Geotechnical Properties of Pozzuolanic Soils Employed in Base Courses of Paving Structures

Propriétés géotechniques des pouzzolanes utilisées dans la couche de base des chaussées

G. MORALDI, PROF.ING., *Head of Soil Mechanics and Pavement Materials Laboratory of the Air Ministry, Rome, Italy*
G. CALABRESI, DOTT.ING., *Soil Mechanics Laboratory, Istituto di Scienza delle Costruzioni, University of Rome, Rome, Italy*

SUMMARY

This paper examines the properties of two pozzuolanic soils forming large deposits in the neighbourhood of the cities of Rome and Naples.

In part I the mechanical properties of these soils are evaluated by means of the most typical tests used in soil mechanics. Particular attention is paid to the possibility of employing these pozzuolanic soils as base course materials in pavements. A serious drawback is the crushing of the grains under repeated traffic; results of tests and recommendations are given in this regard.

In part II, some fundamental properties of these soils are analysed more thoroughly including suction-moisture relationships and shear resistance characteristics in saturated and unsaturated conditions. An experimental formula is given as a means for evaluating the shearing resistance in the unsaturated state from the shearing resistance of saturated samples.

SOMMAIRE

Dans cet article on étudie les propriétés de deux pouzzolanes qui proviennent de gisements très abondants dans les alentours des villes de Rome et de Naples.

Dans la première partie sont décrites les propriétés mécaniques de ces sols, évaluées au moyen des essais les plus communs de géotechnique routière. On insiste surtout sur l'utilisation des pouzzolanes en couches de base; malheureusement, sous l'action de la circulation les grains se brisent et produisent des fins. Les résultats et les recommandations en tiennent compte.

Dans la seconde partie on discute une analyse plus approfondie de certaines propriétés fondamentales, telle que la relation entre la succion et la teneur en eau, et la résistance au cisaillement sous différentes conditions d'humidité. En particulier on a établi une relation empirique au moyen de laquelle on peut évaluer la résistance d'échantillons non saturés au moyen de la résistance présentée par des échantillons saturés.

THE PECULIAR PROPERTIES of pozzuolanic soils, and the possibility of their economic use as base course materials in airport and highway pavements, has stimulated a co-operative research programme with the Soil Mechanics Laboratory of the Air Ministry and the Laboratory of Soil Mechanics of the Istituto di Scienza delle Costruzioni of the University of Rome taking part.

This research, which is still in progress, has already led to some conclusions, which are detailed in this paper. Part I examines the engineering properties of these soils that are related to their behaviour in pavement structures; part II reports results dealing with some fundamental properties such as shear resistance and suction moisture characteristics.

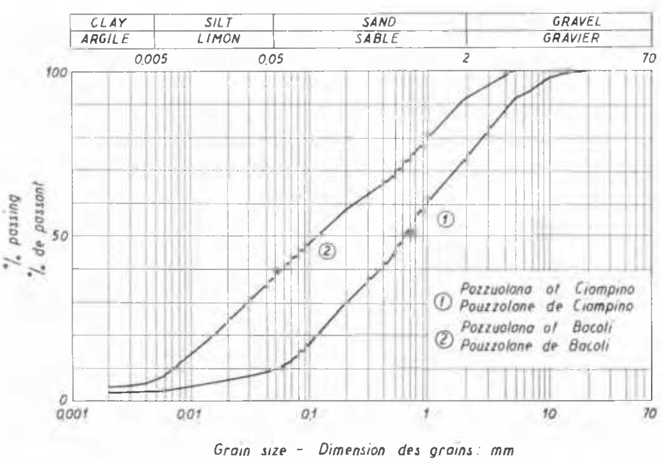

FIG. 1. Particle size distribution.

MATERIALS

Two types of pozzuolanas were investigated. One, dug near Ciampino, is typical of the deposits existing in the neighbourhood of the city of Rome, having a grey-red colour when dry; its grain size composition is reported in Fig. 1 (curve 1). The other soil, from Bacoli, is typical of the pozzuolanas found near the city of Naples, having a grey colour; its grain size composition is reported in Fig. 1 (curve 2). The former soil can be classified as a gravelly silty sand, the latter as a silty sand. It must be emphasized, however, as pointed out in the work of Penta *et al.* (1961), that a grain size classification is purely formal, based on the shape and composition of the grains.

