# CHARACTERIZATION OF BOUHANIFIA DAM DREDGED SEDIMENTS, (CITY OF MASCARA) FOR THEIR VALORIZATION IN THE FIELD OF ROADS CONSTRUCTION

# CARACTÉRISATION DES SÉDIMENTS DE DRAGAGE DU BARRAGE BOUHANIFIA, WILAYA DE MASCARA, EN VUE DE LEURS VALORISATION EN CONSTRUCTION ROUTIÉRE

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**Abstract -** The rate of siltation of dams in Algeria is highly significant, which makes it important for these sediments to be dredged and rationally managed, it appears necessary to find potential solutions to effectively respond to the management issues after dam dredging. The study of the treatment and recycling of dam dredged sediments in the construction industry makes it possible to solve these problems. The Bouhanifia dam is among the oldest dams in Algeria. The significance of its siltation rate, which reaches a very high level of its initial capacity, leads us to think about a domain for the valorization of its dredged sediments. The work envisaged in this research focuses on the characterization and the valorization of the sediments dredged from Bouhanifia dam. The results of the study of the physico-chemical, mineralogical, and mechanical characteristics have enabled us to use these sediments as additions to civil engineering materials. From mechanical characterization tests (Proctor-CBR tests) on different mixtures (sediments and tuff), it shows that the sediments studied can be used in road construction.

**Keywords:** Dams, Dredging, Sediments, Roads, Valorization

**Résumé -** Le taux d'envasement des barrages en Algérie est très élevé, ce qui rend important le dragage et la gestion rationnelle de ces sédiments. Il apparaît nécessaire de trouver des solutions potentielles pour répondre efficacement aux problèmes de gestion après dragage des barrages. L'étude du traitement et du recyclage des sédiments dragués des barrages permet de résoudre ces problèmes. Le barrage de Bouhanifia fait partie des plus anciens barrages d'Algérie. L'importance de son taux d'envasement, qui atteint un niveau très élevé de sa capacité initiale, amène à réfléchir à un domaine pour la valorisation de ses sédiments. Ce qui nous a conduits à étudier l'utilisation potentielle de ces sédiments dans le domaine du génie civil. Les travaux envisagés dans cette recherche portent sur la caractérisation et la valorisation des sédiments dragués du barrage de Bouhanifia dans le domaine de la construction des routes. Les résultats de l'étude des caractéristiques physico-chimiques, minéralogiques et mécaniques nous ont permis d'utiliser ces sédiments comme ajouts aux matériaux de construction. A partir d'essais de caractérisation mécanique (essais Proctor et California Bearing Ratio (CBR)) sur différents mélanges (sédiments et tuf), ils montrent que les sédiments étudiés peuvent être utilisés en construction routière.

**Mots clés :** Barrages, Dragage, Sédiments, Routes, Valorisation

# 1-Introduction

Bouhanifia dam located 400 km northwest of Algiers, and 25 km from the city Mascara built-in 1929 with an initial capacity of $73.10^6$ $m^3$ is one of the 18 most silted dams out of 57 dams in Algeria with a siltation rate of 0.73 $m^3$ per year, resulting in a lost capacity of 60% [12]. It is a 54 m high rock fill dam with an upstream face waterproof mask of two bituminous concrete layers of 6 cm thickness and a protective reinforced concrete coating. The crest level is 464 m long and 5 m wide, while the base width reaches 125 m [18], (Fig.1).


**Figure 1:** Bouhanifia dam: a) downstream face of the dam structure; b) upstream face of the dam structure

**Figure 1:** Barrage de Bouhanifia: a) partie avale du barrage ; b) partie amont du barrage

The dam forms a part of the three dams (Ouizert, Bouhanifia and Fergoug), installed in the watershed area of Wadi the El Hammam which represents a focal point of the three valleys (Melrir, Hounet and Sahouet). The Hounet Wadi is formed by the confluence of the Sefioum and Berbour valleys; the Sahouet valley is formed by the confluence of the Taria and Saïda valleys, which both supply the Ouizert dam, enlarged by the Fekan valley [13]. The hydrographic network has a drainage density of 1.7 km/km$^2$ and the main valley has an average slope of 5.7 m/km, (Fig.2).

