GRAVEL AND CRUSHED STONE BASE COURSE MATERIALS USED IN THE AASHO ROAD TEST

JAN. 1963

NO. 4

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ABSTRACT

This paper presents the results of a laboratory investigation of the behavior of the AASHO Road Test gravel and crushed stone mixtures subjected to repeated loading. Cylindrical specimens were stressed triaxially to levels approximating those which would be found in the base course of a highway pavement. The repetitive loadings were applied with equipment developed in the laboratories of the School of Civil Engineering at Purdue University.

The materials used in the study were obtained from the site of the AASHO Road Test. The gravel and crushed stone with grain size distribution equal to that used in the Road Test and compacted to the mean density levels found in the field were the subject of primary interest. Variation in percent fines and degree of saturation were considered to have a great effect on these basic gradations. Therefore, the percent passing the number 200 mesh sieve was varied so that three mixtures of each material were obtained. These three mixtures were tested at three levels of saturation.

The effects of these variables on the deformation-rebound characteristics of the materials under repeated loads were studied. From these studies, the advantages and disadvantages of each material, concerning their value as base course materials, were found and are reported in detail. Also, a comparison between the laboratory and field performance of the two AASHO materials is presented.

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INTRODUCTION

The variable of base course type was included at several locations in the flexible test sections of the AASHO Road Test at Ottawa, Illinois. These special test sections were in the form of wedges and each was 160 feet in length. Base thickness and type were the only variables in the various sections.

Materials used in the special base course studies included cement treated gravel, bituminous treated gravel, untreated crushed stone and untreated gravel. The test sections were divided into 40 foot sub-sections for purposes of analysis; performance was related to the mean thickness of base. A three inch surface was used in the special sections in which stone and gravel were compared. No sub-base was used in loop 3 whereas in loops 4 and 5, 4 inches of sub-base was included in the design. The typical section as outlined in the AASHO Road Test Report (5) included a shoulder of crushed stone materials.

During the winter of 1960, personnel from the Road Test contacted Purdue University to determine if tests could be performed to evaluate the special base course materials. It was hoped that a test would be devised wherein appropriate strength parameters could be assigned to the materials which in turn could be related to relative performance. It soon became apparent that it would be extremely difficult to devise a single test which would describe the properties of all of the materials since tensile strength was of importance when considering the bituminous and cement treated gravels whereas the properties defining the gravel and crushed stone were associated with cohesion and angle of internal friction. As a result, it was decided to study in detail the gravel and crushed stone materials with the hope of determining why these materials behaved as they did under conditions of test traffic.

A series of repeated triaxial tests were therefore performed on the crushed stone and gravel base course materials. Specimens were compacted to density and moisture levels compatible with those existing in the prototype pavement. This paper summarizes the data obtained in this study and presents an analysis of the test data in light of relative performance in the road. Some inconsistencies were noted when considering the relative performance of these materials in the laboratory as opposed to the field. As a result, the analysis presented herein is, to some extent, qualitive in nature, but it is hoped that it will be of interest to the engineering profession and will assist engineers in formulating criteria for design.

GRAVEL AND CRUSHED STONE BASES AND THEIR FIELD PERFORMANCE

The crushed limestone used in the special test sections was the same type as that used in the factorial sections. It was a well graded material having sharp angular grains, while the gravel base material was a well graded uncrushed gravel. Average grain size distribution curves for each are shown in Figure 1. These grain size curves were obtained by averaging values determined from many tests made on samples taken from the road. The crushed stone base contained 11.5 percent passing a No. 200 mesh sieve while the gravel base contained 9.1 percent passing a No. 200 mesh sieve. The crushed stone was non-plastic and the gravel had a plasticity index of 3.5 percent.

The maximum dry densities, based on Standard AASHO compaction, were 139 and 140 lbs per cubic foot for the crushed stone and gravel respectively. Percent field compaction was 101 percent for the crushed stone and 104 percent for the gravel. It should be remembered that these are average values and they must be treated as such.

The field performance of the gravel sections was inferior to that of the crushed stone. In fact, the relative performance of the gravel was such that it

was not included in a major portion of the analysis presented in the AASHO Road Test Report. Benkelman, Kingham and Schmidt in their report to the International Conference on the Structural Design of Asphalt Pavements (2) state "The gravel base sections failed early in the test and are omitted from the analysis of performance". They further state, "It appears that the gravel material possessed a level of internal stability that might be considered adequate for loads operating on loop 3, nearly so for the loads on loop 4 but definitely not for those on loop 5".

Figures 2, 3 and 4 illustrate field performance data for the gravel and crushed stone bases. It can be noted in Figure 2 that the number of load applications at a serviceability index equal to 2.5 was invariably less for gravel sections than for the other base materials. In the case of loop 5, (22.4 Kip Load) there was no apparent orderly relationship between depth of gravel base coarse and load application at serviceability index 2.5. This suggests an inherent weakness in the gravel material itself.

Figure 3 shows pavement deflection as a function of base thickness at various seasons. It is significant to note that the deflection values of the pavements built over the crushed stone bases were (with one exception) greater than the deflections of corresponding pavements containing the gravel base. Deflection of pavements over both base materials was higher in the spring than in the fall. Figure 4 presents seasonal deflections for the 9 inch base thickness. Here again, with one exception, the stone bases are seen to have resulted in greater deflection than the gravel bases.

The deflection data shown in Figures 3 and 4 were obtained by use of the Benkelman beam. This test measures the pavement's surface deflection due to the application of a static load. The measured value includes the deflection of pavement surface, base, subbase and subgrade.

LABORATORY TESTING PROGRAM

The repeated loading device used for the tests is shown in Figure 5. It consists of a conventional triaxial cell with load supplied by means of compressed air. The loading device contains a pressure cylinder and solonoid valves which can be controlled electrically to apply repeated loads of varying magnitude, interval and duration. Records of total deformation, elastic rebound and permanent deformation at various intervals throughout the test were obtained. A 15 psi confining pressure was used on the specimens throughout the testing program. A deviator stress of 70 psi was selected on the basis of approximate stresses that existed at the base course level in the road test pavement.

The materials from the road test were separated in the laboratory on various sieves. The aggregates were then recombined to yield a gradation corresponding to the average measured in the test pavements (see Figure 1). Three levels of amount of material passing a 200 mesh sieve (6.2, 9.1, and 11.5 percent) were studied, resulting in the study of six gradations, three for the crushed stone and three for the gravel. As comparisons of laboratory and field performance were of interest, all samples were tested at field dry density levels; 141 lbs. per cubic foot for the crushed stone and 145 lbs. per cubic foot for the gravel.