PART I

Index Properties and Classification

In Table I the principal index properties of both soils and their classification are reported. The soils possess no liquid limit, are not plastic, and are composed of highly porous grains. The pores of soil 1 are mostly permeable, those of soil 2 partly permeable, as is shown by the different values of specific gravity determined on pulverized and non-pulverized material.

Behaviour under Traffic

Judging from Table I and Fig. 1 the two soils would not be considered acceptable as base course materials, because of

TABLE I. INDEX PROPERTIES OF THE TWO SOILS

	Pozzuolana of Ciampino 1	Pozzuolana of Bacoli 2
Effective grain size: D 10 (mm)	0.05	0.007
Coefficient of uniformity: D 60/D 10	19	34
w_L (per cent)	n.d.*	n.d.*
w_P (per cent)	n.d.*	n.d.*
I_P (per cent)	n.p.†	n.p.†
γ_s(gram/cu.cm.)	2.78	2.41
γ_s, pulverized material (gram/cu.cm.)	2.78	2.52
Sand equivalent (per cent)	52	26
Classification		
High. Res. Board	$A_1 - b$	A_4
Casagrande	GF	ML
Fed. Aviation Agency	E_2	E_5

*n.d. = non-determinable.
†n.p. = non-plastic.

their grading, which is outside the range of grain size specifications commonly accepted. With respect to classification, pozzuolana 1 might be accepted, being an A1-b material in the H.R.B. classification, but pozzuolana 2 would be rejected, being an A-4.

Nevertheless experience shows that both soils have performed quite satisfactorily as base courses of flexible pavements in two heavily trafficked airports for over 12 years, and as sub-base courses in airport and highway pavements.

Yet an experimental section of a heavily trafficked road, where pozzuolana 1 was used as a base course layer under a flexible pavement, soon showed distress under traffic and requires frequent maintenance This apparent contradiction, and the economic interest of their use, justified a deeper examination of the engineering properties of these soils.

Moisture/Density Relationships—Bearing Capacity

In Table II are reported the modified A.A.S.H.O. max dry density, the optimum moisture content, and the soaked and unsoaked max C.B.R. values at 100 per cent modified A.A.S.H.O. compaction.

TABLE II. MECHANICAL PROPERTIES OF THE TWO SOILS

	Pozzuolana of Ciampino 1	Pozzuolana of Bacoli 2
Mod. A.A.S.H.O. max γ_d (gram/cu.cm.)	1.56	1.41
Mod. A.A.S.H.O. w_{opt} (per cent)	19	20
Max unsoaked C.B.R. at $\gamma_{d\ max}$ (per cent)	123	150
Max soaked C.B.R. at $\gamma_{d\ max}$ (per cent)	115	120
Expansion after soaking (per cent)	0	0
Coefficient of permeability k at $\gamma_{d\ max}, w_{opt}$ (cm./sec.)	5.4×10^{-6}	1.1×10^{-6}

It must be noted that soaking does not affect the C.B.R. values which are unusually high, with a peak close to the optimum moisture content. The peak is sufficiently flat to ensure a bearing value of +80 per cent for a water content of ±3 per cent from optimum. The swelling is practically zero. In this respect both materials seem exceptionally good for use in a base course. Such a property can be explained by a very high angle of shearing resistance that the materials possess even in a saturated condition (Figs. 6 and 7) although it is difficult to define such an angle.

Evolution of Density and Bearing Capacity under Repeated Compaction Cycles

It is, however, doubtful if this characteristic will remain unaltered under heavy traffic because the grains are soft and brittle, and show a tendency to break and to build up fines under repeated stresses.

