REVIEW OF EXPANSIVE SOIL STABILIZATION METHODS.

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Abstract: Expansive soils for engineering have a challenging behavior. Due to its capacity of great variation in volume when losing and gaining moisture it needs to be stabilized. In this way, many materials and stabilization methods are researched with a view to reconciling with the environment and long-term efficiency. In this study, through a systematic literature review, publications, studies and scientific innovations for stabilization methods were sought. It was found that year after year studies are made to try to find new efficient and definitive methodologies, but despite having a periodicity, the volume of research is still limited.

Keywords: Expansive soils; Paving; Stabilization.

REVISÃO DE MÉTODOS DE ESTABILIZAÇÃO DE SOLOS EXPANSIVOS.

Resumo: Os solos expansivos para a engenharia têm um comportamento desafiador. Devido a sua capacidade de grande variação de volume ao perder e ganhar umidade ele necessita ser estabilizado. Dessa maneira, muitos materiais e métodos de estabilização são pesquisados tendo em vista a conciliação com o meio ambiente e uma eficiência de longo prazo. Neste estudo, através de uma revisão sistemática de literatura, foi procurado publicações, estudos e inovações cientificas para métodos de estabilização. Constatou-se que ano após ano estudos acontecem para a tentativa de encontrar novas metodologias eficientes e definitivas, mas apesar de ter uma periodicidade, o volume de pesquisas ainda é limitado.

Palavras-chave: Solos expansivos; Pavimentação; Estabilização.

1. INTRODUCTION

The Expansive soils are materials that are characterized by volumetric variation by varying their water content; this variation can cause an increase in volume due to water absorption, or reduction in volume due to water loss. Although the solution to remove and replace the expansive soil for another without this characteristic is still used, this may become unfeasible with large volume transport over long distances, and mainly because it causes environmental impacts by reason of it is necessary a place to unload the material. In this context, soil stabilization is of great importance for allowing the use of local soils, instead of importing other soils.

Stabilizing expansive soils without digging them out is an economical procedure for road construction. Although a variety of additives have been employed to improve the strength [1]. Especially in the case of highways built on expansive soils, methods of controlling this volume variation are very important to preserve the pavement structure. Therefore, protection and maintenance of the unpaved shoulder of the highway underground are essential elements for the protection of the integrity of the roads and related paved structures [2].

Soils can be stabilized in a chemical, physical or mechanical way. In addition to the remedial methods. According the Transportation Research Record 1219 [3], mechanical stabilization includes all improvements to either soil or soil mass properties without the addition of stabilizing agents; chemical stabilization for expansive clay soil property improvement consists of changing the physicochemical environment around and inside clay particles, changing the nature of the water that moves into and out of the voids, and effecting behavioral changes in the soil mass as a whole; and remedial treatments are actually after-the-fact stabilizers of expansive clay soils and the facilities on which they are built.

Then, the option for one or another stabilization method is influenced by a number of factors, among which stand out: the economic factors, the purpose of the work, the characteristics of the materials and the properties of the soil that must be corrected. In this context, the present study aimed to evaluate the contributions of the research developed on the stabilization methods of expansive soils, with a view to identifying some aspects to be explored, such as, for example, the use of methods for inserting formulations that promote stabilization, but that do not require too much automation in the injection process for the materials reach the required depth, and that can be applied with the highway in operation.

2. METHODOLOGY

This review was developed through a search for patents and technical publications, such as articles, thesis, dissertations, course completion work, and books that include stabilization methods for expansive soils. The research was carried out through a priority search, being developed with the support of the Intellectual Property Center of SENAI CIMATEC.

In order to identify the works related to the stabilization methods of expansive soils applied in road works, a survey was carried out in the last 45 years during the period from February 3rd to 14th 2020, through several patent databases: INPI (National Institute of Industrial Property), ESPACENET (European Patent Office), USPTO (United States Patent and Trademark Office), SCIELO (Scientific Electronic Library on line), Portal of Journals of CAPES, WIPO (World Intellectual Property Organization), Google patents and Derwent Innovation.

In order to obtain a more assertive research, it was adopted search descriptors (keywords) and Booleans connector "AND" best suited for data collection since it provides results that must contain these descriptors in the same document, regardless of the number of words that may exist between them. The keywords used were: "Expansive soil", Method, Stabilization, Moisture and Pavement.

Quotation marks ("") were used to search for words in the exact way they are written ("Expansive soil"), without any other words between them in any field.

