Bituminous Sandstone Mixtures

Charles T. Metcalf, Graduate Research Assistant
W. H. Goetz, Research Engineer
Joint Highway Research Project
Purdue University

In certain sections of the state of Indiana sources of recognized aggregates for use in bituminous construction are very few, and the transportation of aggregates to the job site from remote locations becomes necessary. Often the distance over which the aggregate must be moved is considerable, and the importation involves the expenditure of a sizeable sum of money, which it would be desirable to reduce or eliminate. In some of these sections of the state, notably the south-central and southwestern portions, there are local deposits of sandstone which, if they could be used, would obviate the necessity of hauling in aggregates from outside sources. It was in recognition of this problem that the study was initiated. The purpose of the study was to provide a basis for the reasonable utilization of sandstone in bituminous mixes which are to serve as the surface courses of highways. Realizing that sandstones as a class fail to meet Indiana specifications, it is not proposed to use sandstone in wide general practice. Rather, its use is under consideration where it can serve as an economic alternate in lieu of other aggregates. The approach to the problem has been divided into two sections. The first of these is a study of the properties of representative Indiana sandstones. The second is a study of the properties of asphalt-sandstone mixtures in reference to sandstone characteristics.

The initial phase of the work consisted of an investigation of the locations of sandstone in Indiana. The outline map of Figure 1 shows the general extremities of the Mississippian and Pennsylvanian geologic formations which contain the most extensive and prominent sandstones. Extending eastward from the western boundary of Indiana are the formations of the Pennsylvanian period. The Post-Alleghanian age of this period outcrops adjacent to the Wabash River and is represented by the weakly-cemented Merom sandstone, which is the only major sandstone member of this age. East of the Post-Alleghanian formation is the Alleghanian formation, where the coal measures of Indiana are located. Little or no sandstone is to be found in this age. At the base of the Pottsvillian formation, which follows next, is found the Mansfield sandstone, which is possibly the single sandstone of widest extent in Indiana. Essentially the Mansfield is a weakly-cemented, medium-to-coarse-grained, ferruginous sandstone of high porosity; and it may occur as a massive formation tens of feet in thickness, or as thin, flaggy ledges separated by sandy shales. The Mansfield abuts the Chester series of the Mississippian period. There are several sandstone members found in the Chester occurring in connection with limestone and shale members which separate the individual sandstones. For use as road metals, the

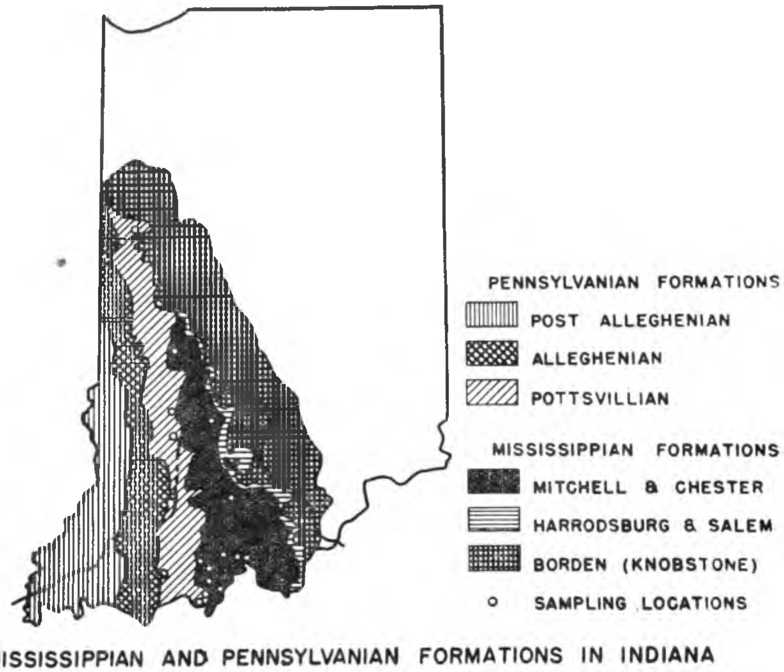

FIGURE 1. Outline map of Indiana geologic formations in sandstone region.

sandstones of the Chester are probably the best suited to the requirements; however, many of these sandstones occur only in limited exposures and their consideration is limited to a specific locality. Just east of the Chester series are the Harrodsburg and Salem series, which are composed chiefly of limestones. Beyond these formations is the Knobstone series, which consists of thinly-bedded sandstones and shales. In general, the most abundant deposits of sandstone are found at the base of the Pottsvillian formation and in the Chester series. The properties and type of formation of these sandstones will vary to some extent from place to place.

