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Valorization of Mediterranean sediments in a treatment plant Study of the geotechnical characterization and permeability

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Abstract:
The marine sediments find their re-employment with or without treatment in the construction of harbour and road works. These applications impose a complete methodology for the hydraulic and mechanical characterization of sediments. This methodology is proposed for project SEDIMARD 83 and is applied to marine sediments of the Mediterranean coast. After having defined the basic properties of these sediments, column decantation and oedometric tests were carried out on 6 different sediments. The relations between permeability and void index are then deduced. These tests of decantation correspond to a self-weight settlement of the sediment. In order to simulate the consolidation of these same sediments under loading, some oedometric tests were carried out in parallel. First, the physical and chemical properties of these sediments are given and it is shown that certain among them for the same area (the Mediterranean), remain nearly constant. So, dehydration and sieving treatments (raw sediment/desanded sediment/dehydrated sediment) modify them.
The analysis led to obtaining the usual settlement parameters of consolidation but also to defining a relation between permeability and void index. Continuity has been well observed between the results issued from these two tests.

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1. Introduction

Valorization of the marine sediments constitutes an important issue in the management of the latter. Recent research works concern mainly road and construction materials. The aims of these research works are always ambitious, but in all the cases stabilization and/or solidification of marine sediments is a major problem. Failures are frequently observed as for the applications on site. Let us point out the most outstanding recent works. COLIN (2003) and LEMEE (2006) carried out on river and marine sediments that take well into account the economic aspect of the problem. SEMCHA (2006) even developed a construction material (tile) starting from dam reservoir sludge.
Finally, the valorization of dredged fine materials can be treated on a hierarchical basis (LEVACHER *et al.*, 2007a) according to the defined objectives as shown in table 1.

Table 1. Possible fields of valorization.

Objective	***Application and field concerned***
1- Shovel ability of the product during the stabilization/solidification step.	*Transport and landfilling for contaminated fine materials and or storage disposals.*
2- Land deposit as for filling old quarries and underground cavities.	*Filling materials.*
3- Construction of embankments without loading.	*Self weight consolidation in urban, harbour areas.*
4- Construction of embankments under loading.	*Materials for embankments and industrial or harbour platforms.*
5- Valorization in road construction.	*Sub layers road materials.*
6- Valorization in manufactured materials.	*Materials for construction (bricks, tiles).*

Any valorization relating to the re-use of the marine sediments in embankments imposes an adequate characterization (LEVACHER *et al.*, 2005). It relates to the study of the main properties that are the physical, chemical, hydraulic, and consolidation properties. It is those which are presented afterwards for a series of 6 studied Mediterranean sediments.
A basic geotechnical characterization of dredged natural sediments for any valorization must contain some physical properties such as water content, grain size distribution, fine particles composition with the content of clays (<2 µm), sand composition, plasticity index and Atterberg limits and blue methylene values.
The size ranges of natural sediments concerned by valorization in public works vary from 0 to 5 mm, including fines particles and sands. Beyond this maximum size, the coarse materials contained in the sediments can be re-used as aggregates. The size range of the sediments studied for a re-use in embankments is very frequently of 0 to 2 mm.

For any reuse in embankment works, hydraulic, consolidation and resistance properties are obtained from the decantation in column and œdometric consolidation tests. They include respectively:

- the permeability-concentration (*k-C*) relationships and law of decantation,
- the permeability-concentration (*k-C*) relations for consolidated materials,
- the coefficients of consolidation and creep, the indices of compression and swelling,
- the content of water-cohesion (*W-Cu*), or concentration (*C-Cu*) relationships.

And considering environmental aspects, chemical characterizations must include carbonates content, the organic matters content and the content of contaminants. The nature and content of the components in marine sediments are governing the type of stabilization techniques. In fact, the presence of carbonates or silicates could lead to using chemical treatments with polymers or by alkali activation (LEMEE, 2006; LIANG, 2008). The presence of organic matters disturbs the mechanism of stabilization with the hydraulic binders as for the contaminants.

Finally, this complete characterization gives all the necessary elements for reuse of the untreated sediments in embankments (confined or not) and makes it possible to consider a treatment of stabilization and/or solidification with additives. For the other uses with treatment of stabilization and/or solidification, a second series of studies is essential which includes various phases of validation for indicators: compaction and mechanical, environmental and economical ones (SANNIER *et al.*, 2008).

The characterization presented and discussed afterwards is applied to six Mediterranean harbour sediments and relates to the physical, chemical and hydraulic properties and this, for use in embankment or stabilized public works material.

This basic characterization concerns physical and mechanical properties, *i.e.* the chemical properties related mainly to the degree of contamination are not included in this study and the environmental behavior of the studied sediments is not approached (LEVACHER *et al,* 2007a; LEVACHER *et al*, 2007b; LEVACHER *et al*, 2008). This characterization relates to the main geotechnical properties: (water contents *W*, Atterberg limits, granulometry) and chemical ones (contents of carbonates and organic matters *MO*). One of the objectives of the study is to characterize and to identify groups of sediments from various origins so as to optimize the treatment processes by group of sediments and not individually per sediment.

2. Materials and methods

The marine raw sediments are coming from the Arsenal of Toulon, from the ports of Bandol, of Cannes, of Sanary-Lavandou, of Saint-Mandrier and from the old part of Marseilles harbour (Vieux Port de Marseille). They were dredged and brought on a specific site to be treated and possibly to be valorized as construction material there. This site for treatment called "pilot plant" was the object of the "SEDIMARD 83" project (GROSDEMANGE *et al.*, 2008).

The sediments tested are directly coming from the "pilot plant", they are originate from two types of samples:

- natural or raw sediments sampled from the storage basin of this treatment or "pilot" plant, the coarse elements being removed by sifting (elimination of macro waste) and by dry sieving (0/50 mm);
- sediments sampled after the operations of desanding (wet sieving to 3 mm, and granulometric sorting by hydrocyclone) and dehydration by filter press in the "pilot plant".

