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Strength Evaluation of Clayey Sand Admixed with Wollostonite with A Special Reference To Construction of Geotextile Reinforced Subgrade

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Abstract

Objectives: To enhance the performance of subgrade constructed using Clayey sand. Clayey sand is a commonly found inferior soil and it is made to be suitable for flexible pavement construction. This study is intended to make Clayey sand suitable by admixing with Wollastonite and embedding with geotextile reinforcement. **Methods:** The study involved laboratory tests to determine the optimal dosage of Wollastonite to stabilize clayey sand. Tests included Unconfined Compressive Strength (UCS) and California Bearing Ratio (CBR) evaluations. Subsequently, geotextile reinforcement was incorporated with the Wollastonite-stabilized soil to further enhance its strength characteristics. **Findings:** The research revealed that Clayey sand, in its original form, is unsuitable for subgrade construction due to its poor strength properties. Admixing with Wollastonite significantly improved its strength and expected performance was observed at a specific dosage. Further enhancement was achieved by embedding geotextile reinforcement, which increased both UCS and CBR values. The combination of Wollastonite stabilization and geotextile reinforcement yielded requisite strength for Clayey Sand with respect to strength and stability thus making it suitable for subgrade construction of the flexible pavement. These findings are consistent with existing literature on soil stabilization techniques, but the usage of Wollastonite and geotextile in this context presents a novel approach. The results highlight the potential of this method to address the scarcity of suitable subgrade soils, offering a viable solution for pavement construction projects with inferior soils. **Novelty:** The study introduces Wollastonite and geotextile reinforcement as effective methods to stabilize and enhance the strength of Clayey sand for subgrade construction in flexible pavements.

Keywords: Soil Stabilization; Clayey Sand; Subgrade; Wollostonite; Geotextile; Unconfined Compressive Strength; California Bearing Ratio

1 Introduction

Aggregates are often costly, it is critical to keep the aggregate layer thickness of subgrade in pavements as low as possible for a given service life. The design of the pavement layers is extremely important with respect to the strength of the subgrade soil over which they need to be laid. Subgrade life is purely depending on the strength properties and type of soil used in the construction[(1)]. The strength of the soil subgrade is usually mentioned in the form of the California Bearing Ratio (CBR) of soil. Weak subgrade fundamentally requires more number and soil layers with more thickness whereas stronger subgrade does well with less number and relatively thinner pavement layers[(2)]. The pavement system in total and therefore the subgrade jointly must sustain various wheel loads and hence traffic volume. At many instances, subgrade soils are found to be inadequate with reference to strength resulting to detrimental effect on roadways and other structures built on such soils[(3)]. Roadways constructed on these inferior soils suffer from lower serviceability eventually the roadway becomes rough, causing discomfort for drivers, accidents, and creating a potentially hazardous condition[(4)]. Since no availability of good soils for subgrade construction at many work sites, it has become essential to go for soil stabilization. Soil stabilization is a technique that involves a process to treat weak soil that is not suitable as it is and with the purpose to keep up or improving the performance of this weak soil as a subgrade construction material. Further, quality soils have become scarce and costly in many worksites due to enormous construction activities being taken up for the improvement and development of pavement facilities. The pavement industry also looks for procedures for improving lower-quality soils that are readily available for utilization in roadway construction[(5)].

Soil stabilization is broadly referred to as one of the efficient options for improving soil properties and is considered as an efficient solution for soil improvement. Given the thickness of the aggregate layer by mixing local weak soils with stabilizers it is possible to make better use of them for subgrade construction. The use of stabilizing materials is intended to provide strength that allows for a lower construction cost as well as better performance with regard to pavements. A variety of stabilization methods has been proposed within the construction of pavement to improve the performance behavior of subgrade[(6)]. These methods are suggested by many investigators to stop the potential damage. Experiences concerning improvement in the functional behavior of soil subgrades showed a big enhancement in strength and a notable reduction in deformation when subgrades are treated by a group of admixtures namely cement, lime, fly ash, etc[(7)] But it is found that there is a lack of data with reference to the type of additive(s) is to be added for a specific type of soil and to form them suitable for subgrade construction. Stabilization of soils is often accomplished by means of mechanical or chemical modifications. Mechanical stabilization is related to the compaction of soil mass that leads to the densification of soil by the application of weights[(8)]. The chemical stabilization process involves blending or infusing/injecting soil thoroughly mixed with chemically active compounds such as fly ash, cement, lime, and sodium/calcium chloride with/without visco–elastic materials such as bitumen[(9)]. Normally, the primary and widely used chemical admixtures are cement and lime. These additives are most often related to improving the strength of subgrade soils and may be used with a spread of soils. This kind of stabilization technique could extend the life of a pavement. Thereby the transportation and construction costs have environmental impacts that could be often reduced and satisfactory performance of the pavements built on these inferior soils is achieved[(10)]. Furthermore, in many instances, this can be accomplished by adopting techniques such as a stabilizing approach with various types of materials and reinforcing with geotextile. The stabilizing agent improves the strength parameters of the subgrade of pavement and leads to its long-term performance. When it comes to the process of stabilizing soil it is vital to comprehend the soil properties that are involved in the mix and the resultant product following mixing. Furthermore, it is crucial to assess the effectiveness of the soil stabilized after mixing. Hence, investigating and exploring the viability of such soils for subgrade construction could be the need of the hour. Stabilization would facilitate pavement construction in developing a more robust, long-lasting, and reliable road network with proper planning.

