# Vibroflotation application in soft soil treatment

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# Contents

## What is discription of soft soil?

- Big pore ratio,high water-content,strong compression
- Low strength, large longitudinal/ lateral deformation
- compressed stability take a long time

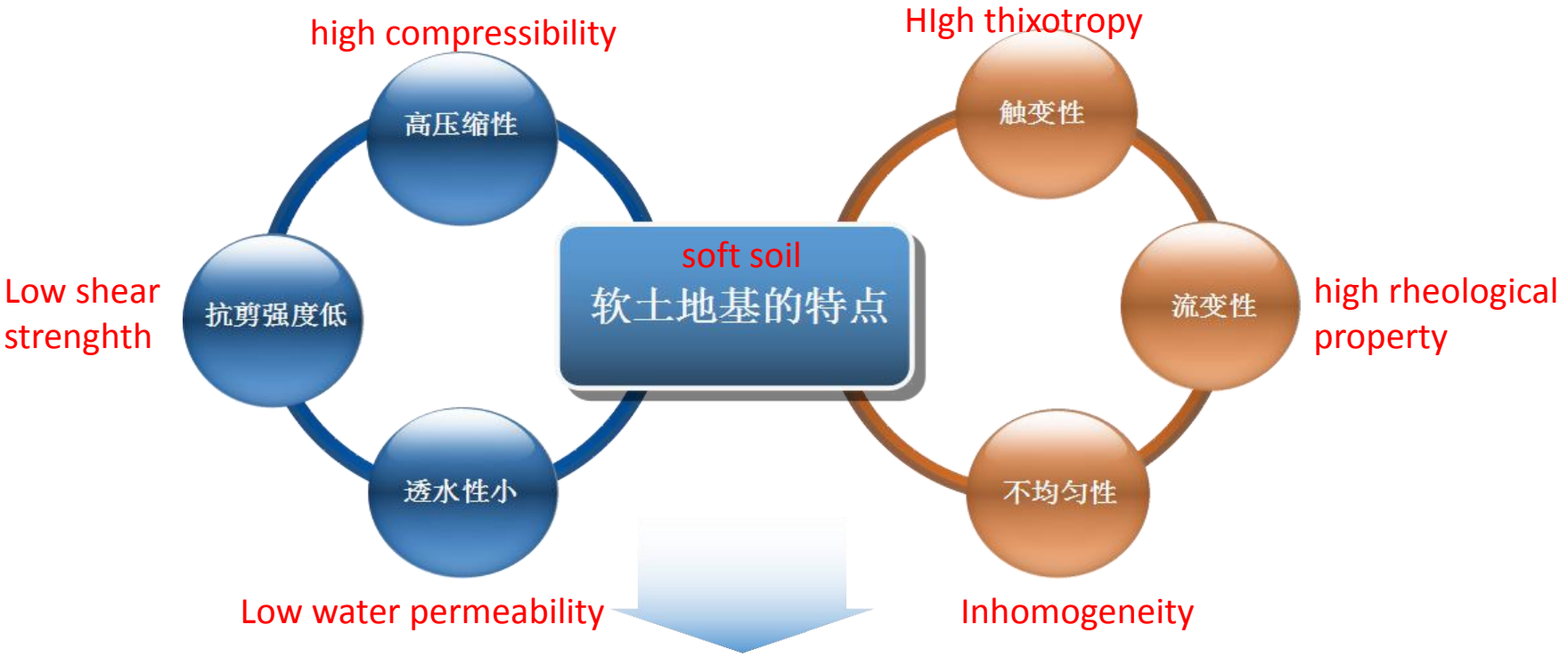
**By properties of soil layer**

- Silt clay
- Soft backfill and mixed backfil soil
- Other high compressible soft soil layer

**By category of soil layer**

| charicateristic index | Natural water-content (%) | Natural pore ratio | Vane shear strenghth (kPa) |
|---|---|---|---|
| Value of index | ≥35 (or liquefied limit) | ≥1.0 | <35 |