Table 1 shows a summary of the density data obtained in the study. Loose density was obtained by pouring the material into a container of known volume and maximum density was obtained by controlled vibratory compaction. It is seen that relative densities corresponding to field conditions were 92 and 80 percent for the gravel and crushed stone, respectively.

Moisture content was also of interest in this study as it was postulated that degree of saturation would have great effect upon performance. An attempt was made to maintain three levels of degree of saturation; 70, 85 and 100 percent. However, due to slight variations in moisture content and dry unit weight, the resulting degrees of saturation varied from 63 to 98 percent. All samples were compacted at a moisture content corresponding to a degree of saturation of 70 percent. The test samples were compacted using impact procedures. A 5.5 pound hammer having a free fall of 12 inches was used. The compactive effort was varied for each gradation and a series of dry density points was obtained. These points, when plotted against a semi-log scale of compactive effort, produced a straight line relationship. All test samples were then compacted at the required compactive effort to produce the desired dry density.

The compacted test samples were then either tested at the 70 percent saturation level or, if higher saturation levels were desired, the moisture content was raised to the approximate degree of saturation desired. This was accomplished by means of the saturation mold shown in Figure 6. The moisture content in the samples was increased by applying a vacuum to the mold and allowing water to enter through perforations in the mold. By continually weighing the samples during the wetting process, it was possible to obtain approximate degrees of saturation selected for the test. The samples were then wrapped and stored in a controlled humidity room for an additional day so that moisture equilibrium could be achieved.

Originally, it was hoped to test both the gravel and crushed stone samples at a degree of saturation approaching 100 percent. However, the crushed stone materials were so pervious that the water invariably migrated toward the bottom of the sample with the result that, except for low degrees of saturation, moisture distribution was not uniform throughout the length of the sample. This was particularly true for those samples above about 80 percent saturation. This phenomenon, however, did not occur in the gravel specimens and it was possible to maintain a relatively uniform moisture gradient throughout these samples. As a result of the above, tests reported in this paper for the crushed stone materials are for degrees of saturation up to 81 percent whereas the degrees of saturation reported for the gravel are as high as 98 percent.

Test Results

Figure 7 shows a typical load-time trace for two load cycles. Load was measured by means of a proving ring; load impulse was transmitted from strain gages mounted on the proving ring to an electronic pen recorder. It will be noted that a slight residual load was maintained on the sample between deviator load intervals.

Figures 8 through 11 show the deflection and rebound histories of the test samples. The values of deflection represent accumulative axial deflection from beginning of test. The values of rebound represent individual load cycle rebound. Each curve on these graphs represents the average for two test samples. The results obtained from tests on the three gradations for both the crushed stone and gravel materials are shown. A general orderly relationship between degree of saturation and deflection at any given cycle is noted.

DISCUSSION

It is an established principle of pavement design that it is necessary to consider the pavement structure as a whole. Every design engineer could list numerous factors which one must consider when designing a pavement. These might include soil type, type and volume of traffic, climatic conditions (precipitation and freezing temperatures), grade and alignment of the road bed, drainage characteristics of the materials in the pavements, strength properties of the components and many others. An interaction exists among the factors just listed. An illustration of this pertains to the selection of base course materials in the northern tier of states as contrasted to the types of base course materials used in the southern states. The adverse effects of frost action in the northern states in some cases override other design considerations making it necessary to construct base courses using non-frost susceptible materials. Other illustrations could be given which relate base course quality to internal drainage of the subgrade, rainfall belts, etc.

The primary purpose of the base course in the flexible pavement is to provide shearing resistance and some stiffness to the pavement structure. Thus, it is apparent that permanent stability and relative thickness of the component layers of the pavement are of primary concern.

In connection with the performance of the gravel and crushed stone base courses used in the AASHO Road Test, consideration should be given to two factors that may be significant. First, the cross section of the flexible pavement contained a granular shoulder (crushed stone) and the subbase was carried through the shoulder from ditch to ditch. Second, the road test experiment was conducted in an area where frost can be a problem, particularly from the standpoint of loss of pavement support during the frost-melt period. The area under consideration has a mean freezing index of about 500 degree days and the mean maximum depth of frost penetration below the pavement surface (by measurement) was 40 inches in February, 1959, 25 inches in March, 1960 and 32 inches in February, 1961.

At this point it should be re-emphasized that from the standpoint of field performance, the crushed stone materials were superior to the gravel materials. This was true even though surface deflection under load was many times greater for the crushed stone bases than for the gravel bases.

Figure 12 shows variation of deflection and rebound with saturation level during repeated loading in the laboratory for the crushed stone and gravel samples. These deflection and rebound data were taken from Figures 8 through 11. It will be noted that the gravel samples were tested at degrees of saturation ranging from about 69 percent up to about 98 percent. The degree of saturation of the crushed stone samples, however, varied between 63 and 82 percent. The most striking feature of these test results is that, for a given degree of saturation, the crushed stone samples deflected and rebounded more than corresponding gravel samples.

Data in Table 1 show that the relative densities of the crushed stone samples, with one exception, were lower than for corresponding gravel samples. The average relative density values for field conditions were 92 percent for the gravel bases and 80 percent for the crushed stone bases. Differences in relative densities no doubt explain in part why the gravel deflected less than the stone in the laboratory at corresponding degrees of saturation.

Information was obtained from Road Test personnel regarding in-place moisture contents of the base materials at various times of the year. Degree of saturation in each case was computed from field moisture content data, average density data and specific gravity values furnished by Road Test personnel. A summary of these data is shown in Table 2.

The degree of saturation of the crushed stone at time of placement in the summer of 1958 was 68 percent. By the spring of 1959, the value had decreased to 56 percent and the following spring, its value was 55 percent. Tests made in the summer of 1960 indicted a degree of saturation of 44 percent. Corresponding to these figures, the gravel material was placed at a degree of saturation of 94 percent and when tested in the spring of 1959, the gravel was found to be 86 percent saturated.

Table 2 lists accumulative sample deflection from beginning of test and single cycle rebound values of the laboratory specimens at degrees of saturation equal to those indicated by field tests. These deflection and rebound data were taken from Figure 12. It is to be noted that, using field degree of saturation as a basis of comparison, the gravel specimens had larger total deflection and single cycle rebound values than the crushed stone specimens.

Comparisons of laboratory values of accumulative sample deflection (accumulated axial deflection of the test sample from beginning of test) at 1000 load cycles provides a method of evaluation of the stability of the test specimens in the laboratory. A comparison of the stability of the two materials in the field is provided by reference to the performance data given in Figure 2. Using the values of total deflection given in Table 2 as qualitative performance values and by a comparison of these values with the charts of field performance given in Figure 2, it can be seen that good correlation of field and laboratory data was achieved.

