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Studies and Full Scale Tests for the Development of a Ravine Filling with a Depth of about 12.00m

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***Abstract*—**In compaction works, the most often used codes and standards are those for road embankments and refer to a maximum filling height of 3.00m. When filling a height greater than 3.00m, such codes are no longer valid and thus their application may lead to technical difficulties in the process of compaction and to the achievement of a sufficient degree of compaction. For this reason, in the case of controlled fillings with heights greater than 3.00m it is necessary to formulate and apply a number of special techniques, which can be determined by performing a full scale test. This paper presents the results of the studies and full scale tests conducted for the stabilization of a ravine with vertical banks and a depth of about 12.00m. The fillings will support a heavy traffic road connecting the two parts of a village in Vaslui County, Romania. After analyzing two comparative intervention solutions, the variant of a controlled filling bordered by a monolith concrete retaining wall was chosen. The results obtained by the authors highlighted the need to insert a geogrid reinforcement at every 2.00m for creating a 12.00m thick compacted fill.

***Keywords*—**Compaction, dynamic probing, stability, soil stratification.

I. Introduction

Cohesive soils, non-cohesive soils and rocks provide a base support for all constructions, while also constituting a building material that is easily accessible in large quantities on Earth. Due to the rapid and massive development of human population, it is necessary to increase the areas of developable land [13]. This involves changing the natural terrain profile by creating platforms, terrain stairs, roads, etc., changes that affect the stress state of the geological basis. The works to modify the natural terrain profile involve excavation at ground level and work areas with cut filling. In excavation works, the emphasis is placed on the stability of trench walls, whereas in fillings the emphasis is placed on the degree of compaction. In the design process of structures founded on fillings, engineers should consider the implications of filling on the behavior of the future construction, particularly where compaction is not performed properly.

Compaction works use most often codes and standards provisions for road embankments, which refer to fillings with a maximum height of 3.00m. When filling a height greater than 3.00m, these provisions are no longer valid in all situations and their application may lead to technical difficulties in the process of compaction and may result in the failure to achieve the compaction degree provided for by the project. For this reason, in the case of controlled filling with heights greater than 3.00m it is necessary to formulate and apply a number of special regulations which are determined by performing a full scale test polygon. Another important aspect in compaction works is the quality control for verifying the conformity of the actual values achieved on site after the execution of compaction works with the geotechnical parameters considered in design calculations. The consequences of bad compaction works may be catastrophic in some cases. This paper discusses the issues above and analyzes a case of achieving a compacted fill with a height of 12.00m that supports a heavy traffic road.

Compaction is a process of increasing the density of the soil by reducing the air volume of the pores through the use of mechanical means, which usually involves static compaction, vibrations, strokes or a combination thereof. The quality of compaction is influenced by maximum dry unit weight γ_{dmax}, porosity n, the granulometric composition of compacted soil and optimum moisture w_{opt} . These parameters affect the shear strength of the particles during compaction work and in normal exploitation. If the soil being compacted has a moisture content below the optimal humidity, the shear strength between the particles will be greater. If the moisture content of the soil being compacted is greater than the optimal moisture, a rearrangement of the particles occurs by repression. Since the unit weight of the soil is influenced by the unit weight of the water, in design and compaction works the dry unit weight is used. If the moisture content is greater than the optimal moisture, the degree of compaction will be smaller because water is an incompressible fluid that takes up a large part of the compaction energy. Since reaching a degree of compaction of 100%, i.e. total expulsion of the air between the particles, is expensive and requires a long period of time, the current practice is to achieve a degree of compaction of 95%-98%, or more than 98% in some particular cases. It should be noted that the degree of compaction is influenced largely by the nature of the soil and the compaction energy.

This paper presents the results of the studies and full scale tests conducted for the stabilization of a ravine with vertical banks and a depth of about 12.00m. The fillings will support a main road with heavy traffic load, which connects the two parts of a village in Vaslui County, Romania.

