REPUBLIC OF LEBANON

COUNCIL FOR DEVELOPMENT
AND RECONSTRUCTION

CONSEIL DE DEVELOPPEMENT
ET DE RECONSTRUCTION

الجمهورية اللبنانية
مجلس الإنماء والإعمار

MISE A JOUR DES ETUDES ET ASSISTANCE TECHNIQUE POUR LA CONSTRUCTION DU BARRAGE DE BISRI

BARRAGE BISRI

AVANT PROJET DETAILLE

PIECE 3 : RAPPORT GEOLOGIQUE

3-1: GEOTECHNICAL NOTE CONCERNING THE SILTY CLAY OF THE FOUNDATION

February 2015

Updated February 2016

DAR AL HANDASAH NAZIH TALEB & PARTNERS
دار الهندسة نزيه طالب وشركاه
Founded 1956

NOVEC

Table of Content

List of Tables

List of Figures

QC	Ref:	L1214D / 1643
	Revision: (02)	Date: February 20th, 2015
	☐ Draft	☑ Final
	Signature:	

1 INTRODUCTION

Bisri dam rests on a lacustrine deposit of almost 120m maximum depth which have been formed as a consequence of the large landslide which had blocked the river at Anane village (about 1.5 km downstream from the dam site). The deposit correspond to the siltation of the reservoir during the recent quaternary period. These soft soil stratums which cannot be removed due to their thickness, must be taken into account in designing the dam.

Many geological and geotechnical studies were carried out in this deposit. This note did not object to the synthesis of all these studies but to extract key data and assess the geotechnical parameters of the lacustrine deposit.

Disparities between the various recognitions have appeared and it became necessary to make a critical analysis of the results based on geological information to try to explain and evaluate credible parameters for the study of the dam. Hopefully a reliable CPTu soundings have been conducted in 2015, leading to the most relevant geotechnical parameters to be used for the evaluation of the undrained shear strength and settlement.

This note focuses more on silty clays of the lacustrine deposit. Sandy-gravel present in the stream, which thickness may reach 30m is presented in the note dedicated to construction materials. Sandy-gravel are clean and well graded and do not raise any particular geotechnical problem.

2 THE FORMATION OF THE LACUSTRINE DEPOSIT

It is established that the valley was blocked by successive landslides of which the first would be dated at around 15,000 years (as proposed by an expert from the University of Beirut based on the average yearly deposit thickness). The dam would have been formed gradually. Deposits are made by sequences which may explain the existence at various depths within these deposits of coarser materials that may result from lateral inflows as slope wash or colluvium.

Also successive investigations have all shown that groundwater in the bedrock underlying the deposit showed some artesianisme. It is a few meters on 3 holes and the spring that was discussed in the 1996 [1] investigation report between el. 400 and 415 [2]. The geological survey (drawing GG23-01 of the synthesis geological report) indicates the position of boreholes having been subject to artesianisme and the communication observed between the borehole BDC39 and the spring identified in 1996 near borehole BDC24 located at a distance of about 600m.

This means that when the level of the successive phases of deposition was lower than the current level, the influence of artesianisme was necessarily more significant. This is an important observation that may partly explain the disparities and certainly sometimes different results from what one might expect from a deposit made in the absence of artesianisme. This phenomena has however a very local impact as it is shown by the CPTu soundings.

[1] See §5.1, pages 22 et 23, Raport on Supplementary Investigations, ECIDAH, June 1997.

[2] See logs of boreholes BDC15, BDC24, BDC35 carried out in 1982-1984 and BDC39 carried out in 1996.

3 COMMENTS ON THE GEOTECHNICAL DATA

Regarding the lacustrine deposit, investigations of 1983 and 1997 include SPT sounding in boreholes under drilling. They include also laboratory tests on “intact” samples. The logs give a detailed description of the recovered cores.

The 2013/2014 investigations also include core recovery with SPT, which was added to the dynamic penetrometer tests (DCPT) whose results are reported in SPT equivalents without providing information on the conversion process. It is outlined that DCPT sounding is uncommon and not able to provide as relevant information as CPTU. Therefore, their contribution to the geotechnical analysis of the deposit was very limited and was confined to a qualitative characterization. In these conditions, an extensive CPTU sounding campaign was carried out in 2015.

The CPTU program carried may be summarized as follow:

- 30 soundings carried out between October 8 to December 12-2015;
- 1,590 m of sounding and 30 dissipation tests
- Maximum depth 76.5m (CPTuVR6)
- Penetration rate (PR) of 2cm/s was not always respected, (Low PR in gravel and for depth > 40m).

Tests performed are considered of relative good quality and should lead to fairly reliable geotechnical parameters.

The interest for the 1997 investigations is that they provide a very detailed description of the land, allowing in particular to see that the lacustrine clays contain numerous inter beds of fine sand or silt. Often these beds a few millimeters thick, which is quite characteristic of this type of deposit. The second advantage is the quality of laboratory testing probably related to the sampling method.

For example, Table 1 reproduces the synthesis of these laboratory testing (Report ECIDAH June 1997 volume I / III). It shows that the samples are both saturated and the measured consolidation pressures are substantially higher than the soil weight at the recovery level. These results are considered consistent and usable.

Table 1

FIGURE 14 SUMMARY OF CONSOLIDATION TEST RESULTS BISRI DAM - 1983 and 1996 GEOTECHNICAL INVESTIGATION																	
Date	Boring	Sample	Depth (m)	Elev. (m)	γ_d (g/cm³)	G_s	e_0	e_{Pc}	S_r (%)	W_n (%)	LL	PI	C_r	P_c (t/m²)	C_c	P_0 (t/m²)	OCR P_c/P_0
1983	BDC-15	-	43.0	395.9	1.232	2.65	1.15	1.09	96	41.7	48.8	21.4	0.025	145	0.41	40.0	3.6
	BDC-15	-	67.4	395.9	1.329	2.61	0.96	0.88	100	37	58.3	29.2	0.053	130	0.33	58.5	2.2
	BDC-18	-	55.0	398.4	1.204	2.55	1.11	1.03	94	41.2	57.7	28.5	0.040	106	0.36	53.0	2.0
	BDC-19	-	50.5	398.6	1.271	2.57	1.02	0.95	101	40.3	56.5	27.7	0.063	100	0.38	47.0	2.1
	BDC-24	-	15.5	415.0	1.202	2.64	1.19	1.14	94	43	-	-	0.090	115	0.44 to 0.57	29.0	4.0
1996	BDC-46	GUS-39	55.0	411.4	1.39	-	0.94	0.84	-	35.9	-	-	0.015 to 0.025	60	0.43	63.0	1.0
	BDC-46	GUS-48	68.5	411.4	-	-	1.06	0.97	-	-	-	-	0.070	61	0.40	74.0	0.8
	BDC-52	GUS-19	25.0	397.1	1.33	-	1.03	0.95	-	38.3	-	-	0.013 to 0.033	60	0.50	24.0	2.5
	BDC-52	GUS-21	31.0	397.1	-	-	0.91	0.86	-	-	-	-	0.055	62	0.35	30.0	2.1
	BDC-52	GUS-23	38.5	397.1	1.37	-	0.96	0.88	-	36.1	-	-	0.025 to 0.038	66	0.50	37.0	1.8
	BDC-52	GUS-30	62.5	397.1	1.42	-	0.89	0.84	-	38.1	-	-	0.01 to 0.023	86	0.44	60.0	1.4
	BDC-52	GUS-33	71.5	397.1	1.25	-	1.15	1.08	-	37.4	-	-	0.005 to 0.025	89	0.49	63.0	1.4
	BDC-53	GUS-15	50.0	414.8	-	-	0.76	0.70	-	-	-	-	0.050	87	0.29	58.0	1.5
	BDC-53	GUS-17	58.0	414.8	-	-	0.96	0.92	-	-	-	-	0.053	87	0.37	65.0	1.3

We shall see later that SPT soundings associated with these tests also appear relatively consistent with laboratory tests.

