ROADWAY AND RUNWAY SOIL MECHANICS DATA[1]

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SYNOPSIS

The data reported are a continuation of those reported at the 1941 meeting of the Highway Research Board in the discussion of soil water phenomena They concern principally the problem of permanency of clay soil densification, the relations of density from the dry to the saturated conditions, to total moisture fluctuation, total density change, total volumetric change, intermediate moisture change, intermediate volume change, and the relation of intermediate moisture contents to volumetric changes.

Although the investigations are not complete, the data are thought to be significant with relation to the process of controlling volumetric soil changes by means of densification

The behavior of structures composed of soil is governed by fundamental laws which, when determined, are just as definite as the laws governing the behavior of structures made of other materials, such as wood, glass or steel Large parts of most roadways and airport runways must be built of this universal material, and it is reasonable to presume that those parts have definite physical characteristics governed by definite laws and should be designed, constructed and maintained in accordance therewith.

It often has been said that if it were not for water coming in contact with clay soil the subject of soil mechanics would be very simple. The importance of internal as well as external drainage has been reiterated before

In considering soil as an engineering material, one of the great difficulties encountered is change in volume due to moisture fluctuation. Many pavement failures are caused by volumetric changes of underlying soil It is therefore evident that any process that has as its objective the control of volumetric changes is a most important factor Densification is now generally being adopted as one means of controlling volume changes. An important current problem relative to compaction is whether or not the densities compacted into highly expansive clay-soil substructures during construction remain constant thereafter, and if not, what are the subsequent effects on the overlying pavements During the past four years the Research Division of the Texas Highway Department has made extensive laboratory investigations in an effort to obtain definite information as to what actually happens to compacted clay soils of different types under different conditions of consolidation.

A brief preliminary report of these experiments was made at the 1941 meeting of the Highway Research Board, and during 1942 the laboratory experiments have been continued The test specimens experimented with were compacted to different degrees of density ranging from 90 to 130 lb per cu. ft. dry weight.

Although these investigations have not yet been completed, it appears that definite reports can now be made on the following phases of this research work

Permanency of clay soil densification

From the dry to the saturated condition, the relation of:

- Density to *total* moisture content fluctuation
- Density to *total* density change
- Density to *total* volumetric change

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[1] Detailed data and comments on this research work are available in Texas Engineering Experiment Station Series 67 to 70, inclusive, A and M. College, College Station, Texas

- Density to *intermediate* moisture contents
- Density to *intermediate* volumetric change
- Intermediate moisture contents to volumetric changes

Other less obvious phenomena

The data that follow are a continuation of those shown on Pages 466 to 470 of *Proceedings,* Highway Research Board, Vol 21, and although the experiments have not yet been completed, the additional data compiled to date are graphically presented at this time for whatever they may be worth to the engineering profession in roadway and runway design, construction and maintenance It appears, however, that certain definite statements now can be made; and while presenting the data, attention will be invited from time to time to some of the more obvious phenomena.

During 1942, the experimental work was continued with six sets of test specimens made of three different samples of clay soil designated as SI, SII, and SIII, with plastic indexes of 22, 26, and 57, respectively The six sets were designated as 6-SI, 7-SI, 8-SI, 1-SII, 2-SII, and 1-SIII, and each set consisted of from three to five groups designated A, B, C, D, and E, depending on the number of groups in a set. Each group consisted of three or four test specimens numbered in the order 1, 2, 3, 4 While molding the test specimens, all in a group were treated in the same way, as nearly as practicable, so that all three or four specimens would be near the same density when dried to constant weight at 100 deg F It also was desired that the test specimens in the different groups be of dry densities, as follows. "A" 90 to 95; "B" 100 to 105; "C" 110 to 115; and "E" 120 to 130 lb. per cu. ft.[2] After a set was molded wet, and dried to constant weight at 100 deg. F, all the test specimens were placed together and treated as nearly as practicable in the same manner

