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EFFECT OF CEMENT ON COMPRESSIBILITY AND SWELL OF SAND-EXPANSIVE CLAY MIXTURES

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ABSTRACT: This paper investigates the effect of adding low percentages of cement on the swelling and compressibility characteristics of sand-expansive clay mixtures. The use of highly plastic clay is known for reducing the hydraulic conductivity which is the main goal of waste containment barriers. However, liners can act as cover layers, road base, or a supporting ground. Excessive swell is likely to cause damage to light structures. Recent studies called for using clay with low plasticity that is just enough to fill the voids. Other researchers suggested adding fillers of fine powder. This study is an attempt to reduce the high plasticity with the addition of cement. The expansive clay used in this research was obtained from Al-Qatif region in the Eastern Province of Saudi Arabia. For these mixtures, the sand was considered the host material, and the clay content varied between 10% to 40% by dry weight of sand. The proposed cement content is put as low as 1, 2, and 4% by the dry weight of mixture at curing periods of 1, 7, and 28 days. A series of one-dimensional odometer tests were conducted to evaluate the swelling potential, swelling pressure, and compressibility characteristics of mixtures. Laboratory compaction tests were performed to determine optimum moisture content and maximum dry density. The addition of cement was found to improve the engineering properties of the mixtures and stabilize and control the swell and compressibility of the liner material

Keywords: Cement, Compressibility, Mixtures, Sand-clay, Swell.

1. INTRODUCTION

Liner systems are considered as an essential component of various waste containment systems such as solid and hazardous waste landfills. The main purpose of these liners is to preclude the migration of water or leachate to the soil and groundwater below the landfill. It is common practice to mix clay material with a coarse-grained soil as a landfill liner material. It is generally assumed that the coarser fraction of the mixture contributes to the relatively high shear strength and high compacted density, while the hydraulic conductivity of the soil is governed by the proportion and index properties of the finer fraction [14]. Mitchell [9] reported that mixing a sand-sized fine aggregate with clay enhanced the compaction and mechanical properties. Recently, a few of researches [2,5,10,12,16] have investigated the efficiency of sand-natural clay mixtures using available local clay resources. The idea of using local clay is considered more appealing than importing high quality processed bentonite to promote sustainability and reduce the costs of importing foreign material.

Expansive soils possess a unique property of volume change potential (shrinkage and swelling) in response to a variation in the moisture content [17,8]. The swelling of soil is attributed to the presence of clay minerals that have the potential for swelling and shrinkage under changing moisture conditions. Expansive soils are found in many locations in Saudi Arabia. This soil covers an area of about 800,000 km^2 of Saudi Arabia [13]. Volume changes due to swelling and during loading are the main factors controlling the performance of sand- expansive clay mixtures and affect their hydraulic conductivity [18]. Therefore, prediction of the swelling and compressibility characteristics of sand-expansive clay mixtures is an important criterion for the engineering design of liners systems. Excessive swell is likely to cause damage to light structures. Recent studies called for using clay with low plasticity and that is just enough to fill the voids. The use of cement with expansive soils performs to reduce volumetric changes and increases the shear strength [11]. This study is an attempt to reduce the high plasticity with the addition of cement to the mixtures. This study aims to investigate the compressibility and swelling behavior of mixtures of sand- expansive clay from Al-Qatif city (SQM). Test parameters considered included clay content (10%, 20%, 30%, and 40% by dry weight of sand), cement content (1%, 2%, and 4% by dry weight of sand) and curing periods (1, 7 and 28 days). All SQM were prepared at optimum moisture content conditions.

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2. MATERIALS

2.1 Sand

Sand material has been widely used as a host material in various studies of sand-clay mixtures and has been used in this study. In this study, the sand used was quality controlled sand which is locally used in concrete construction throughout Saudi Arabia. The sand material is free of any organic matter and suitable for use in this study. Geotechnical characterization of sand material included grain size distribution and specific gravity. A summary of geotechnical characterization data is provided in Table 1. The sand was classified as uniform poorly-graded sand (SP) according to the Unified Soil Classification System (USCS).

