Effects of Delay Time on Compaction and Strength Properties of Stabilized Granular Soil

B Siva Manikanta Kumar [1[0000-0001-6280-7465]] Ch. Sreenivasulu[2] Suresh Prasad Singh[3[0000-0002-5818-3415]]

[1]M.Tech, Civil Engineering Department, NIT Rourkela, Rourkela-769008
E-mail: 217ce1426@nitrkl.ac.in
[2] M.Tech, Civil Engineering Department, NIT Rourkela, Rourkela-769008
E-mail: 218ce1278@nitrkl.ac.in
[3]Professor, Civil Engineering Department, NIT Rourkela, Rourkela-769008
E-mail: spsingh@nitrkl.ac.in

Abstract. Weak and marginal soils are conventionally stabilized with chemical stabilizers like lime and cement. During construction, sometimes inevitable delays occur between mixing of stabilizer with the soil and compaction, which have adverse effects on the geoengineering properties of the stabilized soil structures. The present study emphasizes on the effects of delay time on compaction and strength properties of a granular soil stabilized with three different stabilizers i.e. lime, cement and slag based geopolymers. In this study, these three different stabilizers were added with soil in different proportions varying from 0 to 15% of the dry soil and the effect of time lag was studied individually. The optimum moisture contents (OMC) and maximum dry densities (MDD) of these mixtures were determined after a time lag of 0, 3, 6, 12, 24, 48, 72, 168 hours. Further, cylindrical specimens of size 36 mm diameter and 72 mm length were prepared for all these mixes compacted to MDD at OMC taking into the effects of delay. Before conducting the UCS test, these specimens were cured at an average temperature of 30 0C for 0, 7, and 28 days in closed secure environment for assuring the prevention of moisture loss while curing. It was observed that, the delay time significantly affect the OMC and MDD of mixes and it is more noticeable in case of cement and geopolymer binders than the lime. Similarly, delay time affects the strength of cement and geopolymer stabilized mixes more adversely than lime stabilized mixes.

Keywords: Soil stabilization, Delay time, Compaction Characteristics, Strength properties.

1 Introduction

When cement added to soil and the saturated sample compacted and cured results into a hard durable soil cement mixture. When the mixture of soil and cement is properly compacted at the time of construction, it becomes resistant to deterioration due to moisture and weather and also its deformation does not happen due to heavy traffic loads. Baghdadi et al. (1995) found that cement kiln dust (CKD) can significantly decrease the optimum moisture content and increase the maximum dry density of pure kaolinite when the CKD content is less than 50%. Miller and Azad (2000) observed an increase in the optimum moisture content and a decrease in the maximum dry density when CKD was added into three types of soil with different high, medium, and low plasticity and concluded that the effect of CKD on optimum moisture content and maximum dry density is obviously a function of soil and CKD type as well as compaction method. Soil stabilization is a well-established discipline within geotechnical engineering. Cement is preferred for lowly cohesive (sandy) soils but it loses effectiveness for highly plastic soils. Cement is the most commonly used stabilizer and its popularity is due to its ability to gain strength quickly and to obtain desirable mechanical properties with relatively low amounts of stabilizer.

Addition of lime to soils improves the workability and increases the strength of the mixtures, although strength gains are not as great as those due to addition of cement. For clayey soils, lime is generally used as a stabilizing agent because it flocculates the clay and increases the plasticity. Cementation ultimately results in slowing the Pozzolanic reaction. Clay is flocculated by cement due to free lime content. When both cement and lime are added to the soil, the lime causes ease mixing, and the cement gives strength and durability. Currently chemical stabilization of soils is the most common method. Stabilizers like cement and lime are used. But due to more usage of cement, it has given rise to environmental issues like dust generation and CO_2 emission. Geopolymer is a developing material as an alternative to cement. Aside from the environmental problems geopolymer stabilized soils have shown advanced properties to satisfy the microstructural and mechanical properties. When compared to compressive strengths of OPC specimen, light weight GGBS based geopolymer stabilized specimen has given 200-350% more strength.

Time elapses between mixing and compaction vary depending upon the construction method employed. During construction, a time lag may elapse between soil–lime mixing and compaction due to hitches or technical breaks for logistic reasons. In reviewing literature, conflicting recommendations and opinions can be found concerning the influence of delayed compaction. Studies developed by the Louisiana Department of Transport in the early sixties pointed out that a delay longer than 48 hours results a lower strength of the soil–lime mixtures. Mitchell and Hooper (1961) found that a 24 hour delayed compaction reduces the dry unit weight and the long-term strength, whereas the swelling was found to increase.

