Compaction Control of Soil-Rock Mixtures at Odelouca Dam

Andrea Brito
Laboratório Nacional de Engenharia Civil (Author(s) Affiliation)
andreabrito@lnec.pt

Laura Caldeira
Laboratório Nacional de Engenharia Civil
laurac@lnec.pt

ABSTRACT

Recently, soil-rock mixtures are being used in the construction of embankment dam shoulders. This situation represents new challenges to compaction techniques and their control as well as to the determination of the characteristics of the fill that results from the compaction method, as those characteristics suffer important changes according to the relative percentage of the existing fractions.
For the execution control of the soil-rock mixtures from the Odelouca dam borrow areas, presently being constructed at South of Portugal, a series of vibratory compaction tests and rammer compaction tests were performed to estimate reference values for the maximum dry density and optimum water content of these materials. Odelouca dam is a zoned earth fill dam, with 76 m height with clayey soil at the core and weathered schist with a significant fraction of oversized particles at the slopes.
This paper presents the results of these tests. Following the methodology, developed in 1994, by Torrey & Donaghe, a set of correction equations of the Proctor reference values (obtained on a partial finer fraction passing in the ¾" sieve) for the extrapolation of the control properties of integral material for schistose material is presented. Additionally a new methodology based in different parameters is proposed.

Keywords: Soil-rock mixtures, compaction, control, vibratory tests, rammer compaction tests.

INTRODUCTION

The utilization of non traditional materials, such as the soil-rock mixtures, in the earthworks construction by economical and environmental reasons, has put some problems.
Usually, in the earthworks construction, this kind of material results from the rocky bulky extraction without explosives, and it can include some oversized particles (about 0,5 m or more).
The Junta Autónoma das Estradas Standards (1998) consider as soil-rock mixture, materials of continue gradation, which the plus ¾" (19 mm) fraction is between 30% and 70%, the minus No.200 fraction is between 12% and 70% and the maximum particles dimension ($D_{máx}$) has to be inferior to 2/3 of the layer thickness after compacted and to 0,40 m.
Recently, especially in highways and roads engineering, some attention was been addressed to the soil-rock mixtures, due to the deficient behaviour presented by some roads, forcing, in many cases, the application of corrective measures. Frequently, these materials present an

evolutive nature, with a friable coarser fraction, that, with the construction process and in the service phase, suffers an alteration of their nature and of their gradation.

On the other hand, embankment control of dams constituted by soil-rock mixtures is still a subject that needs investigation, considering that is necessary to extrapolate current test results, been reach by truncated gradation, for the construction conditions of the embankments.

USCOLD (1988) reports that has been recognized by several geotechnical engineers that the inclusion of rock particles in otherwise fine grained soils can have a significant influence on the engineering properties of the material, depending, among others things, upon the relative percentage of soil and rock present in the mixture.

Thus, and having for reference the shoulders of Odelouca dam, constituted by weathered schist and greywacke, with a significant fraction of oversized particles, this paper presents results from vibratory and rammer compaction tests, carried out for the deduction of corrective expressions to apply in the embankment quality control with this type of materials.

ODELOUCA DAM DESCRIPTION

Odelouca dam is a zoned earth fill dam, with 76 m height, presently being constructed in Algarve, in south of Portugal. The crest of dam, with 11 m of width, is about 415 m long (*Figure 1 a)*).

The embankment materials are clayey soil, at the core, and weathered schist and greywacke, with a significant fraction of oversized particles, at the shoulders (*Figure 1 b)*).

