INFLUENCE OF INITIAL MOISTURE AND DENSITY ON THE VOLUME CHANGE AND STRENGTH CHARACTERISTICS OF TWO TYPICAL ILLINOIS SOILS

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SYNOPSIS

This paper describes the test procedure and data obtained in a laboratory examination of the volume and moisture changes which occur in soils subjected to a ready supply of water and a prolonged period of drying. Tests were conducted at varying densities and moisture contents. Shear strengths are given for saturated moisture conditions at variable densities.

The report should be useful to engineers in the consideration of specifications limiting moisture and density for embankment compaction since it shows how final volume change and bearing capacity of embankment soils are affected by moisture and density at the time of construction.

For a given compacted density the volume change of soil on subsequent wetting is shown to vary inversely with its initial moisture content (on drying it varies directly). The bearing capacity varies directly with compacted density for a given initial moisture content.

This study was made to determine the variation in the expansion, shrinkage, and resistance to shear of two Lawrence County soils compacted to various densities and at different moisture contents. It was undertaken because several of the soils being used in the construction of some of the highway embankments on Federal Aid Route 13, in Lawrence County showed moisture contents exceeding 110 percent of their optimum moisture content.

Originally, the specifications permitted the use of soils in embankment construction whose moisture content did not exceed 120 percent of their optimum moisture content, but more recently the upper limit was reduced to 110 percent on the assumption that this limit would insure higher fill densities, less volume change, and higher bearing values.

On this particular project, densities were obtained which exceeded the 90 percent of maximum Proctor wet weight per cu ft requirement of the specifications even though the embankment materials, in some cases, reached a moisture content of approximately 150 percent of their optimum moisture content.

SOILS USED IN THE INVESTIGATION

Two soils obtained on the Lawrence County project were used in this investigation. Sample No. 45-3673 was typical of the soil taken from the cuts at Sta 131 and 140 and used in the construction of the embankments between Sta 75 and 125, and between Sta 145 and 155. This soil was an A-4-2 brown clay loam with an optimum moisture content of 13.8 percent and a maximum wet weight of 135.2 lb per cu ft. Sample No. 45-3674 was typical of the soil taken from the cut at Sta 181 and placed in the embankment between Sta 185 and 189. It was also typical of the soils encountered in the majority of the shallow cuts on this project. It classified as an A-4 brown silty clay with an optimum moisture content of 21.2 percent and a maximum wet weight of 124.4 lb per cu ft.

Additional physical characteristics of these two soils are given in Table 1.

TEST SPECIMENS

The test specimens used for the combined expansion and shrinkage tests, the shrinkage determinations, and the resistance to shear were made from that portion of each of the two soils which passed a No. 4 sieve. Portions of oven-dry soil sufficient to produce compacted specimens of the desired density were wetted to the required moisture content and seasoned for 24 hours under controlled humidity. The moisture content at the time the test specimens were prepared was in all cases within 0.5 percent of the desired moisture.

The test specimens used in the expansion and shrinkage determinations were soil cylinders $3\frac{5}{16}$ in. in diameter and $2\frac{1}{2}$ in. in height. The apparatus used in the preparation of these cylinders consisted of hollow metal cylinders, $3\frac{5}{16}$-in. inside diameter, with removable base plates and a tight fitting piston $2\frac{1}{2}$ in. in height. The compaction force was exerted by an Olsen testing machine of 100,000-lb capacity. An adjustable stem, a tripod, and an Ames dial graduated to 0.0001 in. were used to determine the height of the compacted specimen. The test specimens were prepared in quadruplicate by compacting the required quantity of wetted soil in the metal cylinders by static pressure to 85, 90, 95, and 100 percent of the maximum Proctor wet weight at moisture contents of 80, 90, 100, 110, 120, 135, and 150 percent of wet optimum moisture. The static pressure applied in compacting the specimens was variable but of an intensity to produce a final rebound of $2\frac{1}{2}$ in., the last $\frac{1}{4}$ in. of compaction being made at the rate of 0.05 in. per min. The compacted height of the cylinders was determined by the tripod assembly, a previous zero reading having been taken on the stem, plate, and compaction piston in contact with the base plate. One-half of these test cylinders were allocated for combined expansion and shrinkage tests; the remaining counterpart consisting of 112 cylinders was allotted for shrinkage determinations.

