RECLAMATION

Managing Water in the West

Guidelines for Earthwork Construction Control Testing of Gravelly Soils

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

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Guidelines for Earthwork Construction Control Testing of Gravelly Soils

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Scope

The purpose of this document is to provide guidance on earthwork construction control testing of soils containing oversize particles. This guidance can be used by Reclamation's field laboratories, and it will also be useful for other agencies and private industry.

Laboratory compaction tests have maximum particle size limitations. While in-place density tests in gravelly soils can provide density results of the total material, a comparison of the total material to a compaction test on finer material would not be valid. Therefore, there is a need for corrections on the degree of compaction.

Reclamation has not published a procedure for implementing corrections. Reclamation's standard specifications state that the required density will be reduced according to a *D* ratio reduction graph printed in the *Earth Manual*, yet the exact procedure has been left to the discretion of the laboratory chief. This manual will provide uniform guidance on correction procedures.

Geotechnical engineers often specify gravelly soils in construction in part because gravelly soils containing fines are excellent construction materials. Additionally, they have high shear strength and low compressibility when compacted. With a minimum percentage of fines of about 25 percent, the dirty gravels (GM or GC) become virtually impervious. Clayey gravel (GC) is the most preferable material in zone 1, the impervious core, of an embankment dam.

Reclamation frequently uses soils with high gravel and cobble content for construction. Often the best construction materials contain significant gravel and cobble sizes up to 5 to 7 inches in maximum dimension. The problem with this type of soil is that as the gravel content increases, it interferes with the compaction of the minus No. 4 sieve size fraction. This report will review Reclamation's experience with gravel corrections and other published methods of correcting for gravels.

Overview

To determine the degree of compaction in earthwork, one must first measure in-place density and then compare that in-place density to a laboratory maximum density. Reclamation's procedure for determination of percent compaction is given in standard procedure USBR 7255 [1] where percent compaction is defined as:

$$\text{percent compaction} = \frac{\text{in-place dry density}}{\text{laboratory maximum dry density}} \times 100$$

For soils containing about 10 to 15 percent more fines and where water is required for adequate compaction, the laboratory maximum density is evaluated by the "Proctor" impact compaction test (USBR 5500 [2]). Table 1 shows a summary of impact compaction tests with the maximum particle size and energy per unit volume delivered by the test.

Table 1.—Laboratory impact compaction test results

Test	Soil	Mold			Hammer weight (lb)	Drop height (In)	No. of layers	Blows per layer	Compactive effort (ft-lb/ft^3)
		Dia. (in)	Height (In)	Vol. (ft^3)					
Original Proctor	- No. 4	4	5	0.045 (1/22)	5.5	12	3	25	8,250
USBR 5500	- No. 4	4¼	6	0.050 (1/20)	5.5	18	3	25	12,375
ASTM D 698 Method A	- No. 4	4	4.5	0.033 (1/30)	5.5	12	3	25	12,375
ASTM D 698 Method C	- ¾ in	6	4.5	0.074 (1/14)	5.5	12	3	56	12,375
California 216G	-¾ in	2⅞	10-12	0.041 (1/24.2)	10	18	5 10	20 20	36,300 72,600
ASTM D 1557 Method A	- No. 4	4	4.5	0.033 (1/30)	10	18	5	25	56,000
ASTM D 1557 Method C	-¾ in	6	4.5	0.074 (1/14)	10	18	5	56	56,000

Reclamation uses a maximum particle size of No. 4 sieve in their impact compaction test. ASTM International (ASTM) has two Proctor compaction standards, D 698, *Standard Effort* [3], and D 1557, *Modified Effort* [4]. Both ASTM standards allow for either minus No. 4 or minus ¾-inch sieve size particles in their test. Reclamation uses a $\frac{1}{20}$-ft^3 mold and a 5.5-pound hammer dropped 18 inches, which is equivalent to the ASTM "standard" effort of 12,375 ft-lb. For the 4-inch mold in ASTM, the volume is $\frac{1}{30}$ ft^3. The energy used in USBR 5500 and ASTM D 698 is equivalent.

Reclamation uses the rapid compaction test (USBR 7240 [5], ASTM D 5080 [6]) for routine control of silty or clayey soils. The rapid compaction test is a three-point Proctor compaction test that works on an adjusted wet density basis. The test allows for determination of a *D* value that is equivalent to percent compaction. In this document, the degree of compaction is referred to as the *D* ratio:

$$D \text{ ratio} = D \text{ value} = \text{percent compaction} = D$$

The *D* ratio is the ratio of the in-place dry density in the compacted fill (γ_{df}) to the laboratory maximum dry density (γ_{dlab}), expressed a percentage:

$$D = (\gamma_{df} / \gamma_{dlab}) \times 100$$

Both density measurements should be for the same soil particle size distribution.

The rapid compaction test also allows for determination of the optimum moisture content without the oven drying. This is advantageous because oven drying takes 12 to 16 hours to obtain results whereas the rapid compaction test can be done in an hour or two.

A flow chart of the test procedure is shown in figure 1. The data sheet showing in-place density and degree of compaction is shown in figure 2. Reclamation has used the same proven procedure for over 30 years. The steps to determine the *D* ratio are:

1. In-place density is determined by sand cone test or for gravelly soils with other replacement methods such as test pit with sand or water replacement.

