

Development and Practice of Soft Foundation Treatment Technology



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1 General

1.1 General

In the process of design and construction of a project with soft soil foundation, consideration must be drawn to the soft soil treatment. Otherwise, it could not only cause construction difficulty, prolong the construction period, increase the cost, but also would seriously threaten the safety of the project.



1 General

1.1 General



1 General

1.2 Features of soft foundation

- ① Large natural water content and void ratio
- ② Poor permeability
- ③ High compressibility
- ④ Low shear strength
- ⑤ creep

1 General

1.3 Soft foundation treatment method

At present, the widely used soft foundation treatment methods mainly include drainage consolidation method, pile foundation method, reinforcement method, displacement method and squeezing method.



2 Drainage consolidation method

2.1 General

The drainage consolidation method mainly **drive** sand well or plastic drainage wick into the soft foundation, and preloading or vacuum preloading act on the upper part of the drainage plate, so as to **drain** the water in clay, and improve the consolidation and bearing capacity of the soft soil.

Drainage consolidation technology includes drainage system and preloading system. According to different ways of preloading, the drainage consolidation method can be divided into two types: preloading with weight mass (surcharge) and preloading with vacuum, and it can be divided into another two methods according to the different drainage system: sand well method and plastic drainage plate method.

2 Drainage consolidation method

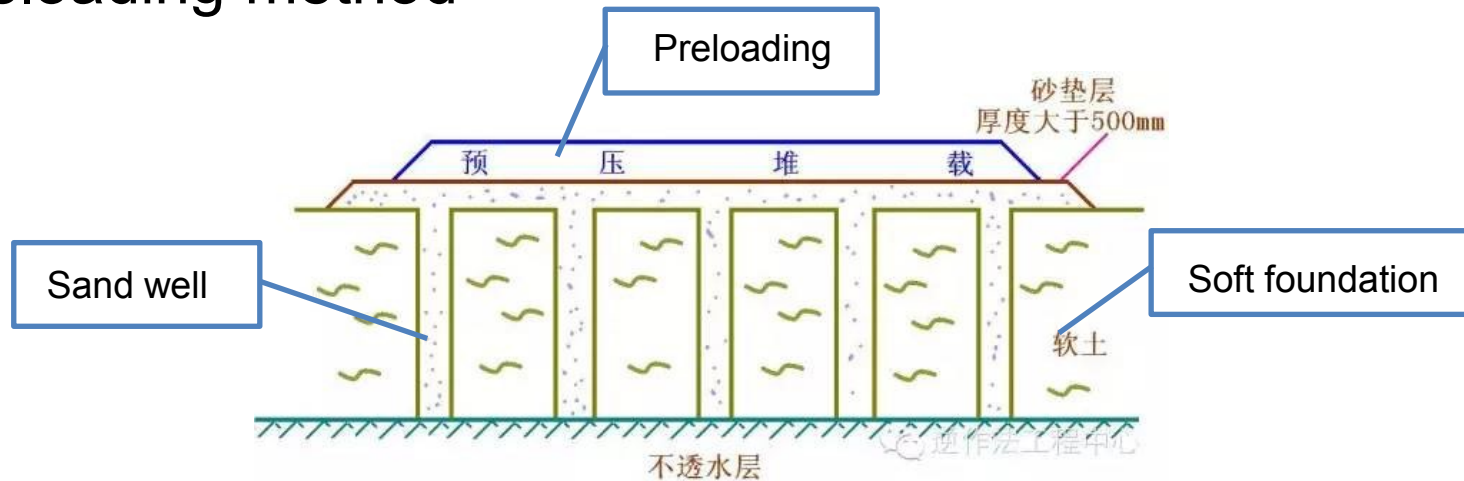
2.2 Preloading method

According to soil consolidation theory, for weight mass preloading method preloads on the natural foundation by loading extra weight, and accelerates the water drainage in the soft soil by using the drainage wick or sand well, thus reducing the soil porosity and quickening the consolidation of the soil, so as to improve the bearing capacity of foundation, reduce the settlement of foundation and reinforce the soft soil foundation.

