Field compaction control by way of correlation between elasticity module and layer rigidity with moisture content

http://dx.doi.org/10.1590/0370-44672017720134

Daniel Pinto Fernandes[1]
Jéssika Cosme[2]
Gilberto Fernandes[3]

[1]Universidade Federal de Alagoas – UFAL,
Centro de Tecnologia, Maceió – Alagoas - Brasil.
daniel.fernandes@ctec.ufal.br

[2]Universidade Federal de Ouro Preto – UFOP,
Escola de Minas, Núcleo de Geotecnia,
Ouro Preto – Minas Gerais - Brasil.
jessikacosme@hotmail.com

[3]Centro Universitário do Cerrado Patrocínio - Unicerp,
Departamento de Engenharia Civil,
Patrocínio – Minas Gerais - Brasil.
gilberto@unicerp.edu.br

Abstract

The present research had as its basic objective to contribute with the improvement in the quality control evaluation of the compacting process in road works. The real contribution of the survey is to establish an innovative way of controlling the compaction process in the field, with employment of the Humidity versus Rigidity and the Humidity versus Elasticity Module curves, turning the methodology faster and more efficient than the conventional procedures. In fact, to date, the compacting control procedures contemplate methods that are inaccurate and limited by several constraints, rendering the technique unfeasible and time consuming, in detriment of the work schedule. Thus, this study proposes to define a rational correlation criterion between the geotechnical characterization with results obtained in the laboratory using conventional methods and the elastic parameters obtained by applying the rigidity meter of compacted soils, based on a statistical treatment of data concerning the infrastructure of experimental road and railway sections. The results obtained in the research were the correlation curves for Humidity versus Rigidity, and for Humidity versus Elasticity Module, for the material of the deposit, with the corresponding equations. Thenceforth, with the correlation curves, it will be much easier to obtain the moisture content that the soil requires on the earthworks. By measuring the modulus of elasticity or rigidity through the stiffness meter of compacted soils, the respective curve checks if the value of the soil moisture content is compatible with the variation of the moisture content in the project.

Keywords: compaction, correlation, humidity, elasticity modulus, rigidity.

1. Introduction

The earthwork landfills are constructions known and executed by humanity since ancient times. The raw material used in these kinds of earthworks essentially exists in the earth's crust - the soils and / or the rocks. Most soils are underlying bedrock material weathered and consisting of voids filled by air or water, with variable characteristics over time, and it is often necessary to improve their properties. There exist many techniques of improving soil properties, such as compaction. The compaction processed soil layers can arise naturally through the own weight of the materials and the action of atmospheric agents, which through drying cycles, filtering rainwater, among other consequential factors, eventually with time end up forcing the soil layer to settle down, thus giving it better resistance and permeability characteristics. However, this slow process could take years, centuries or even millennia, until it reaches the degree of consolidation necessary for a particular construction, resulting in the need for a much faster process.

In 1933, Proctor, cited by Baptista (1976), Pinto (2006) and Senço (2008), observed that the application of a particular compaction energy resulted in a relationship between the specific dry mass and the moisture content of the soil. From this observation, there was an evolution in the techniques of compression, which until then were realized in an empirical way. A compaction methodology was developed that would take into account the most suitable moisture for obtaining a maximum compaction density within a specific amount of energy. In this manner, whether in the execution of pavement layers, land masses, cargo road and railway landfills, land dams, airports and other works that require the construction of embankments, it is possible to obtain the highest possible densities as a safety and stability factor. It should be added that increasing the apparent specific mass also implies in an improvement of the compacted soil impermeability, which is ultimately, a stability factor. Technological control is defined as the use of any aspect of human knowledge, be it in the form of methods and procedures or even tools, devices or equipment, in order to enable the execution and optimization given activity results.

The use of technological control in earthworks must be present from the planning of the activities to the verification and confirmation of the results obtained. The present work introduces a new way to control compaction of road embankments, specifically the control of moisture content, through the correlation between elastic parameters of the soil deposit (resilience modulus and stiffness index), and the conventional geotechnical characterization of the material (Faria, 2004). The main objective is to establish a rational correlation criterion between laboratory test results (moisture content) and the variables obtained by application of the compacted soil rigidity meter in an experimental section to generate a soil characteristic curve in the study and formulation of equations that govern the behavior of this soil with respect to the Humidity x Elasticity Modulus and Humidity x Rigidity one.

