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Methodology: A Review in Modelling and Predictability of Embankment in Soft Ground

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Abstract**—**Transportation network development in the developing country is in rapid pace. The majority of the network belongs to railway and expressway which passes through diverse topography, landform and geological conditions despite the avoidance principle during route selection. Construction of such networks demand many low to high embankment which required improvement in the foundation soil. This paper is mainly focused on the various advanced ground improvement techniques used to improve the soft soil, modelling approach and its predictability for embankments construction. The ground improvement techniques can be broadly classified in to three groups i.e. densification group, drainage and consolidation group and reinforcement group which are discussed with some case studies. Various methods were used in modelling of the embankments from simple 1-dimensional to complex 3-dimensional model using variety of constitutive models. However, the reliability of the predictions is not found systematically improved with the level of sophistication. And sometimes the predictions are deviated more than 60% to the monitored value besides using same level of erudition. This deviation is found mainly due to the selection of constitutive model, assumptions made during different stages, deviation in the selection of model parameters and simplification during physical modelling of the ground condition. This deviation can be reduced by using optimization process, optimization tools and sensitivity analysis of the model parameters which will guide to select the appropriate model parameters.

Keywords**—**Embankment, ground improvement, modelling, model prediction.

I. Introduction

When bearing capacity and settlement criteria of soil is insufficient for construction of the civil engineering structures then engineers have to improve the soil strength. This improvement in engineering properties of soil is called ground improvement [1], [2]. There are various methods of ground improvement under practice since long time for the improvement of foundation soil and the embankment slopes; they are compaction, dynamic compaction, soil-soil mixing, soil mixing with admixture, pre-loading, de-watering, vibro-replacement, jet grouting, and deep cement mixing. These techniques can be broadly classified in to three groups i.e. densification group, drainage and consolidation group and reinforcement group.

Embankment construction is common during construction of highway and railway which are the major mode of connectivity in developing countries. Most of the countries are focused on the development of transportation sector. In this context, China is leading from the front in developing the railways and expressways where soft ground is widely distributed. In mainland China, especially along the coastal area; soft marine clay, in midland; expansive soil, alluvial soil, marsh soil, lacustrine deposit, and collapsible soil and in western or northwest part; collapsible loess are very common [3]. Recently, several high-speed passenger railway lines are under construction and more than 10,000 kilometer long railway lines will be constructed within 15 years. According to the China National Highway Network Plan, 45,000 kilometer long highways will be constructed in the future. Some of these railways and highways have to be constructed on problematic soils and the treatment of such soils is expected to cost a considerable amount of money over the total budget [4].

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II. Ground Improvement in Embankment

According to the Chinese Technical Code for Ground Treatment for Buildings JGJ79-2002 (China Building Research Institute, 2002), ground treatment methods for buildings mainly include over-excavation and replacement, dynamic compaction, vibro-compaction, vibro-replacement, preloading, vacuum preloading, sand or gravel columns, cement-flyash-gravel (CFG) columns, rammed-cemented-soil columns, rammed-soil columns, lime columns, lime-soil compaction columns, grouting, solution injection, deep mixing, jet grouting, and lime-soil columns. Among these methods, ten or more ground treatment methods have been adopted in the construction of highways and regular/high speed railways embankment in China including fill preloading, vacuum preloading, combined fill and vacuum preloading, dynamic compaction, deep mixing, with different reinforcement elements, and pile-net composite ground. For a composite ground, rigid piles are sometimes used as ground reinforcement elements in addition to DM columns, sand columns or gravel columns. The embankment of high-speed railway is required to have high strength and stiffness, excellent stability and durability in post-construction stage which is mainly dominated by its foundation. Since the requirement of post-construction settlement of high-speed railway embankment is generally much stricter than that of highway pavements ground improvement is essential in many cases [5]. Some of the advanced ground improvement techniques area discussed in next section.

A. Drainage and Consolidation Group

Vertical Drain: Pre-fabricated vertical drains (PVD) are very useful to dissipate the excess pore pressure during construction and operation of embankment. During construction the PVD will accelerate the consolidation process eventually reduces the post construction settlement. Similarly, during operation the PVD can dissipate the cyclic pore pressures, reduces the lateral movements and increases the strength of the underlain soft formation [6]-[8]. The required length of PVDs can be determined based on design loads, and soft clay deposit thickness and properties.