## Feature of soft soil layer and undisirable performance




**Problem of strength and stability**

**Large longitudinal settlement/horizontal settlementnt/ uneven settlement**

**Problem of liquefaction,instability and collapse of saturated soil**

## Purpose need to achieve from foundation treatment

Improve shear strengnth

Refrain from shear failure of soil layer when under normal load

Improve compression performance

Refrain from the over settlement, horozontal displacement and uneven settlement of the foundation

Improve permeability performance

Accelerate consolidation and the settlement of soil layer, refrain from liquefaction and instability of foundation soil

# The common treatment of soft soil foundation

| | Classifiaction | Work principle |
|---|---|---|
| Replacement method | Soil replacement cusion/removing silt replacement /dynamic replacement/ gravel pile replacement | A composite foundation formed by replacing weak soil layers with better materials of physical mechanics |
| Drainage consolidation method | Preloading method/Vacuum combined preloading/lower water level method | The saturated soft soil is drained by external load to decrease the pore ratio and increase the shear strength |
| Infuse the solidificatio method | Deep mixing method, high-pressure injection grouting method, squeeze grouting method | To insert or mix cement, lime, or other chemical solidified slurry to form a reinforcement in the foundation |
| Vibro-compaction method | Dynamic method/ Sunk pipe gravel pile method/Vibroflotation | Form the composite foundation by gravel pile and the soil layer is compacting. |
| reinforcement method | Reinforced cusion method,/low-strength concrete pile,/reinforced concrete pile,/long and short pile | Set the high strength, large modulus of reinforcement into soil layer, such as geogrid, geotextile, etc |

A foudation treatment method by joint action of horizontal vibration and high pressure water shock to :

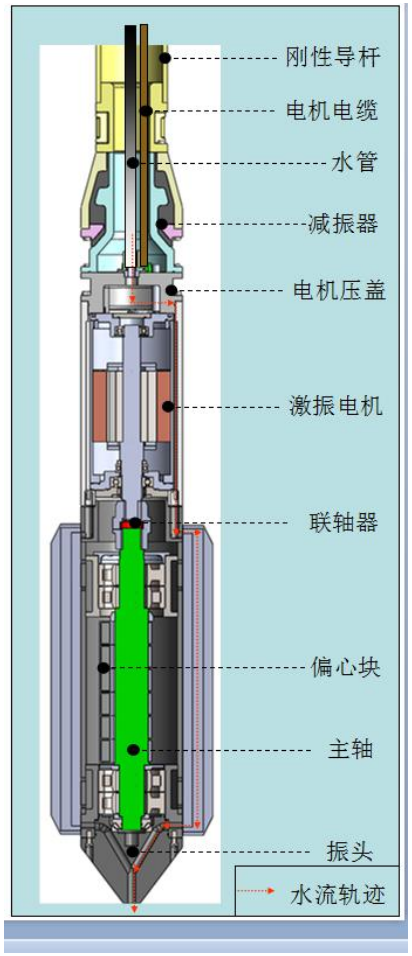
Compact the loose sand layer or

formed in soft soil of gravel column to compose the composite foundation with original soil together

**After 40 years development , vibroflotation has become a mature and commonly technology of foundation treatment**

| Stages in germination | Stages in promotion | Stages in mature |
|---|---|---|
| 1977-1994 | 1994-2005 | 2005-2017 |
| BHIDI reserched &produced the first vibroflot and developed the application in utility industry | Promoted to many industries and acheived mature gradually. | The model, and types of vibroflot gradually completed. Industry standard released and inplemented. |

