

Study For the Use of Oran Marine Sediments

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Abstract

The port of Oran is considered the most important port on the western seaboard of Algeria, it therefore plays a key role in the economy of the region. The siltation of ports is a natural phenomenon that can represent a real obstacle to the development of fishing and trade activities and to which it is necessary to provide environmentally friendly solutions. To maintain these activities, managers must undertake dredging operations. Considerable effort is required to develop recovery techniques to minimize traditional disposal methods (disposal at sea or deposition) which may present definite risks to the ecosystem.

As part of our study, we focused our research on methods for the recovery of marine sediments from the port of Oran in construction (building and public works). In this article we present an experimental study on the dredging sediments of the port of Oran. The physical, chemical, mineralogical and geotechnical characterizations were carried out with a view to a thorough knowledge of this material and its possible reuse for environmental protection purposes.

Keywords: Marine sediments, Dredging, Environmental protection, Characterization, valorization

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1. Introduction

The natural siltation occurring in ports areas can obstruct waterways and prevent these infrastructures from fulfilling their primary function as a shelter for boats. This often involves the implementation of expensive and time-consuming dredging operations to restore depths compatible with navigation [BESSENASSE, 2003] [REMINI, 2007] [MAROUF, 2018], [HUGUET 2019], [DELBECQ, 2023].

The economic activity of many ports in Algeria is hampered by the natural phenomenon of sediment accumulation. Dredging is a necessity; however, the storage of the dredged sediments (DS) is a problem for harbour managers. The easy and low-cost solution of dumping sediments at sea raises environmental concerns that could eventually be alleviated by considering these sediments as a new source of construction materials [Kazi Aoual-Benslafa, 2014].

Study For the Use of Oran Marine Sediments

Geotechnical environmental recovery of dredged material and their use in achieving some engineering works is a path increasingly explored by researchers in recent years, and is therefore a research area in harmony with the concept of sustainable development.

The research aims to develop sediment management methods that must meet a set of economic, technical and environmental criteria, and programs to protect, clean up the most threatened aquatic habitats [AGOSTINI, 2006], [GUYADER and COLIN, 2012]. The recovery of dredged material is sought to reduce dredging costs and meet a need for materials for three types of uses (spreading [NEDELEC, 2011], primary or developed construction materials [ZENTAR, 2008], backfilling for infrastructure construction [Bataillard, 2017], etc.).

The study of BOURABAH treats exploitation of dredging sediments of the dam Cheurfas (Algeria) and their valorization in road embankments. These analyses showed that a treatment by sand, lime and cement proved to be necessary. Various formulations were elaborated in this direction and a synthesis of the mechanical characteristics was elaborated in accordance with the standards and the classification of materials used in road embankments [BOURABAH, 2011].

The incorporation of calcined sediment up to 20% substitution of cement does not affect the durability of the material, besides 10% substitution of cement, improve mechanical and environmental behavior. From an environmental point of view and life cycle, mortars formulated containing treated sediments are considered inert with respect to the inert waste storage facilities reference (ISDI-France) [AMAR, 2016].

The results of the work EL MAHDI on sediments highlight the substantial contribution of these materials to improving the performance of concrete and support their use as self-consolidating concrete. These results contribute to reducing the footprint of CO₂ in concrete, as well as mining. Also, contributes to understanding the behavior of sediments in concrete from certain analyzes and treatment. Thus, identify aggressive environments suitable for the use of sediments [EL MAHDI, 2020].

The preliminary study of E. SILITONGA performed on fine dredged sediments revealed the identification of the mechanical characteristics measured on the mixes is compatible with their use as a base course material and for the final part, the fine dredged sediments were used for the construction of the platform road in situ [E. SILITONGA, 2010].

The results obtained by BANOUNE on the different studied formulations are promising and show that the addition of lime in the sediments favorably influences the geotechnical parameters [BANOUNE, 2016]. The different sediments are classified from a geotechnical point of view and treated with hydraulic binders. Even if the sediments belong to the same geotechnical class, they show different responses in terms of mechanical behavior and in particular, swelling and tensile strength [MAHERZI, 2014].

After physico-chemical characterisation, mineralogical and mechanical, the environmental impact of the raw sediments of the Port and the potential for use of these materials in experimental road construction are evaluated. In order to improve the mechanical Characteristics of raw sediments,

Study For the Use of Oran Marine Sediments

in view of the imposed constraints for their uses in layer foundation, the sand of the Someca career has been used to optimize the granular composition of the material [AZRAR, ABRIAK, 2014], [SCORDIA, 2008], [BOUDLAL, 2016].

Solidification is a process by which waste containing heavy metals is fixed or trapped in a solid for example the cement matrix [POJASEK, 1979] [TSENG, 1988]. This technique (stabilization/solidification) applied to sediments has multiple advantages: on the one hand to have a solid product and on the other hand to stabilize and immobilize inorganic contaminants [BOUTOUIL, 2000].

In order to find a solution to environmental problems, many treatment processes (physico-chemical [FRÉDÉRIC, 2006], biological [MAMINDY-PAJANY, 2011], thermal [Ramaroson, 2008], etc.) allow to eliminate or stabilize the pollutants contained in dredging products.

