic Mix.

Mixes	Voids %	Hubbard-Field Stability lbs. 77°F. Dry	Hubbard-Field Stability lbs. 140°F. Wet
7.10; 5.90; 3.6	12.7	2650	920
7.20; 5.80; 3.6	7.4	3400	1350
7.30; 5.70; 3.6	7.0	3900	1600
7.10; 5.90; 3.7	11.7	2800	700
7.20; 5.80; 3.7	5.7	3700	1500
7.30; 5.70; 3.7	2.7	3800	1650
7.40; 5.60; 3.7	5.0	3850	1850
7.10; 5.90; 3.8	6.0	2900	680
7.20; 5.80; 3.8	2.6	2750	1050
7.30; 5.70; 3.8	1.5	2850	1100

TABLE XVIII. Freezing-Thawing. Sand, Limestone Dust Mastic Mix.

Mix	Volume Change		Moisture Content		
	Max %	Range %	Max %	Range %	
7.10; 1.90; 9.7	1.2	1.4	0.6	0.4	No Failure
7.20; 1.80; 9.7	1.2	1.2	0.5	0.3	" "
7.30; 1.70; 9.7	1.2	1.6	0.4	0.3	" "
7.10; 2.90; 9.5	3.8	7.6	0.4	0.3	" "
7.20; 2.80; 9.5	1.2	1.6	0.4	0.3	" "
7.30; 2.70; 9.5	0.8	1.2	0.5	0.4	Checks at 6 Cycle. Porous
7.10; 2.90; 9.6	1.2	2.0	0.5	0.4	No Failure
7.20; 2.80; 9.6	1.2	2.0	0.4	0.3	" "
7..30; 2.70; 9.6	—2.7	3.1	0.3	0.2	" "
7.40; 2.60; 9.6	0.8	1.6	0.4	0.3	" "
7.10; 2.90; 9.7	1.2	2.0	0.4	0.3	Checks at 6 Cycle. Porous
7.20; 2.80; 9.7	2.7	3.3	0.2	0.1	No Failure
7.30; 2.70; 9.7	2.8	2.0	0.1	0.1	" "
7.10; 2.90; 9.8	7.5	7.5	0.4	0.3	" "

TABLE. XIX. Freezing and Thawing. Sand, Limestone Dust Mastic Mix.

Mix	Volume Change		Moisture Content			
	Max %	Range %	Max %	Range %		
7.10; 2.90; 2.5W	0.8	0.8	0.6	0.4	O.K.	4 Cycles
7.20; 2.80; 2.5W	—0.8	0.8	0.3	0.2	O.K.	
7.30; 2.70; 2.5W	0.8	0.8	1.7	1.6	O.K.	
7.10; 2.90; 2.6W	0.8	1.2	0.3	0.2	O.K.	
7.20; 2.80; 2.6W	0.4	0.4	0.2	0.2	O.K.	
7.30; 2.70; 2.6W	0.4	0.4	0.3	0.2	O.K.	
7.40; 2.60; 2.6W	0.4	0.4	0.9	0.8	O.K.	
7.20; 2.80; 2.7W	0.9	0.4	0.1	0.1	O.K.	

TABLE XX. Sand and Loess Mastic Mixes.
150-200 pen A.C.

Mix	Voids %	Hubbard-Field Stability lbs.	
		77°F. Dry	140°F. Wet
8.10; 190; 2.7	16.5	2700	500
8.20; 1.80; 2.7	12.2	3600	850
8.30; 1.70; 2.7	16.4	4200	Swelled
8.10; 1.90; 2.8	17.4	2650	380
8.20; 1.80; 2.8	13.1	3400	800
8.30; 1.70; 2.8	12.7	4200	1100
8.40; 1.60; 2.8	11.0	4500	Swelled
8.10; 1.90; 2.9	13.8	3100	650
8.20; 1.80; 2.9	10.6	3350	1100
8.30; 1.70; 2.9	9.8	4350	1400
8.40; 1.60; 2.9	8.4	4550	Swelled
1.10; 2.90; 3.5	15.7	1800	480
1.20; 2.80; 3.5	11.3	2200	840
1.30; 2.70; 3.5	10.3	3300	720
1.10; 2.90; 3.6	10.3	1800	580
1.20; 2.80; 3.6	7.3	2700	920
1.30; 2.70; 3.6	9.0	3150	800
1.40; 2.60; 3.6	9.9	3500	Swelled
1.10; 2.90; 3.7	6.7	2000	540
1.20; 2.80; 3.7	3.6	2200	860
1.30; 2.70; 3.7	4.6	2700	860
1.40; 2.60; 3.7	8.9	3400	Swelled

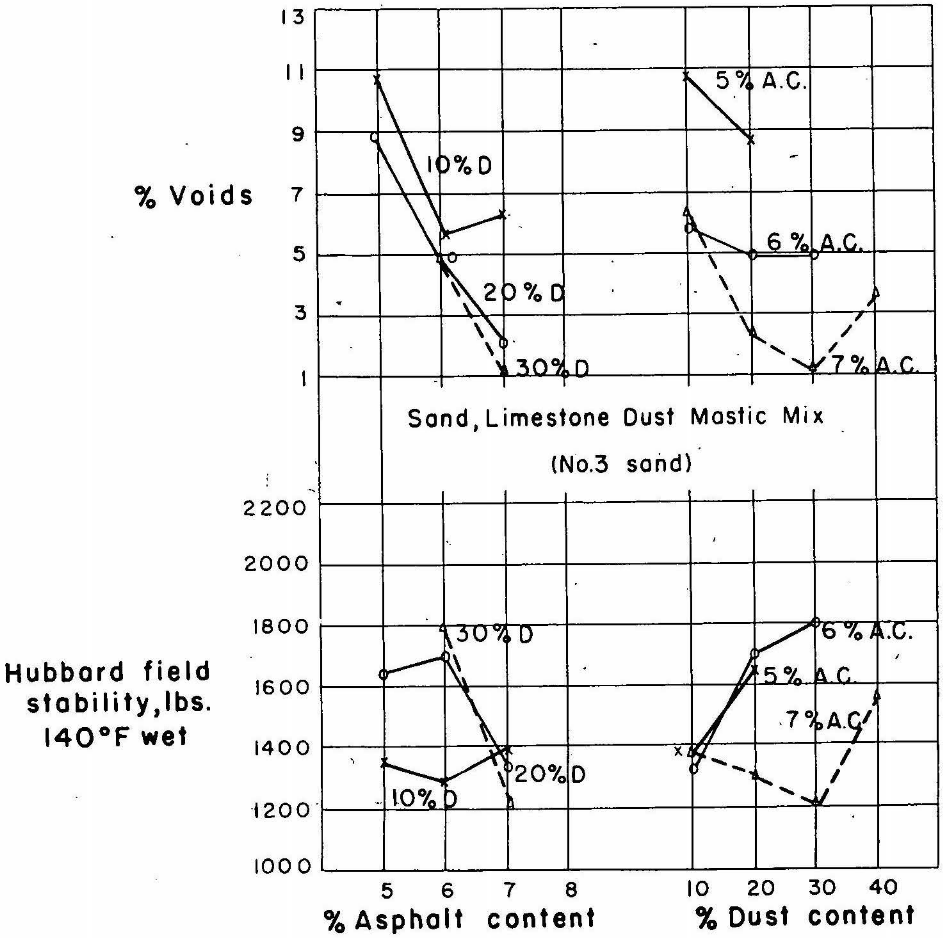

Fig. 18. Stability, voids, sand No. 3, limestone dust mix.

dry and 140°F wet, and void content determinations were made for each mix (figures 16, 17, 18, 19, and 20). For this group of eighty mixes the freeze-thaw test was not found critical, and was conducted upon selected mixes only.

Sand No. 1, a blow sand found naturally in many sections of Iowa and the United States, has a particle size distribution in which most of the particles are between the No. 40 and No. 80 sieves (table II). In a sand mastic mixture composed of this sand and limestone dust, the optimum dust content is about 30 percent at an optimum asphalt content of about 8 percent (figure 16). The stability of this sand mastic mixture is about 1200 pounds, and it has a void content of about 5 percent. It is suitable for a pavement carrying intensive mixed traffic[33].

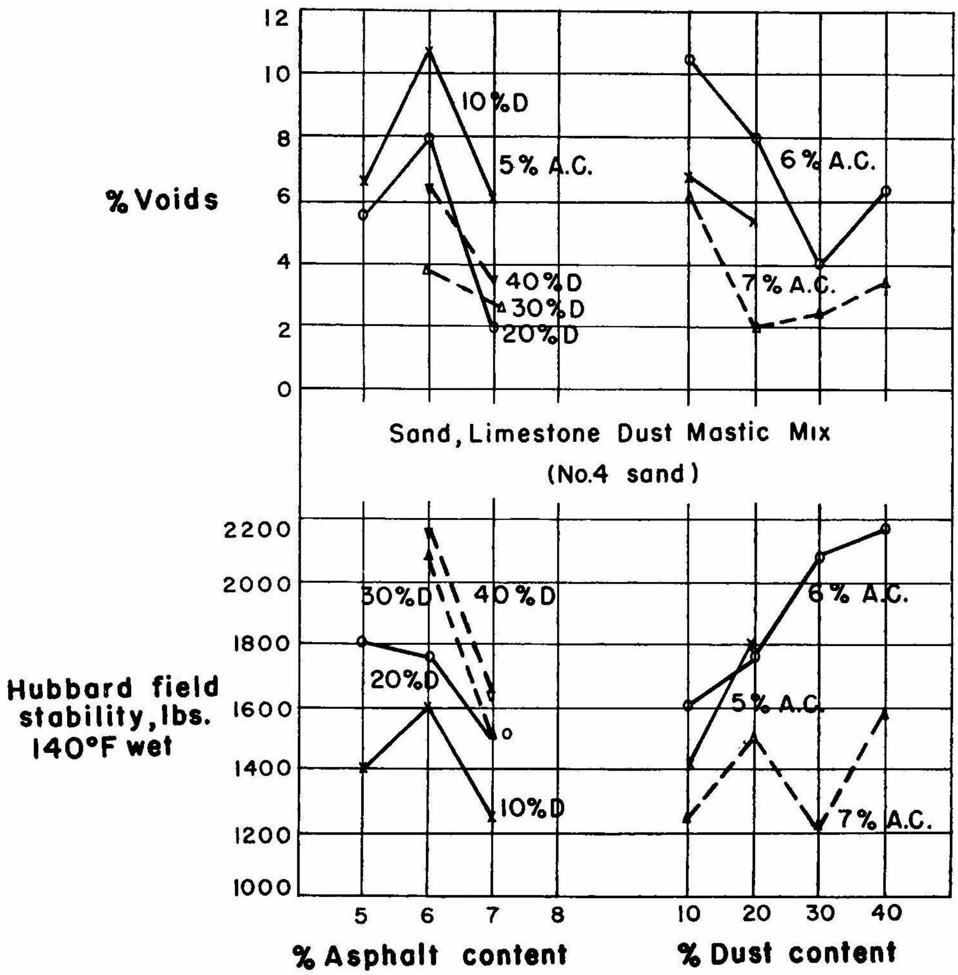

Fig. 19. Stability, voids, sand No. 4, limestone dust mix.

