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Behavior of sediment from the dam FERGOUG in road construction

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Abstract. In Algeria, wastes are often stored in such conditions that do not meet standards. Today and more than ever, we really must implement an environmentally management of wastes. Recovery of waste in Algeria has a considerable delay due to the absence of a policy favorable to the development of waste management. But many researchers have shown the possibility to reuse dredged sediments in road construction. Through Europe, recent research works have been already performed on dam sediments. Present study fits into the context of the valorization of dredged sediments from Fergoug dam. They are found in considerable quantities and mainly composed of mineral phases, organic matters and water. The reservoir sedimentation poses problems for the environment and water storage, dredging becomes necessary. Civil engineering is a common way of recycling for such materials. Dredged sediments have not the required mechanical characteristics recommended by the standards as GTR guide (LCPC-SETRA 1992). So as to obtain mechanical performance, dredged sediment can be treated with cement, lime, or replaced materials like quarry sand. An experimental study has been conducted to determine physical and mechanical characteristics of sediments dredged from dam. Then different mixtures of sediment and/or quarry sand with hydraulic binders are proposed for improving the grain size distribution of the mixes. Finally, according these mixtures, different formulations have been tested as alternative materials with dredged sediments.

Keywords: dredged sediment; dam sediment; valorization; road engineering; sediment characterization; mechanical behavior

1. Introduction

The study concerns the Fergoug dam. It is a typical case of study where solid matters from eroded areas are continuously deposited. Due to the loss of its discharge volume dam managers have recourse

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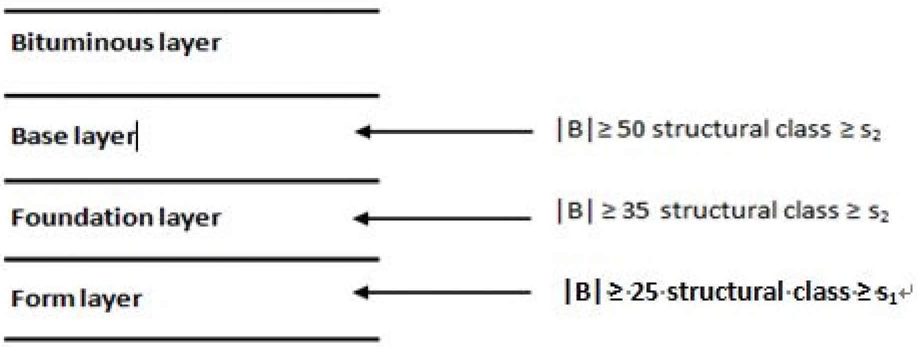

Fig. 1 Scheme of road section and recommended engineering properties specified in assises de chaussées: guide d'application des normes pour le réseau routier national (1998)

to dredging operations of sediments. The first experiment of dredging with a sucker dredger in Algerie was made on this dam. From 1986 to 1989, 10 million m3 of mud were extracted and deposited downstream in coarsely arranged zones. The mud is involved again by erosion to oued la Macta (E.N.R.B 1984). In this way, it is necessary to manage dredged sediments not as waste but as a resource considering environment regulations if any contamination is. So dredged raw materials must be safely stored and prepared as alternative materials for building and public works. For example, reuse of dredged sediment in road construction requires the checking of specific geotechnical, mechanical, environmental and economic criteria.

A cross-section road is composed of some layers with different thicknesses. Each structural material of each layer must be in accordance with specifications recommended by national standards. The main recommended tests to evaluate the suitability of a specific material are Proctor and tensile tests. Proctor test evaluates the material compaction (French standard NF P94-093, 1993). The measured engineering characteristic is the water content value which insures an optimal compaction of the material, WOPN. Directly after this test, the Bearing immédiat Index (IBI index), which determines the capacity of a material to support under construction the circulation of the building machines (French standard NF P94-078,1992) is measured.

Fig. 1 provides the recommended characteristics for the different road layers as specified in assises de chausses: guide d'application des normes pour le réseau routier national (1998)

2. Materials and methods

After a description of the dam site from where the sediments are dredged, characteristics of them and added materials are given. A developed methodology is implemented to identify mixes with optimum mechanical properties.

