APPLICABILITY OF HILF?S METHOD TO COMPACTION CONTROL OF SOIL-ROCK MIXTURES

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Authors

Name	E-mail	Institution	Country
BRITO Andrea**(main author) (speaker)**	andreabrito@lnec.pt	National Laboratory for Civil Engineering	Portugal
CALDEIRA Laura		National Laboratory of Civil Engineering	Portugal

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1. Introduction

In the embankment construction, the materials resulting from the compaction must comply with certain requirements included in the project specifications. Depending on the material type, is opportune to ensure certain values of various parameters, such as unit weight, deformability, permeability and shear strength, in order to verify the assumptions established in the project. Generally, the requirements for road and railway embankments are less restrictive than the requirements for embankment dams and specified only in terms of deformability and strength.
However, the direct and individualized determination of each of these parameters involves a workload and carrying out times incompatibles with the current construction rhythms, so the option is to make direct or indirect assessment of relevant properties from which to consider the remaining guaranteed.
An indirect way to control the characteristics of an embankment of compacted soil is the determination of the embankment dry density and the water content. These two parameters thus become gauges of the embankment quality.
Nevertheless, the precise determination of water content takes overnight oven drying. Because of that, in 1959, Dr. Jack Hilf [1] proposed a fast method of construction control, which alleviated the need to determine water content.
However, this method was developed for fine soils. So, this article presents a testing program performed in a soil-rock mixture that allows establishing the applications conditions and the applicability of Hilf's method to this kind of material.

2. Hilf's method description

In 1959, Hilf [1] proposed a method of construction control using wet densities only. According to [2], Hilf's method is one of the compaction control methods that allows the determination of the degree of compaction and the optimum water content deviation without the previous knowledge of the corresponding water content, as well as the ignorance of the Proctor reference curve.
This method allows, with certain closeness, to justify the decision of acceptance or rejection of layers within a sufficiently short term, without causing significant disruptions or interruptions to the construction work.
Basically, the proceeding consists in performing an in situ sand cone test (ASTM D1556 [3]) for the density determination of the layer in analysis. Then, the material collected in the embankment is taken to the laboratory. The sample is divided in at least three specimens. One specimen, with the in work placing humidity, is subjected to a compaction Proctor test and the respective dry density is determined. In a proper graphic (for this kind of tests, see Figure 1), the obtained density value is plotted in the 0% of water content deviation vertical line – point A.
Next step consists in adding to the second specimen about 2% of weight of water and to perform a new compaction test, in aim of the new density determination. The new density value, referred to in situ water content (transformed density), is

plotted in the +2% of water content deviation vertical line in the graphic (point B).
The determination of a third point (point C) depends on the relative position of points A and B. If point B has a transformed density higher than point A, a 4% of material weight of water is added to the third specimen. A new compaction test is performed and the corresponding density is determined. Dividing this value for 1.04, we find out the dry density referred to the natural water content is calculates (point C). The correspondent value is plotted in 4% deviation vertical line, in the same graphic.