The watershed wadi El Hammam covers an area of 5,560 km$^2$ [2, 8], the southern part of the watershed is covered by grain and vegetable crops, whereas, in the northern part, almost a quarter of the area is covered by forest [9, 2].

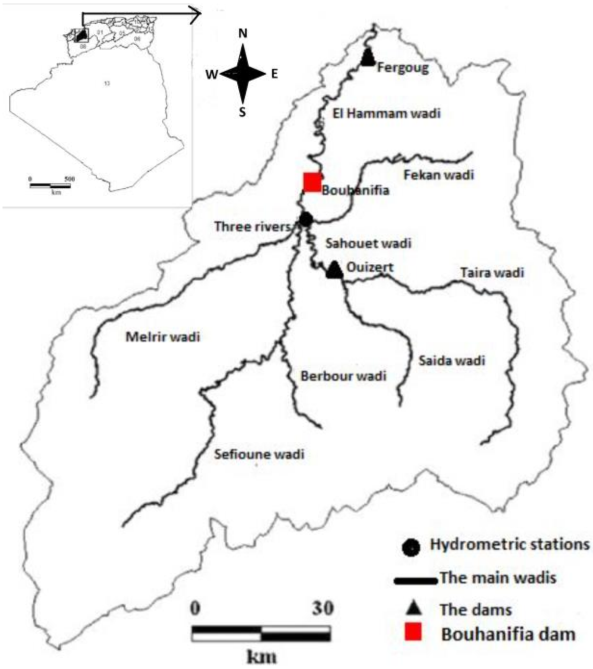



**Figure 2:** Geographical location of Mactaa and Bouhanifia watershed areas in Algeria, modified from [2]

**Figure 2:** Localisation géographique des basins versants El Mactaa et Bouhanifia, modifier à partir de [2]

In 2011, the National Algerian Agency of Dams launched a desalting project for Bouhanifia Dam, in cooperation with Hydro dragage – SPA, where dredging of 6 million cubic meters of sediments was planned. Hence, several research studies have been undertaken to use the sediments extracted as construction material in the civil engineering domain such as cement [15, 13, 3] and ceramic [14]. On the other hand, multiple kinds of research are being developed concerning the reuse of fine soils in pavement construction [1, 5, 6, 7, 11, 16, 17, 19, 20] . Within this context, the aim of the present work focuses on the valorization of Bouhanifia dam dredged sediments in roads construction. The study of physical, chemical, mineralogical characteristics and mechanical performance tests (Proctor-CBR) of Bouhanifia dredged sediments admixed calcareous tuff is expected to show the feasible use of these in road construction.

## 2 - Materials and Methods

Different samples of Bouhanifia dam dredged sediments were sampled from the storage basins situated a few kilometers from the dam. A mixture of several sediments specimens was formed for the study herein. A sample of a calcareous tuff was collected from the quarry of Ain Baidah in Oran. Tuff is a very common natural material in Algeria composed mainly of calcium carbonates and extracted from limestone, gypsum or gypsum-limestone deposits [4].

The calcareous tuff (T), the Bouhanifia dredged sediments (S) and three mixtures of Sediments and tuff (5% S + 95% T, 10% S + 90% T, 20% S + 80% T) were characterized by physical, chemical, and mineralogical studies and a short-term mechanical performance test (modified Proctor and CBR). The physical studies were carried out at the laboratory of Public Works of Western Algeria and the Hydraulic Technical Control Laboratory of Oran, Algeria. The chemical and mineralogical studies were performed at the geotechnical laboratory of the Department of Civil Engineering and the sedimentary laboratory of the Department of Earth Science, both at the University Of Coimbra, Portugal.

The particle size distribution of sediments and tuff was obtained by the combination of sieving and laser methods to evaluate the respective percentages of gravel (> 2 mm) (XP P 94-041), sand (2 mm-63 µm), silt (63-2 µm) and clay (< 2 µm) (BS ISO 13320:2020).