The interest of 2014 investigations is the confirmation of the stratigraphy, in the clarification on the types of soil near the surface as well as in the confirmation of the identification parameters of lacustrine clays and consolidated drained strength.

However the 2014 results, the SPT or compressibility tests show disparities with 1997results. The explanation for this disparity is probably due to several factors. Water contents and dry densities are generally comparable to the previous results. Saturation rates, characteristics of a good preservation of samples are close to 100%.

Instead, <u>œdometer tests show for the 2014 campaign, low consolidation pressures below the geostatic load</u>. Samples' disturbance, at constant water content, as frequently occurs with silty materials always hard to recover especially at great depth, is likely to be the cause.

Moreover artesian conditions may have varied between the two campaigns making samples recovery most delicate in 2014. Other factors may have played as the drilling rate or the core barrel retrieving. However, elements allowing to assess the impact of such factors are not available.

As these tests are very important in the evaluation of the lacustrine deposit's settlement under the dam weight, it has been considered essential to carry out further in-situ testing (CPTU) to sort out this issue and get more reliable parameters. This position was also motivated by the somehow questionable maximum settlement estimated to more than 8m based on œdometre test results.

Interpretations that follow give a small advantage to the results of 1997, without neglecting the results of 2014, especially as the in-situ trials (see Figure 11 and Figure 12) reputed reflecting undisturbed ground gave for both SPT and DCPT low resistance to penetration, with virtually no change with depth. This should not be ignored, even if other SPT and DCPT gave, which is more common, a significant improvement with depth.

Hopefully, CPTU soundings helped in dispelling the doubts raised by this situation.

4 LACUSTRINE CLAY GEOTECHNICAL PARAMETERS EVALUATION

4.1 Identification Parameters

4.1.1 Water Content and Dry Specific Weight

Whatever the origin of the measures, the site is characterized by a lack of significant increase in dry density with depth. Table 1 above and Table 2 below, both derived from both investigations are examples of this observation. This is discussed later. It is probably related to the mode of sampling very difficult in this type of soil and what is more, at large depts.

Table 2

TEST DATA SUMMARY - ASTM Designations D422, D2140, D2216, D2974, D4318, D4972 - BS812_parts117&118

Sample I.D	Depth m	BS soil classif.	Size distribution Gravel %	Sand %	Fines %	Silt %	Clay %	Atterberg limits LL %	PL %	Moist. cont. %	Bulk dens. g/cm³	Saturated dens. g/cm³	Void ratio	Organic content %	$SO4^{--}$ cont. ppm	CL^{-} cont. ppm	PH	e	ws	Υsat	Υd	Ic
BHVL1	5,00	SM	0	78	22	15	7	21	5	20	1,69	1,71	0,420	-	43	86	7,60	0,93	-0,03	2,85	2,92	1,5
	9,00	SM	0	73	27	16	11	21	4	30	1,71	1,72	0,435	-	-	-	-	1,07	0,02	2,61	2,55	1,1
	13,50	SM	0	56	44	35	9	25	3	32	1,72	1,73	0,451	-	41	83	7,58	1,09	0,03	2,58	2,50	1,0
	16,50	CH	0	14	86	21	65	64	39	33	1,96	2,01	0,596	-	-	-	-	0,85	-0,06	3,03	3,22	2,8
	21,00	CH	0	7	93	24	69	67	32	33	1,95	2,02	0,627	5,6	31	69	7,78	0,86	-0,05	3,01	3,18	2,1
	25,50	CH	0	0	100	32	68	54	26	34	1,92	1,98	0,630	6,7	-	-	-	0,90	-0,04	2,91	3,03	2,1
	33,00	CH	0	1	99	40	59	51	33	42	1,96	2,04	0,622	-	33	71	7,70	0,97	-0,01	2,77	2,80	2,9
	38.80-39.00	CH	0	0	100	41	59	52	32	40	1,86	1,93	0,631	-	-	-	-	1,05	0,02	2,64	2,60	2,5
	45,00	CH	0	0	100	42	58	56	36	36	1,89	1,96	0,628	-	34	68	7,71	0,96	-0,02	2,80	2,84	2,9
	51,00	CH	0	0	100	33	67	54	35	37	1,83	1,87	0,594	-	-	-	-	1,04	0,01	2,66	2,62	2,8
	57,00	CH	0	0	100	35	65	57	34	39	1,85	1,94	0,607	-	31	63	7,68	1,04	0,02	2,65	2,61	2,4
	64,50	CH	0	0	100	38	62	56	35	40	1,83	1,93	0,618	-	-	-	-	1,08	0,03	2,59	2,52	2,5
	66,00	CH	0	3	97	36	61	57	34	37	1,89	1,96	0,621	-	32	64	7,70	0,97	-0,01	2,77	2,80	2,5

e= indice des vides
ws=teneur en eau de saturation
Υsat= densité saturée
Υd = densité sèche

Head of laboratory section

F/ASSACO

Ic= indice de consistance

The following may be said about Table 2:

- The data in columns "void ratio and organic content" are not to be considered. The void ratio recalculated from the total density measurements are given in column "e".
- Summaries and average values of the saturated water content and dry density from the two investigations are representative.

4.1.2 Plasticity Index

Figure 1, drawn from all of the Atterberg limits measures enables the following observations:

- The 1997 measures provide plasticity index slightly higher than in 2014. This is probably related to the testing procedure. Therefore average values should be considered.
- The difference in the plasticity index provided by the Lebanese and the Moroccan laboratories, carried out in 2014, for comparable liquid limit, comes probably from differences in the plastic limit relatively difficult to do.
- The highest plasticity index are a priori the most representative.

Figure 2 shows the distribution of the plasticity index with depth.

In case the top 20/25 m, where the presence of more or less continuous granular materials logically reduce the average plasticity index, then, most of the PI values are between 20 and 30%. An average value of 25% should be considered, with an upper limit of 30%.

