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A more rational utilization of some old in situ tests

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ABSTRACT: SPT and Plate Load Test are among the most used in situ tests, at least as far as foundation design is concerned. This paper presents improved versions of these old tests which were lately used in our professional routine practice. The SPT has been replaced by the SPT-T which is the SPT complemented by torque measurements. Notwithstanding costing about the same, the reliability of the SPT-T is many folds higher than that of the traditional SPT. The conventional Plate Load Tests are being replaced by similar tests on mini plates, 5" (12.7cm) in diameter, carried out either above or below the water level, within a 6" (15.24cm) in diameter cased hole.

1. SPT - A BRIEF RETROSPECT

The predecessor of the SPT was introduced early in this century, 1902, by Gow. The sampler, as it is used today, is the work of Mohr and Fletcher , 1927. The first attempt for the standardization of this test happened in 1930 by Fletcher and Mohr, but its popularity became evident only after the publication of the book Soil Mechanics in Engineering Practice by Terzaghi and Peck, 1948. Along this almost a century of existence three State of the Art Reports have been presented, de Mello (1971), Nixon (1982) and Décourt (1989). Some very good reviews should also be remembered like for example Skempton (1986) and Stroud (1988).

The most important single factor affecting the energy that effectively reaches the sampler and therefore the N values has been properly analyzed among others, by Schmertmann and Palácios (1975) and Kovacs (1994). In Brazil this subject has been analyzed principally by Belincanta(1985-1998), Décourt et al (1989). It is also worthwhile to mention that an ISSMFE Committee chaired by S. Thorburn, finally succeed in elaborating an International Reference Procedure for the SPT, Décourt et al (1988).

It must be recognized that in these papers almost all the factors affecting the penetration resistance have been recognized and properly analyzed, leaving little to be done in the future, except, perhaps, the analyze of the behavior of sands in calibration chambers what, notwithstanding being highly recommended, hasn't been done yet.

2. THE SPT-T, THE ULTIMATE IMPROVEMENT OF THE SPT

Ranzini (1988) suggested that torque measurements might be added to SPT in order to obtain more reliable values of the adhesion between piles and soil, using the adhesion between the SPT sampler and the soil as an intermediate step. But the first SPTs with torque measurement were carried out only in early 1991 by Engesolos, the first results being reported by Décourt and Quaresma Filho (1991). This new test was denominated SPT-T, by these authors.

Since that time, the author has no more used the SPT in his design jobs, using instead only the new SPT-T.
In Brazil there are presently two trends as far as the practical utilization of SPT-T data is concerned. The pioneer work of Décourt and Quaresma Filho (1991-1994) has been towards a better understanding of the soil behavior through the determination of the "static" and therefore much more reliable T values, as compared with the "dynamic" N_{SPT} values. Even the identification of the collapsibility of soils may be easily made through comparisons between T and N_{SPT} what is an application of this test formerly hardly believed to be possible. The updating of all the formerly existent correlations via the Neq concept, to be further defined, was also considered to be a major concern. The other

trend limits the use of this test for pile design only, Alonso (1995).

3. EXECUTIVE PROCEDURE

Upon the conclusion of the penetration of the sampler into the ground (the N_{SPT} determination) the anvil is removed and an adapter is placed. The idea is solely to create a male type connection in order that a torque moment could be applied, using common torque meters. The maximum value of this moment, designated by T, is registered. In Brazil, where this moment is read in kgf.m units, the order of magnitude of T and N_{SPT} turns to be the same. It is important to observe that the value of T is always referred to a 45 cm penetration of the sampler into the ground. Sometimes the residual value of T is also recorded.

4. THE TORQUE RATIO

Since long ago it has been said that the intricate properties of soils, specially those presenting a cohesive-frictional behavior, could not be assessed via a single parameter, in this case the penetration resistance N. The SPT-T provides two independent measurements of the soil resistance and what is of paramount importance, practically in the same place.

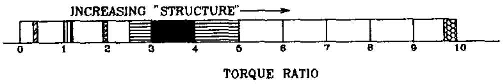
The SPT is well known to be a highly disrupting test. In structured soils it is therefore reasonable to suppose that it will measure the behavior of a remolded soil rather than that of an almost intact one. The torque T is a measurement of the tortional effort required to overcome the friction between the sampler, driven 45 cm into the ground, and the soil. It is reasonable to suppose that the region where this side resistance is measured is much less disturbed by the penetration of the sampler into the ground than the region just below its tip.
For this reason, it seems reasonable to suppose that the ratio T/N would probably be an indirect measure of the soil structure. The ratio of T by N was called Torque Ratio (T/N).

