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Cement Soil Stabilization as an Improvement Technique for Rail Track Subgrade, and Highway Subbase and Base Courses: A Review

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Abstract

This research paper summarizes published research works on the suitability of cement as an effective chemical stabilizer to improve the strength and durability requirements of sand to be used as subgrade and base courses for rail track and road construction respectively. Advantages and problems associated with soil stabilization using chemicals have also been briefly discussed in this report. It has been confirmed that ordinary Portland cement is an effective chemical stabilizer to improve both the index and strength properties of soils, however, the optima percentage of cement contents are varied from a soil type to another. In addition, further research has to be carried out as the percentage of cement content varies from region to region and from soil characteristics to another. This is necessary so as to determine the optimum percentage of cement content that would yield the desired subgrade CBR values with some other index properties to meet the specified requirements in any selected design manual.

Keywords: Maximum dry density • Stabilization • Subgrade • Unconfined compressive strength • Cement • Optimum moisture content • Soil • Track subgrade • Stabilizer

Introduction

Soil is one of the most important and primary media for any construction work. The strength and durability of any structure depends on the strength properties of soil. It has been found from several studies that, due to the detrimental characteristics of organic soil, the shear strength and bearing capacity of this soil are very low, while the compressibility is very high [1]. Soil is a mixture of minerals, organic matter, gases, liquids, and countless organisms that together support life on Earth.

Deficient soils are regarded as soils which do not meet some or all the criteria required for their satisfactory performance as geotechnical structures. These could either be for base courses for road, embankment for dam or road, subsoil base for foundation, clay liners for containment of leachates and backfill for retaining walls [2]. In the tropical region, these soils could be lateritic soils, black cotton soils, collapsible soils or any other tropical soils [3].

Soil stabilization refers to the procedure in which a special soil, a cementing material, or other chemical or non-chemical materials are added to a natural soil or a technique use on a natural soil to improve one or more of its properties. One may achieve stabilization by physically mixing the natural soil and stabilizing materials together so as to achieve a homogeneous mixture or by adding stabilizing material to an undisturbed soil deposits and obtaining interaction by letting it permeate through soil voids [4].

Cement is one of the most common additives used as a stabilizing agent for expansive soils. Extensive evaluations have been carried out on the cement stabilization of expansive soils. However, cement stabilization usually results in high stiffness, and makes the soil brittle, which is undesirable in dynamic loading conditions such as pavement systems [5].

Advantages of soil stabilization

- Technical advantage
- Economic advantage
- Savings by Design
- Saves Time
- Winter Working
- Saves Environmental Impact
- Saves Waste
- Saves Landfill Taxes [5].

Possible problems due to soil stabilization

The stabilization of soil also causes the following problems (IRC:SP:89-2010)

- Due to thermal and shrinkage cracks stabilized layer may be crack.
- Crack can reflect through the surfacing and allow water to enter the pavement.
- If CO_2 has access to the material, the stabilization reaction is reversible and the strength of layer can decrease.
- The construction operation requires more skill than unsterilized materials [6].

Cement soil stabilization

Soil cement stabilization is soil particles bonding caused by hydration of the cement particles which grow into crystals that can interlock with one another giving a high compressive strength. In order to achieve a successful bond the cement particles need to coat most of the material particles. To provide good contact between soil particles and cement, and thus efficient soil cement stabilization, mixing the cement and soil with certain particle size distribution is necessary [7].

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Advantages of cement stabilization

While several reagents can be used for Soil Stabilization, Portland cement has advantages that make it more economical and easy to use than others:

- Cement is manufactured under strict ASTM standards, ensuring uniformity of quality and performance
- Cement's success in Soil Stabilization is supported by more than 50years of use on a variety of projects
- Cement has a long-term performance record
- Using cement can minimize volume increase compared with other reagents
- Cement is a non-proprietary manufactured product, readily available across the country in bag or bulk quantities.

