

Lithostabilization of Expansive Marl Excavated from Diamniadio by Sand Addition for Road Construction Valorization

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Abstract

The soils in the Diamniadio urban hub are expansive and have low bearing capacity. Construction in this area often requires the removal of native soils over certain depths, generating significant volumes of marl excavated materials that clutter construction sites. Due to their poor geotechnical properties, the reuse of these excavated materials in construction poses major challenges to engineers. This study investigates the effects of lithostabilization on the physical and mechanical properties of marl excavated from the Diamniadio urban hub to enable its valorization in road subgrade applications. Sand additions of 15%, 25%, 35%, and 45% were tested, using both dune sand (DS) and beach sand (BS). Results show that adding sand increases the bearing capacity of the marl, reduces its water sensitivity, and makes it suitable for construction use. It was observed that the granulometry of the added sand has a positive effect on lithostabilization outcomes.

Keywords

Lithostabilization, Excavated Material, Marl, Dune Sand, Beach Sand, Swelling, Diamniadio, Road Subgrade

1. Introduction

The Diamniadio urban hub is the first urban hub created by the Government of Senegal as part of its decentralization policy and the decongestion of Dakar. This highly strategic area is characterized by the presence of expansive clays and marls with low bearing capacity, difficult workability, and susceptibility to shrink-swell

phenomena. Such soils, widespread in many countries worldwide especially in arid and semi-arid regions such as Senegal cause significant damage to structures due to variations in water content.

In Diamniadio, the construction of buildings, roads, and highways faces serious challenges, with the premature appearance of cracks, heaving, settlement, and even structural failure. To ensure the durability of infrastructures, some practitioners recommend removing part of the clays and marls and replacing them with more resistant and durable soils. However, this substitution generates large deposits of excavated materials on worksites and requires significant investment to source quality borrow materials. Due to their poor geotechnical properties, reusing marl excavated materials in construction poses major difficulties for engineers.

Nevertheless, the geotechnical properties of marls can be improved through lithostabilization. This article is part of the broader effort to valorize local materials, in particular by improving the physical and mechanical characteristics of marl excavated from the Diamniadio urban hub through the addition of sand. The dune sand and beach sand used in this study were sourced respectively from the Sébikhotane quarry and the Bargny beach, both of which are located near the Diamniadio urban hub.

The reuse of these excavated materials would help avoid bulky soil deposits, preserve natural reserves, and reduce transportation costs, which can be very high. Indeed, the mechanical performance and durability of marls can be improved by lithostabilization through sand addition. Several studies have demonstrated the effectiveness of using sand as a stabilizing material [1]-[3]. Didier [4] showed that 10% sand is enough to reduce the swelling pressure of montmorillonite by 50%. Aola (1987, cited in [5]) stated that adding sand increases maximum dry density and decreases optimum moisture content of expansive clays. Rao (1987, cited in [5]) showed that adding 40% sand to India's Black Cotton soils increased CBR, compressive strength, friction angle, and cohesion.

This study is based on a literature review followed by an experimental approach to achieve the stated objectives.

2. Methodology

The marl used in this study was sampled from excavated materials taken from foundation pits of a construction site located in the Diamniadio urban hub (**Figure 1**). The sampled deposits consist mainly of beige marls with traces of whitish limestone and belong to the Bargny formation, which dates from the Middle Eocene [6]. This formation is composed of the Rufisque and Cap des Biches members. The Lutetian zone is characterized by clayey and slightly sandy marls with planktonic foraminifera, as well as marl-limestone alternations.

The stabilizing materials were obtained from the Sébikhotane dune quarry (for dune sand) and from Bargny (for beach sand). Both sites are located close to the Diamniadio urban hub (**Figure 1**). Due to the proximity of the sampling site to the sea, the sand collected from Bargny exhibits a slightly salty taste.

