Sodium Chloride Stabilization of Urban Soils Prone to Tubing Phenomena

Cinthya Alvarado, MSc[1], Aaron Pérez, Eng[2], Luz Rosas, Eng[3], Hernán Alvarado-Quintana, PhD[4]
[1]Universidad Privada del Norte, Perú, cinthya.alvarado@upn.edu.pe
[2]Universidad Nacional de Trujillo, Perú, pereztacanga@gmail.com
[3]Universidad Nacional de Trujillo, Perú, luzandrearosasrodriguez@gmail.com
[4]Universidad Nacional de Trujillo, Perú, halvarado@unitru.edu.pe

Abstract*– In this research, it is proposed to stabilize the soil surrounding the water and sewerage networks with sodium chloride to avoid the formation of holes produced by leaks that cause fines dragging that weaken the soil and cause collapse, a phenomenon known as piping or internal erosion. The soil was characterized by the SUCS and AASHTO methods, carrying out the tests of sieving granulometry, sedimentation granulometry, consistency limits, and natural humidity. The compaction test was carried out by means of the modified Proctor test on the standard sample and the samples with the addition of NaCl, to obtain the maximum dry density and humidity, using them as a reference in the unconfined compression, CBR, and permeability tests. For each test, 4 repetitions were carried out for the standard samples and for the samples that were added with NaCl whose doses were 1.5, 3, and 4.5% by weight. At the end of the tests, it was determined that the type of standard soil is sandy clay soil with medium plasticity, classifying it as a "CL" soil according to the SUCS method and "A-6" for the AASHTO method. By adding 1.5% sodium chloride to clay soil, the best properties are obtained; having a 315% increase in the CBR index, an 82% increase in unconfined compressive strength, and a 21% reduction in permeability.

***Keywords*-- Stabilization; Piping; Permeability; Bearing capacity; Soil**

I. INTRODUCTION

Peru has been affected by the phenomenon of the child in a cyclical way, which during the last years 1982-1983, 1997-1998, and 2017-2018 stalked our population causing great human and economic losses. The territory of La Libertad is considered very vulnerable due to the physical characteristics of its soils and, this is associated with natural phenomena that occur as intense rains, mudslides, as well as the prolonged seismic silence that La Libertad has been experiencing for years means that, alarmingly, we must be vigilant to act in the face of any eventuality [1]. According to a report from the Regional Emergency Operations Center (COER) with information received through the Damage Assessment and Needs Analysis report (EDAN), La Libertad was the region most affected by the phenomenon of the coastal child in 2017. Damages were greater than in other regions of northern Peru. A total of 42 streams were activated, something that had never happened in the history of the region and Trujillo withstood the passage of seven landslides that passed through various streets and avenues of the city, as shown in Fig. 1.

Digital Object Identifier (DOI):
http://dx.doi.org/10.18687/LACCEI2022.1.1.345
ISBN: 978-628-95207-0-5 **ISSN:** 2414-6390

Regarding basic services, 25,966 m of drinking water pipes and 84,006 m of sewage and drainage pipes were affected [2]. This added to the fact that 40% of the sewage pipes had exceeded their useful life, with very deteriorated pipes that could be between 50 and 70 years old [3]. With the intense 6-hour rains that the city of Trujillo endured, the sewage pipes were clogged, generating leaks through the cracks due to their age, causing the formation of sinkholes [4], as shown in Fig. 2. After the phenomenon of the coastal child in 2017, the appearance of sinkholes has intensified even more [5].

What is sought is to investigate the problem that occurs in the streets of the city of Trujillo due to the piping phenomenon, which causes the failure and collapse of its tracks in the form of sinkholes, which are usually produced by natural phenomena that fill with water the sewage networks intensifying the filtrations; and propose an alternative solution.

Fig. 1 Floods in the city of Trujillo, Peru, in 2017 due to the phenomenon of the coastal child.