2. Soil obtained from the test hole is screened to obtain the control fraction (minus No. 4 soil) for compaction.

3. The gravel is washed, and its surface saturated weight and volume (specific gravity) are determined.

4. The wet density of the control fraction is determined by subtracting the weight and volume of rock.

5. The *D* ratio is determined on an adjusted wet density basis.

6. For gravelly soils, the *D* ratio is reduced by using a *D* ratio reduction factor from figure 3.

Reclamation's approach uses a direct comparison of the in-place control fraction density to a three point rapid compaction test on the control fraction material from the test hole.

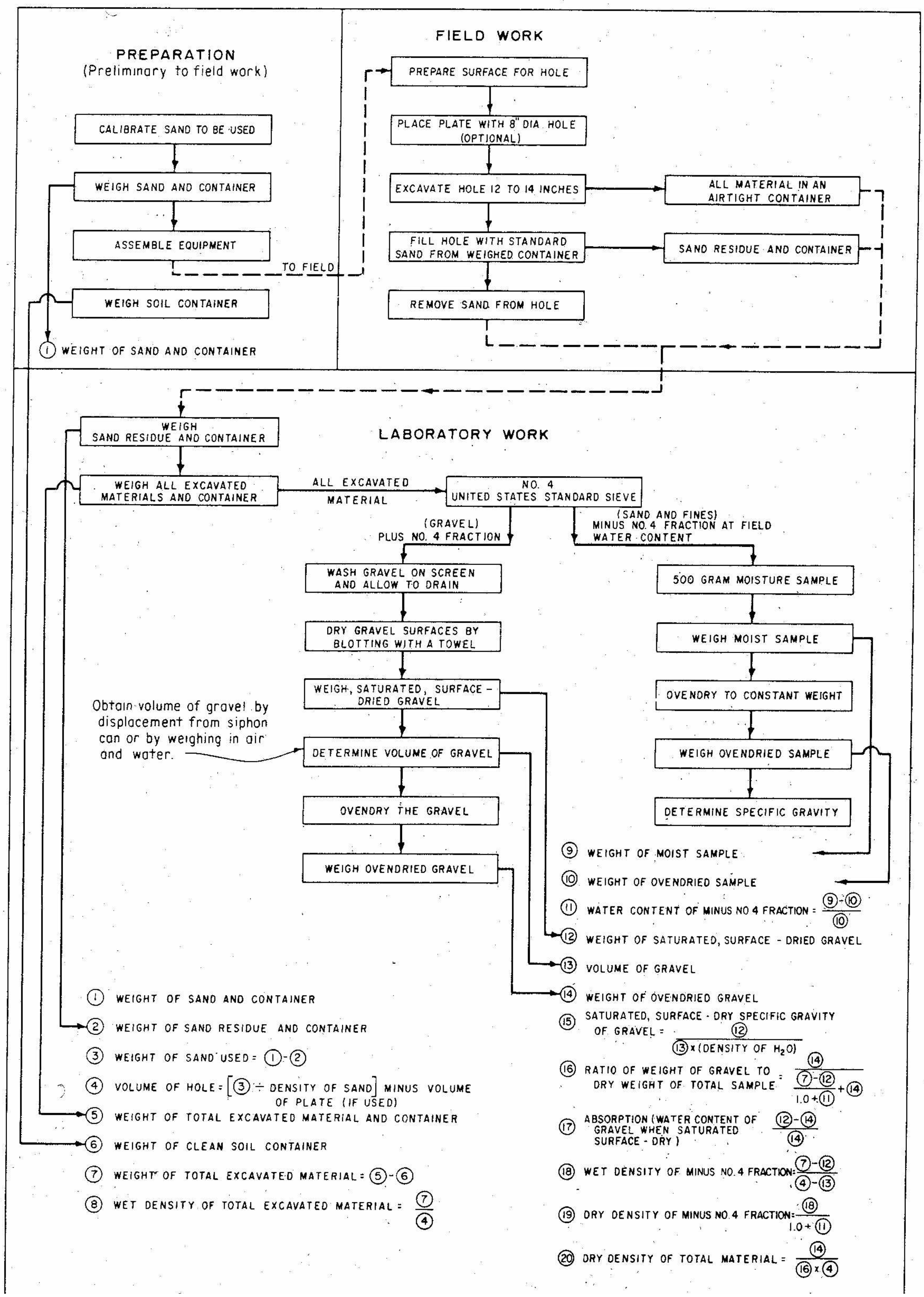

Figure 1.—Reclamation's procedure to determine *D* value for control of silty and clayey soils.

Form 7-1425(11-58)
Bureau of Reclamation

FIELD DENSITY TEST RECORD
(Including Rapid Compaction Control)

TEST NO. Example FEATURE ____ TESTED BY ____

LOCATION ____ OFFSET ____ ELEV. ____ ZONE ____ COMPUTED BY ____

SOURCE OF MATERIAL ____ DATE OF TEST ____

(1) Wt. Sand & Can, No. 1 ____ 94.1 lbs.

(2) Wt. Sand Residue & Can ____ 16.3 lbs.

(3) Wt. Sand used, [(1) - (2)] ____ 77.8 lbs.

(4) Wt. Sand in plate, No. 4, ____ 11.0 lbs.

(5) Wt. Sand in Hole, [(3) - (4)] ____ 66.8 lbs.

(6) Sand Calibration ____ 84.4 pcf.

(7) Vol. of Hole, $\frac{(5)}{(6)}$ ____ 0.791 ft³

(8) Wt. Wet Soil, Rock, & Can ____ 115.7 lbs.

(9) Wt. of Can, No. 2, ____ 3.2 lbs.

(10) Wt. Wet Soil & Rock ____ 112.5 lbs.
(8)-(9)

(11) Wet Density Soil & Rock $\frac{(10)}{(7)}$ ____ 142.2 pcf.

