



HAL
open science

Evolution of deformation parameters during cyclic expansion tests at several experimental test sites

Philippe Reiffsteck, Sonia Fanelli, Gilles Desanneaux

► **To cite this version:**

Philippe Reiffsteck, Sonia Fanelli, Gilles Desanneaux. Evolution of deformation parameters during cyclic expansion tests at several experimental test sites. ISC'5, 5th international Conference on Geotechnical and Geophysical Site characterisation, Sep 2016, GOLD COAST, Australia. 6 p. hal-01589900v2

HAL Id: hal-01589900

<https://hal.science/hal-01589900v2>

Submitted on 19 Sep 2017

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Evolution of deformation parameters during cyclic expansion tests at several experimental test sites

Ph Reiffsteck & S.Fanelli

Univ Paris Est IFSTTAR, Marne la Vallée, France

G. Desanneaux

CEREMA, DirTer Ouest, Saint Brieuc, France

ABSTRACT: For thirty years, cyclic pressuremeter expansion tests carried out at different experimental sites have helped develop a rich and extensive database. The results from these high quality tests allowed stress-strain parameters to be derived at low and medium strain levels. These cyclic tests were carried out using Ménard and self-boring pressuremeters. Around fifteen sites were studied covering a wide range of behavior from sandy soils to clayey materials at stress histories varying from normally consolidated to overconsolidated. This paper will present the sites and test programs with their main geotechnical characteristics. The paper will focus on the evolution of shear modulus with the number of cycles, the material type, the amplitude ratio as well as the ratio of mean expansion pressure to the at-rest horizontal stress.

1 INTRODUCTION

Ménard pressuremeter test equipment allows operators to achieve monotonic expansion tests (EN ISO 22476-4 similar to NF P94-110-1 ASTM D4719) and cyclic tests (NF P94-110-2) (AFNOR, 1999 and 2000). These tests include an unload-reload cycle performed in steps, in the same conditions as the Ménard pressuremeter test described in the EN ISO 22476-4 standard. The conventional expansion test using the drilling conditions recommended by the EN ISO 22476-4 standard and with the proposed loading program, does not give usable results directly for deformability prediction of geotechnical structures especially when the knowledge of modulus in the small strain range is required (Combarieu and Canépa, 2001).

Tests with unload-reload loops allow the determination of the cyclic deformation modulus. The values obtained are intermediate between the modulus in small strains obtained in the laboratory or with in situ wave propagation tests, and the conventional Ménard modulus (Ménard, 1960, Borel and Reiffsteck, 2006). However, a single cycle is insufficient to identify the evolution of soil characteristics under cyclic loading (Dupla and Canou, 2003). The present study, conducted as part of the national project SOLCYP (research project on the behavior of piles under cyclic loads, see the website for more information www.pnsolcyp.org) was an opportunity to perform multi-cycle tests with a probe inserted into a pre-drilled hole or by self-boring technique.

2 EXPERIMENTAL DEVICE

The principle of the test is to measure changes in the volume injected during the application of pressure cycles.

2.1 *Equipment*

The idea is to be able to perform cavity expansion cyclic tests with a pressuremeter probe inserted in the ground by self-boring or in a pre-drilled hole. The equipment used, developed by Jean Lutz SA company, is a pressure volume controller (CPV) (PREVO type), able to control solenoid valves by a PC computer via a specific application program. Measuring the change in volume during probe expansion is done either by measuring the volume of water injected or by measuring the movement of a feeler probe (Figure 1a and b).

The principle of operation is as follows. The various manual operations are carried out either directly on the CPV or by the software program. The cyclic control is performed on the basis of a test file accepting any type of signal, harmonic or multiple frequencies. The monitoring is done in real time on a datalogger.

