Improving the bearing resistance of subgrade sandy soil using hydrated lime

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Abstract. Soil stabilisation refers to any process by which the strength, stiffness and bearing capacity of road foundations are improved by mechanical, chemical, electrical, or thermal means. The main aim of this research was to estimate the optimum lime content (OLC) required to stabilise a loose sandy soil, and to achieve this aim, experimental work was carried out to evaluate the characteristics of lime-treated sand based on determining maximum dry density (MDD), optimum moisture content (OMC), and soil bearing resistance (CBR) at 1, 3, and 7 days’ curing. The hydrated lime was used in proportions of 0, 4, 6, 8, and 10% by dry weight of the soil. The results indicated that the MDD increases as the lime proportion increased from 0 to 8%; however, a slight reduction in the soil density was observed at 10% lime inclusion. Additionally, the results revealed that the soil bearing resistance under both soaked and unsoaked conditions were improved significantly with increasing lime content. Overall, addition of 8% lime with 7 days’ curing duration, improved the stability and strength of subgrade sand soils. The findings of this work thus confirm the benefit of adding lime in field application stabilisation schemes for geotechnical and pavement engineers.

1. Introduction

The most important components of most infrastructure facilities are roads. Flexible pavements consist of multi-layers systems, with surface layers, bases, subbases, and subgrades; of these, the compacted subgrade is the most important layer, as it provides stability to the pavements’ structure by transmitting traffic loads safely to the soil strata below. A major facet of good pavement design is thus the evaluation of subgrade strength, which plays an important role in estimating the required total thickness of the pavement [1]. Weak soils, such as loose sands, organics, and soft clays, are not prima facie suitable materials for roads construction projects, as they do not provide the necessary physical properties for construction applications. However, several researches have studied soil stabilisation using various additive materials such as lime, fly ash, and cement to improve the engineering properties in order to increase the bearing capacity of such subgrade layers and to decrease settlement [2]. The most attractive technique, which is widely used in soil stabilisation, especially in geotechnical applications, is lime stabilisation[3]. This technique has a significant effect on fine-grained soil with many advantages: it is an economic technique that decreases soil plasticity, enhances soil workability, and increases the mechanical properties of soil such as CBR values, unconfined compressive strength, shear strength, and tensile strength [4][5].
2. Methodology

To achieve the aim of this paper, a sample of subgrade soil was collected from a site in Karbala city. The collected soil was then stabilised using hydrated lime in various proportions, and a series of tests conducted to select the optimum lime content to be added to subgrade soil, based on testing the soil properties for various trials at three different curing times. Figure 1 shows a flowchart of the work conducted.

![Flowchart of testing of samples](image)

**Figure 1.** Flowchart of testing of samples

3. Materials and Testing

3.1. Soil

The subgrade soil sample was collected from Al-Senaee, located on the Najaf road in Karbala at 32°34'28.49"N and 44°2'37.33"E. Figure 2 shows an aerial photo of the sample site.
The soil as collected was tested in the laboratory to identify its classification and characteristics. As illustrated in Table 1, the soil was classified as A-3 according to the American Association of State Highway and Transportation Officials (AASHTO) and as poorly graded sand (SP) according to the Unified Soil Classification System (USCS). The grain size distribution curve is shown in Figure 3. The modified proctor compaction test recommended by [6] was also carried out to achieve optimal moisture content and maximum dry density based on the removal of air voids. Figure 4 shows the proctor compaction test, after which both soaked and unsoaked CBR tests were carried out to determine the basic physical properties of the soil as per [7]. Figure 5 illustrates the soaked and unsoaked CBR test curves.

Table 1 Basic physical properties of subgrade soil

| Property                  | Test Results | Test Source |
|---------------------------|--------------|-------------|
| Soil Classification       | A-3          | [8]         |
|                           | SP           |             |
| OMC %                     | 7.8          | [8]         |
| Max. Dry Unit Weight, kN/m³ | 20           | [9]         |
| Specific Gravity (Gs)     | 2.66         | [10]        |
| Dissolved salts %         | 1.24         | [11]        |
| Uniformity Coefficient (Cu) | 3.70        | [8]         |
| Curvature Coefficient (Cc) | 0.69        |             |
| CBR soaked, %             | 20           | [12]        |
| CBR unsoaked, %           | 24           |             |
| Liquid Limit              | /            |             |
| Plastic Limit             | /            | [13]        |
| Plasticity Index          | /            |             |
| Angle of friction (ɸ)    | 35.25        | [14]        |
| Cohesion (C)              | 10.15        |             |
Figure 3. Proctor compaction curves natural soil.