Tubing or suffusion is an erosion problem that begins with the removal under a hydraulic gradient of the smallest soil particles that are not confined, when the hydraulic load drags these particles, it is easier for them to take the next larger size so that a "tube" is generated in the ground from the surface to the interior. Piping begins when soil particles are dragged into the mass due to erosive forces generated by the flow of water. When the particles begin their removal, they leave small channels where the water passes with greater speed and drag power, so that the tubing phenomenon increases continuously, increasing the diameter of the channels that they form within the embankment [6].

Fig. 2 Appearance of sinkholes in the sewage network intensified by the rains and floods of the coastal child phenomenon in Trujillo, Peru, 2017

This type of erosion occurs primarily in incoherent soils that have very little resistance to seepage forces. Clay soils, thanks to their cohesion, have greater resistance to tubing, except for dispersive clays [7]. Reference [8] argues that three conditions must exist for tubing to occur: There must be a seepage flow path and a water source. There must be erodible material within the flow path and this material must be carried by the seepage flow. And there must be an unprotected outlet (open, unfiltered), from which the eroded material can escape.

If the soil within a seepage zone is washed away by flowing water, a pit or trench is formed. This produces a concentration of water and an increase in the hydraulic gradient because the flow path is shortened; As a consequence, the seepage becomes more violent and the hole deeper, making its way upstream at an increasing speed towards the place where the water comes from. This produces an opening or conduit in the soil and the process of this continuous erosion is called siphoning or piping [9].

Tubing is the term most often used to describe problems related to seepage forces. Reference [10] describe the phenomenon of retrograde tubing as the process of soil particle removal under an outgoing hydraulic gradient, resulting in the formation of a duct from the water outlet. He calls it retrograde since the process always happens from the downstream side to the upstream side against the direction of the water flow.

Soil stabilization is an effective alternative for improving soil properties [11]–[17]. Soils with high clay content generally have low shear strength and have the tendency to swell when their moisture content is allowed to increase [18]. The addition of salts to the organic clay coagulates the soil, thereby causing the clay particles to expose themselves to the lime for pozzolanic reactions [19]–[21].

Sodium chloride is formed by crystals, easily soluble in water, which has the property of attracting and holding water, this characteristic means that sodium chloride can serve as a link between particles. Sodium chloride is formed by crystals, easily soluble in water, which has the property of attracting and holding water, this characteristic means that sodium chloride can serve as a link between particles. It is used to avoid the effect of water evaporation and reduce the freezing temperature. It also controls humidity changes in the granular layers, generating increases in resistance or making them constant [22].

There are publications on this subject, which are detailed below: Reference [23] carried out a parametric study on the influence of two variables, the level of effective stress and the initial content of fines, on the mechanism of suffusion. The mechanical consequences of suffusion are evaluated by performing drained monotonic compression tests on the eroded samples. Supplemental samples without suffusion are tested for comparison purposes. The test results reveal that, with the progress of suffusion, the hydraulic gradient decreases, and the hydraulic conductivity increases. Large amounts of fines are eroded and consequently, contractive volumetric stress is produced. The larger effective confining pressure leads to a lower degree of suffusion. Monotonic compression tests indicate that suffusion would cause soil strength reduction in the main stage of drained shear.

Reference [24] investigated the behavior of clayey soil stabilized with lime and sodium chloride with percentages of 2.5%, 7.5%, and 12.5%. The soil sample was obtained from a pit at a depth of 1 m in the city of Puyo, with which the laboratory tests were carried out with altered and unaltered samples. They used Sodium Chloride salt in granular form that they pulverized for a better reaction with the clay particles. For the simple compressive strength test, they used blocks that were tested at 7, 14, and 21 days. As a result, they obtained that the higher the percentage of sodium chloride used as a stabilizer, the better its workability and its compaction is faster when making the blocks for the simple compression test. With the soil stabilized with lime, they observed that it also improves its workability, but not as much as sodium chloride. To perform a stabilization with Sodium Chloride, less water is required to reach its optimum moisture content, while the opposite occurs for stabilization with Lime since it requires a greater amount of water to reach its optimum moisture content.

