Effect of Compaction Method on Stability and Swell Pressure of Soils

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Test data are presented for two soils, a silty clay and a sandy clay, comparing the stabilities at various water contents and densities of partially saturated samples compacted by impact methods, static pressure, and kneading action; the stabilities of samples prepared by these three methods and soaked to near saturation at constant density are also compared. A possible explanation for the different effects of the compaction methods is suggested and some of the difficulties of preparing saturated samples in the laboratory are discussed.

Data are also presented comparing the deformation characteristics in triaxial-compression tests of silty-clay specimens prepared by impact, static, and kneading compaction in the laboratory with those of the same soil compacted by sheepsfoot and rubber-tired rollers in the field.

A comparison is also made of the stability and swell pressures developed at various densities for samples of a sandy clay compacted by kneading and static methods and subsequently saturated by exudation of moisture under static load; the great difference in test results obtained is illustrated.

● THE object of a laboratory compaction test is to reproduce in the laboratory the compaction effects produced by equipment in the field. Not only should laboratory-compacted samples exhibit the same relationship of density versus water content as the soil compacted in the field, but since the laboratory samples are used for design purposes, they should also possess the same deformation characteristics under load. At the present time, three main methods of compaction are in use for the preparation of samples in the laboratory. In the majority of tests, the soil is compacted by dropping a weight onto the surface of the soil, a process referred to as impact compaction. In some cases the soil is compacted by subjecting it to a static load which is built up slowly to some predetermined value and then released, a process referred to as static compaction. In other methods, the soil is compacted by repeatedly applying a predetermined pressure to small areas of the soil, maintaining the pressure for a small element of time and then gradually reducing the pressure, a process termed kneading compaction.

It has long been recognized that samples having the same water content and density but prepared by impact and static compaction have different stress-strain characteristics (1). Recent investigations have shown this to be true also for samples prepared by kneading and static compaction (2). It becomes important, therefore, in order to satisfactorily design a pavement on the basis of laboratory tests, to know which method of compaction reproduces most closely the effects of field equipment and the magnitude of the differences in stability of a sample resulting from the use of different compaction methods.

Relatively little information is available on the extent to which the stabilities of laboratory compacted samples compare with those of samples compacted in the field. Some tests conducted by the Corps of Engineers have shown that samples of a silty clay taken from the field have different stress-strain characteristics from those prepared in the laboratory by impact and static compaction; additional data are presented in this paper to compare these results with those for the same soil compacted by kneading action. However, the main purpose of the investigations described is to illustrate the extent to which different methods of laboratory compaction affect the stability of soils and to draw tentative conclusions with regard to the qualitative nature of these effects.

In the pavement-design procedure used by the California Division of Highways, the expansion or swell pressure developed by a soil is used to determine the desirable pavement thickness. The effect of compaction method on the swell-pressure characteristics of soils, as measured by the California design procedure, is therefore also important and has been included within the scope of the investigation.

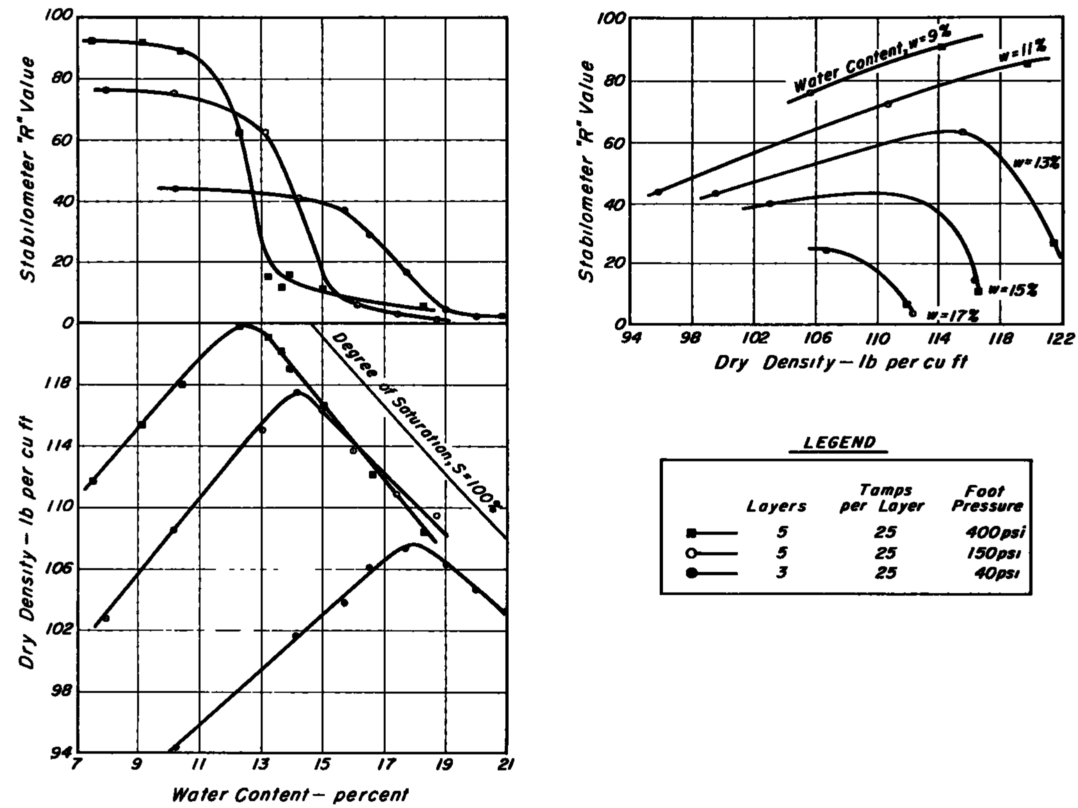

Figure 1. Water content, density, and stability relationships of silty clay for kneading compaction.

EFFECT OF COMPACTION METHOD ON THE STABILITY OF PARTIALLY SATURATED SOILS

Comprehensive series of tests were made on two soils, a silty clay from Vicksburg, Mississippi, and a sandy clay from Pittsburg, California, to determine the effect of impact, static, and kneading compaction on the relationship between dry density, water content, and stability. For each soil and for each method of compaction, series of tests were made to establish the relationships between dry density and water content and between stability and water content at each of three different compactive efforts. For each soil, the compactive efforts were selected to give results over approximately the same range of densities and water contents for each of the three methods of compaction; this range was approximately between the densities obtained in the standard Proctor and the modified AASHO compaction tests.

For tests at any one compactive effort, the soil was first oven-dried and samples were then mixed at about six different water contents. Each sample was placed in a sealed container and allowed to condition for one day prior to compaction. Specimens 4 inches in diameter and 4½ inches in height were then prepared using the selected method of compaction and compactive effort. After the density of the compacted soil had been determined, the upper 2¼ inches of the specimen was trimmed off and used for water-content determination while the lower 2¼ inches was tested in a Hveem Stabilometer and a measure of its stability

the two soils are reproduced in Figures 4 and 8. Figure 4a compares the stabilities at various water contents and densities, for specimens of the silty clay compacted