So 12 samples corresponds to the 6 Mediterranean dredged ports : raw and desanded sediments. All the sediments were sampled and conveyed in laboratory at two dates: on March 19, 2007 and March 6, 2008. The transport and the conservation of sediments were carried out in hermetic plastic barrels, of a capacity of 20 L. After routing in laboratory, the physical and chemical properties of the materials were determined as of their arrival. Then the tests of decantation and consolidation followed.
The locations (port) and references (nature and sampling dates) of the samplings are given in table 2.

Table 2. References of the tested sediment samples.

Harbour	***Sediment references***	***Reception date***	***Reception date***
Arsenal de Toulon	*ARS/BRUT*	*March 2007*	*March 2008*
Arsenal de Toulon	*ARS/DD*	*March 2007*	*March 2008*
Bandol	*BAN/BRUT*	*March 2007*	-
Bandol	*BAN/DD*	*March 2007*	*March 2008*
Cannes	*CAN/BRUT*	*March 2007*	-
Cannes	*CAN/DD*	*March 2007*	*March 2008*
Sanary-Lavandou	*SAN/BRUT*	*March 2007*	-
Sanary-Lavandou	*SAN/DD*	*March 2007*	*March 2008*
Saint-Mandrier	*STM/BRUT*	*March 2007*	-
Saint-Mandrier	*STM/DD*	*March 2007*	-
Vieux Port de Marseille	*VPM/BRUT*	*March 2007*	-
Vieux Port de Marseille	*VPM/DD*	*March 2007*	*March 2008*

The samplings are listed as follows:

- Location of sampling as "ABC/", three letters naming the concerned place *i.e.* the original harbour,
- Nature of samples "raw" or "desanded and dehydrated" , respectively called BRUT or DD,
- Sampling year 2007 or 2008 is mentioned in sections relating to the temporal evolution of the properties of the sediments.

Some of the sediments in 2008 are missing because they already were pretreated (absence of raw sediments) or were totally valorized (case of the sediment of Saint-Mandrier).
The methods of determination the physical characteristics are standard. The water content is obtained by drying at 105 °C according to standard (NF P 94-050). The water contents were determined at the date of reception of the barrels of sediments in laboratory for all the sediments. Before any measurement of water content, sediments are mixed for homogenization.
The limits of Atterberg are water contents which delimit behavior of materials: plasticity W_P and liquid W_L limits obtained with standard NF P 94-051. As 95% of sediment particles pass through the sieve at 2 mm, granulometry laser testing was carried out. The apparatus used, Coulter LS230, makes it possible to explore a broad range of particles going from 0.04 to 2000 µm. In the case of the presence of coarse particles, a dry sifting is operated until 5 mm.
The contents of organic matters were given starting from the measurement of the percentage by weight of organic matter *MO* after calcination of materials at 550 °C, during 4 hours according to standard XP P 94-047. This method by loss on the ignition is one of the means of appreciating the state of decomposition of the organic matters.
The use of a Bernard calcimeter allows to obtain carbonate contents in accordance with standard NF P 94-048.
The hydraulic properties are obtained by the techniques used for the studies of sedimentation and consolidation of saturated fine grained soils. These properties provide the parameters necessary for the settlement calculations for placing in the embankment the sediments treated or not (relation between the permeability k and the solid matter concentration C).
The tests of decantation are carried out for different initial concentrations. These are representative of the sediments sampled according to the dredging procedures. The test with the column of decantation consists in the implementation of a mixture of fine homogeneous material of initial concentration Ci in a transparent tube of outside diameter 54 mm, thickness 2mm and total height of 2 m for the low concentrations (50 g/l). For the concentrations of 250 g/l, the transparent tubes have the following characteristics: outside diameter 94 mm, thickness of 3 mm and height of 2 m. During the process of decantation, the evolution height of the sample is followed according to time by the measurements brought closer for the first six hours, namely: 30 s, 1 mn, 2 mn, 4 mn, 6 mn… 30 mn, 35 mn, 40 mn,… 1h, 1h10, 1h20,… and 2h, 2h20, 2h40, 3h00, 3h30, 4h, 5h, 6h, 24h, then every 24h. The period of observation was 10 days. In the absence of effective stresses, the sedimentation or decantation velocity Vs of a mud or a fine sediment resting on an impermeable bottom (negative to indicate a fall) under the action of its own weight can be calculated using the relation of BEEN (1980) following:

$$V_s = -\frac{k}{\rho_s}\left[\frac{\rho_s}{\rho_o}-1\right]C \tag{1}$$

In which ρ_s is the density of the solid phase (≈ 2550 kg m^{-3} for a mud or organic fine sediment), ρ_o is the density of water (1000 kg m^{-3}), C is the dry matter concentration (ratio of the solid mass on total volume), k is the coefficient of permeability. Knowing that the coefficient of permeability of a mud or a given fine sediment depends on its concentration, the theory of sedimentation of KYNCH (1952) is compatible with the formulation of BEEN (1980). The research works completed by SANCHEZ (2000) shows that in the case of soft muds, the relation between k and C frequently obey to the following empirical law:

$$k = A_1\, exp\left(-A_2\frac{C}{\rho_s}\right) \tag{2}$$

where A_1 (m s^{-1}) and A_2 are specific parameters to each mud or fine sediment. The parameters of this law can be evaluated directly starting from experimental curves of decantation by a graphic method developed by KYNCH (1952) and modified by SANCHEZ & GROVEL (1993).

The consolidation under vertical load was studied with the oedometer, test standard used in soil mechanics. Knowing that this test applies on the fine soils with water content lower than that of the marine sediments, the sample tested was loaded first under a low consolidation stress of 12.5 kPa, then 25, 50, 100, 200 and 400 kPa for all the tests.