After the specimens of a set were molded (wet) and dried the first time, they then were carried through several cycles of wetting and drying sufficiently slowly that the structure of the specimen would not be ruptured. Figure 1 shows the 1-SIII set when dried to constant weight at 100 deg. F immediately after being molded wet. For brevity, a picture of the specimens when saturated with water is not shown here because very little difference from Figure 1 could be detected, except that the saturated specimens were somewhat larger and were darker in color. Figure 2 gives an idea of the time allowed for the specimens to dry slowly—approximately 90 days in that instance[3]

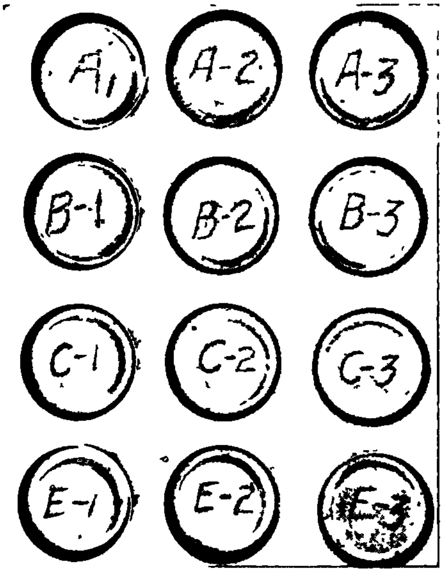

Figure 1. Showing the 1-SIII Test Specimens When Dry the First Time After Being Molded Wet.

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[2] The densities of the Group "C" specimens turned out to be so nearly the same as the densities of Group "D" that in some instances the "D" specimens were neglected

[3] Perhaps these specimens could have been dried more rapidly without cracking them, especially between moisture contents of approximately 12 and 5 per cents.

Because of the similarity of the graphs plotted to date and for brevity, the graphical data of only one specimen of each group of one set are shown

PERMANENCY OF CLAY SOIL DENSIFICATION

(a) The permanency of the original density of the clay soil depended largely upon the moisture content of the soil structure at the time additional water came in contact with it, and (under certain conditions) the rapidity with which additional water came in contact with the soil structure When the soil specimen had slowly absorbed a certain amount of moisture by capillarity, it then could be submerged in water without disintegration.

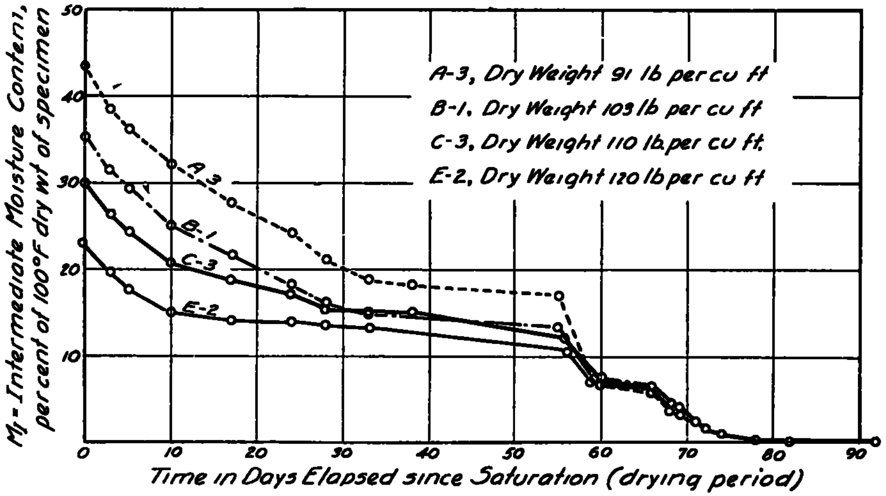

Figure 2. Drying Time, Set 8-SI, Lineal Shrinkage 15.7, Plasticity Index 22.5

(b) When the clay soil specimen was compacted to a certain density, and then carried through several cycles of wetting to saturation and drying to constant weight at 100 deg F, slowly enough that the texture of the soil mass was not ruptured, every test specimen returned practically to its first dry density and to its first wet density in every cycle, regardless of the original density to which the specimen was compacted See Figure 3

