GROUND IMPROVEMENT TECHNIQUE TO IMPROVE WEAK SOIL DEPOSITS

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ABSTRACT:
Rapid construction of high embankments on soft soils often leads to shear failure at the base. A combined ground improvement technique including vertical sand drains and in-situ deep soil mixing (DSM) is proposed to improve the shearing resistance as well as to reduce the compressibility of soft soils using a numerical model. The design of DSM columns along with the vertical sand drains will be discussed. Design charts are developed for a combined treatment method based on the spacing; diameters of the DSM columns as well as time and spacing of the sand drains which will suffice in selecting the economical alternative for a given time and consolidation settlements.

Keywords: Weak Soils, DSM Columns, Consolidation Settlements.

INTRODUCTION

Rapid construction of high embankments on soft soils often leads to shear failure at the base of the embankment. To avoid such failures, one needs to allow ample consolidation time before the next stage of construction is scheduled. This method is safe, yet, very time consuming. In recent times, introduction of vertical drains including sand drains and prefabricated vertical drains (PVD) together with preloading by means of surcharge loading has brought down the consolidation period from years to months. However, vertical drains can only accelerate the consolidation process and seldom improves the shearing resistance of the foundation soil. At times, speedy surcharge may cause shear failure. This failure may be attributed to the inadequate dissipation of pore pressures generated due to sudden loading (either due to embankment or surcharge) resulting in a great amount of shear in the soft clay, or due to inadequate un-drained shear strength and bearing capacity of the soil stratum.

In this paper, a new combined ground improvement technique is proposed to take care of the consolidation and improving the shearing resistance of the soft soil. Insertion of deep soil mixing (DSM) columns along with sand drains is one such method. DSM is a ground improvement technique in which soft soils are strengthened by mixing them with the grout materials such as quicklime, cement, lime-cement or ashes in proper proportions forming in-situ soil cement columns [1]. These columns act as reinforcement to the weak soil stratum and absorb major portion of the load coming on to it. This method gave satisfactory results under both static and dynamic loading conditions. Here in this technique both DSM columns and sand drains are introduces together, ensuring both increased strength and quickened consolidation. A parametric study has been conducted to produce the design charts by varying the spacing and diameter of the DSM columns and sand drains, also optimizing the young's modulus value of DSM columns which ensures both safety and economy. The complete analysis has been carried out by using finite element code using plaxis-2D software.

BACKGROUND

In general, the soft soil deposits have been treated by individual ground improvement methods. Each method has its own merits and demerits. The most common method of ground improvement in soft soils would be vertical drains [2, 3 and 4]. As the embankment is constructed in layers a short stabilized column is sufficient in satisfying the stability requirement under normal filling rate. Sand drains together with surcharge and preloading are considered to as the most cost and time constrain effective solution for the consolidation of saturated compressible soils [5]. In recent years the reinforcement of soil foundations with deep soil mixing columns has expanded a great deal around the world, which allows increase in stability, reduction of settlements, greater speed of execution and reduced cost [6]. Experimental and numerical modeling of consolidation by sand drains supporting embankments were analyzed by several researchers [7, 8 & 9]. Short DSM columns were used to improve the shallow soft soils, and long prefabricated vertical drains (PVDs) were inserted between DSM columns to promote the consolidation of deep soft soils under the embankment load [10]. Not much information is available on combined ground improvement techniques in the literature. Hence there is a need to address this issue. As a part of this objective, numerical studies are adopted to verify the efficacy of the proposed method.

DESCRIPTION OF THE PROBLEM

The problem deals with the construction of a 6m height embankment of slope 1:2 (V/H) on a foundation soil of 8 m thick normally consolidated soft clay which lies on an impermeable and rigid soil stratum. The ground water table is assumed to be at the level of the ground surface. Analysis consists of three stages where in first with surcharge, second with surcharge and sand drains in the clay bed and finally with surcharge, sand drains and deep soil mixing columns. Sand drains and DSM columns are installed in a square grid pattern. The clay bed is assumed to have a vertical permeability of $2m^2$/year and horizontal permeability of $4m^2$/year. A surcharge load of 60 kPa is assumed to act uniformly over the embankment.