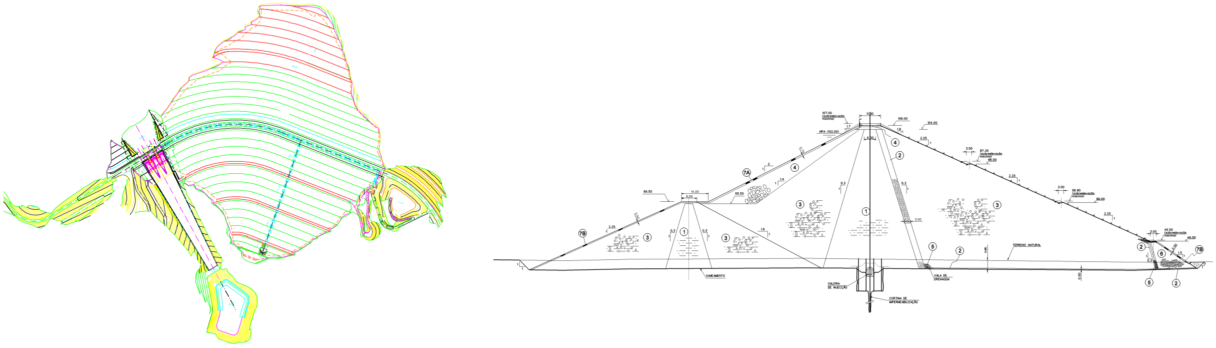
COMPACTION CONTROL EQUATIONS

Houston and Walsh (1993) report that, in order to have into account the coarser fraction influence in the quality control, four different methodologies can be adopted. The *Method 1* consists in performing compaction tests in large moulds, using the entire material as it occurs in the field, for the evaluation of the mixture maximum dry density and the corresponding optimum water content. *Method 2* consists in performing compaction tests in moulds of smaller dimensions, using the "scalp-and-replace" method. *Method 3* consists in performing compaction tests with the material passing the ¾" (19 mm) sieve in a 6" (15,24 cm) mould; the plus ¾" material is discarded; this method is only valid when the plus ¾" material is less than 10% by weight (ASTM – D698-00a). The last method (*Method 4*) consists in performing compaction tests on the minus No.4 fraction, for the determination of the maximum dry density and optimum water content for this fraction; correction of these results, taking into account the percentages of coarser and finer fractions, to obtain an estimate of maximum dry density and optimum water content of the field soil (through ASTM – D4718-87, ASTM 1994 Annual Book or USBR – 5515-89).

Method 1 is a very expensive and time-consuming technique, therefore, is rarely used. *Methods 2* and *4* are frequent used for materials having between 10% and 60% of the coarser particles. *Method 3* is only suitable to mixtures with reduced percentage of coarser particles and that the behaviour is clearly controlled by the finer matrix.

Some studies, carried out by the Junta Autónoma de Estradas (JAE) and the Laboratório Nacional de Engenharia Civil (LNEC) in Portugal (JAE/LNEC, 1994), suggested the use of the scalp-and-replace method and the correction of the values obtained in the tests, w^F_{opt} and $\gamma^F_{d\,máx}$, to the calculation of the optimum water content and the maximum dry density of the mixture, as a function of the percentage of the coarser particles (retained in the n.º 4 sieve or in the ¾" sieve of the ASTM series).

Additionally JAE/LNEC (1994) states that, related to *Methods 2* and *4*, the ¾" sieve is not the most appropriate for the coarser material separation, due to the fact that it can produce very high percentages.



a) b)

Figure 1. a) Odelouca dam plant. b) Odelouca dam cross-section

For the maximum dry density correction, the same authors suggest the application of the following equation:

$$\gamma_{d\ máx}^{T} = \frac{100}{\dfrac{P_C}{\gamma_d^C} + \dfrac{P_F}{\eta\, \gamma_{d\ máx}^{F}}} \tag{1}$$

where $\gamma_{\mathrm{d\ máx}}^{\mathrm{T}}$ is the maximum dry density of the total material, $\gamma_{\mathrm{d}}^{\mathrm{C}}$ the dry density of the coarser fraction, $\gamma_{d\ máx}^{F}$ the dry density of the finer fraction, obtained in the compaction test using the scalp-and-replace method, $\mathrm{P_F}$ the weight percentage of the finer fraction, $\mathrm{P_C}$ the weight percentage of coarser fraction and η some correction coefficient, giving by

$$\gamma = -5\times 10^{-5} P_C^2 + 0{,}0013 P_C + 0{,}9958 \tag{2}$$

For the water content correction, it is systematically use the following weighting equation:

$$\mathrm{w_{opt}^{T}} = \frac{\mathrm{P_F w_F + P_C w_C}}{100} \tag{3}$$

where $\mathrm{w_{opt}^{T}}$ is the water content of the total material, $\mathrm{w_C}$ the water content of the coarser fraction and $\mathrm{w_F}$ the water content of the finer fraction, usually taken as the w_{opt}^{F}, obtained in the compaction test.

In 1994, Torrrey and Donaghe (1994) introduced a new method based in results from tests performed by them, which was calibrated from data till then published for soil-rock mixtures. They performed compaction tests, with standard proctor energy, in different moulds and in materials composed by gravel, sand and non plastic silts or high plasticity clays.

These authors, for the result treatment, defined two additional quantities:

- the density interference coefficient, $\mathrm{I_c}$, giving by:

$$\mathrm{I_c} = \frac{\mathrm{100 F_F}}{\mathrm{P_G G_M}} \tag{4}$$

where $\mathrm{F_F}$ is the fraction density factor, giving by $\mathrm{F_F} = \gamma_{\mathrm{d}}^{\mathrm{F}} / \gamma_{\mathrm{d\ máx}}^{\mathrm{F}}$, $\gamma_{\mathrm{d}}^{\mathrm{F}}$ the dry density of the finer fraction, $\mathrm{P_G}$ the coarser content (the minus ¾" (19,1 mm) or minus No.4 (4,76 mm) fraction) and $\mathrm{G_M}$ the bulk specific gravity of the coarser fraction.