2.1 Description of dam site

Raw sediments used in this study come from the Fergoug dam. They are sampled from deposits of the eroded solid matters. Dam Fergoug is located at 20 km upstream of Perrégaux on Mascara road in Algeria as shown on Fig. 2. It is an earth dam with a storage capacity was 17 million m3 in 1970, was

Fig. 2 Fergoug dam site

Fig. 3 Dredging operation through the outlet pipe

subjected to a progressive silting.

After seven years in 1977 its capacity has dropped to 9.67 million m3; an annual rate of siltation exceeding one million m3, has been described by Semcha (2006) and (Bourabah et al. 2008).

This situation is catastrophic for the ecologic system, see Fig. 3.

2.2 Sediments preparation

The sample are taken manually at the surface, from three points upstream of the dam of Fergoug and transported in plastic bags, the stockpiling on a natural drying bed to the air significantly reduces their initial water content before undergoing a pre-treatment and homogenization. The raw sediments were first air dried, then dried at 105c° to avoid any modification or alteration of their characteristics, particularly organic matter. At the end of drying, it is necessary to crush and sift to obtain a granular class 0/2mm this fraction will be used and considered as dried sediments, Fig. 4 shows different steps

Fig. 4 Sediment preparation for geotechnical characterization

for sediment preparation useful to physical determination and geotechnical characterization.

The characterization aims to identify the physical and mechanical properties, which may prevent or encourage valorization (Agostini 2006).

2.3 Physical, geotechnical and mechanical analysis

The main physical, geotechnical and mechanical characteristics determined for sediments tested are: particles size distribution, quantity and the activity of clay fractions, organic matter contents, Atterberg limits and absolute density. The values obtained have allowed classifying both materials according to the guide in use, in France, for road materials classification GTR (1992).

The particle size distribution (also called grain size distribution or texture) is one of the most important characteristics of soils. The particle size distribution has an effect on several properties of the material such as the compaction, the permeability, the moisture content, etc. The particles size distribution of the sediments was determined by combining the hydrometer method according to French test standard NF P 94-057 (1992) for particle size less than 80 µm in diameter.

The results show that the sediments show that the sediments are composed mainly of fine particles (particles size less than 80µm).

The activity of clay minerals in the sediments is evaluated by methylene adsorption method, according to test standard NF P 94-068 (1993). According to the blue methylene values (BV=5, 4), the sediments present a relatively active fraction fine and are classified as a clay soil. In practice, this type of material requires treatment before use in road construction.

The organic matter content (OM), for both sediments, was determined using two methods: By ignition method at 450 °C according to test standard XP P 94.047 (1998) and by sulfochromic oxidation according to test standard NF ISO 14235 (1998). In the second method, the organic matter content is deduced from the proportion of organic carbon.

The Atterberg limits are determined according to test standard NF P 94 051(1993) where the liquid limit is measured by using Casagrande apparatus and the plastic limit by rolled thread technique. The

Table 1 Identification and geotechnical parameters of dam Fergoug raw dredged sediments

Parameter	**Value***
Initial water content w (%)	90.4
Organic matter content (%) at 450°C	7.17
Solid particles density (t/m^3)	2.60
Methylene blue value (g/100g)	5.4
Plastic limit, PL (%)	25
Liquidity limit, LL (%)	58
Plasticity index, PI (%)	33
Grain size distribution**	
Clay fraction (<2µm) (%)	9.8
Silt fraction (2 à 63 µm) (%)	28.9
Sand fraction (>63µm) (%)	61.1
Average diameter (µm) (%)	34.8
W_{OPN} (%)	17.73
Dry unit weight, $\rho_{d\ OPN}$ (t/m^3)	1.49
IBI W_{OPN}	18.04
GTR class	F 11*** A3F 11***
Color	grey-black
PH	8.41
Main minerals	Quartz, Calcite, Illite

*: Average value; **: Grain size distribution by granulolaser;
***: Classification GTR: LCPC-SETRA (2000)

liquidity limit (LL) of sediments, was found to be 58%, while the plastic limit (PL), was found to be 25%.

The particle density (ρs) is measured using a helium pycnometer was found to be 2.60 t/m3. The measured value is less than the reference value obtained for standard materials (about 2.70 t/m3). This difference can be explained, by the presence of organic matters which are lighter than mineral particles.