Most of the particles of sand No. 2, called a fine sand, are between the No. 10 and No. 40 sieves (table II). In a sand limestone dust mastic mix the optimum dust content is about 30 percent with an optimum binder content of 6 percent (figure 17). The stability of this sand mastic mix is 1350 pounds with 3 percent voids. It is suitable for a pavement carrying intensive mixed traffic.

Sand No. 3, called a concrete sand, is similar to Sand No. 2 in gradation. In a sand-limestone dust mastic mix using this sand, the optimum dust content is 30 percent with 6 percent asphalt content. This sand mastic mix has a stability of 1800 and a void content of 5 percent (figure 18). It is suitable for pavements carrying intensive mixed traffic.

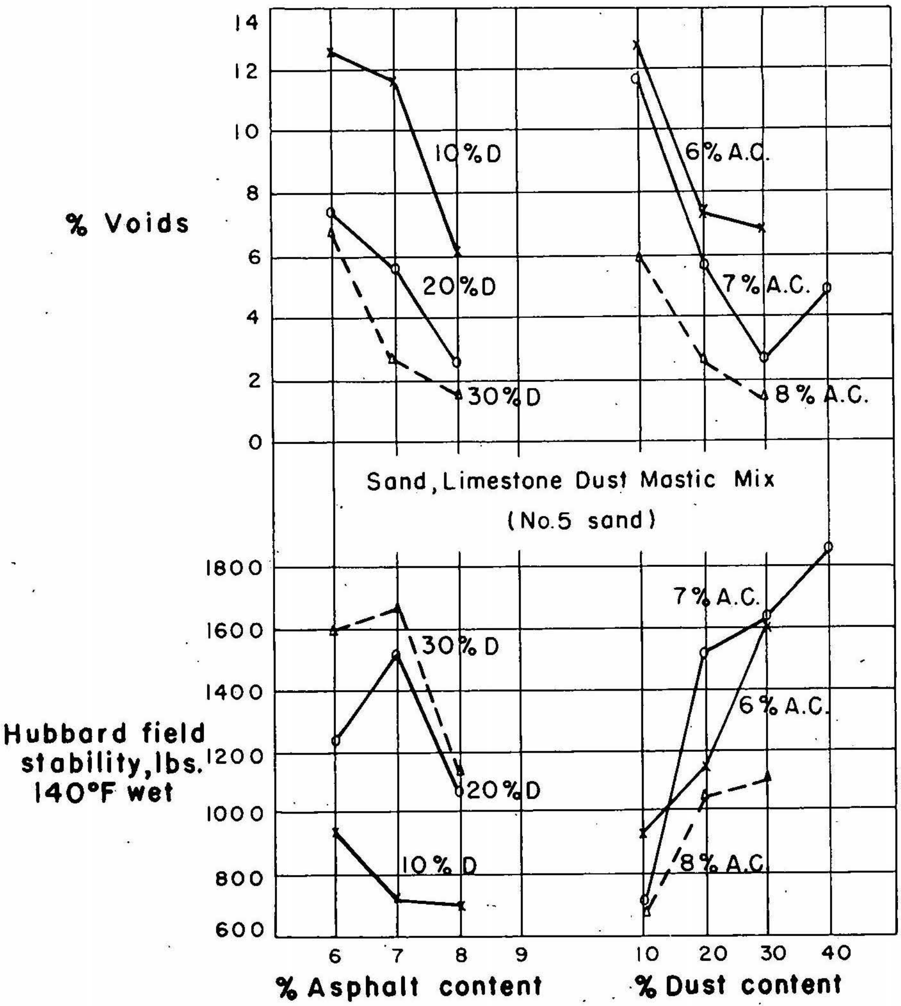

Fig. 20. Stability, voids, sand No. 5, limestone dust mix.

Sand No. 4, also called a concrete sand, is somewhat finer and more uniformly graded than sand No. 3. Sand mastic mixes using this sand and limestone dust have an optimum dust content of 30 percent with an asphalt content of 6 percent (figure 19). The stability of this mix is 2100 pounds, making it suitable for heavy traffic pavements. This high stability is probably due to the better gradation of the sand.

Sand No. 5, called "plaster sand" is finer than sand No. 4, but not quite as fine as Sand No. 1. A sand mastic mix using this sand and limestone dust has an optimum dust content of slightly over 30 percent at 7 percent asphalt content. The stability of this combination is about 1700 pounds (figure 20), thus it is suitable for intensive mixed traffic.

The optimum asphalt content in all of these mixes is 7 percent or less, which is about one-half of the required amount for the limestone dust mastic alone. It may be concluded that an asphalt paving mixture suitable for pavements carrying intensive mixed traffic may be prepared with local ungraded sands and limestone dust when such a mix is prepared by the atomization method.

Sand-Loess Mastic Mixes

Sands No. 1 and No. 2, which are very poorly graded, represent the gradation limits within which most local, ungraded sand will lie. When the laboratory supply of these sands was exhausted, sands No. 14 and No. 3, which have similar gradations, were used.

Sand No. 1, Loess No. 8 Mastic Mixes. In this combination of materials the optimum loess content is about 30 percent with 8 percent asphalt. The stability of such a sand-loess mastic mix is about 1300 pounds with 10 percent voids (figure 21), making it suitable for intensive traffic pavements.

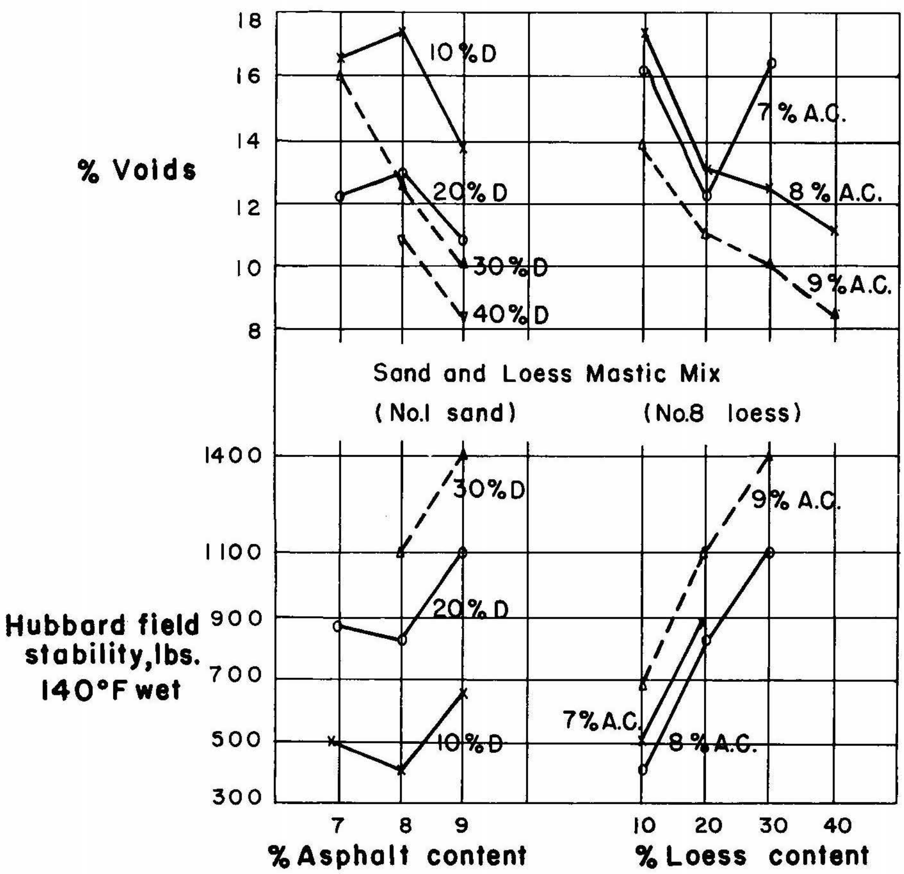

Fig. 21. Stability, voids, sand No. 1, loess No. 8 mix.

TABLE XXI. Freezing and Thawing. Sand Loess Mastic Mix.

Mix	Volume Change		Moisture Content		
	Max %	Range %	Max %	Range %	
1.10; 2.90; 3.5	1.5	1.1	0.8	0.6	No Failure 4 Cycles
1.20; 2.80; 3.5	2.8	2.8	1.1	0.9	" " " "
1.30; 2.70; 3.5	5.6	5.2	1.6	1.4	Slight Crumbling 3rd Cycle
1.10; 2.90; 3.6	+0.4	0.8	0.7	0.6	O.K.
1.20; 2.80; 3.6	—2.8	4.0	0.8	0.7	O.K.
1.30; 2.70; 3.6	4.0	4.0	1.5	1.3	Slight Crumbling 3rd Cycle
1.10; 2.90; 3.7	—1.2	0.8	0.5	0.4	O.K.
1.20; 2.80; 3.7	0.8	0.8	0.5	0.4	O.K.
1.30; 2.80; 3.7					

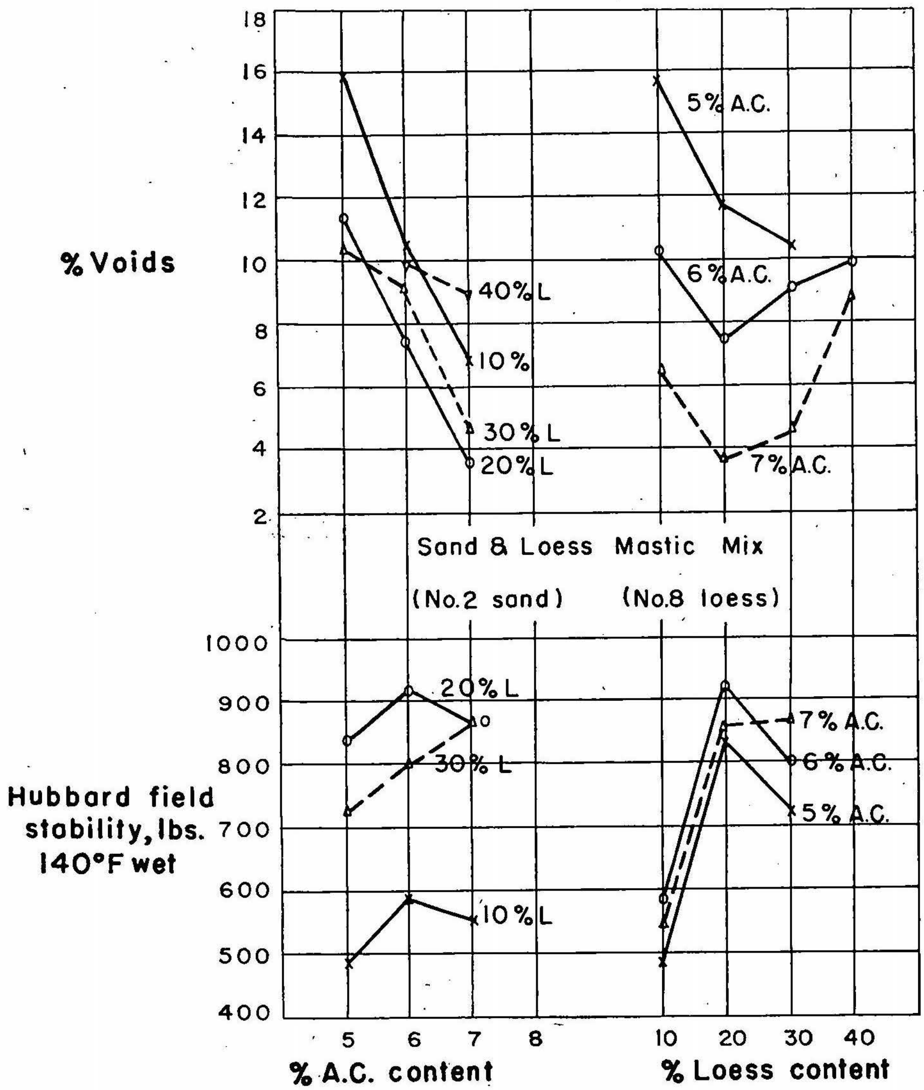

Fig. 22. Stability, voids, sand No. 2, loess No. 8 mix.

