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A wet-weight test method which eliminates oven-drying operations, density relationships, water content and optimum water content consideration in the relative compaction testing of untreated and treated soils and aggregates is reported. The present Test Method No. Calif. 216 for determining relative compaction provides a dry density Method A for soils containing over 10% by weight of particles retained on a 3/4" sieve, and a wet weight Method B for soils with 10%, or less, by weight of retained 3/4" particles. The application of a relative volume concept to soils with over, or under, 10% by weight of retained 3/4" particles permits the replacement of both Method A and Method B by a single wet weight test procedure. Results are generally reportable in less than an hour irrespective of gradation or water content. While designed for use in conjunction with sand volume operations the relative volume concept may also be applied to advantage with nuclear gage or other means of earthwork compaction evaluation.

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HIGHWAY RESEARCH REPORT

WET WEIGHT RELATIVE COMPACTION TESTING UTILIZING RELATIVE VOLUME CONCEPT

FINAL REPORT

April, 1968

STATE OF CALIFORNIA
TRANSPORTATION AGENCY
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT
NO. M & R 642833

STATE OF CALIFORNIA—TRANSPORTATION AGENCY

RONALD REAGAN, Governor

DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPARTMENT
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April 1968

Final Report
M&R No. 642833
NP.

Mr. J. A. Legarra
State Highway Engineer

Dear Sir:

Submitted herewith is a research report titled:

WET WEIGHT RELATIVE COMPACTION TEST UTILIZING RELATIVE VOLUME CONCEPT

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Principal Investigator

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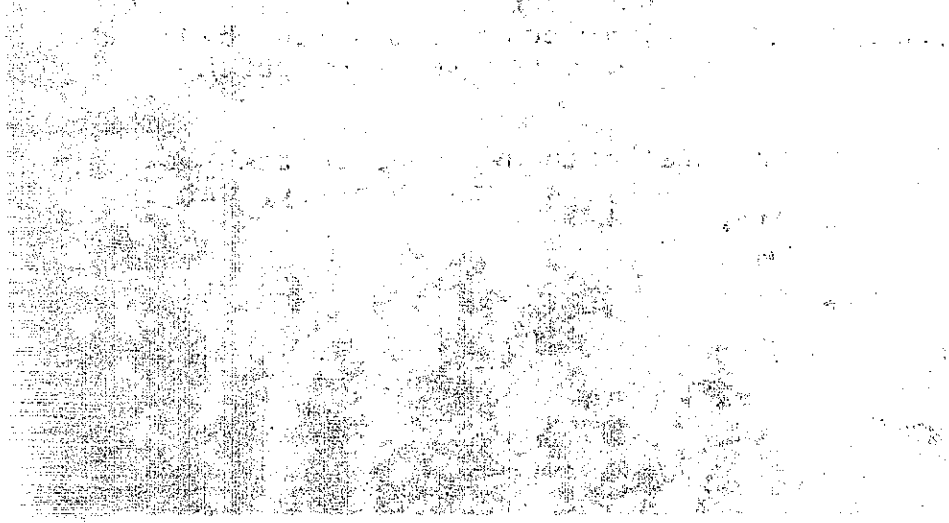
Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

REFERENCE: Smith, Travis W.; Maxwell, William S.; "Wet Weight Relative Compaction Testing Utilizing Relative Volume Concept," State of California, Department of Public Works, Division of Highways, Materials and Research Department. Research Report 642833, April 1968.

ABSTRACT: A wet-weight test method which eliminates oven-drying operations, density relationships, water content and optimum water content consideration in the relative compaction testing of untreated and treated soils and aggregates is reported. The present Test Method No. Calif. 216 for determining relative compaction provides a dry density Method A for soils containing over 10% by weight of particles retained on a 3/4" sieve, and a wet weight Method B for soils with 10%, or less, by weight of retained 3/4" particles. The application of a relative volume concept to soils with over, or under, 10% by weight of retained 3/4" particles permits the replacement of both Method A and Method B by a single wet weight test procedure. Results are generally reportable in less than an hour irrespective of gradation or water content. While designed for use in conjunction with sand volume operations the relative volume concept may also be applied to advantage with nuclear gage or other means of earthwork compaction evaluation.

KEYWORDS: Soils, soil compaction, test methods, construction control, earthwork, embankments, density, relative density, wet weight, weight-volume relationship.



