Surprising Soil Behaviour in Soil Sampling

G.M.F. Jannuzzi, F.A.B. Danziger, I.S.M. Martins

Abstract. Thick wall (6.6 mm wall thickness) plastic samplers, 97.2 mm in internal diameter (area ratio of 29%), 700 mm in length (length of soil sample 640 mm), with a cutting edge angle of 23°, without clearance and with a sampler head have been used to collect very soft clay samples at Sarapuí II test site. Very good to excellent and good to fair quality samples have been surprisingly obtained in most cases, which were attributed to a combination of five factors: the absence of an inside clearance, the low friction of the plastic sampler, the small "trick" to close the top of the sampling rods assuring that suction would be imposed on the top of the sample, the very careful handling and trimming process, combined with no extrusion of the sample, and the small ratio between specimen diameter and sample diameter. It is still too early to propose the use of thick wall plastic samplers - in combination with the procedures outlined above - to be used in regular undisturbed soft clay sampling, and more research is needed to identify the role of each procedure in the final result. However, if confirmed, the procedures adopted will allow significant cost saving with respect to the use of thin wall brass (or stainless steel) samplers.

Keywords: sampling, soft clay, sample quality.

1. Introduction

It is well known that the quality of the sample plays an important role on the results of laboratory tests. There are several types of samplers to collect samples of soft clay, both onshore and offshore.

The Sherbrooke sampler (Lefebvre & Poulin, 1979) is generally considered the best onshore sampler (*e.g.*, Hight *et al.*, 1992), since a block sample with a large diameter (250 mm) is carved into the soil. However, when used in very soft soils it might be unsuitable, since it does not have a lateral support and the sample is retrieved mostly by the diaphragm that cuts the soil at the bottom of the sampler. Therefore, when the block is retrieved, failure of the sample due to its self-weight may occur, as observed by Oliveira (2002) when sampling in a very soft clay at Barra da Tijuca, Rio de Janeiro.

Piston samplers are generally considered able to provide good quality samples (*e.g.*, Lunne *et al.*, 1997, Tanaka & Nishida, 2007), both when displacement method and preaugering are used. However, they are more difficult to operate than simple thin wall tubes (or Shelby tubes). Although piston samplers have been used in Brazil for a long time (*e.g.*, Costa Filho *et al.*, 1977, Lacerda *et al.*, 1977), the Brazilian practice has been mostly related to the use of thin wall tubes, fitted with a sampler head with a suction ball valve to help keeping the sample during recovery.

A number of authors (*e.g.*, Hvorslev, 1949, Kallstenius, 1963, Lefebvre & Poulin, 1979, La Rochelle *et al.*, 1981, Baligh *et al.*, 1987, Hight *et al.*, 1992, Tanaka & Tanaka, 1999) have studied the factors that affect the quality of the sample. Lunne & Long (2006) have recently reviewed the role of the sampler characteristics, as listed below, in the sample quality:

- Sample diameter;
- Wall thickness;
- Cutting edge angle;
- Inside clearance;
- Inside friction;
- Outside friction.

Reference must be made to Lunne & Long (2006) to a detailed analysis of each factor. Very briefly it must be stated that the larger the sample diameter, the smaller the wall thickness and the cutting edge angle the better the quality of the sample. Concerning the sample diameter, the Brazilian standard NBR 9820 (1997) is more stringent than other standards, once the minimum external diameter allowed for sampling in regular conditions is 100 mm. In fact, samplers with 75 mm in diameter are commonly used in many countries (Lunne & Long, 2006).

The presence of an inside clearance is still an issue. Numerical analyses have indicated (*e.g.*, Baligh *et al.*, 1987, Clayton *et al.*, 1998) that inside clearance might be responsible for sample disturbance. Some well-known samplers do not have internal clearance, such as the Laval sampler (La Rochelle *et al.*, 1981) and the Japanese thin wall standard piston sampler (Tanaka & Tanaka, 1999). However, once the main purpose of the inside clearance is to reduce the inside friction, a number of samplers do have an internal clearance, especially when long samples are to be retrieved, as in the case of offshore samplers (Lunne & Long, 2006).

As mentioned before, inside friction is one of the main causes of disturbance, and the smaller the inside fric-

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tion the better the quality of the sample. Outside friction must also be reduced, once it is able to generate shearing stresses in the soil below the cutting edge (Eide & Andresen, 1977).