2.2 Expansive Clay

The expansive clay used in this study was natural clay obtained from Al-Qatif town. This is located in the eastern province of Saudi Arabia. Al-Qatif clay represents a typical expansive soil generally encountered in the Arabian Gulf coastal region. This type of clay is extremely fissured in the natural unsaturated state and exhibits significant volume changes when the water content is altered. Several previous research studies conducted to investigate the geotechnical characteristics of Al-Qatif clay revealed the clay to be highly plastic and highly expansive [1,3,4,6,15,16]. The volume change potential is due to the high amount of expansive clay minerals such as attapulgite, smectite, and illite [4,7]. Clay samples were obtained from the bottom of a test pit excavated to a depth of about 2.0 to 3.5 meters below ground surface and transported to the laboratory for detailed geotechnical, chemical, and mineralogical characterization. Summary of physical properties of Al Qatif Clay data is provided in Table 2. Also, the chemical composition of this type of clay given in Table 3. Mineralogical characterization of Al-Qatif soil was performed using the X-Ray diffraction (XRD) technique. The XRD analysis shown in Fig.1 illustrates that minerals mainly present in the Al-Qatif soil are attapulgite, quartz, dolomite, illite, and muscovite, also the presence of montmorillonite which is a typical swelling mineral, is noteworthy.

2.3 Cement

Ordinary Portland cement (OPC-Type I) was used as the cementing agent in this study. The OPC is a product of Yamama Saudi Cement Company, Riyadh. Characterization tests results indicated that the specific gravity of the cement was 3.12.

Table 1 Properties of Sand

Property	Value
Specific gravity	2.66
Range of particle size (mm)	0.1 – 0.6
Coefficient of uniformity	1.737
Coefficient of curvature	1.078
USCS classification	Poorly graded sand (*SP*)

Table 2 Physical Properties of Al Qatif Clay

Property	Value
Liquid limit (%)	140-150
Plastic limit (%)	45-50
Plasticity index (%)	95-100
Specific gravity	2.76
USCS classification	CH
Swelling potential (%)	20 - 25
Swelling pressure (kN/m^2)	500 - 600

Table 3 Chemical Composition of Al-Qatif Clay

Chemical Compound	Percentage (%)
Na_2O	0.50
MgO	4.92
Al_2O_3	15.82
SiO_2	55.86
K_2O	5.22
CaO	1.74
FeO	9.39

3. TESTING METHODS

3.1 Sample Preparation of Mixtures

To study the effect of cement, some of the parametric variables of soil should be considered as constants for every sand expansive clay mixture such as initial water content and dry density. Three different percentages of ordinary Portland cement content used in the experiments were: 1, 2, and 4% by the dry weight of sand. These amounts were added to four different sand expansive clay (Qatif) mixtures with 10, 20, 30, and 40% expansive clay. All mixtures were under three different curing periods, 1, 7, and 28 days. The expansive clay obtained from the field was air-dried, pulverized, and sieved using sieve No. 40. Target proportions of oven-dried sand, clay, and cement were hand-mixed under dry conditions to obtain a homogenous blend. Desired water content was then added and mixed thoroughly and stored in plastic bags for at least 16 hours in humid area to allow time for the soil particles to hydrate as recommended by ASTM Standard D 698-00. Samples were prepared by static compaction in a stainless steel odometer ring of 63.5 mm in diameter and 20 mm high to target unit weights. Silicon grease was applied to the inner surface of the ring to reduce side friction. A porous stone and filter paper were placed at the bottom and top of the compacted sample. The final sample height was kept at 16 mm providing a 4 mm recess to allow for potential expansion of samples.

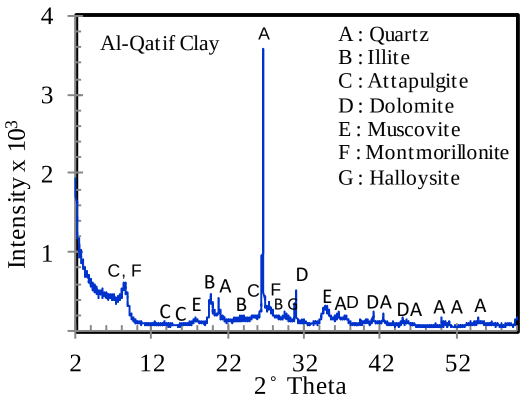

Fig. 1 X-Ray diffraction of Al-Qatif expansive clay.

