Geothecnical issues concerns the material removal and reuse of pyroclastic soils

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ABSTRACT: This paper presents the results of a work developed on pyroclastic fall deposits from Sabatino volcano complex, typical of the subsoil of the area placed in the North of Rome (Italy). The particular physical and mechanical properties of the materials are related to the geological origin of the deposits, their formation environment and mechanisms. The geotechnical description follow the scheme recently proposed on pyroclastic flow deposits. The case study concerns the material removal and reuse of pyroclastic soils for road embankments; especially the compaction issues are treated because sometimes these soils are not included in specification standards despite that overall they have good mechanical characteristics. The work presents the results of an experimental investigation by means of laboratory and on site tests and offers a way of managing these problems.

1 INTRODUCTION

Pyroclastic soils is more widespread throughout many Italian regions and across the world. This phenomena is more common in the younger geological areas which are characterized by a higher level of geological risk. Moreso they are closer to the topographic surface due to their young genesis. Consequently this kind of geotechnical complex soil is frequently found in the volume soil interested in the building in question.

The complexity involved requires greater synergy between Geology and Geotechnic compared to what is normally required for other kinds of sedimentary soils. It’s common knowledge that geotechnical standards used for clay, silty and sandy soils are badly applied to pyroclastic soil.

This is true for the more important standard (A.S.T.M., CNR-UNI, U.S.C.S., A.G.I. 1963, B.S., UNI) but even for the procedures of the more common laboratory tests as direct shear and oedometer test. In this landscape the present paper uses a descriptive model (Cecconi, Scarapazzi, Viggiani 2014) that allows to check and highlight the main geotechnical characteristics useful for many applications. In the second stage an example is shown about excavation and compaction of pyroclastic soil near Fara in Sabina (Rome).

2 GEOTECHNICAL COMPLEXITIES

The peculiarity of this soils derives from the genesis itself (Croce, Penta, Esu 1961): fragments erupted from the volcano usually at very high temperatures and fast solidification; this condition doesn’t permit the formation of crystal structures but only a glassy amorphous paste. It is the glassy nature that causes an important structure fragility. Consequently it is very difficult to obtain a good quality class of sampled soil and so a correct evaluation mainly of mechanic characteristics. Some paradoxical and more common examples are: pyroclastic soil without any cohesion but with vertical natural walls, up to ten meters high, or pyroclastic soil characterized by Young Modulus having very low levels but appears very concrete. The crumble nature amplify the effects when the excavated material is re-used and compacted for road embankment, river bank, refill etc. In these situation the strict application of standard technical specifications advice agonist the use of this kind of soil that have a crumble behavior under static and cyclic load. Contrary to this reason the common practice show a good use of pyroclastic soil in many engineering application.

An additional problem came from the depositional sedimentary process that changing the energy vs time cause an important stratigraphical complexity. The presence in the underground of many different layers require, for the applicative use, a careful subdivision in geotechnical unites.

3 CASE STUDY

The geological and geotechnical study, presented in this paper, has been developed during the realization of the new industrial centre of Passo Corese in the council of Fara in Sabina (Rieti). Pyroclastic soils in the area came from activity of Volcano Sabatino District begun about 550.000 years (CIONI et alii, 1993) and characterized with a complex of volcanoes centers very articulated in the time and in the space (Figure 1).

