Laboratory evaluation of sampling quality of a new A+ sampler for natural fine soils

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ABSTRACT

This paper presents a comparison of sampling disturbance measured by consolidation tests between two high quality samplers and stationary piston samplers. University G. Eiffel and Cerema have used their université Laval sampler and a new sampler on a soft organic clayey soil experimental site. This paper present first the new sampler designed to sample almost undisturbed soil specimens. The objectives of this sampler are to collect natural fine soils such as clay or silt, normally to medium overconsolidated for depths up to 10 m. This sampler is designed to preserve the saturation state of the specimen. An inner diameter of 150mm core barrel allow to keep the sampler relatively compact, even with the size of a ball valve used to close the sampler. Tests on Pont de Cran clayey site are presented and laboratory tests results on specimen sampled using both samplers show the quality of the specimen and the efficiency of the samplers using void ratio criteria.

Keywords: sampler, sampling quality, remoulding, consolidation.

1. Introduction

The study of the influence of sampling process and test procedures on the measured characteristics highlighted the need for a good comprehension of the phenomena in play at the time of the various sampling stages and laboratory tests (Hvorslev 1949; La Rochelle et al. 1981, Tanaka et al. 1996). In order to perform reliable studies on the deformability of soils, low area ratio and large sample sizes are recommended. Thus for the most demanding category A referred in ISO standard 22475-1, in line with these criteria, the properties of soils and rocks are assumed to remain unchanged during sample collection, handling, transport and storage. However, the sampling categories do not correspond exactly to a hierarchy of value or quality because they overlap.

For fine soils, the most used sampler is the stationary piston sampler with a diameter higher than 70 mm usually 100 mm, but for trimming in the lab, triaxial specimen with the least suspicion of disturbance, large diameter corers have been designed and tested. The best known are the samplers developed by université Laval and université de Sherbrooke in Quebec (La Rochelle et al. 1981; Lefebvre et Poulin 1979). However, both have been design principally for clayey fine soils. This paper presents the design of a new large sampler nominated A+ to emphasise the improved quality sought. In order to investigate the performance of the developed sampler and compare the quality of the specimens taken by the sampler, with that taken with other samplers, samples were taken at a French experimental site at le Pont de Cran. Laboratory tests such as oedometer tests are presented and discussed.

1.1. Sampler presentation

The objectives of such a sampler are to collect natural fine soils (clay or silt), normally to moderately overconsolidated for depths up to 10 m without casing. These soils will be at most of a firm consistency (in the sense of ISO standard), that is to say having a cohesion of 50 kPa (for higher values of cohesion the traditional sampler work well and these soils are less sensitive to the sampling). The ability to preserve the interstitial pore water and the level of saturation of the sample, which means keeping the pore water pressure at its initial value, will be a plus.

The techniques for closing a sampler are numerous:
- mechanical systems to close,
    - core catchers composed of spring blades, shells, knives (Kim et al., 2008),
    - sphincter with an inflated membrane (Larsson et al.,),
    - ball valve (Sanven et al. 2007),
- chemicals to seal,
    - two-component epoxy resin,
    - freezing or gel (Kazuo and Kaneko 2006).

The core catchers have the defect of not being waterproof (for example: it would be possible to place on the université Laval sampler, université de Sherbrooke sampler type knives that would fold under the holster, but this solution would not allow the sampling of poorly cohesive soils.) the sphincters will have trouble shearing slightly overconsolidated soils. Freezing is long and expensive, the epoxy resin used mainly in the oil industry requires a setting time, and gel can not keep heavy soft samples in the liner. There the ball valve remains the more versatile solution.

This sampler must be adaptable to most drilling machines used in French Public Works laboratories and companies. This implies to keep standard drill rods and a diameter not exceeding the capacity of the drilling rods clamps.

1.2. Proposed design for a A+ sampler

The first request made of an inner diameter of 200 to 250 mm is therefore reduced to 150mm. An inner diameter of 150mm core barrel would allow with the size of the ball valve to remain relatively compact.

