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IN-PLACE STABILIZATION OF SOIL-AGGREGATE MIXTURES WITH BITUMINOUS MATERIALS

Progress Report

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IN-PLACE STABILIZATION OF SOIL-AGGREGATE MIXTURES WITH BITUMINOUS MATERIALS
Progress Report

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This research project was initiated in February 1972 as part of the Research Laboratory's continuing efforts to utilize economical and available roadway materials for construction purposes. The primary purpose of the study is to obtain additional information concerning the design of asphalt-aggregate combinations when mixed in-place for stabilizing and reconstructing existing shoulders and bases using available aggregate and, if possible, reclaiming older asphalt surfaces and using these as part of the asphalt addition. Previous studies of the Research Laboratory in this general area have been described in a series of reports (1, 2, 3, 4), all of which have shown asphalt stabilized aggregate mixtures to be a practical and desireable construction material. Lacking, however, have been recommendations for proper design strength values and a basic understanding of the inter-relationship of such variables as asphalt types, mixing time, curing time, compaction requirements, and quantity of asphalt. Such information was requested as a result of work completed under Research Project 69 F-111 concerning shoulder reconstruction (1). Also, additional specifications are needed to control both materials preparation and construction procedures. Answers to these problems will be sought in the overall objectives of this project. The study, as initially proposed, was to be conducted in two phases; a preliminary study involving a limited number of different aggregates and bitumens, and a more comprehensive study using a wider range of materials and investigating several factors which might influence results (5). The preliminary study has been completed and is the subject of this report.

Purpose

The purpose of this portion of the study was to determine acceptable stability criteria for mixture design, to investigate relationships between compaction and strength, and to provide information needed for planning more comprehensive phases of the study.

Scope

Mixtures composed of dense graded aggregates and granular materials and two types of liquid asphalt were prepared and tested in the laboratory for unit weight and strength. The mixtures were prepared with varying proportions of asphalt and aggregate and were molded at two different compactive efforts for each mixture.

Triaxial shear test results obtained with typical untreated graded aggregates were compared with results obtained on the asphalt mixtures. Supplemental measurements of curing rates and solvent evaporation were also made for the several mixtures.

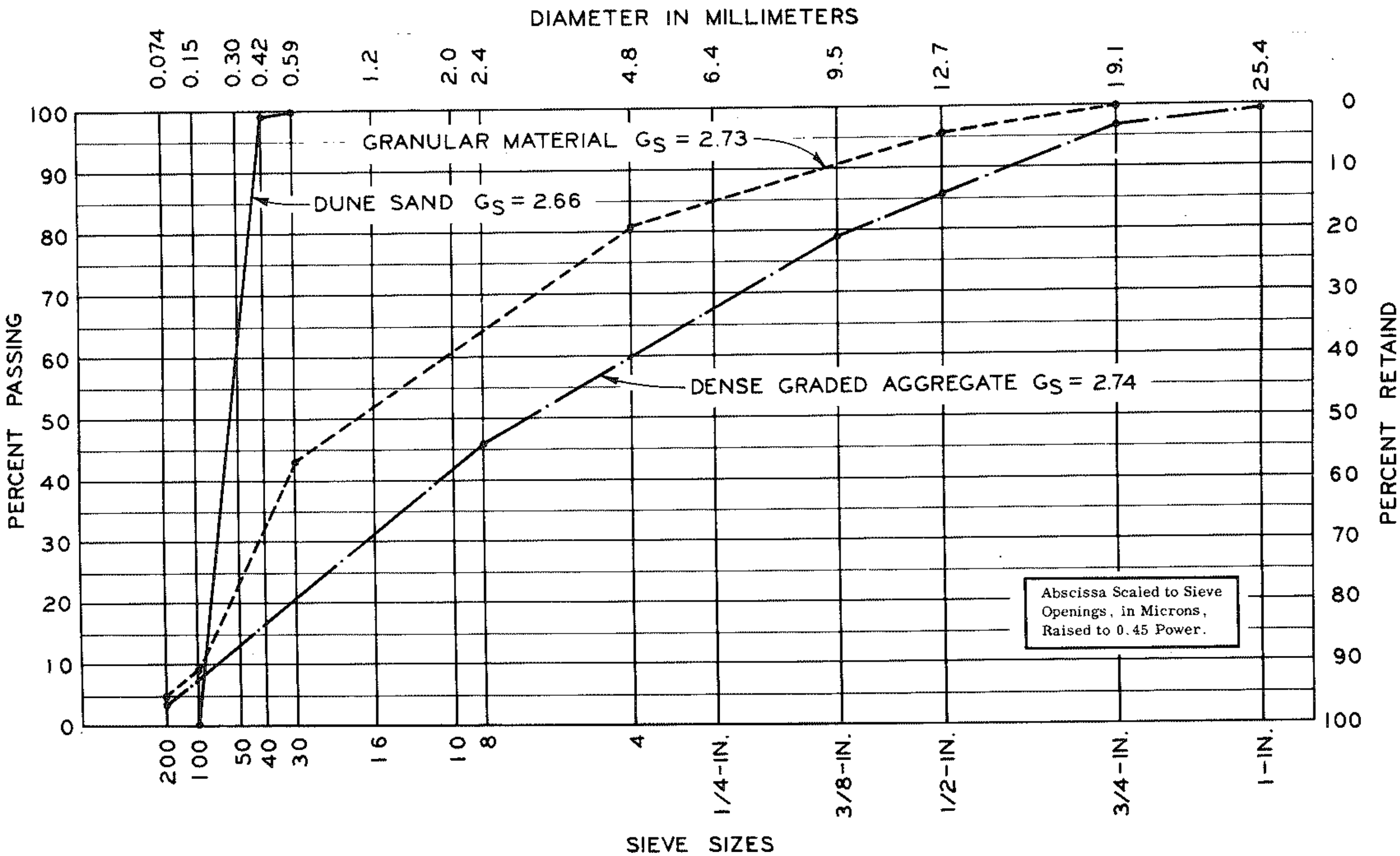


Figure 1. Grain size distribution of aggregates used in bituminous stabilized mixtures.

Materials

Asphalts - Two commonly used liquid asphalts were included: an emulsion and a medium curing cutback meeting Department Specifications for MS-2S and MC-800, respectively.

Soils - Three granular soils were used: a dense graded specification aggregate (22A); a granular material and a dune sand. Grain size characteristics of the materials are given in Figure 1.

A dense graded 22A aggregate with a portion of crushed particles was felt to represent the better quality material which might be stabilized in shoulder reconstruction whereas the granular material, without a crushed portion and of a sandier gradation, was thought to represent a lower quality material that might be encountered and which would be more economical to use. Furthermore, bituminous stabilized 22A, when compared with unstabilized 22A, should provide a direct indication of the effectiveness of the bituminous stabilization process.

Each aggregate was mixed with varying amounts of asphalt to determine the relationship of asphalt content to strength and density. The several aggregate-asphalt mixtures were formed into test specimens by applying compactive efforts equal to those used in the AASHO T-180 and the Marshall test methods. AASHO T-99 compaction effort was attempted but the samples would not hold together during removal from the mold. Dune sand samples disintegrated upon removal from molds even at the higher compactive efforts, and for this reason were deleted from this initial phase of the program. Throughout the study three replications of each sample condition were prepared and tested, thus each data point shown in the figures represents the average of three individual values.