TABLE 1
PHYSICAL CHARACTERISTICS OF TEST SAMPLES

Item	Sample Number	
	45-3673	45-3674
Percent passing 1-in. sieve	100.0	
" " $\frac{3}{4}$- " " . .	99.8	
" " $\frac{1}{2}$- " "	99.6	
" " $\frac{3}{8}$- " " .	99.1	
" " No. 4 sieve . .	98.2	
" " No. 10 " ...	96.9	
" " No. 20 " ..	95.0	
" " No 40 " .	89.1	100.0
" " No. 100 " .	62.9	99.2
" " No 200 " .	55.8	99.0
Percent sand..	45	3
" silt . .	28	52
" clay	27	45
" colloids	15	26
Specific gravity	2.61	2.53
Liquid limit .	27.4	40.3
Plastic limit	12.0	17.5
Plastic index.	15.4	22.8
Field moisture.... .	15.0	22.5
Shrinkage limit	13.6	23.4
Shrinkage ratio	1.9	1.6
Volume change	3.4	

The test specimens for the shear test were $3\frac{1}{2}$ in. square and $\frac{3}{4}$ in. in height. The required quantity of wetted soil was compacted in the shear box by static compression to the desired density. Duplicate specimens were prepared at the saturated densities and moistures obtained from the expansion test data for the cylinders molded at 85, 90, 95, and 100 percent of maximum Proctor wet weight and at moisture contents of 80, 100, 120, 150 percent of the wet optimum moisture. Saturated moisture as used in this report is defined as the moisture content, expressed as a percent of the oven-dry weight of soil, which a test specimen had attained at the conclusion of the expansion test. Saturated density is the wet weight per unit volume of the test specimen at the end of the expansion test.

TEST PROCEDURES

All tests were made in duplicate as follows:

Combined Expansion and Shrinkage Tests—The test specimens used for the combined expansion and shrinkage tests were immersed in water while still in the metal cylinders in which they were molded. However, perforated plates were placed over the bottoms of the cylinders before they were placed in the water. These plates permitted the entrance of the water into the base of the specimens and the water level in the tank was such as to produce a 1-in. head on the top surface of the test cylinders.

The water soaking process was continued until the expansion during an 8-hr. period was less than 0.5 percent of the original compacted height of the soil cylinder. The amount of expansion was measured to 0.0001 in. with the equipment previously mentioned The specimens were weighed both prior and subsequent to immersion to determine the amount of water taken up by the soil during the soaking period.

Upon completion of the expansion tests, the cylindrical soil specimens were removed from the metal cylinders, slowly dried under controlled humidity, room-dried for a period of 48 hr, and oven-dried to constant weight at 105 C. The specimens were then coated with paraffin, their oven-dry volume determined by means of the Eureka specific gravity determinator, their shrinkage calculated, and their moisture loss determined.

Shrinkage Tests—The soil specimens used exclusively for the shrinkage tests were removed from the metal cylinders in which they were molded and then dried and tested as in the case of the previous tests.

Shear Tests—A translatory or simple direct shear apparatus with a sample container consisting of two separate parts, called the upper and lower frame, was used for these tests. In this apparatus, the shearing load causes a unilateral movement of the upper frame while the lower frame is held in a fixed position. The rate of movement or strain was approximately 0.05 in. per min and the resistance to shear was measured by means of an Ames dial in contact with a calibrated spring.

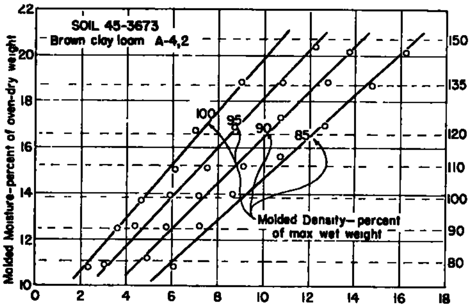

Figure 1. Volume Decrease From Molded to Oven-Dry Volume

TEST DATA

The test data are shown in graph form in Figures 1 to 18, inclusive. The odd numbered figures represent the data for Sample No. 45-3673, while the even numbered figures were produced from the data for Sample No. 45-3674.

While no definite conclusions can be drawn from these data, because the tests were made entirely under controlled laboratory conditions and only two soils were used during the investigation, the data are of particular interest since they provide indications as to what may be expected in the case of other soils.