Finally it was decided to develop a sampler which would have the following characteristics:

- strict compliance and even higher requirement than the Hvorslev index values indicated in the French standard and the ISO 22475-1 (CEN, 2021),
- use of a proven locking technique,
- sampling stage close to université Laval sampler, decoupling the rotation and pushing function,
- complete filling of the corer to preserve an intact sample with interstitial fluid and pressure of this one.

These choices lead to the concept illustrated in Fig. 1, the sampler consists of a body with an internal case of about 150 mm internal diameter complemented by a rotary outer tool provided with a ring gear to bore the borehole and a ball valve closing system.

1.3. Working principle

The following procedure has been developed to realize the sampling with this new sampler (Figure 1):

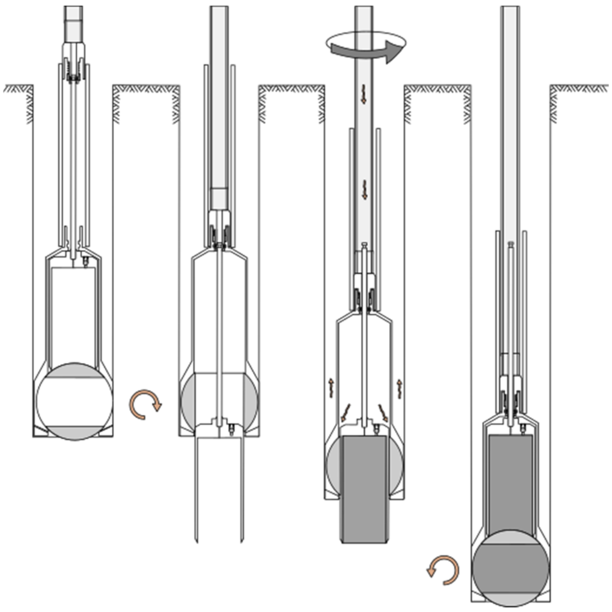

Figure 1. Sampling stages

1. positioning phase. The outer body is attached to the drill rods, so that the drill head supports friction along the walls of the borehole and descends without blocking. This requires an additional locking system (outer shell - "inner" rod) which will be locked in the downward phase and must be unlocked at the beginning of the next phase. The borehole walls must be maintained using bentonite mud as for the université Laval sampler to avoid the maximum wall collapse that would hinder the descent.

2. pushing phase. Once ball valve opened, outer barrel is disconnected from drill rods. Theses rods connected to a smaller inner rod, are used to push inner sampling tube on depth of penetration,

3. circulation of fluid is initiated and descending phase in rotation of the outer barrel starts. Inner barrel is not rotated. The drilling fluid (water injected through the drill string) rises along the body of the sampler,

4. closing phase of the ball valve. This closure is triggered by the docking of the inner tube in the outer barrel,

5. whole sampler is retrieved from borehole and operations to seal the sampling tube follow.

1.4. Construction

Fig. 2 and 3 show the final design of the sampler: the ball valve closing system, the inner casing and the compressed air reservoir needed to feed the various pneumatic jack actioning the closing system.