Following the erosion processes of loess soils composing the surface layer, landslides occurred that have endangered the overall stability of the site, and thus the stability and structural integrity of the buildings in its immediate vicinity. The analyzed site is located at the base of 3 slopes resulting in the creation of slope torrents during heavy rains; this significantly

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increased the degree of erosion of the analyzed area and caused the emergence of a deep ravine leading to the interruption of the road linking the two parts of the village.

In order to restore the continuity of the road, two intervention solutions were considered, for which pros and cons were weighed, as shown in Table I.

II. Works Analyzed

A. Determination of the Filling Characteristics

The geotechnical investigation works carried out on site include boreholes and super heavy dynamic penetration tests, type DPSH-B as in [2], [3], [9]-[11]. The investigations were carried out to a depth of 18.00m relative to the upper elevation of the ravine and a depth of 6.00m below the bottom of the ravine. The geotechnical investigation work revealed an uneven stratification, as shown in Table II. The standard Proctor tests [12] produced the following values for dry unit weight and optimum compaction moisture, namely γ_{dmax}= 17.17kN/m^3 and w_{opt}= 16.47%. The determination of compaction technology required the realization of an experimental polygon [4]. The experimental polygon, i.e. a controlled fill with a height of 6.00m, was executed to check the possibility of using current technologies employed for fills with a height smaller than 3.00m.

Fig. 1 Site overview

Fig. 2 Torrents of water discharging on site

TABLE I
Comparative Analyses of the Proposed Intervention Solutions

Intervention solution	Pros	Cons
1. Concrete bridge	- solves the problem of road continuity and heavy vehicle traffic; - related work for bridge construction lead to site stabilization;	- requires deep piles foundations; - requires shores and embankments protection with gabions; - requires pad gabions and gabion thresholds to prevent land erosion; - requires regularization of river bed sides; - high execution time and costs; - special design technology, which requires specialized manpower for this kind of work; - major interventions on the natural land around the site;
2.Controlled filling bordered by a monolith concrete retaining wall	- relatively low execution time; - current execution technology; - stabilizes the area surrounding the site without additional auxiliary constructions; -reasonable execution costs; - enables collection and removal of rainfall from the 3 adjacent slopes;	- requires a large volume of soil compacted fillings; - due to the great height of the fill, technical problems emerge in the compaction works.

The verification of the degree of compaction achieved was conducted through a dynamic penetration test DPSH-B and the sampling of each elementary layer as in [1]. Chart analysis results, in terms of dry unit variation (Fig. 3), showed a decrease of concomitant with increased thickness of the compacted filling. The most significant decrease was obtained following a 2.00m thick filling. It can be concluded that using current methods of compaction could reduce the degree of compaction with increasing thickness of compacted fill. The main causes of a low degree of compaction are: Heterogeneity of soils deposits used for fills non optimal value for optimal moisture content and failure of compaction technology. The authors have not intended to determine the influence of each of these factors on the degree of compaction. It was concluded that changes are needed in the manner of achieving the required degree of compaction by inserting geogrid reinforcement at every 2.00m [5]-[7].

TABLE II
MEAN GEOTECHNICAL PROPERTIES OF THE SOIL

Depth [m]	Soil description	I_C [%]	γ_d [kN/m^3]	e [-]	N_{30} [blows/30cm]
1,00	- topsoil	-	-	-	-
8,50	- yellow clayey silt	0,72	14,11	0,88	12
11,50	- yellow silty clay	0,72	14,88	0,80	19
18,00	- clay	0,90	16,40	0,64	23