The materials studied are of marine origin from the port of Oran (Casablanca and Safi quays). The objective of this work is to contribute to the valorization of the sediments in BPW (Building and Public Works). By comparing the values of the physical and mechanical parameters (identification tests, Proctor, compression) in the context of aspects related to the valorization of sediments from the Casablanca and Safi quays, the characterization methodology described in the GTS [soil technical guide, 2000], showed that it was possible to valorize sediments in all pavement layers without adding additional material.

2. Presentation of application sites- port of Oran

The port of Oran is located at the bottom of a gulf that is limited to the east by the tip of the needle of Jebel Kristel and to the west by Cape Falcon.

The port of Oran, considered the most important port on the western seaboard, therefore plays a key role in the economy of this region (Figure 1).

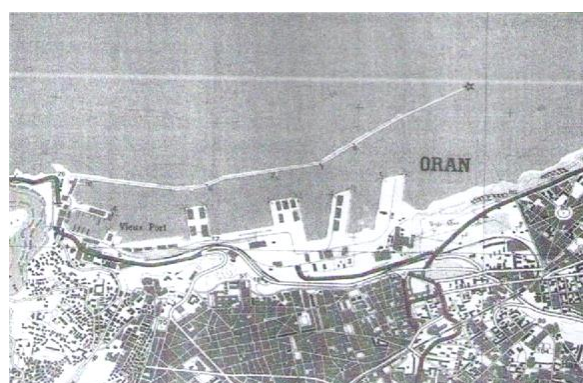


Fig 1 Overview of the Port of Oran.

This port offers a lake of 128ha divided into seven (07) basins protected by jetties totally close to 3500ml. The port also covers about 200 pleasure craft with a 522m layout line.

Study For the Use of Oran Marine Sediments

3. Sample preparation

In order to ensure the proper operation of the Oran port, the managers used a dredging of the various quays using a bucket dredge when dredging the quays of Casablanca and Safi (see Figure 2).



Fig 2 Sediment Sampling Sites (Casablanca and Safi quays).

The sediment collected was discharged into 100-litre plastic cans, ensuring proper closure to preserve the sediment in its natural state (see Photo 1).



Photo 1 Natural air drying of sediment from Casablanca and Safi quays

Some of the sediment was then removed and dried in open-air plastic bins for a few weeks to remove moisture (see Figure 3).

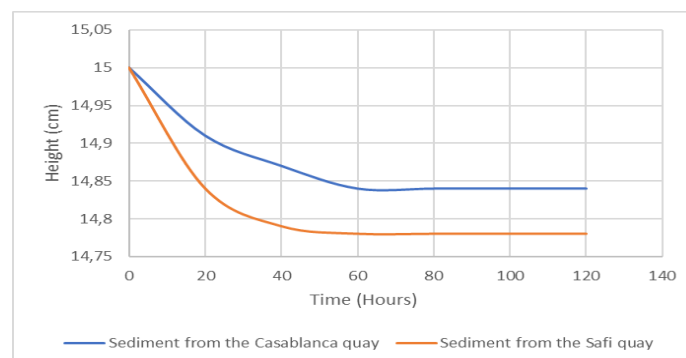


Fig 3 Variation in sediment column height as a function of time.

Study For the Use of Oran Marine Sediments

A complete mixing of the sediments of all futs would have been interesting, we have for this purpose, homogenized separately the sediments with the help of a mixer. The mixing is carried out for about ten minutes until the material has a homogeneous consistency [DUAN, 2008].

3.1 Sample Color

According to the MUNSEL code, the sediment of the Casablanca and Safi quays represents a black-willing colour [MUNSSELL Code, 1994].

3.2 Physical Properties Analysis

3.2.1 Initial water content

Water content tests were performed on Casablanca and Safi sediments at 40C° as a function of time, then on the same samples at 105C° according to NF P 94-050. Tables 1 give the results of the sediment contents of the Casablanca and Safi quays.

Table 1 Water state of sediment.

		40 C°		105C°
Sample	Quay	W (%) 24h	W (%) 120h	W (%) 24h
C1	Casablanca	30,71	53,93	58,79
C2		31,98	57,11	58,89
C3		29,55	58,89	60,71
C4		27,80	56,30	58,06
S1	Safi	35,93	58,40	63,38
S2		35,26	59,98	62,82
S3		33,33	60,52	63,36
S4		33,82	59,77	61,05

The average water content in the sediment of Casablanca quay at 40C° after 120h of drying is 56.57(%), that after drying at 105C°, it is 59.11(%).

The average water content in the sediment of Safi quay at 40C° after 120h of drying is 59.66 (%), that after drying at 105C°, it is 62.65 (%).

The difference of about 3(%) observed between the 40C° tests and of 105 C° can was caused by one of the activity or combination of bound water and organic matter.

3.2.2 Determination of particle size distribution

The structure is determined by wet in order to remove the finest particles of the largest. The fraction below 80µm is analyzed by the sedimentometric method, which complements that made by sieving. The results obtained on the port sediments of Oran show a zero clay fraction, the silty

Study For the Use of Oran Marine Sediments

fraction (10.5~14%) and the sandy fraction (80~83%). This allows for classes of these sediments in the sand category (following the triangular classification diagram of sediments according to their texture (West Public Works Laboratory).