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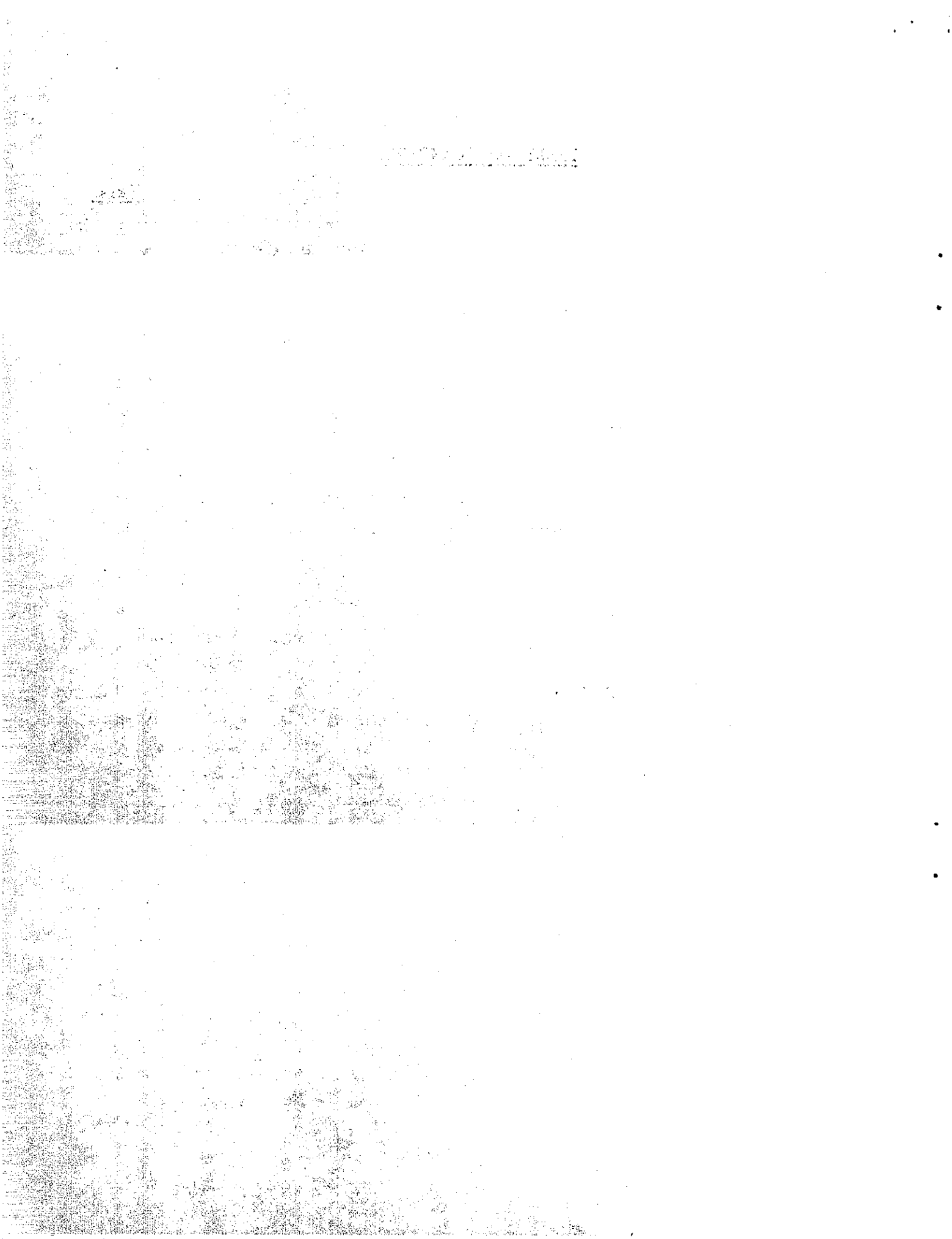

INTRODUCTION

For this report highway embankments, subgrades, bases, structure backfills and native ground will be classified as earthwork and the term soil will include all soil types, grain sizes, aggregate sizes and combinations thereof.