Problems associated with cement stabilization

Despite the many benefits, there are problems associated with cement stabilized materials that entail due considerations. The main problems that will have pronounced negative effects if not controlled are cracking and carbonation. These problems are happened in the compacted stabilized layer after construction [8].

In cement-stabilized bases, cracking is attributed to materials characteristics, construction procedures, traffic loading, and restraint imposed on the base by the subgrade [9]. The most common type of crack in cement-stabilized base is shrinkage crack. Shrinkage cracks are related to loss of water, cement content, density of compacted material, method of compaction, and pretreatment moisture content of the material to be stabilized. Cement treated materials begin to lose their moisture through evaporation immediately after they are placed if proper curing is not exercised. The loss of moisture then will lead to the drying and subsequent development of shrinkage cracks. Further, the final strength of the cement treated materials will be reduced as hydration of the cement is hampered due to lack of sufficient moisture in the mix [10].

The contribution of cement hydration in the development of shrinkage cracks is less as compared to water loss. Nevertheless, excessive amount of cement aggravates the development of cracks in two ways:

- Higher amount of cement in the mix causes greater water consumption during hydration which in turn increases the drying shrinkage;
- Increased amount of cement increases the rigidity and tensile strength of the treated materials. As a result, widely spaced wide cracks are developed. The wider spacing of the cracks is attributed to the higher tensile strength and the wider width of individual cracks is due to the distribution of total shrinkage of the material within smaller number of the widely spaced cracks [8].

Literature Review

Soil Stabilization is the alteration of soils properties to improve their engineering properties. Stabilization can increase the shear strength of a soil and/or control the shrink-swell properties of a soil, thus improving the load bearing capacity of a sub-grade/base courses to support pavements and railway track superstructure.

Many literatures have been reviewed on the effectiveness and to what percentage content of cement as a stabilizer to improve different problematic soils in different part of the world and the summaries are highlighted below:

Saksham et al., investigated the criteria for improving the engineering properties of soils used for railway track base courses, sub base courses, and sub grade by the use of chemical stabilizer (cement) mixed with the soil to effect the desired properties [11]. The experimental investigation was carried out on both untreated and stabilized soil sample obtained from ABU PUR, Modinagr UP, in India. These tests include grain size analysis, Atterberg's limits (Shrinkage, Plastic and Liquid limits), Proctor Compaction Test, Direct Shear Test, California Bearing Ratio Test.

- According to Unified Soil Classification System (USCS) the soil sample is SC (Silty Sands)/SM (Clayey Sands).
- It was established that the maximum dry density increases while the optimum moisture content decreases when 2%, 4%, and 6% cement were added to soil sample as compared with the untreated sample and the values of MDD increases up to 1.06 while OMC reduced up to about 0.89 for the stabilized 6% cement content.
- With due investigation, the result of direct shear test indicates that for every interval increment of cement content, the value of cohesion "c" decreases while the corresponding value of angle of shearing resistance "ϕ". For untreated soil, c=1.6 and phi=38, for 2% cement, c=1.1 and phi=40, for 4% cement content, c=0.6 and phi=41 and for 6% cement content, c=0.6 and phi= 40.
- For the California Bearing Ratio Test, Max subgrade CBR values are 5.07%, 6.62%, 8.23% and 10.15% for untreated soil sample, 2%, 4%, and 6% cement contents respectively [11].

Therefore, the conclusions were made from the results of investigation of a SC (Silty Sands)/SM (Clayey Sands), with an increase in cement content, liquid limit, plastic limit and plasticity index decreases as compared with the untreated sample. MDD increases while OMC decreases for increments in cement content as compared with untreated soil sample. Also, for every increment in cement content, the values of cohesion decreases while the corresponding angle of shearing resistance increases as compare to untreated soil sample. There was a sharp increment in the subgrade CBR values for every increment in the percentage of cement content and the CBR of sample stabilized with 6% cement content and compacted of 5 layers with heavy energy of 55 blown in each layer fulfilled the criteria proposed by AASHTO soil classification. Since the effectiveness of cement as a soil stabilizer has been investigated and confirmed, so, to optimally increase the bearing capacity of SC/SM soil to be used for subgrade of railway track, 6% cement content or more is recommended [11].