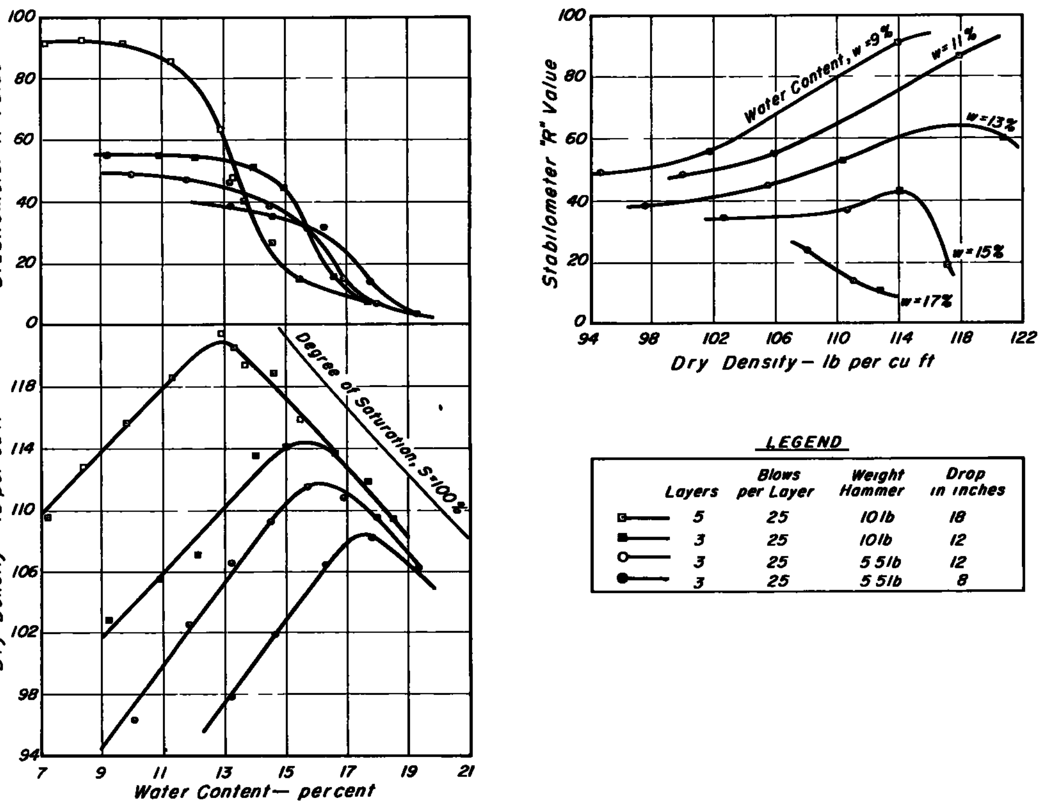

Figure 2. Water content, density, and stability relationships of silty clay for impact compaction.

obtained by determination of the resistance or R value (2). The resistance value is used as an index of stability in the California method and has been correlated with the required thickness of pavement for various types of loading conditions.

The results of these tests on the silty clay, for kneading, impact and static compaction procedures respectively, are shown in Figures 1, 2, and 3. Similar results for the sandy clay are shown in Figures 5, 6, and 7. On the left of each of these figures the test data is presented and on the right is shown the relationship between density and stability at various constant values of the water content; this latter relationship was in all cases interpolated from the test results shown on the left of the figure.

For purposes of comparison, the relationship of density versus stability for

by kneading and impact methods. It will be seen that, in general, the curves for these two methods of compaction are similar in form but that kneading compaction produces slightly higher stabilities at the lower densities and impact compaction results in somewhat higher stabilities at the higher densities. The higher densities on the curves in this type of plot are associated with the higher degrees of saturation; thus at higher degrees of saturation impact compaction produces the higher stabilities, while at lower degrees of saturation, kneading compaction produces higher stabilities. Comparison of the densities at which impact compaction begins to give higher stabilities with the position of the line of optimums for the compaction curves in Figures 1 and 2 will show that it is at water contents just below and above the optimum water content for the particular compactive effort being

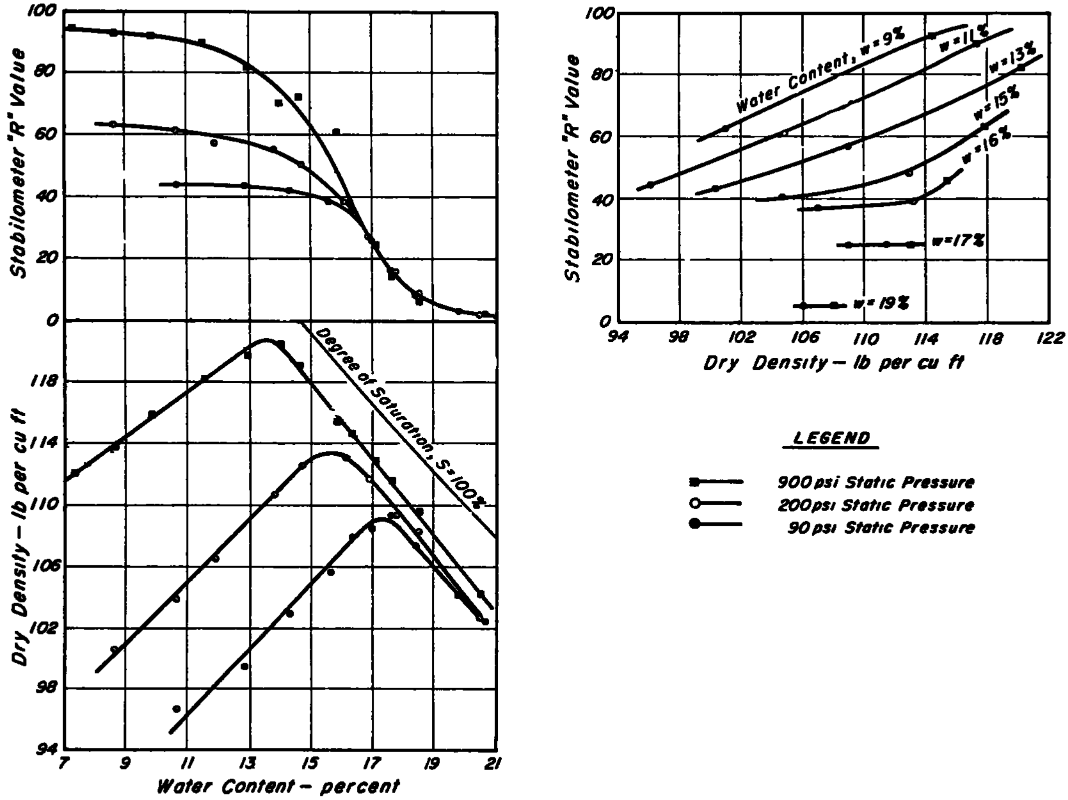

Figure 3. Water content, density, and stability relationships of silty clay for static compaction.

used that impact compaction causes higher stability than kneading compaction; at water contents well below optimum, kneading compaction results in the higher stabilities. However, at no stage is there any great difference between the results obtained by these two methods.

It is interesting to note that both kneading and impact compaction result in samples which, at lower degrees of saturation, show an increase in stability with increase in density at a given water content but at the

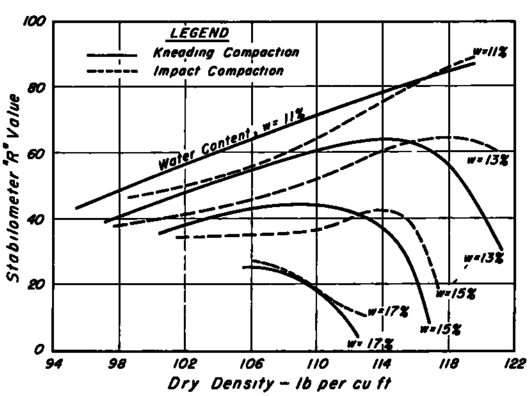

Figure 4a. Effect of kneading and impact compaction on density versus stability relationship at constant water contents for silty clay.