Criteria

As initially proposed, samples of untreated shoulder aggregate were to be tested for stability in order to establish criteria for acceptable quality of stabilized mixes. Furthermore, it was proposed that the stabilities of mixtures be measured by their unconfined compressive strength. Sample preparation and laboratory testing for unconfined compressive strength is relatively simple and rapid but can be used only with materials having sufficient cohesive strength to enable samples to be handled and tested without lateral confinement.

Triaxial shear strength tests were performed on several aggregates typical of those used in shoulder bases. Lateral confinement provided by

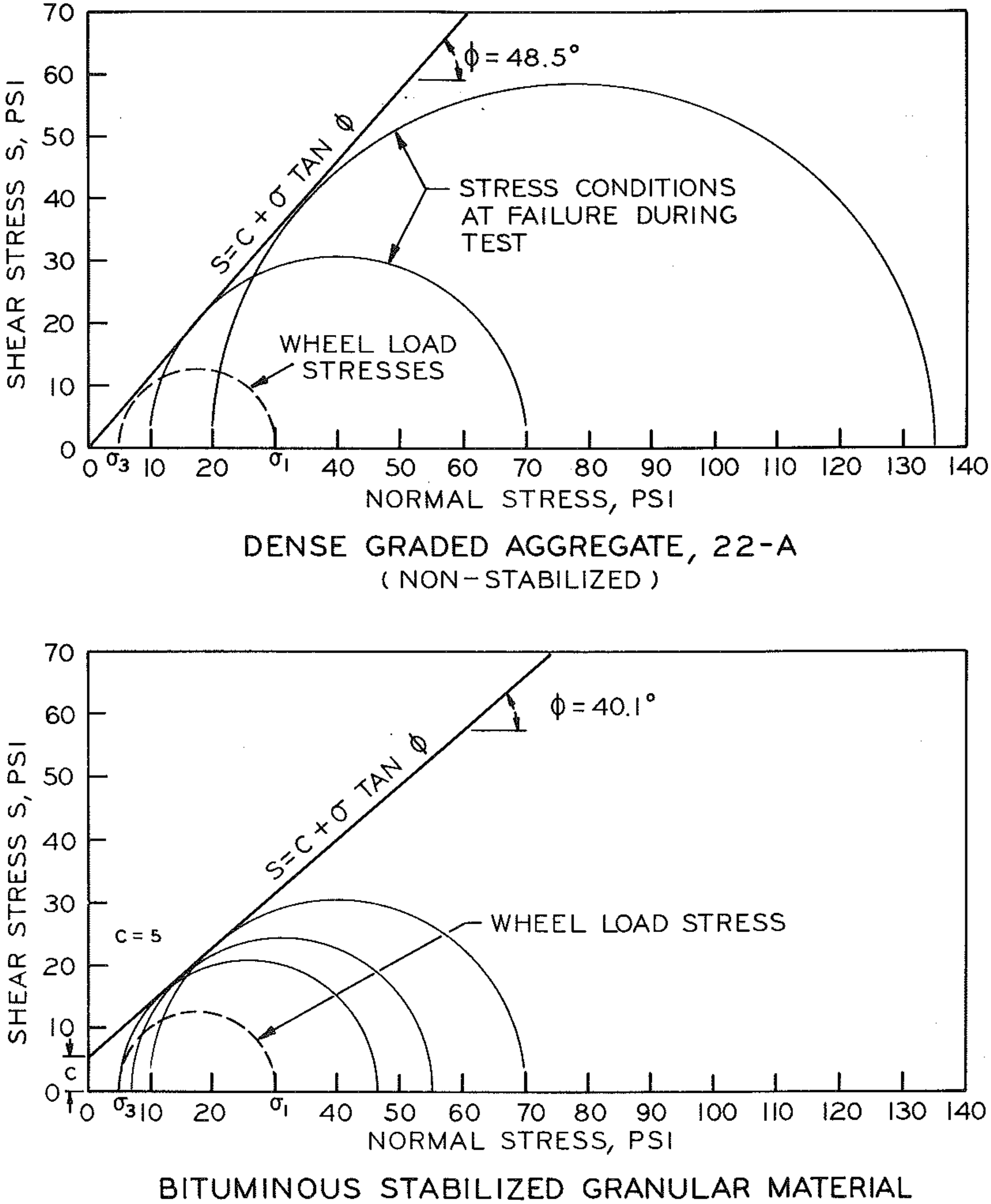


Figure 2. Strength characteristics of a dense graded aggregate and a stabilized granular material.

the triaxial method was required since these materials possess no cohesive element of strength. Results of these tests are presented in Table 1, along with triaxial test results obtained for the stabilized mixtures used in this preliminary study. In order to compare untreated shoulder aggregates with stabilized mixtures, test results are presented graphically in the form of Mohr circles[1] for one of the aggregates and one of the mixtures (Fig. 2). The upper diagram in this figure represents the test results obtained on the 22A aggregate sample, while the lower shows test results obtained with a bituminous stabilized granular material.

TABLE 1
TRIAXIAL SHEAR TEST RESULTS

	Sample	Friction Angle, Ø	Cohesion, C, psi	Material Description
Aggregates	1	48.5	0	22A Aggregate, 7% P-200
	2	36.5	0	23A Aggregate, 15% P-200
	3	44.0	0	23A Aggregate, 7% P-200
	4	46.5	0	23A Aggregate, 7% P-200
	5	38.0	0	Uniformly Graded Sand
Stabilized Mixtures	1	42.4	7.5	22A Aggregate, 1.5% MC-800
	2	38.7	9.0	22A Aggregate, 2.0% MC-800
	3	51.4	0	22A Aggregate, 3.0% MC-800
	4	40.1	5.0	Granular Material, 2.0% MC-800
	5	43.4	4.0	Granular Material, 3.0% MC-800

Although it was proposed to use the strength of existing shoulders (untreated material) as a criteria for bituminous stabilized mixtures, consideration of a selected design wheel load should also be of value. A wheel load on the paved surface will produce both vertical and horizontal stress components acting on an element of soil within the base (Fig. 3). The vertical stress level is related to the wheel load and depth within the layers and the horizontal, or confining component, is a function of the soil modulus, depth, Poisson's ratio, and stress levels involved. A wheel load of 9 kip has been estimated to result in a vertical component, σ_1, of 30 psi and horizontal confining pressure, σ_2, of 5 psi (6); these values are the major and minor principal stresses used in plotting the Mohr circles of Figures 3 and 4.

[1] The Mohr circle concept is explained in reference (7) as well as in most soil mechanics and mechanics of materials texts.

Stress conditions within the shoulder base, due to the design wheel load, are represented in Figure 2 by the dashed Mohr circles to allow direct comparison with failure envelopes for the two test materials. Both mixtures have adequate shear resistance to support this load since their failure envelopes do not pass through the wheel load stress circle. The failure envelope for the 22A aggregate, however, is nearly tangent to the circle, a condition which would indicate incipient failure.