According to Obianigwe et al., in a published experimental research work titled soil stabilization for road construction: comparative analysis of a three-prong approach where the comparative effects of cement, sodium chloride and brick dust on clay soil found at location during road construction in Otta, Ogun State, Nigeria, was carried out using various percentage of 2%, 6%, 10% and 14% cement contents mixed with clay soils [12]. Laboratory tests for determination of both the index and strength properties of the clay soil sample both before and after the stabilization. The tests include; natural moisture content, sieve analysis, Atterberg limits, specific gravity and compaction for index and strength properties respectively. And the results are summarized as follows:

Geotechnical properties before stabilization

The result of the particle size analysis of the sample showed that more than 6.18% of the soil sample passed the No. 200 sieve. Using AASHTO system of classification, the soil is found to belong to the sub group A-2-7 (i.e., Clayey Sand) and poorly graded sand with clay (SP-SC). The specific gravity was found to 2.62, LL, PL, and PI were found to be 43.8, 23.5, and 20.3% respectively while MDD, OMC, and Soaked CBR were determined to be 16.7 kN/m^3, 17.1% and 8% respectively [12].

Geotechnical properties after stabilization with cement

The results of the tests on the specific gravity indicate a decrease in SG with cement content up to 6% after-which there was a drastic increase in SG up to 14% where it starts to decrease with further increment in cement content. Also, with progressive increment in cement content in the clay soil, LL, PL, and PI reduce up to 14% after which a nearly stabled value was observed with further increment in percentage of cement content. Optimum Moisture content (OMC) was found to increase with increase in percentage cement content until 10% where further increment in cement content was found to cause corresponding decrease soil-cement optimum moisture contents. Also, the Maximum Dry Density (MDD) was found to increase with increase in percentage cement content. For the CBR, there was an increase in CBR values from 2% up to 6% cement content after which there was a decrease in CBR value up to 10%

before later increased with further increment in cement content to 14%. The improvement in CBR value may be attributed to change of soil structure from dispersed to flocculate [12].

It is concluded that, Portland cement has been confirmed suitable for improving geotechnical properties of A-2-7/CL soil (AASHTO and USC systems respectively) having approximately 6.18% passing the BS No. 200 sieve. It has been found that 14% by weight of sand is optimal for stabilizing an A-2-7 soil with and this will effectively reduce the plasticity of the natural soil to meet the requirement for use as subgrade for railway track and subbase and base course materials for highway construction. It is therefore recommended for silty clay; optimal 14% cement content will be required to stabilize the soil in order to meet the requirements in terms of plasticity and CBR values for subgrade railways track, subbase and base courses materials for road embankment construction [12].

Ashraf et al., experimentally determined the optimum cement content for the stabilization of soft soil and the durability analysis of cement stabilized soil [13]. The experimental investigation was carried out on three different soil samples obtained from Bandartia, Mohora and Khulshi hills of Chittagong with the labels (S-1), (S-2) and (S-3) respectively. The physical parameters of these samples are determined, and the results are:

- According to MIT Soil Classification System, the soil samples are found to be Sandy Silt and some clay (38, 47 and 15%), Sandy Silt and some clay (39, 49, and 12%) and Silty sand and some gravel (9, 8, 0% with around 2% gravel in it) for (S-1), (S-2), and (S-3) respectively.
- Specific Gravity (G) are respectively 2.5, 2.5, and 2.67 for (S-1), (S-2), and (S-3).
- Liquid Limits are 26% and 25.5% for (S-1) and (S-2) respectively while the plastic limits are 20.45% and 20.00% for (S-1) and (S-2) respectively and their corresponding plasticity index values are 5.55% and 5.50% respectively.
- Salinity content was also verified and their values are 3%, 0% and 0% for (S-1), (S-2) and (S-3) respectively [13].