The Atterberg limits of dredged sediments, tuff and mixtures of sediments with tuff were performed using the Casagrande and the rolling methods to determine the liquid and the plastic limits respectively following the standard (NF P94-051). The liquidity limit LL is defined as the water content conventionally corresponding to closure over 1 cm of the groove applied to the soil sample plated on the Casagrande cup after 25 strokes, this limit is determined graphically from the average line adjusted to the pairs of experimental values (number of knocks (N), water content (w)) (Fig. 4). The plasticity limit is defined as the water content at which a hand-made roll of a soil paste cracks when it reaches a diameter of 3 mm (NF P94-051).

The mineralogical characterization of sediments and tuff were determined using an X-ray diffractometer (Philips PW 3710), with a Cu tube used, at 40 kV and 20 mA. The mineralogical composition of the fraction lesser than 2 µm was obtained in oriented samples before and after heating up to 550 ºC and treatment with ethylene glycol. The percentage of the clay minerals in the samples was determined through the peak areas of the identified minerals using specific correction parameters. The X-ray diffraction of the total powder was performed to identify the other minerals present.

The modified Proctor test was performed following the standard (NF P 94-093) to determine the optimum water content corresponding to the maximum dry density of the samples studied.

The results of the compaction carried out on the different formulations are presented in (Fig.6)

The California bearing ratio (CBR) test of sediments, tuff and the three mixtures was performed following the standards (NF P 94-078). The CBR test is a punching shear used to define a bearing index ICBR. Practically, for a given soil, the bearing index ICBR is the greater of two values: pressure at 2.5 mm of sinking/0.7; pressure at 5 mm of sinking/1.05 [4].

The results of the CBR test of sediments, tuff and mixtures are presented in (fig.7 and 8).

## 3- Results and discussion

### 3.1 - Physical geotechnical analyses

### 3.1.1 - Particle size distribution

Figure 3 shows the particle size distribution curves for Bouhanifia dam dredged sediments and Calcareous tuff. The dredged Sediments are fine-grained soil mainly composed of silt (≈54%) with sand (≈39%) and a small fraction of clay (7%), while tuff is mainly constituted of coarse-grained particles ranging from 80 mm to 0.5 mm, mainly composed of gravel (68%), with some sand (16%), silt (15%) and a small fraction of clay (1%).

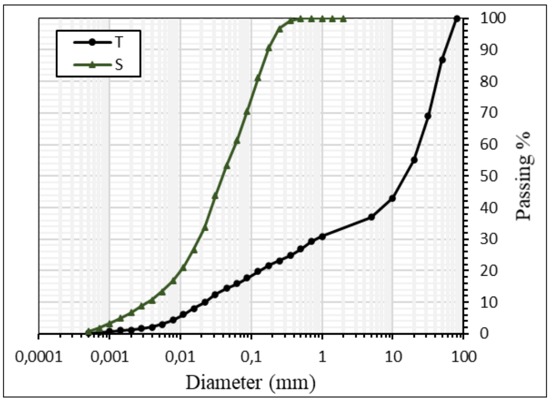



**Figure 3:** Particle size distribution curves of Bouhanifia dam dredged sediments and calcareous tuff

**Figure 3:** Courbe granulométrique des sédiments de dragage du barrage Bouhanifia et le tuf calcaire

### 3.1.1 - Atterberg limits

Figure 4 exhibits the variation of the water content of the dredged sediments, calcareous tuff and sediments admixed tuff as a function of the number of knocks applied on the Casagrande cup, where, the water content corresponding to 25 knocks of each mixture represents the liquid limit. The results of the tests are shown in table 1 and discussed afterwards.