3. Results

3.1 Geotechnical characteristics of the Mediterranean sediments

3.1.1 Granulometry and distributions of the sediments

The grading curves of all the samples are well distributed between 1 µm and 5 mm. Granulometric test results carried out on rough and desanded/dehydrated sediments noted DD show that there is no significant variation in the shape of the size distribution curves and the six sediments are in fact relatively similar (figure 1). The narrowest size distribution envelope concerns the desanded and dehydrated sediments.

Clayey fraction (< 2µm) represents 5% (SAN, BAN, CAN) to 15% (ARS) of the sediments. It is stabilized around 10% for sediments DD. The silty fraction (2-20 µm) varies from 20% to 45% of raw materials. It is stabilized between 30 and 40% for sediments DD. The sandiest sediment is that referred into SAN. The most clayey sediments are those of the Arsenal of Toulon (ARS) and of the old port of Marseilles (VPM), see figure 1.

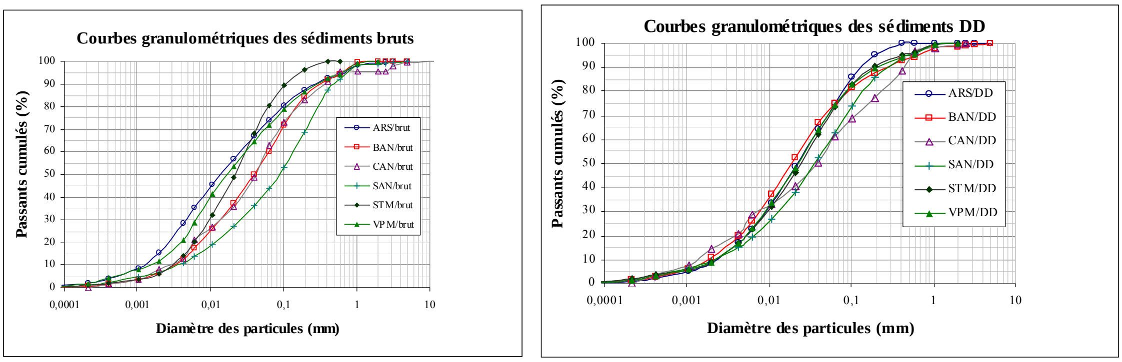

Figure 1. Raw and desanding/dehydrated DD sediments grain size distributions (note : courbe granulométrique = grain size distribution curve, raw=brut).

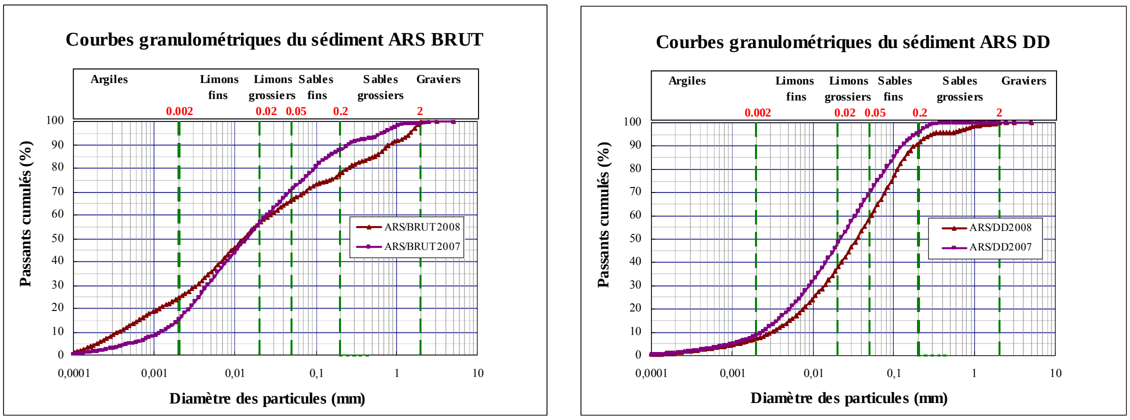

Figure 2. Sediments grain size distributions evolution, sampled in 2007 and 2008 (Note : courbe granulométrique = grain size distribution curve, raw=brut).

From grain size analysis of the sediments sampled over the two periods of 2007 and 2008, no significant granulometric modifications are observed whatever the studied sediment. This is illustrated on figure 2 for raw and desanded/dehydrated sediment from Toulon Arsenal.

3.1.2 Initial water contents of the sediments

The granular cycle of sorting and solid-liquid separation applied is presented on the diagram of figure 3. It makes it possible to pass the sediment of the raw state (basin of storage, figure 3) in a state of desanded-dehydrated (DD) at the end of the cycle. Measurements of water contents *W*, could be carried out during this cycle, on the raw and desanded-dehydrated sediments, at different dates corresponding to the sampling from 2007 and 2008 (see table 3). Measurements of water contents were made by SANNIER (2008) at the time of dredging in 2007 on the raw sediments. Thus, four stages of measurement of *W* are reported in table 3:

1) during dredging, measurements on site in 2007 for a series of raw sediments,
2) sampling at the "pilot plant" in 2007, measurements in 2007, with two series for comparison between raw and desanded/dehydrated sediments,
3) sampling at the "pilot plant" in 2007, stored in laboratory, measurements in 2008, with two series for comparison between raw and desanded/dehydrated sediments,
4) sampling at the "pilot plant" in 2008, measurements in 2008, with a series of raw sediments (without STM) and two values for the sediment ARS for a comparison between raw and desanded/dehydrated sediments.

