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DIVISION OF
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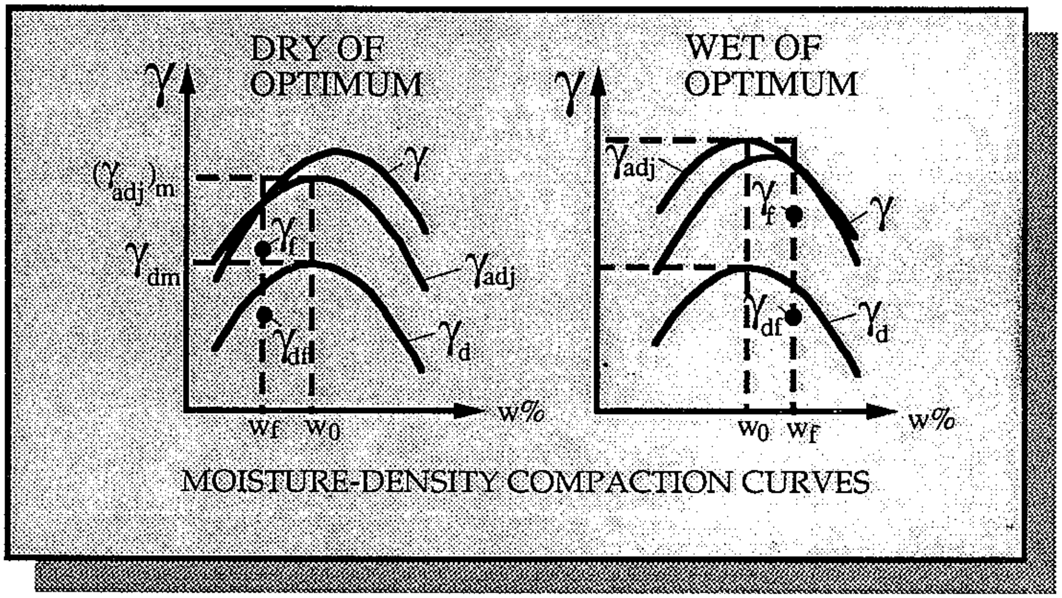
93-08

DEVELOPMENT OF NEW TEST METHODS FOR DETERMINING RELATIVE COMPACTION OF UNTREATED AND TREATED SOILS AND AGGREGATES



September 1992

Presented By:

James E. Morris

State of California
Department of Transportation
Division of New Technology, Materials and Research
Office of Geotechnical Engineering

Minor Research Report

PROPOSED NEW TEST METHODS

FOR

RELATIVE COMPACTION

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CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quality	English Unit	Multiply By	To Get Metric Equivalent
Length	inches (in) or (")	25.40 .02540	millimetres (mm) metres (m)
	feet (ft) or (')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2) square feet (ft^2) acres	6.432×10^{-4} .09290 .4047	square metres (m^2) square metres (m^2) hectares (ha)
Volume	gallons (gal) cubic feet (ft^3) cubic yards (yd^3)	3.785 .02832 .7646	litre (l) cubic metres (m^3) cubic metres (m^3)
Volume/Time (Flow)	cubic feet per second (ft^3/s)	28.317	litres per second (l/s)
	gallons per minute (gal/min)	.06309	litres per second (l/s)
Mass	pounds (lb)	.4536	kilograms (kg)
Velocity	miles per hour (mph) feet per second (fps)	.4470 .3048	metres per second (m/s) metres per second (m/s)
Acceleration	feet per second squared (ft/s^2)	.3048	metres per second squared (m/s^2)
	acceleration due to force of gravity (G)	9.807	metres per second squared (m/s^2)
Density	(lb/ft^3)	16.02	kilograms per cubic metre (kg/m^3)
Force	pounds (lb) kips (1000 lb)	4.448 4448	newtons (N) newtons (N)
Thermal Energy	British thermal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds (ft-lb) foot-kips (ft-k)	1.356 1356	joules (J) joules (J)
Bending Moment or Torque	inch-pounds (in-lb) foot-pounds (ft-lb)	.1130 1.356	newton-metres (Nm) newton-metres (Nm)
Pressure	pounds per square inch (psi) pounds per square foot (psf)	6895 47.88	pascals (Pa) pascals (Pa)
Plane Angle	degrees (°)	0.0175	radians (rad)
Temperature	degrees fahrenheit (°F)	$\frac{°F - 32}{1.8} = °C$	degrees celsius (°C)
Concentration	parts per million (ppm)	1	milligrams per kilogram (mg/kg)

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Introduction

California test methods for determining relative compaction of soils and aggregates include California Test Method (CTM) 216 - "Relative Compaction Of Untreated and Treated Soils and Aggregates", and CTM 231 - "Relative Compaction Of Untreated And Treated Soils and Aggregates By The Area Concept Utilizing Nuclear Gages". Currently, CTM 216 is used primarily to determine laboratory compacted maximum density, but the method also includes procedures for determining field densities by the sand cone method. The compaction equipment to determine laboratory densities is unique to CTM 216 and is not widely used outside Caltrans. It is therefore difficult or costly to obtain the equipment, and many private laboratories are not familiar with its use. Additionally, most private labs familiar with ASTM relative compaction testing methods are not familiar with the use of the CTM equipment or procedure. Their use of ASTM equipment and methods on Caltrans and local assistance projects has caused difficulty for Caltrans independant assurance testing personnel who don't have the equipment or training in ASTM methods.

CTM 231 utilizes the nuclear gage to determine field densities. The test method uses a statistically based procedure known as the "area concept" which includes procedures for selecting areas to be tested and for sampling materials for use in the laboratory compaction portion of CTM 216. Both test procedures are based on what is referred to as the "wet" method, or relative compaction on a wet weight basis. The CTM procedures do not use soil moisture contents, which are determined by drying the soil samples, as is more commonly the practice when obtaining ASTM or AASHTO relative compaction. Caltrans procedures do provide a rapid, accurate determination of relative compaction for construction control purposes.

The rationale behind the procedures and methodology used in the California test methods is not widely understood. Private and State testing laboratories have incurred difficulty assessing contract compliance when the test procedures were not strictly followed. The procedures were perceived to be flawed by lab technicians not familiar with their use. This is partly because the test forms and some of the procedures are very abbreviated and provide little explanation.

CTM 216 and 231 contain procedures and features that are redundant between the two since these tests were developed at different times. The two test methods actually consist of several tests that are interrelated, which can be confusing to first time users.

Most private geotechnical engineering firms and testing laboratories are familiar with ASTM and AASHTO standards. Equipment for these test procedures is readily available commercially. Therefore, in 1988, Standard

Special Provision M03 was written to allow substitution of either the commonly used ASTM D1557 and D2922 tests, or the AASHTO T180 and T238 tests for CTM 216 and 231. This introduced several problems on projects where these test methods were used by private testing laboratories. The ASTM and AASHTO tests for determining moisture/density relationships are very basic, encompassing only the determination of laboratory maximum density and field densities. They do not include, for example, procedures on sampling of materials, or how often laboratory maximum densities are to be obtained. Where these tests were used, Caltrans independent assurance testers (IATs) observed that the number of nuclear gage field density tests conducted was low and that laboratory maximum density tests were infrequently performed. However, the IATs could not argue that the ASTM procedure was not being followed because those procedures contain no requirements for testing frequency. If ASTM and AASHTO test methods were to be used, these details, and even how relative compaction is calculated, need to be included in the contract specifications.

Another problem with the ASTM and AASHTO tests is that they were not written for construction control purposes, even though they are commonly used for such by public agencies and private consultants. For example, under the ASTM procedure, certain soil types must be hydrated for up to 36 hours before testing can continue. Also, soil moisture contents are determined through oven-drying for 24 hours. Such time delays are not responsive to a contractor waiting to see if his construction method has met project compaction specifications. Consequently, virtually all entities using the ASTM or AASHTO testing formats have had to modify the test procedures.

Objective

Improve the presentation, eliminate redundancies, and provide elucidation of the "wet" procedure, in the test methods for relative compaction. In addition, develop an alternative procedure for determining laboratory maximum density that utilizes more standard equipment.

This will be accomplished by: 1) Developing a new test method that includes the various components of CTM 216 and CTM 231 that pertain to the "wet" procedure, the "area concept" and the calculation of relative compaction. 2) Incorporating into the appendix of the new test method a discussion explaining the "wet" method. 3) Revising CTM 216 so that the test method includes only procedures for determining laboratory maximum density. 4) Developing, as an alternative in CTM 216, the use of the Proctor compaction mold (Modified AASHTO test) based on the "wet" method. 5) Revising CTM 231 so that the test method includes only procedures for determining field densities using the nuclear gage.

Background

In 1929 the California Division of Highways adopted test procedures for evaluating soil and aggregate compaction which related field dry densities to laboratory compacted maximum dry densities. This ratio was referred to as relative compaction, and the test method was developed by O.J. Porter. The compaction cylinder was originally called the Porter Field Cylinder and later the California Impact Apparatus. The California Impact Test utilized a 2.8-inch (7.11cm) diameter cylinder in which soil specimens between 10 and 12 inches (25.4-30.5cm) in height, were compacted in 5 layers, using a 10 lb. (4.53kg) rammer and a free drop of 18 inches (45.7cm) (Figure 1). The equipment and compaction procedure are basically the same now, as when first developed.

At about this time R.R. Proctor working as Field Engineer at the Bureau of Waterworks and Supply for the City of Los Angeles, developed similar methods to evaluate soil compaction, and in 1933 he wrote a series of papers on Soil Compaction for the Engineering News Record introducing his test procedures. Based on a 4-inch diameter, 4.6-inch high compacted sample, the Proctor laboratory compaction test utilized a hand striking method and 5.5 pound (2.49kg) rammer. This is the same compaction cylinder used to develop the Std. AASHTO and Mod. AASHTO tests.

In 1956 the Division of Highways adopted a "wet " procedure as an alternative to the "dry" procedure developed in 1929. This method was developed because of the need for rapid determination of relative compaction for construction control purposes. The alternative "wet" procedure was restricted to materials with less than 10% by weight retained on the 3/4-inch (19mm) sieve. The procedure allowed determination of the relationship of field dry density to lab maximum dry density without having to obtain moisture contents. Accurate determination of moisture contents usually required over-night oven drying, particularly with fine-grained soils. A more timely procedure was needed to evaluate the compaction of fill materials on State contracts. The moisture-density relationship and optimum moisture content were not obtained, but an accurate determination of relative compaction was rapidly determined. The "wet" procedure is basically the same today as in 1956.

In 1957 Dr. J.W. Hilf of the Bureau of Reclamation presented a paper at the ASCE conference in Mexico City, which introduced a similar "wet" procedure. He later published a paper entitled *A Rapid Method of Construction Control for Embankments of Cohesive Soil* (1), where he showed that the exact ratio of field dry density to laboratory maximum dry density could be determined without knowing the moisture contents. His procedure outlined the development of a laboratory "converted" wet density curve using the Proctor equipment, where the ratio of field wet density to maximum "converted" wet density is equal to the ratio of field dry density to lab maximum dry density.

In 1966 California adopted nuclear field density procedures in the form of California Test Method 231-F. This method also included procedures for statistically selecting the field density test locations, known as the "area concept", and for selecting field samples to make up a composite sample for determination of the lab maximum density. This test procedure referenced CTM 216 for determining lab maximum density. CTM 231-F used the "wet" method exclusively and did not allow determination of relative compaction based on dry densities.

In 1971 the "dry" method was dropped from CTM 216 and soils with greater than 10% retained on the 3/4-inch (19mm) sieve were included in the "wet" method. This made the procedures consistent with CTM 231, as nuclear gage density testing was being routinely utilized.

Relative Compaction and Maximum Dry Density

The definition of relative compaction is the ratio of the field dry density to the maximum laboratory dry density, expressed as a percent.

$$\text{Relative Compaction} = \frac{\text{Field Dry Density}}{\text{Lab Compacted Maximum Dry Density}} \times 100$$

Laboratory compaction tests to obtain compacted dry densities include the California Impact Test (CTM 216), ASTM D1557 and AASHTO T180. Figure 2 provides a comparison of the three test methods. Both ASTM and AASHTO tests provide four methods that use 4-inch and 6-inch diameter compaction cylinders. A compaction study by F.N. Hveem (2) using the 4-inch diameter cylinder and Modified AASHTO procedures, compared maximum dry densities to those obtained using CTM 216. Although the compactive effort in CTM 216 was lower, several soils in Hveem's study compacted to higher dry densities using CTM 216, than with the Modified AASHTO test. This is most likely due to the smaller compaction cylinder diameter with CTM 216, and the associated greater ratio of the rammer foot area to the cylinder area. In general, the study found the maximum dry densities determined by the two methods to be very close.

Wet Procedure and Maximum Adjusted Wet Density

Reports by Caltrans explaining the "wet" procedure have used what is called the "relative volume concept" (4)(5). Since the California Impact Apparatus is a variable volume compaction cylinder, the volume of soil removed in the field, as determined by a sand cone test, for example, could easily be compared to the minimum volume obtained in the laboratory compaction test. The ratio of field volume to the laboratory minimum compacted volume, was shown to be equal to relative compaction based on dry densities. Unfortunately, this straight forward explanation of the "wet" procedure, using a variable volume compaction cylinder and a sand cone test, cannot be easily applied to tests using a fixed volume compaction cylinder (ASTM and AASHTO) and field densities as determined by a nuclear gage test.

The early test procedures of CTM-216 utilized a term called "adjusted " wet density. The "adjusted" wet density in this procedure is identical to J. W. Hilf's "converted" wet density in his "wet" procedure, which was developed for the fixed volume Proctor compaction cylinder. In both "wet " procedures, relative compaction is determined from the ratio of the field wet density to the laboratory compacted maximum "adjusted" or "converted" wet density. The "adjusted" wet density of a lab compacted specimen is the wet density expressed in terms of the field water content. It is not a true wet density except for a compaction specimen compacted at the field moisture content.

If the "wet" procedure is explained in terms of "adjusted" wet densities, instead of the "relative volume concept", it can be more broadly applied to wet densities, i.e., fixed volume laboratory compaction and nuclear gage density tests. The following mathematical proof equates relative compaction based on dry densities to that from wet densities.