Continued

Unit weight	Bulk unit γ (kN/m ³)	16.54 - 19.69
	Dry density γ_d (kN/m ³)	10.11 - 16.61
	Unit weight of solid particles γ_s (kN/m ³)	28.1
Methylene blue value	VBS (%)	7.1
Proctor Normal test	Optimum water content ω_{op} (%)	14.1
	Maximum dry density γ_{dmax} (kN/m ³)	17.82
CaCO₃ content (%)	C_{CaCO_3}	41.8 - 72
GTR classification		A2
CBR test (96 h) (%)	CBR test (96 h) (%)	05
	Swelling at 96 h (%)	5.3
Oedometer test	Initial void ratio e_0	1.58
	Swelling pressure (kPa)	186 - 457
	Free swelling at 96 h (%)	22

Table 2. Geotechnical characteristics of dune and beach sand.

	Property	Dune sand (DS)	Beach sand (BS)
Grain size analysis	$\Phi < 2$ mm	100%	99.2%
	$\Phi < 0.080$ mm	11%	2%
	Curvature coefficient C_c	1.61	1.02
	Uniformity coefficient C_u	3.50	1.89
Unit weight	γ_d (kN/m ³)	16.03	15.52
	γ_s (kN/m ³)	24.88	26.18
Proctor Normal test	Optimum water content ω_{op} (%)	9.8	6.38
	Maximum dry density γ_{dmax} (kN/m ³)	17.5	17.7
Sand equivalent	Visual	70	98
	Piston	57	92
GTR classification		B1	B1

To assess the influence of lithostabilization on the mechanical performance of the studied materials, portions of sand were added to the marl excavated materials. The dry marl was first crushed and sieved through a 5 mm mesh. Mass proportions of 15%, 25%, 35%, and 45% sand were added to the sieved marl and thoroughly mixed by hand before being moistened. The mixture was thoroughly blended until a sufficiently homogeneous material was obtained. It was then placed in an airtight container and left to cure for four hours at room temperature before testing.

The physical and mechanical behavior of the different formulations was determined through a series of geotechnical tests. The test results made it possible to assess the influence of lithostabilization on the mechanical performance of the Diamniadio marl excavated materials. To evaluate the suitability of the improved materials for use in embankments and road subgrades, the results were compared to recommended standard values.

3. Results and Discussion

3.1. Geotechnical Characterization of the Study Materials

The physical characterization of the marl spoil involved particle size analysis, determination of soil consistency state, specific gravity, and methylene blue value. The mechanical characterization tests were mainly focused on shear strength, bearing capacity, swelling potential, and compressibility of the marl spoil. **Table 1** summarizes the geotechnical characterization results of the marl spoil collected in the Diamniadio urban hub. **Figure 2** and **Figure 3** respectively show the particle size distribution curve and the Proctor curve of the raw marl spoil.

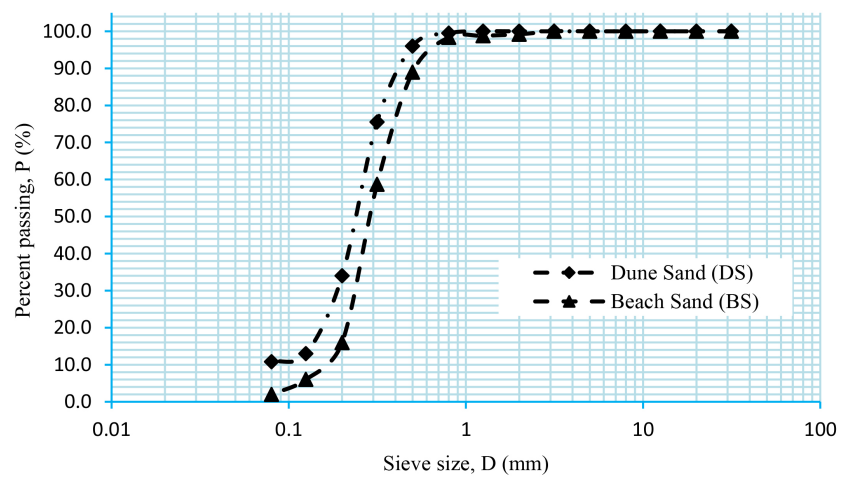


Figure 2. Grain size distribution curve of sands.