To examine this property pozzuolana 1 (which is the coarser of the two) was subjected to repeated cycles of compaction at constant water content in the A.A.S.H.O. and in the C.B.R. mould with 100 per cent mod. A.A.S.H.O. compaction. The grain size of the materials, as well as the density and the unsoaked C.B.R., were measured progressively.

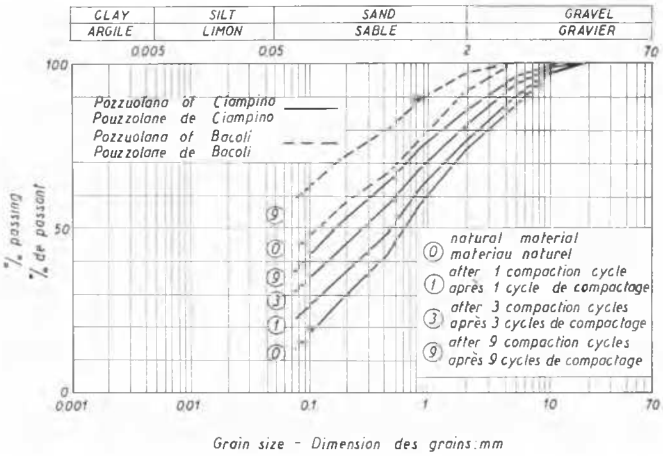

FIG. 2. Evolution of the particle size distribution with repeated compaction cycles.

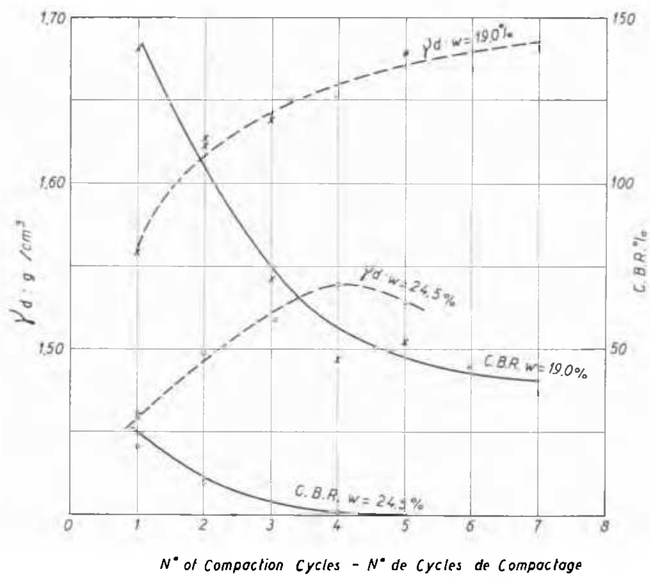

FIG. 3. Evolution of the dry density and of the C.B.R. with repeated compaction cycles.

Fig. 2 shows the progressive change in grain size of the fraction retained on no. 200 sieve, and Fig. 3 shows the evolution of the density and of the unsoaked C.B.R. at different moisture contents.

The production of fines is remarkable and is accompanied by a decrease in the bearing capacity of samples compacted at optimum and higher than optimum moisture contents. The density, in contrast, tends to increase, which means that the fines produced find their way into the voids between the grains.

But most significant of all is the evolution of the sand equivalent value (Fig. 4) which shows that soil 1 drops after one cycle from an original value of 52, typical of a granular material suitable for use in a base course, to 25 and after 6 cycles to 17 which is typical of an unsuitable material. The sand equivalent of soil 2 drops in a similar way. The reduction is not accompanied by the appearance of plasticity as is to be expected with such soils. It is very probable that the material, originally non–frost-susceptible, may become such; this property has not been analysed, however, because of the mild climate of the regions in which pozzuolanas are found and employed.

The production of fines explains the contradictory behaviour of pozzuolanas as base course materials in runways and heavily trafficked roads. In runways, where traffic is negligible, results are excellent; in roads the progressive production of fines leads to a loss in bearing capacity and to pavement distress.

It is recommended therefore that soils of this type should not be used arbitrarily in base courses, but should always be employed in airport pavements under a sufficient cover of pavement, and only as sub-base courses in roads carrying heavy traffic. Research is now being done to discover how pozzuolanas behave with cement, lime, and bituminous stabilization.