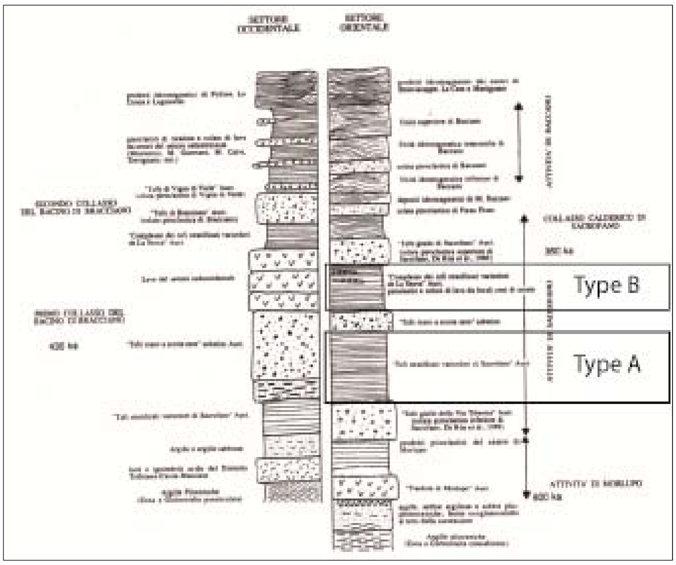
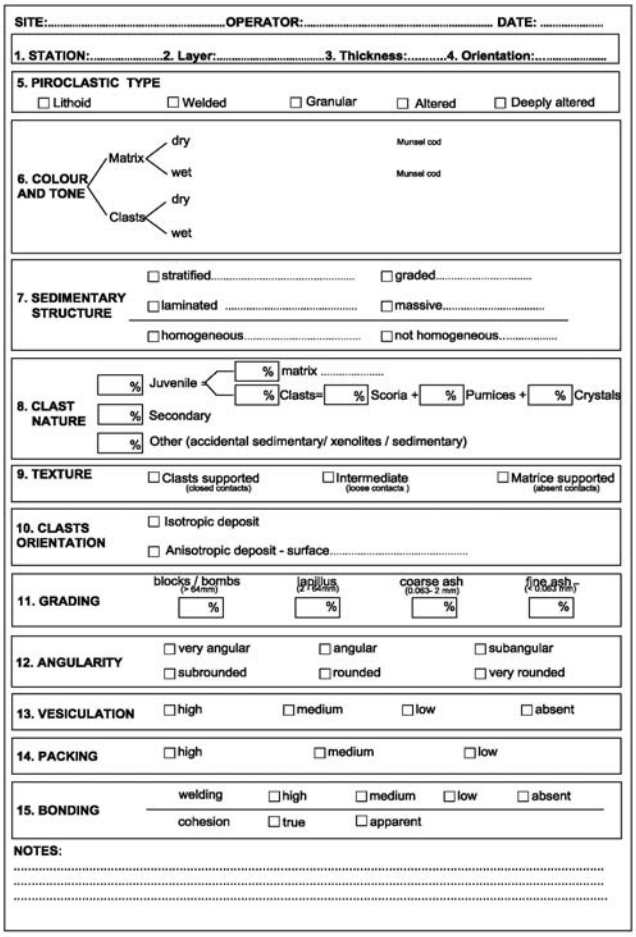


Figure 1. Geological sketch of layers in the sabatina area (Marra & Rosa, 1995) and pyroclastic types.

The older sediments are located in the Morlupo-Castelnuovo di Porto area, where some eruptive centers spread off trachitic lava together with pyroclastic and freatomagmatic products. At a later stage the volcano activity moved westward building the eruptive centre of Sacrofano, a calderic structure that had released an high quantity of ignimbrite products, as the Units of prima Porta and of via Tiberina, and falled products as Tufi varicolori di Sacrofano and Tufi stratificati di La Storta. For 400.000 years the centers have extended themselves towards West where the calderic structure of Bracciano Lake (ROSA, 1995 and DE RITA et alii, 1996) was gradually born. Between 250.000 and 80.000 years the volcano activity reduced at a monogenic volcanism.

This developed cones of scoria and eruptive failure represented on Nord side of the Bracciano depression, freatomagmatic centres that built the tuff cone of Monte Razzano, and maar of Martiganno, Stracciacappa and Baccano (Lytosome of Martignano). Chemical compositions of sabatini products are usually included in the potassic serie (SCHERILLO, 1937, 1940, 1941, 1943; CONTICELLI et alii, 1997). The geological sketch of this area, as recorded in the scientific cartography (Geological Chart of Italy 1:100.000 and Mancini et alii 2004), shows the presence of undifferentiated pyroclastic deposits composed by successions of ocher tuff, lithoid yellow tuff, lapillus level, cineritic layers, leucititic scoria and white pomice-stone and rare paleosoils. The above mentioned description is the same in the geological report related to the final design. In this situation our contribution is inserted and an in depth analysis concerned to executive project. The geological survey has been executed by means of some natural walls (Figure 2) and several archeological trenches. The model showed in Figure 3, as defined in the summary, has been used for soil description.