Sand No. 2, Loess No. 8 Mastic Mixes. In this combination of materials the optimum loess content is about 25 percent with 6 percent asphalt. The stability is 900 pounds and the void content is 8 percent, making the mix suitable for lightly travelled pavements (figure 22).

Sand No. 14, Loess No. 12 Mastic Mixes. This combination of materials has an optimum loess content of about 35 percent at an asphalt content of 8 to 9 percent. This sand-loess mastic mix has a relatively high stability of 2000 pounds and a void content of 12 percent. The apparently high void content is probably due to the coarser gradation of the loess. Under

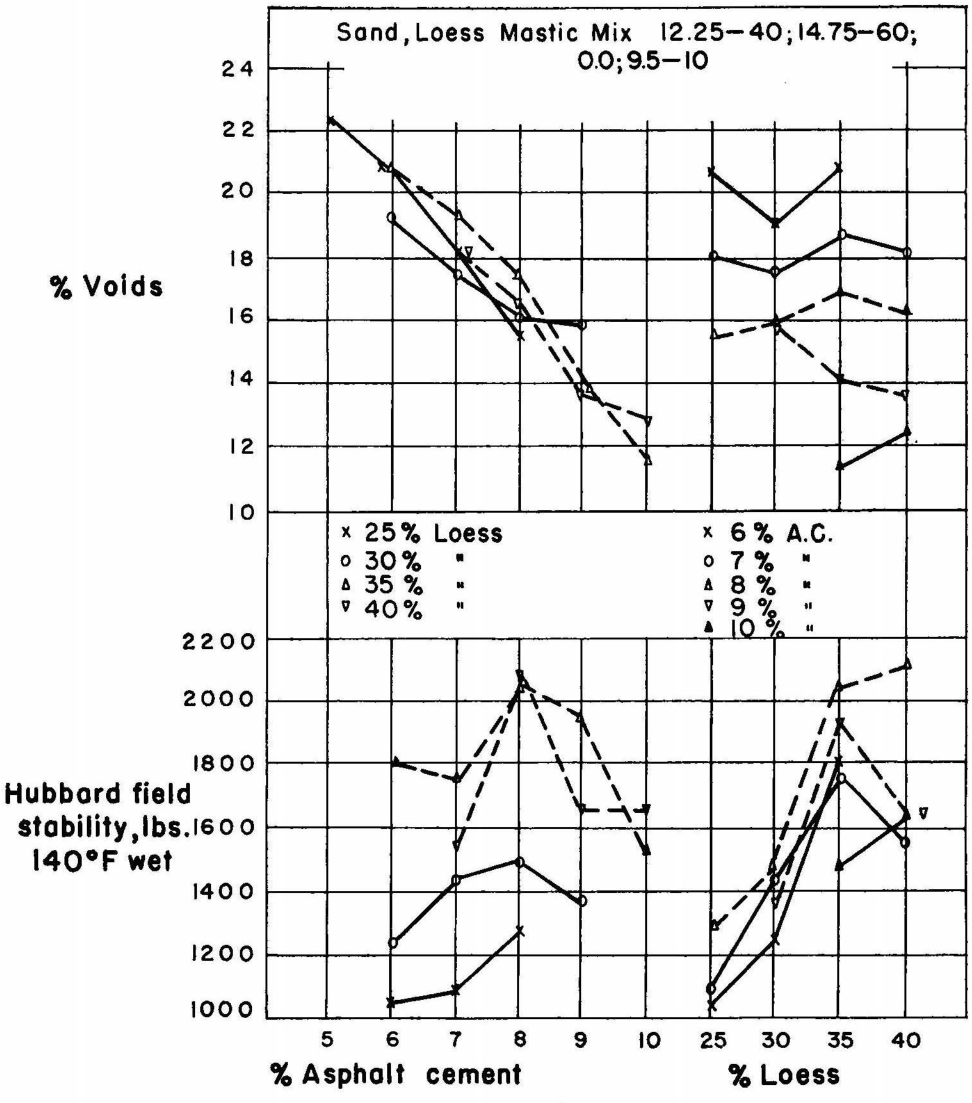

Fig. 23. Stability, voids, sand No. 14, loess No. 12 mix.

Hubbard-Field criteria, this mastic mix would be suitable for heavily travelled pavements. The behavior of this mix under traffic will be discussed later under Test Roads.

Sand No. 3, Loess No. 12 Mastic Mixes. For these materials the optimum loess content is about 30 percent with about 8 percent asphalt. The stability of such a sand-loess mastic mix is about 1700 pounds and void content about 6 percent (figure 24). It may be used for intensive mixed traffic pavements.

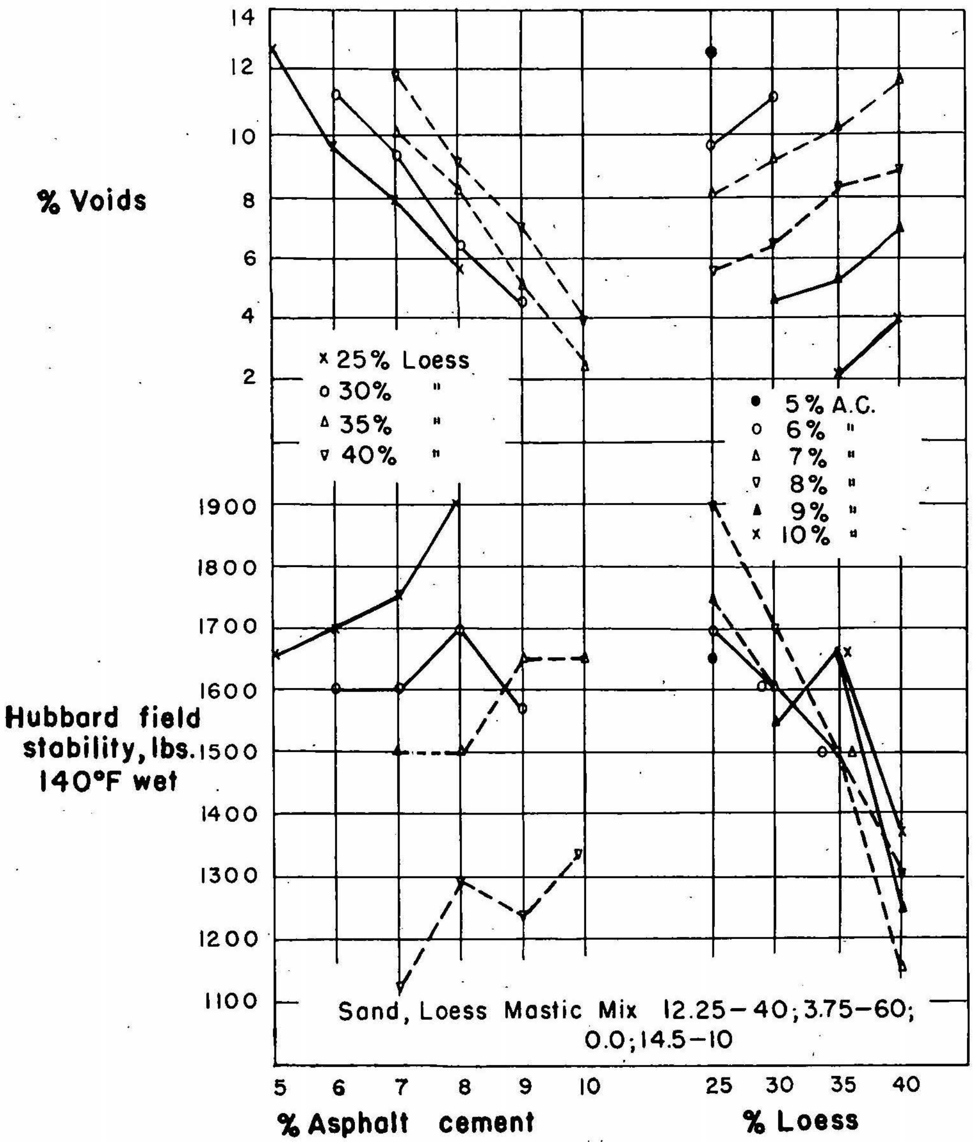

Fig. 24. Stability, voids, sand No. 3, loess No. 12 mix.

Sand-Dirt Mastic Mixes

Another abundant and cheap material is the soil of the B horizon lying under the top soil. Such a material may be composed of some sand, silt, and clay, with very little organic matter. For identification this material is referred to as "dirt". It pulverized easily in the commercial hammer-mill of the pilot plant. The material designated as Dirt No. 10 (table II) was used with various combinations of sands (figures 25, 26).