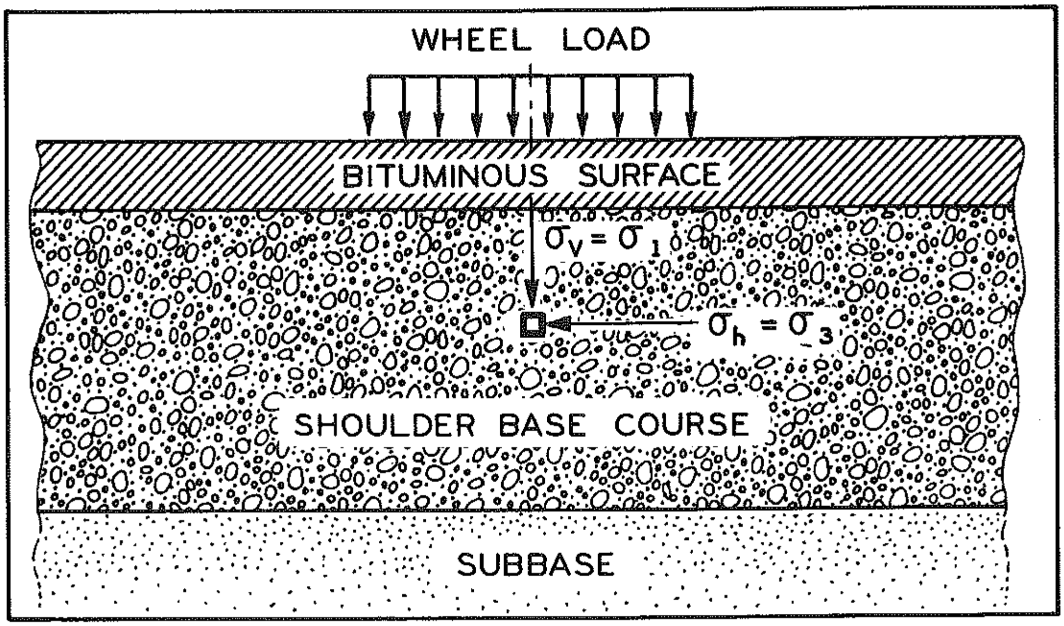
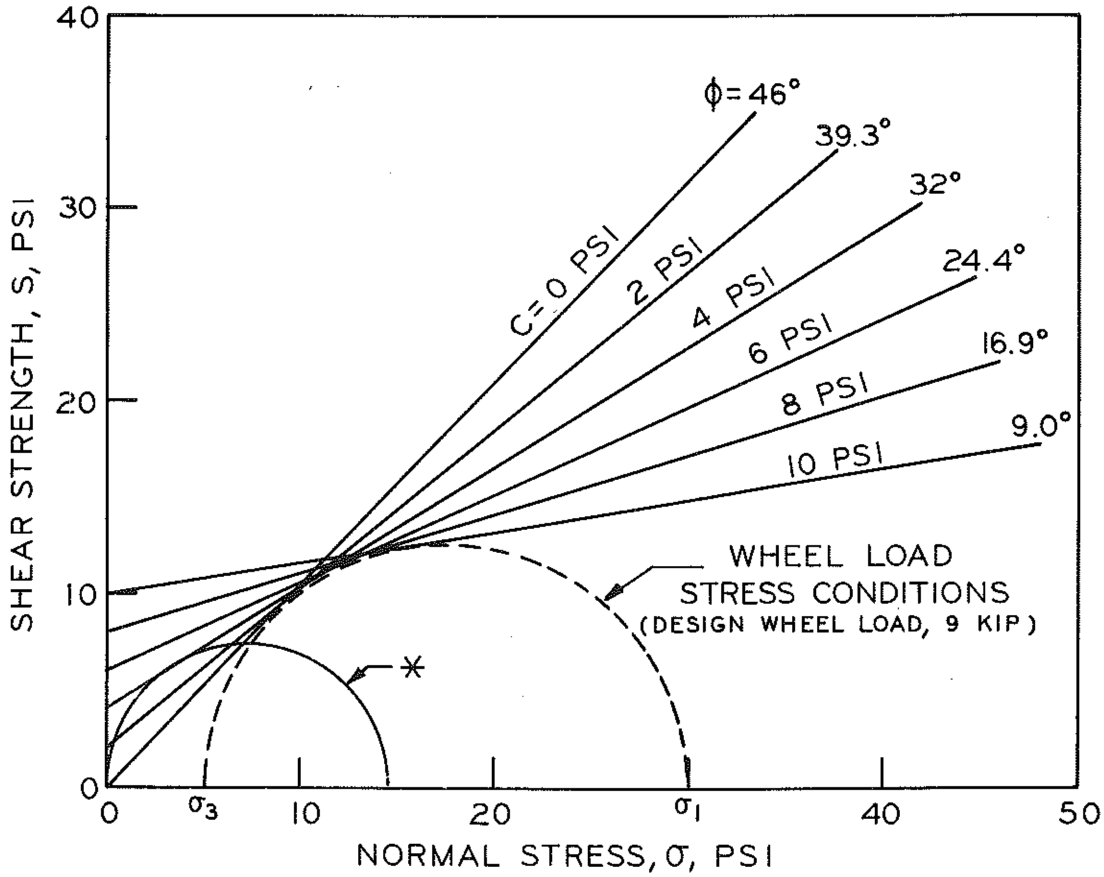


Figure 3. Principal stresses in the shoulder base caused by wheel loads.

Stress conditions imposed by the design wheel load can be used to develop relationships between cohesion, friction angle, and the required unconfined compressive strengths. In Figure 4, stresses imposed by the design wheel load are shown as the dashed circle. Failure envelopes for several acceptable materials, i.e., materials having just sufficient shear strength to resist the wheel load stresses, are shown.

As a limiting condition for acceptance, the failure envelope for any stabilized mixture would be tangent to the wheel load circle. Several hypothetical materials meeting this condition are represented in Figure 4. Each of these failure envelopes is described by a cohesion value, C, and angle of internal friction, ϕ. This relationship between C, ϕ, and unconfined compressive strength for acceptable materials can be represented by a graph



*This circle represents failure stress conditions in unconfined compression for a material having a cohesion of C = 4 psi and internal friction ϕ = 32 .

Figure 4. Relationship of friction angle, cohesion and strength required to resist design wheel load.

such as shown in Figure 5. If, for example, as shown by the arrows on Figure 5, a material was known to possess internal friction of 30° or more, then the minimum confined compressive strength required to support the design wheel load would be 15.5 psi.

In addition to mix design based on strength, mixed-in-place construction will require on-the-job control of density and total liquid content. In order to develop the full intergranular shear strength at the high level of compaction or density that is required, the amount of liquid in the voids of the mixture must be below saturation to avoid creation of pore water pressure during compaction. Pore water pressure would reduce the effective intergranular stresses and weaken the mixture, creating a rolling, rubbery action under wheel loads until after the excess liquid (water and volatiles) has been removed by drainage and drying.

The final phase of this study will be concerned with the development of mix selection and job control procedures to assure that stabilized mixtures meet or exceed the above strength requirements and will also consider durability under environmental conditions. Factors to be controlled will include asphalt type and quantity, water content, compaction, and curing.