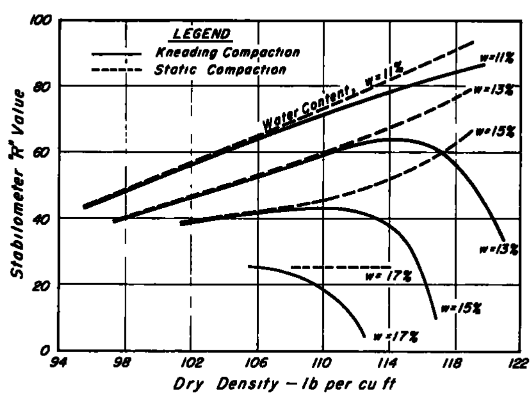

Figure 4b. Effect of kneading and static compaction on density versus stability relationship at constant water contents for silty clay.

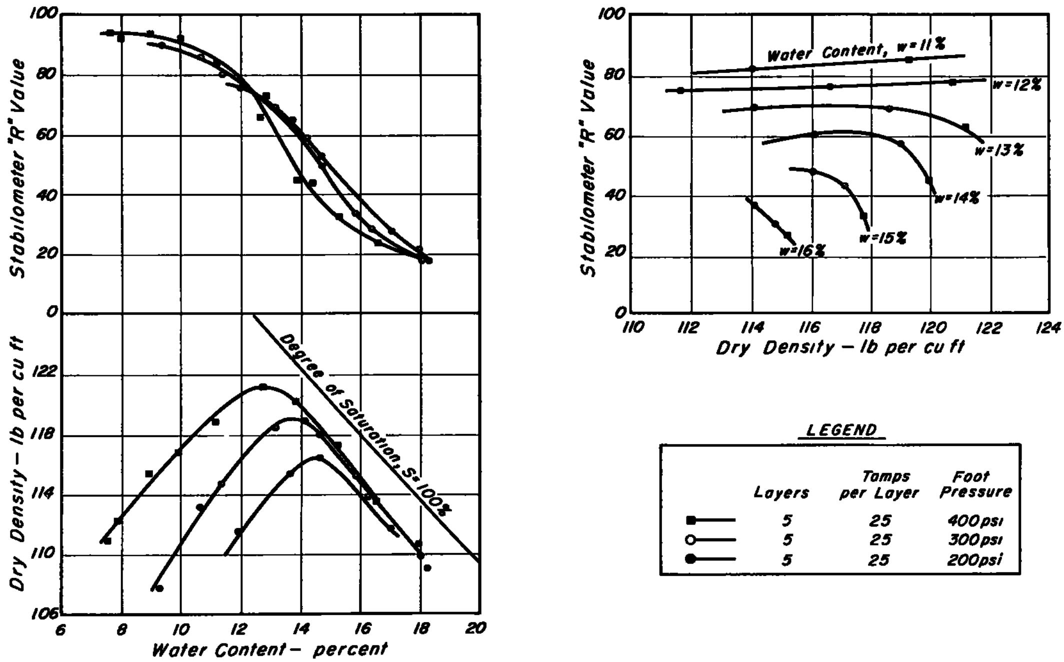

Figure 5. Water content, density, and stability relationships of sandy clay for kneading compaction.

higher degrees of saturation show a reduction in stability with increase in density at constant water content. This reduction in stability with increase in density is more pronounced for specimens prepared by kneading compaction than for those prepared by impact compaction.

The stabilities at various water contents

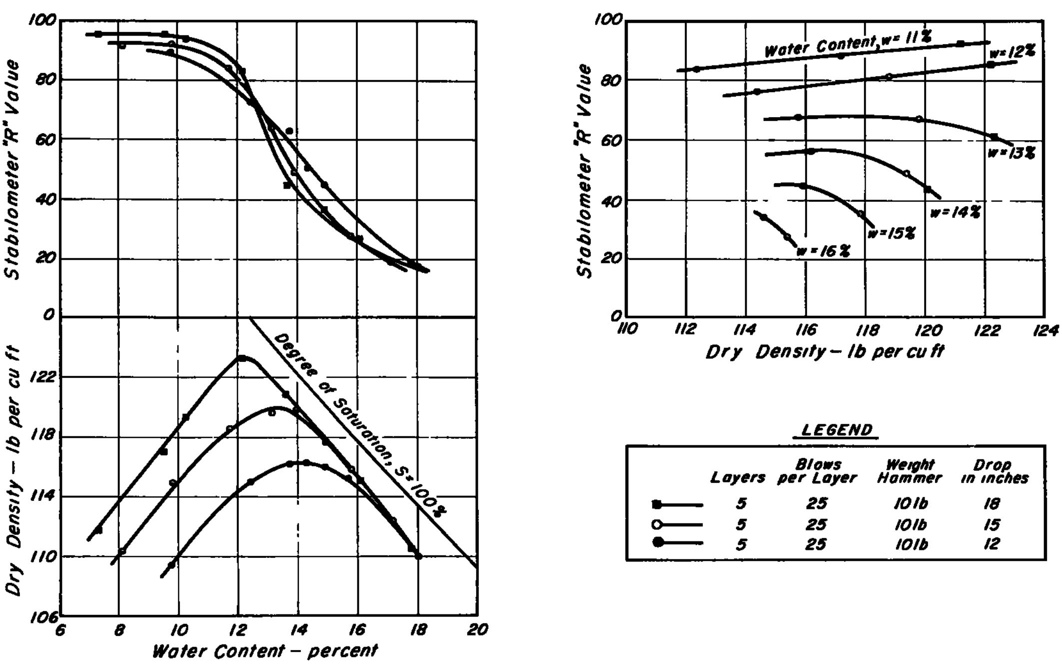

Figure 6. Water content, density, and stability relationships of sandy clay for impact compaction.

and densities of samples of silty clay prepared by kneading and static compaction are compared in Figure 4b. The most-important difference in the results for these compaction methods is that samples prepared by static compaction always show an increase in stability with an increase in density at any water content, while for samples prepared by kneading compaction the stability is reduced if, at water contents greater than about 12 percent, the density is increased at the higher degrees of saturation. This difference results in a considerable discrepancy between the stabilities of samples prepared by static and kneading methods. For example, at a water content of 15 percent and a density of 116 lb. per cu. ft. the resistance value of a sample prepared by kneading compaction is only 22, while that for a sample prepared by static compaction is 56, an increase of approximately 150 percent. In terms of

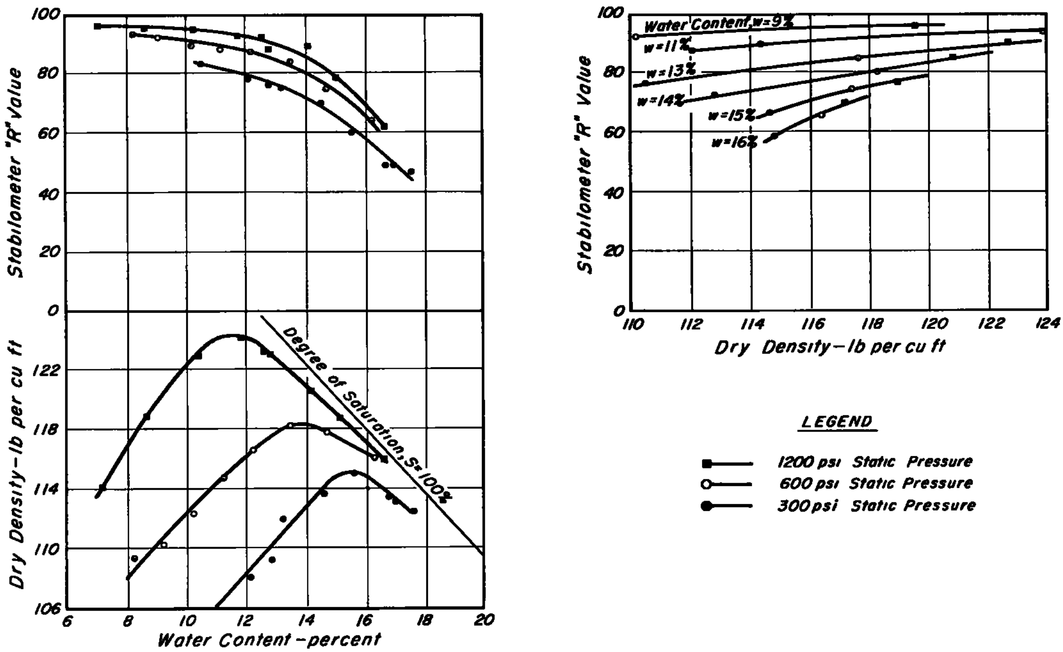

Figure 7. Water content, density, and stability relationships of sandy clay for static compaction.