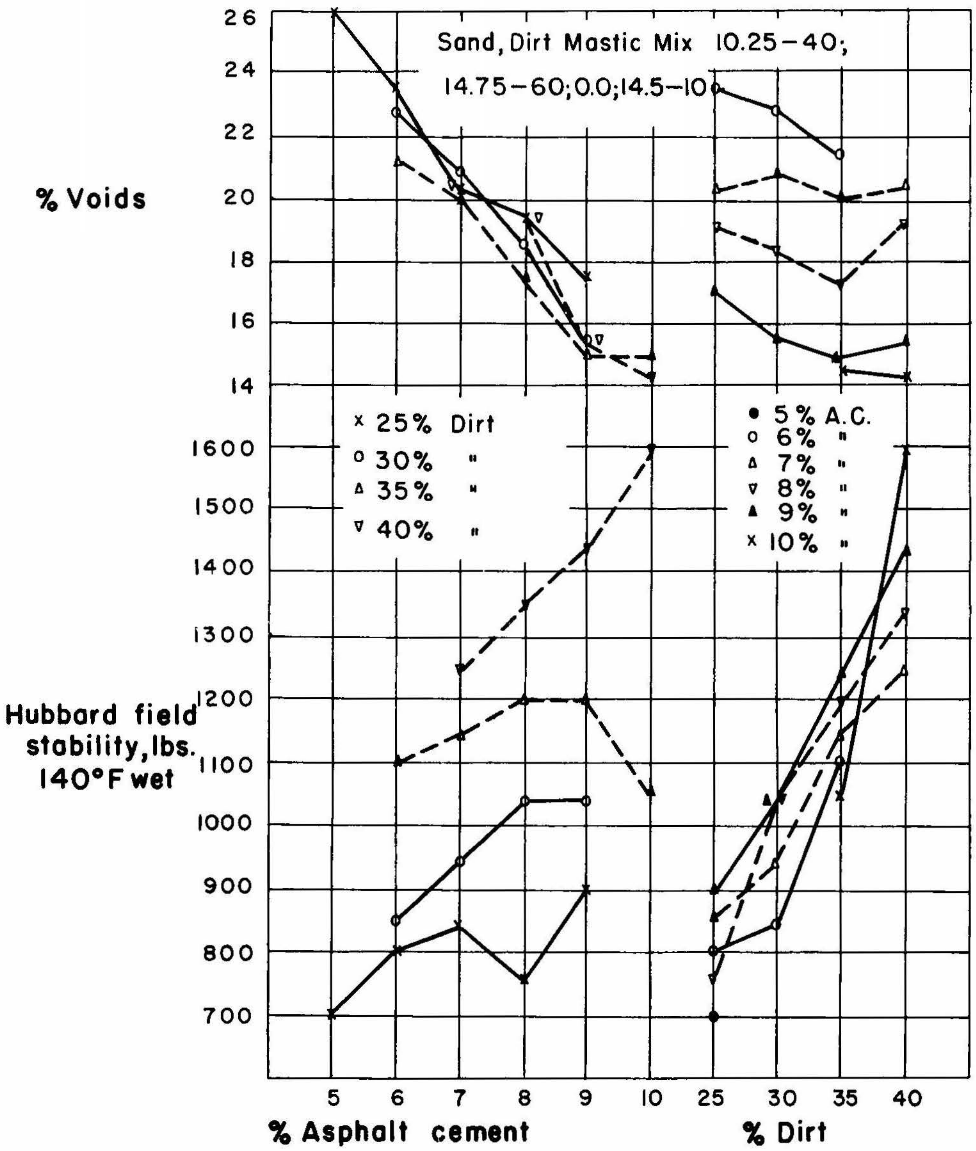

Fig. 25. Stability, voids, sand No. 4 dirt mix.

Sand No. 14, Dirt No. 10 Mastic Mix In this combination of materials the optimum quantity of Dirt is about 40 percent with an asphalt content of about 9 percent. Such a sand-dirt mastic mix has a stability of about 2100 pounds and 4½ percent voids making it suitable for heavy traffic pavements (figure 26).

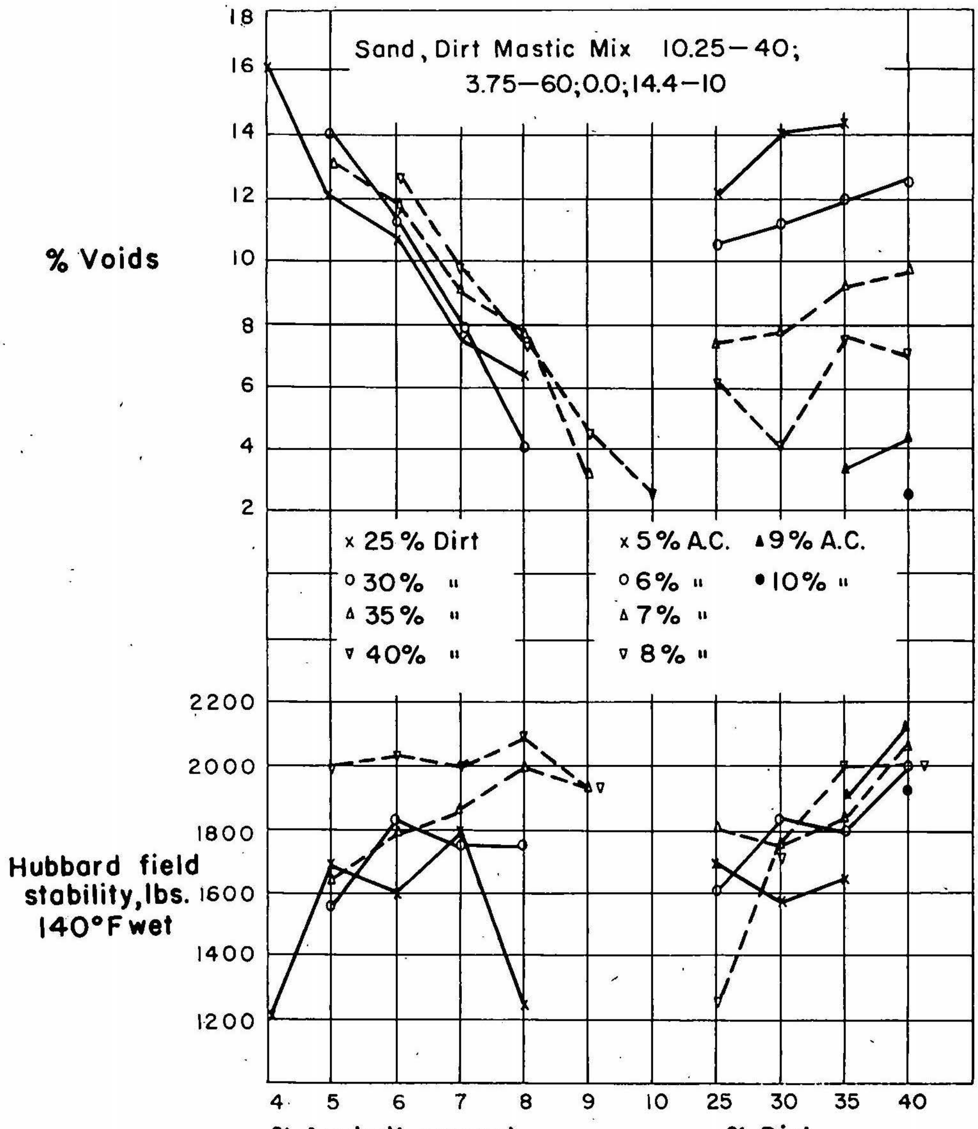

Fig. 26. Stability, voids, sand No. 3 dirt mix.

Mastic mixes of sand-dirt can be produced by the atomization process, and they may be used for light and heavily travelled roads. The results indicate that the gradation of the pulverized dirt was a little coarse for the fine sand but excellent for the coarse sand.

Gravel Mastic Mixes

Many areas in Iowa and around the country have abundant supplies of fine gravel, designated as Class B gravel in Iowa[20] (table IV). Tests were conducted to determine whether this material could be used with loess or dirt mastics satisfactorily. The stability of the mixtures was determined by the Marshall method.

Gravel No. 7, Loess No. 12 Mastic Mixes. Tests indicated an optimum loess content of 35 percent with an asphalt content of 9½ percent. The Marshall stability was 950 pounds. It showed 12½ flow, 7½ percent voids and a unit weight of about 131 pounds per cubic foot (figure 27). Under Marshall criteria such a mix would be suitable for heavily travelled highway pavements[18].

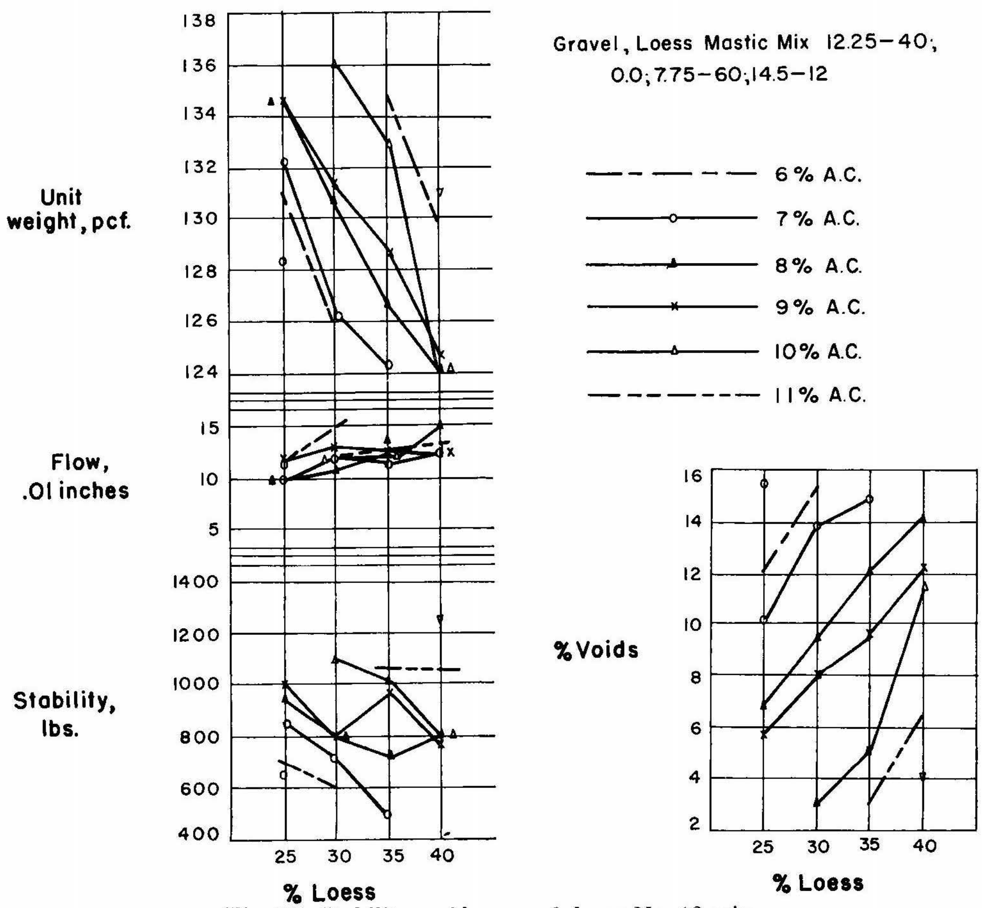

Fig. 27. Stability, voids, gravel, loess No. 12 mix.

