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A study on comparing D1557 and D4718 ASTM standard tests to select the appropriate criteria for controlling the crust compaction of Herat earthen dam and evaluating the results of test embankment

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ABSTRACT:

Herat dam is located at the south-western part of Herat region at Yazd province, Iran. This dam is an earthen dam with clay core. Coarse aggregate materials used in the dam crust are exploited from Hasan Abad village mines located at about 12 Km from the site. These materials completely (100%) pass through a sieve of 200 mm size and sand component constitutes more than 60 percent of the materials. In the present study, modified compaction as well as minimum and maximum density tests were used based on the ASTM standard to evaluate and control the compaction of crust materials. According to the type of the grading curve of materials used in Herat dam and results obtained from test crust compaction, it was shown that ASTM standard modified compaction calculation methods are not suitable for controlling the compaction of crust materials, and it is better to control the compaction based on the relative density. Moreover, compaction criteria was tested and determined based on the results obtained from operating the test embankment according to the thickness of embankment, type of the roller, number of roller passes, and type of the material and moisture content.

Keywords:

Herat dam, test embankment, modified compaction test, density test, crust compaction

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INTRODUCTION

Controlling the compaction of earthen dams are done in order to implement soil compaction based on the detailed studies. This means that layers' thickness, obtained density, uniformity of compaction, water content according to soil type and aggregation can establish the stability of the dam body in static and dynamic conditions (Liu *et al.,* 2014). In construction operations, control and implementation criteria should be revised according to the type of materials (Vafaeian, 2003). In discussions about material control, most technical specifications are a function of compaction and dry density of materials (Rahimi, 2003). Based on the common technical specifications of dams, test embankment must be constructed using desired devices before starting to embank the crust in order to determine materials compaction to specify relative moisture, weight per unit volume, type of compacting machines, number of roller passes, and thicknesses of layers. To this aim, the operation was followed in two steps: First, materials existed in the river were more accurately sampled and classified. In the next step, a test embankment was implemented in the workshop with different thicknesses using different materials and available rollers in order to obtain the most appropriate thickness and method for the crust layer compaction. To control the crust compaction, according to the more accurate sampling of materials and based on the standard ASTM (American Society for Testing and Materials) the modified compaction tests (D1557 and D4718) and minimum and maximum density tests (D4253 and D4254) were conducted and the results are presented here to select the appropriate method.

Modified compaction test

In part D of modified compaction test (D1557), first samples are passed through a sieve of 3/4 inches (19 mm) and the passed soil is compacted in a metal mold of 6 inches diameter and 2124 cubic centimeters volume. The soil is mixed with different amounts of water and is compacted in five equal layers by 55 beats of a 10-pound hammer falling from a height of 18 inch on each layer. The moisture content of compacted soil and its corresponding dry density is plotted on the curve of dry density versus soil moisture percent and then the maximum dry density and the corresponding optimum moisture content are obtained. This curve shows that soil moisture content has a significant effect on soil compaction. On the other hand, type of soil (grading curve, shape of soil particles and grains, solid particles density, etc.) and compaction energy per unit volume of soil also play significant effects on the shape of compaction curve, the maximum dry density and the optimum moisture content. If the compaction energy per unit volume of soil is not changed, then method D in the modified AASHTO density test is selected as the desirable compaction method. The maximum dry density and the optimum moisture content will depend on the soil grading curve (Kotzias and Stamatopoulos, 1992). The results obtained from this test for a type of materials used in Herat dam crust are illustrated in Figure 3.

According to the soil compaction curve presented in Figure 3, the optimum moisture content was 9.5 percent and the maximum dry density was equal to 2.10 grams per cubic centimeters.

Now the question arises that, if the maximum dry density and the corresponding optimum moisture content are obtained for a given type of soil from compaction test conducted on the part finer than 3/4 inches (passed through a sieve of 3/4 inches), the values for real soil samples compacted at the site containing particles larger than 19 mm are provided by D-4718 standard of the American Society for Testing and Materials

Method based on ASTM-D4718 Standards

ASTM-D4718 standard provides dry density and moisture content of soils containing coarse particles using dry density and moisture content of the same soil in a situation where coarse particles are removed. Using this standard, one can determine dry density and moisture content of the soil coarse particles. The last case is usually used when the values of dry density and moisture content of the soil compacted at the site are given using on-site standard method of determining soil density. In order to correct the dry density and moisture content of finer part of the soil (e.g. passed through a sieve of 3/4 inches in the modified compaction test using D method), equation 1 is proposed to determine the dry density and moisture content of the real soil.

$$\gamma_{dc}=100\gamma_{df}.\gamma_w.G_M\ l(\gamma_{df}p_c+G_M\gamma_w p_f) \quad (1)$$

Where, 'γ_{dc}' is corrected dry density for the real soil containing coarse particles; 'γ_{df}' is dry density for a part of soil where the coarse particles are removed; 'G_M' is the real density of coarse aggregates; 'γ_w' is water weight per volume (equal to 1 g/cm^3 or 9.802 kN/m^3); 'p_c' is percent weight of coarse aggregates; and 'p_f' is percent weight of finer particles (coarse aggregates are removed) with p_f= -100p_c.

The corrected moisture content is calculated from equation 2:

$$\omega=(\omega_F p_{F+}\omega_C p_c) \quad (2)$$

Where 'ω' is corrected moisture content of the soil containing coarse aggregates; 'ω_F' is moisture content of the finer part and 'ω_C' is moisture content of coarse aggregates.