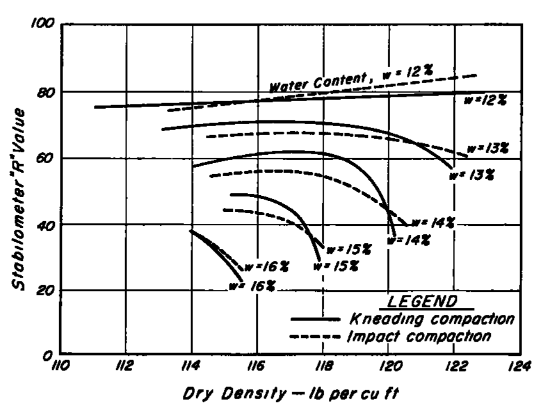

Figure 8a. Effect of kneading and impact compaction on density versus stability relationship at constant water contents for sandy clay.

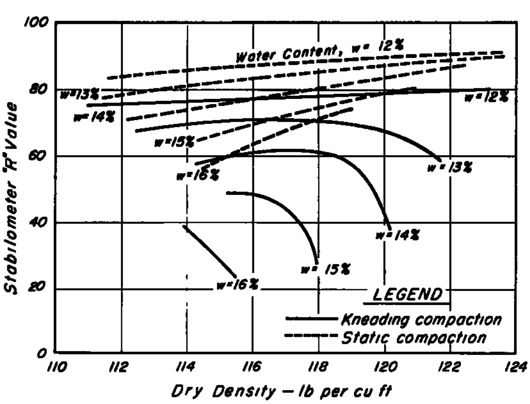

Figure 8b. Effect of kneading and static compaction on density versus stability relationship at constant water contents for sandy clay.

pavement thickness for a typical flexible pavement designed by the California procedure for a highway with heavy traffic, a resistance value of 22 would indicate a required thickness of pavement and base of about 18 inches, while a resistance value of 56 would indicate a required thickness of only about 9 inches. If kneading compaction most satisfactorily reproduces the effects of field compaction, the dangers of designing a pavement for a partially saturated subgrade condition on the basis of tests on samples prepared by static compaction are immediately evident.

At lower degrees of saturation, the stabilities of samples of the silty clay prepared by static and kneading compaction appear to be almost identical. Thus, at equal water contents and densities, the stabilities of samples prepared by static compaction were always equal to or greater than those of samples prepared by kneading compaction. Comparison of the curves in Figures 4a and 4b show this to be true also for static and impact compaction.

The stabilities of samples of sandy clay prepared by kneading and impact compaction are compared in Figure 8a. As for the silty clay, kneading compaction gives slightly higher stabilities at lower degrees of saturation, and impact compaction gives slightly higher stabilities at the higher degrees of saturation; for this soil it is approximately for samples compacted on the dry side of the optimum water content for the particular compactive effort being used that kneading compaction gives the higher stabilities and for samples on the wet side of optimum that impact compaction gives the higher stabilities. However, both methods of compaction again show that at higher degrees of saturation, an increase in density may lead to a decrease in stability.

Comparison of the stabilities resulting from kneading and static compaction of the sandy clay in Figure 8b, shows that, for any given water content and density condition within the range investigated, static compaction gives the higher stability. Furthermore, in contrast to the results for kneading and impact compaction, the samples prepared by static compaction show a consistent increase in stability with increase in density, even at higher degrees of saturation. As a consequence of this, there are again large differences in stability between samples prepared by static and kneading compaction or by static and impact compaction at the higher degrees of saturation. For example, at a water content of 15 percent and a dry density of 118, the resistance value of a sample compacted by static pressure was 75, compared with a resistance value of 27 for a sample prepared by kneading compaction.

From the results presented in Figures 4 and 8 for the two soils investigated, the following general conclusions may be drawn:

1. At a given density and water content, samples compacted by static pressure have higher stabilities than samples prepared by kneading or impact compaction; this is particularly true at higher degrees of saturation when there is a large difference between the stabilities of samples prepared by static and impact or static and kneading compaction.

2. At any given density and water content, samples prepared by impact and kneading compaction have similar stabilities, with kneading compaction resulting in somewhat higher stabilities for samples compacted on the dry side of the optimum water content and impact compaction producing higher stabilities for samples compacted at water contents above the optimum for the particular compactive effort being used.

3. For samples prepared by impact or kneading compaction, an increase in density may cause an increase or decrease in stability depending on the water content and the range of densities involved; for samples prepared by static compaction, an increase in density always results in an increase in stability.

EFFECT OF TAMPING PRESSURE ON STABILITY OF PARTIALLY SATURATED SOILS

In the tests on samples of silty clay prepared by kneading compaction, the different compactive efforts were obtained by varying the tamping pressure from 40 to 400 psi. It is of interest to determine how, for any given water content, the stability of a sample will vary with the tamping pressure used to compact it. Such results may be interpolated from the data in Figure 1, and the variation of the resistance values of samples with the tamping pressure used in the compaction tests, for a series of constant water contents, are shown in Figure 9. The relationships of water con-

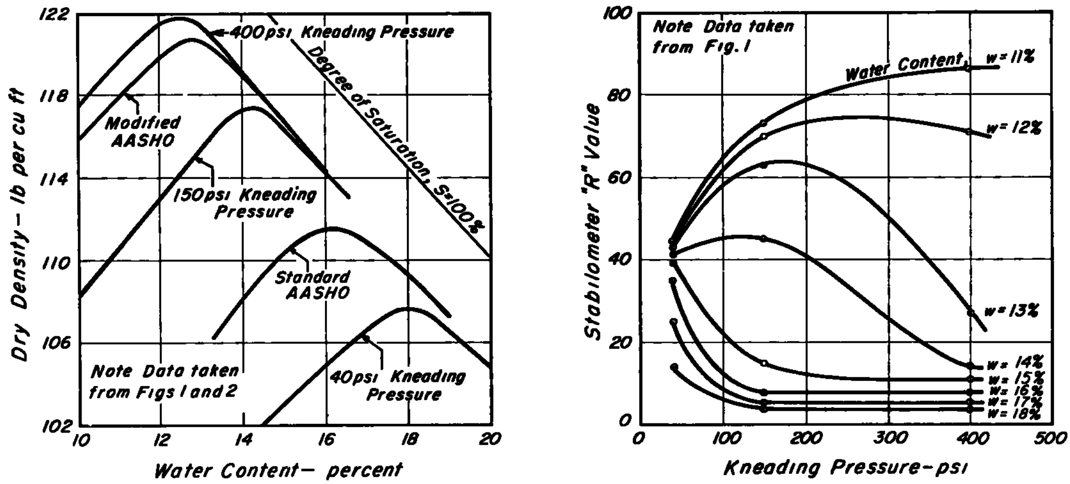

Figure 9. Density versus water content and stability versus kneading-pressure relationships for silty clay.

tent versus density resulting from these tamping pressures are shown on the left of Figure 9, together with the curves obtained by the standard AASHO and modified AASHO compaction tests for comparison.