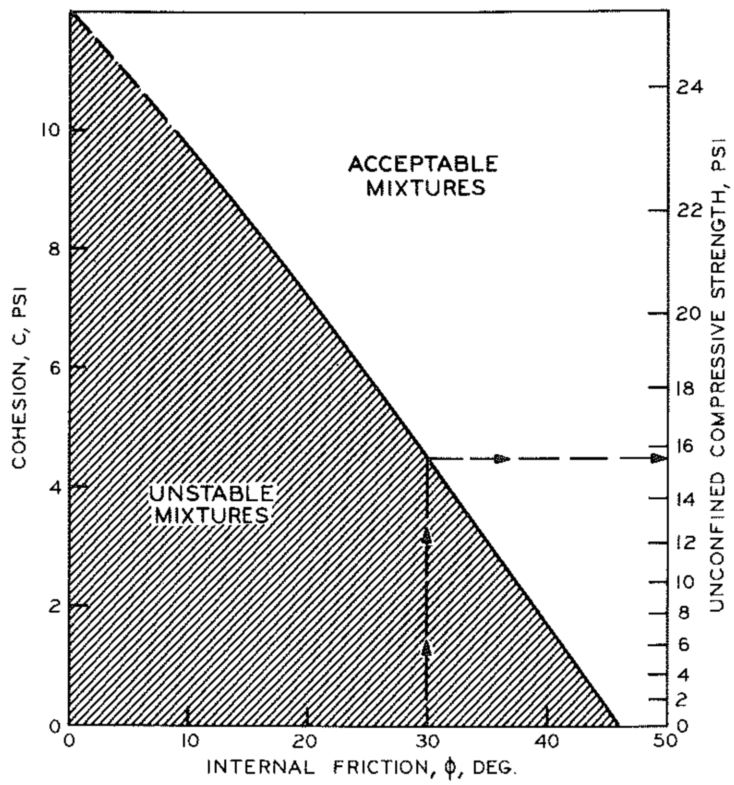


Figure 5. Relationship of cohesion internal friction and unconfined compressive strength to the design wheel load.

Evaluation of Factors Effecting Mixtures

Aeration and Curing - Aeration refers to the evaporation of both hydrocarbon volatiles and water from the mixture, most of which should occur between the addition of the asphalt and the compaction of the material. An excess of liquid (liquid asphalt plus water) in the mix at the time of compaction can result in reduced shear strength if excess pore pressures are generated within the voids of the mixture at the level of compaction required.

After compaction, a mixture continues to dry slowly and also to cure or harden and gain strength. Although mixtures of initially low strength may eventually acquire sufficient stability, stabilized shoulder bases require certain minimum stability values almost immediately in order that highways may remain open to traffic during construction. Effects of both aeration and curing on stability, as illustrated in Figure 6, were taken from available literature (8). Although the data shown in Figure 6 were obtained with a fine grained soil, the trends are typical of all asphalt stabilized materials. With no aeration (or drying as described in Fig. 6), the material shown has little initial strength and required about 14 days to acquire the major portion of its final stability. Mixtures dried prior to compaction possess higher initial stabilities, but acquire lower final values. It is indicated, however, that excessive drying should be avoided; according to Figure 6 final stabilities after five hours of drying were 14 percent lower than final values with no drying.

During this preliminary study only dry aggregates were used so that aeration concerned volatile loss alone. In a test to measure the rate of volatile loss, dry aggregate was mixed with medium curing asphalt and the loss in weight after various durations of mixing was determined. The weight loss, expressed as a percentage of the amount of solvent initially in the mixture, is shown in Table 2. One value obtained from the literature (9) is shown for comparison, where the material involved was a moist soil mixed with a cutback.

TABLE 2
EVAPORATION OF HYDROCARBON VOLATILES

Material	Evaporation Loss, Percent of Total Volatile in Mix	
	Brief Mixing	Prolonged Mixing
MC-250	0.67 @ 7 min.	8.88 @ 196 min.
MC-800	1.47 @ 7 min.	10.29 @ 301 min.
MC-0*	1.21 @ 7 min.	----

*From Reference (9).

The rate at which mixtures gain in strength after compaction can be important in determining how soon the material can be subjected to traffic loads. Gain in strength with time is also an important factor in planning

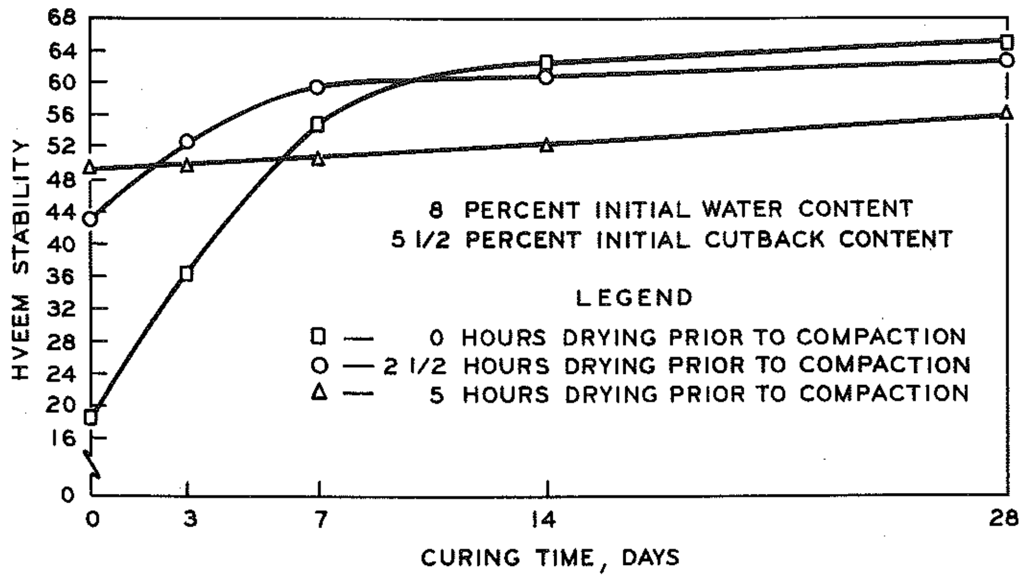


Figure 6. Influence of aeration and curing on stability (after Herrin).

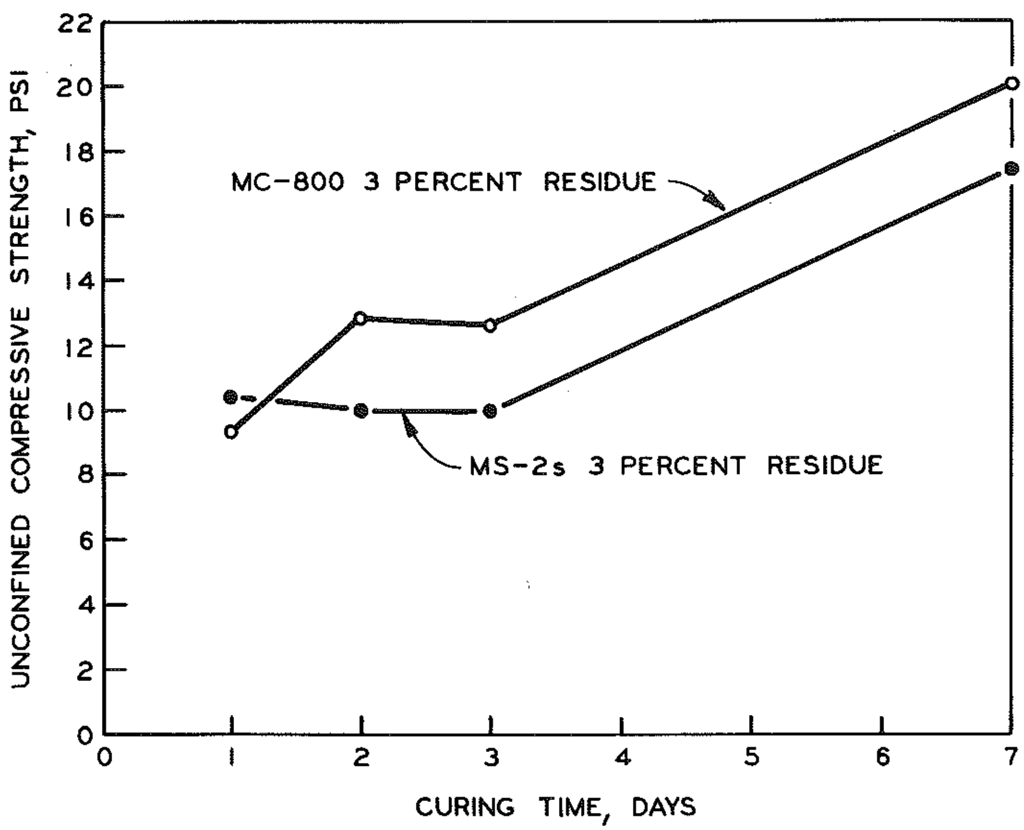


Figure 7. Relationship of strength to curing time for dense graded aggregate mixtures.

the laboratory test program. It is imperative that comparative samples be tested after equal curing periods so that curing effects will not influence results.