The simple modelling method was applied to the analysis of a test embankment at the Hangzhou-Ningbo (HN) Expressway in eastern China. Analyses using drainage elements to represent the effect of the PVDs were also conducted. It is worth mentioning that using the concept of equivalent hydraulic conductivity, the FEM analysis can be conducted using standard commercial finite element programs [9]. The results obtained using the simple modelling method are compared with those obtained using drainage elements in terms of settlements, excess pore water pressures, and lateral displacement profiles. The results of both types of FEM analysis are also compared with the measured field data. The effectiveness of the simple modelling method has been demonstrated and verified by successfully simulating a large scale laboratory model test and a test embankment constructed in eastern China as shown in *Fig. 1*. These comparisons show that for most practical purposes the simple method can yield a result as good as that obtained using discrete drain elements to represent the behaviour of the PVDs.

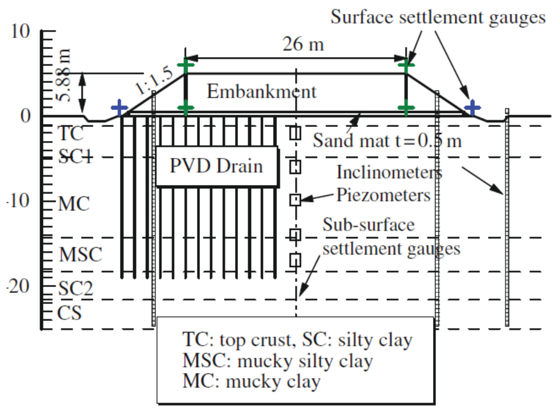

Fig. 1 Prefabricated Vertical Drain [9]

Combined preloading: The combined method (*Fig. 2*) proposed by [10] is a simple idea leading to the solution of construction problems form combined preloading. In this new approach care should be taken to following problems: firstly, the conventional electrodes are hard and stiff so that they can easily break the geo-membrane which is used to cover the electrode during the settlement of the ground.; secondly, the electrical circuit and drainage pipes of the conventional electro-osmosis system cannot work under geo-membranes and may be damaged by surcharge loading. This method was modified and verified by the field test carried out on a reclaimed land in Wenzhou, China, in 2011.

The consolidation mechanism can be explained with the help of combined electro-osmotic, vacuum drainage and preloading consolidation. First of all, vacuum pressure is applied in the electrode which generates negative pore pressure inside vertical drains which further extended to the soil in the periphery of the vertical drains. The hydraulic head difference in the vertical drain and the surrounding soil causes the flow of water towards ePVD. In the meantime, DC voltage is applied to the soil through ePVDs causing the flow of the cations presence in water towards cathodes along with the water molecules which enhance the flow of water. More importantly, this process also activates the water molecules in the diffuse layer near the surface of the soil particles which reduces the distance of diffused double layer of the clay particles. Using other mechanical means like vacuum preloading, surcharge preloading it is very hard to achieve this phenomenon. Therefore, electro-osmosis is very effective for the fine-grained soil with thick diffused double layers such as silts and clays. Surcharge preloading in combination with ePVD also has an important role. The increased pore pressure due to external load augmented the consolidation process along with electro-osmosis and vacuum.

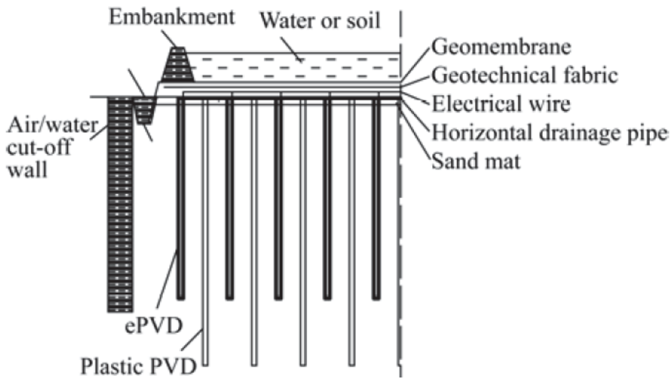

Fig. 2 Electro-osmosis, vacuum and surcharge combined preloading [10]

B. Reinforcement Group

Column Type Reinforcement: Among different type of improvement techniques, the column type reinforcements are widely used (as shown in Fig. 3). These conventional column-type reinforcement elements can be classified into three categories based on the used materials, the installation methods, and the behavior and failure modes of the elements. They are sand columns; stone columns, composite column, deep mixed (DM) column and piles. Some of the frequently used methods in construction of embankment in soft ground are discussed below.