Sediment aptitude to compaction is defined by specific parameters which are the optimum water content, the maximum dry density and the immediate bearing index. These parameters were evaluated using normal Proctor test. This test consists to compact different sediments at various water content according to given process and energy, are run under standard NF P 94-093 (1993). The results show that the maximum dry density reached is 1.49t/m3 and the optimum water content is 17.73%. After compaction, immediate bearing index (IBI) was measured, which can indicates sediment ability to support site engines; Immediate Bearing Index (IBI) is 18.04 for sediments Studied.

According to the guide in use in France for road materials classification GTR (1992), the studied sediments are classified as moderately organic materials as the organic matter content is higher than 3 %. This class of material is indicated as a Class F material. According to particles size distribution, the bleu methylene value and the Atterberg limits, the sediments of dam Fergoug are classified as A3F11, results shown in Table 1.

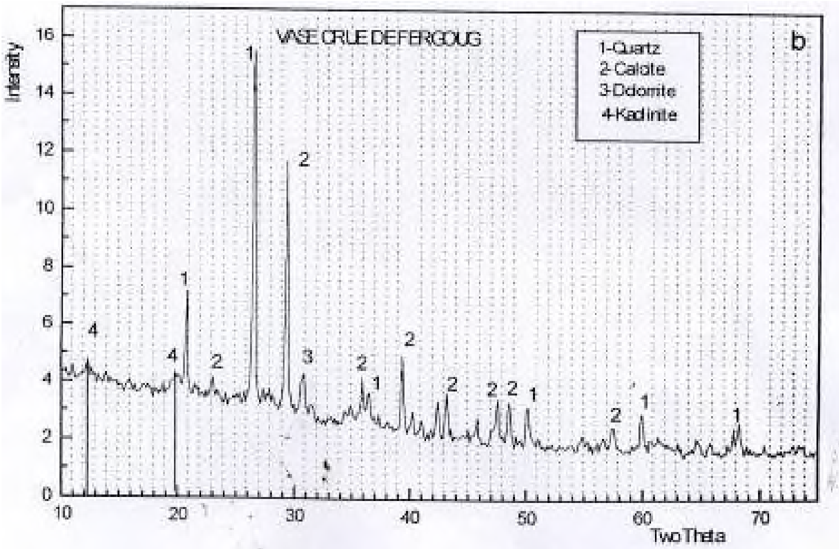

Fig. 5 Crystalline phases detected by the diffraction of X -rays of sediment dam Fergoug

Table 2 Chemical analysis results

Elements	**Symbol**	**Content (%)**
Silica	SiO_2	62.68
Lime	CaO	12.51
Magnesia	MgO	0.37
Alumina	Al_2O_3	7.39
Iron oxide	Fe_2O_3	0.71
Sulphate	SO_3	0.17
Chloride	CL	0.00
Loss on ignition	LOI	16.39
Total		100.00
Carbonate	$CaCO_3$	22.73
Carbon dioxide	CO_2	10.00
Water combination	H_2O	6.39

2.4 Chemical and mineralogical analysis

Results from X-rays diffraction analysis made on the Fergoug dam raw sediments see Fig. 5, give a list of main crystalline minerals: presence of Quartz (SiO_2) with significant peaks as carbonates (calcite ($CaCO_3$) and (dolomite), and a small quantity of Alumina (Al_2O_3) represented in the form of Kaolinite (Al_2O_3 $2SiO_2$ $2H_2O$).

These results confirmed by the chemical analysis are shown in Table 2.

On the basis of the results of Table 2, it is interesting to note that the main mineralogical components of dam sediment are silica, followed by carbonates, then lime and finally alumina. Silica and alumina are minerals which constitute the structure of clays. The presence of

Table 3 Chemical compositions and specific gravity of binders

Composition	Lime (0/2mm)	Ordinary Portland cement CEM
CaO (%)	94.50	63.43
SiO_2 (%)	0.95	22.76
Al_2O_3 (%)	0.12	5.96
MgO (%)	0.45	0.21
Fe_2O_3 (%)	0.06	3.57
Specific gravity (g/cm^3)	3.40	3.10

Table 4 Formulation of the mixtures tested

Mixtures	Sediments (%)	Quarry sand (0/4mm) (%)	Lime (0/2mm) (%)	OPC CEM II/A 42.5 (%)
Raw sediment RS	100	0	0	0
Formulation 1 F1	96	0	4	0
Formulation 2 F2	91	0	2	7
Formulation 3 F3	61	30	2	7
Formulation 4 F4	63	30	0	7

calcium carbonate indicates that the sediment belongs to the group of marl clay; Maherzi (2013). Moreover, one notices that the loss on ignition is rather significant, which confirms the presence of organic matter in sediments.