2 Materials

Portland slag cement (PSC) of Konark brand is used as a stabilizing agent. The properties of PSC are given in table 1. Lime (Calcium hydroxide) is of Loba chemie brand used as another chemical agent with 95% purity and placed in sealed container. River Sand - River sand from Koel River is used as a base material. The properties of river sand have given in table 2. Ground granulated blast furnace slag - Slag used for study is blast furnace slag obtained from the Rourkela steel plants. Slag was 10 mm in size initially which is grounded in a ball mill and sieved through 75 mm sieve before mixing to prepare samples. GGBS used is milky white in colour and has specific gravity of 2.82. Sodium hydroxide - Laboratory grade sodium hydroxide pellets with 98% purity were used to prepare solution. Figure below shows the image of NaOH pellets.

Table 1. Physical properties of Portland slag cement

Physical property	Value
Specific gravity	3.0
Consistency of cement	33.5%
Initial setting time	2hr 38min
Final setting time	9hr 45min

Table-2. Physical properties of River sand

Physical property	Value
Specific gravity	2.64
Uniformity Coefficient (Cu)	3.0
Coefficient of Gradation (Cc)	0.925
Maximum Dry Unit Weight (MDD)	17 kN/m^3
Optimum Moisture Content (OMC)	15.1%

3 Methodology

Using different percentages of cement and lime (i.e. 2.5, 5, 7.5, 10 and 15%) mixed with sand, and 5, 10 and 15% of slag based geopolymer using sodium hydroxide (NaOH) as an activator by dry weight of the soil. The maximum dry density and optimum moisture content are determined by using light and heavy compaction test, as per IS-2720(7, 8). The delayed compaction (3hrs, 6hrs, 12hrs, 24hrs, 48hrs, 3 days and 7 days) for the samples with different percentages of cement, lime and slag based geopolymer are studied. Using the mix, samples are prepared and cured for curing periods of 0, 7 and 14 days at a constant temperature of 30^{o}C and UCS test is conducted as per IS-2720 (10).

4 Result and discussion

4.1 Compaction characteristics

With increasing lime content, the maximum dry density (MDD) is increased and the corresponding optimum moisture content (OMC) is decreased for both light compaction and heavy compaction test. In case of sand-lime mixture, the MDD increased from 18 to 19.2 kN/m^3 and OMC decreased from 17.2 % to 13.1 % for light compaction as shown in Fig 1 and 2. For heavy compaction, the MDD increased from 19.1 to 20.3 kN/m^3 and OMC decreased from 16 % to 11.7 % as shown in Fig 3 and 4.