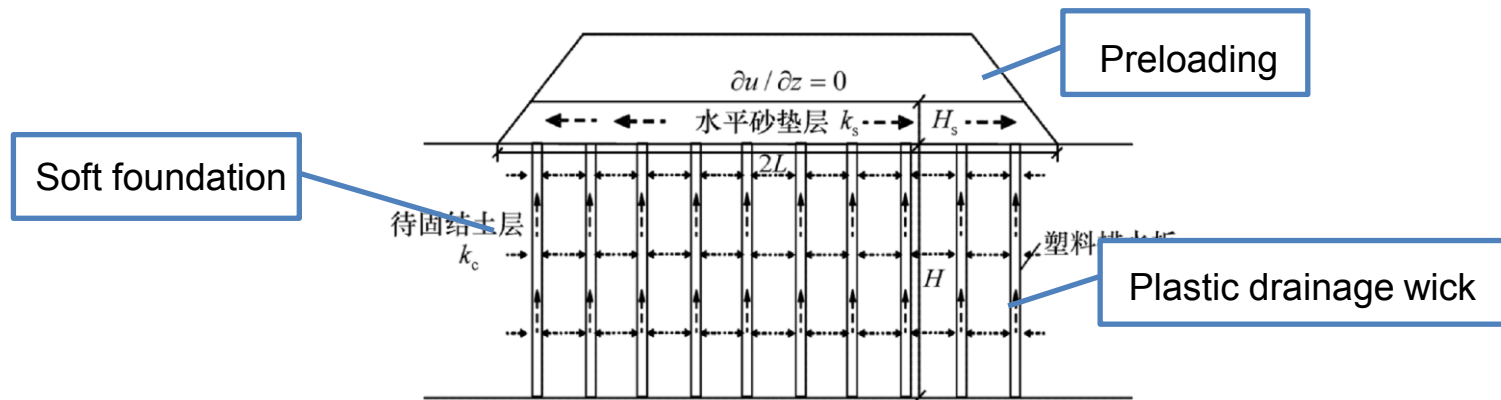


2 Drainage consolidation method

2.2 Preloading method



Schematic diagram of combined preloading method for sand well



Schematic diagram of combined preloading method for drainage plate

2 Drainage consolidation method

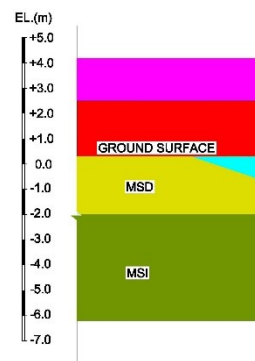
2.2 Preloading method



Photos of construction with preloading method

2 Drainage consolidation method

2.2 Preloading method





Status of Lusail Project in Qatar

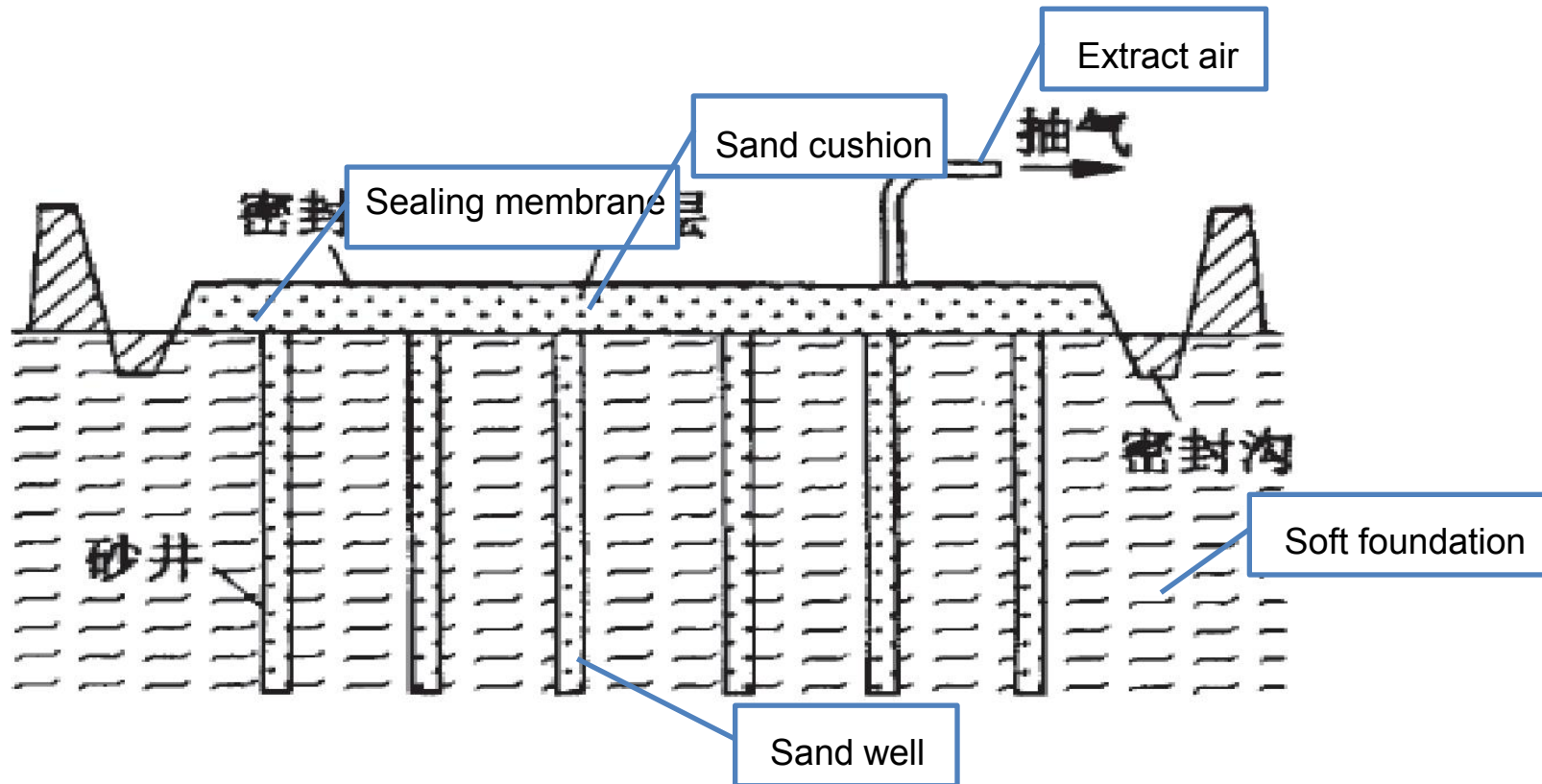
2 Drainage consolidation method

2.2 Vacuum preloading method

Vacuum preloading method is a kind of foundation treatment method which set up vertical plastic drainage **wick** or sand well in the soft clay, and place sand cushion on the **surface**, and then cover thin **membrane** for sealing, after that, extract the air to make the drainage wick and sand cushion in vacuum state in the purpose of draining out the soil moisture to pre-consolidate the soil and reduce later settlement of the foundation.