## Vibroflot structure

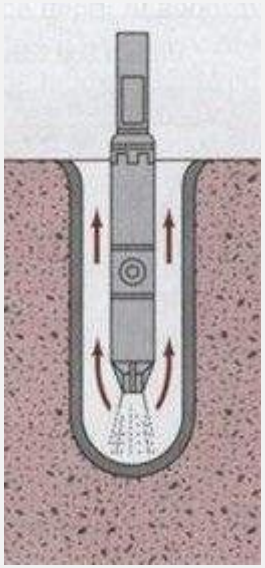



## External interference of vibroflotation method to original soil layer

**Vibration**

Soil particle strongly vibrate and liquidaction take place

**Water impact**



High pressure water impact bring out some soft soil

**replacement**

Fill in the stone and compact to form gravel pile

# Vibroflotation principle

**Vibrate to compact**

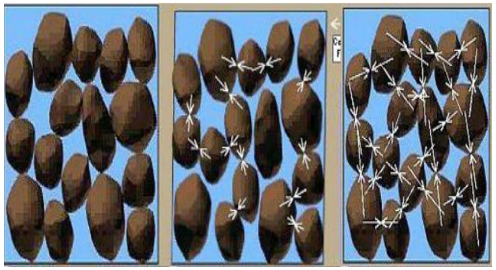
Soil particle were vibrated to liquifaction and realignment condition which make soil compaction

**Weak soil replacement**

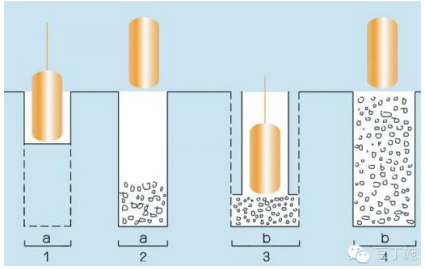
Some weak soil were replaced by compacted gravel pile which have better physical and mechanical properties. Composite foundation was formed

**Formed permeable pile**

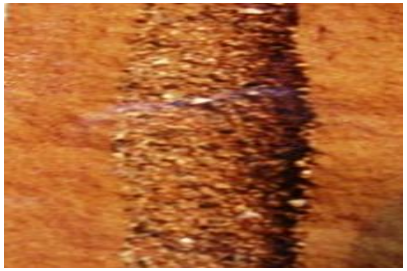
The formed gravel pile can works as drainage pipe insert in soil layer. The drainage situation of soil was improved



Decrease the pore ratio, to realize the pre-settlement and reduce the excessive water pressure, which can decrease the total settlement and increase the anti-shearing ability




Form the stronger composite foudation system to improve the bearing capacity



Accelerate solidifacation of soil , rapidly scatter and disappear the excessive water pressure which was generated from earthquake. Upgrade the seismic capacity

## Vibroflotation effect

**1. Presedimentation**

The majority of settlement occured before load placed. Absolute settlement reduced

**2. Soil compaction**

Reduced pore ratio decrease the differential settlement and hizontal displacement

**3. Composite foudation**

Improved loading-bearing system increase bearing capacity of foudation

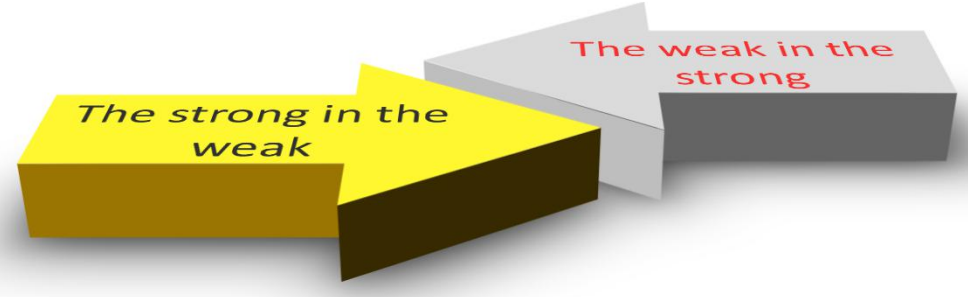
**4. Drainage performance**

**Improved drainage property accelerate the soil consolidation and reduce settlement. Increase dearing capacity while imprive anti-liquifaction behaviour**

