UNIVERSITY OF ZIELONA GÓRA

CEER CIVIL AND ENVIRONMENTAL ENGINEERING REPORTS

CIVIL AND ENVIRONMENTAL ENGINEERING REPORTS

E-ISSN 2450-8594

CEER 2023; 33 (4): 0073-0094
DOI: 10.59440/ceer/181197
Original Research Article

IMPROVED OF MECHANICAL CHARACTERISTICS OF GARGAR MUD BY MINERAL ADDITIVES

Fouzia BENHADJ ZIANE MOKHTARI[1], Abdelkader YOUCEFI[1], Abdelmoumen Aala Eddine DRISS[2], Mohamed GHRICI[2]

[1]University of Sciences and Technology of Oran - Mohammed Boudiaf, Faculty of Mechanical Engineering, B.P 1524, 31000 El Manouar, Oran, Algeria

[2]Geomaterials Laboratory, Civil Engineering Department, Hassiba Benbouali University, 02000 Chlef, Algeria

Abstract

The operational dams in Algeria lose 32 million m^3 of water storage capacity each year, and fifteen of these dams are threatened by siltation. This investigation forms a component of a management strategy for dredged silt in the Gargar Dam, the third-largest dam in Algeria with considerable sedimentation. This paper comprises two main axes: a detailed experimental study based on the studied dam mud's physico-chemical, rheological, and mechanical analysis. The second part is based on the study of the valorization of Gargar mud to be acceptable for use in road civil engineering. In order to obtain this goal, the Gargar mud was treated with lime (0-6%), sand (20%), and natural pozzolana (20%). Test results show that the properties of Gargar mud are significantly improved after treatment, and the soil becomes more friable and more resistant; it can therefore be used as a foundation layer in road civil engineering.

Keywords: Gargar dam, mud, dredge sediment, lime, pozzolana

1. INTRODUCTION

All Dams worldwide are more or less exposed to siltation, but with sedimentation rates that differ from one region to another. The scarcity of water resources characterizes the countries of North Africa like Algeria, Morocco, and Tunisia, thus joining all the arid and semi-arid lands. However, these countries are part of a mountainous zone (Tellian), characterized by an aggressive climate with alternating dry and wet years and heavy autumn rains that are devastating for the soils, mainly because they occur in a period when plant cover is reduced or non-existent [1,2]. Remini and Toumi [2] studied 74 dams, of which 70 are located in northern Algeria and four others at the Sahara entrance. Five hydrographic basins emerge from the map of Algeria, such as Chellif Zahrez, Oranie Chott Chergui, Algérois Hodna Soummam, and Constantinois Seybousse Mellegue in the northern part. The Sahara hydrographic basin

[1] Corresponding author: Mohamed GHRICI, Geomaterials Laboratory, Hassiba Benbouali University of Chlef, 02000 Chlef, Algeria, m.ghrici@univ-chlef.dz

occupies the entire hydrographic network of southern Algeria. Of the 74 dams in service, 11 are located in the Oranie hydrographic basin, 15 in the Chellif Zahrez hydrographic basin, and 21 in the Algerois hydrographic basin. On the other hand, the Sahara hydrographic basin has only four dams. Figure 1 represents the siltation rate of Algerian dams studied in 2014; according to Remini and Toumi [2], the Chelif basin-Zahrez dams are the most threatened by this problem caused by erosion due to the nature of the soil and the absence of forestation.

The siltation of dams causes enormous problems such as dam capacity reduction, the plugging of the drainage organs, the safety of the structure, the sedimentation of the irrigation canals, and it even has an impact on the quality of the water (Fig. 1). Thus, it is necessary to empty or reduce the proportion of these sediments in dams. Evacuating sediments from dams to the environment hurts flora and fauna on one side and the geometry of the watercourse downstream on the other. Therefore, this soil must be treated before storage or reuse.

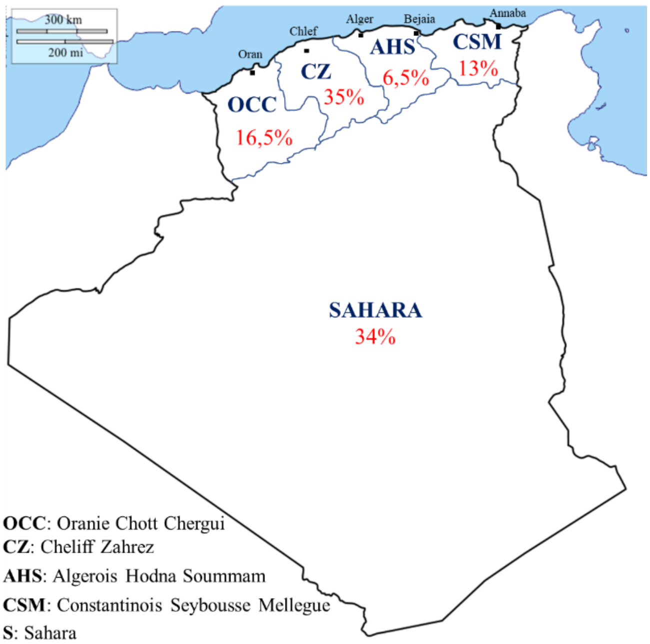


Fig. 1. Siltation rate of Algerian dams in 2014

Specific studies have been conducted for valorizing sediments from dams to reuse them as building materials such as brick, ceramic products, artificial pozzolan, addition for the manufacture of cement, and road engineering. To manufacture the brick, the sediments of the eleven most silted Algerian dams were used; the results show that the silt has the same characteristics as that of the yellow clay used by all the brickyards in Algeria [3]. For the ceramic products, Benasla et al. [4] studied the mud from the Oued Fodda dam with a view to its valuation in the field of construction materials, more particularly in ceramic floor tiles; the physical and chemical analyses of the mud confirm that the combination of 13% of mud from the Oued Fodda dam, 16% of sandstone and 71% of shale with a temperature of 1000 °C is sufficient to have a tile that meets the international standards and requirements ISO 13006. Chikouche et al. [5] noted that the dredging sludge could be successfully used as a pozzolanic additive to produce an eco-cement using heat treatment. As an additive to concrete, Safer et al. [6] studied the possibility of the dredged sediments' valorization to use as a component of vibrated concrete; the authors noted that the mud from Chorfa dam could be successfully valorized to use as partial cement replacement material in concrete. So, the mud collected during dredging activities is no longer considered as waste but rather as a natural resource respecting the principles of sustainable development. Safhi et al. [7] used the sediments extracted from Dunkirk dam (France) in the fabrication of self-consolidating concrete (SCC), and they found that after adding 20% of treated sediments, the compressive strength considerably increased compared to the mixture without sediments addition. In road engineering, Bourabah et al. [8] found that the geotechnical properties of the sediments collected from the Cheurfas dam by dredging were successfully improved after their mixing with sand, lime, and cement. The treated sediments also meet the requirements imposed by the technical recommendations of the GTR technical guide. Thus, it can be successfully used in the design of road embankments. The same behavior was observed by Banoune et al. [9] and Slama et al. [10]. Banoune et al. [9] treated the sediments of both the Kherrata dam and Soummam River with hydraulic binders for valorization in road construction when they found that the addition of cement or lime decreases the sediment's plasticity, improves compressive strength and increases the immediate and after immersion bearing index. Slama et al. [10] used polluted dredged sediment in road engineering after their treatment with lime, sand, and blast furnace slag.

In this work, after the presentation of the Gargar dam, which suffers from siltation, we present at first the characterization of the dam sediments. After choosing the type of sediment used, we study the effect of lime, sand, and natural pozzolana on the sediment's geotechnical properties and verify the possibility of using them after treatment in the geotechnical field, especially in road engineering.

2. GARGAR DAM

2.1. Location of Gargar dam

The Gargar dam is the third largest dam in terms of volume, with a capacity of 450 million m^3, after the Beni Haroun and Koudiat Acerdoune dams which occupy a storage capacity of 998 million m^3 and 650 million m^3, respectively. It is located in the Wilaya of Rélizane, 350 kilometers west of Algiers (Fig. 2). It is a part of the Chellif Zahrez watershed; these structures are the most vulnerable to the problem of siltation [3].