2. Evaluation of Sample Quality

Specimen can be defined as the portion of the soil trimmed from the sample to be used to carry out the test. Therefore, it must be pointed out that what is called sample quality is indeed specimen quality in most cases, provided that the final evaluation is carried out on the specimen, and not on the sample. However, once the designation sample quality is broadly used in the technical literature, it will be kept in the present paper.

The sample quality depends on a number of factors, from the sample retrieval from the ground (which affecting factors were presented in the previous section) until the extrusion (when performed), final trimming and positioning into the test apparatus. Sample extrusion, although carried out routinely, has been questioned and a procedure in which the tube sample is cut in short lengths has been proposed (Germaine, 2003, quoted by Ladd & DeGroot, 2003), as illustrated in Fig. 1.

No definitive method exists to determine the absolute sample quality (Ladd & DeGroot, 2003). The influence of sample disturbance in consolidation tests has been studied for a long time (*e.g.*, Schmertmann, 1953). Sample disturbance reduces the yield stress, σ'_{vm}, (or the overconsolidation ratio, OCR) and the compression index, C_c, in the range of lower effective stresses. Moreover, the "S" shaped curve for a good sample is "smoothed", as illustrated *e.g.* by Coutinho (1976) for the Sarapuí soft clay (Fig. 2).

The observations above are of qualitative nature. Quantitative criteria to evaluate the sample quality have been proposed, and the one suggested by Lunne *et al.* (1997) is very much used nowadays (Table 1). This criterion is based on the $\Delta e/e_o$ ratio, where $\Delta e = e - e_o$ is the difference between the void ratio at the vertical effective stress in the field, e, and the initial void ratio, e_o.

The use of the criterion included in Table 1 implies the need of performing the tests. The evaluation of the sample quality prior to the tests can be done, and X-ray pictures have been used for many years (*e.g.*, Hvorslev, 1949). Measurements of initial suction in the sample, comparison of shear wave velocity measured on the specimen with that obtained in situ have also been used (*e.g.*, Hight & Leroueil, 2003, Landon, 2004, Lunne & Long, 2006, Tanaka & Nishida, 2007).

3. Sample Quality of Brazilian Soft Clays

Oliveira (2002) and Coutinho (2007) considered that the limits established by Lunne *et al.* (1997) are too strict to the very soft plastic organic Brazilian clays, and suggested to release them (Table 2). Andrade (2009) proposed more classes in the modified criterion (Table 3).

4. Surprising Behaviour

4.1. General

According to the Brazilian standard NBR 9820 (1997) the tube samplers do need to have a clearance. As

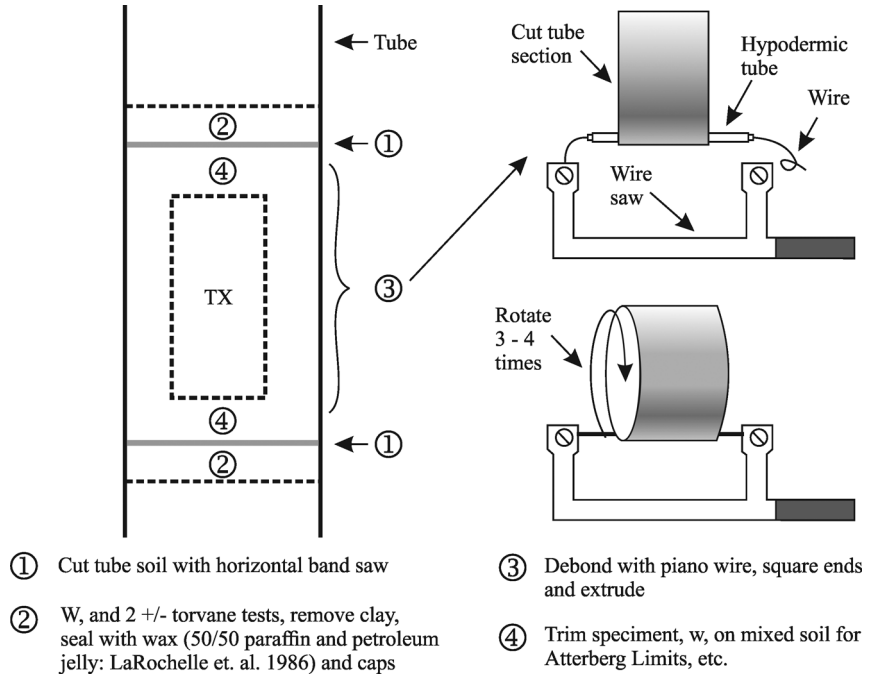

Figure 1 - Procedure for obtaining test specimen from tube sample (Germaine, 2003, after Ladd & DeGroot, 2003).