2.5 Binders and additives

A large number of additives are proposed for ground stabilization. The most common additives
used are ordinary Portland cement, lime, fly ash (FA). In present study, hydrated lime (L) and ordinary Portland cement (OPC) and quarry sand (QS) are used as binders and mineral
respectively. Chemical compositions and specific gravity of binders are given in Table 3.

The 0/4 mm sand comes from Hasnaoui quarry located in the region from Sidi Bel Abbes, Algeria. Its specific gravity is 2.65 and sand equivalent values are 85.98% and 83.33% for visual and piston measurements respectively.

2.6 Mixing and curing conditions

Sediments are classified as fine silty sand materials with a 7% level of organic content. A such material is difficult to reuse in the road construction because of their sensitivity to water and their compressibility. In addition, a Proctor-IBI testing on raw sediment revealed a low index immediate bearing capacity IBI. To increase the mechanical performance of sediments, addition of granular correctors followed by treatment with hydraulic binders (OPC cement and/or L lime) is used. Different mixtures are gathered in Table 4.

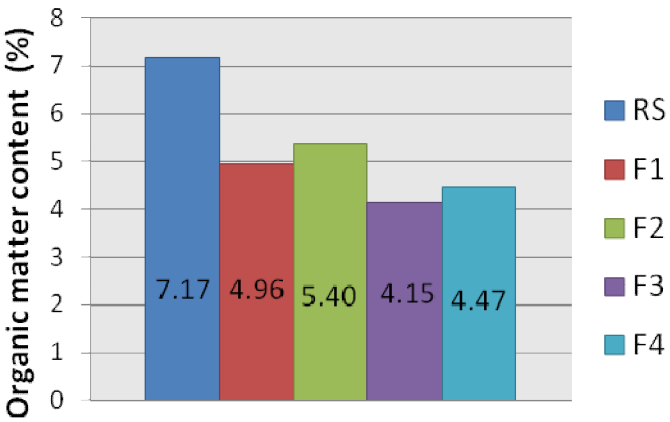

Fig. 6 Organic matter content values for the treated sediments

Table 5 Effect on Atterberg limits in mixtures

Formulation	RS	F1	F2	F3	F4
LL (%)	58	75	73	53	52
PL (%)	25	38	30	28	31
PI (%)	33	37	43	25	21

2.7 Results and discussion

2.7.1 Organic matter content of the mixtures

Organic matter (OM) has prejudicial consequence if its level is >5% in material characteristics for road construction applications due to their swelling structure and inhibition of binder hydration, (Miraoui et al. 2008). Obtained results reported in Fig. 6 show clearly the OM presence in mixtures. Each given value represents average of three measurements.

For untreated or raw sediments, organic matter was 7.17%. Considering 4 mixtures after processing OM values tend to values between 5% and 4%. A clear OM decrease is observed, this could have an important incidence on geotechnical and mechanical behavior of sediments. Organic matter can also have an impact on binder hydration during treatment stage.

Also, these values will be necessary to establish a first classification of different sediments according to the French GTR guide.

2.7.2 Atterberg limits effect on mixtures

The consistency limits for raw sediments are 58% for the liquid limit (LL) and 25% for the plastic limit (PL). This induces a plasticity index of 33%. After treatment we can see a decrease in the liquidity limit. It is 53% and 52% for F3 and F4 respectively and an increase for F1 and F2. We can also observe an insignificant increase in the plastic limit.

The values are 38 % for F1, 30% for F2, 28 % for F3 and 31% for F4. These variations have resulted in the decrease of the plasticity index for F3 and F4. This confirms that the addition of sand significantly reduces the plasticity of the sediments. This is certainly related to the degradation of organics and clays, the different results are reported in Table 5 and shown in Fig. 7.