MODEL STUDIES AND VALIDATION

The soil parameters used in the analysis are obtained from various parametric studies. Plane strain model has been considered for the analysis. Various model types have been assigned to soil layers based on their natural stress strain behaviors to carry out the consolidation analysis, which include soft soil model, Mohr coulomb model and linear elastic material models. The details of material properties are given in Table 1. A finite element mesh is constructed using 15-node triangular plane strain elements. The boundary conditions are defined using standard fixities, available inbuilt in PLAXIS-2D. Various properties of the soil strata adopted for the analysis are listed in the table below.

DESIGN OF SAND DRAINS AND DSM COLUMNS

The model adopted is as shown in Fig. 1. It includes a clay bed of 8m height upon hard strata which is assumed to be in normally consolidated state without any past stress history. An embankment of 6m height and a surcharge load is to be placed on the embankment to quicken the consolidation. Analysis has shown that the stratum has failed due to excessive load coming from the rapid construction of embankment and surcharge (See Fig. 1). To ensure pore pressure dissipation and also to quicken the consolidation process, sand drains are introduced, whose properties are included in Table 1. The design chart between consolidation time with spacing of vertical drains has been presented in Fig. 3. However, there is a shear failure in the foundation soil as shown in the Fig. 2. Henceforth, DSM columns of relatively moderate strength (with a young's modulus of 30 MPa) are adopted, since the aim of the project is to facilitate gain of shear strength and to allow quick consolidation. The design chart for DSM columns is given the Fig. 4. For an adopted area ratio of 11%, 0.6m DSM column diameter an effective spacing of 1.6m is obtained for the DSM columns.

Finite element analysis has shown that the stratum has gained enough shear strength upon the introduction of these columns at its respective spacing. With reference to the general mandrel sizes adopted in the field, a sand drain of 0.2m diameter is assumed and is arranged in a square pattern. Spacing of sand drains are designed based on its zone of influence, which is 1.6m. Thus each sand drain is so laid that they come exactly at the center of four DSM columns. A sand blanket of 0.4m thick is laid over the clay bed to facilitate drainage of upcoming pore water. Embankment is then constructed over it adopting staged construction as stated above. PLAXIS-2D analysis reveals that the structure is safe and is also economical one for the given loading conditions and construction period.

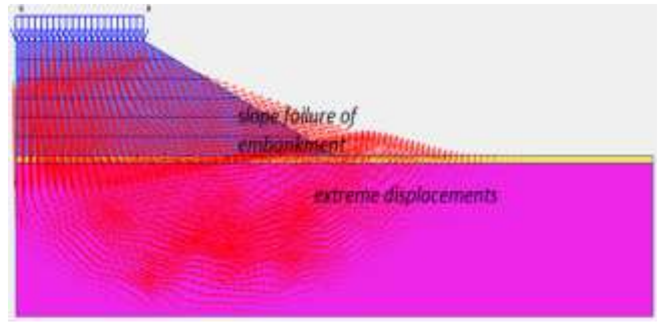

Fig. 1 Total displacement arrows under rapid loading of embankment construction

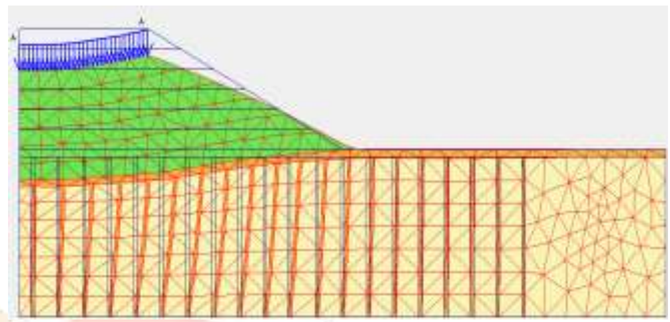

Fig. 2 Deformed mesh for sand drains model after rapid loading construction of the embankment

