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Stiffness methods for compaction control: The geogauge device

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ABSTRACT: Soil compaction is a critical point in the construction of highways, airports embankment and foundations. The current specifications address embankment compaction in terms of density and water content. However, achieving a certain physical properties does not guarantee acceptable performance. So, a comprehensive experimental testing program is under development, on compacted layers to investigate the feasibility of developing a stiffness-based specification for embankment soil compaction quality control. In this paper the correlation between the *geogauge* device output and *in situ* density and water content measured in dam under construction are presented and discussed.

1 INTRODUCTION

Soil compaction is essential in the construction of highways, airports, bridges and dams. Typically compaction is controlled by measuring the dry density and the water content of the compact soil. These physical properties are compared with target values determined in laboratory tests, and it is expected that in this way adequate mechanical and deformability properties have been achieved. Presently, there is a current trend towards measuring the soil stiffness modulus instead its dry density and water content. This approach, especially in transportation infrastructures, is supported by the concept that the performance requirements (e.g., maximum soil strength and minimum compressibility) may not correspond to the maximum soil dry density at its optimum water content. But the use of stiffness measurements for control introduces the difficulty that its strong dependency on both water content and dry density.

A comprehensive experimental testing program is under development in an effort to correlate the readings of three soil compaction control devices (*geogauge*, light dynamic cone penetrometer and portable falling weight deflectometer), based on stiffness methods, to soil dry density and water content, measured by nuclear and traditional methods (sand cone density and microwave oven heating tests, respectively).

In the present paper, an analysis of the *geogauge* results is included, with two major objectives. The first is to show the feasibility of employing the *geogauge* in order to estimate *in situ* soil stiffness modulus. The second objective is to illustrate the correlation between the results of *geogauge* and water content and density.

2 EXPERIMENTAL WORK

With the objective of determining soil *in situ* stiffness modulus of a dam in construction, 11 test points on the upstream shell, 6 test points on the downstream shell and 6 test points on the core material were selected. Since the modulus is dependent on unit weight and water content of the soil, these properties were also determined in-place by nuclear moisture-density test and cone sand density tests.

Soil samples from each test point were collected in the same general area as the field test locations and stored to further laboratory characterization.

2.1 *Laboratory study*

Laboratory tests included index tests and Proctor compaction tests with standard effort. Table 1 presents a summary of index and compaction results. Figure 1 shows the typical grain size distribution of upstream, downstream and core materials.

2.2 *Field study*

Figure 3 summarizes the field tests performed at the different locations and Figure 4 presents the layout of the field tests carried out at each location. In each point, three *geogauge* measurements were taken. The nuclear density gauge was used to measure in-place dry unit weight and water content. The cone sand density test was used to measure in-place unit weight, according ASTM D 1556. Soil samples were also collected from this site for water content determination by microwave oven heating tests, according ASTM D 4643.

2.3 *In-place density and water content test*

At every station of each point, in the same location that the stiffness measurements were performed, water content and dry density were determined. The water content was measured both using a nuclear density gauge (w_{NDG}) and a microwave oven heating in the laboratory (w_{MW}).

Table 1. Index and compaction tests results.

	Proctor test					Classification	
Location	Max dry density (kN/m^3)	Optimum water content (%)	Fines (%)	w_L (%)	PI (%)	AASHTO	USCS
Upstream and downstream shells	18.32	15.5	14.86	N/P	N/P	A-1-b(0)	SM
Core	16.2	17.74	50.79	17.9	20.9	A-6(8)	CL

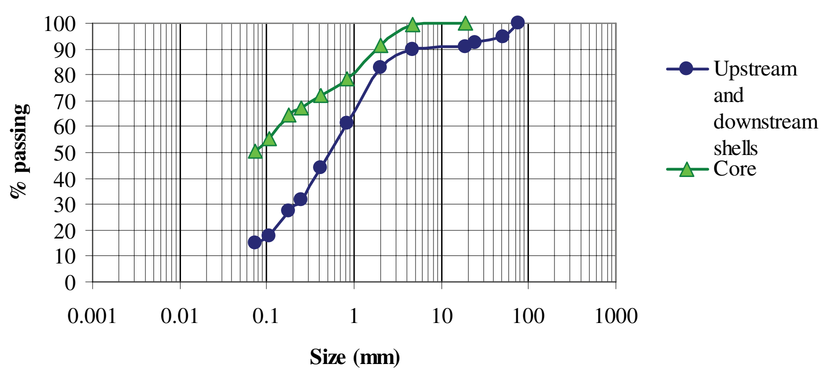


Figure 1. Grain size distribution of upstream, downstream and core materials.