It is understood that failure of the gravel base courses nearly always took place during the spring of the year. The period of time which elapsed between spring break up and the date the moisture content determinations were made is not known. Therefore, it is impossible to estimate the exact moisture level at the critical time of frost melt. However, for purposes of comparison, a conservative estimate of the degree of saturation at the end of the spring thaw must be the computed value of 86 percent for the gravel base. In all probability the value was higher sometime during the spring thaw. Tests made in Indiana (6) indicate the degree of saturation of this type of material often approaches 100 percent during the critical spring-melt period. This period, incidentally is short lived and, in many cases, only lasts from several days to severalweeks depending upon the amount of precipitation which occurs during the frost melt. The degree of saturation of 86 percent for the gravel is in contrast to 56 percent for the crushed stone.

Figure 13 shows variation of coefficient of permeability with density for these two materials. For the density levels at which the materials were placed in the field, the coefficient of permeability of the gravel was about 0.01 feet per day as compared to a value of about 7.5 feet per day for the crushed stone material.

On the basis of their grain size distribution (Figure 1), both of these materials are potentially frost susceptible. However, as indicated by the high permeability of the crushed stone, the voids of the crushed stone mixture were no doubt too large to promote capillary rise. Furthermore, as indicated by the field degrees of saturation, free water was quickly dissipated at the shoulder base contact.

Since the gravel gradation falls into the frost susceptible class, and since its coefficient of permeability is practically nil, active frost action would be expected. Further, as this base is difficult to drain, free water resulting from surface infiltration would remain in the base for a longer period of time. Pore pressures associated with the high degree of saturation of the gravel materials probably effected performance to a high degree. Barber (1) has shown that pore pressures in base courses can result in greatly reduced bearing capacity. This fact alone could probably account for the difference in performance of the two materials.

The laboratory test data suggest that performance of the materials in the field was closely associated with the design of the pavement section coupled with the drainage characteristics of the gravel and crushed stone. Thus, it becomes unimportant that one material was a gravel and the other a crushed stone, but it is significant that the stone was free drainage whereas the gravel was not. Angularity of grains per se no doubt had an effect on the strength of the materials but in addition (for constant gradation) crushed materials nearly always have higher permeability than predominately rounded materials.

The laboratory data indicate that the crushed stone used in the special test sections (for a given degree of saturation and at field density) was more resiliant than the gravel. This observation is suggested when considering the rebound values obtained during the repeated triaxial tests.

SUMMARY

Data presented herein have not explained fully the reason for difference in performance of the gravel and crushed stone materials. There is an apparent anomalie, using measured deflection of the test pavement under load and rebound values found in the laboratory, when comparing these values at the degree of saturation of the materials found in the road. Further research should be conducted to clarify this point. There is, however, good correlation, using field moisture levels as a comparison, between field and laboratory stability of the two materials.

Data presented have illustrated some of the factors which affected stability of the gravel and crushed stone materials used in the Road Test. The writers believe it is significant that the coefficient of permeability of the crushed stone was appreciably higher than that of the gravel. It is also significant that the gravel's field degree of saturation was appreciably greater than the stone's and in the laboratory, at these moisture levels, the gravel specimens deflected more and showed greater rebound than the stone. This suggests that climatic factors, geometric section and permeability had significant effect on the performance of the two materials.

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5. Highway Research Board, "The AASHO Road Test", Special Reports 61E and 61B, 1962.

6. Shelburne, T. E. and K. B. Woods, "1943 Survey of Secondary Roads (Spring Break Up)", Report to the Advisory Board of the Joint Highway Research Project, Purdue University, 1943. (Unpublished).

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TABLE 1. SUMMARY OF RELATIVE DENSITY DATA

Material	Gradation (% Passing No. 200 Sieve)	Loose Density (pcf)	Average Field Density* (pcf)	Maximum Density (pcf)	Relative Field Density ** %
Gravel	6.2	126.6	145.0	145.6	97
	9.1***	127.0	145.0	146.6	92***
	11.5	126.7	145.0	145.8	96
Crushed Stone	6.2	113.3	141.0	141.6	98
	9.1	113.5	141.0	144.9	88
	11.5***	118.9	141.0	146.3	80***

* Also density used in laboratory tests

** Difference between field and loose densities divided by difference between maximum and loose densities

*** Average values from road

TABLE 2

ACCUMULATIVE DEFLECTION AND SINGLE CYCLE REBOUND OF TRIAXIAL SPECIMENS AFTER 1000 LOAD APPLICATIONS AND AT MOISTURE CONDITIONS CORRESPONDING TO VARIOUS DATES DURING THE ROAD TEST

Date	Degree Saturation %		Laboratory Accumulative Deflection (inches)		Laboratory Single Cycle Rebound (inches)	
	Gravel	Stone	Gravel (9.1% Fines)	Stone (11.5% Fines)	Gravel (9.1% Fines)	Stone (11.5% Fines)
Fall 1958	94	68	0.45	0.06	0.0145	0.011
Spring 1959	86	56	0.11	< 0.04	0.0125	< 0.009
Spring 1960	--	55	----	----	------	-----
Summer 1960	--	44	----	----	------	------