RELATIONS, FROM DRY TO SATURATED CONDITIONS

In the graphs comparisons will be made using the density of the soil when the test specimen was dry at 100 deg F, and also using the density of the expanded soil in the specimen when the test specimen was saturated. In Figure 3 attention also is invited to the density fluctuation from the dry to the saturated condition of the test specimen The 91-lb per cu ft. Group "A" specimen fluctuated 17 lb while the 105-lb. Group "D" specimen fluctuated 22 lb. per cu ft This phenomenon will be referred to later in Figure 6

Relation of Density to Total Moisture Content Fluctuation

(a) The moisture content of each specimen, when saturated with water, was practically the same in each cycle, regardless of the density to which the soil specimen was originally compacted See Figure 4.

(b) The percentage of water absorbed by the soil specimen when saturated in each cycle varied inversely with the dry

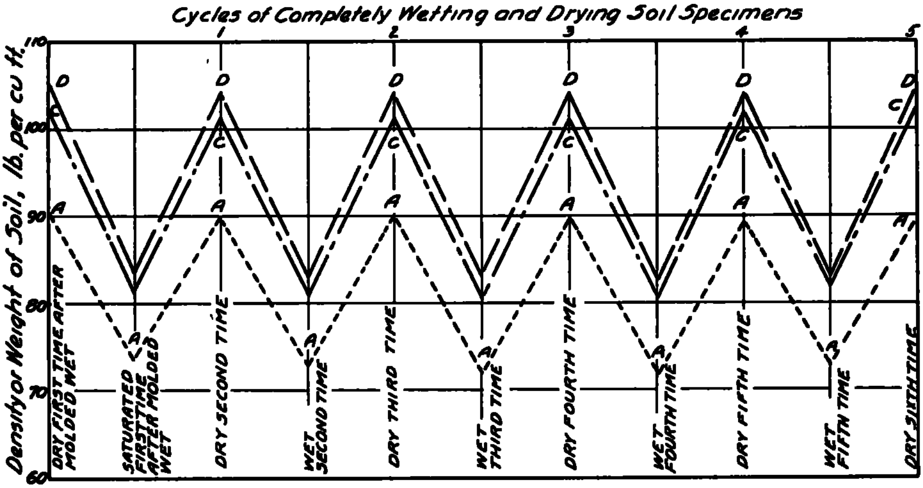

Figure 3. Effect of Wetting and Drying on Density, Set 6-SI, Group Averages

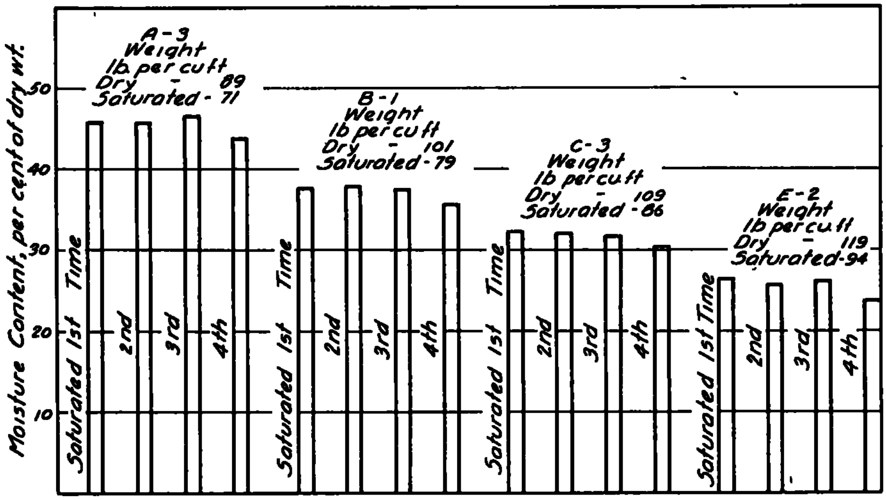

Figure 4. Relation of Wetting and Drying to Moisture Content When Saturated. Plasticity Index 22.5, Set 8-SI, Lineal Shrinkage 15.7

density of the soil specimen. See Figure 5[4]

Relation of Density to Total Density Change

In general, although the densest specimens of each set had absorbed the smallest percentages of moisture when they all reached saturation (and vice versa), the total fluctuations in densities of the test specimens, between their dry and their saturated conditions, were greatest in the densest, and smallest in the least dense specimens. See Figure 6.

