Some experimental observations on the behaviour of a complex soil

Quelques observations sur le comportament experimentale de un sol complex

L.Montrasio & C.Schivazappa – *University of Parma, Parma, Italy*

ABSTRACT: The paper presents the results of an experimental analysis of the mechanical behaviour of a *complex soil*. The expression *complex soil* indicates a soil consisting of a fine matrix (sand, silt or clay) and of stone inclusions of sizes ranging from few to several centimetres that may be present in varying percentages. In practical terms, these types of soil are difficult to deal with due to the complexity in characterising them both *in situ* and in laboratory. Through this paper and on the basis of experimental results, it has been tried to identify and understand some aspects of the mechanisms governing their behaviour with the aim of simplifying investigations for geotechnical characterisation.

RÉSUMÉ: L'article présente les résultats d'une analyse expérimentale sur le comportement mécanique d'un *sol complexe*.
Par *sol complexe,* on entend un sol constitué d'une matrice fine (sableuse, limoneux ou argileux) dans lequel sont inclues des pierres d'une taille pouvant aller de quelques centimètres à quelques dizaines de centimètres et dont les pourcentages peuvent varier. En pratique, ces sols sont difficiles à traiter à cause de la difficulté que l'on a à les classifier tant sur le terrain qu'en laboratoire. Par cette note, nous avons cherché à identifier et à interpréter, sur la base des résultats expérimentaux, quelques aspect des les mécanismes qui en règlent le comportement avec comme objectif final, celui de simplifier les enquêtes pour leur classification géotechnique.

1 INTRODUCTION

The expression *complex soil* identifies a soil composed of a silty clayey matrix and of systematic inclusions of coarse stone material, that may be present in different percentages.

The most problem related to these particular soils is linked to the difficulty in characterising them: it is indeed problematic both sampling and performing classical *in situ* or lab tests (Montrasio 1998).

There may be two main solutions to the problem, namely:

- The execution of large scale tests, which are however very costly (Holtz & Willard 1961, Hussain & Katti 1980);
- The elimination and replacement of the coarse fraction with the aim of deriving the mechanical characteristics by testing the fine matrix only (Fragaszy et al. 1990, 1992) if the percentage of inclusions doesn't exceed a certain value. In the opposite case the behaviour is governed by the inclusions and no indications on the possibility of simplifying the geotechnical characterisation are available at the moment.

One of the aspects on which this paper deals, is just to identify the situations in which the behaviour is governed by the matrix and the ones in which it is governed by the inclusions.

2 FLOATING AND NON FLOATING CONDITIONS

A complex soil can be found in conditions defined as follows: *floating*, when inclusions are not in contact, and *non floating*, when they are in contact.

In the first case, the mechanical behaviour is governed by the fine matrix, in the second case by the inclusions: in this case the fine matrix can be considered as a filling.

The first problem is to distinguish *floating* from *non floating* conditions. The mere percentage of inclusions wouldn't lead to a significant distinction between the two situations; in fact the percentage of inclusions varies also in function of the geometry that changes in function of the deformation level.

Considering a bi-dimensional problem, an element of complex soil can be represented, in a simplified way, by a continuous fine matrix and by rigid, equidistant and round inclusions. Supposing that the matrix can be deformed infinitely and that the deformation is only vertical, the link between the percentage of inclusions (p) and the maximum deformation (ε_{max}), separating the contact from the non-contact condition, can be derived (Montrasio 1998):

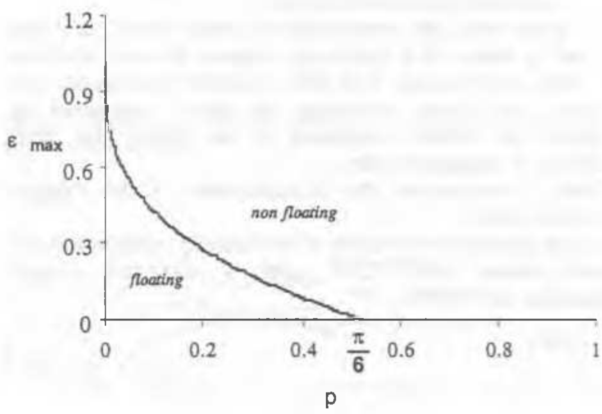

Figure 1. Representation of (1).