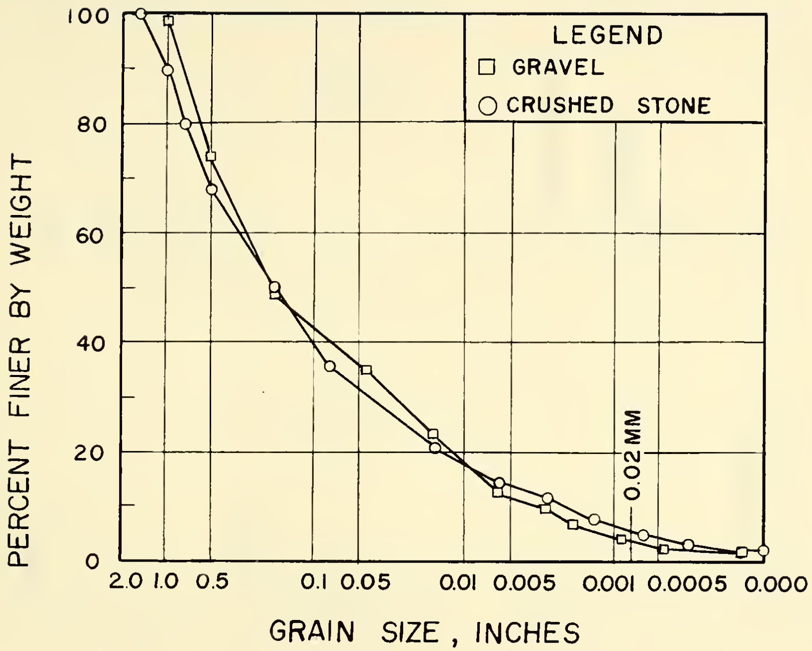

FIG. 1 GRAIN SIZE DISTRIBUTION CURVES

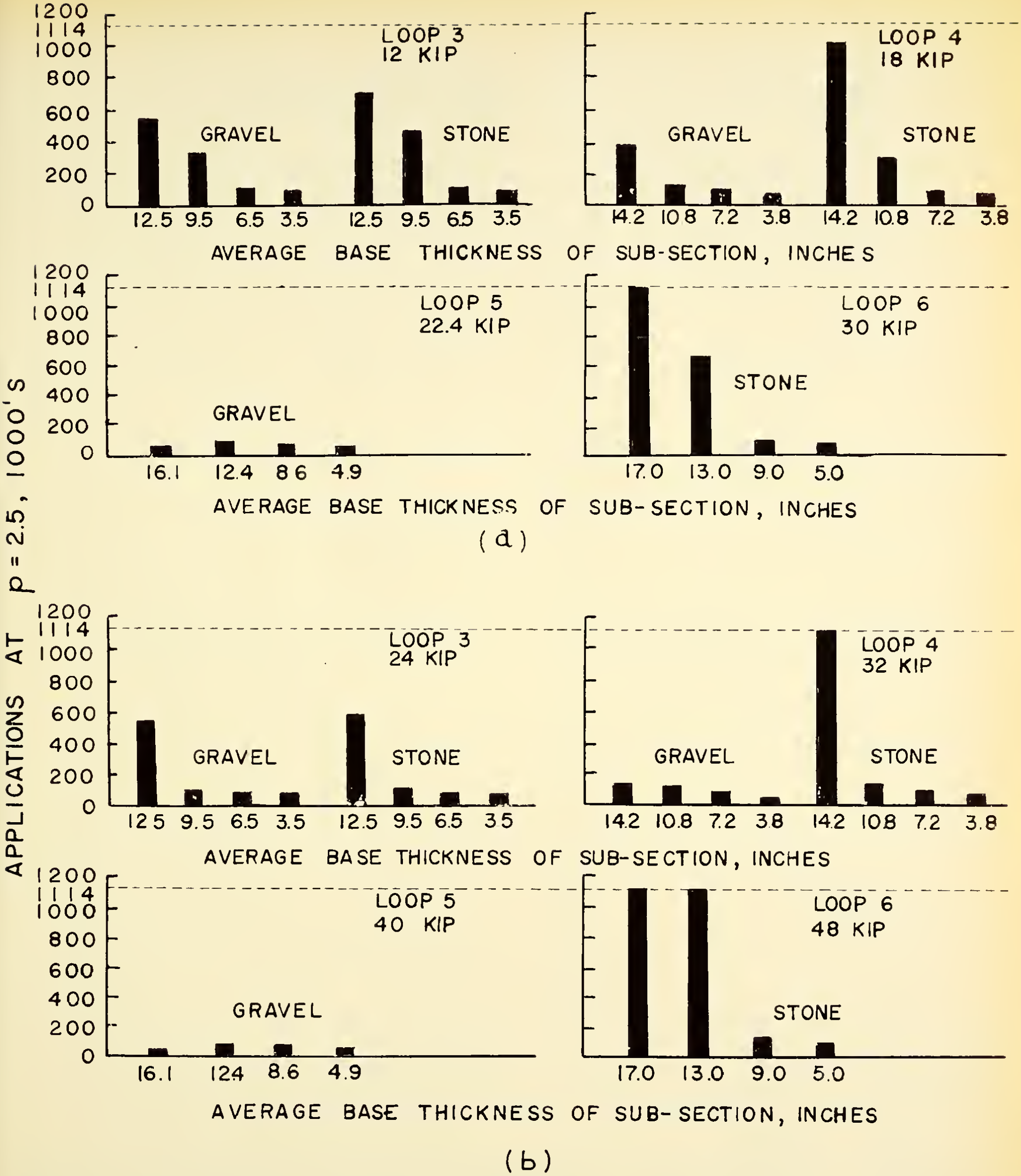

FIG. 2. PERFORMANCE DATA, SPECIAL BASE TYPE EXPERIMENT, (a) SINGLE AXLE LOADS, (b) TANDEM AXLE LOADS. (FROM BENKELMAN, KINGHAM AND SCHMITT)

