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Simplified technique achieving low cost and high performance impact for construction in very deep very soft ground sites

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Abstract Geotechnical engineers are still facing the true harmful problems of the very deep deposits of very soft clay soils for structural foundations. It is believed that the current used methods of geotechnical engineering improvement in soft clays are justified on the basis that pre-knowledge of the potential problems can lead to economic benefits if the planning, design, and construction of projects can be modified to suit the problems to provide increase of its strength, reduction of total and differential settlement, reasonable cost, and shorten construction time. Therefore, the cost-effective alternatives play significantly an essential role to evaluate considerably the efficiency among the widely used current methods in this true problematic field. From this considerable point, vast experience has been acquired to solve this problem through soft ground improvement before turning to deep foundations which need considerably huge cost especially for the very deep very soft ground. Unfortunately, the improvement magnitudes of the most widely used current techniques do not suit even fairly with their required cost and their installation difficulty which need highest level of accuracy.

In this paper, innovative convenient type of foundation system has been laboratory tested to evaluate the significance through the aspect of cost-effective alternative which is clearly unachieved by the currently used techniques. This novel technique was achieved by high efficiency rate, simplicity for execution, huge increase of strength under footings, rapid rate of construction process, considerable saving in the required cost, and significantly reduce total and differential settlement.

Introduction

In Egypt, very soft clays occur predominantly in the coastal areas and fairly in the inland areas. Practicing geotechnical engineers from all around the world have made significant contributions over the past years to establish better technique which can be suited to the soft ground improvement and the

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project requirements. The required performance in the very soft ground must provide the following elements that are simple execution, satisfied improvement of its low shear strength, mitigation of total and differential settlements, shortening construction time, and reducing construction costs as possible. The possibility to obtain the highest possible degree of each of the previous element together defines significantly the high efficiency of the improved technique.

This part gives an overview of the currently used techniques, through the technical and economic aspects, that are commonly used all over the world. Moreover, these methods must be executed in sites by specialty contractors to improve the performance of the soft ground. Also, this part is intended to give a general understanding of each one and how each improves the soft ground performance.

The widely used current improvement techniques are divided into five ways: sand drains, granular piles, deep mixing method, rammed aggregate piers**,** and reinforced soil foundations.

Ground improvement by vertical drains

Applications of sand drains have been reported [1–9]. Recent sand drain applications in Japan were reported [10,11].

Because of very low clay permeability of soft clay subsoil, the primary consolidation takes considerably time to complete. To relatively shorten this consolidation time, vertical drains are installed together with preloading by soil embankment prior to placement of the final permanent construction load which must be placed with standard low pressure earthmoving equipment due to the natural weakness of the soft ground to avoid occurring of the shear rupture of it leads to consume long time to obtain the possible complete compression which may reach up to 8 months [12]. In China (1980), the vacuum pressure is performed as preloading instead of soil embankment. Vacuum-induced consolidation uses atmospheric pressure to apply a temporary surcharge pressure. A porous layer of sand or gravel is placed over the soft ground and it is covered with an airtight membrane, sealed into the soft clay and the prefabricated installed vertical drains (PVDs) under the porous layer. The air is then pumped out of the porous layer producing the pressure. The spacing of sand drains or (PVDs) is designed to reduce the primary consolidation time to an acceptable duration, the closer the drains are installed, the shorter the drainage distance and consequently, the relatively shorter time is obtained. In this method, the pore water squeezed out during the consolidation of the clay due to the hydraulic gradients created by preloading can flow a lot faster in the horizontal direction toward the drain. There are some essential and sophisticated considerations that affect deeply the success of this technique such as compressibility characteristics, stress history, magnitude and rate of loading, and the relationship between the area of loading and the thickness of the soft layer. Bergado et al. [13] studied the efficiency of this technique on an improved soft ground, and it has been proved that the obtained performance is being unsatisfied when putting into consideration, the significant natural weakness of very soft clay, its huge cost, tedious effort, required difficulty and accuracy to execute, needs specialty contractors to carry out, and the long time required. Moreover, Balasubramaniam et al. [6] confirmed that this unsatisfied obtained improvement occurs only at shallow depths as the result of sand drains with preloading is not effective at deeper depths.

Ground improvement by stone columns

Stone columns are composed of compacted gravel size stone particles constructed vertically in the soft ground by the displacement method to improve its performance. The ground improved by compacted stone columns installed in soft ground to create composite ground. The stone is typically graded crushed hard rock, although natural gravel and pebbles have been used, the greater the friction angle of the stone leads to the greater the modulus and shear strength of the column. When the composite soft ground loaded, the stone columns deform by bulging into the subsoil strata and distribute the stresses at the upper portion of the soil profile rather than transferring the strength into the deeper layer causing the soil to support it. Thus, the strength of the composite ground can be increased and the compressibility reduced. Applications of sand drains have been reported [14–16]. The performance of this technique is increased by increasing the numbers and diameters of the installed stone columns through the required improved area. Also, the degree of performance depends significantly on the end support of the stone columns, the firm or rigid supports are considerable better than the weak soft end [17].

The improvement in this technique is also not satisfied practically comparing to the required high cost to carry out as its performance varying between 25% at the area displacement (a_s) 0.1 and 150% at (a_s) equals 0.7 for the site soil cohesion equals to 0.45 kg/cm^2 with firm end strata where (a_s) is defined as the ratio of the stone columns area over the required improvement whole area. These improved percentages are considerably reduced for the long depth soft ground [18].

Ground improvement by soil mixing

Soil mixed mechanically mixes soil with a binder to create in situ cemented soil. Mixing with dry lime and cement was developed to treat soft clays. Application of this method for deep mixing started in the late 1970s in Japan [19–21]. The increase in strength and the corresponding decrease in compressibility of the soft ground by using cement or/and lime slurry which is jetted into the soft ground by a reasonable pressure from the rotating nozzle are significantly less than using the dry cement and/or dry lime powders which are pumped through a nozzle pipe with the aid of compressed air [22]. The process of jet grouting is started by drilling the injection pipe to the desired depth through the soft ground and then jet grouting is initiated as a bottom-up process to form the adequate mixing column. Repetition of this process must be implemented to obtain as possible as the homogenous treated soil, and this tedious process needs specialized contractors and long time to execute and quality control, moreover high cost. Mixing 10% of lime or/and cement slurries leads to increase the unconfined compressive strength to about 2.0 to 5.0 times depending on the diameter and distances between the mixing columns [23]. This technique has also the same previously mentioned disadvantages which are summarized in high cost and low performance impact.

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