Figure 1

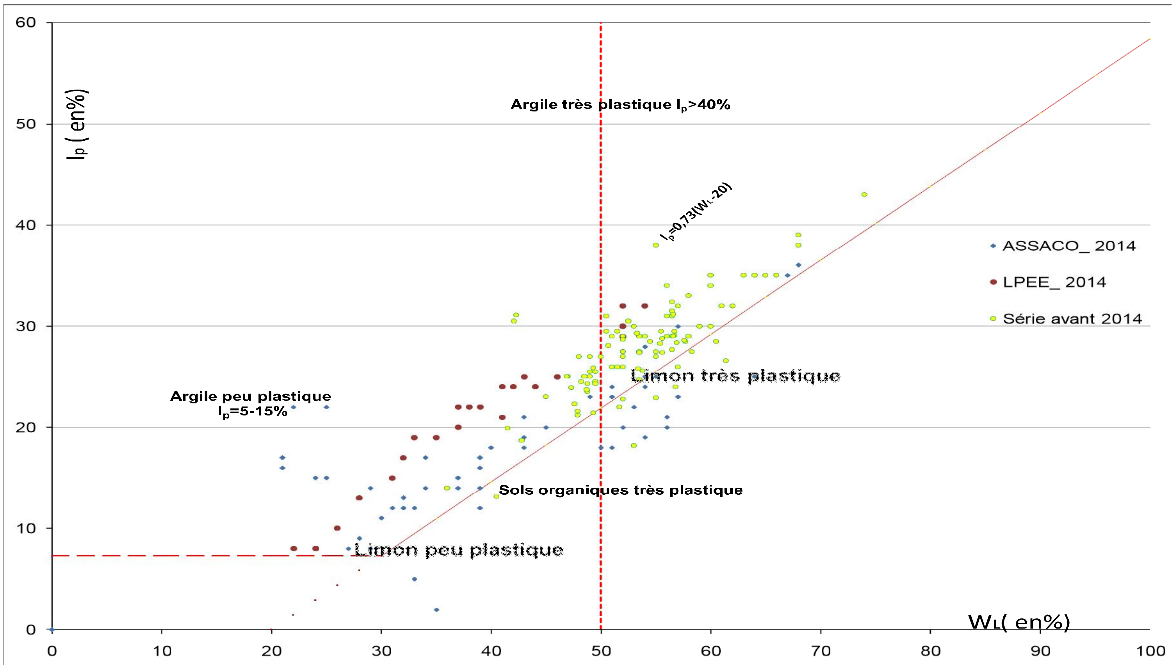
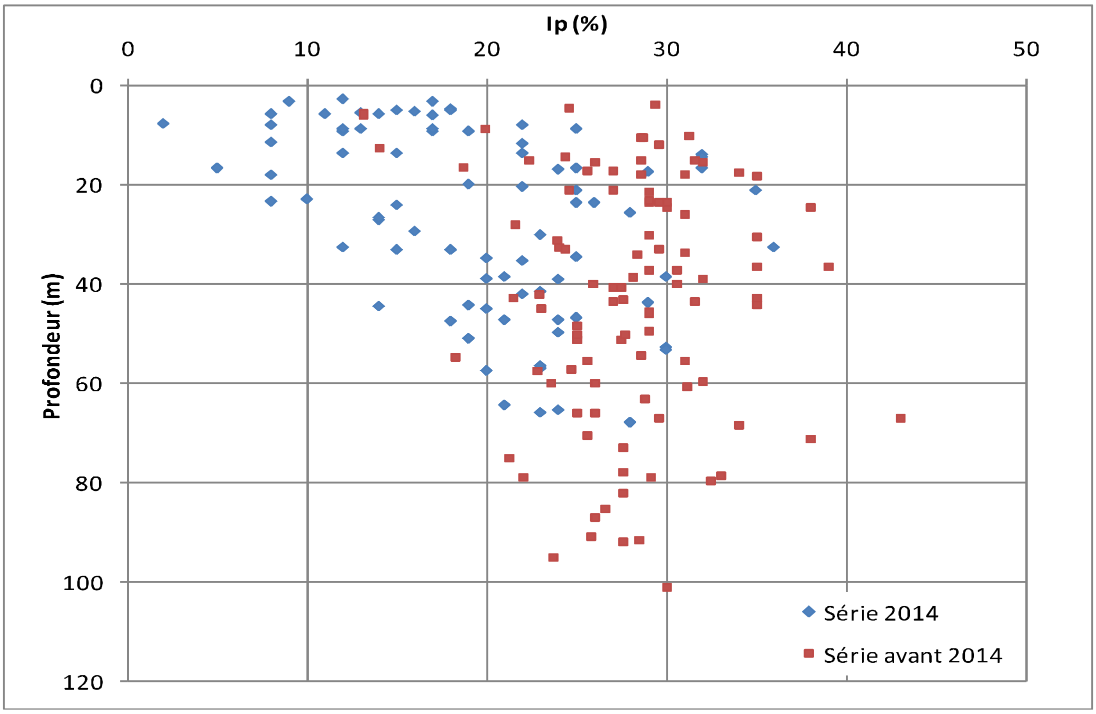


Figure 2



4.1.3 Organic Matter Content

Measurements of the organic matter content were made in Lebanon by the fine ignition method and Morocco by a chemical method recommended by the French standardization committee.

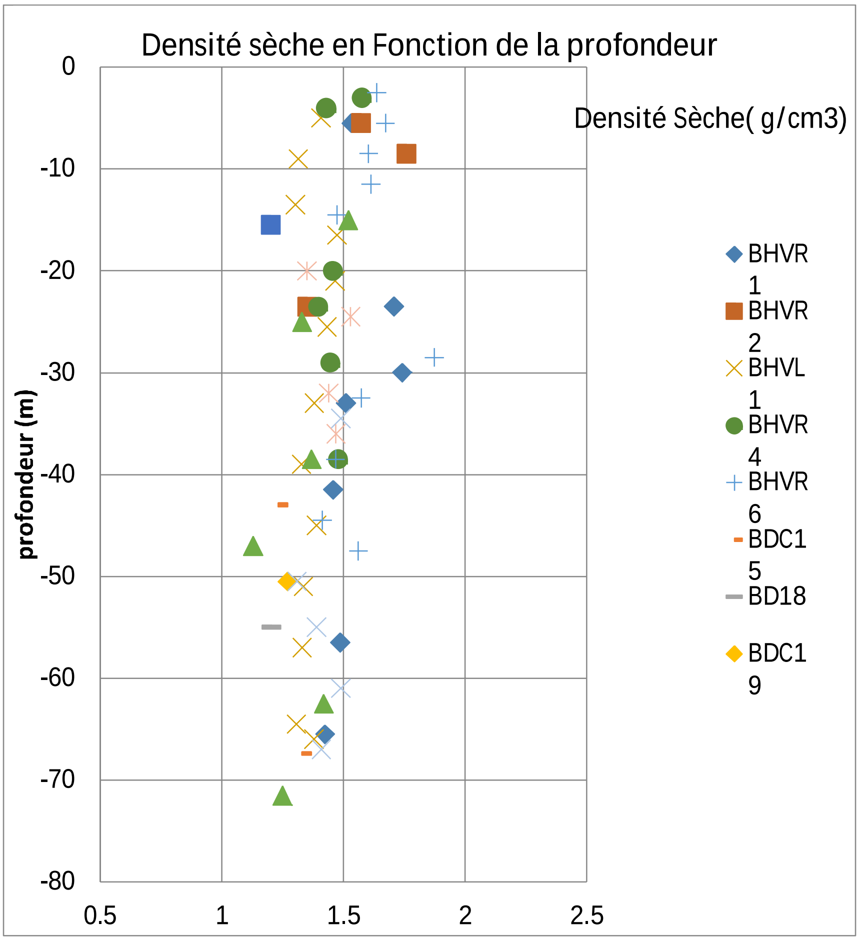
The method by ignition has the disadvantage of causing early destruction of the clay sheets, leading to an overestimation of the organic matter content.