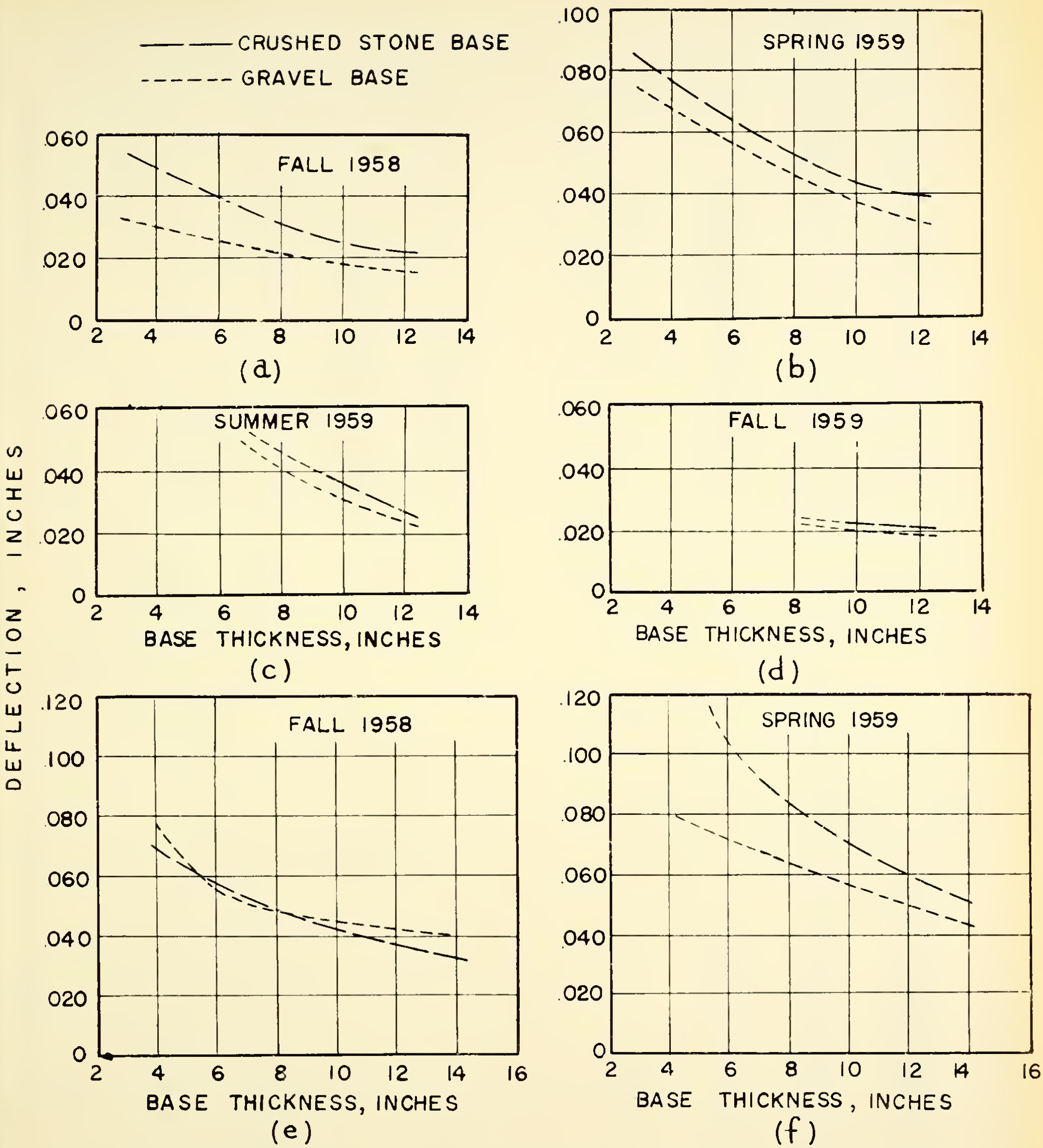

FIG. 3. SPECIAL BASE TYPE EXPERIMENT, RELATIONSHIP BETWEEN BASE THICKNESS AND DEFLECTION, (a), (b), (c) AND (d) 12 KIP SINGLE AXLE LOAD, LOOP 3 ; (e) AND (f) 18 KIP SINGLE AXLE LOAD, LOOP 4. (FROM HIGHWAY RESEARCH BOARD SPECIAL REPORT 61-E)

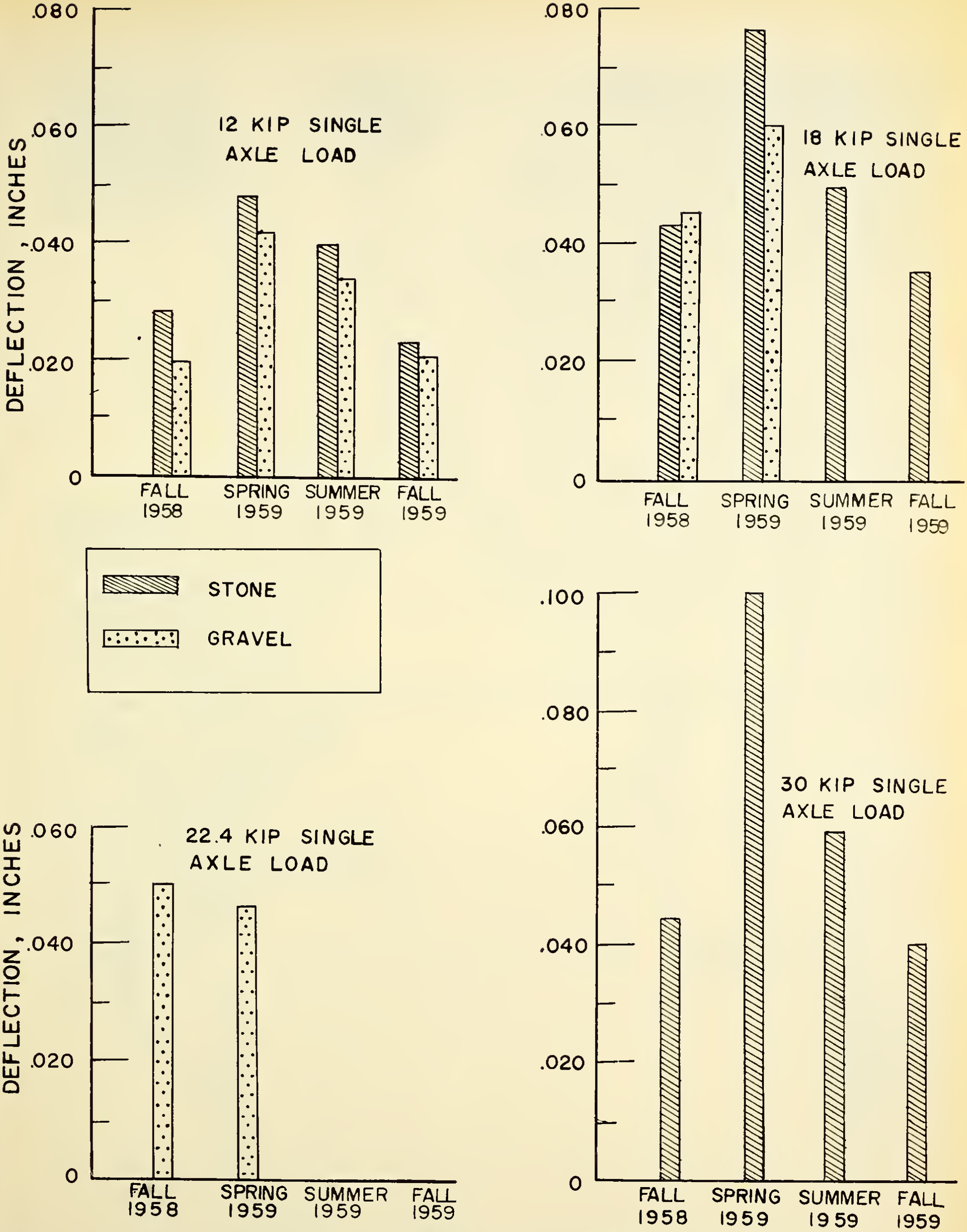

FIG. 4. SPECIAL BASE EXPERIMENT, SEASONAL DEFLECTION FOR 9-IN. BASE THICKNESS. (FROM HIGHWAY RESEARCH BOARD SPECIAL REPORT 61-E)