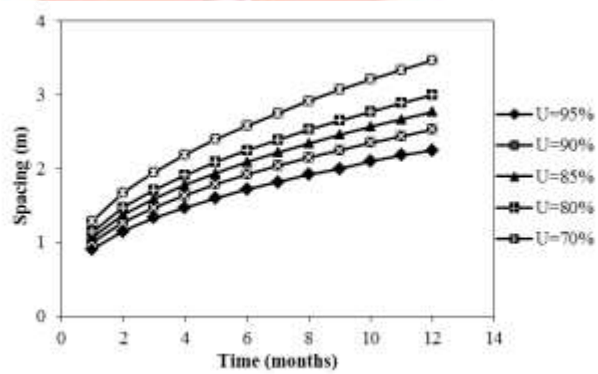

Fig. 3 Time Versus Spacing design chart for sand drains at various degrees of consolidation

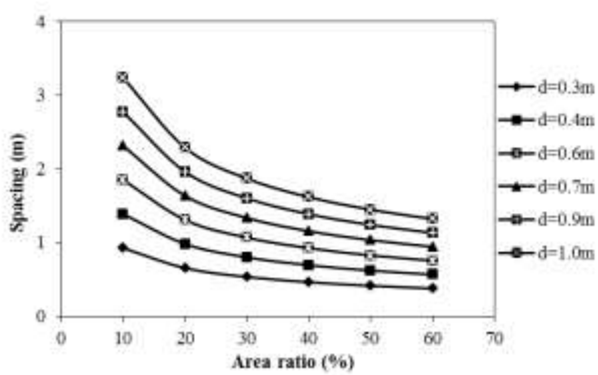

Fig. 4 Area ratio Versus Spacing design chart for DSM columns under typical range of diameters

Table. 1 Details of material properties used in numerical analysis

Soil type / Property	Sand	Clay	Fill	DSM columns
Material model	Mohr coulomb	Soft soil	Mohr coulomb	Linear elastic
Material type	Drained	Undrained	Drained	Non-porous
γ_{unsat} (KN/m^3)	17	15	16	17
γ_{sat} (KN/m^2)	20	18	20	-
k_x&k_y	1	10^{-5}	1	-
E_{ref} (KN/m^2)	5000	-	3000	30000
N	0.3	-	0.3	0.3
C_{ref} (KN/m^2)	1	-	15	-
Φ (○)	30	10	30	-
Ψ (○)	5	0	0	
C_c	-	0.39	-	-
C_s	-	0.046	-	-
$e_{initial}$	-	0.9	-	-
C (KN/m^2)	-	24	-	-

ANALYSIS AND DISCUSSION OF RESULTS

The soil strata are analyzed for its safety under anticipated external loading conditions in the following three cases.

Case I: Stratum is analyzed for its stability under staged construction of embankment followed by placement of surcharge load to enable quick consolidation.

The settlement profile clearly defines the shear failure of the soft clay. The analysis shows that the clay layer failed to dissipate its excess pore pressures generated due to the external loading, which led to its shear failure. Thus a means is to be provided in order to dissipate the excess pore pressure, for which we have adopted sand drains. Sand being a highly permeable material to clay enables the pore water to squeeze out quickly and thereby reducing the time of consolidation.

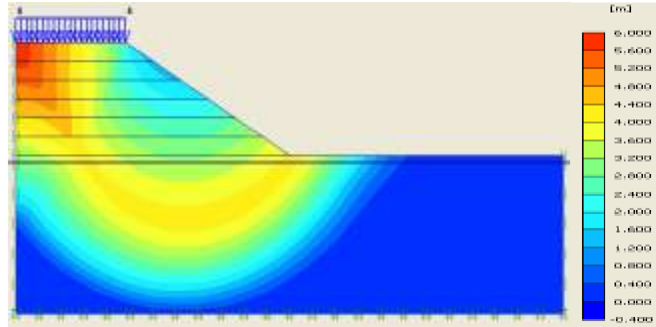

Fig. 5 Total displacement shadings under rapid loading of embankment construction

Case II: Stratum is analyzed for safety by introducing sand drains followed by staged construction.