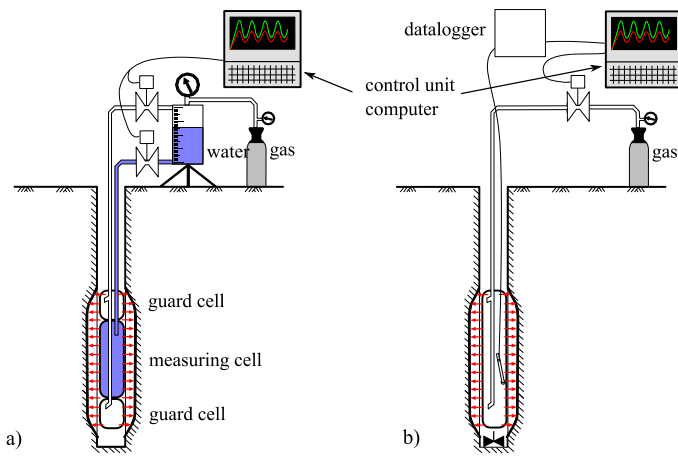


Figure 1. Architecture of the cyclic (a) Ménard pressuremeter, (b) self-boring pressuremeter

2.2 Test Method

During the 70s, the Association for Research in Marine Geotechnics bringing together different companies, consulting firms and research institutes in the field, coordinated numerous cyclic pressuremeter test campaigns on several sites. Details of the experiments are summarized in several reports and articles of the Symposium Pressuremeter and Offshore Applications held in Paris in 1982 (Jézéquel and Méhauté, 1982; Puech et al., 1982). Three types of tests were carried out; we present the two used in this study:

- cyclic loading test between two pressure limits p_M and p_m (Figure 2 a),
- loading tests between two variable pressure limits, whose average is however constant, the lower bound kept greater than the earth pressure at-rest p_0 (Figure 2 b).

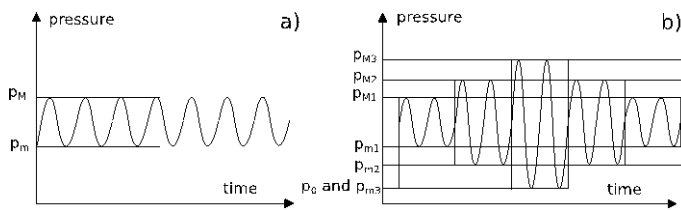


Figure 2. Different types of cyclic tests

The parameters used for the cyclic tests described above consisted in carrying out the test in pressure controlled mode and adapting the frequency to the type of soil in an attempt to remain drained using a stress level of 0.8 ($R_c = \Delta p_{cyc} / p'_0$), a frequency varying from 0.01 to 0.05 Hz and a number of cycles equal to 50.

The initial pressure p_m used to start the cyclic portion of the test is defined as the horizontal stress up to the earth pressure at-rest (effective preferably) and the maximum pressure p_M equal to $(1 + 0.8) p_m$ (Dupla and Canou, 2003). The pressure p_m , which was taken equal to p_0 , was defined from previous Ménard type expansion test results by the method proposed by Briaud (1992).

2.3 Cyclic modulus definition

The interest of achieving cycles with the pressuremeter to obtain small strain modulus in values appeared very early (Ménard, 1960). From the beginning, several moduli were defined from experimental curves.

In the first zone designated as "elastic", the modulus reaches a quasi-independent value of the level of deformation. It is called the "initial" G_0 (or G_{max}) module.

The curves in their monotonic part provide a "secant" modulus ($G_{s,1}$) defined by the slope of the line connecting the origin to the current point and in their cyclical part, another secant modulus ($G_{p,N}$) determined by the slope of the line connecting the two reversal points of the cycle N . The largest cyclic modulus is calculated using equation 1 using the notation in Figure 3:

$$G_{p,N} = \frac{\Delta p}{\Delta V / V_{mean}} \quad (1)$$

The loop in these unloading /loading sequences is ellipsoidal. It represents the energy dissipated by plastic deformation. The evolution of the cycles tilt or modulus during the cycles is used to assess the soil behavior. We can evaluate the cyclic hardening or softening and accumulation of deformation, stabilization, relaxation or ratchet? effect.