Currently the determination of the moisture content in the field, through simple and expeditious tests presents several problems. The "frying pan" and "alcohol" methods can burn soil particles, especially in the presence of decomposed organic matter. Already the Speedy Test method, using calcium carbide ampoules, can induce inaccurate results in little-plastic soils. In addition, the technique is restricted to the assessment of the moisture content by means of an equipment calibration table (Gilbert, 1988). The hothouse method, used in the laboratory, is incompatible with the field routine. Other methods, such as the "infrared oven", are expensive.

Thenceforth, with the developed method, the value of the modulus of elasticity and rigidity index is provided by the equipment, and the moisture content of the soil is measured in the curves obtained, eliminating the application of conventional methods, contributing to a faster and more efficient process.

2. Materials and methods

The methodology applied was based on the laboratory characterization, through conventional soil tests of a loan area located along the BR-356 Highway, Km 107. The physical model was constructed to obtain the elastic parameters of the soil, through the compacted soil rigidity meter. With the results, the laboratory parameters were correlated with those measured in the physical model. Figure 1, shows the field studied in this research.

Figure 1
Deposit on the BR Highway -356 km 107.

In the laboratory phase, the following tests were performed: Granulometry Test (NBR 7181/2016), Atterberg Limits (ABNT NBR 6459/2016; ABNT NBR 7180/2016), Compaction Test (NBR 7182/2016) and CBR - California Bearing Ratio Test (NBR 9895/2016). The physical model proposed in the research was based on the execution of a compacted subgrade in Proctor Normal, utilizing the laboratory results previously obtained. In this way, the correlation of the Modulus of Elasticity and Rigidity parameters provided by the rigidity measuring equipment of compacted soils with the values of moisture contents of the samples studied, one being in the optimum humidity measured by the compaction test, and another two were one in the dry branch and another in the humid branch of the compaction curve.

2.1 Field campaign - rigidity meter of compacted soils

The experimental phase of the research was carried out with the use of a compacted soil stiffness meter. It is a portable device for performing in situ measurements of stiffness and elastic modulus of soils and was developed from technology owned by the US Army. This is an opportunity to improve the technological control of the compaction process and construction of pavements aiming to run most enduring works (Batista, 2007).

The device works by applying sinusoidal charges to the surface soil and measuring the resulting displacements. The equipment has a cylindrical shape, 280 mm in diameter and 254 mm high, weighing about 10 kg. It consists of a ring-shaped metal base with an outer diameter of 114 mm, an inner diameter of 89 mm and a thickness of 13 mm, which rests directly on the ground. During the test, the applied force and the displacement are measured at 25 different vibration frequencies, in the range of 100 to 196 Hz. Each test lasts about 75 seconds, allowing for a fast and efficient analysis of the compacted layers (Fernandes, 2005).

On the outside part of the Asphalt Railroad Laboratory in the School of Mining at the Federal University of Ouro Preto, three holes with dimensions of 1.0 m x 1.0 m x 0.2 m were opened, as shown in Figure 2, in order to compact the sample and test materials with three different humidity levels according to the compaction test, representing a subgrade layer.

Figure 2
Holes to be compacted.

The compaction of the holes was subdivided into 4 layers of 5cm, totaling 20 cm of thickness, and was executed with the use of the percussion compactor. In the first hole, compaction was performed in the dry branch of the compaction curve (w = 18.8%) obtained in the laboratory. The second hole material was compacted near its optimum moisture (w = 21.5%). Finally, the last hole was compacted with the material in the humid branch of the compaction curve (w = 25.9%). After compacting with the use of the percussion compactor, the degree of compaction achieved was determined by performing the Sand Bottle test. Figure 3, shows the entire sequence described in the compaction process.

Figure 3
Sequence of compaction of the holes.

Jointly with the Sand Bottle test, the final humidity of the layers was measured with the moisture-determining scale, collecting a fraction of soil in each perforation. With the use of this equipment, it was possible to affirm that the laboratory conditions were reached in the field.

