Evaluation of the Improvement of Sand Dunes Soil in Fortaleza with Soil Stabilization and Cement Addition

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ABSTRACT

The present paper undertakes an evaluation of mechanical properties and behavior of soil, analyzing mixtures with cement addition and other soils following the mechanical soil stabilization technique. Sand samples were collected from aeolian deposits with low bearing capacity, presenting an average CBR (California Bearing Ratio) value of 10,00%. Studied soil was collected from a dune field in the district of De Lourdes, in the city of Fortaleza, in the state of Ceará. From the characterization tests, it can be observed that the analyzed soil qualifies as a uniform sand in the Unified Soil Classification System (USCS). Analyzed material in this research shall be used as a sub-base and base for pavements. In this manner, a necessity to improve the soils load bearing capacity was verified, with the goal of obtaining 40% CBR (indicated in the project), through the use of mechanical soil stabilization techniques and addition of cement to the natural soil. Behavior of mixtures with added cement, and mechanical stabilization were analyzed as per a laboratory analysis program, through characterization tests, compaction tests and CBR tests. Through the results of the CBR tests, it was noted that soil stabilization did not present a significant improvement in bearing capacity, on the other hand, the addition of 5% of cement provided an expressive increase in California Bearing Ratio when compared to the bearing capacity of the natural soil.

KEYWORDS: Soil improvement; CBR; Soil Cement; Mechanical stabilization.

INTRODUCTION

Pavement materials are becoming ever more scarce and hard to obtain, due to various factors. In this manner, they may add costs to the project and degrade the explored region (ARAÚJO; BARROSO, 2007). Soils and other materials found in nature are not always ready to be directly employed in pavement structures. Occasionally, additives made up of other materials are necessary as a form of altering some soil characteristics and pavement materials, to provide them with the needed qualities.

The aim of this paper is to analyze sandy soil samples collected from eolian deposits in the city of Fortaleza, for the purpose of application in pavements. The study proposes a comparative analysis of improvement of soil bearing capacity, through the addition of cement and mechanical stabilization.

Such studies are of great importance to improve the understanding of the mechanical behavior of soils, relevant to diverse applications in engineering, including pavement projects, to provide future alternatives on the application of new materials, different from those utilized in conventional pavements, making the project financially viable.

THEORETICAL FRAMEWORK

This section presents the theoretical basis of the study, were the historical context of soil cement and works done with the material are presented. Addressing as well, the California Bearing Ratio and mechanical stabilization.

Soil Cement

Soil-cement is the final product of adding together soil, Portland cement and water that, compacted to the optimum water content and maximum density, in previously established measurements, acquires resistance and durability through the hydration reactions of cement (ABCP, 1986). According to Oliveira (1994), the chemical stabilization modifies soil properties through physical-chemical reactions between soil grains and the added products wither by the creation of a matrix that cements or envelopment of grains. These physical-chemical reactions may result in the formation of new materials.

Amongst the numerous soil chemical stabilization process that have been progressively used in many countries, Portland Cement stabilization is accounted for (ENAMORADO, 1990).

According to Concha (1986), cement stabilization is a chemical process, with cement hydration reactions, that create links between the surface of hydrated cement particles and the parts of cement particles that are in contact with these cement particles. Adding cement to soil creates a material that does not suffer great volumetric changes through the absorption or loss of water, does not deteriorate completely when submerged in water, and also presents elevated compressive strength and durability due to lower permeability (GRANDE, 2003).

Pereira (2012) states that the consumption of cement increases with the amount of fine particles present in the soil. Therefore, to stabilize a clay soil, a larger amount of cement would have to be added than it would be necessary to stabilize a well-graded sand. The exception occurs when it comes to uniform sands, which need more cement than sand soils with traces of silt and clay.

History of soil cement in pavements

According to Pitta (1995), the first News of attempts to obtain a low-cost construction material, durable and with well-defined technological properties through the mixing of soil with Portland cement, comes from Sarasota, Florida (USA), where and Engineer called Bert Reno experimented with paving the Oak Street road using a compost of sea-shells, beach sand and Portland cement in 1915.