## Purpose need to achieve from foundation treatment

## Vibroflotation conducts a situational work

In relative hard soil, the diameter of formed gravel pile is situationally smaller

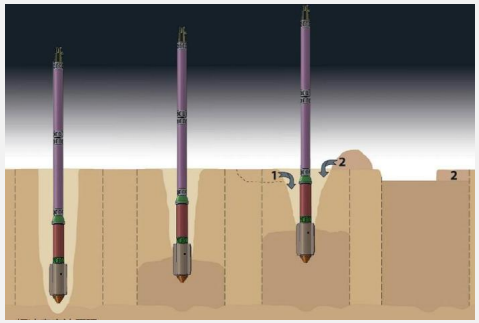



In relative soft soil, the diameter of formed gravel piles is situationally bigger

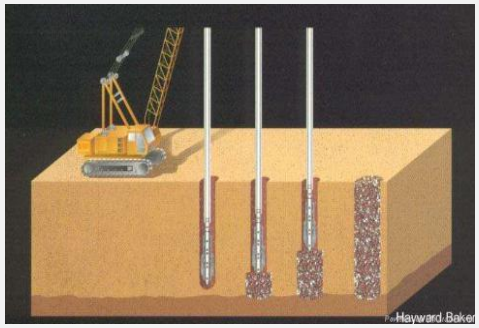
The diameters of gravel pile will be defferent in defferent soil layer and the entire pile looks like a calabash