It is therefore necessary to consider only the values resulting from the method recommended by the French standard. Thus, organic matter content remain generally low, less than 3%, with no significant effect on the behavior of clays.

4.1.4 Density

Figure 3 below shows the dry density versus depth. Again, the sample disturbance impacted the measured values. This may explain the lack of density increase with depth.

Figure 3



4.1.5 Activity / Consistency

The activity of silty-clays which provides information on its mineralogy, determined on fifteen samples, vary between 0.5 and 1.5 (Figure 4), indicating that they are inactive to normal.

Consistency, defined as the ratio of the natural water content to the liquid limit, varies considerably. Some samples qualified of liquid were disregarded considering they are obviously disturbed. Almost the third of samples has a soft consistency (<0.5) to very soft (<0.25).

Figure 4

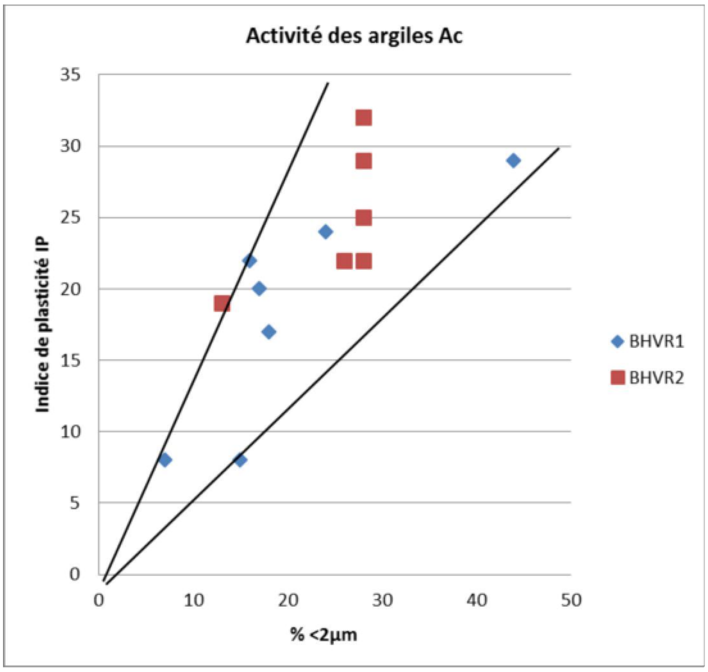
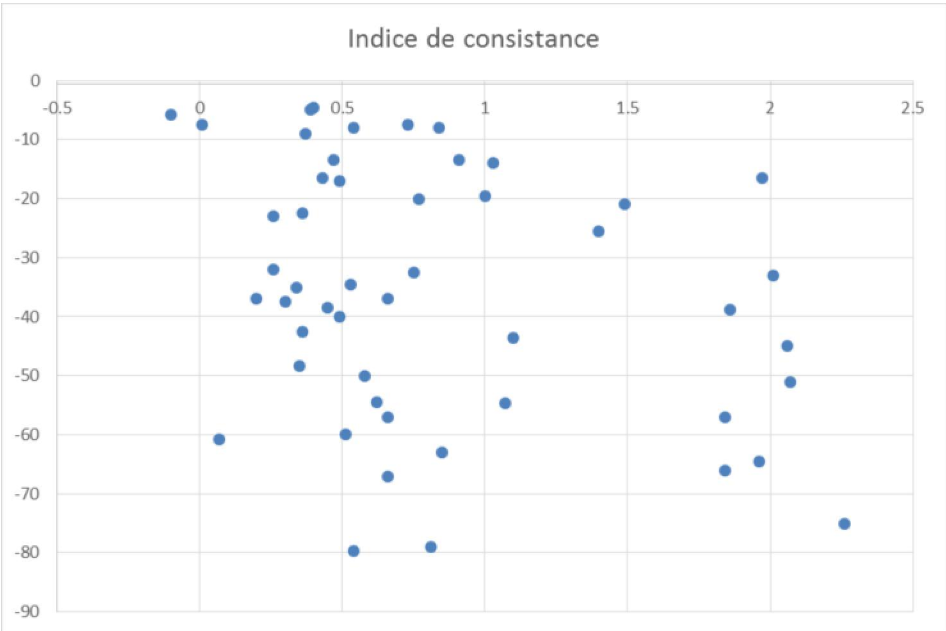


Figure 5



4.2 Compressibility

Several series of tests were made in the USA in 1983 and 1997, then in Morocco in 2014.

The 1983 tests give very high consolidation pressures. The lack of test curves make it is difficult to take into account these results.

1997 tests seem reliable. Table 3 summarizes the results of these tests, classified according to the depth.

Table 3

Echantillon	prof (m)	σ'v0 (kpa)	σ'p(kpa)	Yd (kN/m3)	SPT (N)	OCR	σ'p(kpa)dossier	OCR (dossier)	Cc/1+e
BDC 52-19	25	275	500	1,27	12	1,8	600	2,2	0,25
BDC 52-21	31	330	600	1,41	15	1,8	620	1,9	0,18
BDC 52-23	39	400	600	1,37	20	1,5	660	1,7	0,26
BDC 53-15	50	500	720	1,53		1,4	850	1,7	0,16
BDC 46-39	55	545	600	1,39	29	1,1	600	1,1	0,22
BDC 53-17	58	570	700	1,38		1,2	850	1,5	0,19
BDC 52-30	63	620	780	1,42	30	1,3	840	1,4	0,23
BDC 46-48	69	670	600	1,31	24	0,9	600	0,9	0,19
BDC 52-33	72	700	850	1,26	27	1,2	870	1,2	0,24

As indicated above, measured water contents are close to the water content of saturation and consolidation pressure values are, with one exception, greater than the geostatic stresses.

For three of these tests, applied load reaches 4.8 MPa insuring therefore obtaining the virgin curve of the material. The other tests have been charged up to 1.46 MPa which is low given the depth of some samples. Despite this compressibility index (Cc / 1 + e) are comparable for the two test series, averaging 0.21. The reliability of these tests is thus demonstrated.