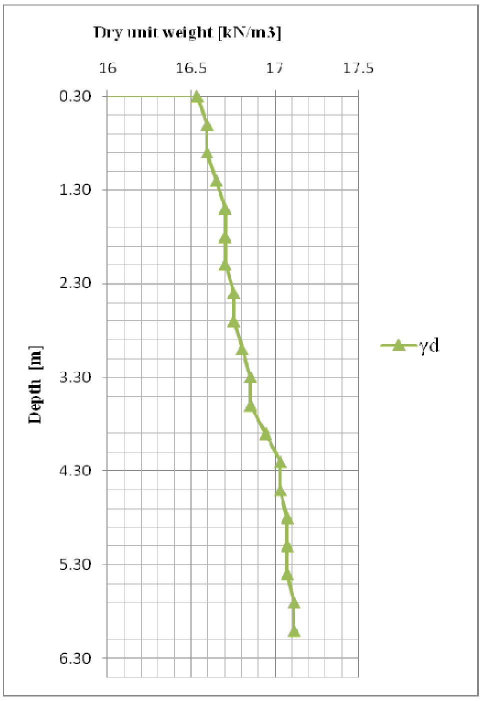
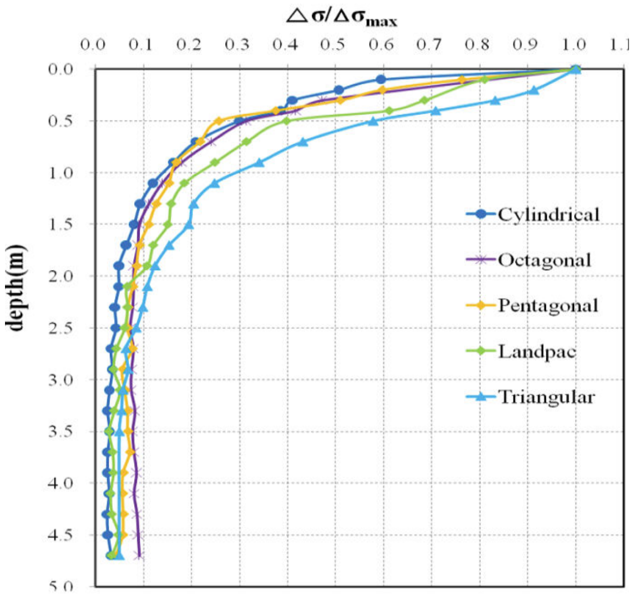
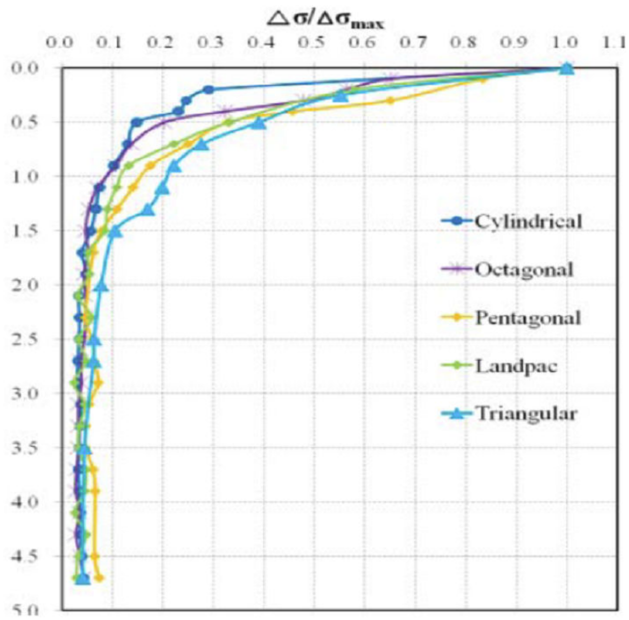


Fig. 3 Dry unit weight variation with depth

The manner in which the geogrids were introduced and the results obtained will be presented in the paper. Similar conclusions about the degree of compaction decreasing with the increase in thickness of the compacted layer were reached by other authors [6], who showed that the depth of influence of the compaction roller is influenced by the modulus of elasticity of the soil and the type/form of the roller (see Fig. 4). In the case analyzed, to maintain a relatively constant degree of compaction and a dry unit weight by height, we proceeded by dividing the filling in "elementary" layers with a height of 1.80m, separated by a layer of compacted gravel with a thickness of 20.0cm provided in the middle with a layer of biaxial geogrids. To support and board the slightly reinforced volume of compacted soil, a reinforced concrete retaining wall with a "Z" shape was designed and provided with a vertical wall with a height of 2.00m as shown in Fig. 5.