In this phase of the study, samples were molded to one specific density and allowed to cure for various periods of time prior to testing for unconfined compressive strength. Strength of both the emulsion (MS-2S) and cutback (MC-800) mixtures increased substantially after three days of laboratory curing (Fig. 7). Higher strengths obtained with the MC-800 are due to differences in characteristics of the residues. Had an optimum residue content been selected for each asphalt type, their strength relationship may have been different than that shown in Figure 7. Curing periods of less than one day were not included because the unconfined samples were not strong enough for handling. Test procedures which would allow for curing periods of a few hours should be considered since many projects will involve traffic loading soon after compaction. Triaxial or Marshall testing would provide the needed confinement.

Storage of Mixtures Before Compacting

It is often important to know how a material will perform when it has been mixed and stockpiled for a prolonged period of time prior to compaction on the grade. Field samples obtained for laboratory testing may often be stored several days, or weeks, prior to compaction and testing. The influence of such storage on the density and stability or strength values obtained should be known. A recent experimental project[2], involving the evaluation of a cold-mix black base, also illustrated the need to know the effect of prolonged storage on the characteristics of uncompacted mixtures. In this project, the mixture (using an MS-2S emulsion) was stockpiled at the job site for several weeks before placement as a base course. The influence of storage time for such material, as shown in Figure 8, illustrates the need for obtaining, preparing, and testing samples of such material in phase with construction operations so that laboratory strength values will be indicative of field strengths. In this study of storage time effects, two bituminous stabilized mixtures were prepared using; 1) an MS-2S emulsion; and, 2) an MC-800 cutback mixed with a dense graded aggregate, 22A, containing 3 percent moisture at the time of mixing. After mixing, each of the materials were stored in sealed plastic bags for selected time periods and compacted and tested for stability, flow, and density, using the Marshall method. Each mixture contained 3.5 percent asphalt residue.

[2] Evaluation of Cold-Mix Black Base, Experimental Highway Construction - Work Plan No. 20, Research Project 72 D-27.

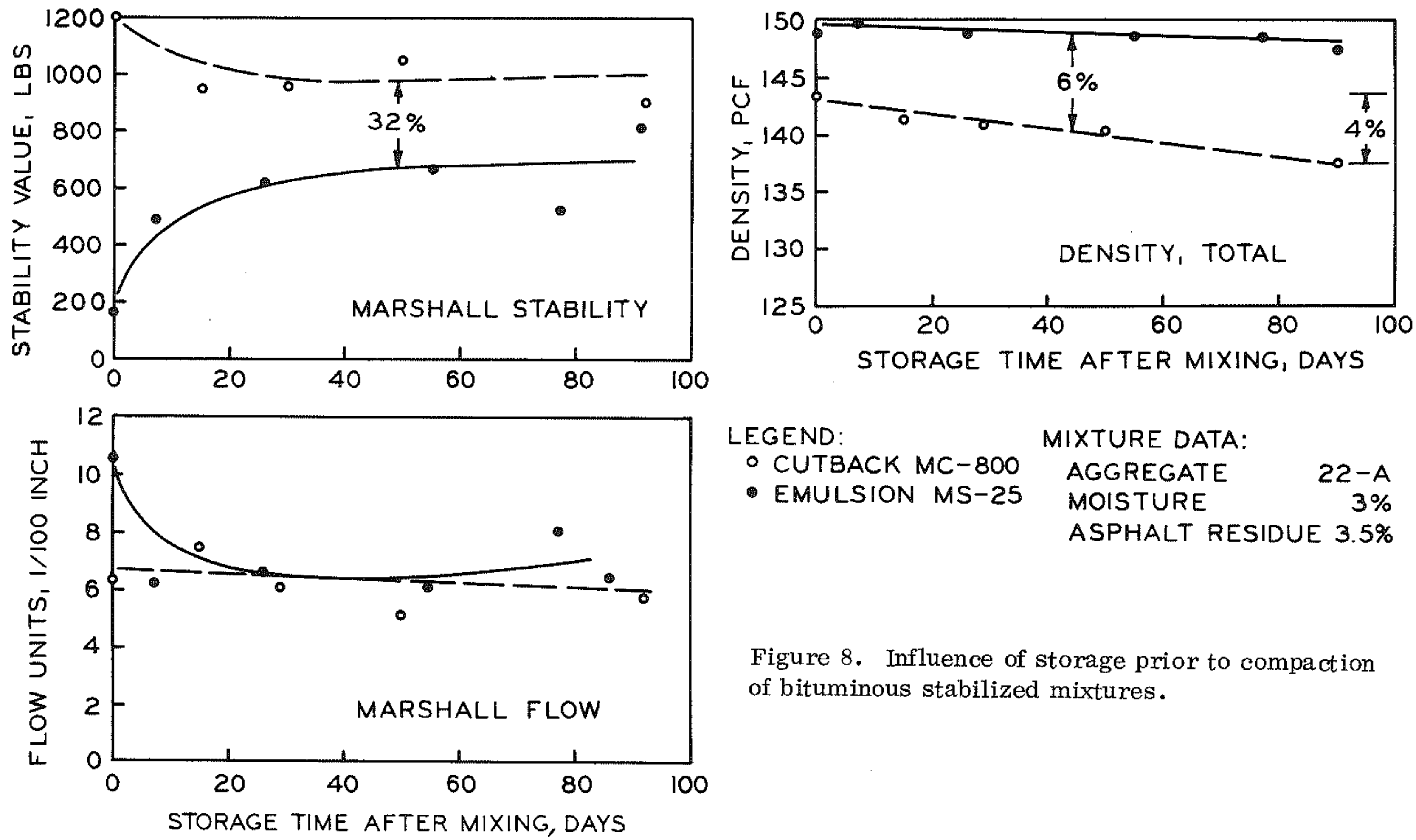


Figure 8. Influence of storage prior to compaction of bituminous stabilized mixtures.

As shown in Figure 8, the initial strength of the MC-800 mixture is slightly reduced after prolonged storage. In contrast, the emulsion mixture shows a significant increase in stability accompanied by a corresponding reduction in flow during the first 10 days of storage. Compactability of density of the mixtures was not greatly affected by storage although total compacted density of the MC-800 mixture was reduced by 4 percent after 90 days. Although comparison of the two asphalts was not the purpose of this test it is interesting to note that even with higher densities (6 percent higher) the emulsion mixture had stability values 32 percent less than the MC-800 mixture.

Density and Strength Relationships

The influence of liquid bitumen content on compacted density and strength must be known for adequate job control and to assure that the constructed base has adequate resistance to wheel loads. Material properties which can be measured readily in the field with current soil inspection techniques are moisture content and density. Use of nuclear gages should also provide some measure of bitumen content when proper procedures are employed. The relationships between strength, density, and liquid content (as measured in the laboratory) must be translated into job control values for use by project personnel.