If sieve number 4 is selected to separate coarse and fine parts, these equations are valid for soils that up to 40% of their grains remained on a sieve number 4. This instruction is also valid for soils remained on sieves larger than number 4, e.g. sieve of 19 mm, but the limiting percent of larger particles may be lower. However, the mentioned instruction is valid when the larger part consisted of particles that remained on a sieve of 19 mm for materials with up to 30 percent coarse aggregate (Shukla, 2011).

If coarse aggregates are defined as particles remained on a sieve of 3/4 inches, these equations can be used for soils having up to 30% particles residue on this sieve. As can be seen, according to this standard, the domain of coarse aggregates percent that can be corrected using these equations is less for larger grains. It can also be seen that correction is negligible for soils having low coarse particles (P_C). Therefore, the organization or institute that uses this standard can define a minimum value for percentage of coarse particles so that no correction is needed for lower percentages. According to this standard, if this minimum value is not specified, 5% would be considered as the correction criterion (Esmaieli, 1998).

If coefficients are calculated and applied on maximum dry density of D1557 test, the maximum corrected dry density will be equal to 2.37 tons per cubic meter which is not consistent with the results obtained from test embankment in which the density of materials were equal to 2.18-2.3 tons per cubic meters. It may be due to the remaining of more than 40 percent of coarse particles on sieve number 4. Therefore, this test is not appropriate for controlling the materials compaction.

Vibrating table test and determination of relative density

Soil pores represent on-site compaction of granular soil. Relative density of soil is defined by equation 3 and is expressed in percent (Braja, 2007).

$$D_r = \frac{e_{max}-e}{e_{max}-e_{min}} \times 100 \quad (3)$$

Where 'e_{max}' is the ratio of maximum soil pores; 'e_{min}' is the ratio of minimum soil pores; and 'e' is ratio of pores in the desired soil.

'D_r' varied from 0 for loose granular soil to 1 for the same soil in compacted mode. Soil engineers express the compaction of sedimentary granular soils based on their relative density. In practice, due to difficulty of determining on-site pores ratio, equation 4 is used to determine relative density.

$$D_r = \left[\frac{\gamma_d - \gamma_{d(min)}}{\gamma_{d(max)} - \gamma_{d(min)}}\right] \times \left[\frac{\gamma_{d(max)}}{\gamma_d}\right] \quad (4)$$

Where, '$\gamma_{d(min)}$' is dry density in the most loose case (for 'e_{max}'), '$\gamma_{d(max)}$' is dry density in the most compacted case (for 'e_{min}'), and 'γ_d' is on-site dry density.

D4253 and D4254 tests of ASTM provide the process of determining the minimum and maximum densities of granular soils. This process requires a mold of 2830 cm^3 volume for sand. To determine the minimum dry density, dry sand is poured into the mold using a funnel of 12.7 mm diameter. The average height of sand falling into the mold is maintained at 25.4 mm. Then '$\gamma_{d(min)}$' can be calculated using equation 5.

$$\gamma d(min) = \frac{w_s}{v_m} \tag{5}$$

where 'W_s' is the weight of sand required for filling the mold and 'V_m' is the volume of mold.

Maximum dry density is determined by shaking the sand inside the mold for eight minutes. In this case, an overhead with a weight of 14 kN/m^2 is added to the top of the sand. The mold is placed on a table vibrating with a frequency of 3600 cycles per minute and a vibration amplitude of 0.635 mm. '$\gamma_{d(max)}$' can be determined at the end of vibration by the given weight and volume of the sand (Braja, 2003).

According to standard ASTM D4253, determining the maximum density using vibrating table is used for soils with less than 15% grains finer than sieve number 200. Minimum density is also obtained from standard ASTM D4254 and can be used in the relative density equation. Results obtained from this test for this sample assuming Dr= 0.85 are presented in Table 4. These results are consistent with the results obtained from test embankment in which the densities of materials were 2.18 -2.3 tons per cubic meter.

MATERIALS AND METHODS

According to the detailed studies reported for Herat dam, the specifications of materials sampled from the site, the basis of design and calculations are described in Table 1 (Kakhi, 2002).

Crust materials of Herat reservoir dam were provided from Hasan Abad mine at a distance of about 12 kilometers from the dam body including coarse aggregates with a few fine grained materials. The amount of fine grained materials under a sieve number 200 was about 10 percent, and the amount of gravel materials between sieve number 200 to sieve number 4 was about 23 percent, and about 60% of the materials were sands, and about 2% of them were cobble stones. PI of fine grained materials finer than sieve number 200 were about 5 to 14 percent and the optimum moisture content was about 6.5% (Kakhi, 2011).

Figure 1 shows a grading curve related to a specific type of materials used in construction of Herat dam crust.

The general type of materials were as follows: From the river surface to a depth of about 2.5 meters, materials were clean sand and gravels with a small amount of cohesive fine-grained materials (mainly GP-GC). In the lower depths of the river, cohesive fine-grained materials were increased and soil classification became close to GC.

