Ménard Pressuremeter Tests cross-checked under the ARSCOP program in sandy soils

C. Jacquard[1] , M. Rispal[2]

Fondasol, Avignon, France, catherine.jacquard@fondasol.fr [1], michel.rispal@fondasol.fr [2]

ABSTRACT: This paper presents a campaign of comparative tests performed on two sites with Ménard Pressuremeter probe in a sandy soil below water table. It is known that the performance of pressuremeter tests in such soil is delicate and depends very much on the know-how of the operator. The goal of this campaign is to compare under the ARSCOP program the current practice with the recommendations of the standard EN 22 476-4. The principle consists in carrying out a series of drillings to perform several pressure tests in each of them. The pressuremeter tests carried out in the reference borehole (open hole rotary drilling with slurry circulation and probe with flexible cover) are compared to those performed in boreholes carried out with other drilling tools (such as self-drilling probe TUBA®, ROTOSTAF® tools or other types of probe equipment such as slotted tube). A discussion of the relevance of the requirements of Table C.2 of the standard EN 22 476-4 for the soil concerned follows.

Keywords: Ménard pressuremeter; limit pressure; Ménard modulus

1. Introduction

The ARSCOP program is a collaborative French research project, which consists in reviewing usual procedures on the one hand for Ménard pressuremeter tests (first axis) and on the other hand for geotechnical designs based on Ménard pressuremeter tests (second axis). It started in 2016 and finishes in 2020.

In 2019, a campaign of cross tests has been carried out to compare the current practice with the recommendations of the standard EN 22 476-4 [1]. Two sites constituted of sand soils have been tested: one situated in the south west of France at Messanges [2] has been performed by Fondasol, and the second situated in the south east of France at Fos-sur-Mer [3] has been performed by Sol-Essais.

We will first describe the program performed on each campaign, and then will discuss the results obtained and propose some recommendations for pressuremeter tests in sandy soils.

2. Campaign at Messanges

2.1. Site description

Figure 1. Location of the site of Messanges- Sand quarry of Durruty (Google Earth)

The site of Durruty sand quarry is situated to the east of the village of Messanges in south West of France (Figure 1). The sand is a sand dune with grain size mostly between 0.25 and 0.5 mm.

The depth of the water table is between 2 and 3 m.

2.2. Program performed

The campaign was held in 2019 between 26th of August and the 5th of September. A drilling machine of Fondasol

carried out 7 boreholes (SP1 to SP7), and a drilling machine of Apageo performed one borehole (SP8). All boreholes were 11m deep, and 8 tests were carried out in each hole, from 3m depth to 10m depth. All tests were performed in accordance with procedure B of the ISO 22 476-4 standard (tests carried out after a one meter drilling stage length in order to ensure a good pocket quality with BX probes). The reference drilling SP1 was performed with a 63.5 mm (2''1/2) tricone bit under slurry circulation, and tests were performed by using a probe with the flexible cover sleeve and a 3mm thick membrane (FSM). The other boreholes were also drilled in accordance with the standard, but with other types of probes or equipment to see if this had any influence on the measured values: probe with a harder flexible cover, long central cell in a slotted tube (LST), and a short central cell in a slotted tube (SST) (see Table1).

The length of the central measuring cell of the probes (l_c) and the inside diameter (d_c) of the calibration cylinder are given in Table 2, which also provides calibration parameters: the ultimate pressure loss p_{el}, the volume loss factor a, the volume obtained in the volume loss calibration test Vp, and the original volume of the central measuring cell Vc.

2.3. Results

The measured values are presented in Figure 2. The Messanges site is composed of two layers of sand: medium sand between 3 and 8m depth and very dense sand between 8 and 10m. Considering the number of tests in each layer, we only analyze here the first layer for the following analysis. The average values μ and the standard deviation σ obtained in medium sand for Ménard limit pressure p_{LM} and for Ménard pressuremeter modulus E_M are reported in Table 3, as well as the E_M/p_{LM} ratio.