PART II

The peculiar behaviour of the examined volcanic soils, as indicated in Part I, has led to closer investigation of some mechanical properties of these soils at the Soil Mechanics Laboratory of the Istituto di Scienza delle Costruzioni of the University of Rome.

Suction Measurements

The first field explored was the suction/moisture content relationship. According to the absence of shrinking and swelling effects and to the lack of plasticity observed in the preliminary tests, the total soil moisture potential appears to be scarcely influenced by osmotic and adsorption pressures. Therefore it can be inferred that the internal soil water suction has a definite value as it is mainly dependent on the surface tension at the air-water menisci.

Consequently, the suction developed by a partly saturated sample, brought in contact with an external body of water through a porous medium, can be accepted as a measure of the true internal soil water suction. Since the porous medium should have pores sufficiently small to remain full of water at all negative pressures encountered in the tests, a fine-grained ceramic was used having a permeability of $k = 3.3 \times 10^{-6}$ cm/sec and an air-entry value of 1.8 kg/sq.cm.

The tests were performed in a common 1½-in. triaxial cell, on the base of which a disc of this ceramic, about 5 mm thick, was sealed by means of a thin steel ring. A dry coarse-grained porous stone on the top of the sample, connected with the exterior, keeps the pore air pressure at atmospheric value.

The suctions developed were measured with a Bishop type of null indicator, so that any flow of water into or out of the sample was avoided. The equilibrium pressure at the external side of the null indicator was applied by means of a hand-driven screw cylinder, and the pressures measured with a mercury manometer.

The tests on the two pozzuolanas were performed on the fractions passing the A.S.T.M. no. 10 sieve. The samples were compacted at the same density in a specially built small-scale ramming compactor at mod. A.A.S.H.O. max dry density, with an accuracy of ±0.01 gram/cu cm. Having set the sample on the cell base, suction measurements were made after the system had reached equilibrium (0.5 to 2 hours). The explored field of moisture contents extended from 11 to 28 per cent for the Ciampino, and from 8 to 29 per cent for the Bacoli pozzuolana.

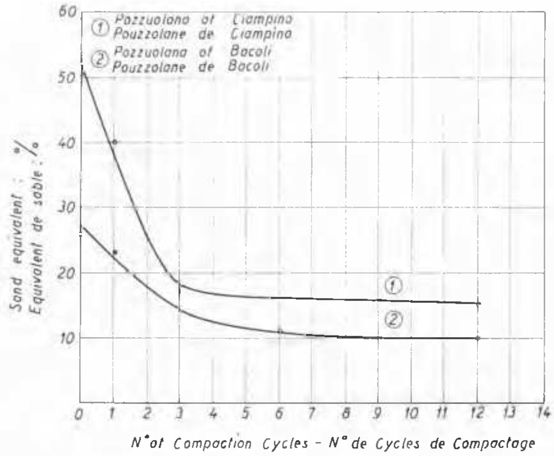

FIG. 4. Evolution of the equivalent sand value with repeated compaction cycles.

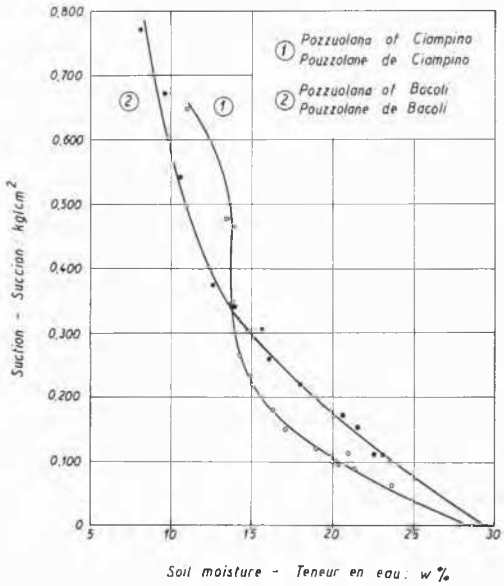

FIG. 5. Suction-soil moisture relationships.

