Lime-cement columns with PVDs for embankment on soft consolidating soil

Prakash K. G.\textsuperscript{a}, A. Krishnamoorthy\textsuperscript{b}

\textsuperscript{a}Research Scholar, Department of civil Engineering, Manipal Institute of Technology, MAHE, Manipal-576104, Karnataka, India.
\textsuperscript{b}Professor, Department of civil Engineering, Manipal Institute of Technology, MAHE, Manipal-576104, Karnataka, India.

Abstract

The effectiveness of providing lime-cement (LC) columns along with Prefabricated Vertical Drains (PVDs) on the stability of embankment constructed on soft consolidation soil is investigated. Providing LC columns or PVDs separately or combining LC columns with PVDs is compared. Two-dimensional plane strain finite element method is used for the analysis. The parameters considered for the study are the variation of settlement and excess pore water pressure at various time intervals during the consolidation of foundation soil. From this study, it is concluded that, LC columns along with PVDs are the most effective technique compared to providing LC columns or PVDs separately to reduce both the displacement and excess pore water pressure for the embankment constructed on soft consolidating soil.

Keywords: embankment; lime-cement columns; PVD; soft consolidating soil; finite element analysis;

1. Introduction.

The fast urbanization due to the increasing population, limited availability of sites, an increase in the price of land is reflected in the scarcity of ideal land with appropriate geotechnical properties. Consequently, construction of embankment on soft soil is becoming common with in-situ improvement, though it was earlier treated as unsuitable. Embankment constructed on soft soil may pose high compressibility, less bearing capacity, greater settlement, instability, which typically leads to long delays in construction and expensive remedial works. Many kinds of ground improvement techniques are being adopted nowadays, like replacing the existing ground and substituting with appropriating materials economically, filling from lightweight materials in embankment during construction, embankment construction in stage-wise and allowing time for consolidation, provision of reinforcement during embankment construction, placing of vertical drains, provision of columns in foundation soil etc. If one type of ground treatment method does not meet the requirement, due to its limited application and scope, a comprehensive application can be adopted by combining various kinds of ground treatment methods. To design embankments on soft soils, it is essential to take into account the multiple constructive techniques that allow solving the problems usually associated with this kind of construction: overall stability deficiency and large settlements that develop slowly [1].

The embankment construction by supporting from In-situ lime-cement (LC) columns is used in wide range. The LC columns created by mixing lime and cement as a partial replacement into the foundation soil, beneath the embankment have been widely used for rapid construction. It is one of the most popular and appropriate method with several benefits, it increases the bearing capacity and fastens the rate of consolidation, decreases post-construction settlement and lateral movement, also significantly improves slope stability. The efficiency of LC columns to enhance soft soil has been extensively investigated through the field as well as laboratory model studies [2-9].

The other technique that works completely on accelerating the consolidation process, without contributing the additional stiffness to soil is using of prefabricated vertical drains (PVDs). PVD is one of the most frequently used techniques in soft soil improvement, for accelerating the process of consolidation and it is widely using in construction of embankment over the last few decades. PVD is one of the synthetic and slender drainage element, comprising from the drainage core covered, with a filter of geotextile: usually, PVDs cross section will be in rectangular from the mandrel it is installed into the soil at required spacing. The vertical drains installation will shortens the drainage path and accelerates consolidation process. Flow around the PVDs is axisymmetric, when the PVDs are installed in soft soil. By considering actual locations of PVDs and their influence zone to model the flow around requires three-dimensional analysis. However, the three-dimensional modelling of the vertical drain system needs considerable computational time, especially, whenever more number of vertical drains are used, Two-dimensional plane strain finite analysis is used for analysis, a variety of matching procedures, to transform axisymmetric flow all around PVDs, into one dimensional horizontal flow is the other technique, suggested for modelling the soft soil with vertical drains. The most widely used matching procedures for converting the
axisymmetric flow to one dimensional flow are those suggested by Hird et al. [10] and Chai et al. [11]. Both laboratory and field tests for embankments in full scale have also carried out for applicability [12-15] of two-dimensional analysis carried out using these matching procedures. The embankments constructed on soft soil provided with the vertical drains is investigated from finite element analysis by Hird et al. [10], Chai and Miura [13], Shen et al. [14], Yildiz [15], Borges [16].

Thus, it can be noted that the LC columns are stiffer than soft soil and effective to increase stability due to their higher stiffness. However, the low permeability of LC columns is one of the limitations. On the other hand, PVDs do not contribute any additional stiffness to the soft soil, however, the high permeability largely contributes to accelerate consolidation. Hence, the combination of PVDs with LC columns to improve the settlement beneath embankment constructed above soft soil is investigated. The effectiveness of PVDs with LC columns is compared with the effectiveness of using only PVDs or LC columns. The parameters considered for the study are the variation of settlement, pore pressure with time, the settlement profile of the ground immediately after the construction of embankment and at the end of consolidation of foundation soil. The embankment on soft consolidating soil provided with LC columns and PVDs is modelled as two-dimensional plane strain problem and is solved using finite element method.

2. Method of Analysis

Fig. 1 shows the finite element discretisation of embankment on soft consolidating soil with LC columns and PVDs considered for the study. As shown in the Fig.1, the embankment of height 5 m, width 14 m and 1:1 side slope is constructed on the soft soil of thickness 10 m.