The current relative compaction test identified as Test Method No. Calif. 216-F consists of Part I dealing with the excavated sample - sand volume method of earthwork density determination, and Part II pertaining to compacting specimens of the excavated sample in the impact test apparatus and the derivation of the reported test result. Part II includes a Method A for soils having over 10% by weight retained on a 3/4" sieve and a Method B for soils with a lesser +3/4" content. Method A, a relative density method, involves the removal of the +3/4" fraction from the soil to be compacted in the impact test apparatus and a compensation for the removed fraction requiring labor and time consuming oven-drying of soil samples. End results are frequently not reportable for 24 hours. Method B is a density-oriented relative volume procedure devoid of direct density relationships and soil drying operations. Results may normally be reported within 20 minutes to an hour.

OBJECTIVE

The substitution of a single, simplified procedure for Methods A and B and the total elimination of all oven-drying to reduce costs and expedite construction control testing.

SUMMARY AND CONCLUSIONS

Utilizing a relative volume concept in lieu of the relative density concept in relative compaction determination permitted the development of a test suitable for all testable soils irrespective of grading or water content. Impact test results are normally reportable within less than an hour. The procedure does not require additional testing equipment, alteration of existing equipment or special indoctrination of personnel. The severity of the present density control testing is not altered. While designed for use in conjunction with sand volume operations the relative volume concept may also be applied to advantage with nuclear gage or other means of earthwork density determination.

RECOMMENDATION

It is recommended Methods A and B of Part II of Test Method No. Calif. 216 be replaced by the relative volume method, and that the remainder of Test Method No. Calif. 216 be revised with the deletion of all water content and density computations.

RELATIVE VOLUME TESTING

Relative volume testing does not entail a radical departure from the current Test Method No. Calif. 216 but simply a different concept of applying test findings to assess the compactness of earthwork. The earthwork sampling and the impact test handling of the earthwork soil remains unchanged and the end results are for all practical purposes unchanged. While references are made to the current Test Method No. Calif. 216 a detailed recounting of the current method is not deemed to be within the scope of this report.

PRELIMINARY INVESTIGATION

The original intent was to modify the slow and laborious dry density Method A of Test Method No. Calif. 216. Samples of earthwork under construction on various contracts were tested in accordance with Method A to establish an initial relative compaction for each sample. Subsequent work was devoted to attempts to simplify Method A and still retain the same degree, or severity, of construction control, i.e., retain or very closely approximate the initial relative compaction established for the respective sample. The Method A compensation formula for the retained 3/4" fraction of the earthwork soil excluded from impact test compaction was rewritten in several ways, and a substitution of wet sample weights and gravities for corresponding Method A formula dry weight values was accomplished. While these improvements simplified the calculations and dispensed with the oven-drying handicap the basic deficiencies of density testing remained. It was evident an entirely new approach was essential. The test data for each sample were converted to volume units and recomputed in terms of volumes and relative volumes. The result was a single and simple test method for soils with over, or under, 10% by weight retained on the 3/4" sieve and with any water content.

FUNDAMENTALS OF RELATIVE VOLUME CONCEPT

Soils with less than 10% by weight retained on a 3/4" sieve will first be considered. A sample of the soil under test is excavated from the earthwork and its weight and volume are determined. Exercising caution to preserve the earthwork water content a series of equal weight representative specimens are weighed out of the excavated sample. Being of equal weight and water content the individual specimens will each have the same volume of soil solids; and being of the same soil and water content as the total excavated sample the following proportional relationship will prevail.

$$\frac{\text{Wt. of Specimen}}{\text{Wt. of Total Exc. Spl.}} = \frac{\text{Vol. of Specimen}}{\text{Vol. of Total Exc. Spl.}}$$

From this relationship the volume which each specimen occupied in the earthwork may be computed, e.g.

Assume:

Weight of Each Excavated Sample Specimen = 2700 gms.
Weight of Total Excavated Sample = 8975 gms.
Volume of Total Excavated Sample = 4358 cu. cms.

Compute:

$$\text{Earthwork Volume of Each Specimen} = \frac{2700}{8975} \times 4358 = 1311 \text{ cu cms}$$

A specimen is compacted in the impact test apparatus and its test compacted volume is related to the volume occupied by the specimen when in the earthwork to obtain the volume ratio, or relative volume, which is multiplied by 100 for an end result in terms of percent relative compaction. In the following example calculation, the specimen earthwork volume is the 1311 cu cms above derived and the test compacted volume is assumed to be 1192 cu cms.

$$\% \text{ Relative Compaction} = \frac{\text{Specimen Test Compacted Volume}}{\text{Specimen Earthwork Volume}} \times 100$$

$$= \frac{1192}{1311} \times 100$$

$$= 90.9$$

APPLICATION OF RELATIVE VOLUME CONCEPT

At the location where the relative compaction is to be determined a sample of the earthwork is excavated and placed in containers designed to retain the water content. The volume of the resulting excavation is measured by conventional sand volume procedure in either cu cms or cu ft units. The excavated sample is transported to the field laboratory where it is weighed in grams.