After 1931, with the revolutionary discovery by Robert R. Proctor on the relation between moisture content and dry unit weight in soil compaction, the key that allowed the undertaking of scientific studies that progressively defined the current technical standard of stabilizing soils with cement was found. Many experiments with soil cement were done by the South Carolina Department of Transportation, with the goal to obtain low-cost pavements, but usable in any time of the year. Achieved results showed how promising the resulting material was, defined as: "…a hardened product, which does not deteriorate under pneumatic actions nor does it deform in humid weather, neither does it disintegrate or form mud." (PITTA, 1997).

The use of soil cement and of soil improved with cement has shown to be a economically viable technical solution in many regions of the country, having begun in Brazil in 1935, with the acceleration of highway construction in that era (MACEDO, 2004). Pitta (1995) found that the first roadway built with soil cement in Brazil, from an initiative by the Brazilian Association of Portland Cement (BAPC) and authorized by the Civil Aeronautics Directory was constructed at the Santos Dumond Airport, in the year 1940. It was composed of a short runway of about 1,600m².

According to Heise (2004), the first construction sites in Brazil that used soil cement were the Petrolina (PE) Airport and residential buildings in Petrópolis (RJ) in the early years of 1940. PITTA (1997) states that in 1973, a survey indicated 96,000,000 m² of soil cement in highways, roads and Brazilian airports, and at the end of 1980, there were 100,000,000 m² for the same type of application.

Yoon and Farsakh (2008) indicated an increase in simple compressive strength with the increase of cement quantity for a soil sample classified as HRB A-2. The authors evaluated variations in quantities of cement of 8%, 10% and 12% of cement, in mass.

Pinheiro et al. (2015) conducted laboratory tests in soil primarily composed of sand and silt, and on some tests, pebbles were detected. CBR values, for the soil without cement, were between 10% and 14%, after adding cement, a considerable gain of bearing capacity was noted. The values of CBR were 46%, 87% and 121% for additions of 1%, 3% and 5% of cement, respectively. Lopes (2012) concluded through his work that the mechanical behavior of cement sand is directly tied to the void ratio. Cement acts on sand by creating a cohesive interception, which may be considered nearly non-existent in sand in its natural state. This cohesion increases with the increased use of cement.

Cunha (2014) worked with a silty-sand soil and concluded that after the addition of cement there was an increase in bearing capacity of the soil, significantly improving its properties. There was also a considerable increase in the tolerated load by the mixed material.

Dosage

The dosage of a soil cement mixture, for a specific soil, consists in the investigation of the quantities of cement, water and dry unit weight that must be achieved after compaction, to guaranty a durable and resistant finished product (MARAGON, 1992).

According to DNIT (2010a) and DNIT (2010b), in the chemical stabilization of soils with Portland cement, so as to achieve significant hardening in soil, the soil cement mixtures must be prepared in soil mass, with cement percentages above 5%. The improved soil with cement has its properties improved partially, with an emphasis on workability alongside a certain increase in bearing capacity, low percentages of cement are used to this end, in the range of 3%.

Macedo (2004) cites that soil is the predominant element in the soil cement mixture, and the one that need most control during mixing, due to having quite variable characteristics, different from cement and water that are materials that normally present great uniformity.

Ingles and Metcalg (1972) observed that the effects due to increasing the amount of cement also depend on the type of soils used for the mixture. For sandy soils, the authors noted a tendency for increased shrinkage and decrease of permeability. For clay soils, a tendency for permeability increase was verified and a decrease in potential expansion. The viable range of hydraulic binder use for soil stabilization for roadway use lies between 5% and 9% of cement in relation to the total mass. Above these percentages, costs become quite high, in many cases making the stabilization method unviable from a financial perspective (LIEDI et al., 2006). On the cement ratio, the Brazilian Association of Portland Cement (BAPC), recommends 7% as the lowest cement content to be used. Vargas (1977) recommends a content of 7 to 14% Portland cement in relation to the compacted soil volume.

Mechanical Stabilization of Soil

Sousa (2014) explains that stabilization occurs through compaction, particle size correction and plasticity or by the adding of substances that provide cohesion, resulting from cement hydration or particle agglutination.

