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LABORATORY COMPACTION TESTS OF COARSE-GRADED PAVING AND EMBANKMENT MATERIALS

By

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Airport Division

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LABORATORY COMPACTION TESTS OF COARSE-GRADED PAVING AND EMBANKMENT MATERIALS

SUMMARY

This report presents the results of a laboratory study conducted to determine the applicability of the Proctor type of compaction test to the compaction of coarse-graded materials A coarse-graded material or mixture is defined as one containing an appreciable amount of plus 4 material (i e , material which would be retained on a No 4 sieve) Three representative granular materials (gravel, limestone, and slag) were tested through a range of carefully controlled artificial gradations in which the ratio of coarse to fine fractions was varied Certain other variables which significantly affected the test results were investigated in detail

These tests indicate that a modified Proctor procedure can be used successfully to compact coarse-graded materials in either a 4- or 6-inch diameter mold. The maximum density of mixtures of coarse and fine materials increased with increasing percentages of coarse material, up to a point of optimum gradation Beyond this point the further addition of coarse material resulted in lower densities The optimum gradation for the materials used in this study occurred when the mixtures contained about 40 to 60 per cent of coarse material When the mixture contained more than 80 per cent of coarse material, results obtained from the Proctor compaction test were erratic

Degradation of coarse aggregate during compaction increased with increasing percentages of coarse material. Breakage in the 4-inch mold was negligible when the plus 4 material was less than 30 per cent

The increase in maximum density which is gained by adding coarse materials to fine-graded mixtures can be accurately predicted by a correction formula applied to the density of the finer, or minus 4, portion of the material. Correction formulas were not applicable to mixtures coarser than the optimum gradation.

INTRODUCTION

In the standard Proctor soil compaction test[1] and in some of the modifications of this test, all of the particles retained on the No 4 sieve are removed from the sample before it is compacted in the mold This is done because the presence of the larger particles might prevent adequate consolidation of the material in the relatively small container used The standard mold used in the Proctor test is 4 0 inches in diameter and 4 6 inches high, with a volume of 0 033 cubic feet Because the coarser portion of the material is removed, the test results obviously cannot be translated directly into specification requirements covering the compaction of coarse-graded material

Various expedients have been used in an effort to modify the Proctor test procedure or to evolve a correction factor for extending the test to cover coarse-graded materials One of the most obvious changes is to use a larger test mold, usually about 6 inches in diameter and 6 inches high Objections might be raised that it requires additional special equipment and that additional work and material are required for compacting each sample. The latter objection is valid on a job requiring several hundred compaction samples

When large molds are used, it is customary to increase the number of hammer blows so that the energy expended per unit volume is equal to that used in the test with the standard mold. Tests have indicated, however, that this will not necessarily give equal values of maximum density for the same material compacted in molds of different sizes Attempts have been made to remedy this defect by determining, through extensive experiments with fine-graded material, the correct number of blows for obtaining equivalent results. In order to achieve either equal compaction or equal densities for the same material, other experimenters have used the same number of blows for molds of different sizes but have varied the size and weight of the hammer

Some engineers feel that elimination of the material retained on the No 4 sieve is too stringent a requirement and allow the use of all material passing a 3/4-inch or larger sieve When this is done, it is sometimes necessary to decrease the number and increase the thickness of material layers in order to accommodate the larger particles The total number of blows usually remains the same as that used in the regular test for soil or fine-graded mixtures

When the larger-sized material is

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[1] ASTM Standards 1949, Part 3, American Society for Testing Materials (ASTM), Philadelphia, Pa., pp 1180-1182

eliminated from the sample before testing, it is customary to correct the maximum density obtained from the test by computing the theoretical effect of including the coarser particles The Civil Aeronautics Administration specifies that the compaction test[2] be performed only on the material passing the No. 4 sieve, and the following correction is used

$$D = \frac{P_f \times D_f}{100} + \frac{P_c \times 0\ 90 D_t}{100} \qquad (1)$$

where

D = Maximum dry density of total sample in pounds per cubic foot,

D_f = Maximum dry density of material passing the No 4 sieve in pounds per cubic foot,

D_t = Bulk specific gravity of material retained on the No. 4 sieve multiplied by 62 36,

P_f = Percentage of material passing the No 4 sieve,

P_c = Percentage of material retained on the No. 4 sieve.

This formula is based on the assumption that addition of the coarse material will hinder the compaction of the finer material and thus introduce additional voids into the finer fraction This allowance for additional voids may vary with different specification writers who use this general type of formula

In a study of the compaction characteristics of combinations of fine-grained soil and gravel, Zeigler compared laboratory densities with those predicted by a theoretical formula of a different form[3] When converted to the same terms as Equation (1) this relationship can be expressed as

$$D = \frac{100}{\frac{P_f}{D_f} + \frac{P_c}{D_t}} \qquad (2)$$

In these tests, controlled portions of No. 4 to 3/4-inch size gravel were added to the soil in 10 per cent increments and in amounts from 0 to 50 per cent In all cases the theoretical densities predicted by Equation (2) were higher than those obtained by laboratory testing. Values obtained by Equation (1) gave a better comparison

Some specification writers provide for the removal of oversized material, either above the No. 4 size or above the 3/4-inch size, from the test sample but substitute for it an equal weight of smaller-sized granular material. Such action assumes that the smaller particles will have substantially the same effect on the test result as would the larger particles which were removed.

From the preceding discussion it is evident that there is a wide variation in compaction tests and specifications for coarse-graded materials commonly used in pavement base and subbase construction From the standpoint of the contractor, the inspector, and the materials laboratory technician, some standardization is most desirable.

Herner analyzed some existing compaction data in an effort to evaluate the effectiveness of the Proctor test when used with mixtures containing plus 4 material[4] As a result of this analysis it was recommended that a comprehensive series of compaction tests be made on coarse-graded materials, in order to provide answers to the following questions

1 What are the upper limits of size and proportion of coarse material which can be included in the standard Proctor test without obtaining erroneous results?

2. If a portion of the coarse material is removed from the sample for the purpose of testing, what formula should be used for converting the results to specification requirements applicable to the whole sample?

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[2] Standard Specifications for Construction of Airports, U. S. Department of Commerce, CAA Office of Airports, Washington, D. C., January 1948, p 572.

[3] Edward J Zeigler, "Effect of Material Retained on the Number 4 Sieve on the Compaction Test of Soil," Highway Research Board, Proceedings of the Twenty-Eighth Annual Meeting, Vol. 28, pp. 409-414, 1948.

[4] Raymond C. Herner, "Study of Laboratory Compaction Tests and Specifications of Coarse-Graded Materials," unpublished paper, CAA Technical Development and Evaluation Center, July 1949.

3. Is the Proctor type of compaction test applicable to the testing of harsh mixtures containing little or no fine-grained material, and if not, what are its practical limits?

The present study was initiated to obtain answers to these questions through controlled laboratory testing of various coarse-graded mixtures

DESCRIPTION OF MATERIALS

Three contrasting granular base-course materials (gravel, crushed limestone, and crushed slag) were used in this study From each of these materials there were obtained three carefully separated portions the minus 4, the plus 4 to minus 3/4-inch, and the plus 3/4-inch to minus 1 1/2-inch fractions. These fractions were combined in selected proportions to give a wide range of gradations. For convenience in reporting, the fine, medium, and coarse fractions have been designated A, B, and C, respectively.

The limestone and slag fractions were each obtained from a single, individual source of supply, while the gravel fractions were obtained from two different sources. The minus 4 gravel was screened from a well-graded mix, the plus 4 portion of which was discarded The medium and coarse fractions were obtained as washed gravel, each from a different source Consequently, these fractions varied somewhat in physical characteristics. For a special series of tests, a concrete sand was used in place of the normal minus 4 portion of the gravel. This material is designated as fraction A_1

The appearance of each fraction of the three basic materials is shown in Figs 1, 2, and 3 The physical characteristics are summarized in Table I

COMPACTION EQUIPMENT

All of the test samples were compacted by means of a Rainhart Automatic Tamper No 62, modified by the addition of a motor drive and a counter for controlling the number of blows applied to each layer of the sample. The rate of tamping was 45 blows per minute. The equipment was designed for use with either a 4- or 6-inch mold. Interchangeable striking heads, each with an end area of 3.14 square inches, were provided for use with the different mold sizes. The striking surfaces were in the form of sectors of a circle, with the apex toward the center of the mold. The radii were such that the curved outside edge of the hammer just cleared the inside edge of the particular mold being used

When using the 4-inch mold the hammer weight was 10 pounds For the 6-inch mold this weight was increased to 22 5 pounds by the addition of a removable cast-iron block to the shaft immediately above the striking head. The tamping equipment, set up for operation with the 6-inch mold, is shown in Fig 4

During operation the tamping weight was automatically raised and turned in such manner that the striking head made a complete coverage of the sample surface in 7 blows. The hammer was released by an adjustable trigger device set to control the desired height of free fall

The 4- and 6-inch molds were both 4 6 inches high (standard height for Proctor test) with volumes of 0 033 and 0.075 cubic feet, respectively. They were slightly tapered to permit easy removal of the samples.

TESTING PROCEDURES

Modified AASHO (American Association of State Highway Officials) compaction effort was used for all tests For the usual form of this test, in which only the minus 4 portion of the material is included, the sample is tamped in 5 layers by means of a 10-pound hammer falling from a height of 18 inches. Twenty-five blows are applied to each layer.

Because of the large aggregate (1 1/2-inch top size) included in the present study, it was found necessary to increase the layer thickness to a compacted height of at least 1 1/2 inches The procedure for preparing the samples was therefore modified so that each sample was constructed in 3 layers of approximately 1 1/2 inches each compacted with 42 blows of the hammer In this way the compactive effort was equal to that of the normal test When using the 6-inch mold the procedure was identical except that the hammer weight was increased to 22 5 pounds, thereby furnishing unit energy equal to that applied to the 4-inch sample

Individual points of the compaction curve were obtained by using a different sample of material for each moisture content The proper amount of each fraction required to construct the sample was carefully weighed and stored in a separate container. In the early stages of these tests all of the individual fractions were mixed together prior to the addition of water, but erratic results were obtained by this method. After several exploratory tests, a procedure was adopted in which all of the plus 4 material was soaked in water overnight prior to mixing with the minus 4 fraction The minus 4 portion was slaked for a period of 15 minutes to 1 hour before mixing with the coarse aggregate All mixing was performed by hand Identical combinations were compacted at different moisture contents until the condition of maximum density and optimum moisture was reached

After compaction, the tops of the samples were trimmed level with the top of the mold This operation was very difficult to perform properly when high percentages of coarse material were used If a large piece of material was protruding above the required sample height it could be removed, in which case finer material was added in its place, or it could be allowed to remain, in which case material at some other point in the sample would be removed in an amount approximating the volume of the protruding portion of the aggregate In neither case was there any way of reproducing, in the modified portion of the sample, the identical density or gradation of the original material A compromise of these methods was generally used at the discretion of the operator Fig 5 illustrates the condition of the top portion of a typical coarse-graded sample during leveling In extreme cases it was necessary to rebuild practically the entire top section of the samples

After leveling, the sample was weighed to the nearest gram and its moisture content determined by drying in an electric oven at a constant temperature of 105°C The entire sample contained in the 4-inch mold and 3000-gram or larger portions of those contained in the 6-inch mold were used to determine the moisture content. It was found that the use of smaller moisture samples did not reflect the average moisture conditions throughout the whole specimen

A sieve analysis using the 3/4-inch and the No 4 sieves was made of most of the samples after testing in order to determine the amount of degradation during compaction

All tests of the physical characteristics of the materials were made according to ASTM procedures

TEST RESULTS

The basic compaction results are shown in Tables II, III, and IV, and in Figs 6 through 17 Individual compaction curves from which the points on these gradation-density curves were obtained have not been shown because, in most cases, they represent typical moisture-density relationships

The tables show the maximum density and optimum moisture obtained for each gradation in both the large and small molds, the percentages of each fraction A, B, and C before and after compaction, and the fineness modulus of each of the samples before compaction The fraction sizes indicated by an asterisk do not represent test values but are percentages interpolated from plotted data The figures show the maximum density plotted against the corresponding gradation Separate curves are shown in Figs 6 through 16 for the two mold sizes and for the gradation both before and after compaction