$$\varepsilon_{max} = 1 - 2 \cdot \sqrt[3]{\frac{3 \cdot p}{4 \cdot \pi}} \qquad (1)$$

Figure 1 shows the ε_{max} -p curve resulting from (1) that separate the *floating* from the *non floating* condition.

3 EXPERIMENTAL TESTS

Standard triaxial tests have been carried out on cylinder samples of 70mm diameter and 150mm height. Dimensions have been established according to the maximum size allowed by the triaxial equipment available, and the minimum size required for inserting significant inclusions.

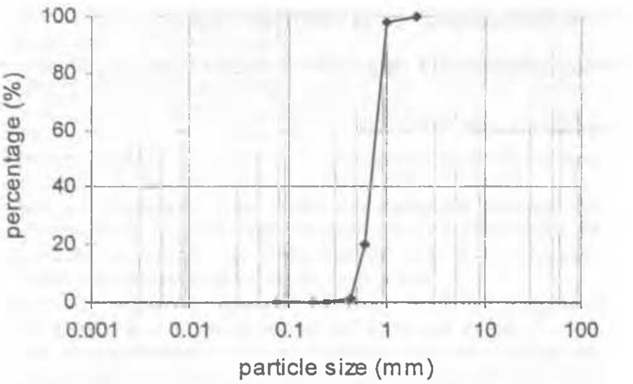

Figure 2. Particle-size curve of Ticino sand.

The matrix was Ticino sand (Baldi et al. 1982) whose particle-size curve is shown in Figure 2.

A sand matrix presents the advantage to permit both to perform tests in the shortest time possible, and to control the compaction. The dry sand was laid down by pluvial deposition directly in the triaxial cell.

The inclusions employed were of two different types: glass beads and porphyry fragments. Porphyry fragments presents average diameters ranging from 13 to 16mm.

Glass beads had two different diameters (24.6 and 15.8mm). The glass was chosen because of its specific weight, that is very similar to that of a rock (granite or basalt), besides being easily available in commerce. Beads surface was made rough in order to obtain a better contact with the sand.

For some tests, the arrangement of beads was orderly and obtained by means of a distributor, whereas for other tests the distribution was random. Two kind of orderly dispositions was arranged: the former consisting of layers superposed to guarantee the vertical alignment of the beads, the latter consisting of staggered layers.

Table 1 summarised the characteristics of the samples submitted to tests.

All the samples were subject to isotropically consolidated and drained triaxial tests (CID) until a maximum vertical deformation of 15-18%.

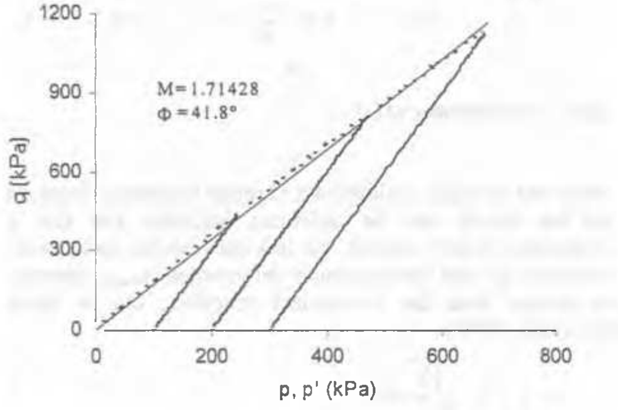

Figure 3. Failure envelope of Ticino sand.

4 EXPERIMENTAL RESULTS

The first tests were carried out on the sand without inclusions, in order to obtain the shear strength and deformability characteristics of the matrix.

