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REVIEW

Improving Bearing Capacity of Weak Soils: A Review

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ABSTRACT

Weak soils, such as soft clay and loose sand, have a poor bearing capacity, making them incapable of bearing the load of superstructures that will be imposed on them. As a result, engineers must have a solution to the issue of poor bearing capacity in weak soils before embanking into building on them. This paper reviewed the use of stone columns, piled rafts, and geogrids for improving the bearing capability of weak soils. Important findings from recent research are also discussed. From the review of the previous researcher's findings, it was found that modelling approaches such as physical modelling (full scale, centrifuge, laboratory scale) and numerical modelling are used to study bearing capacity improvement.

1. Introduction

The growing cost of land and the limited availability of suitable construction sites motivate engineers to think improving poor soil deposits. A number of ground improvement techniques have been designed to economically improve marginal sites. Ground improvement approaches are a more cost-effective and long-term alternative to piling and deep foundations [1]. To cope with soft soil issues, a variety of soil improvement techniques have been used. Stone columns, piled raft and geogrids are among the popular methods ground improvement techniques with a traceable record of success.

Stone columns became well established in France in the 1830s. It was apparently used to improve native soil [2]. In Germany stone column was used for the first time in the mid-1930s and it used on frequently in Europe and North America since the 1950s and 1972, respectively [1,3]. Stone columns have been used in many difficult foundation sites around the world to improve bearing capacity, minimize total and differential settlements, and improve structural stability. Many challenging foundation sites around the world have used stone columns to increase bearing capacity, minimize total and differential settlements, accelerate consolidation, improve slope stability, and increase liquefaction resistance [2,4]. Stone column also reduced liquefaction menace and ease of construction [5]. Stone column technique has been widely applied all around the world for the foundations of structures with significant settlement potential.

Raft on pile-foundation systems is used in poor sub-soil to transfer the load into deep bearing layers; however, it is

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uneconomical to use long piles to enter the bearing layer in a highly extended non-bearing soil [6]. Thus, the piled raft foundation structure is the most cost-effective foundation structures that fell between the raft (relatively inexpensive) and the raft on piles (very rigid and expansive) foundation systems. The behaviour of a piled raft is based on the dynamic relationship between pile-soil, pile-raft, raft-soil, and pile-pile [6]. One of the most advantages to the piled raft foundations is that it is not necessary to meet geo-technical bearing capacity; only structure is required [7].

Geogrid is a geosynthetic reinforcement agent used to stabilize soft soil in order to offer easier, more practical, and environmentally sustainable solutions [8]. Geogrid reinforcement installed on a soft clay subgrade layer foundation with granular filler is widely used in unpaved roads, slopes, and major stabilized areas such as parking lots or oil drilling work platforms [9]. Alawaji, (2001) [10] researched the impact of strengthening a sand block underneath a collapsible soil with geogrid, and it was noticed that the rate of slump reduction surpassed a threshold of 75% after reinforcements.

In this paper, review of previous research findings of weak soils bearing capacity improvement using stone column, piled raft and geogrid are presented.

2. Stone Column

The stone column, also known as vibro-replacement, or granular piles, is a ground improvement technique that involves the formation of vertical columns of compacted aggregate into the soils to be strengthened by compacting stone aggregates in a vertical hole as shown in Figure 1. Stone columns improve the engineering behaviour of soft clay and loose silt by accelerating the consolidation of soils due to a shorter drainage path. Stone column also increases load carrying capacity due to the inclusion of stronger granular material [2]. Moreover, vertical columns of aggregates when compacted into the soft clay mitigate settlement of the soil [11].