From the Mansfield and Chester formations nineteen sandstones were sampled and brought into the laboratory for examination of their properties. Because of the nature of a sandstone, two of its properties set it apart from other rock types: first it is a porous material capable of a large absorption; second, it is friable and subject to excessive degradation. To investigate these properties as a basis of identifying a sandstone, the porosity of each of the nineteen sandstones was determined

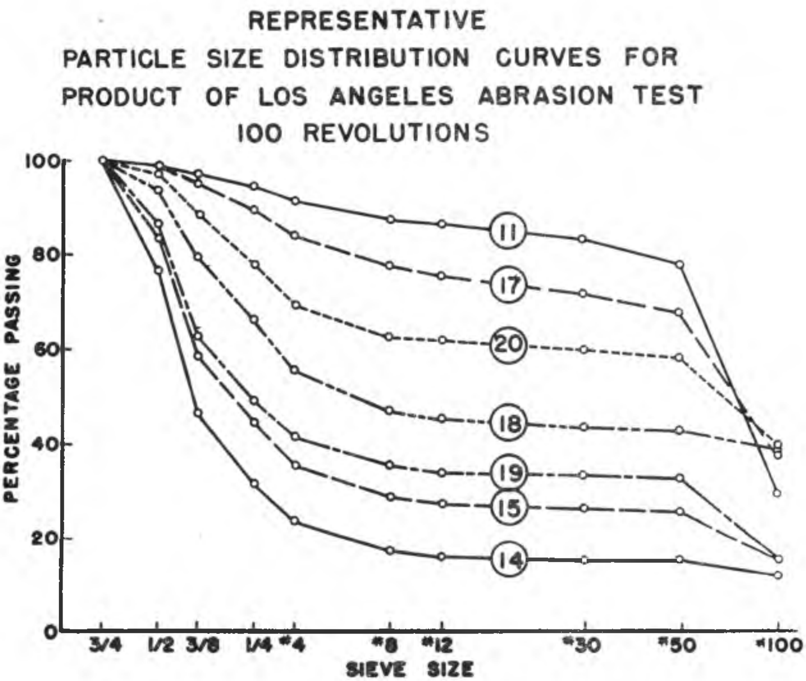

FIGURE 2. Gradation curves for several sandstones showing the range in the magnitude of degradation of sandstones.

in the laboratory, and Los Angeles abrasion tests were performed on each of the samples. The determination of the porosity of a sandstone sample has its basis in a method outlined by Sweet[1] in which the porosity can be determined if the apparent specific gravity, the corresponding absorption, and the true specific gravity are known for a given sample. The Los Angeles tests were performed according to ASTM Specifica-

---

[1] Harold S. Sweet. "A Study of Chert as a Deleterious Constituent in Aggregates," *Engineering Bulletin of Purdue University,* Research Series No. 78, Vol. 25, No. 1, January, 1942.

tion C 131-46, using a Los Angeles B grading. At the completion of 100 and 500 revolutions, sieve analyses were made on the product of the Los Angeles machine.

Figure 2 shows gradation curves for several of the sandstones at the completion of 100 revolutions. The curves represent the wide range in the magnitude of degradation which can occur with sandstones. Sandstone No. 14, which is a relatively tough sandstone, represents one extreme; while the friable No. 11, which practically has been reduced to its component sand grains, represents the opposite extreme. It is important to note the characteristic similarity of the curve shapes of these degraded sandstones. The distribution of the coarse sizes reflects the toughness of the sandstone as a composite rock material; while the distribution of the fine sizes indicates the grain-size distribution of the component sand grains which are displaced from the rock mass by the abrasive action of the test. Thus a sandstone exposed to the Los Angeles test produces a characteristic degradation curve which has a steep slope in the coarse sizes and then flattens and drops off sharply when the sizes of the component sand grains control the grading.