Table 3 shows two sets of σ'p values, the "dossier" is the value provided in the 1997 report, the other value is calculated as part of this note. The latter is slightly lower but still in the same order of magnitude.

Figure 6 and Figure 7 respectively give the consolidation pressure and the OCR as function of the depth.

Figure 6

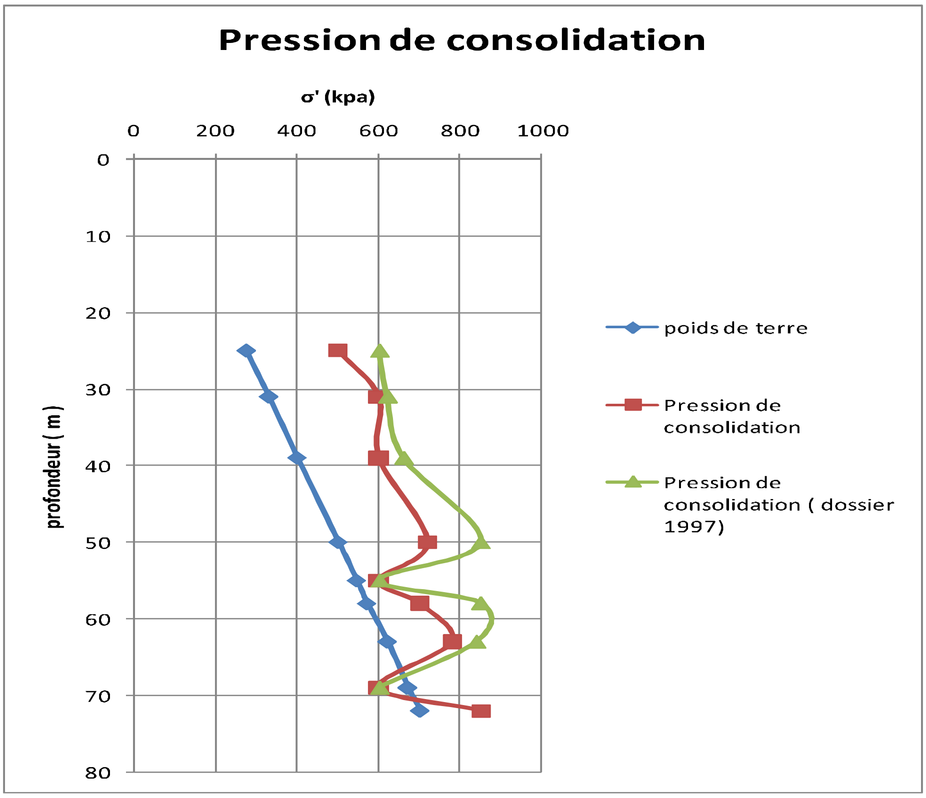


Figure 7

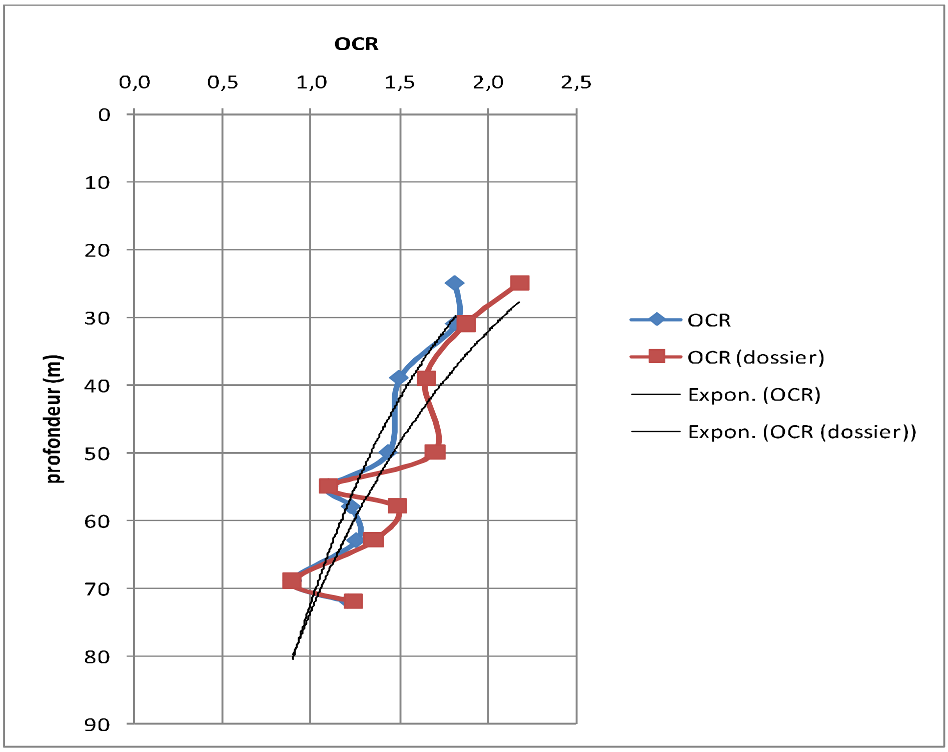


Figure 6 and particularly Figure 7 show a decrease in the over-consolidation with depth.

Based on these elements it was considered that below 70 m deep clays are normally consolidated.

This conclusion, however, is based on a small number of results. It is therefore not guaranteed. If this were found, however, that would be rather paradoxical.

Indeed these deposits are obviously the oldest and should at least have the over-consolidation related to aging ("aging effect"). Even with a low coefficient of creep, OCR matching aging from 10 000 to 15 000 years can be of the order of 1.1 to 1.2. This is in the range of the accuracy of available information. For safety reasons it was recognized that the deep clay is normally consolidated.

The small compactness of the clays associated with this deep low over-consolidation led to the conclusion that can be formulated as a hypothesis, that the lacustrine bottom deposits of 20 to 30 meters, at least, were made in conditions special, perhaps related to artesianisme raised earlier, creating conditions of deposit under low intergranular stresses.

However, testing under extreme vertical stress (up to 4.8 MPa for some) showed no collapse of the clay structure.

The behavior of these clays remains therefore normal for such type of material, despite their low compactness under high stress.

- Comments related to œdometer tests carried out in Morocco in 2014.

These tests have mostly been made on deep samples. They gave consolidation pressures below the geostatic stresses.

The hypothesis of an under-consolidation of deep clays being rejected by the results discussed above, it is possible that, in addition to a slight samples' disturbance (we know it takes very little for the consolidation pressure to decrease in these materials, known to be silty and difficult sample), too low weight has been applied during testing.

It should be noted that, while void ratios are comparable in tests of 1997 and those of 2014, the values of (Cc / 1 + e) are lower in 2014. Thus, the virgin curve would not have been reached in 2014.

(A rule recommended by experts in laboratory testing, to be certain of reaching the virgin curve it is desirable to load the sample until a final void ratio of about 0.4 * initial e. 2014 tests are often quite far).