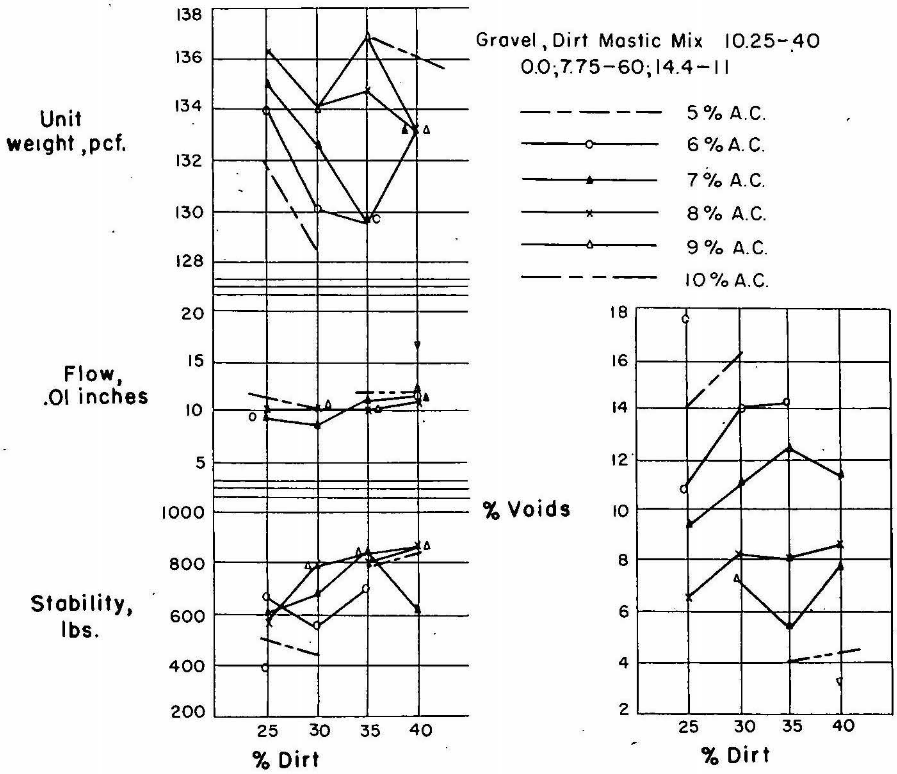

Fig. 28. Stability, voids, gravel, dirt mix.

Gravel No. 7, Dirt No. 10 Mastic Mixes. This combination of materials had an optimum dirt content of 35 percent with an asphalt content of 9 percent. The Marshall stability was 850 pounds, with a flow of 10, five percent voids and a unit weight of approximately 137 pounds per cubic foot (figure 28). This mixture is also suitable for heavily travelled highways.

Sand-Asphalt Mixes

Attention has been focused on the use of sand-asphalt mixes using local sands and various types of asphalts. Where sands are of unit size, very little success has been attained when usual mixing procedures were applied. Relatively well graded sands with 10 to 15 percent fines, however, generally showed good results. The atomization process for use in sand asphalt mixes was tested. The results indicated that the atomization process gave results similar to those of the conventional mixing process, in that relatively well graded sands containing some fines were required to produce satisfactory sand asphalt mixes.

ASPHALT PAVING MIXTURES PREPARED BY THE ATOMIZATION PROCESS

In the preparation of asphalt paving mixtures containing ungraded aggregates by the atomization method the more important factors are the gradation of the mineral dust, the properties of the asphaltic mastic, the function of the mastic in the mix, and the proportion of the various ingredients.

Preliminary laboratory tests indicated that some mineral dusts could not be used in making satisfactory mastics because of their extreme fineness. Since materials of such fineness are not readily available, and since normal processing of mineral dusts does not produce such fineness, the investigation was not carried any further. Mineral dusts having the gradation of limestone dust No. 7 (table II) appear to be the most desirable. This gradation, however, is not essential. What is essential is that the mineral dust must have enough material passing through the 200 mesh to result in at least 15 percent of such material in the total paving mixture. This is necessary if low void content is desired in mixtures containing very fine sand, such as blow sands.

The properties of the mastic are of great importance in ungraded aggregate mixes because the physical properties of the total paving mixture depends upon them to a large degree. The mastic must have enough strength to carry traffic loads, and must be resistant to climatic conditions. For the durability of the pavement each particle, rather than aggregations of particles, must be coated with a thin film of asphalt. The mastic in the mix bonds together the aggregate particles and fill the voids between the aggregates. The interlocking of the aggregates makes the mix stronger. The mastic may also serve as the main body of the mix with coarser aggregates added to increase bulk and to reduce asphalt content.

The quantity of the mastic in a mixture is important. The tests indicate that 30 to 40 percent of mineral dust with the proper binder content gives the best results. An interesting relationship appears in the sand limestone dust mixes (figures 16 to 20). The optimum percentage of mineral dust, plus the percentage of binder, plus the percent of voids in the compacted mix is about equal to the percentage of voids in the sand, as determined by the Chapman Flask method. This relationship is not as clear with other mineral dusts as it is with the sand-limestone, but it may be used initially in developing the actual design of the mix. Tests for proper design include those for stability, freeze and thaw, and moisture absorption.

DESIGN OF ATOMIZATION PROCESS MIXTURES WITH UNGRADED AGGREGATES

The steps in designing an asphalt paving mixture containing ungraded aggregates using the atomization process are as follows:

1. Determine whether or not a mastic may be formed of the selected mineral dusts and asphalt cement by the atomization process.
2. Prepare a series of mastics containing the mineral dust and a range of asphalt contents. Tests to determine the optimum asphalt content that will coat all dust particles, will give a Hubbard-Field stability of at least 1000 pounds, will resist twelve cycles of freezing and thawing, and will have a moisture absorption of not more than 2 percent.
3. Determine the approximate percentage of voids in the ungraded aggregate by the Chapman Flask or other suitable method.
4. Calculate the approximate proportion of mineral dust, asphalt, and ungraded aggregate when the voids in the ungraded aggregate are just under-filled by the best mastic as determined in 2.
5. Prepare aggregate mastic mixes with proportions of mineral dust and asphalt slightly below and slightly above the quantities calculated in 4.
6. Determine the best proportion of materials as indicated by stability, voids, and freeze and thaw tests.
7. Prepare an aggregate mastic mix of optimum proportions and check properties for suitability as a paving mixture.

TEST PAVEMENTS

Laboratory tests are not dependable in evaluating field performance of paving mixtures. This is particularly true in ascertaining the effects of traffic wear. A newly developed laboratory process must be tested for commercial practicability and economic feasibility before it can be accepted. The mixes and procedures developed were therefore field tested at first in small pilot plants and field test sections. Then the tests were made in larger pilot plants and larger test sections, and finally in full scale production plants and large test roads.

The first and second groups of test pavements were laid on various streets on the campus of Iowa State University where they could be observed daily. This field testing was done during 1953 and 1954. In 1957 a number of full scale test roads were sponsored by the Iowa Highway Research Board in cooperation with various counties. They were built by contractors as research projects HR-44, in Ringgold County, HR-56, and HR-57 in Carroll County, and HR-58 in Audubon County.

Campus Road Test, 1953

The first group of test roads was laid during the summer of 1953 on the campus of Iowa State University to test under actual traffic the wear resistance of mixes developed in the laboratory (figures 29, 30)[11].

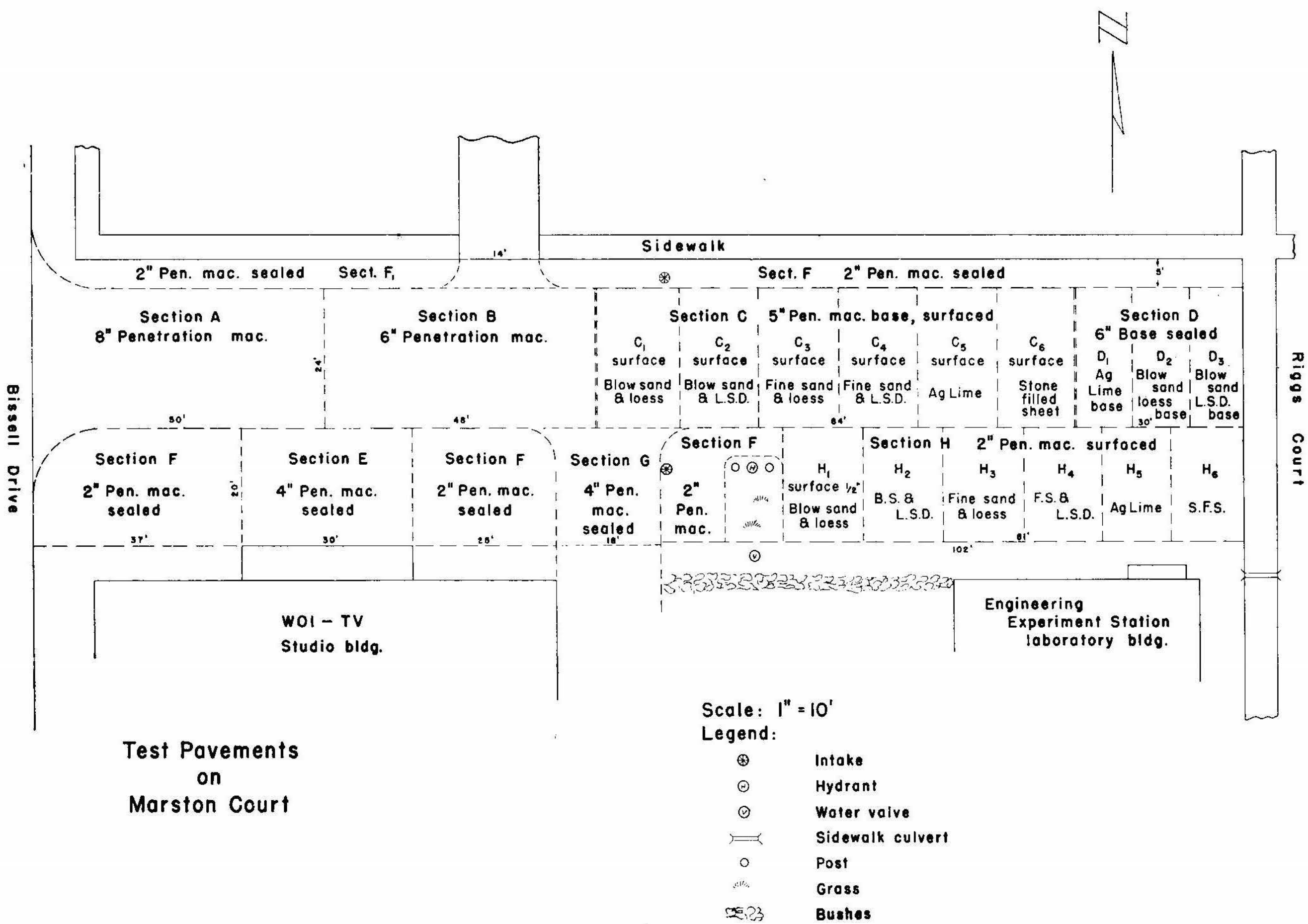

Fig. 29. ISU Campus, 1953.