2 Drainage consolidation method

2.2 Vacuum preloading method



Schematic diagram of vacuum preloading method

2 Drainage consolidation method

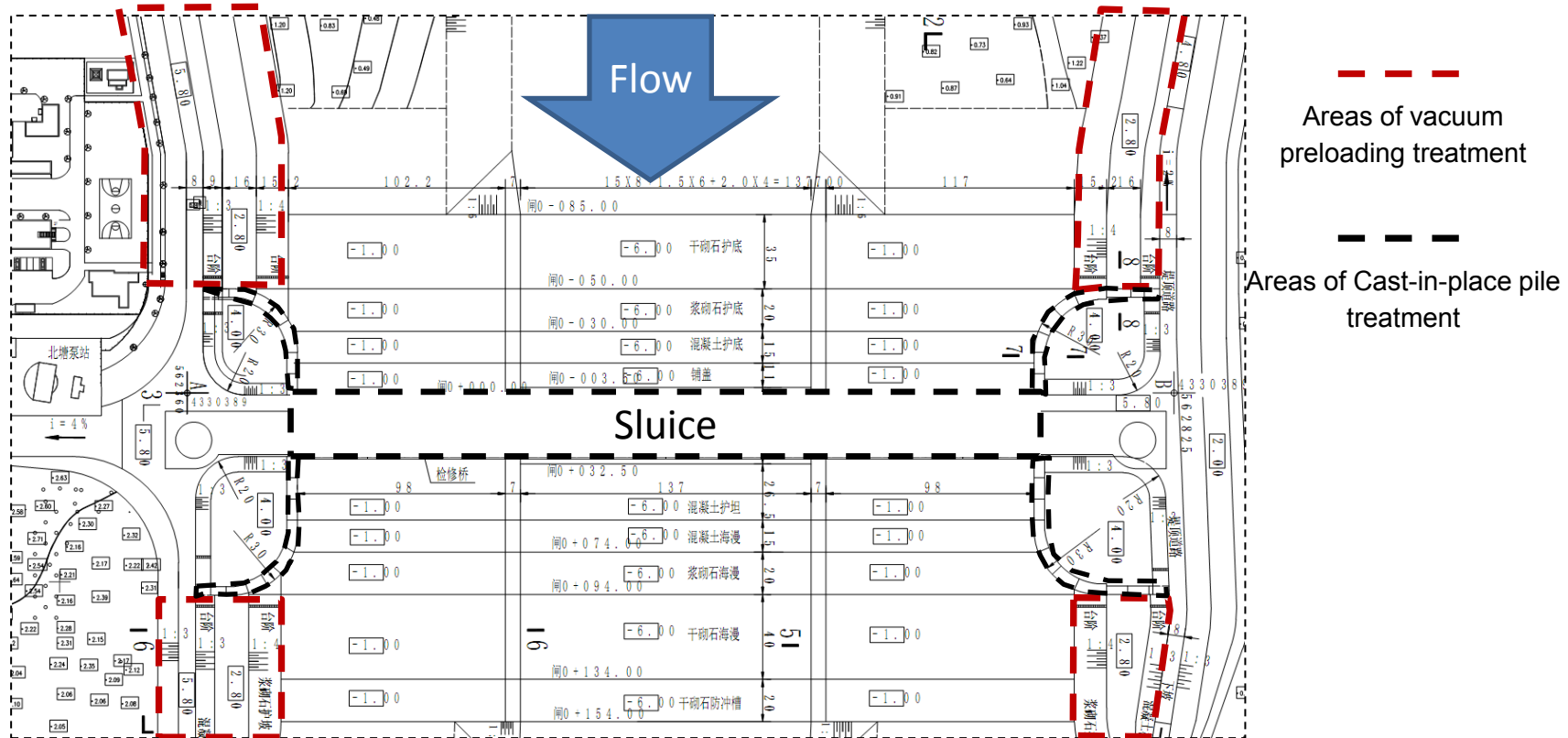
2.2 Vacuum preloading method



Photos of construction with vacuum preloading method
in Yongdingxin River sluice

2 Drainage consolidation method

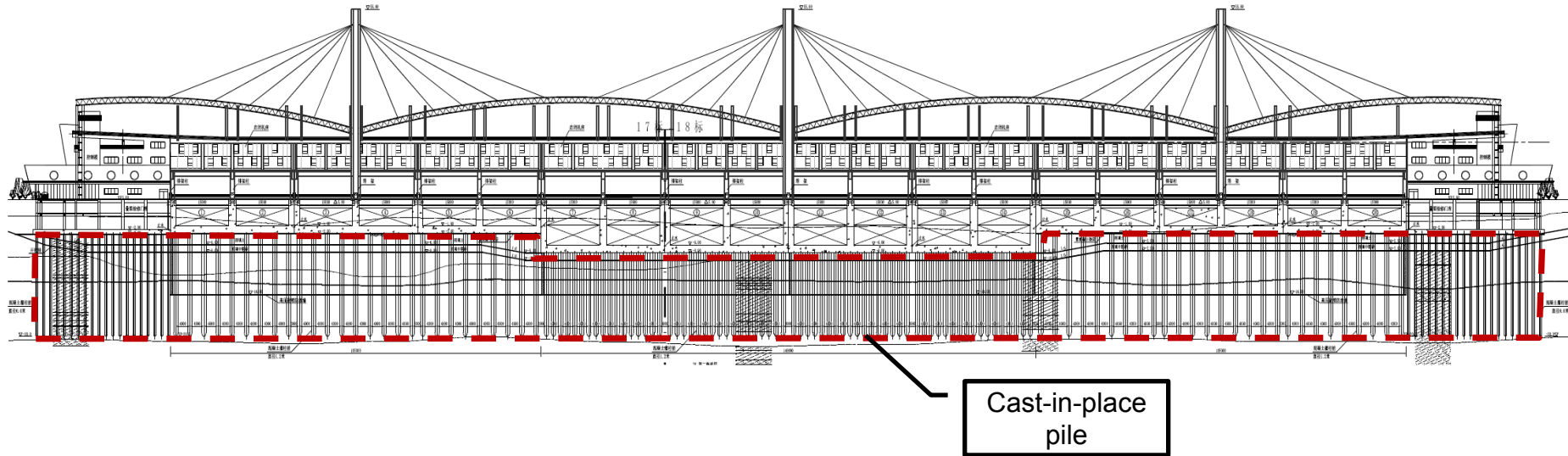
2.2 Vacuum preloading method



Areas of different treatments in Yongdingxin River sluice

2 Drainage consolidation method

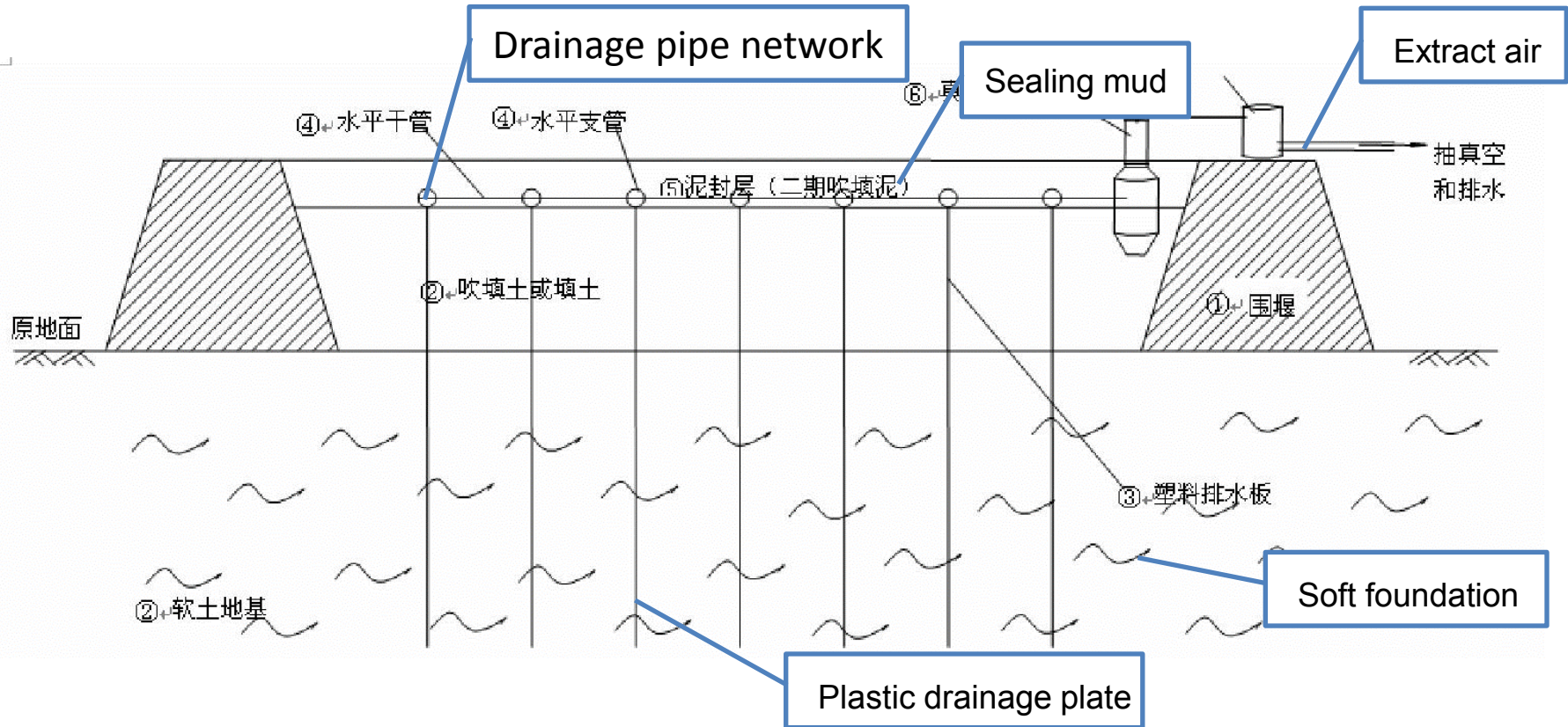
2.2 Vacuum preloading method



Longitudinal section of Yongdingxin River sluice

2 Drainage consolidation method

2.2 Vacuum preloading method



Principle diagram of vacuum preloading reinforcement for
Yongdingxin River sluice

2 Drainage consolidation method

2.2 Vacuum preloading method



Status of Yongdingxin River sluice

3 Pile foundation method

3.1 General

The piling method uses various piles pattern to form a vertical reinforced composite foundation with surrounding soil so as to improve the bearing capacity or stability of the foundation. According to the different construction methods of pile, piles can be referred to as mixing pile, high pressure jet pile, vibroflotation pile, cast-in-place pile, precast concrete pile, etc. According to the different pile body materials, it can also be divided into cement soil mixing pile, cement pile, concrete pile, gravel pile, cement fly ash gravel pile (CFG pile), etc.