(a)



(b)

Fig. 4 The depth of influence of different types of roller for soils with [6]: a) E=10.00 MPa; b) E=50.00 MPa

B. Site Stability Analysis

A study was carried out to compare the stability of the site in the following situations:

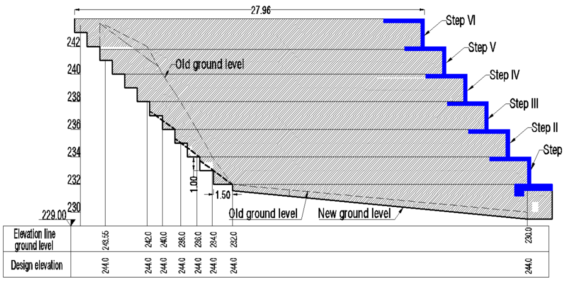
- initial situation;
- compacted fillings bordered with a concrete retaining wall;
- compacted fillings reinforced with geogrids and bordered with a concrete retaining wall;

- compacted fillings reinforced with geogrids inserted in a gravel layer and bordered with a concrete retaining wall.

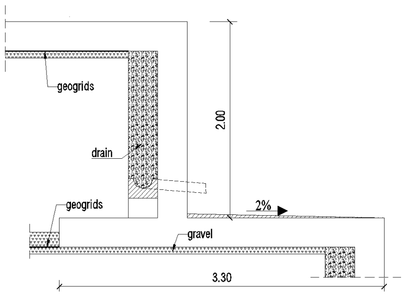
For each situation we considered three load levels from the road situated above the filling, namely:

- without charge – 0.00 kN;
- one car per way – 2 x 57.5 kN;
- two cars in reverse directions – 4 x 57.5 kN.

The site stability analysis for characteristic transverse profile was performed with Plaxis 2D V8 program.



(a)



(b)

Fig. 5 (a) Retaining wall cross-section H=12.00m
(b) Retaining wall step detail H=2.00m

The behavior of the site soil and fill soil was defined using the Mohr-Coulomb model. The stability analysis of the characteristic profile was performed using the iterative Lazrad method, present in the Plaxis program as the "Phi-c reduction" method. Table III presents the results of the analyses performed and Figs. 6-13 show the calculation models used and the total displacements for the last loading step for each model.

An increase in safety factor was evidenced in all three cases of compacted fillings bordered by a concrete retaining wall which have been reinforced by using a layer of geogrid placed at a distance of 2.00m from one another. In terms of compacted filling total displacements, the lowest value was obtained, as normal when using a geogrid placed in a granular soil layer. In this case, the cooperation between geogrids and the soil fill was significantly better. Therefore, the use of geogrids placed in a granular soil layer was considered the optimal solution for achieving a compacted fill with a height of 12.00m.