Table 1. Program realized on Messanges site

BH	Type of drilling	Type of probe/equipment
SP1	Tricone 63.5mm(OHD), under slurry circulation	3mm thick pure rubber cover (RC)
SP2	Tricone 63.5mm(OHD), under slurry circulation	Textile strips rubber cover (TRC)
SP3	Tricone 66mm(OHD), under slurry circulation	Long cell + slotted tube (LST) 49/63 probe and thin steel strips
SP4	Tricone 66mm (OHD), under slurry circulation	Short cell + slotted tube 49/63 (SST) probe and thin steel strips
SP5	Tricone 66mm(OHD), under TUBA® system	Short cell + slotted tube 49/63 (SST) probe and thin steel strips
SP6	Tricone 63.5mm(OHD), under slurry circulation	Short cell + slotted tube 46/60 (SST) probe and thin steel strips
SP7	Tricone 63.5mm(OHD), under slurry circulation	Flexible protection of thin textile strips - Lutz
SP8	Roto STAF® system	Long cell + slotted tube (LST)- Apageo

Table 2. Probes characteristics on Messanges site

BH	probe	d_c (cm)	l_c (cm)	a (cm3 /MPa)	Vp (cm3)	Vc (cm3)	pel (MPa)
SP1	RC	6.5	21	2.54	272	425	0.22
SP2	TRC	6.5	21	0.76	144	553	0.22
SP3	LST	6.8	37	2.60	338	1006	0.30
SP4	SST 49/63	6.8	21	1.54	138	625	0.37
SP5	SST 49/63	6.8	21	0.69	185	578	0.36
SP6	SST 46/60	6.5	21	2.25	189	508	0.30
SP7	TRC	6.5	21	5.35	185	512	0.17
SP8	LST	6.6	37	3.20	137	1127	0.35

Table 3. Average values of pLM and EM between 3 and 8m on Messanges site (45 tests)

	SP1	SP2	SP3	SP4	SP5	SP6	SP7	SP8
μ p_{LM}	1.35	0.88	1.71	1.62	1.53	1.42	1.27	1.35
σ	0.27	0.27	0.43	0.23	0.62	0.39	0.59	0.48
μ−σ	1.07	0.61	1.28	1.39	0.92	1.03	0.68	0.87
μ +σ	1.62	1.15	2.15	1.85	2.15	1.8	1.85	1.83
μ E_M	7.0	6.0	21.1	18.9	14.9	14.1	7.4	19.4
σ	2.2	2.4	5.7	6.1	2.8	6.8	4.6	6.1
μ−σ	4.8	3.7	15.4	12.8	12.1	7.3	2.8	13.3
μ +σ	9.1	8.40	26.8	25.1	17.7	20.9	12	25.5
μE_M/p_{LM}	5.2	6.9	12.4	11.7	10.9	9.8	5.5	14.6

2.4. Discussions

The average Ménard limit pressure p_{LM} in the reference borehole SP1 is 1.35 MPa; considering all 45 tests the mean value is 1.39 MPa, with a standard deviation of 0.43 MPa. If we exclude values that are above or below μ+/-σ in each drilling from this analysis, we derive to an overall average p_{LM}= 1.28 MPa and a standard deviation of 0.32

MPa for the 31 remaining values (see Table 4). The observed differences in average reflect more the variations of soil resistance than a difference of behavior due to the probes characteristics used to carry out these tests.

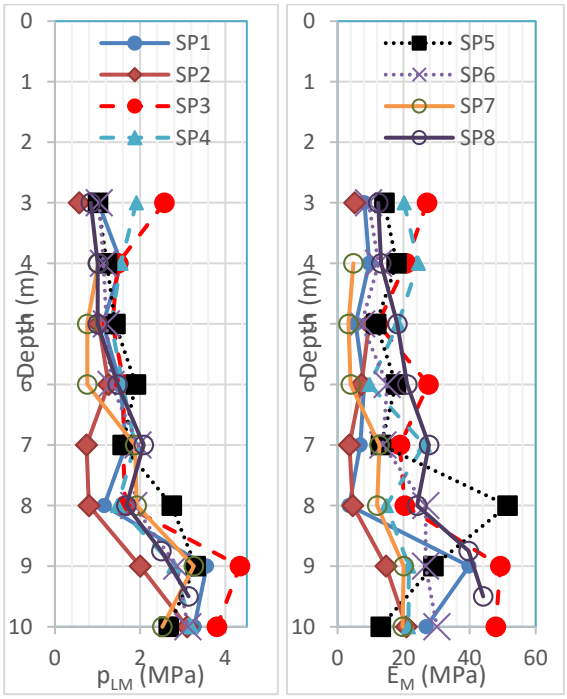

Figure 2. Pressuremeter modulus (E_M) and limit pressure (p_{LM}) measures for MESSANGES site

Table 4. Average values pLM between 3 and 8m on Messanges site without extreme values (31 tests)