For mixtures composed of fractions A plus B and of fractions A plus B plus C, the gradation was plotted in terms of the percentage of material retained on the No 4 sieve For the skip-graded samples (fractions A plus C) and the very coarse samples (fractions B plus C), the densities were plotted against the percentages of material retained on the 3/4-inch sieve Curves are also included to show the theoretical changes in density due to varying amounts of plus 4 aggregate as computed by Equations (1) and (2), previously discussed Fig 17 compares results between gravel mixtures compacted in the 4-inch mold in which different materials (fractions A and A_1) were used for the minus 4 fraction

Figs 18 through 21 show the relationships between mold size and degradation of the sample during compaction In these figures the degradation percentage is the numerical difference between the percentages of the material retained on the indicated sieve size (No 4 or 3/4-inch) before and after compaction

Figs 22, 23, and 24 show complete sieve analysis curves for the basic combinations (A plus B, A plus C, A plus B plus C) of each material at gradations near the optimum before and after compaction in the 4-inch mold Table V gives the fineness modulus of each mixture before and after compaction

The compaction test results obtained in this study can be considered representative for coarse-graded mixtures In analyzing the data, however, it should be realized that a high degree of accuracy was not always attainable with some of the coarser gradations As the ratio of coarse to fine material increased the Proctor compaction procedure became more difficult to perform properly, and the results were often erratic Further, for certain gradations the particles of the mixture tended to segregate during preparation of the samples Since the mixtures were not homogeneous but consisted of particles of different specific gravity and other physical characteristics, the effect of segregation was significant In the compaction of the coarser samples, density variations as high as three pounds per cubic foot were attributable to this segregation

With the majority of mixtures the tests could be performed quite satisfactorily, and clearly defined values were obtained For the less satisfactory samples, the maximum density and optimum moisture content represent the best average values that could be interpreted from the data. This fact is mentioned in order to emphasize the point that certain irregularities in the test results are probably due to experimental error rather than to specific trends in the data

DISCUSSION OF RESULTS

Although it is impossible to segregate entirely the effects of different variables, as indicated by the test data, the more important ones will be discussed separately as far as possible

Effect of Gradation

The effect of sample gradation on the maximum density obtainable from a given mixture is clearly shown in the graphs. Except for combinations of very coarse fractions, all of the mixtures yielded a density increase with increasing coarse aggregate content up to an optimum gradation beyond which the densities decreased rapidly with increased amounts of coarse material The optimum combinations varied for the individual materials and with the particular fractions used to form the sample In general, however, optimum density was reached when the samples contained 40 to 60 per cent of plus 4 material. The maximum density gradations correspond closely to gradations[5] established by Fuller for concrete mixes

For all combinations containing a minus 4 fraction (A plus B, A plus C, A plus B plus C), the maximum densities obtained with each type of material were the same except that the gravel samples using skip-grading (fractions A plus C) attained a maximum density two to three pounds per cubic foot higher than those of other gravel combinations See Fig 7 This combination also showed the highest amount of degradation during compaction

These tests show that for normally graded materials the size of the coarsest particle does not significantly affect the maximum density at the optimum gradation This indicates that smaller aggregate can be substituted for larger without erroneous results in cases when it is desirable to limit the top size of the coarse fraction.

For the very coarse-graded samples containing fractions B plus C, no optimum gradation was found See Figs. 12 and 16 Within the range of experimental error, all combinations containing B plus C fractions of a given material reached substantially the same maximum density These values were considerably lower than corresponding densities obtained with other combinations Degradation was quite high for the coarse-graded mixtures

All of the findings showing the effects of gradation on density were consistent The fact that the optimum point occurs at the same gradation, regardless of mold size, indicates that the decreasing density beyond this point is a function of the gradation and is not due to arching or restriction in the mold

Effect of Mold Size

The influence of mold size varied with the type and, to less extent, with the gradation of the materials compacted. For the gravel and limestone the effect of mold size was very small In most of these tests slightly higher densities were obtained in the 4-inch mold for the fine-graded mixtures At or near the optimum point the densities approached equality Beyond this point, as the mixtures became harsher there was a slight but inconsistent separation At the point of 100 per cent coarse material, equal or higher densities were obtained in the 4-inch mold

With the crushed slag, higher densities were obtained with the smaller mold in all tests. The differences were significant, averaging about 3 or 4 pounds per cubic foot The slag was the most difficult material to test accurately, but even with possible experimental error the results definitely show that significantly higher densities for this material were obtained in the smaller mold It should be noted that the slag was inherently harsher than the gravel and limestone used

In general, these tests indicate that there is no undue particle interference in the 4-inch mold and that this size is satisfactory for tests of coarse mixtures For such mixtures it produces higher densities than the 6-inch mold because there is less confinement in the latter

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[5] William B Fuller and Sanford E Thompson, "The Laws of Proportioning Concrete," Transactions of the American Society of Civil Engineers, Vol LIX, p 67, December 1907

Effect of Varying the Minus 4 Portion of Sample

In all of the compaction tests the densities of the coarser mixtures were compared with the density of the minus 4 portion of each material In order to study the possible effect of a variation in this fraction upon the density-gradation relationship, a series of tests were conducted using the B fraction of the gravel but replacing the normal A fraction with a minus 4 fraction of concrete sand (A_1). The results are shown in Table II and Fig 17.

Although the influence of the different minus 4 materials was quite apparent on the fine side of the gradation-density curve, there was no significant difference in the maximum densities obtained at the optimum point Beyond this point the curves were similar Breakage values were about the same for each condition. Additional tests are necessary to determine the exact role of the minus 4 fraction in tests of this sort

Degradation.

The density of compacted samples is greatly influenced by the amount of degradation taking place during their preparation Tables II, III, and IV, and Figs. 6 through 16 include the percentages of each fraction before and after compaction As previously mentioned, the asterisks in the tables indicate interpolated values

For most of the samples, only a small amount of breakage occurred in mixtures finer than those yielding optimum density. Beyond this point the breakage generally increased with increasing percentages of coarse material. An exception to this occurred in the skip-graded samples, composed of fractions A plus C, where there was considerable degradation when the coarse aggregate exceeded 20 or 30 per cent Degradation was high for the coarse mixtures of fractions B plus C. The amount of degradation was not affected by variations in moisture content of the samples It should be noted that the above breakage information is based only on the change in fraction size expressed in terms of minus 4 or minus 3/4-inch values

The curves shown in Figs 18 through 21 were plotted in order to obtain more conclusive information concerning relationships between mold size and degradation of the sample during compaction. Fig. 18 shows the magnitude of breakage of the samples during compaction in the 4- and 6-inch molds, based upon the amount of material retained on the minus 4 sieve at the start of the tests. The indicated degradation percentage is the numerical difference between the percentages of the material retained on the No. 4 sieve before and after compaction In this test there was no significant difference between the amount of breakage for gravel, limestone, and slag A single curve, therefore, is representative of all these materials

It is shown in the data that breakage increases with increasing percentages of coarse material No appreciable breakage occurred, however, until the plus 4 material exceeded about 30 per cent in the small mold and 20 per cent in the large one The earlier breakage in the large mold was to be expected, since the hammer used to compact the samples in the larger mold was much heavier than that used for the smaller. After breakage began, the rate of degradation was greater in the smaller mold

Fig 19 shows similar information based upon the amount of material passing the 3/4-inch sieve before and after compaction The results are similar to those based on separation of material on the No. 4 sieve However, the amount and rate of breakage varied with the material tested, and the breakage started at lower percentages of coarse material

Figs 20 and 21 show the breakage in the small mold plotted against breakage in the large mold, for material retained on the No. 4 and the 3/4-inch sieves These values are compared with a 45-degree line representing equal breakage in each mold Considerable scattering of the points is apparent, but in general it is indicated that for lower percentages of breaking (fine material predominating) the greater degradation occurred in the large mold At higher values of breakage (coarse material predominating) the greater degradation occurred in the smaller mold

The curve representing "hammer energy ratio" indicates the ratio between the weights of the hammers used in the large and small molds This curve was included in order to determine whether breakage during compaction was proportional to the foot-pounds of energy delivered to the sample per unit area of the hammer striking surface. Only a few points fall near this line

A complete sieve analysis for all samples before and after compaction was not made, because this would have been too time-consuming Instead, samples of each material were selected for detailed analysis at points near the optimum gradation for each basic combination, namely A, A plus B, A plus C, A plus B plus C. Figs. 22, 23, and 24 show the complete sieve analyses for these selected samples before and after compaction in the small mold The fineness moduli of the mixtures before and after compaction are listed in Table V No particularly significant trends are indicated by the data shown in the same table

In general, for all material retained on the No 4 sieve (including plus 3/4-inch material when present with at least an equal amount of minus 3/4-inch material) no serious breakage occurred when less than 40 per cent of the mixture was retained on the No 4 sieve With 40 per cent plus 4 material, the breakage was only 2 per cent in the small mold and 3 per cent in the large mold

Based on the percentage retained on the 3/4-inch sieve, significant breakage began with samples containing about 18 per cent coarse material in the 4-inch mold and about 10 per cent in the larger These results indicate that the Proctor type test using the 4-inch mold can be used satisfactorily when the sample contains as much as 40 per cent of well-graded plus 4 material, of which about 15 to 20 per cent can be of 1 1/2-inch maximum size Beyond these points the density is greatly affected by degradation This effect is emphasized when using skip-graded mixtures and where coarse material predominates

For other than breakage considerations the over-all test data and operational experience indicate that up to 50 or 60 per cent of plus 4 material containing not more than 25 per cent plus 3/4-inch material is permissible in the 4-inch mold Beyond this value operational difficulties increase

Comparison with Theoretical Densities.

Figs 6 through 17 include the theoretical density-gradation curves computed from Equations (1) and (2). Equation (1) more nearly predicted the results obtained from the tests Equation (2) gave better results only when the concrete sand was used as the minus 4 fraction of the gravel See Fig 17 For all other tests the results obtained by this formula were consistently too high.

Neither formula was applicable beyond the optimum gradation In using a formula of this type, therefore, it is necessary to know the limit of its applicability or the point of maximum density beyond which the addition of coarse material causes diminishing density Possibly this could be done by developing an equation similar to (1) or (2) which would give a curve sloping upward from the coarse end of the graph to a point of intersection with the curve now used The intersection of the two curves would establish the point of maximum density and the limit of use for each curve Extensive test data would be required to establish definitely the feasibility of such a method and to define clearly the relationships The present information shows that Equation (1) is quite accurate in predicting the increase in densities resulting from the addition of coarse material to the minus 4 portion, up to the point of maximum density attainable for the particular fractions used

The information presented in this report and that of other investigations indicates that the Proctor type of test can be used successfully for compacting normally graded materials containing 3/4-inch material and larger With the larger size aggregates, however, the testing operations become increasingly difficult It appears that a logical compromise would be to limit the top size of coarse aggregate to 3/4-inch and correct the density for any plus 3/4-inch material contained in the sample It is believed that Equations (1) or (2) could be modified to serve this purpose

Comparison of Laboratory and Large Scale Compaction Data

In order to determine the suitability of the Proctor type test for setting up field compaction requirements for coarse-graded mixtures, the densities obtained in laboratory tests were compared with densities obtained on similar materials under normal construction procedures

In Fig 9, Point A represents an average density obtained in a highway base course in Indiana Field densities in this case checked quite closely with those obtained in the laboratory by means of the Standard Proctor compactive effort, using the whole sample (up to 3/4-inch size) in the test Points B, C, and D in Figs 6, 8, and 11, respectively, represent the field densities obtained on several CAA airport construction projects using materials and gradations within the range covered by this study Although exact comparisons between the field data and the laboratory results are not justified, the positions of the points indicate that a specification of 95 per cent laboratory density would have been a reasonable requirement for field compaction of these materials

In connection with another experimental project now under way at this Center, 10-foot by 10-foot experimental base courses using the same materials tested in this study are compacted by means of vibratory equipment The densities obtained are generally about 5 pounds per cubic foot less than the maximum for similar gradations obtained by means of the modified Proctor laboratory test Degradation of materials under the vibratory compaction is small, being about 3 per cent based on amounts passing the No 4 sieve