## By effect

### Vibro-compaction



### Vibro-replacement




## By feed style

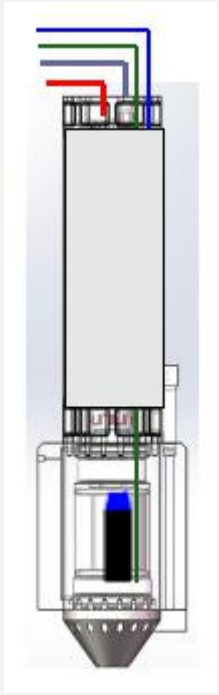
### Tranditional feed


### Bottom feed

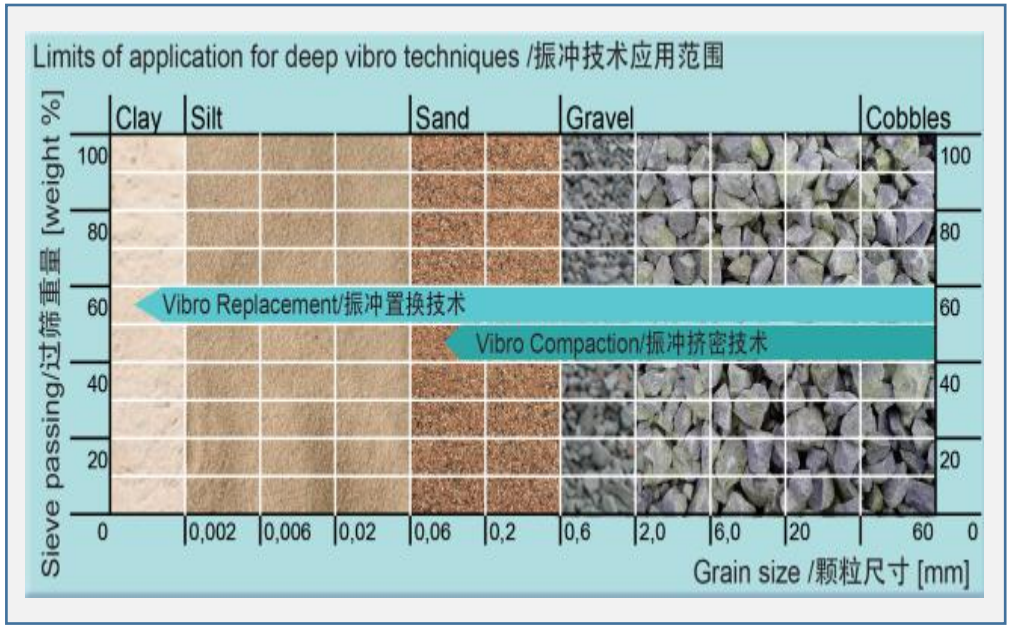
## By equipment

### Electric-driven

### Hydraulic-driven



## Application condition of soil



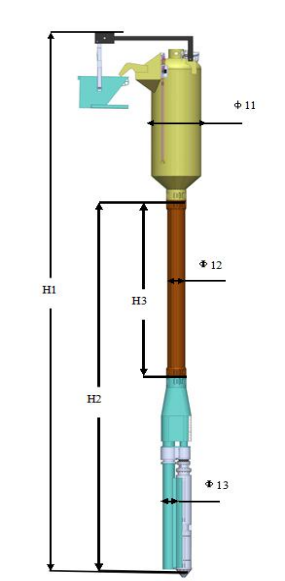

New technique

The bottom feed method made vibroflotaion applied to bigger range of soil types.Vibrolotation beigan to treat silty clay where the shearing stregnth without drainage is less than 20Kpa

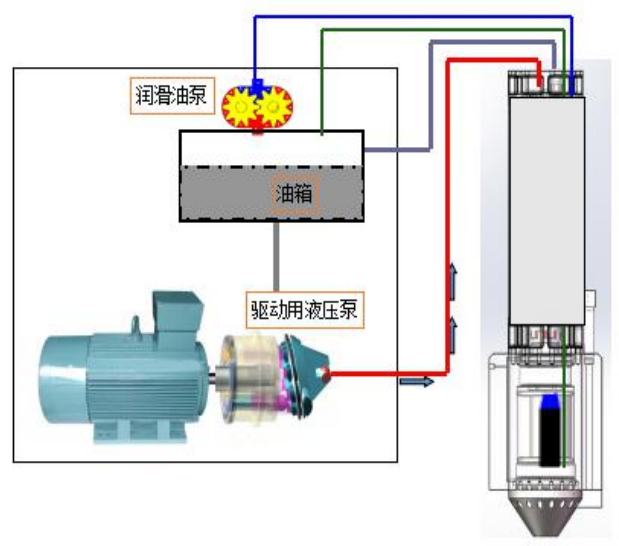
### Applicable to soil

- Gravel, sandy, silty , clay , artificial soil
- Compaction and anti-liquefaction treatment of liquefiable soil
- Silt clay with Cu(shearing stregnth with drainage) of less than 20Kpa(Tranditional vibroflotation method)