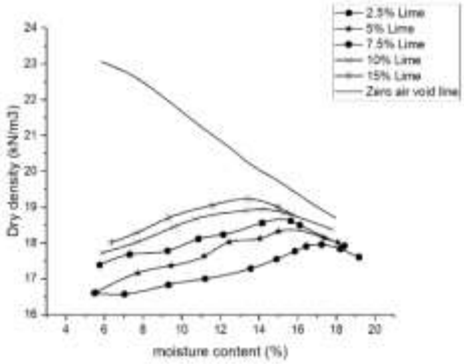

Fig 1. Light compaction curves of sand lime mixes

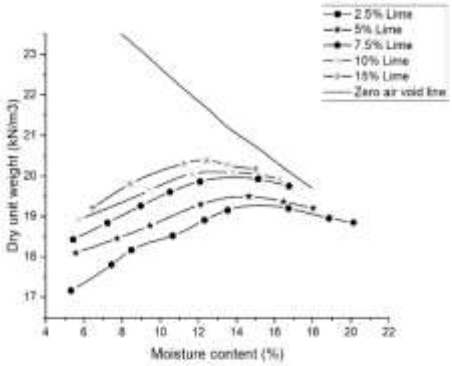

Fig 2. Heavy compaction curves of sand lime mixes

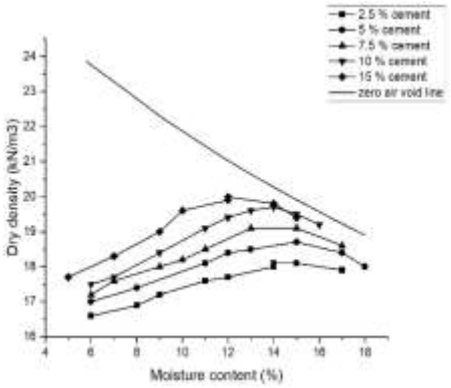

Fig 3. Light compaction curves of sand cement mixes

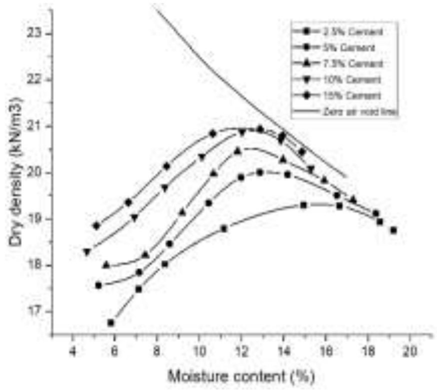

Fig 4. Heavy compaction curves of sand cement mixes

It has been observed that, the MDD increased by 6.29 % and the OMC decreased by 26.9 % when lime content increased from 2.5 % to 15%. In the same way, for sand-cement mix in light compaction, from the Fig 5 it is observed that the MDD increased by 10.49 % and OMC decreased by 19.35 % when the cement content is increased from 2.5 % to 15 %. Similarly, for heavy compaction MDD increases by 8.8 % and OMC decreases by 20% with the increase of cement content from 2.5 % to 15 % as shown in Fig 6. In the same way slag based geopolymer MDD increased from 19.92

to 21.26 kN/m^3 and OMC decreased from 10.81 % to 8.85 % for heavy compaction and incase of light compaction MDD increased 19.27 to 20.69 kN/m^3 and OMC decreased from 12.45 % to 9.86 % as shown in Fig 7 and 8.

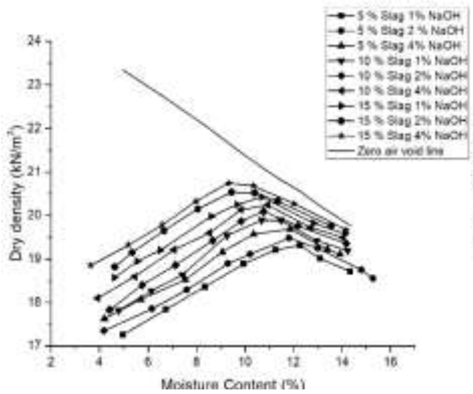

Fig 5. Light compaction curves of sand and slag based geopolymer mixes

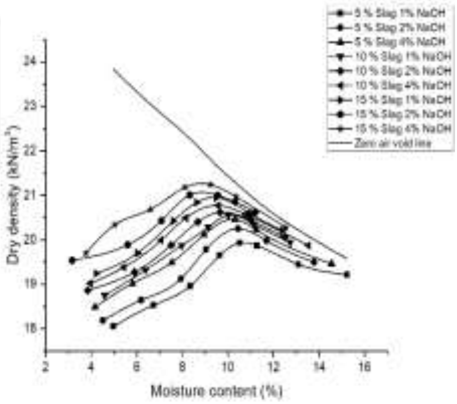

Fig 6. Heavy compaction curves of sand and slag based geopolymer mixes

4.2 Delayed compaction

Sand-cement mixture, sand-lime mixture, and slag based geopolymer samples are mixed at obtained optimum moisture content (OMC) from the compaction characteristics graphs. The samples are compacted by light compaction and heavy compaction test after a delay period of 0, 3, 6, 12, 24, 48, 72 and 168 hours. For light compaction of sand-lime mix with increasing delay time the dry unit weight is reducing. From Fig 7 it is observed that for 48 hours delay period and 2.5 % lime content the MDD is 14.1 kN/m^3 and for 48 hours delay period and 15% lime content the same is 17.3 kN/m^3 i.e. increase in MDD by 22.69 %.

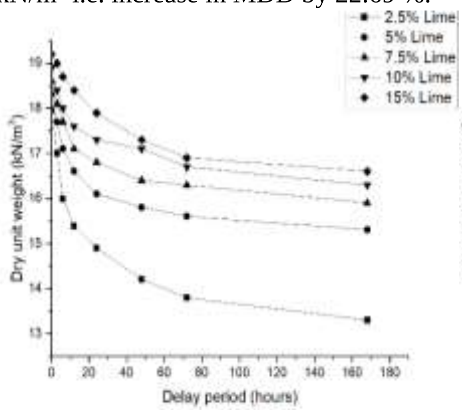

Fig 7. Variation of dry unit weight of sand lime mixes with delay time (light compaction)