- the optimum water content factor, $\mathrm{F_{opt}}$, evaluated by

$$F_{opt} = \frac{100 w_{opt}^{F}}{P_G w_{opt}^{T}} \tag{5}$$

where w_{opt}^{F} represents optimum water content, obtained in the compaction test, of either the minus ¾" (19,1 mm) or minus No.4 (4,76 mm) fraction, w_{opt}^{T} the water content of the total material and P_G the weight coarser content.

To calculate F_F, the authors appealed to the following equation:

$$F_F = \frac{\gamma_{d\,máx}^{T} G_M \gamma_w P_F}{100\gamma_{d\,máx}^{F} G_M \gamma_w - \gamma_{d\,máx}^{T} \gamma_{d\,máx}^{F} P_C} \tag{6}$$

The result values of I_c and F_{opt} of each test were represented as a function of coarser content (the minus No.4 (4,76 mm) fraction), P_G. This representation allowed to verify that the proposed parameters (I_c and F_{opt}) are independent of type of fines present and to propose the following correlations, deducted for the clayey soils mixtures:

$$\log I_c = 1{,}614 - 1{,}025 \log P_G, \quad P_G \le 0{,}50 \tag{7}$$

$$I_c = 1{,}406 - 0{,}0132 P_G, \quad 0{,}50 \le P_G \le 0{,}70 \tag{8}$$

$$\log F_{opt} = 1{,}812 - 0{,}730 \log P_G \tag{9}$$

According to the cited authors, the expression (7) would be valid for coarser percentages till 50% (for larger percentages the relation is no linear), the expression (8) was approximated and conservative for gravel percentages between 50 and 70% and the expression (9) is valid for all performed tests.

TESTING PROGRAM

To perform the shoulders quality compaction control of the Odelouca Dam, composed by weathered schist and greywacke with a significant fraction of oversized particles, two approaches were been used.

The first approach consisted in performing vibratory compaction tests. This is a technique extremely use in the construction of highways and roads and very similar to the applied in the field. It is also applied for the rockfill laboratory sample reconstitution. It is then necessary to establish some safe criteria for the comparison of in situ and laboratory results.

The other approach is the rammer compaction tests, known as standard Proctor compaction tests, but carried out in an appropriate dimension mould, bigger than the large mould of the standard tests, in the Toni-tecnik compactor. Naturally, it was necessary to adapt the standard procedures E 197-1966, due to the equipment and samples scope. There are two main reasons to apply this technique. The first is because it is the traditional technique used in the earthworks control. The second reason is because there is specialized bibliography that presents some related studies which will allow comparing the results obtained.

The two methodologies will be described in the next points.

Vibratory compaction tests

After extraction and the in advance material homogenization for experimental embankment construction, different samples were gathered from different piles, here identified as lot. The vibratory compaction tests were perform on the lot materials 1, 4 and 5, whose total distribution curves can be seen in *Figure 2*, as well as upper and lower limit distribution curves defined in the dam's Project. As seen from *Figure 2*, the tested lots gradations are very similar.