5. A NEW SOIL CLASSIFICATION.

The knowledge of both T and N values of the SPT-T provides the basis for a new soil classification. Differently from the formerly existent classification systems, which are based on remolded soil properties, this classification takes into account the soil structure. The first soils investigated were those belonging to the Tertiary Sedimentary Basin of São Paulo (TSBSP) which are supposed to be little sensitive. These soils are typically sandy silty clays and silty clayey sands. For this soils the average value of the torque ratio was found to be about 1.2.
The same order of magnitude was also initially found for the torque ratio of sedimentary over consolidated sands of this basin, known as basal sands. For the residual soils of the city of São Paulo, which are predominantly derived from granitic, gnaissic and migmatic rocks, the average value of T/N is about 2.0. For the unsaturated collapsible clays of the city of São Paulo (av. Paulista region) this ratio is about 2.5. For clayey collapsible soils of the interland of São Paulo T/N is 2.5 or even higher, approaching sometimes 5.0.

For medium sensitive saturated soft clays from the quaternary period, largely found along the littoral of the state of São Paulo this ratio is about 3 to 4.

These information resumed the knowledge available up to four years ago and a table summarizing all these data was presented by Décourt and Quaresma Filho (1994). This same table, updated is presented in fig 1.



	SOIL	T/N
	SEDIMENTARY SANDS, LOWER BOUND	≈0.3
	SOIL FROM THE TSBSP	≈1.2
	SAPROLITIC SOILS - SP	≈2.0
	COLLAPSIBLE POROUS CLAYS	2.5/5.0
	SOFT MARINE CLAYS OF SANTOS	3.0/4.0
	SEDIMENTARY SANDS, UPPER BOUND	≈10

Fig. 1 Soil classification on the basis of the torque ratio (T/N)

6. THE EQUIVALENT N CONCEPT (Neq).

Most of the correlations often used in Brazil have been established for the soils of the Tertiary Sedimentary Basin of São Paulo (TSBSP). For these soils and for N_{SPT} values neither too high nor too low it was found that the T-values, measured in kgf.m units, were, on average, 1.2 times the N_{SPT} values.

Décourt (1991b) postulated that even for soils outside the TSBSP the correlations established for the soils of the TSBSP could be used, provided Neq values were used instead of the directly measured N_{SPT} values.

The Neq was defined as the torque T measured in kgf.m divided by 1.2

$$Neq = T / 1.2$$

In other words what is being postulated is that it is the torque T rather than N_{SPT} that is effectively related to the soil behavior.

7. SPT-T IN SEDIMENTARY SANDS

7.1 THE INFLUENCE OF THE MAGNITUDE OF N_{SPT} VALUES.

More recently a certain amount of T and N_{SPT} data on sedimentary sands became available. These soils, originally considered to be of a simple behavior, are in reality the most complex ones, at least as far as torque ratios are concerned. Apparently similar soils may present T/N values ranging from as low values as 0.30 to as high values as 10, what means a more than 30 folds difference.

At this very moment, there isn't any definitive explanation for this broad range of values of the Torque Ratio.

Belincanta (1996) followed by Décourt (1996) pointed out that the torque ratio was not a constant as have been previously assumed but it is rather a function of the N_{SPT} value.

This observation is particularly important in the case of sedimentary sands. To check the correctness of this observation the results of tests in four sites are presented in figure 2. Three of them were along the shore of São Paulo state (Santos, Bertioga and São Sebastião) and the fourth in Mogi das Cruzes, 40 kilometers from the shore. All samples were classified as fine silty sands.

The tendency for decreasing the torque ratio values and therefore Neq/N with the increase of N_{SPT} was clearly evidenced.

For comparison purposes the correction of the N_{SPT} values proposed in the first edition of Soil Mechanics in Engineering Practice (1948) was also plotted. It must be stressed that for allowing fair comparisons to be made, the original Terzagui and Peck, correction was adapted for the much more efficient Brazilian SPT ($E_i \approx 72\%$) as compared to the old cathead American SPT, ($E_i \approx 45\% - 50\%$) which probably was the one considered in that book. (N_{TP})

$N_{BR} \approx N_{TP} / 1.5$ $\qquad$ $(N_{BR})_{corr.} = 10 + (N_{BR} - 10) / 2$

Just for sake of curiosity this expression was also extended to low values of N_{SPT}, what definitely was not intended to be done by Terzagui and Peck. These authors are to be commended for their fantastic feeling. Fifty years ago they predicted a tendency very