The materials of Hasan Abad river were exploited from the surface to the depth of about 2.5 m with a length of about 11.5 km and were deposited in two

Table 1. Specifications of materials collected from the site

Materials	Density		Strength parameters		Permeability (cm/s)
	Moist t/m^2	Saturated t/m^2	Cohesion	Friction angle	
Core	2.08	2.12	-	-	$1*10^{-7}$
UU	-	-	0.75	11	-
CU	-	-	0.57	22	-
CD	-	-	0.17	32	-
Crust	1.95	2.17	0	40	$3*10^{-4}$

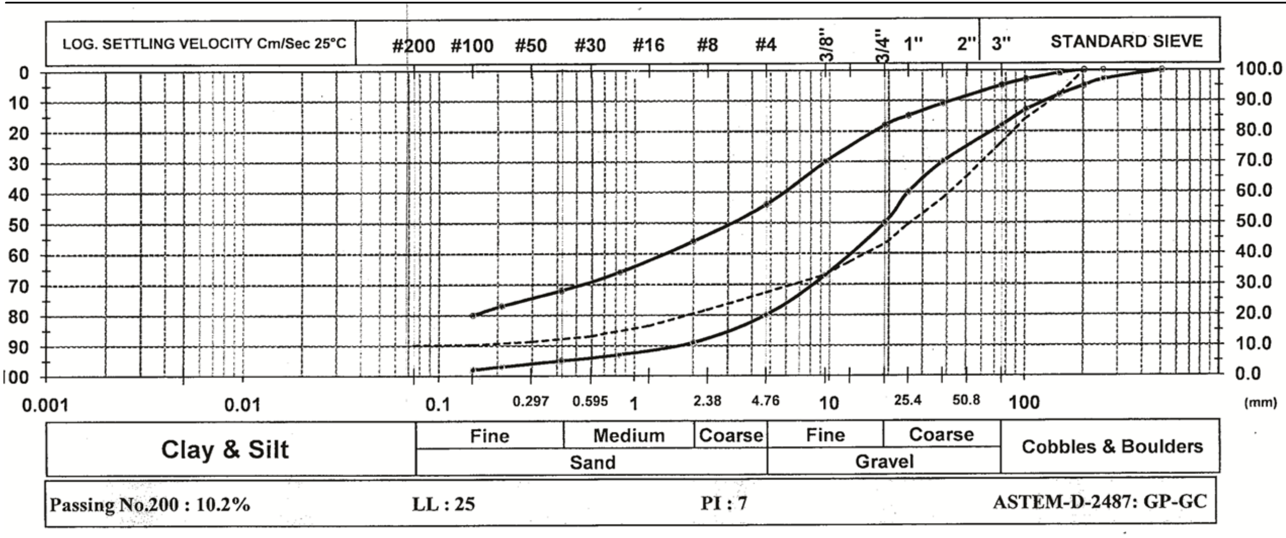

Figure B1. The grading curve of materials used in herat dam crust

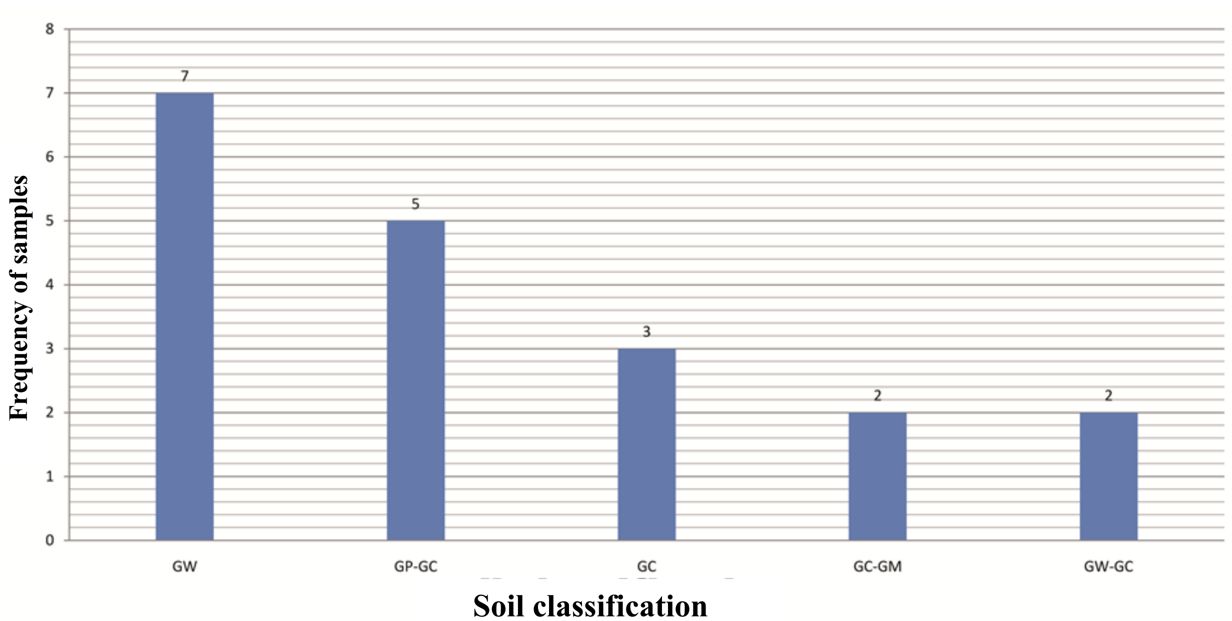

Figure 2. The frequency of different classes of coarse aggregate materials used in Herat dam crust

separate depots inside the workshop. The volume of these two depots were about 400 thousand cubic meters. One of these depots was used as concrete materials and the other one was used for the dam body. Figure 2 shows the frequency of different classes of coarse aggregate materials used in Herat dam crust.