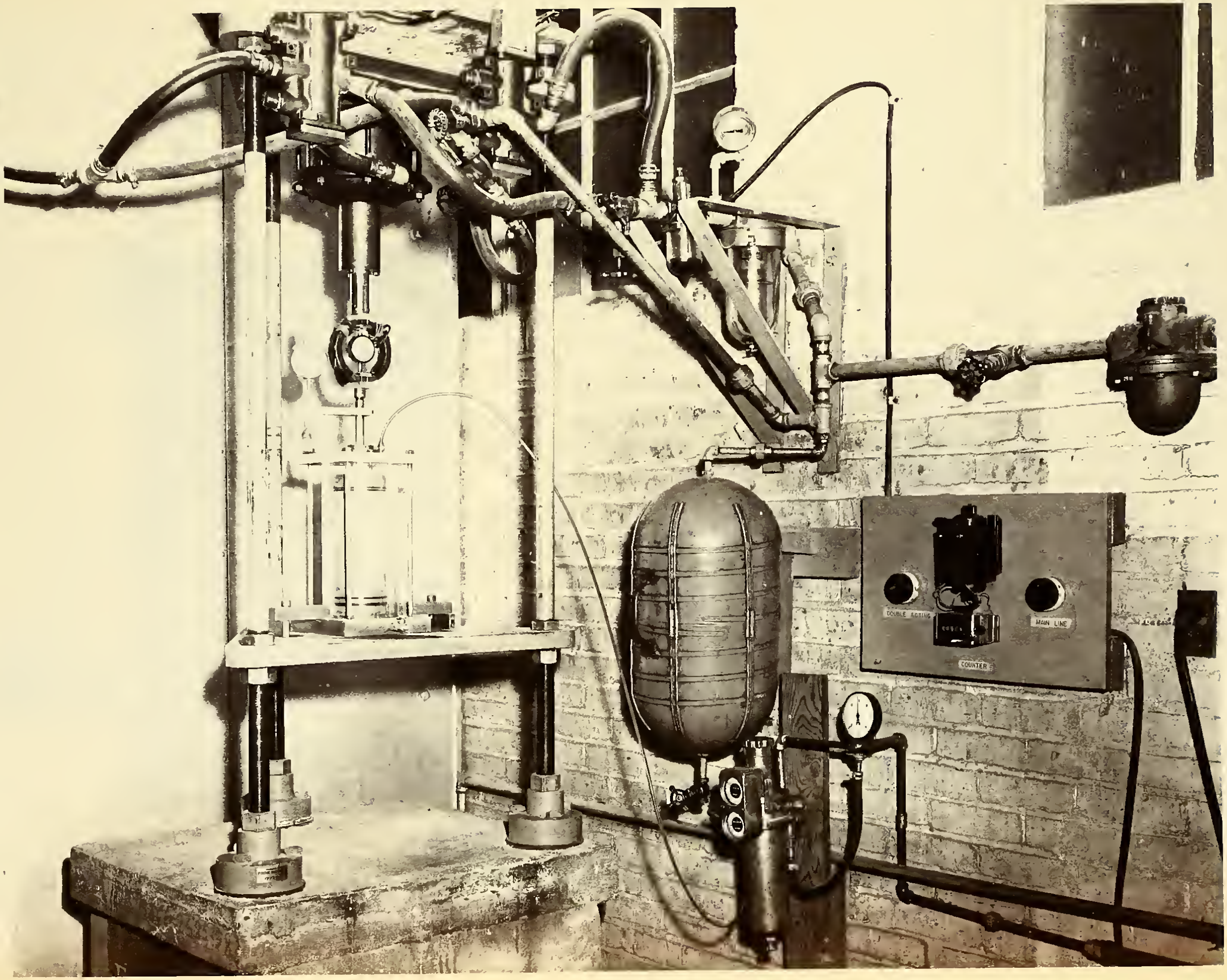

FIG. 5 EQUIPMENT USED FOR REPEATED LOAD TESTS

FIG. 6 SATURATION MOLD AND CELL

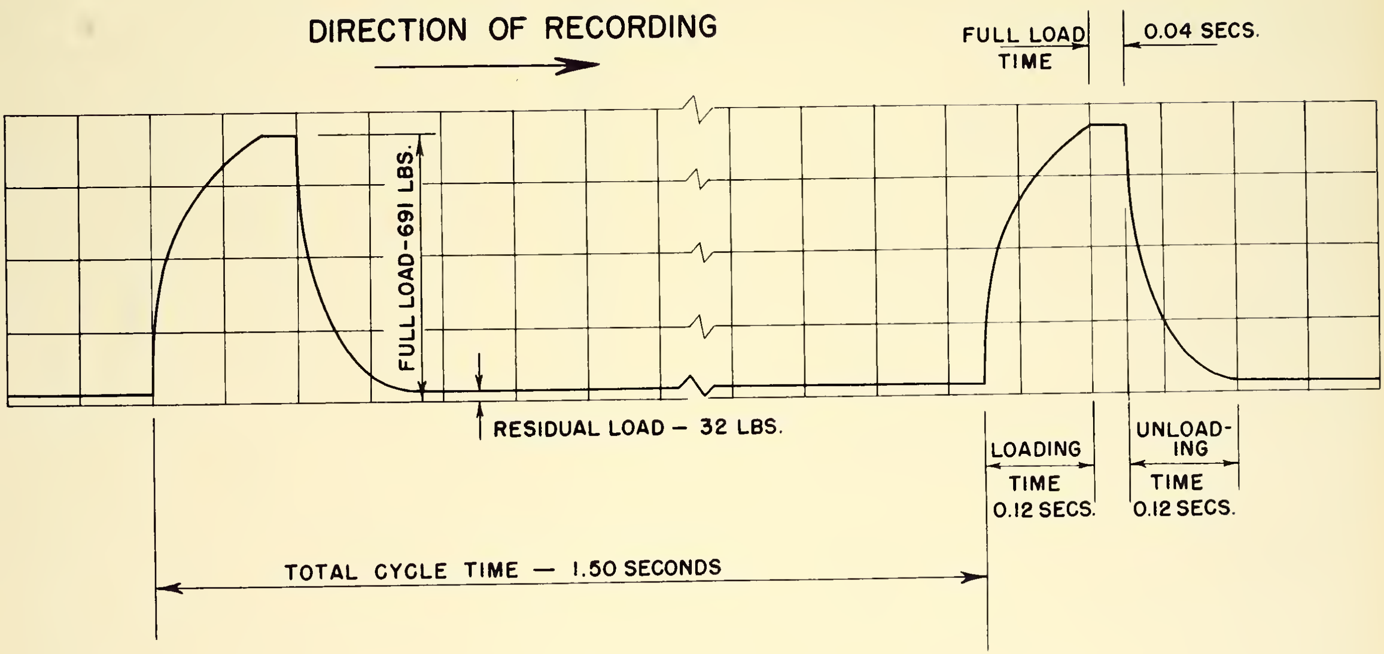

FIG. 7 TYPICAL LOAD — TIME TRACE FOR TWO LOAD CYCLES

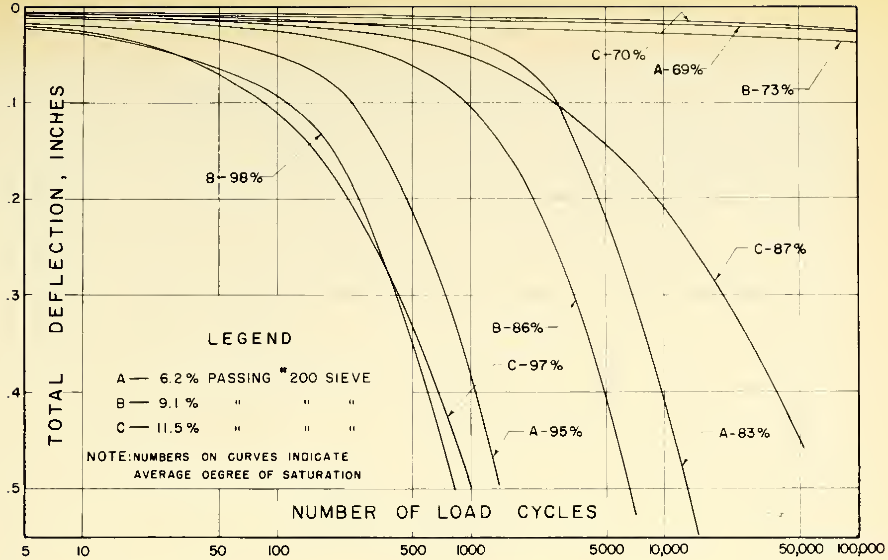

