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embankments with and without moisture density control

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16. Abstract

In 1965 the AASHTO Blue Book entitled Guidelines for Geometric Design made provision for the compaction of embankments without moisture and density control in Articles 203.60 and 203.11. Construction without moisture and density control is allowed under Item 203.12 of the Colorado Highway Division Standard Specifications.

This particular Colorado study was initiated to gather and analyze facts on the performance of embankments constructed without moisture and/or density control, and to draw specific conclusions which might assist designers of future roadway embankments. An Interim Report entitled EMBANKMENT CONSTRUCTION WITHOUT MOISTURE DENSITY CONTROL, INTERIM REPORT, JUNE 1967 was written to describe the initial work and possible construction savings by eliminating moisture and density requirements, or eliminating only density requirements. A second report, EQUILIBRIUM MOISTURE AND DENSITY CONDITIONS IN COLORADO SUBGRADE SOILS, SECOND INTERIM REPORT, APRIL 1968, gave an analysis of moisture and density correlations for embankments in Colorado and throughout the world. This final report is an attempt to analyze all of the data gathered so far and present significant conclusions which can be used by roadway designers and constructors.

It appears that moisture control, at least, is essential. Both moisture and density control are worth the extra cost in the top 4 feet of swelling soils having plastic indices of 20 or more.

17. Key Words Moisture, compaction, roadway, stability, embankment, equilibrium moisture, bearing strength, and earthwork.		18. Distribution Statement	
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IMPLEMENTATION

This research project was initiated to serve the very practical need for guidance to Design Units on the use of specifications allowing compaction of subgrades without moisture density control. As the project developed and facts were established, they were put into practice immediately. The interim and final reports show examples of special provisions and specifications.

The first two interim reports, EMBANKMENT CONSTRUCTION WITHOUT MOISTURE-DENSITY CONTROL, June 1967, and EQUILIBRIUM MOISTURE AND DENSITY CONDITIONS IN COLORADO SUBGRADE SOILS, April 1968, contained information which was put into use at that time. The same information and various modifications of the original specifications have been used since 1968 in the design of roadways - particularly in areas of swelling soils. Considerable improvement in the performance of roadways in these areas has been observed, leading to the conclusion that some assistance may have been provided to Colorado Highway Design and Construction Engineers.

The examples of specifications and the reports on performance of the various experiments may also aid highway engineers in other States who have similar problems and a desire to save the cost of complete moisture-density control where this is an especially expensive item.

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EMBANKMENTS WITH AND WITHOUT MOISTURE DENSITY CONTROL

INTRODUCTION

Articles 203.10 and 203.11 in the Blue Book entitled GUIDELINES FOR GEOMETRIC DESIGN AASHTO, make provisions for compaction of embankments not constructed with moisture and density control. This study was initiated to determine whether there would actually be a savings by deleting moist density control, or whether poor performance and extra maintenance would overshadow this initial savings in construction.

Seventeen projects have been evaluated periodically by using nuclear and conventional test methods. These projects included ones having full moisture and density control, moisture control only, and moisture density control only in the top four feet of the embankment.

Item 203.10 on page 91 of the Standard Specifications for the Division of Highways, State of Colorado, shown on the following page, specifies that the type of composition required for each project will be as called for on the plans for the project.

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shall be finished, where practicable, so that no water will collect or stand therein. When necessary to remove fencing, the fencing shall be replaced in as good condition as it was originally. The Contractor shall be responsible for the confinement of livestock when a portion of the fence is removed.

203.10 Embankment Construction.

Embankment construction shall consist of constructing roadway embankments, including preparation of the areas upon which they are to be placed; the construction of dikes within or outside the right-of-way; the placing and compacting of approved material within roadway areas where unsuitable material has been removed; and the placing and compacting of embankment material in holes, pits and other depressions within the roadway area. Only approved materials shall be used in the construction of embankments and backfills.

The type of relative compaction required shall be as called for on the plans or as designated.

When the source of embankment material is not designated on the plans, approval of the source will be contingent on the material having a resistance value of at least 25 when tested by the Hveem Stabilometer, and a maximum dry density of not less than 90 pounds per cubic foot.

Rocks, broken concrete, or other solid materials more than 6″ in greatest dimension shall not be placed in embankment areas where piling is to be placed or driven.

When embankment is to be placed and compacted on hillsides, or when new embankment is to be compacted against existing embankments, or when embankment is build ½ width at a time, the slopes that are steeper than 4:1 when measured at right angles to the roadway shall be continuously benched

Item 203.12 on page 96 of the Standard Specifications, shown on the following page, provides for construction without moisture and density control.