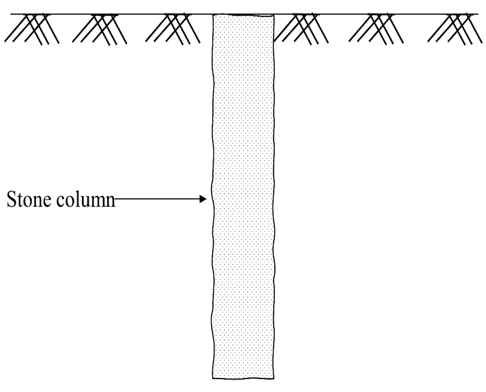

Figure 1. Stone column

During the last two decades, a great deal of researches on stone column had been undertaken by many researchers all over the world. The stone columns soft soil improvement technique and its effect on bearing capability were described using a substantial number of experimental evidence and theoretical studies. Many experimental studies have been conducted on the use of a stone column to improve the bearing capability of soft clay, using both physical and computational modelling. According to. Madun et al. (2018) [12] increasing the diameter of the stone column increases the carrying capacity of the stone. In contrast, increased stone-column length reduces soil settlement. Consistent with Nayak et al. (2020) [11], side incarceration by the geogrid and basal layer increases the load-bearing capacities of clay treated with ordinary stone column, geogrid-encased stone column, and geogrid-encased stone column with the horizontal basal layer by 60 to 256 %.Other research has found similar findings on the impacts of stone column geometry [13-15] and the effect of using geotextile to encase the stone column for enhancing the bearing pressure of soft clay [16].

According to Naseer et al. (2019) [17], the sand column technique is more appropriate in clay with a higher shear strength. For instance, when the shear strength of clay (su) was 32 kPa, the composite ground showed little improvement in ultimate loading capacity and no improvement when su = 14 kPa. The ultimate load-carrying capacity was increased by increasing the length to diameter ratio (L/D) up to the critical value of L/D = 4. The ultimate load-carrying capacity decreased as the spacing between the columns increased. As the sand column is loaded alone, it bulges at the point of highest axial tension, which is centered at a depth 1.5 times the column's diameter. No bulging has occurred when the entire area is loaded.

3. Piled Raft

A piled raft is a low-cost form of ground improvement that includes adding piles to a raft foundation as shown in Figure 2 to increase its effective size, withstand horizontal loads, enhance load carrying capacity, and minimize settlement and differential settlement. According to Card & Carter, (1996) [18] the basic principle of the piled raft embankment design is transferring the bulk of the load to piles underneath the embankment, total settlements can be minimized. Concurrently, differential settlement of the embankment between piles could well be reduced by maximizing load distribution between pile groups and the raft. Padfield, (1983) [19] defined piled raft techniques and explored their configuration in terms of pile group arrangement and raft stiffness. This tech-

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nique was used to maximize the load sharing between piles and the raft for massive, heavily loaded structures to mitigate the settlement and achieve an affordable structural design. The use of a piled raft to minimize settlement of a piled bridge abutment and approach embankment built on soft compressible clay was defined by Reid & Buchanan, (1983) [20] the load was transferred to the pile caps by a "membrane", which spans between the caps of the pile in the catenary. Bağriaçik et al. (2018) and Banerjee et al. (2020) [21,22] carried out studied on pile numbers and pile lengths under the raft subjected to a uniform vertical loading. The settlement aspects for an efficient design of a piled raft subjected to vertical loadings have been addressed. It is found that the required piled group-raft area ratio (Bg/Br) [21,22] investigated the differential settlement of piled rafts and discovered that settlement increases as the length of the pile is decreased. Therefore, for an effective configuration of piled raft in layered soil, the Bg/Br ratio should be between 0.4 and 0.6, where Bg is the piled area and Br is the raft area [21]. According to Sharma and Sanadhya (2020) [23], increasing the stiffness of the granular pile and bearing stratum causes decreases top displacement and settlement ratio as well as increase in normalised shear stresses near the raft and percentage load transfer to the raft.

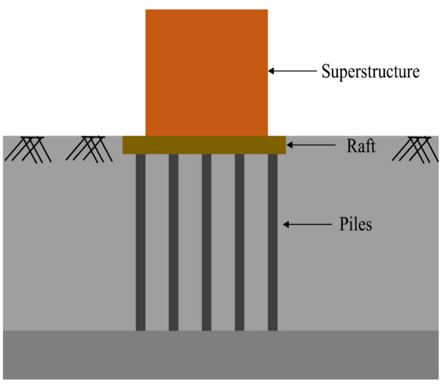

Figure 2. Piled raft foundation

Hamed et al. (2020) [24] discovered that the ultimate load of a pile increases with increasing L/D and decreases with increasing d/D, where L, d and D are pile's length, internal diameter and external diameters respectively. Similarly, Majeed and Haider (2018)[25] identified numerical analysis as the most cost-effective method of estimating pile potential because both field and numerical results agreed so well. Zheng (2018) [26] discovered that grouting strengthens the soil strength around the pile, decreases settling, and increases the pile's bearing capacity. Other related researchers studied the effect of the piled raft foundation system and found advantages to the piled raft foundation system as compared to conventional foundation systems (Al-Obaidi and Mahmood, 2018; Abdel-Azim , 2020)[6,27].