The degradation values obtained in this study were further compared with values obtained by Shelburne, in which similar materials were compacted by means of a 10-ton steel roller[6] Shelburne's work concerned the testing of surface treatment aggregates which contained particle sizes up to 3/4-inch and which had been placed on rigid and flexible bases in quantities of 40 pounds per square yard Under the action of seven round trips of the roller, the degradation of the materials placed on the flexible base compared closely with the degradation values shown in this report This indicates that degradations due to the laboratory test are within a range of those to be expected under certain extreme field conditions

All of the above records indicate the general applicability of the Proctor type of test for field compaction control of coarse-graded materials. The records are somewhat sketchy, however, and should be supplemented by extensive experimental correlation of field and laboratory data

CONCLUSIONS

In this study a carefully controlled laboratory evaluation has been made of the applicability of the Proctor type compaction test to the compaction of coarse-graded materials Some of the findings represent definite conclusions, while others require substantiation by field data Comparative field information concerning certain phases of the study is meager In these cases the laboratory results can be compared only in a general way to observed field values

For the range of materials used in this study, the following conclusions appear warranted

1. The Proctor type of test, using a standard 4-inch mold, was found to be suitable for determining the maximum density and optimum moisture content of coarse materials and mixtures In testing the harsher mixtures, however, serious operating difficulties were encountered

2 For practical purposes it is believed desirable to limit the upper size of the aggregate to 3/4-inch When necessary to remove any plus 3/4-inch material, the densities can be corrected by means of an equation similar to (1) or (2) or by replacing plus 3/4-inch material with minus 3/4-inch coarse material

3 The test results were not appreciably affected by a difference in mold size except with certain slag gradations for which higher densities were obtained in the 4-inch mold No significant particle interference was indicated when using the 4-inch mold

4 Maximum densities of mixtures of graded aggregates increased with increasing percentages of coarse material up to an optimum gradation Beyond this point the further addition of coarse material resulted in decreasing densities The optimum gradation occurred when the sample contained 40 to 60 per cent of plus 4 material

5 Maximum densities for well-graded mixtures of a given material were the same regardless of the general gradation of the plus 4 fraction On this basis smaller aggregate can be substituted for larger, if it is desired to limit the top size of the sample for the purpose of testing

6 Degradation of samples during compaction increased with increasing percentages of coarse material No appreciable breakage occurred in the 4-inch mold until the plus 4 material exceeded about 30 per cent

7 Equation (1), used for predicting the increase in maximum density gained by adding coarse-graded material to fine-graded mixtures, was found to be applicable to most of the materials used in this study when the materials were combined in mixtures ranging from fine up to those producing maximum density Beyond this point the correction formula did not apply

8 Variations in the characteristics of the minus 4 fraction of coarse-graded mixture affected the densities of only those samples containing predominantly minus 4 material When plus 4 gravel was added individually to two different minus 4 fractions, the optimum gradation and corresponding densities were approximately the same

9 From a limited series of observations, the densities obtained in the laboratory by the Proctor type of compaction test appear to agree with densities obtainable with either vibratory or roller types of field equipment Further tests conducted for the specific purpose of comparing field and laboratory density values appear desirable Such tests should include studies of the degradation of materials under the action of different types of laboratory and field compaction equipment

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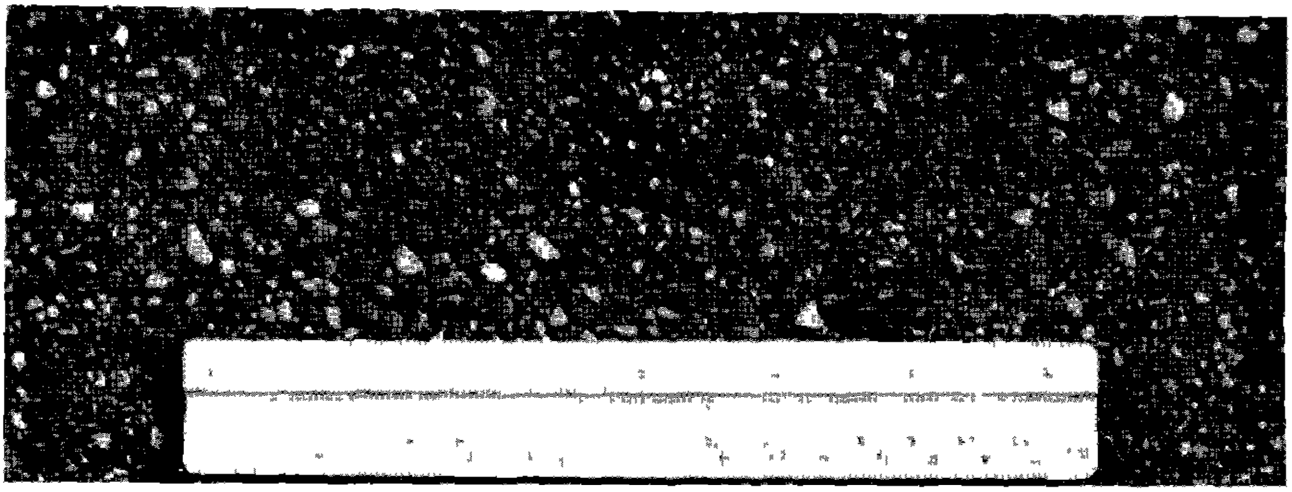
[6] Tilton E Shelburne, "Crushing Resistance of Surface Treatment Aggregates," Engineering Bulletin, Purdue University, Vol XXIV, No 5, Research Series No 76, September 1940



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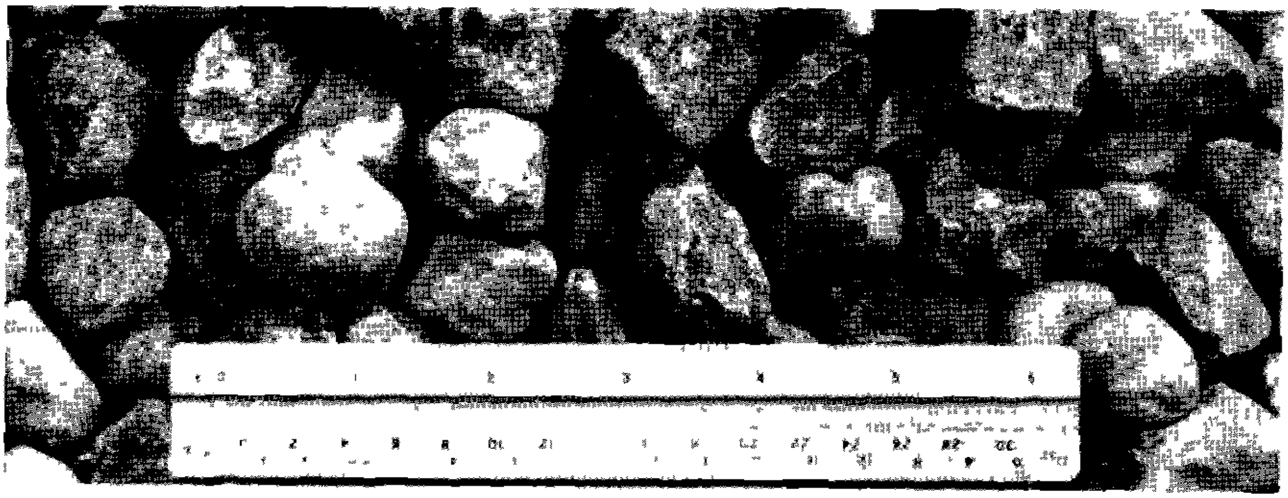
FRACTION B



FRACTION C

CAA TECHNICAL DEVELOPMENT
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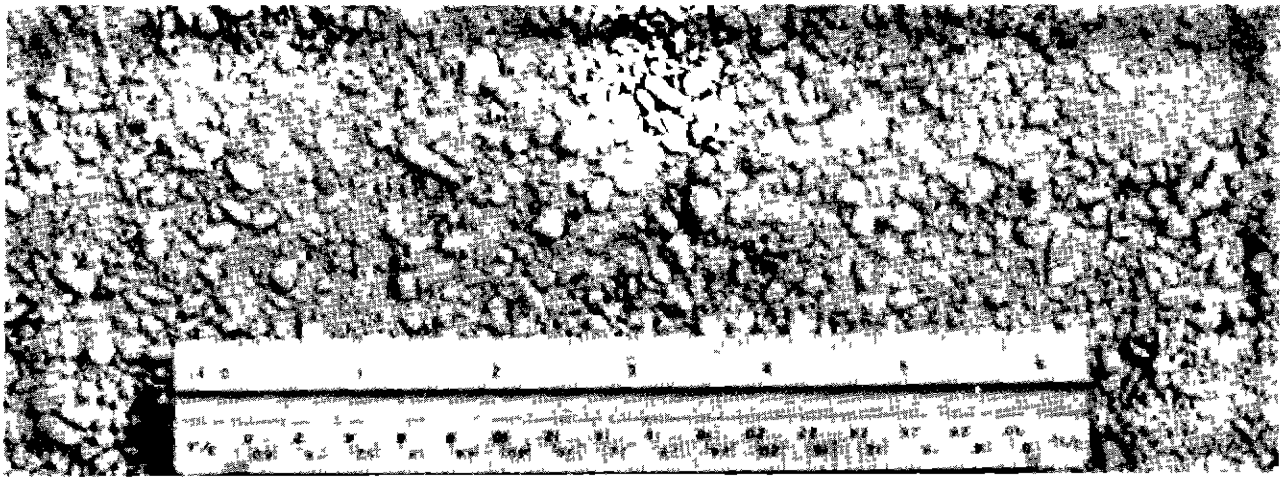
Fig 1 Appearance of the Three Fractions of Gravel



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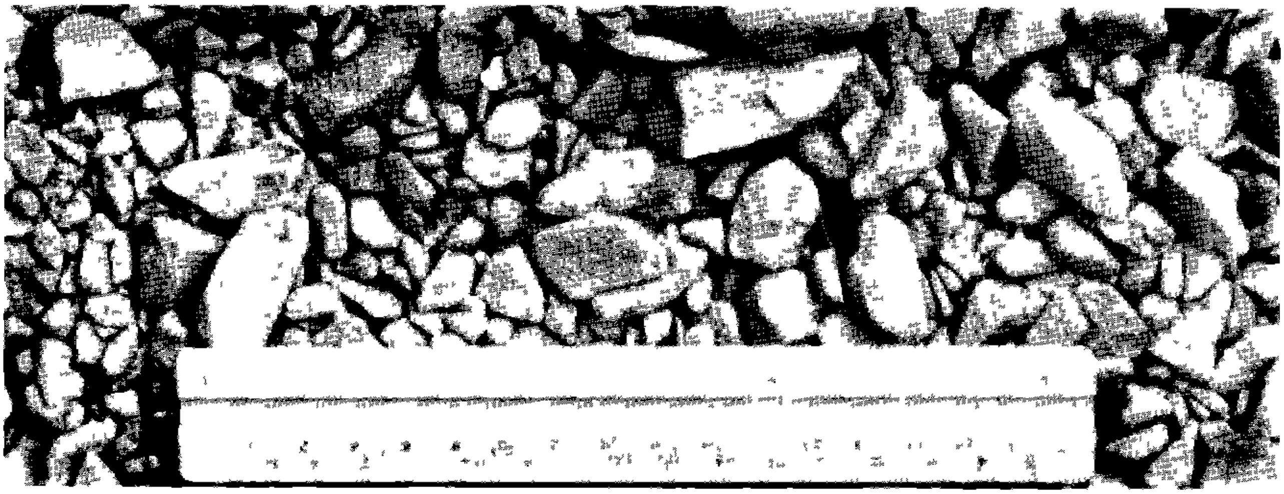
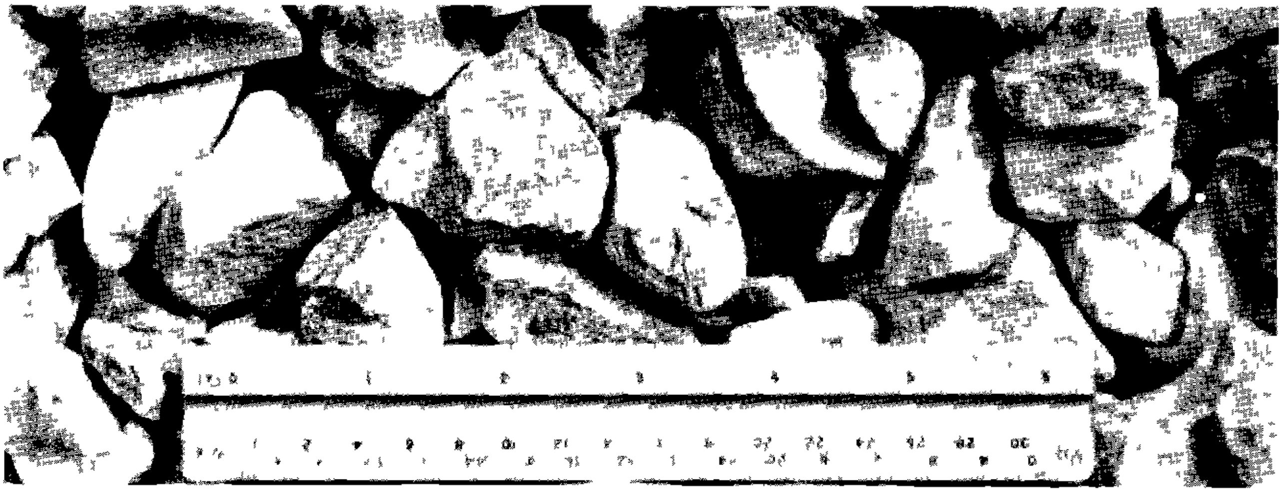


