Research progress of soft soil foundation treatment technology

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Abstract: With the extensive improvement of infrastructure in China in the past ten years, the soft soil foundation is becoming more and more complicated. Therefore, the improvement of soft soil foundation treatment has become a difficult problem that today's engineering designers have to face. This paper systematically reviews the development of soft soil foundation treatment technology in our country, and emphatically introduces the development process of foundation treatment at home and abroad, especially in our country in recent years, which embodies the cross and comprehensive application of various foundation treatment technologies and forms a unique composite reinforcement technology.

Key words: soft soil foundation treatment; Overview; Composite reinforcement technology; Composite foundation

Introduction

With the continuous development and progress of society, especially in China's coastal cities, it is even more necessary to build high-rise buildings, docks and roads on weak foundations. In this process, more and more complicated soft soil foundation treatment problems will be encountered, thus providing opportunities and challenges for the development of new soft soil foundation treatment technologies. In the past ten years, the development of soft soil foundation treatment has been mainly carried out in three directions: first, gradually from a single reinforcement method to a multi-method composite form; Second; Gradually from the consumption of high manpower, materials and expenses to the development of mechanical and economic methods; Third, gradually from high energy consumption, high pollution technology to new low carbon technology, the harmonious development of man and nature. Therefore, reasonable and effective treatment of soft soil foundation has become a key issue in engineering construction.

1 Definition of soft soil

Generally speaking, soft soil refers to silt, muddy soil, dredger fill, miscellaneous fill and saturated loose silt and silt. This kind of soil has high compressibility, low strength, high natural water content, large natural void ratio, low shear strength, small permeability coefficient and other engineering characteristics. Under the action of external load, the bearing capacity of the foundation is usually low, the deformation of the foundation is large, the uneven deformation is also large, and the deformation stability lasts a long time. Therefore, China's Ministry of Construction stipulates that soft soil is defined as any one that meets the following three characteristics: (1) fine clay with mainly gray
appearance;(2) the natural water content is greater than or equal to the liquid limit;(3) natural pore ratio is greater than or equal to 1.00[1].

2 Principles and Objectives of Soft Foundation Treatment

In principle, the treatment of soft soil foundation should first consider the use of natural foundation. For the design of silt and muddy soil, a better soil layer should be used as the foundation bearing layer. The upper covering soil layer is relatively thin. Attention should be paid to the protection of the bottom surface of the soft soil foundation trench during construction to reduce disturbance. For flushing and miscellaneous construction wastes and industrial wastes with stable performance, they can be used as foundation when the uniformity and compactness are good. If the foundation is weak and cannot meet the requirements, it needs to be treated. According to the engineering conditions and the different soil conditions or composition of the foundation, the purpose of treatment can be divided into the following five types: (1) improving the shear strength of the foundation soil to keep the foundation stable;(2) reduce the compressibility of the foundation and increase the compression modulus of the foundation soil, thus reducing the settlement or uneven settlement of the foundation;(3) improving the permeability of the foundation soil or reduce the water pressure;(4) improving the dynamic characteristics of the foundation, preventing liquefaction of the foundation, and improving its vibration characteristics to improve the seismic performance of the foundation;(5) improve the bad foundation characteristics of special soil, thus eliminating or reducing the foundation deformation caused by the subsidence or expansion and contraction of soil, and avoiding building glass damage or affecting its normal use.

3 Common Treatment Methods for Soft Soil Foundation

There are many types of soft soil foundation treatment methods, which can be divided into temporary treatment and permanent treatment according to time. According to the depth of treatment, it can be divided into shallow treatment and deep treatment. According to the treatment principle and mechanism, it can be roughly divided into the types of changing foundation structure form, drainage N consolidation method, artificial foundation and dynamic compaction method[2].

3.1 dynamic compaction method

Dynamic compaction method is internationally known as dynamic compaction method or dynamic consolidation method. It is a foundation consolidation method initiated by French Menard Technology Company in 1969[3].China introduced dynamic compaction technology for the first time in the late 1970s. After that, several tests have been carried out and remarkable results have been achieved. As a foundation treatment method with wide applicability and high economic benefits, dynamic compaction method has achieved great response in China's engineering field, and has been quickly applied to industrial and civil buildings, highways, docks, airports and other projects throughout the country, thus accumulating a lot of experience[4].The principle of dynamic compaction reinforcement is a foundation treatment technology that generates an impact force on the foundation through strong tamping energy and forms a shock wave in the foundation. Under the impact force, the rammer punches the upper soil mass, damages the soil mass structure, forms a tamping pit, and compresses the surrounding soil by power, thus reinforcing the foundation.

3.2 Replacement of Cushion

The replacement cushion method refers to digging out all the weak and unfavorable soil layers within the treatment range below the foundation bottom surface, replacing them with loose materials with good soil quality and low compressibility, and rolling or ramming them to serve as the bearing stratum to bear the pressure from the upper part. Then sand, crushed stone, fly ash, dry slag, soil (lime soil, lime ash) or other materials with stable performance and no erosion are used as the cushion layer to improve the bearing capacity of the bearing layer and reduce the bearing pressure of the natural soil layer under the cushion layer, thus reducing the settlement of the foundation. The sand cushion layer should pay strict attention to water content during construction, control water content, and adopt layered paving and compaction methods.