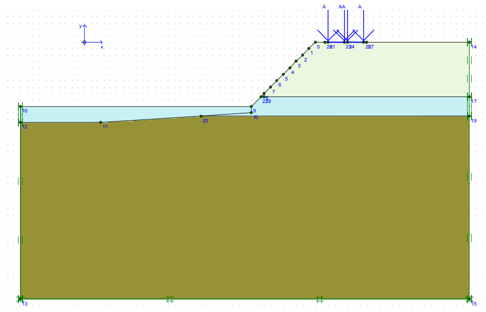


Fig. 6 Model 1

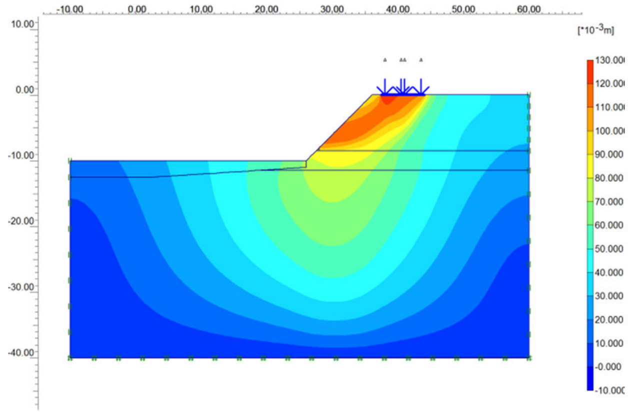


Fig. 7 Model 1 total displacements U_{tot}=12.561cm

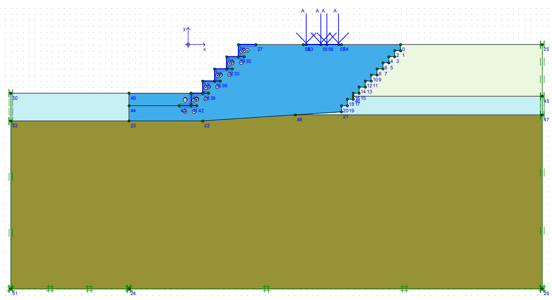


Fig. 8 Model 2

TABLE III
RESULTS OF ANALYSES PERFORMED

Model number	Model description	Assumption I Without charge		Assumption II One car 2x57.5 KN		Assumption III Two cars 4x57.5 KPa	
		Total displacements [cm]	Safety factor [-]	Total displacements [cm]	Safety factor [-]	Total displacements [cm]	Safety factor [-]
1	Original situation	7.885	1.151	10.061	1.038	12.561	1.000
2	Compacted fillings with a concrete retaining Wall	6.992	1.831	7.094	1.835	7.180	1.835
3	Compacted fillings with a concrete retaining wall and geogrids	6.988	2.497	7.090	2.448	7.180	2.562
4	Compacted fillings with a concrete retaining wall, a layer of gravel with geogrids	6.956	1.837	7.059	1.836	7.148	1.836