FIG. 8. DEFLECTION HISTORY OF GRAVEL SPECIMENS

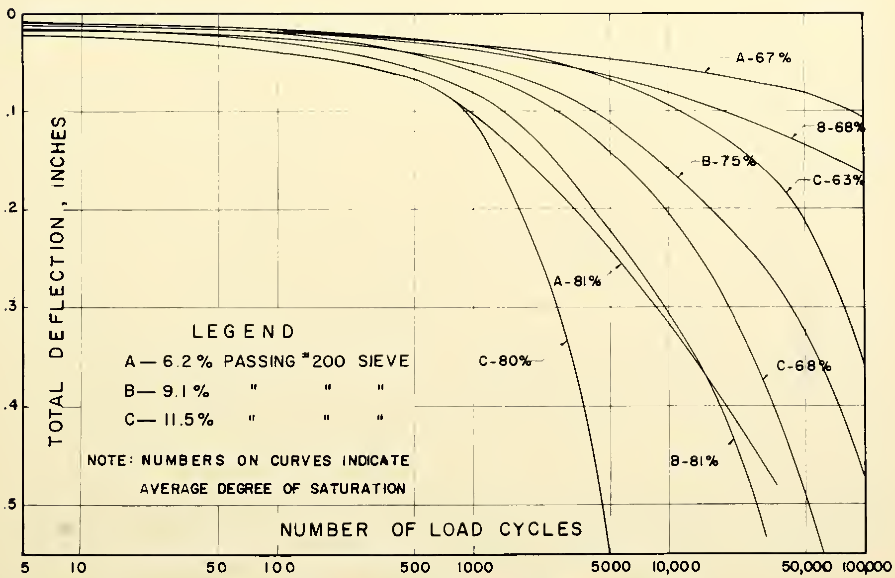

FIG. 9. DEFLECTION HISTORY OF CRUSHED STONE SPECIMENS

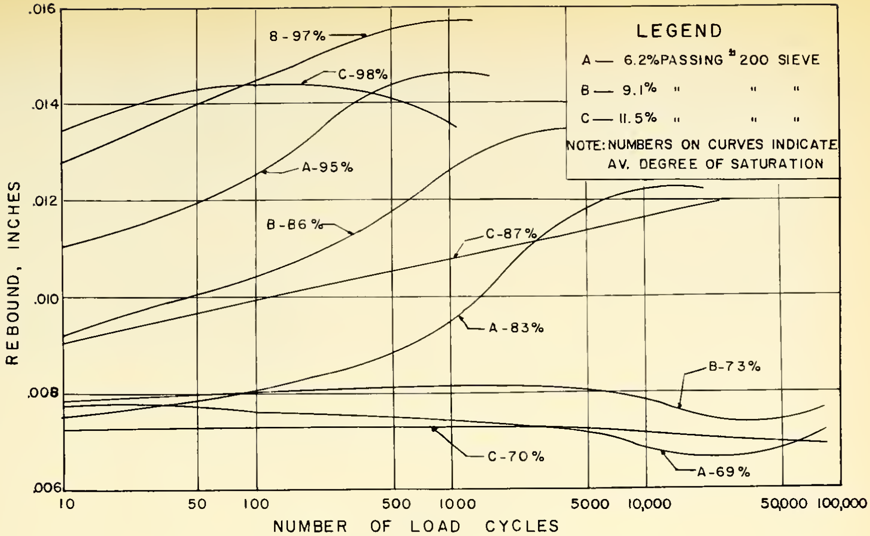

FIG. 10 REBOUND HISTORY OF GRAVEL SPECIMENS

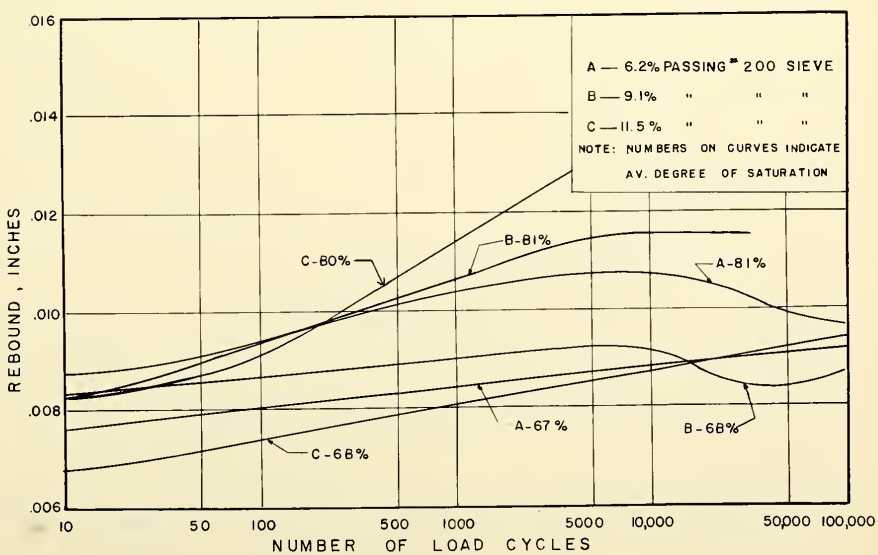