Reviewing results obtained from figures indicate that the most frequent types of soil were from GW and then GP-GC classes. Studies showed that the maximum materials residue on the sieve number 200 was about 17% and the maximum PI was about 14%. Considering the specifications of figures, the materials of Hassan Abad river were mainly of types GW and GP-GC, the average residual below the sieve number 200 was about 6-10%, and the average PI of materials was about 5-10. It should be noted that materials used in this test embankment were provided from Hasam Abad mine from the depth of less than 2 m which were mainly from GP-GM class with a fine grained percentage less than 10%, and about 55% of materials were passed through 3.4 inch sieve.

Analyzing the stability of herat dam body

In this section, we present the results of static

Table 2. Allowed safety factors considered in the slope stability analyses

1	End of construction	1.3 and 1.4	Downstream and Upstream Slopes
2	Reservoir leakage Partially full	1.5	Upstream slope
3	Rapid water drop in the reservoir	1.5	Upstream slope
4	Stable leakage from maximum and normal Level	1.5	Downstream slope
5	Cases 1, 2, and 4 with earthquake	1.0	Seismic coefficient according to the case

Table 3. Results obtained from stability analysis of herat dam body slopes in different loading conditions

Slope	Slip surface	Loading	Type of analysis	Static	Seismic coefficient of 0.15	Seismic coefficient of 0.2	Seismic coefficient of 0.22	Pore pressure coeficient	Description
Upstream	Circular	End of construction	Effective stress	2.045	1.416	1.284	1.201	Core 0.4	
Upstream	Circular	End of construction	Total stress	2.044	-	-	-	-	UU
Downstream	Circular	End of construction	Effective stress	2.001	1.365	1.203	1.174	Core 0.4	
Downstream	Circular	End of construction	Total stress	2.003	-	-	-	-	UU
Upstream	Circular	Half full reservoir	Effective stress	2.103	1.353	1.186	1.098	-	
Upstream	Circular	Stable leakage	Effective stress	3.163	1.259	1.126	1.04	-	
Downstream	Circular	Stable leakage	Effective stress	3.063	1.460	1.323	1.204	-	
Upstream	Circular	Rapid discharge	Total stress	2.247	1.477	-	-	-	CU

Table 4. The results of minimum and maximum density test

$\gamma_d(\frac{t}{m^3})$	D_r	$\gamma_{d(max)}(\frac{t}{m^3})$	$\gamma_{d(min)}(\frac{t}{m^3})$
2.16	0.85	2.24	1.76

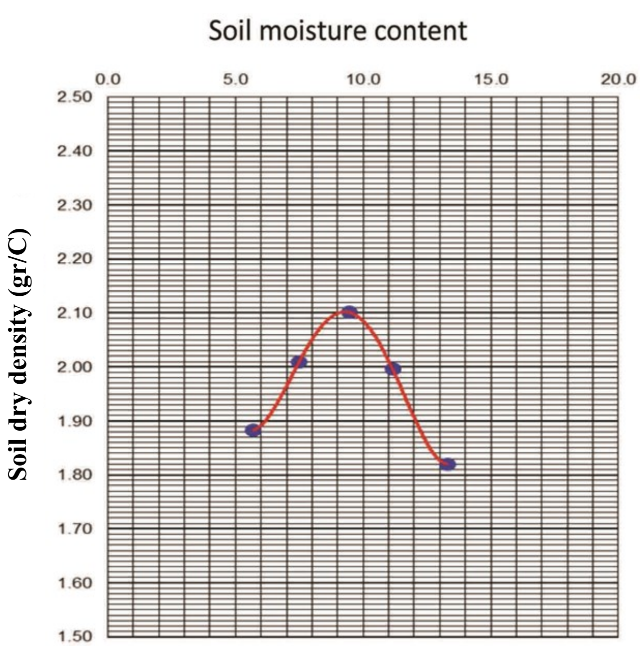

Figure 3. Compaction curve obtained from one of the materials used in heratdam crust

and quasi-static analyses using limited equilibrium method for Herat dam. These analyses were the basis of the dam geometry control based on physical and geo-mechanical properties of different materials used in body and foundation. The aim of conducting these analyses was analyzing the dam slope stability under various loading conditions and operating at static mode and under seismic forces (Gohari and Rouhimehr, 2012). The stability of the dam body slopes was analyzed using SLOPE W computer program which is a component of GEOSLOPE program. Earthquake effects can be considered using a quasi-static method. In this method, seismic forces can be applied on the main body as a fixed and horizontal force equal to a part of weight of each element which is possible using seismic coefficient (Javaheri and Pakniat, 2012).