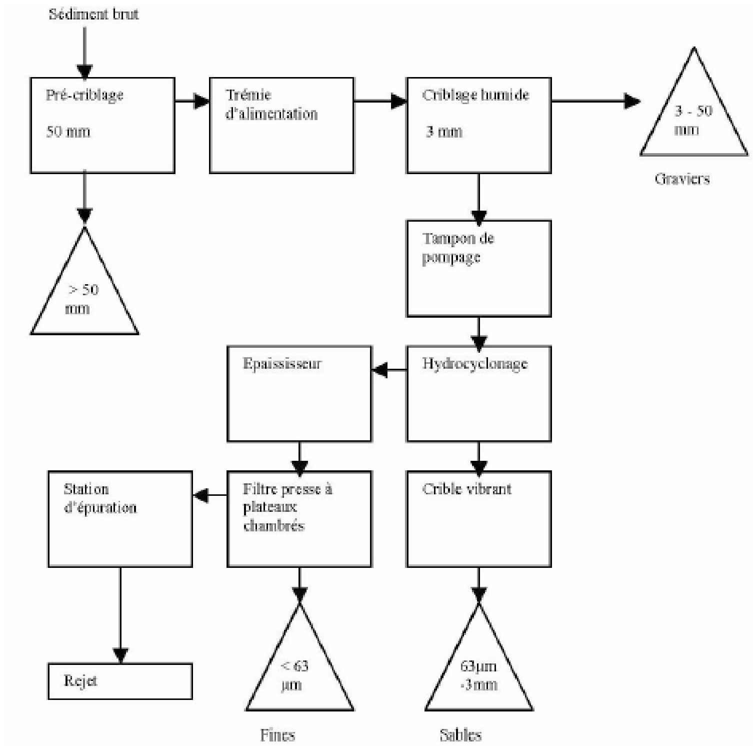

Figure 3. Different cycles of treatments of the "pilot plant".

The water contents were determined when the barrels of sediments were received in laboratory dated March 19, 2007 for the two series of sediments. They were again measured on March 6, 2008 with those of six complementary batches (see table 3). They are the water initial contents, very useful data before operations of pre treatment. Initial water contents for raw sediments measured at the barrels reception day are lower than those corresponding to the dredging water contents for 4 sediments. This can be explained because of the decantation of the raw sediments in the basin of storage. For the two others (STM and VPM), a mixing of water staying at the surface in the storage basin when sampling sediments cause the water content to increase close to 20%).
The water contents carried out in 2007 and 2008 for samplings dated 2007 are similar for the whole of the raw and DD samples. For samples ARS, BAN, CAN and SAN the

variations remain inferior to 6.4% except for BAN/DD whose values go from 28.7 to 42%. For STM and VPM samples with high initial water contents *W*, the variations reach 13.8%. The differences between *W* of the samples dated 2007 and 2008 (measurements 2008) remain also low except for ARS/BRUT and SAN/DD, see figure 4. If one does not take into account this last sample SAN/DD, we observe that the desanded and dehydrated sediments have nearly the same water content average, this attests to the good performance of the pilot unit for these operations.

Table 3. Initial water contents of the tested sediments samples.

Sediment references	***Initial water content W (%)*** *Samplings 2007 Measurements 2007*	***Initial water content W (%)*** *Samplings 2007 Measurements 2008*	***Initial water content W (%)*** *Samplings 2008 Measurements 2008*
ARS/BRUT	*21.4*	*15*	*41*
ARS/DD	*46.9*	*44*	*45*
BAN/BRUT	*19.7*	*18*	-
BAN/DD	*28.7*	*42*	*44*
CAN/BRUT	*18.1*	*16*	-
CAN/DD	*49.3*	*43*	*48*
SAN/BRUT	*22.7*	*23*	-
SAN/DD	*52.5*	*52*	*32*
STM/BRUT	*81.3*	*70*	-
STM/DD	*83.3*	*89*	-
VPM/BRUT	*80.5*	*75*	-
VPM/DD	*64.8*	*51*	*47*

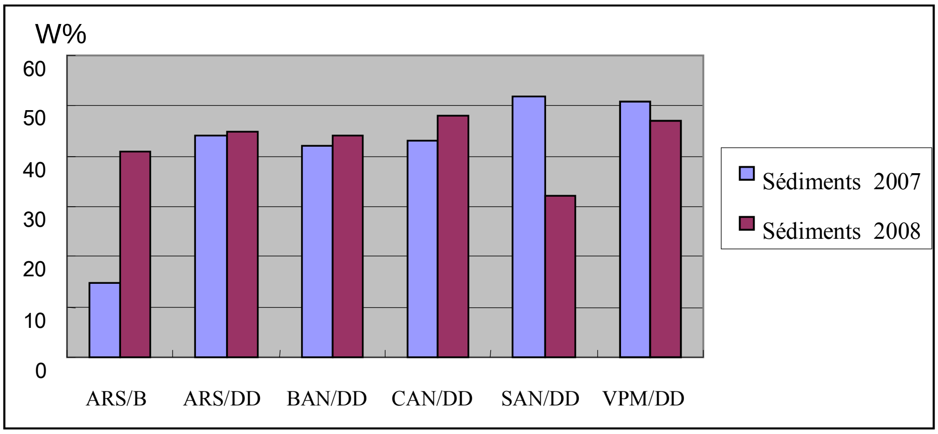

Figure 4. Distribution of water contents measured in 2008 on samples dated 2007 and 2008

The whole of these variations seem to result from heterogeneity within the sampling and of the sample size for the measurement of *W*. As for the measurements carried out in 2008 on the sampling dated 2007, the successive openings of the barrels took place to carry out the other tests of characterization and formulation *i.e.* for stabilization treatments of the sediments.
In addition, it is noted that the initial water contents on the desanded and dehydrated sediments are higher than those of the raw sediments except for sample VPM (see table 3). This is explained by the fact that in the cycles of pretreatment (figure 3), there is a wet sifting before the operation of hydrocycloning.
The raw sediments underwent an operation of sifting, crest lowered to 5 mm, an operation necessary for running out the tests of characterization according to the standards. A measurement of the water contents was carried out on the raw samples issued from the "pilot plant" in 2007 before and after the cresting operation. We do not observe any significant variation as shown in figure 5, the water contents are nearly identical. Percentage of the particles > 5 mm is lower than 1% (figure 1). Two groups of sediments emerge: one including the samples STM and VPM whose water content is approximately 80%, and the other samples with a content W nearing 20%.