Sediments are classified as sandy-loam soils in the Taylor diagram (Figure 4).



The sediments of the Casablanca and Safi quays

Fig 4 Triangular classification of fine soils [DÉGOUTTE et al, 2005]

The particle size distributions of the sediments of Casablanca (C1, C2) and Safi (S1, S2) quays shown in Figure(5).

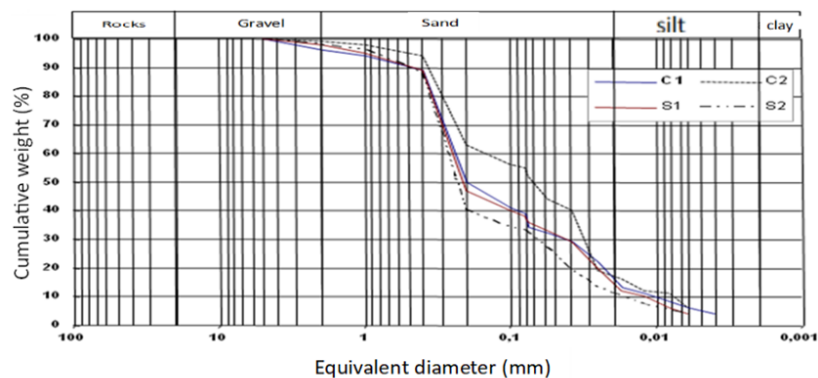


Fig 5 Marine sediment particle size analysis.

3.2.3 Methylene blue value

The methylene blue (VB) value test is carried out according to NF P94 068, it allows to have the clay activity of the sediments.

Study For the Use of Oran Marine Sediments

Table 2 Sediment argilosity of the Casablanca (C1, C2) and Safi (S1, S2) quays.

The sediments	Volume of methylene blue (ml)	Weight (g)	VB
C1	75	70	1,028
C2	55	50	1,089
S3	35	50	0,68
S4	25	50	0,49

According to the technical Guide for the Construction of Embankments and Form Layers [GTR, 1992], based on the methylene blue value, sediments from the Casablanca (C1, C2) and Safi (S1, S2) quays are placed in the sandy loam group.

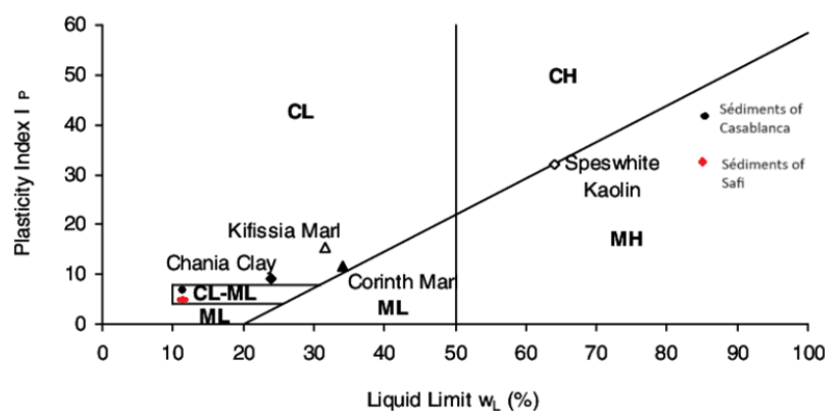
3.2.4 Atterberg Limits

These limits are measured on the fraction of soil that passes through the 0.40mm sieve (NF P94 051) (see table 3).

Table 3 Atterberg boundary of sediments Casablanca (C1, C2) and Safi (S1, S2) quays.

Sample	Liquidity limit Wl (%)	Plasticity limit Wp (%)	Plasticity index Ip=Wl-Wp
C1	28,125	18,425	9,7
C2	28,65	20,505	8,145
S1	29,8	18,4	11,4
S2	30,625	19,735	10,89

To determine the sediment states, we carry the results obtained on the Casagrande diagram according to the liquidity limit and the plasticity index (see figure 6).



Figur 6 Classification of fine soils on the Casagrande diagram [PHILIPPONAT AND HUBERT, 1977].

Study For the Use of Oran Marine Sediments

On the basis of these results, and according to the Casagrande plasticity abacus, we can classify our soil as a weakly clayey (little plastic) soil.

3.2.5 Organic Matter Content

Table 4 shows the amount of organic matter contained in the sediments of the Casablanca (C1, C2) and Safi (S1, S2) quays.

Table 4 Estimated Percentage of Organic Matter.

Sediments	C _{om} (%)
C1	4,08
C2	4,26
S1	4,44
S2	3,85

The average organic matter content in the Mostaganem basin (sediments Casablanca (C1, C2) and Safi (S1, S2) quays) does not exceed 10% (SONATRACH Research and Development Centre). According to the two classifications BCL (Bridge and Pavement Laboratory Classification) and GTR (technical Guide for the Construction of Embankments and Form Layers), our sediment belongs to the group of soil weakly organic percentage of organic matter (about 4% < 10%).