3 Pile foundation method

3.2 Mixing pile

Mixing pile uses cement and lime as cement agent to produce a series of physical and chemical effects between the cement agent and soft soil, and form cement reinforced soil pile which has higher compressive strength than the natural soil, and has the characteristics of integrity, water stability and small compressibility, to improve the strength and stability of soil and reduce the total settlement and lateral deformation. The construction is fast and no preloading is needed.

3 Pile foundation method

3.2 Mixing pile



Construction of cement
soil mixing pile

Photo of pile body
excavation of mixing pile

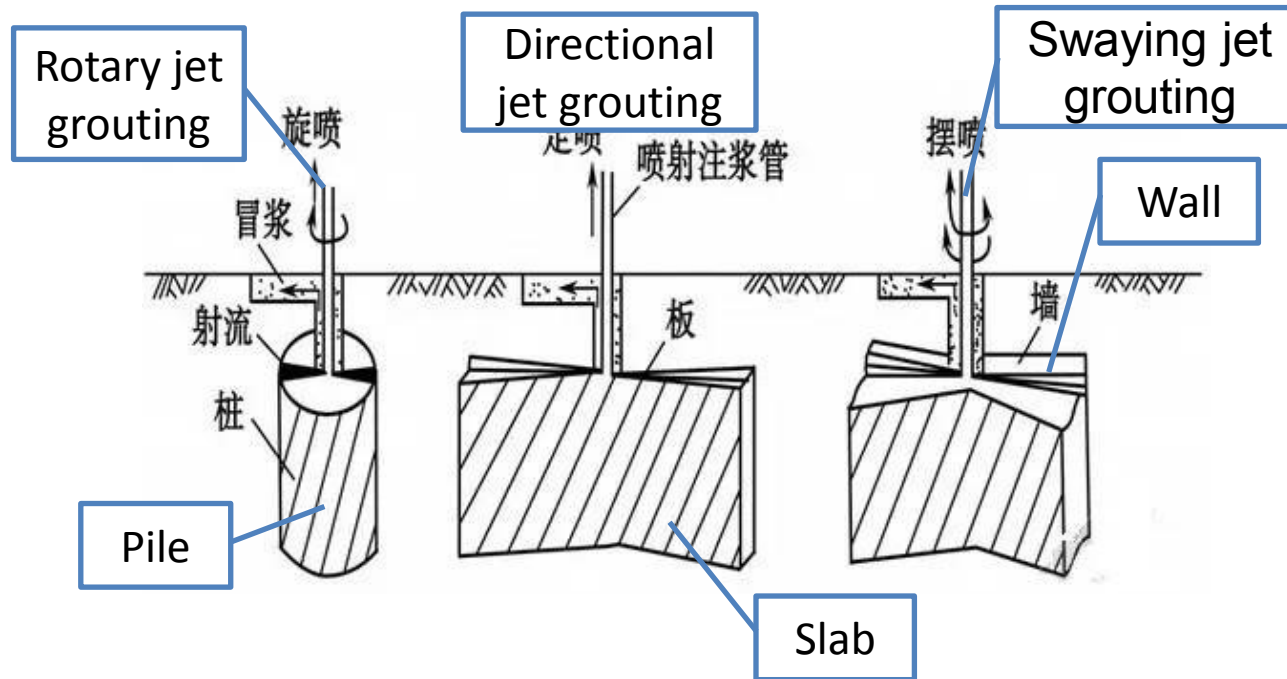
3 Pile foundation method

3.3 High pressure jet pile

The high-pressure jet pile is made by putting the grouting pipe with nozzle into the predetermined position of the soil layer through drilling machine. The slurry or water is ejected from the nozzle through high pressure, which will impact and destroy the soil. At the same time, lift up the drill rod gradually at a certain speed, and mix the soil particles and the slurry with grouting, after the slurry is solidified, it will form a jet grouting pile, which can effectively reduce the water content of soil, improve the bearing capacity of foundation and prevent soil liquefaction.