The next step was the measurement with the stiffness meter of compacted soils for the determination of soil elastic modulus and the corresponding rigidity of the layers in the three subgrade tiers. Procedures for the use of the equipment are standardized by Standard ASTM D 6758-02 (Standart Test Method for Measuring Stiffness and Apparent Modulus of Soil Aggregate in-Place by Electro-Mechanical Method). Figure 4, shows the measurement procedure with the use of a compacted soil stiffness meter.

Figure 4
Test with the rigidity
meter of compacted soils.

Thenceforth, it was possible to correlate these values to obtain a characteristic curve for this soil and the formulation of equations that govern the behavior of this soil with respect to Humidity x Modulus of Elasticity and Humidity x Rigidity. Similarly, the correlation of the Modulus of Elasticity and Rigidity parameters were obtained by the compacted soil rigidity equipment with the values of adopted moisture content study from the soil studied.

3. Results

All of the laboratory and field tests performed at the Laboratory of Railways and Asphalt / UFOP are presented below. All the tests implemented followed the ABNT standards for classification of the quarry as a subgrade material.

3.1 Granulometric analysis

The granulometric distribution curve, in Figure 5, was obtained by the sieving and sedimentation tests. A clay predominance was verified in the soil coming from the quarry. Thereby, the material was classified as Sand-Silt Clay of brown color.

Figure 5
Granulometric distribution curve.

3.2 Classification of soils

For the classification of the soil as pavement material, besides the granulometry test, the Liquidity Limit and Plasticity Limit tests were carried out, in addition to the determination of the Plasticity Index, presents in Table 1.

Liquidity Limit	35.6%
Plasticity Limit	20.0%
Plasticity Index	15.6%

Table 1
Plasticity Index.

Equation 1 presents the calculation performed for the determination of the Group Index, using the granulometric parameters and plasticity of the studied soil.

$$IG = 0.2 * a + 0.005 * a * c + 0.01 * b * d \quad (1)$$

Being, a = 29.5; b = 40.0; c = 0; d = 5.4. Then: IG = 9

For the classification of the soil by the unified system (SUCS) and by the road system (TRB – Transportation Research Board), the results of the granulometry tests, limits of consistency and group index were used.

The soil was classified according to the Transportation Research Board (TRB) as an A6 soil, which according to DNIT (2006) is a clayey, plastic soil, generally having 75% or more of material passing through a 200 mesh sieve. The soils of this group commonly suffer a high volume change between the dry and humid states, with a behavior considered from very low grade to poor quality as layered subgrade materials.

In the SUCS classification system, the soil used in this research is classified as CL, that is, inorganic clay of low and medium plasticity - gravel, sandy and silty soils.

3.3 Compaction and support index california

Table 2 shows below the maximum dry mass, optimum humidity, support capacity and material expansion determined by Compaction California Bearing Ratio tests.

Specific maximum dry mass	1.613 g/cm³
Optimum humidity	22.9%
Expansion	0.7%
California Bearing Ratio (CBR)	2.0%

Table 2
Mechanical characteristics of the soil.

The compaction test was performed with normal compaction energy and the compaction curve is presented in Figure 6.

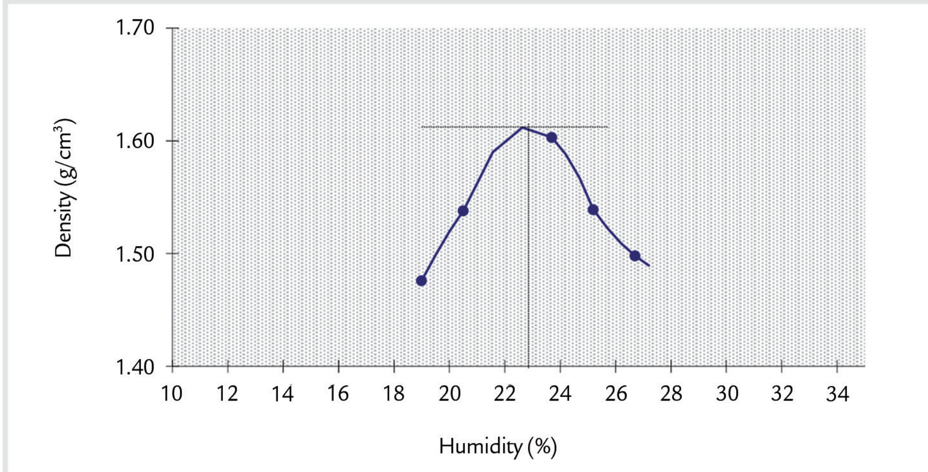

Figure 6
Compaction curve.