FRACTION B



FRACTION C

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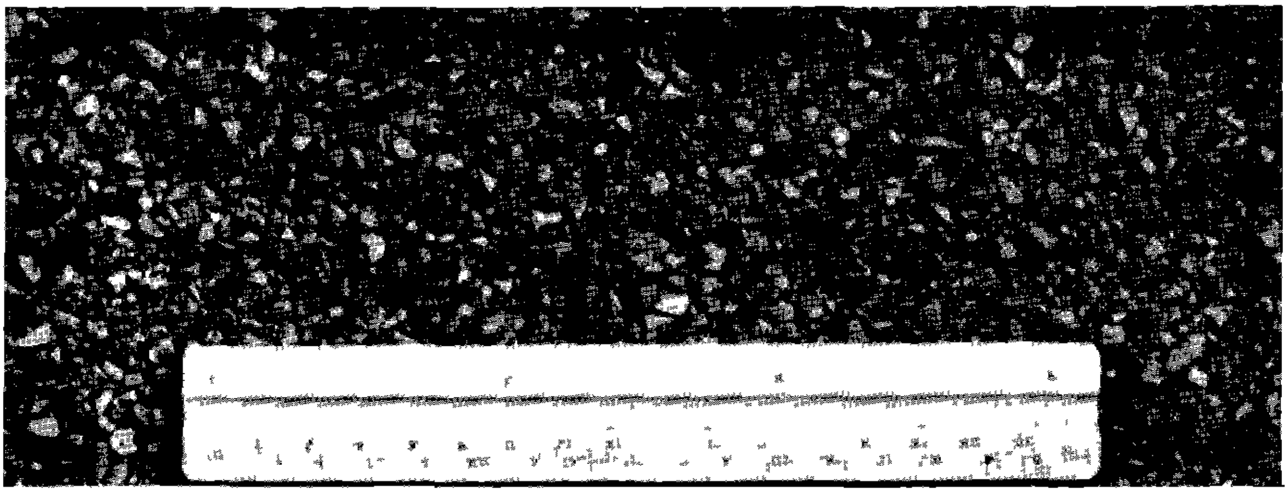
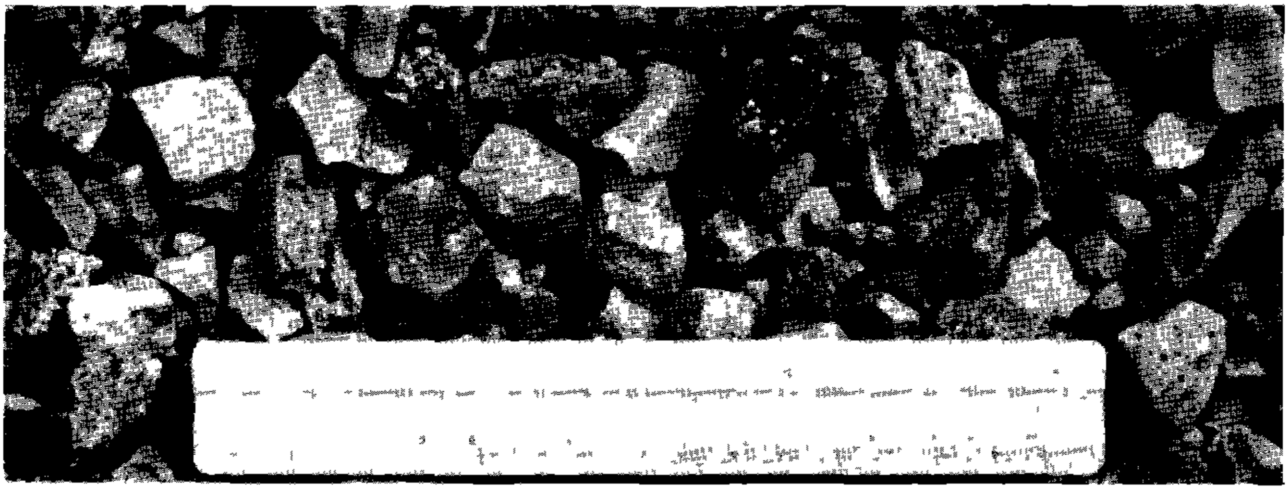
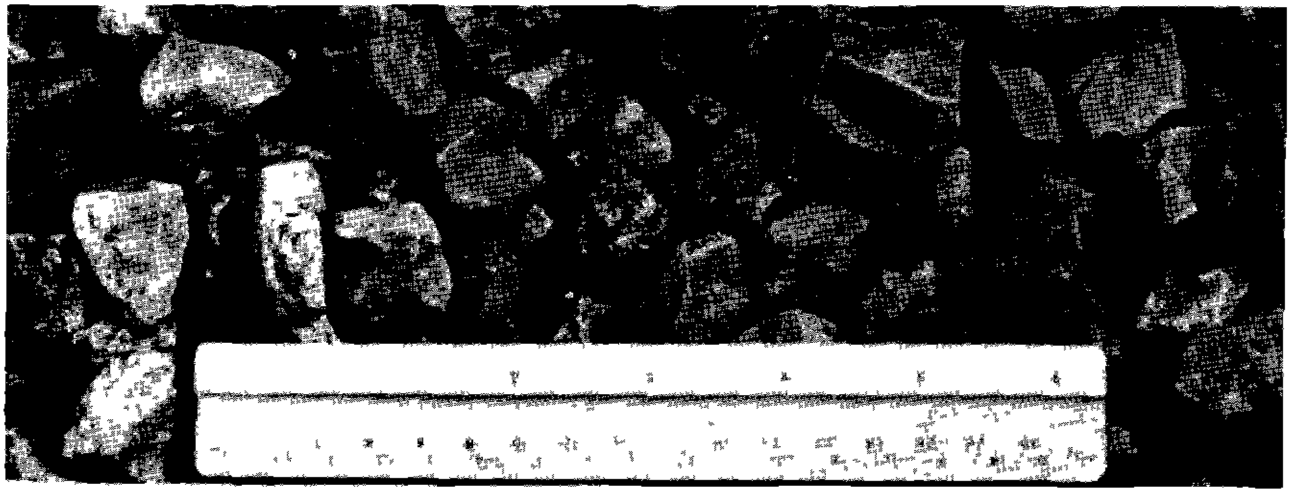
Fig. 2 Appearance of the Three Fractions of Limestone



FRACTION A



FRACTION B



FRACTION C

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Fig. 3 Appearance of the Three Fractions of Slag

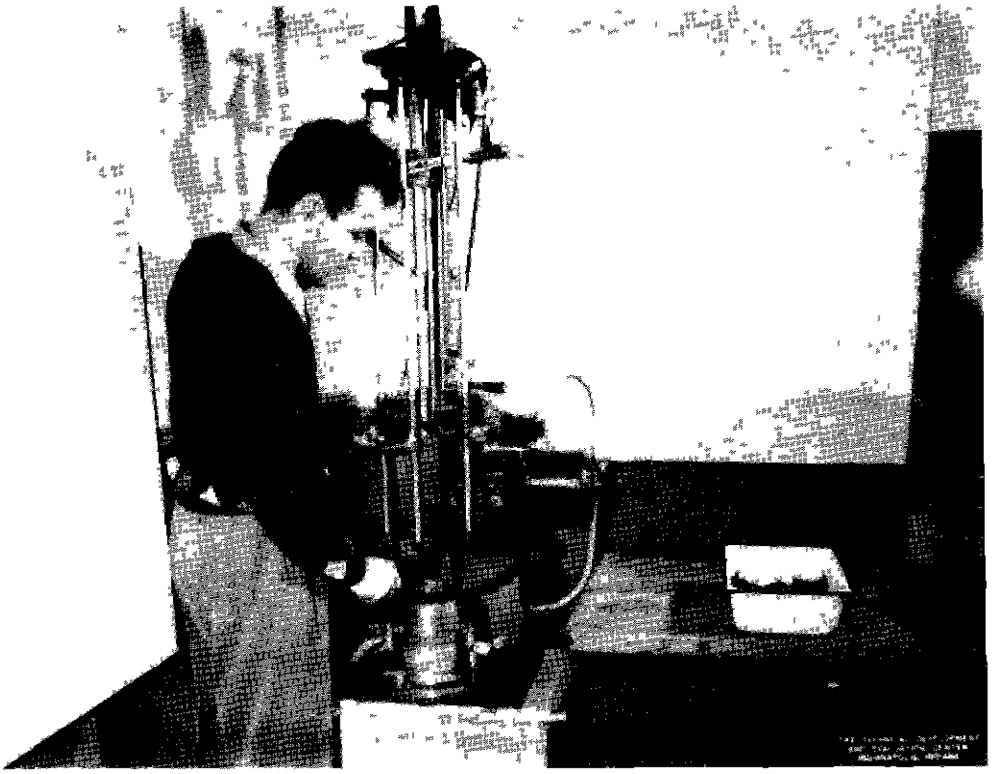

Fig 4 Automatic Tamping Equipment Used to Compact Samples

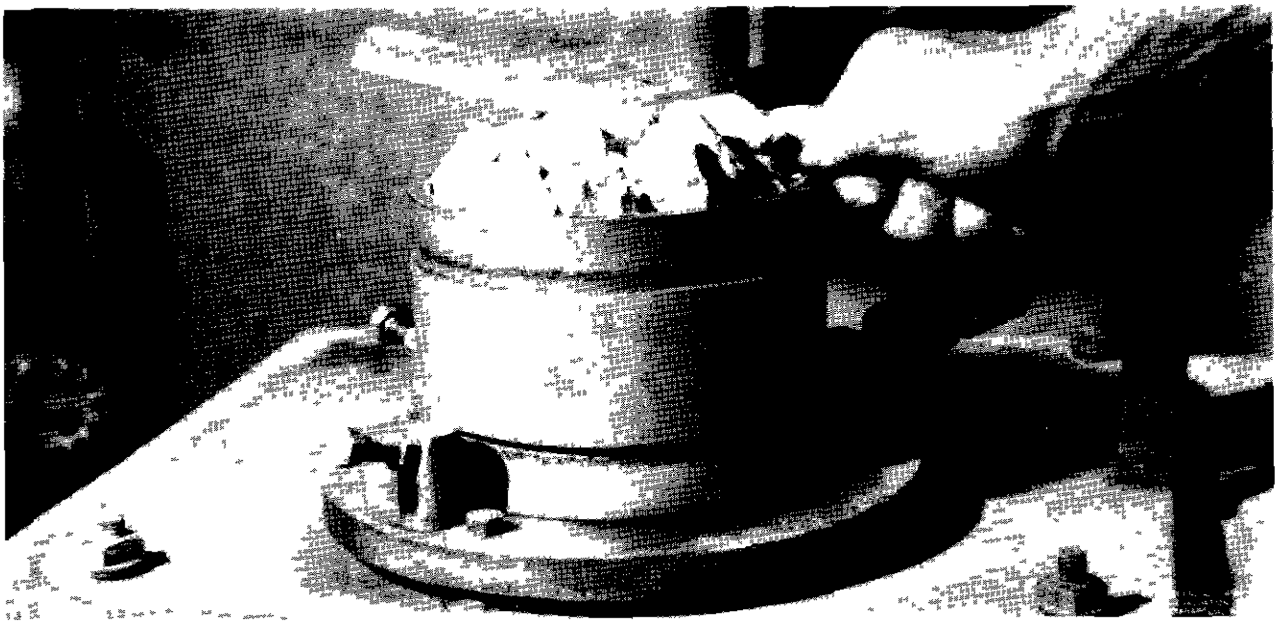

Fig 5 Appearance of the Top Section of a Sample of Coarse-Graded Material After Compaction