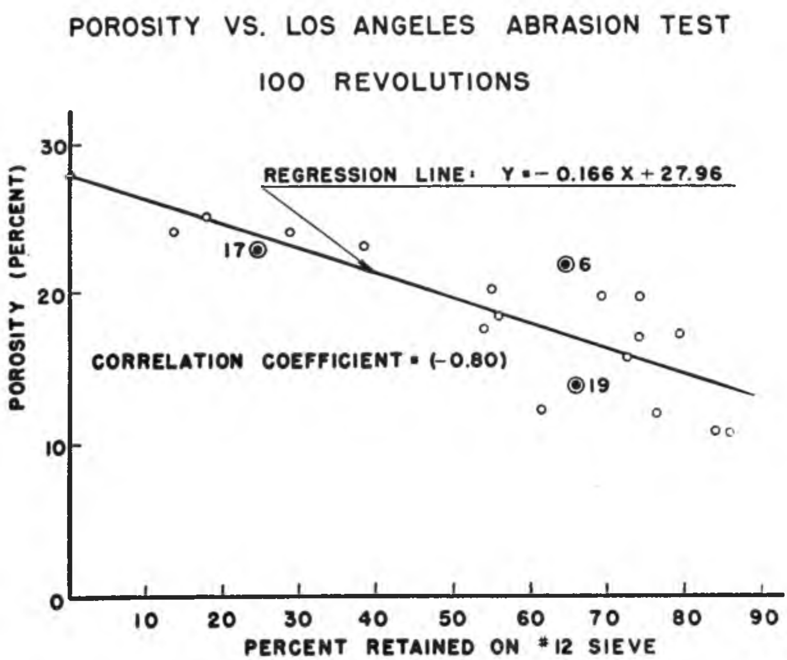

FIGURE 3. Rectilinear correlation of porosity with Los Angeles abrasion test results at 100 revolutions. (Numbered points refer to the sandstone sample numbers.)

The diagram of Figure 3 illustrates the rectilinear correlation existing between porosity and the results of the Los Angeles test at 100 revolutions. The correlation coefficient of 0.80 is reasonable evidence of some influence of porosity upon the results of the Los Angeles test. In order to investigate the combined effect of porosity and abrasion rating upon the properties of asphalt-sandstone mixtures, sandstones No. 17, 19, and 6 were selected to be mixed with asphalt in the preparation of compacted test specimens. These sandstones were chosen because of the relation between their porosities and Los Angeles ratings, which is indicated in Figure 3. Nos. 17 and 6 have approximately equal porosities; but No. 6 is relatively tough, while No. 17 is very weak and friable. No. 19 has a strength approximately equal to that of No. 6, but it has a substantially lower porosity. The 100-revolution Los Angeles rating was used as the basis of selection, rather than the 500-revolution rating, because of the fairly well-defined differentiation between the abrasive characteristics of the individual sandstones at 100 revolutions. At 500 revolutions much of this differentiation was lost because of the excessive degradation of the sandstones under the magnitude of the abrasive action at the extended period. In a study of the crushing resistance of surface-treatment aggregates, Shelburne[2] found that the Los Angeles abrasion machine at 100 revolutions gave a good indication of the amount of degradation under road rolling, while at 500 revolutions the degradation of aggregates was much greater than that encountered under field conditions. To test compacted asphalt-sandstone mixtures, the Marshall stability test was chosen from among several recognized stability tests. The Marshall test is a relatively new type of empirical test which has recently undergone extensive investigation by the U. S. Army Corps of Engineers[3]. The Army Engineers studied the Marshall method in conjunction with a large field-test section to correlate laboratory results with field behavior. Traffic tests were performed on the test section, and a laboratory compaction method was developed to produce compacted densities in the laboratory equivalent to densities in the test section at the completion of 500 to 1,500 coverages of the traffic vehicles. This compaction procedure recognizes and makes allowance for the increase in the density of a pavement which occurs under traffic. The correlation

[2] T. E. Shelburne. "Crushing Resistance of Surface-Treatment Aggregates," *Engineering Bulletin of Purdue University,* Research Series No. 62, Vol. 22, No. 5, Sept., 1938.