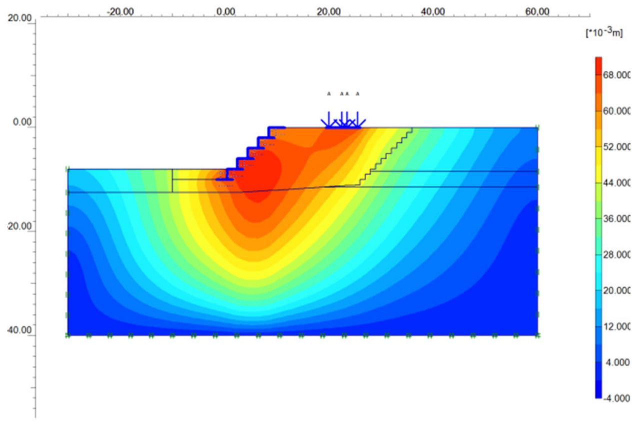


Fig. 9 Model 2 total displacements U_{tot}=7.18cm

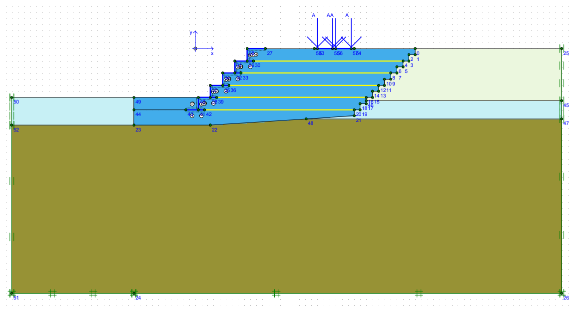


Fig. 10 Model 3

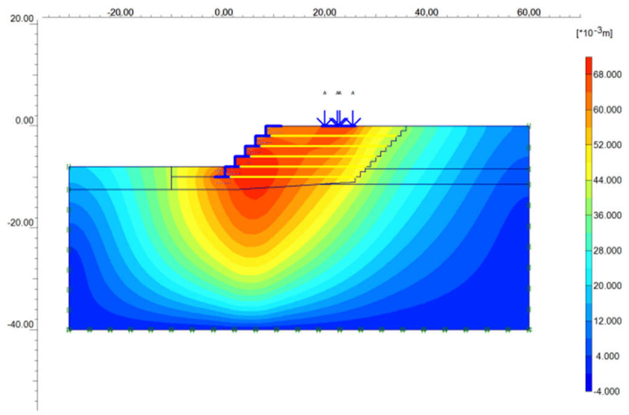


Fig. 11 Model 3 total displacements U_{tot}=7.18cm

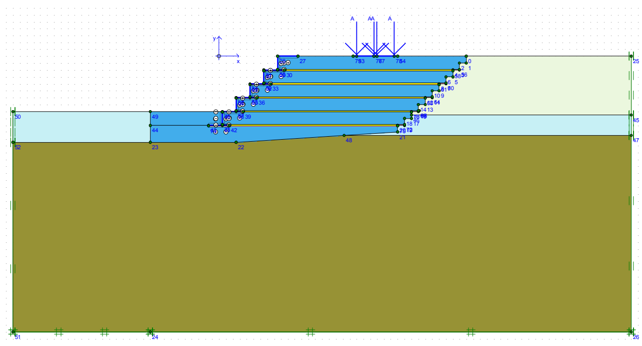


Fig. 12 Model 4

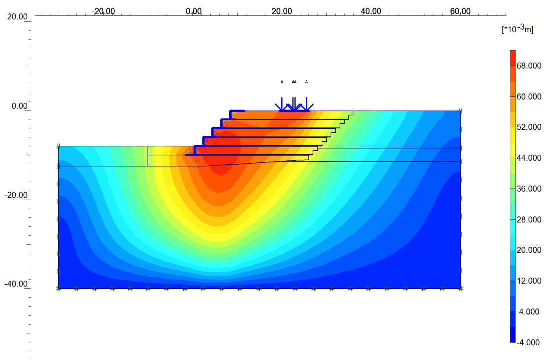


Fig. 13 Model 4 total displacements U_{tot}=7.148cm

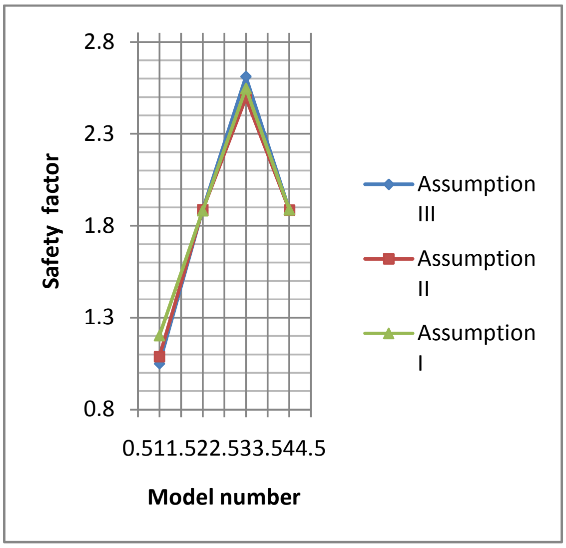


Fig. 14 Stability factor for the models for each loading assumption

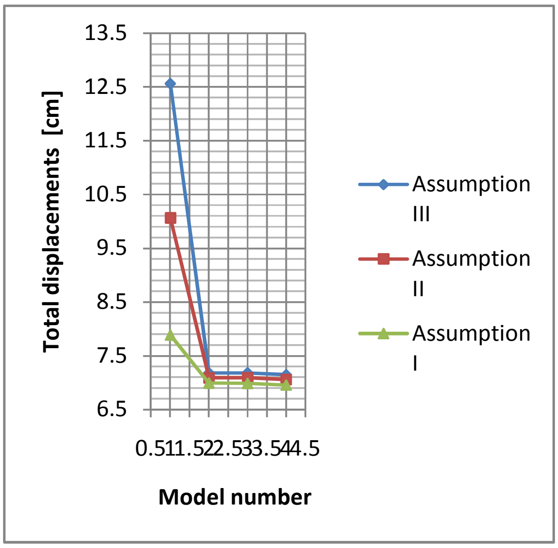


Fig. 15 Total displacements for the models for each loading assumption

C. Checking the Quality of the Controlled Fillings

After reaching the height of 12.00m, a dynamic penetration test type DPSH-B was performed on the compacted fill; the test allowed for the determination of dry unit weight and pore index throughout their depth, as well as of the degree of compaction. In accordance with the Romanian standards [2], [3], in the first phase, the dynamic cone penetration resistance R_d was determined, based on which, using empirical equations [8], the static cone penetration resistance R_p, dry unit weight γ_d and void ratio e were determined.