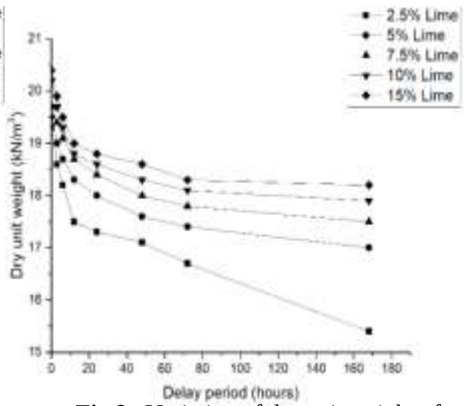

Fig 8. Variation of dry unit weight of sand lime mixes with delay time (heavy compaction)

For heavy compaction of sand-lime mix from Fig 8 it can be observed that for 168 hours delay period at 5 % lime content MDD is 17 kN/m^3 and 15 % lime content has 18.2 kN/m^3. It is also observed that for the higher percentage of lime or cement content the decrease in MDD is rapid initially with increasing delay time and then it stabilizes but for the lower percentage of lime or cement content the slope of the curve is lesser from the beginning. Compared to lime for sand-cement mix 2.5 % cement content the MDD is 15 kN/m^3 and for 48 hours delay period and 15 % cement content the same is 18.2 kN/m^3 i.e. increase in MDD by 21.33 % it can be seen in Fig 9. For heavy compaction of sand-cement mixes from Fig 10 it can be concluded that for 168 hours delay period at 5% cement content MDD is 16.4 kN/m^3 and at the same period of time 15 % cement has 17.8 kN/m^3.

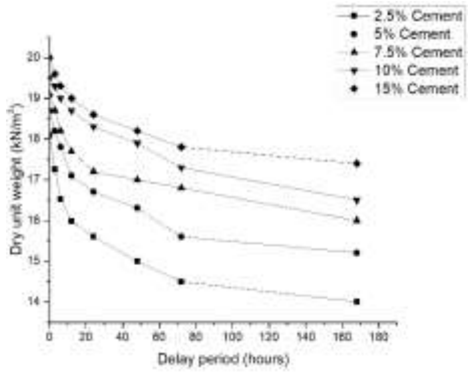

Fig 9. Variation of dry unit weight of sand cement mixes with delay time (light compaction)

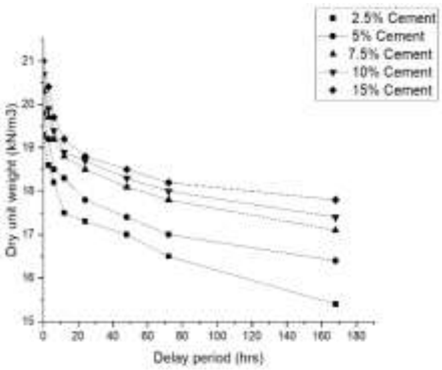

Fig 10. Variation of dry unit weight of sand cement mixes with delay time (heavy compaction)

In case of slag based geopolymer mixes for 5 % slag and 1 % NaOH for a delay period of 72 hours MDD is 14.5 kN/m^3 and for 15 % slag 1 % NaOH in case of same delay period MDD is 16.4 kN/m^3 as shown in Fig 11. For heavy compaction as shown in Fig 12, 1 % NaOH for a delay period of 24 hours MDD is 17.8 kN/m^3 and for 15 % slag 1 % NaOH of the same delay period MDD has the value 19.7 kN/m^3 i.e. increase in MDD by 10.67 %.

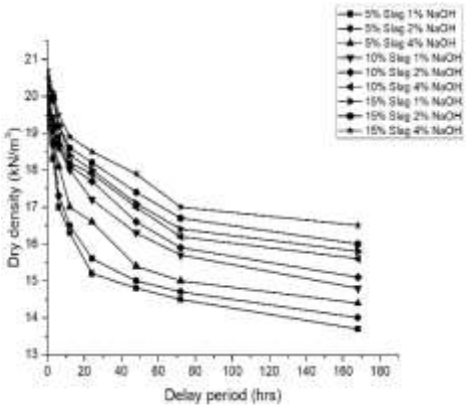

Fig 11. Variation of dry unit weight of slag based geopolymer with delay time (light compaction)