Reference [25] investigated sodium chloride as a chemical stabilizer for clay soils, to reduce their high plasticity, support capacity, and volume instability depending on humidity. He determined the optimal concentration of sodium chloride to achieve an improvement in physical and mechanical properties through laboratory procedures. He worked with different percentages of sodium chloride, 2%, 5%, 10%, 20%, 30%, and 50%. The results were that the plasticity index dropped to a value of 9.4 with the addition of 50% sodium chloride, with the initial plasticity index being 38.2 without adding sodium chloride and a considerable variation in the CBR (support capacity), achieving a value of 4.1% by adding salt at 5%, with the initial CBR being 1.8%, this being the optimal concentration to add to this type of clay soil.

Reference [26] studied the stabilization and durability of the sub-base with the use of aggregate from the Challhua quarry with the addition of sodium chloride in percentages of 2%, 4%, and 6% made in the city of Huaraz. The purpose was to increase the CBR index with the addition of sodium chloride in the different percentages mentioned and also to verify its durability, modifying its physical and mechanical properties. As a result, it was obtained that the addition of sodium chloride in a percentage of 2% increased the CBR by 3.1% with respect to the standard, so the resistance was improved, in addition, in the durability test, the percentages of loss were obtained, being 9.36% and 5.56% of the coarse and fine aggregate, respectively, for which the material has great resistance to wear.

According to this background, the problem to be investigated was to determine what is the influence of the sodium chloride dosage on the unconfined compressive strength, permeability, and bearing capacity (CBR) of urban soils in the city of Trujillo. prone to tubing? and the hypothesis that was worked on was that as the dosage of sodium chloride is increased in a range of less than 5%, the unconfined compressive strength, and the support capacity (CBR) increase while the permeability of the material decreases. I usually. The importance of this research is to provide an economic, natural, and simple alternative to reduce the formation of sinkholes caused by the phenomenon of piping in the city of Trujillo. The proposal is to use sodium chloride in small dosages as a soil stabilizer adjacent to the sewerage network pipes to reduce their permeability and improve their support capacity.

II. MATERIAL AND METHODS

A. Material

The investigated soil was obtained from La Encalada - El Golf - in the city of Trujillo, surrounding a sewage network. A pit was made and random samples were taken for the characterization tests: humidity, sieve granulometry, Atterberg limits, soil classification, and modified proctor; and for the response variables to investigate: unconfined compression, CBR support capacity, and soil permeability. Commercial grade sodium chloride was used for stabilizer additions according to design.

B. Research Design

A unifactorial experimental design was used, with the factor or independent variable: Percentage of Sodium Chloride with four levels (0%, 1.5%, 3%, and 4.5%) and three response or dependent variables: Support capacity (CBR index) measured in percentage (%), Unconfined compressive strength (kg/cm^2) and Permeability (cm/s). All the experimental tests were done in triplicate, so the total number of tests per response variable was 12.

C. Process

First, the samples brought from the field to the laboratory were reduced to test size by the quartering method. Humidity was then determined following the NTP 339.127 standard and using a drying oven at a temperature of 105°C, precision balance, and drying cans. Next, the granulometric analysis was carried out by sieving following the ASTM D422 standard, for which the Tyler series of sieves and a precision balance with a sensitivity of 0.1% were used. Then, the specific gravity of the soil was determined following the procedure of the ASTM D854 standard using a pycnometer connected to a vacuum pump for the deaeration of the suspension. Then the Atterberg limits were determined according to the ASTM D423 standard and using the liquid limit kits (Casagrande spoon and accessories) and plastic limit, drying oven, drying cans, and precision balance. Next, the granulometric analysis was carried out by means of a hydrometer following the ASTM D422 standard and using the complete Humboldt brand hydrometry kit. With the information obtained in the previous tests, the soil was classified according to the SUCS unified soil classification system following the ASTM D2487 standard and the AASHTO Meted M145 system following the ASTM D3282 standard.