By definition:

$$\text{Relative Compaction (R.C.)} = \frac{\text{Field Dry Density}}{\text{Lab Compacted Maximum Dry Density}} = \frac{\gamma_{df}}{\gamma_{dm}}$$

For the general case of any lab compacted specimen (not just the maximum density), the ratio (D) of field dry density (γ_{df}) to lab compacted dry density (γ_d) is:

$$D = \frac{\gamma_{df}}{\gamma_d} = \frac{\gamma_{df}\,(1+w_f)}{\gamma_d\,(1+w_f)} = \frac{\gamma_f}{\gamma_d(1+w_f)}$$

, where γ_f is the field wet density and w_f the field moisture content.

By applying algebraic manipulation to the term in the denominator :

$$\gamma_d\,(1+w_f) = \gamma_d\,(1+w_f)\,\frac{(1+w)}{(1+w)} = \frac{\gamma_d\,(1+w)}{\frac{(1+w)}{(1+w_f)}} = \frac{\gamma}{\frac{(1+w)}{(1+w_f)}} = \frac{\gamma}{1+\frac{(w-w_f)}{(1+w_f)}} = \frac{\gamma}{1+\frac{(w-w_f)W_s}{(1+w_f)W_s}}$$

γ is the wet density, W_s is the weight of solids, and w is the moisture content of the specimen.

$$\gamma_d(1+w_f) = \frac{\gamma}{1+\frac{(wW_s - w_f W_s)}{W_s(1+w_f)}} = \frac{\gamma}{1+\frac{\Delta W_w}{W_{tf}}} = \frac{\gamma}{1+z}$$, where z is referred to as added water, as a percentage of the field wet weight.

$$z = \frac{\Delta W_w}{W_{tf}} = \frac{\text{change in weight of water (added or subtracted water)}}{\text{total wet weight at field moisture content (original wet weight)}}$$

$\frac{\gamma}{1+z} = \gamma_{adj}$, Where γ_{adj} is defined as the <u>Adjusted Wet Density</u> or the wet density expressed in terms of the field water content.

Therefore, $\gamma_d(1+w_f) = \gamma_{adj}$ and, $D = \frac{\gamma_f}{\gamma_d(1+w_f)} = \frac{\gamma_f}{\gamma_{adj}}$

For the special case of the maximum dry density (γ_{dm}) :
$\gamma_{dm}(1+w_f) = (\gamma_{adj})_m$, where $(\gamma_{adj})_m$ is the maximum adjusted wet density and:

$$\text{Relative Compaction (R.C.)} = D_{rc} = \frac{\gamma_{wf}}{(\gamma_{adj})_m} = \frac{\text{Field Wet Density}}{\text{Lab Maximum Adjusted Wet Density}}$$

The maximum adjusted wet density ($(\gamma_{adj})_m$) can be obtained by plotting γ_{adj} versus z or any other convenient variable, such as the change in weight of water, which is the practice in CTM 216.

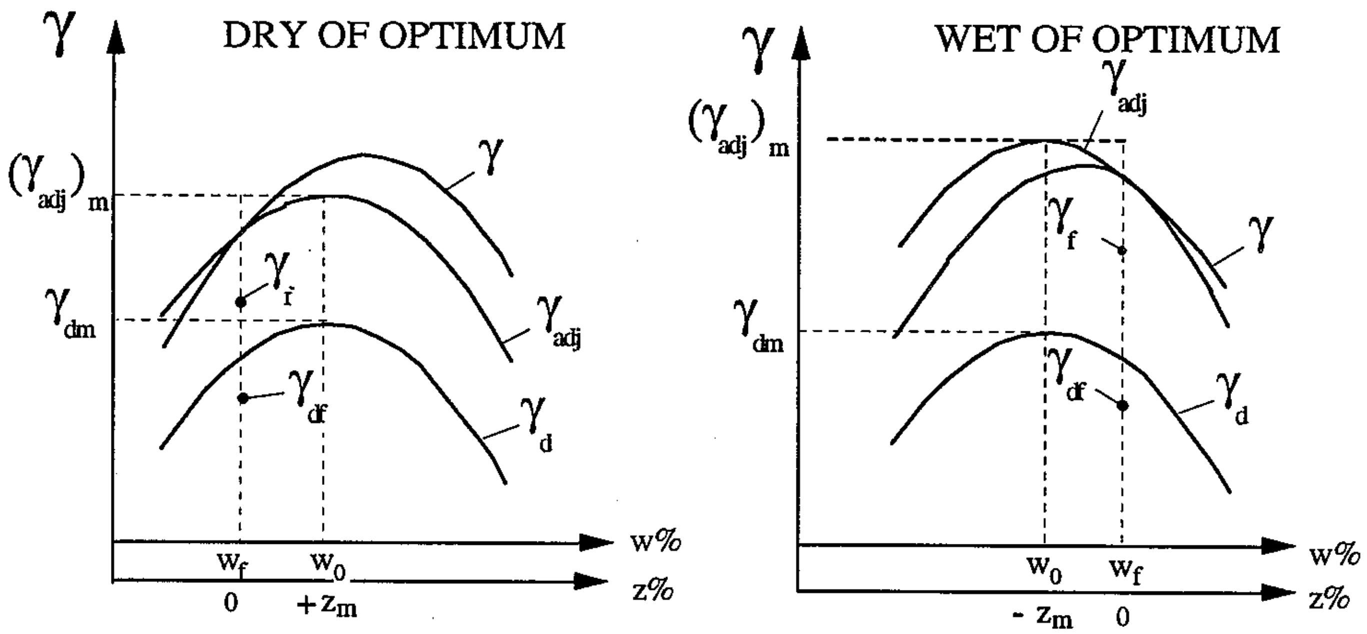
The following relationship shows that the densities obtained in the 1978 version of CTM 216 are the adjusted wet densities as defined above. Table 1 of CTM 216, which is titled California Impact Test Apparatus Conversion Table, uses the tamper reading and weight of test core (compacted specimen) in grams to obtain density in grams per cubic centimeter. The tamper reading corresponds to the compacted total volume (V_t), and the weight of the test core is the total weight at the field moisture content (W_{tf}). Table 1 of CTM 216 simply divides W_{tf} by V_t to obtain the adjusted wet density as follows:

$$\frac{W_{tf}}{V_t} = \frac{W_s(1+w_f)}{V_t} = \gamma_d(1+w_f) = \gamma_{adj}$$

Using a fixed volume compaction cylinder, adjusted wet density is calculated from the relationship:

$$\gamma_{adj} = \frac{\gamma}{1+z}$$

The following moisture-density diagrams illustrate the relationship between dry density, wet density and adjusted wet density.



MOISTURE-DENSITY COMPACTION CURVES

$$\text{Relative Compaction} = \frac{\gamma_f}{(\gamma_{adj})_m} = \frac{\gamma_{df}}{\gamma_{dm}}$$

γ_d = Lab Compacted Dry Density

γ = Lab Compacted Wet Density

γ_{dm} = Lab Compacted Maximum Dry Density

γ_{adj} = Adjusted Wet Density

$(\gamma_{adj})_m$ = Lab Maximum Adjusted Wet Density

γ_{df} = Field Dry Density

γ_f = Field Wet Density

w = Moisture Content of Lab Compacted Specimen

w_f = Field Moisture Content

z = added water, as a percentage of the field wet weight

z_m = z corresponding to the maximum dry density

Note that the maximum "true" wet density does not occur at the same moisture content as the maximum dry density and maximum adjusted wet density. If the "true" wet density was erroneously used, the diagrams show the effect on relative compaction for field moistures wet and dry of optimum.

Importance Of Maintaining The Field Moisture Content In The "Wet" Method

One of the most important aspects of the "wet" method is that the laboratory compaction specimens must first be weighed while still at the field moisture content. Figures 3, 4 and 5 illustrate the errors that can be introduced if the field moisture content is different than the moisture content of the initial laboratory compacted specimens. This illustration is based on actual laboratory compaction data, but the field densities, and moisture losses are hypothetical.

Figure 3 shows the dry, wet and adjusted wet density compaction curves representing a soil for which the field moisture and the initial lab moisture were both 21 percent. Note that this moisture content is at the location where the wet density curves intersect and is about 5 1/2 percent above optimum. The calculation at the bottom of the Figure 3, based on a field wet density of 110 p.c.f. (1.76g/cc) and maximum adjusted wet density of 126.5 p.c.f.(2.03g/cc), gives the correct relative compaction of 87.0 percent.

Figure 4 shows the compaction curves for the same data where the adjusted wet density curve has shifted, due to a 3 percent loss in moisture between the field and the lab. The wet and dry density curves are the same, but the adjusted wet density curve is lower. The calculated relative compaction is 89.3 percent. Figure 5 shows the same compaction data for a 9 percent moisture loss between the field and the lab tests. The calculated relative compaction is now 94.0 percent.

The same type of error can occur if water is added to a fill, after lab compaction samples have been taken and prior to a field density test. This occurs, for example, when a retest is performed without a second lab compaction test, and correction for the moisture difference is not made.

CTM 122

A proposed draft version of new California Test Method 122, "Method For Determination of Relative Compaction of Untreated and Treated Soils and Aggregates" is presented as Attachment A. This procedural method outlines how relative compaction is to be determined and refers to proposed revisions of CTM 216, "Method of Test For Laboratory Maximum Adjusted Wet Density of Untreated And Treated Soils And Aggregates" and CTM 231, "Method of Test For Field Wet Density Utilizing Nuclear Gages".

The intent is to incorporate into CTM 122 those items that have to do with procedures, such as, selecting test locations and how samples are obtained ("area concept"), and how relative compaction is calculated ("wet method"). These various items have been taken from different parts of CTM 216 and CTM 231 with minor modification. Terms, such as "adjusted wet density", have replaced the misleading "wet density", for example. Appendix A of CTM 122 includes an explanation of the "wet" procedure, as previously discussed. Appendices B and C include the Non-biased Sample Plans, and sample calculations for using "Common" densities, which were taken from CTM 231.

Revisions To CTM 216

The proposed draft revision of CTM 216 is presented in Attachment B. The test method focuses on the determination of laboratory maximum adjusted wet density only, and does not include procedures for field density as per the sand cone test. The title has been changed to "Method Of Test For Laboratory Maximum Adjusted Wet Density".

The proposed revision includes two methods, both based on the "wet" procedure. Method A includes procedures for determining maximum adjusted wet density utilizing the California Impact Apparatus. This is basically unchanged from the current CTM 216. Method B includes procedures utilizing the 4-inch Proctor compaction mold based on the modified AASHTO test. The procedure most closely resembles AASHTO T180, Method C, which allows a maximum aggregate size of 3/4 inch (19mm) but does not correct for oversized material. The proposed revision uses the same rock correction procedure as is currently used in CTM 216. Probably the most significant change for lab personnel using the revised procedure, for those not using Method B, is in the proposed test form. The proposed test form is discussed later, since it is utilized by all three test methods.

Revisions To CTM 231

The proposed revision of CTM 231 "Method of Test For Field Wet Density Utilizing Nuclear Gages" is presented in Attachment C. The test method focuses on the determination of field wet density utilizing nuclear gages and no longer includes procedures pertaining to the "area concept" and the "wet" method, which have been moved to CTM 122.

The procedures for operating the nuclear gage have not been changed, except for how the readings are reported. The procedures require determination of the wet density of each test site. These individual site densities are then averaged to obtain the values for the whole test area, instead of averaging the density counts and then determining the corresponding densities. This provides for a better understanding of the wet density variations within the test areas, which is important in establishing the limits and size of test areas.

The newer nuclear gages allow input of calibration data and can read out densities and moistures directly, eliminating the need for calibration tables. This capability may be available with future revisions to the procedures for developing calibration tables as presented in CTM 111.

New Test Form

The revisions to CTM 216 and CTM 231, and the development of the proposed CTM 122 require new test forms to replace the current form TL-2148 (Figure 6). This is the currently used form for determining relative compaction and procedures for its use are presented in CTM 231. The proposed double-sided test form (MR-2148A & 2148B) is presented in Figures 7 and 8. The additional room on the form reduces the use of abbreviations, and allows for better organization. Changes in the proposed test form are discussed as follows:

MR - 2148A

The test form has been reorganized for entry of test data from CTM 231- Field Wet Density - Nuclear Gage on Side A, and entry of test data from CTM 216 - Laboratory Maximum Adjusted Wet Density on side B. The calculations for CTM 122- Method For Determination Of Relative Compaction Of Untreated And Treated Soils And Aggregates are performed on Side B also.

The format of the test form on side A is similar to the form as it occurred in 1971 for CTM 231. There are now six columns for test site data instead of eight. More than six test sites are rarely used. If necessary, columns could be split to provide for more test sites. Although not an alternative in the revised test procedure, which is intended for use with the "wet" method, the test form also provides for the determination of dry densities.

MR - 2148B

Side B of the test form includes a block for calculations in CTM 216 to determine the adjusted wet density using Method A (Calif. Impact Apparatus) and Method B (4-inch Proctor mold).

To reduce confusion when using "common" maximum adjusted wet densities, often referred to as common composite test maximums, a separate data block is provided on the test form. This allows calculations pertaining to data from previous test areas to be on the form. These calculations are currently done on a separate calculation sheet.

Although not an alternative in the proposed test procedure, the test form provides for input of moisture contents and determination of dry densities. This will allow for easy comparison of relative compaction using the "wet" method, with relative compaction based on dry densities.

Conclusion

The proposed draft test revisions have been completed, which include new California Test Method 122, "Method For Determination of Relative Compaction of Untreated and Treated Soils and Aggregates", revised CTM 216, "Method of Test For Laboratory Maximum Adjusted Wet Density of Untreated And Treated Soils And Aggregates" and revised CTM 231, "Method of Test For Field Wet Density Utilizing Nuclear Gages". Draft versions of CTM 122 and 216 were distributed and comments solicited at the District Materials Engineers meeting. Comments have been limited, but favorable.

Recommendations

1. Conduct a minor laboratory study to compare maximum adjusted wet densities, as determined by Method A (California Impact Apparatus) and by Method B (4-inch Proctor mold) of the proposed revision of CTM 216. This study should also compare the maximum dry densities, for different soil types, to expand on the work by F.N. Hveem.

2. Conduct a study of recent developments in nuclear gage technology and equipment. Revise the current nuclear gage specifications as necessary. Revise the current test method for nuclear gage calibration (CTM 111), to take advantage of the newer nuclear gages and their internal calibration capability. Additional revision to the nuclear gage operating procedures in CTM 231 is recommended to accomplish this.

3. Study the use of the commercially available mechanical drop hammer for the Proctor compaction mold.

4. Develop a separate field density test utilizing the sand cone method.

Implementation

Develop a program to implement the test methods on a trial basis with selected District construction projects. Make appropriate revisions, and provide training to adopt test methods on contracts statewide.