- Recommendation for average settlement estimation using œdometric method.

Given the clay high proportion in the lacustrine deposit, the œdometric calculation method seems best suited for evaluating settlements.

The calculations must take into account within the top 20 to 30 m the actual stratigraphy often sandy to prevent any overestimation of the settlements. If necessary modules of sandy areas can be assessed by other methods.

Clays' settlement calculation can be done by using the following parameters:

σ'p =OCR* σ'v, OCR evaluated using Error! Reference source not found., with OCR =1 above 70m depth.

Cc/1+e = 0.21

Cs ~0.04

Cv = 10-7 m^2/s

Ch =10*Cv

Ch value is somehow high because it takes into account interbedded fine sand to silty sand layers.

4.3 Evaluation of the Clay Strength

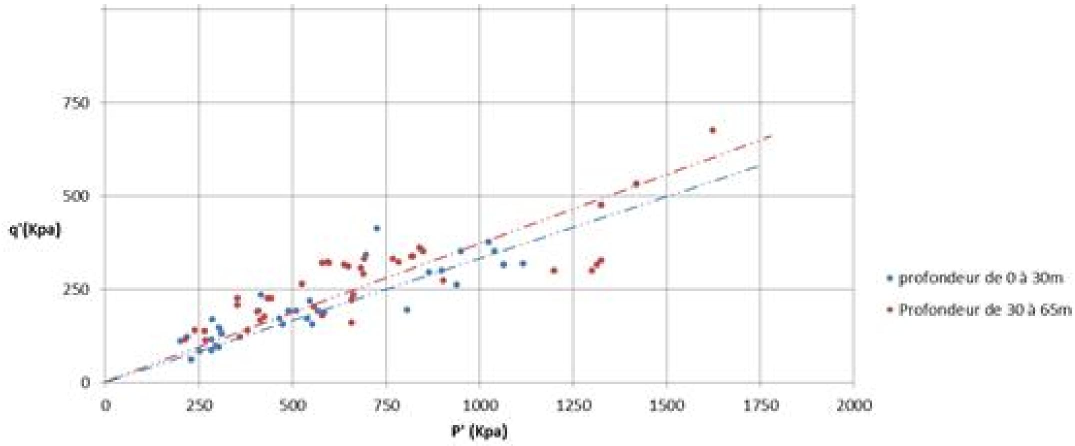
4.3.1 Triaxial Tests

Triaxial CU+U tests were conducted either in 1997 or in 2014 campaigns, on samples supposed undisturbed. A total of 30 tests are available. Corresponding output is comparable between both campaigns.

The synthesis of all triaxial testing was done in a diagram (p', q'), the result is shown in Figure 8 below. Outliers were eliminated, such as the test for P43 sample of borehole BDC39 at 64m which gave an effective friction of 7.7°, or the CUS17 of BDC52 at 20.50m which resulted in an effective friction of 32.2°.

The graph shows a distinction between samples located above and below 30m depth due to the difference observed in plasticity measured in these horizons. Indeed average plasticity index corresponding the top 30m of the deposit is close to 21% while it is around 25% at the bottom.

Figure 8



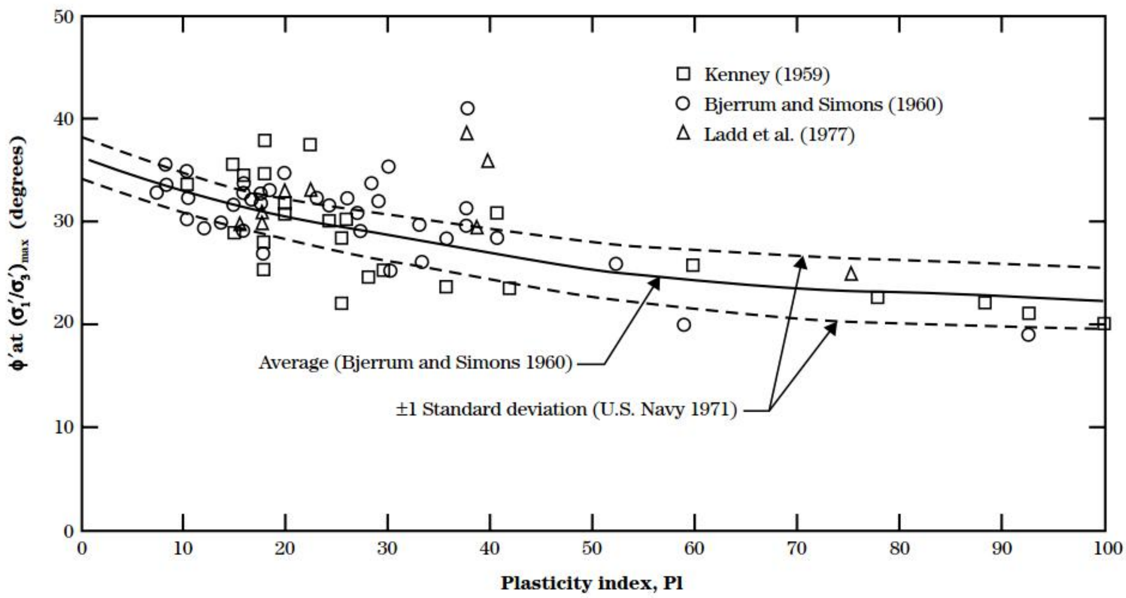
The trend lines presented in the graph, passing by the origin (zero cohesion), are located below the 2/3 of each set of points (top and bottom). They give respectively a friction 19.3° for the portion between 0 and 30m and 21.7° for the portion between 30 and 65m. It would have been more logical to have a stronger friction in the top.

It is appropriate in these conditions to hold that, according to the triaxial tests, the long-term shear parameters for silty clays of the foundation are characterized by an effective friction angle between 20 and 22° and zero cohesion.

4.3.2 Correlation with the Plasticity Index

The following graph (Figure 9), given in several references, provides an estimation of the pic effective friction angle as function of the plasticity index.

Figure 9



According to this graph, for a plasticity index between 20 and 30%, the effective friction is greater than 20°. It is rather more than 25°.

The shear test results would be slightly pessimistic. It is proposed nonetheless to consider an effective friction angle of 22° for the clays of the lacustrine deposit whatever the depth is. In the stability calculations, a sensitivity analysis on this parameter is carried out, considering 20° ands 24°. Of course in the sandy gravel much higher friction should mobilized.

A friction angle of 22°, however, remains realistic because during the construction of the dam, foundation, especially in the upper part will be subject to significant distortions, such as to give ground near the residual friction with zero cohesion.

4.3.3 Undrained Strength

Undrained strength is evaluated using correlations between Cu and N(SPT), then φ' is derived from : $Cu = \sigma'v(\text{or } \sigma'p)*\sin\varphi'/(1+\sin\varphi')$.

A doble calibration made using data of Table 3 lead to:

Cu=8N (kPa) and φ' = 22°.