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203.12 Compaction of Embankments Not Constructed with Moisture and Density Control.

Except for rock embankments and the first layer of fills over swampy ground, embankment materials shall be deposited in layers not exceeding 8 inches in thickness before compaction.

Compaction shall be obtained by routing construction equipment, compactors, or both, uniformly over the entire surface of each layer before the next layer is placed.

Dumping and rolling areas shall be kept separate, and no lift shall be covered by another until compaction complying with the above requirements is obtained.

203.13 Proof Rolling.

Proof rolling with a heavy rubber tired roller will be required as designated on plans or when ordered. Proof rolling shall be done after specified compaction has been obtained. Areas found to be weak and those areas which failed shall be ripped, scarified, wetted if necessary and recompacted to the requirements for density and moisture at the Contractor's expense.

The heavy rubber tired proof roller shall have a minimum capacity of 50 tons. The operating weight of the roller shall be not less than 12½ tons per wheel. The roller shall be equipped with pneumatic tires of equal size and type spaced evenly across the entire width of the roller. Tires shall be inflated to a minimum pressure of 70 pounds per square inch and a maximum pressure of 90 pounds per square inch. Air pressure in the tires shall be maintained within a tolerance of 5 pounds per square inch. The axle arrangement on the roller shall be such that oscillation of each individual tire or oscillation of

Typical revision of Item 203.12 by Special Provision has been as shown below:

May 29, 1973

REVISION OF SECTION 203

COMPACTION OF EMBANKMENTS

In subsection 203.11 of the Standard Specifications delete the sixth paragraph and replace with the following:

Density requirements will not apply to portion of embankments, bases of cuts and bases of embankments constructed of materials which, as determined by the Engineer, cannot be tested in accordance with any of the above procedures for determining maximum dry density. Compaction for all materials which cannot be tested by any of the above procedures, shall be in accordance with subsection 203.12

Subsection 203.12 is hereby deleted and shall be replaced with the following:

203.12 Compaction of Embankments Constructed without Moisture and Density Control.

Earth embankment materials shall be deposited in layers not exceeding 8 inches in thickness before compaction. Rock embankment shall be placed in accordance with the requirements of subsection 203.10. Rock embankments permitted to be placed in layers, cast, or end-dumped shall be spread in layers.

Each layer of rock embankment material shall be compacted by heavy vibratory compactors or other approved compactors. Compactors shall be routed uniformly over the entire surface of each layer. At least one compactor shall be in simultaneous operation with each separate embankment placement operation.

Each layer of earth embankment material shall be compacted by routing construction equipment, compactors, or both, uniformly over the entire surface of each layer before the next layer is placed. Specific types of compactors will be furnished and used when shown in the project provisions.

Rock embankment is defined as materials with 50% or more by weight, at field moisture content, of particles larger than a No. 4 sieve.

A lift shall not be covered by another lift until compaction complying with the above requirements is obtained.

The report, EMBANKMENT CONSTRUCTION WITHOUT MOISTURE-DENSITY CONTROL, INTERIM REPORT, issued by the Colorado Division of Highways in June 1967[1], described the initial work and possible construction savings by eliminating moisture and density requirements or only density requirements. Another report, EQUILIBRIUM MOISTURE AND DENSITY CONDITIONS IN COLORADO SUBGRADE SOILS, SECOND INTERIM REPORT, April 1968[2], gave an analysis of moisture and density correlations and a tendency of moisture to approach equilibrium. That report emphasized the importance of factors such as plasticity index, drainage, type of clay, etc.

This Final Report is an attempt to analyze all the data available and give some conclusions and recommendations.

DATA PRESENTATION

Figure 1 shows some of the sites which were studied to obtain field data.

Table 1 is a list of sites divided into four categories. The construction date and type of soil are also given.

Table 2 is a detailed listing of the performance of swelling and nonswelling soils according to whether or not they had moisture-density control during construction. GOOD performance is indicated by a PSI above 3.2 after 10 years service. A FAIR rating indicates a PSI between 3.2 and 2.5, and a POOR rating is indicated by a PSI below 2.5.

DATA ANALYSIS

Most attempts to analyze density have led to no significant conclusions. This may be due to the heterogeneous character of soils in different embankments and within any one embankment itself.

Moisture variations are also difficult to analyze but some results have been obtained. The report, EQUILIBRIUM MOISTURE AND DENSITY CONDITIONS IN COLORADO SUBGRADE SOILS, SECOND INTERIM REPORT, April 1968[2], showed success in correlating moisture with Plasticity Index and other factors.