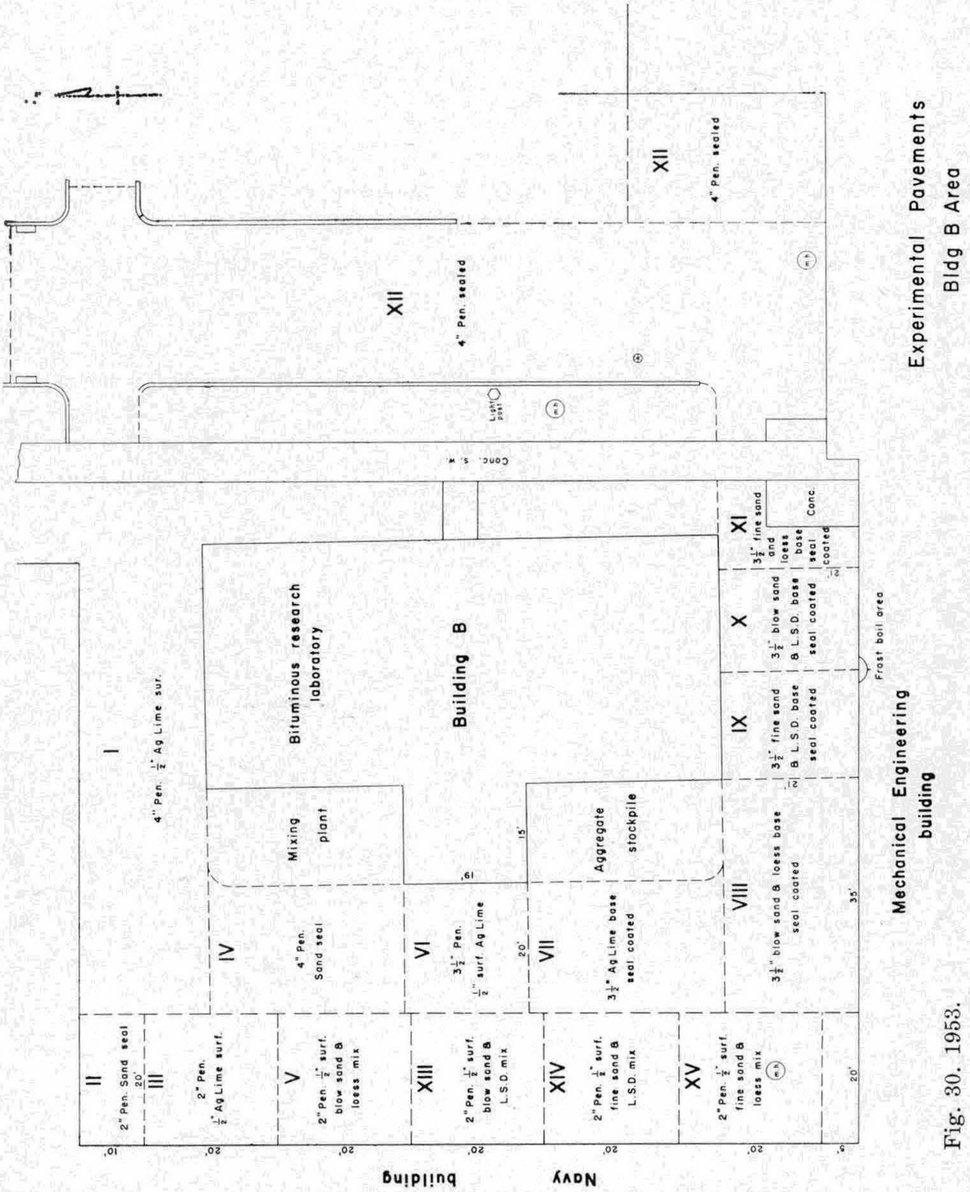

Fig. 30. 1953.

The loess and dirt used as the mineral dust in some of the mixes was dried and heated in an oven to 350°F., and then passed through an 8″ laboratory pulverizer. The final gradation of the mineral dust corresponds with that identified as No. 8 in table II.

The various mixes were prepared in a Barber-Greene Mixall adapted to the atomization process (figure 31). The mixer was set up as a small stationary pilot plant (figure 32).

The required quantity of sand to make a 300 pound batch was measured volumetrically into the skip of the Mixall. This material was then discharged into the dryer, where it was dried and heated to 350°F. The hot sand was then discharged into the mixer, where the required quantity of mineral dust was added at atmospheric temperature, about 80°F. After 10 seconds of dry mixing the atomized asphalt in the proper quantity was added, and mixing was continued for 30 seconds. The finished mix was delivered in wheelbarrows, spread by hand, and compacted by pneumatic and steel rollers[11]. All the work was done by university students.

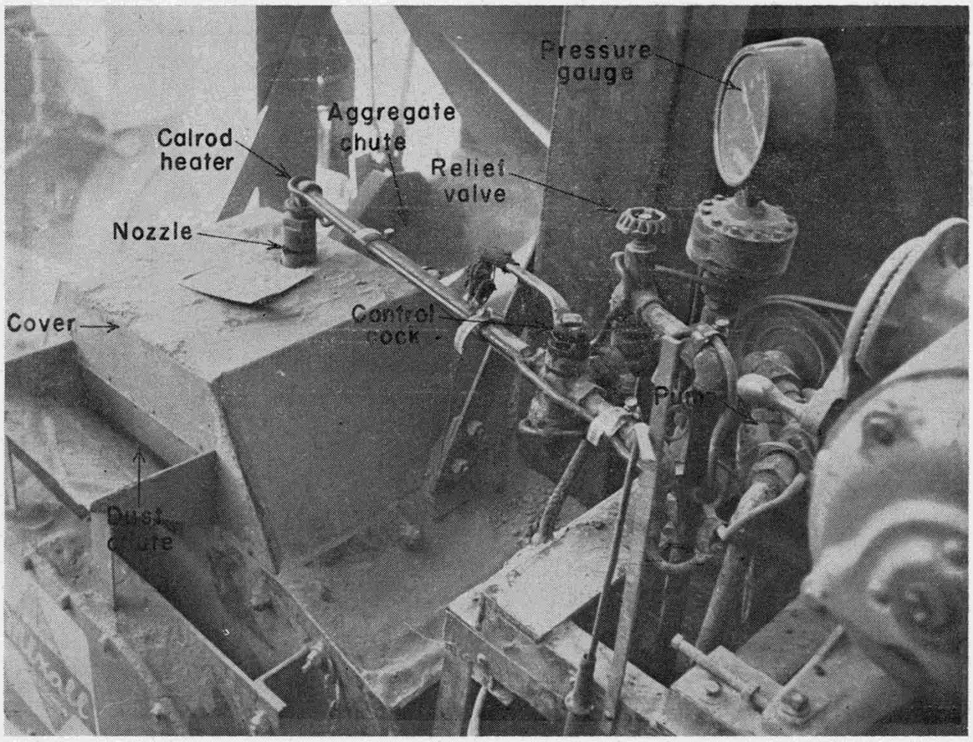

Fig. 31. Atomization spray system on B-G Mixall.

The following mixes were prepared and laid:

(1). Blow sand-loess mixture containing 75% sand, 25% loess with 6% 150-200 pen. A. C.

(2). Fine sand and loess mixture containing 75% sand, 25% loess with 6% 150-200 pen. A. C.

(3). Blow sand and limestone dust mixture containing 75% blow sand, 25% limestone dust and 5½% A. C. The asphalt content of this mix is quite critical.

(4). Agricultural limestone mixture containing 15% fine sand, 85% ag lime and 6% 150-200 pen. A. C.

These test sections were observed for one year under traffic which varied from 200 to 3000 vehicles per day. All the test sections performed satisfactorily.

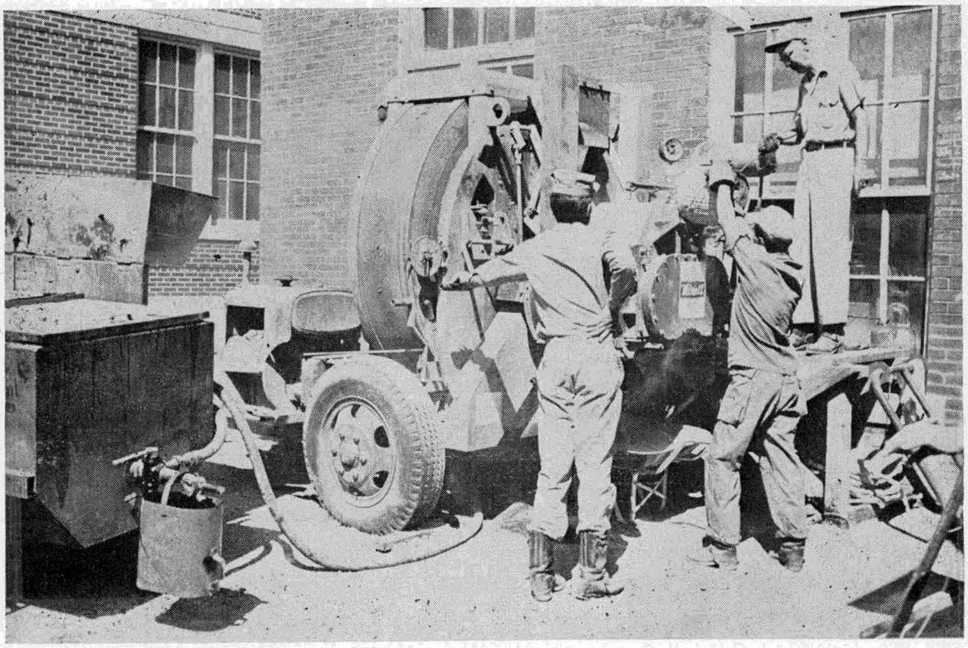

Fig. 32. B-G Mixall in operation.

Campus Test Road, 1954

After the test sections laid in 1953 had served satisfactorily for one year, they were removed and replaced by larger sections. The mixes were prepared in a larger pilot plant, and were laid during the summer of 1954 by student labor[12].

Since this test road required about 60 tons of pulverized mineral dust, this test provided an opportunity to check the economic feasibility of preparing such material. With the cooperation of the Iowa Manufacturing Co. a full scale pilot plant was set up. This plant was a 25 ton, rotary drum dryer with a standard cold feed and a hot elevator, which discharged into an 18 inch hammermill pulverizer with ½ inch manganese bars set 1/16 inch apart, mounted on a platform for discharging into barrels (figure 33).

The raw loess No. 12 and dirt No. 10 containing about 19 percent moisture were fed into the dryer at a rate which reduced the moisture to about 10 percent and heated the material to about 350°F. The dried material was then fed to the hammermill where the moisture was reduced to less than ½ percent, and a gradation shown in table II was secured

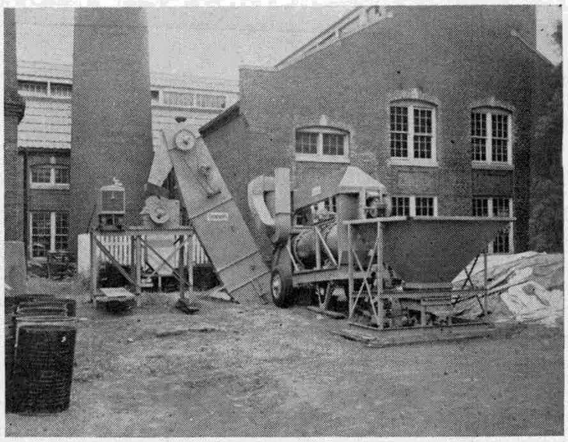

Fig. 33. Commercial mineral dust pulverizing pilot plant.