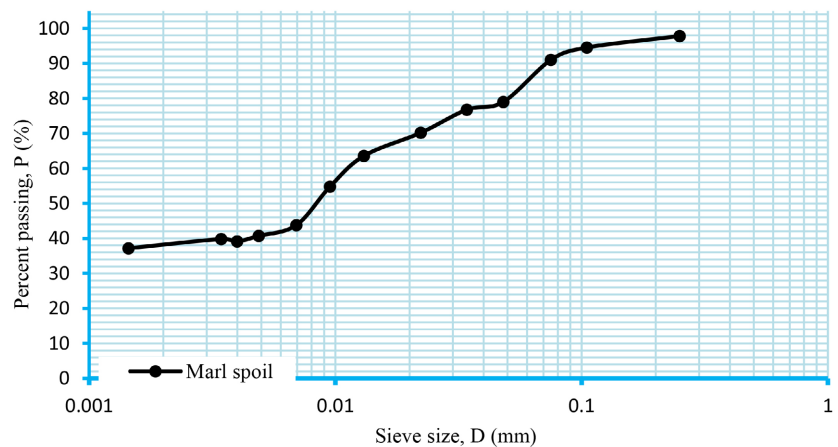


Figure 3. Grain size distribution curve of marl spoil.

The dry density values obtained and reported in **Table 1** indicate that the marl spoil ranges from loose to dense soils. Particle size analysis of the samples confirms that they are primarily composed of fine soils, with most particle diameters smaller than 0.08 mm. It also shows that the spoil contains significant clay fractions (38%) (**Table 1**).

The Atterberg limit test results reveal that the studied spoil consists of low-plasticity clays. According to the indirect classification proposed by [7], the marly-limestone spoil has a high swelling potential. The methylene blue values (VBS) confirm the clayey nature of the spoil, indicating high swelling susceptibility based on the [8] classification table. The results of the physical characterization classify the spoil as fine soils of type A2 according to the GTR classification system. The calcium carbonate content obtained further confirms that the spoil mainly consists of marly to marly-limestone soils. In fact, boreholes carried out in the sampling area show a subsurface composed of compact blackish clays with limestone concretions, overlain by alternating layers of beige marl, marly limestone, and whitish limestone.

Free swelling recorded after 72 hours of immersion in the oedometer reveals that the marls from the Diamniadio urban hub are potentially expansive (**Table 1**), with a high risk of shrink-swell behavior. The swelling pressures obtained from marls sampled on the same site range between 186 kPa and 457 kPa.

Bearing capacity tests show that the marl spoil is unsuitable for use as subgrade material for road pavement. The swelling values of the marl spoil after CBR mold immersion largely exceed the maximum allowable swelling value for platform materials, which is 1% [9].

The geotechnical characterization of the marl spoil therefore demonstrates that these materials cannot ensure satisfactory performance when used as backfill without prior treatment, particularly in the presence of water. In their raw state, these soils are difficult to use and highly susceptible to shrink-swell risks.

3.2. Lithostabilization of Diamniadio Marly-Limestone Spoil

To modify the properties of the marl spoil and improve its mechanical performance, lithostabilization was carried out. Sand contents of 15%, 25%, 35%, and 45% of dune sand (DS) and, separately, beach sand (BS) were added to the marl spoil. **Table 2** presents the geotechnical properties of the lithostabilizing sands. Dune sand from Sébikhotane has a poorly graded and wide particle size distribution with 10.8% fines, while beach sand from Bargny is poorly graded and uniform, with only 2% of particles smaller than 0.08 mm (**Figure 2**).

The results of the physical and mechanical characterization of the mixtures are presented in **Table 3** and **Table 4**. **Figure 4** and **Figure 5** respectively show the Proctor compaction curves of the marl spoil mixed with dune sand and with beach sand.

Table 3. Influence of dune sand (DS) on the geotechnical properties of marl spoil.