## Mutual advancement of equipment and construction techlology




Bottom feed vibrflot

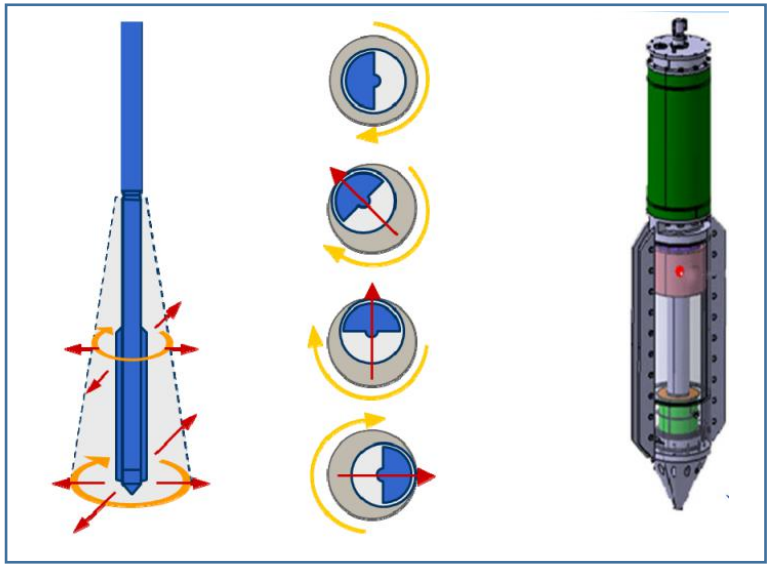



Hydraulic-driven vibroflot

Dry method vibroflot

- In 2006, with the bottom feed equipment launching, vibroflotation began to used in silty clay situation
- In 2006, the first hydraulic vibroflot was launched in China. It has stronger vibrate force which significantly improved the compaction effect and has longer service life.
- In 2011, the dry vibroflot launched.Vibroflotation beganto use in the place where sewage discharge was limited.

## Principle of vibroflot



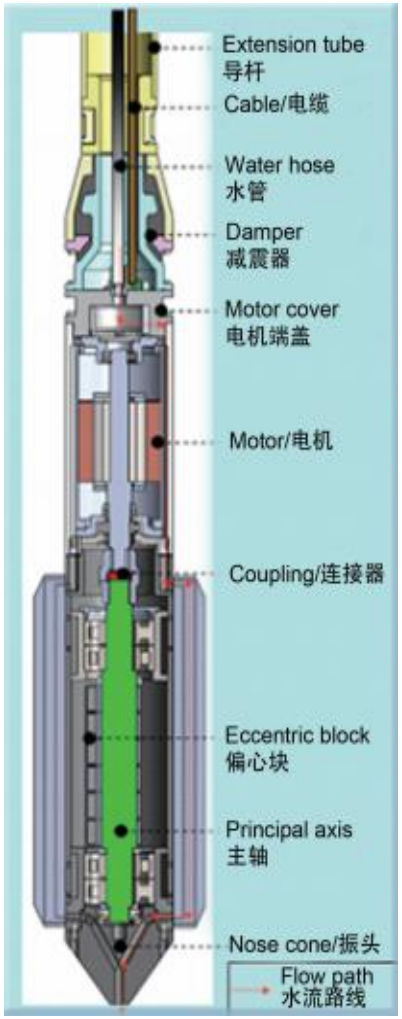
## Power model of vibroflot

| Specifications | BJZC-426-130 | BJZC-426-150 | BJZC-426-180 | BJZC-450-260 |
|---|---|---|---|---|
| Power/kW | 130 | 150 | 180 | **260** |
| Rotation speed/rpm | 1450 | 1450 | 1450 | **1450** |
| Amplitude (at Tip)/mm | 17.2 | 18.9 | 18.9 | **32** |
| Centrifugal force/kN | 208 | 276 | 276 | **520** |
| Weight Vibroflot/kg | 2320 | 2516 | 2586 | **3280** |
| Diameter/mm | 426 | 426 | 426 | **450** |
| Length/mm | 2963 | 3023 | 3100 | **3770** |
| Diameter of the length work pile/mm | (1000-1200) | (1000-1200) | (1200-1500) | **(1500-1800)** |

Strong vibration produced by eccentric block driven by motor works with high pressure impact to produce the effect of vibrating and water impact

Curent power model of vibroflot in China:30KW,45KW,55KW,75KW, 130KW,150KW,180KW和260KW

75KW， 130KW， 150KW and 180KW are most popular




## Advantage of BVEM vibroflot

- Designed with optimal structure which can bring high efficiency of drilling.
- High performance motor, amplitude and frequency stability
- The optimized vibrator, the vibration force is higner strong
- The shock absorber with national patent. Good performance and longer service life
- The whole cast steel design, the strength is high, the toughness is good
- The overall heat treatment forging is superior to wear resistance
- The extension rod adopts single - root - embedded connection to reduce wear and tear