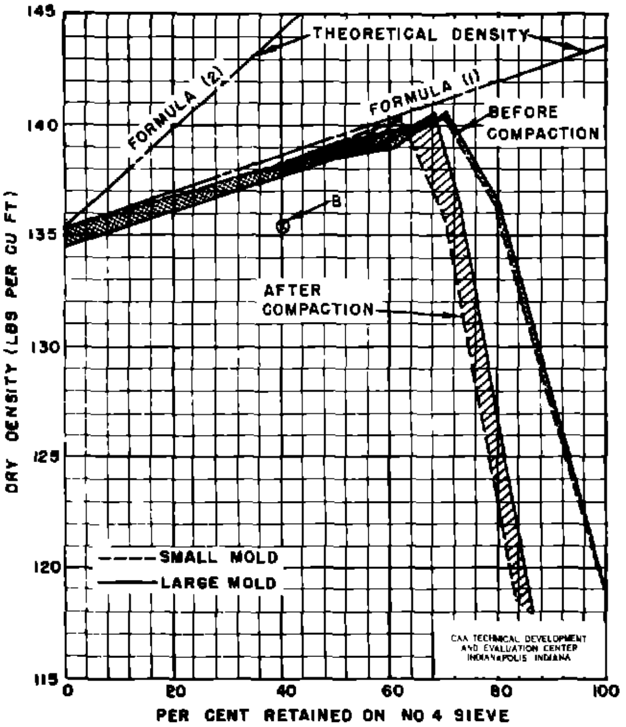

Fig. 6 Gradation-Density Relationship for Gravel (Fractions A+B)

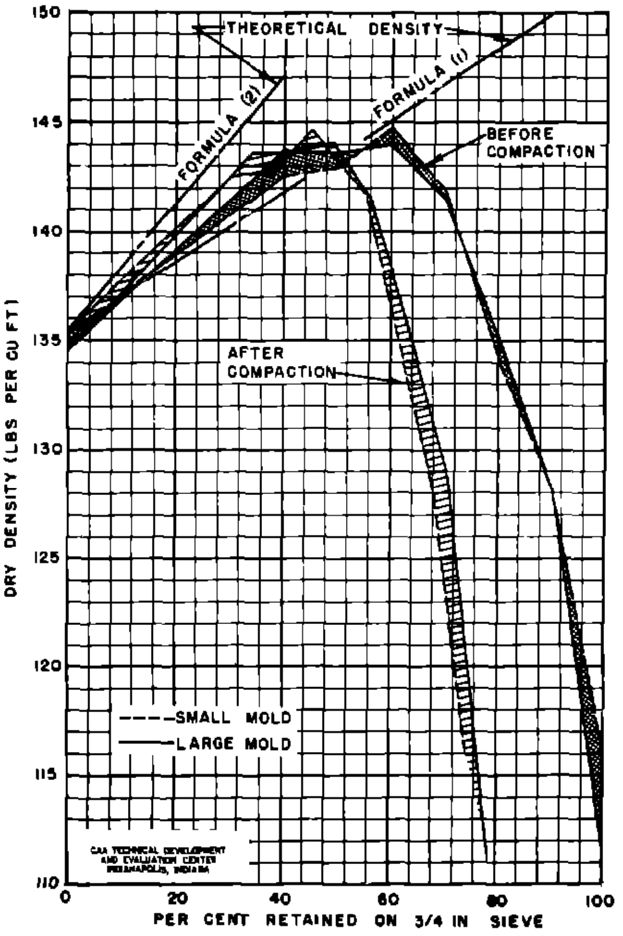

Fig 7 Gradation-Density Relationship for Gravel (Fractions A+C)

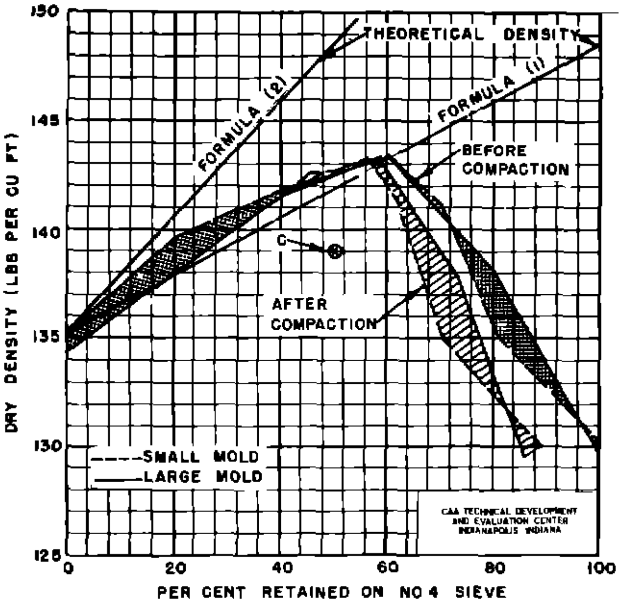

Fig 8 Gradation-Density Relationship for Gravel (Fractions A+B+C)

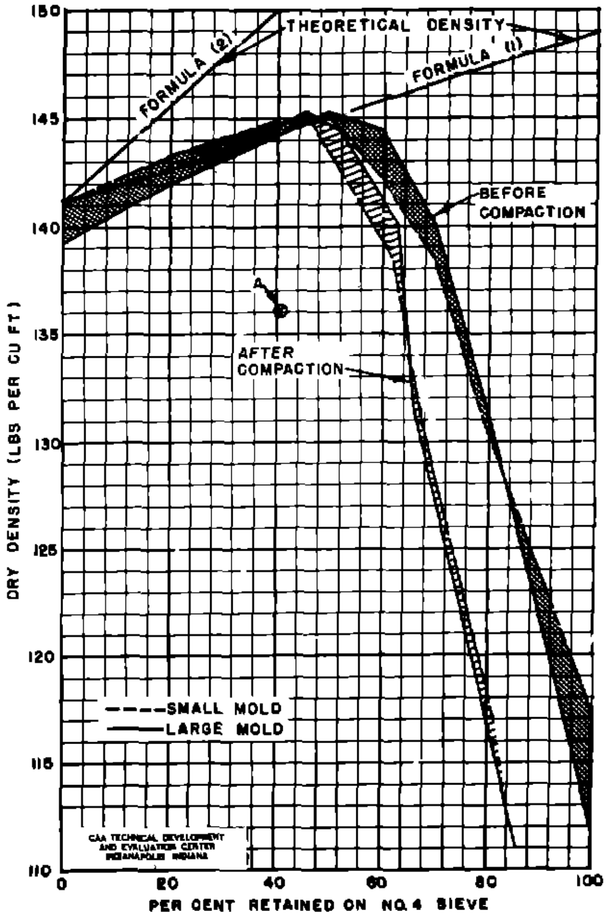

Fig. 9 Gradation-Density Relationship for Limestone (Fractions A+B)

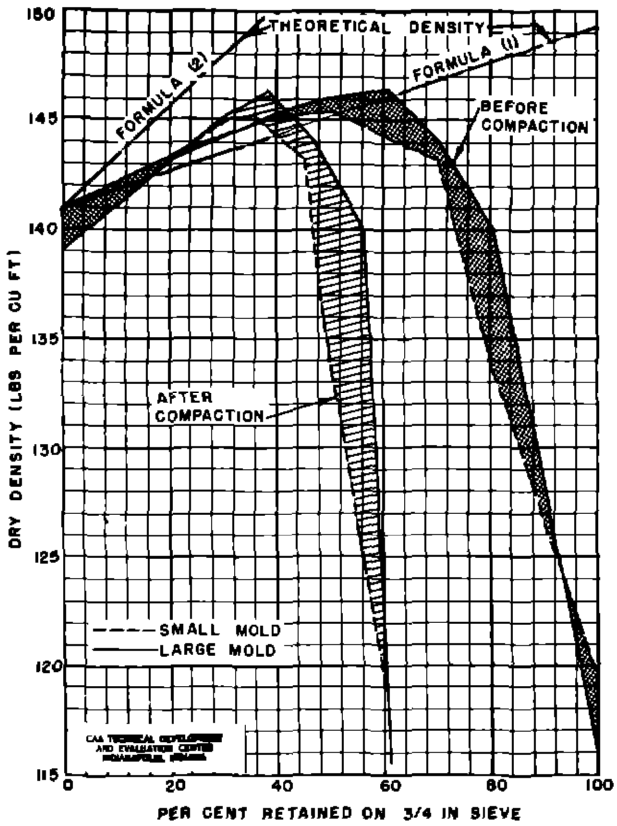

Fig. 10 Gradation-Density Relationship for Limestone (Fractions A+C)

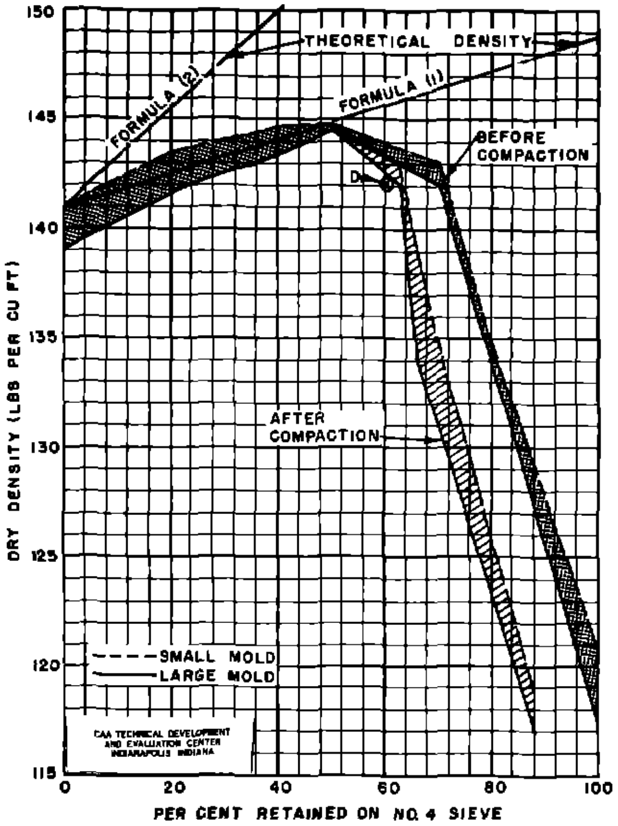

Fig. 11 Gradation-Density Relationship for Limestone (Fractions A+B+C)

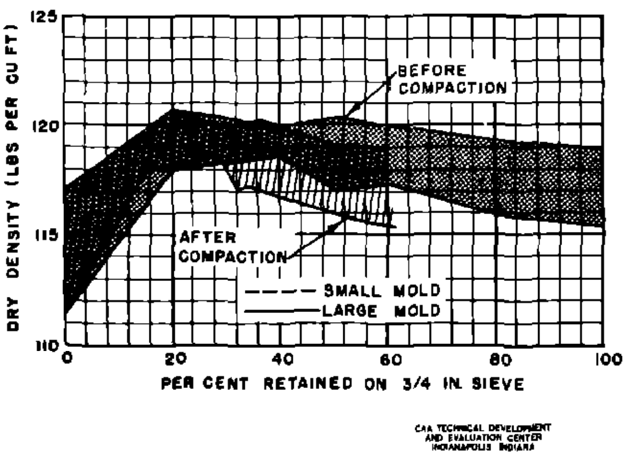

Fig. 12 Gradation-Density Relationship for Limestone (Fractions B+C)