[3] "Investigation of the Design and Control of Asphalt Paving Mixtures," *Technical Memorandum No. 3-254* Department of the Army, Corps of Engineers, Mississippi River Commission.

between the laboratory and the field effected by the Army was the primary reason that the Marshall test was selected for this study.

The Marshall testing apparatus, shown in Figure 4, consists of a device for applying a compressive load to a semi-confined test specimen at the rate of two-inches-per-minute vertical rise. The test specimen is cylindrical in shape, and it is tested by placing it on its side between the

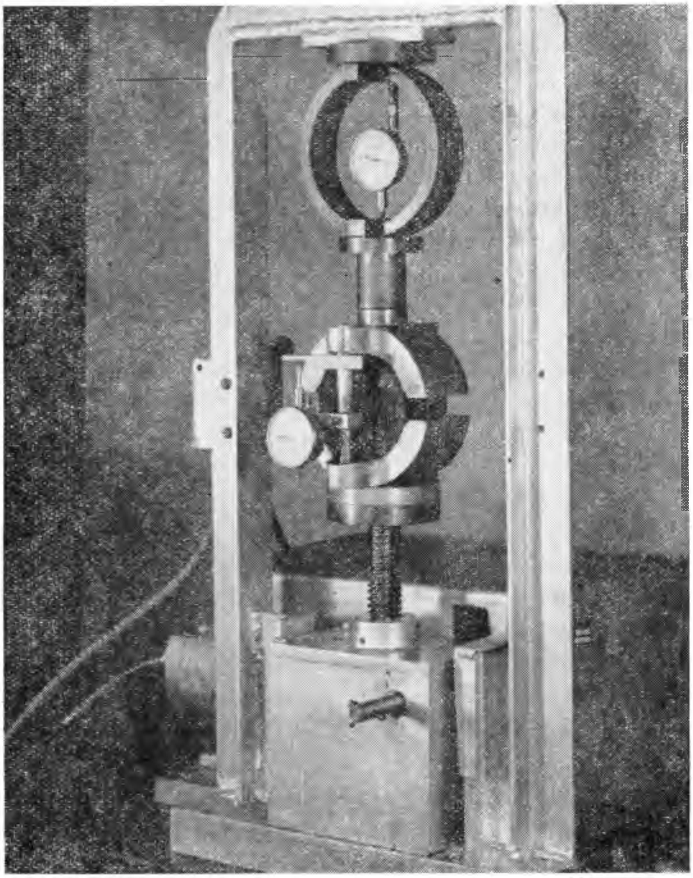

FIGURE 4. Marshall testing apparatus.

two halves of the cylindrical breaking head. The stability of the specimen is recorded as the maximum load in pounds indicated on the load dial during the interval of the test. For a given aggregate and grading, increasing the asphalt content will increase the stability to an optimum value, after which the stability will decrease. Stability values will reflect variations in grading and other physical factors, and it is therefore considered that the maximum stability value can be used as a basis for comparison of asphalt mixtures. Unlike several of the other commonly accepted stability tests, the Marshall stability value for a mix is not the only criterion for selecting an asphalt content for use in paving operations. Application of the design method developed by the Army Engineers for the Marshall test takes into consideration three additional factors in combination with the stability of a mix. One of these factors is a result of the testing process and is termed "flow," which is the amount of displacement of the specimen which occurs up to the moment of the maximum load on the specimen. The other two factors, percent voids in total mix and percent voids filled with asphalt, are properties of the compacted test specimens. The selection of an asphalt content for a satisfactory pavement mix is mutually dependent upon the limiting criteria of the four governing design factors as mentioned above and the ability of a specific mix at some asphalt content to meet the requirements of these criteria. For a surface course, the adoption of a design with asphalt content based on one of these factors alone is not justified. Since this report is concerned with a comparison of individual sandstones and their consequent behaviors in asphalt mixtures, those factors incident to design alone have been disregarded, and stability values have been used as the measure of comparison.