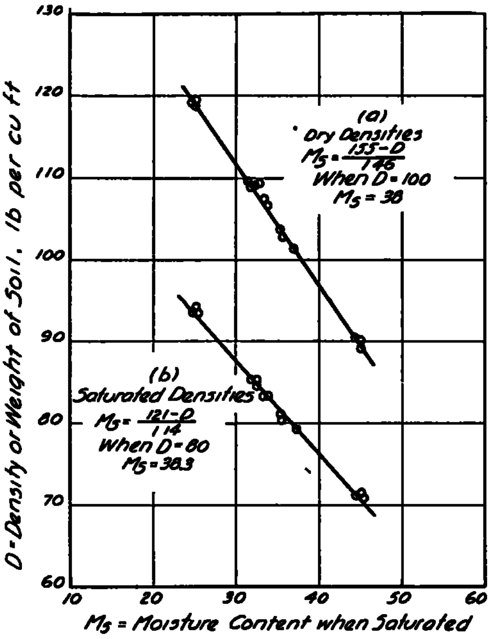

Figure 5. Relation of Density to Moisture Content When Saturated. Set 8-SI

Relation of Density to Total Volumetric Change

In Figure 6 the densest specimen, expressed in pounds per cubic foot, indicated the greatest total density change, and, in general, the plotted data for each set of specimens formed a straight line That phenomenon might be construed to mean that the greatest total volumertic change occurred in the densest test specimens of a set The graphs of Figure 7, however, which show the relation of the density (expressed in pounds per cubic foot) to the total volumetric change (expressed as a percentage of the dry volume), do not substantiate that conclusion. As a whole, the total volumetric change shown in Figure 7 does not bear the same simple relationship to the degree of

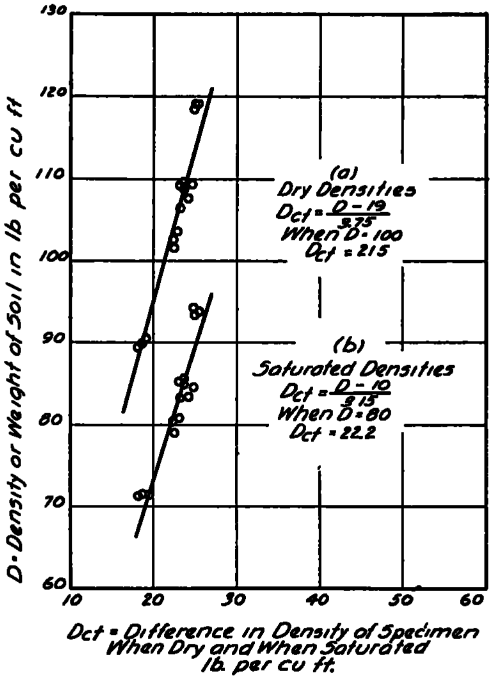

Figure 6. Relation of Density to Total Density Change from Dry to Saturated Condition. Set 8-SI.

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[4] The graphs shown in Figures 5, 6, and 7 were drawn to fit the plotted points as nearly as practicable with the eye, and the equations of the graphs shown in these three figures were computed from those approximate lines to gain a *general idea* only of the relation between the dry density and saturated density conditions

density of the test specimen shown in Figure 6 There is a much greater dispersion of the plotted points in Figure 7, and the general tendency of the median is curvilinear The graphs of the data compiled to date have not formed a sufficiently constant pattern to substantiate definite statements regarding the relation of the density to the volumetric change of the test specimen More research on this subject should be performed