Diamond Brand Cement with literature compressive strength at 3, 7, and 28 days 2.57, 3.56, and 5.9 ksi respectively. And initial, final setting times and fineness of 162 minutes, 353 minutes and 353 m^2/kg respectively. The following laboratory tests which include standard compaction test, unconfined compression test and durability test were carried out on each of the soil sample with different cement contents of 0%, 2%, 4%, 6%, 8% and 10% and the results are summarized below:

Strength characteristics of soil-cement stabilization

Stress-strain response was recorded for each of the mixtures which were cured for 0, 7, 14, and 28 days to produce the stress-strain curves

- For S-1 sample, the max strength after 28days curing of 8% cement content is found to be approximately 15 times greater than that of 0% cement content. So, further increment in cement content resulted to compressive strength decrement by 0.98% compared to that of 8% cement content.
- For S-2 sample, the max strength after 28days curing of 8% cement content is found to be approximately 16 times greater than that of 0% cement content. So, further increment in cement content resulted to compressive strength decrement compared to that of 8% cement content. However, up to 8% cement content increment, the strength is observed to be almost uniform.
- For S-3 sample, the max strength after 28days curing of 10% cement content is found to be approximately 25 times greater than that of 0% cement content. So, further increment in cement content resulted to significant increase in compressive strength compared to that of 10% cement content [13].

Durability characteristics

- It was observed that after completion of 7 days cycle of wetting, all the three samples with 0% cement content could not retain shape and spread flat.
- There was a slight change in volume and weight found with 2%, 4%, and 6% cement contents after the completion of 7 days cyclic wetting and drying.
- The volume and weight remained almost the same for 8% and 10% cement contents after 7 days cyclic wetting and drying.
- Also, it was observed during durability test that the 2 days cycled sample provides higher unconfined compressive strength (UCS) compared to that of 7 days cycled sample. This invariably means that the longer the cyclic period, the decrease the strength [13].

Compaction characteristics of stabilized soil

Figures 1-3 show the variations of maximum dry density and optimum moisture content with different percentages of cement content for soil samples S-1, S-2 and S-3 respectively. These figures are generated from the experimental results carried out [13].

It can therefore be concluded that, for any ground condition with predominance in sand or sand silty, 8% - 10% cement content will be effective to increase the unconfined compressive strength to 11 to 12 times greater than when with 0% cement content. And if such stabilized soil is to be used as railway track subgrade, the subgrade CBR will be very high and this will drastically reduce the thickness of embankment which will invariably reduce the cost of railway track construction. It can also be concluded that the longer the cycled period the lower the unconfined compressive strength of samples.

Thus, it is recommended that for any site condition with predominance in sand or sand silty, cement is effective as a stabilizer with the cement contents of 8% to 10% so as to achieve 11 to 12 times compressive strength greater than with 0% cement content [13].

Masrur et al., experimentally evaluated the performance of cement and slag stabilized expansive soils sampled from Austin and San Antonio, Texas and

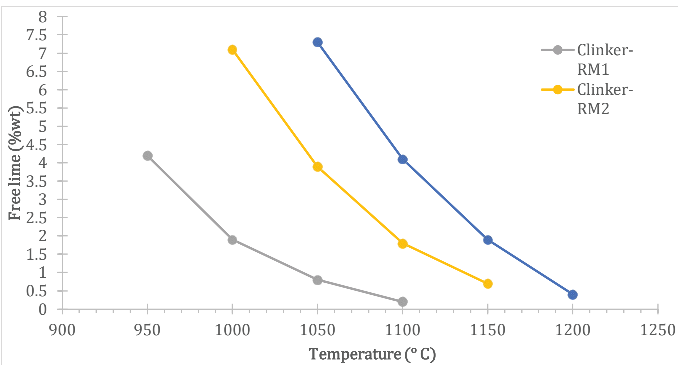

Figure 1. Variation of maximum dry density and optimum moisture content with percentage cement content for soil sample S-1.