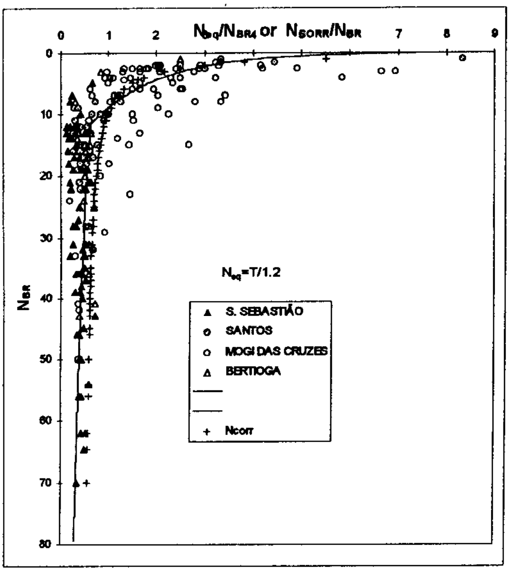


Figure 2 Variation of Neq/N_{BR} and N_{corr}/N_{BR} with N_{BR}

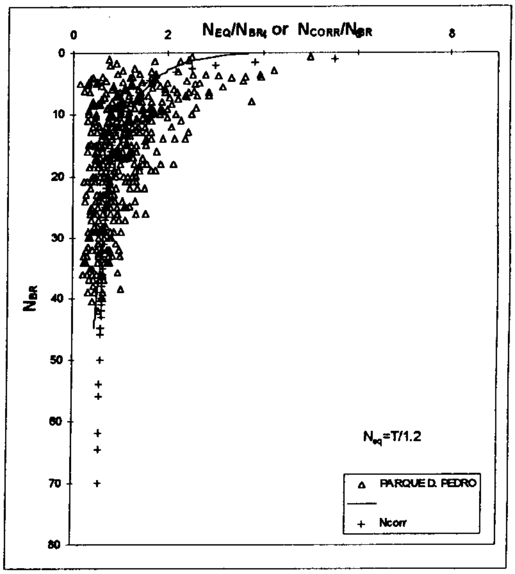


Figure 3 Variation of Neq/N_{BR} and N_{corr}/N_{BR} with N_{BR}

similar to that presented in figures 2 and 3. By the way, unfortunately this correction was omitted in the 2nd edition of this book, (1967).

A similar result was obtained for the basal sands of the TSBSP and is presented in figure 3.
All these data clearly suggest that the direct use of unconnected N_{SPT} values in sands leads to unreliable conclusions, varying from conservative to very conservative for low N_{SPT} values, to unsafe, for higher N_{SPT} values.
The unreliability of the low N_{SPT} values was also pointed out by Stroud (1988).

7.2 THE INFLUENCE OF THE STATE OF CONSOLIDATION.

It is postulated that the state of consolidation of sandy sediments may also have an important influence in the torque ratio values. A tendency seems to exist of higher Torque Ratio values for higher over consolidation ratios, however definitive conclusions would only be possible upon carrying out comparative tests in calibration chambers.

8. LOAD TESTS ON MINI PLATES; EXECUTION PROCEDURE

These tests have been performed on circular steel plates with 5" (12.7 cm) in diameter inside a 6" (15.24cm) diameter casing. The presence of the water level is not a restriction for carrying out these tests what represents a major advantage over the former plate load tests.
For applying loads two systems are in common use. When pressures up to 500 kPa are sufficient for defining the foundation rigidity the loads are applied using weights, like for instance the weights used in oedometer tests. When higher loads are required, jacks have to be used. More details about these procedures may be found in Décourt and Quaresma Filho (1996).

9. UNIQUENESS OF THE NORMALIZED STRESS-SETTLEMENT CURVE IN A LOAD TEST.

The pioneer work of Briaud and Jeanjean (1994), followed by Décourt (1994-1995) have demonstrated that the stress-settlement curve for shallow foundations is unique, provided the stresses were normalized by the conventional failure stresses and the settlements, were normalized by the equivalent widths of the foundations. The conventional failure stress is defined as the stress corresponding in the load-test, to a settlement of 10% of the equivalent width of the foundation (Beq). The equivalent width of the foundation is the width of a square foundation with the same area of the foundation being tested.

10. THE BASIC CURVE

Since four years ago a simple but very reliable method developed by the author for predicting settlements has been tested. The soil response is recognized to be highly non linear.

A law of variation of the settlements normalized by the equivalent width of the foundation with the stresses, normalized by the stress corresponding to the conventional bearing capacity (q_{uc}) has been established.

Some examples of the successful application of the basic curve for predicting settlements may be found in Décourt (1995).
For sands, q_{uc} in kgf/cm² units (kPa x 10^{-2}) may be assessed as a function of T, in kgf.m units.

shallow foundations .... $q_{uc} \approx T$

This formula is an extension of the originally proposed by Décourt (1991a) $q_{uc} \approx 1.2N$, considering the recommended use of Neq derived from T instead of N and that Neq = T/1.2 as shown in item 6.