Tests were performed on sand at 82% relative density and consolidated by effective pressures of 100, 200 and 300 kPa. The failure envelope obtained is shown in figure 3; the average friction angle resulted 41.8°, accordingly to the Ticino sand characteristics found in literature.

Table 1. Characteristics of samples and arrangement of inclusions.

Name	Av.D.	N.b.l.	N.b.p.l.	d.lr.	p	Dr
	mm			mm	%	%
A – sup. layers	24.5	5	4	5.4	29.2	74.2
B – stag. layers	24.5	4	4	12.9	23.2	92.5
C – stag. layers	24.5	6	4	0.0	35.2	71.5
E – stag. layers	24.5	5	5	5.4	36.7	72.5
F – sup. layers	24.5	5	3	5.4	21.8	80.5
G – sup. layers	24.5	3	4	25.4	17.4	93.6
H – sup. layers	15.7	7	5	5.4	13.4	97.3
M – sup. layers	15.7	8	7	3.0	21.5	95
N – sup. layers	15.7	8	10	3.0	30.8	85.6
O – stag. layers	15.7	7	5	5.4	13.4	95
Q – sup. layers	15.7	8	8	3.0	24.6	89.5
1R - Random	15.7	-	-	-	13.4	95
2R - Random	15.7	-	-	-	21.5	95
3R - Random	15.7	-	-	-	30.8	85.6
4R - Random	15.7	-	-	-	36.5	90
1RP - Random porph.	14	-	-	-	21.5	95
2RP - Random porph.	14	-	-	-	13.4	95
3RP - Random porph.	14	-	-	-	30.8	85.6

sup. = superposed stag. = staggered porph. = porphyry
Name = name and characteristics of the arrangement
Av.D. = average diameter N.b.l. = number of bead layers in the sample
N.b.p.l. = number of bead per layers d.lr. = distance between layers
p = inclusion percentage Dr = Dr of the sand matrix

Successively tests were carried out using beads arranged into superposed layers. Figures 4a and 4b show the results of the tests A and G (beads having a diameter of 24.5mm in percentages of 29.2 and 17.4% respectively) compared to the corresponding tests on sand. It can be observed the considerable difference in the q-ε diagrams. Starting from ε = 5-6%, the q-ε curve, for the tests on sand with inclusions, evidences a curvature variation and successively a remarkable peak; this confirm a change in the behaviour starting from a certain deformation level.

Figure 4c shows the results of the same tests on samples with beads of 15.7 mm diameter and inclusions percentages p = 21% (test M). Results are qualitatively similar to the previous ones and the same observations can be derived.

For all the tests with inclusions disposed in superposed layers the continuation of the test, especially for higher percentages, highlights a strong localisation of deformations, which causes a sudden achievement of the ultimate condition.

Other tests were carried out with samples containing inclusions arranged both into staggered layers, and randomly, in the same percentages of the superposed disposition. Test results are shown in figures 5a and 5b respectively: they are similar for the two different dispositions and reveal a non-substantial variation of the behaviour with respect to the tests on the sand alone.

It can be observed that for the superposed disposition the beads come in contact for deformations levels lower than in the staggered and random disposition. In these last cases only for the tests on samples with the greatest percentages of inclusions (tests identified as C, E, F, G) it can be noted a change of trend in the q-ε diagram for large values of ε (13-16%).

This seems to evidence a dependence of the triaxial behaviour not only on the percentage of inclusions but also on the beads' disposition. Further, tests were carried out with porphyry fragments disposed randomly.

The test results of figure 6 show a trend characterised by a peak in the q-ε diagram and a gradual improvement of the mechanical characteristics (resistance and stiffness) with increasing the inclusion percentage, accordingly to what observed by (Holtz & Willard 1961).