Different seismic factors from 0.15g to 0.23g were used in various loading modes. Permissible safety factors in static analysis were selected according to USCORP guidelines and allowed safety factors suggested by USBR were also considered. Safety factors allowed in

Table 5. The maximum thickness proposed for each layer with different materials based on determined values

Material	Compacting tool	Acceptable Range for compacted layers (m)
Impermeable core	Rubber wheel roller	0.15-0.2
	Tamping foot roller with special maul	0.1
Impermeable layer interface	Special maul	0.1
Filter and drain	Vibrating roller	0.25
Transition zone	Vibrating roller	0.4-0.5
	Special vibrating roller	0.2
Gravel	Vibrating roller	0.65-0.8
	Special vibrating roller	0.6
Mixed	Vibrating roller	0.4-0.5

Table 6. Maximum implementation thicknesses of layers after compaction in meters for various rollers and applications

Type and static weight of roller (weight of wheels is provided individually in brackets)	Embankment				Sub-base	Base
	Gravel (1)	Sand	Silt	Clay		
Towed Vibrating						
6 tons	0.75	0.6*	0.45*	0.25	0.2*	0.3*
10 tons	1.5*	1*	0.7*	0.75*	0.6*	0.4*
15 tons	2*	1.5*	1*	0.15*	0.8*	-
6 tons with tamping feet	-	0.6	0.45*	0.2*	0.2	-
10 tons with tamping feet	-	1	0.7*	0.4*	0.6*	-
Self-propelled vibrating	-	-	-	-	-	0.75*
7 (3) tons	-	0.2*	0.2*	0.15	0.3*	-
10 (5) tons	1.5	1*	0.7*	0.5*	0.4*	-
8 (4) tons with tamping foot	-	0.4	0.3*	0.2*	0.3	-
11 (7) tons with tamping foot	-	0.6	0.2*	0.3*	0.4	-
15 (10) tons with tamping foot	-	1	0.7*	0.4*	0.6	-
Tandem vibrating	-	-	-	-	-	0.15*
2 tons	-	0.3	0.2	0.1	0.2	0.25*
7 tons	-	0.4*	0.3	0.15	0.3*	0.7*
10 tons	-	0.5*	0.35*	0.2	0.4*	0.35*
13 tons	-	0.6*	0.45*	0.25	0.45*	0.35*
18 tons with tamping feet	-	0.9	0.7*	0.4*	0.6	-

*More appropriate application
(1) For rollers designed for gravels

quasi-static analysis were considered as described above. Selected permissible safety factors are presented in Table 2 (Pourgoodarzi, 2000).

The minimum safety factors obtained from slope stability analysis for Herat dam body are presented in Table 3 (Pourgoodarzi, 2000).

According to the results obtained from slope stability analyzes conducted in static or quasi-static loading conditions, it can be concluded that, Stability of the dam body in all modes of dam functionality is guaranteed based on accepted safety standards.

In quasi-static conditions, slope stability is guaranteed in all modes. There is enough margin of safety in terms of dam services in maximum possible earthquake mode which indicates that dam body deformations will be at an acceptable level during the maximum earthquake.

The test embankment

The maximum thickness proposed for each layer for different materials are presented in Table 5. However, a supervisor engineer can order other

Table 7. Results obtained from test embankment

N0.	On-site Density	On-site Moisture Content	Thickness	Type of Roller	Number of Passes	Type of Materials	Bed Type
1	2.30	5	31	20 tons	8	Hasan Abad	Soiled bed
2	2.21	6.3	38	20 tons	8	Hasan Abad	Soiled bed
3	2.24	5.4	32	20 tons	8	Hasan Abad	Soiled bed
4	2.26	5	39	20 tons	8	Hasan Abad	Soiled bed
5	2.34	6.5	37	20 tons	8	Hasan Abad	Soiled bed
6	2.19	5	35	20 tons	8	Hasan Abad	Soiled bed
7	2.18	5.3	32	20 tons	8	Hasan Abad	Soiled bed
8	2.39	6.9	38	10 tons	8	Hasan Abad	Soiled bed
9	2.30	6.5	34	10 tons	8	Hasan Abad	Soiled bed
10	2.28	10	30	10 tons	8	Hasan Abad	Soiled bed
11	2.27	6.4	31	20 tons	8	Hasan Abad	Soiled bed
12	2.32	6	80	20 tons	8	In the workshop	Rocky bed
13	2.40	6.9	28	20 tons	8	Hasan Abad	Rocky bed
14	2.24	8	30	20 tons	8	Hasan Abad	Rocky bed

instructions based on the results of tests conducted on the test embankment. Table 6 shows the maximum implementation thicknesses of layers after compaction in meters for various rollers and applications (Fell *et al.,* 1992).

According to the preliminary results of test embankment which indicate the impossibility of achieving the desired compaction for large thicknesses with rollers available in the workshop, a multilayer embankment with thicknesses between 40-30 cm was planned. Eight roller passes were used in all layers. QX520 smooth vibrating roller of 20 tons static weight and HEPCO HCB100 smooth vibrating roller about 10 tons of static weight were used in this test embankment. The results are given in Table 7.

According to the results, the average density was equal to 2.28 tons per cubic meter. The minimum and maximum densities were equal to 2.18 and 2.4 tons per cubic meter, respectively. Frequency of each range of dry density is presented in Figure 4. As shown in this figure, in 65% of cases densities were more than 2.25 tons per cubic meter, and only in 14% of cases densities were less than this value. It should be noted that the average thickness of layers was 33 centimeters. Different factors including moisture content, weight of roller, grading of materials, and thickness of layers affected materials compaction. Each factor is briefly described in the next sections.

The effect of moisture content

The results showed that moisture content had a significant effect on soil compaction. Figure 5 shows the average moisture content for each range of density. The figure clearly shows that achieving higher densities is possible with increasing moisture content. Based on all measured points, the relationship between density and moisture is shown in Figure 6. This figure also shows an increase in density with increasing moisture content within the test range. By removing two samples having very high densities (about 2.4) the slope of the sample will even be greater.