3.2.6 Solid Grain Density Measurement

The test to identify the density of solid grains by using the pycnometer according to the standard (NF P 94-054), gave the following values:

- Sediment of the Casablanca quay is 2.46g/cm³ ($\gamma_s = 24.6 \text{ KN/M}^3$)
- Sediment from Safi quay is 2.30g/cm³ ($\gamma_s = 23 \text{ KN/M}^3$)

3.3 Chemical and Environmental Analysis

3.3.1 PH Determination [CLEMENT, 2003]

Table 5 shows that the PH in the four sediments (C1, C2, S1, S2) is slightly different. The PH of C1 and S1 is slightly more basic than that of C2 and S2, this basicity can be attributed to the presence of carbonates.

Study For the Use of Oran Marine Sediments

Table 5 Marine sediment pH values for Casablanca (C1, C2) and Safi quays (S1, S2)

Quay	Sample	PH
Casablanca	C1	8,21
	C2	8,33
Safi	S1	8,26
	S2	8,31

3.3.2 Determination of chemical elements

The chemical analysis of the marine sediments of the Safi and Casablanca quays was carried out by the L.W.P.W (West Public Works Laboratory). The results of the analyses are presented in Table (6).

Table 6 Chemical analysis of marine sediments (West Public Works Laboratory, Oran).

Features	Symbols	C1	C2	S1	S2
Silica	SiO ₂	45,00	44,47	54,96	53,89
Carbonate	CaCO ₃	45,45	45,45	34,09	35,00
The lime	CaO	25,09	24,94	18,75	19,31
Magnesia	MgO	0,34	0,37	0,28	0,26
Alumina	Al ₂ O ₃	3,67	4,53	4,19	4,37
Iron oxide	Fe ₂ O ₃	0,51	0,47	0,42	0,44
Sulphates	SO ₄	Null	Null	Null	Null
Fire loss		25,62	25,51	21,64	21,92
Carbon dioxide	CO ₂	20,00	20,00	15,00	15,40
Combination water	H ₂ O	5,62	5,51	6,64	6,52

In general, the main constituents are silica, carbonates and lime. The silica constitutes the sand as well as the limestone of the soils held shells, moreover, we notice that the loss to the fire is quite important which proves the existence of organic matter.

3.3.3 Environmental Analysis

Table 7 Sediment analysis results (mg/Kg) (SONATRACH Research and Development Centre, Boumerdes) (Maritime Studies Laboratory).

Study For the Use of Oran Marine Sediments

Basin name	N ^o station	(*) Threshold Recommended by Environmental Management					
		Lead (*) 250	Zinc (*) 500	Chrome (*) 250	Nickel (*) 75	Mercury (*) 1,5	Cadmium (*) 3
Ghazaouet	S1	62,65	353,1	47,49	342,6	1,41	0
	S2	4,4	48,23	8	74,48	0,44	0,15
Mostaganem (Casablanca and Safi)	S3	42,24	390,8	34,16	342,5	1,64	0,08
	S4	89,65	355,5	118,3	399,6	1,02	0
	S5	104,1	472,7	72,68	336,5	4,64	0,04
Tenes	S6	96,11	135,9	74,52	46,67	3,9	0
Bejaia	S7	90,3	1475	108,2	78,25	1,55	0
Skikda	S8	53,16	1120	474,0	39,82	0,78	0
	S9	90,94	1048	643,2	39,48	1	0
	S10	88,05	523,2	162,7	6,42	0,9	0
Bejaia	S11	162,9	872,4	94,83	0	1,14	0
Tenes	S12	117,6	817,5	109,9	0	1,75	0,2
Mostaganem	S13	87,1	322,5	79,02	0	0,24	0
Arzew	S14	87,11	212,1	39,86	0	0,4	0
Fishing	S15	104,3	437,7	91,22	6,94	3,7	0

For the sediments of Casablanca and Safi quays (material studied in this work in the Mostaganem basin), the proportions of Nickel and Mercury exceed the recommended threshold.

- Hydrocarbon content

The contents of total hydrocarbons are as follows (in table 8):

Table 8 Hydrocarbons in the sediments of Casablanca quay (C1 and C2) and Safi quay (S1 and S2).

	C1	C2	S1	S2
Hydrocarbon content (mg/kg)	1000	1000	2000	2000

Compared to the threshold value recommended by the environment Direction (300mg/kg), these values indicate significant contamination of the sediments of the Casablanca and Safi quays.

3.3.4 Percentage of calcium carbonate

In order to determine the calcium carbonate content, Dietrich-Fruhling calcimetry is used.

Table 9 Percentage values of calcium carbonate in marine sediments (West Public Works Laboratory).

Study For the Use of Oran Marine Sediments

Marine sediments	C1	C2	S1	S2
Carbon percentage (%)	45,45	45,45	34,09	35,00

The classification of table 9 indicates that the sediments belong to the Marne group.