3.3 preloading consolidation method
Pile-load preloading method: pile-load preloading method refers to applying load to saturated soft soil foundation by filling and other loading, and gradually discharging pore water in the soil by static pressure to promote consolidation deformation of the soft soil foundation, so as to improve the effective stress of the soil layer, enhance the strength of the foundation and reduce the settlement of the foundation. It can be divided into single-stage loading or multi-stage loading according to the soil quality. According to the stacking materials, it can be divided into gravity preloading, pressure preloading and water preloading[6].

Vacuum preloading method: The vacuum preloading method refers to laying sand cushion layer on the surface of soft soil foundation to be reinforced, then embedding vertical drainage pipes, and then isolating it from the atmosphere with airtight sealing film. The film is embedded in the soil around. Through the water absorption pipes embedded in the sand cushion layer, the vacuum device is used for air extraction to form vacuum and increase the effective stress of the foundation[7]. The relative surcharge preloading method needs to consider the problems of high transportation and construction costs due to a large number of surcharge sources, instability of the site due to large-area surcharge, and large lateral displacement[8]. The vacuum preloading method does not need to consider the stability of foundation. The vacuum load can be quickly applied to the design value in a short time, so the preloading time can be significantly reduced[9].

3.4 Compaction Method

Compaction method mainly refers to the process of compacting some soft and thick foundation with compaction piles. The actual operation of the compaction pile is also relatively simple. First, the casing pile should be squeezed into the foundation, where the soft soil is squeezed around the casing pile and densified. At the same time, the hole is formed due to the squeezing of the casing pile. Then, the casing pile is pulled out and filled with sand or gravel, lime, lime soil, soil and other materials and compacted. The main purpose of doing this is to combine the material in the hole with the surrounding squeezed soft soil layer to form a composite soil layer, which will jointly act as a bearing layer to bear the pressure from the upper building, thus improving the overall bearing capacity of the soft soil foundation and reducing the settlement of the foundation[10].

3.5 vibroflotation method

Vibroflotation method is a foundation treatment method that generates horizontal or vertical vibration force through vibroflotation device and vibrates surrounding soil with pressure water to improve foundation bearing capacity, increase foundation stability, reduce settlement and further improve earthquake liquefaction resistance. This law originated in Germany in 1936. It was used for the first time in 7.5 m subsolting sand foundation of a building in Berlin, and its bearing capacity and relative density have more than doubled[11]. China began to study vibroflotation method and trial-produce vibroflotation device in 1970s. In 1977, Nanjing Academy of Water Resources Sciences and the Water Resources Planning and Design Institute of the Ministry of Communications cooperated to develop the first vibroflotation device in China. It was first applied to the hull reinforcement workshop of Nanjing Shipyard and achieved satisfactory results even though the equipment was crude at that time[12].

3.6 chemical reinforcement method

The methods described above, whether they are dynamic compaction method, preloading method or cushion replacement method, all use various mechanical or external forces to encrypt the soil, but they do not change the chemical composition of the original foundation soil in essence, thus they are all physical reinforcement methods. As the name implies, the chemical reinforcement method uses the addition of new materials to change the chemical properties of foundation soil. Therefore, the chemical consolidation method is to use certain chemical materials or chemical reactions to fill and reform the soft soil foundation, promote the consolidation of the soft soil layer, reduce the compressibility of the soil layer, and improve the bearing capacity of the foundation. There are many chemical slurries used to reinforce the foundation by chemical reinforcement method. The common materials are: cement slurry[13], water glass slurry[14], acrylamide slurry[15] and pulp waste slurry. Chemical reinforcement method can be divided into pressure grouting method, high-pressure rotary
spray method, deep mixing method and electroosmotic silicification method according to the particle size of foundation soil and the properties of chemical grout. Select the best scheme according to different engineering and soil conditions.

4 New Development of Soft Soil Base Treatment

4.1 Development of Soft Soil Foundation Treatment Methods

4.1.1 Multi-flocculant Combined with Vacuum Preloading Method

As mentioned earlier, when the soil has the characteristic of high water content, the vacuum preloading method will be taken into account in site treatment. However, as soft soil is mainly composed of fine particles, when it passes through the drainage membrane, the blockage often occurs near the prefabricated vertical drainage in the process of vacuum preloading. Therefore, the drainage capacity is significantly reduced, which often leads to insufficient consolidation and poor geotechnical properties of soil. In response to this problem, Wang Jun and others proposed a method of multi-flocculant combined with vacuum preloading[16] to treat dredged slurry. The method is mainly realized by pretreating dredged mud with lime[17] and anionic polyacrylamide (APAM)[15] before vacuum. The reinforcement principle of this method is that a certain amount of lime and APAM are added to make small and medium particles in soft soil form larger lumps, i.e. flocculated state, thus improving void ratio and air permeability. This forms a new kind of natural soil, which is easier to be consolidated by vacuum preloading. At last, the optimum ratio of lime to APAM content is determined to be 2:0.1 during vacuum preloading.