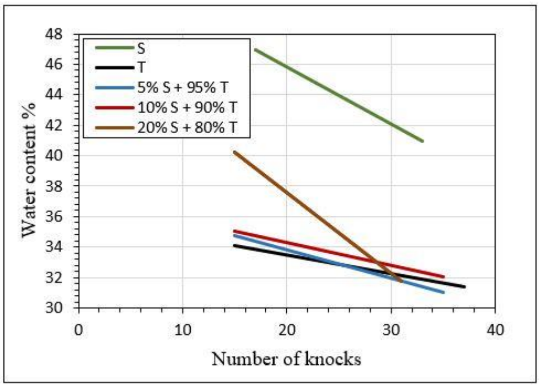



**Figure 4:** Liquid limit curve for dredged sediments, calcareous tuff and sediments – tuff mixtures

**Figure 4 :** Variation de la limite de liquidité des mixtures (sédiments et tuf) en fonction de la teneur en eau

**Table 1 :** Physical characteristics of Bouhanifia dam sediments and tuff

**Tableau 1 :** Caractéristiques physiques des sédiments et tuf calcaire

| Parameters | Standard | N° of Sp | S | T | 5% S + 95% T | 10% S + 90% T | 20% S + 80% T |
|---|---|---|---|---|---|---|---|
| Gravel (%) | XP P 94-041 | 3 | 00.00 | 68.00 | 64.6 | 61.2 | 54.4 |
| Sand (%) | BS ISO 13320:2020 | 3 | 39.00 | 16.00 | 17.15 | 18.3 | 20.6 |
| Silt (%) | BS ISO 13320:2020 | 3 | 54.00 | 15.00 | 16.95 | 18.9 | 22.8 |
| Clay (%) | BS ISO 13320:2020 | 3 | 7.00 | 01.00 | 1.3 | 1.6 | 2.2 |
| W (%) | NF P94-050 | 2 | 14.27 | 07.90 | 8.22 | 8.5 | 9.8 |
| γ (g/cm³) | NF P 94-054 | 5 | 02.69 | 02,84 | 2.55 | 2.64 | 2.66 |
| SE (%) | NF P 18-598 | 2 | 04,56 | 04,68 | 09,70 | 09,84 | 10.12 |
| OM (%) | XP P94-047 | 3 | 06.76 | 10.00 | 09.84 | 09.68 | 09.35 |
| MBV | NF P94-068 | 4 | 4,36 | 00.41 | 2.64 | 3.53 | 5.56 |
| pH | NF ISO 10390 | 2 | 07.90 | 08.86 | 8.81 | 8.76 | 8.67 |
| LL | NF P94-051 | 9 | 45.00 | 32.8 | 32.90 | 33.50 | 34.70 |
| PL | NF P94-051 | 9 | 21.93 | 19.48 | 19.22 | 19.77 | 18.19 |
| PI | NF P94-051 | 9 | 23.00 | 13.00 | 14.00 | 14.00 | 17.00 |
| CI | NF P94-051 | 9 | 1.33 | 01.91 | 1.76 | 1.76 | 1.47 |

N° of Sp: Number of specimens per test

Table 1 summarizes the physical characteristics of the dredged sediments of Bouhanifia dam and the tuff. The organic matter content (OM) and the methylene blue values (MBV) of sediments are significant, which is an indication of a large presence of colloids and clay minerals. In contrast, tuff is characterised by negligible methylene blue value indicating the absence of clay minerals in its composition. These results are confirmed by the Atterberg limits results: in general, dredged sediments are very cohesive soils representing medium to very plastic fine clayey sand and silt; the liquid and plastic limits and also the plasticity index of sediments are higher than those of tuff.

As exhibited in figure 4, incorporating 5 to 10% of sediments to the calcareous tuff doesn't change significantly the liquid limit of this last, whereas going beyond 20% of sediments introduced in tuff increases the water content hence, the liquid limit of the mixture goes toward that of sediments.

## 3.2 – Chemical characterization

The chemical characterization results are summarized in (Tab.2). The dredged sediments are dominated by $SiO_2$ with a considerable amount of $Fe_2O_3$ and traces of $Al_2O_3$. Tuff is predominantly constituted by $CaCO_3$ with a significant amount of $SiO_2$ and traces of $SO_3$ which is completely absent in the dredged sediments. The presence of $CaCO_3$ in Tuff and sediments is an indication of the presence of minerals such as calcite and dolomite.