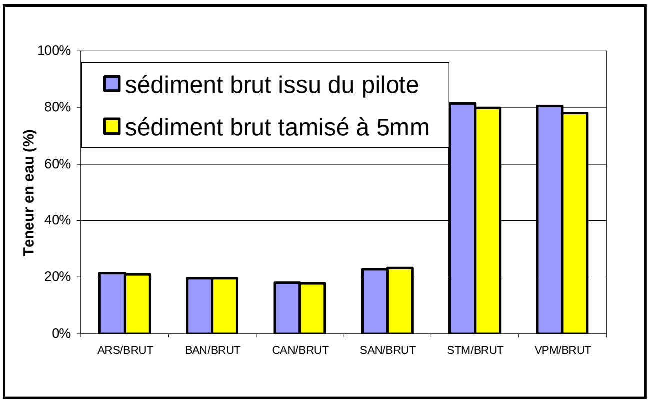

Figure 5. Compared water contents of raw and sifted raw sediments – sampling in 2007and measurements in 2007.
(Note : sédiment brut issu du pilote = raw sediment issued from the "pilot plant; sédiment brut tamisé à 5 mm = raw sediment sieved at 5 mm).

3.1.3 Atterberg limits and classification of the sediments
Values of the Atterberg limits measured on the sediments sampled in 2007 and 2008 are given in table 4. The limit values made it possible to classify these sediments as silts and organic soils, according to the Casagrande plasticity chart (see figure 6).
For measurements of 2007, the values of the limits are most representative because they relate to the two series of sediments. Three groups of samples are observed:

1) a group of raw samples (ARS, BAN, CAN and SAN) with a value of IP < 8%, in the area of the "organic silts and soils with a low plasticity",

2) a group of samples DD shifted towards a IP value of 20%, and whose values of W_L are in the interval $70 < W_L < 80\%$ except for the VPM/BRUT sample,
3) a formed group of samples SAN/DD and STM with a *IP*>20%. They are connected with "organic silts and soils with high plasticity".

Table 4. Atterberg limits of the tested sediment samples.

Measurements	***2007***			***2008***		
References of sediments	***Liquidity limite W_L (%)***	***Plasticity limite W_P (%)***	***Plasticity index I_P (%)***	***Liquidity limite W_L (%)***	***Plasticity limite W_P (%)***	***Plasticity index I_P (%)***
ARS/BRUT	*36,73*	*30,49*	*6,24*	*43,3*	*36,64*	*6,65*
ARS/DD	*77,39*	*58,75*	*18,64*	*72,38*	*55,91*	*16,46*
BAN/BRUT	*30,55*	*25,41*	*5,14*	-	-	-
BAN/DD	*71,23*	*55,4*	*15,83*	*70,64*	*65,89*	*4,74*
CAN/BRUT	*26,97*	*21,96*	*5,01*	-	-	-
CAN/DD	*71,57*	*53,14*	*18,43*	*58,31*	*52,43*	*5,87*
SAN/BRUT	*32,85*	*32,28*	*0,57*	-	-	-
SAN/DD	*97,26*	*58,43*	*38,83*	*63,8*	*57,25*	*6,54*
STM/BRUT	*121,14*	*95,18*	*25,96*	-	-	-
STM/DD	*118,41*	*94,18*	*24,23*	-	-	-
VPM/BRUT	*77,33*	*58,1*	*19,23*	-	-	-
VPM/DD	*87,38*	*72,72*	*14,66*	*84,98*	*65,39*	*19,58*

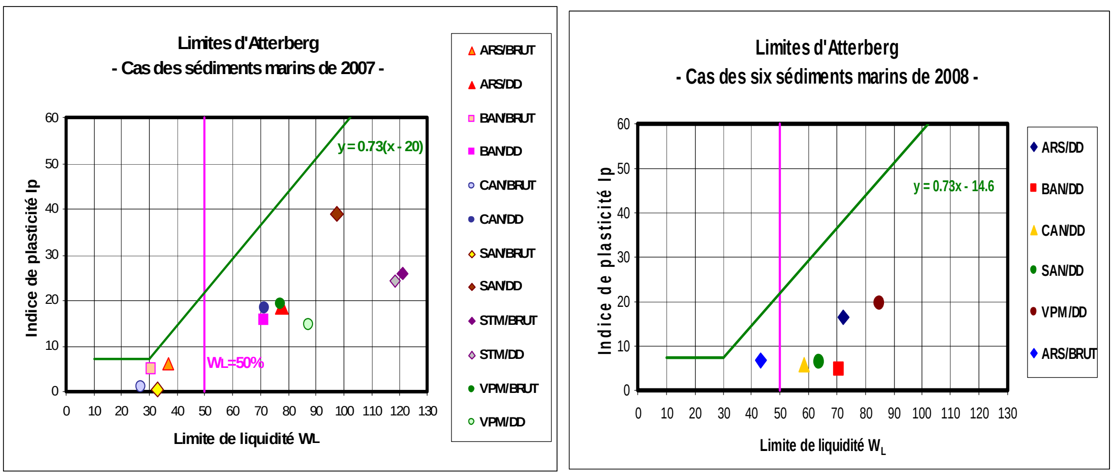

Figure 6. Fine sediments evolution from organic low plastic silts and soils to organic high plastic silts and soils in Casagrande chart.

For measurements of 2008, the values of the limits concern the desanded samples and ARS/BRUT sample. It is observed that:

1) ARS/BRUT sample remains well located with a value of IP close to 8%, in the zone of the "organic silts and soils with low plasticity",
2) DD samples are shifted with the same tendency observed for the second group in 2007.

These are organic soils which pose problems of stabilization/solidification with hydraulic binders (SANNIER *et al*, 2008).

3.1.4 Organic matter and carbonate contents of the sediments

The organic matter values measured on the sediments are more important (11 to 19.3%) on the desanded and dehydrated sediments that on the raw sediments (2.7 to 17.2%), see table 5. If we consider the sediments DD and their granulometry 0/2mm, the values of the contents of organic matter remain high compared to the marine sediments coming from the large French estuaries which are lower than 10% (COLIN, 2003).