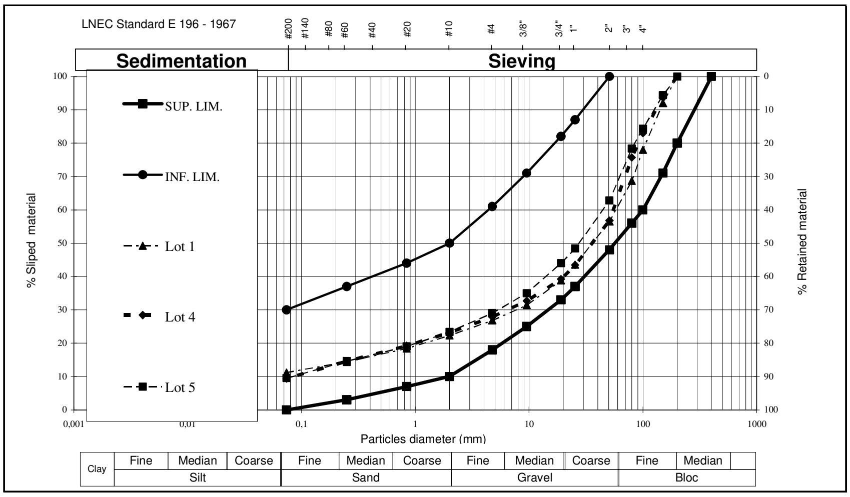


Figure 2. Total distribution curves from the tests samples

The vibratory compaction tests had been carried out based on specifications, duly adapted, that are reported in BS1377: Part 4 (1990).
Considering the mould diameter to be used in the tests ((ϕ=300 mm), the mixture particle maximum dimension was limited to 2" ($\phi \approx$6Dmax) and the tests were been performed with variables coarser material fractions (the minus ¾" (19,1 mm) fraction) present in the mixture. For the determination of each point of the compaction curve, the materials had been place in two layers, each one with 52 mm height (after compaction), above one previously compacted base layer.
Lack of previous experience concerning to the time vibration to apply to this kind of material, it was opted to measure the variation of height as a function of the vibration time, for each of the two layers and for the set of two layers, and, on the basis of this, the correspondent dry density variation.
To validate the use of the vibratory tests for compaction studies, one first stage, the results reached by this technique, performed with the minus ¾" (19,1 mm) fraction, were compared with conventional standard Proctor test results. The same results were obtained after 9 minutes of vibration. Following, vibratory compaction tests with different percentages of the coarser material (between 30% and 67,7%), using the available lots, were performed.
Figure 3 shows the compaction curves reached after 9 minutes vibration for the lot 1 materials, with different coarser fractions. The optimum points taking into account in the tests are also signalized. Given the monotonically increasing course of the curve defined for P_C=60%, as approach, it was adopted as optimum point the determination with the higher water content.

Rammer compaction tests

The second test program was perform in a large-scale compactor (Toni-tecnik), using different soil-rock fractions – P_C=30%, P_C=40%, P_C=50% and finally P_C=60% – as it occurs in the field, to obtain the maximum dry density and the corresponding optimum water content. The material used in the tests was proceeding from lot 5, collected in one of the borrow areas. *Figure 3* shows total distribution curves from lot 5 before the test execution. The compaction curves obtained as well as the reference test optimum point performed with soil constituted only by the finer fraction, are presented in *Figure 4*.
As one can realize, the maximum dry density values are all between 20,2 to 20,3 kN/m^3, not varying from mixture to mixture. With regard to the water content, bigger variations occur, being the higher value record for the mixture with the higher percentage of fines, as it would be expected, since the finer fraction can absorb higher amount of water than coarser fraction.

Results analysis

The Torrey and Donaghe (1994) approach was adopted in the tests results analysis. The values of interference coefficient of the dry density, I_C - on the basis of the previous determination of the compacting degree of the finer fraction, F_F (by the application of equation (6)), and in the application of equation (4) - and the corrective factor of the optimum water content, F_{opt}, calculated by equation (5) have been evaluated.

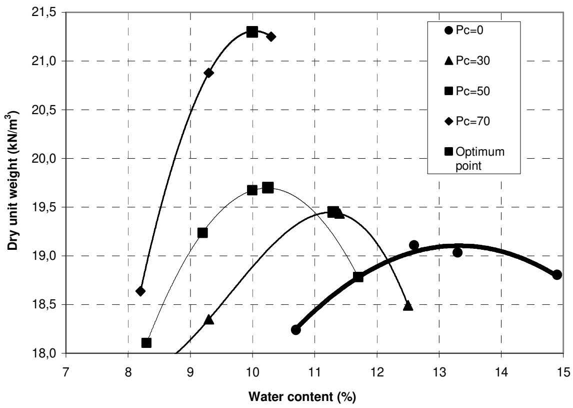


Figure 3. Compaction curves of the lot 1 materials, after 9 minutes of vibration

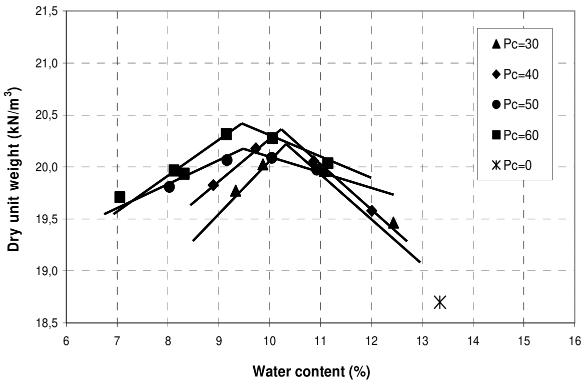


Figure 4. Compaction curves from rammer compaction tests

The results, in terms of maximum dry density ($\gamma^T_{d\,máx}$) and optimum water content (w^T_{opt}) for the total material, respectively, for the vibratory compaction tests and for the adapted Proctor tests, are presented in Table 1. In addition, and for each lot, it is transcribed the standard Proctor reference values ($\gamma^F_{d\,máx}$ and w^F_{opt}) and the calculated values of F_F, I_C and F_{opt}, admitting that the value of the density of the coarser fraction is the average value of the tested blocks ($G_M = 2,43$).