The capacity of this unit operated by student labor was about six tons per hour. The operation of this unit indicated that loess and dirt could be pulverized into a mineral dust commercially and economically.

The mixes used in this test pavement were also prepared in a Barber-Greene Mixall adapted to the atomization process and operated as a portable unit at the site of the paving (figure 34). The proper quantity of un-

Fig. 34. Putting mineral dust into mixer.

graded aggregate to provide a 200 pound batch was measured volumetrically into the skip of the machine. The material was then dumped from the skip into the drier, where it was dried and heated to about 350°F. After heating, the material was discharged into the mixer and the proper quantity of mineral dust was added immediately. A 15 second dry mix period was used to permit the mineral dust to heat up to the aggregate temperature, then the proper quantity of asphalt was added in an atomized form. As soon as the asphalt had been introduced into the mix, the mix was discharged into a wheelbarrow. A 200 pound batch was prepared in about

Table XXII. Properties of Test Pavement Mixes in the Campus Test Road (1954).

Section No.	Lift*	Description	Code	Lab. Compacted Stability‡	Lab. Compacted Voids	Cores Voids
1 & 2	Top	Agricultural Limestone	0.0; 6.85 + 14.15; 0.0; 13.7	2400	12.0%	15.6
	Middle		0.0; 6.85 + 14.15; 0.0; 13.6½	2900	13.5%	21.8
	Bot.		0.0; 6.85 + 14.15; 0.0; 12.6	2650	14.7%	22.7
3	M & T	Blow Sand Loess Mastic	12.30; 14.70; 0.0; 11.8	1340	19.0	19.9
	D.	Mix	12.30; 14.70; 0.0; 13.7½	1250	19.4	25.5
4	T & M	Fine Sand Loess Mastic	12.30; 3.70; 0.0; 13.8	1600	8.0	13.1
	B.	Mix	12.30; 3.70; 0.0; 13.7½	1250	13.4	15.5
5	T.	Blow Sand Dirt Mastic	10.30; 14.70; 0.0; 14.7	2010	18.9	26.8
	B.	Mix	10.30; 14.70; 0.0; 14.7	1650	17.6	32.6‡
6	T.	Fine Sand Dirt Mastic	10.30; 3.70; 0.0; 14.7	1900	6.8	14.0
	B.	Mix	10.30; 3.70; 0.0; 14.7	1600	7.0	17.6‡
7 & 8	T.	Gravel Loess Mastic	12.25; 0.0; 7.75; 11.7	1130	9.4	16.6
	B.	Mix	12.25; 0.0; 7.75; 11.7	1100	9.4	18.3
9	T.	Stone Filled Blow Sand	12.19; 14.46; 8.35; 11.7	780	18.0	19.31
	B.	Loess Mastic Mix	12.19; 14.46; 8.35; 11.6½	860	15.0	17.0

*Indicates top, middle, or bottom lift of pavement.
†Stability in pounds Hubbard-Field, Section 7, 8, 9, Marshall.
‡Bottom lifts compacted by Jackson Vibrator due to restricted area.

ninety seconds with an average output of about three tons per hour. About 320 tons of mix were prepared in this manner for the test road. Until 15 percent sand was added, the agricultural limestone, which frequently had as much as 20 percent moisture, caused some drying difficulties and created a serious dust nuisance.

The mixes were discharged into wheelbarrows, wheeled to the paving area and dumped. The mix was then spread and raked by hand to a depth of 3 inches for a 2 inch compacted depth and 4½ inches for a 3 inch compacted depth (figure 35). The mix was then compacted by an 8 to 12 ton tandem roller. Each lift was laid on the lower lift without a tack coat, though several days elapsed between some lifts. Sections 1, 2, 3, 4, and 7 (figure 36), were laid in three two-inch compacted lifts, and sections 5, 6, 8, and 9 were laid in two three-inch lifts. The entire pavement was laid upon an untreated, natural ground road-bed, which had been graded and rolled.

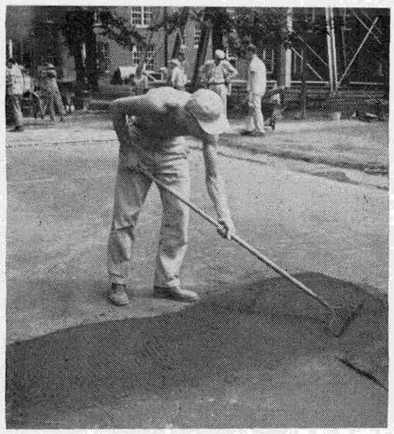

Fig. 35. Laying a test pavement by hand.

Samples representative of each mix laid in the several lifts were obtained for testing (table XXII).

This test pavement is subjected to about 3000 vehicles per day with a small portion of heavy delivery trucks. After about three months in service sections 5 and 9 showed some traffic wear. These sections were then sealed with a light sand seal. The exceptionally satisfactory service given by these test sections for about 2½ years prompted the construction of additional test pavements through normal contracting procedures.

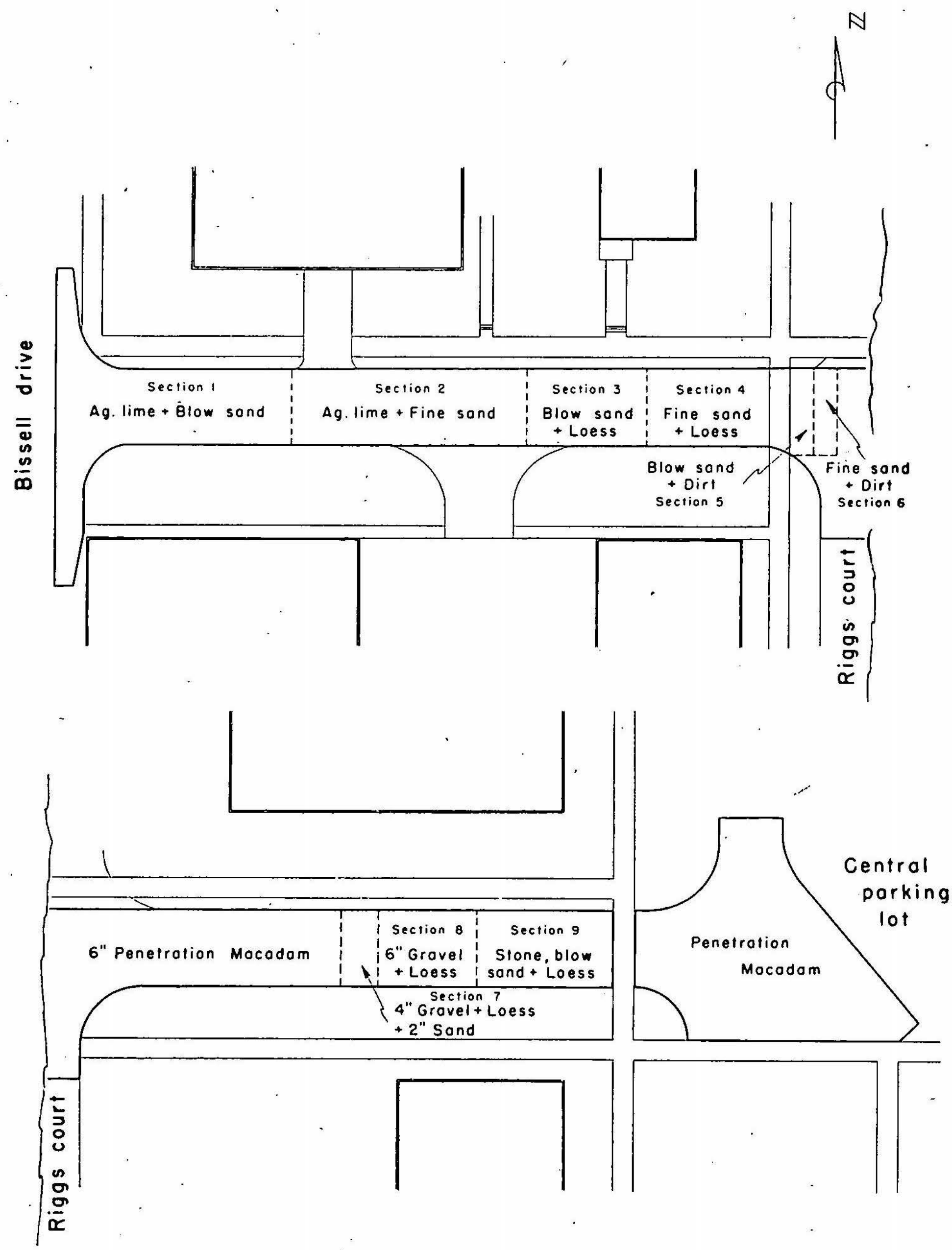

Fig. 36. Campus test road, 1954.

TABLE XXIII. Test Roads Built by Iowa Highway Commission Contracts

Project	Type of test	Length of road	Road type	Location	Year
HR-44 SN-1669	Atomization Process (& Foamed Asphalt	1 mile 6 miles	Farm to Market	Ringgold Co.	1957
HR-56 SN-821	Atomization Process	2 miles	Farm to Market	Carroll Co.	1957
HR-57 TP-1-57	Atomization Process	2 miles	Farm to Market	Carroll Co.	1957
HR-58 SN-242	Atomization Process	2.5 miles	Farm to Market	Audubon Co.	1957

Ringgold County Test Pavement, 1957

The Ringgold County Test Road was the first of several test roads constructed by the Iowa Highway Commission (table XXIII) using local ungraded aggregate mixes prepared by the atomization process. The test was sponsored by Ringgold County and the Iowa Highway Research Board. This road was built under regular contract as Iowa Highway Research Board Project HR-44 (Iowa Highway Commission Project SN-1669) on county trunk road "A" from S ¼ Cor. Sec. 6-67-29 north to U. S. 169 in Mount Ayr.

The first part of this project was to determine whether the atomization process could be used in a continuous type plant. In the second part the full length of six miles of test road was constructed.

The first part of this project was undertaken under a negotiated contract with the Concrete Materials Company of Cedar Rapids, Iowa. Under the contract the Concrete Materials Co. erected a Cedar Rapids continuous plant in their quarry ten miles south of Mount Ayr. The atomization unit adapted to this plant was furnished by the Barber-Greene Company, and the soil pulverization unit was furnished by the Iowa Manufacturing Company.

Since the Concrete Materials Company quarry had a large stockpile of agricultural limestone that had been accumulating for a number of years, the plant and process were checked out with this material as a unit aggregate. Other mixes were also prepared including a Class B asphaltic concrete using run of crusher aggregate, and a similar mix with the addition of a small quantity of pulverized Kansas till.