The test specimens of the asphalt-sandstone mixes were originally prepared, using each of the three sandstones proportioned separately to fit gradation No. 1 (see Figure 6), which is a relatively coarse grading consisting of 70 percent of the material larger than the No. 4 sieve. The batches of these sandstones were mixed with an asphalt cement (of a nominal 180 to 200 penetration) at varying asphalt contents, starting with an asphalt content below the optimum content for stability and increasing the asphalt content in increments of one percent until the optimum content was established.

The diagram of Figure 5 shows the stability curves for each of the three sandstones along with a stability curve for a non-absorptive limestone, which has been included for comparative purposes. The properties of the materials used in these mixes are shown below:

	Apparent Sp. Gr.	Porosity %	Water Absorption 24 hr.	Los Angeles Loss (100 rev.)	Los Angeles Loss (500 rev.)
1. Sandstone No. 17	2.44	22.9	8.17	75.5	99.9
2. Sandstone No. 6	2.52	22.0	8.57	35.0	98.3
3. Sandstone No. 19	2.55	14.0	4.07	34.0	88.8
4. Limestone	2.72	......	0.7	......	28.7

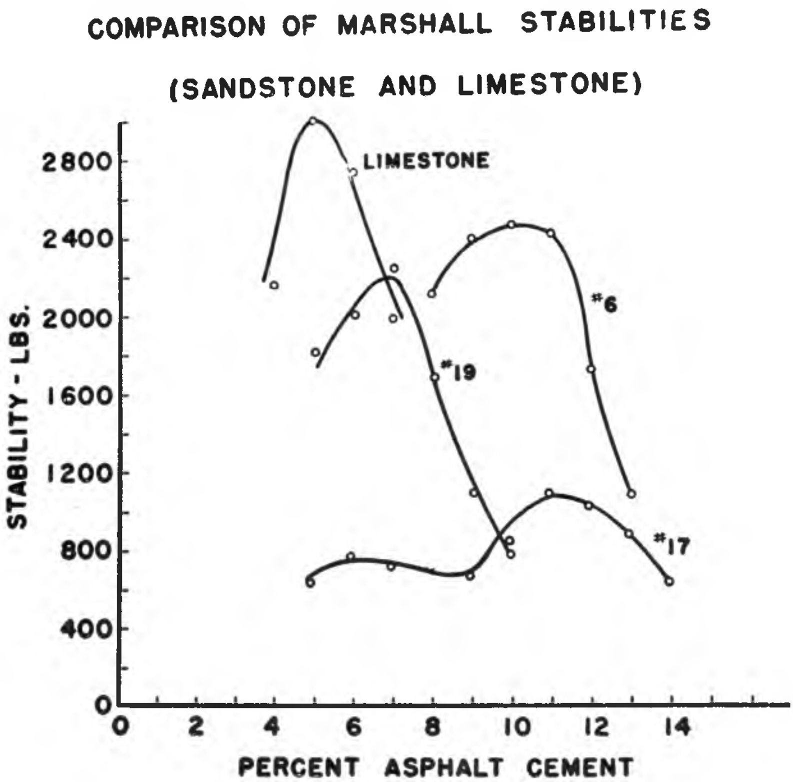

FIGURE 5. Marshall stability curves for asphalt mixtures made separately with Greencastle limestone and sandstones No. 17, No. 6, and No. 19.

Because of the excessive degradation which occurred in the sandstones in the mixing and compacting processes, comparison of sandstone and limestone mixes could not be based on mixtures in which the original gradation of the limestone was the same as that of the sandstone. To offset this grading inequality, the limestone whose stability curve is shown in Figure 5 was graded to correspond to the extracted grading of sandstone No. 17 (see Figure 6). Comparison of the optimum asphalt content of the non-absorptive limestone with that of sandstone No. 17 shows that the sandstone required approximately 6.5 percent more asphalt to establish the optimum stability. Careful examination of the stability curves of sandstones 17 and 6 shows that No. 6 required approximately 1.5 percent less asphalt to establish optimum stability even though the porosities and water absorptions of the two sandstones are approximately the same. A possible explanation of this circumstance lies in the ability of sandstone No. 6 to resist degradation more readily than

No. 17 (see Figure 6). The relation of the comparatively high stabilities of sandstones No. 19 and No. 6 with the comparatively low stability of No. 17 reflects the influence of the more favorable Los Angeles ratings of Nos. 19 and 6. The difference between the optimum asphalt contents of No. 19 and No. 6 shows the influence of the difference in porosity of the two sandstones. Regardless of the variation in the stabilities of the three sandstones, each of them exceeds the minimum stability requirement of 500 pounds established by the Army for satisfactory pavement performance.