3.3.5 Determination of electrical conductivity

The electrical conductivity of the soil is an index of the content of soluble salts in this soil, it expresses approximately the concentration of ionizable solutes present in the sample that is to say its degree of salinity.

sedement Quay	electrical conductivity (dS.m-1)	Salinity classes
Casablanca (C1, C2)	1,36	the electrical conductivity of the aqueous extract at 25 C° is salted [Amir, 2005]
	1,30	
Safi (S1, S2)	1,49	
	1,31	

Table 10 Percentage values of electrical conductivities in marine sediments

3.4 Mineralogical Analysis

3.4.1 X-ray diffraction

We carried out DRX analysis at the «materials chemistry» laboratory of the University of Oran.

The information obtained from the X-ray diffractograms of the sediments allows the identification of two distinct crystalline phases calcite and quartz. We note that the intensity of the peaks of the different phases (calcite and quartz) is more important for the sediment of Casablanca and Safi which reflects a higher concentration of these phases in the sediments. (see figures 7).

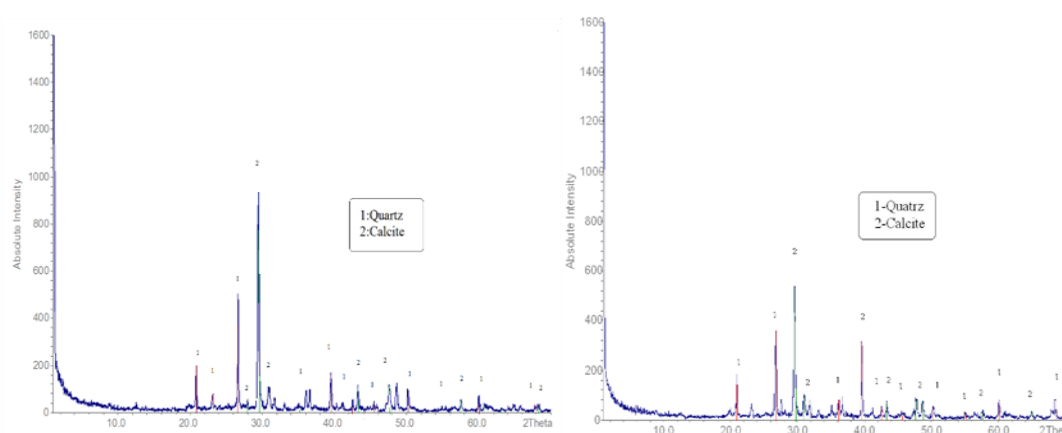


Fig 7 Crystalline phases of the marine sediment of Casablanca and Safi quays.

Study For the Use of Oran Marine Sediments

3.4.2 Differential Thermal Analysis (DTA)

The differential thermal analysis is completed the (X-ray) analysis, the device used is in the geomaterials laboratory (Higher Normal School, Oran) of recent «Entapimètre» type, connects to the data acquisition system and the microcomputer.

Two types of curves appear, one representing the linear variation of temperature, and the second the differential thermal analysis sign on an axis system (temperature-time) (see Figure 8).

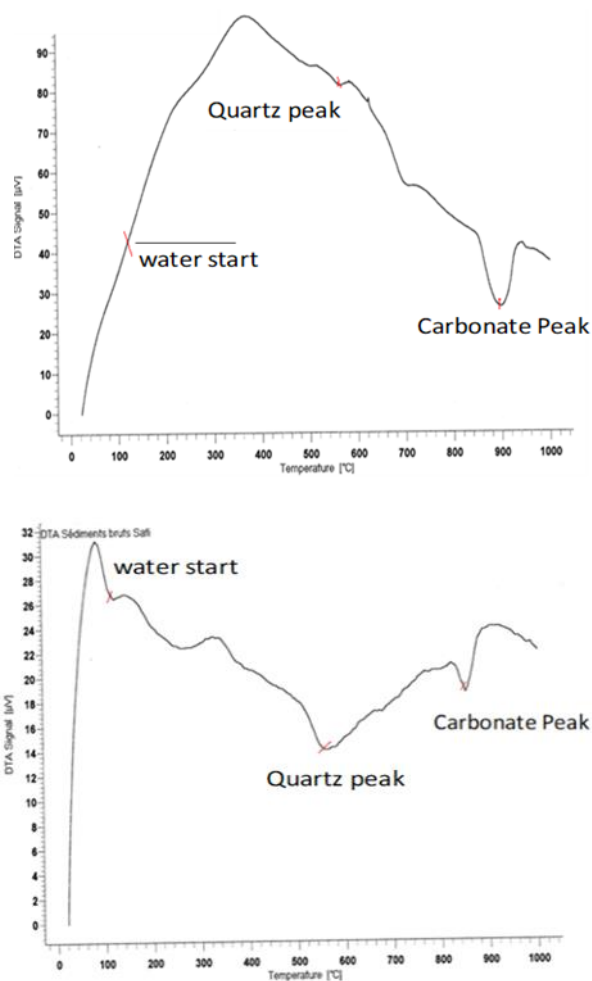


Fig 8 Casablanca and Safi sediment ATD curve.

Based on the results of the differential thermal analysis of the two sediments (Casablanca and Safi quays) (Figure 8), we note endothermic peaks around (100 C°) corresponds to the departure of water.