The analysis of the table allow to confirm that, at the optimum point, the fines present a compacting degree F_F which tends to be lesser how higher the coarser content be. In the carried tests, the fraction density factor varied between 89% (in lot 1, with 50% of coarser particles) and 98% (in lot 5, with 30% of coarser particles), for the vibratory compaction tests, and between 89% (in the lot 5, with 60% of coarser particles) and 102% (in lot 1, with 30% of coarser particles), for the Proctor Tests.

The logarithms I_c values are plotted versus the corresponding logarithms P_c values in *Figure* 5 for both types of tests. For the vibratory compaction test results, the following expression can be derived:

$$\log \mathrm{I_c} = 1{,}7193 - 1{,}0802 \log \mathrm{P_G}(\%) \quad (\mathrm{R}^2 = 0{,}9929) \tag{10}$$

and for the rammer compaction test results, the following one:

$$\log I_C = 1{,}9067 - 1{,}1909 \log P_G \quad (R^2 = 0{,}9983) \tag{11}$$

Proceeding in a similar way relatively to F_{opt} (*Figure 6*), it is verified that the values of the coefficient R^2 deduced for F_{opt} are inferior to the ones founded for I_C. The corresponding interpolation equations are as follows, for vibratory compaction tests:

$$\log \mathrm{F_{opt}} = 1{,}873 - 0{,}845 \log \mathrm{P_G}(\%) \quad (\mathrm{R}^2 = 0{,}9769) \tag{12}$$

and for the rammer compaction tests:

$$\log F_{opt} = 1{,}8535 - 0{,}8291 \log P_G \quad (R^2 = 0{,}9983) \tag{13}$$

Table 1. Values of F_F, I_c and F_{opt}.

			Vibratory compaction tests					Rammer compaction tests				
Lot	Proctor reference test	Pc (%)	w^T_{opt} (%)	$\gamma^T_{d\,máx}$ (kN/m³)	F_F	I_c	F_{opt}	w^T_{opt} (%)	$\gamma^T_{d\,máx}$ (kN/m³)	F_F	I_c	F_{opt}
1	$\gamma^F_{d\,máx} = 18{,}9\ kN/m^3$ $w^F_{opt} = 14{,}6\%$	30	11,3	19,4	0,955	1,31	4,307	10,4	20,2	1,018	1,42	4,679
		40	-	-	-	-	-	10,1	20,3	0,995	1,04	3,614
		50	10,2	19,7	0,889	0,73	2,849	9,5	20,2	0,948	0,79	3,074
		67,7	10,0	21,3	0,922	0,56	2,157	-	-	-	-	-
		70	-	-	-	-	-	9,3	20,3	0,903	0,63	2,616
4	$\gamma^F_{d\,máx} = 18{,}8\ kN/m^3$ $w^F_{opt} = 13{,}5\%$	40	10,8	19,9	0,954	0,98	3,125	-	-	-	-	-
		50	10,1	20,0	0,916	0,75	2,673	-	-	-	-	-
5	$\gamma^F_{d\,máx} = 18{,}7\ kN/m^3$ $w^F_{opt} = 13{,}5\%$	30	10,8	19,8	0,984	1,35	4,120	10,4	20,2	1,012	1,39	4,231
		40	9.6	19,8	0,951	0,98	3,495	10,1	20,3	0,986	1,02	3,267
		50	9,7	20,7	0,974	0,80	2,738	9,5	20,2	0,936	0,77	2,779
		60	9,8	20,5	0,906	0,62	2,270	9,3	20,3	0,887	0,61	2,366

Some water content determinations were made for each fraction present in the mixture. It was evidenced one small oscillation of the coarser fraction water content relatively to the average value (equal to about 4,7%). This variation practically turned out to be independent from the water content of the total material.

To improve the correlation between the experimental results and the interpolation expression, it was considered relevant to test a new methodology. It was admitted that the coarser fraction water content was constant. On the basis of the optimum water content of the total material, it was then evaluated the water content of the finer fraction, by the equation (3). *Figure 7* shows the results and the interpolation curve for each test, which improves a little the R^2 value.