Roller weight

Increased compaction by increasing the compaction energy and weight of roller is a general

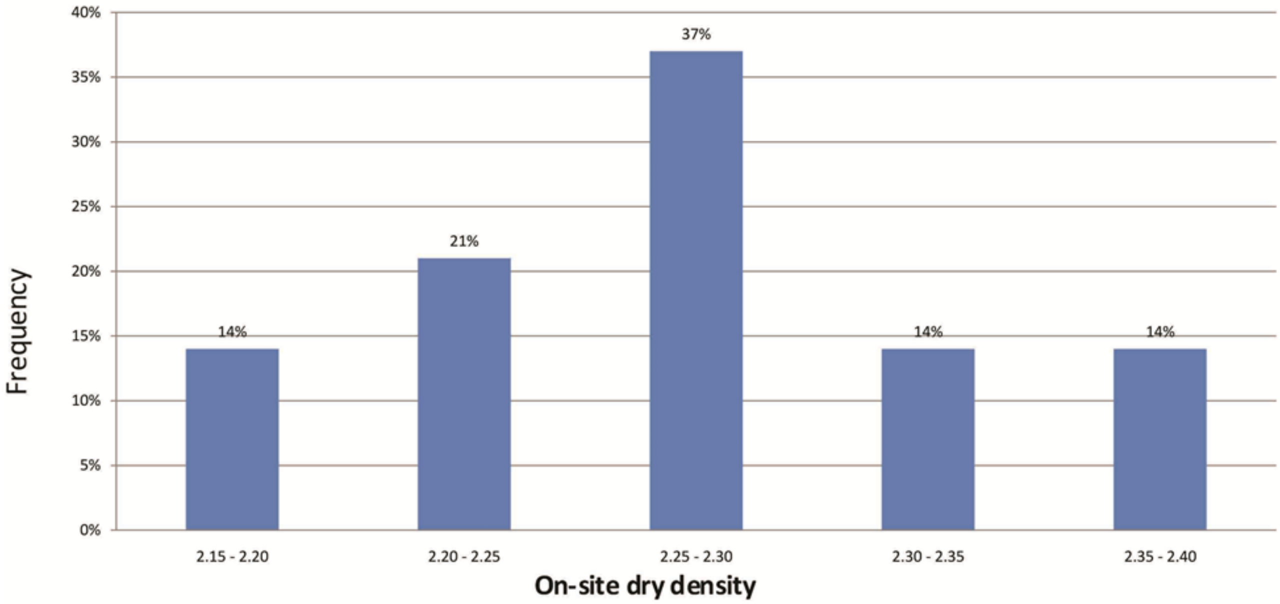

Figure 4. The frequency of each range of dry density

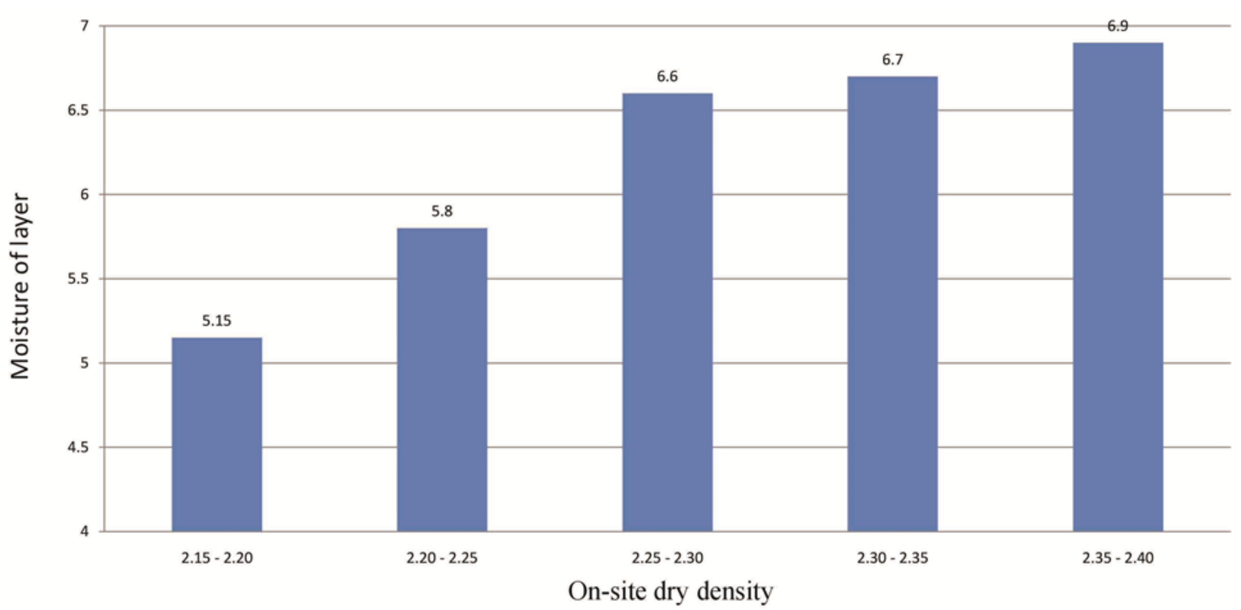

Figure 5. The average moisture content for each range of density

principle accepted in soil compaction discussion. The results shown in the table indicate that average density of materials for 7 samples compacted with heavy roller (with static weight of 20 tons) measured on soiled bed was equal to 2.25. This value was equal to 2.31 for four samples compacted with lighter roller (with static weight of 10 tons). It shows that increasing the weight of roller would reduce the density. To explain this phenomenon, it should be noted that studying the layer moisture content shows that average moisture in three samples compacted with HCB100 roller was equal to 7.45%. This value was equal to 5.5% for seven samples compacted with QX520 heavy roller. Therefore, higher moisture content and possible changes in grading have increased compaction and the positive effect of heavy roller on compaction cannot be ignored. In the project future fills, at the same conditions, a contractor can evaluate the performance of a heavier roller in compaction (Kakhi, 2009)