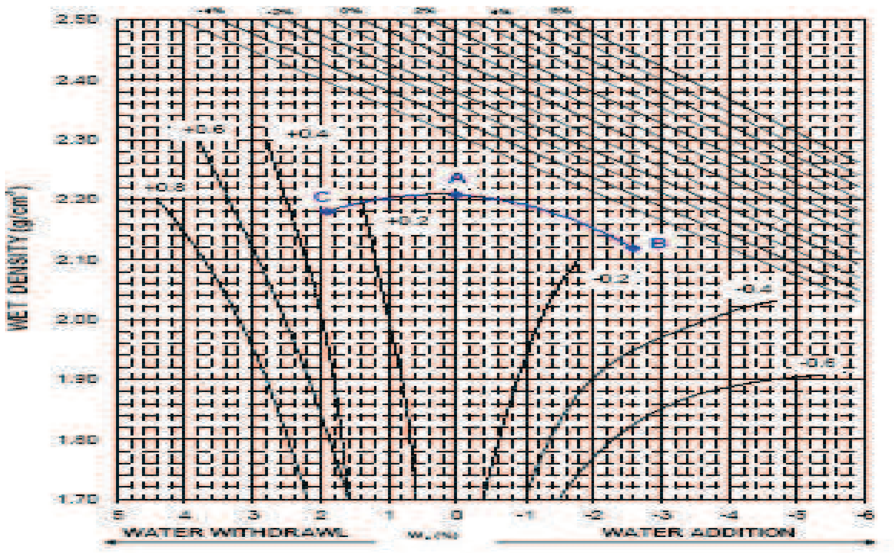


Figure 1 – Hilf`s method graphic

On the other end, if point B was a transformed density inferior to point A, the specimen should be dried (in about 2% of its weight) to perform a new compaction test. The three obtained points are sufficient to define the parabolic curve, corresponding to the transformed density related to the in work placing water content, if the endpoints have ordinates below the midpoint. Otherwise it's necessary to perform another compaction test, with a different quantity of water, to determine a fourth point.
After that, the three points closer to the maximum transform density must be chosen. Through these points a vertical axis parable (named the transform wet density curve) should be drawn and its peak coordinates are calculated (point with the maximum density).
The degree of compaction (D) is then evaluated by the expression:

$$D = \frac{\text{In situ density}}{\text{Density corresponding to the parabole peak}} \quad (1)$$

The compaction efficiency (C) can be express by:

$$C = \frac{\text{In situ density}}{\text{Density at 0\% deviation water content}} \quad (2)$$

The difference between the optimum water content and the in situ water content (wopt -w) is the abscissa of the parable peak. This value is corrected by adding the indicated value in the curve closest to the peak, taking into account the correction sign.
As one can realize by the brief description, this method is relatively quick and easy to use, giving results with a high degree of approximation, and is therefore widespread in the compaction control of embankments. Nevertheless, the method only provides relative magnitudes (of compaction degree and water content deviation). So, it is common to complement with the overnight oven determination of the in situ water content and the specimens water content after compaction tests, which allows the assessment of the dry density and establishment of the compaction curve based on three points.

3. Testing program

As mentioned above, this method was developed only for fine soils. So, in order to set the applications conditions and the applicability of Hilf's method to soil-rock mixtures, a testing program was implemented. First step consisted in performing a

Proctor test to establish the reference compaction curves for the passing material in the ¾" sieve, from the ASTM series, and for the passing in the #4 sieve.
The material used in this study comes from the Odelouca Dam shells and it is composed by weathered schist and greywacke with a significant fraction of oversized particles. In Figure 2 it's possible to see the size distribution curves of the material used in the tests.