One method of job control which has been used required the treated aggregate to be compacted at a total liquid content equal to the optimum water content of the aggregate alone, as determined in the AASHO T-99 test to determine the Moisture-Density Relations of Soils (3). The total liquid content would consist of liquid asphalt plus field moisture in the aggregate. A preselected asphalt content, based on laboratory tests (or perhaps experience), would then require control of field moisture to achieve the optimum value for total liquid content. This part of the study attempts to explore the concept of using such an optimum water or liquid asphalt content for the design of bituminous stabilized mixtures using aggregates and granular materials which might typically be used for mixed-in-place construction in Michigan.

Conventional density-moisture relationships for the two granular soils used in this study, were determined using both the AASHO T-180 method and the Michigan Cone Test (Fig. 9). The dry aggregates were then mixed with various amounts of liquid asphalt, compacted, cured for one day then tested for unconfined compressive strength. Samples were compacted using two different compactive efforts; 1) that employed in the AASHO T-180 test for the moisture-density relationship of soils; and, 2) a compactive effort equivalent to that employed in the 50 blow (per sample face) in the Marshall test. This latter method provided 23 percent more compactive effort than the T-180 method used in this study.

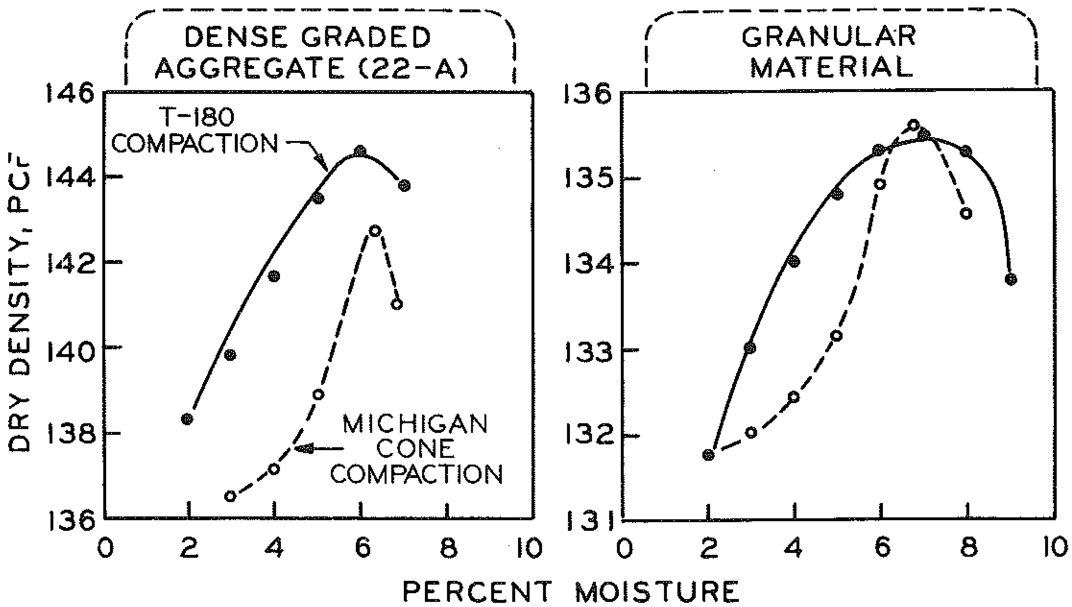


Figure 9. Moisture-density relationships for the aggregates used in the study.

Figure 10 shows the relationship between unconfined compressive strength, compactive effort and asphalt content for the MC-800 mixtures. Similar results were obtained for the emulsion mixtures; the two types of mixtures (emulsion vs. cutback) are compared in Figure 11.

These data show that, in contrast to maximum density and optimum moisture values normally obtained for moist soils and aggregates (Fig. 9), optimum asphalt contents with respect to density were not always achieved. Had greater amounts of asphalt been used a maximum density may have been observed but the sample strengths were so low at the higher asphalt content (Fig. 10) that more asphalt was not added. Lower strengths observed at the higher asphalt contents indicates the need for adequate testing of proposed mixtures so that excess asphalt is not employed. It is possible that the strength-asphalt content relationship may change after longer curing periods. If, in addition, water absorption and freezing effects are also considered, higher asphalt contents may be beneficial from a durability standpoint.

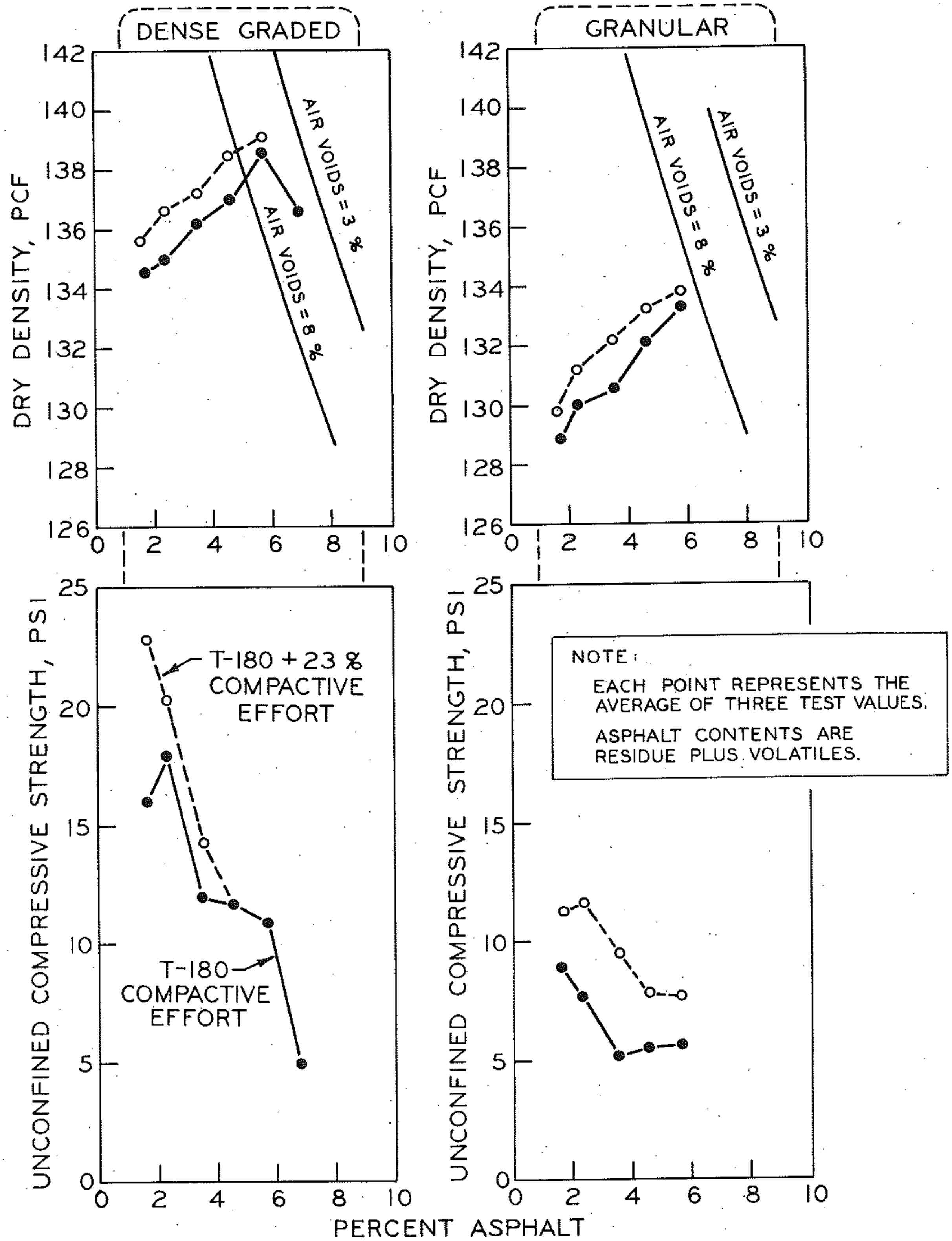


Figure 10. Strength-density relationships for a bituminous stabilized mixture (MC-800 liquid asphalt).