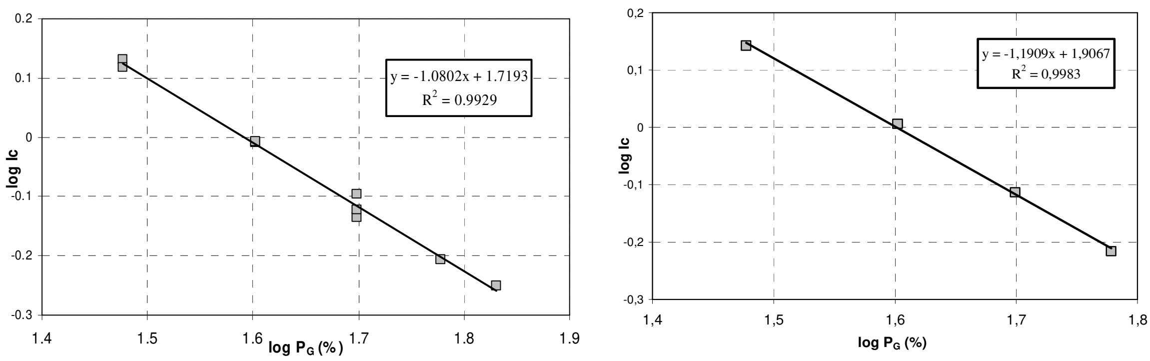
The equations of the curves are as follows

$$w_F = 319{,}17 P_G^{\ 3} - 406{,}84 P_G^{\ 2} + 177{,}15 P_G - 11{,}369 \quad (R^2 = 0{,}9809) \tag{14}$$

for the vibratory compaction tests, and

$$w_F = 26{,}071 P_G^2 - 12{,}793 P_G + 14{,}412 \quad (R^2 = 0{,}9801) \tag{15}$$

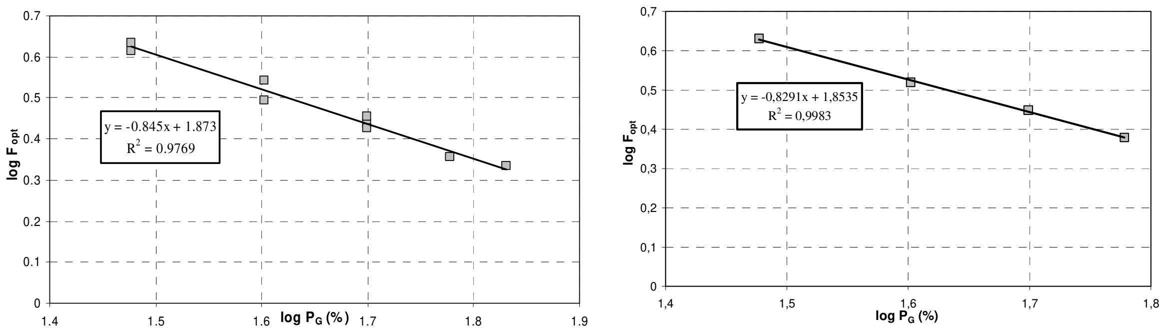
for the rammer compaction tests.



a) b)

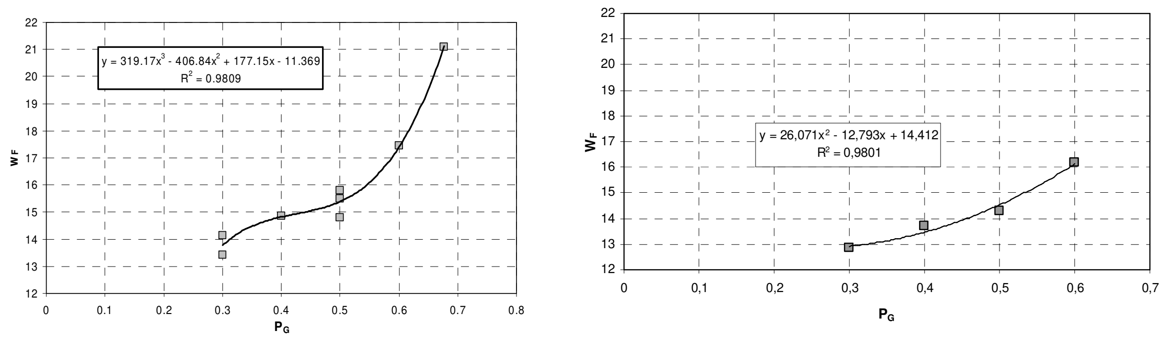
Figure 5. – Bi-logarithmic correlation between I_c and P_G: a) vibratory and b) rammer compaction tests