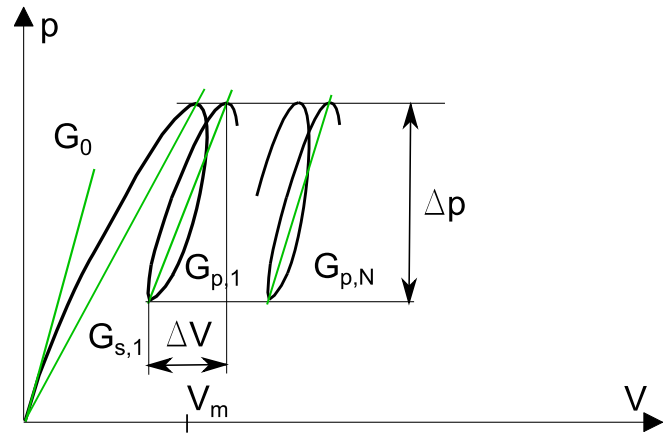


Figure 3. Calculation of cyclic modulus

The interpretation is based on the evolution of the characteristic area of the loading and unloading loops and the secant modulus of the hysteresis loops (Figure 3).

3 CYCLIC TESTS

3.1 Saint Briec Regional Laboratory tests

In the late 70s, the Laboratoire des Ponts et Chaussées of Saint Briec conducted several test campaigns involving the self-boring pressuremeter

with cyclic expansion (132 mm diameter PAF76 model). These tests included hundreds or thousands of cycles (duration of 24 to 72 hours). They were carried out on two main sites: Cran and Plancoët (Méhauté and Jézéquel, 1980).

3.1.1 Plancoët site

The site consists of a flat land bordering the river Arguenon. The deposit is composed of very loose fine soils: silts at the surface (0-4 m), followed by fine sand (especially from 6 to 9 m) and clays (10 to 12 m) with some inclusions of gravel and sand. The bedrock is at 15 m. The groundwater table fluctuates depending on the season from 0.30 to 1.50 m.

3.1.2 Cran site

The alluvial plain of the Vilaine, downstream from Redon, is a sedimentary valley of nearly 2 km wide. A clay deposit thickness of 10 to 20 m, rests on a layer of sand and gravel that covers the bedrock. At Cran, the right bank is comprised of a soft marine clay deposit 17 m thick resting on bedrock (shale and phanites??).

3.2 Solcyp project tests

Validation tests were performed on three sites: Gosier, Cran and Merville. The last two sites were the subject of numerous studies in the research project programmed by the French public road Laboratories (LCPC now IFSTTAR). The characteristics that have determined the choice, was a relatively overall homogeneity to a minimum depth of 5 to 10 m.

3.2.1 Gosier site

The first tests with the new equipment has been undertaken on the Gosier site in Guadeloupe (French Antilla) located in a potentially liquefiable area, instrumented and studied in the ANR project Belle Plaine. Ménard pressuremeter tests (incremental tests) were performed to complete the profiles obtained by piezocone penetration test. The tests were also used to assess the pressure p'_0 to use, then two cyclic pressuremeter soundings were conducted.

Figure 4a shows a plot of the corrected pressure using the volume variation obtained for the four tests from the MC2 series. After a first part that corresponds to the rise in the average monotonic load, the cyclic phase between p_M and p_m shows the stabilizing trend of almost all tests, even if it has never been reached. Apparently, the 7 m depth test shows a significant accumulation of volumetric strain due to the presence of a soft clay layer.