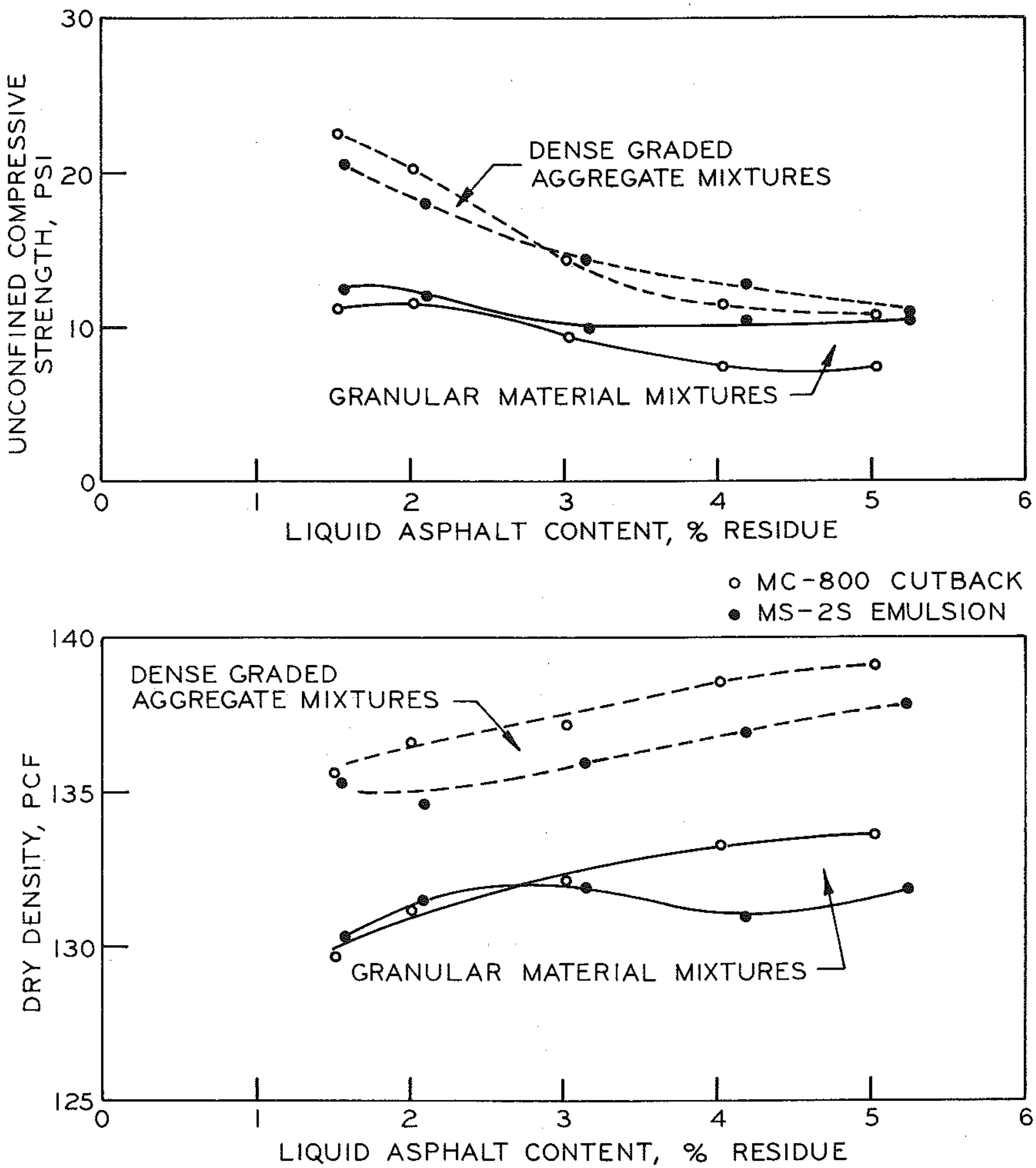


Figure 11. Density-strength-asphalt content relationships for bituminous stabilized mixtures.

Effects of the different aggregates and the two asphalt types used in this phase of the study are illustrated in Figure 11. The dense graded aggregate yielded mixtures which were both stronger and of higher density than the more sandy granular material. Differences measured between the two asphalt types were not as pronounced as differences between the two soil materials, although somewhat stronger mixtures were obtained with the MS-2S emulsion; even though densities for these mixtures were 2 pcf less than densities with the MC-800 mixtures.

In addition to strength, other factors such as water absorption, wet to dry strength ratios, and air voids, are considered in various mix design techniques (8). Although these factors were not specifically evaluated in this study, the void ratio for each of the mixtures is also plotted as a function of asphalt content in Figure 10. Air voids from 3 to 5 percent of total sample volume are generally recommended for bituminous mixtures (8).

The density and unconfined compressive strength relationships developed in Figures 10 and 11, provide little basis for mixture design except to illustrate the weakening effect of excessive asphalt. If, however, a friction angle of 30° is assumed[3] then, according to the chart of Figure 5 an unconfined compressive strength of 15.5 psi or over would be required to achieve stability. The dense graded materials, shown in Figure 10, compacted to T-180 effort, would thus require 2.7 percent asphalt or less for 15.5 psi strength.

Construction Application

Reconstruction of shoulders along I 96 in Ottawa County (Federal Project I-96-1(50)47, Job No. 70063 and 70064) during 1974 will involve dense graded aggregate materials similar to those used in this study. In order to provide preliminary construction information and to also explore the use of the Marshall method of mix design (ASTM Designation D-1559) samples of the shoulder materials were obtained for mix design testing. The aggregate, containing three percent water, was mixed with MS-2S emulsion and each compacted sample was air cured for one day prior to testing. Three percent moisture is a value considered appropriate (8) for mixed-in-place stabilization of granular materials and seems to be a reasonable value for

[3] Published values of ϕ typically range from 3o to 40° for sands and gravels; (7, 11) the lowest ϕ measured in this study was 38.8°, Table 1. A ϕ of 30° would thus seem reasonably conservative if, for example, the data of Figure 10 along with the chart of Figure 5 were to be used in selecting a mix proportion.