The effect of layer thickness

As expressed in the previous section, the

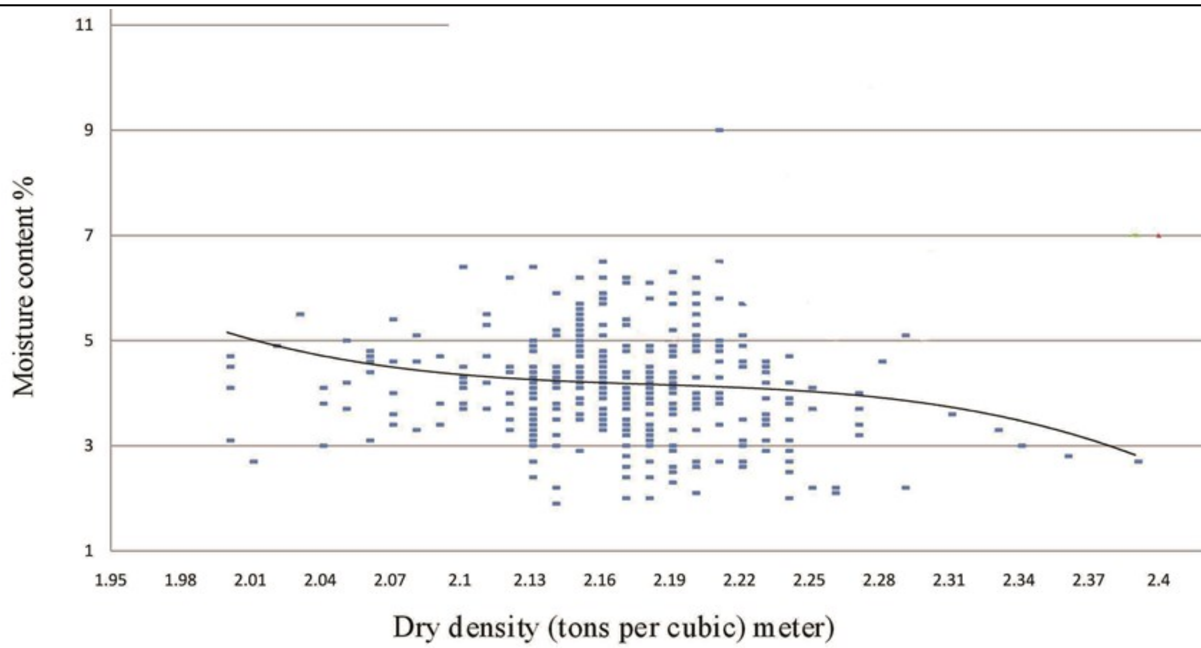

Figure 6. The relationship between density and moisture

average thickness of layers were equal to 33 cm which led to an average dry density equal to 2.28 tons per cubic meter. Figure 7 presents the average thickness of layer in any given range of dry density. The general expectation was to increase density by reducing the thickness of layer, which is evident in a wide range of thickness changes, and it was confirmed by the results obtained from the previous test embankment. Two density tests conducted on layer with a thickness of 54 cm compacted with HCB100 roller showed that density of 2.25 and 2.21 tons per cubic meter were measured respectively for the top 30 cm and lower 24 cm in a pilot hole. In the second pilot hole just the density of the lower 30 cm was measured which is equal to 1.95 tons per cubic meter. It is important to note that the average moisture content of this layer is equal to 205% which is significantly less than the optimum compaction value.