previously shown, the presence of the clearance is still an issue. Therefore it has been argued by the authors of the present paper that the presence of the clearance would be responsible for the classification very good to excellent seldom being obtained for Brazilian samples, which led to the suggestions to release the Lunne *et al.* (1997) criterion presented in the previous section. In other words, the need for releasing the Lunne *et al.* (1997) criterion would be a consequence of the sampling procedure and not a consequence of the characteristics of the Brazilian very soft clays. It must be pointed out that a piston sampler similar to the Japanese sampler, 76 mm in diameter, 1 m in length and no inside clearance was developed by Bertuol *et al.* (2010) and successfully used in a very soft clay from Rio Grande do Sul, south of Brazil.

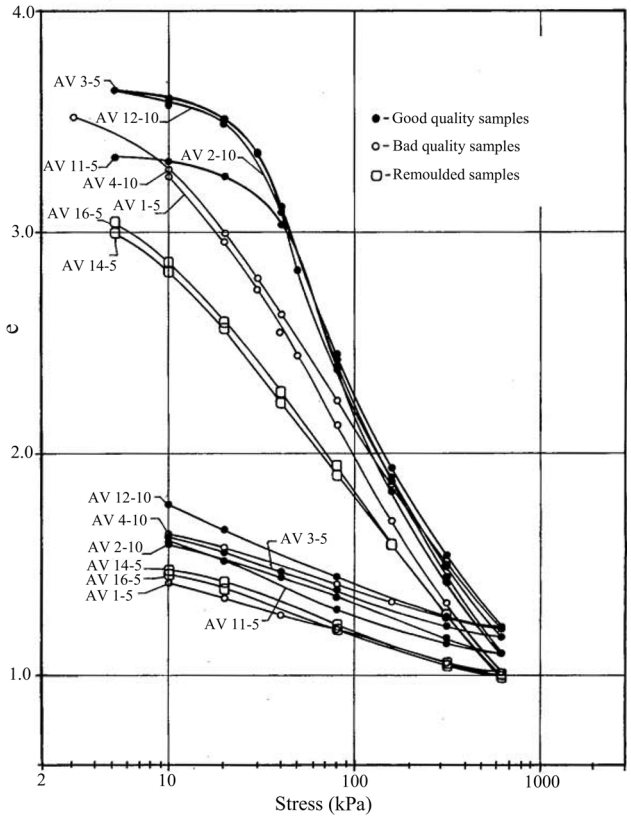

Figure 2 - Influence of sample disturbance in consolidation tests in the case of Sarapuí soft clay (adapted from Coutinho, 1976).

Besides, as mentioned in section 1, although piston samplers have been used in Brazil, this kind of sampler demands a procedure which is not straightforward, and thin wall tubes, fitted with a sampler head to help keeping the sample during sample recovery, are commonly used. However, the use of thin wall tubes might demand a significant time to guarantee the proper retrieval of the sample. In fact, hours are needed in some cases to allow the pore pressure generated during the penetration of the tube sampler to dissipate and provide the necessary strength on the soil at the contact with the tube.

In order to solve this problem, and still keeping the simplicity of the operation, a new sampler is under development at COPPE, Federal University of Rio de Janeiro. This new sampler will cut the sample from the bottom as done by the Sherbrooke sampler.

To compare the quality of the samples from the new sampler, sampling series were planned. The first series of tests would be performed with a thick wall plastic tube sampler (97.2 mm in internal diameter, 6.6 mm in wall thick-

Table 1 - Lunne *et al.* (1997) criterion to evaluate sample disturbance.

OCR	$\Delta e/e_o$			
	Very good to excellent	Good to fair	Poor	Very poor
1-2	< 0.04	0.04-0.07	0.07-0.14	> 0.14
2-4	< 0.03	0.03-0.05	0.05-0.10	> 0.10

Table 2 - Lunne *et al.* (1997) criterion to evaluate sample disturbance modified by Oliveira (2002) and Coutinho (2007).