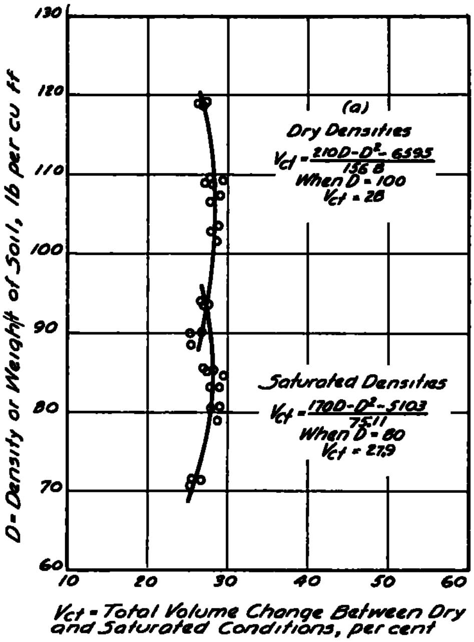

Figure 7. Relation of Density to Volumetric Change from Dry to Saturated Condition. Set 8-SI.

Graphs pertaining to the relation of volumetric change (expressed as a percentage of the dry volume of the specimen) to the moisture content (expressed as a percentage of the dry weight of the soil specimen) from the dry to the saturated condition of the specimens are shown in Figures 8 through 11, and when studied in detail may assist in solving this problem.

Relation of Density to Intermediate Moisture Contents

Each set of test specimens, in one cycle of wetting and drying, were weighed and their volumes determined from time to time during the slow evaporation of the moisture contents from saturation to constant weight at 100 deg. F as illustrated in Figure 2 A comparison of the intermediate densities with the corresponding moisture contents are shown graphically in Figure 8.

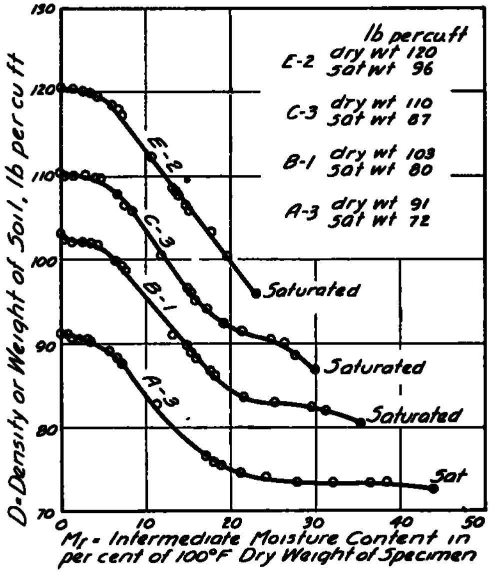

Figure 8. Relation of Density to Intermediate Moisture Contents. Set 8-SI

In Figure 8 it is noted that between the approximately 6 and 20 per cent moisture contents, the graphs of the different density specimens generally are parallel to one another, but not so for moisture contents above 20 per cent

It is noted that the rate of loss of moisture as compared with the change in density was not uniform throughout the entire drying period

Relation of Density to Intermediate Volumetric Changes

The weight and volume determinations made from time to time during the drying of the test specimens, as previously described, also were used for computing the corresponding volumetric changes, expressed as percentages of the 100 deg F oven-dry volumes of the specimens

Comparisons of the intermediate densities with the corresponding volumetric changes of these differently compacted 8-SI clay soil specimens are shown graphically in Figure 9