3.2 Experimental Program

A series of one-dimensional odometer tests were performed to evaluate the swelling and compressibility behavior of mixtures following ASTM D4546. The procedure of all tests involved four main stages: dry loading, free swell (swelling under seating load), wet loading, and unloading. Dry loading was applied under a seating load of 7 kPa for a few minutes (15 min) to make sure the air is expelled and there was contact between the rod and cover cap of the sample. Free swell involved the inundation of samples under the same seating load of 7 kPa with continuous monitoring of vertical strain (heave). Equilibrium heave is assumed to be attained when no further deformation is recorded. In most cases, time to reach equilibrium heave was about 24 to 36 hours. After equilibrium, samples were incrementally loaded up to 400 kPa with a standard load increment ratio of one. Each stress was maintained until primary consolidation was completed (typically 24 hours). The vertical deformation of the sample during the test was monitored using an LVDT. These vertical deformation measurements were used to evaluate vertical strain at the end of each loading stage. After reaching maximum compression stress, the samples were unloaded (rebound) with a load increment ratio of a quarter. Finally, when removing the sample water content was determined using gravimetric methods. The time required to complete the entire test is typically 8 to 10 days.

4. DISCUSSION AND TEST RESULTS

The results of odometer tests are presented as plots of vertical strain versus logarithm stress for SQM at 40% clay content with all cement contents and curing periods considered in this study in Figs2, 3, and 4; respectively.

From these figures, it is apparent that, though all the specimens had an initial surcharge pressure of 7 kPa, the final or equilibrium vertical strain at the end of the process of swelling (during inundation) was different for different specimens having varying cement content. The equilibrium vertical strain was the highest for the sample having 1% cement content especially, for a 1day period. However, the equilibrium vertical strain decreased with the increase in cement content, indicating that swelling is decreased with increasing cement content. The amount of cement content used in different mixtures samples replaced the particles of swelling clay and thus reduced the expansion of SQM. Hence, the equilibrium vertical strain of the sample having 4% cement content starting with the same initial vertical strain was the lowest. Also, it's clear that as cement content increased, changes in the trends and decrease in curvature of compressibility curves were observed. This trend was observed for most of SQM. Similar strain-log stress curves were obtained in the other SQM percentages.

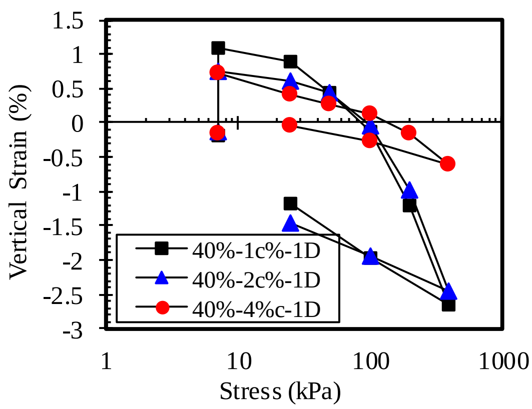

Fig. 2 Relationship between vertical strain and log stresses of sand with 40%Qatif under 1-day curing.

4.1 Compressibility Characteristics

To quantitatively assess the changes in the compressibility of the SQM, the compression index (C_c) and rebound index (C_r) were evaluated. The compression index (C_c) is defined as the slope of the linear portion of the vertical strain– log vertical stress curve. C_r is the slope of the unloading curve on the vertical strain– log vertical stress curve.

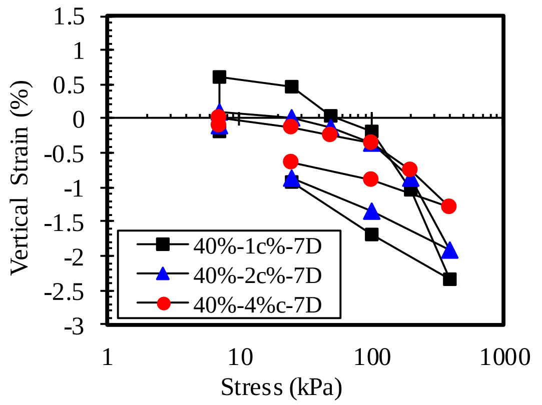

Fig. 3 Relationship between vertical strain and log stresses of sand with 40%Qatif under 7-days curing.