FIG. 11 REBOUND HISTORY OF CRUSHED STONE SPECIMENS

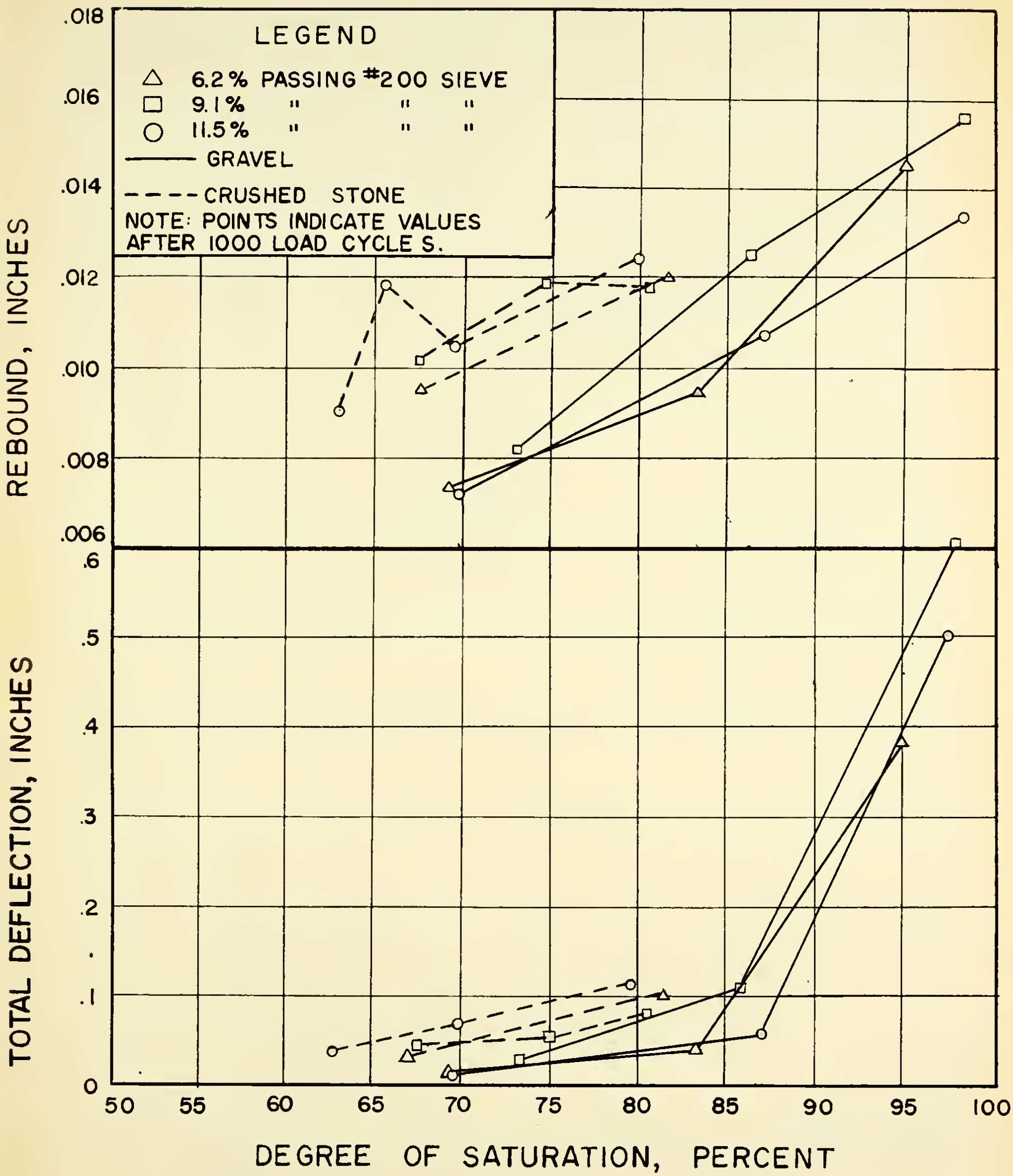

FIG. 12. DEFLECTION AND REBOUND AFTER 1000 LOAD CYCLES.

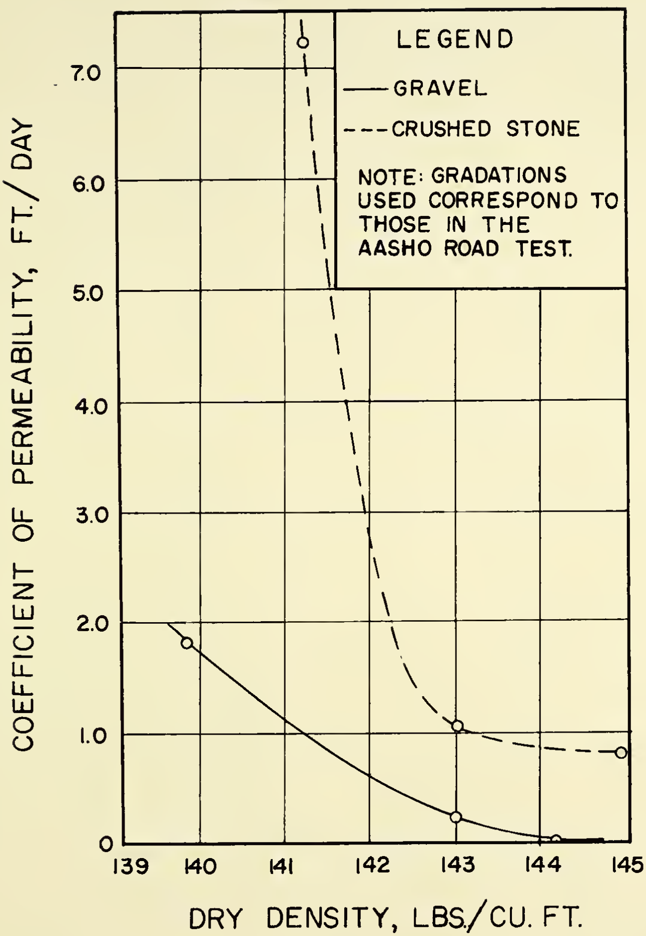

FIG. 13. VARIATION OF COEFFICIENT OF PERMEABILITY WITH DRY DENSITY.