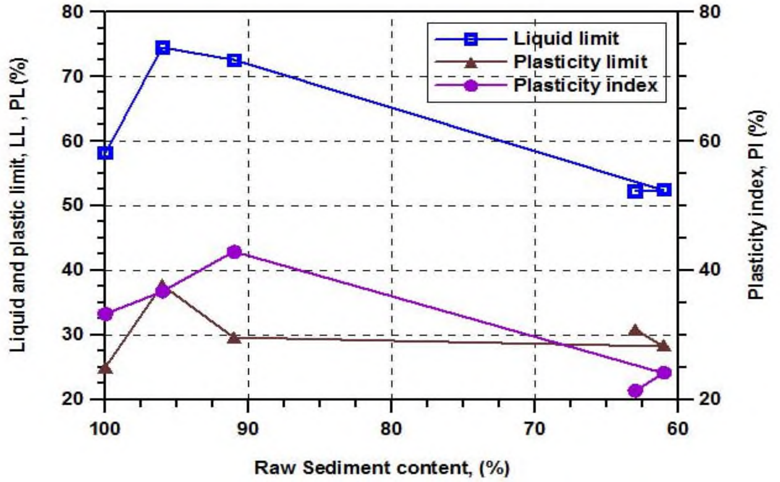

Fig. 7 Atterberg limits of the mixtures

Table 6 Normal Proctor parameters and immediate bearing index IBI values obtained on mixtures

Mixtures	**RS**	**F1**	**F2**	**F3**	**F4**
$\mathbf{W_{OPN}(\%)}$	17.73	19.57	20.00	16.22	16.00
$\gamma\mathbf{d_{OPN}}$ **(g/cm^3)**	1.49	1.35	1.38	1.64	1.58
IBI à $\mathbf{W_{OPN}}$	18.04	18.04	13.12	26.33	32.80

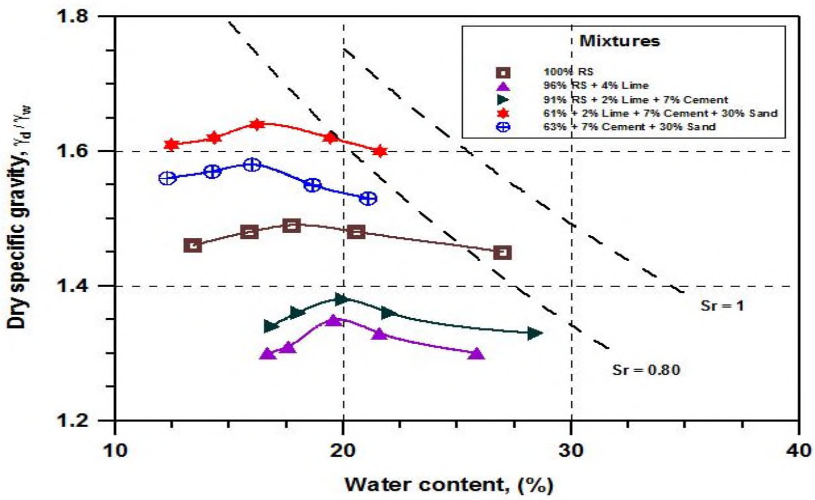

Fig. 8 dry specific gravity vs water content for raw sediments and all mixtures

2.7.3 Mechanical characteristics of mixtures

Compaction tests

To explore the ability of the defined mixes to be used as a sub-form layer in road structure, the mechanical behavior of designed material is undertaken following the French test standard, has been described by Achour (2013). The main mechanical characteristics which allow