3.4 Compaction control - elasticity module correlation and rigidity of the layer with moisture

The elastic modulus and soil rigidity obtained with the compacted soil stiffness meter were performed at five different points of the compacted holes (edges and center of the bores). The Figures 7, 8 and 9 presented below, show the values obtained in each of the three drills and the average value.

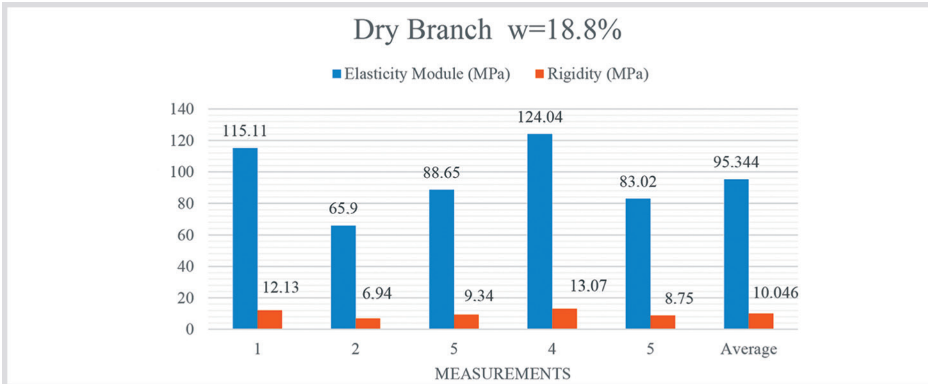

Figure 7
Measures of the bores in the dry branch with humidity equal to 18.8%.

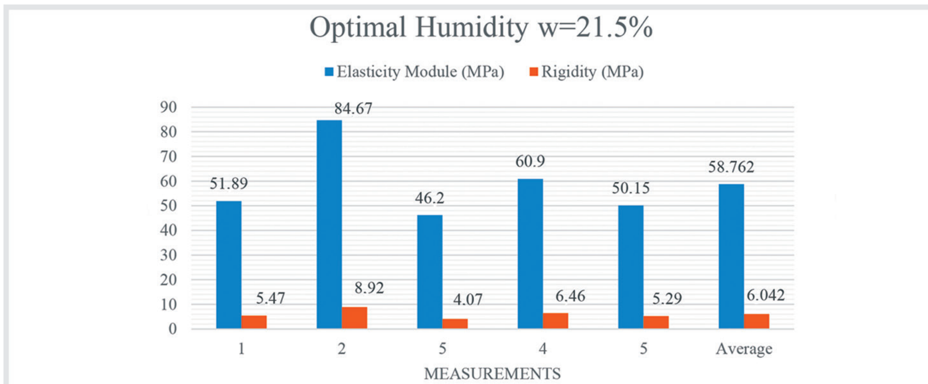

Figure 8
Measures of the bores in optimum humidity with moisture equal to 21.5%.

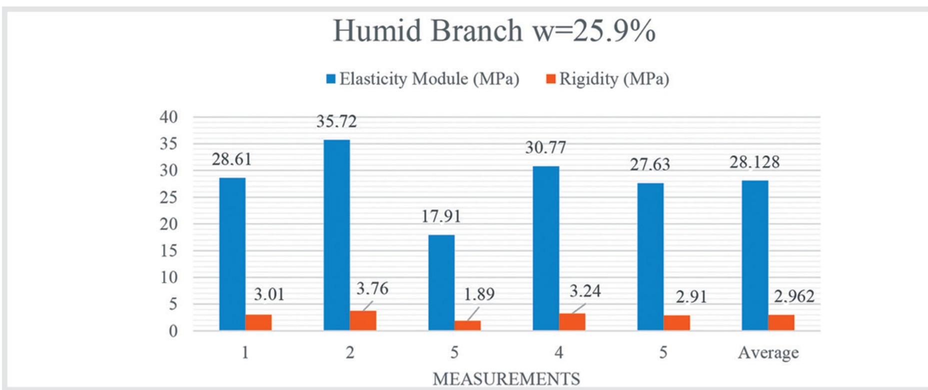

Figure 9
Measures of the holes in the humid branch with humidity equal to 25.9%.