Fig. 2. Localization of the Gargar's Dam

2.2. Siltation of the Gargar dam

According to Remini and Benfetta [11], the Gargar dam is threatened with accelerated siltation after only 15 years of operation (Fig. 3). The filling rate in 2014 was around 27% of the total capacity of the dam, with an annual filling rate of 1.4%/year, which means that the successive deposits of mud seriously threaten the dam. If desilting measures are not implemented in the near and mid-term, the Gargar dam will be abandoned in 2060 at this rate of filling. Figure 4 represents the diagram of the evolution of the Gargar dam capacity during the period from 1989 to 2014, according to the results of the study carried out by Remini and Benfetta [11]. It is interesting to see, graphically and schematically, the regression of the dam's capacity as a function of time compared to the initial state. As shown in Figure 4, the water capacity of the dam reduced from 450 million m^3 in 1989 to 330 million m^3 in 2014 [11].

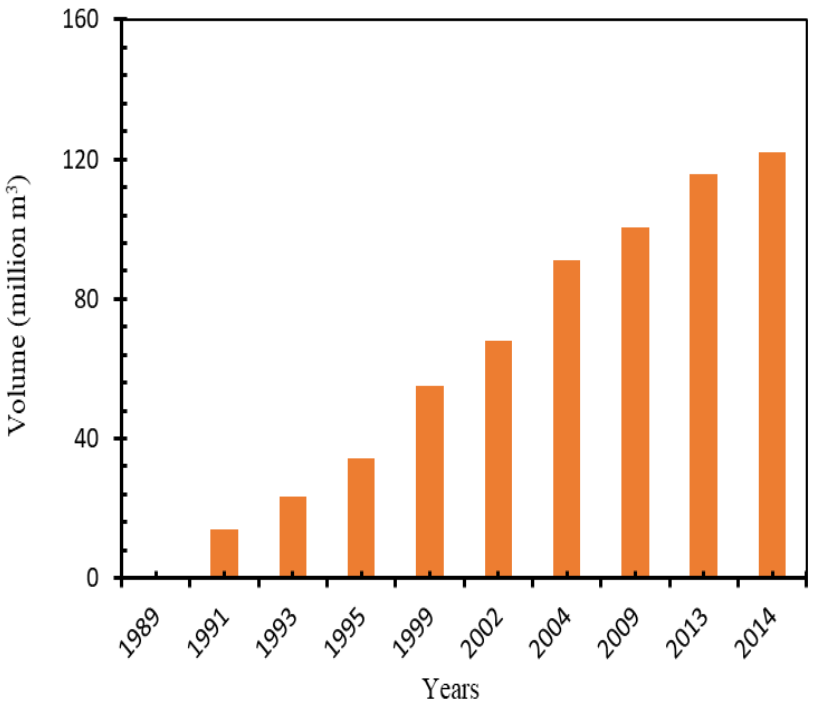


Fig. 3. Evolution of siltation in the Gargar's dam [11]

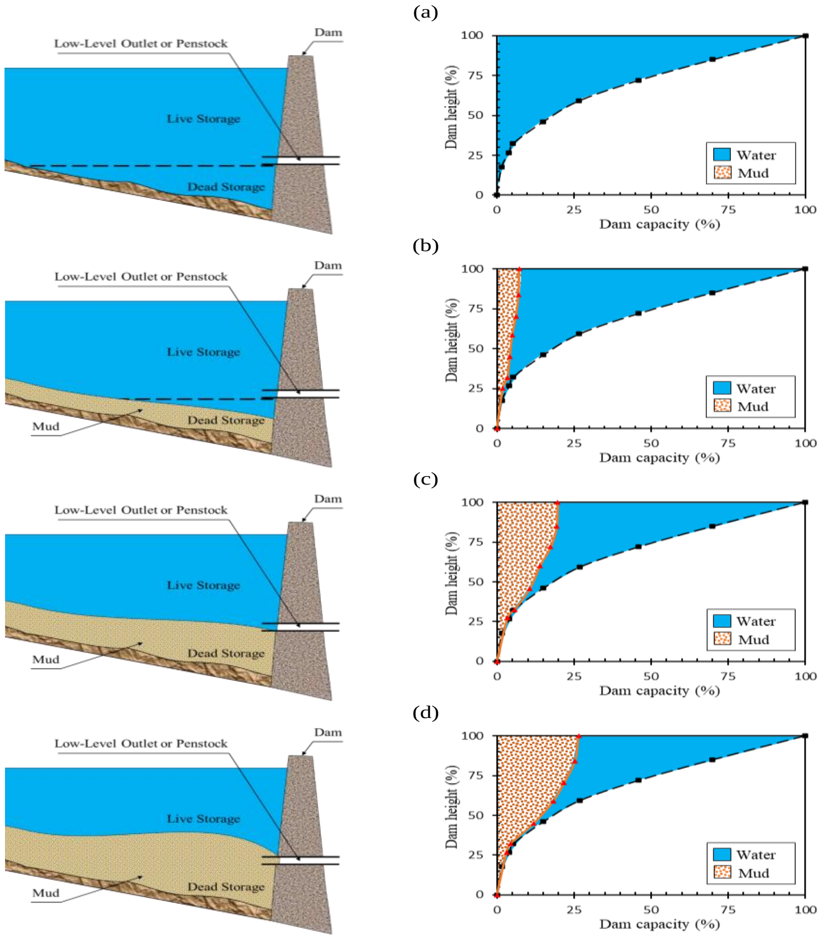


Fig. 4. Evolution of the capacity of the Gargar dam (Diagram executed according to the results of Remini and Benfetta [11]. (a) 1989, (b) 1995, (c) 2004, (d) 2014

2.3. Gargar mud identification

To study the behavior of the mud of the Gargar dam, regardless of the physical, chemical, mineralogical, and geological aspects, identification tests were carried out on five different samples, as shown in Figure 5. The 1st sample was from the release of draining; the second was taken at 200 m upstream of the dam, the third one at 4000 m, the 4th was collected at 5000 m, and finally, the 5th one at 8000 m always upstream.

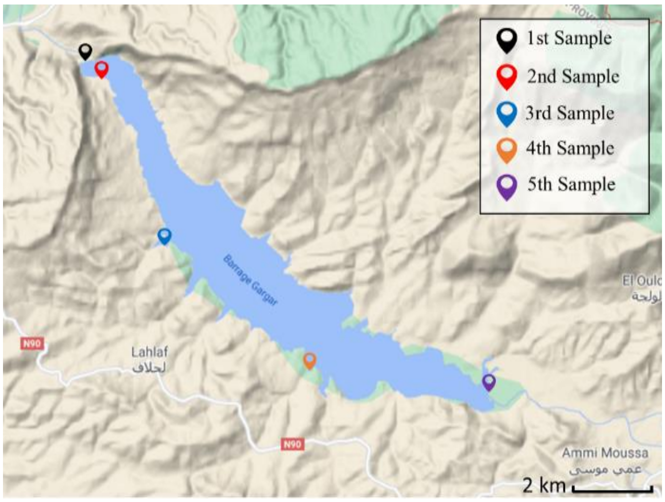


Fig. 5. Sample collection sites

The studied soil was collected, placed in plastic bags, and transported to the laboratory for identification. Each variety of soil was categorized according to the standardized tests. In Table 1, the geotechnical characteristics of soils are displayed. Figure 6 represents the particle size distribution and the classification of the collected samples. As indicated, the studied samples have two different behaviors depending on their classification when samples 1 and 2 are classified as high plasticity clay soils, while the other samples behave like low plasticity clays.