As mentioned before, the tests had been carried with coarser fractions between 30 and 70%. In the sense of validate the tests application conditions, Figure 8 and Figure 9, respectively show the fraction density factor, F_F (calculated by equation (4) and admitting G_M = 2,43) and the maximum dry unit weigh of the total material, $\gamma^T_{d\,máx}$, versus the percent coarser fraction.



a) b)

Figure 6. – Bi-logarithmic correlation between F_{opt} and P_G : a) vibratory and b) rammer compaction tests



a) b)

Figure 7. – Correlation between w_F and P_G : a) vibratory and b) rammer compaction tests

The figures analysis allows concluding that expressions (12) and (13) present fraction density factor values higher then 100%, for percent coarser fractions inferior to 20%, in the vibratory compaction tests, and 35%, in the rammer compaction tests, which does not seem to have any real counterpart. For these percentages of coarser fractions, it's verified that the maximum dry density of the total material is practically equal to the dry density of the finer fraction. In the remaining domain, the curves have a very regular path and always exceeding the deduced values on the basis of the expressions (7) and (8), with the exception of percentages next to 60% of coarser material since expression (13) equals these expressions.
Relatively to expression (1), it can be observes that is only a good adjustment between P_C=40% and P_C=60%, moving away sufficiently from the experimental results in the remaining intervals.

To taking into account the previous objections and to confer consistency to the presented corrections, it is suggested that the application of expressions (12) and (13) been limited to coarser fractions higher, respectively than, 20% and 30%. For inferior percentages, it is proposed a value of F_F equal and constant to 100%.
Complementally, from F_{opt} – given the expressions (9), (14) and (15) – and by application of the equation (5) (with w^F_{opt} equal to 13.35%), and w_F – given by expressions (16) and (17) - calculated by equation (3) (with w_C equal 4.7%), the values of the optimum water content of the total material, w^T_{opt}, versus the percent coarser fraction were evaluated (Figure 10).

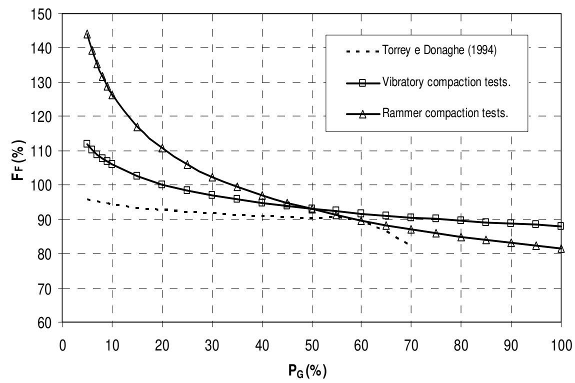


Figure 8. – Fraction density factor as function of the coarser fraction

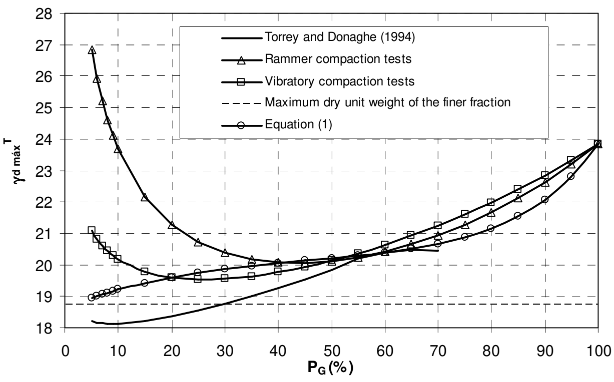


Figure 9. – Maximum dry density of the total material as function of the coarser fraction

The results calculated from the equations (9), (14) and (15) show that the optimum water content of the total material is always monotonically decreasing with the percent coarser fraction, being the values gotten for the Odelouca mixtures (expression (14) and (15)) always superiors to the deduced ones for Torrey and Donaghe (equation (9)). For reduced percentages of coarser fraction, both expressions present excessive values to the optimum water content relative to the normal Proctor. On the other hand, for higher coarser fraction percentages, they tend asymptotically to water contents (of 5,9%, expression (9), 8,5%, expression (15), and of 8,8%, expression (14)) well superior to the gotten ones for the coarser fraction (about 4.7% on average). Thus, one suggests that the field of application of these expressions is limited inferiorly to 10% of coarser fraction and superiorly to 70%.

The alternative expression (16) presents a very different path from the remains, especially for extreme percentages of coarser fractions (reduced or very high). It is point out that its deduction was based on tests with mixtures with percent coarser fractions between 30 and 70%. Comparing with the previous expressions, it will have some meaning from 25% until about 65% of percent coarser fraction, not seeming believable for superior percentages, where the curve evolves, first, in an ascending way, quickly descending, until the water content of the coarser fraction.