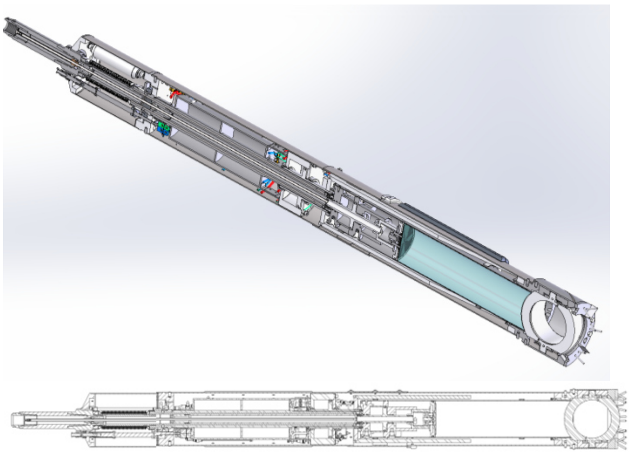

Figure 2. Cross section of A+ sampler

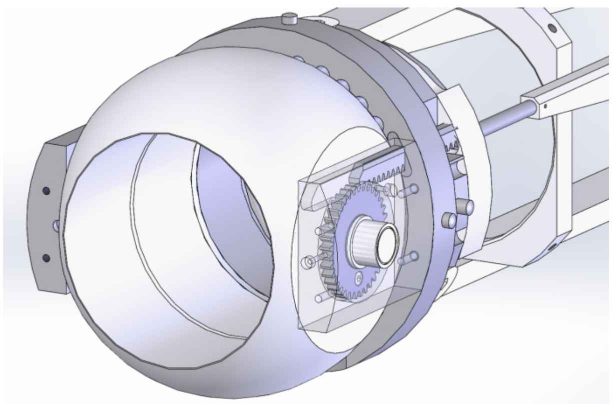

Figure 3. Ball valve arrangement of A+ sampler

A specific trailer has been designed and built to help handle the sampler and attached it to the drill rig (Fig. 4).

Figure 4. Trailer used to handle the sampler

During the first trial in the workshop and on site, difficulties have arisen due to the long inner splined mechanical shaft allowing the decoupling of the rotation drilling to the pushing action. The pneumatic circuit managing opening and closing of ball valve have also shown some fragility.

2. Tests on sites

The sampler has been tested in sandy soils (Fig. 5) and clayey soils (Fig. 6).

Figure 5. First tests of A+ sampler on Saint Malo beach

The first test performed in sand have shown that ball valve closing system work well even with the particle incoming and the pressure needed to make the ball to rotate was correctly designed.

A second test was performed in le Pont de Cran experimental test site in soft organic clay (Fig. 6).

Fig. 7 shows the quality of the cutting created by the teeth of the cutting shoe. This last design was inspired by the université Laval sampler.

Once retrieved from the borehole the cutting shoe is unscrewed and access to the ball valve allow to start the dismounting phase.

A metallic door is open on the body of the sampler and a hydraulic system is connected to the sampler (Fig. 8). The sample is moved in the liner and two plugs fitted with a gasket are fixed at each end of the sampling tube.

Figure 6. Sampling at Pont de Cran site

Figure 7. Quality of the cuttings

Figure 8. Insertion of bottom sealing cap

Figure 9. Sample container ready for storage

The sample in its container can be transported to the laboratory for further experiments. A new metallic cylinder is inserted in A+ sampler and sampling operations continue.

3. Sample quality evaluation

To evaluate the quality of the samples obtained using the new sampler, it was compared on a single site to seven types of sampler: Pushed sampler without casing (1 profile); Stationary piston sampler PS 100 mm (3 profiles) with three area ratio, Stationary piston sampler PS 80 mm with two area ratio, (5 profiles); université Laval sampler 200 mm (2 profiles). All the test campaigns were realized in the same period of the year between March and May, rainy season in this region.

3.1. Samplers characteristics

Table 1 gives the main characteristics of the samplers. The dimension and ratio are computed accordingly to 22475-1 standard (Fig 10).

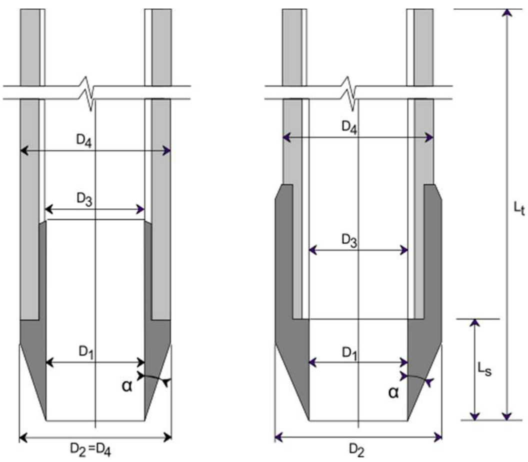

Figure 10. Definition of sampler dimensions

$$C_a = \frac{{D_2}^2 - {D_1}^2}{{D_1}^2} \cdot 100;\ C_i = \frac{D_3 - D_1}{D_1} \cdot 100;\ C_o = \frac{D_2 - D_4}{D_4} \cdot 100$$

Table 1 compares the different samplers used for sampling quality. All samplers have the same taper angle for their cutting shoes in the limits fixed by ISO 22475-1 standard.