% Dune sand (DS)		0	15%	25%	35%	45%
Specific gravity	γ_s (kN/cm ³)	28.1	26.4	26.6	26.8	26.3

Continued

Atterberg limit test	w_L (%)	44.2	30.8	32.1	24.2	19.27
	w_P (%)	22.29	17.1	15.7	16.91	12.13
	I_P (%)	21.9	16.52	16.40	7.3	7.15
Proctor test	ω_{op} (%)	14.1	9.4	8.8	8.4	8.4
	γ_{dmax} (kN/cm ³)	17.82	19.80	19.82	20.23	20.80
CBR test	CBR (96 h)	5	9	11	14	12
	Swelling (%)	0.82	0.094	0.074	0.047	0.023

Table 4. Influence of beach sand (BS) on the geotechnical properties of marl spoil.

% Beach sand (BS)		0	15%	25%	35%	45%
Specific gravity	γ_s (kN/cm ³)	28.1	27.1	26.2	26.7	26.4
Atterberg limit test	w_L (%)	44.2	33.6	23.89	20.41	20.41
	w_P (%)	22.29	17.1	12.81	8.83	16.53
	I_P (%)	21.9	16.5	11.08	11.58	3.88
Proctor test	ω_{op} (%)	14.1	11.15	7	6.2	8.2
	γ_{dmax} (kN/cm ³)	17.82	19.19	20.48	21.28	20.73
CBR test	CBR (96 h)	5	7	8.8	14.8	10
	Swelling (%)	0.82	0.118	0.110	0.070	0.047

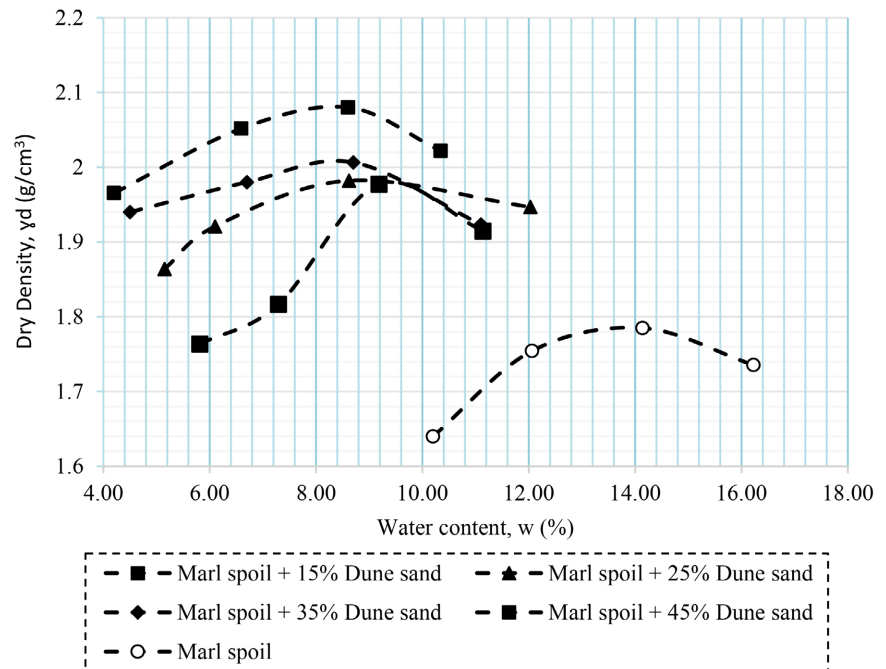


Figure 4. Compaction curve of marl spoil stabilized with dune sand (DS).