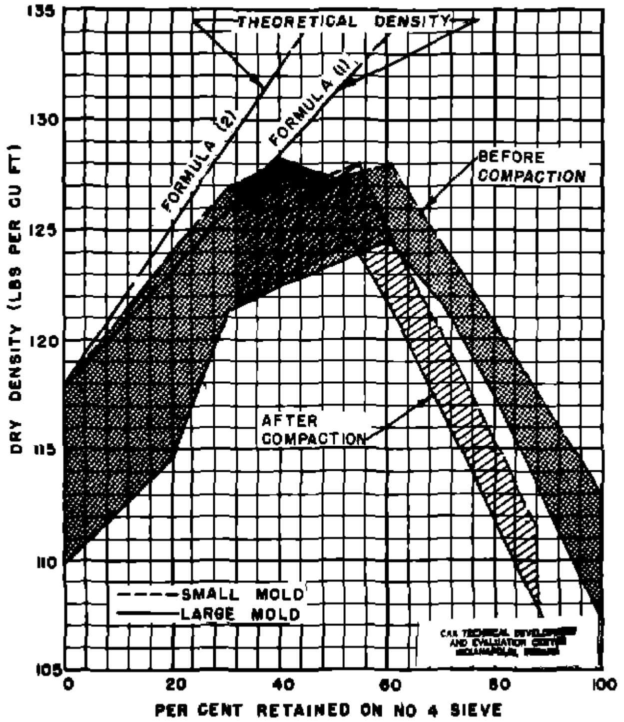

Fig. 13 Gradation-Density Relationship for Slag (Fractions A+B)

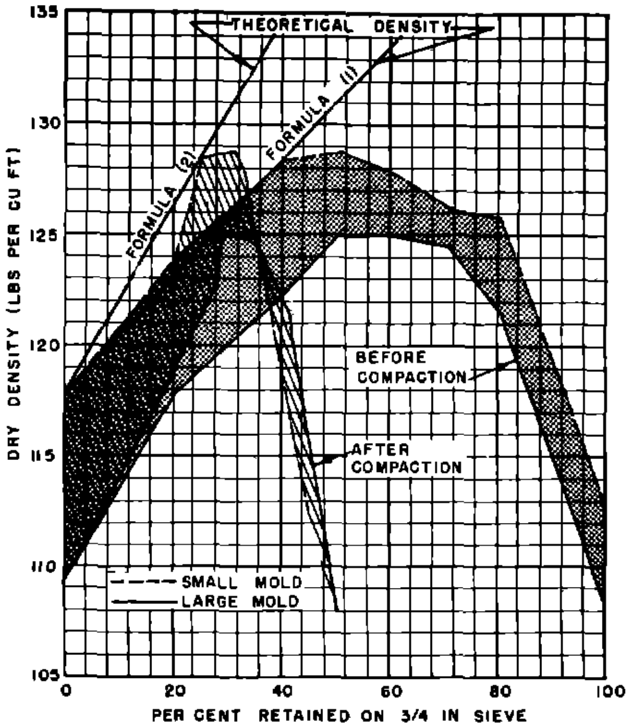

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Fig. 14 Gradation-Density Relationship for Slag (Fractions A+C)

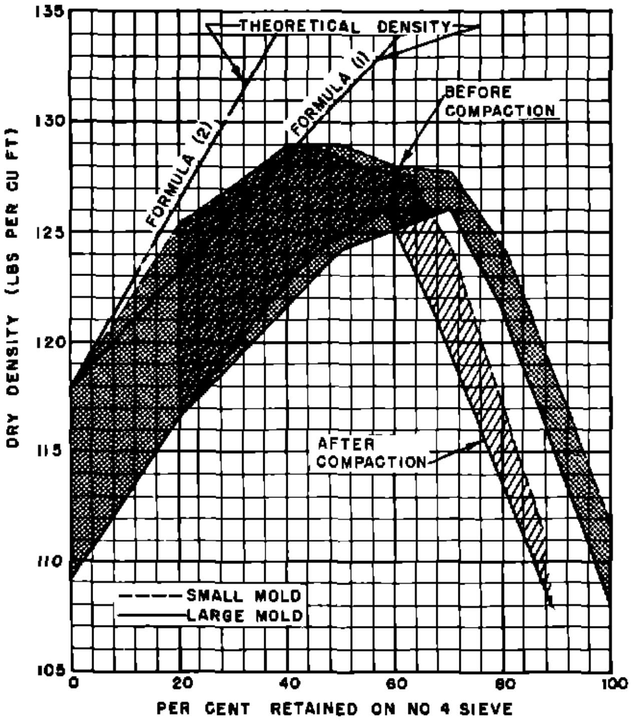

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Fig. 15 Gradation-Density Relationship for Slag (Fractions A+B+C)

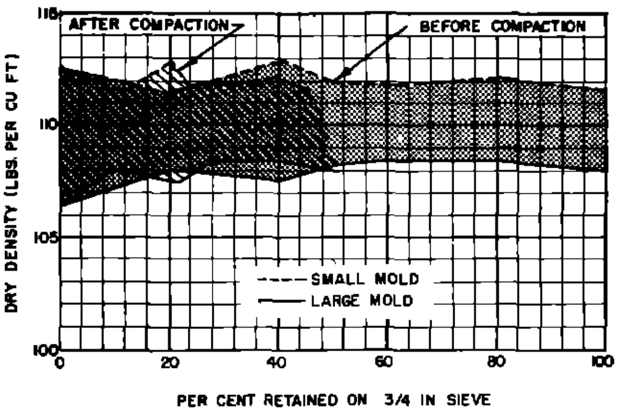

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Fig 16 Gradation-Density Relationship for Slag (Fractions B+C)

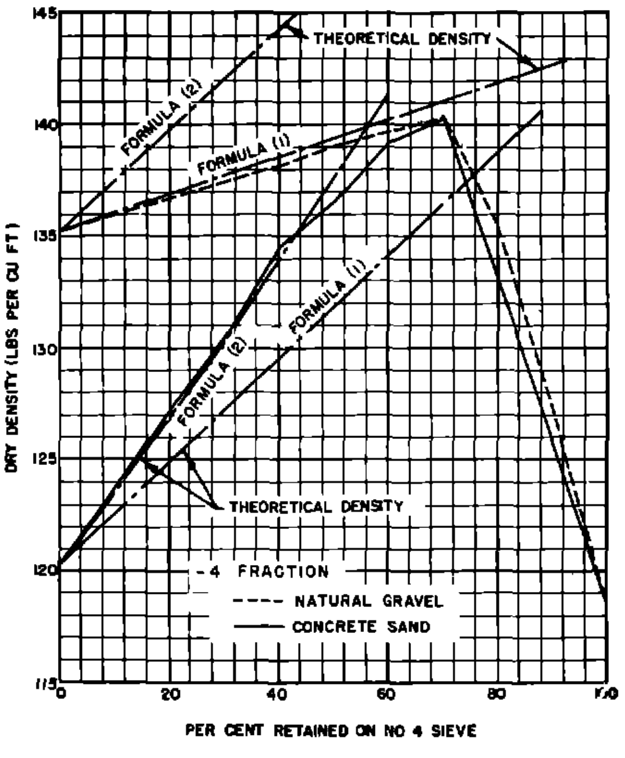

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Fig. 17 Gradation-Density Relationship for Gravel Using Two Different Minus 4 Fractions With Fraction B (4-Inch Mold)

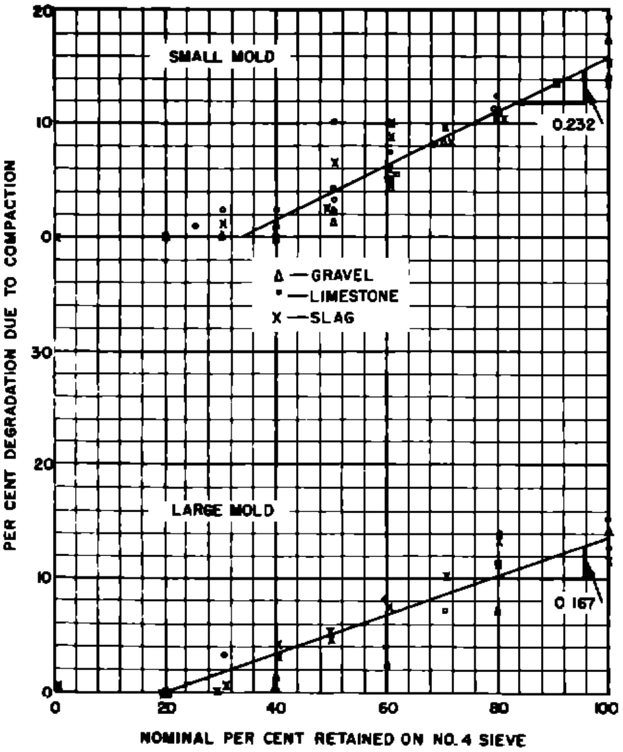

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Fig. 18 Degradation as a Function of the Plus 4 Material

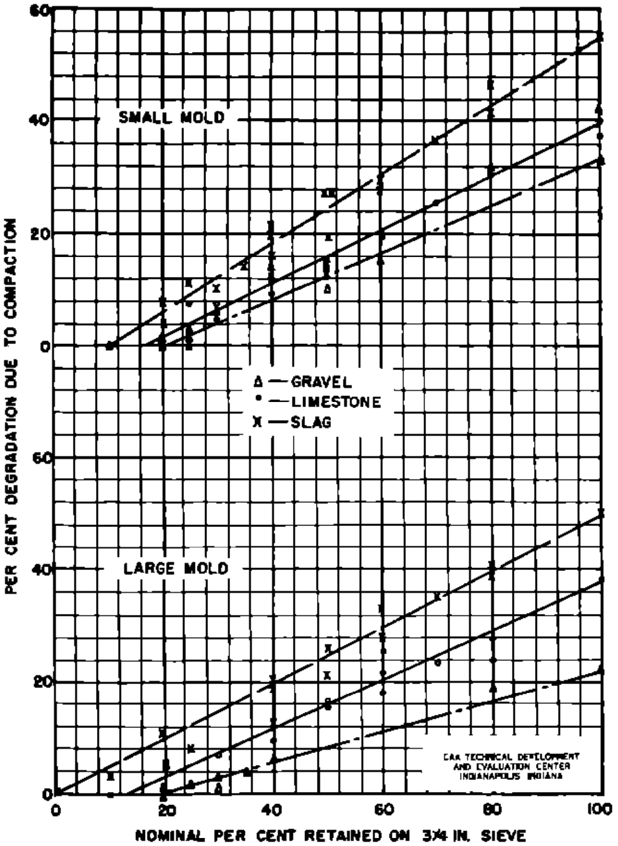

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Fig. 19 Degradation as a Function of the Plus 3/4-Inch Material

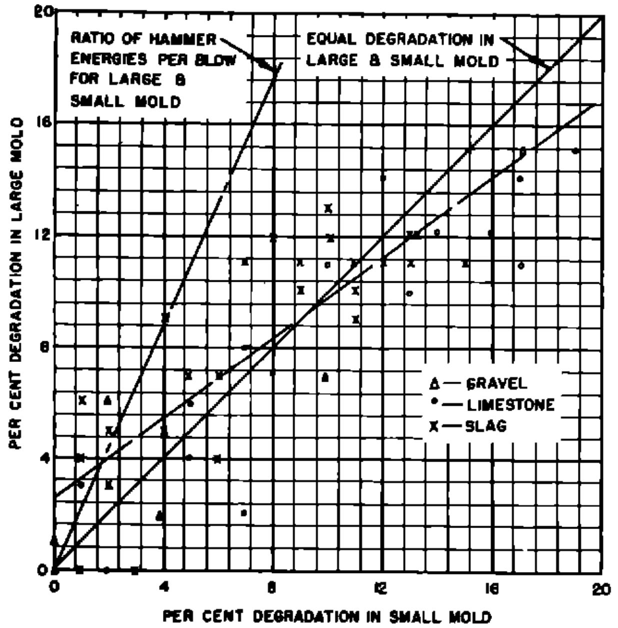

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Fig. 20 Degradation of the Plus 4 Material as a Function of Mold Size