Because the stockpile of ag lime had been accumulating over a period of years, it was well saturated with moisture, as high as 16 percent. Handling and drying this material was sometimes difficult. Special vibrators were required to prevent jamming of the material in the cold bin and feed. Drying was dusty, and the fines in the material tended to pelletize. But most of the pellets were broken up in the mixer and had little effect on the mix. When fresh ag lime direct from the crusher was used these problems disappeared.

The Kansas till was processed by several passes of a Seaman Andwall Pulvermixer for preliminary pulverization and aeration. Due to the heavy rains before the work started the moisture content of the till was high and aeration was difficult. The aerated till was then passed through a grizzly and was dried to about 10 percent moisture, then it passed through a hammermill. Because the till was about 56 percent clay, the resultant material was buck-shotted by the pulverizer. Although the pulverization was unsatisfactory, the results obtained indicated that the problems could be overcome by redesign of the pulverizer system.

It was found that the plant, which was started on April 25, 1957, could be satisfactorily operated with the atomization process. Nine atomizing nozzles operated at a pressure of 240 pounds, with asphalt cement 150 to 200 penetration grade at 280°F and aggregate at 325°F. With the estimated asphalt content of the ag lime mix at 9 percent, and the mixer operating at 375 feet per minute peripheral speed, the plant output was 90 tons per hour. An excellent mix having a Hubbard-Field stability of about 2500 pounds was produced.

The trial mixes prepared during the first part of this project were laid on the county trunk road "A" for a distance of one mile, six miles south of Mount Ayr. These mixes were very sensitive to rolling temperature, particularly when rolled with an 8 to 12 ton tandem steel roller. Rolling procedure was developed to include pneumatic rolling at a temperature of 200°F and steel rolling at a temperature of 100°F.

The second part of this research project, HR-44, involved the construction of six miles of paving using materials and specifications developed during the first part of the project. A separate construction contract was awarded in the normal manner for this six miles.

The paving plant used for the production of asphaltic concrete on this project was modified to include atomizing nozzles, and the pump was set to supply 100-120 penetration asphalt heated to between 285°F and 320°F at a rate of not less than 90 gallons per minute. The peripheral speed of the tip of the mixing paddles was set at not less than 390 feet per minute.

As constructed, the experimental sections may be described as follows:

Section A. Six inches of fine graded asphaltic concrete produced by the impact method using agricultural limestone. Approximate length of section: 2 miles.

Section B. Four inches of ¾ inch maximum size asphaltic concrete topped with 2 inches of fine graded asphaltic concrete (same mix as Sec. A), all produced by the impact method. The aggregate for the ¾ inch asphaltic concrete was produced under specifications for rolled stone base material. Approximate length of section: 2 miles.

Section C. Four inches of rolled stone base covered with 2 inches of fine graded asphaltic concrete (same mix as Sec. A) produced by the impact method. Approximate length of section: 2 miles.

Fine Graded Asphaltic Concrete. The fine graded asphaltic concrete used in all three sections had the following characteristics:

Gradation of Agricultural Limestone

Sieve No.	*Percent Passing*
4	98-100
8	98-84
30	50-38
50	32-10
100	21-8
200	16-7 (Average 13.2)

Asphalt content by extraction: 4.7% to 9.8%—average 7.9%. Hubbard-Field stability at 140°F wet: 2150 lb. to 5975 lb.—average 3460 lb. Voids in compacted mix: 2.0% to 13.2%—average 7.3%.

Asphaltic Concrete—¾" Maximum. The asphaltic concrete produced with rolled stone base aggregate had the following characteristics:

Gradation of Rolled Stone Base Aggregate Used in ¾ in. Maximum Asphaltic Concrete

Sieve	*Percent Passing*
¾ in.	98-96
½ in.	95-81
⅜ in.	83-65
4	58-39
8	38-26
30	23-12
50	20-10
100	19-7
200	18-6 (Average 8.4)

Asphalt content by extraction: 4.8% to 6.4%—average 5.6%. Marshall stability: 635 lb. to 2550 lb.—average 1070 lb. Voids in compacted mix: 5.3% to 13.9%—average 8.3%.

Evaluation. Although some difficulties were experienced, the impact process was judged to be successful and a good road was secured. After two and a half years of service during which the road carried a heavy volume of trucks hauling crushed stone from the quarry, Mr. M. A. Rubek, County Engineer of Ringgold County reported as follows[31]: ". . . basically our asphaltic bituminous project is a success, and this type of construction has great possibilities in the State of Iowa."

Carroll and Audubon County Tests, 1957

In 1957 contracts were let for three additional experimental projects using the impact method for the production of asphaltic concrete. Two of these projects were in Carroll County, the third in Audubon County.

They are identified as follows:

Research Project Number	*Construction Project Number*	*Location*
HR-56	SN-821	Carroll County—Willey north approximately 2 miles.
HR-57	TP-1-57	Carroll County—from S.W. Corner of Sec. 15-82-33 on County road "D" north approximately 2 miles
HR-58	SN-242	Audubon County—from Gray east to junction of U. S. 71 approximately 2½ miles.

The plant requirements were the same as for the Ringgold County project. For all three projects the asphaltic concrete was produced from fine graded gravel obtained from a pit in Carroll County, loess soil from Carroll County and asphalt cement, penetration grade 100 to 120. Gravel particles larger than ¾ inch were crushed and returned to the mix. The loess soil was dried and pulverized so that no lumps were retained on the No. 4 sieve and not more than 50 percent of the soil was retained on the No. 200 sieve.

The contractor set up a Pioneer continuous type asphalt plant in an area adjacent to the gravel plant. The asphalt plant was adapted to the atomization (impact) method by the same unit and spray bar used on the Ringgold County project. This plant produced the mixes at the rate of 150 tons per hour for all three projects.

After several unsuccessful attempts, this contractor developed an efficient, and inexpensive method of pulverizing the loess. This method is as follows: The loess was excavated from the designated pit by a dragline and transported to the plant. The raw loess contained as much as 18 percent moisture at times. The loess was passed through a rotary drum dryer where the moisture content was reduced to about 10 percent and the larger lumps were broken down. After drying, the hot loess was passed over a 3″ screen, then into an ordinary feed mill rotating at 3500 rpm and fitted with a 1/16″ screen. This feed mill satisfactorily pulverized the loess to meet specifications at the rate of about 25 tons per hour. The pulverized loess, which had about 5 percent moisture, was fed to a bin from which it was proportioned and fed into the hot elevator of the plant. When the pulverized loess came into contact with the hot gravel in the hot elevator, its retained moisture was quickly evaporated. The hot, dry blend of aggregate and filler as fed into the mixer contained about 19 percent loess.

The analysis of the mix secured by extraction of samples taken from the plant and road were as follows:

Gradation % Passing	*Project* TP-1-57, Carroll	SN 821, Carroll	SN 242, Audubon
No. 4 sieve	89-84	92-83	96-85
No. 8 sieve	82-76	85-76	87-78
No. 30 sieve	58-51	58-50	61-48
No. 50 sieve	35-29	34-28	35-25
No. 100 sieve	19-15	18-13	17-12
No. 200 sieve	13-9	12-8	13-8
% A C	Av 7.6 (6.1-8.6)	Av 7.5 (6.1-9.0)	Av 7.4 (6.5-8.5)
Marshall Stability	Av 1436 (750-1700)	Av 1105 (750-1700)	Av 1340 (780-1740)
% Voids	Av 12.2 (9.0-17.5)	Av 11.7 (9.0-17.5)	Av 14.2 (9.5-18.7)

A relatively wide range in the gradation of the aggregates can be noted from the above table. It is also noted that the range is widest on Project SN-242. This variation may be attributed to stockpile segregation. The gravel was stockpiled for all three projects at one time. Since Project TP-1-57 was built first, followed by SN-821 and SN-242, the range in variation as the stockpile was depleted became wider.

During production the impact unit gave some trouble, as indicated in the wide range of asphalt content in the samples tested. This variation in gradation and asphalt content is responsible for the variations in stability and void content noted above and also for the behavior of the mixes under traffic.

The mixes were laid in three two-inch lifts in the following manner. The mixes at about 225°F were spread by a Barber-Greene and a Pioneer Paver. Pneumatic rollers followed the pavers by about 200 feet. This was followed by steel rollers. No tack coats were used between lifts. Paving started on project TP-1-57 on September 5 followed by project SN-821 and completed on Project SN-242 on November 1, 1957. Paving on Project SN-242 was interrupted several times by cold and inclement weather.

Immediately upon opening to traffic, the pavement on Carroll County Project TP-1-57 was subjected to a heavy volume of heavy, high speed, seed corn, transport trucks. After about three weeks of this traffic, several large transverse cracks opened up in one section. This was caused by slippage between lifts. Some extensive ravelling was also noted in some sections. This was attributed to mixes having low asphalt content. The cracks were plugged immediately, and the ravelled area was seal-coated early in 1958. Only slight ravelling was noted thereafter, but the surface was seal-coated in 1959. The pavement on Project SN-821 served excellently except in one spot where ravelling was noted. Here the mix was found low in asphalt content, and this pavement was also seal coated early in 1959.

The pavement on Project SN-242 was laid in October under severe weather conditions. It should also be noted that the haul from plant to road was about 24 miles. Soon after completion of this project severe ravelling of the top lift was noted in several sections. This may be attributed to low asphalt content and the low temperature of the mixes when laid. No repairs were made until 1959, when the ravelled areas were plugged and the road was seal coated. Ravelling had decreased when the road was inspected in 1959, and the surface was healing in the warm weather.

RESULTS

After three years of service Mr. Mark Morris, Director of the Iowa Highway Research Board, reports on these projects[25] as follows:

> "The asphalt concrete in research projects No. HR-44 in Ringgold County, in HR-56 and HR-57 (Carroll County) and in HR-58 in Audubon County are in good condition after three years of service . . The roadway surfaces in HR-56, HR-57 and HR-58 ravelled uniformly and extensively. All have been given an armour seal coat and HR-57 and HR-58 are now in especially good condition. Neither of these projects has any cracks of any kind in the roadway surface courses."

These test roads proved that satisfactory, serviceable roads can be built with asphaltic mixes containing local ungraded aggregates prepared by the atomization process. The mastic theory of the design of such mixes is sound, and loess and other local materials can be readily and economically pulverized into a suitable mineral dust for use in these mixes.

The study also showed that the atomization process is limited to the use of hot dry aggregates, and that adaptation to continuous plants is still beset with a number of problems such as attaining uniform continuous coordinated flow of asphalt, maintaining uniform pressure, and preventing the clogging of the system and nozzles. These are problems of design of the system that undoubtedly can be solved. A serious problem inherent in the atomization process is the need for modifying the mixer speed and mixer paddle tip settings. This prevents rapid changeover of plant operations between conventional operations and atomization process operations. Another problem is that the extremely high pressure of 300 pounds is needed to pump the hot asphalt at 300°F. This is quite hazardous if a pipe or pump should blow out. And incidentally, on the test road jobs plant personnel tended to shy away from the pump unit.

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