SITE:..OPERATOR:.. DATE: ....

1. STATION:..................2. Layer:...........................3. Thickness:..........4. Orientation:....................

5. PIROCLASTIC TYPE
☐ Lithoid ☐ Welded ☐ Granular ☐ Altered ☐ Deeply altered

6. COLOUR AND TONE
Matrix: dry — Munsel cod; wet — Munsel cod
Clasts: dry; wet

7. SEDIMENTARY STRUCTURE
☐ stratified.................................... ☐ graded..............................
☐ laminated .... ☐ massive..............................
☐ homogeneous.................................... ☐ not homogeneous..................

8. CLAST NATURE
% Juvenile = % matrix ....
% Clasts= % Scoria + % Pumices + % Crystals
% Secondary
% Other (accidental sedimentary/ xenolites / sedimentary)

9. TEXTURE
☐ Clasts supported (closed contacts) ☐ Intermediate (loose contacts) ☐ Matrice supported (absent contacts)

10. CLASTS ORIENTATION
☐ Isotropic deposit
☐ Anisotropic deposit - surface..

11. GRADING
blocks / bombs (> 64mm) % lapillus (2 ÷ 64mm) % coarse ash (0.063- 2 mm) % fine ash (< 0.063 mm) %

12. ANGULARITY
☐ very angular ☐ angular ☐ subangular
☐ subrounded ☐ rounded ☐ very rounded

13. VESICULATION
☐ high ☐ medium ☐ low ☐ absent

14. PACKING
☐ high ☐ medium ☐ low

15. BONDING
welding ☐ high ☐ medium ☐ low ☐ absent
cohesion ☐ true ☐ apparent

NOTES:
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....
....

Figure 3. Description model

In the following the geotechnical description coming from the use of mentioned model are noted. Point A Level 2 – Figure 4 – Pyroclastic soil welded (or coherent) with changeable colors between brown and yellow, grain size of sandy gravel (sublevel 2a) that on the upper level gradually became gravelly sand (sublevel 2b). The structure is layered on the bottom part and chaotic on the upper part. Ties of several nature and degree are present: “true” ties represented by a weak natural concrete and “apparent” ties, indeed depending on capillary tension, having different resistance in relation to the degree of saturation. Point B level 12 – Figure 5 – Granular and massive pyroclastic soil, grain size gravel; the ties are mainly depending on friction due to the high grains angularity. The structure presents itself with a high porosity (sublevel 12a). On the upper part of the level there is the transition to gravel with sand

Figure 2. Natural wall and location of observation point.

having a layered and very soft coherence tie (sublevel 12b). In the upper part of the layer the pyroclastic soil appears more altered.

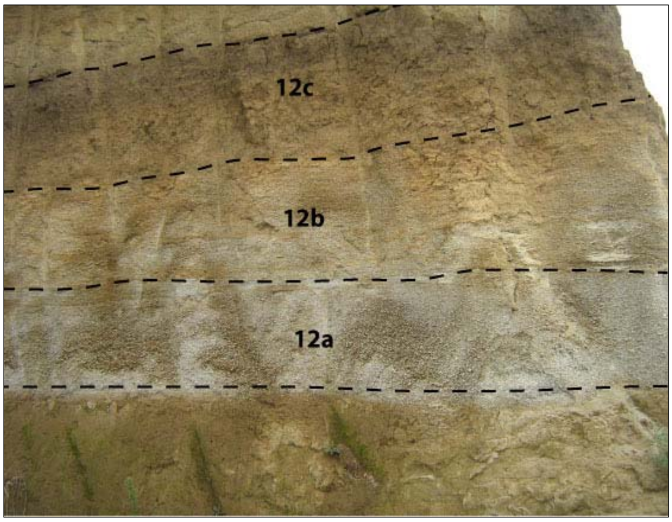

Figure 4. Point A

The structure is massive and the intergrain bonds are low (sublevel 12c). The usage of this predescribed model proved itself very useful in the soils management in phase of excavation and reuse. With particular mention to the stability conditions of the excavated areas is possible to have some important indication from the fore-mentioned reading.