According to Macedo (2004), mechanical stabilization consists in stabilizing natural soil through modifying its composition, which is done by mixing two or more types of soils and separation of one of the soil fractions. With this, a well graded soil is achieved, satisfying the physical requirements necessaries for a base or stabilized cover.

California Bearing Ratio (CBR)

The California Bearing Ratio test consists in determining the bearing capacity of compacted soil, compared to the penetration resistance of a standardized piston at controlled penetration pressure and velocity and the resistance, in the same conditions, of a standardized graded gravel. This ratio is expressed in percentage. The California Bearing Ratio (CBR) is the maximum value obtained from the ratio, in percentage, between calculated or corrected pressure, for penetrations of 0,1 and 0,2 inches, and the standard pressure, for the same penetrations. Through the CBR test, it is possible to know what the expansion of pavement soil will be when it is saturated, and provide signs of soil resistance decrease with saturation. Despite the fact of having an empirical quality, the CBR test is used worldwide and serves as a basis for designing flexible pavements (SENÇO, 2007)

CASE STUDY

The present study was conducted in the municipality of Fortaleza, in the state of Ceará. With the goal of making a comparative analyses of the evolution of sand soil bearing capacity with improvement by mixing another type of soil and adding cement. The studied soil samples correspond to sand collected in a dune field in the district of De Lourdes, the studied area indicated in Figure 1, bordered by Santos Dumont Avenue and the Soares Dutra and Mascarenhas de Morais streets. It is worth noting that the collected and tested samples were labelled in the following manner: ‘A’ followed by a number, for sand samples without any additions (A1 through A5), and letters 'AM' followed by two numbers, to represent samples of sand mixed with other soil types used in chemical stabilization, in the proportions of 50% and 70% of sand (AM50 and AM70, respectively). A mixture of cement (5% content) with sand soil was also carried out, with the intent of verifying its behavior. For this sample, the designated name was AM5.

Figure 1: Sample collection location

The analyzed soil behavior was studied based on a laboratory test program, through the undertaking of characterization, compaction and California Bearing Ratio tests.

RESULTS AND ANALYSIS

Results and analysis of conducted tests with soil and its respective additives are presented below.

Characterization tests

Charactirization tests consist of a sieve analysis test (ABNT 2016a) plastic index (ABNT, 2016b) and liquid index (ABNT, 2016c). Sieve test curves of the pure sand soil samples are presented in Figure 2. It was found that the analyzed soil samples were not plastic, therefore, characterizing the material as a uniform sand in the Unified Soil Classification System (USCS).