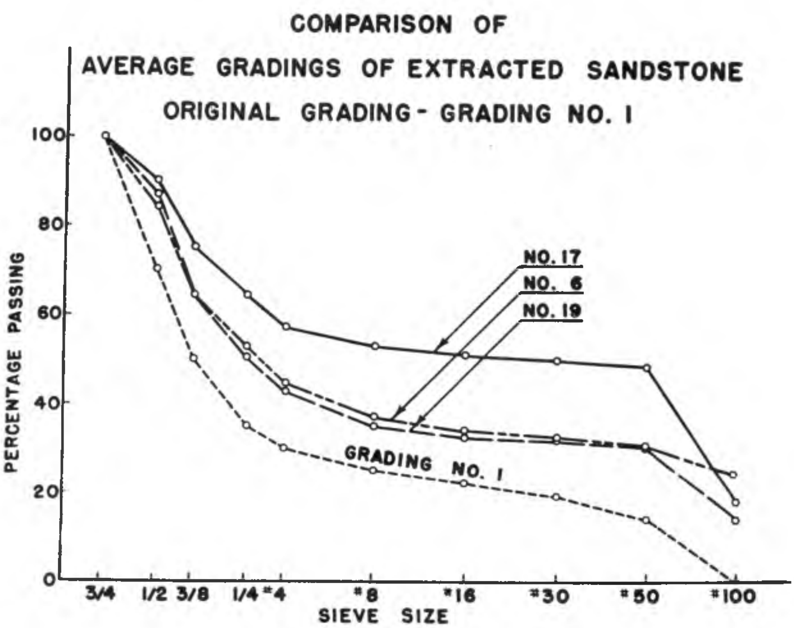

FIGURE 6. Extraction gradation curves showing the extent of the degradation which occurred in the mixing and compacting of the individual asphalt-sandstone mixtures.

To investigate the effect of laboratory mixing and compacting upon the degradation of the sandstone in asphaltic mixes, the extraction of the asphalt from tested specimens was executed to free the aggregate for separate examination. The diagram of Figure 6 shows the gradation curves of the extracted sandstones whose original grading was grading No. 1. Sandstones No. 6 and No. 19, whose Los Angeles ratings at 100 revolutions are approximately the same, show approximately equivalent degradation as the result of laboratory mixing and compacting; while sandstone No. 17 has undergone substantially greater degradation.

A striking similarity to the curve shapes of the sandstones at the completion of 100 revolutions in the Los Angeles machine (see Figure 2) is evident, which suggests that the action of the Los Angeles machine is similar to that of the mixing and compacting operations.

At the completion of the first series of tests, grading No. 2 was substituted for grading No. 1, and each of the sandstones was mixed and tested at this grading. In grading No. 2 (see Figure 7), the percentage of the coarse fraction was increased to 85 percent. This change produced a slight change in the stability of sandstone No. 17, at the same optimum asphalt content, but resulted in no significant change in the stabilities of the other two sandstones. To compare the absorptive property of sandstone No. 6 with that of the non-absorptive limestone, the limestone was proportioned to the extracted grading of sandstone No. 6, whose original grading was No. 2 (see Figure 7). Comparison between sandstone No. 6 and the limestone at approximately equivalent gradings showed that sandstone No. 6 required approximately 6 percent more asphalt than the limestone to establish optimum stability. Since the extracted gradings of sandstones No. 6 and No. 19 are almost the same, a tentative comparison of limestone and sandstone No. 19 showed that sandstone No. 19 required about 3 percent more asphalt than the lime-