3 Pile foundation method

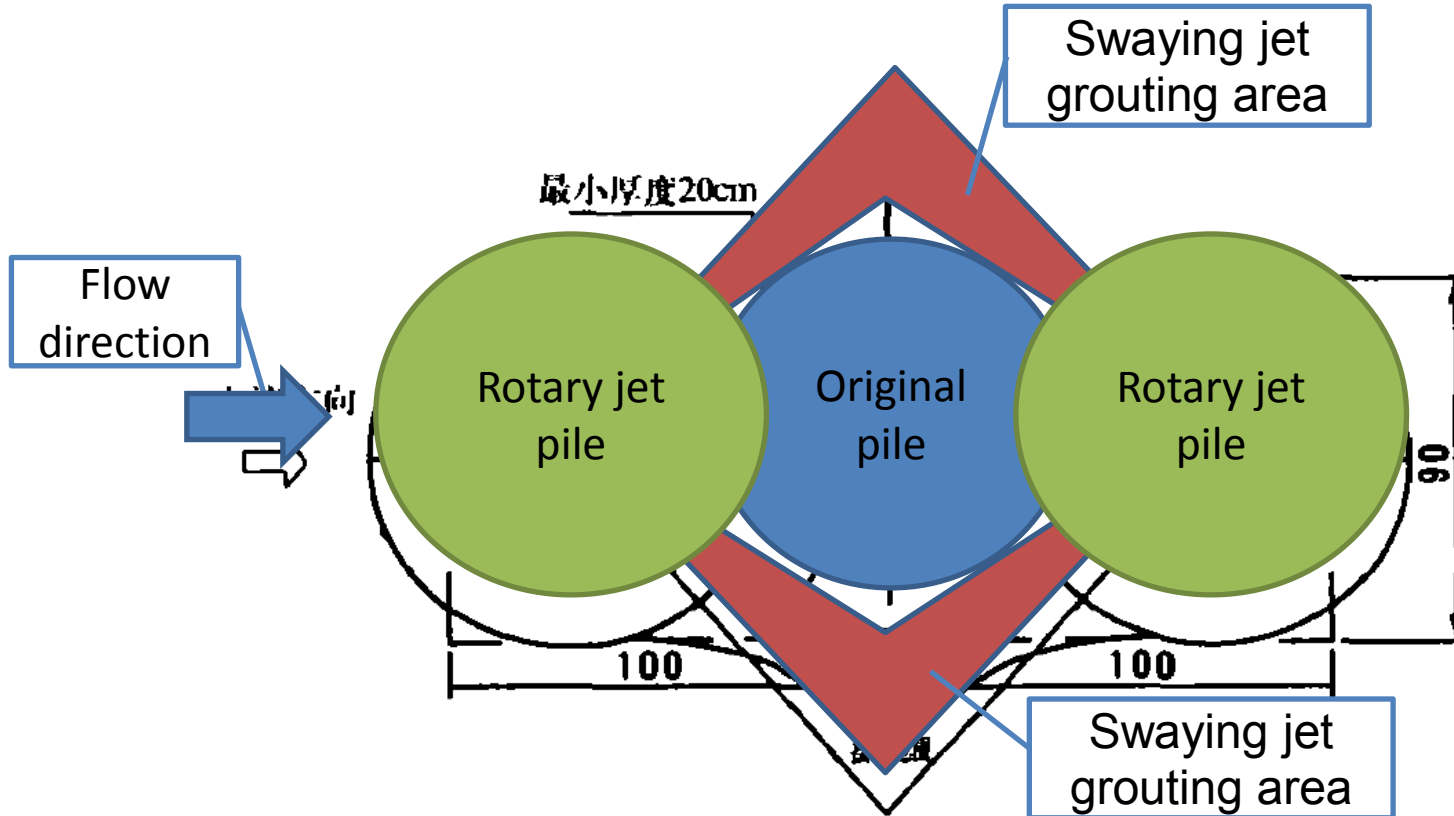
3.3 High pressure jet pile



Three types of high pressure jet grouting

3 Pile foundation method

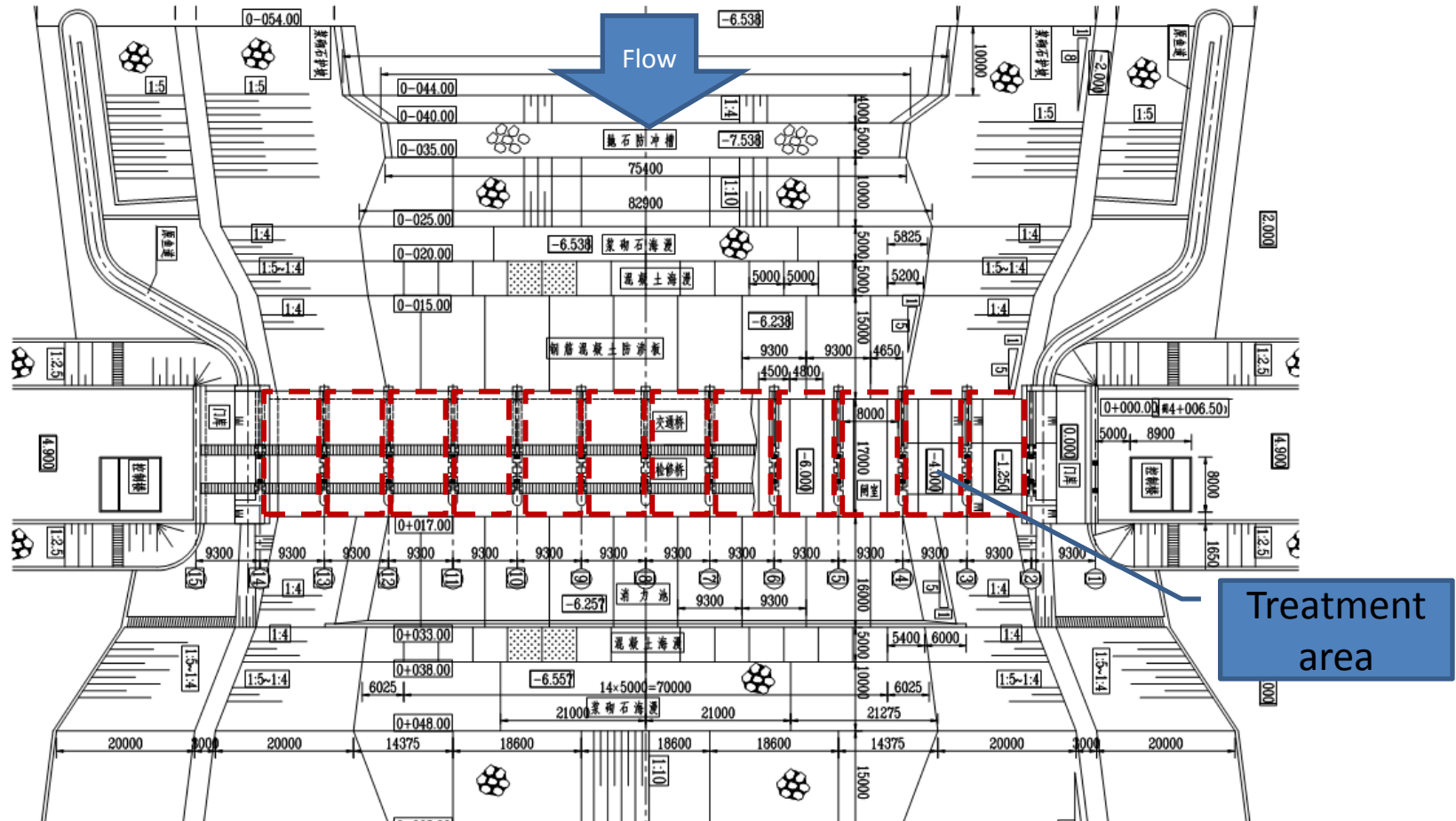
3.3 High pressure jet pile



Schematic diagram of reinforcement of original cast-in-place piles on Jiyunhe River Tidal Sluice foundation