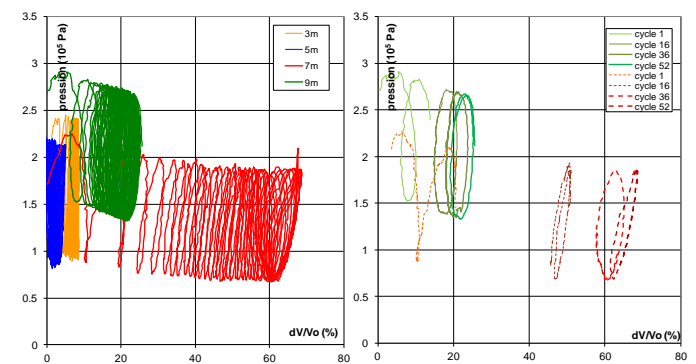


Figure 4. a et b PMT cyclic expansion tests at the Gosier site

3.2.2 Cran site

The tests carried out in 2011 were located close to the series made in 1979. At the 2 m depth, the test curve shown in Figure 5a shows high accumulation volume (of the order of 900 cm³) leading to the conclusion that the test was performed in the soft layer and the initial pressure inferred from previous studies had been overestimated. The signal obtained shown in Figure 5a is rather noisy because the amplitude of the pressure range is small, and an interaction between the control of the water and air circuits could not be corrected on time during the test.

3.2.3 Merville site

On the experimental site of Merville (North), the top soil at 1.5 m depth has the texture of low plastic silt affected by the fluctuation of the water-table and it covers the Flanders clay (overconsolidated) of Ypresian from 1.5 to 42 m depth..

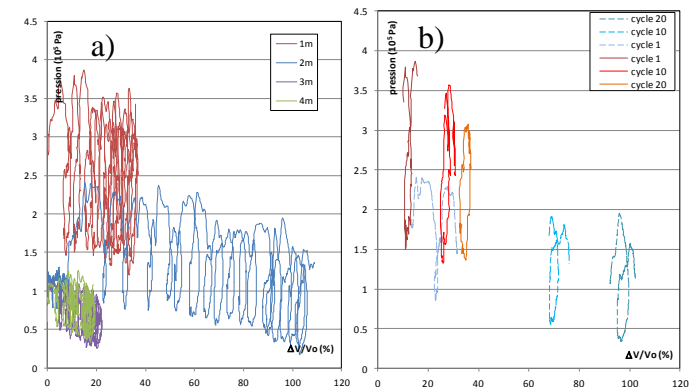


Figure 5. a et b SBP cyclic expansion tests at the Cran site

A self-boring pressuremeter sounding with cyclic tests: 6, 8, 10 and 12 m deep, alternating with monotonic expansion tests at 5, 7 and 11 m, was performed (Figure 6 and Figure 7a). The first three cyclic tests were performed with the same amplitude fixed from the monotonous expansion tests. The last test was performed with amplitude based on the 11 m test.

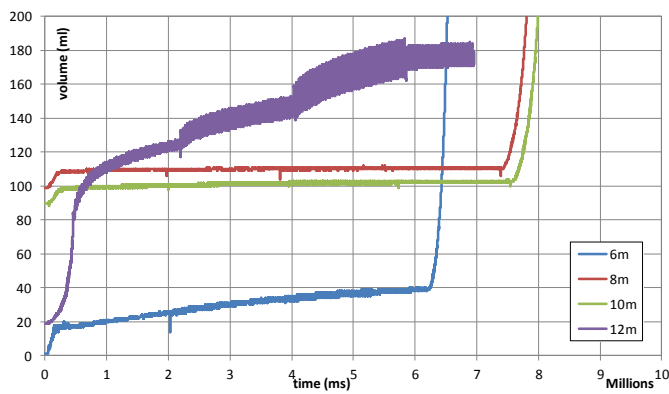


Figure 6. SBP cyclic expansion tests at the Merville site

60 kPa amplitudes have led to inaccurate results because on one hand the pressure source was set to too high pressure and therefore the solenoid valve of the buffer chamber was struggling to regulate and secondly that value is low and close to the magnitude of the precision of the servo. It is therefore necessary to adjust the amplitudes to depths and re-evaluate the method of determination thereof.