Exercising caution to avoid any change in water content or soil composition, a series of three, or more, exactly equal weight specimens are weighed out of the excavated earthwork sample. The weight of the individual specimens to be such that when compacted in the impact test apparatus the height of the respective specimens will be within a range of 10 to 12 inches. Being of equal weight and identical water content the individual specimens will each have the same volume of soil solids which is determined as set forth in the self explanatory test report form.

Water is added to and/or removed from the specimens to provide for three, or more, varied water contents which appear to be appropriate for the soil under test. Adding water simply increases the water content of the voids in the specimen mass and removing water lowers the void water content. The amount or volume of the soil solids in any specimen is not affected by changing the water content provided soil particles are not lost in the process. The appropriate range of water contents is decided by testing personnel based on experience, visual inspection and feel of the wetted soil.

Following water content adjustment the specimens are compacted in the impact test apparatus in precisely the same way as outlined in the current Test Method No. Calif. 216-F, i.e., each specimen is compacted in the mold in 5 approximately equal weight layers by free dropping the 10-lb tamper 20 times on each layer from a height of 18". After the compaction of the fifth layer the piston is placed in the mold and seated on the compacted specimen by 5 additional drops of the tamper. With the tamper foot resting atop the piston the tamper shaft graduation most nearly coinciding with the top of mold is read. The volume of the compacted specimen indicated by the tamper reading is obtained from a conversion table on the test report form.

Due to their varying water contents the specimens will compact to varying volumes in the impact test mold. The relative volume, or relative compaction, is always based on the volume of the most compact specimen, i.e., smallest volume test compacted specimen, and the formula of a foregoing topic is better written:

$$\% \text{ R.C.} = \frac{\text{Specimen Test Compacted Smallest Volume}}{\text{Specimen Earthwork Volume}} \times 100$$

SOILS WITH RETAINED 3/4" FRACTIONS

When it appears the retained 3/4" fraction of the earthwork sample will exceed 10% by weight the entire sample is split on a 3/4" sieve and the impact test specimens are weighed out of the passing 3/4" portion. Thereafter the specimens are processed as outlined in the preceding topic.

The retained 3/4" fraction is washed to remove adhering fines. It is then weighed in air and in water to determine its volume. A proportional +3/4" fraction volume compensation is computed and applied to both the specimen earthwork volume and specimen test compacted volume. The compensation is computed only once for a given test regardless of the number of specimens. When a number of tests on soil containing essentially the same nature of retained 3/4" material are anticipated a constant may be developed to minimize the weighing in air and in water operations. The compensation procedure is detailed on the self-explanatory test report form.

SINGLE SPECIMEN TESTS

In that the relative volume and relative compaction are always based on the smallest volume impact test compacted specimen the number of specimens to be compacted may often be reduced in the following way. If the first specimen denotes a relative compaction meeting specifications it is necessary to compact a wetter or drier specimen to check if a smaller volume is attainable. If the second specimen also denotes a passing result a third specimen wetter or drier than the first and second specimen is test compacted. While three specimens covering an estimated range of about 6% water content are normally sufficient to pinpoint the smallest volume, additional specimens are occasionally needed.

When any specimen signifies a relative compaction below the specification minimum there is no reason to compact additional specimens. If a smaller volume were reached it would only lower the relative compaction result which already failed to meet specifications. Thus, if the first specimen end result fails to satisfy the specifications the test is terminated. If the first specimen result is passing and the second specimen result is failing, the test is concluded at this point, etc. While the current Test Method No. Calif. 216-F provides for a similar shortening of the test, the dry density of Method A or adjusted wet density of Method B must be computed for each test specimen, whereas in relative volume testing the tamper reading alone determines if computations must be performed as will be illustrated. The one, or two, specimen approach frequently minimizes the preparation of test specimens. After weighing them out of the earthwork sample the water content of only one is adjusted. If the end result for this specimen is less than the specification minimum there is no reason to adjust the water contents of the other specimens. A similar situation applies if two specimens are processed. Deferment of the water content adjustment pending the test compaction of the first one, or two, specimens also allows the operator to better judge the most appropriate water contents for subsequent specimens.