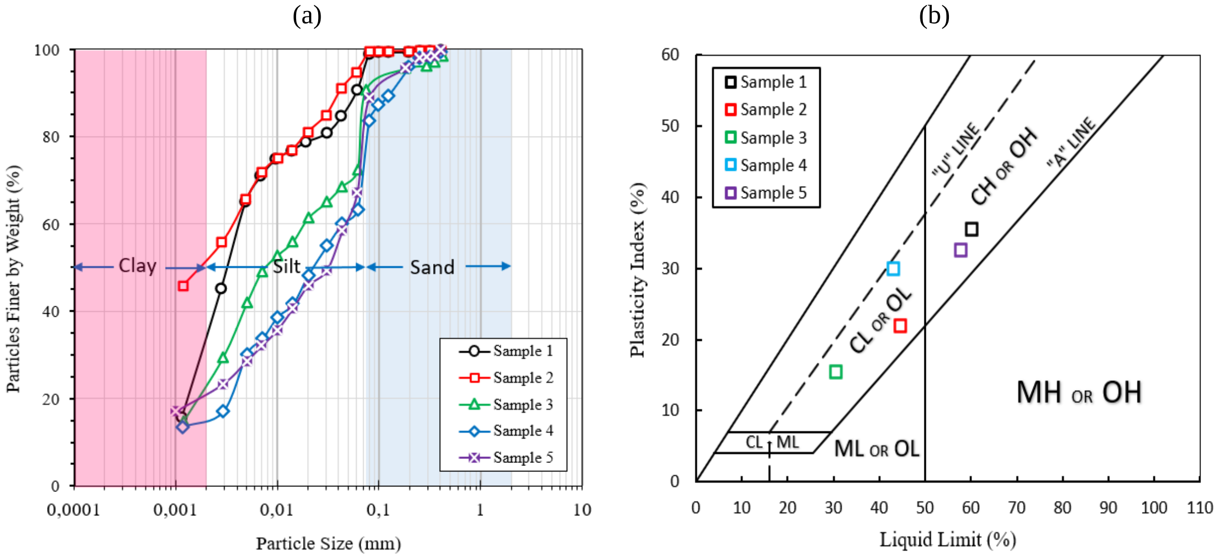


Fig. 6. Identification of the samples studied. (a) Particle size distribution, (b) Casagrande plasticity chart

Table 1. The geotechnical properties of the collected samples

Geotechnical Parameters		Unit	Variation				
			Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Sampling distance		(m)	1	20	400	500	800
Natural water content		(%)	47.61	58.55	40.63	65.12	51.13
Specific gravity of soil solids		(g/cm^3)	2.55	2.46	2.68	2.50	2.58
Grain size distribution	Sand	(%)	4	2	8	20	16
	Silt	(%)	61	46	68	65	63
	Clay	(%)	35	52	24	15	21
Ranking index	Natural state		1.50	1.18	1.38	1.30	1.44
	Deflocculated state		3.25	1.73	1.87	1.62	1.49
Asymmetry index	Natural state		0.68	0.90	0.87	0.90	0.75
	Deflocculated state		0.41	0.70	0.70	0.73	0.73
Liquid limit (LL)		(%)	60.35	44.78	30.70	43.20	57.96
Plastic limit (PL)		(%)	24.94	22.87	15.35	13.25	25.45
Plasticity index (PI)		(%)	35.41	21.91	15.35	29.95	32.51
Activity (A_c)		(%)	02.36	01.75	02.56	05.99	02.03
$CaCO_3$ content (%)		(%)	15.20	22.06	29.41	19.61	25.00
USCS classification			CH	CL	CL	CL	CH

2.4. Rheological behavior of Gargar's mud

The rheological properties were studied with the rotary viscometer "Rheomat 30" with two coaxial cylinders. It was necessary to calibrate this equipment with two Newtonian fluids (the Glycerin and Filtrate 40 oil used to lubricate vehicle gearboxes) whose characteristics are known.

Figure 7 represents the shear stress variation as a function of speed for the different studied samples with different concentrations. As reported in Figure (7-a), the results obtained show that the maximum difference between the viscosity value of the standard fluid and that calculated experimentally with the geometry (Rheomat-30) is relatively small, the error is less than 10% so that we can be sure of the correct operation of the device. Due to the complexity of the resulting clay-grain mixtures' components, we will only try to highlight their general characteristics by empirically modeling the behavior in the wide range of velocity gradients.

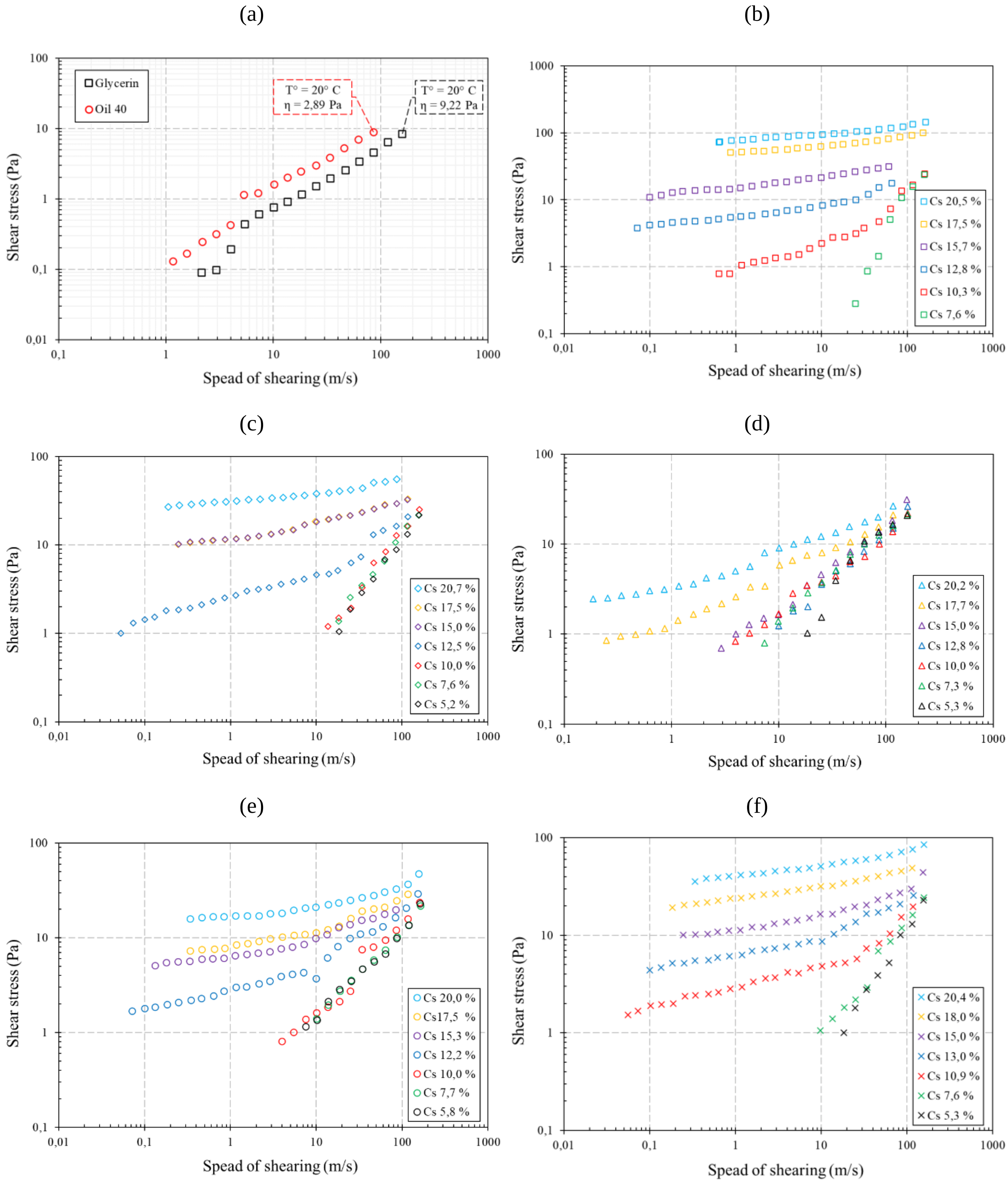


Fig. 7. Shear stress variation as a function of speed for the different studied samples with different concentrations (Cs). (a) Glycerin and Oil-40, (b) sample 1, (c) sample 2, (d) sample 3, (e) sample 4, (f) sample 5

The pseudo-curves of creep give rise to two parts curved part characterizing partial shear and the linear part representing the total shear. For high concentrations, it can be seen that the point characterizing the velocity gradient delimiting the partial shear from the total shear is very high (Fig. 7-b to f). On the other hand, for low concentrations, the total shear dominates almost the entire pseudo-rheogram. It is therefore concluded that this mud behaves at low concentrations (C_{vLim}< 12.8%) like a Newtonian fluid whose Bingham representation is well adapted; beyond this concentration (12.8-15-17-20%), it behaves like a non-Newtonian fluid whose characteristics can be described by the values of three parameters of a Herschel-Bulkley's law [12].

2.5. Influence of concentration on viscosity

Figure 8 shows the variation of shear stress and plastic viscosity as a function of Solid particle concentration. The pseudo rheogram plot allows us to see the influence of the concentration on the shear threshold and the viscosity. It can be seen that as the concentration of the mixtures weakens and the viscosity ηp decreases (Fig. 8-b), it is concluded that the parameters τ0 and ηp vary in the same direction without always being proportional to each other (Fig. 8-a). The concentration C_v corresponding to the point of intersection of the two lines is called the C_{vLim} concentration limit. It separates Newtonian behavior from non-Newtonian behavior. This concentration has been defined by Migniot [13] as a critical value above which a dam vase is easily eroded; above this threshold, it becomes difficult to erode.