ATTEMPTS TO RELATE MOISTURE WITH DEPTH

Since soil types and plasticity indices vary from one location to another and vary in different lifts or layers in the same embankment, a composite of moisture data must be correlated using some common factor. Figure 2 shows a composite of sites with moisture and density control in the top four feet of embankments only. It shows "Relative Moisture"

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FIGURE 1

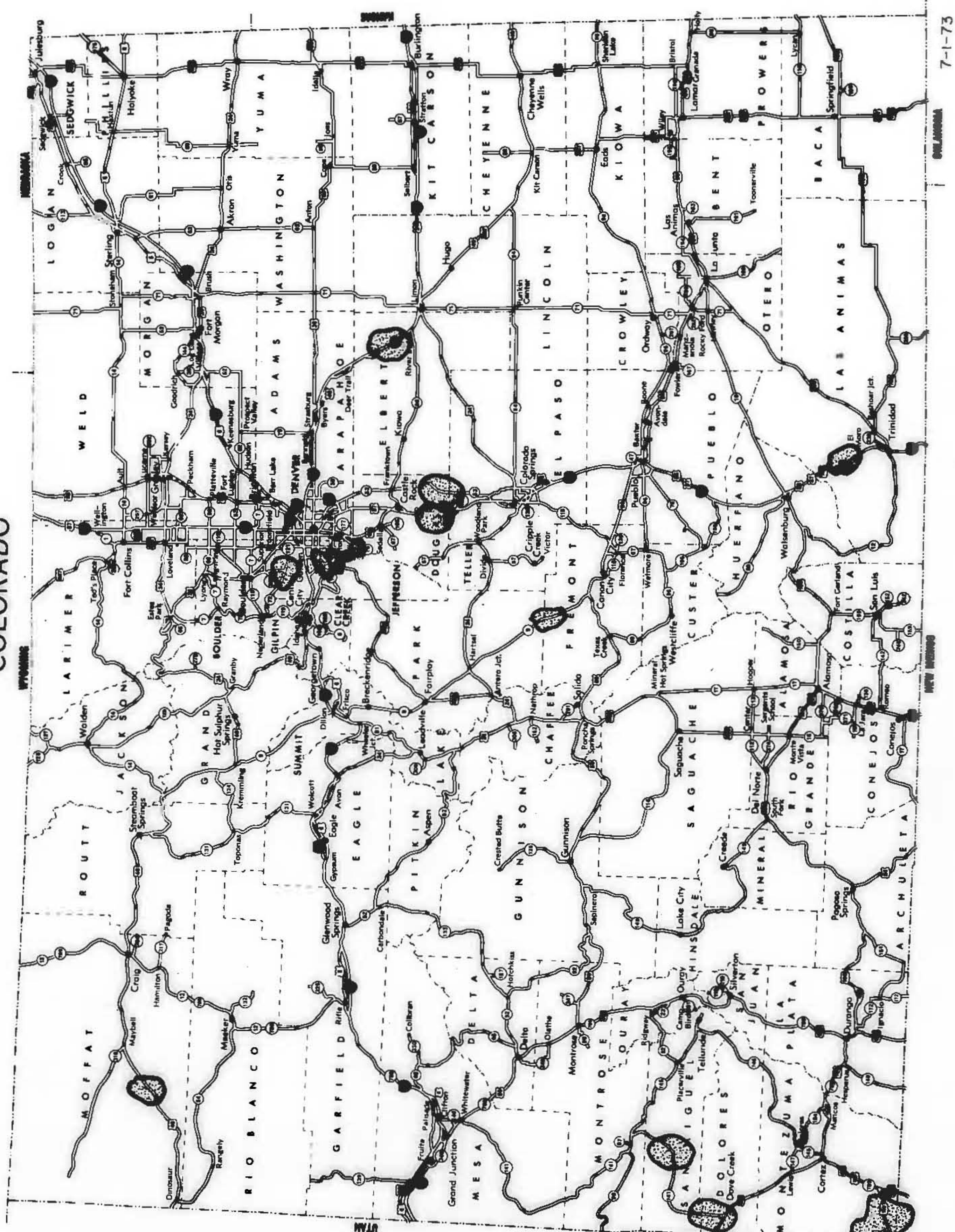

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Table 1

LIST OF TEST SITES

Group	No.	Location	Const. Date	Soil Class Range	Performance	1974 P.S.I.
No Moist. or Dens. Control	1.	El Paso Co. Line N.-SH 83 (S 0170(10))	1968	A-1-b(0) A-2-4(0)	Fair	3.0
	2.	Turkey Creek Canyon-E (F 016-1(38))	1969	A-1	Good	3.5
	3.	Larkspur-Palmer Lake (FAP 275G)	1927	A-2-4(0) A-2-6(1)	Poor but Old	2.2
	4.	Four Corners-SH 160 (S 0158(1))	1960	A-6(11) A-7-6(20+)	Poor	2.0
	5.	Four Corners-SH 41 (FLH 10(1))	1964	A-2-4(0) A-7-6(20+)	Poor	2.8
	6.	Guffy-South - SH 9 (C 14-0009-07)	1970	A-1-b(0) A-4(0)	Good(New) (Shallow Embankments)	3.7
Moist. Control No. Dens.	7.	Hogback - I 70 (I 70-3(45))	1969	A-2-4(0) A-7-6(10)	Fair	3.1
	8.	Boulder Co. Line-SH 128 (S 0022(2))	1967	A-1-b(0) A-7-6(9) A-7-6(18)	Fair	3.2
Full Control in Top 4' only	9.	Elk Springs-East SH 40 (F 005-1(10))	1967	A-2-4(0) A-3(0)	Poor	2.0
	10.	Ludlow-South I 25 (I 25-1(37))	1968	A-6(10) A-7-6(18)	Good	3.6
	11.	Waterton (CC 10-0075-06)	1970	A-7-6(20)	Fair	
Full Moist. Dens. Control	12.	Slick Rock (S 0137(12))	1964	A-4(3) A-6(7) A-7-6(20)	Fair	3.2
	13.	Dove Creek-North (S 0137(1))	1960	A-7-6(14) A-7-6(18)	Fair	3.1
	14.	Deer Trail (I 70-4(39))	1965	A-2-4(0) A-7-6(18)	Fair	3.2
	15.	El Paso Co. Line-S (S 0170(10))	1965	A-2-4(0) A-4(3)	Fair	3.3
	16.	Boulder Co. Line-E (S 0022(2))	1966	A-1-b(0) A-7-6(18)	Poor	2.6
	17.	N. of Ludlow-I 25 (I 25-1(58))	1969	A-6(10) A-7-6(18)	Good	3.2
	18.	Soda Lakes-East (F 016-1(40))	1964	A-1-b(0) A-7-6(15)	Good	3.2

Table 2

GROUP	BEHAVIOR
NO MOIS-DENS CONTROL	