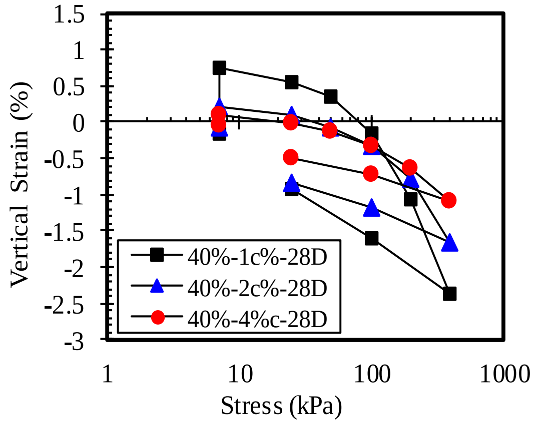

Fig. 4 Relationship between vertical strain and log stresses of sand with 40%Qatif under 28-days curing

The compression (C_c) of SQM with cement content under the curing period considered in this study (1,7, and 28 days) is shown in Figs.5,6 and 7, respectively. Also, the variation of rebound index (C_r) with a cement content of SQM under all curing period is illustrated in Figs.8,9 and 10.

These figures suggest that both percent of cement and curing time influence compression and rebound indices, but the effect is more pronounced on the compression index. This increased tendency to resist compression and rebound can be accounted for by the cementing ability provided by cement. Also, it's apparent from all figures the effect of a small amount of cement (1% and 2%) on C_c and C_r was a significant effect compared to the large cement content (4%).

4.2 Swelling Potential

The swell potential is defined as the ratio of increase in height (Δh) to the original height of the sample (h) when fully inundated under prescribed vertical stress (in this study 7 kPa) and is expressed as a percentage. Swell potential written in the form of the following equation was determined according to the definition given by Jennings in 1963. It is written as,

$$SP(\%) = (\frac{\Delta h}{h}) \times 100 \quad (1)$$

The variation of swelling potential with cement content under different curing period for all mixtures is illustrated in Figs.11 to 13. The amount of swell potential undergone by the specimen reduced with the increase in cement content.

The swelling potential values for SQM decrease as mixed with cement. There is a negligible or no effect of the cement content on the swelling potential at mixtures with 10 and 20 % expansive clay content as shown in figures 11 to 13. This negligible effect is due to the low amount of expansive clay between particles of sand inside the mixtures. On the other hand, the effect of cement on swelling potential for mixtures with 30 and 40% expansive clay content was clear and influential with a clear decrease in swell potential with the increase in the amount of cement. This reduction in swelling potential is due to a large amount of clay in the mixtures and consequently, the effect of cement was prominent. In terms of the curing period, there is a noticeable decrease in the swelling potential with increasing curing days for samples that contain 2% and 4% of cement content more than samples with 1% of cement.

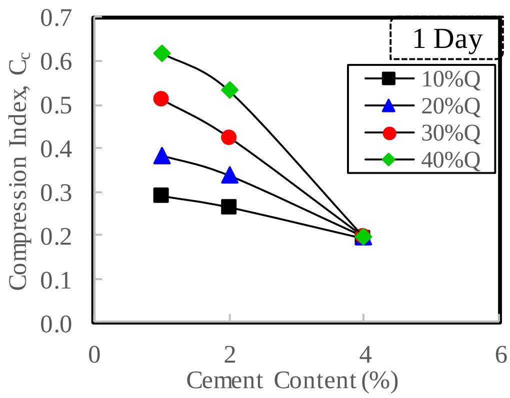

Fig. 5 Variation of compression index (C_c) with cement content under 1-day curing.