(12) Dry Density Soil & Rock, $\frac{(11)}{1+(28)}$ ____ 129.9 pcf.

(13) Wt. Wet Rock[a] & Pan ____ 50.0 lbs.

(14) Wt. of Pan ____ 2.6 lbs.

(15) Wt. Wet Rock,[a] [(13) - (14)] ____ 47.4 lbs.

(16) Wt. Rock in Water ____ 27.7 lbs.

(17) Volume of Rock[a] $\frac{(15)-(16)}{62.4}$ * ____ 0.316 ft³

(18) Sp. G. of Rock,[a] $\frac{(15)}{[(15)-(16)]}$ ____ 2.41

(19) Wt. Dry Rock & Pan ____ 49.5 lbs.

(20) Wt. Pan ____ 2.6 lbs.

(21) Wt. Oven Dry Rock ____ 46.9 lbs.
[(19) - (20)]

(22) Rock Water Content, $\frac{[(15)-(21)]}{(21)} \times 100$ ____ 1.1 %

(23) Wt. Wet Soil, [(10)-(15)] ____ 65.1 lbs.

(24) Wet Density of Soil, $\frac{(23)}{[(7)-(17)]}$ ____ 137.1 pcf.

(25) Wt. Dry Soil, $\frac{(23)}{1+W_f}$ ____ 55.8 lbs.

(26) Wt. Dry Soil & Rock, [(25) + (21)] ____ 102.7 lbs.

(27) Percentage of Rock, $\frac{(21)}{(26)} \times 100$ ____ 45.7 %

(28) Water Content, Soil & Rock, $\frac{[(10)-(26)]}{(26)} \times 100$ ____ 9.5 %

(29) Fill Cyl. Needle[b] ____ 860 p.s.i.

(30) Needle at opt.[b] ____ p.s.i.

RAPID CONTROL VALUES

(31) D = ____ %

(32) C = ____ %

(33) $W_o - W_f$ = ____ %

(34) Fill Water Content, W_f ____ 16.7 %

(35) Fill Dry Density, -No. 4, $\frac{(24)}{1+W_f}$ ____ 117.5 p.c.f.

(36) Max. Lab. Dry Density ____ p.c.f.

(37) Cylinder Dry Density ____ p.c.f.

(38) Opt. Water Content, W_o ____ %

Method	Passes		
Tamping roller	✓	Canal Lining	✓
Tractor treads		Embankment	
Equip. Tamp.		Str. B'kfill	
Power Tamp.		Unified Soil Class.	GC
Hand Tamp.			

REMARKS ____

* Or $(17)_A$ by measuring the water displaced from a siphon can; then:
$(18)_A = \frac{(15)}{(17) \times 62.4}$

(a) Wet surface dried condition.
(b) If obtained for moisture control by needle moisture test.

Figure 2.—Data summary sheet showing determination of in-place density and degree of compaction.

Summary of Reclamation's Experience and Current Practices

Reclamation performed research on gravelly soil compaction problems and published two earth materials reports (EM-509 and EM-662 [7, 8]). The research was on the effect of gravel on the density that can be achieved based on the minus No. 4 control fraction. The results of these studies are summarized in table 2 and figure 3. Researchers used a large compactor capable of testing three different types of soils (sandy gravel, silty gravel, and clayey gravel) containing cobbles as large as 3 inches with various gravel contents.

Table 2.—Criteria for control of compacted dam embankments (from the *Earth Manual* [10], table 3-2, p. 273)

Type of material	Percentage of plus 4.75-mm (+No. 4) fraction by dry mass of total material	Percentages based on minus 4.75-mm (-No. 4) fraction					
		15 m (50 ft) or less in height			15 m (50 ft) or greater in height		
		Min. acceptable density	Desired avg. density	Moisture limits, W_o-W_f	Min. acceptable density	Desired avg. density	Moisture limits, W_o-W_f
Cohesive soil: Soils control-led by the laboratory compaction test	0 to 25	*D*=95	*D*=98	-2 to +2	*D*=98	*D*=100	2 to 0
	26 to 50	*D*=92.5	*D*=95	-2 to +2	*D*=95	*D*=98	Note'
	More than 50'	*D*=90	*D*=93	-2 to +2	*D*=93	*D*=95	
Cohesionless soils: Soils control-led by the relative density test	Fine sands with 0 to 25%	D_d=75	D_d=90	Soils should be very wet	D_d=75	D_d=90	Soils should be very wet
	Medium sands with 0 to 25%	D_d=70	D_d=85		D_d=70	D_d=85	
	Coarse sands and gravels with 0 to 100%	D_d =65	D_d=80		D_d=65	D_d=80	

[1] Cohesive soils containing more than 50 percent gravel sizes should be tested for permeability of the total material if used as a water barrier.
[2] For high embankment dams, special instructions on placement moisture limits will ordinarily be prepared.

The difference between optimum water content and fill water content of dry mass of soil is W_o-W_f , in percent. *D* is fill dry density divided by laboratory maximum dry density, in percent. D_d is relative density as defined in the *Earth Manual*.

In the first study (EM-509), the researchers only considered the change in total density. They found that the total density increases as gravel content increases until the gravel content reaches about 60 to 70 percent, and at that point, total density decreases.