Plasticity Index 20 El Paso, Turkey Creek, Larkspur, Four Corners, Guffey	Compacted at about 115 pcf and 4-8% moist. Went 108-112 pcf and 4-13% moist. Cut sections show minor distress. Fill sections fairly good but some irregular settlement. Opt was 129 pcf and 9%.
Plasticity Index 20 El Paso, and Four Corners	Compacted at about 105 pcf and 6% moist. Opt nearer 20%. Cut sections show bad distress. Full sections show some distress and bad undulations due to uneven swell and settlement. Heterogenous moist and density now. Went to 102 pcf and 4% to 20% moist.
MOIST CONTROL-NO DENS CONTROL	
Plasticity Index 20 Hogback and Boulder County	Completed at about 120-127 pcf and 7-10%. Went to 115-122 pcf and 17%. No cut sections to observe. Fill sections at Boulder showed very little distress. Hogback finally showed settlement in 1974 resulting in some cracking of the surface and bad undulation appearance. Opt 125 and 9%.
Plasticity Index 20 Boulder and Hogback	Compacted at about 91-108 pcf and 16% moist. West to 95 pcf and 18%. No cut sections. Fill sections at Boulder showed very little distress. Hogback took 4 years to show distress but finally showed undulations and surface cracking. Opt 103 to 107 and 18-22%. Fairly homogeneous.
MOIST-DENS CONTROL TOP 4' ONLY	
Plasticity Index 20 Elk Springs	Density data lacking. Moist went to about 11% and sections looked good until 1973-1974. Some surface distress under heavy oil rig loadings.
Plasticity Index 20 Waterton, Elk Springs and Ludlow-S	Compacted at about 110 pcf and 14% moist. Stay at about 110 pcf and 20%. Fairly uniform moist and density throughout. Surface distress very minor except at Elk Springs under heavy oil rig traffic lately.
MOIST-DENS CONTROL THROUGHOUT	
Plasticity Index 20 El Paso County Line, Boulder County Line, Soda Lakes and Slick Rock	Compacted at about 123-127 pcf and 15%. Went to 125-128 pcf and 14%. Little or no distress in 1974.
Plasticity Index 20 Slick Rock, Dove Creek, Deer Trail, Boulder County	Compacted at 95-105 pcf and 17-20%. Went to 95-104 pcf and 16-20%. Gradual deterioration in the form of shallow undulations, but very serviceable in 1974.