4. Effect of Geogrid on Bearing Capacity of Soil

For about 40 years, geogrids have been researched and used as reinforcement in the base course layer of lightweight pavementsPerkins & Ismeik, (1997)a, (1997)b [28,29]. Some of the early research on application of geogrid are summarized in Table 1.

Table 1. Early applications of geogrid material

Reference	Description of application
Barker, (1987) [30]	Used for open-graded base course material on airport runways. One trial section with geogrid reinforcement was built and compared to one control section with similar geometry and properties.
Anderson & Killeavy, (1989) [31]	To stabilize the base layer of a truck parking yard, a geogrid was combined with a weak nonwoven geotextile separator in a field trial.
Barksdale et al., (1989) [32]	Using geogrid and geotextile, an experimental and finite element simulation analysis was carried out. In an indoor test track, pavement test sections were built and loaded with moving wheel.
Cancelli et al., (1996) [33]	In an indoor metal test tank, cyclic load plate experiments are performed using five geogrids and one geotextile. The fine sand subgrade's strength varied from 1 to 18 CBR, and it was produced by varying the material density.
Jeon, (2010) [34]	The study for assessing the long-term efficiency of two different geogrid forms (textile and membrane-drawn) wih design strengths of 8 and 10 t/m, respectively. The estimated long-term creep deformation of the woven geogrid showed that 60-65 % of the ultimate loading level was the optimum value for satisfying the creep criterion. The result indicated that textile geogrid had high long-term deformation tolerance relative to membrane-drawn geogrid.
Das, (2016)[35]	Geogrid was used in the soft subgrade, sub-ballast and ballast layers, to minimize track settlement and, maintenance frequency.

Some of the recent studies of geogrids application include those by Hamidi and Abbeche (2020) [36] who investigated the effects of geogrids on loose soil bearing capacity. Their findings revealed that decreasing the distance between the geogrid reinforcement increases the soil's bearing capacity. The appropriate depth of the first reinforcing layers at the footing's bottom is 0.25B. The bearing capacity of the reinforced soil increases as the gap between the geogrid reinforcement is decreased.

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The optimal distance of reinforcing of the geogrid is therefore 0.25B. In addition, reinforcing of the soil with geogrid decreases the slope impact on soil's bearing capability by 15% and 45%, for slopes 15° and 35°, respectively.

Similarly, Abu El-Soud and Belal (2019) [37] find it possible to increase their bearing capacity and reduce settlements of sand dune if geogrid reinforcement is placed at the right position within the sand dune. It takes roughly 0.25B of geogrid burial, 0.75B of vertical geogrid spacing, and 7.5B of geogrid length under the strip footing to mobilize the full bearing capacity of sand-geogrid composite. Bearing capability and settlement requirements necessitate three and four layers of geogrid, respectively.

Moreover, Preetha et al. (2019)non-uniform settlements and shear distribution. The soil stabilization is one such method to improve the process and it depends upon the soil condition and the nature of soil according to the desired requirements of footing. This study aims to increase the index and engineering properties of soil by addition of the natural fiber (sisal) [38] discovered that the subgrade's load capacity was increased by sisal fiber 2,5 times. Other related study reports that the usage of various geosynthet-ic materials to increase bearing capacity and minimize foundation settlements (Azzam and Nasr, 2015; Ahmad et al., 2016; Aria et al., 2017) [39-41].

5. Conclusions

The following conclusions can be drawn from a review of the approaches used to improve the bearing capacity of weak soil.

Weak soils, such as soft clay and loose sand, have a poor bearing capacity, leaving them incapable of carrying the load imposed by the superstructure. As a result, engineers must solve the problem of low bearing potential in poor soils before embanking and constructing on them.

The use of stone columns, piled rafts, and geogrids to improve the bearing capacity of poor soils was reviewed in this article.Important recent research results are also discussed.

Based on the results of previous researchers, it was discovered that modeling methods such as physical and numerical modelling are used to study bearing capacity improvement

Conflict of Interest

The author wishes to note that he has no conflicts of interest in relation to this article.

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