OCR	$\Delta e/e_o$			
	Very good to excellent	Good to fair	Poor	Very poor
1-2.5	< 0.05	0.05-0.08	0.08-0.14	> 0.14

Table 3 - Lunne *et al.* (1997) criterion to evaluate sample disturbance modified by Andrade (2009).

OCR	$\Delta e/e_o$					
	Very good to excellent	Very good to good	Good to fair	Fair to poor	Poor to very poor	Very poor
1-2.5	< 0.05	0.05-0.065	0.065-0.08	0.08-0.11	0.11-0.14	> 0.14

Figure 3 - Thick wall plastic sampler.

ness, area ratio of 29%), with a cutting edge of 23°, without clearance. The sampler length is 700 mm, and the length of soil sample is 640 mm (Fig. 3). A sampler head regularly used with thin wall samplers was machined to fit in the thick wall plastic sampler (Fig. 4).

Poor quality samples were expected to be obtained, which would be in between the 2 extremes of the very good to excellent quality samples expected with the new sampler and the very poor quality samples obtained by a process of completely remoulding in the laboratory. However, this was not verified, as shown below, and very good to excellent and good to fair quality samples were surprisingly obtained in most cases with the thick wall plastic sampler.

4.2. The test site

The Sarapuí soft clay test site has been used since the 1970's as a research site, and a number of in situ and laboratory tests have already been performed (*e.g.*, Lacerda *et al.*, 1977, Werneck *et al.*, 1977, Ortigão *et al.*, 1983). A general report about the deposit was provided by Almeida & Marques (2003). In the last fifteen years, however, security reasons have prevented the use of the test site. A new area (named Sarapuí II) in the same deposit, 1.5 km from the previous area and inside a Navy Facility, has been used since then (Fig. 5). Two researches on pile behaviour have been carried out at the Sarapuí II site (Alves, 2004, Francisco, 2004, Alves *et al.*, 2009). The initial tests with the torpedo-piezocone (Porto *et al.*, 2010, Jannuzzi *et al.*, 2010,

Figure 4 - Sampler head regularly used with thin wall brass sampler machined to be used with the thick wall plastic sampler.

Figure 5 - Sarapuí II test site with respect to the early Sarapuí I test site.

Henriques Jr. *et al.*, 2010) were also performed at Sarapuí II test site.

A number of in situ tests have been performed at Sarapuí II. In fact, 9 boreholes for SPTs (performed each meter in Brazil), 7 CPTUs, 51 vane tests (in 5 deployments), 4 T-bar tests and 4 SDMT tests were conducted (Jannuzzi, 2009, 2013), both in natural soil and under an old embankment (Jannuzzi *et al.*, 2012). The very soft clay material in this particular area varies from 6.5 m to 10 m. The Atterberg limits, natural water content and specific gravity are shown in Fig. 6 and a typical piezocone test in Fig. 7.

4.3. Samples collected

4.3.1. General

Once the aim of the sampling series with the plastic thick wall sampler was to allow a comparison with the new sampler, the same procedure to collect the samples in the case of thin wall brass sampler regularly used at COPPE, Federal University of Rio de Janeiro and by many other institutions was used. In other words, care was taken with respect to all sampling steps, whenever possible. This includes:

i) Proper cleaning of the sampler prior to its insertion into the ground;
ii) Proper cleaning of the borehole; this was not always achieved, because of the way it is regularly executed, by wash boring and using a sharp cutting metallic device with 2 jetting bits, manually controlled, precludes careful control of the excavation of the borehole;
iii) Proper control of the rate of penetration of the sampler, with a device adapted at the tripod regularly used to perform SPT in Brazil. Although this procedure had already been used in the past, the most common procedure is to simply push the rod stem with the sampler manually;
iv) Proper control of the penetrated length of the sampler;
v) Care when retrieving the sampler;
vi) Proper handling, storage and transportation to the laboratory.