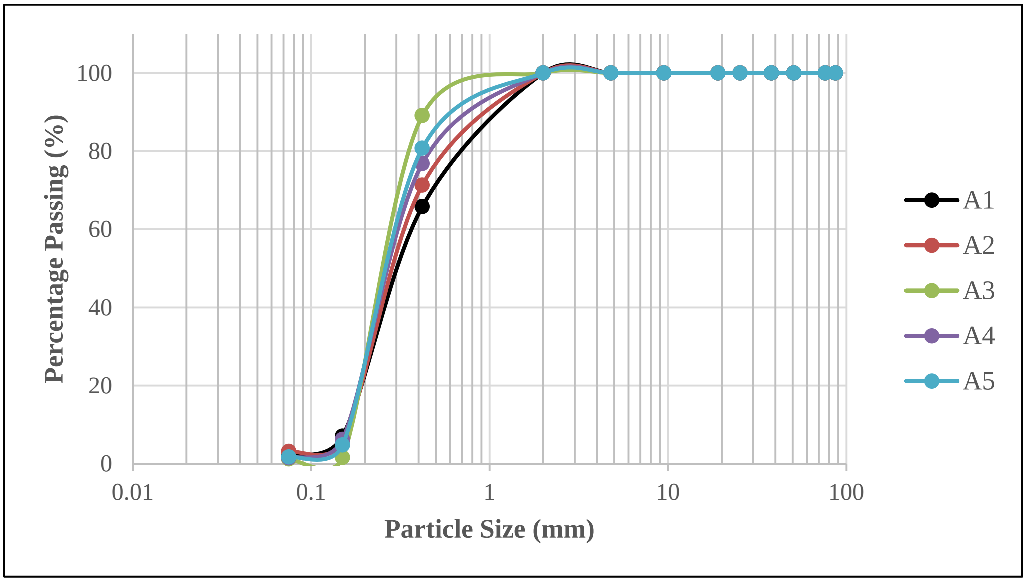

Figure 2: Sieve test curves for pure sand samples

Based on the sieve test results, it can be noted that the materials possess few fines (silt and clay) passing through sieve #200 (0,075mm), generally being classified as a type A-3, by the HRB System. In Table 1, the granulometric composition of studied materials is presented.

Table 1: Granulometric composition of materials

Sample	Pebbles (%)	Coarse Sand (%)	Medium Sand (%)	Fine Sand (%)	Silt and Clay (%)
A1	0,00	0,00	34,19	63,96	1,85
A2	0,00	0,00	28,70	68,16	3,15
A3	0,00	0,00	10,90	87,85	1,25
A4	0,00	0,00	23,18	75,34	1,48
A5	0,00	0,00	19,25	79,00	1,75

Compaction Tests

Normal Proctor energy was utilized in the compaction tests, according to the ABNT (2016d) standard, to obtain the optimum moisture content and maximum dry unit weight of the pure samples and the mechanically stabilized soil mixtures. In Figure 4, results for pure soil samples compaction curves are presented, in Figure 3, the results for the mechanically stabilized soil mixtures are presented.