Figure 4. Grain size distribution

Figure 5. Determination of soaked and unsoaked CBR for desired dry unit weight

3.2. **Hydrated Lime**

Hydrated lime, also known as calcium hydroxide, appears as a fine white powder. The hydrated lime used in this research to stabilise the subgrade soil was supplied by Karbala lime plant. The basic chemical properties of hydrated lime are summarised in Table 2.
Table 2 Basic properties of hydrated lime

| Property                           | Test results |
|------------------------------------|--------------|
| Extinguishing Time (sec)           | N/A          |
| Cao (%)                            | 67.85        |
| Ca (OH)$_2$ (%)                    | 89.57        |
| Co$_2$ (%)                         | 2.84         |
| Weight of litre (gm/L)             | 500          |
| Degree of fine on sieve 90 macro (%) | 6.0          |

3.3. Testing methods

Standardised test methods were used to identify the basic soil indices, as shown in the last column of Table 3. The California Bearing Ratio (CBR) was selected to identify the strength properties of treated and untreated soil samples, based on ASTM C1883.

3.3.1. Treated soil preparation. Stabilisation of the subgrade soil with lime was carried out to determine the optimum proportion of lime, and these experiments were carried out by mixing different percentages of lime with standard soil samples. For each sample, a series of laboratory tests including the Modified Proctor compaction test and the CBR test (soaked and unsoaked) were carried out to identify the geotechnical properties of the subgrade soil, as summarised in Table 3. For CBR tests, the soil samples were mixed with lime at the optimum water content and compacted in a mould. The samples were then cured in the moulds with both humidity and temperature controlled for 1, 3, and 7 days. After these curing times were complete, the unsaturated CBR samples were tested, while the soaked CBR samples were left in water for 4 further days.

Table 3 Properties of the treated soil

| Property                           | Percentage lime content |
|------------------------------------|-------------------------|
|                                    | 4 % | 6 % | 8 % | 10 % |
| OMC %                              | 9.1 | 8.6 | 8.5 | 8.9  |
| Max. Dry Unit Weight, kN/m$^3$      | 19.94 | 20.16 | 20.22 | 20.12 |
| 1-day CBR soaked, %                 | 41.40 | 42.65 | 62.85 | 58.11 |
| 1-day CBR unsoaked, %               | 39.63 | 75.76 | 78.55 | 100.34 |
| 3-day CBR Soaked, %                 | 51.89 | 62.15 | 64.5 | 79.32 |
| 3-day CBR unsoaked, %               | 50.44 | 69.43 | 101.82 | 98.33 |
| 7-day CBR soaked, %                 | 69.09 | 65.87 | 68.35 | 84.43 |
| 7-day CBR unsoaked, %               | 82.266 | 85.15 | 98.296 | 106.3 |

4. Results

4.1 Maximum dry unit weight and optimum moisture content of mixtures

The optimum moisture content and the maximum dry density of the untreated soil were 7.8% and 19.97 kN/m$^3$, respectively. In general, any addition of hydrated lime resulted in an increase in both maximum dry density and optimum moisture content, as shown in Figures 6 and 7. The maximum dry
density increased from 19.97 kN/m$^3$ in the natural soil to a maximum value of 20.22 kN/m$^3$ for the specimen treated with 8% hydrated lime. The increase in the maximum dry density may be the result of fine particles of lime filling the macro spaces between sand particles; thus, if too much lime is added, this separates the sand particles from each other, which gradually decreases the resulting dry density. The increase in the optimum moisture content with the addition of hydrated lime may be due to the increase of the fine fraction, as confirmed by other studies [15] [16].