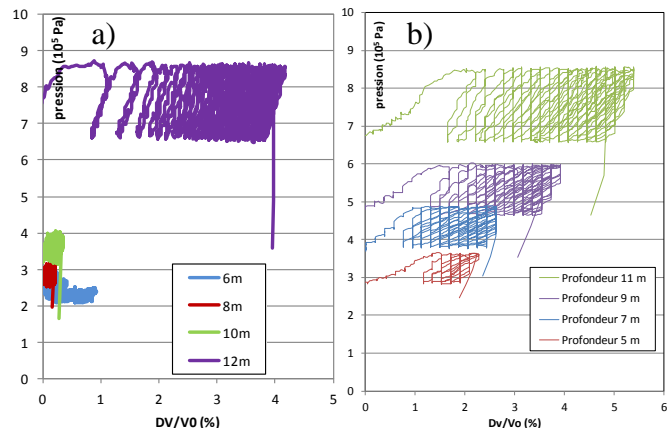


Figure 7. (a) Self boring and (b) pre-drilled cyclic expansion tests – first fifty cycles - Merville site

Right next to the self-boring tests, a Ménard pressuremeter sounding was performed in a borehole drilled meter by meter using a continuous flight auger with cyclic tests at 5, 7 and 11 m which gave comparable results (Figure 7).

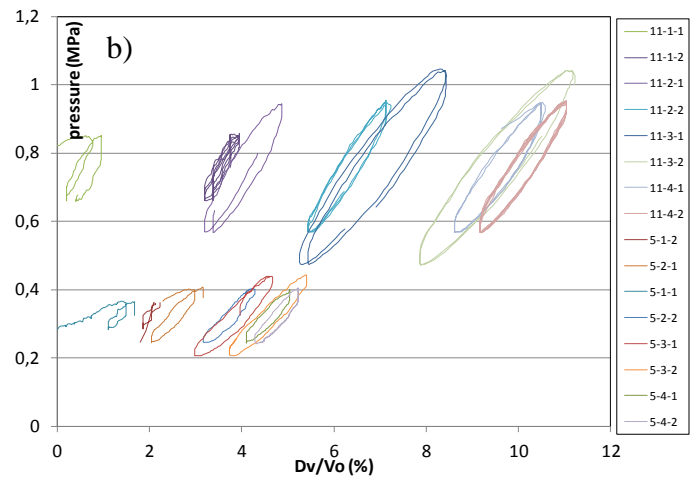
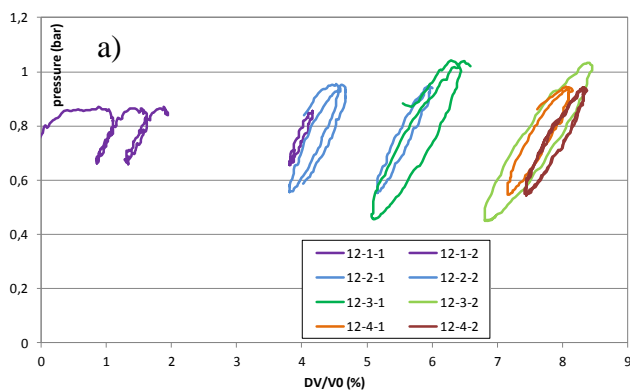


Figure 8. (a) Self boring and (b) pre-drilled cyclic expansion tests – all test sequence - Merville site

4 DISCUSSIONS

A first observation is that the signal obtained shown in Figures 4 to 7 is noisier than the one given in the articles of Jézéquel and Le Méhauté (1982) because the control of the pressure volume controller by ball screw using a volume rate of 2 % / min is more stable than a servo pressure valve. The resulting cycles have singular points with a flat part and no jog.

Various experiments have shown that a minimum of 50 cycles is required to get a clear evolution of the secant modulus and it is not possible to be limited to a few numbers of cycles – 3 to 10 for example – to obtain representative results. Note that the variation of the secant modulus of 50 to 500 cycles was 10% on average and from 500 to 5000 of 3%.

Although the protocol differences due to the development of these equipment and testing protocols do not allow a detailed comparison, the observed volume accumulations are of the same order of magnitude with various insertion modes. The quality of pre-drilling is essential for a test with a minimum initial injected volume. On two sites (Gosier and Cran) regardless of the insertion mode, the large accumulation of strain at some levels is a possible indicator to locate layers with low resistance to of cyclic loading (Figures 4 and 5).