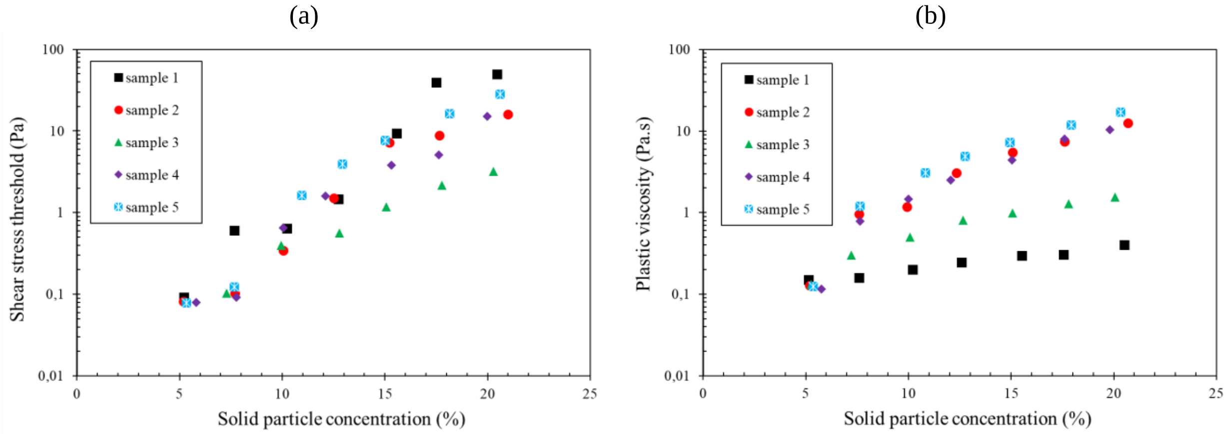


Fig. 8. Shear stress and plastic viscosity variation as a function of Solid particle concentration

3. STABILIZATION OF GARGAR MUD

3.1. Material and methods

In this paper, we studied the effect of adding different combinations of lime, sand, and natural pozzolan on the mud collected from the release of draining of the Gargar dam (sample 1). As reported in Table 1, the studied mud collected at location 1 (Fig. 5) consisted of 35% clay, 61% silt, and 4% sand. The soil studied was classified as a high plasticity clay soil with a liquid limit, plastic limit, and plasticity index equal to 60.35%, 24.94%, and 35.41, respectively. Figure 9 represents the particle size distribution of the material used.

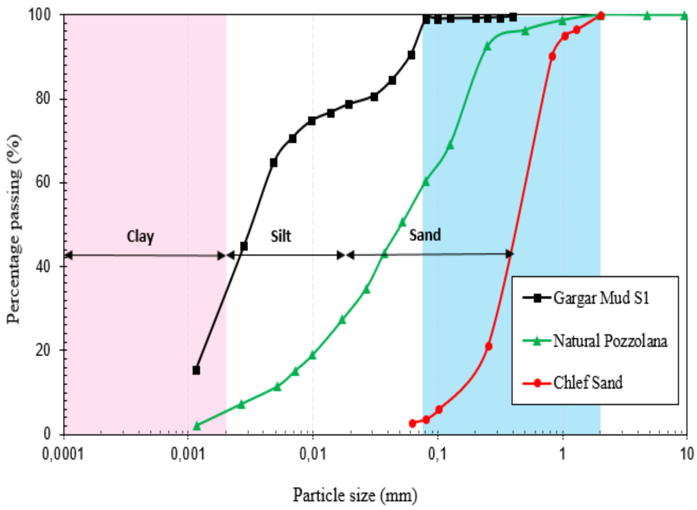


Fig. 9. Particle size distribution of the material used

The lime used was a commercially available hydrated lime produced by SARL-BSM company located in Saïda-Algeria; this type is typically used for construction purposes. Pozzolans are generally siliceous materials with no cementitious reactions themselves, but when combined with calcium lime, they create compounds with cementitious characteristics. The natural pozzolana used in this research was a material of volcanic origin extracted from the Bou-Hamidi deposit in Ain-Temouchent-Algeria. Table 2 represents the physico-chemical properties of lime (L) and natural pozzolana (NP).

Table 2. Physical and chemical properties of mineral additives

Geotechnical Parameters			**Variation**	
			L	**NP**
Color			White	Red
Specific Gravity		(g/cm^3)	2.24	2.85
Bulk Density		(g/cm^3)	0.72	1.022
Specific Surface -Blaine-		(cm^2/g)	11663	8737.2
Particle Fineness less than 45 µm		(%)	64.87	-
Normal Consistency -Vicat W/L		(%)	69.5	-
Set Time -Vicat- (min)	Initial		80	-
	Final		40	-
Calcium Oxide [CaO]		(%)	> 83.3	9.4
Magnesium Oxide [MgO]		(%)	< 0.5	3.88
Iron Oxide [Fe_2O_3]		(%)	< 2	8.36
Alumina [Al_2O_3]		(%)	< 1.5	17.45
Silica [SiO_2]		(%)	< 2.5	46.83
Sulfite [SO_3]		(%)	< 0.5	0.36
Sodium Oxide [Na_2O]		(%)	0.4 – 0.5	4.32
Carbon Dioxide [CO_2]		(%)	< 5	-
Calcite [$CaCO_3$]		(%)	< 10	-

The sand of Oued-Chlef, which crosses the town of Chlef to the west of Algiers, is classified as medium sand with 0.45 mm of average diameter, known by its rounded shape (alluvial sand) and its non-plastic silt. Table 3 represents the principal properties of Oued-Chlef sand.

Table 3. Principal properties of Chlef sand

Material	**G_s (g/cm^3)**	e_{max}	e_{min}	**Cu (D_{60}/D_{10})**	**D_{10} (mm)**	**D_{50} (mm)**	**Grains shape**
Chlef Sand	2.68	0.99	0.54	3.2	0.15	0.45	Rounded

3.2. Stabilized soil mixtures and testing procedures

A series of laboratory tests were conducted on the selected mud: Atterberg limits, compaction (Proctor normal), California bearing ratio, and unconfined compressive strength. Lime, sand, and natural pozzolana were used for mud stabilization. 3% and 5% lime was added to the studied soil before and after mixing with 20% sand, 20% natural pozzolana, and 20% lime+20% NP. A total of 10 combinations was studied, as represented in Table 4.

Table 4. Combinations of untreated and treated samples

Combination	Mixtures (%)			
	Soil	L	S	NP
L0S0P0	100	0	0	0
L3S0P0	97	3	0	0
L5S0P0	95	5	0	0
L0S20P0	80	0	20	0
L3S20P0	77	3	20	0
L5S20P0	75	5	20	0
L3S0P20	77	3	0	20
L5S0P20	75	5	0	20
L3S20P20	57	3	20	20
L5S20P20	55	5	20	20

S: Sand ; L: Lime ; NP: Natural pozzolana

The Atterberg limit tests were performed according to the method given in the American standards ASTM D4318-2017 [14]. Initially, the predetermined preset amount of sand, pozzolana, and lime was combined with the air-dried soil (sieved using a number 40 sieve) in dry conditions (Table 4). The paste produced after adding distilled water was left to sit for about 24 hours before being tested. Prior to conducting experiments, the mixtures were thoroughly remixed for at least 15 minutes. The room's temperature was kept at 202 °C for the liquid and plastic limits experiments.

The process outlined in ASTM D698-2000 [15] was used to figure out the maximum dry density (MDD) and optimum moisture content (OMC) of the studied combinations. Prior to compaction, the soil mixtures (both with and without additives) were thoroughly mixed for an hour.

Unconfined compressive strength (UCS) tests were conducted on samples compacted with their optimum compaction characteristics following ASTM D2166-2000 [16]. In order to study the effect of curing time on soil stabilization, tests were performed at 1 and 28 days. After curing and before carrying out tests, the mass and dimensions of samples were recorded. The strength of specimens was recorded during the UCS test until the sample failed.

The California Bearing Ratio is frequently used when designing pavement routes. It is a common measure for determining the strength of soils. The CBR test was conducted according to the ASTM D1883-2007 [17]. The studied specimens were prepared according to their maximum dry density and optimum moisture content. After soaking in a water bath for four days, three samples from each soil combination were examined. The saturated state reflects how the subgrade would act in a flood or a strong rainfall.