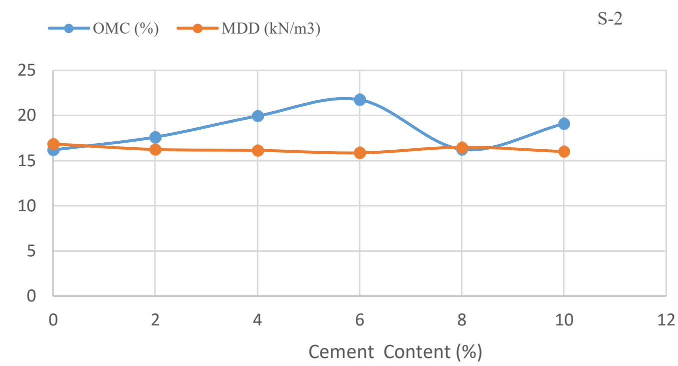

Figure 2. Variation of maximum dry density and optimum moisture content with percentage cement content for soil sample S-2.

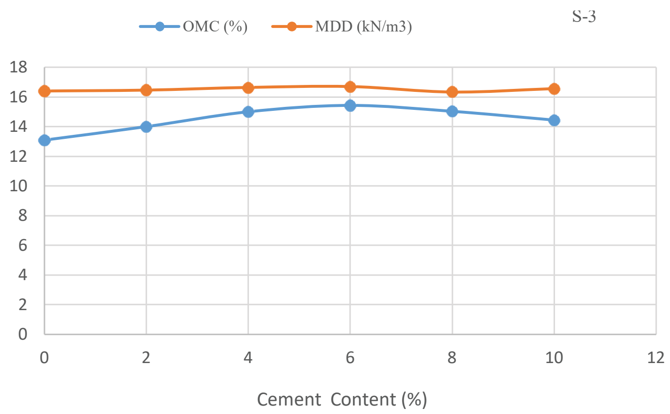

Figure 3. Variation of maximum dry density and optimum moisture content with percentage cement content for soil sample S-3.

these soil samples are labelled Soil-S and Soil-L. An expansive soil being a problematic soil with excessive shrinkage and swelling properties and it typically consists of fine smectite clay minerals such as montmorillonite with illite, claystones, residual, and sedimentary soils that absorb large amount of water and swells. According to Unified Soil Classification System (USCS), both soils were classified as high-plasticity clay (CH).

In an untreated state, clay content of soil-L (58%) was found to be higher than that of Soil-S (40%) resulting in a higher plasticity index (PI) of Soil-L (49%). Soil-L had a higher OMC (28%) and lower MDD (14.5 kN/m^3) due to its higher clay content at standard proctor compaction energy [14].

Two types of cement were used as stabilizers, Type I/III cement and Type V cement with the following percentage cement contents: 8%, 12% and 16% separately for each of cement type and the tests results are summarized below:

Atterberg limits

For high-plasticity clay, addition of stabilizing agents decreased the LL and PI in all mixtures. And for Type I/III cement there was a decrease in LL with corresponding increment in PI when 8%, 12% and 16% cement contents were separately added to stabilize samples from Soil-S and Soil-L. While for the Type V cement there was decrease in LL with corresponding decrease in PI when 8%, 12% and 16% cement contents were separately added to stabilize samples from both Soil-S and Soil-L [14].

Unconfined compressive strength

For Soil-L, the unconfined compressive strength increases with both increments in percentage content (8%, 12% and 16%) of Type V cement and number of curing periods while there was an increment in UCS of sample stabilized with Type I/III cement with increase in the number of curing periods only with 8% cement content [14].

For Soil-S, the unconfined compressive strength increases with both increments in percentage cement content (8%, 12% and 16%) of Type V cement and number of curing periods while there was an increment in UCS of sample stabilized with Type I/III cement with increase in the number of curing periods only with 8% and 12% cement contents [14].