For Cu(N) this is very similar to the common approach (Cu= 7N)

In conclusion, given the laboratory results on one hand, and approximations using correlations on the other hand, it seems prudent for a dam of the importance of Bisri to consider:

φ' = 22°.
Cu = 8N

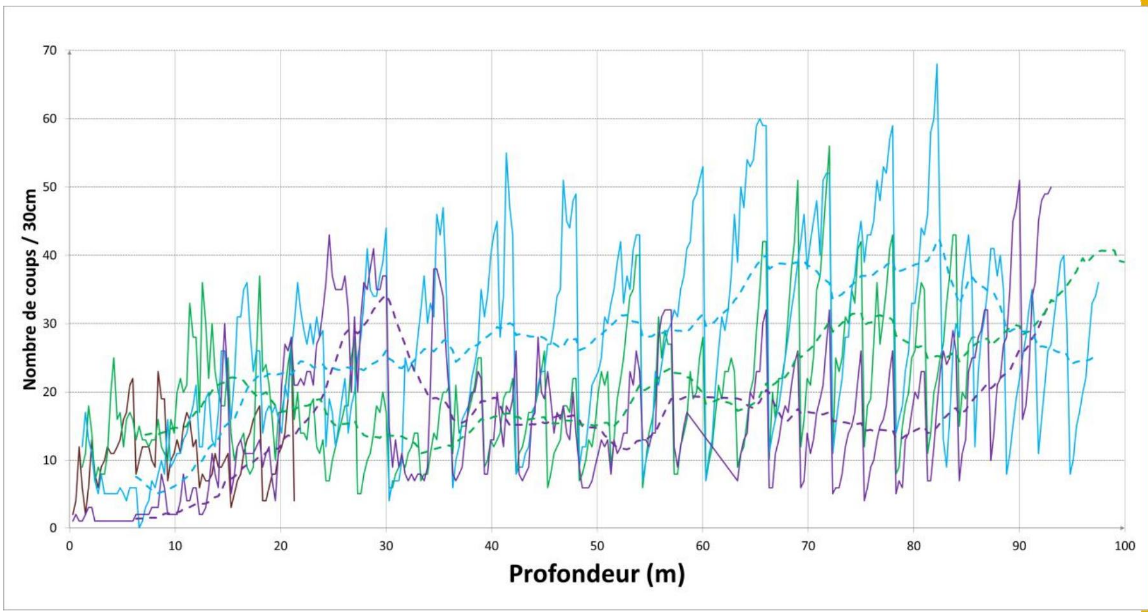
4.4 SPT and DCPT Soundings

Analysis of SPT and DCPT soundings presented here was carried out before conducting CPTU testing. The latter results presentation and analysis are covered by a separate note. Comparison of both findings is given where necessary.

Figure 11 brings together all the results of SPT and DCPT soundings. Figure 12 provide moving averages of DCPT trials. They both show a great dispersion in the resistance to penetration of the soil, especially on top 30m. The presence of blocks may explain the significant fluctuations relieved, however for DCPT carried out by 3m deep passes, there is systematically, for each pass, an increasing of the penetration resistance followed by a sharp drop corresponding to the sounding stoppage and the driving of the support casing. This should weaken again the bottom of the borehole so that the DCPT resistance decreases again.

Figure 10 below illustrates this. The continuous line curves correspond to the raw results uninterpretable and the dashed curves give the moving average of 21 measured values giving the trend of penetration resistance variation with depth. Thus in this figure, the purple curves (solid and dotted lines) corresponding to DCPVR4, show a very low tendency of resistance increase with depth up to 80m. The curves in green and blue respectively corresponding to DCPTR2 and 9, show a resistance increase trend with depth.

Figure 10 Example of raw resistance to penetration (continuous curves) and moving average (dashed curves) for DCPT soundings



When only the SPT results, summarized in Figure 11 below are considered, disregarding the results of two or three them with no improvement with depth (that could be in connection with artesianisme raised above) and based on averages, it is possible to identify a trend from N ~ 10 to 20m depth to N ~ 25-30 to 80 / 90m depth (see Figure 13 below).

This trend line is not far from the curve established from the data in Table 3 used to calibrate the strength parameters. It is also consistent with the trend lines of in Figure 12, for the NSPT equivalent deducted from DCPT soundings.

The concordance between various approaches is done by taking into account for the assessment of the vertical stress, σ'p as defined above.