![Figure 6](image_url)

**Figure 6.** Changes in maximum dry density with the addition of hydrated lime.

![Figure 7](image_url)

**Figure 7.** Changes in optimum moisture content with the addition of hydrated lime.

4.2 California bearing ratio (CBR) test

Figures 8 and 9 display the results for the soaked CBR test, and unsoaked CBR test, respectively. The results show that the addition of hydrated lime significantly increased the CBR values. These results were in good agreement with those of [5,15,17]. The CBR values for untreated soil were 24%
for the unsoaked sample and 20% for the soaked sample. All treated samples exhibited an increase in CBR value as the percentage of the added lime increased: when the lime percentage was 10%, the CBR value increased to 442.92 for the unsoaked sample and 422.15 for the soaked sample. This increase in CBR value is due to the gradual formation of cementitious compounds, the calcium-aluminate-hydrates (C-A-H), calcium-aluminum-silicate-hydrates (C-A-S-H), and calcium-silicate-hydrates (C-S-H) that are linked with pozzolanic reactions and lime renewed hydration [5,15,16]. The curing time also has a significant effect on CBR value.

The laboratory tests showed that the values of CBR for lime at 8% and 10% were very close; thus, taking into account economic and environmental factors, the optimum amount of lime and curing time for the laboratory setup were determined to be 8% with 7 days curing time.

![Figure 3](image.png)

**Figure 8.** Variation in CBR values for soaked samples with the addition of hydrated lime.

![Figure 4](image.png)

**Figure 9.** Variation in CBR value for unsoaked samples with the addition of hydrated lime.
To verify the results of this study, they were compared with the results of other research. The first study utilised was [18], where hydrated lime was also used to stabilise sandy soils. Figures 10 and 11 show a comparison of the maximum dry density results and the CBR values respectively, which indicate that an increase in the percentage of lime used leads to an increase in the amount of maximum dry density as well as an increase in the value of CBR. These results were identical to those of the current research in terms of behaviours, with the differences lying only in the precise CBR values. The percentage increase in CBR value was 170% for virgin soil fixed with 5% lime in that study, while the increase in the current research was 220% for virgin soil stabilised with 5% lime.

![Figure 10](image1.png)

**Figure 10.** Variation in maximum dry density with the addition of hydrated lime.

![Figure 11](image2.png)

**Figure 11.** Variation in CBR value with the addition of hydrated lime.

The second study examined, [19], used hydrated lime to stabilise high plasticity silty soil (MH). Figures 12 and 13 illustrate the results for maximum dry density and CBR respectively, showing that the study matched the current study with regard to a curing period of seven days. The dry density...
decreased with the increase in the percentage of lime, however, unlike the results seen in the current study, indicating an increase in the dry density with the increase in the percentage of added lime. The CBR value found by [19] was 200% that of virgin soil after reinforcement with 9% lime, while the CBR for that percentage of lime in the current study was 380% that of virgin soil.

![Figure 12](image1.png)

**Figure 12.** Variation in maximum dry density with the addition of hydrated lime.

![Figure 13](image2.png)

**Figure 13.** Variation in CBR value with the addition of hydrated lime

The third study was [20], in which hydrated lime was used to stabilise an artificial soil mixture to represent expansive soil formation. The soil mixture consisted of 60% bentonite clay and 40% silica sand. Figures 14 and 15 shows the results for the dry density and CBR values, with the study using a curing time period of three days. The dry density values increased with the increase in hydrated lime percentage, as did the CBR values. The CBR value for 9% addition of lime in [20] was 900% that of...
virgin soil, while the CBR value in the current study was 365% that of virgin soil for the corresponding rate of added hydrated lime and curing time.

![Maximum Dry Density Chart]

**Figure 14.** Variation in maximum dry density with the addition of hydrated lime.

![CBR Value Chart]

**Figure 15.** Variation in CBR value with the addition of hydrated lime

5. **Conclusions**

The following points can be concluded from the test results:

1. The value of the maximum dry density is increased with increasing percentages of lime up to 8%, after which it decreases with further increases in lime content.
2. Application of hydrated lime increases California Bearing Ratio (CBR) values by up to 4.2 times in saturated conditions and up to 4.4 times in optimum water content conditions in comparison to untreated natural soil.

3. Curing time plays an important role in increasing CBR value.

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