It will be seen that an increase in tamping pressure may lead to an increase or decrease in stability of the compacted soil depending on the water content at which the soil is compacted. The optimum water content as determined by the modified AASHO compaction test for this soil is about 13 percent. A tamping pressure of 400 psi. results in densities comparable to those obtained by the modified AASHO test; yet, if this pressure is used at a water content of 13 percent, the compacted soil has a lower stability than would be obtained for any tamping pressure between 40 and 400 psi. It is interesting to note that, for compaction at this water content, the maximum stability would be obtained by using a tamping pressure of about 175 psi. which, according to the positions of the compaction curves shown in Figure 9, would produce a relative compaction of about 95 percent. However, an increase in tamping pressure from 175 to 400 psi., would reduce the resulting stability of the soil by over 50 percent.

For compaction at the optimum water content as determined by the standard AASHO compaction test, the stability decreases as the tamping pressure increases

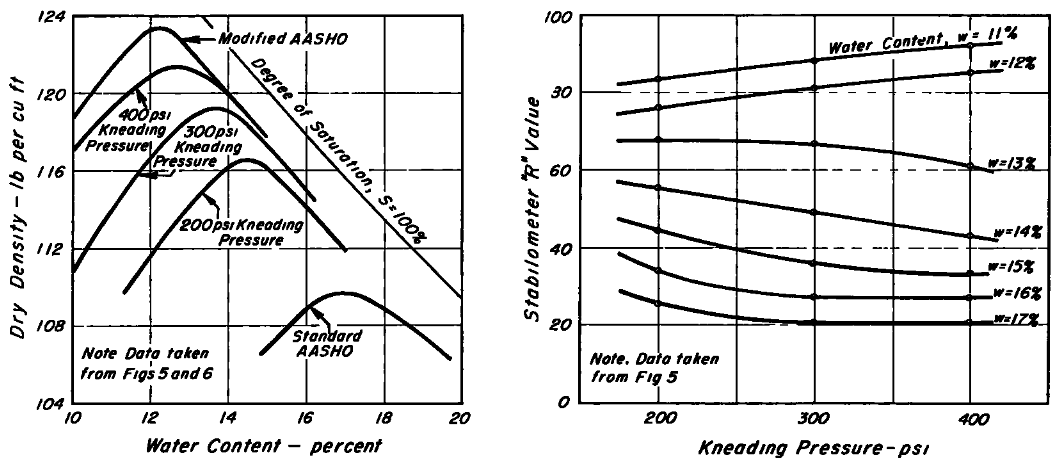

Figure 10. Density versus water content and stability versus kneading-pressure relationships for sandy clay.

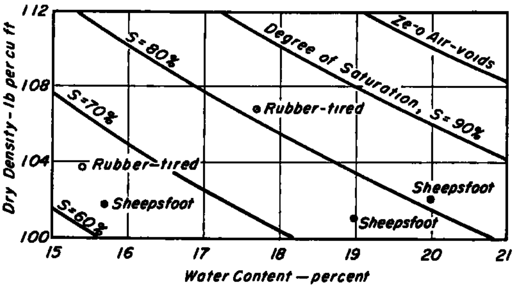

Figure 11. Water content versus density relationship for field-compacted samples of silty clay.

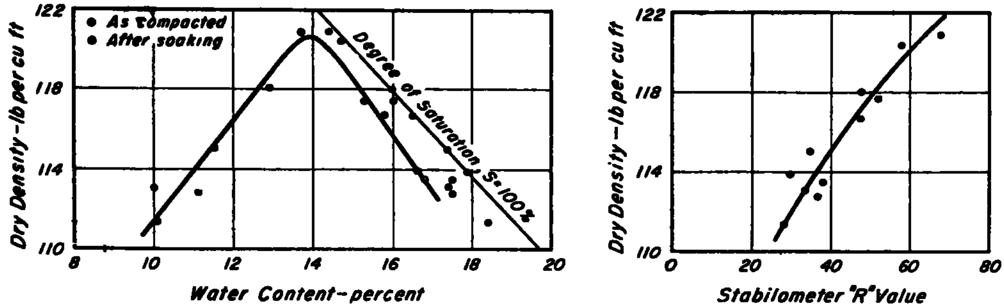

Figure 12a. Density versus water content and density versus stability of samples soaked at constant density for static compaction.

from 40 to 150 psi., but beyond this point, further increase in tamping pressure has no effect on stability; presumably the ultimate bearing capacity of the soil is reached at a pressure of about 150 psi. and tamping pressures exceeding this value cause shear failure and no change in condition of the soil.

The significant effects which the water content and the kneading pressure used for compaction may have on the resulting stability of a partially saturated soil are clearly evident from the curves in Figure 9. For this silty clay at water contents more than 1 percent below the optimum for the modified AASHO compaction test, an increase in tamping pressure at least up to 400 psi. had a beneficial effect on stability; at water contents more than 1 percent above this optimum, an increase in tamping pressure above 40 psi. had a deleterious effect on stability. Near the optimum water content for the modified AASHO test, the most-desirable tamping pressure decreased as the water content increased. Unfortunately, the tamping pressures used in the laboratory tests have not been correlated with those producing similar degrees of compaction in the field, but the nature of the effects produced by field equipment will be similar to those obtained in the laboratory.

The relationships between stability and tamping pressure at various constant values

TABLE 1- SUMMARY OF TEST RESULTS

Water Content - percent	15.4	15.7	17 7	19.0	20.0
Dry Density - lb per cu ft	103.7	101 7	106.8	101.0	102 0
Modulus of Deformation at 1% Strain					
Field Compaction - sheepsfoot roller		320		130	120
Field Compaction - rubber-tired rolle:	400		180		
Lab. Compaction - Impact - Corps of .ng.	330	330	120	120	45
Lab. Compaction - Impact - Univ. of Calif.	290	250	155	120	90
Lab. Compaction - Kneading - Univ. of Calif.	350	300	195	130	90
Lab Compaction - Static - Corps of Eng.	330	320	225	160	-
Percent Difference between Moduli of Deformation for Field and Laboratory Compaction					
Laboratory Impact Compaction	-22.5	-9.5	-23.5	-7.5	-44.0
Laboratory Kneading Compaction	-12.5	-6.5	+8.5	0	-25.0
Laboratory Static Compaction	-17.5	0	+25.0	+23.0	-

of water content for the sandy clay are shown in Figure 10. The general form of these curves is similar to that for the silty clay, though the effect of tamping pressure on stability is not so great. Furthermore, at the optimum water content for the modified AASHO compaction test, an increase in tamping pressure above 200 psi. caused a slight reduction in stability. The effect of water content at compaction, for any given tamping pressure again has an important effect on stability. For a tamping pressure of 300 psi., compaction at the optimum water content for the standard AASHO test (17 percent) would produce a sample with a resistance value of only 21, compared with a value of about 80 for compaction at the optimum water content for the modified AASHO test (12 percent).

of silty clay compacted by sheepsfoot and rubber-tired rollers in the field were compared with those of samples, at the same densities and water contents, prepared by static and impact compaction in the laboratory. Through the courtesy of the Waterways Experiment Station at Vicksburg in supplying some of the soil used in the tests, this comparison has been extended to include samples prepared by kneading compaction.