At 573 C°, an endothermic peak shows the transformation of quartz α into quartz β , relative displacement of atoms with a volume increase of about 8.29% and around 900 C° an endothermic peak corresponds to carbonate.

Study For the Use of Oran Marine Sediments

4 Contribution to valorization in road technology

4.1 Sediment classification according to the GTR

The physical characteristics measured in this study were chosen according to the proposed valuation.

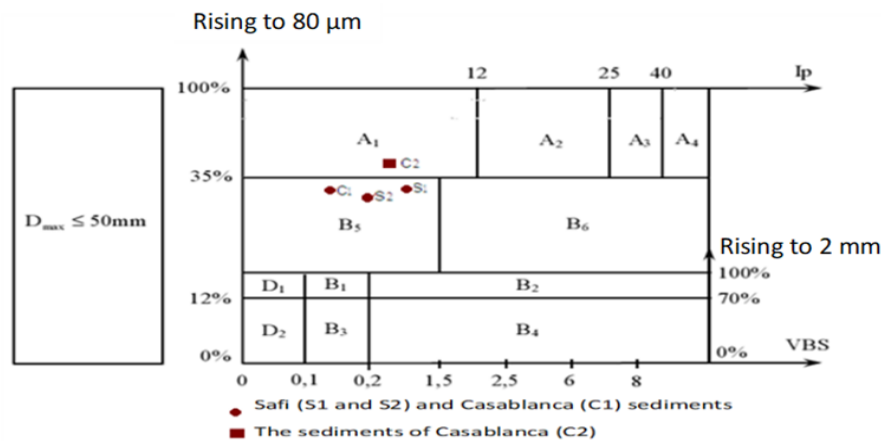


Fig. 9 Sediment classification according to [GTR, 1992].

Determination of compaction characteristics (Proctor test). The compactability of the raw sediments is evaluated through the Proctor test (NF P 94 093).

Table 9 Proctor test results (normal and modified) for Casablanca and Safi sediments.

Test type	Sedement	Temperature	$\gamma_{d \text{ opt}}$	$W_{\text{opt}} (\%)$
Proctor Normale	Casablanca	50C°	1,43	34,15
		105C°	1, 45	34,05
	Safi	50C°	1,35	27,28
		105C°	1,36	28,58
Proctor Amends	Casablanca	50C°	1,84	24,67
		105C°	1,83	23,89
	Safi	50C°	1,71	19,87
		105C°	1,72	21,79

4.2 The index of immediate lift

The immediate lift index is evaluated from the CBR test (Proctor – IPI).

Study For the Use of Oran Marine Sediments

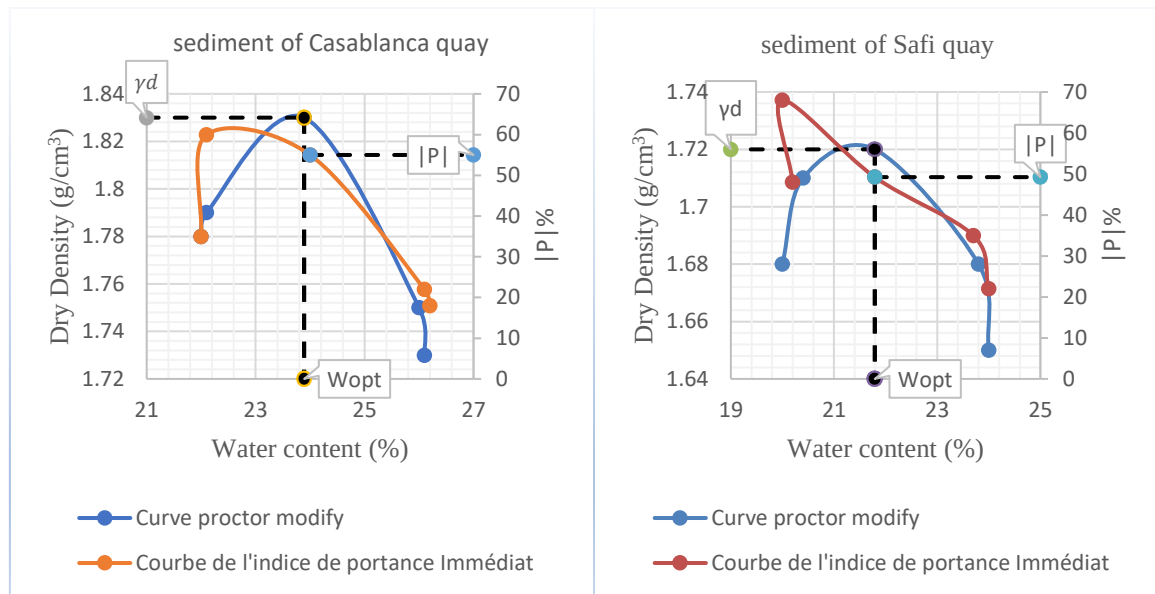


Fig 10 Proctor curve – IPI Immediate Lift Index in sediment of Casablanca and Safi quays.