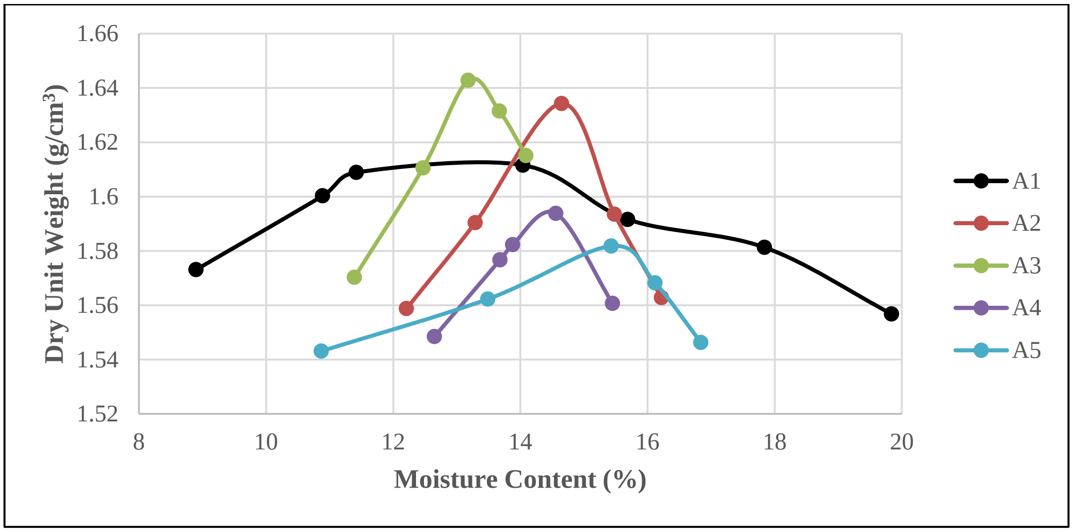

Figure 3: Compaction Curves of Mechanically stabilized soil mixtures

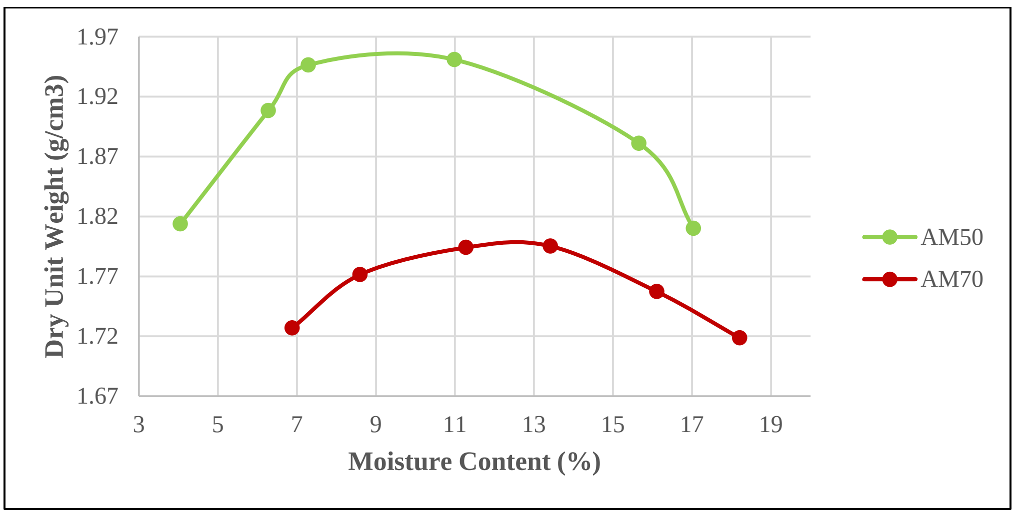

Figure 4: Compaction curves of Pure Sand

Table 2 presents the obtained results for materials without additives and the mechanically stabilized materials. It may be noted that the optimum moisture content of pure soils, varied between 13,3% and 15,5%, and the maximum dry unit weight indicated a variation from 1,58 to 1,64 g/cm³, presenting, standard deviation of 0,99 and 0,02, respectively. It may also be observed that the average maximum dry unit weight for the pure sand samples was 1,61 g/cm³ and the average optimum moisture content was of 14,34%.

Table 2: Compaction test results

Sample	Dry Unit Weight (g/cm^3)	Optimum Moisture Content (%)
A1	1,61	13,30
A2	1,63	14,70
A3	1,64	13,30
A4	1,59	14,90
A5	1,58	15,50
AM 50	1,59	9,70
AM70	1,79	12,60

It should be pointed out that the mechanically stabilized materials showed dry unit weight values superior to those of unmixed soils, as was expected, since the unmixed soil is granular, and the mixed soil is comprised mostly of fines, therefore, filling parts of the granular soil voids, thereby, granting the mixture with a less uniform gradation and consequently, a soil mass with a lower void ratio.

California Bearing Ratio Tests

The CBR (California Bearing Ratio Test) consisted in determining the bearing capacity of the materials and their respective expansion, in accordance to the ABNT (2016e) standard. At Figure 5, the load-penetration curves of the CBR test with unmixed samples are presented. It can be noted that sample A2 was the one that presented a higher bearing capacity ratio compared to the other studied sand samples, presenting a discrepant behavior from the other samples. While the other samples presented similar behavior until penetration levels of up until 2,54mm. For a penetration of 5,08 mm, different pressure values can be noted for each sample, directly influencing the respective materials bearing capacity.

