Modeling the Response of Wrap-faced Reinforced Lime Treated Soil Retaining Walls under Static Condition

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Abstract. This paper presents model studies conducted on geotextile wrap faced reinforced soil walls under static conditions in a rectangular model box. Untreated and lime treated clay was used as backfill soils. Numerical modeling has been done by PLAXIS software. The surcharge pressure, angle of the slopes, and different number of reinforcement layers were varied in model tests. The influence of these various parameters at different elevations of the retaining wall, settlement at the crest, and horizontal face displacement are presented in this paper. The tests were conducted at 45\(^{\circ}\) and 60\(^{\circ}\) slopes. It was seen that vertical crest settlement and horizontal displacement of reinforced soil wall decrease with an increase in reinforcing layers.

Keywords: Geosynthetics, Reinforced soils, Wrap-faced retaining walls, Lime, Numerical modeling.

1. Introduction

Reinforced soil technology has acquired broad recognition due to its constructional, functional, and cost-effective benefits for constructing walls even in less space [1]. The usage of this technology for soil retaining structures has increased enormously in infrastructural projects across the world. Retaining walls are amongst the earliest geotechnical structure since civilization. Depending upon the purpose of the project, these walls can be permanent or temporary [2]. Various researchers have done work on laboratory models of reinforced soil walls under different conditions [3, 4], and at the same time, various field studies have been done by different investigators [5, 6, 7]. Some work [8] has been done to examine the behavior of the reinforced soil wall subjected to overburden pressure and seismic loads with backfill as cement treated. The facing element in this wall was geotextile. One of the significant outcomes of this work was that the cement-treated backfill soil can provide more stability to such walls, even during earthquakes.

Some of the researches have also been done on reinforced soil structure based on numerical modeling [9, 10, 11] to study the behavior of such walls under static and dynamic conditions. The wraparound walls are built by folding an extended reinforcing component (geogrid and geotextile) through 180\(^{\circ}\) [12] to form the facing and fixing it back into the fill (Fig.1). The present paper is based on the ongoing research work by authors, in which studies are made to investigate the bearing capacity improvement, horizontal face displacement, settlement reduction of a wrap faced reinforced soil retaining wall with untreated, and lime treated clay soil backfill.
2. The Material Used in The Study

2.1. Laboratory Model Tests

Figure 2 depicts a graphical observation of the experimental model device applied in this study. The test box is a rectangular-shaped steel box, having inner dimensions of 1000 mm x 1000 mm and 800 mm (LxWxD). The walls of the tank have a thickness of 6 mm. The tank walls were supported from the outer surface using the horizontal steel beam fixed at the half-depth of the tank. The inner wall of the tank is made to decrease friction with the soil to a minimum by applying a galvanized coat on the inside wall. The loading system consists of a hand-operated mechanical jack and pre-calibrated proving ring to apply the load manually to the footing soil system.

Figure 2. Schematic diagram of typical test rectangular wall configuration

2.2. Model Footing

The model footing was a steel square plate with plan dimensions of 120 mm x 120mm and with a thickness of 25 mm. A thin layer of geotextile was pasted on to the base of the model footing with Epoxy glue to create a roughness. The load was transmitted to the footing through a ball bearing that was placed between the footing and the proving ring.
2.3. Test Material
Locally available soft clay was used as the backfill material, and with its classification as CH according to the Unified Soil Classification System. The characteristics of untreated and lime treated clay used as a backfill are given in Tables 1 and 2. In the present study, 7% (by dry weight of clay) of lime was used to treat the clay that was used as a backfill material on wrap faced reinforced soil retaining wall (WRSW).

| Table1. Properties of untreated clay. |
|-------------------------------------|
| Parameter                           | Value  |
| Specific gravity                    | 2.75   |
| Liquid limit (%)                    | 67.88  |
| Plastic limit (%)                   | 34.69  |
| Shrinkage limit                     | 19.50  |
| Plasticity index (%)                | 33.19  |
| Optimum moisture content (%)        | 26.00  |
| Maximum dry density (kN/m³)         | 15.33  |

| Table2. Properties of lime treated backfill clay. |
|-----------------------------------------------|
| Parameter                                     | Value  |
| Specific gravity                              | 2.62   |
| Liquid limit (%)                              | 60.59  |
| Plastic limit (%)                             | 43.86  |
| Shrinkage limit                               | 15.18  |
| Plasticity index (%)                          | 16.73  |
| Optimum moisture content (%)                  | 21.00  |
| Maximum dry density (kN/m³)                   | 16.00  |