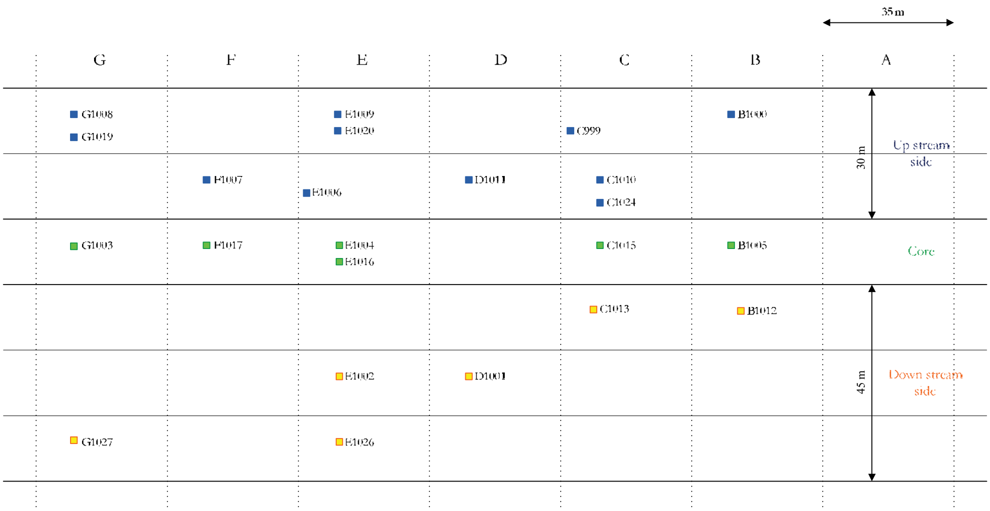
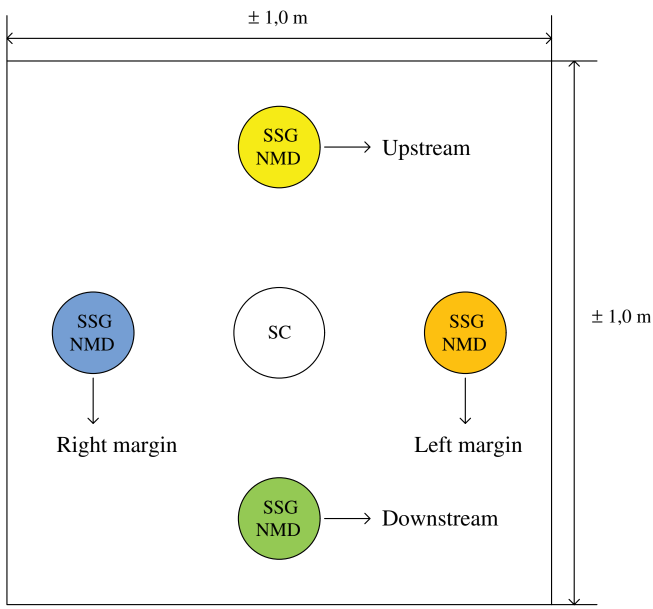


Figure 2. Location of different tests.



SC–Sand cone density test
SSG–Soil stiffness gauge
NMD–Nuclear moisture-density test

Figure 3. Layout of the field test measurements.

The Figure 4 illustrates the comparison between laboratory and nuclear density gauge water contents.