Shrinkage Data—The shrinkage, or volume decrease (from the molded to the oven-dry condition), of the test specimens, which were not subjected to the water-soaking procedure, is shown in Figures 1 to 4, inclusive. These shrinkages are plotted against the respective percents of molded moisture in Figures 1 and 2, and against the respective molded wet weights in Figures 3 and 4.

The data in Figures 1 and 2 show that the volume of each of these soils decreases for each particular compacted density in direct proportion to the increase in the moisture content of the test specimens at the time of their compaction. Shrinkages also increase with increased compaction moisture, and decrease in density.

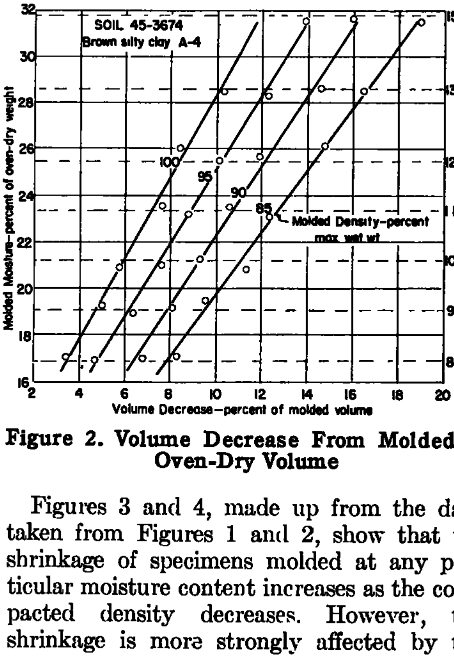

Figure 2. Volume Decrease From Molded to Oven-Dry Volume

Figures 3 and 4, made up from the data taken from Figures 1 and 2, show that the shrinkage of specimens molded at any particular moisture content increases as the compacted density decreases. However, the shrinkage is more strongly affected by the density of the test specimens molded at the highest constant moisture, or the shrinkage increases with increased compaction moisture and decrease in compaction density.

Figures 5 to 8, inclusive, show the volume decrease, or shrinkage, for the test cylinders first subjected to expansion by water-soaking and then to slow shrinkage to oven-dry volume. The total volume change, from the saturated to the oven-dry condition, is expressed as percent of the original molded volume. These shrinkages are plotted against the respective percents of molded moisture in Figures 5 and 6, and against the respective molded wet weights in Figures 7 and 8.

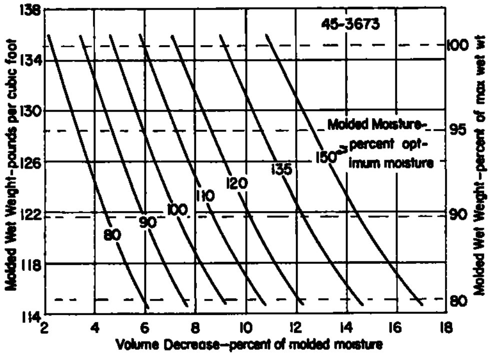

Figure 3. Volume Decrease From Molded to Oven-Dry Volume

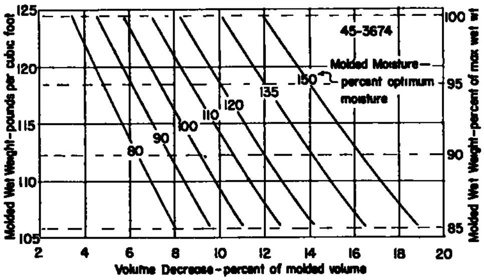

Figure 4. Volume Decrease From Molded to Oven-Dry Volume

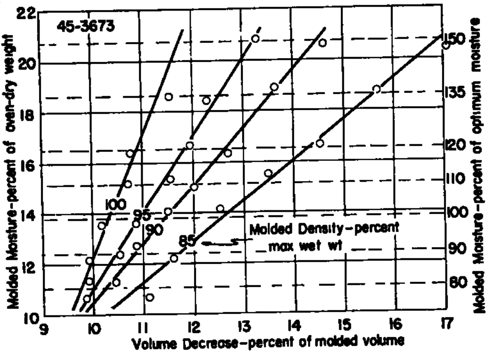

Figure 5. Volume Decrease From Saturated to Oven-Dry Volume

The data in Figures 5 and 6 indicate that for a constant molded density, the decrease in volume becomes greater when the molded moisture is increased, and that the molded moisture most strongly affects the volume decrease in the case of the specimens compacted to the lowest constant density.