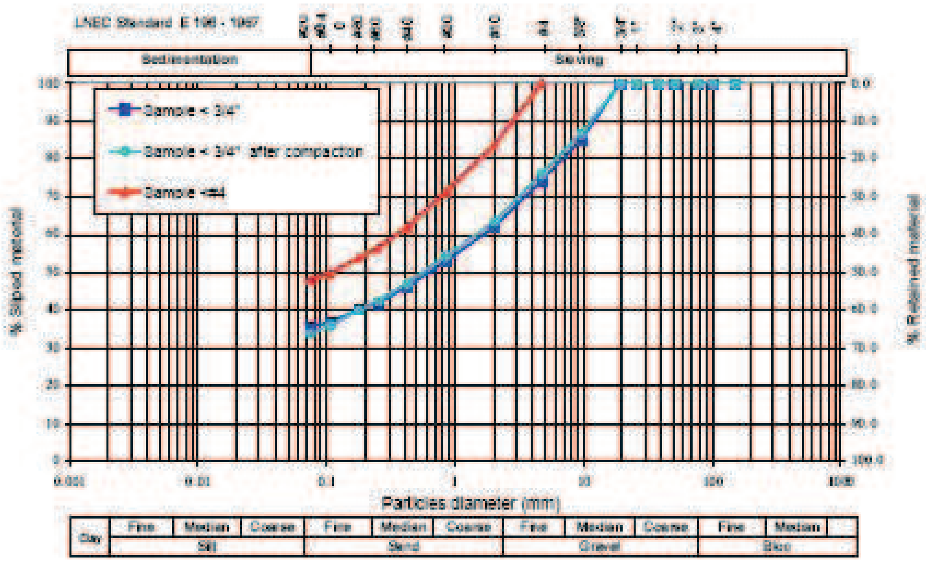


Figure 2 – Total distribution curves from the tests samples

As one can realize by regarding the sample with particles with dimensions less than ¾", before and after compaction, there are no gradation evolution with compaction.
Figure 3 shows the reference compaction curves obtained for the two samples analyzed. The optimum water content is equal to 14.5% and 12.5%, respectively, for the minus # 4 sieve material and for the minus ¾" sieve material, and the maximum dry density is, in that order, equal to 18.56 and 19.22 kN/m3.
After the determination of the Proctor reference curve, Hilf's method was applied, in laboratory, simulating for three in situ water contents, differing approximately 1% from each other for the two material gradations. The results are presented in Figure 4 to Figure 6 and in Table 1.

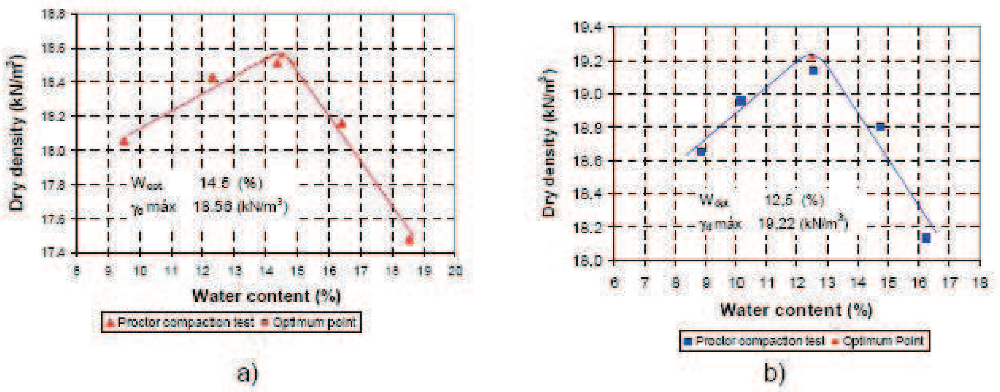


Figure 3 – Proctor reference compaction curves for: a) the minus number 4 sieve material and b) the minus ¾" sieve material

Subsequent to the application of the Hilf's method, the material was set overnight in the oven for drying and the water content was found (results obtained with Hilf's method and with the oven drying for the three contents tested is presented in As one can realize by regarding Table 2 the water content deviation error varied between -0.7 and 0,9 and degree of compaction error is very close to 1 for all the points and for the two material gradations analyzed.

Table 2.
The water content deviation error (*Dw error), express in Table 2, is defined by the expression:*