After reading the titles and abstracts, the files that had a greater focus on the research topic were identified, being downloaded and read in full. The inclusion criteria for publications were: articles, books, theses, and dissertations, which addressed the use of mathematical models in predicting the behavior of pavements and soils, published between 1990 and 2020, in English or Portuguese, and articles available in the whole. All works published outside the period and in languages other than those defined were excluded, and articles with availability only upon payment.

3. RESULTS AND DISCUSSION

With the prospecting of works described in the methodology, the number of articles found with the informed descriptor was 42. Of these articles, after excluding those that had nothing to do with the objective of the work, the 9 most relevant articles were highlighted in the Table 1.

Table 1 - Research on expansive soil stabilization methods applied to road works.

Stabilizing Material	Stabilizing Method/Methodology	Main Results	*Ref.
Dairy manure compost (DMC) and biosolids compost (BSC) mixed with topsoil at different proportions to form four types ofcompost manufactured topsoils (CMTs)	Seventeen CMT test plots of different treatment widths and thicknesses including a control plot with no CMT cover material were constructed at Stephenville, Texas and these sections were heavily instrumented with moisture and temperature sensors.	Results indicated that the BSC amendments provided the best subsoil enhancements by controlling moisture and temperature fluctuations from the high temperature environment, thereby reducing shrinkage cracks in subsoils and in the adjacent paved highway shoulders. The DMCs were less effective in mitigating shrinkage cracking due to low amounts of fibrous or	[4]

Stabilizing Material	Stabilizing Method/Methodology	Main Results	*Ref.
		organic matter. Both design and construction specifications for CMTs were also developed. This application will enhance recycling efforts by converting wastes into usable compost, mitigate future pavement cracking, and lessen premature maintenance costs.	
Lime, natural volcanic ash (VA) and their combinations	Laboratory tests performed on different concentrations of stabilizers included Atterberg limits, California bearing ratio (CBR), swell percent and unconfined compressive strength (UCS)	The added stabilizers improved greatly the physical-mechanical properties of Black Cotton Soils (BCS). The use of combinations of lime and VA showed superior results when compared with the single stabilizer. Overall, the use of VA can reduce the consumption of lime in BCS stabilization and actualize the utilization of vast resources BCS as a low-cost roadbed material.	[5]
Lime	Five lime residue percentage in the soil were tested with different curing times. Several tests were conducted, such as particle-size distribution, Atterberg limits, compaction, California Bearing Ratio, unconfined compressive strength, and uplifting pressure.	The lime residue can be used to stabilize the expansive clay found in the Recôncavo Baiano region. The results show that the stabilized soil can be used as a subgrade of the pavement. The results are promising in terms of stabilized soil use in the pavement layers (sub-base and base).	[6]
SiCC column	Investigate the effect of SiCC column on the CBR of compacted expansive soil. Two groups of specimens (A and B) were prepared for CBR test	The SiCC column significantly increases the CBR of expansive soil on both dry and wet side of optimum moisture content. The specimen compacted on the dry side exhibit a higher	[7]

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Stabilizing Material	Stabilizing Method/Methodology	Main Results	*Ref.
	under soaked condition (wet and optimum moisture).	CBR than the specimen compacted on the wet side of optimum moisture content.	
Flyash and Aluminum Chloride	Twenty soil samples were prepared with a mix of flyash (0% to 15%) and aluminum chloride (0% to 2%) and the resulting soil matrixes were subjected to laboratory testing.	CBR enhancement and simultaneous reduction in the swelling nature of soil.	[8]
Alkalis of Calcium Hydroxide [Ca(OH)2] or Potassium Hydroxide (KOH), and Cementitious Geopolymers.	Laboratory tests: Atterberg limits, maximum dry density (MDD), optimum moisture content (OMC), unconfined compressive strength (UCS).	The combination of volcanic ash and alkalis reduces the plasticity index greatly. Potassium hydroxide is found to be more efficient in solidifying the BCS than Ca(OH)2. The swelling percentage of BCS can be decreased and increased mechanical strength.	[9]
Class C fly ash geopolymer (CFAG)	Moreland clay stabilization with CFAG (5, 10, and 20%) was studied and then its performance was compared with a traditional soil stabilizer which is cement (10%). Consolidation tests were performed 7, 14, and 30 days after the samples were prepared.	From the compression index (CC) and swelling index (CS) values it was concluded that even though cement is by far the best soil stabilizer the application of a higher percentage of CFAG, a satisfactory level of soil stabilization can be achieved.	[10]
Sand cushion and cohesive nonswelling (CNS) soil cushion	Field tests of different percentages	The field heave measurements of footings, pavement slabs, and canal lining panels cushioned with the proposed chemically stabilized soil (CSS) mix revealed that the CSS cushion can effectively reduce their heave and hence it can be recommended as an	[11]