3 Pile foundation method

3.3 High pressure jet pile



Treatment area of cast-in-place piles on Jiyunhe River Tidal Gate foundation

3 Pile foundation method

3.3 High pressure jet pile



Status of Jiyunhe River Tidal Sluice

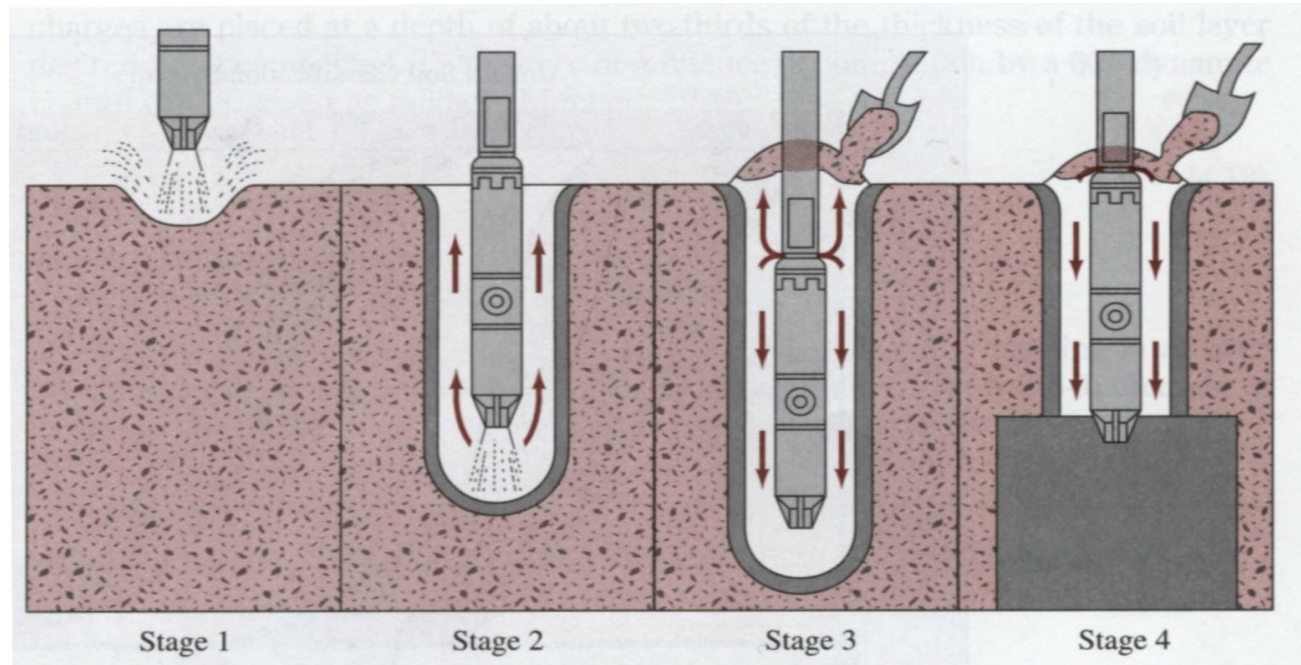
3 Pile foundation method

3.4 Vibroflotation pile

The vibroflotation method adopts vibroflot, a machine tool similar to insert-type concrete vibrator (with upper and lower jet nozzles). Under the action of vibration and impact load, first, a hole is formed in the foundation, and then filled with sand and gravel, and compacted or rammed in layer, so that the foundation is reinforced.

3 Pile foundation method

3.4 Vibroflotation pile



Stage 1: The jet at the bottom of the vibroflot is turned on and lowered into the ground

Stage 2: The water jet creates a quick condition in the soil. It allows the vibrating unit to sink into the ground.

Stage 3: Granular material is poured from the top of the hole. The water from the lower jet is transferred to the jet at the top of the vibrating unit. This water carries the granular material down the hole.

Stage 4: The vibrating unit is gradually raised in about 0.3-m lifts and held vibrating for about 30 seconds at each lift. This process compacts the soil to the desired unit weight.

3 Pile foundation method

3.4 Vibroflotation pile



Construction of vibroflotation gravel pile



Status of Haibowan water control project

3 Pile foundation method

3.5 Cast-in-place pile

Cast-in-place pile is to make a hole first, and then put reinforcement cage and pour concrete into the hole. it can be divided into cast-in-place bored pile and immersed tube cast-in-place pile according to the holes forming method.

The cast-in-place pile can be used for various kinds of soft foundation treatment. It has the advantage of little disturbance to the natural foundation, and the bearing capacity of the foundation will be greatly increased, at the same time, it has high requirement on construction technology and the cost is usually high.