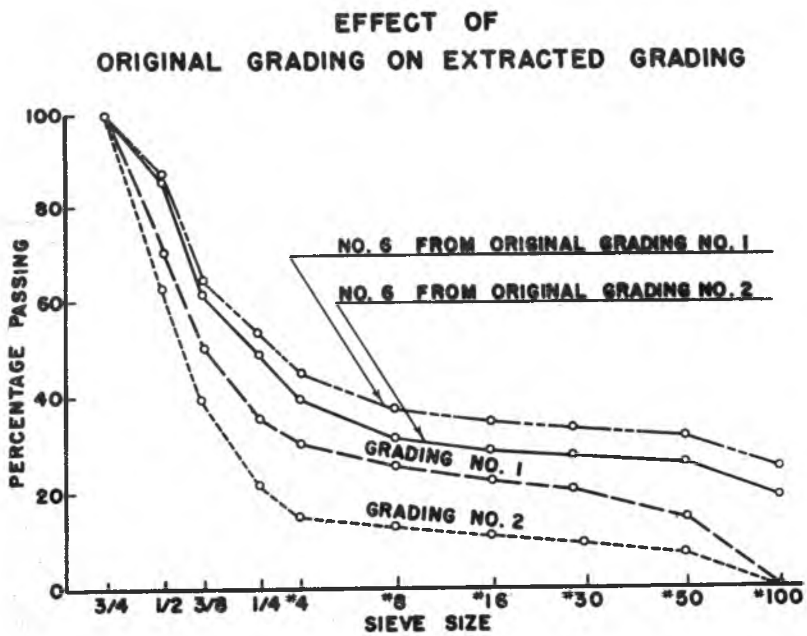

FIGURE 7. Gradation curves of sandstone No. 6 showing the comparison between the compacted gradings of mixtures prepared from separate original gradings.

stone to establish the optimum stability. The change in the grading of the limestone (to the extracted grading of sandstone No. 6) produced a striking reduction in the stability of the limestone mix below that of the original limestone mix. The resulting stability was below those of sandstones No. 6 and No. 19, a fact which minimizes the importance of aggregate type and emphasizes the importance of aggregate gradation. This serves notice that equivalent stabilities can be produced with a substantially poorer aggregate, although it is not proof that high stabilities can be produced with all aggregates which are classified as poor.

The diagram of Figure 7 shows the effect of the change in the original grading, from No. 1 to No. 2, on the degradation of sandstone in

FIGURE 8. Sandstone broken open at the completion of the asphalt absorption test, showing the extent of asphalt absorption.

the mixing and compacting operation. The increase of the coarse fraction in grading No. 2, as compared with grading No. 1, has caused the same degradation curve shape to be maintained, but has shifted the curve downward, which is evidence of the smaller percentage of fine material, or sand grains, present in the compacted mixture prepared from grading No. 2. Sandstone No. 6 has been used in the diagram to illustrate the principle, but the effect of the change in the grading was the same for each of the other sandstones.

To investigate the asphalt absorption properties of sandstones by a method other than comparison with a non-absorptive limestone, the asphalt absorbed by seven sandstones was determined by direct immersion in a bath of asphalt cement heated to 275°F. The procedure followed in this absorption determination was one which has been developed by Goshorn[4]. One thousand grams of each of the sandstones was immersed in the asphalt for a period of three hours, after which the percent of asphalt absorbed was computed from the relationships of weight and bulk volume of the sandstones. The sandstones shown in Figure 8 have been broken open at the completion of the hour immersion to show the extent of the asphalt absorption. In many of the other individual pieces broken open, absorbed asphalt appeared to have permeated the sandstone. The values of the excess asphalt necessary to establish maximum stability for a mix made with absorptive sandstone over that required for non-absorptive limestone compare favorably, on a relative basis, with the amounts of asphalt absorbed by the respective sandstones as determined by direct means as indicated in the table below.

	Excess Asphalt Based on Comparison with Limestone (percent)	Asphalt Absorption by Direct Immersion (percent)
1. Sandstone No. 17	6.5	6.95
2. Sandstone No. 6	6.0	7.94
3. Sandstone No. 19	3.0	3.44

A possible explanation of the smaller amount of excess asphalt to establish the optimum stability of sandstone No. 6 as compared with sandstone No. 17 lies in the ability of sandstone No. 6 to resist degradation more readily than No. 17. Direct immersion reveals that sandstone No. 6 is capable of absorbing more asphalt than No. 17 (subject to the evaluation of the experimental error) which seems to point to another factor which influences the amount of excess asphalt necessary for a sandstone mix.