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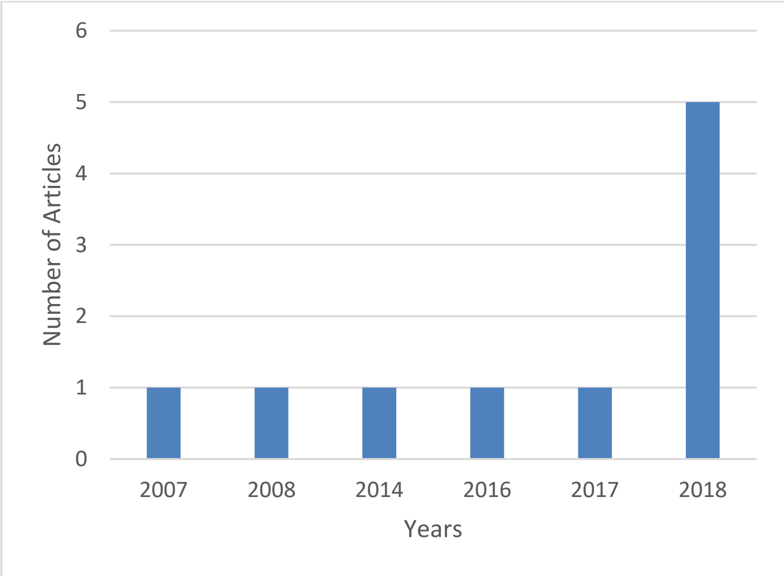
Stabilizing Material	Stabilizing Method/Methodology	Main Results	*Ref.
		alternative to conventional CNS cushion in localities of scarcity for suitable CNS materials.	
Marble waste	An experimental program was conducted on sand-expansive soil enhanced with marble waste, abundantly found as a by-product of construction industry, obtained from two different sources with different gradations, denoted as marble powder (MP) and marble dust (MD). One-dimensional swell, volumetric shrinkage, consolidation, unconfined compressive and flexural strength tests were conducted on expansive soil–sand mixtures with 5, 10 and 20% waste marble inclusions over curing periods of 7, 28 and 90 days.	Test results showed that 10% marble powder and 5% marble dust by dry mass were the optimum amounts for mitigating the swell–shrink potential and compression index as well as yielding the highest unconfined compressive and flexural strength values. Moreover, the rate of reduction in swell potential versus the flexural strength over the curing periods studied is highest in 10% MP- and 5% MD-included specimens, the latter being more insensitive to this change. The soil mixtures displayed brittle behavior after marble addition, hence its utilization as a secondary additive to sand-amended expansive soil is recommended for soils exposed to lower flexural loads such as light traffic.	[12]

Analyzing the articles, it was observed that all stabilization methods researched are aligned with the preservation of the environment. In addition, the stabilization methods contained in this research sought to increase the resistance of the soil, either by mixing with more resistant materials or adding elements of cement capacity, but always moving towards the attempt to increase resistance.

The analyzed articles showed positive results of the various mixtures and of the materials and methods used for soil stabilization. Considering the objective of this review, it is possible to verify that these methods can be used and have proved useful depending on the expansive soil to be stabilized.

The graphs below presented in Figure 1 demonstrates that, even though this theme is very important (expansive soils can cause several problems if not treated correctly), the number of studies has been very small, demonstrating that there is still a lot to develop surrounding the aspects of stabilization.

Figure 1: Number of Articles over the years



4. CONCLUSION

It is almost always more economically to stabilize expansive clay soils during construction, rather than leaving the soil unstable, thus risking the need for remedial treatment. Stabilization can be performed more economically at the beginning of construction than when repairs are needed to adjust in an unstable situation. Unstable expansive clay soils do not need to be accepted for use. Even now, much is known about the stabilization of these problematic soils, and stabilization processes are economical alternatives to potential problems.

In this way, the main results of the experiments prove that the soil stabilization methods are most effective when there is also have an increase in mechanical strength. Thus, the factor of economic and executive viability is decisive for what type of stabilization should be used. Therefore, there is opportunity for new techniques and methodologies for stabilizing expansive soils, focused mainly on the environmental issue and the chemical composition of stabilizing agents.

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