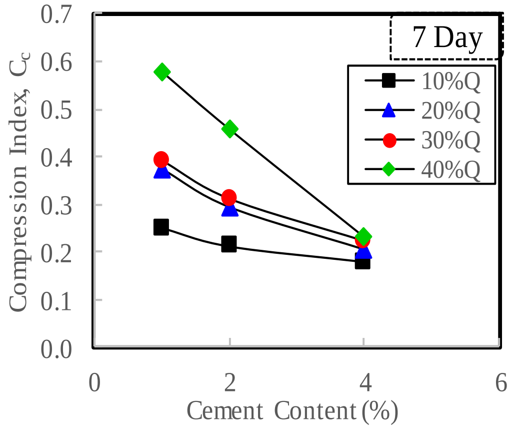

Fig. 6 Variation of compression index (C_c) with cement content under 7-days curing

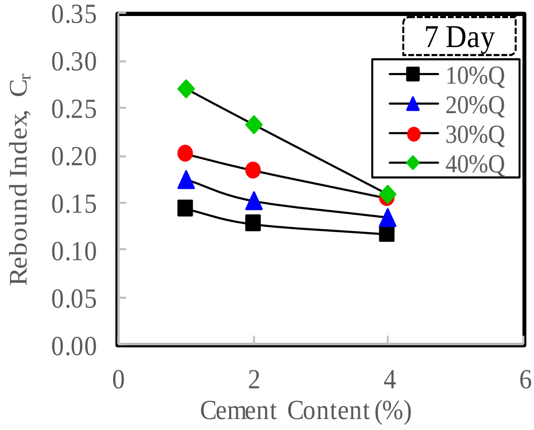

Fig. 9 Variation of rebound index (C_r) with cement content under 7-days curing

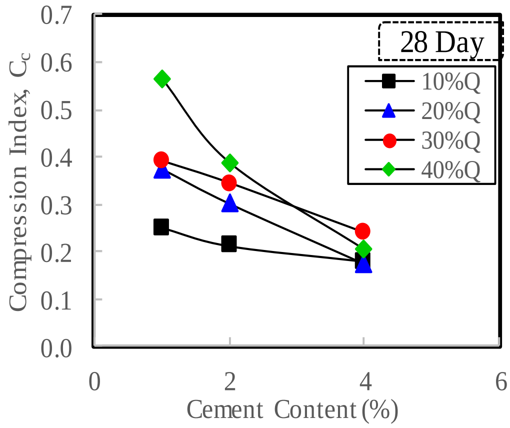

Fig. 7 Variation of compression index (C_c) with cement content under 28-days curing.

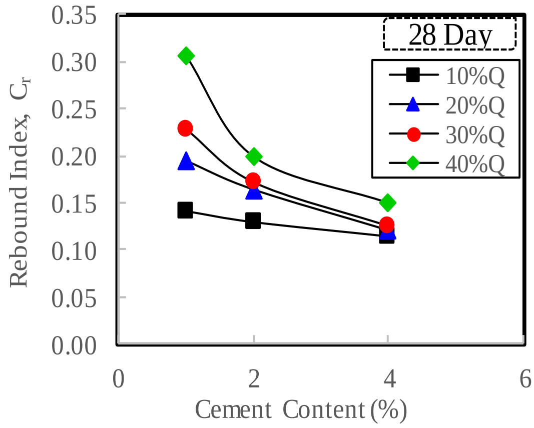

Fig. 10 Variation of rebound index (C_r) with cement content under 28-days curing

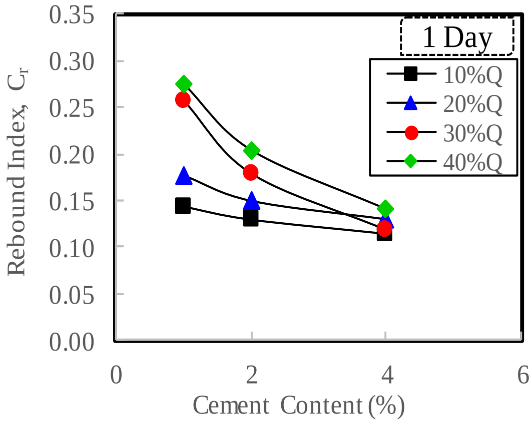

Fig. 8 Variation of rebound index (C_r) with cement content under 1-day curing

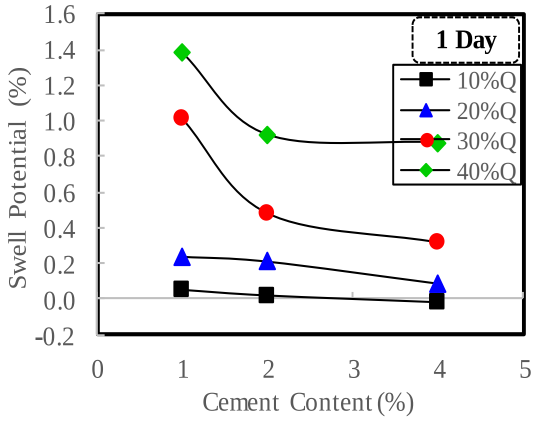

Fig. 11 Variation of swelling potential (SP) with cement content under 1-day curing