As for the carbonate contents of the sediments, a greater disparity on the levels of the values was noted. This disparity can be explained by the method used for the determination (calcimetry) and by the natural variability on small quantities of sediments used for these measurements. The values obtained on the sediments sampled in 2007 and 2008 are shown in table 6.

Table 5. Organic matter contents of the tested sediments samples.

Sediment references	***Organic matter contents (%)***	***Sediment references***	***Organic matter contents (%)***
ARS/BRUT	*5.1*	*ARS/DD*	*14.0*
BAN/BRUT	*3.1*	*BAN/DD*	*11.6*
CAN/BRUT	*2.7*	*CAN/DD*	*11.4*
SAN/BRUT	*3.5*	*SAN/DD*	*13.1*
STM/BRUT	*17.2*	*STM/DD*	*19.3*
VPM/BRUT	*13.7*	*VPM/DD*	*16.7*

Table 6. Carbonate contents of the tested sediment samples.

Sediment references 2008	***$CaCO_3$%***	***Sediment references 2007***	***$CaC0_3$%***	***Sediment references 2007***	***$CaC0_3$%***
ARS/B	*16.26*	*ARS/B*	*32.98*	*BAN/B*	*27.82*
ARS/DD	*13.63*	*ARS/DD*	*16.79*	*CAN/B*	*16.69*
BAN/DD	*17.47*	*BAN/DD*	*25.93*	*SAN/B*	*23.05*
CAN/DD	*21.81*	*CAN/DD*	*21.66*	*STM/B*	*16.49*
SAN/DD	*19.89*	*SAN/DD*	*11.03*	*STM/DD*	*13.61*
VP M/DD	*20.9*	*VP M/DD*	*13.63*	*VPM/B*	*21.24*

3.2 Hydraulic properties of the sediments

3.2.1 Decantation parameters

The tests of decantation in columns carried out at concentrations of 250 g/l, make it possible to identify two types of behaviour. Sediments ARS, BAN, CAN and SAN behave in an identical way during the decantation. The behavior of two other samples (STM and VPM) differs clearly. The first show a very important and immediate settlement (- 0,60 m) whereas samples STM and VPM have a settlement of 0,30 m, *i.e.* a reduction of 50%, see figure 7.

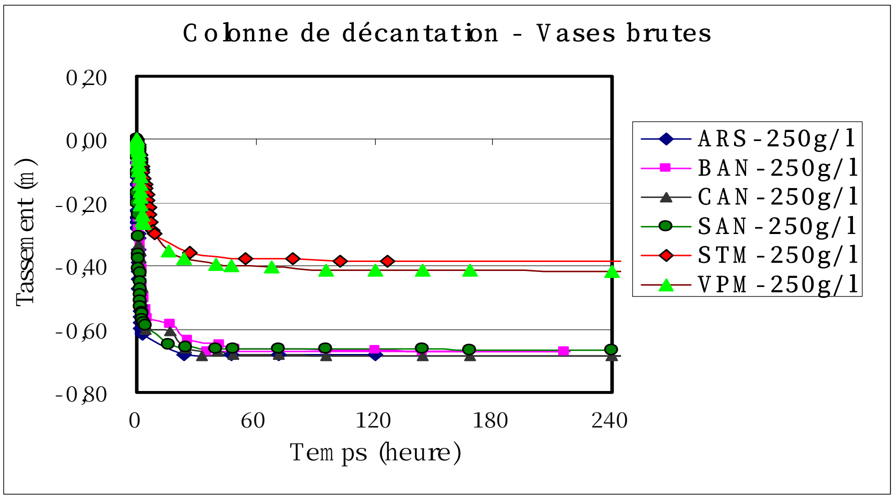

Figure 7. Settlement in column versus time forMediterranean raw sediments. (Note : colonne de décantation = decantation column; vase brutes = raw sediments; tassement = settlement; temps= time).

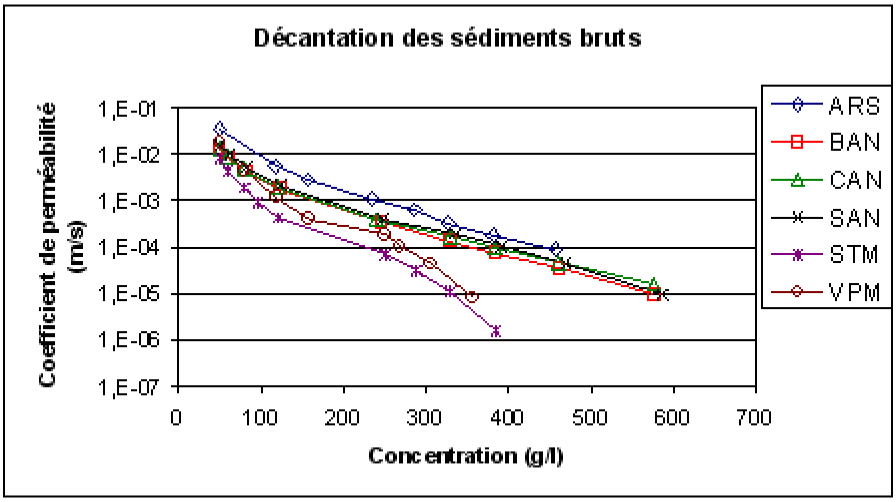

Figure 8. Relationships k-C for Mediterranean raw sediments. (Note : sédiments bruts = raw sediments).

For these same sediments and initial concentrations of 50 g/l and 250 g/l, the tests with the column allow to determine the evolution of the coefficient of permeability k versus the concentration C. The relation between k and C also illustrates this distinction (figure 8).

3.2.2 Consolidation parameters

The oedometric tests provided the consolidation parameters (compression coefficient, consolidation coefficient, creep coefficient) and allowed to obtain supplementary data for the k-C relation. Thus, figure 9 shows the variation of the coefficient of permeability k with the void ratio e for the whole of the tests of decantation (high initial void ratio) and of consolidation, and enables to observe the continuity of the evolution.