In the second study, the focus was on what density could be attained in the fine control fraction as gravel content was increased. The theoretical density of the fine fraction can be calculated using the following equation developed by Ziegler [9]:

$$\gamma_{DT} = \frac{1}{\frac{1-P_G}{\gamma_{DFF}} + \frac{P_G}{62.4G_S}} = \frac{1}{\frac{P_{FF}}{\gamma_{DFF}} + \frac{P_G}{62.4G_S}}$$

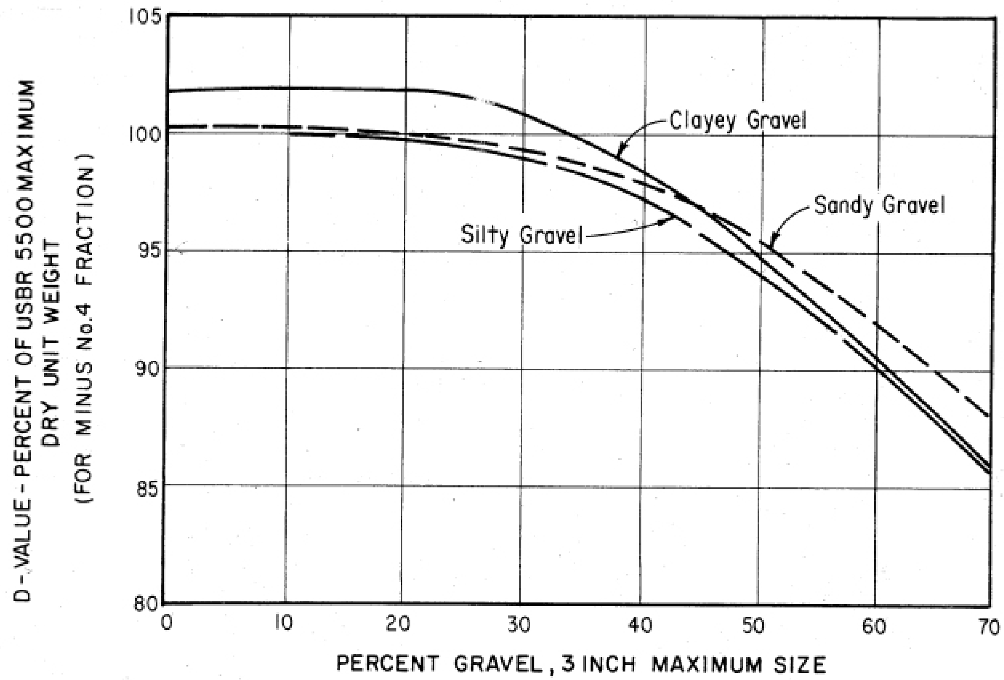

Figure 3.—*D* ratio of control fraction versus gravel content.

where:

γ_{DT} = dry density of the total material, lb/ft^3
P_G = percent coarse fraction (oversize), percent
P_{FF} = percent of fine fraction (control fraction), percent
γ_{DFF} = dry density of the fine fraction, lb/ft^3
G_S = oven dry specific gravity, dimensionless

The equation above is intuitively clear in that the sum of the fine and coarse fraction densities equal the total material density.

Application of the Ziegler equation assumes that the voids in the gravel are completely filled with the fine material. The results of the research are shown in figure 3. Figure 3 is the curve currently used by Reclamation to predict the required *D* ratio of the fine (control) fraction.

The research indicated that gravel interferes with compaction of the fine fraction for gravel contents greater than 20 to 30 percent. For gravel contents greater than 60 or 70 percent, the voids are not filled. The lack of completely filled voids explains the reduction of maximum dry density of the total material.

In a second research program (EM-662) in 1963, a wider range of gravels was tested. That research also showed that grain size distribution of the gravel has an effect. For well graded gravel (GW), interference occurred at about 30 percent whereas for poorly graded gravel (GP), interference occurred as low as

10 percent. A dual curve with a lower range was recommended for poorly graded materials. Their *D* ratio reduction curves for the minus No. 4 fraction did not go below 90 percent at 65 percent gravel. That report recommended multiplying the *D* ratio reduction factor times the specified degree of compaction. No correction is required for gravel content less than 10 percent.

It was also observed in both research programs that at the higher gravel content, the water content of the control fraction had to be higher than optimum to achieve maximum density. Reclamation has not developed moisture adjustment factors for gravelly soils. At gravel content of 50 percent or higher, one can assume optimum moisture in the control fraction is 2 to 3 percent higher than optimum.

Figure 3 is currently used by Reclamation to correct for oversize. The current practice is to read the required *D* ratio right off of figure 3. However, the research was based at 100-percent effort/compaction requirement, and in many cases, only 95 to 98 percent compaction is required on smaller embankments. Table 1 was taken from Reclamation's *Earth Manual*. This table allows for lower values to some extent. The desirable values for an embankment less that 50 feet tall would be 98 percent with a minimum if 95 percent if no gravel were present. If there is more than 50 percent gravel, 93 percent is desired, and 90 percent is a minimum. Reclamation's research [7, 8] and some internal memoranda [11] instruct field staff to multiply the desired degree of compaction by the value from figure 1. This is less conservative than reading directly off of the graph.

Findings of Other Organizations

U.S. Army Corps of Engineers

The U.S. Army Corps of Engineers (USACE) performed an extensive study of earth rock compaction in the 1980s culminating in final reports in the early 1990s [12, 13]. The USACE derived a "density interference coefficient," I_c, as:

$$I_c = R_c / P_g \bullet G_m$$

R_c is equivalent to the *D* ratio reduction factor in figure 3. The USACE compiled *D* ratio reduction factors equivalent to Reclamation's as shown on figure 4. *D* ratio reduction factors from the American Association of State Highway and Transportation Officials (AASHTO) [14] and the Naval Facilities Engineering Command (NAVFAC) [15] are also included along with their data. Notes on the AASHTO method are in appendix A.