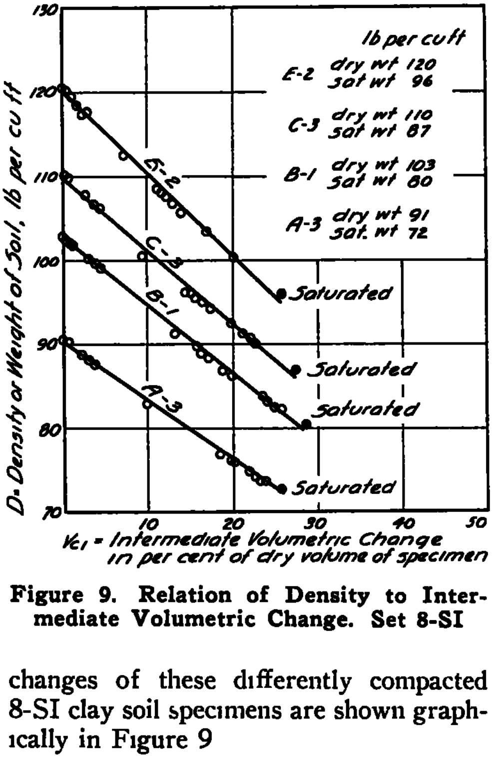

Figure 9. Relation of Density to Intermediate Volumetric Change. Set 8-SI

Relation of the Intermediate Moisture Contents to Volumetric Changes

These data indicate that·

1. There was a critical moisture content (ranging from approximately 20 per cent in the SI soil to 25 per cent in the SIII soil), above which the behaviors of the different density specimens of a soil were very different, but at that critical point the graphs of a soil set (drying from saturation) converge From the point of convergence down to oven-dryness at 100 deg F the graphs of a set of specimens were very close together This indicated that between the "point of convergence" and the dry condition of the soil, the behaviors of the different density specimens were practically the same, regardless of the density to which the clay soil was consolidated
2. Between the saturated condition and the point of convergence, the least dense "A" specimen in each set lost very little of its volume while it was losing a large percentage of its moisture On the other hand, the dense "E" specimen in each set immediately began losing its volume at practically the same rate it lost moisture and continued to do so at the same rate all the way down to approximately 6 per cent moisture content for the SI soil, 5 per cent for the SII, and 3 per cent for the SIII soil
3. All the specimens in each of the three sets continued to lose volume with loss of their moisture content until they very closely approached their zero moisture contents at 100 deg F , but below approximately 6, 5, and 3 per cent moisture contents for the respective soil specimens, the ratio of moisture change to volumetric change grew larger as the specimens approached their zero moisture contents.
4. The ill effects of non-uniformity in roadway construction has been

emphasized heretofore.[5] It is difficult, if not impossible, to make every item absolutely uniform in a roadway, and one of these difficulties is in consolidating all soil to the same degree of density It therefore becomes necessary to do all that is practicable to overcome non-uniformities in construction If it is found that the degree of densification of clay soil materially affects its amount of volumetric change with subsequent moisture content fluctuations, it appears that where practicable, the roadway and the runway should be so designed that the moisture content of the soil under the pavement will never become greater than that of the point of convergence, as discussed in paragraphs 1 and 2 and shown in Figure 10.

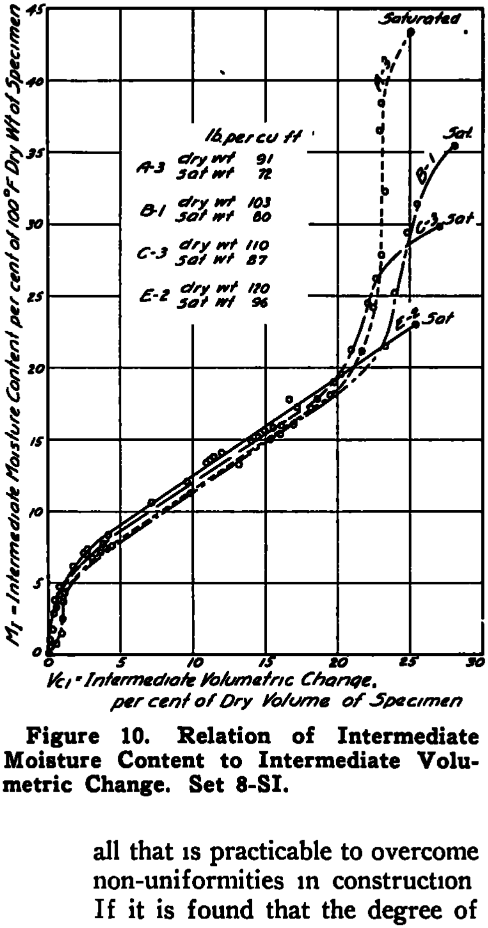

Figure 10. Relation of Intermediate Moisture Content to Intermediate Volumetric Change. Set 8-SI.