$$\Delta W_{error} = \Delta W_{Hilf} - \Delta W_{Proctor} \quad (3)$$

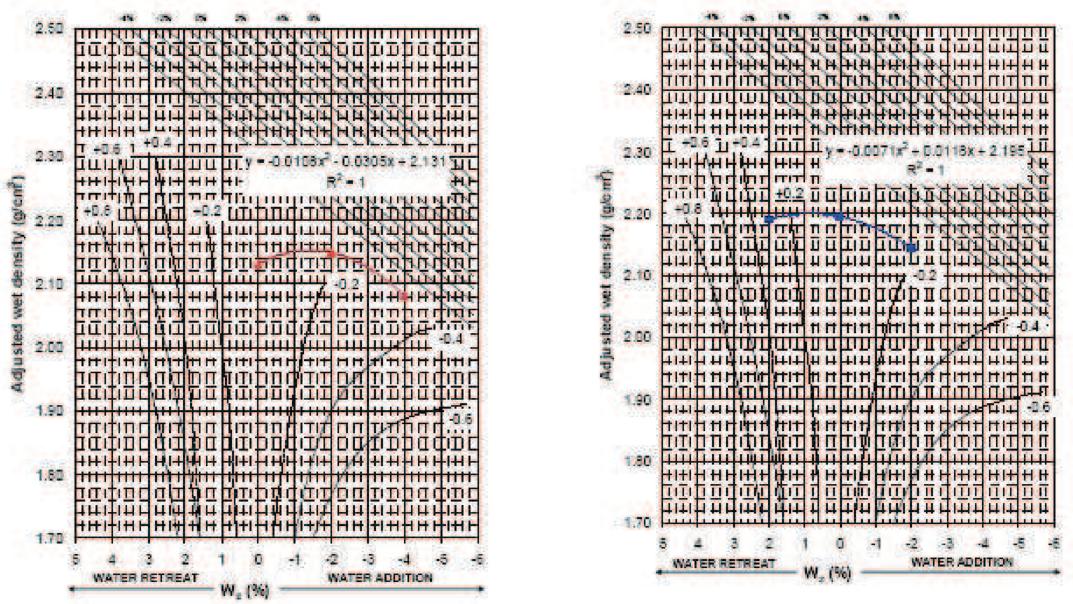
where, ΔW_{Hilf} is the water content deviation obtained with the Hilf's method appliance and $\Delta W_{Proctor}$ is the water content deviation obtained with the difference between the oven after content and the Proctor water content.
The degree of compaction error (D_{error}), also presented in Table 2, can be express by:

$$D_{error} = \frac{\gamma_{adj\ p}}{(1+W)\times\gamma_{d\ max}}$$

where γ *adj p* is the parable peak obtained in Hilf's method appliance, *woven* is the oven water content and γd max €is the Proctor dry density.

Table 1 – Results of the Hilf's method for the three points

Material	Point	Δw (%)	γ_{adj} (kN/m³)	$\gamma_{adj,p}$ (kN/m³)	$W_{opt} - W$ (%)
Minus ¾" sieve	1	0	21.88	21.70	0.60
		2	21.60		
		-2	21.00		
Minus number 4 sieve		0	21.31	21.10	-0.38
		2	20.91		
		-2	21.11		
Minus ¾" sieve	2	0	21.53	21.58	0.93
		2	21.48		
		-2	21.02		
Minus number 4 sieve		0	20.91	21.12	-1.57
		-2	21.08		
		-4	20.41		
Minus ¾" sieve	3	0	21.27	21.89	2.65
		2	21.88		
		4	21.54		
Minus number 4 sieve		0	21.19	21.24	1.18
		2	21.19		
		4	20.80		



a) b)

Figure 5 – Application of Hilf's method for the second set of tests: a) the minus # 4 sieve material and b) the minus ¾" sieve material