Volumetric change

Both untreated cases of Soil-S and Soil-L had high volumetric swell potential ranging from 12% to 18%. Addition of stabilizers resulted in a decrease in swelling to below 1% both when Type I/III and Type V cement types were added [14].

It can be concluded that, an addition of stabilizer (cement Type I/III and Type V) decreases both the LL and PI of a high-plasticity clay. Also, it has been confirmed that UCS of expansive soils increased with an increase in stabilizer content and curing period. Optimum cement content required for treating an expansive soil is likely to be between 8%-10% as further increase in cement content may not necessarily increase the strength rather it may lead to the impairment of expected performance. Also, addition of cement (Type I/III and Type V) to an expansive soil resulted in a huge decrease in swelling potential to less than 1% [14].

Thus, based on the test results and conclusion, cements (Type I/III and Type V) can be recommended for treating an expansive soil with high-plasticity clay using 8%-10% cement content as this would not only improve the Unconfined Compressive Strength but also reduce the swelling potential of such soils to a value less than one (1) [14].

Antik et al., carried out an experimental research work which mainly focused on soil stabilization using cement to improve geotechnical properties such as plasticity, compaction, and unconfined compressive strength of the soil sample collected from behind Kalinga University main building, Naya Raipur, Chhattisgarh [15]. The physical properties of this soil before the stabilization process were determined as follows: LL=45%, PL=27%, PI=18%, SL=20%, G=3%, Sand=52%, Silt=24%, Clay=21%, NMC=7%, MDD=1.96 gm/cm^3, and OMC=14%.

The stabilization of soil with cement was carried out in-situ and the procedure used is highlighted below:

- Subgrade material was spread on top of embankment layer (150mm + 25% loose) and lightly compacted.
- Total work area is marked with equal grids of 2.5 m × 2.5 m size and each grid required 1 bag of cement
- Soil and cement mix by mechanical harrow followed by tractor mounted rotovator
- Moisture added to the soil (+/-1% of OMC)
- Compaction was done using flat roller
- Quality Control and Quality Assurance was conducted as per the frequency [15].

The physical properties of soil were investigated after the stabilization process and the following were observed: LL, PL, and PI increased for every percentage increased in cement content. Unconfined Compressive Strength increased for every increments in both the percentage of cement content and number of curing days [15].

From the test results, it was concluded that, for any silty sand with some clayey contents, cement is effective as a stabilizing agent and the unconfined compressive strength shall varies with both the increment in percentage of cement content and the number of curing days simultaneously. Therefore, based on this conclusion, 1%, 3% or 5% cement contents is recommended for a silty sand soil with certain clayey content depending on the magnitude of unconfined compressive strength required. And this can also be altered by the number of curing periods (days) [15].

According to Zhongjie et al, carried out an investigation on the durability of cement stabilized soils using three different testing methods such as tube suction (TS), 7-day unconfined compression strength (UCS), and wetting-drying durability tests [16]. The soil commonly encountered in Louisiana was used for the investigations and was classified as CL (clay with low plasticity) and A-6 according to the Unified Soil Classification System (USCS) and the AASHTO system, respectively with the following physical indices characteristics 71.7% Silt, 24.5% Clay, 37% LL, 15% PI, 18.5% OMC and 16.4 kN/m^3 MDD. For this investigation, Type I Portland cement was used to stabilize the soil at six different cement dosages 2.5, 4.5, 6.5, 8.5, 10.5, and 12.5% by the dry weight of the soil were adopted to stabilize the soil at four different water contents 15.5, 18.5, 21.5, and 24.5%. Small increments in cement and molding moisture contents were used to check their influences on the properties of cement-treated/stabilized soil. The test results indicate that the water–cement ratio of cement-stabilized soil had the dominant influence on the maximum dielectric value DV, 7-day UCS, and durability of stabilized samples tested, although the dry unit weight of cement-stabilized soil could cause the variation of the results. This study confirms that TS, 7-day UCS, and wetting-drying durability tests are equivalent in predicting durability, and tentative charts to ensuring the durability of cement-stabilized low plasticity soils are developed using their 7-day UCS or the maximum DV values. However, it was recommended that different sources of CL soils should be tested and plotted in the charts with their durability and the 7-day UCS or maximum DV to make these two charts usable for future design and construction.