The present research work encompasses to identify and address the massive shear failure attributable to the low shear strength of subgrade soils by studying the engineering behavior and to determine the optimum dosage of various admixtures for stabilization of locally available marginal soil subgrade. It also evaluated the shear failure criteria of subgrade soil used in the study.

2 Materials used in the study

2.1. Low Quality Soil

Worldwide in the most instances, for the construction of subgrade for pavements the inferior soils have been used because of the paucity of suitable soils. The main reason for the failure of the pavement performance is due to usage of these inferior soils. Hence, there is a dire need for the study of the performance of these soils and make them suitable for the construction of subgrades. Keeping this reason in view, in this study, locally available low-quality soils (LS) have been selected for experimental work which is not suitable for subgrade as it is. The specific gravity of the soil sample considered is 2.51 and the grain size distribution results obtained through sieve analysis and the percentage of gravel is found to be 10, sand 54, silt 17, and clay 19. The soil sample was also tested for Atterberg limits viz., liquid limit (w_L) and plastic limit (w_P) which resulted in 41% and 23 % respectively. Further, the compaction test results yielded optimum moisture content (OMC) of 18% and maximum dry density (MDD) of 1.85 g/cm^3. The strength tests performed on the soil sample gave results of 49kPa for Unconfined undrained condition compressive strength (c_u) and for consolidated drained conditions (ϕ_u) 190 kPa, while the California bearing ratio (CBR) was 5% and coefficient of permeability (k) is 6.01×10^{-5} cm/sec.

2.2. Wollostonite

Wollostonite is a discarded material that powders that are used to stabilize the clayey sand used in the current research. Wollastonite is a Calcium Silicate mineral that has very little Iron, Magnesium, and Manganese substituted for Calcium. It is typically encountered with a white hue. The molecular formula for it is $CaSiO_3$ with its theoretical formula composed of 48.28 % CaO and 51.72 % SiO_2. It is used for the manufacturing of tiles and ceramics because of its chemical properties that are remarkably like cement. Due to this similarity when compared to cement Wollostonite can be utilized as an agent for stabilization. In this study, Wollostonite has been used as an admixing material to enhance the clayey sand's properties (low quality) was chosen. The material utilized in this research study was obtained at Adhipathi Minerals & Chemicals Private Limited, Hyderabad, Telangana. The cost is INR 14,000 for a metric ton (1000 kilograms). Wollostonite is a Calcium silicate mineral ($CaSiO_3$) that is found in all areas below the ground surface. It contains tiny amounts of Iron, Magnesium, and Manganese which are substitutes for Calcium. It is ideally suited to diverse engineering applications across different industries. It is a byproduct of impure limestone that is subjected to high temperatures, with the benefit of less humidity and low absorption of oil. It has chemical properties that are similar to cement and therefore is used in the making of tiles and ceramics. Due to this resemblance to cement Wollostonite has been proposed to improve the soil's properties.

In this study, the anticipated improvement due to stabilization by Wollostonite is improved soil gradation, less plasticity index, an increase in strength, and appropriate durability. Adding optimum amounts of Wollostonite to clayey sand may improve the compressive strength of the unconfined and increase the dry density. Additionally, it is expected to offer higher performance in terms of California bearing coefficient. The chemical and physical properties of Wollostonite are listed in Table 1.