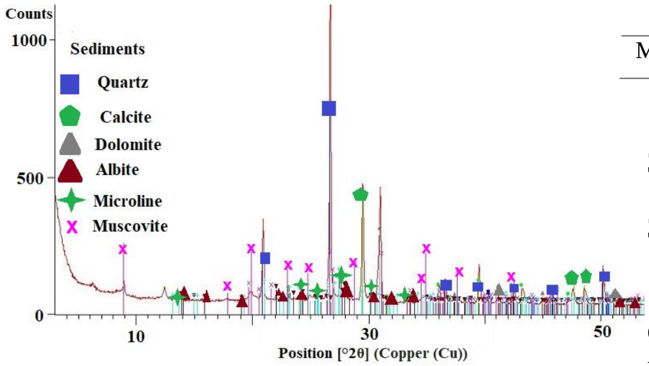
**Table 2:** Chemical characterization of dredged sediments and calcareous tuff

**Tableau 2:** Caractérisation chimiques des sédiments et tuf

| Chemical elements | Standards | S | T | 5% S + 95% T | 10% S + 90% T | 20% S + 80% T |
|---|---|---|---|---|---|---|
| $SiO_2$ % | ISO. 680 | 60.75 | 10.46 | 12.92 | 15.5 | 20.52 |
| $Al_2O_3$ % | NA 237-1990 | 0.84 | 0.00 | 00.042 | 0.0 | 00.17 |
| $Fe_2O_3$ % | NA 237-1990 | 03.16 | 0.64 | 00.766 | 00.892 | 1.14 |
| $SO_3$ (%) | NA 237-1990 | 0 | 0.15 | 00.143 | 0.13 | 0.12 |
| $CaCO_3$ % | NA-2789 | 23.87 | 79.43 | 76.652 | 73.87 | 68.32 |

### 3.2 - Mineralogical analyses

Figure 4 and Table 3 summarize the mineralogical characteristics of Sediments and tuff, Bouhanifia dam dredged sediments are respectively predominant by two types of clay minerals Illite and Kaolinite, while Chlorite and smectite appear in small fractions. Tuff show an absence of clay minerals and a large presence of other minerals such as calcite and a considerable fraction of quartz and microcline, these rock-forming minerals also occur in sediments at different levels, while quartz and muscovite are respectively predominant.



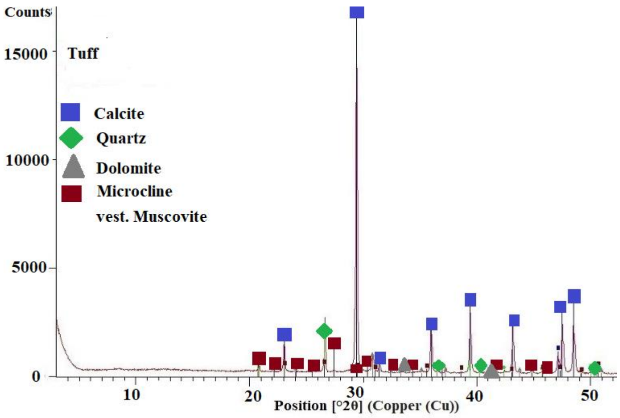




**Figure 5 :** X-Ray diffraction results of Bouhanifia sediments and tuff

**Figure 5:** Résultats de diffraction par rayon X des sédiments de Bouhanifia et de tuf

**Table 3:** Mineralogical characterization of dredged sediments and calcareous tuff

**Tableau 3:** Caractéristiques minéralogiques des sédiments et tuf

| Elements | S | T |
|---|---|---|
| Kaolinite disordered | 23.83% | - |
| Illite, 1 Md | 62.81% | - |
| Smectite; Montmorillonite (Mg, ( | 7.95% | - |
| Chlorite, Mg - Chlorite, Fe | 5.41% | - |
| Quartz | Dominant | considerable |
| Calcite | considerable | Dominant |
| Dolomite | traces | traces |
| Microcline | traces | considerable |
| Muscovite | considerable | - |

### 3.3 - Mechanical performance analyses

#### 3.3.1 Modified Proctor

Figure 5 shows that the incorporation of dredged sediments in tuff in ascending fractions reduces progressively the dry and increases the optimum water content. The addition of 20% of sediments lowers the dry density from 2.22 (g/cm3) to 1.95 (g/cm3), while the optimum water content increases from 9% to 10% respectively. This phenomenon may be explained by the reduction of coarse grains and their replacement by fines particles, due to the mineralogical characteristics, clay minerals such as smectite may swell with the presence of water and increase the retention of this last and the density tends towards those of sediments.