References

1. J.W. Hilf. *A Rapid Method of Construction Control for Embankments of Cohesive Soils.* Bureau of Reclamation. Sept 1961

2. F.N. Hveem. *Maximum Density and Optimum Moisture of Soils* Highway Research Board, Bulletin 159. 1957

3. A.W. Johnson, J.R. Sallberg. *Factors Influencing Compaction Test Results.* Highway Research Board, Bulletin 319, 1962

4. T.W. Smith, W.S. Maxwell *Relative Compaction Of Soils Containing 3/4" Rock.* Calif. Division of Highways. Highway Research Report. July 1968

5. T.W. Smith, M. Hatano. *Rapid Compaction Control Testing Using Wet Method* Transportation Research Record. 1974

CALIFORNIA IMPACT COMPACTION APPARATUS

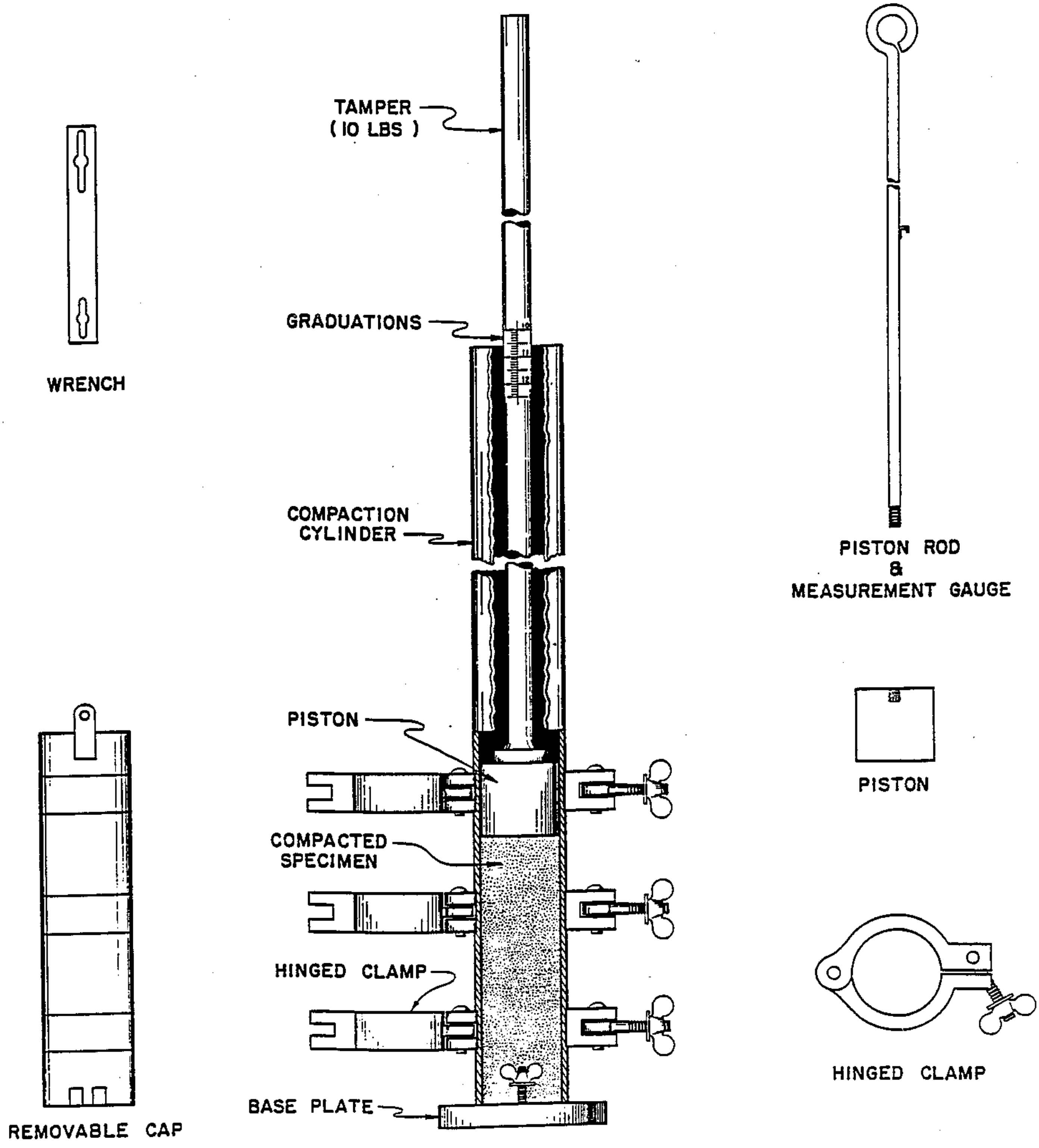


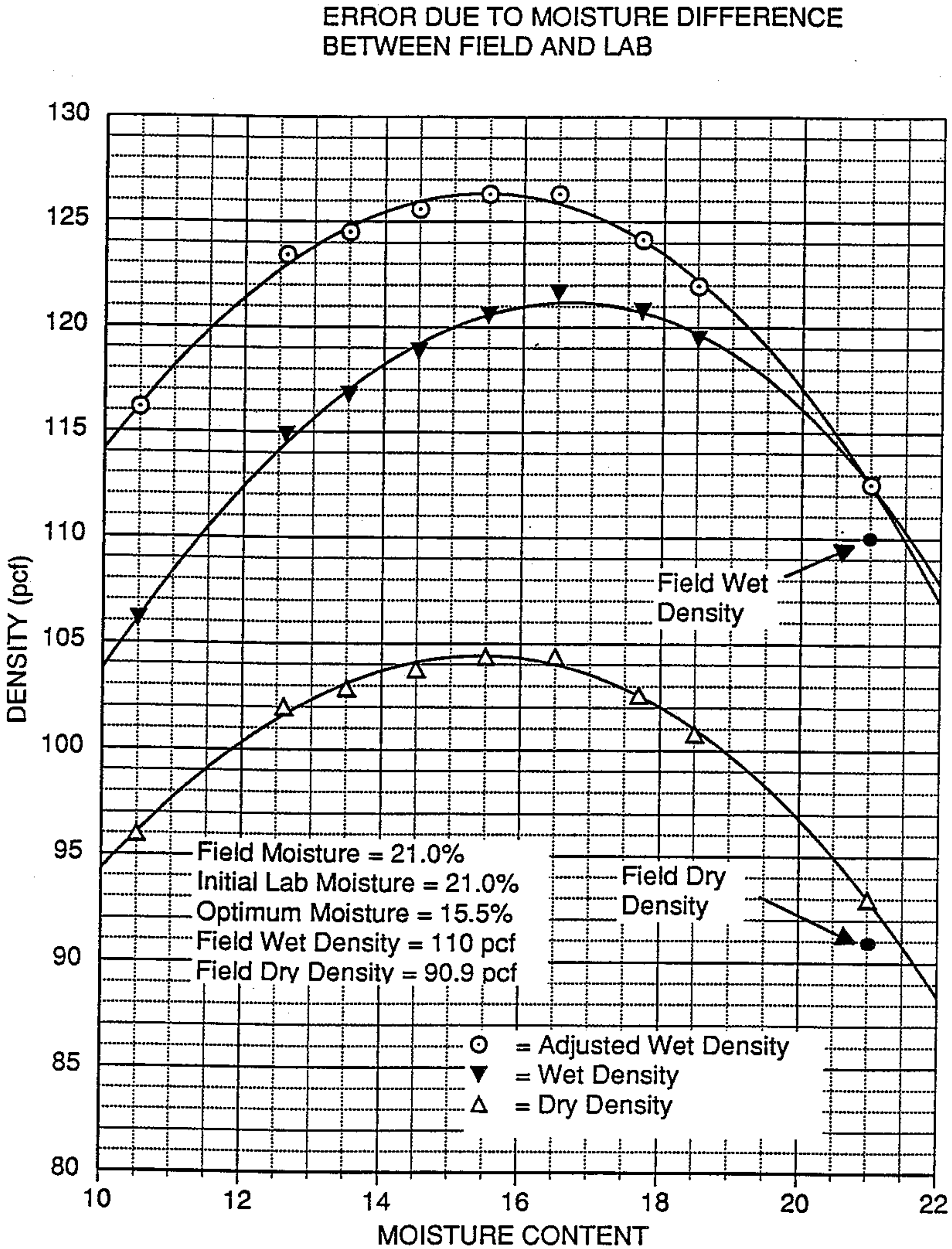
Figure 1

COMPARISON OF COMPACTION TEST METHODS

	CTM 216	ASTM 1557				AASHTO T180			
		Method				Method			
		A	B	C	D	A	B	C	D
MOLD:									
Diameter, in.	2.8	4	6	6	6	4	6	4	6
Height, in.	10-12	4.58	4.58	4.58	4.58	4.58	4.58	4.58	4.58
Volume, cu. ft.	1/20- 1/24 *	1/30	1/13.3	1/13.3	1/13.3	1/30	1/13.3	1/30	1/13.3
LAYERS:									
Number, total	5	5	5	5	5	5	5	5	5
Surface area, sq. in.	7.1	12.6	28.3	28.3	28.3	12.6	28.3	12.6	28.3
Thickness, in.	2.25	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
EFFORT:									
Tamper blows per layer	20	25	56	56	56	25	56	25	56
Ft.-lbs. per cu. ft.	33,500 to 40,000	56,250	56,250	56,250	56,250	56,250	56,250	56,250	56,250
MATERIAL:									
Max. size (passing)	3/4"	# 4	# 4	3/4"	3/4"	# 4	# 4	3/4"	3/4"
Oversize correction	Yes	No	No	No	Yes	No	No	No	No
Reuse of material allowed	No	No	No	No	No	Yes	Yes	Yes	Yes
HYDRATION TIME:	No	0 to 36 hrs - Depends on classification				Minimum of 12 hrs for all materials			
MOISTURE CONTENT:	No ("Wet Method")	Yes, Method D2216 - 230 °F oven				Yes, 230 °F oven at least 12 hrs or const. mass			
METHOD CHOICE:	None	Use method A or B if none is specified Gives recommendations for methods C & D				Use method A if none is specified			

* Note: CT 216 does not require sample triming
- Tamper or rammer is the same for all tests; 10 lbs., 18" drop, 2 in. face dia.
- All tests except CT 216 allow use of mechanical rammer

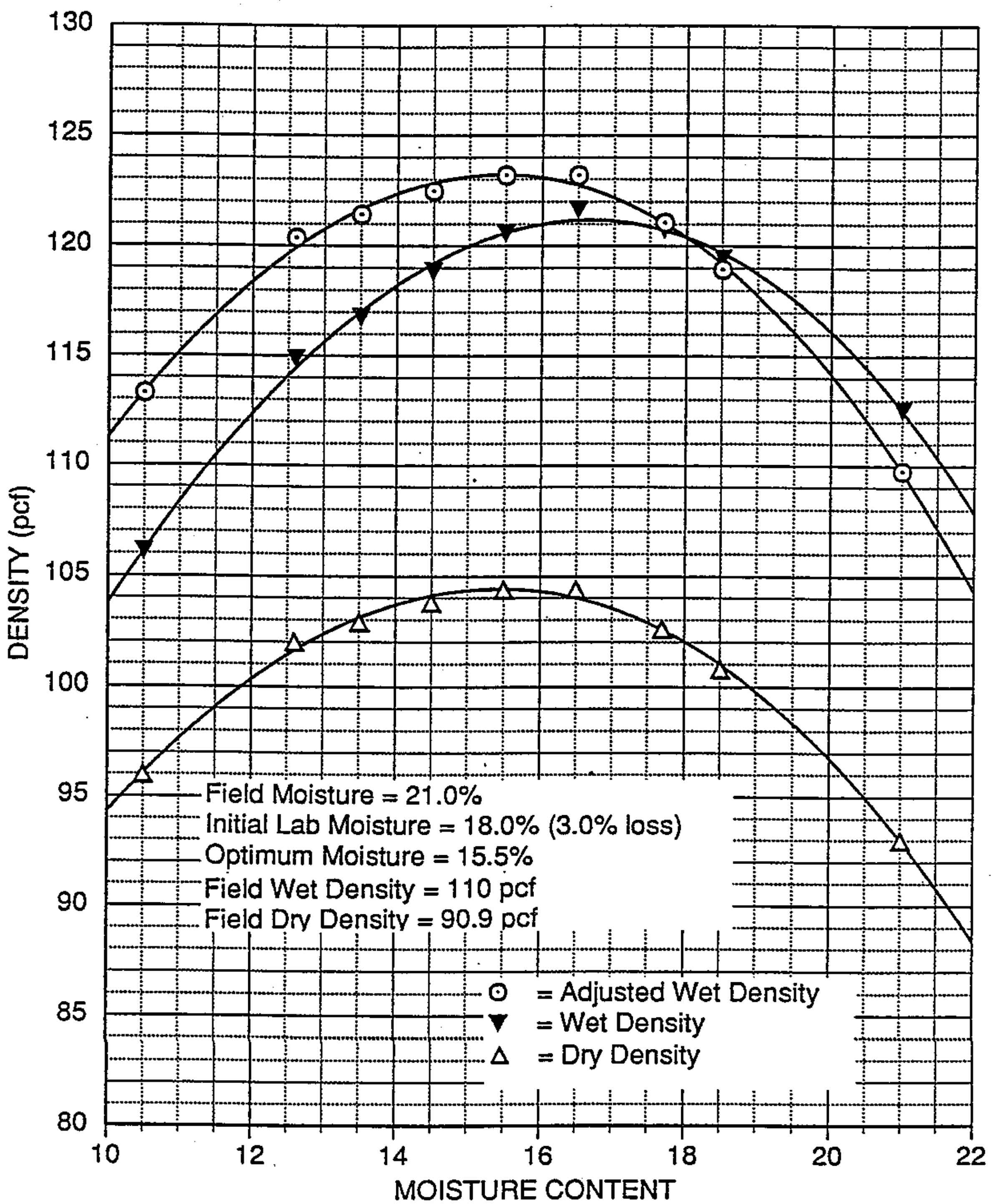
Figure 2



RC = Field Wet Den / Max Adjusted Wet Den = 110 / 126.5 = 87.0% (CORRECT RC)