In the first case the presence of ties, real and apparent, could justify high values of cohesion and elastic moduli and, as a consequence, high shear strength and stiffness. The description highlights that a great superficial alteration could reduce these parameters with a hazard for the stability conditions. In the second case it is shown that friction between grains cause a pseudo-cohesion. This highlights, at least in low pressure range, a dilatance behaviour under shearing effort. On site this phenomena produces vertical natural walls at least up to a limited height.

With reference to deformations it is possible to guess a greater resistance behaviour until breakable pressure. Over this value the gradual breakage of ties produces the structural collapse. It is possible to note how the description can help to guess same aspects of soil geotechnical behaviour which however should be verified by means of laboratory or site tests. In the present case this check was carried out but it’s not an issue of this publication.

4 SOME GEOTECHNICAL ASPECTS

The summery of some index parameters, physical and mechanical characteristics are presented versus the depth (Figure 6-7). In these picture we can see the moisture between 35 and 55% and Plastic Index between 20 and 25%. Resistance characteristics in effective tension, taken from direct shearing test in standard condition, highlights friction angle value between 35 and 37° and cohesion between 8 and 15 kPa (at least on non altered soils). The design included a balance between excavated and reused soil volume. In this view, before the start of the work, a geotechnical qualification about the different kind of soil in order to optimize the possibility of reuse in the different applicative cases was necessary. The soil’s division in a number of litotechnic units, limited but distinctive of geotechnical behaviour, hasn’t been easy due to the high heterogeneity: scorious

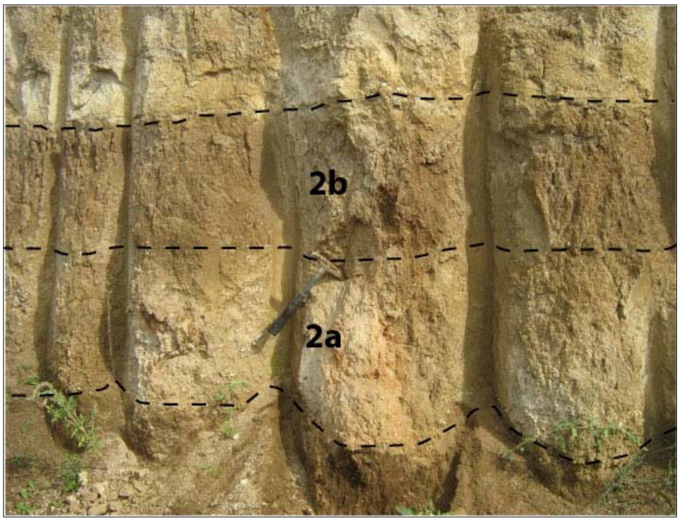

Figure 5. Point B

coarse layers alternate with other levels deeply altered or pumices. For this purpose the above proposed description has been applied. The characterization has been completed with typical tests used in the road applications integrated with laboratory tests for the evaluation of shear strength and stiffness of compacted pyroclastic material. Geotechnical characterization of these soil, in order to the planning in several applicative cases, reach a complete study about the characteristics in the natural condition “on site”, referred to the stability conditions of slopes and trenches, and in the application of the re-usage for example river banks, filling, dikes, road reliefs, etc. In the following we focus on the last aspect referring to a precedent paper (Cecconi, Scarapazzi, Viggiani 2014) about the characterization of pyroclastic soil in its natural condition. In this case study the soil has been characterized by means of: n° 28 Proctor tests, n° 40 particle size and application of road classifications and n° 12 shear tests on compacted soil. This survey permitted the excavated soils to be divided into two main litotechnic units with specific characteristics and behavior.