Once the soil was characterized, the specimens were formed in a cylindrical mold 100 mm in diameter x 200 mm high, and after a curing time of 14 days, the specimen was broken following the ASTM D2166 standard using a Humboldt press. HM300 for the test. In the same way, the soil mixture was compacted in CBR molds with 55, 26, and 12 compaction strokes per layer following the ASTM D1883 standard and tested in the same previous press. Finally, the permeability test was carried out in a compaction mold with constant head water flow inlet and outlet, following the ASTM D2434 standard.

D. Analysis of data

An analysis of variance was performed to assess whether the difference between the studied levels is significant or due to experimental error, independently of the unconfined compressive strength, the CBR bearing capacity, and the permeability of the studied soil. The analysis of variance (ANOVA) was performed at a confidence level of 95%.

III. RESULTS

A. Soil characterization results

Table 1 shows the characteristics presented by the soil studied in the present investigation, a soil classified as CL according to SUCS and A-6 according to AAHTO, which indicates that the soil is a clay soil of medium plasticity. From the granulometric analysis, it was obtained that the soil does not present gravel and only 35.9% sand, and the majority of the soil is composed of clayey and silt material which is 64.1% of the total. Its soil consistency limits result in a plasticity index of 14.9%, medium plasticity for a soil.

TABLE I
INVESTIGATED SOIL STRATIGRAPHY DATA

Characteristics	Results
Natural humidity (%)	4.5
Gravels (%)	0.0
Sands (%)	35.9
Fines (%)	64.1
Liquid limit (%)	34.4
Plastic limit (%)	19.5
Plasticity index (%)	14.9
SUCS	CL
AAHSTO	A-6

Table II shows the results obtained from the compaction tests by modified energy of a clayey soil with different additions of sodium chloride as a stabilizer, this test shows that the optimum humidity (H_{opt}) of the proctor curves as a function of the increase in the amount of sodium chloride was only altered between 0% and 1.5% chloride, later the optimum humidity remained very similar, around 16%.

With respect to the MDS (maximum dry density), the increase in sodium chloride did influence, generating an increase in the compaction densities. The maximum density of the natural soil was 1.57 g/cm^3 and with 4.5% sodium chloride 1.74% g/cm^3 was obtained, which was the highest value obtained during the test.

TABLE II
COMPACTION TEST RESULTS

Specimen	Sodium Chloride			
	0.00%	1.50%	3.00%	4.50%
H_{opt} (%)	14.90	16.20	16.00	16.00
MDS (g/cm^3)	1.57	1.65	1.70	1.74

B. *Unconfined Compression Test*

The results of the unconfined compression tests are shown in Table III and in Fig. 3, where it can be seen that as the soil increases the amount of sodium chloride as a stabilizer, the maximum breaking stress also increases.

Table III shows the data collection of the tests of 3 repetitions carried out for each dosage of sodium chloride used in the investigation with which I calculate their respective averages and to be able to be graphed with a minimum test error.

TABLE III
UNCONFINED COMPRESSION STRENGTH OF SOIL (kg/cm^2)

Specimen	Sodium Chloride			
	0%	1.50%	3%	4.50%
1	0.95	1.73	1.66	1.49
2	0.96	1.73	1.67	1.50
3	0.95	1.72	1.66	1.50
Average	0.95	1.73	1.66	1.50

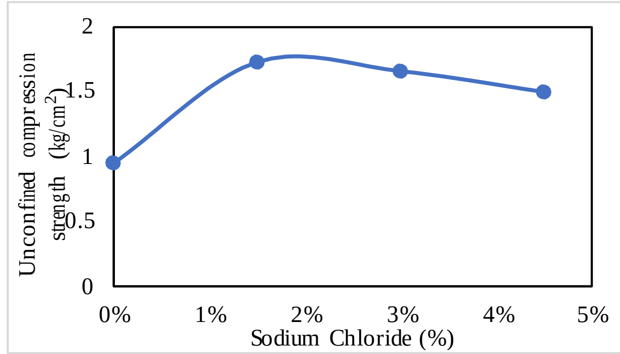

Fig. 3 Unconfined compressive strength of the soil as a function of the percentage of added sodium chloride