Samples were collected every 0.5 m in 2 deployments, in order to cover the whole profile. Six samples were

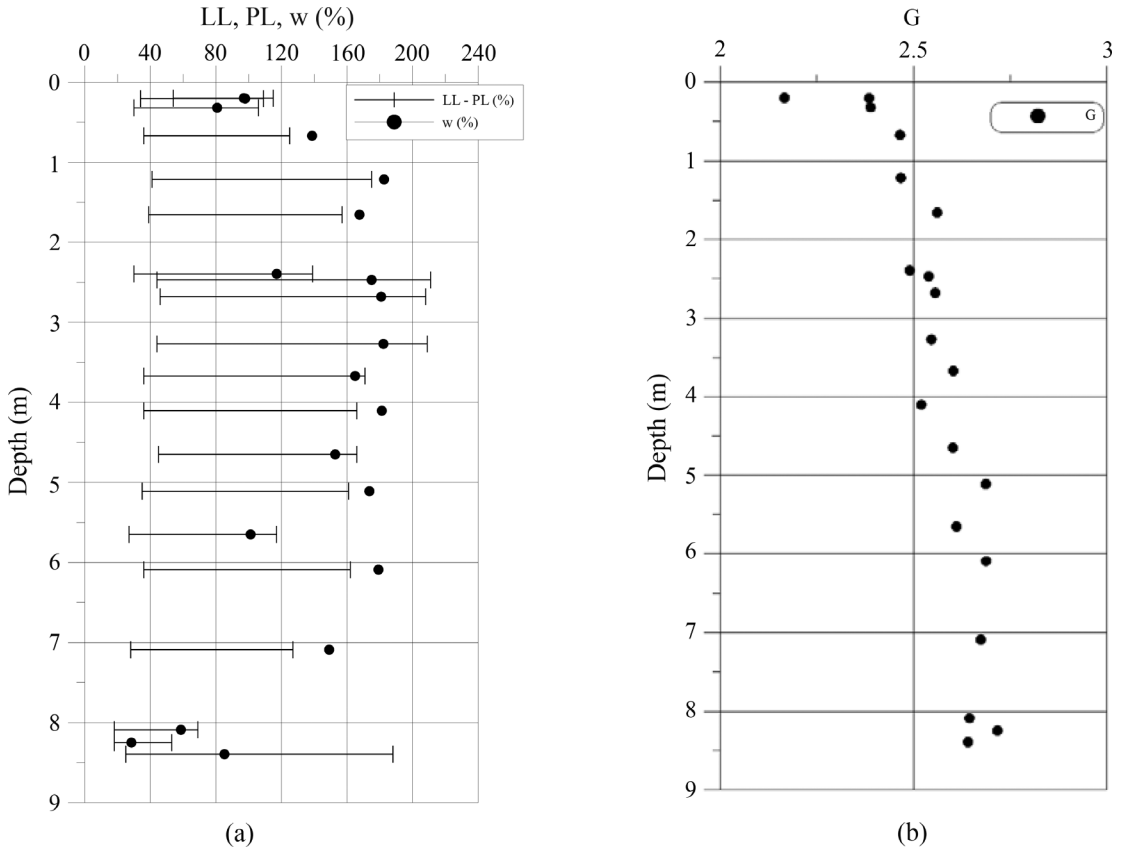

Figure 6 - (a) liquid limit (LL), plastic limit (PL) and natural water content (w); (b) specific gravity (G) from Sarapuí II test site.

randomly chosen to be used for consolidation tests, and the average depth of the corresponding specimens are 1.06 m, 2.10 m, 3.09 m, 4.24 m, 5.40 m and 7.44 m.

4.3.2. Handling and trimming in laboratory

A procedure similar to the one described in section 2 and illustrated in Fig. 1 has been used for a number of years at the Rheology Laboratory of the Group of Geotechnical Laboratories Jacques de Medina, at COPPE, Federal University of Rio de Janeiro. This procedure is illustrated below, see also Aguiar (2008) and Andrade (2009). The first step is to cut a desired slice of the sampler with a band saw (Fig. 8), which must be done with a proper support. The sampler is turned while it is cut, in order not to cut the sample. Despite the thick wall, the procedure is much easier and faster than with the thin brass sampler. Then the sample is cut with a thin guitar string. The next step is to carefully introduce the guitar string, driven by a long thick needle, longitudinally into the slice produced, as shown in Fig. 9.

Then the string is used to separate the sample from the sampler slice by a number of rotations, typically 4. This procedure also provides room for driving the consolidation ring without bulges at the top of the sample. In the case of consolidation tests, the consolidation ring (71.4 mm in internal diameter) is then pushed into the sample with the aid of another ring. Thus, since the consolidation ring thickness is 1.2 mm, the external 12 mm of the sample is removed (which is done in the last step). After this step the guitar string is used again, now in order to allow an easy extrusion of the sample from the sampler. The last step is removing the soil from the outside of the consolidation ring, using the removed material to determine the water content of the soil.