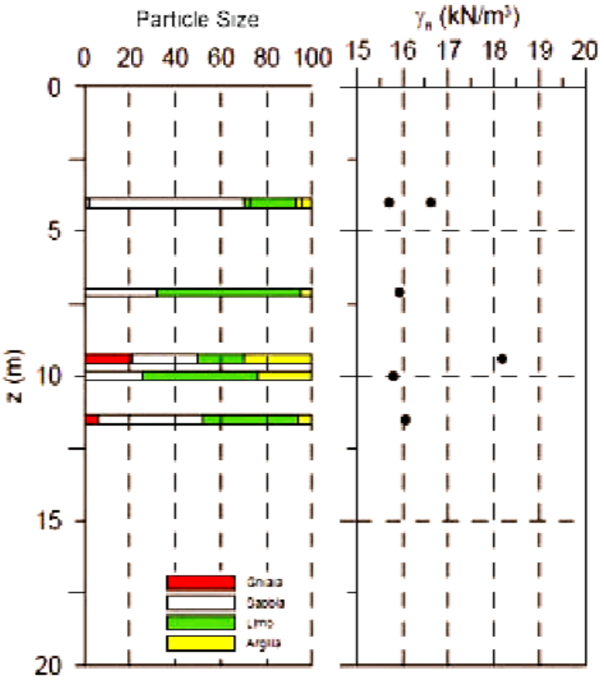

Figure 6. Particle size and moisture vs depth

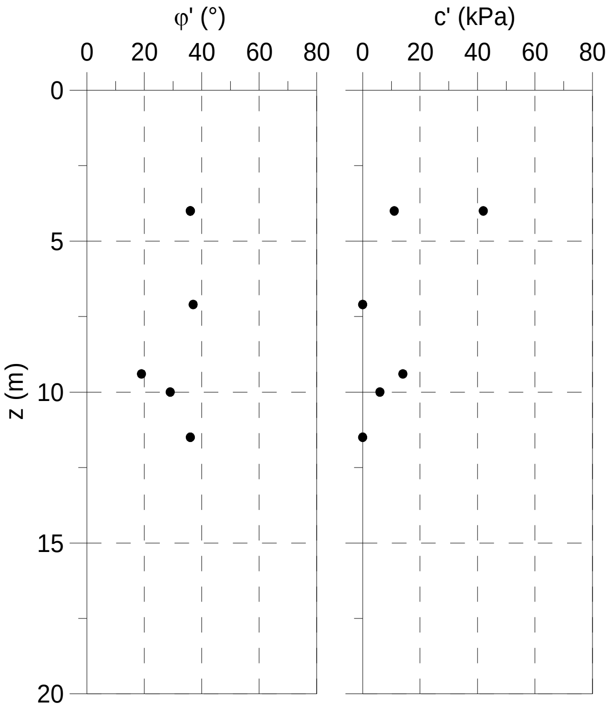

Figure 7. Friction angle and cohesion vs depth

Type A – Coarse piroclastiti made up of grain size materials, including sand and gravel, scoriaceos and so less crumbly and less degradable, more uniform and without high moisture.

Type B – Altered and very altered (with production of clays minerals, type paleosoil) pyroclastic soil made up of fine grain size materials or more coarse but very friable like pomice. Generally this unit is more pressing under a static load and it has a more grain size reduction under a dynamic load.

The proposed subdivision is only in two units; a wider shearing is possible but this wouldn’t find application in the common work of soil movement. In any study of this kind it is important not to lose the real and logistic condition. In this case the operators move scraper that, at the same time, excavated natural walls of more than 2 or 3 meters. Consequently a normal magnitude of the choice units mustn’t be thinner than some meters and a more pushed division would be more expensive, useless and could cause problems between designers and operators.

For this purpose it was necessary to join packs of several layers with similar characteristics. The real application of this criteria had permitted to direct the excavation movement of Type A, better materials, to constitute the compacted soil below foundations. At the same time Type B was used for a less important filling. The graphical representation relates to the compaction curve (Modified Proctor) and the grain size zone typical of Type A and Type B are noted in Figure 8.