Table 1. Properties of Wollostonite

Properties	Wollostonite
Appearance	White
Form	Powder
Hardness (Moths)	5.1
pH	9.0
Melting Point (^{0}c)	1610
CaO	46%
SiO_2	49

Continued on next page

Table 1 continued

Sedimentation	46
Whiteness	89

2.3. Geotextile

The use of geotextiles in construction and pavement applications has long been recognized as a cost-saving technique and performance-enhancing solution over traditional construction techniques. In many engineering applications, a geotextile fulfills a stabilization technique or reinforcement function. In this process, the geotextile allows the soil to take up higher loads and thus supports the soil in providing tensile strength when subject to vertical loads. There are three distinct mechanisms by which a geotextile can stabilize the soil subgrade and improve its resistance to permanent deformation under repetitive traffic loading. Utilization of geotextiles in the layers of pavements provides two basic contributions such as separation and reinforcement. Geotextile reinforcement reduces rutting and hence maintenance costs could be reduced. Geotextile reinforcement within the pavement layers could greatly improve the overall performance of pavements. In most instances, the inclusion of nonwoven geotextile in a subgrade-geotextile-base system has shown improved performance while compensating for the weakness of soil mass. In the present study a non-woven geotextile, the trade name DuPont Typar SF56 was used. This geotextile was so selected that it acts as only reinforcement without contributing to providing extra strength during compression. The properties are given in Table 2.

Table 2. Properties of DuPont Typar SF 56

Property	Value
Mass per unit area	200 g/m^2
Thickness	0.60 mm
Tensile Strength	13 kN/m
Elongation at maximum load	55%
Dynamic Perforation Resistance	22 mm
Resistance to Static Puncture	1.85 kN
Opening Size O_{90}	80 μm
Permeability	35X 10^{-3} m/s

3 Methodology

Keeping in view the advantages of soil stabilization and geotextile reinforcement, the present study was planned to characterize the most predominant type of low-quality subgrade soil in Telangana State, India. In this investigation, its deficient properties for possible strengthening will be studied to make it suitable for pavement subgrade construction. This work is also to evaluate the suitability and performance of low-quality soil by adding admixtures such as Wollostonite. The effectiveness of the low-quality soil was evaluated without and with Wollostonite. New composite clayey sand mixed with Wollostonite was proposed based on laboratory investigations pertaining to Unconfined Compressive Strength (UCS) and California Bearing Ratio (CBR) thus clayey sand (low-quality soil) could be suggested for pavement subgrade construction. The properties of stabilized clayey sand such as compaction characteristics, UCS, and CBR were evaluated and with variations in admixture quantity, these characteristics with respect to the content of admixed Wollostonite were evaluated. The laboratory experiments were conducted by reinforcing the soil with geotextile namely, Typar SF 56, and assessed for its suitability for subgrade construction. Based on the literature review, there's a dire need to propose an efficient, useful, and viable solution for the improvement of subgrade soils with inadequate strength properties. The type of soil has a noteworthy influence over the soil subgrade and its strength. During this study, a poor type of selected soil subgrades within the Telangana State region would be chosen to simulate inferior soil types. This research work is proposed to be undertaken to review the effect caused by the plain clayey sand and combined action of Wollostonite on the variation of strength properties, and optimum dosage of the admixtures. In this study the only admixture i.e., Wollostonite was chosen for the modification of soils. Other stabilization methods including soil reinforcement techniques using geotextile that directly influence the strength characteristics of selected subgrade soils would be proposed.

3.1. Liquid Limit

The Atterberg limit tests were conducted on plain clayey sand samples and clayey sand samples admixed with different percentages of Wollostonite. The liquid limit tests were conducted in accordance with IS: 2720 (part: 5) – 1985. The test results of the liquid limit of the clayey sand samples admixed in different proportions of Wollostonite are presented in Table 3.

Table 3. Liquid Limit Testing with various combinations

Clayey Sand (SC) combination with Wollostonite	Liquid Limit (%)
SC + 0% Wollostonite	41
SC + 5% Wollostonite	37
SC + 10% Wollostonite	35
SC + 15% Wollostonite	28
SC + 20% Wollostonite	34
SC + 25% Wollostonite	36

3.2. Proctor's Compaction Test

To determine the ideal water content (OMC) and the maximum dry density (MDD) of the clayey sand samples as well as Wollostonite as soil sample, standard compaction tests were conducted. The tests were conducted according to IS 2720 (part 8) between 1980 and. The results are presented in Table 4.