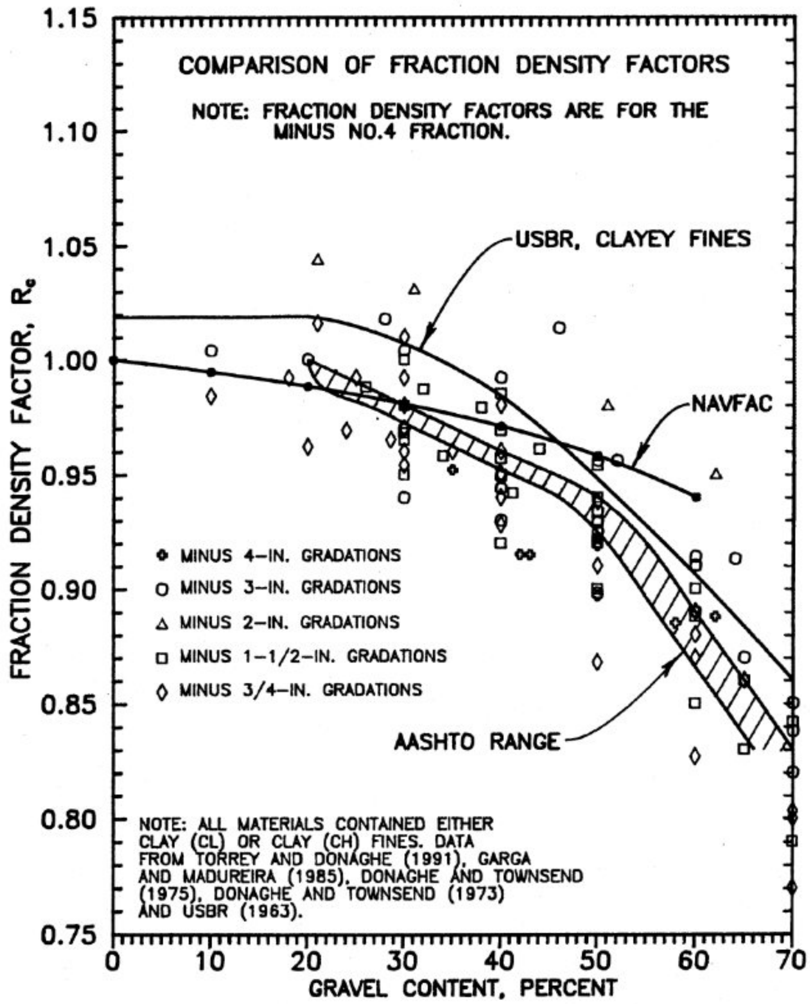

Figure 4.—U.S. Army Corps of Engineers summary of *D* ratio reduction factors.

The USACE approach to the correction is more exacting, and at the same time, their control techniques are different than Reclamation's. They rearranged the Ziegler equation as:

$$\gamma_{t\,max} = \frac{R_c \gamma_{F\,max} \gamma_W G_m}{R_c \gamma_F P_c + G_M \gamma_W P_F}$$

Then substituting I_c for R_c:

$$\gamma_{t\,max} = \frac{P_c \gamma_{f\,max} G_M \gamma_W}{P_f \gamma_W + P_c I_c P_g \gamma_{f\,max}}$$

The USACE also developed an "optimum water content factor", F_{opt}:

$$F_{opt} = W_{fopt} / P_g W_{topt}$$

where:

W_{fopt} = water content of the fine fraction
W_{topt} = water content of the total material

The USACE advocates the following approach for correcting the degree of compaction:

1. Establish curves of I_c and F_{opt} versus gravel content during preconstruction.

2. Develop a family of curves on either the minus ¾ inch or minus No. 4 sieve size material.

3. Determine the bulk specific gravity of the coarse fraction.

4. During fill operations, determine total density, γ_t, the fill water content, W_t, coarse fraction content, P_g, and fine fraction content, P_f.

5. Perform a one point or two point compaction test and determine γ_{fmax} and W_{opt}.

6. Determine the value of γ_{tmax} using the above equations.

7. Determine the degree of compaction.

8. Determine the optimum water content.

The USACE performs compaction control testing differently than Reclamation. Instead of using the rapid method for every density test site, they use a family of curves approach. The family of curves is established prior to construction. Several curves are used to represent the range of material to be tested. The USACE determines the field dry density of the total material most often by use of the nuclear gauge. Traditionally, Reclamation has not used nuclear gauges because of their moisture error. Furthermore, the use of typical curves requires a subjective decision by the operator as to which curve applies. For gravelly soils, the operator either estimates the amount of oversize or has to take a sample under the gauge.

Questions arise as to the procedure given above:

- It is not clear how to establish the I_c and F_{opt} curves in preconstruction. Apparently, it requires performing a series of large scale compaction tests at different gravel contents. If the soils to be borrowed are changed after construction, there may not be sufficient time for developing new curves.

- During fill operations, the USACE advocates determining the fill water content, but measuring moisture content requires overnight drying, unless rapid heating techniques are employed. Likewise, determining the dry mass of gravel would also require overnight drying unless a correlation between specific gravity and adsorption were made in advance. This time delay would make the test results untimely.

Considering the fact that this procedure requires the same screening and additional steps to determine moisture content of the fine fraction and one- or two-point compactions, it appears to be no quicker than the Reclamation rapid method.