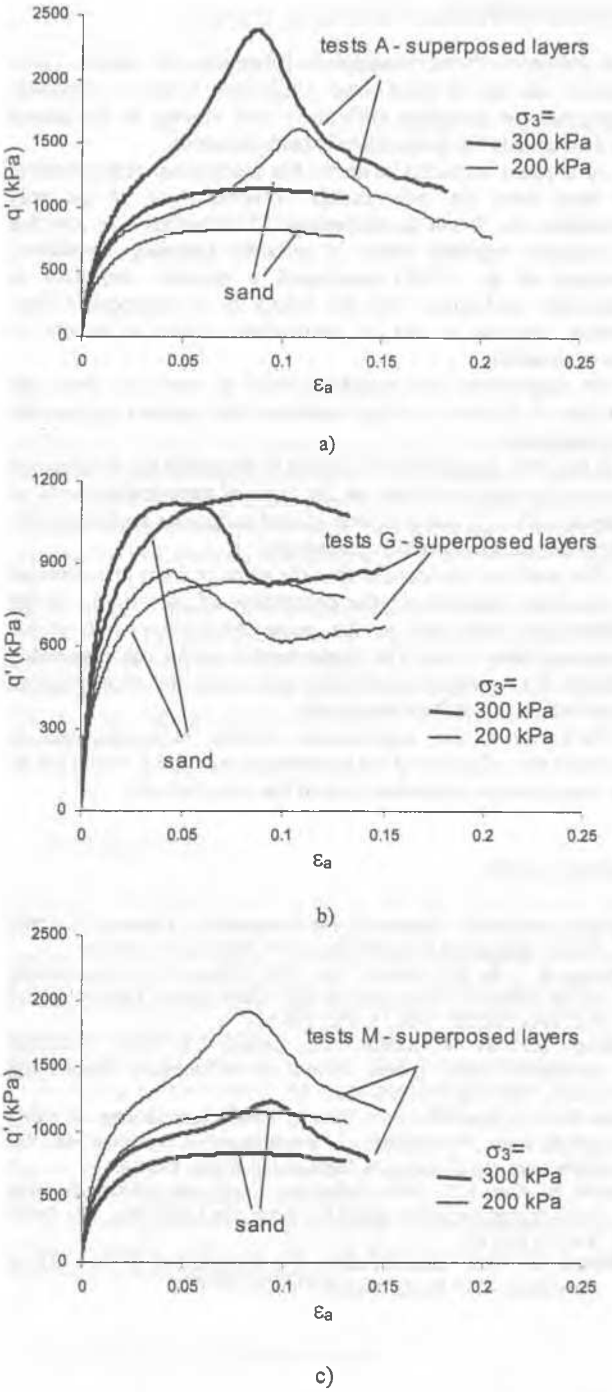

Figure 4. Results relating to arrangements: a) A; b) G; c) M.

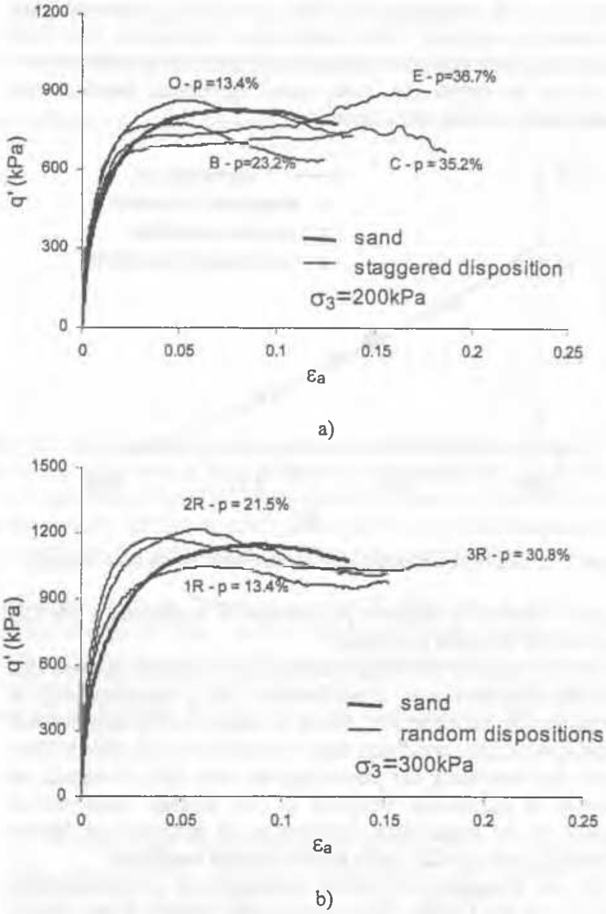

Figure 5. Experimental results relating to a) staggered layers and b) random arrangements.