Ordinary stationary piston samplers LPC type have area ratio close to 20 % accepted by the ISO 22475-1 standard. An effort was made to reduce the cumulative thickness of inner liner and outer barrel. A specific version in stainless steel without liner was also tested.

Table 1. Samplers dimensions

Type	D_1 mm	D_2 mm	D_3 mm	D_4 mm	C_a %	C_i %	C_o %	α °	L_t mm	L_t/D_1
PS	98	102	98	102	8	0	0	5	580	6
SPS	77	85	77.8	88	22	1	0	5	845	11
SPS m	76.9	82.4	77.6	82.4	14.8	0.9	0	5	769	10
SPS	95.8	105	97	105	20	1.2	0	5	1070	11
SPS i	98	102	98	102	8	0	0	5	580	6
SPS m	96.4	103.3	97.2	103.2	14.8	0.9	0.09	5	769	8
Laval	208	218	208	218	10	0	0	5	660	3
A+	149	154	149	154	6.8	0	0	5	750	5

According to the maximum ratio of length to diameter proposed by Hvorslev (1949), ISSMFE (1981) and 22475-1 (2021) all sampler are acceptable. For soft soils, the more favorable ratio is obtained by the université Laval and A+ sampler.

3.2. Experimental site

The site of le Pont de Cran is located in the commune of Rieux in the Morbihan department (Vilaine river crossing downstream from Redon). The site is quite homogeneous with a depth of 15 m of loose, coherent sediments of average consistency.

Three layers can be distinguished (table 2):

- the first two meters, overconsolidated by desiccation, correspond to the highest values of undrained cohesion, around 45 kPa;
- between 2 and 4 m depth, a layer of relatively soft consistency, with an undrained cohesion of about 15 kPa, presents a strong liquidity limit. It can be identified, according to the USCS classification, with a very plastic and weakly organic clay (lO- Ch);
- between 4 and 17 m depth, the clay has a medium consistency; the water content is about 70% and the undrained cohesion is about 38 kPa. The soil can be identified with a very plastic, low organic silt (lO-Sh).

The water table is generally 50 cm deep.

Table 2. General information on le Pont de Cran clay

Depth m	w %	w_L %	I_P %	ρ_d Mg/m^3	e	*OM* %	c_u kPa	C_c	σ'$_p$ kPa	σ'$_{vo}$ kPa)
0 - 2	48	75	30	1.10	1.3	1	45	0.45	160	7
2 - 4	108	125	82	0.66	2.9	3	15	1.64	25	16
4 - 8	64	70	31	0.93	1.8	2	40	0.70	96	30
8 - 17	73	87	47	0.91	1.7	4	39	0.85	105	67

Figure 11 shows typical ground investigation recording at le Pont de Cran obtained by conventional CPT, field vane tests and prebored and self-boring pressuremeter.

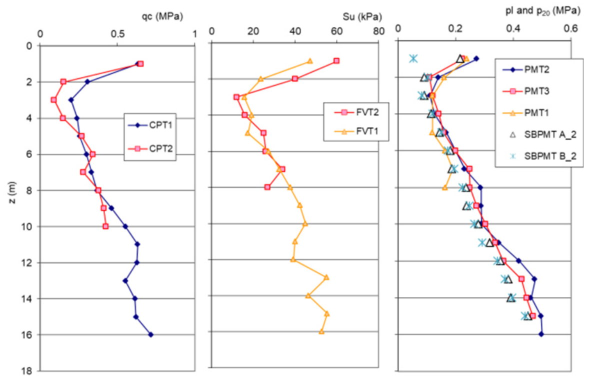

Figure 11. CPT, FVT and PMT records from le Pont de Cran site

Incremental oedometer tests were carried out on 38 cm² specimens with known density and water content. The following procedure was adopted:

- porous stones and papers on both end surfaces provided two-way drainage conditions,
- 24 h load duration on each load step,
- classical loading procedure with doubling of the vertical loading the subsequent load steps,
- intermediate load step at 30 kPa to improve determination of the presonsolidation pressure.