From these curves, the parameters of the Proctor test and the immediate IPI index can be identified. The results are summarised in Table 7:

Table 7 Results of Modified Proctor at Optimum and IPI Immediate Lift Index.

sedement	γ_d opt	Wopt (%)	IPI (%)
Sédiment of Casablanca quay	1,83	23,89	54,99
Sédiment of Safi quay	1,72	21,79	49,23

4.3 Compression test

Among the objectives of the compression test is the determination of the age allowing the putting into circulation of the construction machinery on the treated layer. The road criterion is considered satisfactory if the single compressive strength is greater than 1 MPa [GTR, 2000]. It is therefore a question of estimating with the help of the curves the time necessary for this condition to be verified.



Fig 11 Cylindrical compression specimens .

Study For the Use of Oran Marine Sediments

Figure 12 shows the evolution curves of compressive strengths as a function of time (7, 14, 28 and 60 days).

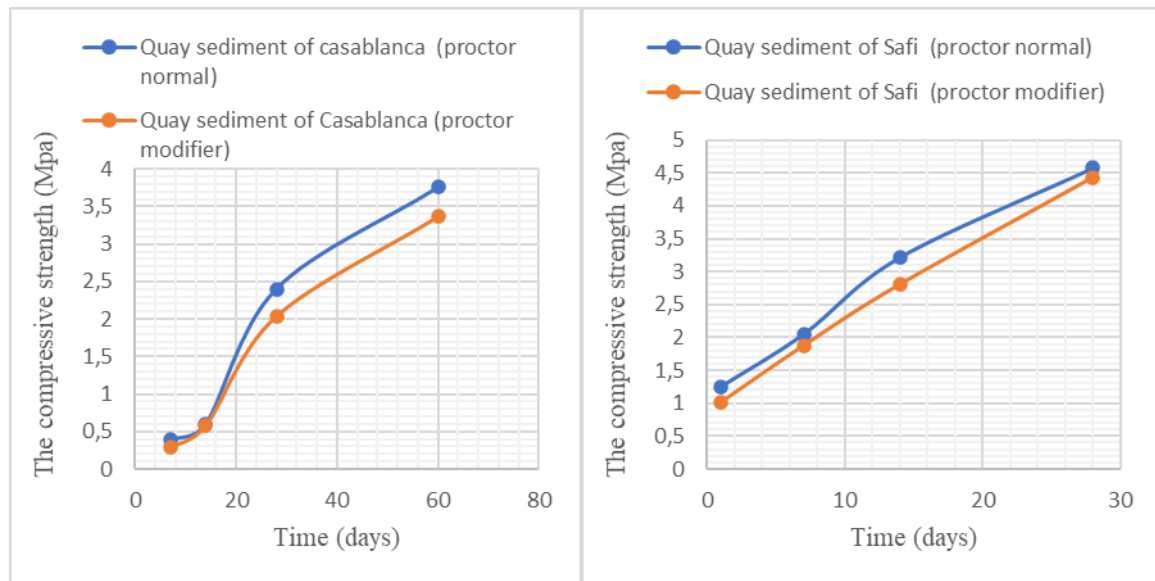


Fig. 12 Compression resistance as a function of conservation time (sediment of Casablanca and Safi quays).

It can be seen that there is a real increase in compressive strength at 28 days (about 2 MPa) and that the growth in values is remarkable at 60 days (about 3MPa). This shows that the sediments of Casablanca and Safi have a long-term behavior due to the decrease in water content and a new modification of the texture of the material.

5 Sediment treatment

The technical guide (Treatment of soils with lime and/or hydraulic binders. Application to the construction of embankments and form layers [GTS 2000]), defines the methods of treatment of materials for the construction of road structures. This guide mentions the use of two of the binders (aerial lime and hydraulic binders) for the treatment of water sensitive soils or too wet to be worked in the state:

Synthetically, the treatment with lime or hydraulic binders (cement) of fine soils presents the following actions:

- in the short term, correction of the water state of the materials, increase of the plasticity limit and the shear strength of the soil, modification of soil compaction characteristics;
- in the long term, improvement of the mechanical characteristics of the soil (pouzzolanic action of lime or cementing of hydraulic binders).

Study For the Use of Oran Marine Sediments

The maximum dosages in hydraulic binders must be of the order of 7% (percentages calculated in relation to the total dry mass) [GTS, 2000]. Since the mechanical requirements in road materials are relatively low and for economic reasons we decided to lower the dosage to 4% ciment (CEM II/A 42.5, provenance Aougaz to Sig).

Leaching tests on stabilized sediments with hydraulic binders (cement) in the case the manufacture of cementitious matrices (concrete or mortar) generally show low levels of percentage of contaminants, complying with the thresholds set by various researchers [SILITONGA, 2010], [SAID, 2015]. may be due to the formation of minerals that incorporate contaminants (heavy metals) into their network or (physical) trapping due to precipitation of these minerals around contaminants [HALE, 2012]. [BATAILLARD, 2017].

Figure 13 shows the evolution curves of compressive strengths as a function of time (1,7, 14 and 28 days).