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versus depth. The difference between optimum and actual moisture is used in this graph in place of actual percent of moisture. Figure 2 indicates some change with both time and depth. Most points are below optimum in a rather narrow band, and may indicate a tendency for equilibrium condition.

Embankments which were constructed with moisture and density control in total or in the top four feet are still stable and have required very little maintenance. At times of the year these are quite dry, while in the spring they are at or above optimum. It appears, therefore, that there is a large seasonal fluctuation of moisture content, at least in the top few feet of any embankment. However, the density (dry weight calculation) fluctuates very little, therefore, the surface courses are stable and in good condition. The material at depth has gained some moisture and has more or less reached an equilibrium. Small changes may continue to occur, but at 5 or 10 feet below the surface, their influence on the surfacing is negligible. The riding qualities of these embankments are quite good. Little or no subsidence or swelling has occurred.

Figure 3 is a composite of sites which were constructed with full moisture and density control. As in Figure 2 relative moisture is plotted against depth. These embankments have maintained a rather constant moisture content very near optimum. A considerable amount of fluctuation has occurred in the top few feet.

Projects which were constructed with moisture but no density control have kept their moisture content at or near optimum. Generally, embankments are stable and in better condition than adjacent projects. Maintenance has been low and the riding quality is considered adequate. Figure 4 shows a composite of these sites.

Densities at or near 95% of the AASHTO T-99 method are usually obtained by construction equipment when moisture is controlled even though density is not required on the plans.

The projects constructed without moisture or density control appear to have widely scattered moisture conditions which fluctuate considerably. Extensive settlement at some locations and swelling at others has required a great deal of maintenance. Also, the poor quality riding surface will probably necessitate reconstruction. Moisture data and field observations indicate a great and damaging seasonal fluctuation in the top four feet