Fig. 3 shows how the average value of the maximum stress of the original soil was 9.85 kg/cm^2, while the maximum value that was 1.73 kg/cm^2 was obtained for the soil mixed with 1.5% sodium chloride, from hence, the values of the maximum stress decreased when the soils presented higher amounts of chloride in their composition.

C. *CBR index test*

The results of the CBR index of clayey soils with additions of sodium chloride are shown in Table IV, they are values of 3 repetitions carried out per dosage and were taken at 0.2" of penetration as required by the regulations.

TABLE IV
CBR INDEX

Specimen	Sodium Chloride			
	0%	1.50%	3%	4.50%
1	9.50	37.20	32.30	25.20
2	9.00	37.80	32.90	25.60
3	9.55	38.00	32.50	25.60
Average	9.35	37.67	32.57	25.47

Fig. 4 plotted the average values of the CBR index obtained, from which we can observe and analyze that the original soils are those that presented the minimum value of 9.35% CBR at 0.2", while the soil mixed with 1.5% chloride of sodium presented the highest value 37.67% at 0.2" of penetration. Giving as a result that with 1.5% sodium chloride it is possible to stabilize a clay soil since it presents a correct margin for improvement.

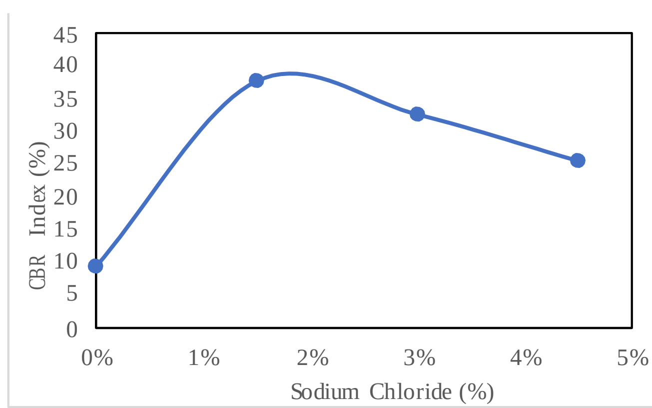

Fig. 4 CBR index of soils based on the percentage of sodium chloride

D. Permeability Test

The results of the permeability index of clayey soils with additions of sodium chloride are shown in Table V and in Fig. 5. The method used was the permeability of variable load by the type of clayey soil, thus obtaining that the soil when it was combined with different amounts of sodium chloride showed a small decrease in the permeability index of the soils. Making reference, it should be noted that the minimum value of 3.4 x 10^{-5} cm/s was obtained when the soil had 4.5% sodium chloride. While the original soil presented a permeability index of 5 x 10^{-5} cm/s. The range of variability of the permeability index between the results obtained between soils with 1.5% and 4.5% sodium chloride is minimal.

