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Geogrid-reinforced lime-treated cohesive soil retaining wall: Case study and implications

Guangqing Yang [a,c], Huabei Liu [b,*], Peng Lv [a,b,c], Baojian Zhang [a,c]

[a] School of Civil Engineering, Shijiazhuang Tiedao University, Shijiazhuang 050043, China
[b] Department of Civil Engineering, City College of New York/CUNY, 160 Convent Ave., New York, NY 10031, USA
[c] Key Laboratory of Traffic Safety and Control in Hebei, Shijiazhuang 050043, China

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ABSTRACT

Lime-treated cohesive soils are used extensively as the construction materials of road embankments. In some cases, vertical embankment is needed, rendering the necessity to employ retaining walls backfilled with lime-treated cohesive soil. In China, geogrid-reinforced lime-treated cohesive soil retaining walls are increasingly used for this purpose. With the objective to reveal the behavior of this type of structure under working-stress condition and to shed light on its future application, a 6.0 m reinforced soil retaining wall was monitored for two years during and post construction. The results showed that the lime-treated soil carried the majority of the gravity load but the geogrid reinforcements also contributed to the integrity of the embankment. Under gravity loading, the backfill deformation was mainly elastic. Backfill compaction during construction was the critical factor influencing the reinforcement deformation and lateral earth pressure at the back of the facing, the latter of which decreased with time after the end of construction due to the increases of both backfill strength and facing displacement. Based on these results, it is inferred that under working stress condition, lime-treated backfill plays a major role in the stability of the retaining wall, while geogrid reinforcements play a secondary role.

1. Introduction

Lime treatment technique is commonly used to stabilize clayey subgrades of road pavements (e.g., Puppala et al., 1996; Qubain et al., 2000; Rogers et al., 2006). Lime-treated cohesive soils are also frequently used to construct highway and railway embankments (e.g., Raymond, 1987; Chen and Yu, 2011; Tang et al., 2011). Usually lime-treated road embankments have inclined slopes on the sides to ensure stability and safety, but in some cases, vertical slope is necessary to reduce land use or to prevent interference with existing facilities. In these cases, retaining walls must be used, and the application of geosynthetic reinforcements with non-structural facing elements has become more and more common in the Chinese practice in recent years.

Extensive investigations have shown that lime treatment technique can significantly increase the stiffness and strength of cohesive soils, and that the strength and stiffness increase with time due to curing (e.g., Puppala et al., 1996; Qubain et al., 2000; Rogers et al., 2006; Consoli et al., 2009, 2011; Tang et al., 2011). Besides curing age, the other factors controlling the strength and stiffness of lime-treated cohesive soils include the amount of lime, porosity, clay minerals, and soil particle size, while modest change of moisture content has only small influence on the mechanical properties (e.g., Rogers et al., 2006; Consoli et al., 2009, 2011; Tang et al., 2011).

Nonetheless, the investigations on the reinforcement of lime-treated cohesive soil with geogrid or geotextile have been rare, although there exist some studies on the fiber-reinforced composites (e.g., Tang et al., 2007; Estabragh et al., 2012). By centrifuge testing, Porbaha (1996) found that the inclusion of geotextile reinforcement could increase the stability and ductility of lime-treated cohesive soil retaining walls. Also by centrifuge testing but assisted by numerical simulation, Ye et al. (2012) found that the inclusion of a layer of geogrid reinforcement could increase the stability of quay walls backfilled with lime-treated cohesive soils. On a related subject, compacted cohesive soils have been used as backfills of geosynthetic-reinforced soil retaining walls (e.g., Farrag et al., 2004; Chen et al., 2007; Benjamim et al., 2007; Guler et al., 2007; Won and Kim, 2007; Ahmadabadi and Ghanbari, 2009; Liu et al., 2009; Yang et al., 2009, 2010), although there are still concerns – among others – on their relatively low friction with geogrid reinforcements (e.g., Bergado et al., 1993; Abu-Farsakh

* Corresponding author. Tel.: +1 212 650 8007; fax: +1 212 650 6965.
E-mail address: hliu@ccny.cuny.edu (H. Liu).

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et al., 2006; Noorzad and Mirmoradi, 2010; Abdi and Arjomand, 2011).

In this study, a 6.0 m geogrid-reinforced lime-treated cohesive soil retaining wall was monitored for vertical earth pressure, lateral earth pressure and reinforcement deformation for two years during and post construction. The objective is to understand the construction and long-term behaviors of this type of earth structure under gravity loading condition. The study hopes to shed light on the future applications of similar structures.