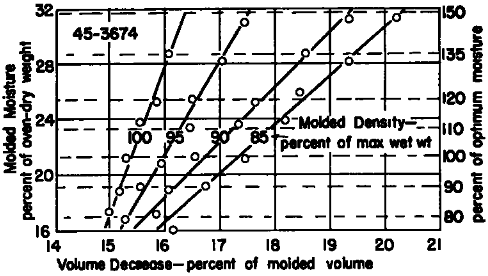

Figure 6. Volume Decrease From Saturated to Oven-Dry Volume

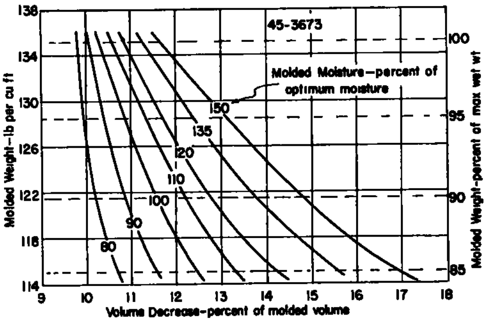

Figure 7. Volume Decrease From Saturated to Oven-Dry Volume

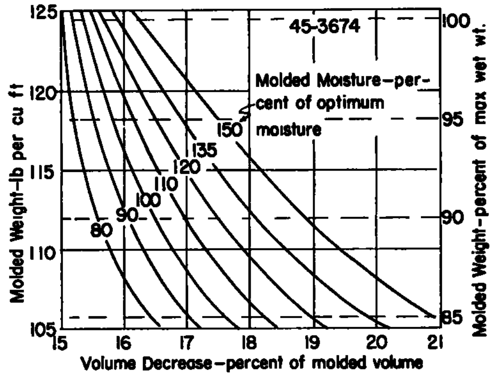

Figure 8. Volume Decrease From Saturated to Oven-Dry Volume

Figures 7 and 8, made up from data taken from Figures 5 and 6, show that for a constant molded moisture, the decrease in volume is greater with a decrease in compacted wet density, and that the change in volume is more pronounced in the case of the specimens molded at the highest constant moisture.

Expansion Data—The volume increases or expansions, which resulted when the test specimens were brought from their molded to saturated condition by water-soaking, are shown in Figures 9 to 12, inclusive. These expansions are plotted against the respective percents of molded moisture in Figures 9 and 10, and against the respective molded wet weights in Figures 11 and 12.

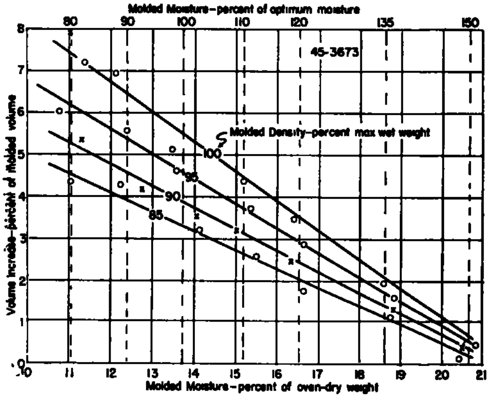

Figure 9. Volume Increase From Molded to Saturated Volume

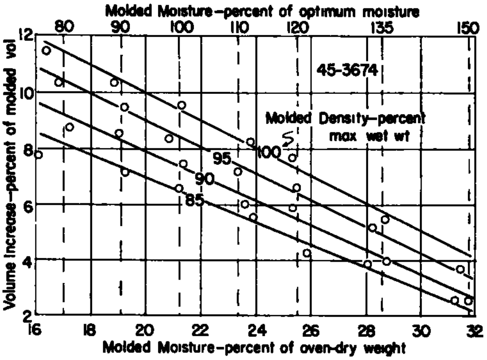

Figure 10. Volume Increase From Molded to Saturated Volume

The data in Figures 9 and 10 show that the volume increase for a constant molded density varies inversely with the molded moisture, and that the degree of volume increase is greatest in the case of specimens molded at the highest wet density.

Figures 11 and 12, prepared from the data taken from Figures 9 and 10, reveal that for a constant molded moisture, the volume increase varies directly with the molded wet density, and that the amount of volume increase is greatest in the case of the specimens compacted at the lowest constant moisture.