3.3. Results

Effect of disturbance on consolidation curves has been a very early observation made by Rutledge (1944). Observation were based on the curvature of e-log(σ') curves and compressibility parameters σ'_p , C_c and C_s derived from theses curves. Figure 11 shows the comparison of e-log(σ') curves measured by incremental loading oedometer. It can be seen that the e-log(σ') relation is affected by sampler type. The smoother transition between the initial recompression and the virgin part of the curve are obtained for the smaller diameters of samplers.

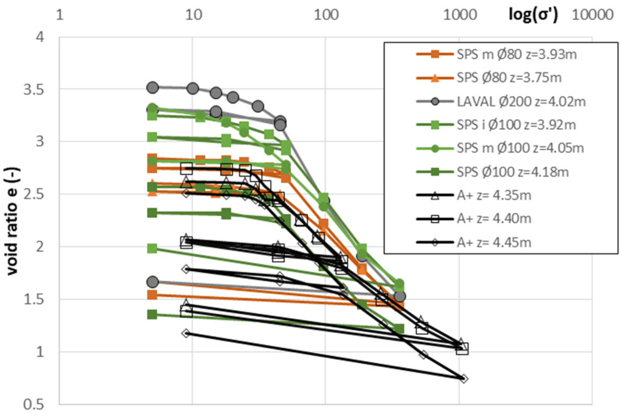

Figure 12. Sample container

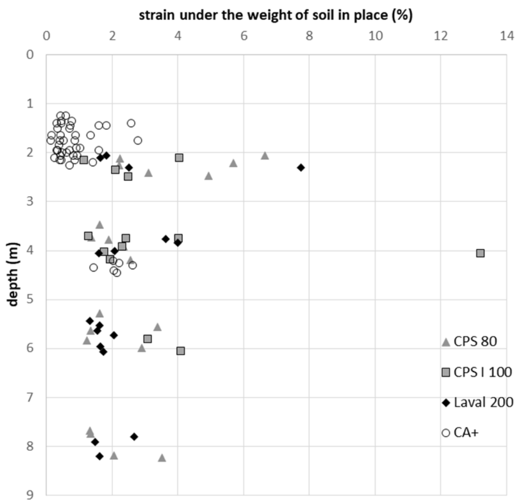

Figure 13. Evolution of area ratio with depth for sampler type

A more quantitative criteria based on oedometer compressibility analysis has been formulated by Berre (1986). The strain under in situ vertical effective stress σ'_{vo} below 2%, insures, in the case of soft clays, a high quality of samples.

This threshold is almost attained by all tested samplers (Fig. 12). Here, we focus on test results below 2 m, the upper layer being influence by water level fluctuation and their recent stress history (Lafond, 1953). The water content of the first layer (more silty and of brownish color) is lower. This transition zone can also be observed from the in situ testing profiles (Fig 11)

Results obtained on specimen trimmed in A+ and université Laval samplers gives values of strain, under in situ vertical effective stress, localized on the graph in the lowest values, the highest values being generally observed for the piston sampler 80 mm.

Figure 13 presents the preconsolidation pressure evolution according to sampler type and depth of sampling. In the zone influenced by the seasonal water level variation, a broader range of values is observed but below in the more soft and then consistent layer, the values stay more constrained.