In the field the soil was compacted in 6-inch lifts by six passes of either a sheepsfoot roller with a foot pressure of 500 psi. or a rubber-tired roller with a wheel load of 20,000 lb. Undisturbed samples were cut from a depth of 12 to 21 inches below the top of the compacted soil and trimmed to 1.4-inch-diameter specimens for test-

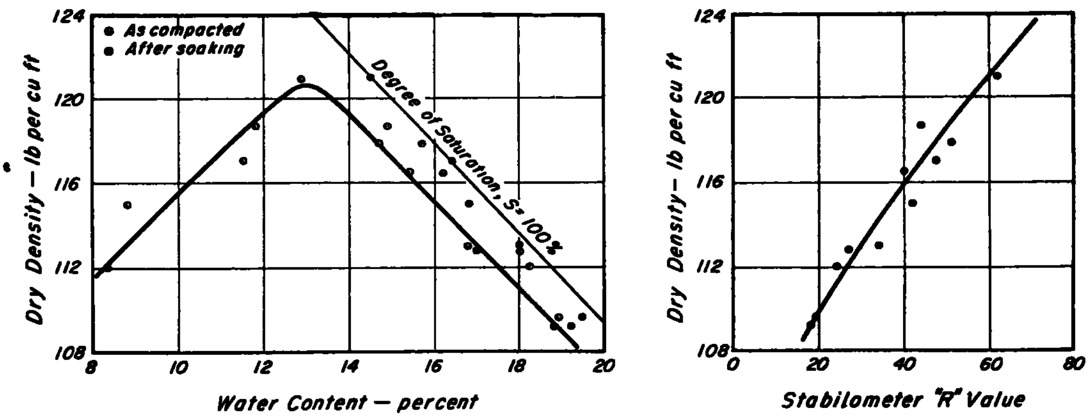

Figure 12b. Density versus water content and density versus stability of samples soaked at constant density for impact compaction.

These results emphasize the importance of careful control of construction conditions and the possible dangers of the arbitrary selection of these conditions on the basis of standard compaction tests, when placing soils for maximum stability under conditions where the water content is unlikely to change appreciably from that at which the soil is compacted.

COMPARISON OF STABILITIES PRODUCED BY FIELD AND LABORATORY COMPACTION PROCEDURES

In a previous investigation conducted by the Corps of Engineers (1), the strength and deformation characteristics, as measured by triaxial-compression tests of the unconsolidated, undrained type, on samples

ing. The water contents and densities of five samples taken from the field are shown in Figure 11, and their moduli of deformation at 1 percent strain, as measured by triaxial-compression tests using a constant lateral pressure of 1 kg. per sq. cm., are presented in Table 1.

In the tests conducted by the Corps of Engineers, the greatest discrepancy between the stress-deformation characteristics of samples prepared in the laboratory by impact and static compaction was found to occur at low strains. In this investigation, the modulus of deformation at 1 percent strain was therefore selected as the basis for comparison of the effects of different compaction methods.

In Table 1 are summarized the moduli of deformation at 1 percent strain of sam-

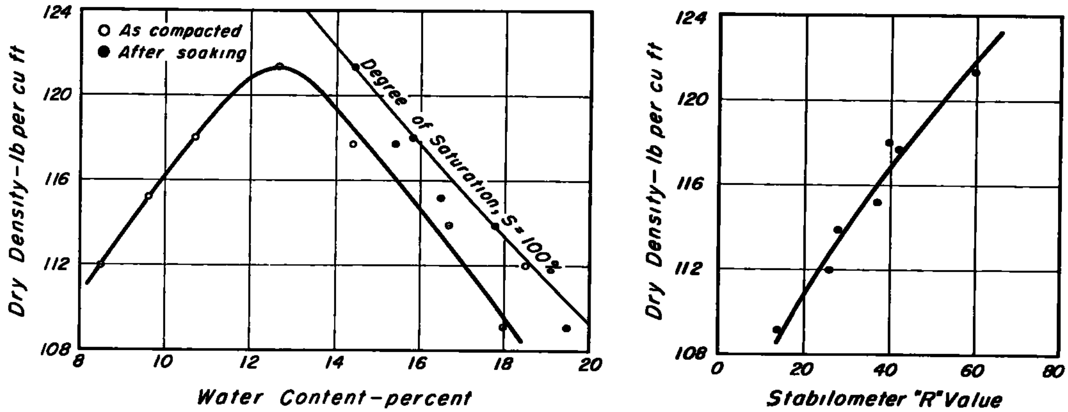

Figure 12c. Density versus water-content and density versus stability of samples soaked at constant density for kneading compaction.

ples at the same water contents and densities as those taken from the field and tested in the same manner but prepared in the laboratory by impact, kneading, and static compaction. In order to ensure that the testing procedure used for the samples prepared by kneading compaction was the same as that used by the Corps of Engineers, test data was also obtained for samples prepared by impact compaction. It will be seen that there is reasonably good agreement between the results of tests on samples prepared by impact compaction conducted in the different laboratories.

To facilitate comparison of the test results, the differences of the moduli of deformation of laboratory compacted samples from those of the field compacted samples, expressed in percent of the moduli of the field compacted samples, are summarized at the foot of Table 1. For samples prepared by impact compaction, the average of the values obtained by the Corps of Engineers and the University of California have been used. It will be seen that, in general, the moduli of deformation of the field compacted samples agree more closely with those of samples prepared in the laboratory by kneading compaction than with those of samples prepared by impact or static compaction.

The relative values of the moduli obtained by the various laboratory compaction methods seem to be in general agreement with the results obtained in the tests previously described. The moduli for kneading compaction are consistently slightly higher than the moduli for impact

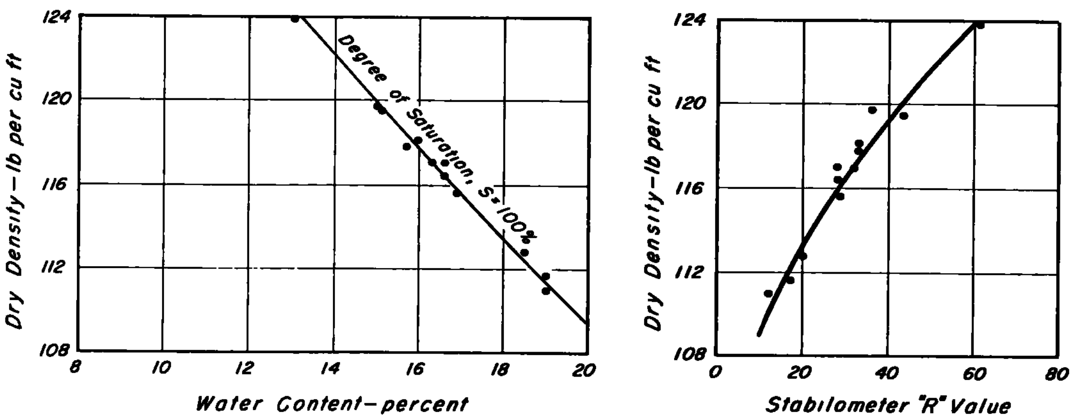

Figure 12d. Density versus water-content and density versus stability of samples prepared by kneading compaction and saturated by exudation.

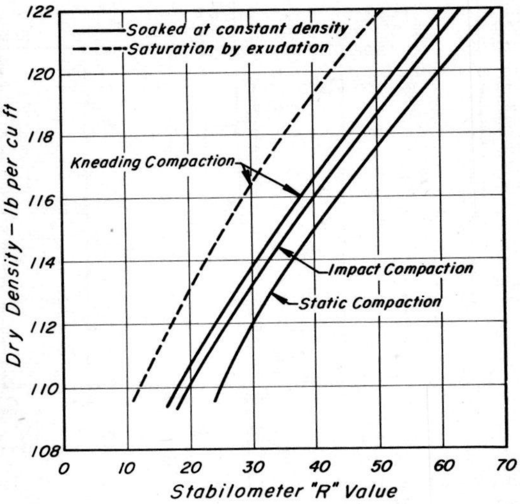

Figure 13. Density versus stability of samples soaked at constant density and samples saturated by exudation.

compaction; and although the moduli for static compaction are approximately equal to those for kneading compaction at the lower degrees of saturation, they are appreciably higher than those for kneading compaction at the higher degrees of saturation.