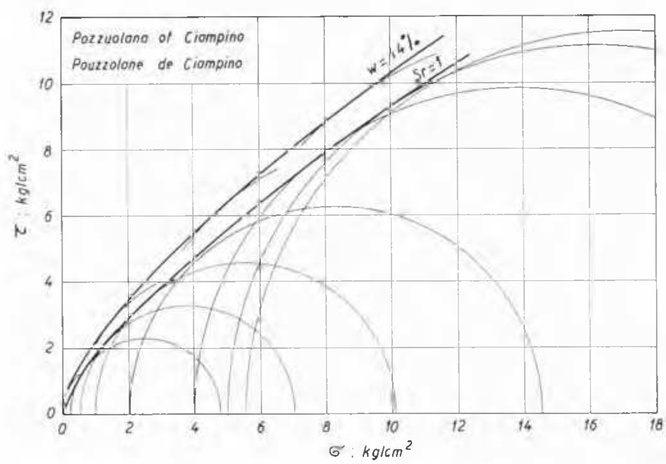

FIG. 6. Failure envelopes in soil 1.

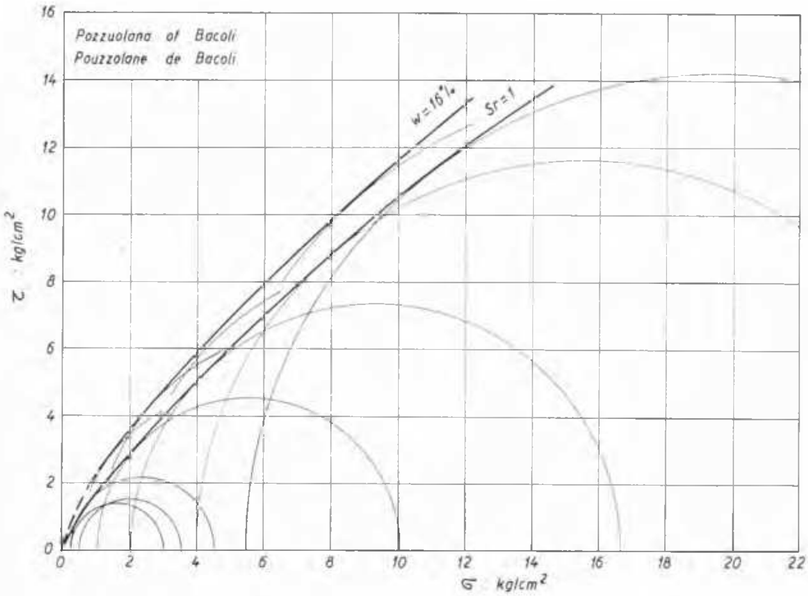

FIG. 7. Failure envelopes in soil 2.

Triaxial Tests

Immediately afterwards a triaxial test was performed, keeping a continuous record of the pore water pressure during the test. The applied rate of strain was 0.12 mm/min.

A series of drained triaxial tests at the same rate of strain on fully saturated samples was also performed on each pozzuolana. Full saturation was secured by a preliminary flow of water through the sample from base to top, followed by the application of a prolonged back pressure of 5 kg/sq.cm. which was maintained throughout the test.

Results

The relationships between suction and moisture content are shown in Fig. 5. It can be seen that suction of soil 1 is more critical than that of soil 2. The results of the most significative triaxial tests at full and at partial saturation for a constant water content have been reported in Figs. 6 and 7.

The failure envelopes are curved and have approximately a parabolic shape probably due to the brittleness of the soil grains, a brittleness also observed by other authors (Croce, 1948; Lazcano 1957; Penta, Croce, and Esu, 1961). Therefore, for practical purposes, the failure envelope can be replaced by a straight line only in limited stress intervals.