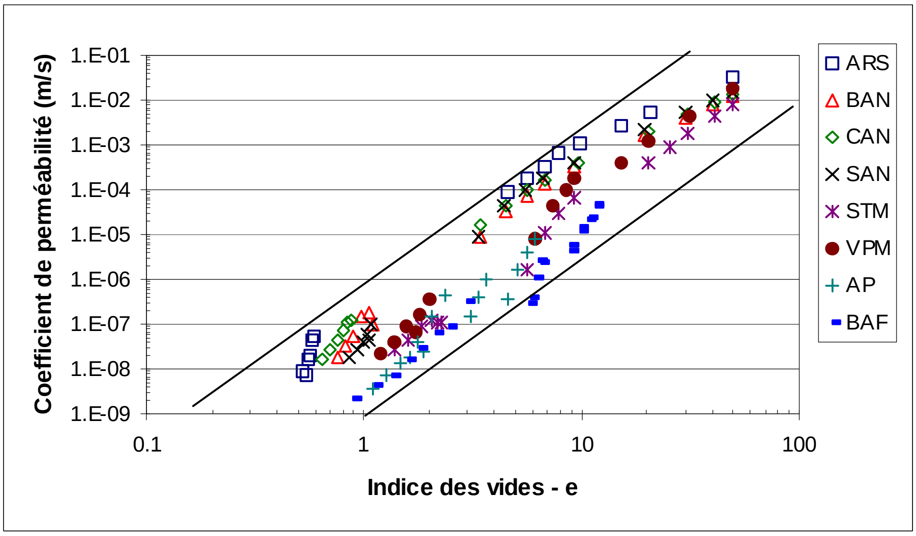

Figure 9. Relationship k-e for raw sediments.
(Note : indice des vides =void ratio).

During this series of œdometric tests, creep tests were run out to determine the coefficients of creep C_α for the raw sediments. Table 7 gives the obtained values.

Table 7. Creep coefficients of the tested sediment samples.

References of sediments	***Creep coefficient*** C_α
CAN/B	*0.0048*
BAN/B	*0.0067*
SAN/B	*0.0081*
ARS/B	*0.0064*
STM/B	*0.0249*
VPM/B	*0.0647*

4. Discussion

4.1 Interest of measurements of the physical and chemical properties of sediments

The water contained in the sediments is an obstacle for the transport and the valorization of the sediments (LEVACHER & DHERVILLY, 2010). Its follow-up must be assured by continuous measurements of the water contents since the initial state (operation of dredging) and during the pretreatments undergone in the cycle of a "pilot plant". In this study, they varied according to the state of the raw and DD sediments in particular by the use of wet sifting (figure 3). In laboratory, the values showed stability over time, the means of transport and of conservation in hermetic barrels being satisfactory.

Granulometry observed shows that sediments are fine grained soils whatever their state acts *i.e.* raw or desanded and dehydrated DD. The grain size range of the two populations is of 0/2 mm, this is the result of the cuts operated in the "pilot plant". From the granulometric point of view, the whole of the six studied sediments is contained in a relatively tight envelope (figure 1), which tends to say that they form the same family of sediments.

The sediments differ from each other by the nature of the components: percentage of the basic elements: fine clays, silts and sands, presence of carbonates or silica (interest for the use of treatment by chemical additives or polymers, LEMEE, 2006 and LIANG, 2008), presence of organic matters (disturbing effects in stabilizations with the hydraulic binders) and of course contents of contaminants in the case of polluted sediments. The clayey phase represents an important parameter for the stabilized/solidified sediments. It influences the hydraulic properties (see section 4.2), in particular if it is associated with the organic matter (table 8 and figure 10). The contents of the chemical components (*MO* and carbonates) of the sediments show, from the values obtained, a rather large dispersion. Also, determination of the content of organic matters in the sediments is difficult, even by respecting the protocol standard (measurement precision) as the variability of the organic matter rates in the sampled sediments exists and the representativeness of measurements is sometimes prone to discussion (LIANG, 2008). However, a repeated number of measurements allows to have a representative average value.

4.2. Compared parameters of compressible soils and sediments

From the tests carried out in decantation columns and œdometric cells, we observe a good continuity of the relation *k-e* (figure 9). These tests may be associated so as to cover broad concentrations of the sediments at dredging, during the cycle of pretreatment and at the time of the implementation in deposits and in filling in embankments.

With regard to the hydraulic and geotechnical characteristics of clayey soils, some range of values are commonly allowed for compressible soils, even very compressible with respect to their classification and workability (SETRA-LCPC, 2000). These parameters make it possible to locate the studied sediments either according to their organic character or their clayey nature. These data on the sediments are useful for design, see table 8.

Table 8. Hydraulic and consolidation properties of the tested samples.

TYPICAL PROPERTIES FOR STUDIED SEDIMENTS						
PROPERTIES	***in situ* water content W (%)**	***Initial void ratio*** e_0	***Compressibility*** $C_c/(1+e_0)$	***Creep index*** C_α	***Permeability coefficient k (m/s)***	***Consolidation coefficient*** C_v (m^2/s)
Sediment ARS	50-200	0.593	0.030	0.133 C_c	10^{-6} à 10^{-9}	10^{-7} à 10^{-8}
Sediment BAN		1.113	0.117	0.027 C_c		
Sediment CAN		0.899	0.091	0.028 C_c		
Sediment SAN		1.102	0.082	0.046 C_c		
Sediment STM		2.332	0.206	0.094 C_c		
Sediment VPM		2.142	0.169	0.047 C_c		
TYPICAL PROPERTIES FOR COMPRESSIBLE SOILS*						
Rich-organic soils	100-200	2 à 3	0.2 à 0.35	0.03 à 0.05C_c	10^{-6} à 10^{-9}	10^{-6} à 10^{-8}
Sludge	60-150	1.5 à 3	0.25 à 0.4		10^{-7} à 10^{-9}	10^{-7} à 10^{-8}
Soft clays	30-100	1.2 à 2	0.15 à 0.3		10^{-9} à 10^{-11}	10^{-7} à 10^{-9}

*Nota: * Properties summarized in the technical guide "Etude et réalisation des remblais sur sols compressibles", SETRA-LCPC (2000).*

Another result of importance relates to the evolution of the coefficient of creep C_α versus the content of the organic matters (figure 10). The presence of a high organic matter contents in the sediments poses problem for the placing in embankment without treatment. The increase of the organic matters content tends to increase creep as seen in figure 10 for the Mediterranean sediments.