The water content results determined with nuclear density gauge device are generally smaller than those obtained by the microwave oven device, especially on the upstream shell and on the core, where the soil was compacted on the wet side. The dry density was determined using a nuclear density gauge ($\gamma_{d\ NDG}$) and the *in situ* density with sand cone device. Combining the sand cone results with microwave oven water content, another set of dry

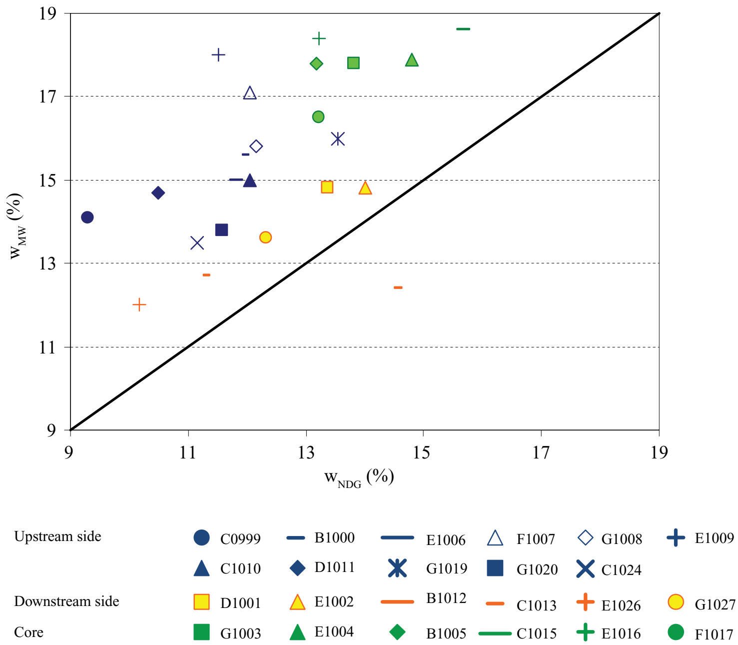


Figure 4. Comparison between laboratory and *NDG* water contents.

density values was calculated ($\gamma_{d\ SC}$). The Figure 5 illustrates the comparison between sand cone and nuclear density gauge dry densities. Some differences were also noted, namely, the dry density results determined with nuclear density gauge device are generally larger than those obtained by the sand cone device, especially on the upstream shell and on the core, perhaps due to the water content differences obtained based on the two evaluation methods.

2.4 *Geogauge testing*

The *geogauge* device uses the concept of applying a dynamic force onto an elastic medium to estimate the elastic modulus of the tested material. The *geogauge* is cylindrical in shape, with a height of 270 mm and a diameter of 280 mm, as shown in Figure 6. The equipment weighs approximately 10 kgf. The device rests at the soil surface by a circular ring, which has an outside diameter of 114 mm and an inside diameter of 89 mm. The *geogauge* is placed and seated on the soil surface by pressing and rotating the unit. The *geogauge* has a shaker that generates a small dynamics force at 25 specific frequencies, ranging from 100 to 196 Hz, in 4 Hz increments (Alshibli *et al.*, 2005). The device has sensors that measure the force, F, and the corresponding deflection, δ, of the foot. The ratio $K = F/\delta$ is the stiffness of the soil. During the test sequence, the *geogauge* records the small deflections, caused by the vibration of the unit, using a geophone sensor embedded in gauge body. Based on the vibration forces and deflections, the machine calculates the *geogauge* stiffness (K_{SSG}) based on the average of 25 stiffness values recorded at the 25 frequencies. The elastic modulus (E_{SSG}) of the soil is then computed. The equation used in calculating the elastic stiffness modulus is:

$$E_{SSG} = K_{SSG} \frac{1-\nu^2}{1.77R} \tag{1}$$

were E_{SSG} is the elastic stiffness modulus in MPa; K_{SSG} is the *geogauge* stiffness reading in MN/m; ν is Poisson's ratio; and R is the radius of the *geogauge* foot (57.15 mm).

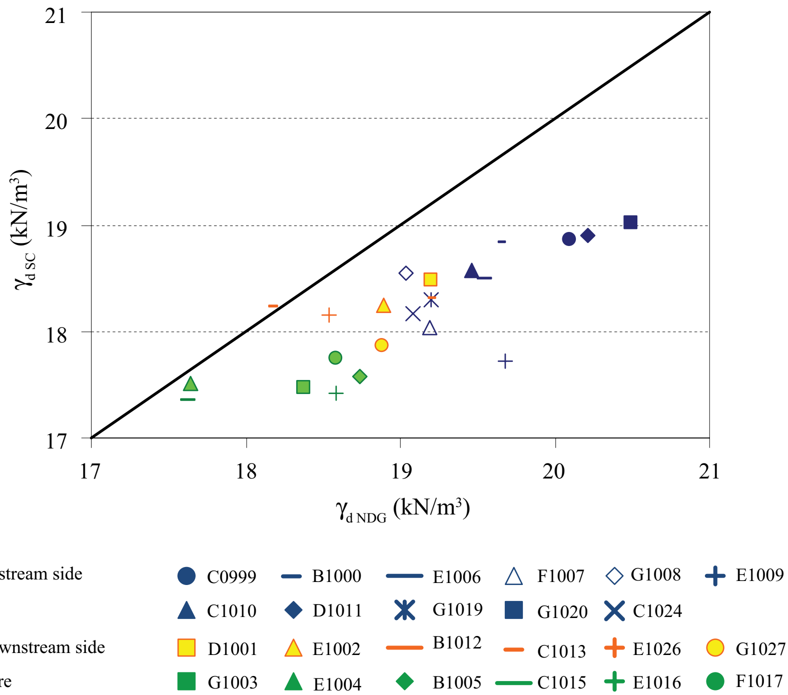


Figure 5. Comparison between sand cone and *NDG* dry densities.

Figure 6. *Geogauge* device.

Geogauge test results suggested that test results were dependent of the surface preparation and how the operator places the device on the soil. The *geogauge* manufacturer recommend that the equipment should be seated on the surface and rotated to reach a contact area between the foot ring and soil greater than 60% of the foot ring surface area.

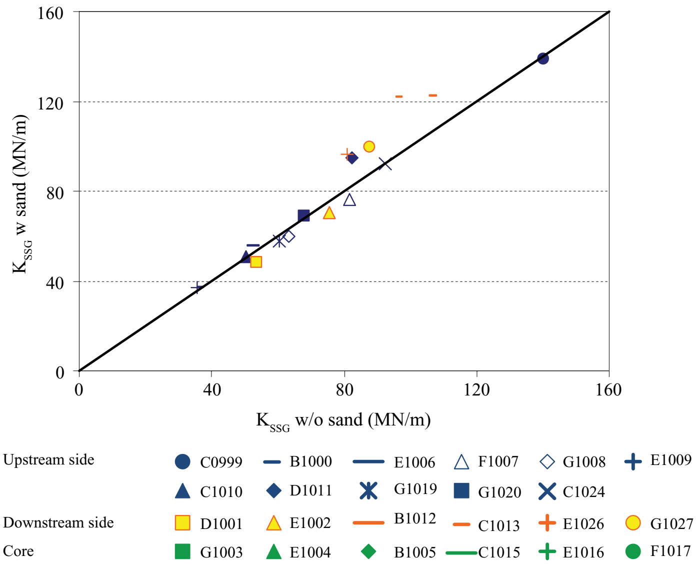


Figure 7. Comparison of *geogauge* stiffness results, with and without a wet sand layer.

To improve the contact area, in this study, the tests on the upstream and downstream shells were performed with and without a wet sand layer, for comparisons purpose. First tests were carried out without the wet sand interface. On each location three readings were taken, without lifting the device. This procedure was repeated at three other locations in each station (see Figure 3). After conducting these tests, a layer of wet sand was placed at each of the four locations and the test procedure was repeated.

Figure 7 shows the comparison of *geogauge* stiffness results of the tests performed with a layer of wet sand, K_{SSG} w sand, and without a layer of wet sand, K_{SSG} w/o sand. No significant differences were recorded, in all locations. Apparently, for the soils tested (clayey and sandy soils) the sand layer interposition is not needed.

3 CORRELATION BETWEEN K_{SSG} AND WATER CONTENT

To check the feasibility of *geogauge* for compaction control purposes, the correlation between soil stiffness and water content was verified along the different locations.

Figure 8a presents the linear relation between soil stiffness, K_{SSG}, and water content, w_{MW}, on the downstream shell materials. This relation shows the soil stiffness increase with decreasing of water content. These results were obtained for water content corresponding to a compaction on the dry side.

The relation between soil stiffness, K_{SSG}, and water content, w_{MW}, presents a large dispersion on the upstream shell and core materials (Figure 8b). Hence, no relation was established between them.

The test results for the upstream shell and core materials show that K_{SSG} is not sensitive to water content changes. This could be explained because the soil has been compacted on the wet side.

The analysis of Figure 8 shows that *geogauge* should not be applied in compaction control when the soil was compacted on the wet side. Thus the use of this equipment in the compaction control of the dam is limited since we have soil layers compacted on the dry side (downstream) and soil layers compacted on the wet side (upstream shell and core). Restricting the application of *geogauge* on the compaction control in roads or railway where landfill layers are compacted only on the dry side.

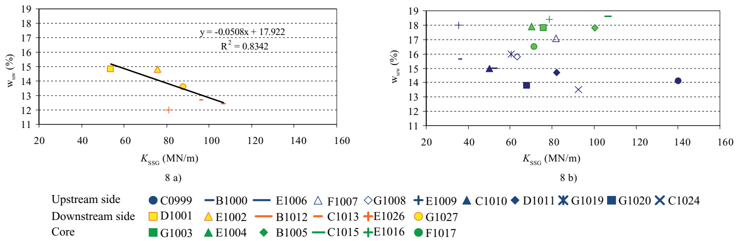


Figure 8. Relation between soil stiffness, k_{SSG}, and water content, w_{MW}.

4 CONCLUSIONS

To verify the conditions of application of *geogauge*, this device was used during the construction of a dam, to control the compaction of the core, upstream and downstream shells.

After relate data from *geogauge* device with results obtained from traditional methods of compaction control, the following conclusions may be allowed:

- The nuclear gauge was inadequate to control of compaction, particularly on wet side. The equipment was unable to correctly detect the deviations in the moisture content.
- To improve the contact area between *geogauge* and the soil surface, the tests on the upstream and downstream shells were performed with and without a wet sand layer. After evaluation of results no significant differences were recorded. Apparently, for the soils tested (clayey and sandy soils) the sand layer interposition is not needed.
- The results of *geogauge* showed good repeatability for the values of the stiffness.
- A linear relation between soil stiffness and water content on the downstream shell materials were obtained. This relation shows the soil stiffness increase with decreasing of water content.
- The relation between soil stiffness and water content presents a large dispersion on the upstream shell and core materials. No relation was established between them.
- The test results for the upstream shell and core materials show that K_{SSG} is not sensitive to water content changes. This could be explained because the soil has been compacted on the wet side.
- The use of *geogauge* in the compaction control of the dam is limited since we have soil layers compacted on the dry side (downstream) and soil layers compacted on the wet side (upstream shell and core).
- The *geogauge* may be used on the compaction control in roads or railway where landfill layers are compacted only on the dry side.

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REFERENCES

Alshibli, K.A., Abu-Farsakh, M. and Seyman, E. (2005). Laboratory Evaluation of the Geogauge and Light Falling Weight Deflectometer as Construction Control Tools. *Journal of Materials in Civil Engineering*, 17(5): 560–569, ASCE.

American Society for Testing and Material. ASTM D1556 (2007). "*Standard Test Method for Density and Unit Weight of Soil in Place by the Sand-Cone Method*", ASTM International, USA.

American Society for Testing and Material. ASTM D4643 (2000). "*Standard Test Method for Determination of Water (Moisture) Content of Soil by the Microwave Oven Method*", ASTM International, USA.