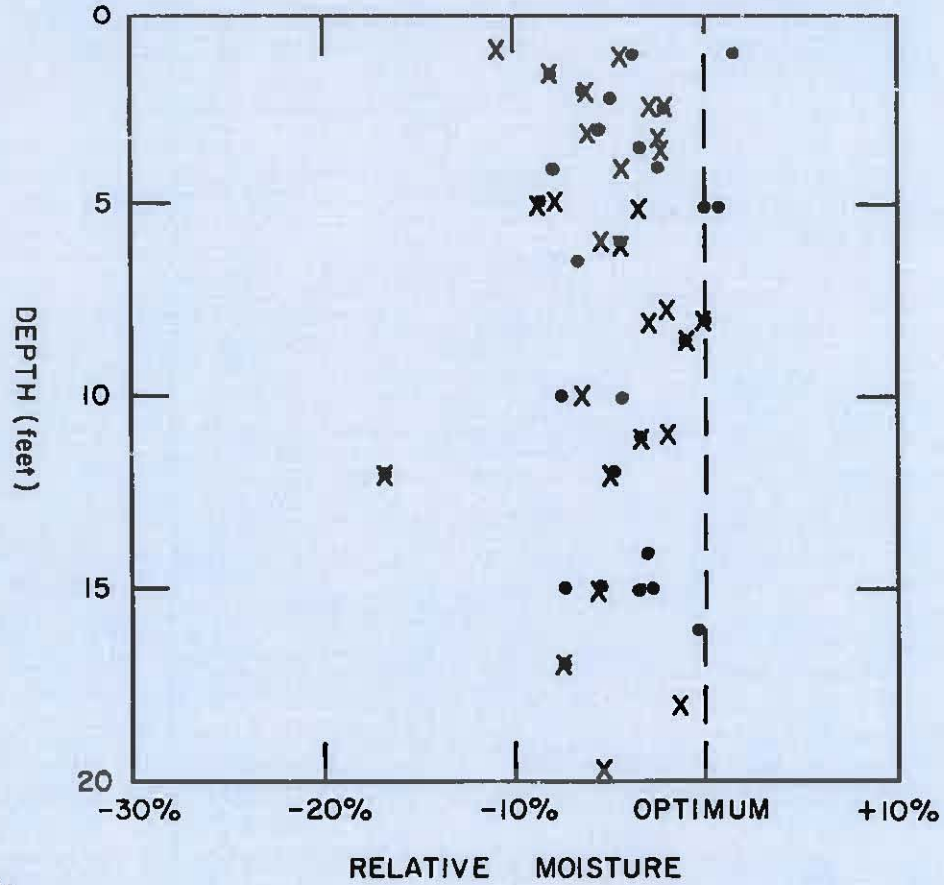

FIGURE 2

COMPOSITE OF SITES WITH MOISTURE AND DENSITY CONTROL IN THE TOP 4 FEET

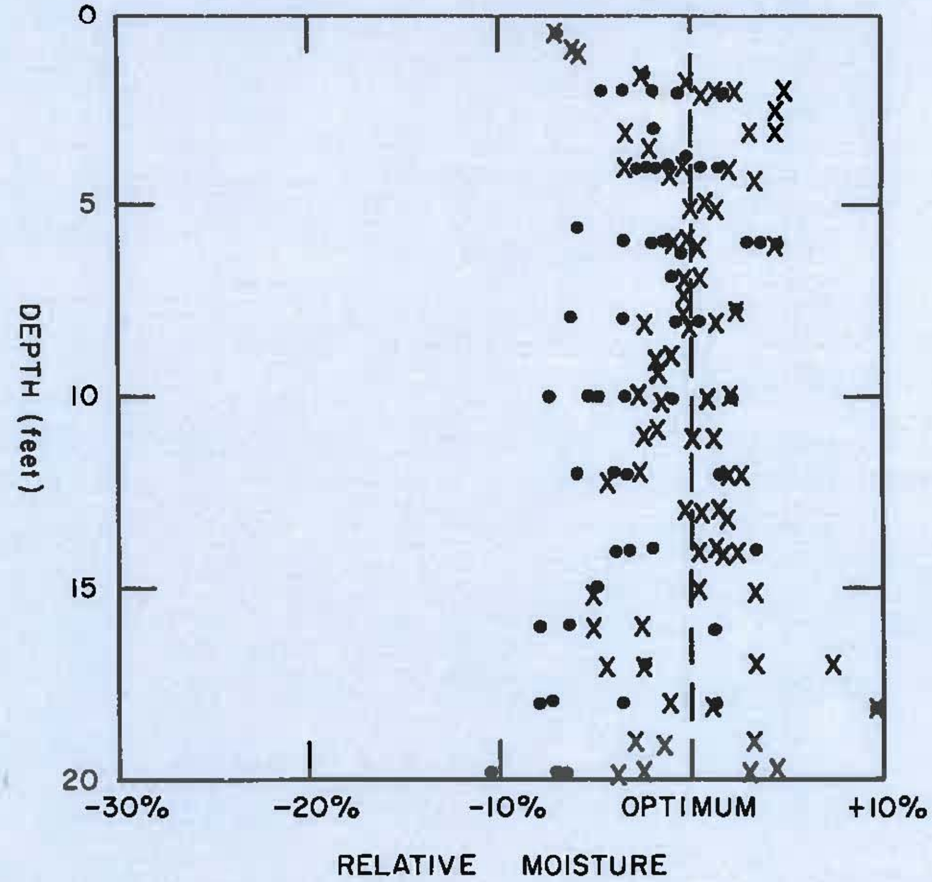

FIGURE 3

COMPOSITE OF SITES WITH FULL MOISTURE AND DENSITY CONTROL

● tests within the first two years after construction

X tests two to five years after construction

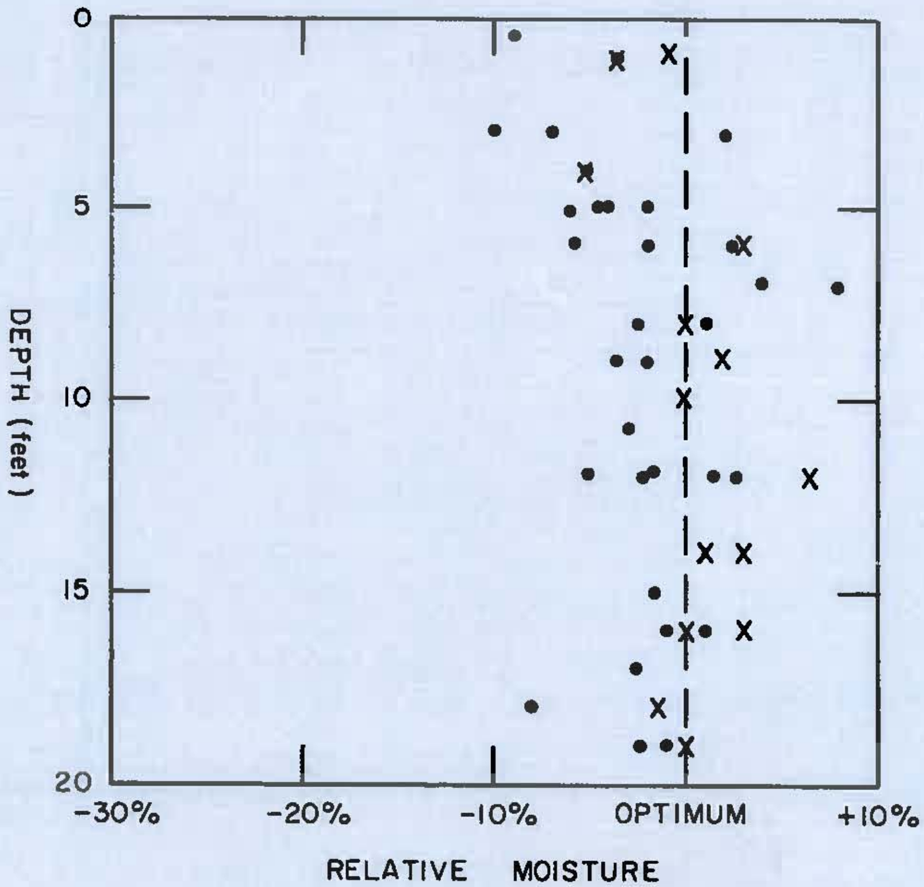

FIGURE 4

COMPOSITE OF SITES WITH MOISTURE BUT NO DENSITY CONTROL

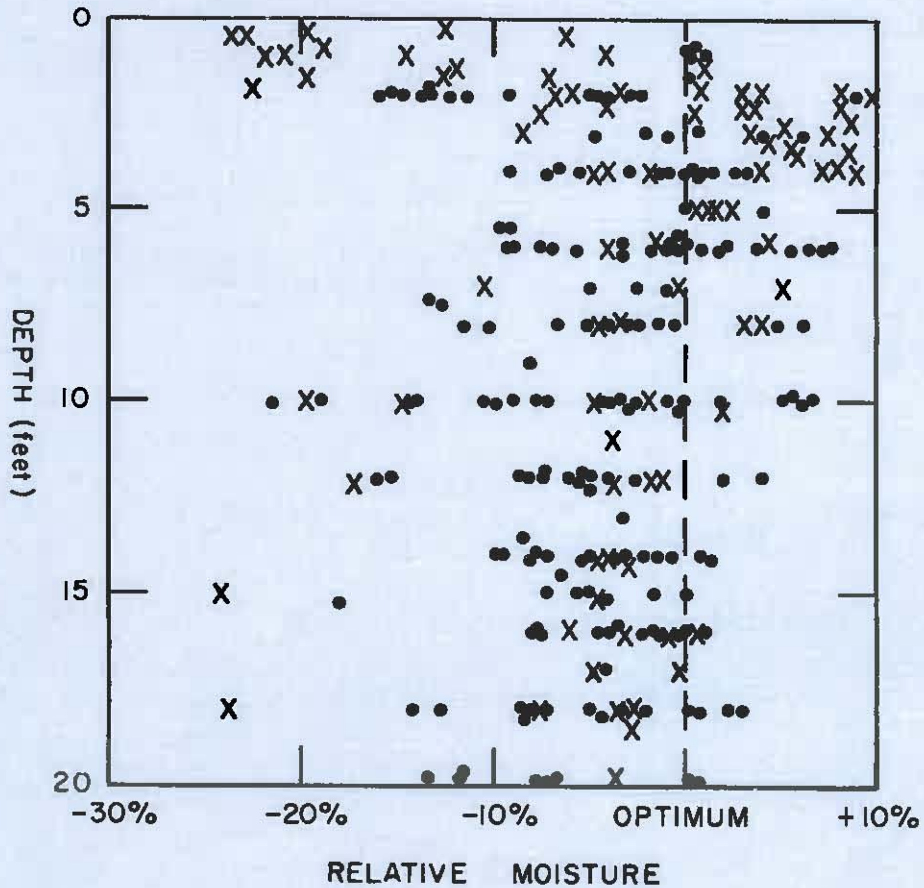

FIGURE 5

COMPOSITE OF SITES WITHOUT MOISTURE OR DENSITY CONTROL

● tests within the first two years after construction

X tests two to five years after construction of these embankments. Figure 5 is a composite of sites with no moisture or density control.

Generally, it can be said that granular materials show an increase in density with time, and there is a need to provide good initial compaction on them.[6] With clayey materials where there is generally a decrease in density with time, the decrease is not a sudden one, or is it large. The Boulder County Line project shows the largest change in density with a 16% decrease at a 6 foot depth over a time period of 4.5 years. The two stations at the El Paso County Line show the least change in density with time. There is an indication that the density on all projects decreases with an increase in depth. At levels deeper than 12 feet, the density of the material decreases less rapidly.