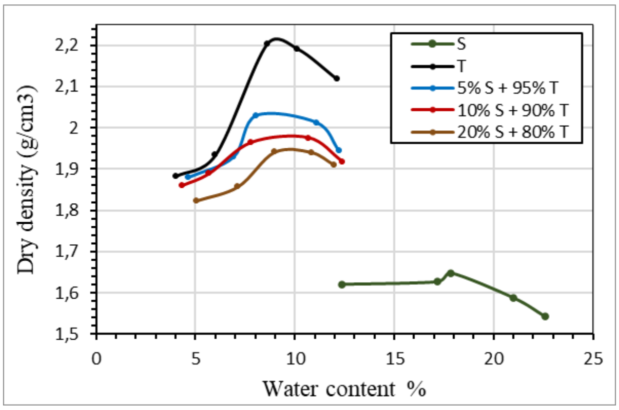



**Figure 6 :** Variation of dry density as a function of water content of tuff sediments and mixtures compacted with a modified Proctor

**Figure 6 :** Variation des densités sèches des sédiments et tuf en fonction des teneurs en eau

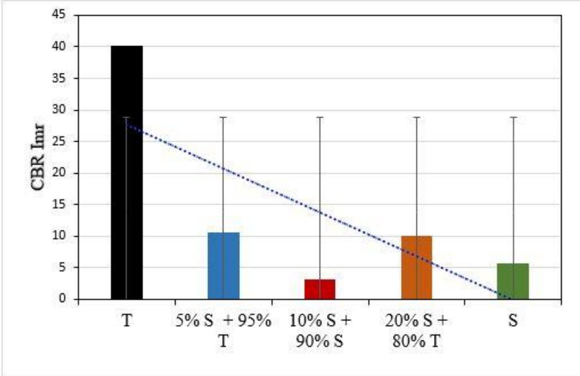



**Figure 8:** Variation of CBR of tuff, sediments and the mixtures compacted in modified Proctor corresponding to 56 drops per layer after four days of immersion in the water

**Figure 8 :**Variation d'indice CBR imbibé des sediments et tuf compactés en Proctor modifié correspondant à 56 coups par couche

### 3.4.2 - California Bearing Ratio Test (CBR)

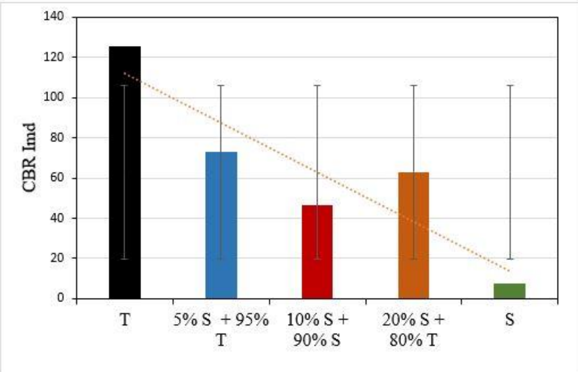



**Figure 7:** Variation of CBR Immediate of Tuff, sediments and the mixtures compacted in modified Proctor corresponding to 56 drops per layer

**Figure 7 :**Variation d'indice CBR immediat des sediments et tuf compactés en Proctor modifié correspondant à 56 coups par couche

The Bearing ratio of the mixtures (sediments-tuff) before and after soaking in water, presents a decreasing line in results up to 10% of sediments incorporated in tuff, while, adding 20% of sediments shows a small increment of the bearing index. Tuff shows a high sensitivity towards the water, a decrease in the bearing index of 80% has occurred after four days of soaking in water.

The bearing capacity of tuff is highly influenced by the addition of dredged sediments even in a reduced fraction and in presence of water.

