

## CONTROL OF COMPACTION ON EMBANKMENT DAM CORE BY NUCLEAR DENSITY METER AND SAND CONE TEST

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### Introduction

Soil compaction is an inherent stage of earth dam construction that intends to improve the mechanical properties of the fill within ranges defined in the project. Through the course of history there have been several reports on dam failures that can be linked to inappropriate compaction, therefore the quality of soil compaction must be evaluated during the construction phase to prevent this failures.

The effects of soil compaction can be quantified by accessing the fill water content ( $\omega_{fill}$ ) and the wet unit weight ( $\gamma_{fill}$ ). Two commonly used methods to measure these proprieties in site are the Sand Cone Test (SCT), associated with the oven method (OVM) in the lab, and the Nuclear Densimeter Gauge (NDG). However, the discussion on the accuracy of the NDG relatively to the SCT has been a recurrent subject discussed by the geotechnical community, particularly in Portugal.

### Objectives

This study is based on the results that were obtained in a joint research at University NOVA of Lisbon and DGRM on compaction quality control on site of fills. This project had two major objectives:

- Study the suitability of using the SCT and NDG methodologies during control operations by comparing the accuracy of the results obtained during the construction of an earth dam and their correlation;
- Evaluate the spatial variation of the control parameters in the dam body when estimated by each one of the SCT and NDG methodologies.

### Methodology

In this study the results from compaction control operations performed during the construction of the Coutada/Tamujaís dam were used to compare both methodologies. The Coutada/Tamujaís Dam is a 22.5 m high earth dam constructed in Vila Velha de Rodão, Centre of Portugal; the axis of the dam is closely oriented E-W, and the construction ended by 2007.

The dam core was formed by arkosic materials classified as SC - clayey sands, and these materials were compacted by six passes of a smooth wheel roller with 16.5 tons. A total of 684 measurements with the NDG and 102 with the SCT undertaken during the core construction quality control were used for the present study. The NDG measurements were taken with the direct method at the depth of 0.3 m. It was defined in the project that for a soil layer to be accepted, the degree of compaction (DC) range should be in the range of 98 and 101%, and the water content deviation between  $\omega_{op}-0.5\%$  and  $\omega_{op}+1.5\%$  %. Both methodologies were used to access the  $\omega_{fill}$  and  $\gamma_{fill}$ . The SCT was used to access  $\gamma_{fill}$ , but the respective  $\omega_{fill}$  was determined using the OVM. The NDG was used to measure both parameters at the site and the Hilf method to evaluate the compaction degree in both methodologies.

Three types of analyses were established:

- Point to point comparison: each one of the SCT observations was individually compared with all the results with NDG performed in its surroundings.
- Point to average comparison: each SCT test was compared with the average of all NDG tests executed in its vicinity.
- Closest point comparison: the results of each SCT test were compared with the ones from the NDG performed at the shortest distance from the SCT site.

The results were plotted in SCT measurements versus NDG measurements scatter grams, and a linear regression was adjusted to each population presented in the graphics.

Additionally, four 3D models were developed for each one of the parameters evaluated. The models were developed with Rockworks<sup>®</sup> 15 software using the inverse-distance with weighting exponent as estimation technique.