Figures 10 and 11, respectively, show the correlation curves between Humidity x Rigidity with its corresponding equation and Humidity x Modulus of Elasticity together with the curve equation. To obtain the curves, the mean values of modulus of elasticity and rigidity of each of the holes with different humidity were used.

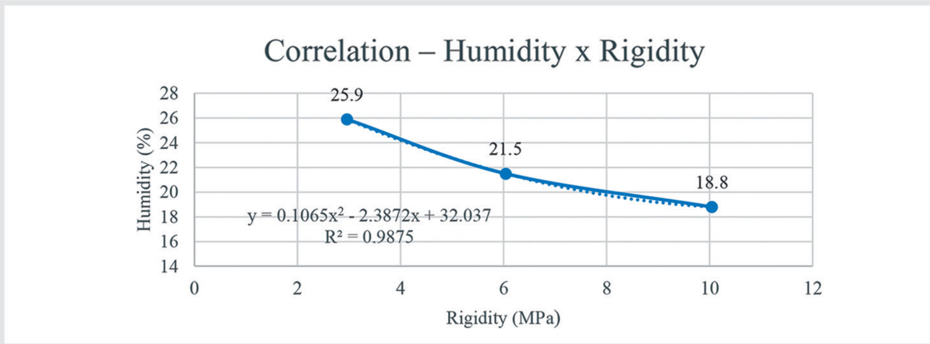

Figure 10
Correlation chart - humidity versus rigidity.

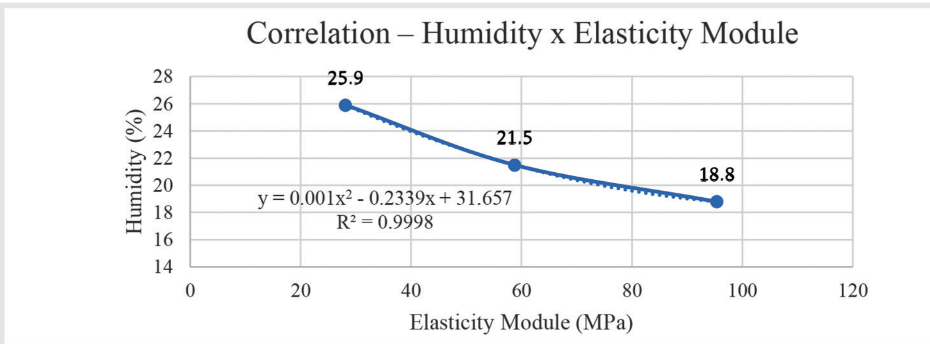

Figure 11
Correlation chart - humidity versus elasticity module.

4. Conclusions

In relation to the mechanical characteristics of the analyzed soil, it was concluded, by the laboratory tests, that the material can be used as a subgrade layer of a flexible pavement, since it presented a CBR of 2% and expansion of less than 1% according to DNIT (2006). The compaction test was performed on Proctor Normal energy and the compaction curve resulted in a specific maximum dry mass of 1.613 g/cm^3 and optimum humidity 22.9%.

With the implementation of the experimental model of the subgrade layer, it was possible to construct two correlational curves, proposed in the work, between the parameters: Humidity X Rigidity and Humidity X Elasticity Module. The correlation curves provided their respective equations with the coefficient of determination (R^2) close to 1, meaning that the applied model was effective for the establishment of correlations as the main objective of this research.
Finally, it is concluded that applying the correlation curves between geotechnical parameters, such as humidity, and field measurements, such as modulus of elasticity and rigidity, obtained in this research through the stiffness meter of compacted soils, obtaining the content of compaction control becomes immediate. The measure of the modulus of elasticity or rigidity through the rigidity meter of compacted soils immediately shows whether the soil moisture value is compatible with the variation of the moisture content in the project. This is a relevant contribution to better control the compaction of the earthmoving layers, making it more efficient, faster and consequently reducing the operational cost of the project.