	SP1	SP2	SP3	SP4	SP5	SP6	SP7	SP8
μ p_{LM}	1.35	0.86	1.54	1.54	1.53	1.18	0.85	1.29
σ	0.23	0.15	0.13	0.06	0.62	0.12	0.15	0.34
μ–σ	1.11	0.70	1.42	1.48	0.92	1.06	0.70	0.95
μ +σ	1.58	1.01	1.67	1.60	2.15	1.30	1.00	1.63

The average Ménard pressuremeter modulus E_M in the reference borehole SP1 is 7.0 MPa; it varies from 6.0 MPa in SP2 (-13% compared to SP1), to 21.1 MPa in SP3 (+304% compared to SP1). We have here 3 result groups : SP1, SP2 and SP7 giving similar and low values of E_M; SP5 and SP6 giving middle values; and SP3, SP4 and SP8 giving extremely high E_M values.

We can first note that the type of the flexible cover such as pure rubber or textile strip cover do not influence the test results, and that the 3 boreholes performed with flexible protection give the same levels of values.

It can be seen that that slotted tubes give systematically higher values of E_M : this was not expected in this case, because probes were not driven in the soil, but were rather only pushed down in a pre-bored hole.

It can also be noticed that the long cell slotted tube 49/63 probe in SP3 and SP8 lead to the higher values of E_M/p_{LM}. Intermediate values of E_M/p_{LM} ratio are given by the tests performed with self drilling systems such as TUBA® system (SP5) and with driven 46/60mm slotted tube in 63.5mm borehole (SP6).

The E_M/p_{LM} ratio is very low for the first group (SP1 ; SP2; SP7); according to Ménard [4], values between 5 to 8 are excepted in alluvial soils such as sands and gravels, silty sands under water level). Cassan [5] explains that the E_M/p_{LM} ratio distribution may present a very great dispersion, even in apparently homogenous sand sites. The example is given for a sand with 2 groups of results: the first has about E_M/p_{LM} =7, the second has about E_M/p_{LM} =13 (see fig.3).

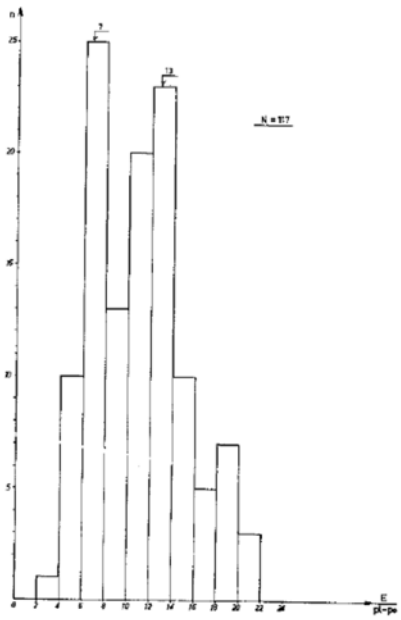

FIG. V.34. — *Sables de la vallée de la Saône.*

Figure 3. Histogram of E_M/p_{LM} ratio given by Cassan [5] relative to 117 Ménard pressuremeter tests performed in sands

3. Campaign at Fos-sur-Mer

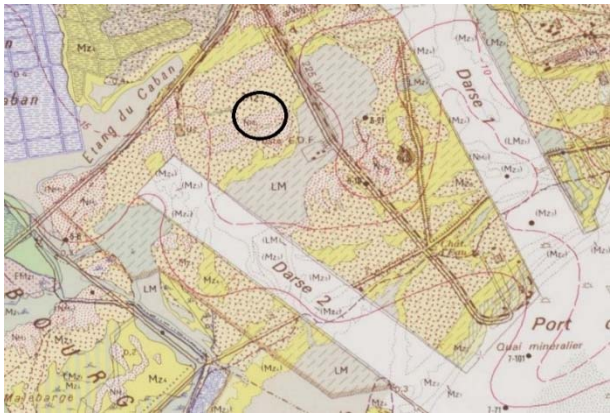

Figure 4. Location of Fos-Sur-Mer site (BRGM)

3.1. Site description

The site is situated near the Etang du Caban at Fos-Sur-Mer (Figure 4). The colluvions are composed of lentils of silts and sands.

The watertable is found between depths of 1.9 and 2m.