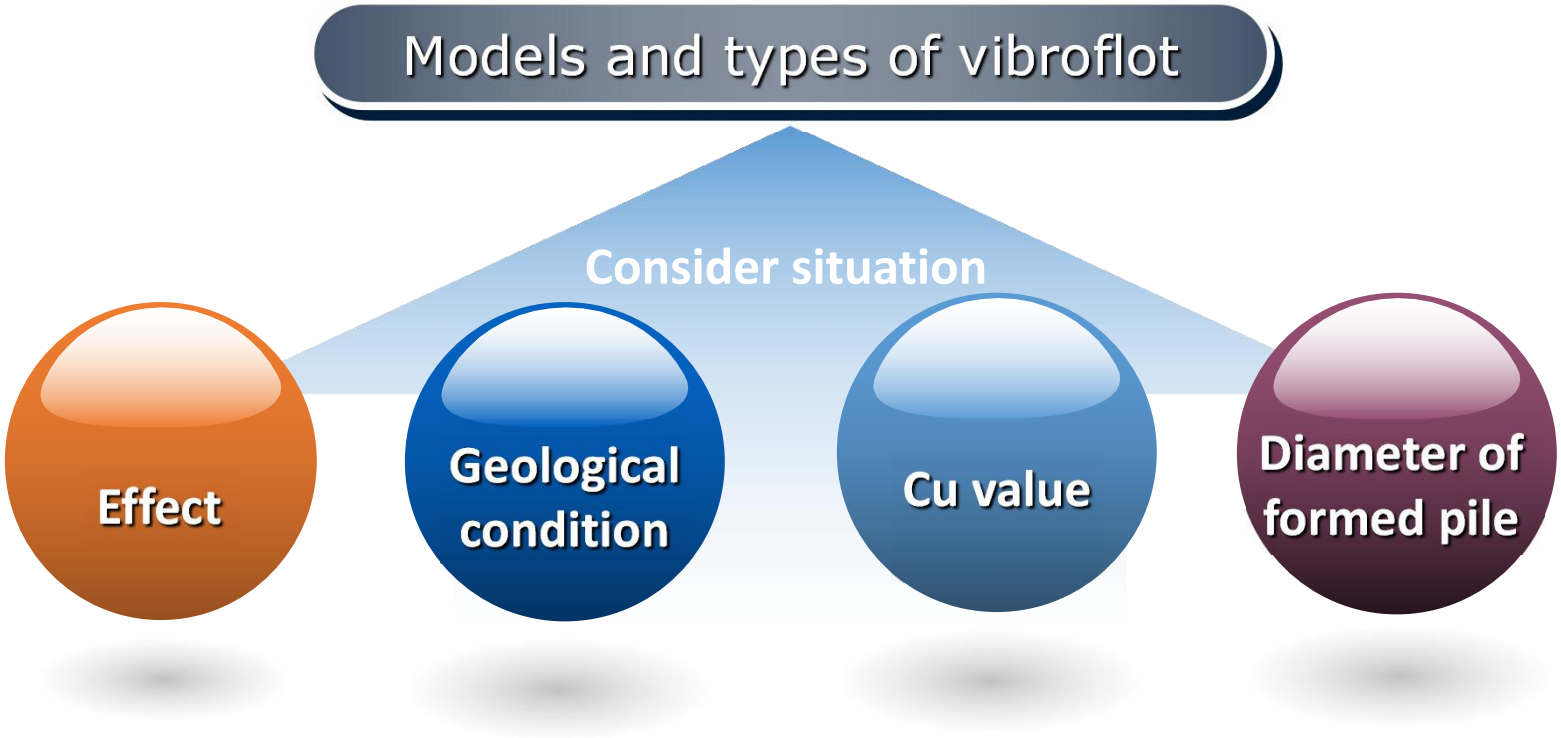




# Vibroflot models and types of BVEM

| 规格型号 specifications | 电机功率 kW motor power | 额定电流 A rated current | 最大转速 r/min maximum speed | 最大振幅 mm maximum amplitude | | | 振动力 Kn vibration force | 质量 kg weigh | 外径 mm external diameter | 长度 mm length | 工作桩径 mm diameter of the length work pile |
|---|---|---|---|---|---|---|---|---|---|---|---|
| BJV30E-325 | 30 | 58 | 1450-1800 | 13.5 | | | 130-200 | 1192 | 325 | 2480 | 600-800 |
| BJV30E-377 | 30 | 58 | 1450-1800 | 20 | | | 150-230 | 1300 | 377 | 2300 | 700-900 |
| BJV45E-325 | 45 | 88 | 1450-1800 | 13.5 | | | 130-200 | 1200 | 325 | 2550 | 600-800 |
| BJV45E-377 | 45 | 88 | 1450-1800 | 20 | | | 150-230 | 1380 | 377 | 2400 | 800-1000 |
| BJV55E-325 | 55 | 108 | 1450-1800 | 13.5 | | | 130-200 | 1240 | 325 | 2560 | 600-800 |
| BJV55E-377 | 55 | 108 | 1450-1800 | 20 | | | 150-230 | 1560 | 377 | 2500 | 800-1000 |
| BJV75E-325 | 75 | 148 | 1450-1800 | 13.5 | | | 130-200 | 1368 | 325 | 2700 | 600-800 |
| BJV75E-426 | 75 | 148 | 1450 | 16 | | | 180 | 2018 | 426 | 2783 | 1000-1200 |
| BJV75E-377L | 75 | 148 | 1450 | 17.5 | | | 188 | 1828 | 377 | 3110 | 1000-1200 |
| *BJV75E-377S | 75 | 148 | 1450-1800 | 25 | | | 208-320 | 1740 | 377 | 2910 | 800-1000 |