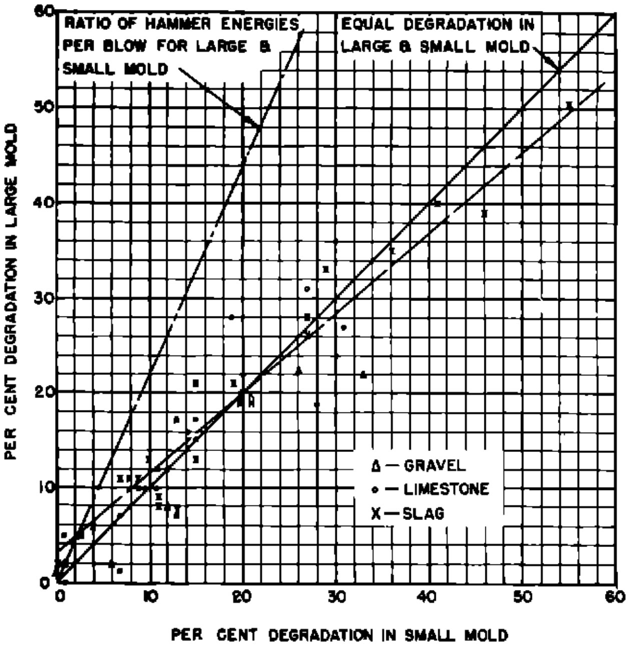

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Fig. 21 Degradation of the Plus 3/4-Inch Material as a Function of Mold Size

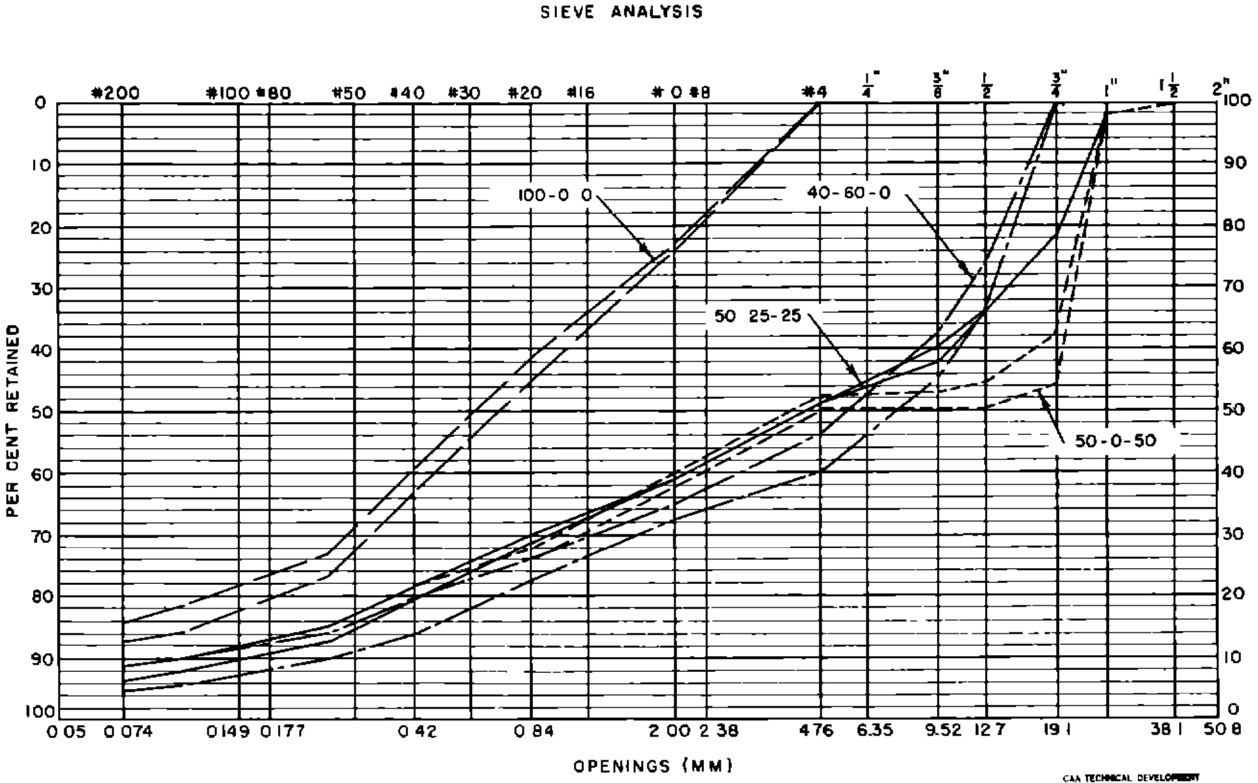

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Fig. 22 Gradation Curves for Different Mixtures of Gravel Before and After Compaction

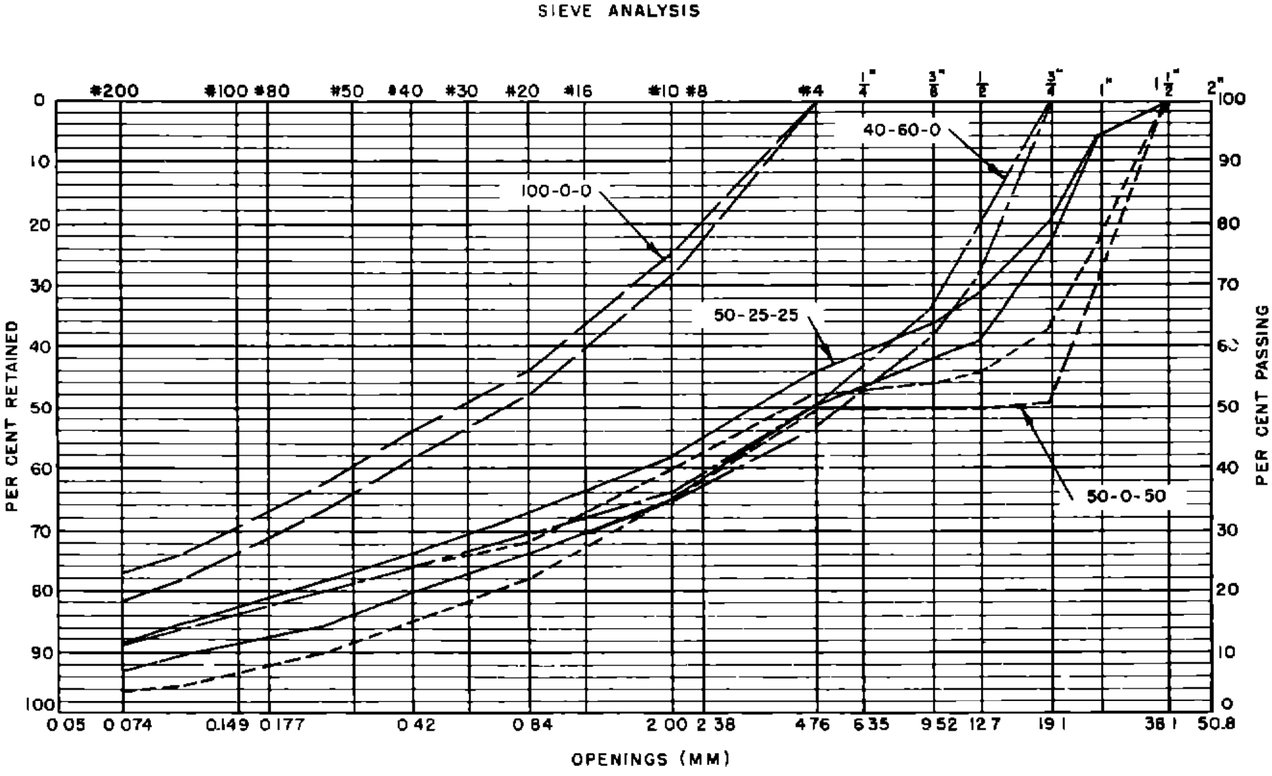

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Fig. 23 Gradation Curves for Different Mixtures of Limestone Before and After Compaction

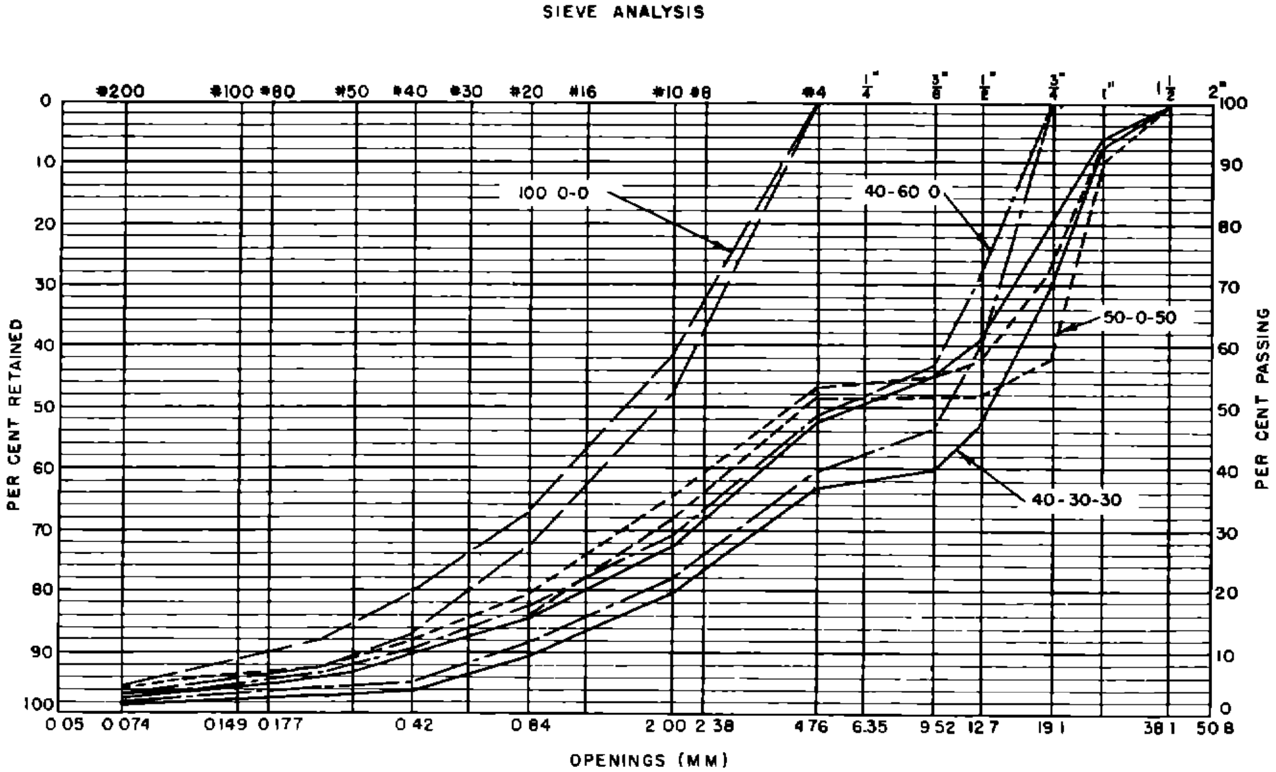

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Fig 24 Gradation Curves for Different Mixtures of Slag Before and After Compaction

TABLE I

PHYSICAL CHARACTERISTICS OF DIFFERENT FRACTIONS OF THE TEST MATERIALS

Fraction Identification		Specific Gravity		Per Cent Absorption	Percentage of Wear Los Angeles Abrasion Test			Per Cent Passing Sieve							
		Bulk	Apparent		Whole Sample	3/4 Inch to 3/8 Inch	3/8 Inch to No 4	1 1/2 Inch	1 Inch	3/4 Inch	3/8 Inch	No 4	No 10	No 40	No 200
-4 fraction of a dense-graded gravel	(A)	- -	2 76	- -	- -	- -	- -	- -	- -	- -	- -	100	76	37	12
-4 fraction of a concrete sand	(A_1)	- -	2 74	- -	- -	- -	- -	- -	- -	- -	- -	100	83	22	1
+4 to -3/4 inch fraction of a washed gravel	(B)	2 56	2 74	2 7	33	30	38	- -	- -	100	31	2	0	0	0
+3/4 inch to -1 1/2 inch fraction of a washed gravel	(C)	2 70	2 79	1 3	22	- -	- -	100	86	2	0	0	0	0	0
-4 fraction of a crushed limestone	(A)	- -	2 75	- -	- -	- -	- -	- -	- -	- -	- -	100	71	42	19
+4 to -3/4 inch fraction of a crushed limestone	(B)	2 65	2 69	0 9	38	34	49	- -	- -	100	26	3	0	0	0
+3/4 inch to -1 1/2 inch fraction of a crushed limestone	(C)	2 66	2 69	0 6	22	- -	- -	100	40	3	0	0	0	0	0
-4 fraction of a crushed slag	(A)	- -	2 72	- -	- -	- -	- -	- -	- -	- -	- -	100	52	13	2
+4 to -3/4 inch fraction of a crushed slag	(B)	2 58	2 69	1 2	29	30	25	- -	- -	100	5	0	0	0	0
+3/4 inch to 1 1/2 inch fraction of a crushed slag	(C)	2 58	2 68	0 8	20	- -	- -	100	80	10	0	0	0	0	0