4.4. Tests performed

Incremental loading (IL) 24 h consolidation tests were conducted at the controlled temperature room of the Rheology Laboratory. The values of $\Delta e/e_o$ *vs.* depth are shown in Fig. 10a, where the Lunne *et al.* (1997) criterion is also indicated. Since the criterion depends on OCR, the obtained values are shown in Fig. 10b. It can be observed that very good to excellent quality was obtained for the samples at 1.06 m and 2.10 m depth, and good to fair at 3.09 m and 7.44 m depth. The samples at 4.24 m and 5.40 m depth did present very poor and poor quality respectively, which could be anticipated from the simple observation of the samples. In fact, it was later found that the method of excavating and cleaning the borehole by wash boring was not efficient at all, and soil from the excavation stayed in many cases inside the borehole, which could not be detected when positioning the sampler at the bottom of the borehole. This means that in these cases this remoulded material was sampled, not the natural soil. This was clearly the case of

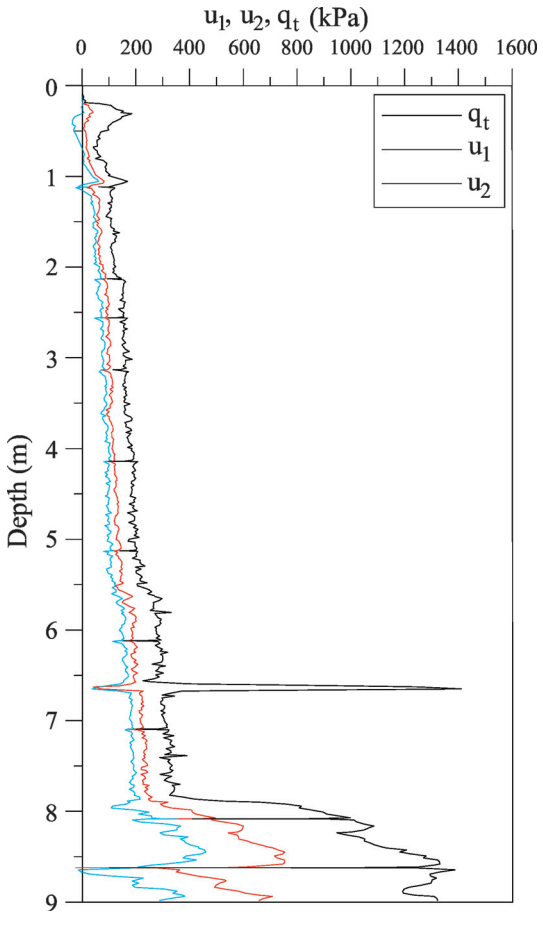

Figure 7 - Corrected cone resistance (q_t) and pore pressures at cone face (u_1) and cone shoulder (u_2) from typical piezocone test at the Sarapuí II test site.

the sample at 4.24 m depth. The specimen at 5.40 m contained a very significant amount of shells, part of which needed to be removed and the specimen completed with lumps of the sample.

The quality of the samples can also be inferred from the trend of OCR *vs.* depth, where it is clearly observed that the values of OCR for the samples at 4.24 m and 5.40 m are underestimated. The compression curve for the test at 2.10 m depth is shown in Fig. 11, where the very good to excellent quality of the sample can be observed by the shape of the curve.

5. Discussion

It might be argued that the surprisingly very good to excellent quality of the obtained samples may be attributed to the very low effective stresses, once the samples corresponding to 1.06 m and 2.10 m have provided the best results ($\Delta e/e_o$ of only 0.006 and 0.013, respectively). It might also be argued that the Lunne *et al.* (1997) criterion is limited to OCR = 4, and the sample at 1.06 m (the best result) has an OCR of 8.5. However, the tests performed at 3.09 m and 7.44 m have also provided good to fair quality samples

Figure 8 - Cutting the tube sampler with a band saw.

Figure 9 - Needle used to guide the introduction of a guitar string longitudinally into the sample.

according to the Lunne *et al.* (1997) criterion. On the other hand, it might be argued that the two samples which presented the very poor and poor results would have provided good to fair results in case the problems mentioned in the previous section did not occur. The results are indeed quite surprising, since the geometry of the sampler used do not fit into any suggestion of adequate geometry of samplers designed to get good samples, as *e.g.* the one by Andresen (1981), shown in Fig. 12. In fact, the cutting edge angle of 23° is not even included in the chart.