DM Column: After the advancement of the deep mixing technology DM column are extensively used in embankment construction. And the commonly used material as an admixture is cement because it is relatively cheap, radially available and effective [11]. The other fact is the physical and mechanical behavior of the cemented soils has been extensively studied [12]-[16] resulting easy design for geotechnical engineers. Column supported embankments are studied by the various researchers to predict the load transfer mechanism, vertical settlement and lateral deformation.

Although this method was found efficient to control the settlements, researches have been conducted to enhance its performance using different techniques [17]-[21]. One of them is modification in shape of column called as T-shaped DM (T-DM) column. A comparative study of the T-DM and DM column for soft ground improvement has been carried out in the field [21] considering that the soil conditions, column strength and embankment load process for both sites are similar as shown in

Fig. 3, the T-DM column installation resulted in 6.5% reduction in cement use and 19% reduction of construction time when compared with the conventional DM column installation. The total settlement and the maximum lateral movement of the T-DM column treated ground were only 67% and 31% that of the conventional DM column treated ground, indicating the performance of the former was superior to that of the latter.

The side and tip resistance of a long DM column cannot be fully mobilized due to the failure of the column material [22], [23]. Under such a condition, the bearing capacity of the column can be improved by including strong and stiff elements. Concrete- DM and steel-DM composite column were developed to overcome the limitations of DM column.

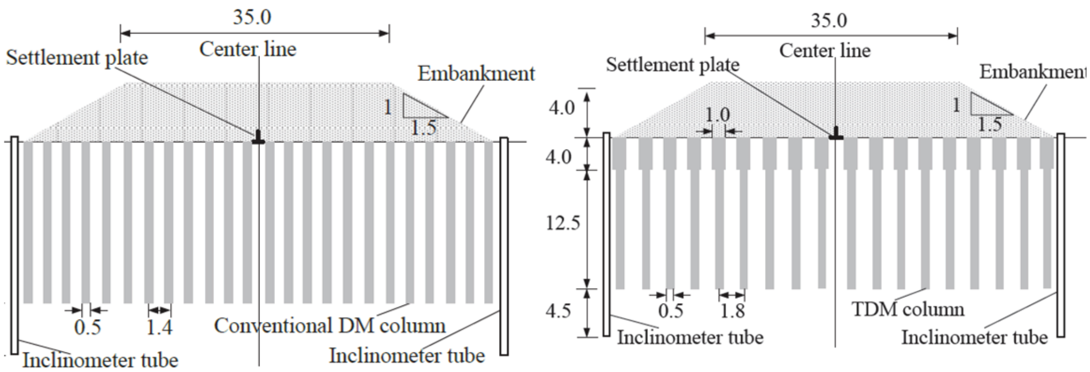

Fig. 3 Conventional DM column and TDM columns [21]