Table 4. Variation of OMC and MDD with different combinations of clayey sand with Wollostonite

Clayey Sand (SC) combination with Wollostonite	OMC (%)	MDD (g/cm^3)
SC + 0% Wollostonite	18	1.85
SC + 5% Wollostonite	16	1.87
SC + 10% Wollostonite	15	1.90
SC + 15% Wollostonite	14	1.96
SC + 20% Wollostonite	17	1.92
SC + 25% Wollostonite	18	1.78

4 Strength Tests on Clayey Sand in various combinations

In this study, UCS tests and CBR tests were conducted on plain clayey sand specimens and by admixing with Wollostonite in different percentages i.e., 0, 5, 10, 15, 20 and 25% and the samples were undertaken for various experimentation viz., liquid limit and Proctor's compaction test. The UCS and CBR tests were performed in order to investigate the shear strength behavior and strength of clayey sand when it could be used as a subgrade of pavement. The detailed testing procedures are discussed herewith.

4.1. Unconfined Compression Strength (UCS) Tests

UCS tests were conducted to determine the unconfined compressive strength, which ultimately could be used to obtain the shear strength of the clayey soil sample. The tests were conducted as per IS: 2720 (part: 10) – 1991.

These tests were conducted on soil samples with a diameter of 100 mm and a height of 200 mm. The large size of samples was so chosen to illustrate and demonstrate a clear picture of the failure mechanism. The samples were prepared by means of static compaction in layers of 25 mm thick. The split mold is used to prepare all the soil samples. For this, the calculated saturated water content was added to soil mass by considering the dry weight of soil corresponding to the maximum dry density for each soil sample.

In the case of Wollostonite admixed Clayey Sand soil samples, 5, 10, 15, 20, and 25 percent of Wollostonite was added for each soil sample by taking the dry weight of clayey soil and was perfectly mixed until a mixture with uniform texture was obtained. Further, the water content exactly equal to the Optimum Moisture Content (OMC) of the plain clayey soil is added. A similar procedure is adopted for clayey soil–Soil-Wollostonite mixture sample preparation. The soil samples were compacted

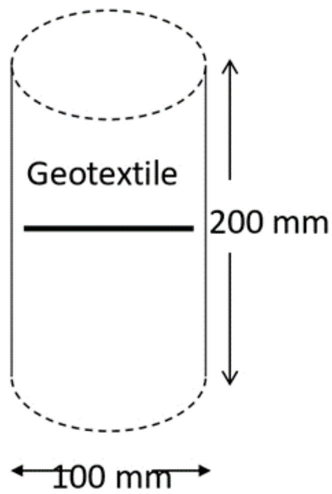

Fig 1. Placement of Geotextile at the middle height of soil specimen

using a compression testing machine to get cylindrical mould. To facilitate mellowing, the Wollostonite admixed soil samples were packed in polythene bags, sealed, and then placed in desiccators for 24 hours before testing.

Further, the soil samples were also tested by placing a geotextile, Typar SF 56 geotextile disc of diameter around 98 mm cut and placed horizontally (perpendicular to the axis of the specimen) exactly at the middle height (100 mm) of the soil specimen Figure 1.

Fig 2. Unconfined Compressive Strength Test Set up

The prepared soil samples of diameter 100 mm and a height of 200 mm were placed on the pedestal of the strain-controlled compression testing machine and loaded until failure. The strain rate of 1.20 mm/min is maintained throughout the testing. The axial deformation was measured by a dial gauge with the least count of 0.01 mm and the compressive load was recorded with the help of a proving ring Figure 2. For each test condition, three soil samples were tested to record average values, and the test results were utilized for analysis.

4.2. California Bearing Ratio (CBR) Tests (Soaked and Unsoaked Conditions)

The general rule is that the California Bearing Ratio (CBR) is a test for the depth of penetration. It is measured in units of force area required to penetrate the soil which is compacted (passing through a 18mm sieve) with the help of an elongated plunger 50mm in size at a frequency of 1.25 millimeters/min. It is used to measure the physical quality of base courses and pavement subgrades. CBR tests are utilized extensively when selecting materials for pavements as well as for managing subgrades. CBR refers to the proportion of mass per sq.inch that is required to penetrate the soil using an ordinary diameter piston at a velocity that is 1.25 millimeters/min. This is the weight needed for the identical space of a normal substance, i.e. CBR = (Test load/Standard load) 100. California Bearing ratio tests were performed to assess the strength of clayey sand, with as well as without Wollostonite. The test was conducted in accordance with IS 2720 (Part:16) from 1987.