In general it may be concluded from these tests that static compaction appears to give the highest modulus values; impact compaction, the lowest values; and field and kneading compaction give intermediate values. While the results are by no means conclusive, they appear to substantiate previous indications that laboratory kneading compaction offers the greatest possibility for satisfactory duplication of field compaction effects.

EFFECT OF COMPACTION METHOD ON THE STABILITY OF SAMPLES SATURATED BY SOAKING

In the large majority of cases, pavement designs are based on the assumption that the compacted subgrade will become saturated at some stage in the life of the pavement which it supports. Thus, the design thickness is usually determined by the stability of a sample compacted in the laboratory and subsequently saturated by soaking at approximately constant density.

The effect of compaction method on the stability of samples treated in this manner was investigated by three series of tests on a sandy clay. In the first series, a number of specimens 4 inches in diameter and $4\frac{1}{2}$ inches high were prepared in metal molds by impact compaction at water contents both above and below the optimum. The density was determined and the upper $2\frac{1}{4}$ inches of each specimen was then trimmed off and used for water-content determination while the remainder of the specimen was maintained at constant density by confining it between two rigid porous plates and subjected to a water pressure of about 10 psi. at one of its ends. The water pressure was maintained until free water was seen to accumulate at the opposite end of the specimen, at which stage the specimen was considered to be saturated; the time required for this to occur was about 7 or 8 weeks. When all of the specimens in the series were saturated in this way, the water pressure was removed, the stabilities of the specimens were measured by Hveem Stabilometer tests, and the densities and water contents were determined. Similar series of tests were performed on samples prepared by kneading and static compaction, the compactive efforts being selected to give samples in the three series with approximately similar density ranges.

The results of these tests are shown in Figures 12a, 12b, and 12c. At the left of each figure is shown the density and water content of the sample as it was prepared

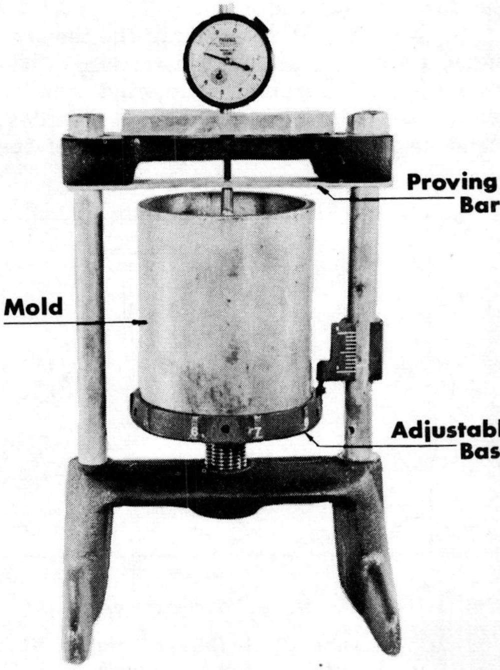

Figure 14. Expansion pressure device.

and after saturation, while on the right is shown the relationship between the resistance value and the dry density of the saturated specimens. It will be seen that only in isolated samples was a condition approaching complete saturation achieved, though the degree of saturation usually exceeded 95 percent. In general the average degree of saturation for samples prepared by impact compaction was slightly lower than that for samples prepared by static or kneading compaction.

The relationships of density versus stability after saturation for samples prepared by impact, static, and kneading compaction are compared in Figure 13. At equal densities, samples prepared by static compaction had the highest stabilities, and samples prepared by kneading compaction had the lowest stabilities. However, the stabilities for samples prepared by impact and kneading compaction did not differ greatly, and this difference might have been due to the slightly higher average degree of

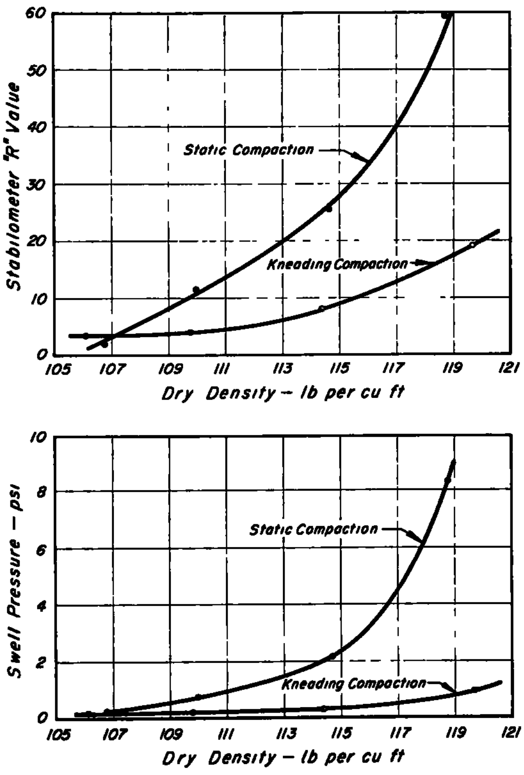

Figure 15. Density versus stability and density versus swell pressure of samples of silty clay prepared by static and kneading compaction and saturated by exudation.

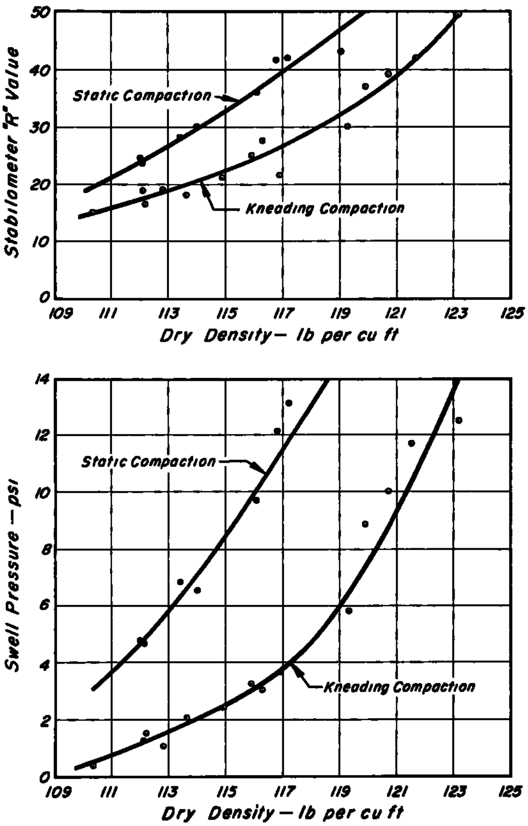

Figure 16. Density versus stability and density versus swell pressure of samples of sandy clay prepared by static and kneading compaction and saturated by exudation.

saturation for the samples prepared by kneading compaction. If the average degrees of saturation for samples prepared by impact and kneading compaction had been the same, the samples prepared by impact compaction might have had the lower stabilities. The stabilities, as measured by the resistance values of samples prepared by static compaction, were from 10 to 25 percent greater than those for samples prepared by kneading compaction. These results are in general agreement with the effects of compaction method on the stabilities of partially saturated soils.

In the California design procedure, samples are prepared by kneading compaction at water contents on the wet side of optimum and are then saturated by applying static pressure until moisture is exuded. It was considered of interest to compare the stabilities of samples prepared by this method with those obtained by the method of saturation previously described. The results of tests conducted in accordance with the

California design procedure are presented in Figure 12d, and the density-versus-stability relationship is shown in Figure 13. It will be seen that, for equal densities, the stabilities of these samples are considerably lower than those prepared by kneading compaction and saturated by soaking. While this difference may be due partly to the influence of the molding water contents on the stabilities of samples even after saturation, it may also be due to an increase in strength due to electrochemical action during the 8-week period of soaking the samples in metal molds. If this should be the case, the influence of this effect during long periods of soaking is clearly of considerable importance and indicates the need for special provisions for the saturation of samples after compaction.