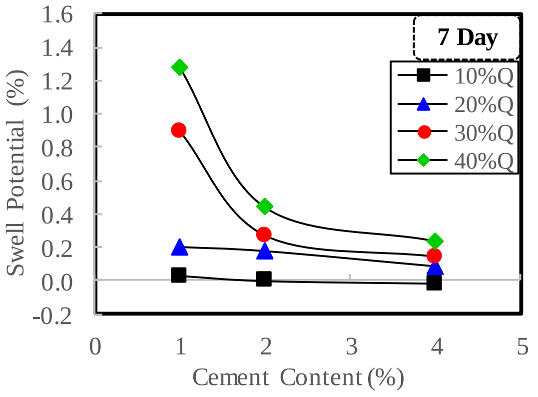

Fig. 12 Variation of swelling potential (SP) with cement content under 7-days curing

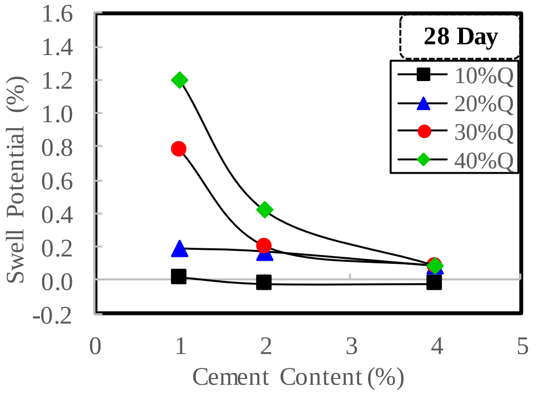

Fig. 13 Variation of swelling potential (SP) with cement content under 28-days curing.

5. CONCLUSIONS

Based on the test results and the above analysis, it can be concluded that:

(1) The compression index (C_c) of SQM decreased significantly with the increase in cement content. Samples at one-day curing showed a decrease in C_c between 35% and 68%. For samples at 7 days curing the decrease in C_c was between 28% and 60%. For samples at 28 days curing periods the decrease in C_c was between 29% and 64%.

(2) The rebound index (C_r) of SQM decreased with the increase in cement content. Samples at one-day curing showed a decrease in C_r was between 21% and 54%. For samples at 7 days curing the decrease in C_r was between 20% and 42%, also, at 28 days curing periods the decrease in C_r was found in the range of 19% to 51%.

(3) Reduction in compression index (C_c) and rebound index (C_r) was more pronounced for SQM at 30% and 40% clay content specimens than in 10% and 20% clay content specimens. This level of reduction encourages the use of high clay content.

(4) Curing periods had a small marked influence on reduction in compression index (C_c) and in rebound index (C_r).

(5) For all SQM at 1 day curing the increase in cement content from 1% to 2% decreased the swell potential (SP) in ranges of 11% to 63%. At the same curing, the increase in cement content from 2% to 4% decreased the swell potential in a range of 5% to 200%.

(6) For all SQM at 7 days curing the increase in cement content from 1% to 2% decreased the swell potential in a range of 12% to 100%. At the same curing, the increase in cement content from 2% to 4% decreased the swell potential in a range of 46% to 200%.

(7) For all SQM at 28 days curing the increase in cement content from 1% to 2% decreased the swell potential in a range of 10% to 200%. At the same curing, the increase in cement content from 2% to 4% decreased the swell potential in a range of 0% to 79%.

(8) It can be concluded that the SQM treated with 2% cement content can be utilized as a stabilizer for this clay and similar clays which minimizes the settlement problems and the same time can reduce excessive swelling and shrinkage.