The USACE method seems to have more uncertainty because the laboratory maximum density of the fine (control) fraction has to be corrected to that of the total material. The nuclear gauge can give misleading data in gravelly soils especially if a large particle is under the gauge. Reclamation recommends rotating the gauge and taking multiple readings if the presence of large particles is suspected.

Regardless, if performed correctly, the USACE test method appears to be the most accurate method for correcting compaction data for oversize particles.

ASTM International

The oversize correction equations in ASTM standard D 4718, *Standard Practice for Correction of Unit Weight and Water Content for Soils Containing Oversize Particles*, are similar to the USACE's equations [16]. The equations are similar except the symbol δ was substituted for γ. For this report, a study was performed to see if Reclamation's procedures for applying the Ziegler equation were the same as those prescribed in ASTM's standards.

Mathematical derivation of the Zielger and USACE equations by hand was not successful. Even some college professors on the ASTM committees have compained that the equations are difficult to convert. Instead of mathematical derivation, Reclamation performed test calculations with some example data. The results of this study are shown in appendix B. This example contains data from five tests performed by Reclamation on Pineview Dam. The gravel content in the samples ranged from 32 to 66 percent. Appendix B shows the standard Reclamation rock processing on lines 15 through 29 (as in the flowchart in fig. 1). It was found that the *dry* density of the fine fraction agreed with that calculated by D 4718 equations as long as the oven-dried specific gravity was used. From this data analysis, Reclamation determined that its methods for rock processing and determination of fine fraction density are equivalent to ASTM methods.

Note that this example does not include a *D* ratio reduction factor. The example also shows how the USACE and most private laboraties would apply D 4718. Most private laboratories use a nuclear gauge to measure density of the total material and compare it to a laboratory maximum density converted to that of the total material. The example shows the correction of the laboratory maximum dry density to dry density of the total material. It can be noted that the required dry density in the field is higher by 2 to 3 lb/ft^3 using the Reclamation approach. Reclamation laboratories have sometimes had to use control methods where D 4718 is specified to determine the maximum dry density of the total material for comparison to total in-place density. A spreadsheet is attached in appendix C that uses D 4718 to determine a theoretical laboratory maximum of the total material. Copies of this spreadsheet are available upon request to the Engineering Geology Group.

AASHTO

AASHTO has the only published test method for correcting required degree of compaction for oversize particles. Standard Test Method T-224-86, *Correction for Coarse Grained Particles in the Soil Compaction Test*, provides a method of correction for gravel. An excerpt from the standard is shown in appendix A.

As shown in appendix A, the correction uses a factor “r” multiplied by the fine fraction dry density of a lab test to correct to the dry density of the total material. The factor “r” is multiplied by the dry density of the fine fraction and then the density is corrected to the dry density of the total material. Again, the correction to maximum density of the total material is typical of private industry users who use the nuclear gauge to determine the dry density of the total material in-place. The lab value of the fine fraction is corrected to the dry density of the total material for direct comparison to the in-place value.

Other Considerations for Earthwork Control of Gravelly Soils

Given the uncertainties in obtaining in-place density and degree of compaction with gravel contents of 50 to 70 percent, consideration should be given to inspection alone. A method specification could be used for these materials. The specification should include lift thickness, moisture content, and number of roller passes. These parameters cannot be specified in advance so the specification should allow for these to be established at the beginning of construction and reexamined periodically during construction. Lift thickness should not be larger than 1 foot for these soils.

The best way to evaluate the compaction process is to cut test trenches and observe the bottom of the lifts for insufficient compaction. At the beginning of the construction, the contractor can perform a “test fill.” Test fills should normally be long enough to allow the compaction equipment to operate at working speed. That distance is normally about 75 feet. Several lifts should be placed, and the fill should be a minimum of three equipment widths wide. Cut an "L" shape trench and inspect the material for adequate compaction.

For soils that contain 10 percent or less fines, they are controlled by the relative density (RD) test, which has a 3-inch control fraction. They are compacted by vibratory roller and can be compacted in lifts as thick as 2 feet. With the larger maximum size of the RD test, there are not as many issues with testing as with silt/clayey gravels. One problem material is crushed rock drain material. This material has grain sizes from 1½ inch to the No. 4 sieve. The typical in-place density test for this material is the test pit with sand replacement, but this test is difficult to perform on uniform gravel. Crushed rock is easily compacted with a 10-ton (static) smooth drum vibratory roller in 2 to 4 passes.

Conclusions and Recommendations

A few agencies have methods for correction of the required degree of compaction. These methods are similar to those used by Reclamation. Figure 4 shows the *D* ratio reduction factors of a number of researchers and agencies. Reclamation's *D* ratio reduction curve seems to fall within the conservative outside edge of the data. It is recommended that Reclamation continue to use the curves in figure 3. In Reclamation's testing practice, the lab determination is performed on the material from the test hole, and the actual gravel is screened and processed resulting in a more reliable control fraction density.

Agencies such as NAVFAC and ASSHTO use similar curves as Reclamation for correcting for oversize effects. The USACE method of correction is the most accurate method, but it is also complicated and not designed for testing by sand cone or test pits. Since the USACE method is more accurate, it could be used on high profile and critical projects.

Looking at the amount of scatter, caution should be used in applying these curves, and since gravelly fill is very strong when compacted, the contractor should be given the benefit of the doubt. Reclamation's preference of holding contractors to 100 percent effort, when specifications allow 95 or 98 percent compaction, should be relaxed. One reason for this is the position of Reclamation's *D* ratio reduction curve compared to the data in figure 4. By keeping its own curve, Reclamation stays on the conservative side of the correction.