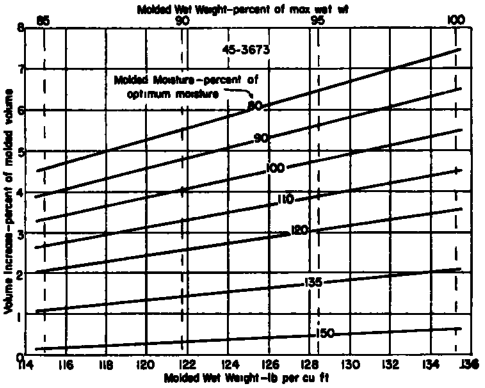

Figure 11. Volume Increase From Molded to Saturated Volume

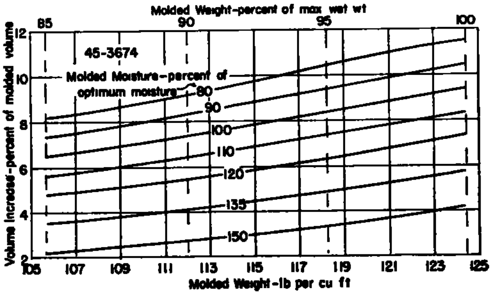

Figure 12. Volume Increase From Molded to Saturated Volume

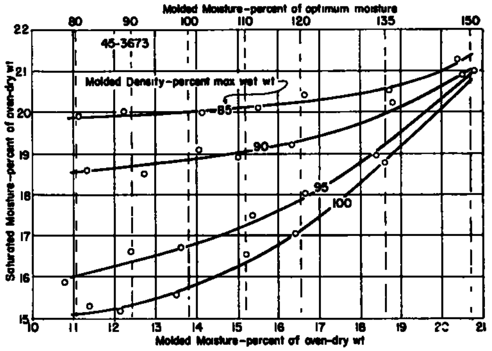

Figure 13. Saturated Moisture Content

Saturated Moisture Data—The moisture content of the saturated specimens is expressed as percent of their oven-dry weight in Figures 13 to 16, inclusive. These saturated moisture contents are plotted against the molded moistures in Figures 13 and 14, and against the respective molded wet weights in Figures 15 and 16.

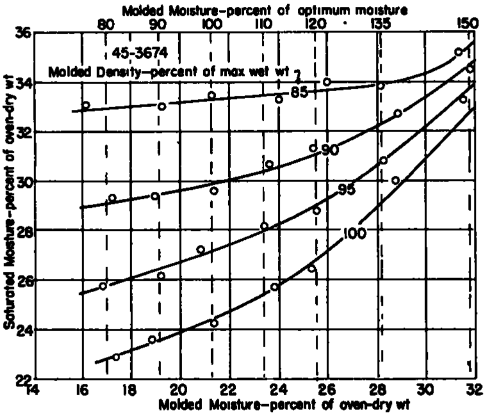

Figure 14. Saturated Moisture Content

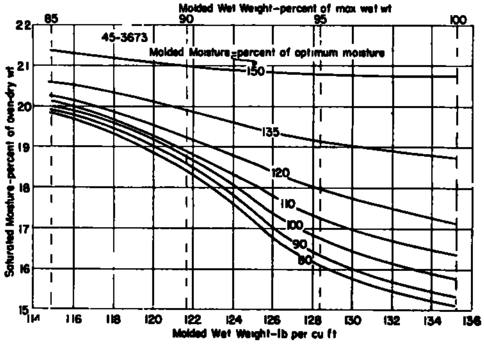

Figure 15. Saturated Moisture Content

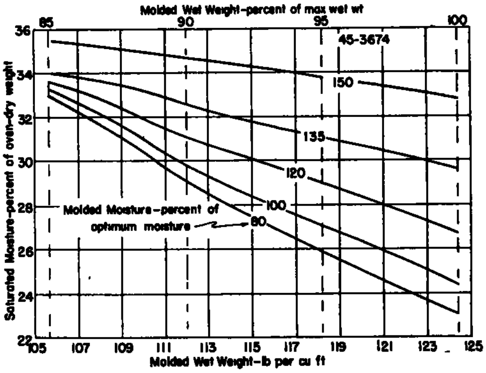

Figure 16. Saturated Moisture Content

The data in Figures 13 and 14 show that for a constant wet density, the saturated moisture varies directly with the molded moisture, and that the molded moisture most radically affects the saturated moisture in the specimens molded at the highest constant density.