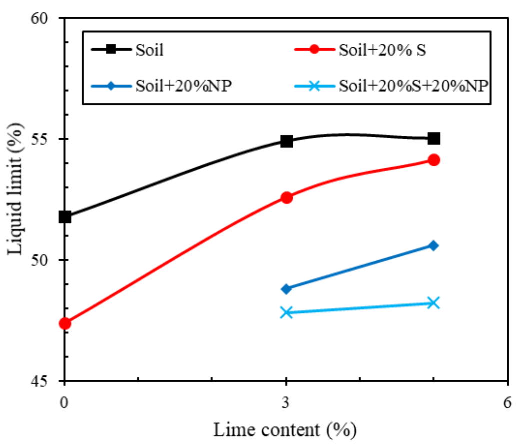
4. RESULTS AND DISCUSSION

4.1. Atterberg limits

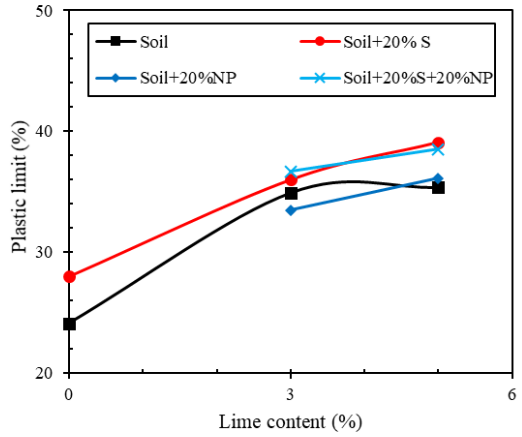
Figure 10 shows the variation of the Atterberg limits (liquid limit, plastic limit, and plasticity index) for the studied soil before and after treatment with the different studied combinations. The addition of lime to the studied soil leads to a significant increase in their liquid limit (LL) and plastic limit (PL); Adding 3 and 5% lime to the clay soil increased their LL from 51.79% to 54.91% and 55% and its PL from 24% to 34.9% and 35.4%, respectively. The same behavior is observed by Osula [18] and Asgari et al. [19]. A considerable increase in the plastic limit was observed after adding lime to the studied soil. Therefore, an essential decrease in the plasticity index (PI) was noted when the PI was reduced by 29% after adding 5% lime. Several researchers have shown the same trend [20-23]. Bell [24] found that the plasticity limit of the clay soils treated with lime depends on their clay mineralogy: the substantial increase in PL for montmorillonite, less strong for kaolinite, and non-significant change for quartz.

It can be noted that the LL decreased after adding 20% of sand to the natural soil; this behavior is due to the replacement of part of the clay particles by granular and non-plastic particles of sand and the lower LL of sand compared to the studied soil. The same results were observed by Goufi et al. [25] when they studied the effect of dune sand on clayey soil with high plasticity (CH).

(a)



(b)



(c)

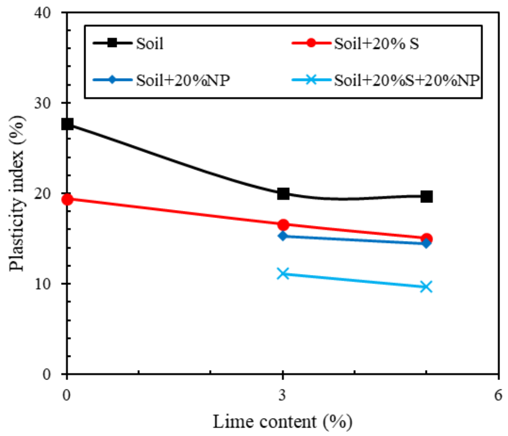


Fig. 10. Variation of the Atterberg limits of the treated soil, (a) liquid limit, (b) plastic limit, (c) plasticity index

When treating soil-sand, soil-NP, and soil-sand-NP with lime, the LL and PL increased with increasing lime percentage. At the same time, LL decreased by adding NP and/or sand to the soil treated with lime. Adding 20% sand, 20% NP, and their combination with the 5% lime-treated soil decreased their LL from 55% to 54%, 50%, and 48%, respectively. These results can be explained by the lower LL of NP and sand and by the more flocculated soil structure produced when adding sand and/or NP to lime stabilization compared to using lime alone [22, 26].

Figure 11 shows the classification of the studied samples on the Unified Classification System of Soils (USCS). As seen, the soil studied is classified as highly plastic clay (CH); after the addition of lime, they change their class to highly plastic silt (MH). After adding 20% of sand to the clay soil, they change this class to clay with low plasticity (CL). Soil treated with 20% sand plus 3% and 5% lime was classified as highly plastic silt (MH). For lime-NP and lime-sand-NP, the treated soil changes its class from highly plastic clay (CH) to loam with low plasticity (ML). The changes in soil classes after treatment are attributed to the flocculation of the clay particles and the cation exchange [22, 26, 27]. From these results, it can be concluded that the treated soil becomes more friable with low plasticity.

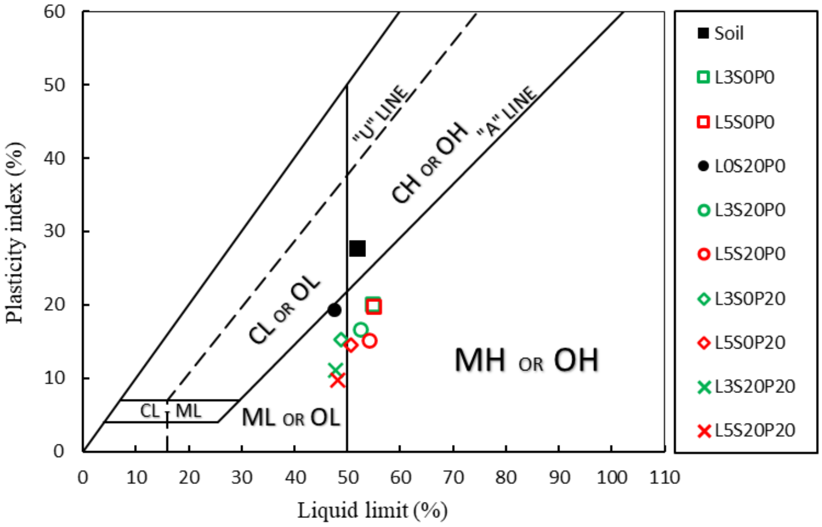
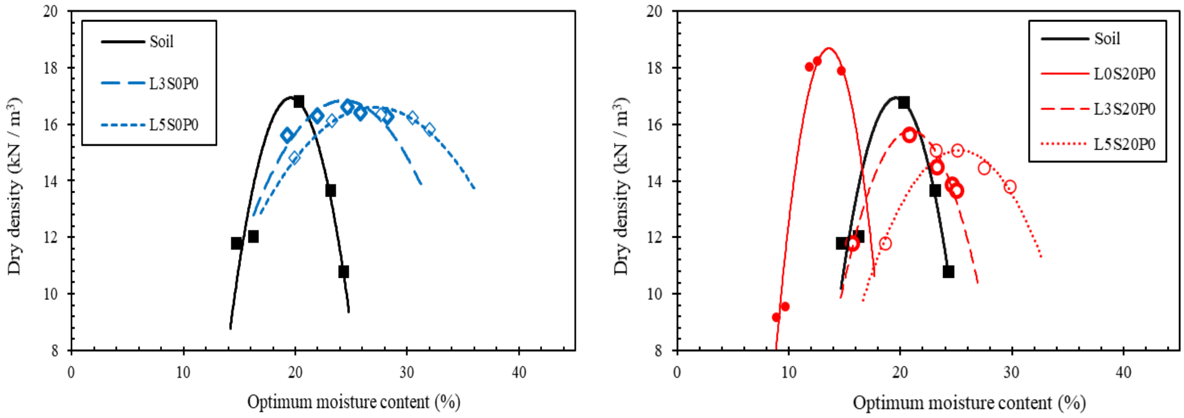


Fig. 11. Change of soil class after treatment with the various combination

4.2. Compaction

The compaction tests were conducted to determine the effect of sand, lime, lime-sand, and lime-sand-natural pozzolan on the compaction parameters such as maximum dry density (MDD) and optimum moisture content (OMC). Figure 12 shows the soil compaction curves before and after treatment with the different combinations. It can be seen that the compaction curves are single peak compaction curves; the dry density increases with increasing water content up to a percentage corresponding to the maximum dry density; this content is called the optimum moisture content.