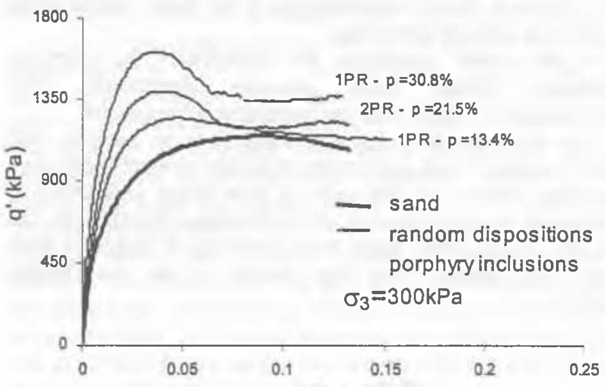

Figure 6. Results of tests on samples containing varying percentages of porphyry fragments.

4 INTERPRETATION OF RESULTS

All the samples tested were, at the beginning of the tests, in a *floating* condition. Progressing the tests the non *floating condition* was clearly evidenced only for the sample characterised by the superposed dispositions: indeed only for them little deformations were sufficient to cause the reaching of the contact between the beads.

For the tests on samples with beads disposed as random or staggered, indeed the contact was not evidenced so clearly. For these dispositions (at the percentage of inclusions considered) the deformation level required to obtain the *non floating* condition was quite large (compatibly with the capacity of the test equipment) and only for the greatest percentages the contact was evidenced.

The same considerations can be derived from the analysis of the results of tests on samples with natural porphyry inclusions, randomly disposed.

For the tests on staggered and random dispositions (both for beads and porphyry fragments) the experimental deformation level causing contact was close to one foreseen by expression (1) while for the superposed disposition it is considerably lower.

This derives from the hypothesis (at the basis of expression (1)) that beads can approach without limitations until contact due to the infinite deformability of the matrix. In reality the sand between two adjacent beads cannot deform infinitely and this causes an anticipate contact.

Figure 7 summarises the results in an ε_{max}-p diagram where the experimental values derived from each of the tests performed are compared with expression (1). The value of ε_{max} obtained from the tests on samples with superposed disposition has been modified to take into account the real deformability of the sand.

It can be noted the quite good agreement between the experimental results and expression (1).

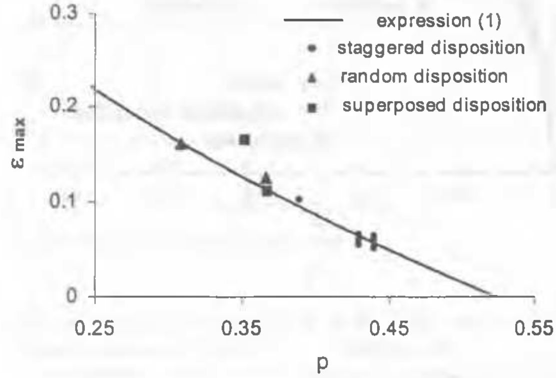

Figure 7. Influence of the percentage of inclusions on the shear strength.

Figure 8 shows a diagram percentage of inclusions - friction angle for all the tests performed.

For the samples with beads arranged in a superposed way (for both the diameters under consideration), the p variation leads to a considerable increase of ϕ, which is caused by the achievement of the *non floating* condition that occurred for small deformation levels. By increasing the percentage by over 30%, however, no increase or significant variation of the friction angle occurs because of the remarkable localisation of deformations (above evidenced) that quickly leads to the ultimate condition.