Figure 11 Summary of SPT soundings results

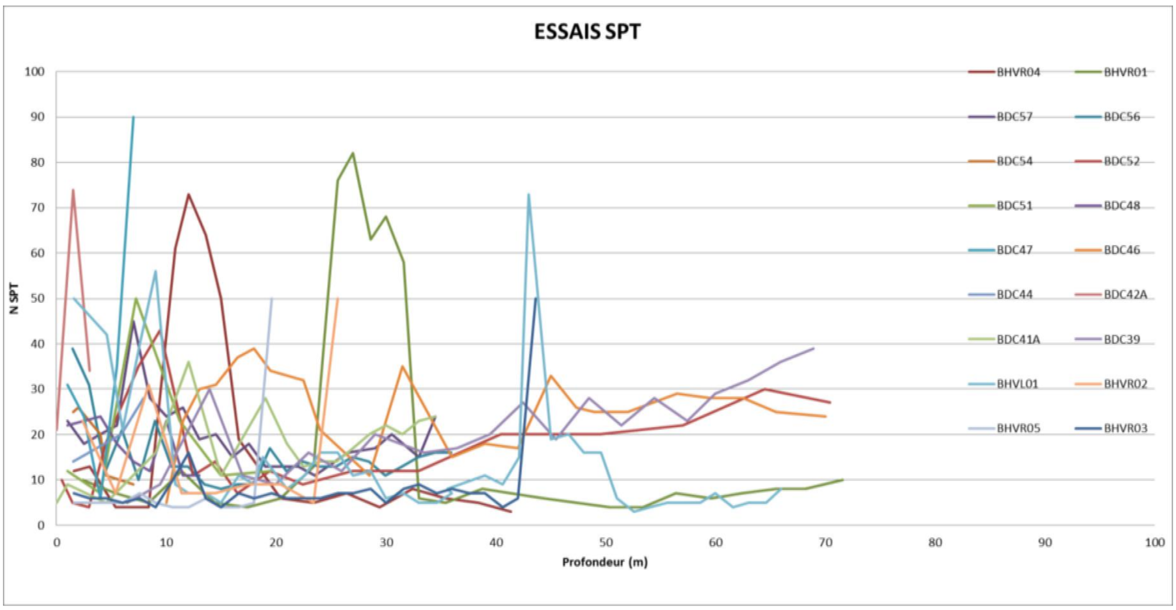


Figure 12 DCPT trend lines presented as NSPT equivalent

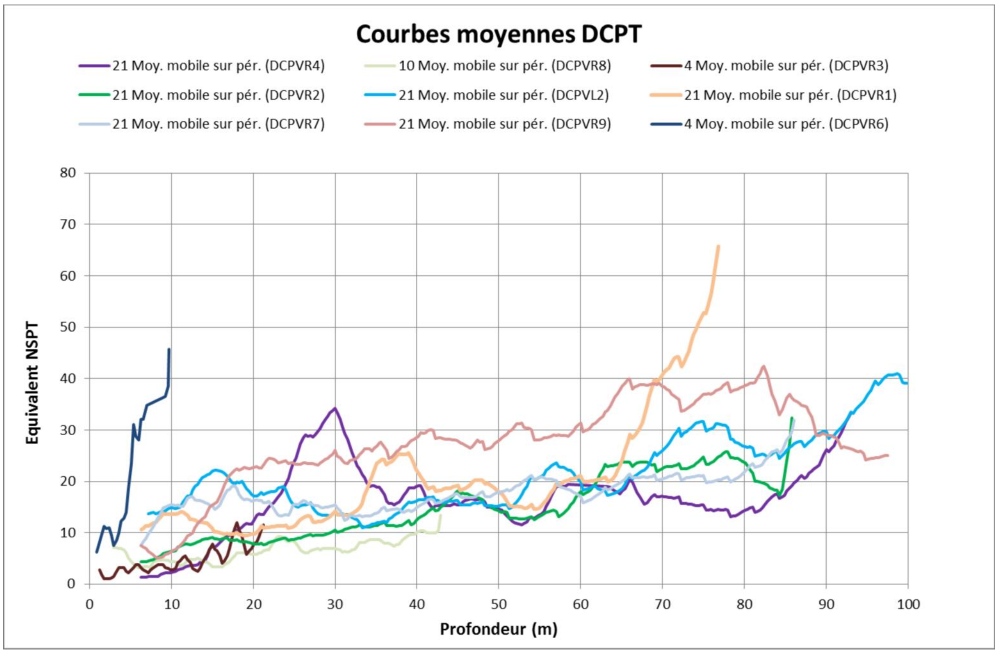
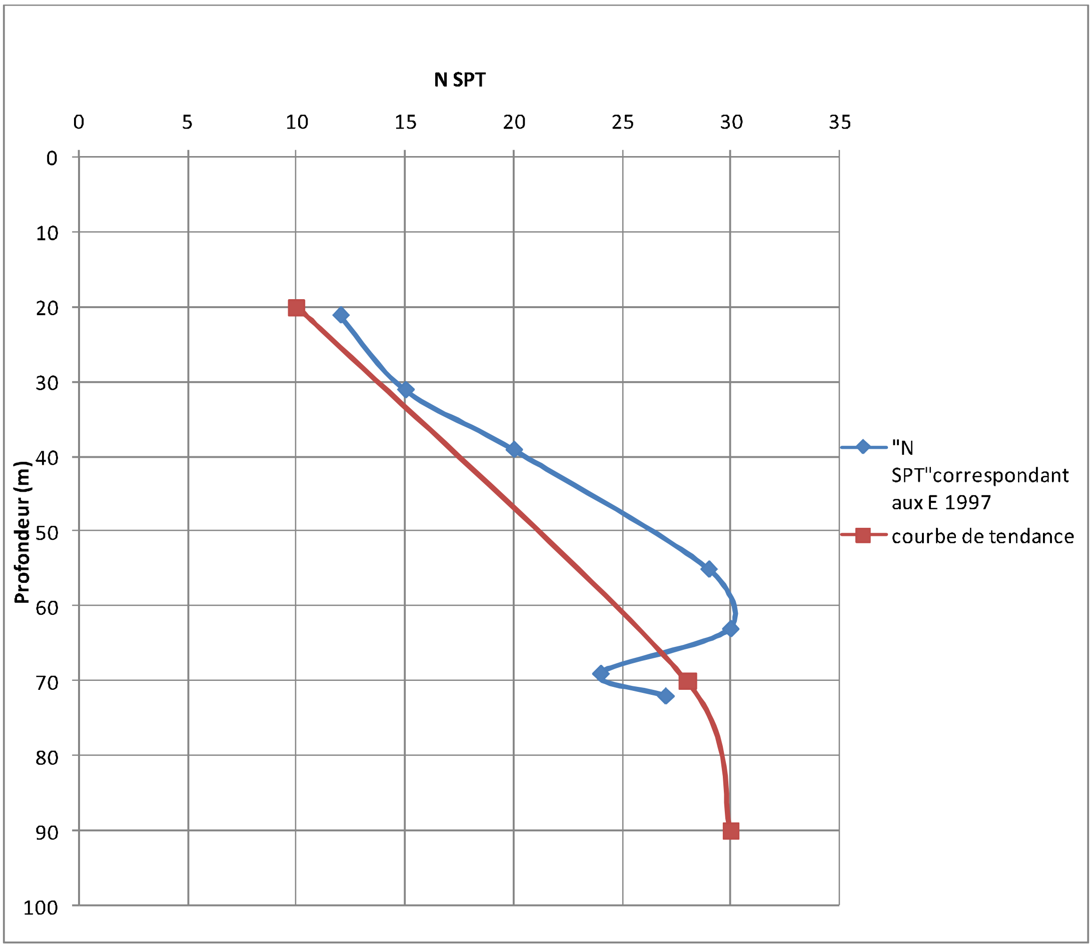


Figure 13



It is worth outlining that the CPTU soundings confirmed these assumptions as it is presented in the corresponding synthesis report.

4.5 Conclusion on the geotechnical parameters considered for clay

On the basis of the analysis presented above, Bisri dam design considered the following geotechnical parameters for the clay of the lacustrine deposit:

Ø' = 22° C' =0

Cu= 8N(SPT) N is derived from the trend line of Figure 13. CPTU soundings suggest Cu= 0.3 σ'v, which is almost equivalent. For example, at 20m and 50m respectively, Cu= 80 and 170 kPa according to SPT and Cu=90 and 180 kPa according to CPTu. CPTU soundings couldn't reach more than 70m depth leaving uncertainties below this depth, which is not too penalizing as soil in these horizons don't participate in the dam stability.

σ'p =OCR* σ'v, OCR given in Figure 7, with OCR =1 deeper than 70m.

Cc = 0.42 derived from œdometer to compare to 0.35 derived from CPTu. The latter is considered more reliable as it represents more undisturbed soil.

Cs ~0.04 (0.05 derived from CPTu)

Cv = 10-7 m2/s almost the same as derived from CPTu (6x10-8m/s).

Ch = 10-6 m²/s (=10x Cv, taking into account interbedded fine silty sand layers.

It is outlined that these parameters were determined from results often widely dispersed. With regard to the large scale of the project, lower averages are considered representative of the geotechnical parameters of foundation, to be used in the dam design. However a distinction is made between the top 30m of the deposit more sandy than clayey.

Undrained strength of the clay and settlement parameters are almost comparable to those derived from CPTU soundings. The conclusions of the end of construction stability analysis and settlement evaluation are therefore reliable while they are on the safe side.