Table 4 recapitulates the classification of Bouhanifia dredged sediments, calcareous tuf and sediment-tuf mixtures according to the technical guide for roads.

Bouhanifia dam sediments belong to the A3ts type of soils, these soils are characterized by a much reduced permeability hence, a significant change in consistency necessities a significant increase in the water content.

The three mixtures of sediments admixed tuff and the calcareous tuff belong to the B6m class, these soils generally present a good traficability due to the presence of a significant granular fraction and can be used as embankments in the absence of heavy rains.

**Table 4:** Classification of sediments according to the technical guide of roads [10]

**Tableau 4** : Classification des sédiments selon le guide technique routière [10]

| Param - eters | S | T | 5% S + 95% T | 10% S + 90% T | 20% S + 80% T |
|---|---|---|---|---|---|
| Passing to 2 mm (%) | 100 | 30 | 33.5 | 37 | 44 |
| Passing to 80µm (%) | 70 | 18 | 20.6 | 23.2 | 28.4 |
| MBV | 24 | 1.69 | 2,64 | 3,53 | 5.56 |
| Ip | 23 | 13 | 14 | 14 | 17 |
| GTR classification | A3 ts | B6 m | B6 m | B6 m | B6 m |
| | Fine-grained soil, very plastic silt | Clayey sand and gravel | Clayey sand and gravel | Clayey sand and gravel | Clayey sand and gravel |

B6m class soils imply a treatment to be used in the base layer. The treatment can be either by hydraulic binders for dry soils with less clay, or more generally, by combining lime (in the form of slaked lime or lime milk) and a hydraulic binder. These soils are treated most generally in place or possibly in a power station.

These conclusions are aligned with the research conducted by Goual, I., (2012) concerning the effect of the incorporation of 20% of quarry waste namely calcareous sand on the geotechnical and mechanical characteristics of a calcareous tuff in the Laghouat region. The objective of the research was first, to test the possibilities of improving the characteristics of this tuff by an economic stabilization technique making it possible to recycle both the quarry waste (calcareous sand) and pulverulent calcareous tuff and second, to verify if the formulation adopted complies with the regulations in force. It has been concluded that the incorporation of 80% of sand in tuff has better mechanical characteristics, namely compression strength, and this formulation has been chosen as the optimal mixture. However, this formulation lies in the collapse of its strength after immersion, and to overcome this problem of the non-stability of the material in a saturated environment, treatment with hydraulic binders was found necessary.

On the other hand, Daheur et al., (2019) have studied the effect of sand on the mechanical performance of calcareous tuff from the City of Ouargla in Algeria, As a result, the incorporation of up to 35% of sand into tuff enhanced the unconfined compression strength of these last, and CBR reaches the maximum value for a percentage of 25% of sand, hence, the proportions of the constituent materials based on 65% tuff and 35% dune sand as chosen can be considered as the optimal formulation., producing the best characteristics meeting the current standards.

## 4 - Conclusion

This research investigates the effect of the dredged sediments of Bouhanifia dam in Algeria on the mechanical behaviour of the calcareous tuf, by which the notable results obtained are:

- Bouhanifia Dam sediments are silty clay soil, whilst calcareous tuff is a coarse-grained soil mainly composed of gravels and silty sand.
- The liquidity limit of tuff is not affected by the sediment when the fraction of this last is less than 20%.
- The incorporation of different fractions of sediments to calcareous tuff decreases the density and the bearing capacity of tuff, whereas the optimum water content increase.
- The CBR index decreases with the fraction of sediments added, however, the incorporation of up to 20% of sediments keeps the bearing index within the standards for the mixture to be used as embankment
- According to LCPC classification, dredged sediments have a very low humidity state that no longer allows the reuse of the soil in technical and economic conditions, while the incorporation of sediments to calcareous tuff permits the use of the soil for embankment or the subgrade layer after treatment with hydraulic binders and/or lime.

These results suggest the possible valorisation of the Bouhanifia dam dredged sediments admixed calcareous tuff as construction materials for roads. In addition, Long-term mechanical performance investigations of similar and different formulations are expected to be performed and discussed in future scientific papers.

Eric Font, every person who has contributed in this work.

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