3 Pile foundation method

3.5 Cast-in-place pile

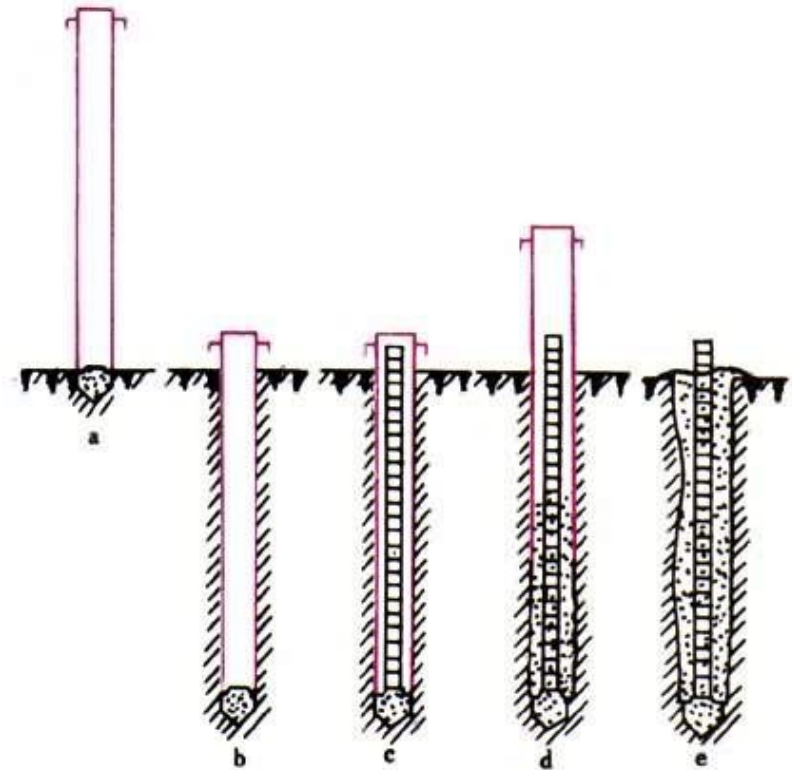


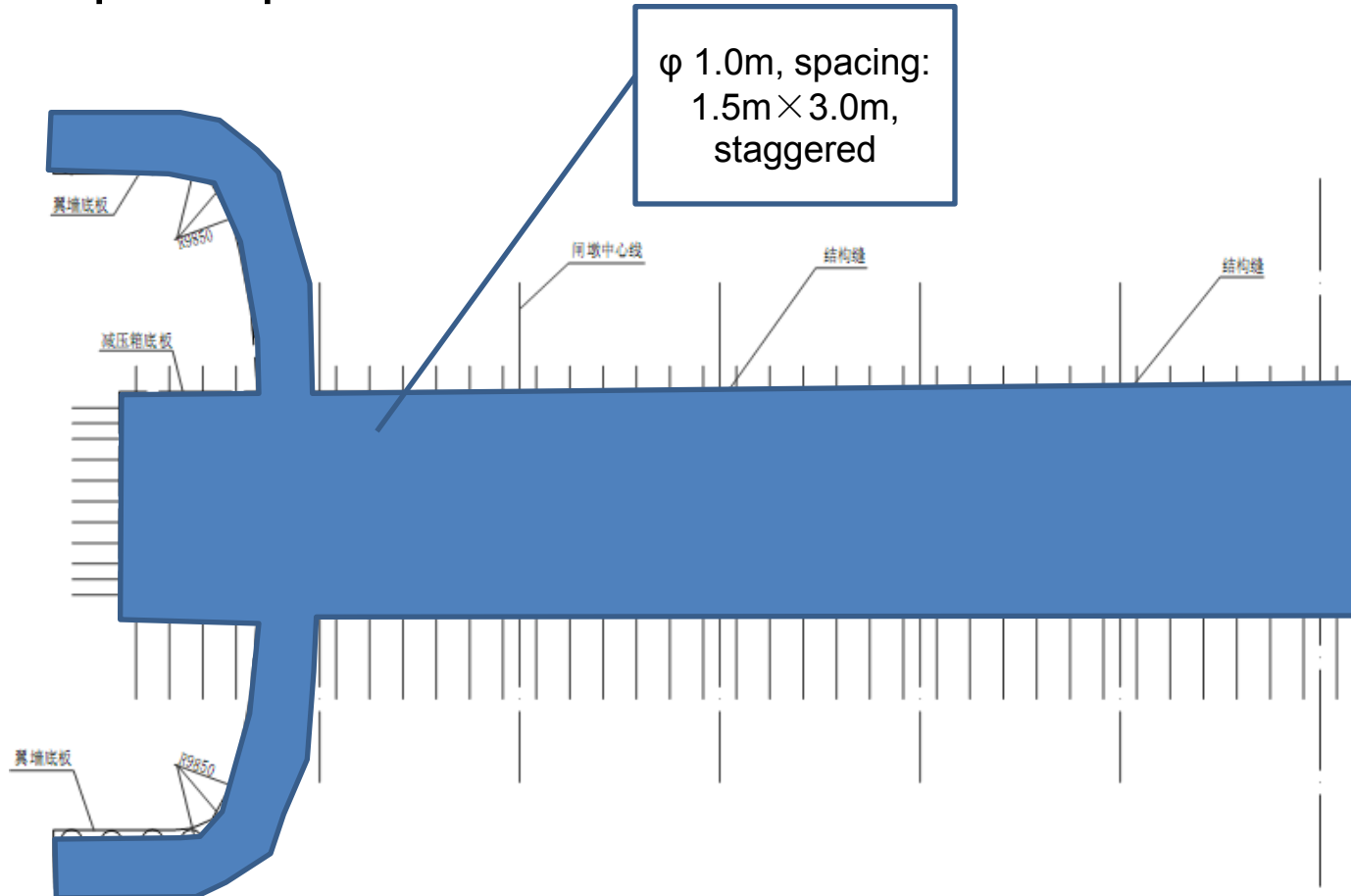
图2 沉管灌注桩施工过程

a 置放桩尖钢管就位 b 沉管 c 放钢筋笼
d 边拔管边灌注混凝土 e 桩制成

Construction of cast-in-place pile

3 Pile foundation method

3.5 Cast-in-place pile



Layout of cast-in-place piles in the Dacongkou sluice

3 Pile foundation method

3.5 Cast-in-place pile



Status of Dachongkou sluice

3 Pile foundation method

3.6 Precast concrete pile

Precast concrete pile is fabricated in plant or near the work site. The pile is driven into, pressed into or pushed into the foundation by the pile driving equipment.

Precast concrete pile is divided into prestressed concrete square pile and prestressed concrete pipe pile, especially the prestressed high-intensity concrete (PHC pile) is widely used due to its high strength, short construction period.