The alternative expression (17) has similar course to expressions (14) and (15) until percentages of about 65% coarser fractions, starting to evolve in a descending way to the water content of the coarser fraction. Thus, it is suggested that the application field of this expression is limited only inferiorly 10% of coarser fraction, being able to be applied in the remaining domain.

CONCLUSION

Having for reference the shoulders of Odelouca dam, this paper presents results from vibratory and rammer compaction tests, carried out for the deduction of corrective expressions to apply in the embankment quality control in soil-rock mixtures.

The Torrey and Donaghe (1994) methodology was adopted in the tests results analysis and correlation equations were established for the determination of the maximum dry density and the optimum water content of the integral material and the optimum water content of the finer fraction as function of coarser fraction percentage.

A comparison of the different expressions is here present, as well as, the conditions of application of each one. The expressions obtain for the correction of the water content deduced by the two approaches give very similar results.

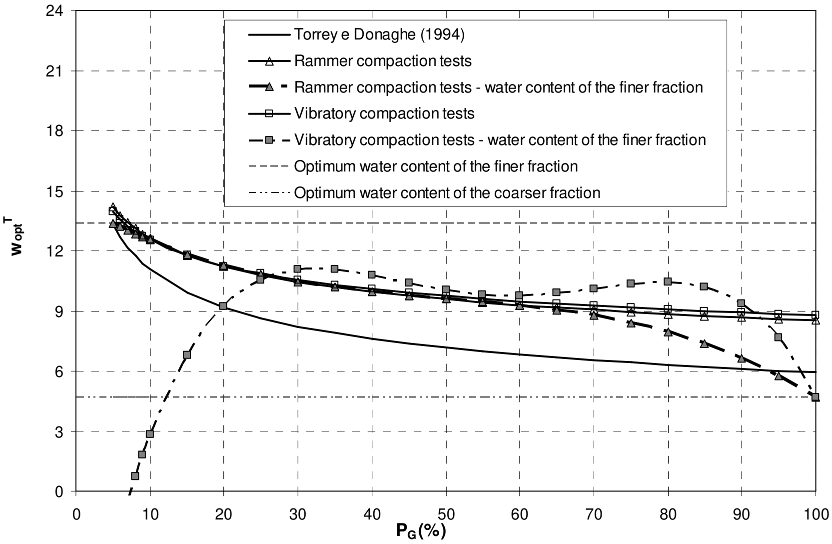


Figure 10. – Optimum water content of total material as function of the coarser fractions

In terms of maximum dry density, as it could be expected, it can be seen that the rammer process is more efficient in mixtures with a small coarser percentage and the vibratory compaction otherwise. Normally, in the field, the soil-rock mixtures are compacted with vibratory rollers. Thus, the equations derived with the vibratory tests, in the author's opinion, should be used.

The most used expressions used in Portugal show some differences in relation to the one's here deduced.

REFERENCES

American National Standard – ASTM – D698-00a (2000). Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3(600 kN-m/m^3)).

American National Standard – ASTM – D4718-87 (2001). Standard Practice for Correction of Unit Weight and Water Content for Soils Containing Oversize Particles.

American Society for Testing and Materials (1994). Annual Book of ASTM Standards. Volume 0408, Soil and Rock, Philadelphia, PA.

BS 1377: Part 4, (1990). Soils for Civil Engineering Purposes. Compaction-Related Tests. BSI 1990.

E 197-1966. Solos. Ensaio de Compactação. LNEC

Houston, S. L.; Walsh, K. D. (1993). Comparison of Rock Correction Methods For Compaction of Clayey Soils. Journal of Geot. Eng., Vol.119, Nº4, 763-778, April, 1993.

JAE (1998). Normas da Junta Autónoma de Estradas. Lisboa, 1998.

JAE/LNEC (1994). Controlo de Construção e Caracterização Físico-Mecânica de Aterros de Mistura de Solo-Enrocamento. Proc. 056/1/11505 . Fevereiro de 1994.

Torrey, V. H. e Donaghe, R. T. (1994). Compaction Control of Earth-Rock Mixtures: A New Approach. Geotechnical Testing Journal, ASTM, VOl.17, No. 3, September 1994, pp. 371-386.

USBR 5515-89 (1989). Procedure for Performing Laboratory Compaction of Soils Containing Gravel. U.S. Dept. of the Interior. Bureau of Reclamation. Denver. Colo.

USCOLD (1998). Construction Testing of Embankment Materials Containing Large Particles. U.S: Committee on Large Dams, April 1988.