EXAMPLE TEST REPORTS

To demonstrate the adaptability of the test method and the report form, the following example test reports identified as Test No. I and Test No. III, respectively, encompass sand volume data in metric units or in pound and cubic foot units for earthwork samples with less than and with more than 10% by weight retained on a 3/4" sieve. The test report form incorporating conversion and coefficient tables is designed to be self-explanatory and to include all computation aids (See Figures 1 and 2).

For both Test No. I and Test No. III a minimum 90% relative compaction was specified. In Test No. I the first impact test specimen relative compaction value was a passing 90.9% which demanded additional specimens to ascertain if the smallest volume had been attained. The tamper reading of 10.8 for the second

specimen being lower than the 11.3 tamper reading for the first specimen indicated a smaller volume and necessitated calculating values for Lines V thru Z. The failing 86.9% relative compaction was reported to the nearest whole number of 87% to terminate the test. It not being known if additional specimens would denote still lower percent relative compaction, the end result was reported as 87%, or less.

In Test III the initial passing 97.1% relative compaction also dictated additional specimens. The tamper readings of 11.2 for the wetter and 11.1 for the drier specimens being larger than the 11.0 for the first specimen disclosed larger volumes so values for Lines V thru Z would be superfluous. The purpose of showing the specimen water content adjustment on the test report is to aid construction forces in assessing the earthwork water content.

AGGREGATE BASE PAY QUANTITIES

The 1964 Standard Specifications employ the Test Method No. Calif. 216 optimum moisture content in arriving at the pay quantity for aggregate base. This value may be readily found with relative volume testing by extruding from the impact test apparatus the smallest volume specimen and oven-drying it for a routine water content determination.

CALIFORNIA TEST APPARATUS

In a general way the relative volume concept may be described as the relating of the earthwork volume of a given quantity of soil to the test compacted volume of the same quantity of the same soil. The California Impact Test is especially adaptable to relative volume testing because the soil is compacted in the test apparatus to varying volumes. In test procedures wherein the soil is compacted to a fixed volume, as in the AASHO or ASTM molds, the relative volume concept may not be directly applied; therefore, the relative volume test marks another breakthrough in compaction control by California with its unique testing apparatus. The current wet weight Method B of Test Method No. Calif. 216 representing an earlier significant advancement in compaction testing in 1954 was also made feasible by the variable volume test apparatus.

NUCLEAR GAGE RELATIVE VOLUME TESTING

As presently used the nuclear gages simply appraise the earthwork density. The actual control test is still the impact test unchanged in any respect. Investigative work in progress indicates the relative volume concept will permit wet weight impact test control instead of the presently stipulated dry weight control for soils with over 10% by weight retained on the 3/4" sieve. It is further indicated the relative volume concept will afford more realistic nuclear gage testing of soils containing less than 10% by weight retained 3/4" fractions than is afforded by the prevailing method. This work which is not a part of the research project under consideration will be reported at a later date.

STATE OF CALIFORNIA DIVISION OF HIGHWAYS

RELATIVE COMPACTION TEST

TEST NO. I

CONT.NO._____ CO._____ RTE._____ P.M._____

STA._____ LINE_____ LT./RT._____ ELEV._____

SOIL_____ FROM_____ S-V TEST BY_____ DATE_____

WATER CONDITION: UNIFORM_____ SPOTTY_____ WET_____ DRY_____

REMARKS:_____

SAND VOLUME DATA		
A	SAND INITIAL WT.	15000
B	RESIDUE WT.	1329
C	SAND USED (A-B)	13671
D	SAND UNIT WT.	1.506
E	VOLUME (C/D)	9078
F	CONE VOL.	4720
G	HOLE VOL. (E-F)	4358
H	28300 (G)	

CONVERSION (U) TO (V)

10.0	1055	11.0	1160
.1	1065	.1	1171
.2	1076	.2	1181
.3	1086	.3	1192
.4	1097	.4	1202
.5	1107	.5	1213
.6	1118	.6	1224
.7	1128	.7	1234
.8	1139	.8	1245
10.9	1150	.9	1255
		12.0	1266