3 Pile foundation method

3.6 Precast concrete pile



Precast concrete square pile



Precast concrete pipe pile

3.6 Precast concrete pile

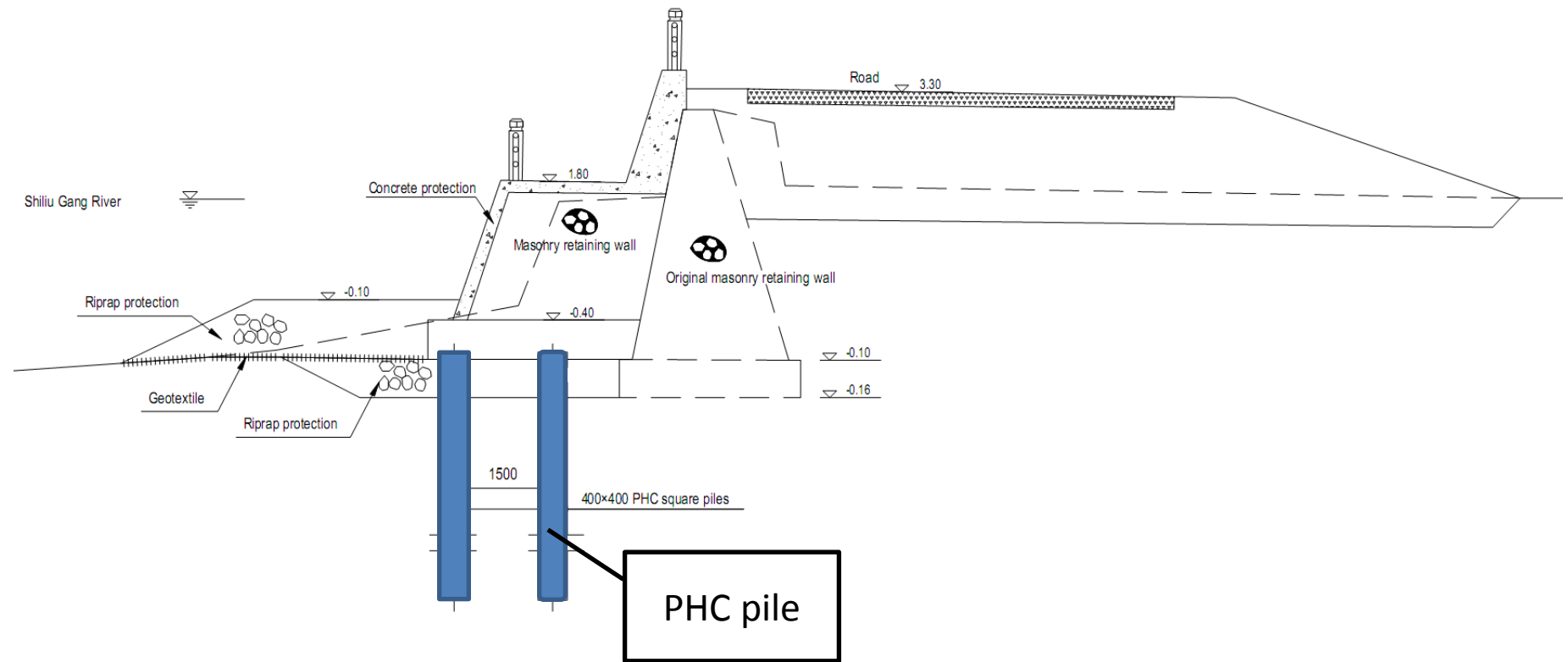


Pipe pile lifting
and centering



Pipe pile driving

3.6 Precast concrete pile



Application of PHC pile in Zhujiang Shoreline Regulation project



Situation of Caoejiang river sluice

3 Pile foundation method

3.7 CFG pile

CFG (Cement Fly-ash Gravel) pile is a kind of variable strength pile made by various pile forming machines, it is between rigid pile and flexible pile. It is made of mixture of gravel, stone debris, sand, fly ash, cement and water. CFG pile and soil work together to form CFG pile composite foundation through the cushion layer. Therefore, it can be designed according to the characteristics and calculation of composite foundation. CFG piles usually do not need reinforcement calculation, and it can use industrial waste such as fly ash and stone debris as admixture to further reduce the project cost.

3 Pile foundation method

3.7 CFG pile



CFG pile

3 Pile foundation method

3.7 CFG pile



Status of Jinzhonghe Tidal Sluice

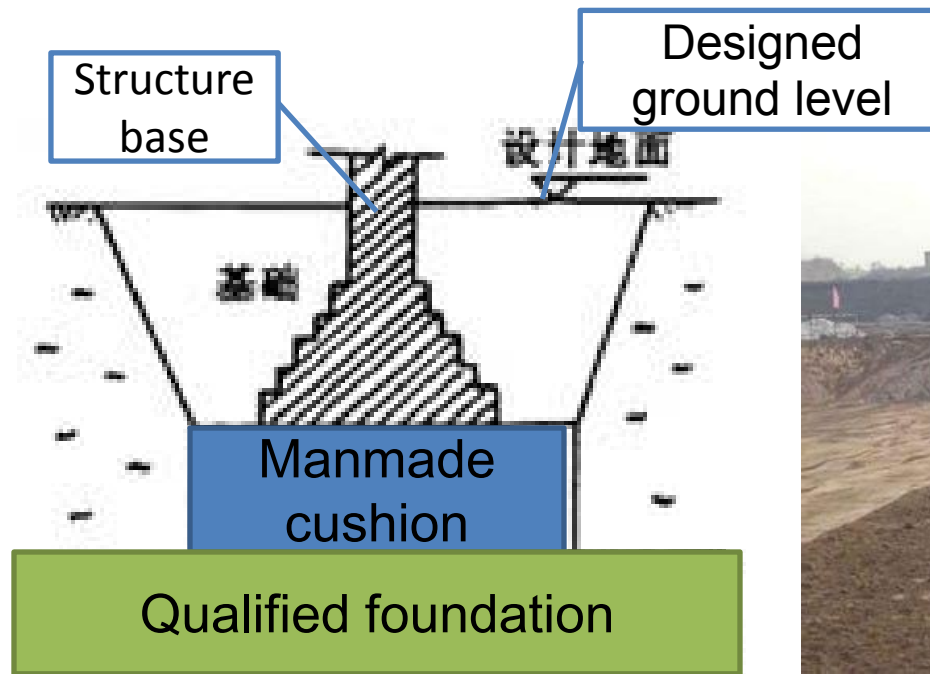
4 Replacement method

Replacement method is a kind of foundation treatment method which can improve the bearing capacity of foundation and reduce the settlement by replacing some or all weak soil or bad soil in the natural foundation with rock and soil materials with better physical and mechanical properties to form double layer or composite foundation.

There are mainly cushion, dynamic replacement and EPS (Expanded Polystyrene) super light filling method.



4 Replacement method



地基用换填法处理

Cushion method

4 Replacement method

EPS super light filling method refers to the use of expanded polystyrene for filling embankment, airport, port and so on to ensure stability of foundation, reduce settlement and improve bearing capacity of the foundation.

EPS has the advantages of ultra light, high compression resistance, high friction coefficient, good water resistance, strong chemical corrosion resistance and convenient construction.



4 Replacement method



EPS super light filling method

5 Squeezing method

Squeezing method can be divided into two types: riprap squeezing and blasting squeezing.

The riprap squeezing method is to squeeze out the silt or silty soil in the original foundation with block stone and particles meeting with the construction requirements by using its own gravity, so as to achieve the purpose of strengthening the foundation.

The blasting squeezing method is to deal with soft foundation by using the principle of removing rock and squeezing silt. During the blasting, the silt in the vicinity of the explosion is squeezed out to form a cavity. After the soft soil is disturbed, the silt is replaced under the vibration of the external force with the filled stone at the designed position, thus increasing the bearing capacity of the soft foundation.

5 Squeezing method



Construction of riprap squeezing method

5 Squeezing method



Construction of blasting squeezing method

6 Conclusions

The various methods of soft foundation treatment have their pertinence, scope of application and limitations. There are great differences in physical and mechanical properties and chemical composition of soft soil around the world. Therefore, it is necessary to choose the soft foundation treatment method suitable for the actual situation and integrate the two or more than two methods in order to achieve the ideal treatment effect.





Thanks!