TABLE V
PERMEABILITY INDEX (cm/s) x 10^{-5}

Specimen	Sodium chloride			
	0%	1.50%	3%	4.50%
M1	5.00	4.00	3.80	3.40

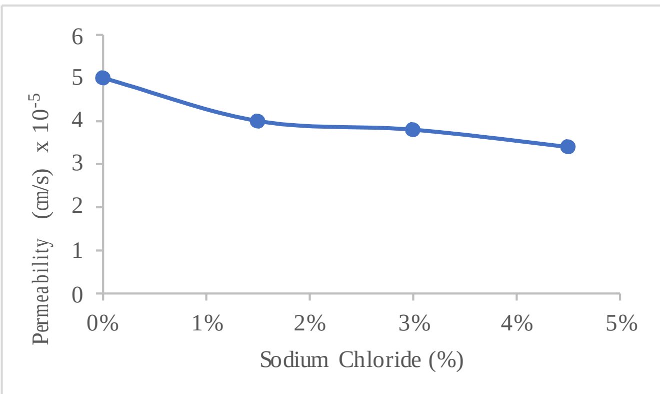

Fig. 5 Permeability of soil based on the percentage of sodium chloride

IV. DISCUSSION

According to the characterization of the soil studied, it is classified as CL soil according to SUCS and A-6 according to AAHTO, whose characteristics are summarized in Table I. This soil contains a high percentage of silt and clay (64.1%), so we could affirm that its susceptibility to piping phenomena is moderately slow and that only in case of high filtration pressures or due to the presence of cracks due to the age of the pipes in the water and sewage networks can this phenomenon appear. This agrees with the literature where it is stated that the susceptibility of soils to the tubing is extremely fast for SM samples, very fast for ML samples, moderately fast for MH and CH samples, and modernly slow for CL, CL sandy, and SC samples.

Of all the soil properties, plasticity may be the most important factor that affects the potential for internal erosion. According to Table I, the plasticity index of the soil studied is 14.9%. Tubing is much more likely to occur in cohesionless (or low plasticity) soils than in cohesive or plastic soils. The probable reason is that the interparticle bonding present in clay soils provides additional resistance to seepage than in silt and coarse-grained soils. The effect of plasticity varies with water content, and this can be complex. Low plasticity soils can be brittle, causing cracks or tubing to develop.

The phenomenon of internal erosion or tubing occurs in non-cohesive soils (loamy sand) or with low plasticity (with a plasticity index of less than 6 percent) and in cohesive soils with a plasticity index greater than 15 percent and with a percentage of silt greater than 40 percent, which would be the case of the soil studied in this investigation with an IP of around 15% and high content of silt. In addition, compacted with the maximum dry density and the optimum moisture content obtained from the compaction tests. The significant factors that influence tubing are the maximum dry density obtained with the compaction energy of the modified proctor test, the percentage of silt that the sample presents in the granulometric composition, and the plasticity index which is defined by the values of the liquid limit and the plastic limit, these last two factors correspond to the nature of the soil.

From Fig. 3 and Fig. 4, it can be stated that the addition of sodium chloride as a soil stabilizer generally increases its resistance, reaching a maximum of 1.5% addition, so we suggest that the soils surrounding buried pipe leaks be stabilized with this dosage to make the soil increase its resistance to internal erosion, this is in agreement with reference [27] that maintains that the erosion phenomenon will occur only when the forces resistant to erosion are less than the forces of the water flow so that the soil particles are removed and carried away by the current. This would also explain what is observed in Fig. 5, in which it can be stated that the addition of sodium chloride lowers the permeability of the soil to values less than 4.1 x 10^{-5} cm/s, which improves its susceptibility to internal erosion phenomena. This can be attributed to the fact that the sodium chloride crystals occupy the interstices between the soil particles, acting as a cementing material that prevents the flow of water, making it waterproof. Likewise, it is explained by the increase in the maximum dry density caused by the interaction of cohesive particles and sodium ions, generating a reduction in the empty space that allows water to enter. This agrees with reference [23] who maintain that the lower the porosity, the lower the permeability.

V. CONCLUSION

From the results obtained, the following was concluded:

From the characterization of the soil study, it was obtained that it is a clay-type soil with medium plasticity according to SUCS: CL

From the compaction tests, sodium chloride improved soil compaction, increasing the maximum dry density and with 4.5% chloride, the maximum value of 1.74 g/cm^3 was obtained.

It is concluded that with the addition of 1.5% sodium chloride, the highest value of unconfined compressive strength of 1.73 kg/cm^2 was obtained, the best CBR value was 37.67% at 0.2" and at 95% of the maximum dry density, and a permeability below 4.1 x 10^{-5} cm/s sufficient to increase its resistance to internal erosion or tubing.