TABLE II

COMPACTION DATA FOR DIFFERENT SAMPLE GRADATIONS OF GRAVEL

(Obtained by Varying the Percentages of Fractions A, B, and C)

Before Compaction				After Compaction									
Per Cent of Fractions			FM	4-Inch Mold					6-Inch Mold				
A	B	C		A	B	C	MD	OM	A	B	C	MD	OM
100	0	0	2.85	100	0	0	135.3	7.6	100	0	0	134.5	7.7
60	40	0	4.26	60	40	0	138.2	6.5	61	39	0	137.7	6.4
50	50	0	4.66	52	48	0*	139.2	6.4	51	49	0*	138.5	6.4
40	60	0	5.08	45	55	0	139.7	6.4	42	58	0	139.0	6.5
30	70	0	5.48	38	62	0*	140.3	6.2	32	68	0*	140.6	6.4
20	80	0	5.90	30	70	0	135.5	5.8	27	73	0	136.2	5.6
10	90	0	6.30	23	77	0*	126.6	4.5	21	79	0*	127.5	5.2
0	100	0	6.70	17	83	0	118.6	2.0	14	86	0	118.2	2.0
100	0	0	2.85	100	0	0	135.3	7.6	100	0	0	134.5	7.7
60	0	40	4.78	61	9	30*	142.5	6.8	2	64	34*	143.6	5.5
50	0	50	5.31	52	10	38	142.8	6.6	3	55	42*	143.6	5.9
40	0	60	5.85	42	13	45	144.6	5.6	4	46	50*	144.0	6.4
30	0	70	6.38	34	11	55*	141.8	6.0	5	39	56*	141.4	5.1
20	0	80	6.92	25	13	62*	134.2	4.1	6	30	64*	134.9	4.8
10	0	90	7.45	17	15	68*	128.4	2.1	7	22	71*	128.1	3.0
0	0	100	8.00	8	18	74*	115.7	1.0	8	14	78	111.3	2.0
100	0	0	2.63	100	0	0	135.3	7.6	100	0	0	134.5	7.7
80	10	10	3.58	80	10	10	139.7	6.8	80	10	10*	138.2	6.0
60	20	20	4.51	61	20	19	142.0	6.2	59	23	18	141.7	5.5
50	25	25	4.98	51	25	24	142.6	6.2	51	27	22*	142.5	5.7
40	30	30	5.47	44	32	24	143.3	6.0	42	30	28	143.5	6.0
30	35	35	5.88	38	39	23	141.2	6.3	38	34	28*	140.8	6.1
20	40	40	6.41	30	43	27	135.3	6.9	27	40	33	138.0	6.2
0	50	50	7.35	12	51	37*	130.2	5.2	12	46	42*	130.6	5.2
Concrete Sand as Minus 4 Material													
100	0	0	2.92	100	0	0	120.5	9.8					
80	20	0	3.68	80	20	0	127.4	9.4	80	20	0	120.4	8.5
70	30	0	4.07	70	30	0	130.5	8.5	70	30	0	125.2	8.5
60	40	0	4.47	60	40	0	134.7	7.6	61	39	0	126.2	7.4
50	50	0	4.85	52	48	0	136.6	7.6					
40	60	0	5.22	45	55	0	139.3	7.6					
30	70	0	5.62	38	62	0	140.2	7.9					
20	80	0	6.01	31	69	0	133.0	6.2					
0	100	0	6.77	17	83	0	118.6	2.0	14	86	0	118.2	2.0
90	0	10	3.43	90	0	10	123.8	8.2	90	0	10	118.6	7.8
80	0	20	3.84	80	0	20	131.0	8.6	80	0	20	123.2	9.0
80	10	10	3.81	80	10	10	129.2	8.5	80	10	10	123.0	9.5
60	20	20	4.71	60	20	20	135.0	7.6	60	21	19	133.5	7.2

Note FM = Fineness Moduli, MD = Maximum Densities, and OM = Optimum Moistures.

* Interpolated Values.

TABLE III

COMPACTION DATA FOR DIFFERENT SAMPLE GRADATIONS OF LIMESTONE
(Obtained by Varying the Percentages of Fractions A, B, and C)

Before Compaction				After Compaction									
Per Cent of Fractions			FM	4-Inch Mold					6-Inch Mold				
A	B	C		A	B	C	MD	OM	A	B	C	MD	OM
100	0	0	2.53	100	0	0	141.0	5.7	100	0	0	139.2	5.7
80	20	0	3.36	80	20	0	143.2	4.9	80	20	0	141.8	5.1
60	40	0	4.25	62	38	0	144.8	5.0	62	38	0*	144.0	5.4
50	50	0	4.65	54	46	0	145.0	4.5	54	46	0*	145.3	5.4
40	60	0	5.06	47	53	0	142.1	5.6	48	52	0	144.3	4.7
30	70	0	5.49	38	62	0	138.4	4.7	37	63	0	140.0	6.0
20	80	0	5.91	32	68	0	130.2	4.2	34	66	0	131.4	4.8
0	100	0	6.80	19	81	0	117.2	1.0	15	85	0	111.3	1.8
100	0	0	2.53	100	0	0	141.0	5.7	100	0	0	139.2	5.7
80	0	20	3.64	80	1	19	143.4	5.3	80	0	20*	143.4	5.2
60	0	40	4.72	60	9	31	145.2	4.7	61	9	30*	145.4	5.2
50	0	50	5.26	51	14	35	145.4	4.6	51	14	35*	146.0	5.2
40	0	60	5.80	43	17	40	144.2	5.0	45	17	38*	146.4	4.5
30	0	70	6.35	35	20	45	143.0	5.3	36	17	47	144.0	4.6
20	0	80	6.89	28	22	50	133.5	2.6	26	18	56*	140.0	3.7
0	0	100	8.00	11	29	60	119.0	1.0	10	29	61*	115.5	2.5
100	0	0	2.53	100	0	0	141.0	5.7	100	0	0	139.2	5.7
80	10	10	3.50	80	10	10	141.6	5.6	80	10	10	141.6	5.6
60	20	20	4.46	60	20	20	144.7	5.0	60	20	20	143.4	4.5
50	25	25	4.95	52	30	18	143.8	5.2	50	26	24	144.5	4.9
40	30	30	5.44	45	32	23	143.8	4.5	44	33	23	143.4	5.5
30	35	35	5.92	37	36	27	143.2	5.6	38	37	25*	142.0	4.8
20	40	40	6.40	30	42	28	134.4	4.2	31	41	28	134.0	5.0
0	50	50	7.38						12	54	34	117.2	1.8
0	100	0	6.75	19	81	0	117.2	1.0	15	85	0	111.3	1.8
0	80	20	7.00	17	64	19	120.6	1.2	14	71	15	118.0	1.6
0	60	40	7.25	16	55	29	120.0	1.0	12	70	18	118.6	1.4
0	50	50	7.37	14	50	36	120.4	1.0	12	54	34	117.2	1.8
0	40	60	7.50	17	42	41	120.0	1.2	11	57	32	117.4	1.6
0	20	80	7.75	13	38	49	119.4	1.0	10	37	53	115.8	1.2
0	0	100	8.00	11	29	60	119.0	1.0	10	29	61	115.5	2.5

*Interpolated Values

TABLE IV

COMPACTION DATA FOR DIFFERENT SAMPLE GRADATIONS OF SLAG
(Obtained by Varying the Percentages of Fractions (A, B, and C)

Before Compaction				After Compaction									
Per Cent of Fractions			FM	4-Inch Mold					6-Inch Mold				
A	B	C		A	B	C	MD	OM	A	B	C	MD	OM
100	0	0	3.67	100	0	0	118.0	11.5	100	0	0	110.0	12.5
80	20	0	4.31	80	20	0	124.2	9.6	80	20	0	114.6	8.7
70	30	0	4.44	71	29	0	126.0	11.0	70	30	0	121.3	9.5
60	40	0	4.96	62	38	0	128.2	8.3	63	37	0	122.5	10.0
50	50	0	5.29	52	48	0	127.9	7.2	55	45	0	123.5	7.2
40	60	0	5.61	46	54	0	128.2	6.8	47	53	0	124.6	6.0
30	70	0	5.92	39	61	0	124.2	5.0	40	60	0	121.6	4.2
20	80	0	6.26	31	69	0	120.6	4.8	31	69	0	117.2	4.6
0	100	0	6.90	15	85	0	112.6	1.8	11	89	0	107.0	1.5
100	0	0	3.67	100	0	0	118.0	11.5	100	0	0	110.0	12.5
80	0	20	4.53	80	0	20	124.0	9.6	80	2	18	117.9	8.5
60	0	40	5.40	64	11	25	128.5	7.9	65	8	27	122.4	7.7
50	0	50	5.84	51	18	31	128.8	6.8	55	16	29	125.0	7.4
40	0	60	6.27	44	23	33	127.9	4.8	49	19	32	125.0	5.2
30	0	70	6.69	37	29	34	126.3	3.8	41	24	35	124.7	4.3
20	0	80	7.14	29	37	34	125.8	3.9	31	28	41	121.7	4.0
0	0	100	8.00	11	44	45	111.6	2.0	9	41	50	107.9	2.0
100	0	0	3.67	100	0	0	118.0	11.5	100	0	0	110.0	12.5
80	10	10	4.43	80	10	10	125.3	9.3	80	10	10	116.7	9.0
60	20	20	5.18	61	23	16	128.9	7.0	64	22	14	121.8	5.8
50	25	25	5.57	56	30	14	128.9	6.7	54	29	17	124.4	6.9
40	30	30	5.94	45	35	20	128.0	6.2	47	36	17	125.3	5.5
30	35	35	6.32	38	41	21	127.8	5.1	40	41	19	126.1	3.7
20	40	40	6.70	30	51	19	124.4	4.1	33	47	20	121.3	4.5
0	50	50	7.45	13	64	23	111.9	1.4	11	65	24	108.3	2.0
0	100	0	6.90	11	89	0	112.6	1.8	11	89	0	107.0	1.5
0	80	20	7.12	13	75	12	111.5	1.2	12	79	9	107.0	2.1
0	60	40	7.30	13	67	20	112.7	1.4	12	67	21	107.5	2.0
0	50	50	7.45	13	64	23	111.9	1.4	11	65	24	108.3	2.0
0	40	60	7.56	12	57	31	111.7	1.4	11	62	27	108.4	2.0
0	20	80	7.78	11	50	39	112.2	1.4	10	50	40	108.4	2.0
0	0	100	8.00	11	44	45	111.6	2.0	9	41	50	107.9	2.0

TABLE V

FINENESS MODULUS OF DIFFERENT MIXTURES BEFORE AND AFTER COMPACTION IN THE SMALL MOLD

	Sample Identification			Fineness Modulus		
	A	B	C	Before	After	Per Cent Change
Gravel	100	0	0	2.63	2.50	4.9
	40	60	0	5.05	4.74	6.1
	40	60	0*	5.19	4.88	6.0
	50	25	25	4.90	4.80	2.0
	50	0	50	5.33	5.07	4.9
Limestone	100	0	0	2.53	2.33	7.9
	40	60	0	4.74	4.48	5.5
	50	25	25	4.87	4.48	8.0
	50	0	50	5.45	4.91	9.1
Slag	100	0	0	3.67	3.42	6.8
	40	60	0	5.55	5.11	7.9
	40	30	30	6.03	5.42	10.1
	50	0	50	5.56	5.24	5.7

* Concrete Sand as the Minus 4 Fraction

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