The geotechnical characteristics and the hydraulic properties relative to the tested sediments constitute a parameters data base. These parameters are necessary to choice and propose a type of valorization. It was also observed that four of the six Mediterranean sediments have also the same creep behavior. This result is very useful for a complementary characterization as a road material.

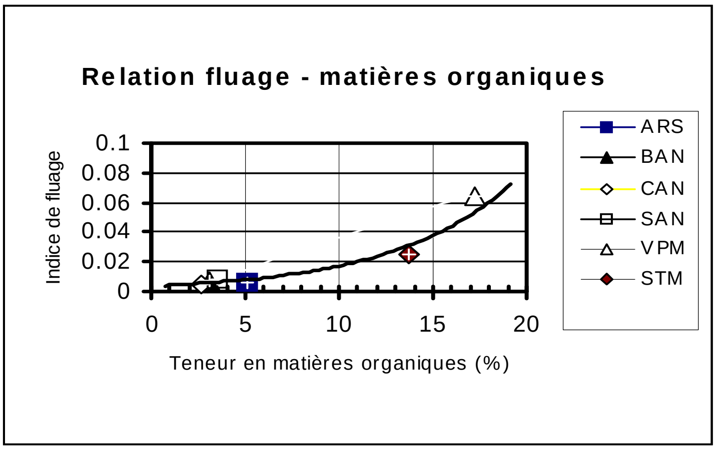

Figure 10. Creep coefficient C_α and organic matter content relationship for the raw sediments.
(Note : indice de fluage = creep coefficient; teneur en matières organiques = organic matter content).

4.3 On the methodology of sediment characterization

We note a good adequacy of the suggested methodology through the geotechnical and hydraulics characterizations. Those allow:

1) to draw up an identity card of the studied Mediterranean sediments,
2) to propose groups or families of sediments according to their geotechnical, hydraulic and hydromechanics properties,
3) to direct the valorization of the sediments towards the suitable beneficial reuses, for example road embankments (hydraulic properties), road and construction materials (contents of clays, silts and sands like the sand concretes, LIMEIRA *et al.*, 2009),
4) to evaluate the good performance of the steps of pretreatment such as sifting, sieving and dehydration, in the "pilot plant" (checking of granulometric cuts).

5. Conclusions

The means of transport and storage of the sediments with hermetic barrels appeared satisfactory. The water contents are stable in time. These measurements of water contents, initial as during the pretreatments, are very useful to ensure a good choice of the types of treatment such as, for example, the knowledge of available water for road materials, mortars and concretes.

But for other applications like the construction of embankments and fillings of cavities, the hydraulic properties must be proposed. The methodology suggested, which is based on tests used in soil mechanics and on tests of sedimentation, allows to obtain very useful data to study the behavior of marine sediments put in fill without preliminary treatment. However, for placing in an embankment with stabilizing treatment, these data

are also necessary to evaluate the effectiveness of these treatments. So, it is only a minimal characterization of sediments before any valorization in fill or equivalent.
Another interest of this methodology is to constitute a database on the properties of the sediments whether in the form of tables (see table 6) by using graphical relations between the permeability and the void ratio (see figure 8) or in the form of fitted curves (see figure 11) giving the relation of the permeability versus the sediment concentration (SANCHEZ & LEVACHER; 2007; DUAN, 2008), equation is given after:

$$k = k_0 \exp\left[-A\left(\frac{C}{\rho_s}\right)^{0,65}\right] \qquad (3)$$

where C is the sediment concentration, ρ_s is the solid phase density, k_0=1,60 m s^{-1} is a parameter with constant value for all the examined sediments, and A is the sediment specific parameter.

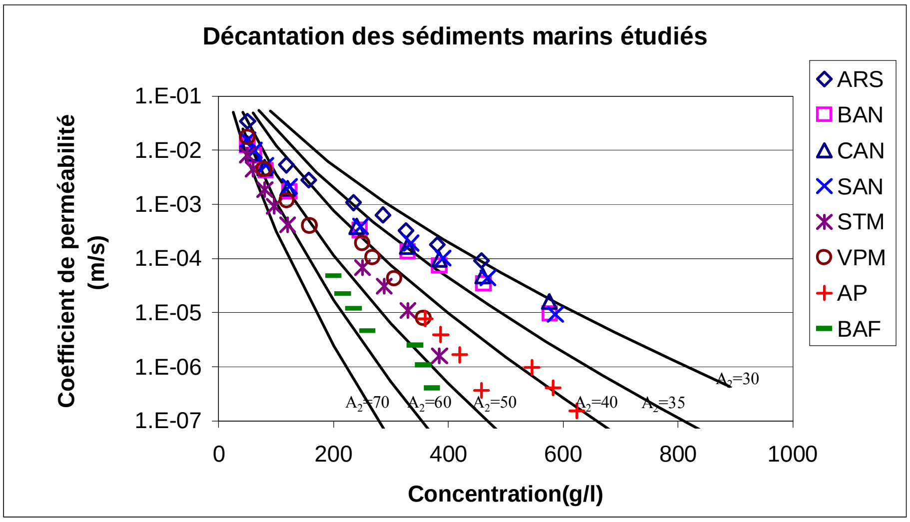

Figure 11. Variation of k in terms of C for the studied marine sediments (Coefficient de perméabilité = permeability coefficient)

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