Figure 3

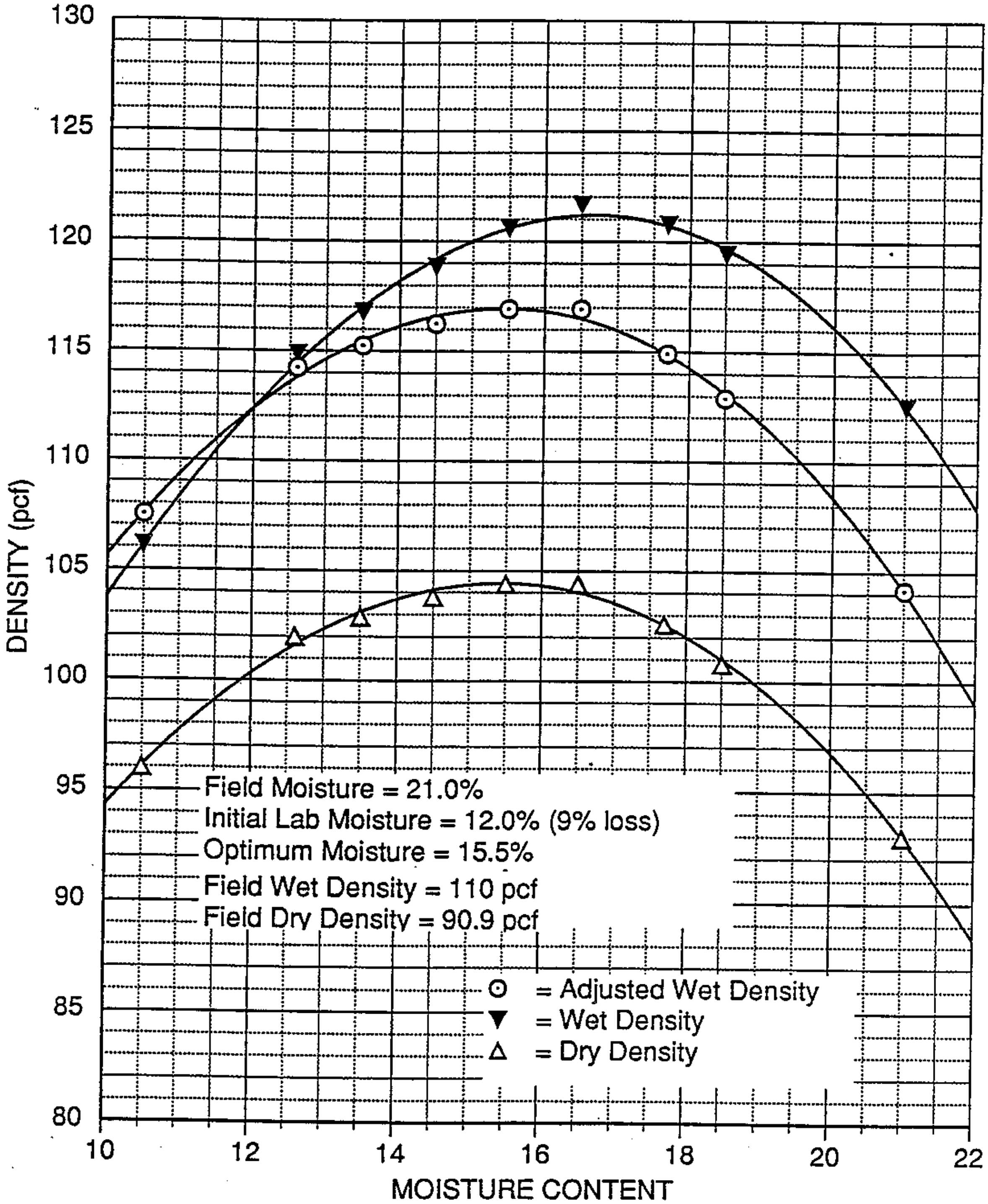
ERROR DUE TO MOISTURE DIFFERENCE BETWEEN FIELD AND LAB



RC = Field Wet Den / Max Adjusted Wet Den = 110 / 123.2 = 89.3%

Figure 4

ERROR DUE TO MOISTURE DIFFERENCE
BETWEEN FIELD AND LAB



RC = Field Wet Den / Max Adjusted Wet Den = 110 / 117.0 = 94.0%

Figure 5

State of California — **RELATIVE COMPACTION TEST – NUCLEAR** — Department of Transportation

Job Stamp	Contract	Test No.
	Type of Material	
	Material From	
	Impact by	Nuclear by
	Date	Date
Show test location and area limits	Non Biased Plan No.	Gage No.

IN-PLACE TEST BY NUCLEAR

	Site	Den. Ct. ___"D.T.	Std. Count Density
A	1		
	2		
	3		Σ
	4		F $\bar{X}$
			Moist Count
	5		1
			2
	6		3
			4
	7		5
			6
	8		7
			8
B	Σ		Σ
C	$\bar{X}$		G $\bar{X}$
CR(C/F)			CR(G/I)
D	$\bar{X}$ Den. gm/cc		H $\bar{X}$ H_2O g/cc
E	$\bar{X}$ Den. Corr. for Moist** ±		

**E = D ± Diff. Bet. $\bar{X}$ Moist. Fr. Common TM & H

Percent Relative* Compaction		Spec.	Individual	
			Moving Av.	

*E/K for 10% ≤ + 3/4"; E/W for > 10% + 3/4"

If Common Test Maximum is used ($\bar{X}$) K or W = | $\bar{X}$ H_2O =

From Tests | Dated

Remarks:

IMPACT TEST DATA

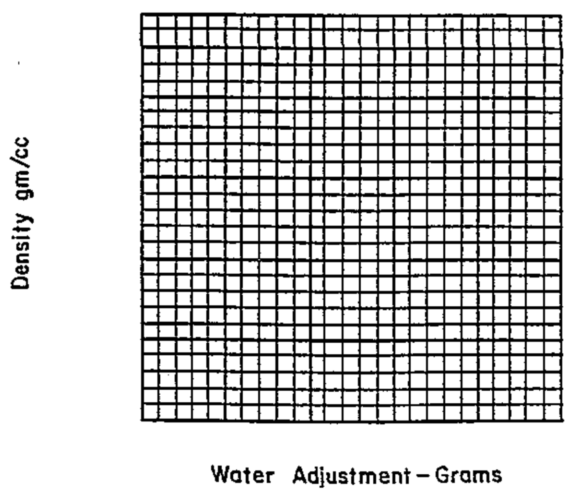
J	Initial Wet Weight of Test Specimen (Grams)				
	Specimen	1	2	3	4
	Water Adjustment				
	Tamper Reading				
K	Wet Density (gm/cc)				

K From Table 1 Test Method 216. Highest Density is Test Max.

L	+ 3/4" Agg. Adj.
	% + 3/4" (Q) Adj.
	20 or less 1.00
	21-25 .... 0.99
	26-30 .... 0.98
	31-35 .... 0.97
	36-40 .... 0.96
	41-45 .... 0.95
	46-50 .... 0.94
	Std. Count Moist.
	Σ
I	$\bar{X}$

SAMPLE FOR ROCK CORRECTION

M	Total Sample Wt. (gm)		
N	+ 3/4" Wt. in Air (gm)		
O	+ 3/4" Wt. in Water (gm)		
P	+ 3/4" Vol. (cc)	(N–O)	
Q	% + 3/4"	100(N/M)	
R	% – 3/4"	(100–Q)	
S	Density of + 3/4"	(N/P)	
T	% + 3/4" / Den. of + 3/4"	(Q/SL)	
U	% – 3/4" / Den. of – 3/4"	(R/K)	
V	Sum of T and U	(T+U)	
W	Adjusted Density gm/cc	(100/V)	



TL-2148 (Rev. 6/82)

Figure 6

State of California	FIELD WET DENSITY - NUCLEAR GAGE CTM 231	Department of Transportation

Job Stamp	Contract	Test No.
	Type of Material	
	Material Source	
	Performed By	
	Date	
	Non-biased Plan No.	Gage No.

Test location and area limits (CTM122)

A	Std. Count Density	
B	Std. Count Moisture	

	Test Site	1	2	3	4	5	6
C	Density Count						
D	Density Count Ratio (C/A)						
E	Wet Den. p.c.f. (den. table)						
F	Moisture Count						
G	Moisture Count Ratio (F/B)						
H	Moist. in p.c.f. (moist table)						
I	Dry Density p.c.f. (E -- H)						
J	Moisture % (E / I--1)						

K	Test Area Wet Density p.c.f. (average line E)	
L	Test Area Dry Density p.c.f. (average line I)	
M	Test Area Moisture in pcf (average line H)	
N	Test Area Moisture % (average line J)	

Remarks:

MR - 2148 A (Draft 4/92)

Figure 7 - Test Form - Side A

State of California **LABORATORY MAXIMUM ADJUSTED WET DENSITY - CTM 216** Department of Transportation

Job Stamp	Contract	Test No.
	Performed By	
	Date	

METHOD A - CALIFORNIA IMPACT APPARATUS

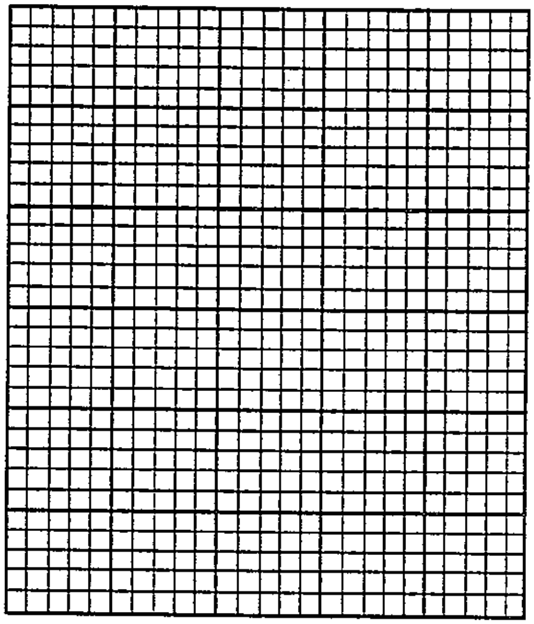
A	Initial Wet Weight of Test Specimen (grams)				
	Specimen	1	2	3	4
B	Water Adjustment (grams)				
C	Tamper Reading				
D	Wet Den (pcf)(A+B)/(Cx1.689)				
E	Adj Wet Den(pcf)(table 1) *				

* or E = A / (C x 1.689)

METHOD B - 4-INCH PROCTOR MOLD

F	Weight of Mold (grams)				
G	Initial Wet Weight of Test Specimen (grams)				
	Specimen	1	2	3	4
H	Water Adjustment (grams)				
I	%Added Water(z%)(H/Gx100)				
J	Weight of Mold and Soil (gm)				
K	Weight of Soil (gm) (J - F)				
L	Wet Density (pcf) (K / 15.12)				
M	Adj Wet Den(pcf)(L /(1+I)				

MOISTURE - DENSITY CURVE



DRY DENSITY BASIS

	Specimen	1	2	3	4
N	Moisture Content **				
O	Dry Den (pcf) ((D or L)/(1+N)				

** From CT 226 or N=(B or H x (1+Test Area Moist %) /A or G)+Test Area Moist % ***

PERCENT RELATIVE COMPACTION - CTM 122

a	Test Area Wet Den (pcf) (CTM231 ***)	
b	Max Adjusted Wet Den (from line E,M or Z)	
PERCENT RELATIVE COMPACTION	(a / b x 100)	SPEC

*** from reverse side of test form

ROCK CORRECTION (use if > 10% material is + 3/4")

P	Total Sample Weight	(grams)	
Q	+ 3/4" Weight in Air	(grams)	
R	+ 3/4 " Weight in Water	(grams)	
S	+ 3/4" Volume (cc)	(Q - R)	
T	% + 3/4"	(Q / P x 100)	
U	% - 3/4"	(100 - T)	
V	Density of + 3/4"	(Q / S)	
W	% +3/4" / Density of +3/4"(T/(V x Adj.factor below))		
X	% - 3/4" / Density of - 3/4"	(U / E,O or M)	
Y	Sum of W and X	(W + X)	
Z	Corrected Max. Adj. Wet Density (pcf)	(6240 / Y)	

+3/4" Aggregate Adjustment

% + 3/4"(T)	Adj. Factor
20 or less	1.00
21 - 25	0.99
26 - 30	0.98
31 - 35	0.97
36 - 40	0.96
41 - 45	0.95
46 - 50	0.94

COMMON MAX ADJUSTED WET DENSITY - CTM 122

c	Test No (previous test areas)		
d	Test Area Moisture (pcf)		
e	Max. Adj. Wet Density (pcf)		
f	Common Test Area Moisture (avg line d)		
g	Common Max. Adj Wet Density. (avg line e)		
h	Test Area Moisture in pcf (CTM 231- line M ***)		
i	Moisture Correction (f - h)		
j	Density Corrected for Moisture Difference (a + i)		
PERCENT RELATIVE COMPACTION	(j / g x 100)		SPEC

Remarks:

MR - 2148B (Draft 4/92)

Figure 8 - Test Form - Side B

DEPARTMENT OF TRANSPORTATION

DIVISION OF NEW TECHNOLOGY, MATERIALS AND RESEARCH
P.O. Box 19128
Sacramento, California 95819
(916) 739-2400

California Test 122
(Draft New. 10/91)

METHOD FOR DETERMINATION OF RELATIVE COMPACTION OF UNTREATED AND TREATED SOILS AND AGGREGATES

A. SCOPE

This procedural method shall be used to determine the relative compaction of untreated and treated soils and aggregates by utilizing the results from California Tests 216 and 231.

Relative compaction in this method is defined as the ratio of the field wet density of a soil or aggregate to the laboratory maximum adjusted wet density of the same soil or aggregate when compacted by a specific test method. This can be shown to be equivalent to relative compaction as determined based on dry densities. A mathematical proof for this is presented in Appendix A. Adjusted wet density is the wet density of a compacted specimen expressed in terms of the fill water content. Whereas the "true" maximum wet density and maximum dry density do not occur at the same moisture content, the maximum adjusted wet density occurs at the same moisture content as the maximum dry density.

This "wet method" allows determination of relative compaction without knowing moisture contents. This significantly reduces the time to obtain test results, which is important for construction monitoring purposes. The test method requires that laboratory compaction tests be performed for each field density test, except under very limited conditions such as base courses or very uniform materials, as discussed in Section E.

The field wet density shall be determined in accordance with California Test 231. The laboratory maximum adjusted wet density shall be determined in accordance with California Test 216.

This standard may involve hazardous materials, operations and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of whoever chooses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. Those using this standard do so at their own risk.