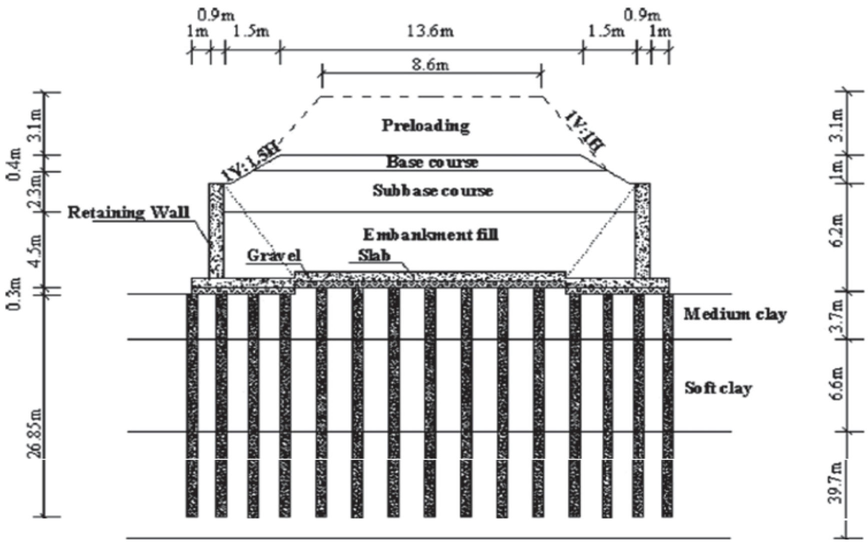

Fig. 4 CFG Pile-Supported High-Speed Railway Embankments over Soft Marine Clay

Cement-Fly Ash-Gravel (CFG) Pile: CFG piles have been successfully used in China to support buildings and embankments. There are various researchers working in the performance of CFG pile; Settlement formula has been developed for stabilized layer in CFG Composite Foundation of High-Speed Railway [24], while a researcher investigated the behavior of embankments supported by CFG piles using a three-dimensional numerical method [25]. Performance of CFG Pile-Supported High-Speed Railway Embankments over Soft Marine Clay was evaluated by [4] in Beijing – Tianjin High-speed railway. Two CFG pile-supported embankments along the Beijing-Tianjin high speed railway in China were monitored and investigated. The proportion of the loads carried by soil and piles, excess pore pressure, settlement, and lateral displacement were evaluated for the embankment shown in

Fig. 4.

Concrete-Sand (Gravel) Composite Columns: Sand/gravel-concrete composite columns were adopted as the ground reinforcement elements in a test section on soft soil

[26]. The backfilling of the embankment is shown in *Fig. 5*. Fill surcharge preloading was carried out. The excess pore pressure in the soil between columns was observed small during the whole backfilling of the embankment. The sand-gravel surrounding the concrete pile accelerated the dissipation of excess pore water pressure induced by the backfilling resulting in the rapid embankment construction.

Geo-synthetics: Geo-synthetics can be used in embankment for drainage, separation and reinforcement and improve the load transfer mechanism to the foundation system. Use of geo-synthetics as basal reinforcement has been shown to effective to reduce the short-term deformations and increase stability [27], [28]. However, it cannot prevent long-term settlement resulting from consolidation and creep behavior of soft soils. The prediction performance of basal geo-grid in the column supported embankment has been carried out by various researcher using numerical simulation tools [27]. Lai et. al. has conducted DEM analysis which showed that efficacy of pile is improved by use of geo-grid as shown in *Fig. 6* [18]. A wide range of geo-synthetics with different properties have been developed to meet highly specific requirements corresponding to various uses in new rail tracks and track rehabilitation. Based on relatively low cost and the proven performance of geo-synthetics in a number of railway applications, many researchers [29]-[31] have conducted experimental programs, field studies and numerical analysis to investigate the effects of the different types of geo-grid railway embankment, track settlement and stress distribution.

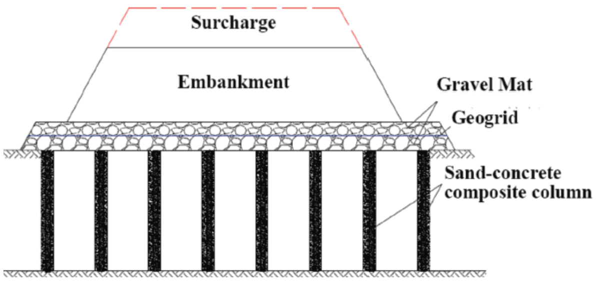

Fig. 5 Sand concrete composite column

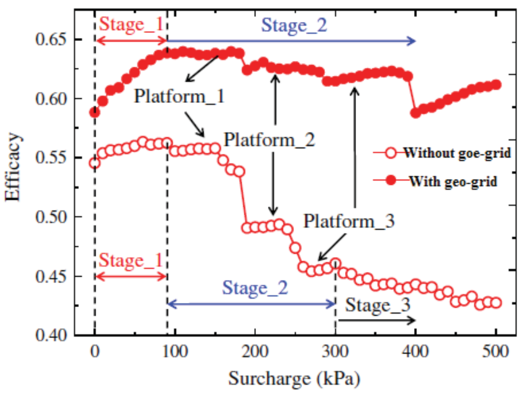

Fig. 6 Pile load efficacy of embankment with or without geo-grid [18]

III. Embankment Design and Performance

Test embankment was constructed to study the significant difference found in the predicted and observed settlement in the series of embankment constructed in the Pacific Highway NSW, Australia (Fig. 7). It was constructed in the soft Ballina clay and PVD was used to accelerate the consolidation of foundation soil. To monitor the deformation, pore pressure and stress extensive instrumentation have been done in the embankment. In-situ and laboratory tests were conducted to determine the high quality soil parameters for prediction of pressures and deformations. Various engineers, scientists and academicians were involved in the prediction. The predicted values for the settlement from the most of the predictor are found to be over-predicted in short time and under-predicted over long time. Similar prediction was found in case of lateral deformation at the end of embankment. Porewater pressure dissipation was also overestimated in most of the predictions.