4.1.2 bamboo net reinforcement method

Land reclamation land is uneven in horizontal and vertical directions. Water content is generally 80%-150% or more. The site is in the state of flowing sludge, and even floating sludge has little bearing capacity. Therefore, the surface layer must be strengthened. The commonly used pretreatment technologies for surface layer sediment and debris flow include multi-layer geogrid and geotextile and sand cushion layer technology, pretreatment technologies for hanging pieces and bamboo chips, sand-free vacuum preloading, etc. Surface pre-treatment bamboo net technology[18] is a surface pre-treatment technology based on bamboo raft technology. Vertical bamboo is inserted into sludge to make the bamboo net enter the frame bamboo net structure. Because this technology makes the bamboo raft into a three-dimensional skeleton, the bamboo net tends to be stable on the plane. Yuanman[20] et al. through the study of Shantou highway embankment treatment project and engineering examples, show that the bearing capacity of untreated super soft soil surface layer is 32.6 kPa. When the surface layer is treated for 3 months, it is 323% higher than that of the earlier treatment and 695% higher than that of the untreated one.

4.1.3 Compound Negative Pressure Consolidation Technology

When facing the soil with large water content, poor permeability and zero bearing capacity in engineering, conventional foundation treatment methods cannot be carried out and foundation treatment faces many difficulties. To solve this problem, a compound negative pressure consolidation technology is proposed. The technology includes three procedures: modified vacuum preloading, electro-osmotic dewatering and dynamic consolidation. Modified vacuum preloading enables the foundation to be initially consolidated with a certain strength to prepare for subsequent work. Electroosmotic dewatering can effectively reduce the groundwater level and soil moisture content before tamping and promote the dissipation of excess pore water pressure after tamping. Electroosmotic dewatering and dynamic consolidation are coupled for many times to reinforce the foundation of dredger fill. Gao Youbin[21] and others used this method in the field. The results show that when applied to the foundation treatment of dredger fill, modified vacuum preloading can rapidly improve the bearing capacity, electroosmosis method can rapidly reduce the underground water level, effectively avoid the occurrence of "spring soil" phenomenon during dynamic compaction, thus improving the optimal tamping energy. Compound negative pressure consolidation technology can be effectively applied to newly reclaimed soft soil foundation.

4.1.4 Microbial Infiltration Grouting Method
Microbial infiltration grouting is a new foundation treatment technology. Its working principle is to improve the compressive strength of the foundation by infiltrating or injecting microbial slurry into sand samples. This method is often compared with saturated grouting method in tests. Among them, Andres Quiros[22] and others have shown through experimental research that the effect of treatment of unsaturated soil samples by infiltration method (average unconfined compressive strength is \((19.7\pm 5.86)\text{MPa}\)) is better than that of saturated soil samples by grouting method (average unconfined compressive strength is \((15.1\pm 5.73)\text{MPa}\)).

4.1.5 chemical electroosmosis

The chemical electroosmosis method is obtained by a series of developments of the traditional electroosmosis method. Its main working principle is to inject chemical solutions near the cathode and anode electrodes respectively. Under the action of direct current electric field, the chemical solutions react chemically to generate corresponding precipitates to reinforce the soil, thereby improving the strength of the soil and accelerating the consolidation rate of the soil. Taiwan's European Zhang Yu and others have carried out a series of laboratory tests on the concentration of chemical solutions, types of suitable soils and treatment effects, and have enriched and perfected the corresponding construction techniques[23]. The research and application of this technology in China is still in its infancy.

4.2 Development of Soft Soil Foundation Treatment Materials

The development in material direction is mainly reflected in geosynthetics and grouting materials. Geotechnical materials are mainly embodied in geosynthetic needle-punched geotextiles, nonwoven geotextiles, geomembranes of PVC, EP, EVA and other new materials, clay liners (GCL) and plastic drain boards. Grouting materials are mainly embodied in the research of inorganic grouting materials such as ultra-fine, dry grinding, wet grinding cement, stable slurry, paste slurry, etc. Acrylate, acid water glass, epoxy, polyurethane, etc. have been developed as organic grouting materials.

5 Conclusion and prospect

In this paper, through a series of brief introduction of soft soil foundation treatment methods, with emphasis on the introduction of new technologies, new methods and new materials, the following conclusions and suggestions can be obtained:

(1) With the continuous improvement and development of reinforcement methods, soft soil foundation treatment gradually develops from a single reinforcement method to a multi-method composite form, and gradually changes from a single physical reinforcement method to a combination of physical reinforcement method and chemical reinforcement method.

(2) With the development of material science and the state's management of energy conservation and environmental protection, soft soil foundation treatment is gradually developing from high energy consumption and high pollution technology to new low carbon technology and harmonious development between human and nature.

(3) With the innovation of management methods, soft soil foundation treatment gradually develops from the consumption of high manpower, materials and expenses to the realization of mechanical and economic methods.

(4) With the rise of reclamation projects and sea-crossing bridge projects in coastal cities, more soft soil foundation problems will be faced in the construction, and relevant engineering and technical personnel and units need to strengthen technical and economic input.

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