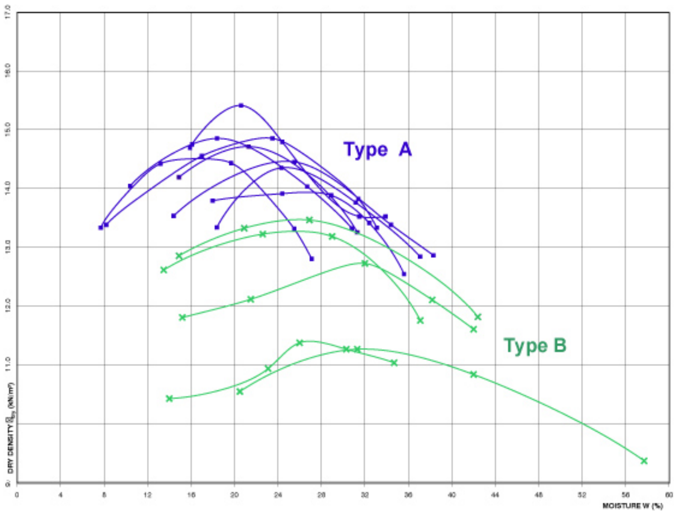

Figure 8. Proctor curves

So that the compaction energy, as defined in laboratory tests, is indeed reproducible on site it is necessary to know the means of compaction and the operative procedures of the operators. It’s not possible for this kind of material, that several regulations defined as “special material”, to calculate the method to reproduce the energy obtained in the laboratory by changing the following parameters: type and weight of compactor, number of passages, eventual vibration frequency, thickness of layers, etc. Some experiences are noted at the bottom where the laboratory test results are compared with tests on site.

These could be useful to understand the behaviour of compaction for this particular soils better.

A test relief was achieved using a coarse pyroclastic soil (Type A). The energize was applied by means of a compactor Dynapac 18 ton changing the number of passages while the vibration frequency (defined as low and high) was equally shared: low frequency in the first half of the passages and high in the remaining part.

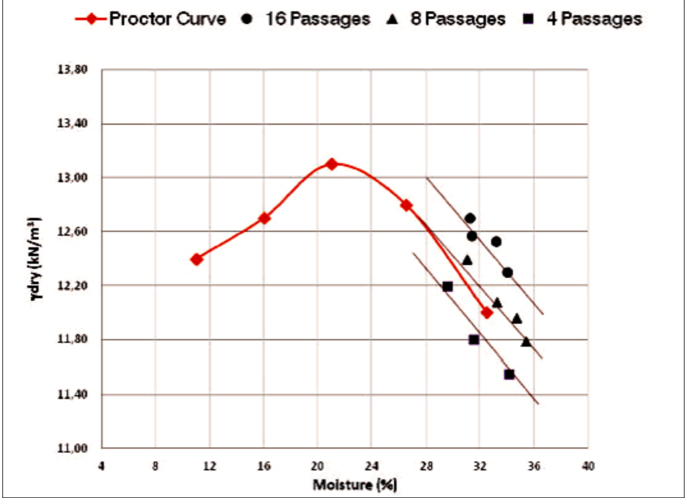

Figure 9. Cone sand tests vs Proctor curve

In Figure 9 the results of volume density tested on site are represented with reference to a typical Modified Proctor. The realization of the laboratory energize was reached, almost in the wet sector, by means of eight compactor passages. In this case the compaction failed, in fact it didn’t reach the 95% of optimum Proctor as predicted, probably because of an excess in moisture.In Figure 10 the values of several in site density cone sand tests are represented, next to it is the value of the linked plate load tests (ϕ 300), compared with the results of the typical Modified Proctor for this soil. In this graphic it is possible to note that, although an equal or higher Modified energize was applied (more than eight passages on layers having thickness of 0.3 m.), the laboratory density was not reached in the range of moisture next to optimum value (about 22%). Several grain size tests were carried out on the material sampled before and after the compaction in order to study the eventually phenomena of crumble and the relation with compaction.