B. NUMBER AND LOCATION OF FIELD WET DENSITY TESTS - AREA CONCEPT

1. A statistical based sampling procedure known as the area concept will be used with this method. The engineer will determine from a series of density tests whether to accept or reject a designated area. The engineer shall determine the area by inspection, based on uniformity of the factors affecting compaction. Insofar as possible, the area designated shall be generally homogeneous for both character of material and conditions of production and compaction. The materials for the designated area shall be of the same soil type and moisture content based on visual classification. Portions of the area which may be observed or suspected to be different from the area as a whole will be excluded from the test. Portions of a test area that have been excluded may be designated as separate test areas. If a relative compaction test is desired for these different portions, they shall be designated as a separate test area or areas and tested separately. Do not designate test areas which include: (1) materials from separate sources unless such materials were intermixed during placing of the compacted area; (2) materials which were placed and compacted by different types of operations or processes; or (3) material placed during different periods of production or in nonadjacent areas.

2. Select a minimum of 5 test sites for test areas 1000 square yards or more by using a set of 10 random sample plans and follow instructions given in Appendix B.

Determine the field wet density in accordance with California Test 231. A plan showing the test location and limits is to be drawn at the top of test form MR-2148A. (figure 1). The wet densities for each test site are determined and then averaged to establish a field wet density representing the designated area.

If the designated test area, described in B-1, is of limited size (e.g. structure backfill, short length of shoulders, or other areas less than 1000 square yards) then a minimum of three test sites are required.

C. DETERMINATION OF LABORATORY MAXIMUM ADJUSTED WET DENSITY

1. For all treated and untreated soils and aggregates, except Class A Cement Treated Bases, obtain equal representative portions of material from each field density test site within the area and thoroughly mix together to form a composite bulk sample 20 to 25 lbs (9 to 11 kg) in weight. Determine the laboratory maximum adjusted wet density (pounds per cubic foot, pcf) on the composite sample in accordance with California Test 216. Record the data on Form MR-2148B. (Figure 2). The moisture content of the composite sample must be maintained in the same state as when the field density tests were performed. If the impact test result is to be used as a "common" maximum adjusted wet density, the moisture content must be determined for each field density test in an area and be averaged (see Section E).

D. PERCENT RELATIVE COMPACTION

1. Calculate percent relative compaction as follows:
Percent relative compaction =
((Field Wet Density)/(Maximum Adjusted Wet Density)) X 100)

2. The relative compaction of the test area must be at or above the specified minimum relative compaction for acceptance of the compaction in the area. The percent relative compaction value is calculated to the nearest 0.1 percent and then reported as a whole number. For rounding the percent relative compaction value ; if the computed value ends in a number with a fractional portion 0.5 or greater, report as the next higher whole number. If the computed value ends in a number with fractional portion less than 0.5, report without changing the whole number.

Example:

Computed Value	Reporting Value
94.5 to 95.0%	95%
95.0 to 95.4	95%

E. COMMON MAXIMUM ADJUSTED WET DENSITY

1. In cases where the materials being tested for relative compaction are very uniform, such as with manufactured aggregate bases, it is permissible to use the same maximum adjusted wet density (CTM 216) for use in different areas in lieu of that specified in Section C. This is known as a "common" maximum adjusted wet density. If a "common" maximum adjusted wet density is to be used for a test area, it must meet certain criteria. In addition, a correction for differences in moisture contents must be made by determining field moisture contents. The field moistures are determined in pcf in accordance with California Test 231 using a nuclear gage. The test area material must comply with the following general criteria:

a. It must be from the same general source (excavation area, balance point, plant, etc.)

b. It must generally have the same visual characteristics of color, gradation and type of soil.

2. A "common" maximum adjusted wet density is initially established by averaging 2 consecutive maximum adjusted wet densities which are within 3.1 pcf (0.05g/cc) and performed within 3 days of each other. The average moistures between the areas represented by the 2 consecutive maximum wet densities must also be within 3.1 pcf(0.05g/cc) .

3. Anytime that a maximum adjusted wet density is determined for an area, it shall be used to calculate the percent relative compaction for that area.

4. A "check" maximum adjusted wet density must be performed at least every 7th calendar day or after the "common" maximum adjusted wet density has been used for 14 areas, whichever comes first.

a. If the "check" test is within 3.1 pcf (0.05g/cc) moisture and density of the "common" density, the two values are averaged to establish a "common" density and average moisture. If it is not, maximum adjusted wet densities must be determined for each compaction test area until the criteria for E-2 of this test method are met.

5. If average relative moistures between areas differ and a "common" maximum adjusted wet density is to be established, a correction is applied. The example in Appendix C illustrates how maximum adjusted wet densities are corrected for differences in moisture to obtain the "common" maximum adjusted wet density.

Any time the engineer judges conditions have changed, a new maximum adjusted wet density should be established by performing laboratory compaction tests.

REFERENCES

California Tests 111, 121, 216, 231,and 312.

End of Text (2 pages) on Calif. Test 122

APPENDIX A

Wet Procedure and Maximum Adjusted Wet Density

Reports by Caltrans explaining the "wet" procedure have used what is called the "relative volume concept (T.W. Smith, W.S. Maxwell *Relative Compaction Of Soils Containing 3/4" Rock.* Calif. Division of Highways. Highway Research Report. July 1968; T.W. Smith, M. Hatano. *Rapid Compaction Control Testing Using Wet Method* Transportation Research Record. 1974). Since the California Impact Apparatus is a variable volume compaction cylinder, the volume of soil removed in the field, as determined by a sand cone test, for example, could easily be compared to a minimum volume obtained in the laboratory compaction test. The ratio of the field volume to the laboratory minimum compacted volume was shown to be equal to relative compaction based on dry densities. Unfortunately, this straight forward explanation of the "wet" procedure, using a variable volume compaction cylinder and a sand cone test, cannot be easily applied to tests using a fixed volume compaction cylinder (ASTM and AASHTO) and field densities as determined by a nuclear gage test.

The early test procedures of CTM-216F utilized a term called "adjusted" wet density. The "adjusted" wet density in this procedure is identical to J. W. Hilf's "converted" wet density in his "wet" procedure, which was developed for the fixed volume Proctor compaction cylinder (J.W. Hilf. *A Rapid Method of Construction Control for Embankments of Cohesive Soils.* Bureau of Reclamation. Sept 1961). In both "wet " procedures, relative compaction is determined from the ratio of the field wet density to the laboratory compacted maximum "adjusted" or "converted" wet density. The "adjusted" wet density of a lab compacted specimen is the wet density expressed in terms of the field water content. It is not a true wet density except for a compaction specimen compacted at the field moisture content.

If the "wet" procedure is explained in terms of "adjusted" wet densities, instead of the "relative volume concept", it can be more broadly applied to wet densities, i.e., fixed volume laboratory compaction and nuclear gage density tests. The following mathematical proof equates relative compaction based on dry densities to that from wet densities.

By definition:

$$\text{Relative Compaction (R.C.)} = \frac{\text{Field Dry Density}}{\text{Lab Compacted Maximum Dry Density}} = \frac{\gamma_{df}}{\gamma_{dm}}$$

For the general case of any lab compacted specimen, the ratio (D) of field dry density (γ_{df}) to lab compacted dry density (γ_d) is:

$$D = \frac{\gamma_{df}}{\gamma_d} = \frac{\gamma_{df}(1+w_f)}{\gamma_d(1+w_f)} = \frac{\gamma_f}{\gamma_d(1+w_f)}$$, where γ_f is the field wet density

and w_f the field moisture content.

APPENDIX A

Applying algebraic manipulation to the term in the denominator :

$$\gamma_d\,(1+w_f) = \gamma_d\,(1+w_f)\,\frac{(1+w)}{(1+w)} = \frac{\gamma_d\,(1+w)}{\frac{(1+w)}{(1+w_f)}} = \frac{\gamma}{\frac{(1+w)}{(1+w_f)}} = \frac{\gamma}{1+\frac{(w-w_f)}{(1+w_f)}} = \frac{\gamma}{1+\frac{(w-w_f)W_s}{(1+w_f)W_s}}$$

γ_w is the wet density, W_s is the weight of solids, and w is the moisture content of the specimen

$$\gamma_d\,(1+w_f) = \frac{\gamma}{1+\frac{(wW_s - w_f\,W_s)}{W_s(1+w_f)}} = \frac{\gamma}{1+\frac{\Delta W_w}{W_{tf}}} = \frac{\gamma}{1+z},$$

where z is referred to as added water, as a percentage of the field wet weight.

$$z = \frac{\Delta W_w}{W_{tf}} = \frac{\text{change in weight of water (added or subtracted water)}}{\text{total wet weight at field moisture content (original wet weight)}}$$

$\frac{\gamma}{1+z} = \gamma_{adj}$, Where γ_{adj} is defined as the Adjusted Wet Density or the wet density expressed in terms of the field water content.

Therefore, $\gamma_d\,(1+w_f) = \gamma_{adj}$ and, $D = \frac{\gamma_f}{\gamma_d(1+w_f)} = \frac{\gamma_f}{\gamma_{adj}}$

For the special case of the maximum dry density (γ_{dm}) :

$\gamma_{dm}\,(1+w_f) = (\gamma_{adj})_m$, where $(\gamma_{adj})_m$ is the maximum adjusted wet density and:

$$\text{Relative Compaction (R.C.)} = D = \frac{\gamma_f}{(\gamma_{adj})_m} = \frac{\text{Field Wet Density}}{\text{Lab Maximum Adjusted Wet Density}}$$

The maximum adjusted wet density ($(\gamma_{adj})_m$) can be obtained by plotting γ_{adj} verses z or any other convenient variable, such as the change in weight of water, which is the practice in CTM 216.

The following relationship shows that the densities obtained in the current version of CTM 216 are the adjusted wet densities as defined above. Table 1 of CTM 216, which is titled California Impact Test Apparatus Conversion Table, uses the tamper reading and weight of test core (compacted specimen) in grams to obtain density in grams per cubic centimeter. The tamper reading corresponds to the compacted total volume (V_t), and the weight of the test core is the total weight at the field moisture content (W_{tf}). Table 1 of CTM 216 simply divides W_{tf} into V_t to obtain the adjusted wet density as follows:

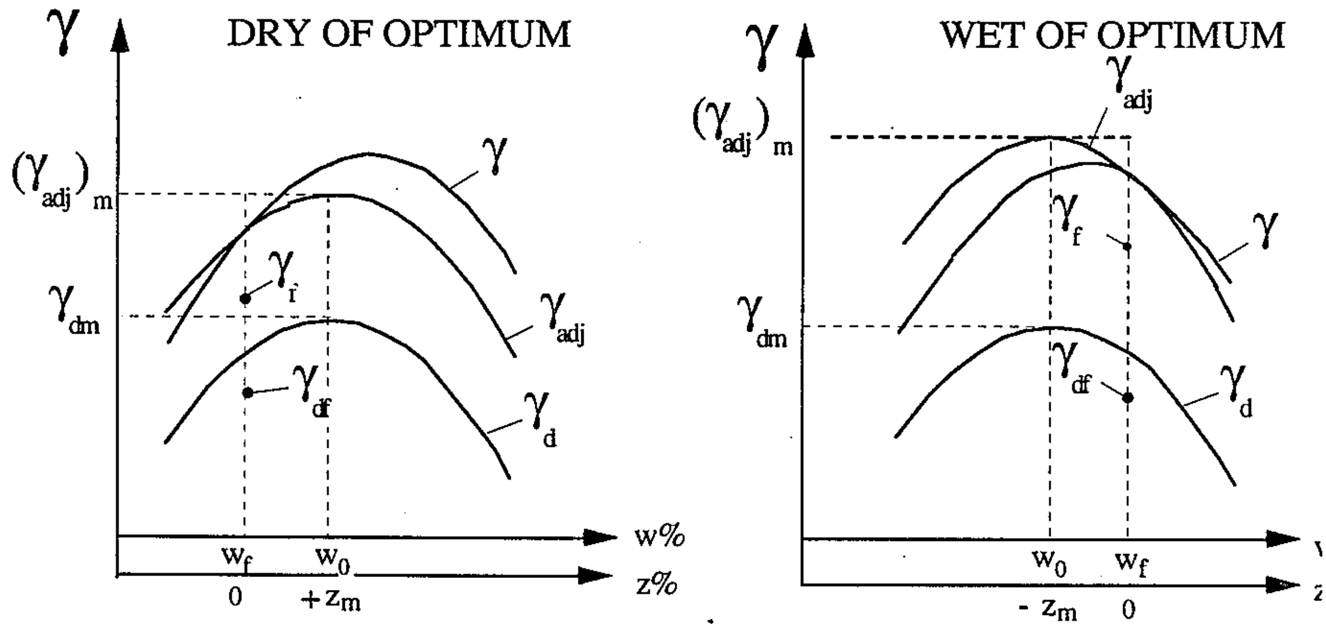
$$\frac{W_{tf}}{V_t} = \frac{W_s\,(1+w_f)}{V_t} = \gamma_d\,(1+w_f) = \gamma_{adj}$$

APPENDIX A

Using a fixed volume compaction cylinder, adjusted wet density is calculated from the relationship:

$$\gamma_{adj} = \frac{\gamma}{1+z}$$

The following moisture-density compaction curves illustrate the relationship between dry density, wet density and adjusted wet density.



MOISTURE-DENSITY COMPACTION CURVES

$$\text{Relative Compaction} = \frac{\gamma_f}{(\gamma_{adj})_m} = \frac{\gamma_{df}}{\gamma_{dm}}$$

γ_d = Lab Compacted Dry Density

γ = Lab Compacted Wet Density

γ_{dm} = Lab Compacted Maximum Dry Density

γ_{adj} = Adjusted Wet Density

$(\gamma_{adj})_m$ = Lab Maximum Adjusted Wet Density

γ_{df} = Field Dry Density

γ_f = Field Wet Density

w = Moisture Content of Lab Compacted Specimen

w_f = Field Moisture Content

z = added water, as a percentage of the field wet weight

z_m = z corresponding to the maximum dry density

Note that the maximum wet density does not occur at the same moisture content as the maximum dry density and maximum adjusted wet density. If the "true" wet density was erroneously used, the diagrams show the effect on relative compaction for field moistures wet and dry of optimum.

NONBIASED SAMPLE PLANS

Once an area is selected on the basis of uniformity, nonbiased location of measurement sites is required for applying statistical control procedures. The nonbiased sample location plans will randomly locate the approximate test sites.

Note: The number of test sites must be determined after the area has been determined and *before* any tests are performed.