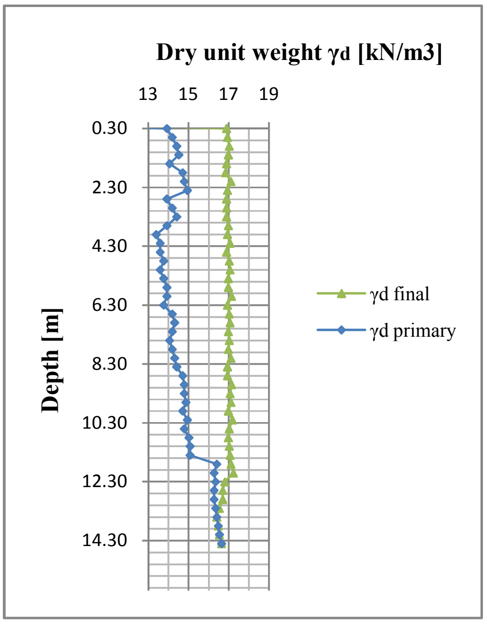


Fig. 16 Variation diagram of the dry unit weight,γ_d , for the two tests

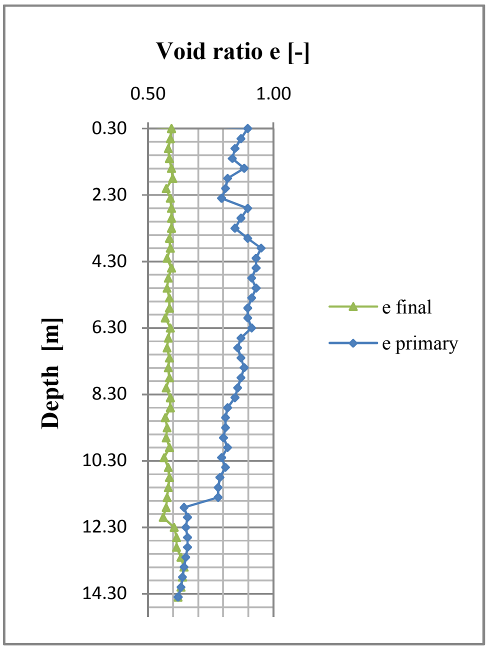


Fig. 17 Variation diagram of the void ratio, e , for the two tests

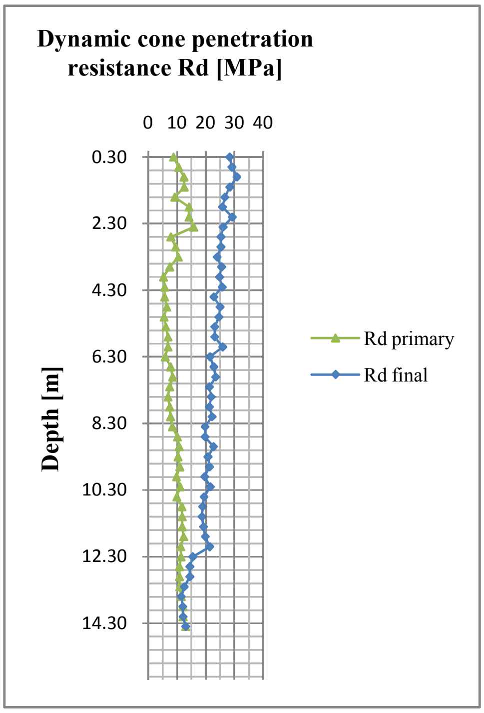


Fig. 18 Variation diagram of the dynamic cone penetration resistance, R_d , for the two tests

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