References

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. ABNT NBR 7182/16. Solo- Ensaio de Compactação. Rio de Janeiro, RJ, 9p. 2016.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. ABNT NBR 6457/16. Amostras de Solo - Preparação para ensaio de compactação e ensaios de caracterização. Rio de Janeiro, RJ, 8p. 2016.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. ABNT NBR 6459/16. Solo – Determinação do Limite de Liquidez. Rio de Janeiro, RJ, 5p. 2016

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. ABNT NBR 7181/16. Solo – Análise Granulométrica. Rio de Janeiro, RJ, 13p. 2016.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. ABNT NBR 7185/16. Solo – Determinação da massa específica aparente, in situ, usando o frasco de areia. Brazilian Association of Technical Standards, Rio de Janeiro, RJ, 8p. 2016.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. ABNT NBR 7180/16. Solo – Determinação do Limite de Plasticidade. Rio de Janeiro, RJ, 3p. 2016.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. ABNT NBR 9895/16. Solo – California Bearing Ratio (CBR – Método de Ensaio). Rio de Janeiro, RJ, 14p. 2016.

AASHTO – T224-10. Standard Method of Test for Correction for Coarse Particles in the Soil Compaction Test, American Association of State and Highway Transportation Officials, 2010.

ASTM D6758-18. Standard Test Method for Measuring Stiffness and Apparent Modulus of Soil Aggregate in-Place by Electro-Mechanical Method, ASTM International, West Conshohocken, PA, 2018.

ALVES, A. B. C. ***Evaluation of the capacity support and technological control of the final layer execution of embankment using the dynamic cone penetrometer.*** Florianópolis: Federal University of Santa Catarina, 2002. (Dissertation-Master degree).

BAPTISTA, C. F. N. ***Pavimentação.*** Editora Globo, 1976. (Tomo 1 e 2).

BATISTA, L. C. M. ***Determinação de parâmetros de deformabilidade de camadas de um pavimento a partir de ensaios de campo.*** Brasília: Universidade de Brasília, 2007. 177p. (Dissertação de Mestrado em Geotecnia).

BS 1377: Part 2 and 4. Soils for Civil Engineering Purposes. Compaction-Related Tests. BSI 1990.

DNER DPT M 92-64 – Determinação da massa específica aparente no solo "in situ" com o emprego do frasco de areia.

DNIT – Departamento Nacional de Infra-Estrutura e Transporte. Manual de Pavimentação. 3ed. Rio de Janeiro, 274p., 2006.

FARIA, P., GOMES, C. Influence of the compaction humidity on the variation of the parameters that express the resistance of the soils. In: LUSO-BRAZILIAN CONGRESS OF GEOTECHNICS, 2. Aveiro, 2004. p. 397-402.

FERNANDES, G. ***Behavior of rail pavement structures with the use of fine soils and / or iron mining residues associated with geosynthetics.*** Brasília: [s.n.], 2005.

GILBERT, P. A. ***Computer controlled microwave oven system for rapid water content determination.*** Vicksburg, MS: Waterways Experiment Station, U. S. Army Corps of Engineers, 1988. 59 p. (Technical Report GL-88-21).

LAMBE, T. W. The Engineering behavior of compacted clay, ***Journal of Soil Mechanics and Foundations Divisions.*** ASCE, 1958. (Proceedings).

NICHOLS, H., DAVID, D. ***Moving the earth: the workbook of escavation.*** (6th, .ed.). McGraw-Hill Professional, 2010.

PINTO, C.S. ***Curso básico de mecânica dos solos em 16 aulas.*** (3ª. ed.). Oficina de Textos, 2006.

SENÇO, W. ***Manual de técnicas de pavimentação.*** (2. ed. ampl.). São Paulo: PINI, 2008.

SOUZA JUNIOR, J. D. ***The effect of compaction energy on soil properties utilized in paving of the state of ceará.*** Fortaleza, CE: Federal University of Ceará, 2005. 211p. (M. A. Dissertation).

TRINDADE, T. P. et al. ***Compaction of soils: theoretical and practical foundations.*** Viçosa, MG: Editora UFV, 2008. 95p.

VEIGA, A. Q. N. V. ***Geotechnical characterization in the lands of the Tifónico Valley Partners-Leiria.*** Coimbra: Coimbra University, 2011. 331p. (Doctoral Thesis).

Received: 20 September 2017 - Accepted: 27 August 2018.