(a) (b)



(c) (d)

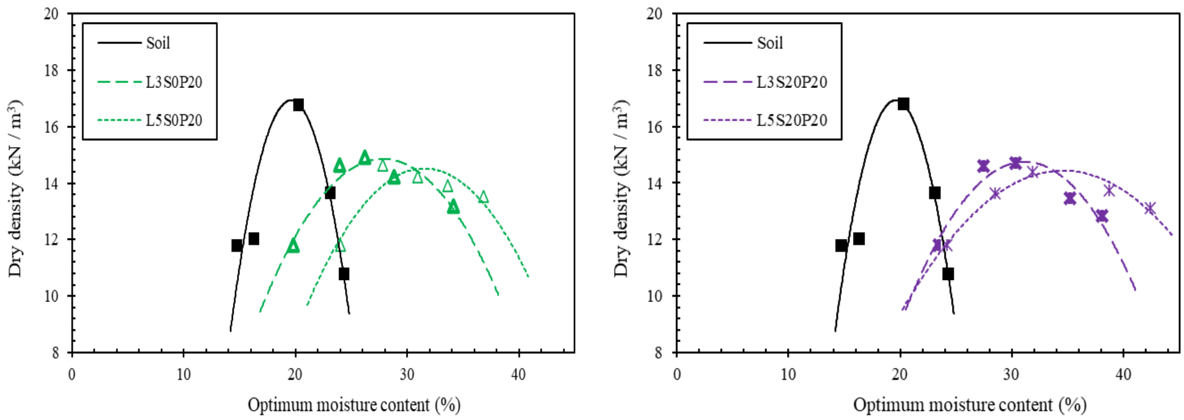


Fig. 12. Compaction curves for the different studied combinations. (a) soil treated with lime, (b) soil treated with sand and sand-lime, (c) soil treated with lime-NP, and (d) soil treated with lime-sand-NP

Table 5 represents the variation of the compaction parameters (OMC and MDD) of the combinations studied. From the results reported in Table 5 and Figure 12-a, it can be noted that adding lime to the studied soil increases the optimum moisture content and decreases the maximum dry density of the soil. The same behavior has been observed by several researchers [23, 24, 28-30]. The reduction in the maximum dry density is due to the low density of lime compared to the clay soil and the flocculation of the particles after treatment of the soil [23, 28]. The increase in the optimal moisture content can be explained by the increased water holding capacity and the additional water requirements for the pozzolanic reaction [22, 28, 31].

Table 5. Variation of the compaction parameters of the studied combinations

Combination	Dry density (kN/cm^3)	Optimum moisture content (%)
Soil	16.80	20.40
L0S20P0	18.40	14.60
L3S0P0	16.42	25.71
L5S0P0	16.35	27.91
L3S20P0	15.67	21.25
L5S20P0	15.23	24.12
L3S0P20	14.83	26.10
L5S0P20	14.65	28.85
L3S20P20	14.48	29.25
L5S20P20	14.30	32.15

Regarding the addition of sand to the soil studied, there is a decrease in the OMC and an increase in the MDD (Fig 12-b). These results are in agreement with the results obtained by Goufi et al. [25]; according to the authors, this behavior can be explained by the following reasons: the density of sand is generally higher than that of clay soils, and the initial void rate decreases with increasing sand content.

As shown in Table 5, adding lime to soil-sand, soil-NP, and soil-sand-NP decreases their maximum dry density and increases their optimum moisture content; these variations are more significant than treating the studied soil alone.

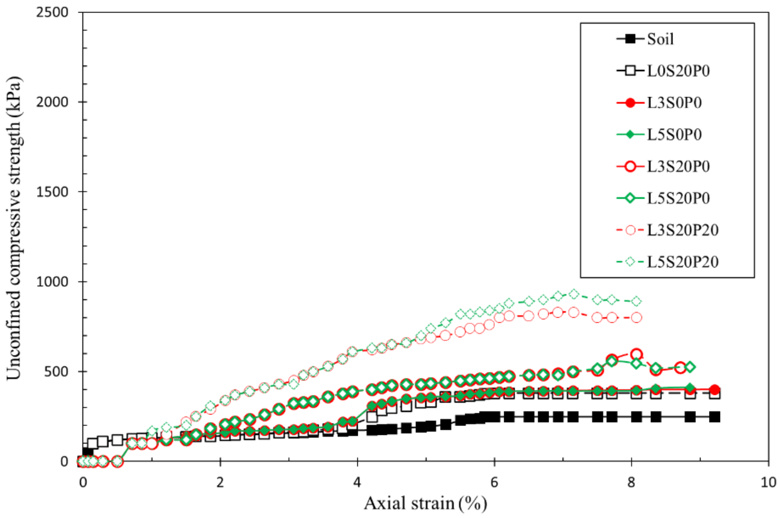
This considerable decrease in the maximum dry density with large increases in optimum moisture content may be explained by the more flocculated soil structure and the additional pozzolanic reactions produced when adding pozzolanic material to the lime stabilization [22, 26].

4.3. Unconfined compressive strength

As known in the literature, the treatment of clay soils with lime causes a considerable increase in the unconfined compressive strength; this stress gain has been mentioned by various researchers [25, 26]. (Figure 13 shows the unconfined compressive strength (UCS) variation of a very plastic clay soil treated with lime, lime-sand, lime-NP, and lime-sand-NP at 1 and 28 curing days. It can be noted that the stress-strain curves of the treated combinations have two different behaviors; in the short term (1 day of hardening), the treated soil behaves like ductile materials with an increase in UCS. In the long term (28 days of hardening), the soil treated with lime, lime-sand, lime-sand-NP behaves like a brittle material with a significant gain in unconfined compressive strength due to the production of pozzolanic products and crystallization of soil particles.

An essential improvement in the unconfined compressive strength (UCS) is observed with increasing the percentage of lime and the curing period (Fig. 14). The strength gained in the short curing periods is due to the short-term reactions such as cation exchange and flocculation/agglomeration which make the soil more granular and friable. A significant increase in unconfined compressive strength was observed after 28 days of curing compared to the untreated soil. UCS drops from 250 kPa for untreated soil to 1238 kPa, 1436 kPa, and 1980 kPa after treatment with 5% lime, 5% lime+20% sand, and 5% lime+20% sand+20 % natural pozzolana, respectively. This increase in compressive strength is attributed to the pozzolanic reaction produced between lime-soil, lime-soil-sand, and lime-soil-sand-NP, which produced new cementation products that bind the particles together. The combination that gives the best stress gain is the mixture of 5% lime + 20% sand + 20% natural pozzolan.

(a)



(b)

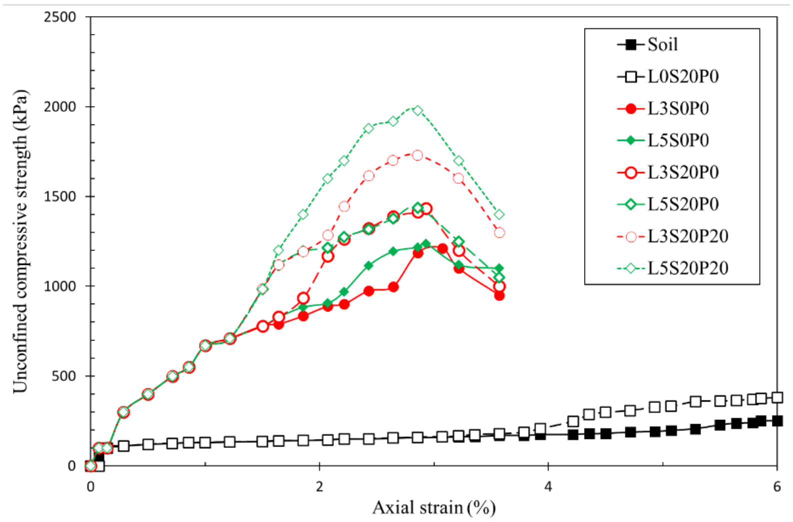


Fig. 13. Stress-strain curve of the studied combinations. (a) 1 day, (b) 28 days

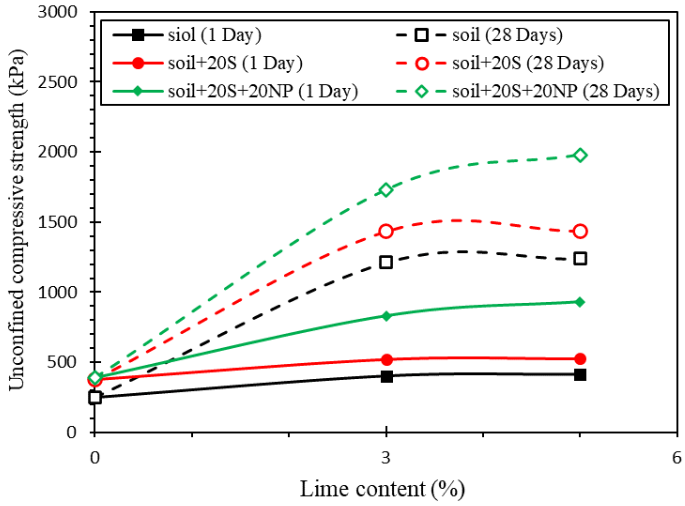


Fig. 14. Effect of additives on the unconfined compressive strength (UCS) variation

4.4. California Bearing Ratio (CBR)

When constructing a pavement, the bearing capability of the subgrade substance is typically assessed using the California Bearing Ratio test (CBR). The subgrade's strength and bearing capability must be evaluated for new roadways' paving designs to support the repeated traffic loads. CBR is regarded as the most practical impact test in transient geotechnical for determining the caliber of the sub-base and base material.