### Results and discussion

#### Point to point comparison

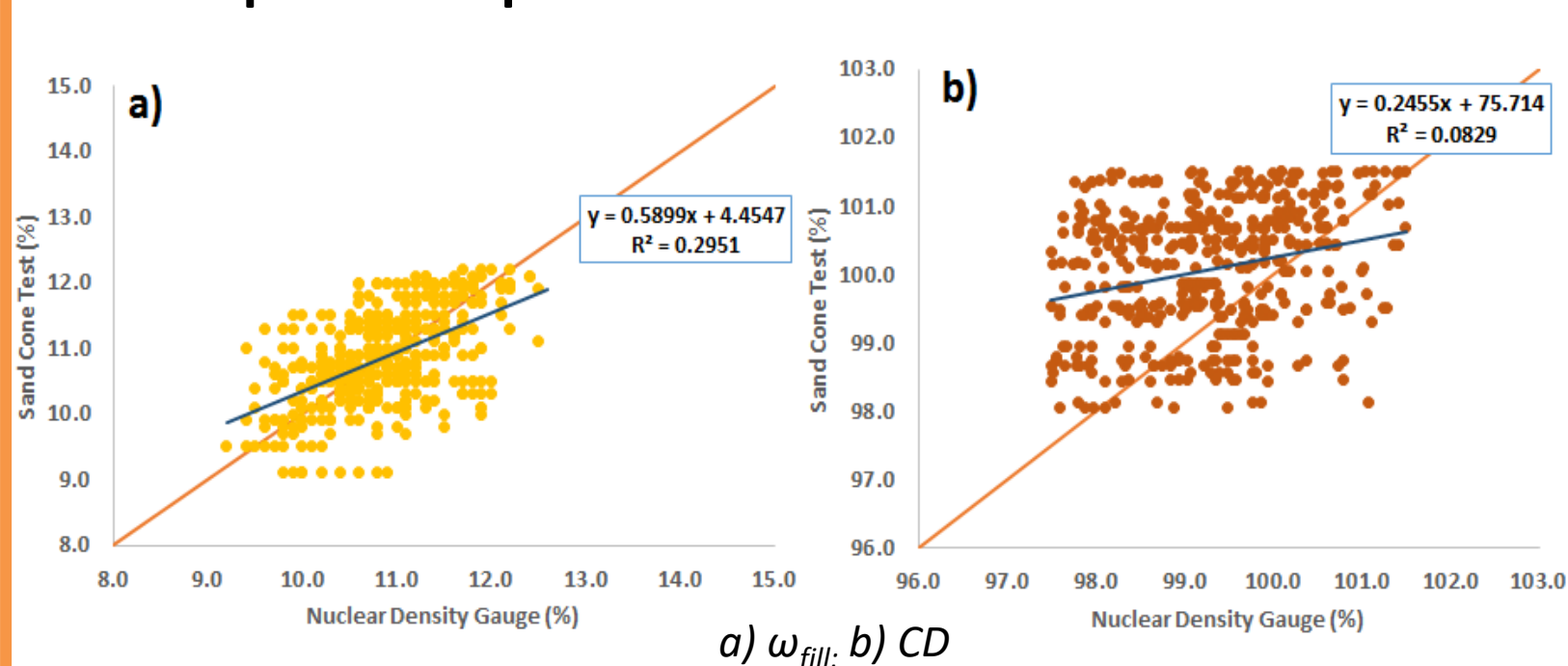


Figure 1 Scatter grams for the point to point analysis results

#### Point to average comparison

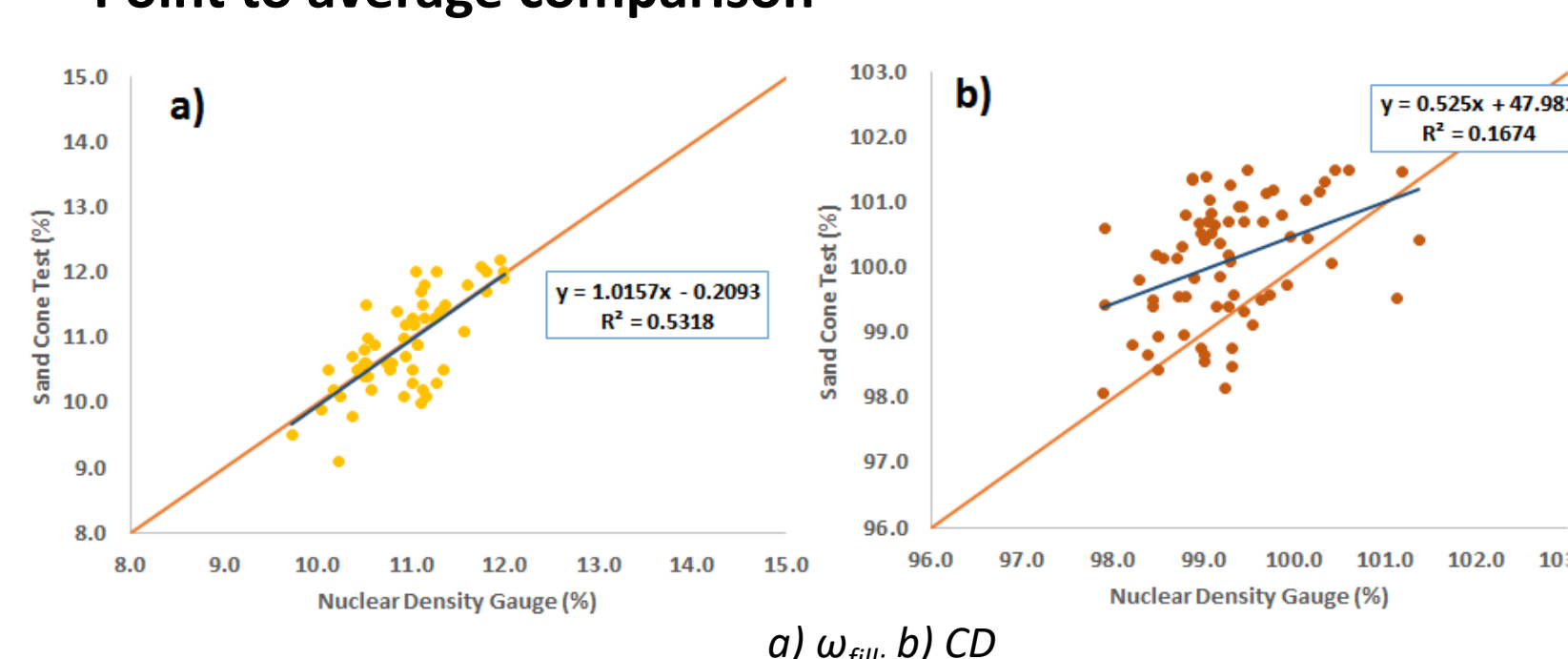


Figure 2 Scatter grams for the point to average comparison

#### Closest point comparison

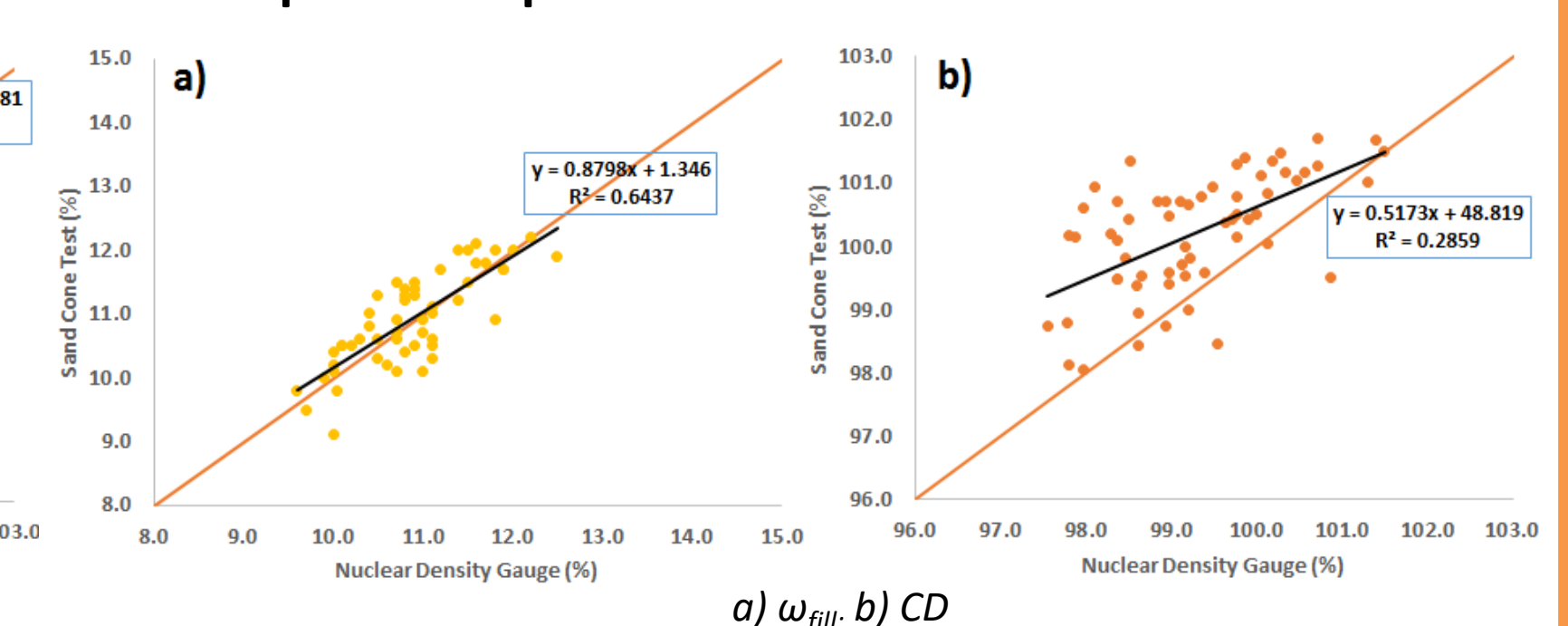


Figure 3 Scatter grams for the closest point comparison

In all the analysis applied to the data, the results from the SCT showed a tendency to be higher than those from NDG for both proprieties.

The lowest  $R^2$  values for both proprieties were obtained with the closest point comparison, being considerably higher for the  $\omega_{fill}$  parameter (Figure 1).

With the point to average comparison the  $R^2$  values increased significantly in particular for the CD results, showing that an analysis relating each SCT value to the average of all NDG values related is more significant (Figure 2).

The highest values of  $R^2$  were achieved with the closest point analysis, showing that the analysis considering tests from both methodologies taken at the shortest distance was the most significant (Figure 3). However even with these highest  $R^2$  values demonstrate the results cannot be explained by a linear equation.