It is recommended to study shorter ranges and less than 1.5% of sodium chloride as a stabilizer of clay soils since with 1.5% the best values of the different properties were shown, and from then on everything decreased.

It is recommended to carry out tests of soluble salts, and chlorides to soils with additions of sodium chloride to determine if the amount within the soil is the minimum necessary for its use in engineering projects.

References

[1] Sedalib S.A, "Plan de emergencia y mitigación de desastres.", Oficina de Gestión de Riesgos de Desastres y Cooperación Técnica, Trujillo, March 2021.

[2] Gobierno Regional La Libertad. "La Libertad fue la región más afectada por El Niño Costero". La Libertad en acción https://www.regionlalibertad.gob.pe/LaLibertadEnAccion/la-libertad-fue-la-region-mas-afectada-por-el-nino-costero/ (accessed February 14, 2022).

[3] J. Aurazo and E. Villavicencio, "Trujillo tendrá obsoletas redes de desagüe al menos 2 años más". El Comercio Perú. https://elcomercio.pe/peru/la-libertad/trujillo-tendra-obsoletas-redes-desaguee-2-anos-324299-noticia/ (accessed February 14, 2022)

[4] "Trujillo: Vehículo se hundió en medio de la pista tras intensas lluvias en la ciudad [Fotos y video]". Peru21. https://peru21.pe/lima/trujillo-vehiculo-hundio-medio-pista-intensas-lluvias-ciudad-fotos-video-210064-noticia/ (accessed February 14, 2022).

[5] "Trujillo: Camión se hunde en medio de pista por forado". El Comercio Perú. https://elcomercio.pe/peru/trujillo-camion-se-hunde-en-medio-de-pista-por-forado-video-nndc-noticia/ (accessed February 14, 2022).

[6] A. Rico and H. Del Castillo, La ingeniería de suelos en las vías terrestres: carreteras, ferrocarriles y aeropistas. México: Limusa, 2005.

[7] F. López and L. Torcal, "Procesos de erosión en túnel (piping) en cuencas sedimentarias de Murcia (España). Estudio preliminar mediante difracción de rayos X y microscopio electrónico de barrido", *Papeles de Geografía*, n.° 11, pp. 7-20, 1986. [Online] Available: https://revistas.um.es/geografia/article/view/42031

[8] R. Fell, P. Mc Gregor, D. Stapledon, G. Bell and M. Foster *Geotechnical Engineering of Dams*, 2nd Edition. Taylor & Francis Group, 2018.

[9] G. B. Sowers and G. F. Sowers, *Introducción a la mecánica de suelos y cimentaciones*, México: Limusa, 1986.

[10] L. Xiangyue and V. Arroyo, "Impacto de fuerzas de filtración y tubificación retrógrada a la inestabilidad de talud y erosión hídrica", *Revista Digital Universitaria UNAM*, vol. 12, n.° 2, 2011.

[11] T. Durotoye, J. O. Akinmus uru, A. S. Ogbiye, and G. O. Bamigboye, "Effect of Common Salt on the Engineering Properties of Expansive Soil," *International Journal of Engineering and Technology*, vol. 6, no. 7, pp. 233–241, Jul. 2016.

[12] H. M. Jafer, "Stabilization of Soft Soils Using Salts of Chloride," *Journal of Babylon University/Engineering Sciences*, vol. 21, no. 5, 2013, [Online]. Available: https://www.researchgate.net/publication/274018931

[13] R. Guttikonda and G. Abhilash, "Stabilization of Black Cotton Soil Using Sodium Chloride," *International Journal of Advance Research, Ideas and Innovations in Technology*, vol. 4, no. 1, pp. 1–5, 2018, [Online]. Available: www.IJARIIT.com

[14] K. Saravanakumar, G. Kandasamy, S. Karthikeyan, M. Kaviyarasan, and M. M. Raj, "An experimental study on the soil stabilization method by adding the calcium chloride and the sodium chloride," *International Journal of Current Engineering and Scientific Research*, vol. 6, no. 3, pp. 119–124, 2019.