Figure 15 shows the load-penetration curve for the CBR tests. It is seen that the resistance of the samples increases with the increase in the penetration and the percentage of additions. The same behavior was observed after the immersion of the samples at four days, with a decrease in load for the untreated soil and soil combined with 20% sand; this decrease in load after immersion can be explained by the swelling of the soil, which changes the structure of the soil and reduces their bearing capacity.

For the other studied combinations, the pressure increased compared to the immediate CBR results, which gives results more significant than 1 for the ratio between CBR 4 days immersion and CBR immediate (Table 6). Thus, all the combinations of soil stabilized with lime, lime-sand, and lime-sand-NP meet the criteria of durability at a young age.

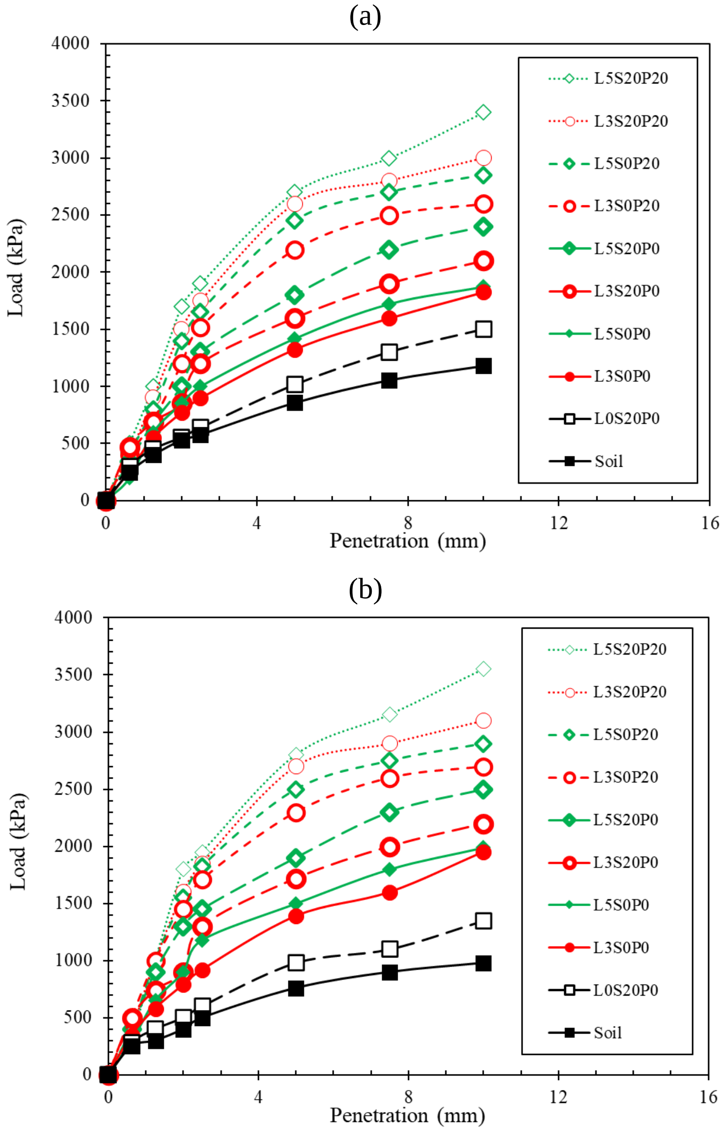


Fig. 15. CBR test load-penetration curve. (a) Immediate CBR, (b) CBR 4 days of immersion

Figure 16 represents the variation of the CBR coefficient for the different studied combinations. It can be seen that a considerable increase in the CBR value was observed after soil treatment with lime, lime-sand, and lime-sand natural pozzolan. This improvement can be explained by the cation exchange reaction between calcium ions of lime and the exchangeable ions of the soil surface, which produced a flocculated soil structure with an open soil fabric; consequently, the internal friction angle significantly improved and resulted in a higher CBR value.

Table 6. Variation of CBR of the studied combinations

Combination	Immediate CBR	CBR 4 days of immersion	CBR immers/Immed
Soil	8.51	7.48	0.88
L0S20P0	9.99	9.65	0.97
L3S0P0	13.20	13.69	1.04
L5S0P0	14.70	17.35	1.18
L3S20P0	17.64	19.11	1.08
L5S20P0	19.11	21.32	1.12
L3S0P20	22.35	24.34	1.09
L5S0P20	25.18	26.85	1.07
L3S20P20	25.73	27.20	1.06
L5S20P20	27.93	28.67	1.03

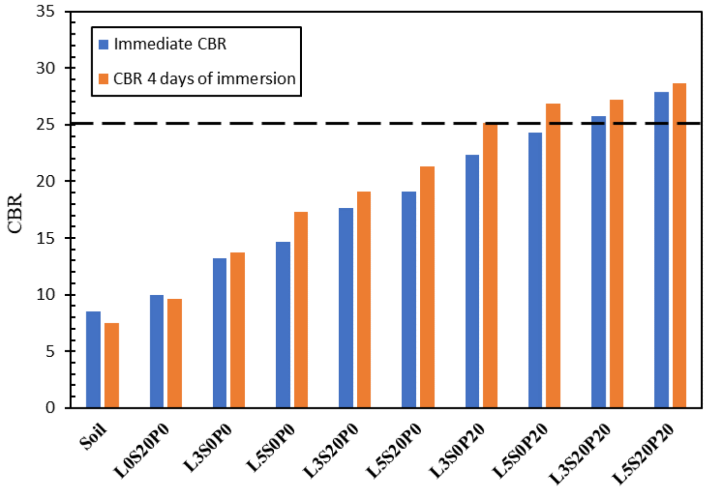


Fig. 16. Variation of the CBR coefficient

The same behavior was observed by other researchers [32-35] when studying the strength and microstructural behavior of lime stabilized subgrade soil in road construction. According to Figure 16, the combinations meeting the load-bearing criteria are soil+20% sand+20% natural pozzolana stabilized with 3% and 5% lime when the load-bearing index is greater than 25, so the stabilized soil can be used as a layer of foundation. The significant improvement in soil strength when combining lime with sand and natural pozzolana can be explained by forming a more flocculated soil structure with a stronger attraction bond than lime alone. The same results were observed by Harichane et al. [26] when studying the stabilization of Algerian clayey soils with natural pozzolana.

CONCLUSION

The problem of water siltation in dams is currently the main concern in Algeria. Most of these structures experience siltation, which reduces their water capacity. This paper aims to valorize dredged sediments from the Gargar dam for road embankment use. From this research, several conclusions can be drawn:

1. Gargar mud becomes more friable with lower plasticity after treatment with the different additives, resulting in considerable change in their classification according to the Unified Classification System of Soils. Using 5% lime and 20% sand reduced the plasticity index of the studied soil from 27.66% to 19.68% and 19.39%, respectively. The lowest value of PI was noted for the studied soil with the combination of 20% sand, 20% NP, and 5% lime when the plasticity of mud decreased by 65% compared to their initial value.
2. Natural pozzolan and sand are known for their high density. Thus, their addition to the studied mud produced a denser soil structure. The addition of 20% sand to the clay soil Gargar mud increases their maximum dry density from 16.8 kN/m^3 to 18.4 kN/m^3. The addition of lime to the studied soils increased their optimum moisture content and decreased their maximum dry density due to lower lime density and the increase in water holding capacity after treatment.
3. After treatment, the studied soil flocculates and produces higher unconfined compressive strength. Increasing the content of additives and curing time produces more stress gain; the optimum results are noted for the specimens treated with the combination of lime, sand, and natural pozzolana. After 28 days of treatment with the combination of 5% lime, 20% sand, and 20% NP, the UCS of mud increased from 250 kPa to 1980 kPa.
4. Despite the considerable reduction in the density of soils after their treatment with the combination of lime, pozzolana and sand, this undesirable behaviour is compensated by an enormous increase in the mechanical resistance of the soil, when the UCS increases 7 times compared to nontreated mud.
5. All soil combinations stabilized with lime, sand, and natural pozzolan meet the durability criteria at the early stage. According to the results obtained, the CBR of the studied soil increased considerably after treatment. However, only the lime-sand-NP combination met the bearing criteria when their index was greater than 25. Thus, to use the Gargar mud as a foundation layer, it must be treated with lime sand and natural pozzolan.