DISCUSSION

Considering the experimental embankment,

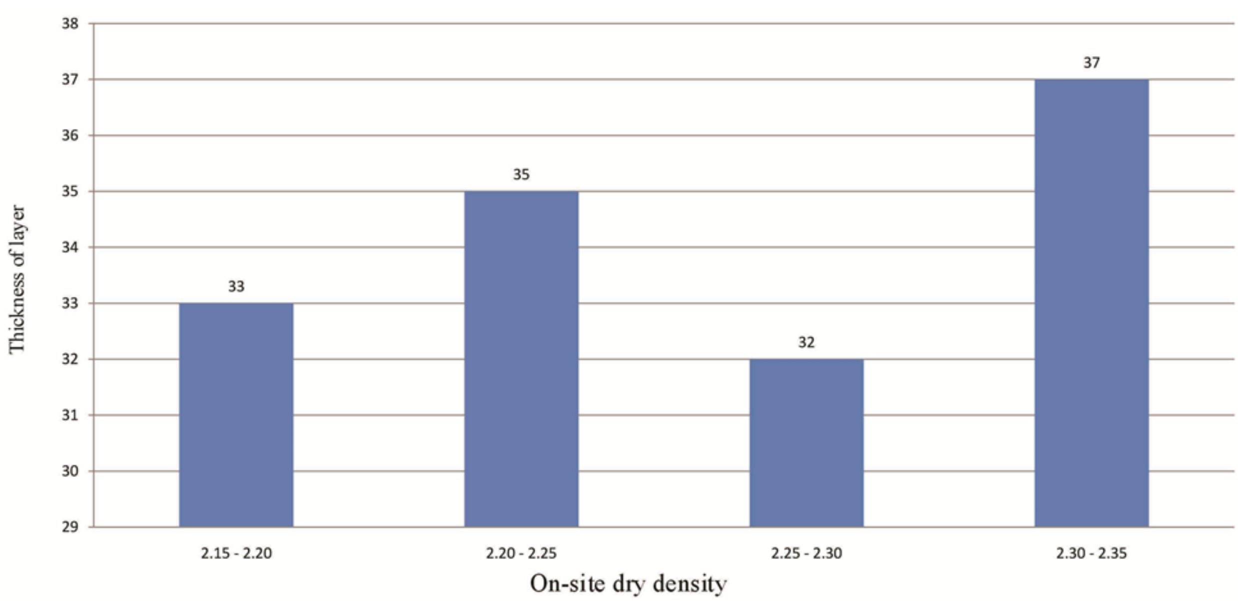

Figure 7. The average thickness of layers

materials of Hassan Abad river were mainly of GP-GC, GW respectively.

Various factors in density of materials has been effective, such as moisture content, weight of rollers and thickness of soil layers. Charts indicate that achieving higher density with increase of moisture content is possible. Also with increasing the weight of rollers, density of materials decreases. In general, with decreasing the thickness of soil layers, density of materials increases. In Herat earth dam, according to preliminary results test which implies the impossibility of achieving the desired density in high thickness with available rollers, several layer with thickness between 30-40 cm was planned. In all of the layers, the 8 pass of rollers have been used. The slope stability analyzes carried out on the Herat earth dam in static and pseudo-static loading conditions shows that:

Stability of the dam body in all modes of dam functionality is guaranteed based on accepted safety standards.

In quasi-static conditions, slope stability is guaranteed in all modes. There is enough margin of safety in terms of dam services in maximum possible earthquake mode which indicates that dam body deformations will be at an acceptable level during the maximum earthquake.

CONCLUSION

According to the type of grading curve of materials used in Herat dam and its crust, it has shown that ASTM standard modified compaction calculation methods are not appropriate for controlling the crust materials compaction, and it is better to control the compaction based on the minimum and maximum density tests (D4253 and D4254) and relative density ratio of 0.85.

REFERENCES

Behpour Gohari M and Rouhimehr A. (2012). Static and dynamic analysis of embankment dams using Geostudio (first ed.). Nashr-E Elm-E Omran Publications. 300 p.

Das Braja M. (2007). Geotechnical engineering principles: Soil mechanics (15th ed.) [In English]. Salekan Center for Cultural Services, vol. 1, 1-992 p.

Das Braja M. (2003). Geotechnical engineering principles: Soil mechanics (first ed.) [In English]. Kotob-E Daneshgahi Press. 500 p.

Esmaili M. (1998). The importance of dry density values correction for soils containing coarse particles in earth-works. *Journal of Geotechnics and Materials Strength*, 81(2):30-39.

Fell R, Macgregor P and Stapledon D. (1992). Geotechnical engineering of embankment dams. 440 p.

Javaheri A and Pakniat A. (2012). Static and dynamic analysis of embankment dams using Geostudio (first ed.). Nashr-E Elm-E Omran Publications. 325 p.

Kotzias P and Stamatopoulos A. (1993). Compaction quality control in granular shell of earth dam. *International Journal of Rock Mechanics and Mining Sciences and Geomechanics*, 30, 115 p.

Liu D, Li Z and Lia Z. (2014). Compaction quality assessment of earth-rock dam materials using roller-integrated compaction monitoring technology. *Automation in Construction*, 44:234 p.

Kakhi M. (2011). Report of results obtained from Herat reservoir dam coarse aggregate quarries tests. Maharab Consulting Engineers Yazd Regional Water Organization, Herat, Yazd, Iran. 100 p.

Kakhi M. (2012). Report of Herat reservoir dam test fill. Maharab Consulting Engineers. Yazd Regional Water Organization, Herat, Yazd, Iran.100 p.

Pourgoodarzi V. (2000). Static analysis of embankment dams. Iranian National Committee on Large Dams, 250 p.

Rahimi H. (2003). Embankment dams (First ed.), Tehran University Press. Tehran, Iran. 459 p.

Shukla SA. (2011). Corrective terms for compaction test parameters. *Journal of Geotechnics and Materials Strength*, 24(11):35-39.

Vafaeian M. (2003). Embankment dams (3th ed.), Isfahan University of Technology, Jihad Daneshgahi Press, Isfahan, Iran.650 p.

Kakhi M. (2002). The second phase studies on the construction of Herat reservoir dam and downstream irrigation and drainage network: Report of quarries and building materials, Zistab Consulting Engineers. Yazd Regional Water Organization, Herat, Yazd, Iran. 100 p.

Kakhi M. (2009). Herat reservoir dam construction plan and related facilities. Zistab Consulting Engineers. Yazd Regional Water Authority, Herat, Yazd, Iran. 100 p.