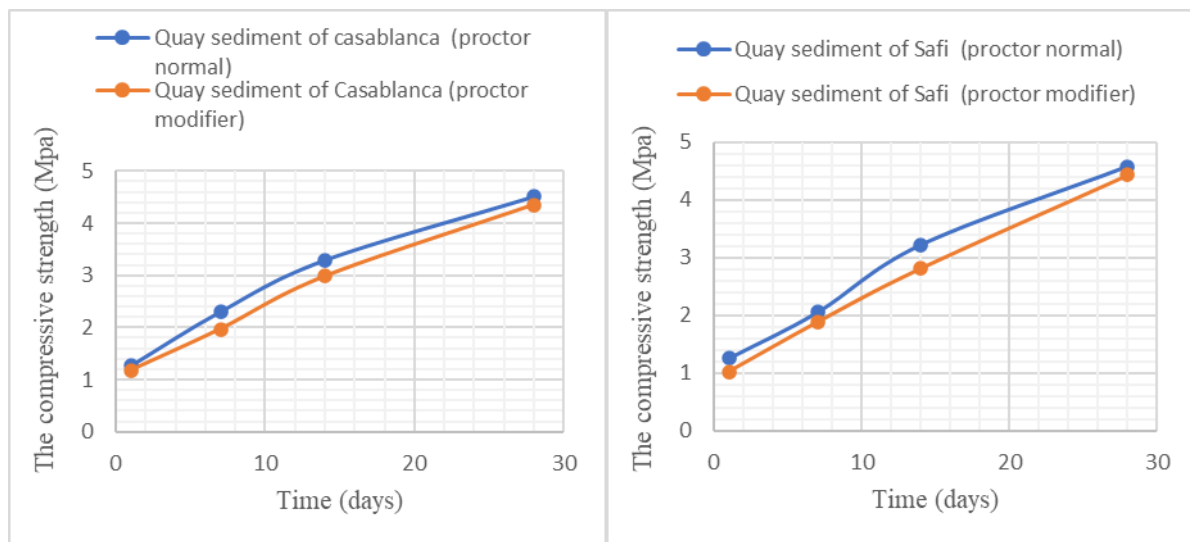


Fig. 13 Compression resistance as a function of conservation time (cement-treated sediment of Casablanca and Safi quays).

It appears clearly in Figure 13 that the addition of cement improves the mechanical properties of the sediments. This growth is explained by the fact that during the hydration of cement, portlandite is gradually formed, which allows the formation by pozzolana of new hydrates resulting from the pozzolanic reaction that improve the cohesion of the material [SCORDIA, 2008], [BOUBAKER, 2008], [SANNIER, 2008], [SILITONGA, 2009]. A shape layer is considered circulaire therefore its compressive strength is greater than 1MPa [GTR, 1992].

According to figures 13 this value is reached from the first day (1d). The initial development of the catch is fast which is particularly interesting in the plan of the valorization of the sediments of

Study For the Use of Oran Marine Sediments

Casablanca and Safi quays in layer of form because it allows to minimize the time of implementation of the upper layers.

6. Conclusion

The objective of this work was an in-depth study of physical (water content, grain size, Atterberg limits, etc.), chemical (major element assay, pH, salinity, etc.) and mineralogical characteristics (X-ray diffraction and thermal analysis) of marine sediments collected from the port of Oran at the time of dredging (quay of Casablanca and Safi), for use in road or other technology.

The sediments are in the form of fine black-to-black materials, according to triangular classification, classified as sandy-loam soils. Mineralogical analyses revealed that they were essentially composed of quartz and calcite.

The physical characteristics defined according to the selected recovery sector allowed the classification of marine sediments according to the technical guide [GTR, 1992] in class B5 and A1, which refers to fine soils with low organic content. From a geotechnical point of view, it was shown that the immediate index of marine sediments in the raw state of Casablanca and Safi quays was sufficient for them to be valued in the shape layer without filler material (IPI > 20%).

The study of the mechanical performance in compression was carried out on cylindrical specimens 5 cm in diameter and 10 cm in height, which allowed on the one hand to verify the possibility of using the sediments of Casablanca and Safi quays. The results obtained make it possible to consider the use of the marine sediments of Casablanca and Safi in the pavement layers.

The use of the hydraulic binder (cement) treatment stabilization method on contaminated sediments should include two aspects: one technique (increasing compressive strength) and the other environmental (trapped contaminants in sediment).

The perspectives of our work focus on the following key points:

- It would be desirable to carry out further in-depth studies on the identification of sediments (nature and elements contained);
- The determination of ICBR/IPI ratio, which makes it possible to assess the durability of the behaviour of the layer in case of immersion at young ages;
- Assessment of the insensitivity of marine sediments to water;
- It is interesting to study the kinetics of the uptake of the treated sediments (evolution of the compressive strength up to 90 days or more of maturation);
- The use of marine sediments in pavements shall be subject to frost resistance analysis;
- the determination of the mechanical tensile performance (tensile strength and compression) which makes it possible to evaluate the mechanical class of marine sediments;
- Assessment of the environmental impact of sediments (organic and inorganic contamination).

Study For the Use of Oran Marine Sediments

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