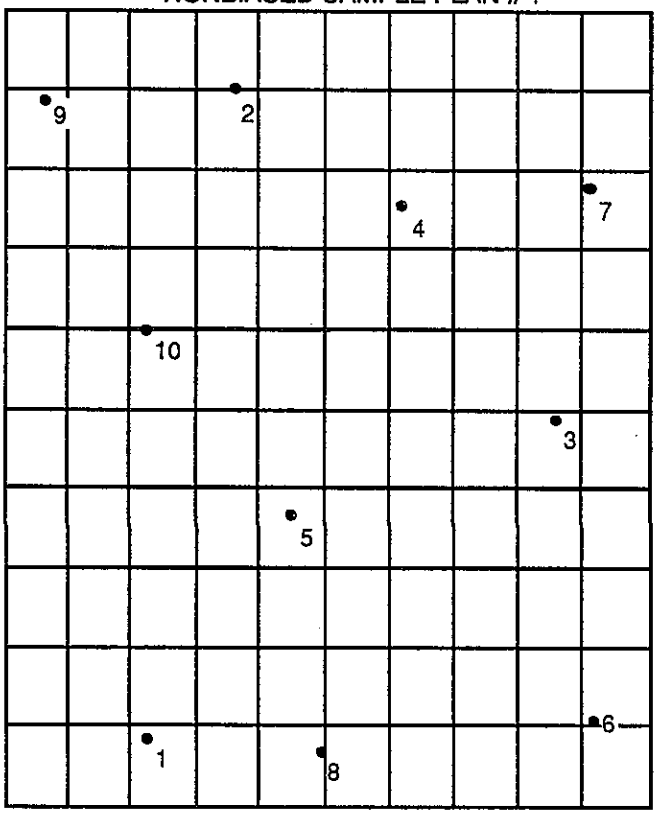
PROCEDURE FOR USE OF NONBIASED SAMPLE

1. One of the following 10 sample plans is selected at random. This may be done by using the last digit from the first nuclear gage reading taken for the daily standard count to determine the nonbiased sample plan from which to select the site locations for the first area. For subsequent areas use the last digit from the second, third, and fourth readings. If five through nine areas are tested, use the second to the last digit from the first through the fourth readings taken for the daily count.

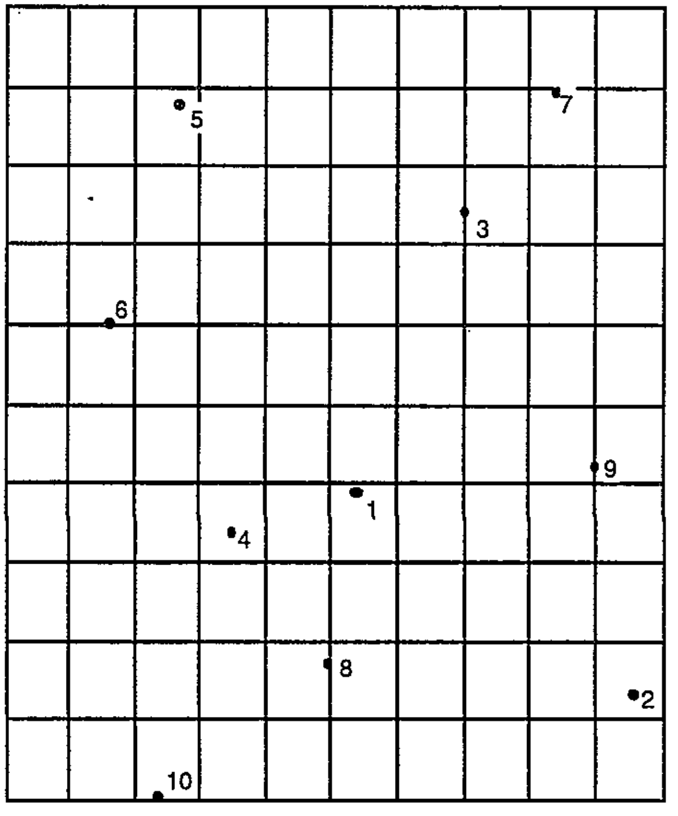
2. Visualize the plan as a map of the area to be sampled.

3. Each dot represents a test site. There are 10 dots numbered from one through ten. If you are to take a five site test series, then use the dots numbered one through five.

NONBIASED SAMPLE PLAN # 1

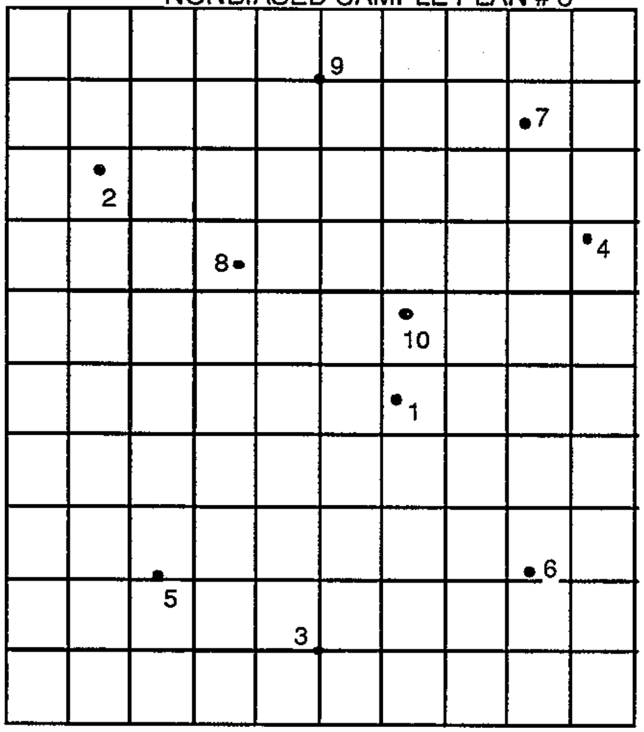


NONBIASED SAMPLE PLAN # 2



APPENDIX B

NONBIASED SAMPLE PLAN # 3



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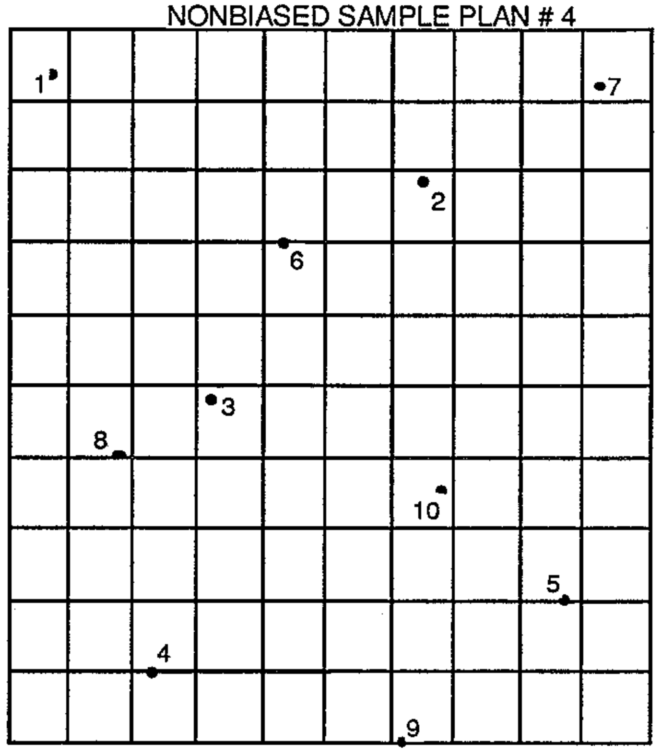

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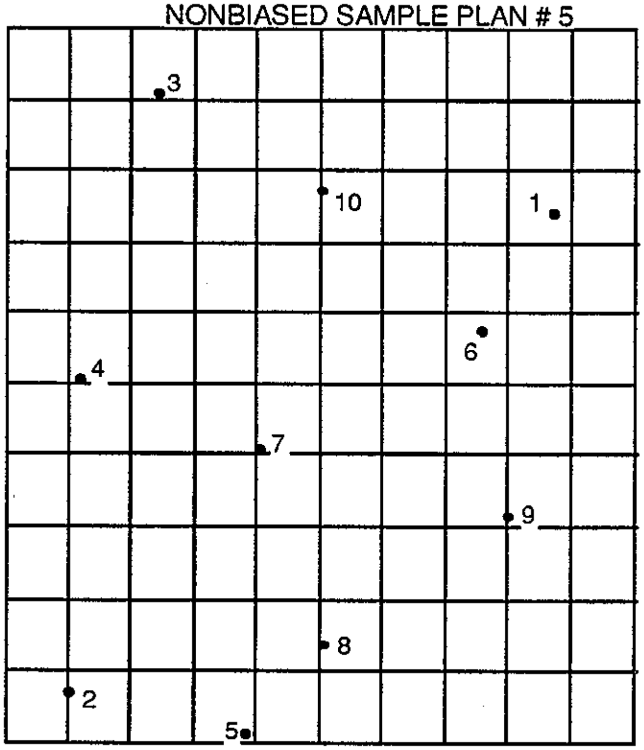

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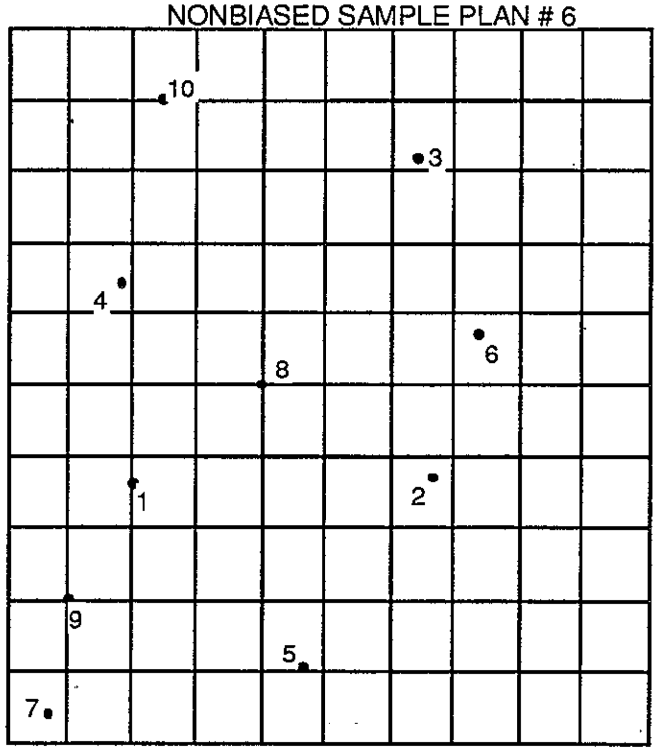
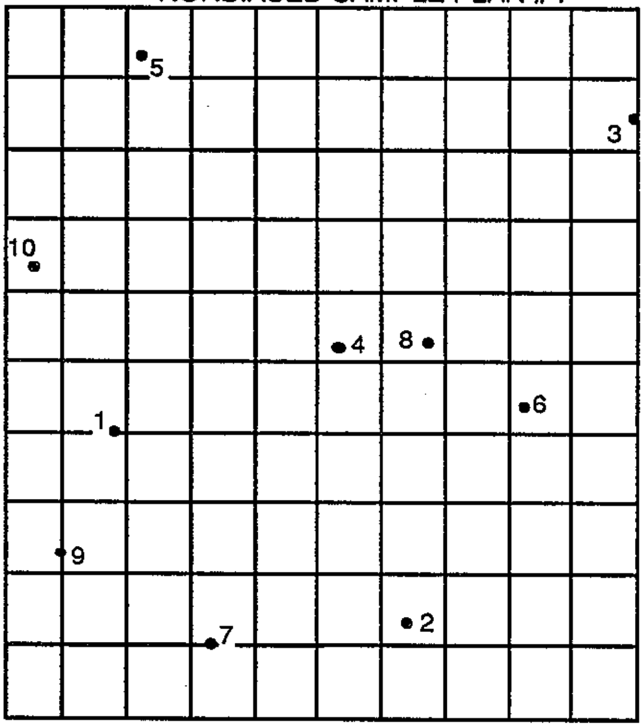