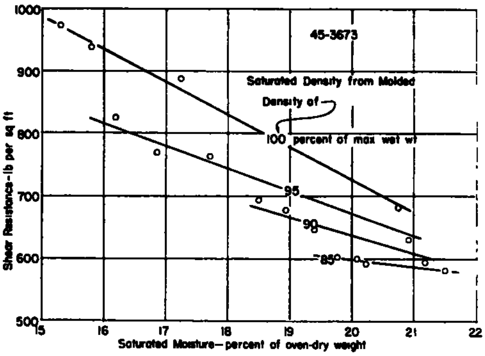

Figure 17. Shear Resistance at Saturated Moisture and Density

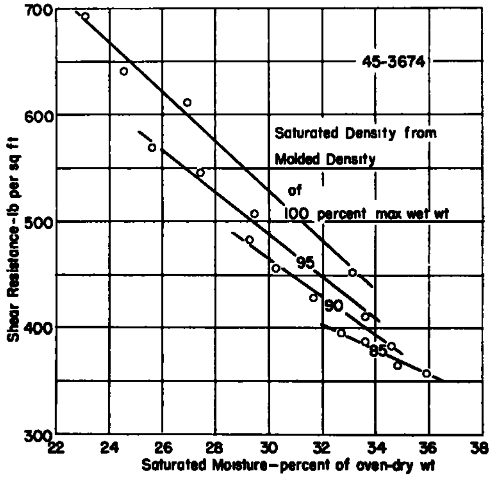

Figure 18. Shear Resistance at Saturated Moisture and Density

Figures 15 and 16, made up from the data given in Figures 13 and 14, indicate that for a constant molded moisture, the saturated moisture varies inversely with the wet molded density, and that the compacted moisture drastically affects the saturated moisture in the specimens molded at the lowest constant moisture.

Shear Data—The resistance to shear of the specimens, molded to constant densities at varying identical moisture contents is shown in Figures 17 and 18. These data show that the shear resistance varies inversely with the saturated moisture, and that the effect of varying saturated moistures is most obvious in the case of the specimens molded at the highest saturated density. A corollary to this interpretation of the shear data is that for a constant molded density the shear resistance varies inversely with the molded moisture, and that the effect of varying molded moistures is most pronounced in the case of test specimens compacted to the highest molded density. Furthermore, the shear resistance of specimens molded at constant moisture varies directly with the molded density, and the effect of molded density is most evident in the case of the specimens prepared at the lowest molded moisture.

GENERAL DISCUSSION OF DATA

As might be expected from a review of the test data given in Table 1, Sample No. 45-3673 was the most resistant to expansion, shrinkage and shear. The test data also checked the supposition that the total volume change, for the two soils, from their saturated to oven-dry condition, would be approximately equal to the sum of the volume increase from a molded to a saturated condition and the volume decrease from a molded to an oven-dry condition, providing their molded density and moisture were the same in both tests. The total volume change assumptions are based on Figures 5 to 8 and the sum of the volume changes in Figures 1 to 4 and 9 to 12.

The test results indicate that minimum total volume change, from a saturated to a dry condition or vice versa, and maximum bearing capacity may be anticipated when compaction is so produced as to provide the highest possible density at the lowest moisture content. Conversely, the maximum total volume change and the minimum bearing capacity may be expected when the compaction effort is such as to produce a low density at a high moisture content.

The trend of the data obtained in the various tests was the same in the case of the two soils tested.

The data contained in this report should be found quite useful to engineers interested in the present moisture and density limits specified for embankment compaction, since they show how the volume change and bearing capacity of embankments are affected by fill moistures and densities.

SUMMARIZATION OF CONCLUSIONS

The major conclusions which may be obtained or inferred from the test data are as follows:

1. Both the bearing capacity and total volume change of an embankment are functions of the moisture content and density of the embankment material at the time of compaction.
2. For a given compacted density, the volume decrease of embankment material, on drying, varies directly with its moisture content at the time of compaction.
3. For a given compacted density, the volume increase of embankment material, upon the addition of moisture, varies inversely with its moisture content at the time of compaction.
4. For a given moisture content at time of compaction, the volume decrease of embankment material, on drying, varies inversely with its compacted density.
5. For a given moisture content at time of compaction, the volume increase of embankment material, upon the addition of moisture, varies directly with its compacted density.
6. For a given compacted density, the bearing capacity of an embankment varies inversely with the moisture content of the embankment material at time of compaction.
7. For a given moisture content at time of compaction, the bearing capacity of an embankment varies directly with the compacted density of the embankment material.