Difference in prediction and monitored value is found mainly due the overestimated rate of dissipation of pore water pressure in the early stage of consolidation. The other causes for the discrepancy are overlooking the changes in permeability [6], [32], [33]due to reduction of void ratio and the effect of smear zone formed after installation of PVD [6], [34]-[36]. Most importantly the different predictors use different tools (i.e. 1-D, 2-D, 3-D computational techniques) and different constitutive models causing the variation. Constitutive model used in predictions are Modified Cam-clay (MCC) model, one dimensional consolidation theory, Soft Soil (SS) model, Soft Soil-Large Deformation (SS-LD) model, Hunter clay model, Hardening Soil (HS) model, Soft Soil Creep (SSC) model, Creep-SCLAY (C-SCLAY-1S) model, Elasto-viscoplastic SANICLAY model [37]. It has been found that different predictors used different model parameters to make their prediction better [37], [38]. Some have used constant compression, swelling and creep index although the compression index of the Ballina clay is stress dependent. Similarly there is not uniformity in choosing basic soil parameters (for example friction angle) among the different predictors [37].

IV. Conclusion

- This study is focused on the ground improvement techniques, their appropriate modelling and prediction of deformation stress during construction and post-construction stages. The finds of the study is summarized as below:
- There various methods used to analyze and predict the embankment performance. Whatever methods and tools used in the predictions of the embankment settlement it has been found that there is no systematic improvement in the accuracy with the level of sophistication [37].
- The model predictability can be improved by using most appropriate constitutive model and the assumptions (i.e. whether to incorporate the effect of creep during primary consolidation or not).

- Before carry out the model simulation, the optimization process using elemental test can be used to select the appropriate model parameters [6], [39]. Similarly, sensitivity analysis is useful to determining the influencing model parameters so that determination of the parameters can be done accurately [35], [38]. Finally, appropriate physical modelling of the field conditions is very important, each and every element (PVD, DMC, CMC, Geogrid, Anchor etc) and the smear zone should be model with appropriate model parameters [38], [40], [41].
- The scale and advancement of ground improvement technique used in construction of infrastructures is increasing day by day. In the meantime, there are lots of limitations have found in using well established methods and tools also which inferred that the requirement of the expediting researches in ground improvement from geotechnical community is necessary.

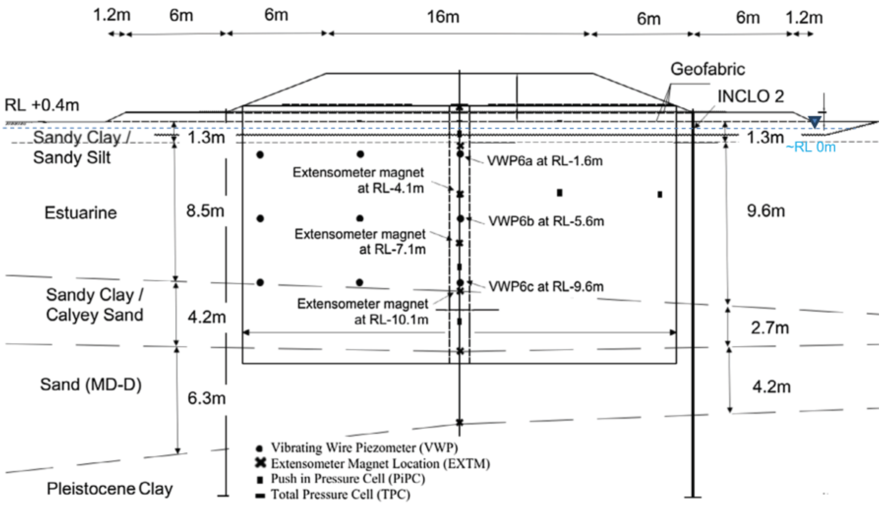

Fig. 7 Test embankment constructed in Ballina clay [32]

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