### Models

#### SCT results

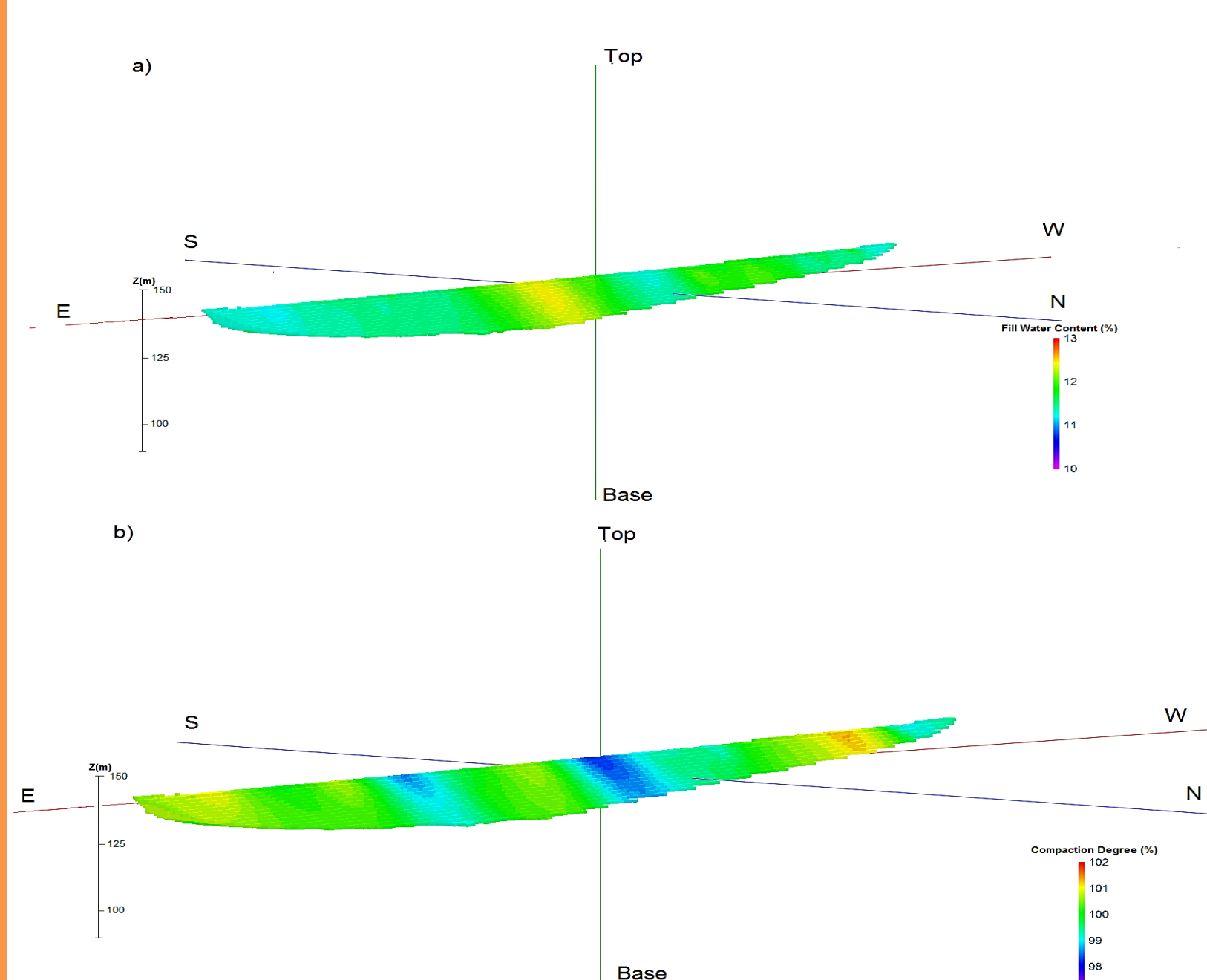


Figure 4 Models for the SCT results of the fill

#### NDG results

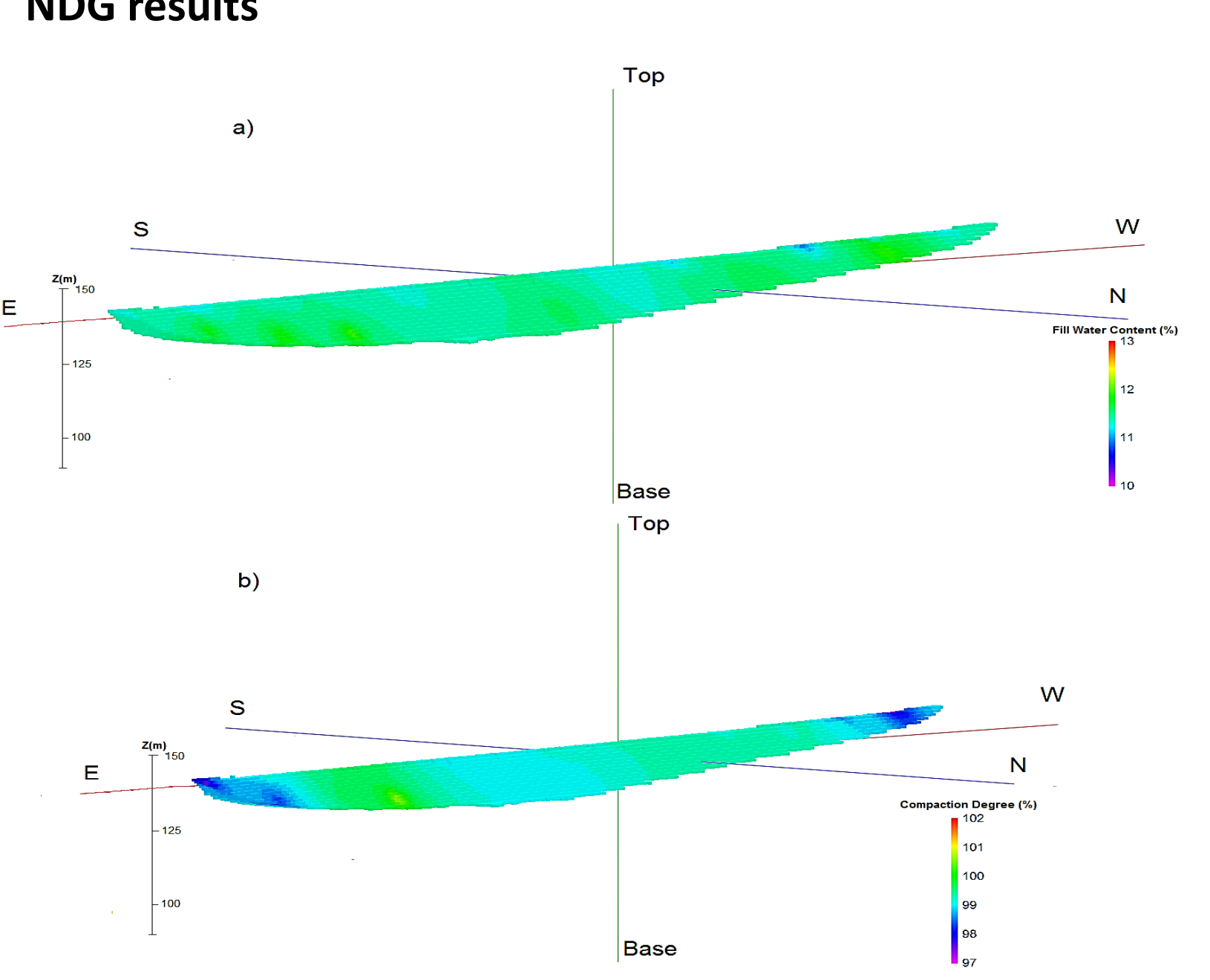


Figure 5 Models for the NDG results of the fill

#### SCT and NDG results

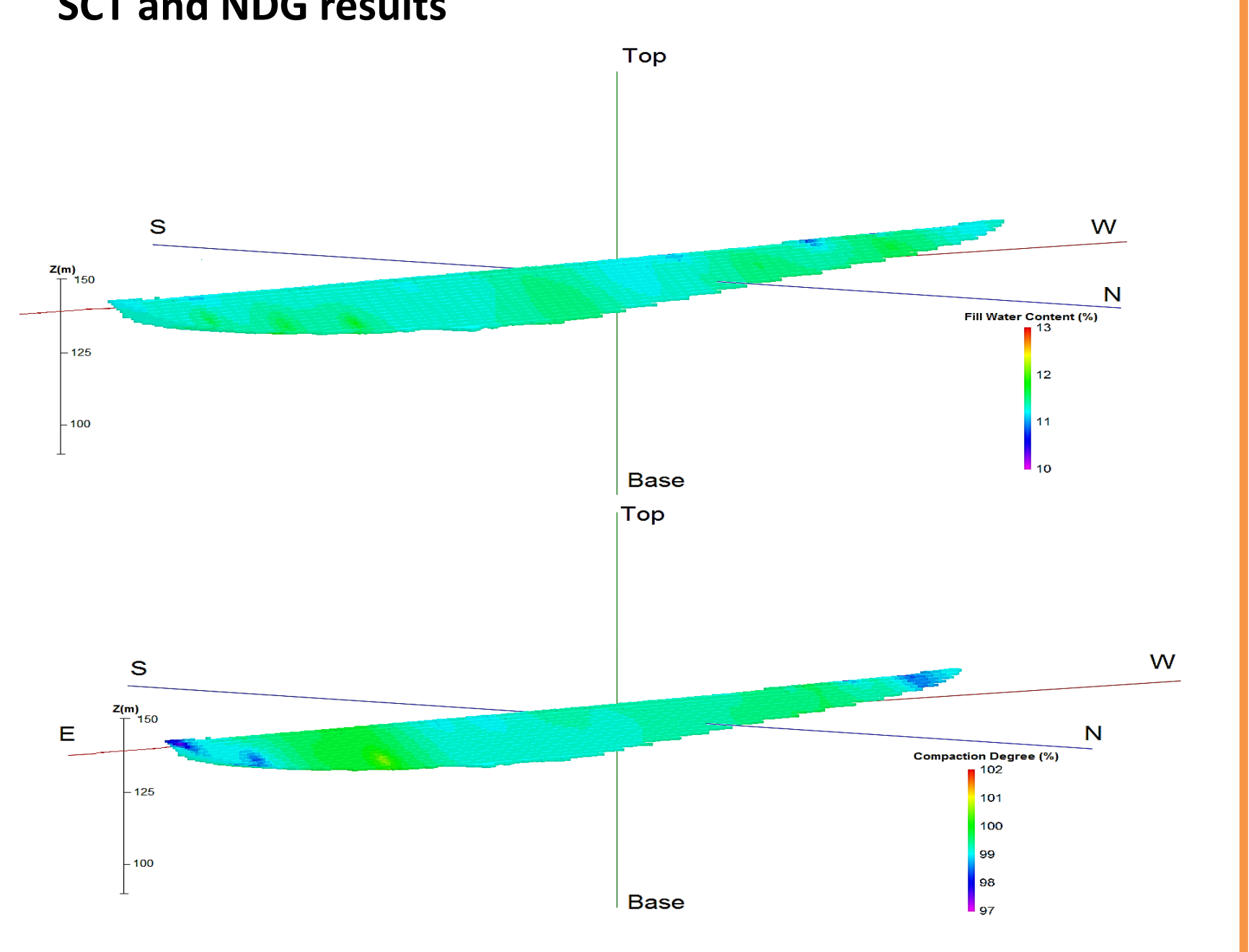


Figure 6 Models for the SCT and NDG results of the fill

As can be observed from Figures 4 and 5, the spatial variability is superior in the SCT models, as a result of the smaller number of SCT tests performed during the core construction. Therefore, the models from both methodologies cannot be directly comparable. Figure 6 demonstrates that the model produced by adding the SCT and NDG results did not motivate substantial modifications in relation to the ones achieved before. This can be justified by the fact that, from the total of points that were used to produce Figure 6 models, only 13% were SCT results.

The DC (Figure 6-b) achieved in the embankment seems to be uniform with the exception of both extremes, presenting lower values, and that the  $\omega_{fill}$  is uniform in all the extension of the core.

### Conclusions

The main conclusions that were obtained from this work are the following:

- The highest values of  $R^2$  were obtained with the closest point analysis. However even these highest values demonstrate that the results cannot be explained by a linear equation, therefore it is recommendable that the SCT methodology should be used to validate the NDG results;
- SCT models had a larger variability; however, both models (a and b in Figures 4 and 5) cannot be directly compared since the amount of NDG tests used to create this model are significantly greater;
- The amount of knowledge about the spatial variability of the compaction parameters that was gained by adding the results from both methodologies in one model was negligible;
- According to Figure 6 models, the degree of compaction achieved in the fill seems to be uniform with the exception of both extremes of the core;
- The results presented by the authors may be invalid for other conditions besides the ones used in the construction of the core, since they are valid for a specific type of soil and compaction equipment.