Recommended Procedure for Oversize Corrections

The procedure for correcting the required *D* ratio would be as follows:

> If the specified *D* ratio is 95 percent, and soil has 50 percent gravel, use figure 3 to get a 95 percent reduction. The required *D* ratio would be:

$$D_{REQUIRED} = 95 \text{ x } 95 = 90\ \%$$

This is a very simple method of reducing the required percent compaction for soils.

If gravelly soils are anticipated on the project, the following additional items can be performed:

- Use a 6-inch diameter mold as provided by ASTM D 698. This allows the control fraction size ¾ inch.
- Sufficient water should be used for compaction. Since Reclamation does not have an easy correction for moisture in the control fraction, it should not specify a range in fill moisture contents. When gravel contents are over 50 percent, the optimum water content of the fine fraction should be increased to 2 to 3 percent higher than fine fraction optimum.
- Follow standard Reclamation procedures for determining in-place density. Start with a large sand cone, up to 18 inches in diameter. For rough surfaces, perform a “template” correction.
- As with our current procedures, gravel must be screened and measured if the gravel content exceeds 5 percent.
- Apply the *D* ratio reduction factors when gravel exceeds 30 percent.

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[13] Torrey, V.H., *Compaction Control of Earth Rock Mixtures: How to Develop and Use Interference Coefficients and Optimum Water Content Factors*, Technical Report GL-91-16, Geotechnical Laboratory, Waterways Experiment Station, U.S. Army Corps of Engineers, 1992.

[14] American Association of State Highway and Transportation Officials, Designation: T 244-86, "Standard Method of Test for Correction for Coarse Particles in the Soil Compaction Test," in "Standard Specifications for

Transportation Materials and Methods of Sampling and Testing," Part 2B, "Tests," Washington, D.C., 1993.

[15] U.S. Department of the Navy, *Foundations and Earth Structures*, Design Manual 7.2, Naval Facilities Engineering Command, Alexandria, VA, 1982.

[16] ASTM International, ASTM D 4718-87, *Standard Practice for Correction of Unit Weight and Water Content of Soils Containing Oversize Particles*, West Conshohoken, PA.

Appendix A

AASHTO Method for *D* Ratio Reduction Factor

AASHTO's *Correction for Coarse Grained Particles in the Soil Compaction Test*, Standard Specifications for Transportation Materials and Methods for Sampling and Testing, Washington DC, 1993, recommends that the following equation be applied to the *D* ratio of the total material dry density:

$$D = \frac{62.4}{\frac{P_c}{G_m} + 62.4\frac{P_f}{r}D_f}$$

where:

- D = adjusted maximum dry density of the total material
- P_c = percentage of coarse particles
- P_f = percentage of finer particles
- D_f = maximum laboratory dry density of the fine fraction
- G_m = bulk specific gravity of the coarse particles
- r = reduction factor based on the percentage of coarse material as follows:

r	P_c
1.0	0.20 or less
0.99	0.21-0.25
0.98	0.26-0.30
0.97	0.31-0.35
0.96	0.36-0.40
0.95	0.41-0.45
0.94	0.46-0.50
0.92	0.51-0.55
0.89	0.56-0.60
0.86	0.61-0.65
0.83	0.66-0.70

Although not expressly stated, the specific gravity should be the oven dried value.

It is not clear if this standard is based on laboratory compaction testing from *standard* proctor compaction (ASTM D 698) or *modified* proctor (ASTM D 1557). There could be differences in compaction effort? It is likely this is based on modified compaction because an example used a *D* of 90 percent, which is only used for modified compaction.

Appendix B

Analysis of ASTM D 4718 Using Reclamation Data

USBR 7-1425 data		Test #1 4+50 zone5a 12/11/03	Test #2 4+55 zone 5A 12/10/03	Test #1 9+50 Zone 5A 12/13/03	Test #2 10+40 zone 5B 11/6/03	Test #1 9+28 zone 5B 11/6/03
7	Total volume - Vt - ft3	1.323	1.4168	1.3193	1.6239	1.8487
10	Total wet mass - Mwt - lb	179.77	193.8	188.2	237.92	270.99
11	Wet density total material - γwt - pcf	135.8	136.8	142.7	146.5	146.6
	Rock Processing					
15	Wet mass rock @ SSD - Mwssdcf - lb	53.62	69.42	67.58	120.03	176.45
16	Rock mass suspended - Mwwcf - lb					
17	Volume of rock - Vcf - ft3	0.337	0.423	0.413	0.737	1.122
18	Bulk specific gravity @ SSD - Gbcf	2.55	2.63	2.62	2.61	2.52
18.a	Mass of water displaced in siphon can - lb	159.12	164.112	163.488	162.864	157.248
21	Dry mass of rock - Mdcf - lb	52.83	68.53	66.91	118.61	173.33
22	Moisture content rock - Wcf - %	1.5	1.3	1.0	1.2	1.8
	Soil Processing/Control Fraction Determination					
23	Wet mass of soil - Mwff	126.2	124.4	120.6	117.9	94.5
24	Wet density of soil - γff	127.9	125.2	133.1	132.9	130.1
6	Water content fine fraction Wff - %	12.4	9.2	13.3	9	8.7
25	Dry mass of soil - Mff -lb	112.23	113.90	106.46	108.16	86.97
26	Total dry mass - Mdt	165.06	182.43	173.37	226.77	260.30
27	Percent coarse fraction - %cf	32.0	37.6	38.6	52.3	66.6
28	Moisture content total material = wt - %	8.9	6.2	8.6	4.9	4.1
29	Dry density fine fraction γff - pcf	113.8	114.6	117.5	121.9	119.7
	Dry density total material γdt - pcf	124.7	128.8	131.5	139.6	140.8
	Theoretical Dry Density of Fine Fraction from D 4718					
	Percentage coarse fraction	32.0	37.6	38.6	52.3	66.6
	Bulk specific gravity (SSD) coarse fraction	2.55	2.63	2.62	2.61	2.52
	Oven dry (OD) specific gravity of the coarse fraction	2.51	2.60	2.59	2.58	2.48
	Dry density of total material	124.7	128.8	131.5	139.6	140.8
	D 4718 predicted dry density fine fraction using bulk (SSD) Gs	113.2	114.0	117.0	120.7	116.6
	D 4718 predicted dry density fine fraction using (OD) Gs	113.7	114.6	117.6	121.9	119.7