ACKNOWLEDGMENTS

This research was sponsored by the General Directorate for Scientific Research and Technological Development (DGRSDT) of the Algerian Minister of Higher Education and Scientific Research

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

1. Hallouz, F, Meddi, M, Mahé, G, Toumi, S and Rahmani SEA 2018. Erosion, Suspended Sediment Transport and Sedimentation on the Wadi Mina at the Sidi M'Hamed Ben Aouda Dam, *AlgeriaWater* **10,** 32.
2. Remini, B and Toumi, A 2017. The Beni Haroun Reservoir (Algeria) Is It Threatened By Siltation? *Larhyss Journal* **29**, 249-263.
3. Remini, B. (2017). Une nouvelle approche de gestion de l'envasement des barrages. *LARHYSS Journal*, 31, 51-81.
4. Benasla, M, Benamara, M and Hadjel, L 2015. Characterization of dredging mud dam Oued Fodda and valorization as a building material. *Journal of Materials and Environmental Science* **6**, 546-558.
5. Chikouche, MA, Ghorbel, E and Bibi, M 2016. The possibility of using dredging sludge in manufacturing cements: optimization of heat treatment cycle and ratio replacement. *Construction and Building Materials*, **106**, 330-341.
6. Safer, O, Belas, N, Belaribi, O, Belguesmia, K, Bouhamou, NE and Mebrouki, A 2018. Valorization of dredged sediments as a component of vibrated concrete: Durability of these concretes against sulfuric acid attack. *International Journal of Concrete Structures and Materials*, **12**, 1-11.
7. Safhi, AM, Rivard, P, Yahia, A, Benzerzour, M and Khayat, KH 2020. Valorization of dredged sediments in self-consolidating concrete: Fresh, hardened, and microstructural properties. *Journal of Cleaner Production*, **263**, 121472.
8. Bourabah, MA, Abou-Bekr, N and Taibi, S 2010. *Geotechnical characterization of dredging sediments for valorization in road embankments: Case of the Cheurfas Dam (Algeria)*. In GeoFlorida 2010: Advances in Analysis, Modeling & Design, Florida, USA, February, 2212-2221.
9. Banoune, B, Melbouci, B, Rosquoët, F and Langlet, T 2016. Treatment of river sediments by hydraulic binders for valorization in road construction. *Bulletin of Engineering Geology and the Environment*, **75**, 1505-1517.
10. Slama, AB, Feki, N, Levacher, D and Zairi, M 2021. Valorization of harbor dredged sediment activated with blast furnace slag in road layers. *International Journal of Sediment Research*, **36**, 127-135.
11. Remini, B and Benfetta, H (2015). Le Barrage Reservoir De Gargar Est-Il Menace Par L'envasement? *LARHYSS Journal*, **24**, 175-192.
12. Hammadi L 2013. Rheology and flow of complex fluids applications to barrage and sludge of wastewater treatment plants, Ph.D. Thesis, University of Sciences and Technology of Oran.
13. Migniot, C 1968. Etude des propriétés physiques de différents sédiments très fins et de leur comportement sous des actions hydrodynamiques. *La houille blanche*, **7**, 591-620.
14. ASTM D4318-17 2017. Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils, ASTM International, West Conshohocken, PA, www.astm.org
15. ASTM D698. 2000. Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft lbf/ft3 (600 kN-m/m^3)). Easton, MD, ASTM – American Society for Testing and Materials.
16. ASTM D2166. 2000. Standard Test Method for Unconfined Compressive Strength of Cohesive Soil. West Conshohocken, PA, ASTM – American Society for Testing and Materials.
17. ASTM D1883-07e2. 2007. Standard test method for CBR (California bearing ratio) of laboratory compacted soils. West Conshohocken, PA: ASTM International.
18. Osula, DOA 1991. Lime modification of problem laterite, *Engineering Geology*, **30**, 141-154.

19. Asgari, MR, Baghebanzadeh Dezfuli, A and Bayat, M 2015. Experimental study on stabilization of a low plasticity clayey soil with cement/lime, *Arabian Journal of Geoscience*, **8**, 1439–1452.
20. Sakr, MA, Shahin, MA, and Metwally, YM 2009. Utilization of Lime for Stabilizing Soft Clay Soil of High Organic Content, *Geotechnical and Geological Engineering*, **27**, 105-113
21. Harichane, K, Ghrici, M, Kenai, S and Grine, K 2011. Use of natural pozzolana and lime for stabilization of cohesive soils. *Geotechnical and geological engineering*, **29**, 759-769.
22. Al-Swaidani, A, Hammoud, I and Meziab, A 2016. Effect of adding natural pozzolana on geotechnical properties of lime-stabilized clayey soil, *Journal of Rock Mechanics and Geotechnical Engineering*, **8**, 714-725.
23. Vitale, E, Deneele, D, Paris, M and, Russo, G 2017. Multi-scale analysis and time evolution of pozzolanic activity of lime treated clays, *Applied Clay Science*, **141**, 36–45.
24. Bell, FG 1996. Lime stabilization of clay minerals and soils. *Engineering Geology*, **42**, 223-237.
25. Goufi, AE, Harichane, K, Harichane, Z, Driss, AAE and Ghrici, M 2022. Improvement of the geotechnical properties of a clay–sand mixture treated with lime. *Innovative Infrastructure Solutions*, **7**, 1-17.
26. Harichane, K, Ghrici, M and Kenai, S 2018. Stabilization of Algerian clayey soils with natural pozzolana and lime. *Periodica Polytechnica Civil Engineering*, **62**, 1-10.
27. Driss, AAE, Harichane, K, Ghrici, M, Sert, S and Bol, E 2023. Effect of Natural Pozzolana on the Unconsolidated Undrained Shear Strength of a Lime-Stabilized Clay Soil. *International Journal of Civil Engineering*, **21**, 1007–1026.
28. Garzon, E, Cano, M, O`Kelly, BC and Sánchez-Soto, PJ 2016. Effect of lime on stabilization of phyllite clays, *Applied Clay Science*, **123**, 329-334.
29. Driss, AAE, Harichane, K, Ghrici, M and Gadouri, H 2021. Assessing the effect of moulding water content on the behaviour of lime-stabilised an expansive soil. *Geomechanics and Geoengineering*, **17**, 896-908.
30. Driss, AAE, Harichane, K and Ghrici, M 2021. Effect of natural pozzolana on microstructural behavior and hydraulic conductivity of lime-stabilized clayey soil. *Innovative Infrastructure Solutions*, **6**, 1-17.
31. Kinuthia, JM, Wild, S and Jones, GI 1999. Effects of monovalent and divalent metal sulphates on consistency and compaction of lime-stabilized kaolinite, *Applied Clay Science*, **14**, 27-45.
32. Dhar, S and Hussain, M 2019. The strength and microstructural behavior of lime stabilized subgrade soil in road construction. *International Journal of Geotechnical Engineering* **15**, 1-13.
33. Fırat, S, Dikmen, S, Yılmaz, G and Khatib, JM 2020. Characteristics of engineered waste materials used for road subbase layers. KSCE Journal of Civil Engineering **24**, 2643-2656.
34. Firat, S, Khatib, JM, Yilmaz, G and Comert, T 2017. Effect of curing time on selected properties of soil stabilized with fly ash, marble dust and waste sand for road sub-base materials. *Waste Management & Research* **35**, 747–756.
35. Onturk, K, Firat, S, Yilmaz, G and Khatib JM 2022. Waste utilization to enhance performance of road subbase fill. *Journal of Engineering Design and Technology* **20**, 455-474.