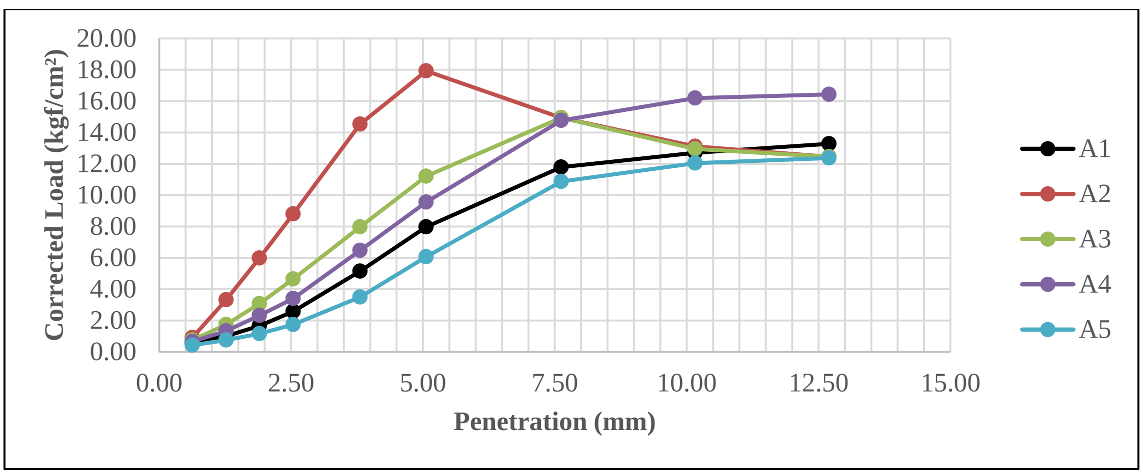

Figure 5: Load-Penetration Curves of unmixed samples

The load-penetration curves of the mixed samples obtained through the CBR test are presented on Figure 6. It can be noted that the curves presented discrepant behaviors as of a penetration value of 2,54mm. The level of load withstood by the materials for a penetration of 5,08mm, infers directly, the respective bearing capacity, therefore characterizing, three materials with distinct mechanical behavior.

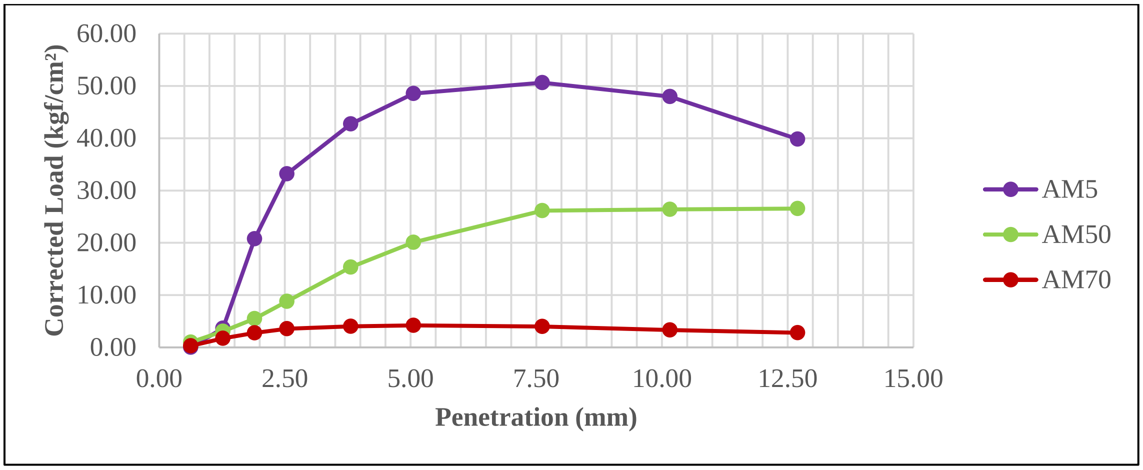

Figure 6: Load-Penetration Curves of mixed samples

Analyzing the curve for sample AM70, it can be noted that a significantly small improvement of bearing capacity occurred compared to the unmixed samples. But sample AM50, presented a bearing capacity ratio superior to all unmixed samples. Sample AM5 was the one that presented the highest bearing capacity of all analyzed material, such a fact can be explained due to the added cement, that not only fills voids in granular soils, but also establishes soil particle cementing, imprinting a cohesive intercept in granular soils, that can normally be considered nearly non-existent in their natural state. At Table 3, the CBR test results are shown, indicating the bearing capacity ratio and expansion values of studied materials.

Table 3: CBR Test Results

Sample	CBR (%)	Expansion (%)
A1	7,60	0,00
A2	17,00	0,00
A3	10,60	0,00
A4	9,10	0,00
A5	5,70	0,00
AM50	19,00	0,00
AM70	12,40	0,00
AM5	63,70	0,00

Based on the results, it may be concluded that sample A2 presented a discrepant value for the unmixed samples. The average CBR values was of 10,00% and the standard deviation was of 4,31. The sample with added cement (AM5) presented the highest value of CBR amongst the studied materials. Samples with mechanical stabilization (AM50 and AM70) presented superior CBR values compared to the unmixed samples. The studied materials did not present expansion.