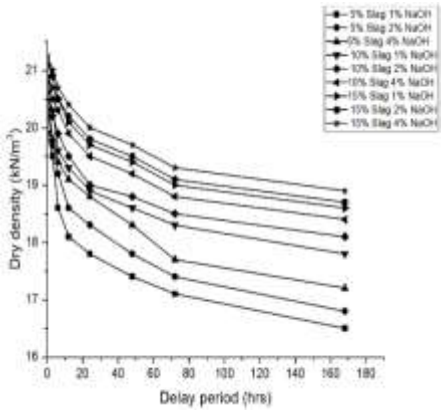

Fig 12. Variation of dry unit weight of slag based geopolymer with delay time (heavy compaction)

4.3 Unconfined compression strength

The unconfined compressive strength for sand lime mixture is increased with increase in percentage and decrease with the delay period. 10 % lime for 7-day curing period 0 hour delay the unconfined compressive strength is 234.5 kPa and for 7 days delay period 102.4 kPa i.e., the compressive strength is decreased by 56.33 % as shown in Fig 13.

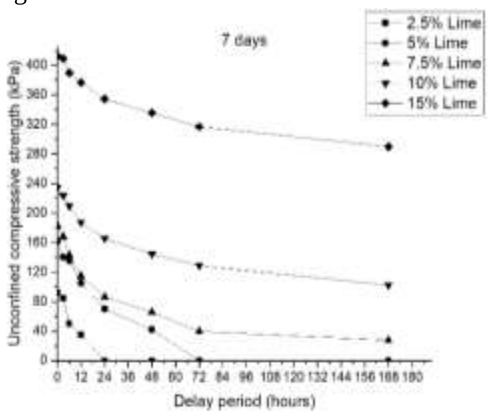

Fig 13. Variation of unconfined compressive strength for different percentages of lime (7 days)

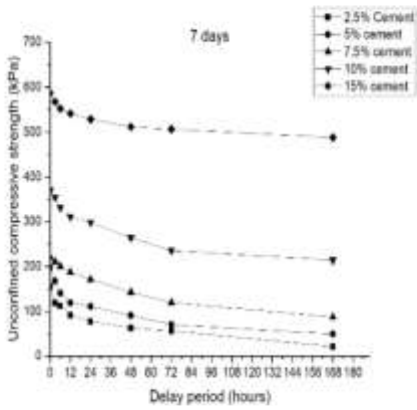

Fig 14. Variation of unconfined compressive strength for different percentages of cement (7 days)

The unconfined compressive strength for sand cement mixture is increased with increase in percentage of slag and decreases with the delay period same like sand-lime mixture. 10 % cement for 7-day curing period 0 hour delay the unconfined compressive strength is 369.6 kPa and for 7 days delay period 214.2 kPa i.e., the compressive strength is decreased by 42.04 % as shown in Fig 14. The unconfined compressive strength for slag based geopolymer mixture is increased with increase in percentage of slag and NaOH activator and decrease with the delay period. 10 % Slag 1 % NaOH activator 7 day curing period with 0 hour delay the unconfined compressive strength value is 261 kPa and 48 hour delay period 152 kPa and for 10 % slag 4 % NaOH solution the 7 day curing period with 3 hour delay 336 kPa and 48 hour delay 265 kPa as shown in Fig 15.

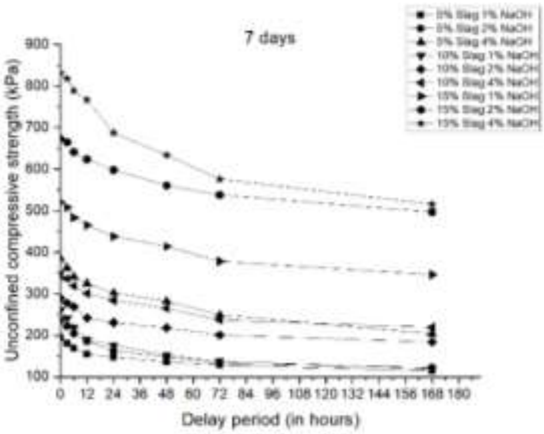

Fig 15. Variation of unconfined compressive strength for different percentages of slag based geopolymer (7days)