For deep foundations like deep plates and non displacement piles with, D/B ≥ 5, one has;

deep foundations.................. $q_{uc} \approx 1.5\ T$

For intermediate embedments (D/B) the rate of increase F of q_{uc} with D/B is given by:

$$\log F = 0.09 + 0.125 \log D/B$$

11. A PRACTICAL EXAMPLE.

One of the most problematic soils found in Brazil has been chosen to illustrate the potential use of these tests. It is a silty sand, from the Cenozoic period, that probably hasn't been pre stressed and that is well known to be a badly collapsible material. This soil covers an important part of the interland of state of São Paulo, including the city of Bauru where the Estadual University of São Paulo has a Foundation Experiment Field.

Agnelli (1992) performed in the area a number of conventional plate load tests (steel circular plates with 80.5 cm in diameter). The results of these tests may be found in Agnelli (1992) and Agnelli and Albiero (1994).

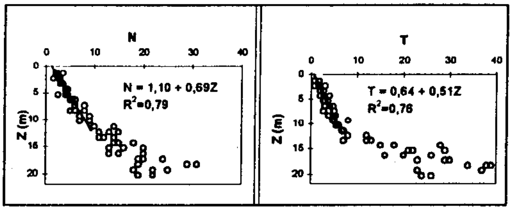


Fig. 4 Variation of N and T with depth (z)

In order that comparisons between the results of load tests performed conventionally be made with the results of load test carried out with mini plates, six of these later tests were performed in this same soil, very close to where the tests by Agnelli (1992) were carried out. Moreover, considering that it is fundamental to perform SPT-Ts instead of SPTs, what hasn't been done by Agnelli, three SPT-Ts have been carried out in the area by Engesolos, very close to where the load tests were performed.

The results of these tests are presented in figure 4. It is clear from these test results that there are two distinct regions, one for depths from zero to about 12.0 m and other for depths greater than about 12.0 m. It may be observed that all strength measurements like N_{SPT}, and T increase approximately linearly with depth, showing a typical Gibson soil behavior. Also shown are the regressions established for depths from zero to 12.0 m. The Torque Ratio (T/N) is on average 0,71.

In figure 5 the results of the twelve load test are presented. The stresses normalized by the conventional failure stresses and the settlements, normalized by the equivalent widths of the plates (Beq = $\sqrt{A}$) are presented.

For the Agnelli tests, the failure loads were obtained through extrapolation procedures, using statistical regressions that presented very high values of R^2.

For predicting the rigidity of the foundations on the basis of T and N values of the SPT-T, it is suggested that the representative values of the resistance parameters of these tests were those corresponding to a depth of 0.7 Beq. below the plate level. This assumption is based on previous comparative analyses carried out by the author.

12. CONCLUSIONS

Significative improvements made in the SPT and in Plate Load Tests allow a much better understanding of the soil behavior, without introducing increase in costs.

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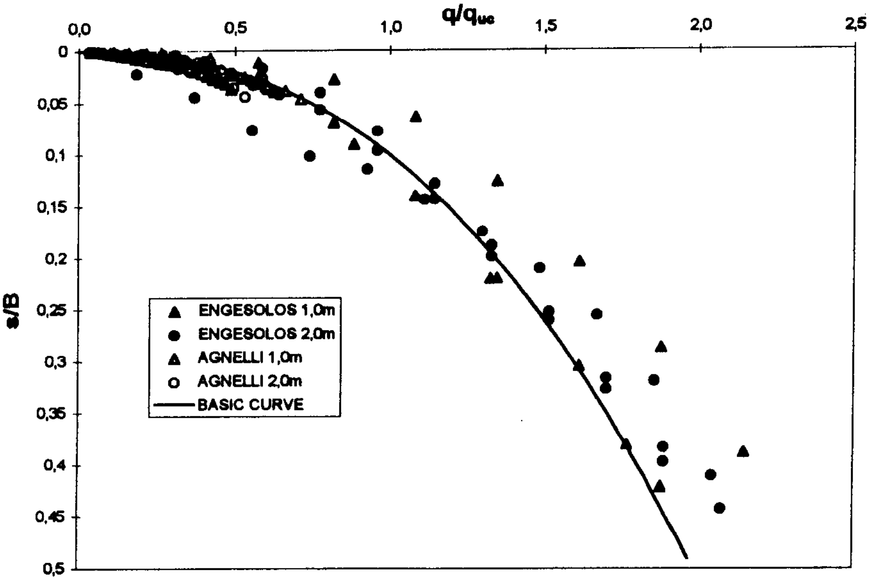

Figure 5 Results of the twelve load tests. Also show the basic curve.

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