EFFECT OF COMPACTION METHOD ON THE STABILITY AND SWELL PRESSURES OF SAMPLES SATURATED BY EXUDATION

Since the stabilities of samples saturated by long periods of soaking were considerably higher than those of samples saturated by exudation and were apparently affected by the test procedure, a further investigation was made to compare the stabilities of samples of two soils, a silty clay and a sandy clay, prepared by static and kneading compaction and then saturated by exudation of moisture under static load. Samples prepared in this way by kneading compaction are used for pavement design by the California Division of Highways, the samples being used to determine the stability of the soil and, also, the swell pressure exerted by the soil when it is confined in a mold and immersed in water; swell pressures are measured in the standard device shown in Figure 14.

The test procedure for each soil was essentially that used by California and may be outlined as follows:

Four or five samples at different water contents on the wet side of optimum were prepared in 4-inch-diameter metal molds by means of the Triaxial Institute Kneading Compactor, using 125 tamps and a tamping pressure of 350 psi. Each sample was then subjected to a static pressure applied at the rate of 600 lb. per min. until moisture was seen to be exuding from the base of the mold; at this stage the sample height was between $2\frac{1}{4}$ and $2\frac{1}{2}$ inches. After release of the pressure, the sample was allowed to stand for $\frac{1}{2}$ hour with the ends of the mold covered. A perforated metal disc with a vertical stem was then placed on top of the sample, and the mold was fitted in the swell pressure device. In this position the lower end of the sample rested on the adjustable base of the device, and the base was adjusted until the stem of the perforated plate on top of the sample was just tight against the proving bar. Water was then poured on top of the sample, and the subsequent deflection of the proving bar over a period of several days was measured by a dial gauge. The proving bars are relatively stiff, a pressure of 1 psi. exerted by the sample causing a deflection of only 0.003 inch; thus, only a slight expansion of the soil is permitted during the swell-pressure measurements. After the maximum swell pressure developed by each sample had been measured, the water was poured off the samples, the dimensions and weight of each sample were determined, and the stability was measured by a Hveem Stabilometer test. Finally the water contents of the samples were determined.

The entire process was repeated for samples at the same water contents, but compacted by static pressure, applied at the rate of 600 lb. per min., until moisture exuded from the base of the mold. The swell pressures and stabilities of these samples were determined as before.

The results of these tests on the silty clay are shown in Figure 15. It will be seen that for a density of about 107 lb. per cu. ft., which is the maximum density as determined by the standard AASHO compaction test for this soil, the resistance values and swell pressures of samples prepared by static and kneading compaction are about the same, but at higher densities samples prepared by static compaction have the higher resistance values and swell pressures. At a dry density of 117 lb. per cu. ft., which is the maximum density as determined by the modified AASHO compaction test for this soil, the resistance value of a sample prepared by static compaction is about 200 percent greater than that of a sample prepared by kneading compaction; and the swell pressure of a sample prepared by static compaction is about 800 percent greater than that of a sample prepared by kneading compaction.

The results of the tests on the sandy clay are shown in Figure 16. As for the silty clay, at equal densities, samples prepared by static compaction have higher resistance values and swell pressures than samples prepared by kneading compaction. For the sandy clay, the maximum density in the standard AASHO compaction test was 110 lb. per cu. ft., and the maximum density in the modified AASHO compaction test was 123 lb. per cu. ft. At a density of 110 lb. per cu. ft., the resistance value of a sample prepared by static compaction is about 30 percent greater than that of a sample prepared by kneading compaction, and the swell pressure is about 400 percent greater; at a density of 123 lb. per cu. ft., the resistance value of a sample prepared by static compaction is also about 30 percent greater than that of a sample prepared by kneading compaction, while the swell pressure is probably about 100 percent greater.

If, as the previous results would indicate, kneading compaction duplicates more closely the effects of field compaction equipment than static compaction, the erroneous values for desirable pavement thickness which would be obtained if designs were based on the results of tests on samples prepared by static compaction are immediately apparent.

PREPARATION OF SATURATED SAMPLES

In the tests described above it has been shown that the compaction of a soil to a saturated condition by the application of static pressure causes the stability and swell pressure of the soil to be higher than those for a similar sample prepared by kneading compaction and then saturated by the application of static pressure. If static pressure causes this difference in measured properties, the question is raised as to the extent to which it affects the properties of the samples prepared by kneading compaction. It would seem likely that the stabilities and swell pressures of samples prepared by kneading compaction and then saturated by the application of pressure until moisture is exuded would be somewhat higher than for samples of the same density, prepared by kneading compaction and then saturated without the application of static pressure.

However, the complete saturation of samples without the application of pressure is not an easy task. In one of the test series previously described an attempt was made to accomplish this by forcing water through the samples. Even after a number of weeks the samples were not completely saturated and the properties of the soil seemed to be affected in some way, possibly by electrochemical action resulting from the use of metal molds. This effect might have been eliminated by the use of plastic equipment, yet even if this were done, a waiting period of perhaps two months before a saturated sample could be obtained would be an undesirable situation for a testing laboratory processing a large number of samples.

Yet another method of saturation might be to soak a sample without necessarily preventing expansion. However, this process would also take considerable time and would probably lead to a nonuniform density and water content in the sample and to a higher degree of saturation at the ends than in the center section.

The preparation of completely saturated samples of clayey soils in the laboratory which will have the same properties as similar samples saturated in the field presents a number of problems, and it would seem that no simple method of accomplishing this has yet been developed. It may well be that the methods of saturation presently being used in various test procedures are entirely adequate for all practical purposes yet this cannot be ascertained until reliable test results for fully saturated soils can be obtained. It is regretted that no simple solution can be offered in this paper, but it is hoped that this brief discussion may stimulate further attention to this problem.

CONCLUSIONS

In methods of pavement design based on the results of tests performed on samples prepared in the laboratory, it is desirable that the test samples should have the same properties as those of the soil compacted in the field. The method of compacting a soil sample in the laboratory has a significant effect on the resulting properties of the soil. The main conclusions, with regard to the effect of compaction method on soil properties, resulting from the investigations described in this paper may be summarized as follows:

1. For the two soils investigated, a silty clay and a sandy clay, samples compacted to equal densities and water contents by kneading and impact methods do not show

any large difference in stability as measured by a Hveem Stabilometer test. At lower degrees of saturation, samples prepared by kneading compaction have higher stabilities and at higher degrees of saturation, samples prepared by impact compaction have higher stabilities.

2. At lower degrees of saturation, samples of the two soils investigated prepared by static compaction have somewhat higher stabilities, in stabilometer tests, than samples compacted by kneading and impact methods to the same densities and water contents; at higher degrees of saturation, samples prepared by static compaction have much-higher stabilities than similar samples prepared by impact and kneading compaction.

3. The moduli of deformation at 1 percent strain, as measured in triaxial-compression tests, for samples of a silty clay compacted in the field by sheepsfoot and rubber-tired rollers are in better agreement with those of samples at equal densities and water contents prepared in the laboratory by kneading compaction than with those of similar samples prepared by impact and static compaction.

4. Samples of the two soils investigated prepared by static compaction and saturated by soaking at constant density have considerably higher stabilities than samples of equal densities prepared by kneading and impact compaction and saturated by soaking at constant density.

5. For the two soils investigated, samples compacted by static pressure until moisture is exuded have much-higher stabilities and swell pressures, as measured by the test procedure of the California Division of Highways, than samples of the same density prepared by kneading compaction and then saturated by exudation.

References

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