2. Field instrumentation

One section of the Bao-Cang Expressway in Hebei Province, China, is adjacent to an irrigation channel to the south and an existing highway to the north. In order to prevent interference with the existing facilities, decision was made to use lime-treated cohesive soil retaining walls with vertical facing as the road embankment, the height of which ranges from 1.95 m to 6.0 m. The total length of the lime-treated cohesive soil retaining wall is approximately 1100 m long. High-Density Polyethylene (HDPE) geogrid was used as reinforcement, together with modular-block facing, for the purpose of increasing stability and reducing cost. Fig. 1 shows part of the embankment after completion.

The foundation soil is stiff and has an allowable bearing capacity of 150 kPa from plate load-test. The top 0.5-m foundation soil was replaced by a granular cushion reinforced with a layer of bi-axial polypropylene (PP) geogrid. Two types of HDPE geogrid were used as the reinforcement in the embankment, the mechanical properties of which are shown in Table 1. The strength and deformation properties were obtained as per ASTM standards. The cohesive backfill soil was treated with 6% of lime, and compacted to a desired dry unit weight of 15.3 kN/m^3. The moist unit weight after compaction was approximately 16.8 kN/m^3. Main portion of the backfill soil was compacted using a single-drum roller compactor. The weight of the drum is 98 kN, resulting in a contact line-load of 47 kN/m underneath the drum. The backfill soil within 1.0 m from the facing was compacted using a hand-operated tamper with much smaller contact pressure. Table 2 shows the mechanical properties of the backfill soil after compaction when the curing time was smaller than one day. At this curing age, the pullout resistance of geogrid is approximately the same as that in the pure compacted fill. The concrete block facing was pre-casted, with a dimension of 0.5 m × 0.2 m × 0.2 m (length × width × height).

Fig. 1. Vertical highway embankment after the end of construction.

Table 1
Properties of geogrid reinforcements provided by the manufacturer.

Parameters	Type A	Type B
Uniaxial tensile strength (KN/m)	≥64.5	≥88.0
Tensile load at 2% strain (KN/m)	≥16.1	≥23.7
Tensile load at 5% strain(KN/m)	≥30.9	≥45.2
Failure strain (%)	≤10.0	≤10.0
Creep strength after 120 years (20 °C) (KN/m)	≥25.5	≥34.0

6 cm of HDPE geogrid was casted in the block, and connected to the geogrid reinforcement using bodkin joints (Fig. 2). Above the embankment, the granular base ($\gamma_d = 17.1$ kN/m^3) was reinforced with two layers of bi-axial PP geogrid, and the thickness of the pavement is 0.3 m, equivalent to approximately 7.0 kPa of distributed load.

The instrumented cross-section is 6.0-m high, as shown in Fig. 3. The lower four layers of reinforcement are Geogrid B at a vertical spacing of 0.4 m, while the remaining layers employ Geogrid A. The top four layers are spaced at 0.6 m. All the reinforcement layers have a length of 5 m. The cross-section was instrumented for lateral earth pressure on the facing, vertical earth pressure at the base of the reinforced soil, and reinforcement deformation (Fig. 3). Among the instrumentations, the reinforcement deformation was measured by means of the inductive flexible displacement sensors (Fig. 4), which were successfully tested in prior field tests (Yang et al., 2009, 2010). Facing displacement was not monitored during embankment construction but was surveyed after its completion by the contractor. The results showed that the post-construction facing displacement was very small. However, the authors were not able to access the complete data, hence it is not reported in this paper.

Sensor readings began immediately after the start of embankment compaction. During construction, readings of pressure cells and flexible sensors were taken after the placement of each reinforcement layer. A monthly reading was carried out for one year after embankment completion. Fig. 5 shows the progress of embankment construction. The construction was interupted for a period of about 100 days due to the winter weather.

3. Analysis of test results

3.1. Characteristics of the vertical earth pressures

The vertical earth pressure increased gradually with fill height, the magnitude of which was approximately equal to the overburden pressure $\sigma_v = \gamma h$. Fig. 6 shows the time-histories of the earth pressures on the pressure cells. Also shown is the calculated value by $\sigma_v = \gamma h$. It can be seen that after the completion of the embankment, the vertical earth pressure decreased slightly, possibly due to non-uniform foundation settlement under the embankment loading. The non-uniform foundation settlement might have resulted in certain backfill-arching, which reduced the vertical stress on some of the vertical pressure cells.

Table 2
Mechanical properties of lime-treated cohesive soil at curing age <1 day.

Parameter	w_{opt}/%	γ_{dmax}/(kN·m^{-3})	I_P	$a_{v1\text{-}2}$/MPa^{-1}
Value	16.8	17.0	13	0.07
Parameter	c/kPa	φ/(°)	c^a/kPa	φ^a/(°)
Value	68	24	2	7

[a] These are the friction resistance between geogrid and soil from pull-out test.