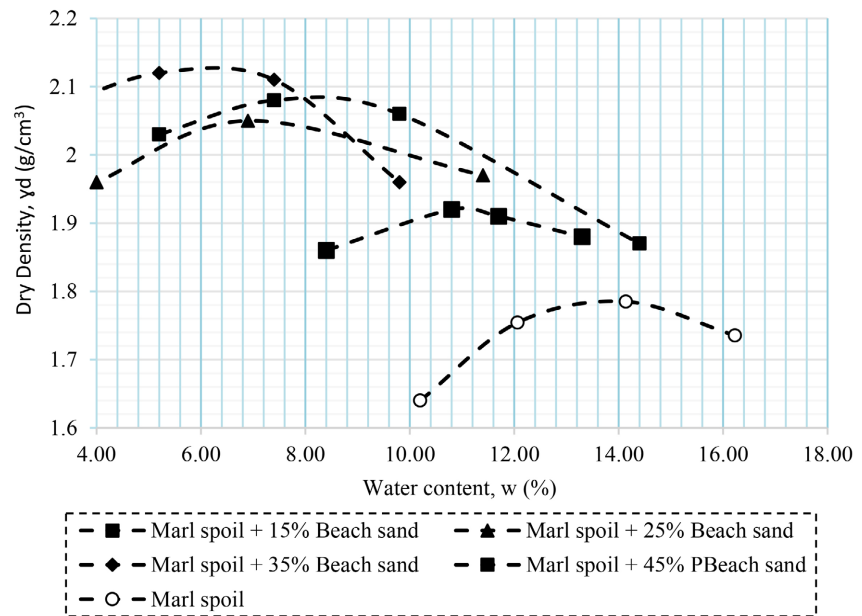


Figure 5. Compaction curve of marl spoil stabilized with beach sand (BS).

3.3. Discussion

Geotechnical characterization of the marl spoil reveals low bearing capacity with a high swelling potential. Several authors, including [10]-[15], have confirmed the expansive nature of soils in Rufisque, which shares the same geological context as the Diamniadio urban hub. The CBR values below 10% and swelling values above 1% render the spoil unsuitable for use as road subgrade.

Lithostabilization with dune sand or beach sand had a positive effect on plasticity, water sensitivity, and compaction performance of the studied materials. The results presented in **Table 3** and **Table 4** show that adding 15% - 45% sand improves the physical and mechanical properties of the Diamniadio marl spoil.

The water sensitivity of the mixtures is illustrated by the shape of the compaction curves. **Figure 4** and **Figure 5** show that the compaction curve of raw marl spoil is sharply peaked, indicating high water sensitivity. In contrast, the Proctor curves of the marl-sand mixtures are progressively flattened and broadened as sand content increases, reflecting reduced water sensitivity. The increase of inert material with added sand simultaneously decreases the amount of active fines, contributing to reduced plasticity.

The optimum water content of raw marl (14.1%) decreases with increasing sand content, reaching a minimum of 6.2% after adding 35% beach sand (BS), before slightly increasing to 8.4% with 35% dune sand (DS) and then remaining stable (**Table 3** and **Table 4**). This suggests that beach sand more effectively reduces water sensitivity than dune sand. This may be explained by the higher fines content of dune sand compared to beach sand, which is much cleaner (**Figure 2**, **Table 2**). Thus, sand type and gradation play a key role in water sensitivity. A shift of Proctor curves toward lower water contents and higher dry densities is also observed. Lithostabilization therefore reduces water sensitivity while increasing the density

of the marl spoil.

For both sands, liquid and plastic limits tend to decrease as sand content increases. Plasticity index is reduced by 67% with 45% beach sand and by 82% with 45% dune sand. This reduction is due to the simultaneous decrease in both liquid and plastic limits, thereby narrowing the plasticity domain. However, the effect of beach sand on marl spoil consistency is stronger than that of dune sand, owing to its lower fine fraction. These findings are consistent with [16]. The reduction indicates a behavioral change of the mixture, from marly soils toward marly-sandy soils, with low-plasticity marl spoil becoming even less plastic.

The reduction in water sensitivity and plasticity of Diamniadio marl spoil may be explained by the decrease in clay fraction caused by sand addition, as sand is generally inert. Increasing sand content raises the inert fraction while reducing the active fine fraction, which decreases clay-water bonding, total specific surface area, and water sensitivity [17]. According to [18], this variation is not linear, meaning the reduction is not only due to decreased clay fraction but also to other factors, such as clay-clay bond reduction, clay dispersion, and lithostabilizer gradation. Satyanaryana [19] also reported that poorly graded particles tend to cluster in voids.

Table 3 and **Table 4** show that the bearing capacity of the marl spoil is improved through lithostabilization. CBR values increase proportionally with sand addition up to 35%, after which they begin to decrease. This decline could be explained by poor particle distribution caused by excessive sand content, leading to larger voids between sand grains. The CBR value at 35% dune sand (14%) is slightly lower than with 35% beach sand (14.8%). However, CBR improvement at lower or higher sand contents is greater with dune sand than with beach sand.