5 CONSIDERATION

In Figure 10 an experimental curve, named as “on site compaction curve”, was built using the higher values of density for each moisture. This shows the biggest in site density, of about 3 or 4 %, is below the maximum obtained in the laboratory test. The site and laboratory curves join each other at a moisture of 6-8% far from the optimum value (about 22 %). At first guess this apparent anomaly could be generated from a couple of errors potentially synergic. In fact the first could be systematic and dependent on the procedure of compaction. In laboratory this occurs in an absolutely energetic manner (weight in free fall) while on site the application is more gradual and relatively slow (a weight rolled along the layer). The grain size test, carried out on site and in laboratory before and after compaction, had proved that, due to the great fragility of piroclastiti, the Proctor test produces more grain size reduction. As a consequence the smaller fragments fill the intergranular void, increasing the volume weight. A second kind of random error, but potentially frequent, concerns the presence of pomice that, especially on site couldn’t be easily kept under control. Thin layers of pomice included in a stratification are automatically mixed together with the other piroclastiti on site which reduce the value of the reachable volume weight. The synergic effect of the two errors, the first furthermore is always present, could be responsible for the important result that on site test density values, carried out during the check phases of reliefs achieved with pyroclastic soil, could frequently prove incompatible with predefined regulation values. We wish to point out that pyroclastic soil should be discarded because they are evolving in grain size and in fact in this case, and in all cases where the material has a particular behaviour, the regulation foresees the use of special studies. This experimental proof suggest not using the test result in an automatic manner without having realized a testing area on site that permits the execution of density and plate load tests.

A demonstration of this topic is shown in Figure 10 where the resistance, obtained from the plate load test, however supplies relatively high values also in cases in which the on site density hasn’t reached the predefined values. These tests often not required for the check of the “body” of relief, but only for the upper layers, generally result to be important. This is especially true for pyroclastic soil, in which the classic geotechnic often fails, because this test allows the effective resistance and deformability to be measured. A proposal, derived from this experience, could be the common execution of the testing area