The moisture at Station 1050+00 in the El Paso project has increased with time while the moisture at Station 992+00 has remained at about the same level as the original moisture level. This increase in moisture content at Station 1050+00 is not accompanied with a progressive decrease in density although overall the density has decreased. The moisture content in the Boulder County Line project has increased from the original moisture level but there is not a progressing increase in moisture content with time. The moisture reached its peak values during the middle time period of the project and has decreased during the final time period of the project. In other words, after the fill was finished the moisture content increased rapidly and now the moisture is decreasing and the fill material is becoming dryer. However, the density time graph shows progressively decreasing density values indicating that the change in density is not caused by changes in the moisture content of the fill material.

At Station 695+25 in the Turkey Creek project, there is an evident decrease in material density with time while the moisture content also decreased with time. However, the optimum moisture content for this material is greater than the recorded moisture values therefore the decrease in moisture may be causing the decrease in density. At Station 616+50 the moisture is definitely increasing with time but there is not enough data to correlate it to density changes.

CONCLUSIONS

Soon after construction or following long periods of drought, subgrade moisture contents increase toward an "equilibrium" value near the soil's plastic limit. Seasonal precipitation causes cyclic/seasonal moisture variations.

The problem is not so much the amount of water in the subgrade, but fluctuations of the amount of water. This is evidenced by the number of cases where pavements on continuously saturated subgrades have yielded good performance and long life, while pavements in desert or arid climates have suffered a great deal of distress. The rainfall in these regions is negligible but sporadic and heavy at times.

The time lag between rainfall and subgrade moisture increase is generally six to eight weeks.

Moisture conditions under the shoulders vary at a faster rate than those under the center of the roadway providing the surface is relatively free of cracks and distress.

Most moisture fluctuations in Colorado subgrades are seasonal or precipitation dependent or both. Precipitation dependent moisture fluctuations are more obvious at sites where there is poor drainage or a cracked or otherwise highly permeable surface. Higher rates of evaporation and evapotranspiration appear to be responsible for drying conditions in the top few feet of most subgrades.

Drainage and soil type are of major importance to consider in attempts to minimize moisture fluctuations and possible failure.

Projects which were constructed with full moisture and density control have maintained a more constant moisture content near optimum. Embankments are generally in good condition.

Embankments which were constructed with Moist Dens Control in the top 4 feet are as good or better than adjacent full control projects. These embankments should be observed in the future.

The material below 4 feet has generally gained some moisture. This is not detrimental since compaction is still sufficient and minor effects at these depths are not reflected at the surface. Embankments constructed with moisture but no density control have kept their moisture content at or near optimum. These embankments are stable and in good condition. When comparing the above projects with others constructed about the same time which had standard moist-density embankment control, there is not enough difference to be measured.

Projects constructed without moisture or density control using clay soils (swelling soils) have widely scattered moisture and density conditions. Considerable distress in the pavement structure is noted.

Moisture fluctuations in the top portions of subgrades are considered to be of prime concern to the eventual success or failure of the roadway structure. Soil types, drainage and surface permeability are the main factors which control moisture fluctuations.

The study definitely confirmed the findings of Phil Fordyee who published this list of requirements for subgrades and subases in the American Concrete Paving Association Newsletter:

1. Excavate clay cuts as soon as possible.
2. Utilize selective grading and cross hauling to get the most unstable, expansive soils in the bottom of fills or along fill slopes; and to get the more stable, less expansive soils in the upper part of the subgrade, in both cuts and fills.
3. Where embankments are more than 6 to 8 feet high, they may be compacted at moisture contents slightly lower than AASHTO T-99 optimum; but it is essential to compact the upper 2½ to 4 feet of all subgrades at slightly above T-99 optimum. Other test methods, such as T-180 should not be used for clay soils because they give moisture contents too low to prevent instability due to swelling.

RECOMMENDATIONS

District, field and design engineers must use their own judgment on each project to consider the possibility of reducing moisture and density requirements. Control moisture and density at least in the top four feet of high embankments was found to be a definite need as a result of this study. Expansive soils will perform more satisfactorily deep within an embankment where they are better protected from drastic changes and their tendency to swell is inhibited by the weight of the overburden. As stated in this and previous reports, a considerable reduction in water and compaction costs may be realized in the use of nonswelling soils by lowering the compacted density requirements.

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The main factors to be considered are economics, soil type including the plasticity index and drainage.

An alternative to requiring expensive moisture and density control in the top few feet of an embankment would be an asphalt membrane envelope and slope protection. This should eliminate seasonal and precipitation connected moisture fluctuations.

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