Linear swelling of lithostabilized marl spoil after 96 hours of immersion decreases drastically with added sand (**Table 3** and **Table 4**). Results show that adding 15% - 45% sand reduces swelling by 88.5% - 97.2% with dune sand and by 90.5% - 98.2% with beach sand. These results are consistent with findings by [1] [18] [20]-[24]. At low sand contents (15%), sand particles are dispersed within the clay matrix, leading to limited porosity changes and moderate swelling reduction. At medium to high sand contents, the added sand creates voids in the soil mass, allowing the structure to absorb clay-induced volume changes, which strongly reduces swelling [18] [24]-[26].

For the same sand content, lithostabilization with beach sand reduces swelling more effectively than dune sand, confirming that beach sand is a better stabilizer for expansive soils. Dune sand is poorly graded with higher fines, which reduce voids in the mixture, while beach sand, with only 2% fines, increases voids and reduces swelling. The coarser the sand, the greater the swelling reduction [4] [19] [21]. Furthermore, beach sand contains salts, and stabilization is enhanced by the combined effect of sand and salts [24].

4. Conclusions

The improvement of the physical and mechanical properties of the Diamniadio

marl spoil through sand addition yields highly promising results. The study shows that adding dune sand or beach sand directly influences plasticity, water sensitivity, swelling potential, compaction behavior, and bearing capacity of the spoil. Lithostabilized marls present very favorable properties that meet the requirements for use in road construction. The study further reveals that the effectiveness of the lithostabilizer is strongly affected by its nature and gradation.

Moreover, this valorization technique offers significant environmental and economic benefits, notably by reducing the volume of waste materials sent to landfills and limiting the exploitation of virgin quarry resources, thus promoting sustainable construction practices.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

- [1] Kaoua, F., Derriche, Z. and Laradi, N. (1994) Contribution à l'étude de la stabilisation des sols gonflants par ajouts de sable. *Algérie Equipement. Revue de l'École Nationale des Travaux Publics*, **15**, 12-15.
- [2] Bahia, L. (1997) Stabilisation d'une bentonite par ajout de sable interaction sol matériau d'amendement. Thèse de Doctorat. Université de Béjaïa-Abderrahmane Mira.
- [3] Bengraa, L., Hachichi, A., Bourokba, S.A. and Benaïssa, A. (2005) Étude de la stabilisation des argiles gonflantes par ajout de sable de carrière. *2ème Journée d'études sur les Sols Gonflants*, Algérie, 13 et 14 novembre 2005, 101-112.
- [4] Didier, G. (1972) Gonflement cristallin et macroscopique des montmorillonites: Sa prévision. Thèse de Docteur Ingénieur, Université Claude-Bernard.
- [5] Khelifa, T. (1994) Étude de la stabilisation des sols gonflants par ajout de sable. Doctoral Dissertation, Thèse de Magister, Université Houari Boumediène.
- [6] Brancart, R.Y. (1977) Étude micropaléontologique et stratigraphique du Paléogène sur le flanc occidental du horst de Ndiass et dans la région de Taïba. Thèse Doctorat de 3^e Cycle, Université de Provence.
- [7] Seed, H.B., Woodward, R.J. and Lundgren, R. (1962) Prediction of Swelling Potential for Compacted Clays. *Journal of the Soil Mechanics and Foundations Division*, **88**, 53-87. <https://doi.org/10.1061/jsfeaq.0000431>
- [8] Chassagneux, D., Stieljes, L., Mouroux, P., Ménilliet, F. and Ducreux, G.H. (1996) Cartographie de l'aléa retrait-gonflement des sols (sécheresse-pluie) à l'échelle départementale. Approche Méthodologique Dans les Alpes de Haute-Provence. Rapport BRGM n R39218, 6.
- [9] CEBTP (1984) Guide pratique de dimensionnement des chaussées pour les pays tropicaux. Ministère des relations extérieures-Coopération et Développement, 157 p.
- [10] Cissé, I. (1985) Caractérisation et méthodes de construction sur sols gonflants: Application aux marnes de Rufisque (Sénégal). Thèse Doctorat Géologie de l'Ingénieur, INPL de Lorraine, 214.
- [11] Thureau, J. (1985) Étude géotechnique des sols gonflants, Problèmes rencontrés au Sénégal, Thèse de Doctorat, École Centrale de Nantes.
- [12] Cisse, I.K., Fall, M. and Rahal, A. (2021) Un cas d'instabilité de sol de fondation: Ex-