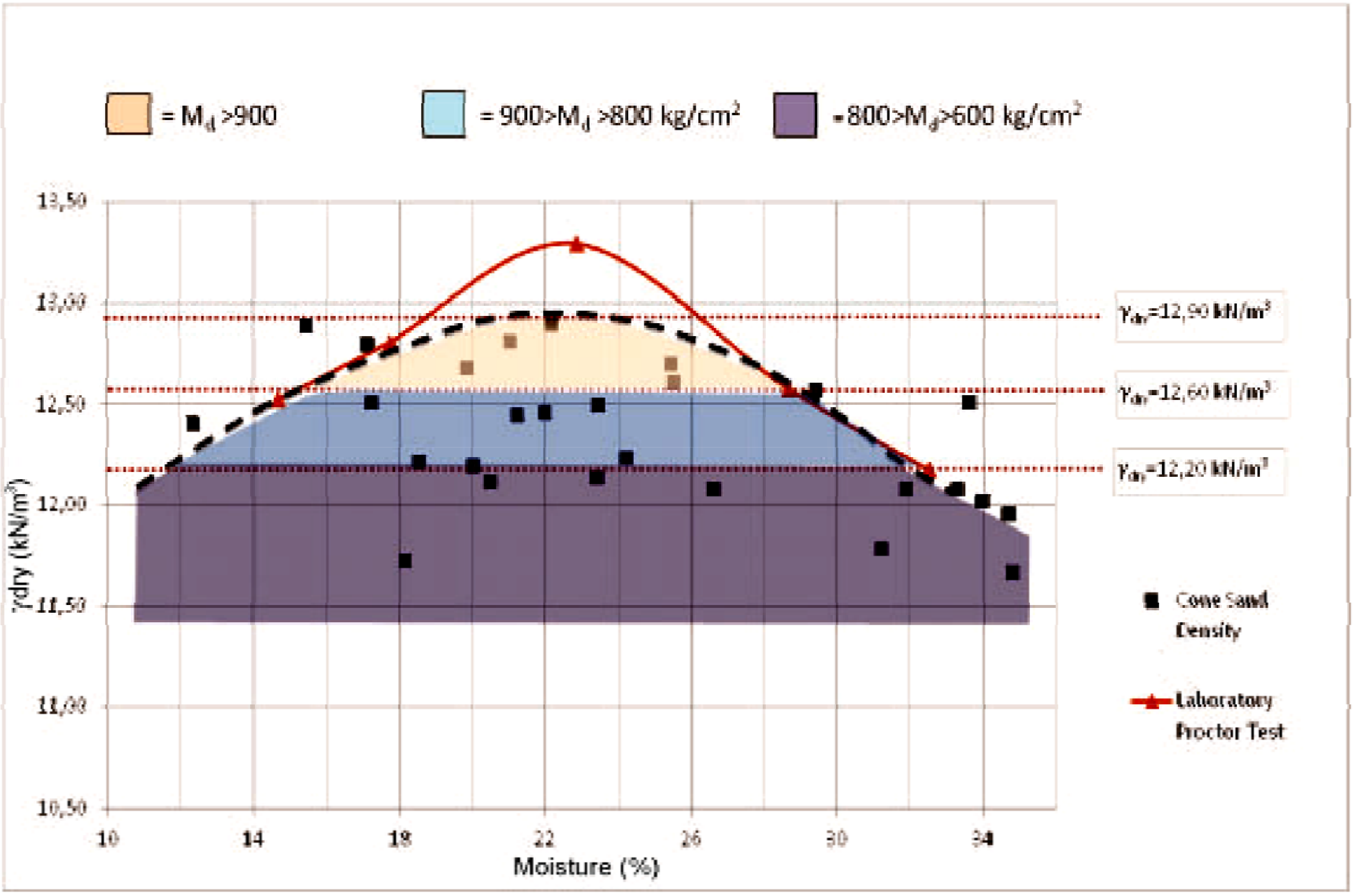

Figure 10. Cone sand tests and plate load tests vs Proctor curve

achieved through standard procedures and by means of available compactors. In this way the density values to reach could be referred to the compaction of the on site curve rather than a laboratory curve. Such operative modes could allow greater operative flexibility in relation to the type of pyroclastic soil, excavation and compaction procedures in the specific work site. In reference to the intrinsic fragility of such soils, often caused by the reduction of grain size after compaction, some experimental considerations could be useful to show and better understand some operational problems. In Figure 11 the grain size curves, obtained from previously sampled soil (before compaction), are compared with the predefined curves in the Technical Specification.

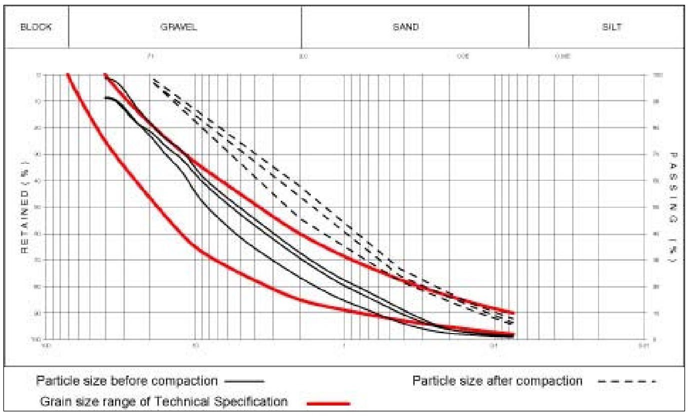

Figure 11. Grain size curves compared with Technical Specification

The same tests were repeated on the material sampled on site after the compaction. The experimentation demonstrates a high grain size reduction (an increase of the fine part and a decrease of the coarse one) that leads to an important burocratic problem during the building phases; in fact the material could belong to a right grain size class before the use and not belong to it afterwards. In relation to this kind of problem the developed study leads us to think that a previously testing area can help to solve it.

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