3.2. Program performed

The campaign was held in 2019 between the 3rd and 7th of June. A drilling machine of Sol-Essais carried out 7 boreholes (SP1 to SP7) of 11m depth in which 8 tests were carried out. 4 profiles (SP1 to SP4) where established with a slotted tube directly vibro-driven in the soil with ground displacement, which is considered acceptable by the ISO 22 476-4 standard [1]. The other profiles were performed in rotary open hole drillings under slurry circulation, which is recommended by the standard, and tests were carried out in accordance with procedure B of the standard; tests were carried out after a one meter of drilling stage in order to ensure a good pocket quality with BX probes. The reference drilling SP6 was totally in accordance with the European standard EN ISO 22 476-4: it was performed with a 63.5 mm tricone under slurry circulation, and tests were performed with a probe that had a 3mm thick pure rubber flexible cover. The other boreholes were performed with other types of probes or equipment.

Table 5. Program undertaken at Fos-Sur-Mer site

BH	Type of drilling	Type of probe/equipment
SP1	Driven slotted tube (DST)	Short cell + slotted tube 49/63 and textile strips rubber cover (SST-TRC)
SP2	Driven slotted tube (DST)	Short cell + slotted tube 49/63 with 3mm thick pure rubber cover (SST-RC)
SP3	Driven slotted tube (DST)	Long cell + slotted tube 49/63 and textile strips rubber cover (LST-TRC)
SP4	Driven slotted tube (DST)	Long cell + slotted tube 49/63 with 3mm thick pure rubber cover (LST-RC)
SP5	Tricone 63.5mm(OHD), under slurry circulation	Long cell + slotted tube 49/63 with 3mm thick pure rubber cover (LST-RC)
SP6	Tricone 63.5mm(OHD), under slurry circulation	Flexible sleeve with 3mm thick pure rubber cover (FSM-RC)
SP7	Tricone 63.5mm(OHD), under slurry circulation	Short cell + slotted tube 49/63 with 3mm thick pure rubber cover (SST-RC)

3.3. Results

Figure 5 presents the values and Table 6 the average and standard deviation of values obtained from this campaign.

Table 6. Average values between depths of 2 and 9m at Fos-sur-Mer site (56 tests)

	SP6	SP7	SP5	SP1	SP2	SP3	SP4
$\mu\ p_{LM}$	0.57	0.85	0.65	0.96	0.82	0.66	0.92
σ	0.17	0.21	0.13	0.23	0.22	0.17	0.22
$\mu-\sigma$	0.40	0.64	0.52	0.73	0.60	0.49	0.70
$\mu+\sigma$	0.74	1.06	0.79	1.18	1.04	0.82	1.14
$\mu\ E_M$	9.3	27.0	13.6	17.7	16.9	15.9	24.1
σ	3.4	11.9	6.2	10.5	10.5	7.8	12.5
$\mu-\sigma$	5.9	15.1	7.4	7.2	6.4	8.1	11.6
$\mu+\sigma$	12.7	38.9	19.7	28.2	27.5	23.7	36.6

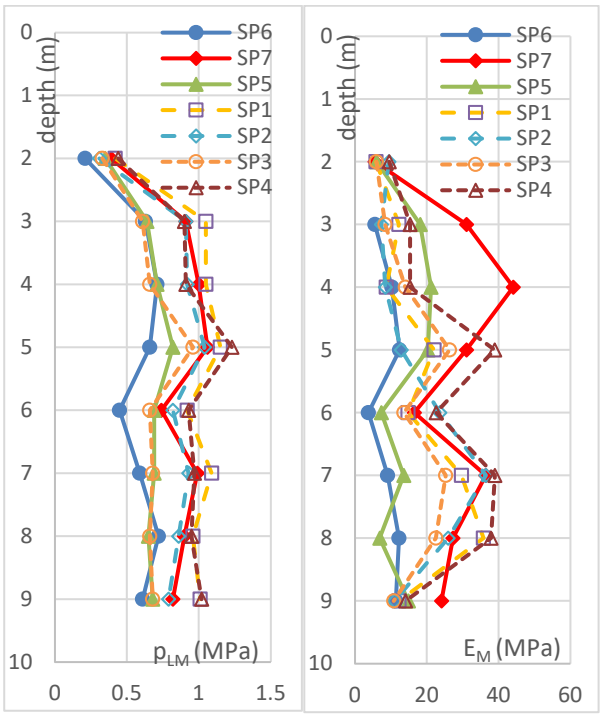

Figure 5. Limit pressure (p_{LM}) and pressuremeter modulus (E_M) measures on FOS-sur MER site

3.4. Discussions

The average Ménard limit pressure p_{LM} in the reference borehole SP6 is 0.57 MPa; it varies in other boreholes from 0.65 MPa in SP5 and SP3 (+14% compared to SP6) to 0.96 MPa in SP1 (+67% compared to SP6). Regarding the type of drilling (OHD vs DST), it was not observed that p_{LM} was systematically lower in OHD, because SP1 is rather high, and SP3 is rather low and both are DST. No tendency can be derived from the length of the cell in slotted tube. Variations of average values from a profile to another is rather due to the heterogeneity of the soil.