[15] H. E. Ali, N. K. Asmel, A. A. Ganiyu, and H. Tijani, "Effect of sodium compounds additives on the strength of cement-stabilized soils," *Engineering and Applied Science Research*, vol. 47, no. 3, pp. 287–296, Jul. 2020, doi: 10.14456/easr.2020.31.

[16] T. T. Abood, A. B. Kasa, and Z. B. Chik, "Stabilisation of silty clay soil using chloride compounds," *Journal of Engineering Science and Technology*, vol. 2, no. 1, pp. 102–110, Apr. 2007.

[17] K. Abbeche, O. Bahloul, and A. Bahloul, "Study of the influence of the saline solution NaCl on the potential collapse of soil," 2016. doi: 10.1051/07001.

[18] H. P. Singh, J. Singh Chana, G. Singh, H. Singh, and M. Singh, "Improvement in the Engineering properties of clayey soil using Sodium chloride," in *International Conference of Advance Research and Innovation (ICARI 2020)*, 2020, pp. 127–129. [Online]. Available: https://ssrn.com/abstract=3569450

[19] N. Z. Mohd Yunus, D. Wanatowski, A. Marto, and S. N. Jusoh, "Strength improvement of lime-treated clay with sodium chloride," *Geotechnical Research*, vol. 4, no. 4, pp. 192–202, Oct. 2017, doi: 10.1680/jgere.17.00001.

[20] M. H. Davoudi and E. Kabir, "Interaction of lime and sodium chloride in a low plasticity fine grain soils," *Journal of Applied Sciences*, vol. 11, no. 2, pp. 330–335, 2011, doi: 10.3923/jas.2011.330.335.

[21] S. Peddaiah and K. Suresh, "Experimental Study on Effect of Gypsum and NaCl in Improvement of Engineering Properties of ClayeySoil," *International Journal of Engineering and Technology*, vol. 9, no. 4, pp. 2771–2778, Aug. 2017, doi: 10.21817/ijet/2017/v9i4/170904409.

[22] R. Ortiz, O. Javier, ; Camacho Tauta, J. Fernando, T. Rivera, and J. Ricardo, "Uso del cloruro de sodio en bases granulares," *Ciencia e Ingeniería Neogranadina*, vol. 16, no. 1, pp. 63–71, Aug. 2006, [Online]. Available: http://www.redalyc.org/articulo.oa?id=91116106

[23] L. Ke and A. Takahashi, "Experimental investigations on suffusion characteristics and its mechanical consequences on saturated cohesionless soil", *Soils and Foudations*, vol. 54, n.° 4, pp. 713-730, Agosto de 2014. [En línea]. Disponible: https://doi.org/10.1016/j.sandf.2014.06.024

[24] F. Moreira and I. Guamán, "Estudio del comportamiento de un suelo arcilloso estabilizado por dos métodos químicos (cal y cloruro de sodio)", B.S. thesis, Technical University of Ambato, Ambato, 2016.

[25] L. Fernández "Estabilización de suelos arcillosos mediante adición de cloruro de sodio (NaCl) para uso de vías terrestres. Estudio de casos: suelos de Chachapoyas, 2016.", B.S. thesis, National University Toribio Rodríguez de Mendoza, Chachapoyas, 2018

[26] R. Cochachin, "Estabilización y durabilidad de sub base usando la cantera de Challhua con adición de cloruro de sodio en 2, 4 y 6% - Huaraz – 2017", B.S. thesis, University San Pedro, Huaraz, 2018

[27] R. Flores, *Flujo de agua a través de suelos*, 4ª ed. México: Asociación Mexicana de Hidráulica - Instituto de Tecnología del Agua, 2000.