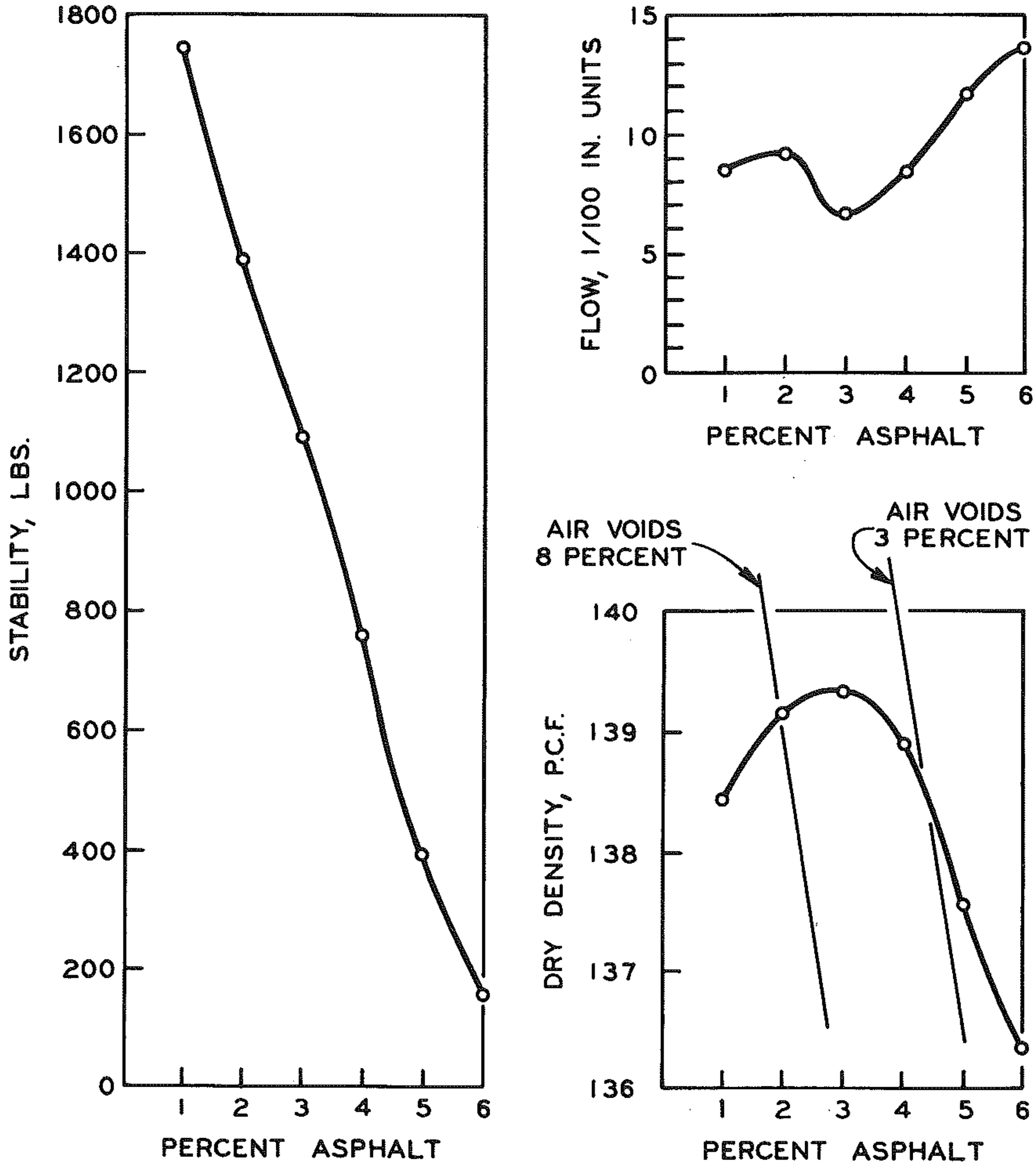


Figure 12. Marshall method mix design results.
Liquid Asphalt - MS-2S
Aggregate - Samples from I 96 shoulders, Ottawa County.
Water Content of Aggregate at Mixing - 3 percent.

field operation. Marshall test results of this mixture are presented in Figure 12. Criteria published by the Asphalt Institute (10) for hot-plant-mix base materials require the following values for stability, flow, and air voids for medium traffic conditions.

Marshall Stability	500 lb, minimum
Flow	8 to 18, 1/100 in. units
Air Voids	3 to 8, percent

Application of these limits to the data of Figure 12 illustrate the several considerations to be made in selecting one particular mixture for use. On the basis of stability alone any asphalt content less than 4.7 percent would be satisfactory; considering air voids[4], liquid asphalt contents ranging from 2 to 4 percent would be permissible although flow values are slightly low. Density values varied by only 3 lb/cu ft within the 1 to 6 percent asphalt range tested.

The Marshall method is easy to use and is a generally accepted procedure for bituminous mix design. However, because Marshall method test results cannot be related mathematically to wheel load shear strength requirements, mixtures for this project also will be tested for triaxial shear strength prior to and after construction.

<u>Proposed Field Testing</u>

Information obtained in this preliminary study provides a basis for field control of construction when using mixed-in-place methods for bituminous stabilization. The Department will be using this method for stabilizing nearly 500,000 sq yd of base materials on four projects, primarily on interstate shoulders during 1974. Job control values of density, moisture content, and bituminous content are being determined by the Research Laboratory for these projects. Research personnel will be sampling and testing the materials on the job sites during the several construction phases. It is expected that this preparatory testing program, along with field data acquired during these construction projects, will substantially complete the proposed research study and will include most of the factors specifically mentioned in the "Recommendations Section" of this report. Final laboratory studies will emphasize the study of factors for which construction experience may show a need.

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[4] The 3 and 8 percent air voids lines shown in Figure 12 were obtained by calculating the various combinations of dry density (aggregate density) and asphalt content which would result in these specific air voids values for the particular materials used in these mixtures.

Conclusions

Although the scope of this preliminary study was limited with respect to the variety of materials involved and was intended, primarily, to provide a basis for a more comprehensive study, certain conclusions can be made that may be of value in connection with upcoming construction projects. These conclusions are somewhat broad and may require modification as further research on specific materials or conditions is completed.

1) Based on shear strength requirements, adequate base course stability can be obtained when liquid asphalts are mixed with aggregates in proper proportions and when the resulting mixture is sufficiently compacted.

2) The initial strength of bituminous stabilized mixtures is drastically reduced if an excess of either liquid asphalt or water is present. Therefore, it is important that; a) excess asphalt is not used; and, b) excess water is removed by aeration prior to compaction.

3) Laboratory tests show that evaporation of liquids from the mixtures during aeration involves loss of water rather than loss of hydrocarbon solvents.

4) Strength of a bituminous stabilized base course mixture will increase if allowed to cure after mixing. Base materials stabilized with medium curing cutback mixtures reach near ultimate strength in about one week under laboratory curing conditions.

5) Aeration of an asphalt-aggregate mixture prior to compaction greatly influences strength. One or two hours aeration provides high initial strength, but longer periods of aeration reduce the ultimate strength.

6) No relationship was found to exist between the optimum moisture content of an untreated aggregate and asphalt content required for maximum stability.

Recommendations

Laboratory studies of asphalt-aggregate mixtures should be continued to more fully evaluate effects of such variables as mixing, aeration and curing times, compaction, aggregate moisture content at mixing, liquid asphalt types, and interactions between variables. Additionally, the laboratory study should include the environmental effects of moisture absorption and frost susceptibility and the use of reclaimed asphalt mixtures.

Specific plans to accomplish the above objectives are as follows:

1) The laboratory study of influencing factors will be performed using the Marshall method of stability testing. The specific strength characteristics of any mixture recommended for construction should, however, be measured by the triaxial test.

2) Mixtures involving various proportions of reclaimed asphalt paving materials will be evaluated for initial strength and durability; differences between cutbacks and emulsions for such reclamation will be determined.

3) The volatile and water loss rate during aeration will be measured on several construction projects for both emulsion and cutback mixtures to determine the proper liquid content at the time of compaction. Total liquid contents can be measured with a nuclear gage in the field and should be correlated with standard laboratory tests for measuring water and volatile contents of bituminous mixtures.

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