USBR 7-1425 data		Test #1 4+50 zone5a 12/11/03	Test #2 4+55 zone 5A 12/10/03	Test #1 9+50 Zone 5A 12/13/03	Test #2 10+40 zone 5B 11/6/03	Test #1 9+28 zone 5B 11/6/03
	D ratio based on USBR					
	Laboratory maximum dry density γdffmax-pcf	123.9	125.6	123.4	128.3	127.3
	Optimum moisture content	10.9	9.7	10.3	8.6	8
	Degree of compaction - based on fine fraction - %	91.9	91.3	95.2	95.0	94.0
	Dratio Redcution Factor	0.99	0.98	0.98	0.94	0.89
	Required for D of 95% effort	94	93	93	89	85
	Pass/Fail	Fail	Fail	Pass	Pass	Pass
	Inplace dry density of ff required for 95%	116.5	116.9	114.9	114.6	107.6
	Required Inplace density of total material based on ff using D 4718, oven dry Gs, to correct -pcf	127.0	130.6	129.4	134.9	134.9
	D ratio using D 4718 lab max…converted to total material - the way the private folks do it with a nuke gage (total material)& a compaction curve corrected to total material.					
	Laboratory maximum dry density of total material based on D 4718 using bulk Gs - pcf	132.4	135.8	134.4	139.5	139.2
	Laboratory maximum dry density of total material based on D 4718 using oven dry Gs - pcf	131.8	135.3	134.0	138.8	137.7
	Degree of compaction - based on total material Bulk SSD Gs- %	94.2	94.8	97.8	100.1	101.2
	Degree of compaction - based on total material oven dry Gs- %	94.6	95.2	98.1	100.6	102.2
	Required inplace density of the total material based on D 4718, bulk Gs	125.7	129.1	127.7	132.6	132.2
	Required inplace density of the total material based on D 4718, oven dry Gs	125.3	128.5	127.3	131.9	130.9

Appendix C

ASTM D 4718 Used to Determine a Theoretical Laboratory Maximum of the Total Material

ASTM D-1557 Method C

Project ____ Feature ____

Tested By ____ Date ____ Checked By ____ Date ____

MO.	DAY	SHIFT	TEST NO.	TYPE	STATUS	BORR AREA	STD COMP METHOD	SOIL CLASS	STATION	OFFSET	ELEV

IN-PLACE UNIT WEIGHT DATA

-1	Mass-Sand & Ca No.	200.00
-2	Mass Sand Residue & Can	59.41
-3	Mass-Sand Used (1)-(2)	140.59
-4	Sand In Template & Cone	13.85
-5	Sand In Hole (3)-(4)	126.74
-6	Density of Calibrated Sand	95.80
-7	Volume of Hole (5)/(6)	1.3230
-8	Total Wet Material & Can	183.07
-9	Mass Can No. ___	3.3
-10	Total Wet Material (8)-(9)	179.77
-11	Wet Unit Weight (10)/(7)	135.88
-12	Dry Unit Weight (11)/1.+(26)	124.74

SPG & Moisture of Oversize Fraction

-13	Wet Oversize Rock & Pan	54.60
-14	Mass of Pan No. ____	0.98
-15	Mass of Wet Rock	53.62
-16	Mass of Rock in Water	32.60
-17	SPG of Rock (20)/(15)-(16)	2.51
-18	Mass Dry Rock & Pan	53.81
-19	Mass of Pan	0.98
-20	Mass Oven Dry Rock(18-19)	52.83
-21	Volume of Rock (20)/(17)X62.4	0.3373
-22	Water Content (15)-(20)/(20)	1.50
-23	Mass wet fine soil (10)-(15)	126.15
-24	Mass Dry Fine Soil (23)/1.+A	112.20
-25	Mass Dry Fine Soil+Rock (24)+(20)	165.03
-26	% of oversize (20)/(25)X100	32.01
-27	% Water Soil & Rock [(10)-(25)/(25)] X 100	8.9

Moisture

-3/4" Fine Material

Dish No.	216
Wet Soil & Dish	602.0
Dry Soil & Dish	566.5
Mass of Dish	281.0
Mass of Water	35.5
Mass of Dry Soil	285.5
(A) Moisture	12.4

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-28	Dry Unit Weight of the Finer Fraction (25-20)/(7-21) =	113.83
###	Laboratory Maximum Dry Density =	123.90
-30	Laboratory Maximum dry density of total material 100/[(100-25)/(28)]+(28)x62.4 =	132.78
-31	Degree of Compaction = (12)/(30) x 100 =	93.94

Remarks: