

INTERNATIONAL WORKSHOP ON COMPACTION OF SOILS, GRANULATES AND
POWDERS / INNSBRUCK / 28-29 FEBRUARY 2000

Compaction of Soils, Granulates and Powders

Edited by

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OFFPRINT



A.A. BALKEMA/ROTTERDAM/BROOKFIELD/2000

Compaction control with a dynamic cone penetrometer

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Abstract: The compaction control consists in measuring the dry density and compares it with the standard Proctor density. The cone resistance in a known granular medium is directly linked to the dry density. It is the comparison between the in-situ penetrogram and a reference curve which permits the compaction. This reference curve corresponds, for a given soil and a required compaction level to the cone resistance (for a passed compaction). A calibration process is necessary to establishes the reference curves. This paper sets out the compaction control method and the calibration Process.

Introduction

The mechanical behaviour of a soil can be approached by two different ways. Either the granular medium is considered as a continuous medium with its constitutive laws, or the material is regarded as a discontinuous medium, through this micro mechanic approach, the global properties are deduced from the locale properties.

The grains parameter (mineralogy, grains, shape, distribution of contacts granulometric range, water content etc...) are used to deduce the macroscopic mechanical behaviour. The granular medium is considered as discontinuous and its grains are supposed unbreakable and insensitive to attrition. With these hypotheses, the granular assembly response to a given stress is dully defined. It is the case for the cone resistance if the dutch formula hypotheses are validated. In a granular medium for a saturation state, the cone resistance depends on dry density.

It is proposed to establish this relationship and to use this property in compaction control.

1 Penetrometric tests in an homogeneous medium

1.1 The penetrometer

The dynamic cone penetrometer with variable energy is used. The principle of the apparatus consists in driving with a hammer a shank string, which is 14mm in diameter with a 2cm² or 4cm² cone. (fig.1). The speed of impact and the depth are measured for each blow. The dynamic cone resistance q_d is calculated by using the Dutch formula. The cone resistance which q_d are function of depth, are

automatically recorded [Gourves91] [Zhou97]. The results can be transferred to a computer to edit the penetrometers.

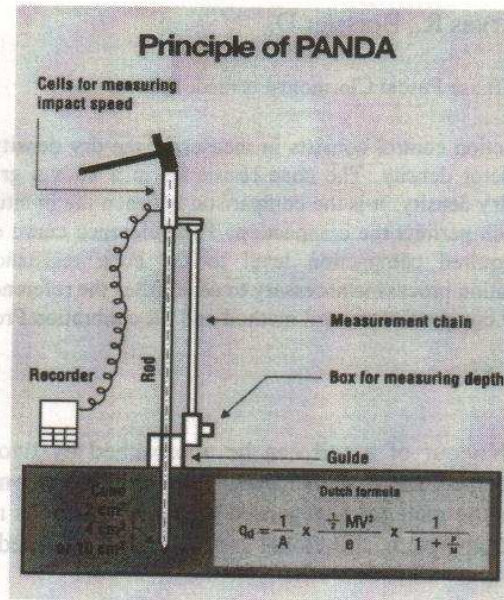


Figure 1: Principle of the PANDA

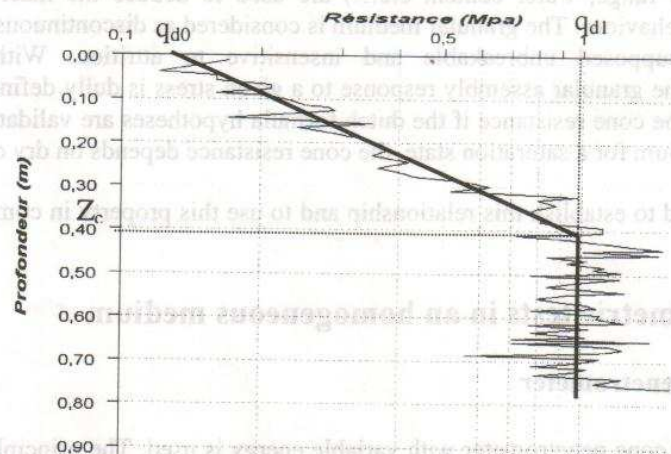


Figure 2: example of a penetrogram in a sand with homogeneous density.

1.2 Classical penetrogram

Many studies have established [Gourves et Al 1995] [Gourves et Zhou 1997] that in a granular medium with is homogeneous density and water content, the penetrogram can be modelled using a system of co-ordinates ($\log q_d; z$) by 2 lines defined by three parameters (fig.2): q_{d0} the cone resistance at the surface, Z_c the critical depth and q_{dl} the cone resistance below the critical depth.

2 Compaction control with a dynamic cone penetrometer

Many studies on dynamic cone penetrometer have proved the extreme sensibility of cone resistance to the dry density. These apparatus are not only well adapted for the detection lack of compaction, but they are also suited to detect the number and the thickness of the in-situ compacted layers. The compaction control with a penetrometer for a given material and a water content is based on the establishment of the relationship between cone resistance q_d and the dry density. With an accurate soil classification enough, for each material contained in a same soil class, the mechanical behaviour is quite the same (the french soil classification GTR [SETRA94] is used in our example). A database set up, for each type of soil, a relationship between the dry density and the parameter of penetrograms (q_{d0} , Z_c , q_{dl}) in an homogeneous medium for different waters contents.

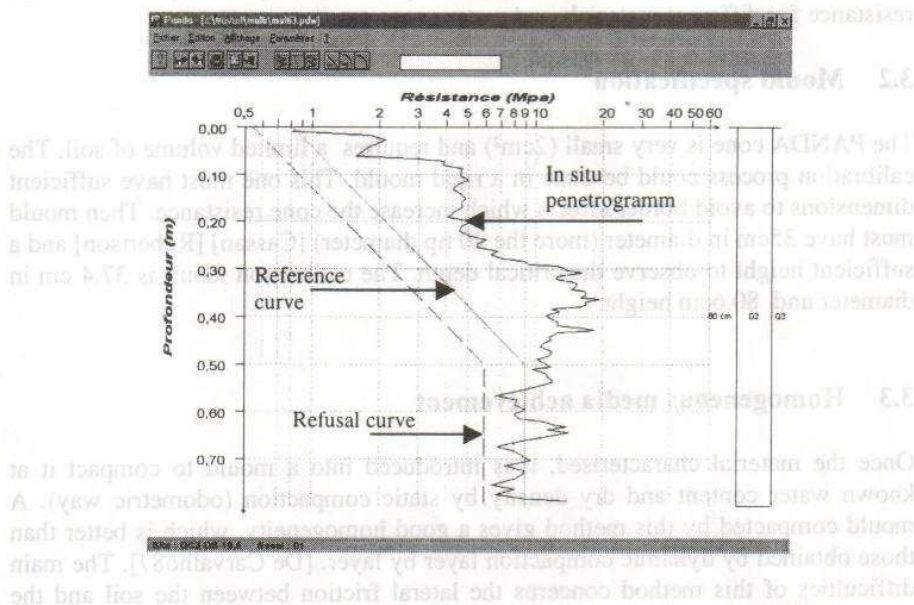


Figure 3: reference and refusal penetrogram.

For a given material and a water content, the cone resistance for the required compaction level is determined by the previous relationship. The compaction control is achieved by comparing the in-situ penetrogram to a reference curve. Another penetrogram is added to the reference one; this penetrogram is called refusal curve. The refusal curve corresponds about 98% of the reference density. The refusal curve takes into account variations in properties within the same granulometric class, the errors in the relationship between dry density and q_d , the experimental errors, and an allowance to fail or not the compaction (fig.3).

3 Calibration Process

3.1 Principle

The principle of the PANDA calibration Process consists in establishing a database. This base contains identified materials according an accurate soil classification. This classification must contain three main type of parameter to characterise the soil behaviour: the granulometric range of the material (in particular the fraction passing the 80 μ m and the 2mm sieve, d_{min} , D_{max} , the coefficient of curvature, and the coefficient of Hazen), the average shape of grains and for the fine material the water sensitivity (fraction passing the 400 μ sieve). The water sensitivity is measured by the Atterberg limits or by the blue methylene value. This database includes the relationship between dry density and the cone resistance for different materials and water contents.

3.2 Mould specification

The PANDA cone is very small (2cm²) and requires a limited volume of soil. The calibration process could be done in a rigid mould. This one must have sufficient dimensions to avoid border effects which increase the cone resistance. Then mould must have 35cm in diameter (more the 20 tip diameter) [Cassan] [Robertson] and a sufficient height to observe the critical depth. The calibration mould is 37.4 cm in diameter and 80.6cm height.

3.3 Homogeneous media achievement

Once the material characterised, it is introduced into a mould to compact it at known water content and dry density by static compaction (odometric way). A mould compacted by this method gives a good homogeneity, which is better than those obtained by dynamic compaction layer by layer. [De Carvalho87]. The main difficulties of this method concerns the lateral friction between the soil and the

surface of the mould. The friction increases with the pressure, then the stress field is not constant inside the soil. A density gradient appears in the height of the mould. To thwart this effect, the compaction is achieved by two layers and the surface of the mould is lubricated [Chaigneau98] (the soil is protected by a thin plastic membrane). With this method, the frictions are sufficiently limited to obtain an homogeneous density mould. The static compaction of this mould needs a 1000kN hydraulic press (fig.4).

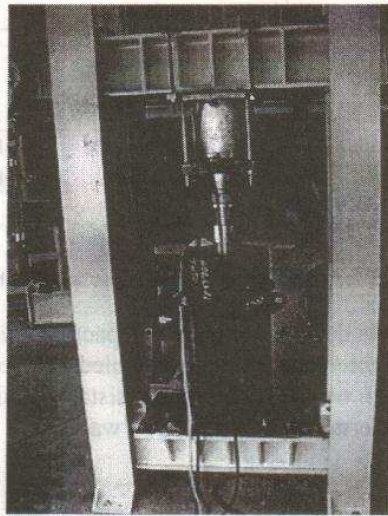


Figure 4: Hydraulic Press.

3.4 Reference curve establishment

If the soil is water sensitive, different tests are achieved with different water contents. The chosen water intervals are : $[0.7 w_{sp} \text{ and } 0.9 w_{sp}]$; $[0.9 w_{sp} \text{ and } 1.1 w_{sp}]$ and $[1.1 w_{sp} \text{ and } 1.3 w_{sp}]$ (w_{sp} : water content at the standard Proctor density). For each material and each moisture content, the soil is compressed to five levels of density. The first density corresponds to the bulk density and the last one the maximum density which is possible to obtain with the press. This maximum obtained is about 110% of the standard Proctor density. This density interval covers the densities, which are most commonly used in backfill compaction. The relationships between cone resistance and dry density are drawn ($\gamma_d - q_{d1}$). This curves are modelled by a logarithmic regression ($\gamma_d = a \ln(q_{d1}) + b$) (fig.5).

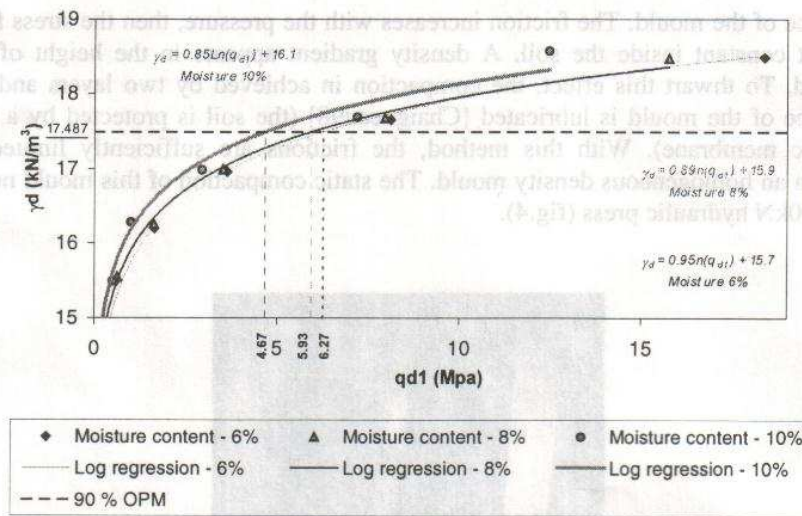


Figure 5: relationship between dry density and cone resistance q_{d1} below the critical depth.

The cone resistance q_{d1} is defined for each compaction level (95%, 98% 100% of the proctor density). A tolerance value is calculated (2% of tolerance on the dry density correspond to 40% on q_{d1}). The cone resistance at the surface (q_{d0}) and the critical depth (Z_c) are determined by the same way.

4 Conclusion

The compaction method proposed is very reliable and was not only used in fine soil but also in coarse soil (up to 50mm). The database contains the non-evolutive materials, which are most commonly used in backfill in the world.

It is possible to control compaction on a large depth (several meters) with a great accuracy to detect the efficiency of a compaction in depth, this is the main interest of the method.

Actually, the database based on the french GTR classification is going to change, to be used with the main international classifications.

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