Analysis shows that the introduction of sand drains has greatly cut down the consolidation period from couple of years to a few months. It has even added to the strength gain of the stratum. But on increase of anticipated external load or further reduction of construction period, these sand drains were observed to buckle and shear off (as shown in Fig. 2 and Fig. 6) resulting in a discontinued path for the pore water to squeeze out. And upon further reducing the spacing of the sand drains to improve its efficiency, it has resulted in an uneconomical section. Hence DSM columns are introduced to further refine the model.

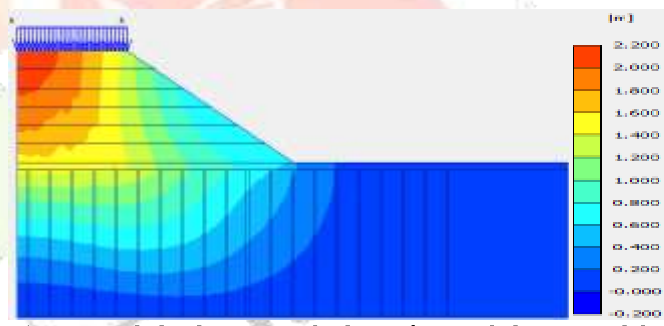

Fig. 6 Total displacement shadings for sand drains model after rapid construction of embankment

Case III: Stratum is analyzed for safety under increased and rapid loading after introduction of DSM columns along with sand drains.

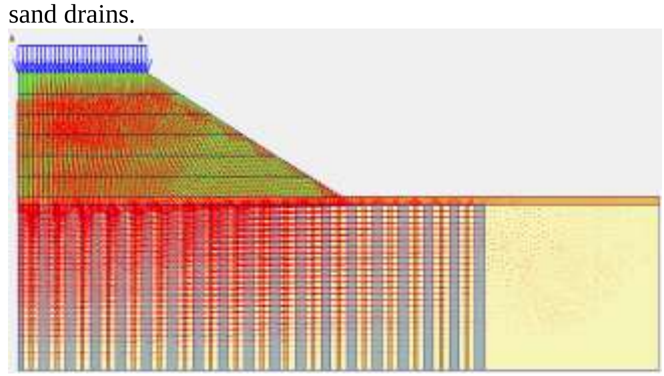

Fig. 7 Total displacement arrows for combined model under rapid loading of embankment construction (safe)

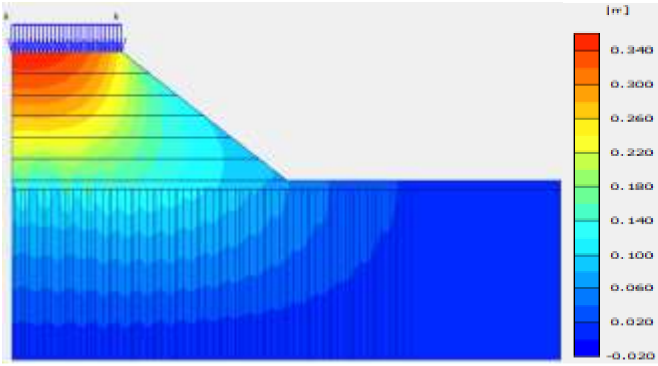

Fig. 8 Total displacement shadings for combined model under rapid loading of embankment construction (safe)

Figs. 7 and 8 depict the settlement behavior of the embankment with sand drains as well as DSM columns. It can be observed that the settlements are reduced on the weak foundation soil (compare Figs. 6 & 8) and the shear stresses are well within the permissible limits. The soil stratum seems to be safe under rapid external loading, resulting in an effective and economical alternative.

CONCLUSIONS

This paper presents a new combined ground improvement technique to achieve quick consolidation under rapid construction of layered embankment on soft clay deposits.

Based on the parametric studies the consolidation time of the soil system depends not only on the permeability but also the stiffness of the sand drains.

The stratum undergoes quick consolidation during the preloading period due to existence of the sand drains. However, it was observed that the rapid construction of embankment layers will result in shear failure at the base of the embankment.

The effect of shear failure due to rapid construction is avoided by the introduction of DSM columns.

Design charts were presented to design sand drains and DSM columns for a given time of consolidation and settlements. These charts will allow choosing an economical alternative of combined ground improvement technique.

Further analysis is required to refine the models to obtain the design charts for combined ground improvement technique.

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