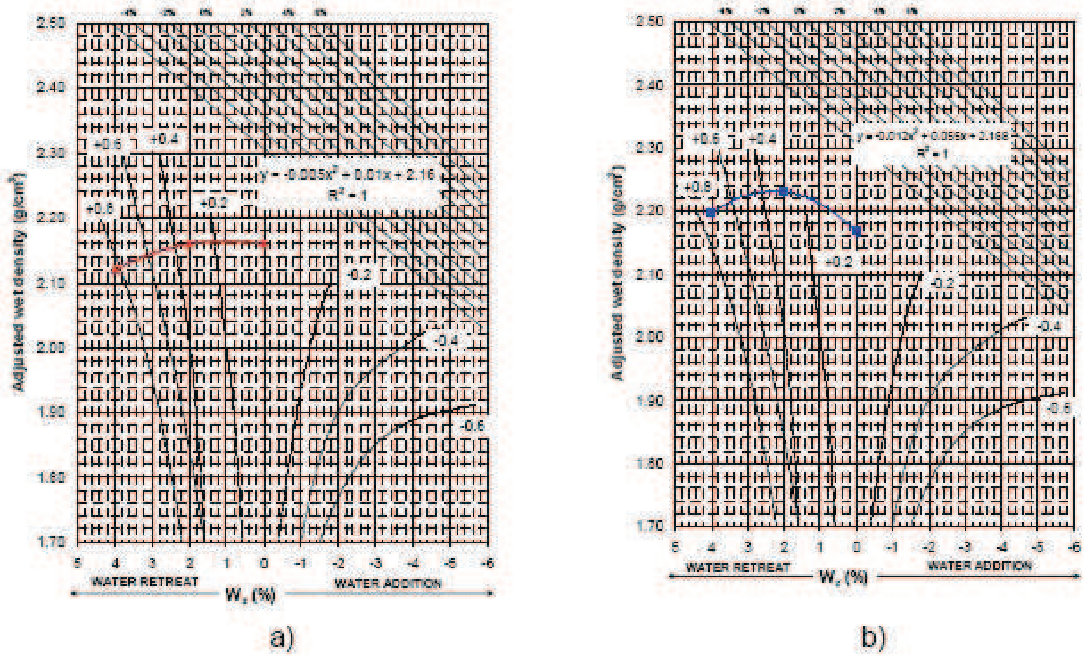


Figure 6 – Application of Hilf's method for the third set of tests: a) the minus # 4 sieve material and b) the minus ¾" sieve material

As one can realize by regarding Table 2 the water content deviation error varied between -0.7 and 0,9 and degree of compaction error is very close to 1 for all the points and for the two material gradations analyzed.

Table 2 – Comparison between the results obtained with Hilf's method and with the oven drying for material near the optimum point, in the dry side and in the wet side of the compaction curve

Material	Point	Hilf's method			Proctor reference test			ΔW_{error} (%)	D_{error}
		ΔW_{Hilf} (%)	$\gamma_{adj.p}$ (kN/m³)	W_{oven} (%)	$\Delta W_{Proctor}$ (%)	$\gamma_{d\ max}$ (kN/m³)	$(1+W_{oven})\gamma_{d\ max}$ (kN/m³)		
Minus ¾" sieve	1	0.599	21.70	13.3	0.835	19.22	21.78	-0.237	0.997
	2	0.925	21.58	12.5	0.024		21.62	0.901	0.998
	3	2.642	21.89	14.5	1.981		22.00	0.661	0.995
Minus # 4 sieve	1	-0.383	21.10	14.8	0.319	18.56	21.31	-0.702	0.990
	2	-1.569	21.12	13.7	-0.838		21.10	-0.731	1.001
	3	1.180	21.24	15.9	1.449		21.51	-0.269	0.987

4. Conclusions and future developments

This paper presents the results from an investigation laboratory study relatively to the applications conditions and the applicability of Hilf's method to coarse soils and soil-rock mixtures.

The tests performed in laboratory allow concluding that:

1. Hilf's method is applicable indifferently for the passing material in the ¾" sieve and for the passing in the #4 sieve.
2. Hilf's method is capable of identify correctly the samples in the wet and in the dry side of the compaction curve for all samples tested.
3. The water content deviations obtained are inferior to 0.9%, even when the water content exceeds 2%.
4. The compaction degree is correctly determined by Hilf's method because the error obtained is inferior to 0,01.

For future developments the authors put in perspective the application of Hilf`s method with large-scale compactors (like Toni-tecnik with mould diameter = 300 mm) where is not necessary to truncate the material gradation curve.

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