In the current investigation, CBR tests were performed using clayey sand that was mixed with different proportions of Wollostonite in accordance with IS 2720 (Part 16)-1987 without soaking and then after a four-day soak. To determine this the soil's weight mass, without the addition of admixture (Wollostonite) is compressed by thorough mixing of the soil to achieve the highest moisture content to get an ideal dry density. Similar to the tests of unconfined compression it was set exactly at the halfway point of the specimen during CBR tests.

5 Results and Discussion

The liquid limit of the clayey sand is enhanced by admixing 5, 10, 15, 20, and 25% of Wollostonite. The liquid limit decreased up to the addition of 15% of Wollostonite and increased after 15%. Further, standard Proctor compaction test results have shown that addition of Wollostonite increased has shown the maximum dry density of the clayey sand at 15%. Hence, it is decided that the optimum quantity of Wollostonite to be admixed could be 15%.

Fig 3. Shear failure of soil specimen stabilized with Wollostonite

Fig 4. Progressive shear failure of soil specimen stabilized with Wollostonite

Sharp shear failure is observed in the case of soil samples admixed with Wollostonite Figure 3. The soil specimen embedded with geotextile has shown a progressive failure. This could be due to the development of frictional forces between soil particles and geotextile. The geotextile placed in the middle of the soil sample facilitated to take more load and the geotextile could constraint the lateral deformation of soil samples. hence it has taken more axial load i.e., Wollostonite stabilized soil reinforced with geotextile has shown a higher strength with progressive failure Figure 4.

UCS test shows that the shear strength of the plain soil gets enhanced by adding Wollostonite up to 15% and then reduced by the addition of Wollostonite above 15%.

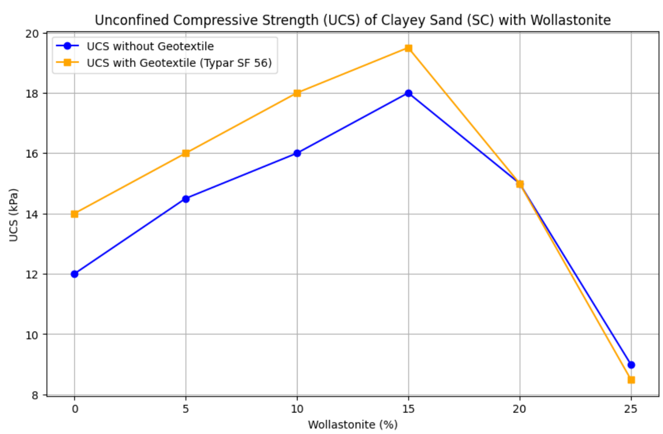

Fig 5. Unconfined Strength of soil sample without and with Geotextile

The addition of Wollostonite and the improvement in shear strength is observed by the reduced axial strain corresponding to peak stress for clayey sand admixed with Wollostonite, thus indicating its improved stiffness Figure 5. The increase in peak stress could be attributed to the cementing action supplied by the Wollostonite with the particles of clayey sand.

Further, Wollostonite could able to reduce the plasticity of clayey sand. The voids present in the clayey sand get filled up thus providing the strength to the soil mass. In the case of the Wollostonite stabilized soil sample, the shear failure was observed Figure 3.

During CBR testing, the CBR value of the Wollostonite added Clayey Sand has been increased than the plain soil sample. The admixing of Wollostonite and the improvement in CBR value could be observed Figure 6.

It could be understood that the clayey soil admixed with Wollostonite could be used as a subgrade soil for flexible pavement construction as it also exhibiting non–plastic nature with improved stiffness. The CBR value has greater significance when Wollostonite is being used as a stabilizing material. This could be due to the decrease in void ratio leading to compactness and frictional forces aroused at the interface between soil and geotextile.

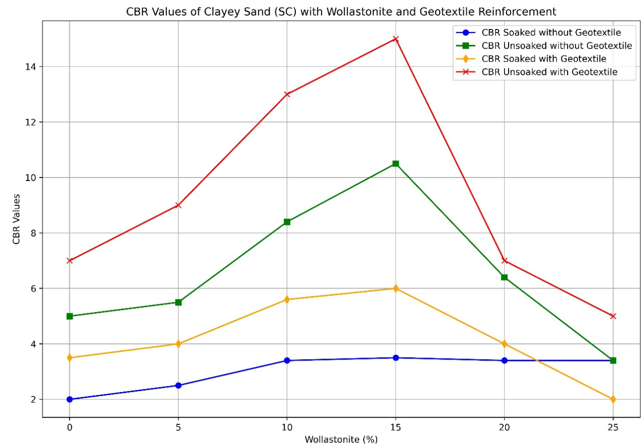

Fig 6. CBR values of soil samples under different test conditions during CBR testing