The absorption of water by each of the seven sandstones was determined by 24-hour immersion, and a correlation of the percent of asphalt absorbed with the percent of water absorbed was attempted. The diagram of Figure 9 shows the results of the rectilinear correlation between the two variables. The analysis indicated a correlation coefficient of 0.98, which is excellent correlation; however, since the correlation is based on seven values only, the significance that can be attached to the relationship is limited. The correlation does indicate that it may be

[4] J. H. Goshorn and F. M. Williams. "Absorption of Bituminous Materials by Aggregates," *Proceedings, Association of Asphalt Paving Technologists*, January, 1942, p. 41.

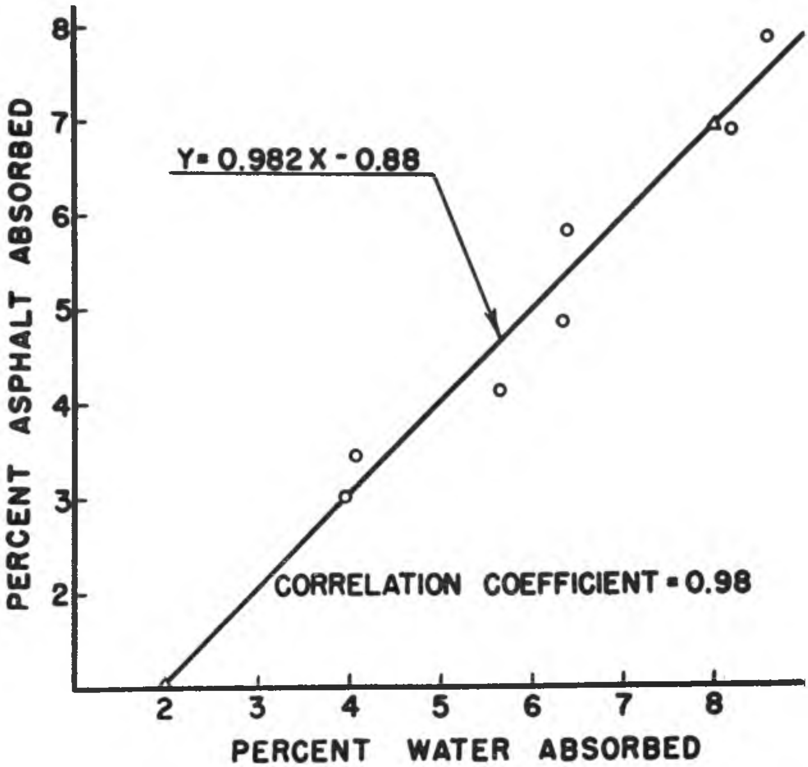

FIGURE 9. Correlation between percentage of water absorbed and percentage of asphalt absorbed.

possible to develop a useful tool for estimating the asphalt absorption of a sandstone through water immersion.

From the results of the study the following conclusions have been formulated which appear to be justified from the data obtained.

1. On the basis of the criteria of Marshall testing established by the Army Engineers, sandstone as an aggregate type can be satisfactorily used in asphalt pavements.

2. Sandstones will degrade materially under the action of mixing and compacting. These degradations are of a similar nature, the extent of which is dependent upon the properties of the individual sandstones.

3. A relative rating of the ability of sandstones to resist degradation in use can be obtained from the results of the Los Angeles abrasion test at 100 revolutions.

4. The amount of fine material in the mixed and compacted sandstone-bituminous pavement can be reduced by an increase in the proportion of coarse to fine aggregate in the original grading.

5. Indiana sandstones are absorptive materials which require a higher asphalt content for satisfactory pavement mixes than do non-absorptive aggregates.

6. The optimum asphalt content of a sandstone-bituminous pavement is a function of the absorptive power of the sandstone in combination with its ability to resist degradation.

7. The absorption of asphalt to be expected in a sandstone-asphalt mixture can be approximated by a direct immersion of the sandstone in heated asphalt for a controlled period of time.

8. Limited data indicate that a relation exists between the amount of water absorbed and the amount of asphalt absorbed by direct immersion of sandstone aggregates.