In summary, it seems that the very good results obtained are due to the following reasons:

i) The absence of an inside clearance. The obtained results do indicate that the inside clearance should be avoided in onshore samplers, differently *e.g.* from the Brazilian standard.

ii) The low friction of the plastic sampler. As mentioned in Section 1, both the internal friction and the external friction affect the sample quality. In the case of the plastic sampler used the very low friction might have contributed to the obtained results.

iii) The small "trick" to close the top of the sampling rods, assuring that suction would be imposed on the top of the sample, reducing the risk of sample sliding inside the sampling tube.

iv) The very careful handling and trimming process, combined with no extrusion of the sample as in the traditional process.

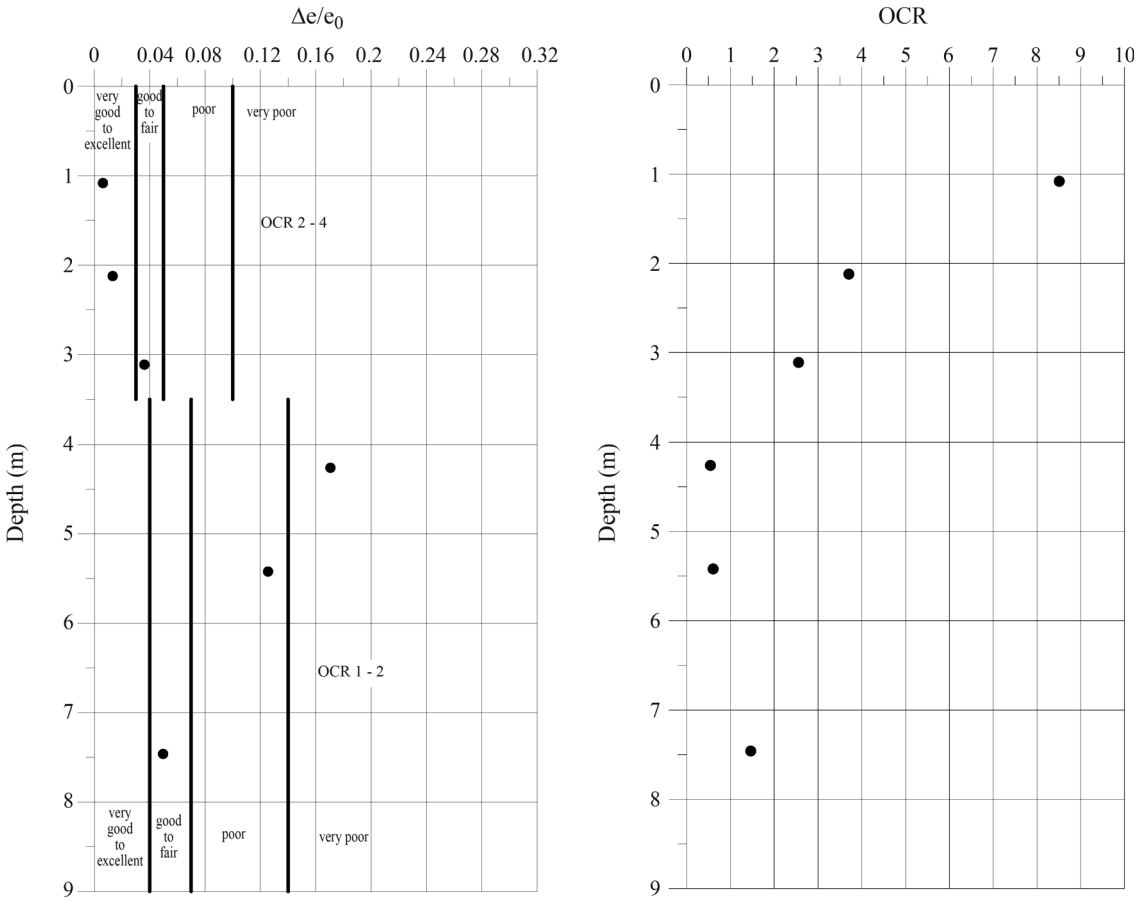

Figure 10 - (a) $\Delta e/e_o$ *vs.* depth for IL 24 h consolidation tests from specimens obtained from thick wall plastic sampler at Sarapuí II test site; (b) OCR *vs.* depth from the same specimens.