CONCLUSIONS

This paper's goal was to evaluate the improvement of granular soils with the addition of cement and mechanical stabilization, presenting positive results in the use of cement and clay soil as a stabilizing agent for the studied sandy soil. It was verified that the stabilizing technique of adding cement could be an alternative that makes possible the use of sandy soils that do not possess satisfactory bearing capacity, decreasing the necessity of obtaining extracted soils from other areas and the improper disposal of material. Through the characterization tests, it has been determined that the aeolian deposit was composed of a uniform sand or a type A-3 soil according to the USCS and the HRB, respectively.

Based on the compaction and CBR tests of the mixtures, it was verified that the material presented a significant improvement in bearing capacity with the addition of cement, presenting an average gain of 53,70%, while the samples with mechanical stabilization (AM50 and AM70) presented a relatively small improvement. According to DNIT (2010c) and DNIT (2010d), a mechanically stabilized sub-base must have CBR ≥ 20% and a mechanically stabilized base must have CBR ≥ 60% depending on the number N. Therefore, only sample AM5 is apt to be utilized as a pavement sub-base, or as a base, in case the N number of the roadway in question is in the order of N $\leq 5 \times 10^6$. Sample AM5 was also the only one to meet the design requirements for its application as a base or sub-base for the studied venture.

REFERENCES

1. Araújo; Barroso, S H A. O uso da técnica de solo-cal para melhoramento das propriedades tecnológicas de um solo da região do baixo Jaguaribe no estado do Ceará. In: XXI Congresso de Pesquisa e Ensino em Transportes, 21., 2007, Rio de Janeiro. Anais... Rio de Janeiro: Anpet, 2007.
2. Associação Brasileira de Normas Técnicas. NBR 7181: Solo - Análise granulométrica. Rio de Janeiro: Moderna, 2016a. 12 p.
3. Associação Brasileira de Normas Técnicas. NBR 7180: Solo — Determinação do limite de plasticidade. Rio de Janeiro: Moderna, 2016b. 3 p.
4. Associação Brasileira de Normas Técnicas. NBR 6459: Solo - Determinação do limite de liquidez. Rio de Janeiro: Moderna, 2016c. 5 p.
5. Associação Brasileira de Normas Técnicas. NBR 7182: Solo - Ensaio de compactação. Rio de Janeiro: Moderna, 2016d. 9 p.
6. Associação Brasileira de Normas Técnicas. NBR 9895: Solo - Índice de suporte Califórnia (ISC) - Método de ensaio. Rio de Janeiro: Moderna, 2016e. 14 p.
7. Associação Brasileira de Cimento Portland. ET-35: Dosagem das misturas de solo-cimento: normas de dosagem e métodos de ensaio. São Paulo: Abcp, 1986. 51 p.
8. Concha, Luis Marcial Collarte. Estudo da fadiga de duas misturas de solo-cimento. 1986. 148 f. Tese (Doutorado) - Curso de Engenharia Civil, Universidade Federal do Rio de Janeiro, Rio de Janeiro, 1986.
9. Cunha, Vinicius Maciel. Avaliação experimental da mistura solo-cimento para aplicação em camadas de base de pavimentação. 2014. 90 f. TCC (Graduação) - Curso de Engenharia Civil, Uniceub, Brasília, 2014