Since, the two-dimensional model possesses symmetry, only one-half of the problem is considered of the study. As shown in Fig. 1, the embankment and foundation soils are modelled using four noded elements with two translational degree of freedom at each node. Three noded elements are used to model the embankment near the toe. LC columns are modelled using two noded line elements with two translational degrees of freedom at each node. Both the horizontal and vertical displacements are prevented at the base of foundation soil, whereas, the horizontal displacements are prevented at both the sides of the problem as shown in figure. LC columns are assumed to behave as linearly elastic, whereas, Mohr coulomb model is used to idealise the behaviour of embankment and foundation soils. The combined matching procedure as proposed by Hird et al. [10] is used to model the PVDs. As shown in the Fig.1, LC columns are provided at 5 m c/c spacing when only LC columns are used. The PVDs are provided at a c/c spacing of 1.0 m when only PVDs are provided. When LC columns and PVDs are provided in combination, LC columns are at a c/c spacing of 3m and PVDs are provided in between LC columns at 1 m spacing. In all the cases the PVDs and LC columns are provided with square pattern. The material properties of LC columns are as shown in Table 1.
Table 1. Properties of embankment and foundation soil and LC column.

|                         | Modulus of elasticity (kN/m²) | Poisson’s ratio | Unit weight (kN/m³) | Cohesion (kN/m²) | Angle of internal friction (Degree) | Coefficient of permeability (m/day) |
|-------------------------|-------------------------------|----------------|---------------------|-----------------|-------------------------------------|-------------------------------------|
| Embankment              | 8000                          | 0.3            | 20                  | 35              | 32                                  | --------                           |
| Foundation soil         | 3000                          | 0.3            | 18                  | 0               | 24                                  | 3.426×10⁻⁵                        |
| Lime-cement column      | 130000                        | 0.3            | 21                  | 175             | 35                                  | 3.426×10⁻⁵                        |

3. Results and discussions

In the present study, the effectiveness of providing LC columns along with PVDs on settlement and pore water pressure is studied at different time intervals, till the complete dissipation of excess pore water pressure in foundation soil. The various combinations considered for the study are:

1) Only LC columns (LC)
2) Only PVDs (PVD)
3) Combination of LC columns and PVDs (LC + PVD)

The variation of settlement at the ground surface beneath the embankment, at the end of construction of embankment and at the end of consolidation for various combinations listed above are shown in Fig. 2a and Fig 2b respectively. In addition, the ground profile without using any ground improvement technique is also shown in Fig. 1 for comparison. From these figures, it can be observed that, the settlement decreases marginally when only PVDs are provided, whereas, the settlement at all the points below the embankment reduces significantly when improved with LC columns. However, the settlement reduces further, when PVDs are provided along with LC columns. This shows that the effectiveness of LC columns can be enhanced significantly, by providing PVDs in between LC columns as shown in Fig. 1. In addition, uniform distribution of settlement from the center of embankment, till the side AB can be also observed, when PVDs are provided along with LC columns compared to the distribution of settlement of soil provided only with LC columns or only with PVDs.

Fig. 2(a): Settlement at the ground surface immediately after the construction of embankment

Fig. 2(b): Settlement at the ground surface after complete dissipation of excess pore water pressure

Fig. 3: Effectiveness of providing LC columns and PVD on time v/s settlement behaviour at point S
The settlement variation at point S (at beneath the centre of the embankment i.e., point S in Fig.1) in different interval of time, from the end of construction of embankment to till the excess pore water dissipation from the foundation soil is shown in Fig. 3. From the Fig.3, it can be observed that the settlement at all the time after the construction reduces significantly, due to the provision of all the types of ground improvement technique listed above. However, the most effective technique is the combination of LC with PVDs followed by only LC columns and the PVDs are the least effective to reduce the settlement after the construction of embankment.

Fig. 4 Variation in excess pore water pressure with time in point X for the soil with LC columns, PVDs, LC columns with PVDs

Fig. 4 shows the variation in excess pore water pressure with time in point X for various combinations. From the Fig. 4, it is observed that, the techniques considered all are effective to accelerate the consolidation process, when compared to the soil without ground improvement techniques. However, among all techniques, the most effective technique to accelerating the process of consolidation is the provision of LC columns with PVDs, followed closely by the provision of only PVDs at 1 m c/c. The provision of LC columns, however, are effective to dissipate excess pore water pressure.

Thus, combination of LC columns and PVDs are not only effective in reduction of settlement but also effective to accelerate the consolidation process and can be used to reduce both the settlement and to accelerate consolidation process.

4. Summary and Conclusion.

Effectiveness of providing LC columns along with PVDs to improve the settlement beneath the embankment constructed on soft consolidating soil is investigated. Effectiveness of LC columns along with PVDs is compared with that of providing only LC columns and only PVDs. The conclusions are drawn from the study are as follows:

1. Provision of either PVDs, LC columns or LC columns with PVDs are effective to reduce the settlement of foundation soil beneath the embankment. However, among all these, provision of LC columns along with PVDs is the most effective technique to reduce the settlement at all the time intervals during and after the construction of embankment.

2. All the three techniques are also effective to accelerate the consolidation process, but the LC columns with PVDs are most effective, followed closely by PVDs to dissipate excess pore water pressure. The LC columns provided individually are however least effective to dissipate excess pore water pressure.

3. Thus, it can be said that LC columns are effective to reduce the settlement significantly. The effectiveness of LC columns can be enhanced further by providing PVDs along with LC columns. The combination not only increases the effectiveness to reduce the settlement but also is effective to accelerate the consolidation process.

5. Future scope in the work.

1. The effectiveness of varying the length of LC columns and PVDs on stability of embankment can be studied.
2. The effectiveness of varying the spacing of LC columns and PVDs on stability of embankment can also be studied.
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