- emple des marnes gonflantes de Rufisque, Sénégal. In: Bligh, G.E.T, Fourie, A.B. and Wardle, G.R., Eds., *Geotechnics for Developing Africa*, CRC Press, 151-159.
<https://doi.org/10.1201/9781003211174-21>
- [13] Fall, M., Ndiaye, M. and Niang, I. (2016) Geological and Geotechnical Investigation of the Residual swelling Soils of Rufisque (Senegal, West Africa). *Journal of Earth Sciences and Geotechnical Engineering*, **6**, 29-47.
- [14] Faye, P.S., Ndoeye, I., Ndiaye, M., Tall, A., Cissé, I.K. and Magnan, J.P. (2017) Prediction of Swelling Kinetics of Expansive Soils of Rufisque (Senegal, West Africa) *Open Journal of Civil Engineering*, **7**, 267-281.
<https://doi.org/10.4236/ojce.2017.72017>
- [15] Faye P.S. (2019) Étude de la cinétique du gonflement des sols. Application au sols expansifs de Rufisque (Sénégal). Thèse Doctorale à ED2DS de l'Université Iba Der Thiam de Thiès.
- [16] Komornik, A., Livneh, M. and Uzan, J. (1973) Strength Characteristics of Expansive Clays Containing Granular Constituents. In: *Proceedings of the 3rd International Conference on Expansive Soils*, Academic Press, 144-158.
- [17] Meziani, F., Kahil, A. and Khettaoui, C. (2022) Effet de la nature du sable sur les caractéristiques physiques d'une argile. *Communication Science et Technologie*, **11**, 46-56.
- [18] Louafi, B. and Bahar, R. (2017) Analyse de quelques mécanismes physiques de la stabilisation d'un sol gonflant par ajout de sable. *13ème Congrès de Mécanique Avril*, Meknès, Avril 2017, 11-14.
- [19] Satyanarayana, B. (1969) Behavior of Expansive Soil Treated or Cushioned with Sand. *Proceedings of 2nd International Conference on Expansive Soils*, Texas, 17-19 August 1969, 308-316.
- [20] Satyanarayana (1973) Behaviour of Expansive Soil Treated or Cushioned with Sand, *3rd International Conference on Expansive Soils*, Haifa, 30 July-1 August 1973, 308-316.
- [21] Suratman, I. (1985) Contribution à l'étude de la cinétique et de la stabilisation du gonflement des argiles. Thèse de Doctorat Ingénieur, INSA de Lyon (France).
- [22] Derriche, Z. and Kebaili, M. (1998) Prévision du gonflement des argiles d'In-Aménas. *Bulletin des Laboratoires des Ponts et Chaussées*, **218**, 15-23.
- [23] Bouzid, F. (1997) Étude de l'aspect physico-chimique des caractéristiques mécaniques d'une argile gonflante: Bentonite. Thèse de Magister, Université des Sciences et de la Technologie Houari Boumediene, 112 p.
- [24] Lamara, M., Gueddouda, M.K. and Benabed, B. (2006) Stabilisation physico-chimique des sols gonflants (sable de dune + sel) *Revue Française de Géotechnique*, No. 115, 25-35.
- [25] Gueddouda, M.K., Lamara, M. and Goual, I. (2007) Caractérisation et stabilisation des sols expansifs effet de l'association (sel + sable de dune) sur les paramètres de gonflement. *Colloque International de Tunis*, Tunis, 11-14 février 2007, 27-43.
- [26] Gueddouda, M.K., Goual, I., Lamara, M. and Goual, M.S. (2012) Comportement mécanique d'un sol expansif stabilisé par ajout de sable de dune. *Revue des Sciences et Sciences de L'ingénieur*, **2**, 16-26.