6 Conclusions

The deficit of better soil resources compels pavement engineers to adopt sustainable practices, under such circumstances it is important to use industrial waste or any such materials. Wollostonite being the refuse from ceramic industries is a beneficiary material in stabilizing the soil, especially the subgrade soil in this paper after the inclusion of Wollostonite the strength of the clayey sand increased with a reduction in OMC from 18% to 14 % and an increase in MDD from 1.85 g/cm^3 to 1.96 g/cm^3 at 15% of Wollostonite. Similarly, under consolidated drained condition the UCS increased from 49 kPa to 190 kPa, and the CBR was tested for soaked and unsoaked condition which yielded an increase of 5% to 15% and from 2% to 6% respectively. This is due to the finesse of Wollostonite allowing it to fill the gaps and provide strength in clayey sand. Further, the strength was enhanced by placing geotextiles which is evident from the test conducted that resulted in higher UCS and CBR values. The gain in the strength could be due to the interfacial frictional forces at the soil-geotextile interface. In order to support sustainability and cost-effectiveness in construction projects, the study suggests incorporating these materials into construction standards, optimizing Wollastonite and geotextile combinations, and carrying out comprehensive field trials to validate findings.

References

1) Yaghoubi E, Sudarsanan N, Arulrajah A. Stress-strain response analysis of demolition wastes as aggregate base course of pavements. *Transportation Geotechnics*. 2021;30:100599–100599. Available from: https://doi.org/10.1016/j.trgeo.2021.100599.
2) Akmaz E, Ullah S, Tanyu BF, Guler EF. Construction Quality Control of Unbound Base Course using Light Weight Deflectometer where Reclaimed Asphalt Pavement Aggregate is Used as an Example. vol. 2674. 2020;p. 989–1002. Available from: https://journals.sagepub.com/doi/abs/10.1177/0361198120934473.
3) Pranav S, Aggarwal S, Yang EH, Sarkar K, A, Singh P, et al. Alternative materials for wearing course of concrete pavements: A critical review. *Constr Build Mater*. 2020;236:117609–117609. Available from: https://doi.org/10.1016/j.conbuildmat.2019.117609.
4) Zhu S, Zhang JX, Shao Z, Li D, Yun H, C. Evolution characteristics of the surface texture of the wearing course on asphalt pavement based on accelerated pavement polishing. *Constr Build Mater*. 2022;333:127266–127266. Available from: https://doi.org/10.1016/j.conbuildmat.2022.127266.
5) Tuladhar R, Marshall A, Sivakugan N. Use of recycled concrete aggregate for pavement construction. *Advances in Construction and Demolition Waste Recycling: Management, Processing and Environmental Assessment*. 2020;p. 181–97. Available from: https://doi.org/10.1016/b978-0-12-819055-5.00010-3.
6) Kawamura M, Torii K. Reuse of Recycled Concrete Aggregate for Pavement. Demolition Reuse Conc Mason V2 [. 2023;p. 726–761. Available from: https://doi.org/10.1201/9781003416562-26.
7) Rahman MM, Beecham S, Iqbal A, Karim MR, Rabbi A. Sustainability Assessment of Using Recycled Aggregates in Concrete Block Pavements. *Sustainability*. 2020;2020(10):4313–4313. Available from: https://doi.org/10.3390/su12104313.
8) Ullah S, Tanyu BF, Zainab B. Development of an artificial neural network (ANN)-based model to predict permanent deformation of base course containing reclaimed asphalt pavement (RAP). . In: and others, editor. Road Materials and Pavement Design . 2021. Available from: https://doi.org/10.1080/14680629.2020.1773304.
9) Singh M, Adhikari A, Maurya MK, Srivastava A, Chhabra RS. Feasibility Study on Use of Washed-Reclaimed Asphalt as a Partial Replacement of Natural Aggregate in Dry-Lean Concrete as Base Course for Rigid Pavement. *Journal of Materials in Civil Engineering*. 2020;32(9):4020266–4020266. Available from: https://doi.org/10.1061/(asce)mt.1943-5533.0003339.
10) Byun YH, Feng B, Qamhia I, Tutumluer E. Aggregate Properties Affecting Shear Strength and Permanent Deformation Characteristics of Unbound-Base Course Materials. *Journal of Materials in Civil*. 2019;32(1):4019332–4019332. Available from: https://doi.org/10.1061/(asce)mt.1943-5533.0003000.