During all tests, a stabilization of cycles means deformations relative to the number of cycles could be observed. Depending on the soil type, the cycles tend to straighten up more or less strongly, as seems to be the case for Plancoët sand and Merville clay.

According to table 2, for granular materials as silt and sand, a ratio $G_{p,50}/G_{p,1}$ close to 3 but for slightly overconsolidated clay (Plancoet, Cran at 1 m, Merville) this ratio drop to 2 and for compressible clay and loose sand (Gosier, Cran at 2 m) become close to 1.5.

Table 1. Test characteristics for first phase of 50 cycles

Site	Borehole	Soil	z (m)	$G_{p,1}$ (10^3 Pa)	a_{M0} (%)	$G_{p,50}/G_{p,1}$
Plancoët	8-3	silt	2	5,19	0,5	1,6
			3	3,46	1	1,8
	7-3		2	1,08	5	3
	8-3	sand	7	9,98	0,5	2,2
	16-1		7	6,49	1	2
	7-3		7	2,69	5	3,3
	8-3	clay	11	8,58	0,5	1,43
16-1	11		6,47	1	1,9	
7-3	11		3,75	5	2,1	
Cran 1	C1	clay	mean	29,9	1,67	1,15
	C2	clay	mean	20	0,99	1,09
Gosier	C2-PMT	sand	7	51,6	0,5	1,60
			9	13,9	3,5	1,41
Cran 2	A0-PAF	clay	1	60,8	10	2,71
			2	25,6	12	1,59
Merville	PAF	clay	6	426	0,8	2,01
			12	294	3,5	1,93
Merville	PMT	clay	5	145	0,6	1,37
			11	255	0,9	1,21

The multi-amplitude test series allow to obtain curves of cyclic modulus evolutions as a function of the depth and magnitude of the cycles for different soil conditions (Figure 8 and Table 2).

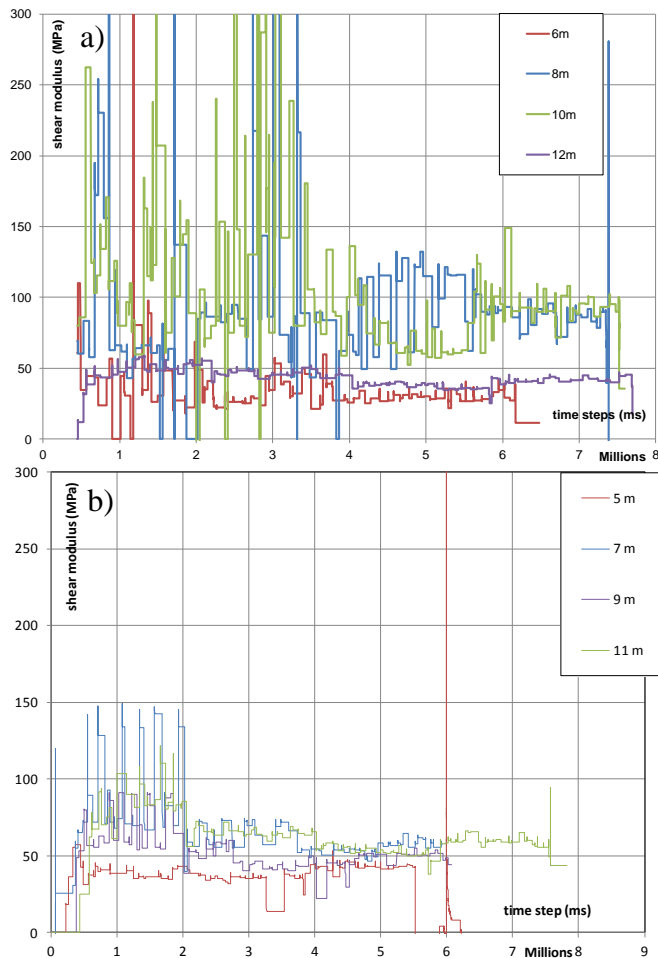


Figure 9. Evolution of loops secant modulus a SBP et b Menard expansion tests Merville site

We observe during these multi-cycle tests on clay that the moduli have changed during phases of dif-

ferent magnitudes but that within the same phase they remained very stable (Figure 9). In the first cycles of a constant amplitude phase, a lower value of the modulus is often observed that tends to increase quickly and to stabilize.