10. Departamento Nacional de Infraestrutra de Transportes. DNIT-ES 142: Pavimentação – base de solo melhorado com cimento - Especificação de Serviço, Rio de Janeiro, 2010a.
11. Departamento Nacional de Infraestrutra de Transportes.. DNIT-ES 143: Pavimentação – base de solo-cimento - Especificação de Serviço, Rio de Janeiro, 2010b.
12. Departamento Nacional de Infraestrutra de Transportes.. DNIT ES 139: Pavimentação - Sub-Base Estabilizada Granulometricamente. Brasília, 2010c.
13. Departamento Nacional de Infraestrutra de Transportes.. DNIT ES 141: Pavimentação - Base Estabilizada Granulometricamente. Brasília, 2010d.
14. Enamorado, M. A. Estudo comparativo entre o método mecânico e o método físico-químico para dosagem do solo-cimento. 1990. Dissertação (Mestrado). COPPE/UFRJ, Rio de Janeiro, 1990.
15. Grande, Fernando Mazzeo. Fabricação de tijolos modulares de solo-cimento por prensagem manual com e sem adição de silica ativa. 2003. 180 f. Dissertação (Mestrado) - Curso de Arquitetura, Departamento de Arquitetura e Urbanismo, Universidade de São Paulo - Escola de Engenharia de São Carlos, São Carlos, 2003.
16. Heise, A. F.. Desenho do processo e qualidade na construção do painel monolítico de solo cimento em taipa de pilão. 2004. 138 f. Dissertação (Mestrado) - Curso de Engenharia Civil, Universidade Estadual de Campinas, Campinas, 2004.
17. Ingles, O. G.; Metcalf, J. B. Soil stabilization – principles and practice. Australia: Butterworths Pty. Limited, 366p, 1972.
18. Liedi, B. B. et al. Pavimentação Asfáltica: formação básica para engenheiros. Rio de Janeiro, 2006
19. Lopes, Francisco Mateus Gomes. Estudo do comportamento mecânico de areias artificialmente cimentadas. 2012. 110 f. Dissertação (Mestrado) - Curso de MecÂnica das Estruturas, Estruturas de Concreto e Alvenaria e Materiais e Processos Construtivos, Universidade Federal do Rio Grande do Norte, Natal, 2012
20. Maragon, Márcio. Utilização de Solo-Cimento em uma Solução Alternativa de Estrutura de Arrimo. 1992. 153 f. Dissertação (Mestrado) - Curso de Engenharia Civil, Departamento de Engenharia Civil, Pontifícia Universidade Católica do Rio de Janeiro Puc - Rio, Rio de Janeiro, 1992.
21. Macedo, Mirtes Maria de. Solos modificados com cimento-efeito no módulo de resiliência e no dimensionamento de pavimentos. 2004. 309 f. Dissertação (Mestrado) - Curso de Ciência em Engenharia Civil, Universidade Federal de Pernambuco, Recife, 2004
22. Oliveira, Luis Carlos Dias de. A estabilização de solos aplicada à habitação, um estudo de misturas de solo-cimento. 1994. 255 f. Dissertação (Mestrado) - Curso de Ciências em Engenharia Civil, Universidade Federal do Rio de Janeiro, Rio de Janeiro, 1994
23. Pereira, Kiev Luis de Araújo. Estabilização de um solo com cimento e cinza de lodo para uso em pavimentos. 2012. 125 f. Dissertação (Mestrado) - Curso de Engenharia Civil, Universidade Federal do Rio Grande do Norte, Natal, 2012.
24. Pinheiro, Rinaldo J. B. et al. Estudo da viabilidade técnica de aplicação de solo residual de riodacito/riolito melhorado com cimento como base de pavimento de baixo custo. In: REUNIÃO ANUAL DE PAVIMENTAÇÃO, 44., 2015, Foz do Iguaçu. Anais... . Foz do Iguaçu: Associação Brasileira de Pavimentação, 2015. p. 1 - 17.

25. Pitta, M. R. Estabilização com solo-cimento. Revista Techne, São Paulo: Pini, n. 17, jul./ago. 1995.

26. Pitta, M. R. (1997). "Pequeno Histórico da Estabilização de Solos com Cimento" ABPv. Boletim Informativo, n° 158 maio/junho.

27. Senço, Wlastemiler de. Manual de Técnicas de Pavimentação. Volume 1. 2ª Ed. São Paulo: PINI, 2007. 761p.

28. Sousa, Alex Torres de. Estudo de parâmetros de dois tipos de solos característicos do Distrito Federal estabilizados com cal. 2013. 70 f. TCC (Graduação) - Curso de Engenharia Civil, UniCEUB, Brasília, 2013.

29. Vargas, Milton. Introdução à mecânica dos solos. Mcgraw-Hill, Editora da Universidade de Sao Paulo, 1977.

30. Yoon, S.; Farsakh, M. A. Laboratory investigation on the strength characteristics of cement-sand as bases material. Journal of Civil Engineering, L.A.,20

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