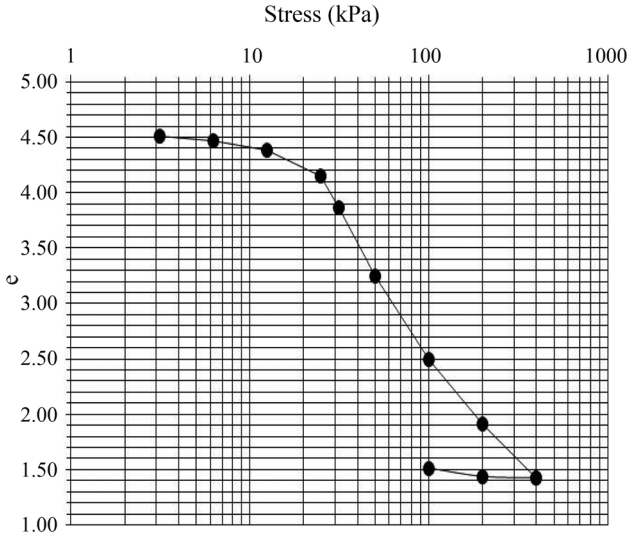

Figure 11 - Compression curve, specimen from 2.10 m depth.

v) The small ratio between specimen diameter and sample diameter, of 0.73. Reference must be made to *e.g.*, Bjerrum (1973), Lunne *et al.* (2006) and Tanaka & Tanaka (2009) on this particular subject.

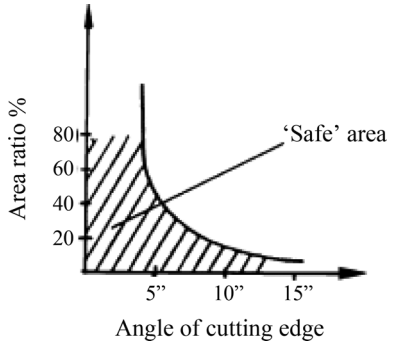

Figure 12 - Relationship between disturbance, cutting edge angle and area ratio (Andresen, 1981).

The combination of these five factors seems to be the key of the very good to excellent and good to fair unexpected quality of the samples obtained with the thick wall plastic sampler. It is still too early to propose the use of thick wall plastic samplers - in combination with the procedures outlined above - to be used in regular soil sampling to obtain undisturbed samples, and more research is needed to identify the role of each procedure in the final result. However, the results are encouraging enough to suggest the con-

tinuation of the research. If confirmed, the procedures adopted will allow significant cost saving, once the brass sampler costs roughly 8 times more than the plastic sampler. Besides, cutting the thick wall plastic sampler in slices is much easier than the thin wall brass sampler, not only because of the effort needed in the procedure, but also because cutting the thin wall sampler must be done with care in order not to deform the sample.

Two points - working in opposite directions with respect to the sample quality evaluation of the tests performed in Sarapuí II soft clay - must still be considered for future research:

- The criterion proposed by Lunne *et al.* (1997) is based on CRS consolidation tests, not in IL tests. Since CRS tests generally produce strains smaller than IL tests, the values of $\Delta e/e_o$ included in table 1 could be a little big larger for the case of IL tests.
- It has been found (*e.g.*, Berre & Bjerrum, 1973) that highly plastic clays are less subjected to disturbance than low plastic clays.

6. Conclusions

Surprisingly, very good to excellent and good to fair quality samples of the very soft plastic organic Sarapuí II clay have been obtained with a thick wall (6.6 mm wall thickness) plastic sampler, 97.2 mm in internal diameter (area ratio of 29%), 700 mm in length (length of soil sample 640 mm) with a cutting edge angle of 23° and no inside clearance, which were attributed to the combination of five factors: the absence of an inside clearance, the low friction of the plastic sampler, the small "trick" to close the top of the sampling rods assuring that suction would be imposed on the top of the sample, the very careful handling and trimming process, combined with no extrusion of the sample and the small ratio between specimen diameter and sample diameter.

It is still too early to propose the use of thick wall plastic samplers - in combination with the procedures outlined above - to be used in regular soil sampling to obtain undisturbed samples in soft clays, and more research is needed to identify the role of each procedure in the final result. However, the results are encouraging enough to suggest the continuation of the research. If confirmed, the procedures adopted will allow significant cost saving with respect to the use of thin wall brass (or stainless steel) samplers.

Acknowledgments

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