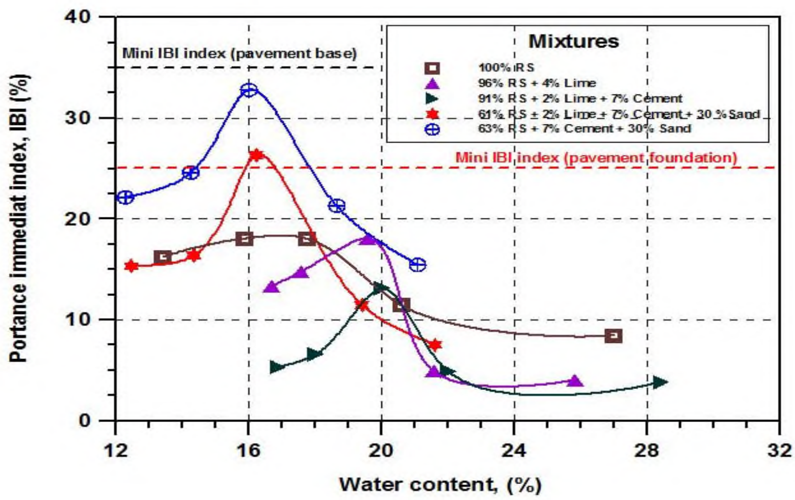

Fig. 9 IBI index vs water content for raw sediment and all mixture

defining the ability of the material to be used as sub-form layer are in the case of this study: the IBI index, the tensile strength (usually measured with Brazilian tests) and the Young Modulus. In this study only the IBI index and the compaction curves will be discussed. Results of all mixes are gathered in Table 6and are shown on Figs.8-9.

IBI index evolution according to water content for raw sediment RS and all mixtures namely F1, F2, F3 and F4 is plotted on Fig. 9.

We can observe on Fig.9 that IBI index values are decreasing as increases water content. It is more pronounced after the optimum. This can causes some difficulties in the traffic ability for engine circulation on site.

It is also observed that the immediate bearing index of mixtures is sensitive to the type of binder used. The addition of quarry sand shows a decreasing amount of water content at the maximum compactness. In the same time, an increase of the dry specific gravity is observed.

Considering lime treatment with formulation F1, the immediate bearing capacity remains comparable to the raw sediment without treatment. It is observed that the reactivity of lime increases the value of the optimum water content and a decrease in density of the optimum Proctor. The action of lime on the flocculation of the clays contained in the sediment causes this trend. When the hydration of lime is initiated, the temperature increases with the intensity of the reaction. Note that, the higher the reactivity of the lime, the more it absorbs water.

For lime and cement mixture i.e. formulation F2, it is noting a decrease in the IBI index. This is due to the presence of organic matter 7.17% (amount > 5%) which inhibits the hydration reaction with the cement. The bearing capacity of the formulation F3 and F4 (IBI ≥ 25%) ensure the trafficability of machines during the road work, has been described by assises de chaussées: guide d'application des normes pour le réseau routier national (1998).

3. Conclusions

Before applying the dredged sediments as materials for road or construction engineering, an indepth study about the physical properties have to be implemented to verify the feasibility of targeted material. In present study, some useful conclusions must be drawn leading to a methodology for treating dam sediment as road material.

Physical properties are determined as initial water content, specific gravity, organic matter amount, Atterberg limits and grain size distribution. This constitutes a minimal characterization. These fine dam sediments have highlighted significant natural water content and a noteworthy presence of organic matter with a percentage of 7.17%. This OM amount influences physical, compaction and mechanical behavior of raw and treated materials. From characterization, dam sediments tested are classified as silty clay. Considering grain size distribution, organic matter content and according to the GTR guide, sediments are classified in A3F11 class. To complete minimal characterization, mineralogy brings to other data highlighting difficulties to operate stabilization of sediments with binders.

The addition of lime alone (formulation F1) increased the value of the optimal water content and decrease the density of Proctor optimum, this action of lime on the flocculation of the clays contained in the sediment causing this trend.

A mixed treatment with 2% of quicklime and 7% cement CEM II / A 42.5 (formulation F2) allowed to show that the results are not satisfactory developed for use in a form layer.
Compaction testing has clearly shown that the addition of quarry sand for both F3 and F4 formulation mixtures fell considerably the water content at the maximum compactness to give a compact material and drier, an advantage for road materials.

The bearing capacity of the formulation F3 and F4 (IBI $\geq$ 25%) ensure the trafficability of machines during the road work. These results give an opportinuties to use sediments in road materials. The next step of this work is to study the mechanical behavior of road material based on treated sediments. In this field, complementary tests are in progress.

Finally environmental tests could be required in the treatment and reuse of dam sediments if any contamination is detected.

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