COEFFICIENTS

% + 3/4"	Y
20-29	1.01
30-40	1.02
Over 40%	1.03

EXCAVATED SAMPLE			WEIGHTS IN GRAMS	
				LESS THAN 10% +3/4" ↓
I	TOTAL SPL. WT.			
J	+3/4" WT. IN AIR			
K	+3/4" WT. IN WATER			
L	+3/4" VOL.	(J-K)		
M	% +3/4"	100 (J/I)		
N	-3/4" WT.	(I-J)		8975
O	-3/4" VOL. *(G-L) or (H-L)			4358
EXCAVATED SAMPLE SPECIMEN				
P	WEIGHT			2700
Q	RATIO	(P/N)		.3008
R	UNCOMPENSATED VOL.	(OQ)		1311
S	+3/4" COMPENSATION	(LQ)		XXXXXXX
T	COMPENSATED VOL.	(R+S)		1311

IMPACT TEST DATA

	SPECIMEN	1	2	3	4
U	TAMPER READING	11.3	10.8		
V	UNCOMPENSATED VOL.	1192	1139		
W	COMPENSATED VOL. (V+S)	"	"		
X	RATIO (W/T)	.909	.869		
Y	COEFFICIENT	-	-		
Z	% REL. COMP. 100 (XY)	90.9	86.9		
	WATER ADJUSTMENT, GMS.	+50	+100		

IMP. TEST BY_____

DATE_____

REMARKS:_____

FAILED 87%, OR LESS

PASSED_____

TEST NO. I

*(G-L) FOR SAND VOLUME WEIGHTS IN GRAMS. (H-L) FOR SAND VOLUME WEIGHTS IN POUNDS.

Figure 1

STATE OF CALIFORNIA DIVISION OF HIGHWAYS

RELATIVE COMPACTION TEST

TEST NO. III

CONT.NO._____ CO._____ RTE._____ P.M._____

STA._____ LINE_____ LT./RT._____ ELEV._____

SOIL_____ FROM_____ S-V TEST BY_____ DATE_____

WATER CONDITION: UNIFORM_____ SPOTTY_____ WET_____ DRY_____

REMARKS:_____

SAND VOLUME DATA		
A	SAND INITIAL WT.	37.7
B	RESIDUE WT.	5.9
C	SAND USED (A-B)	31.8
D	SAND UNIT WT.	95.1
E	VOLUME (C/D)	.334
F	CONE VOL.	.167
G	HOLE VOL. (E-F)	.167
H	28300 (G)	4726

CONVERSION (U) TO (V)

10.0	1055	11.0	1160
.1	1065	.1	1171
.2	1076	.2	1181
.3	1086	.3	1192
.4	1097	.4	1202
.5	1107	.5	1213
.6	1118	.6	1224
.7	1128	.7	1234
.8	1139	.8	1245
10.9	1150	.9	1255
		12.0	1266

COEFFICIENTS

% + 3/4"	Y
20-29	1.01
30-40	1.02
Over 40%	1.03

EXCAVATED SAMPLE		WEIGHTS IN GRAMS	
I	TOTAL SPL. WT.	10055	LESS THAN 10% +3/4" ↓
J	+3/4" WT. IN AIR	3183	
K	+3/4" WT. IN WATER	1874	
L	+3/4" VOL. (J-K)	1309	
M	% +3/4" 100 (J/I)	31.7	
N	-3/4" WT. (I-J)	6872	
O	-3/4" VOL. *(G-L) or (H-L)	3417	
	EXCAVATED SAMPLE SPECIMEN		
P	WEIGHT	2500	
Q	RATIO (P/N)	.3638	
R	UNCOMPENSATED VOL. (OQ)	1243	
S	+3/4" COMPENSATION (LQ)	476	XXXXXXX
T	COMPENSATED VOL. (R+S)	1719	

IMPACT TEST DATA

SPECIMEN		1	2	3	4
U	TAMPER READING	11.0	11.2	11.1	
V	UNCOMPENSATED VOL.	1160			
W	COMPENSATED VOL. (V+S)	1636			
X	RATIO (W/T)	.952			
Y	COEFFICIENT	1.02			
Z	% REL. COMP. 100 (XY)	97.1			
WATER ADJUSTMENT, GMS.		0	+50	-50	

IMP. TEST BY _____

DATE _____

REMARKS:_____

FAILED _____, OR LESS

PASSED 97%

TEST NO. III

*(G-L) FOR SAND VOLUME WEIGHTS IN GRAMS. (H-L) FOR SAND VOLUME WEIGHTS IN POUNDS.

Figure 2