APPENDIX B

NONBIASED SAMPLE PLAN # 7



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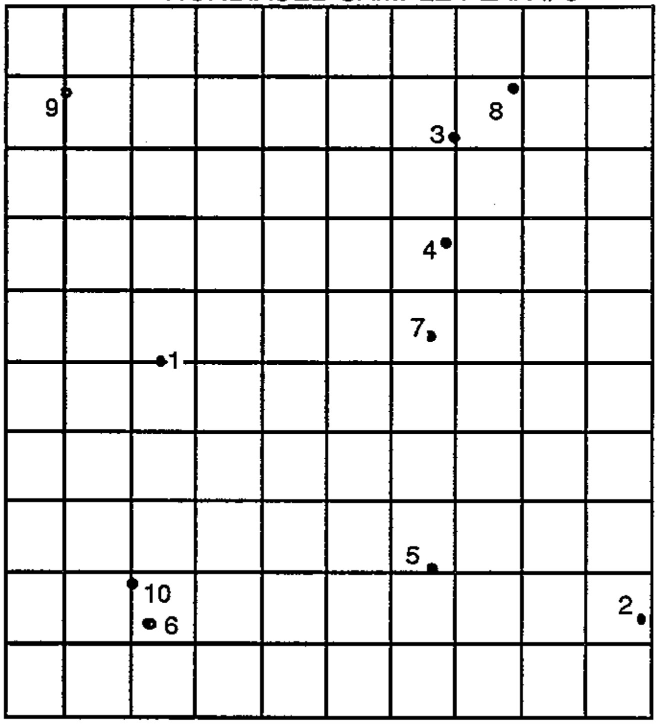
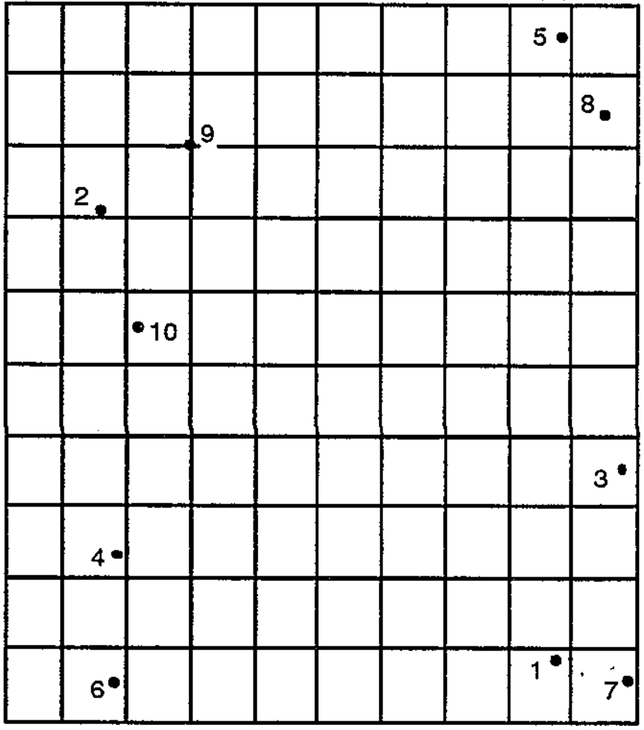
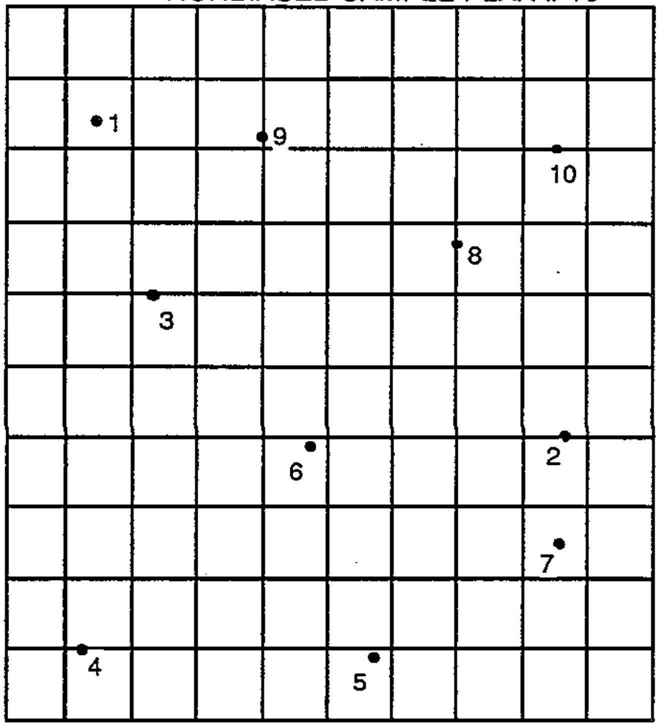


NONBIASED SAMPLE PLAN # 9



NONBIASED SAMPLE PLAN # 10



APPENDIX C

Example: Determination Of Common Maximum Adjusted Wet Density

	Area I	Area II	Area III	Area IV	Area V	Area VI
Date	4-18-89	4-19-89	4-20-89	4-21-89	4-25-89	4-26-89
Average Field Wet Density (pcf)	127.4	134.2	128.6	129.9	132.4	131.7
Average Field Moisture (pcf)	5.62	6.87	8.74	4.99	8.12	6.24
Maximum Adjusted Wet Density (pcf)	134.2	137.3	_____	_____	134.8	_____
Common Maximum Adjusted Wet Density (pcf)	_____	_____	135.8	135.8	_____	135.3
(Average Moisture)	_____	_____	(6.25)	(6.25)	_____	(7.18)
Moisture Correction	_____	_____	-2.50	+1.25	_____	+0.94

a. Area I
% Relative Compaction = (127.4 / 134.2) * 100 = 95%

b. Area II
% Relative Compaction = (134.2 / 137.3) * 100 = 98%

c. Area III
Moisture Correction = ([5.62 + 6.87] / 2) - 8.74 = - 2.50
Common Max Density = (134.2 + 137.3) / 2 = 135.8
% Relative Compaction = ([128.6 - 2.50] / 135.8) * 100 = 93%

d. Area IV
Moisture Correction = ([5.62 + 6.87] / 2) - 4.99 = +1.25
% Relative Compaction = [129.9 + 1.25] / 135.8) * 100 = 97%

e. Area V
% Relative Compaction = (132.4 / 134.8) * 100 = 98%

f. Area VI
Moisture Correction = ([8.12 + 6.24] / 2) - 6.24 = + 0.94
New Common Max Density = (135.8 + 134.8) / 2 = 135.3
% Relative Compaction = ([131.7 + 0.94] / 135.3) * 100 = 98%

DEPARTMENT OF TRANSPORTATION

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California Test 216
(Draft Rev. 1992)

METHOD OF TEST FOR LABORATORY MAXIMUM ADJUSTED WET DENSITY OF UNTREATED AND TREATED SOILS AND AGGREGATES

SCOPE

These test methods shall be used to determine the laboratory compacted maximum adjusted wet density of treated and untreated soils and aggregates. Adjusted wet density is the wet density of a compacted specimen expressed in terms of the field in-place water content. The maximum adjusted wet density is used to determine percent relative compaction using the "wet" method procedure presented in California Test 122. Although the "true" maximum wet density and maximum dry density do not occur at the same moisture content, the maximum adjusted wet density occurs at the same moisture content as the maximum dry density. This allows determination of relative compaction without knowing moisture contents, substantially reducing the time required to obtain test results. A discussion of the "wet " procedure is presented in Appendix A of CTM 122.

Method A of this test method utilizes the California impact apparatus and Method B utilizes the 4-inch Proctor compaction mold. Method A is essentially the same as the compaction portion of the previous California Test 216.

A basic sample of soil is divided into smaller portions. These portions are prepared with varying moisture contents to form test samples, which are individually compacted by a uniform compactive effort, to determine the maximum adjusted wet density for the particular soil under consideration.

This standard may involve hazardous materials, operations and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of whoever chooses to use this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. Those using this standard do so at their own risk.

METHOD A - CALIFORNIA IMPACT APPARATUS

A. APPARATUS

1. The standard California impact compaction test apparatus consisting of a split cylindrical mold, a 10 pound (4.54 kg) tamper, a metal piston, and a piston handling rod.

2. A concrete base block, or an equally rigid body, approximately 1 cubic foot in size.

3. A balance or scale of at least 3 kg. capacity sensitive to 1 g.

4. Miscellaneous mixing bowls, spoons and spatulas.

NOTE; Specifications and calibration of the impact compaction apparatus are covered in California Test 110.

B. BULK SAMPLE

Obtain a bulk sample of soil 20 to 25 pounds (9 to 11.3 kg) in weight at the site of the in-place density test. This is done by obtaining representative samples of equal weight at each in-place density test site and combining them into one composite bulk sample. For this wet weight basis method of test, it is essential that the bulk sample be preserved at the same moisture as prevailed at the time of excavation. Use only tightly covered waterproof containers and protect from high temperature.

C. PREPARATION OF TEST SAMPLES

1. Separate the bulk sample on the 3/4 inch (19 mm) sieve, weigh both the retained and the passing fractions and compute the percentage retained in terms of wet weight of the total basic sample. If 10 percent or more of the total weight is retained on the 3/4 inch (19 mm) sieve, follow the test procedure set forth in Section G of this Method A. If the retained 3/4 inch (19 mm) fraction comprises less than 10 percent by weight of the total basic sample, discard it and divide the passing 3/4 inch (19 mm) fraction into representative test samples of exactly equal weight, each sufficient in amount to form a compacted test specimen 10 to 12 inches (25.4 to 30.5 cm) in height when compacted as specified in the following Section E.

2. It is of the utmost importance that all of the basic sample material be thoroughly mixed. In addition, each test specimen must be representative of the mass, be of equal weight, be weighed in immediate succession, and be placed at once in covered individual containers.

3. The correct weight for each test specimen will depend on the soil type and the moisture content; 2300 to 2700 grams wet weight is the usual range of weight.

4. Record the actual weight of the individual test specimens on line "A" of form MR-2148B,as illustrated in the sample report of Figure 1.

D. COMPACTION OF TEST SPECIMENS

1. Divide one of the test specimens prepared as outlined in the foregoing Section D into five approximately equal portions by either weight or volume measurement. Place one portion in the test mold and compact it with 20 blows of the tamper dropping free from a height of 18 inches (45.7 cm) above the surface of the material in the mold. Repeat this operation for each of the remaining four portions. After the compaction of the fifth portion, place the piston in the mold and level the top of the compacted specimen with five blows of the tamper dropping free from a height of 18 (45.7 cm) inches above the surface of the piston.

2. With the tamper foot resting on the piston atop the compacted test specimen, read the graduated tamper shaft to the nearest graduation at a point level with the top of the mold. Enter this value on line "C" of Form MR-2148B.

3. Obtain the adjusted wet density in pounds per cubic foot from Table 1 corresponding to the tamper shaft graduation reading and record it on line "E".

4. Save the specimen temporarily for possible later use. (See first paragraph of Section E of this Method A).

5. Adjust the moisture contents of the remaining test samples to satisfy the following conditions:

a. The object is to have at least one test sample with a moisture content below test optimum, one close to optimum and one above optimum, at about 2 percent moisture content increments, with a minimum of three test samples.

While the actual moisture contents will not be known, the moisture content of the test specimen with the highest adjusted wet density is the test optimum moisture content even though the moisture content is unknown. Therefore, the primary objective is to have a number of test specimens and a range of moisture contents such that at least one specimen will be compacted at a moisture content less than, and one at a moisture content greater than the moisture content of the specimen having the highest adjusted wet density. If this condition cannot be satisfied with the minimum three test specimens it will be necessary to fabricate additional specimens.

b. The first test sample is generally compacted at the moisture content present in the basic sample. If this sample appears to be considerably drier than the optimum, mix additional water into each of the remaining samples. If it appears to be definitely wetter than the optimum, reduce the moisture content of the other samples by aeration. Partial oven-drying may be used, but do not completely oven-dry the samples and then remix with water. If it appears to be close to the optimum, increase the moisture content of one of the remaining test samples and reduce it in the other one to bracket the initial sample thought to be at optimum.

c.The test optimum moisture content will usually be the minimum moisture content which will ball the soil readily when compressed into a roll by the grip of the hand, but still permit the roll to be broken without crumbling or pulverizing appreciably at the breaking point.

d. The base plate of the test mold normally shows indications of dampness when a soil is compacted at the test optimum moisture content. Free water on the base plate definitely denotes excessive moisture content. A dry, dusty base plate signifies a deficiency of water.

6. After adjustment of the moisture content, compact each of the remaining test samples in the mold, then record the tamper reading on line "C" and the corresponding adjusted wet density from Table 1 on line "E".

7. Regardless of the soil type or particle sizes involved, fresh soil (not soil from previously compacted specimens) must be used in the compaction of each test specimen. The compactive effort being equal for each layer, it is also important that the thickness of layers be equal to assure uniformity of compaction between test specimens.

8. Throughout the compacting operation the test mold must stand either on the standard concrete base block or on an equally rigid body.

9. In reassembling the test mold after removing a core, the wing nuts should be drawn up only finger tight. The purpose of the wrench is to release the mold. Excessive tightening of the nuts distorts the circular cross-section of the mold. In gauging the 18-inch (45.7 cm) height of fall for the tamper, the hook and rod arrangement provided for this purpose should be used.

E. MOISTURE CHANGE-DENSITY CURVE

A moisture-density curve is developed by plotting the adjusted wet density versus water adjustment in grams. The highest point on the curve represents the maximum adjusted wet density.

F. MOISTURE CONTENTS

The moisture content of the specimen with the highest wet density is the optimum moisture. The moisture content of the specimen compacted without addition or reduction of water will also represent the in-place moisture content of the soil at the test site. If either moisture contents are desired or needed, the determination is made in accordance with California Test 226. Once the moisture contents are determined, percent relative compaction can also be determined by relating in-place dry density to lab maximum dry density.

G. CORRECTION FOR OVERSIZE MATERIAL

1. The diameter of the test mold limits the size of particles which may be included in the test to that passing the 3/4 inch (19 mm) sieve. In those instances where the original material from which the test specimen samples are obtained contains 10 percent or more by weight of particles retained on the 3/4 inch (19 mm) sieve, a correction must be applied to the test.

The density correction is calculated by the following:

$$\text{Corrected Density} = \frac{100}{\frac{\%\ \text{of} -3/4''}{G_1} + \frac{\%\ \text{of} +3/4''}{YG_2}}$$

G_1 = Density of -3/4" material (compacted specimen)

G_2 = Density of +3/4" material
Y = Adjustment factor for + 3/4" aggregate

% of +3/4"	Y
20 or less	1.00
21-25	0.99
26-30	0.98
31-35	0.97
36-40	0.96
41-45	0.95
46-50	0.94

2. Record the total weight of excavated sample as shown on line "P" of Figure 1 (Form MR-2148B).

3. Separate the basic sample on the 3/4 inch (19 mm) sieve, wash the retained 3/4 inch (19 mm) material, remove excess surface water by rolling sample in a large, absorbent cloth. Weigh in air and record on line "Q" of Figure 1.

4. Weigh the retained 3/4 inch fraction in water and record on line "R" of Figure 1.

5. The impact test is performed on the passing 3/4 inch (19 mm) fraction as outlined in Section B through D.

6. The remainder of the calculations necessary to compensate for the retained 3/4 inch (19 mm) material are shown on lines "S" through "Z" of Figure 1.

7. When a number of tests on soil containing essentially the same nature of retained 3/4 inch (19 mm) material are anticipated, a constant may be developed to minimize the weighting in air and water operations.

H. SIMPLIFICATIONS FOR CONSTRUCTION CONTROL

Construction control by wet density tests may be expedited. If the relative compaction based on any test specimen density is below the specified minimum it may be immediately reported that the area under test has failed to meet the specifications. It is not necessary to fabricate additional test cores for the reason that if a higher wet density was reached with subsequent test cores the relative compaction based on this higher density would be still lower than that indicated by the single core. When the relative compaction indicated by a single test core is more than the minimum specified, additional cores are necessary to be certain that any increase in wet test maximum density attained with the subsequent cores does not lower the relative compaction value to below the specification minimum.

METHOD B - 4-INCH PROCTOR MOLD

A. APPARATUS

1. Specifications and calibration procedures for the 4.0-inch diameter cylindrical mold (Proctor mold), manual and mechanical rammers are in the ASTM D1557 test method (Modified Proctor). The manual rammer used with the Proctor mold requires a guide sleeve which shall provide sufficient clearance so that the free fall of the rammer shaft and head will not be restricted.

2. A stiff metal straightedge of any convenient length but not less than 10 in. (25.4 cm). The straightedge shall have a straightness tolerance of ±0.005 in. (±0.13mm) and shall be beveled if it is thicker than 1/8-inch (3 mm).