The average Ménard pressuremeter modulus E_M in the reference borehole SP6 is 9.3 MPa, which is lower than all averages, i.e. from 13.6 MPa in SP5 (+146% compared to SP6) to 27 MPa in SP7 (+292% compared to SP6). We have here 3 groups: SP6 and SP5 giving similar low values of E_M; SP4 and SP7 giving high values; and SP1, SP2 and SP3 giving intermediate values of E_M.

When considering one of the CPT (Figure 6) performed on this site, we understand that some gaps in p_{LM} and E_M values between SP5, SP7 and SP6 (all OHD methods) may be due to the heterogeneity of the soil.

Anyway, we have similar results with tests performed in Messanges: flexible cover in a rotary open hole drilling gives significatly lower values than probes in a slotted tube.

Values measured by DST method give relatively homogenous averages (from 15.9 to 24.1 MPa). These values are higher than those measured by OHD method and the probe equipped with a flexible cover (SP6), which was expected.

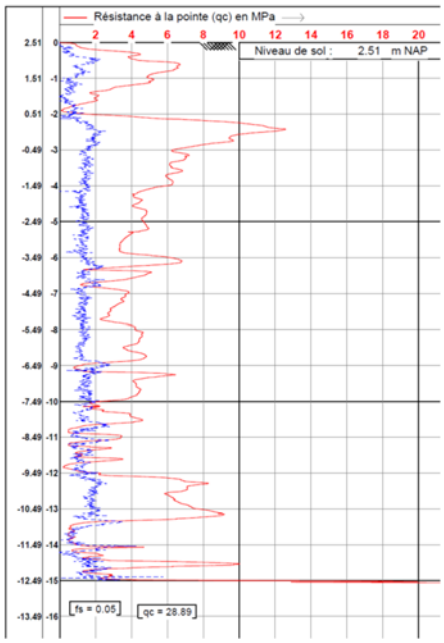

Figure 6. CPT measurement on FOS-sur MER site

4. Results from other sites

Other comparisons were also carried out by Fondasol from other sites.

The first one is located in the city of Bayonne (south west of France) in silty sands: tests were performed in 5 boreholes (SP1 to SP5) during a first campaign in 2017 using a probe protected by a slotted tube in rotary percussion method under slurry circulation. In 2019, tests were again performed in 2 other boreholes (SPE1, SPE2) using rotary drilling with 63.5 mm tricone bit under slurry circulation with a probe that was protected by a textile strips rubber cover. Logs of values are presented in Figure 7.

During the 2017 campaign, 3 groups of soils were described regarding their pressuremeer tests results (see Table 7).

In complementary boreholes performed in 2019, average E_M values in each soil group were systematically lower in a range of about a ratio of 2 compared to the initial measurements.

We had the same trend ratio on a campaign of control tests carried out in the city of Anglet (south west of France).

Table 7. Pressuremeter tests of soils described on Bayonne site

	1 Loose silty sand - 44 tests			2 Medium clayey sand – 6 tests			3 Dense sands – 41 tests		
	p_{LM}^*	E_M	E_M/p_{LM}	p_{LM}^*	σE_M	E_M/p_{LM}	p_{LM}^*	σE_M	E_M/p_{LM}
min	0.3	2.8	5.8	1	10	10	1.20	14.9	10.2
max	1.08	27	27.6	1.10	29	27.9	2.47	73.0	49.0
σ	0.70	10.0	14.4	1.05	17.1	16.2	1.79	39.8	22.7
SD	0.19	5.20	6.1	0.03	7.47	7.1	0.38	14.3	8.5

Table 8. Control Pressuremeter tests of soils described on Bayonne site

soil	nb tests	$p_{LM}^*{}_c$ (MPa)	E_{Mc} (MPa)	$E_{Mc}/p_{LM}^*{}_c$	p_{LM}/p_{LMc}	E_M/E_{Mc}	ratio/ratioc
1	4	0.35	2.35	6.8	2.0	4.3	2.1
2	3	1.16	8.07	7.01	0.9	2.1	2.3
3	2	1.75	20.6	11.1	1.0	1.9	2.0