6. ACKNOWLEDGMENTS

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7. NOTATION

SQM stands for Sand Al-Qatif Mixtures, SP stands for Swelling Potential, C_c stands for Compression Index and C_r stands for Rebound Index.

8. REFERENCES

[1] Abduljauwad S.N., Characterization and chemical treatment of expansive clay in AlQatif, Saudi Arabia, Journal of Engineering Geology, Vol. 31, Issue 2, 1991, pp.143-158.

[2] Al-Rawas A.A., Yahiae A.M., Abdulaziz S.A., and Salem A., Sand–attapulgite clay mixtures as a landfill liner, Geotechnical and Geological Engineering, Vol. 24, Issue 5, 2006, pp.1365-1383.

[3] Al-Shayea N., The combined effect of clay and moisture content on the behavior of remolded unsaturated soils, EngGeol, Vol. 62, Issue 4, 2001, pp.319-342.

[4] Azam S., Influence of mineralogy on swelling and consolidation of soils in eastern Saudi Arabia, Can Geotech J, Vol. 40, Issue 5, 2003,

pp.964-975.
[5] Azam S., Study on the swelling behaviour of blended clay–sand soils, Geotech Geol Eng, Vol. 25, Issue 3, 2007, pp.369-381.
[6] Dafalla M.A., The Compressibility and Swell of Mixtures for Sand-Clay Liners, Advances in Materials Science and Engineering, Vol. 2017, Article ID 3181794, 9 pages, https://doi.org/10.1155/2017/3181794.
[7] Elkady T.Y., Shaker A.A., and Dhowain A. W., Shear strengths and volume changes of sand–attapulgite clay mixtures, Bulletin of Engineering Geology and the Environment, Vol. 74, Issue 2, 2015, pp.595-609.
[8] Jiapei D., Annan Z., Xiaoshan L., Yuhuan B., and Jayantha K., Revealing Expansion Mechanism of Cement Stabilized Expansive Soil with Different Interlayer Cations through Molecular Dynamics Simulation, The Journal of Physical Chemistry C 2020, Vol. 124, Issue 27, 2020, pp.14672-14684.
[9] Mitchell J.K., Fundamentals of soil behavior, John Wiley & Sons, New York, Year 1976, pp.1-422.
[10] Obrike S.E., Osadebe C.C., and Omoniyi S.S., Geotechnical analysis of two Nigerian soils for use as clay liners, Bulletin of Engineering Geology and the Environment, Vol. 68, Issue 3, 2009, pp.417-419.
[11] Phanikumar B.R., Sreedharan R., and Aniruddh C., Swell-compressibility characteristics of lime-blended and cement-blended expansive clays – A comparative study, An International Journal of Geomechanics and Geoengineering, Vol. 10, Issue 2, 2015, pp.153-162.
[12] Pratibha P., and Ameta N.K., Experimental Investigation of Compaction and Hydraulic Conductivity Characteristics of Dune Sand – Clay Mixture from Thar Desert, Electronic Journal of Geotechnical Engineering, Vol. 18, 2013, pp.2645-2651.
[13] Ruwaih I.A., Experiences with Expansive Soils in Saudi Arabia, 6th Int. Conf. on Expansive Soils, New Delhi, India, 1987, pp.317-322.
[14] Shafiee A., Permeability of compacted granule–clay mixtures, Engineering Geology, Vol. 97, Issue 3-4, 2008, pp.199-208.
[15] Shaker A.A., and Elkady T.Y., Hydraulic performance of sand-clay mixtures: soil fabric perspective, Géotechnique Letters, Vol. 5, Issue 3, 2015, pp.198-204.
[16] Shaker A.A. and Elkady T.Y., Investigation of the hydraulic efficiency of sand - natural expansive clay mixtures, International Journal of GEOMATE, Vol. 11, Issue 25, 2016, pp.2410-2415.
[17] Sridharan A., and Gurtug Y., Swelling behaviour of compacted fine-grained soils, Engineering Geology, Vol. 72, Issue 1, 2004, pp.9-18.
[18] Sun D., Cui H., and Sun W., Swelling of compacted sand–bentonite mixtures, Applied Clay Science, Vol. 43, Issue 3-4, 2009, pp.485-492.