2.4. Reinforcement
The nonwoven polypropylene geotextile was used as the facia of wrap faced reinforced soil retaining wall in all the tests. Table 3 shows the properties of the geotextile used in the study. The wide-width strip method [13] was used to determine the tensile strength of the geotextile.

| Table 3. Properties of geotextile. |
|-----------------------------------|
| Property                          | Value  |
| Tensile strength (kN/m)           | 20.50  |
| Warp/Machine direction            | 10.50  |
| Weft/Cross direction              | 20.50  |
| Elongation at break (%)           | -      |
| Warp/Machine direction            | 41.63  |
| Weft/Cross direction              | 51.65  |
| Thickness (mm)                    | 1.50   |
| Mass per unit area (GSM)          | 334.00 |
3. Model Construction and Testing Procedure

The model tests were conducted in the steel tank as discussed above. The model wall was built in lifts of equal height while reinforcing each lift with a layer of non-woven geotextile and keeping facia of the wall also of the same geotextile material (Fig. 3). The overlapping length of geotextile was kept as 125 mm (for 4 layers wall), 100 mm (for 5 layers), and 83.33 mm (for 6 layers). The backfill soil was clay soil, which was compacted to its maximum dry density (MDD). The MDD was also verified in each layer by taking a representative sample in a core cutter of known volume. Wooden formwork was used [14] while constructing the model retaining wall so that all the lifts maintain the desired slope ($\alpha$) with horizontal (Fig. 2). The load on the model wall applied through a mechanical jack. The test tank was kept under a rigid loading frame of 10-ton capacity, to seek the reaction from it when the load was applied through the mechanical jack. A proving ring was also attached to record the actual value of the load. The settlement for each load interval was measured through two numbers dial gauges mounted through magnetic base fixed on one wall of steel tank (Fig. 3a and b).

![Figure 3](image-url)

a) Wrap face wall  
b) Wrap face wall

**Figure 3.** Finished wrap-faced wall profiles: (a) five-layer configuration; (b) six-layer configuration.

4. Results and Discussion

In the model tests, the slope angle ($\alpha$) was changed, and also the number of layers. Initially, all the tests were conducted on pure clay soil, and thereafter all the tests were also conducted on the backfill treated with lime. These tests are defined in Table 4. The vertical spacing between the two layers has been defined as $S_v$. The $S_v$ is different for different numbers of layers. The value of $S_v/H$ has also been defined in Table 4, where $H$ is the total height of the wall, which was maintained as 500mm in all the tests. The horizontal displacement of the model wall was also measured (as a result of the application of load) through linear variable displacement transducers (LVDTs).

The results of horizontal displacement of the wall Vs. the height of the wall is shown in graphical form in Figure 4(for untreated backfill) and Fig.5(for lime treated backfill). It is seen that for a higher number of layers, the horizontal displacement is less for untreated and lime treated backfill. These figures give typical results for 60° inclination of the wall, through the same trend was seen at other inclination also.
Table 4. Test parameters.

| Test no. | No. of layers | Slope angle | Sv/H | Test no. | No. of layers | Slope angle | Sv/H |
|----------|---------------|-------------|------|----------|---------------|-------------|------|
| Untreated backfill clay soil on WRSW | Lime treated backfill clay soil on WRSW |
| N1       | 4             | 45          | 0.25 | N7       | 4             | 45          | 0.25 |
| N2       | 4             | 60          | 0.25 | N8       | 4             | 60          | 0.25 |
| N3       | 5             | 45          | 0.20 | N9       | 5             | 45          | 0.20 |
| N4       | 5             | 60          | 0.20 | N10      | 5             | 60          | 0.20 |
| N5       | 6             | 45          | 0.17 | N11      | 6             | 45          | 0.17 |
| N6       | 6             | 60          | 0.17 | N12      | 6             | 60          | 0.17 |

It is worth noting here that horizontal displacements were recorded by using three linear variable displacement transducers (LVDTs) named U1, U2, and U3, positioned at 150, 300, and 450mm respectively, from the bottom of the tank (Fig. 2).