OTHER PHENOMENA

When closely studied, these data reveal other less obvious phenomena, illustrated in Figure 11, where the densities of the entire specimens, composed of soil, water, and perhaps air, etc , are compared with the corresponding intermediate moisture contents. Hereafter this density will be referred to as the "gross density," "D_g." (Heretofore, the density of the soil alone in the specimen has been considered and has been referred to as "D.") The gross density D_g is obtained by dividing the weight of the specimen (soil plus water, etc.) in grams by its volume in cubic centimeters and multiplying by 62.4.

Figure 11 shows the relation between the gross density and the corresponding moisture content, M_I, where M_I is the weight of the water expressed as a percentage of the dry weight of the soil in the specimen. These curves appear alike in some respects and different in others. Where

D_g = Gross density of specimen in lb. per cu. ft.,

D = Dry density of specimen in lb. per cu ft.,

M_{cx} = Moisture change expressed as a decimal fraction of the dry weight of the specimen, and

V_{cx} = Volumetric change as a decimal fraction of the dry volume of the specimen, then

$$D_g = D\left[\frac{1+M_{cx}}{1+V_{cx}}\right]$$

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[5] See *Proceedings*, Highway Research Board, Vol 18, Part II, pages 339-355 (1938), and also *Proceedings*, American Society of Civil Engineers, February 1940, Axioms 8, 9, and 10, pages 199-201

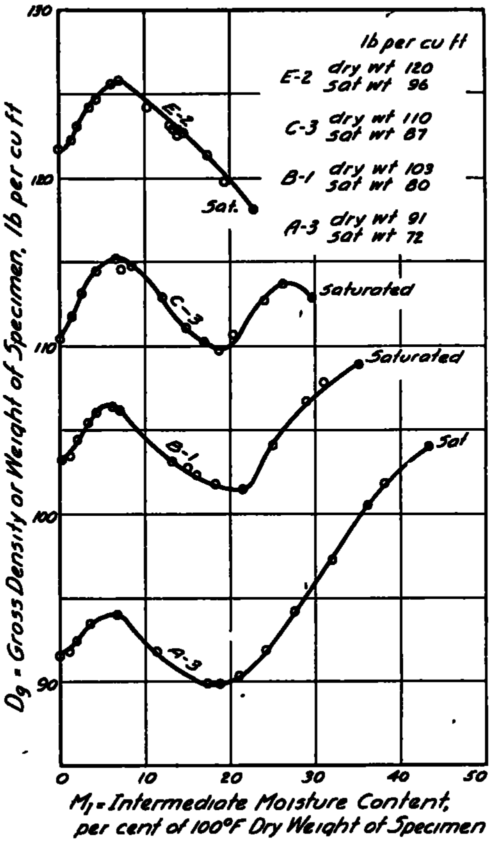

Figure 11. Relation of Gross Density to Intermediate Moisture Content. Set 8-SI

D, the density or weight in pounds per cubic foot of the specimen when it is dry at 100 deg. F, is constant; hence, when M_{cx} in the numerator of the fraction in the foregoing equation changes more rapidly than V_{cx} in the denominator, D_g increases; and vice versa. Figure 11 shows that as the Group "A" specimen gradually dried from its saturated 43 per cent moisture content to its approximately 20 per cent moisture content, D_g gradually decreased; between the approximately 20 and 6 per cent moisture contents, D_g increased in value, and then decreased between the 6 per cent moisture and the dry condition of the specimen This indicates, therefore, that when the Group "A" specimen dried from its saturated to its 20 per cent moisture content condition the ratio between $(1+M_{cx})$ and $(1+V_{cx})$ decreased; the ratio increased between the 20 and the 6 per cent moisture content conditions; and decreased between the 6 and the 0 per cent moisture contents. On the other hand the Group "E" specimen graph indicates that between the saturated (23 per cent) and approximately 6 per cent moisture content conditions the ratio of $(1+M_{cx})$ to $(1+V_{cx})$ increased continuously.