Also, in an research paper published by Eskedil, 2014 on soil samples obtained from the south western part of Ethiopia, Gambella region where an experimental investigation on the effectiveness of bitumen and cement as additives to improve the engineering properties of the soil through soil stabilization for the base course in road construction. Sampling of samples was carried out in three different locations and samples from these locations are labelled 0+000, 3+360 and 5+400 respectively. Quality tests on the natural sand and the additive materials using AASHTO method were carried out. According to the USCS system of classification, the natural sand is classified as poorly graded sand and falls under SP soil group. The cement stabilization test was carried out on this sample using 7%, 8.5%, 9% and 10% cement contents. Moisture-Density test shows an increase in the MDD and the corresponding decrease in OMC with an increase in the percentage cement content from 7% up to 9% while the MDD becomes approximately equal with further increment in cement content. Also, the result of unconfined compression test shows a corresponding increase in compressive strength as the cement content increases. The minimum strength requirement specified in TM 5-822-14/AFMAN 32-8010 for base course is 5.2 MPa, and this criteria is fulfilled by the soil-cement mixtures with cement contents of 10% was 5.9 MPa. Thus, optimum binder content is 10% and above [16].

Economic evaluation of road-base stabilized with cement and bitumen was carried out and was found that road-base stabilized with cement is more economical considering for alternative pavement structures. It was concluded that the engineering properties of the test sand can only improve to meet the base course requirements by adding 74.5% sand, 20% sulfur, and 5.5% bitumen while 10% by weight of sand of Portland cement meets both the strength and durability requirements of base course [16-19].

Conclusions and Recommendations

Conclusions

Based on the experimental research results reviewed in the above published articles, the following conclusions can be made:

- Cement as a soil stabilizer for improving the engineering properties of problematic soils for rail track subgrade and highway base and subbase courses has been investigated and confirmed. Therefore, to optimally increase the bearing capacity of SC/SM soil to be used for subgrade of railway track, 6% cement content is optimal.
- It can also be concluded that, for a silty clay (CM), an optimal 14% cement content for an effective soil-cement with the requirements in terms of plasticity and CBR values for subgrade railways track, subbase and base courses materials for road embankment construction.
- For site condition with predominance in sand or sand silty (SM), cement is effective as a stabilizer with the cement contents of 8% to 10% in order to achieve 11 to 12 times compressive strength compare with that of 0% cement content.
- Based on the test results of the effects cements (Type I/III and Type V) on an expansive soil with high-plasticity clay, it can be concluded that, for treating such site condition to be useful for rail track subgrade and highway base and subbase course, using 8% to 10% cement content would not only improve the Unconfined Compressive Strength but also reduce the swelling potential of such soils to a value less than 1%.
- Also, for SP soil, an optimal cement content of 10% has been confirmed to be adequate to meets both the strength and durability requirements of base course and rail track subgrade.
- It can also be concluded that, 1%, 3% or 5% cement contents will be effective to treat a silty sand (SM) soil with certain clayey content depending on the desired unconfined compressive strength. Also, these UCS values are affected by the number of curing periods (days).

Recommendations

In accordance with the above conclusions, the following recommendations are made:

- Cement has been found effective as stabilizer for all the site conditions investigated in the reviewed experimental research published papers as highlighted above.
- However, further research has to be carried out as the percentage of cement content varies from region to region and from soil characteristics to another. This is necessary so as to determine the optimal percentage of cement content that would yield the desired subgrade CBR values with some other index properties.

Data Availability Statement

No data, models, or codes were generated or used during the study.

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