3. A concrete base block, or any equally rigid body, approximately 1 cubic foot in size.

4. A balance or scale of at least 3 kg. capacity sensitive to 1 g.

5. Miscellaneous mixing bowls, spoons and spatulas.

B. BULK SAMPLE

Obtain a bulk sample of soil 20 to 25 pounds (9 to 11.3 kg) in weight at the site of the in-place wet density test. This is done by obtaining representative samples of equal weight at each in-place density test site and combining them into one composite bulk sample. For this wet weight basis method of test, it is essential that the bulk sample be preserved at the same moisture as prevailed at the time of excavation. Use only tightly covered waterproof containers and protect from high temperature.

C. PREPARATION OF TEST SAMPLES

1. Separate the bulk sample on the 3/4 inch (19 mm) sieve, weigh both the retained and the passing fractions and compute the percentage retained in terms of wet weight of the total basic sample. If 10 percent or more of the total weight is retained on the 3/4 inch (19 mm) sieve, follow the test procedure set forth in Section G. If the retained 3/4 inch (19 mm) fraction comprises less than 10 percent by weight of the total basic sample, discard it and divide the passing 3/4 (19 mm) fraction into representative test samples of exactly equal weight, each sufficient in amount to form a compacted test specimen 5 inches in height when compacted as specified in the following Section E.

2. It is of the utmost importance that all of the basic sample material be thoroughly mixed. In addition, each test specimen must be representative of the mass, be of equal weight, be weighed in immediate succession, and be placed at once in covered individual containers.

3. The correct weight for each test specimen will depend on the soil type and the moisture content; 1900 to 2500 grams wet weight is the usual range of weight. The correct weight will provide sufficient amount of material to form a specimen slightly over the top of the mold, but not exceeding 1/4 -inch when compacted.

4. Record the initial weight of the individual test specimens on line G of form MR-2148B.

5. Record the weight of the test mold on line F.

D. MOISTURE ADJUSTMENT OF SPECIMENS

1. Adjust the moisture contents of the test samples to satisfy the following conditions:

a. The object is to have at least one test sample with a moisture content below test optimum, one close to optimum and one above optimum, at about 2 percent moisture content increments, with a minimum of three test samples. Smaller increments may be required for granular materials.

While the actual moisture contents will not be known, the moisture content of the test specimen with the highest adjusted wet density is the test optimum moisture content even though the moisture content is unknown. Therefore, the primary objective is to have a number of test specimens and a range of moisture contents such that at least one specimen will be compacted at a moisture content less than, and one at a moisture content greater than the moisture content of the specimen having the highest wet density. If this condition cannot be satisfied with the minimum three test specimens it will be necessary to fabricate additional specimens.

b. The first test sample is generally compacted at the moisture content present in the basic sample. If this sample appears to be considerably drier than the optimum, mix additional water into each of the remaining samples. If it appears to be definitely wetter than the optimum, reduce the moisture content of the other samples by aeration. Partial oven-drying may be used, but do not completely oven-dry the samples and then remix with water. If it appears to be close to the optimum, increase the moisture content of one of the remaining test samples and reduce it in the other one to bracket the initial sample thought to be at optimum.

c. The test optimum moisture content will usually be the minimum moisture content which will ball the soil readily when compressed into a roll by the grip of the hand, but still permit the roll to be broken without crumbling or pulverizing appreciably at the breaking point.

d. The base plate of the test mold normally shows indications of dampness when a soil is compacted at the test optimum moisture content. Free water on the base plate definitely denotes excessive moisture content. A dry, dusty base plate signifies a deficiency of water.

2. Record the weight of water added or removed from the specimen on line H. This value is divided by the initial weight on line G, to determine the moisture content as a percentage of the field wet weight (z%). This value, which is not the true moisture content, is recorded on line I.

E. COMPACTION OF TEST SPECIMENS

1. Attach the mold extension collar to the 4-inch diameter mold and compact each specimen in five layers of approximately equal height. Each layer shall receive 25 blows. The total amount of material

used shall be such that the fifth compacted layer is slightly above the top of the mold, but not exceeding 1/4- inch (6mm).

2. In operating the manual rammer, care shall be taken to avoid rebound of the rammer from the top end of the guidesleeve. The guidesleeve shall be held steady and within 5 degrees of vertical. The blows shall be applied at uniform rate not exceeding 1.4 seconds per blow and in such a manner as to provide uniform coverage of the specimen surface.

3. Following compaction, remove the extension collar; carefully trim the compacted specimen even with the top of the mold by means of the straightedge.

4. After cleaning off any soil on the base of the mold, record the total weight of the mold and soil on line J. Determine the final core weight of the specimen in grams and record on line K. Divide the final core weight by 15.12 to obtain the "true " wet density in pcf and record on line L. Divide the "true" wet density by 1 + z% to obtain the adjusted wet density in pcf and record on line M.

6. Regardless of the soil type or particle sizes involved, fresh soil (not soil from previously compacted specimens) must be used in the compaction of each test specimen. The compactive effort being equal for each layer, it is also important that the thickness of layers be equal to assure uniformity of compaction between test specimens.

7. Throughout the compacting operation the test mold must stand either on the standard concrete base block or on an equally rigid body.

F. MOISTURE CHANGE-DENSITY CURVE

A moisture-density curve is developed by plotting the adjusted wet density versus water adjustment in grams. The highest point on the curve represents the maximum adjusted wet density.

G. MOISTURE CONTENTS

The moisture content of the specimen with the highest wet density is the optimum moisture. The moisture content of the specimen compacted without addition or reduction of water will also represent the in-place moisture content of the soil at the test site. If either moisture content is desired or needed, the determination is made in accordance with California Test 226. Once the moisture contents are determined, percent relative compaction can also be determined by relating in-place dry density to lab maximum dry density.

H. CORRECTION FOR OVERSIZE MATERIAL

1. The diameter of the test mold limits the size of particles which may be included in the test to that passing the 3/4 inch (19 mm) sieve. In those instances where the original material from which the test specimen samples are obtained contains 10 percent or more by weight of particles retained on the 3/4 inch (19 mm) sieve, a correction must be applied to the test.

The density correction is calculated by the following:

$$\text{Corrected Density} = \frac{100}{\dfrac{\%\ \text{of-3/4"}}{G_1} + \dfrac{\%\ \text{of+3/4"}}{YG_2}}$$

G_1 = Density of -3/4" material (compacted specimen)

G_2 = Density of +3/4" material
Y = Adjustment factor for + 3/4" aggregate

% of +3/4"	Y
20 or less	1.00
21-25	0.99
26-30	0.98
31-35	0.97
36-40	0.96
41-45	0.95
46-50	0.94

2. Record the total weight of excavated sample as shown on line "P" of Figure 1 (Form MR-2148B).

3. Separate the basic sample on the 3/4 inch (19 mm) sieve, wash the retained 3/4 inch (19 mm) material, remove excess surface water by rolling sample in a large, absorbent cloth. Weigh in air and record on line "Q" of Figure 1.

4. Weigh the retained 3/4 inch fraction in water and record on line "R" of Figure 1.

5. The impact test is performed on the passing 3/4 inch (19 mm) fraction as outlined in Section B through D.

6. The remainder of the calculations necessary to compensate for the retained 3/4 inch (19 mm) material are shown on lines "S" through "Z" of Figure 1.

7. When a number of tests on soil containing essentially the same nature of retained 3/4 inch (19 mm) material are anticipated, a constant may be developed to minimize the weighting in air and water operations.

I. SIMPLIFICATIONS FOR CONSTRUCTION CONTROL

Construction control by wet density tests may be expedited. If the relative compaction based on any test specimen density is below the specified minimum it may be immediately reported that the area under test has failed to meet the specifications. It is not necessary to fabricate additional test cores, for the reason that if a higher adjusted wet density was reached with subsequent test cores the relative compaction based on this higher density would be still lower than that indicated by the single core.

When the relative compaction indicated by a single test core is more than the minimum specified, additional cores are necessary to be certain that any increase in maximum adjusted wet density with the subsequent cores, does not lower the relative compaction value to below the specification minimum.

REFERENCES

California Tests 122, 231, 312, 110

End of Text (6 pages) on Calif. 216

TABLE 1

ADJUSTED WET DENSITIES IN P.C.F.

2200-2700 Grams

Initial Weight of Test Core In Grams

Tamper Reading	2200	2250	2300	2350	2400	2450	2500	2550	2600	2650	2700
10.0	130	133	136	139	142	145	148	151	154	157	160
10.1	129	132	135	138	141	144	146	149	152	155	158
10.2	128	131	133	136	139	142	145	148	151	154	157
10.3	126	129	132	135	138	141	144	147	149	152	155
10.4	125	128	131	134	137	139	142	145	148	151	154
10.5	124	127	130	132	135	138	141	144	147	149	152
10.6	123	126	128	131	134	137	140	142	145	148	151
10.7	122	124	127	130	133	135	138	141	144	147	149
10.8	121	123	126	129	132	134	137	140	142	145	148
10.9	119	122	125	128	130	133	136	138	141	144	147
11.0	118	121	124	126	129	132	134	137	140	143	145
11.1	117	120	123	125	128	131	133	136	139	141	144
11.2	116	119	122	124	127	129	132	135	137	140	143
11.3	115	118	120	123	126	128	131	134	136	139	141
11.4	114	117	119	122	125	127	130	132	135	138	140
11.5	113	116	118	121	123	126	129	131	134	136	139
11.6	112	115	117	120	122	125	128	130	133	135	138
11.7	111	114	116	119	121	124	126	129	132	134	137
11.8	110	113	115	118	120	123	125	128	130	133	135
11.9	109	112	114	117	119	122	124	127	129	132	134
12.0	108	111	113	116	118	121	123	126	128	131	133

DEPARTMENT OF TRANSPORTATION

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California Test 231
(Draft Rev. 5/91)

METHOD OF TEST FOR FIELD WET DENSITY UTILIZING NUCLEAR GAGES

A. SCOPE

This test method provides a procedure for determining the in-place wet density of untreated and treated soils and aggregates.

This standard may involve hazardous materials, operations and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of whoever chooses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. Those using this standard do so at their own risk.

B. APPARATUS

1. Nuclear gage and standardizing block.
2. Miscellaneous tools such as trowels, scrapers, sieve, etc. for site preparation.
3. Guide plate, approximately 12" x 18" x 1/4" (305mm = 457mm x 6.4mm) (Materials Operations Cat. #5210 0530 4)
4. Pin, approximately 13/16" dia. x 24" long (21mm x 610mm) (Materials Operation Cat. #5210 0510 2)

C. STANDARDIZATION OF THE NUCLEAR GAGE FOR WET DENSITY AND MOISTURE

1. Set the standardizing block 5 feet (1.5m) from any object and 25 feet (7.62m) from any other nuclear gage. Place the gage on the standardizing block in the closed (safe) mode and take four (4) one-minute density counts. Repeat the four one-minute counts for moisture in the backscatter position. Record on Form MR-2148A (Figure 1) and in the gage logbook. When the nuclear gage is equipped with electronic circuitry capable of automatically averaging four one-minute density and moisture standard counts simultaneously, place the gage on the standardizing block in the closed (safe) mode and take the average of four one-minute counts. Record the density and moisture standard count averages on Form MR-2148A and in the gage logbook. For additional gage operation information not covered in this paragraph, follow instructions given in the manufacturer's manual.

2. The average of the four one-minute counts determined in C-1 is to be within ± 3 standard deviations (see note) of the value used to establish the calibration table.

If it is not, contact the Radiation Administrative Officer who will establish a new standard count or have the gage sent in to be checked and/or repaired. Perform the standard count *at least* once during every 8 hours of operation.

NOTE: A standard deviation is defined in this test method as $\sigma = \sqrt{n}$; where σ is the standard deviation, and n = number of counts indicated on the gage. This relationship is valid when the number of counts is over 10,000.

D. SITE PREPARATION

1. Remove all loose surface material and prepare a plane surface large enough to seat the gage. Where sheepsfoot and similar type tamping rollers have been used, remove the loose surface material to a depth of not less than 2 inches (51mm) below the deepest penetration by the roller. After the surface has been prepared to a flatness and smoothness within 1/8 inch (3.2mm), use a No. 4 (4.7mm) or smaller sieve to obtain native fines to fill minor depressions, protrusions or to correct slight lack of planeness. Tamp fines and any loosened material with the guide plate.

2. Make a hole using the pin and guide plate. Extract the pin with a pin puller. A drill may be used in lieu of the pin. The depth of hole shall be 12 inches (305mm) deep for the 8 inch (203mm) direct transmission mode with the detector-in-the - rod type of gage. For the source-in-the-rod type of gage, the depth of hole shall be 2 inches (51mm) greater than the transmission depth being used. This hole must be as close as possible to 90 degrees from the plane surface. If the plate does not make contact with the ground, or if it appears that the hole is crooked, make a new hole.

E. FIELD TEST FOR DENSITY DETERMINATION

1. Place the nuclear gage on the prepared surface so that the bottom of the gage is firmly seated in contact with the soil. Insert the rod into the hole to predetermined depth. Adjust the gage so that the rod is firmly against the side of the hole that is nearest to the source or detector tube (s).

Obtain a one minute density count.for each test site and record the data on line C of Form MR - 2148A.

2. Calculate the density count ratio for each site and enter on line D.

3. Find the count ratio and corresponding direct transmission wet density (p.c.f.) on the table supplied with the gage. Record the wet density in p.c.f. on line E of Form MR - 2148A. Calculate the average of theses values and report on line K.

NOTE: No obstruction or foreign element should be within a distance of +8 inches (20cm) on both sides of the *source-detector axis*. Density calibration tables for the various depths are determined in accordance with California Test 111.

F. FIELD TEST FOR MOISTURE

This test is used for cases where moistures are desired or when common maximum adjusted wet densities are used as described in CTM 122.

1. Obtain a standard count for moisture as specified in Section C.

2. For site preparation, use procedure in Section D-1.

3. Place the gage on the prepared surface and take a one minute moisture count. Record the data on line F of Form MR - 2148A.

4. Determine a count ratio by dividing the field count by the standard count for moisture.

5. Find the count ratio and corresponding moisture (p.c.f.) from the table supplied with the gage and record on line H.

NOTE: No obstruction or foreign element should be within a distance of 10 inches (25cm) *from the side of the gage*. Moisture calibration tables are determined in accordance with California Test 111.

REFERENCES

California Tests 111, 122, 121, 216, and 312.

End of Text (2 pages) on Calif. Test 231