Furthermore, the envelopes deriving from tests on fully saturated and on partly saturated samples, at constant water content, i.e. at constant suction values, cannot be superimposed by a translation along the σ axis. This means that for such soils, in a partly saturated state, suction influences the resistance not through a proportional increase of the effective stresses, but through an increase of the angle of shearing resistance. This fact may be explained by the non-uniform action of the internal suction on the grains.

Actually the ratio $\frac{1}{2}(\sigma_1 - \sigma_3)_f/\frac{1}{2}(\sigma_1 + \sigma_3)_f$ at constant values of σ_3 for tests performed at different saturation degrees, is proportional to the suction, following the relationship:

$$\left[\frac{(\sigma_1 - \sigma_3)_f}{(\sigma_1 + \sigma_3)_f}\right]_{S_r<1} = \left[\frac{(\sigma_1 - \sigma_3)_f}{(\sigma_1 + \sigma_3)_f}\right]_{S_r=1} \cdot (1 + C \cdot p_s)$$

where S_r indicates the degree of saturation, p_s, suction pressure, and C, constant of the soil. This is shown in Figs. 8

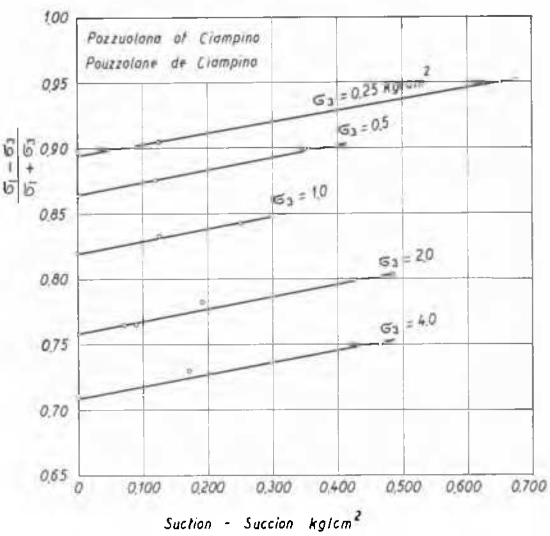

FIG. 8. Shear strength-suction relationships of soil 1.

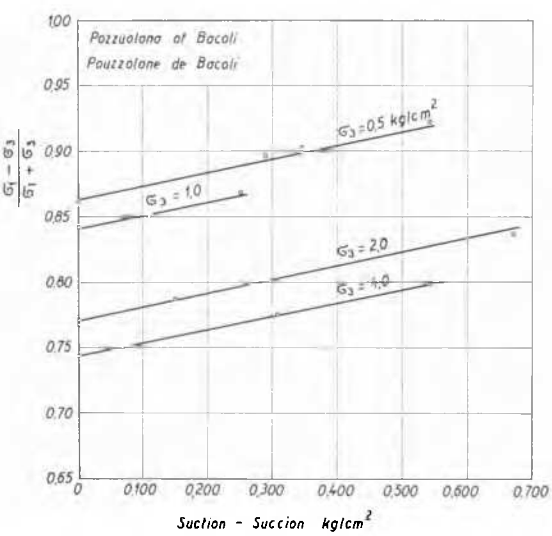

FIG. 9. Shear strength-suction relationships of soil 2.

and 9 for the Ciampino and Bacoli pozzuolanas for which $C = 0.09$ and 0.12 $(kg/sq.cm.)^{-1}$ respectively, for the ranges of moisture contents explored.

REFERENCES

CROCE, A. (1948). Secondary time effects in the compression of unconsolidated sediments of volcanic origin. *Proc. Second International Conference on Soil Mechanics and Foundation Engineering*, Vol. 1, p. 166.

LAZCANO, E. R. (1957). Investigation of a volcanic soil for the construction of an earth dam. *Conference on Soils for Engineering Purposes* (Mexico).

PENTA, F. (1953). Contributo agli studi sulle pozzolane *L'Industria Mineraria* (Sept.).

PENTA, F., A. CROCE, and F. ESU (1961). Engineering properties of volcanic soils. *Proc. Fifth International Conference on Soil Mechanics and Foundation Engineering*, Vol. 1, p. 285.