Figure 4. Effect of reinforcement layers on displacement profile at 60° (Untreated backfill).

Figure 5. Effect of reinforcement layers on displacement profile at 60° (Lime treated backfill).
4.1. Plate loading tests

The test results indicate that there is an increment in bearing capacity when soil is treated by lime, and at the same time, there is a reduction in a settlement when soil is treated by lime. It can be understood by Table 5, which is for a typical case of $45^\circ$ inclination. Horizontal face displacement was recorded at 450 mm height for comparison.

### Table 5. Comparison of model tests results of the untreated and lime treated clay soil.

| S. No | No. of layers | Reduction in horizontal Displacement (when treated with lime) | % Decrease in Settlement when treated with lime | Increase in bearing capacity when treated with lime |
|-------|---------------|---------------------------------------------------------------|-----------------------------------------------|-----------------------------------------------|
| 1     | 4             | 22.14                                                         | 46.35                                         | 22.88                                         |
| 2     | 5             | 20.41                                                         | 37.36                                         | 14.50                                         |
| 3     | 6             | 48.50                                                         | 61.95                                         | 22.38                                         |

Remarks: The addition of 7% of lime significantly increases bearing capacity and reduces settlement

4.2. Numerical Modeling

The test results were validated by numerical modeling, using PLAXIS software. Due to the publication limit of pages, only one case of five layers is being presented in this paper. The model developed in PLAXIS is illustrated in Figure 6. Boundary conditions for the numerical were assigned to represent the real-life situation. The far end boundary of the backfill is fixed in the horizontal direction, displaying the rigid end of the tank. Construction sequence of the numerical model is adopted the same as that of physical model i.e, constructing wall sequentially with front lateral support, subjecting surcharge, and after that removal of supports from top to bottom after building a wall up to full height. The properties of untreated and treated backfill are shown in Table 6.

### Table 6. Material properties of untreated and lime treated clay soil.

| Parameter                   | Name | Untreated clay | Lime treated clay | Value | Unit |
|-----------------------------|------|----------------|-------------------|-------|------|
| Material model              | Model| Mohr-Coulomb   | Mohr-Coulomb      |       | -    |
| Type of material behavior   | Type | Undrained      | Undrained         |       | -    |
| Unit weight                 | $\gamma$ | 19.80 | 19.40 | kN/m$^3$ |
| Poisson's ratio             | $\mu$   | 0.35      | 0.30   | -     |
| Primary velocity            | $V_p$   | 487.11    | 139.30 | m/s   |
| Secondary velocity          | $V_s$   | 234.00    | 74.45   | m/s   |

4.3. Horizontal face displacement and crest settlement on the numerical modeling

As discussed above, the horizontal face displacement and the crest settlement were observed for both untreated and treated backfill soils in the model tank. These results were validated through numerical modeling also. Face displacements along the height of the wall horizontally were observed by pinning the area in wrap-reinforced soil retaining wall depicted in Fig. 2 (represented and positioned by U1, U2, and U3) and vertical settlements also done to simulate wrap faced reinforced soil retaining wall on top of the wall. Test parameters adopted for numerical modeling are given in Table 5. The comparative result of physical model tests and numerical analysis are shown in Table 7. Horizontal face displacement was recorded at 450 mm height for comparison.
5. Conclusions
From the present experimental observations and numerical modeling, the following conclusions can be drawn:

- Crest settlement and horizontal face displacement decrease with an increase in the reinforcing layer on wrap-faced reinforced soil retaining wall (WRSW).
- Lime treated backfill clay material displays better performance than untreated backfill clay on WRSW for slopes 45° and 60°. The reinforced soil slopes of 45° performed better than the slope angle of 60°.
- The numerical modeling results indicate that vertical settlement is decreased by 18.75, 14.29, and 25% for 4, 5, and 6 reinforcement layers respectively for 45° slopes by using lime treated clay as a backfill material, while it is also reduced by 13.89, 19.23, and 42.10% for 4, 5, and 6 layers respectively for the slope angle of 60°.
• The bearing capacity increases with the increase of the reinforcing layers for both lime treated and untreated backfill soil.
• Results from the physical model tests fairly match with the results from the numerical model for both lime treated and untreated soil backfill on WRSW.
• Wrap face reinforcing retaining wall can be a good alternative for problematic soil to be used as a backfill material, in places where such soils are abundant.

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