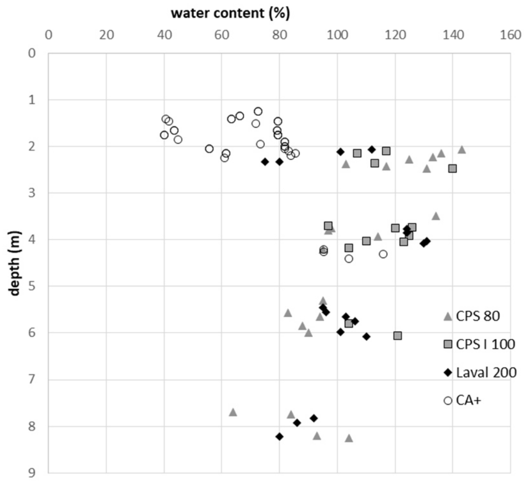

Figure 14. Evolution of water content with depth for sampler type

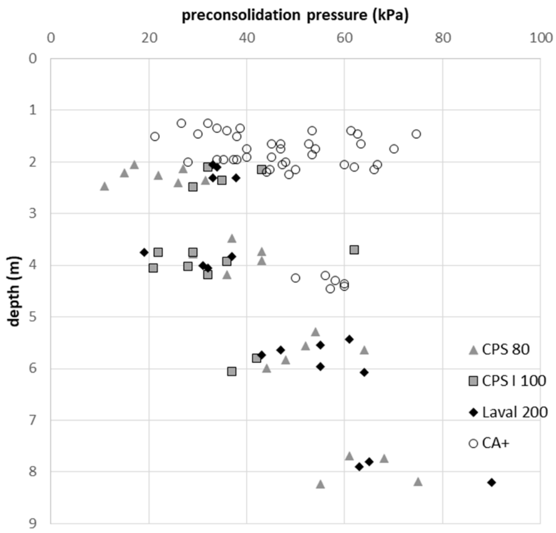

Figure 15. Influence of sampler type on préconsolidation pressure

For the preconsolidation pressure values of the same order are observed. Lowest values are obtained for specimen trimmed from samples retrieved by piston samplers and highest values are obtained from samples retrieved by the larger samplers.

3.4. Discussion

All these tests were not performed at the same time. Several site tests were needed to solve technical issues on the new sampler but these results were gathered over a three-year time span.

The study of the effect of the sampling procedures on the compressibility parameters took into account the randomness nature of the sampling. The specimens were selected from the soil within each sample in order to eliminate the most remolded parts.

These studies have highlighted a strong variability. This variability comes from the sampling techniques, for a part, but also from the natural spatial variability of the le Pont de Cran clay massif. The genesis of the site helps to explain the variability. The soft clays of le Pont de Cran presents some discontinuity and heterogeneity. These discontinuities are linked, on the one hand, to the mode of deposition, and on the other hand to the process of sedimentation and consolidation which is not negligible, since the thickness of the original silts was finally reduced by at least two. The numerous 40 - 45 degree slip planes observed in the samples, are the consequences of this process and of the bank slides. These landslides occur as a result of the evolution of the estuaries over time. It is clear that these discontinuities of sedimentary or dynamic origin are at the origin of the heterogeneity of the site. This may make it less surprising to find that samples taken at the same depth have different physical properties and different mechanical behavior.

4. Conclusions

In 1969, at the special session "soil sampling" of the International Congress of Soil Mechanics of Mexico, Idel et al. (1969) proposed a practical classification of samples. There were five sampling quality classes defined according to the parameters that can be obtained from the soil taken. This classification appears in the European standard, EN ISO 22475-1, and promotes the idea that for tests needing undisturbed samples high quality samplers are needed.

During this research, a new sampler has been developed and tested showing the same ability than université Laval sampler to retrieve large samples of fine soils but also silt and sand. Tests on a clay site have shown that some improvement of the operating principle have to be made. Several mechanical and pneumatic dysfunctionning were corrected allowing to realize a successful sampling campaign.

A comparative study with université Laval sampler and stationary piston sampler has been made, based on oedometric test procedures on the compressibility parameters that take into account the disturbance encountered. Analysis of the first tests realized allow to conclude in the view of the comparable results obtained (e.g. compared to université Laval sampler) that the design was successful.

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