For the staggered or random arrangements, no considerable variation of the friction angle occurs with respect to the case of sand only, as foreseen by for natural complex soils (Holtz & Willard 1961). This is probably due to the spherical shape of the beads that don't favour the natural aggregation between matrix and inclusions, which represents one of the major contributions to the shear strength increasing.

In fact when inclusions are represented by porphyry fragments, friction angle increases significantly (and approximately linearly) with the percentage of inclusions.

It is worth pointing out that while tests on samples with natural porphyry fragments are the ones that have produced more significant results from the point of view of the dependence of mechanical characteristics on the percentage of inclusions, the tests on samples with beads have permitted to highlight more clearly the passage from the *floating* to the non *floating* condition.

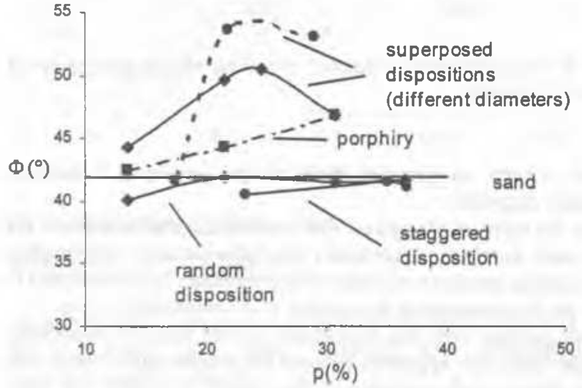

Figure 8. Comparison between experimental and calculated results.

5 CONCLUSIONS

The analysis of the mechanical behaviour of complex soils requires the use of large-sized equipment, which is extremely expensive and therefore difficult to find among the traditional lab instruments for geotechnical characterisation.

So it could be useful to derive the mechanical characteristics of them from the only matrix component or of the only inclusions one. When the percentage of inclusions is so low that no contact between them is possible (*floating condition*), Fragaszy et al. (1990) developed a method consisting in 'replacing' inclusions with the matrix in an appropriate way, thereby creating a sort of equivalent matrix to submit to characterisation.

No experiences are instead present in literature about the analysis of the *non-floating* condition that requires appropriate test equipment.

It has been considered of interest to recognise the *floating* and the *non floating* conditions on the basis of experimental tests on sample made of a sandy matrix and of inclusions represented by spherical beads or porphyry fragments

The tests have evidenced that the passage from one situation to the other depends on the percentage of inclusions, on the deformation level and on the geometrical disposition of the inclusions themselves. The experimental results can reasonably foreseen by a simple expression that relate the percentage of inclusions to the deformation level.

Furthermore, the experimental results have also put in evidence the influence of the percentage and type of inclusion on the shear strength characteristics of the complex soil.

REFERENCES

Baldi G., Bellotti R., Ghionna V., Jamiolkowski M., Pasqualini E. 1982. Design parameters for sands from CPT. *Esopt II*. Amsterdam.

Fragaszy R. J., Su W., Siddiqi F. H. 1990. Effects of oversize particles on the density of clean granular soils. *Geotechnical Testing Journal*, ASTM (GTJODJ), Vol. 13, n°2: 106-114.

Fragaszy R.J., Su W., Siddiqi F.H., Carlton L.H. 1992. Modelling strength of sandy gravel. *Journal of Geotechnical Engineering*, ASCE, Vol. 118, n°6: 920-935.

Holtz W.G., Willard E. 1961. Triaxial shear characteristics of clayly gravel soils, *Proceedings 5 International Conference on Soil Mechanics and Foundation Engineering, Paris*: 143-149.

Hussain B., Katti R.K. 1980. Behaviour of soil rock mixtures in shear and compression. *Proc. of the Int. Symp. On Landslides, New Delhi*, Vol.1: 113-117.

Montrasio L., 1998. Characterization of a complex soil. *II Int. Conf. on Hard Soils – Soft Rocks, Naples*, Vol. 2: 707-714.