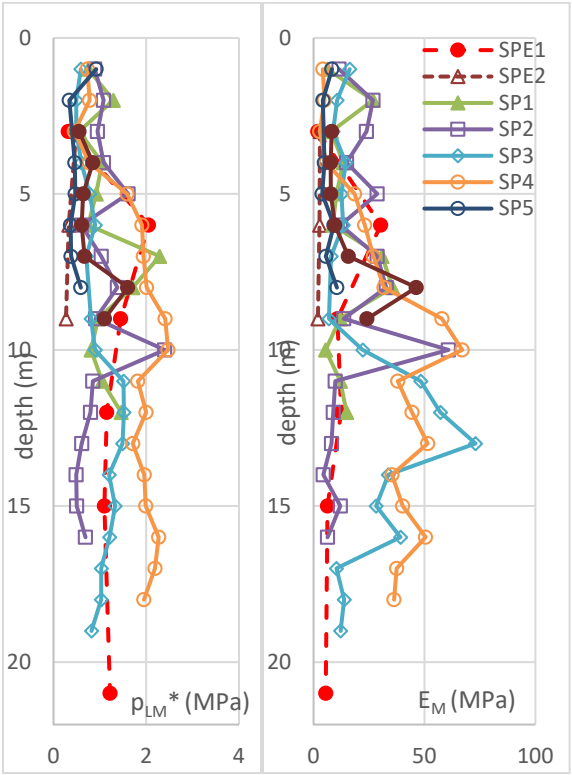

Figure 7. Net limit pressure (p_{LM}^*) and pressuremeter modulus (E_M) measures on BAYONNE site

5. Conclusions

These cross tests performed in medium to dense sandy soils give us several informations:

Regarding the Ménard limit pressure p_{LM}: on both sites in medium dense sand, it is not obviously affected by the kind of probe and equipment choosen for tests realised in a prebored hole, and neither affected by the type of drilling (OHD/vs DST).

Concerning the Menard modulus E_M, these first tests point out significant differences with higher values when slotted tubes are used with DST method (Fos-Sur-Mer site).

In both campaigns, we did not observe significant differences due to the length of the cells in the slotted tubes.

This ascertainment is confirmed by some observations with control tests on other sites.

In loose sandy sand below water table, the standard [1] accepts rotary open hole drilling (OHD) under slurry circulation or roto-percussion with mud; pushed tubes are not suited.

In medium to dense sands, which are the case for the sites presented in this paper, the standard [1] recommends OHD under slurry circulation; pushed tubes are not suited, but driven tubes or vibro-driven tubes are acceptable. Anyway, this seems to give systematically higher values of pressuremeter modulus E_M values.

Within ARSCOP program, we were particularly interested to obtain representative tests, in accordance with the standard ISO 22476-4 (see Figure 8).

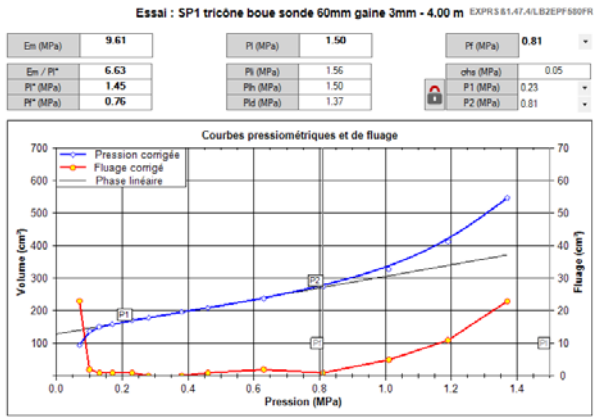

Figure 8. Test performed on Messanges site in SP1 (OHD under slurry circulation with a probe with flexible cover sleeve and a 3mm thick membrane)

Considering that it is much easier to have a successful and representative test with a driven slotted tube in sand,

when it is difficult to insure a good stability of the drilling wall even with slurry circulation, it should be interesting to do further tests, in order to better characterize these differences in modulus values. The goal is to be able to propose a correction factor to the modulus obtained with DST method.

This encourages to continue with ARSCOP program in further cross-tests to be able to propose improved and adapted procedures to difficult soils.

Acknowledgement

We thank the ARSCOP program and Sol Essais for the permission to use their cross tests in this paper.

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