5 Conclusions

The effects of delay time on compaction as well as strength properties of a granular soil stabilized with three different stabilizers such as lime, cement and slag based geopolymers is studied. Stabilizers are added with soil in different proportions. The compaction characteristics (i.e. MDD and OMC) of these mixtures were determined at different time lags. UCS tests are conducted for specimens cured for different curing periods at an average temperature of 30 0C. Based on the test results, the followings are concluded. For specimens prepared at both light and heavy compaction, optimum moisture content reduced while maximum dry density increased by increasing of cement, lime contents and slag based geopolymer content. In delayed compaction, dry unit weight reduced with the time. This reduction of dry unit weight is due to hydration. For 7.5 % cement, dry density is decreased by 18 % for 24 hours when compared to 12 hours and 12 % in case of lime. It indicates that reduction in dry unit weight is faster in case of cement. For 15 % slag 4 % NaOH alkaline activator the dry density is decreased by 16 % for 24 hours when compared to 48 hours. It is also observed that, unconfined compression strength decreased with delay time and increased with the increment of cement, lime and slag based geopolymer. It is observed that the unconfined compressive strength value for 15 % cement is 29 % more when compared to that of 15 % lime after 7days curing period. In unconfined compressive strength test when compared to cement and lime, slag based geopolymer specimens has given good results.

Reference

1. Ali, H., Mohamed, M.: The effects of compaction delay and environmental temperature on the mechanical and hydraulic properties of lime-stabilized extremely high plastic clays. Applied Clay Science, 150, 333-341 (2017).
2. Baghdadi, Z. A., Fatani, M. N., Sabban, N. A.: Soil modification by cement kiln dust. Journal of Materials in Civil Engineering, 7(4), 218-222 (1995).
3. Cheng, Y., Wang, S., Li, J., Huang, X., Li, C., Wu, J.: Engineering and mineralogical properties of stabilized expansive soil compositing lime and natural pozzolana. Construction and Building Materials, 187, 1031-1038 (2018).
4. Di Sante, M., Fratalocchi, E., Mazzieri, F., Brianzoni, V.: Influence of delayed compaction on the compressibility and hydraulic conductivity of soil–lime mixtures. Engineering Geology, 185, 131-138 (2015).
5. Du, Y. J., Yu, B. W., Liu, K., Jiang, N. J., Liu, M. D.: Physical, hydraulic, and mechanical properties of clayey soil stabilized by lightweight alkali-activated slag geopolymer. Journal of Materials in Civil Engineering, 29(2), 401-417 (2016)
6. Ghadir, P., Ranjbar, N.: Clayey soil stabilization using geopolymer and Portland cement. Construction and Building Materials, 188, 361-371 (2018).
7. Quadri, H. A., Adeyemi, O. A., Bobzom, B. G.: Impact of compaction delay on the engineering properties of cement treated soil. Journal of Mechanical and Civil Engineering, *4*(6), 9-15 (2013).
8. Jin, L., Song, W., Shu, X., Huang, B.: Use of water reducer to enhance the mechanical and durability properties of cement-treated soil." Construction and Building Materials, 159, 690-694 (2018)
9. Miller, G. A., Azad, S.: Influence of soil type on stabilization with cement kiln dust. Construction and building materials, 14(2), 89-97 (2000).
10. Mitchell, J.K., Hooper, D.R.: Influence of time between mixing and compaction on properties of lime stabilized expansive clay. High. Res. Board, Bull.Washington, DC, 304, 14-31 (1961).
11. Mujedu, K. A., Adebara S. A., Lamidi I. O.: Influence of Compaction Delay on Cement Stabilized Lateritic Soil. International Conference of Science, Engineering and Environmental technology, 1(5), 29-38 (2016)
12. Okonkwo, U. N.: Effects of Compaction Delay on the Properties of Cement-Bound Lateritic Soils. Nigerian journal of technology, 28(2), 5-12 (2009).
13. Ribeiro, D., Néri, R., Cardoso, R.: Influence of water content in the UCS of soil-cement mixtures for different cement dosages. Procedia engineering, 143, 59-66 (2016).
14. Yıldız, M., Sogancı, A. S.: Effect of freezing and thawing on strength and permeability of lime-stabilized clays. Scientia Iranica, 19(4), 1013-1017 (2012).
15. Zhang, Z., Tao, M.: Durability of cement stabilized low plasticity soils. Journal of geotechnical and geoenvironmental engineering, 134(2), 203-213 (2008).
16. IS 2720: (1980-Part-3 /sec 2) Method of test for soil, Determination of specific gravity.
17. IS 2720: (1980-Part-7) Determination of water content-dry density relation using light compaction.
18. IS 2720: (1980-Part-8) Determination of water content-dry density relation using heavy compaction.
19. IS 2720: (1991-Part-10) Determination of unconfined compressive strength.
20. IS 4332: (1967-Part-1) Method of test for stabilized soils Part 1: Method of sampling and preparation of stabilized soils for testing.