Unlike previous tests at low amplitude performed at the Merville site, Figure 9a shows for the 12 m test (amplitude 6 time higher) lower values of modulus and a immediate decrease of the modulus at the three first phases .

The high variability in the testing phase for the 8 and 10 m depths and the low modulus of variation is linked to the too small amplitude of the cycles. These two phenomena have disappeared for the predrilled tests.

The comparison of cyclic moduli (approximate by a simple spreadsheet function) at Merville (Figure 9) shows a factor of 1 between tests with predrilled and self-boring pressuremeters.

Table 2. Modulus evolution over several amplitudes

Site	tool	z (m)	$G_{p,50}/G_{p,1}$ of phase			
			1	2	3	4
Plancoët	SBP	1	1.83	1.08	0.8	1.27
Merville	SBP	6	0,62	0,57	0,90	1,17
		8	1,23	0,98	0,82	1,12
		10	0,70	0,56	0,45	1,04
Merville	PMT	5	3,16	1,38	0,91	0,99
		7	2,28	1,15	1,01	0,96
		9	1,32	1,56	1,00	1,00
		11	3,46	1,12	0,94	0,96

There is a very similar evolution in the loose soil of Plancoët site and the overconsolidated clay at the Merville site: an important development for the first amplitude and a near stabilization for other amplitudes.

5 CONCLUSION

The various campaigns, with mono or multi amplitude cyclic tests, have shown the value of this test to identify the evolution of shear modulus as a function of number of cycles and the potential of the test to locate the horizons susceptible to liquefaction.

It is better to specify the test conditions for comparability of the datasets and if possible to arrange the measurement of pore pressure at the membrane to estimate potential accumulations of pressure in clayey soils or adapt the speed of the expansion to keep the conditions drained.

6 AKNOWLEDGMENT

The authors thank the national project SOLCYP and the Ministry of Environment Energy, Sustainable Development and the Sea for funding this research

project as well as their colleagues and O. Malassingne, A. le Kouby and J.-L. Tacita.

7 REFERENCES

- AFNOR (1999) Essai pressiométrique Ménard – partie 2 Essai avec cycle, NF P94-110-2, Reconnaissance et essais, pp. 43.
- AFNOR (2000) Essai pressiométrique Ménard – partie 1 Essai sans cycle, NF P94-110-1, Reconnaissance et essais, pp. 43.
- Borel S., Reiffsteck Ph., (2006) Caractérisation de la déformabilité des sols au moyen d'essais en place. LCPC Paris, pp. 132.
- Briaud, J.L., (1992). The Pressuremeter, A. A. Balkema, Rotterdam, Netherlands.
- Combarieu O., Canépa Y. (2001) L'essai cyclique au pressiomètre, BLPC, 233, 37-65.
- Dupla, J.C., Canou J. (2003). Cyclic pressuremeter loading and liquefaction properties of sands, Soils and Foundations, Vol. 43(2), 17-31.
- Jézéquel J.F., Le Méhauté A. (1982) Essais cycliques au pressiomètre autoforeur, Symposium sur la pressiométrie et ses applications en mer, Paris, Éditions Technip, 221-233.
- Le Méhauté A. Jézéquel J.F., (1980) Essais cycliques au pressiomètre autoforeur, Rapports des LPC, FAER 1-05-09-22, 29 pages
- Les Pressiomètres Louis Ménard (1960) Phase de déchargement des essais pressiométriques, Etude théorique et applications, Circulaire 3 pages
- Puech A., Brucy F., Ma E., (1982) Calcul de la capacité axiale des pieux de fondations marines à partir du pressiomètre autoforeur, Symposium sur la pressiométrie et ses applications en mer, Paris, Éditions Technip, 373-388..