| BJV100E-325 | 100 | 195 | 1450-1800 | 13.3 | | | 130-200 | 1500 | 325 | 2710 | 600-800 |
| BJV100E-426 | 100 | 195 | 1450 | 17.2 | | | 208 | 2073 | 426 | 2883 | 1000-1200 |
| BJV100E-377L | 100 | 195 | 1450-1800 | 19 | | | 180-276 | 1880 | 377 | 3215 | 800-1000 |
| *BJV100E-377S | 100 | 195 | 1450-1800 | 25 | | | 208-320 | 1820 | 377 | 2930 | 1000-1200 |
| BJV130E-426 | 130 | 255 | 1450 | 17.2 | | | 208 | 2320 | 426 | 2963 | 1000-1200 |
| BJV130E-377L | 130 | 255 | 1450-1800 | 19 | | | 180-276 | 1900 | 377 | 3355 | 800-1000 |
| *BJV130E-377S | 130 | 255 | 1450-1800 | 25 | | | 208-320 | 1860 | 377 | 2950 | 1000-1200 |
| BJV150E-426 | 150 | 290 | 1450 | 18.9 | | | 276 | 2516 | 426 | 3023 | 1000-1200 |
| BJV150E-377L | 150 | 290 | 1450-1800 | 19 | | | 180-276 | 2100 | 377 | 3445 | 800-1000 |
| *BJV150E-377S | 150 | 290 | 1450-1800 | 25 | | | 208-320 | 1900 | 377 | 2970 | 1000-1500 |
| BJV180E-426 | 180 | 350 | 1450 | 18.9 | | | 276 | 2586 | 426 | 3100 | 1200-1500 |
| BJV180E-377L | 180 | 350 | 1450-1800 | 21 | | | 180-276 | 2140 | 377 | 3485 | 1000-1200 |
| *BJV180E-377S | 180 | 350 | 1450-1800 | 28 | | | 250-384 | 1980 | 377 | 3465 | 1000-1500 |
| BJV240E-426L | 240 | 460 | 1450 | 38 | | | 460 | 3210 | 426 | 3880 | 1500-2000 |
| *BJV240E-426S | 240 | 460 | 1450 | 52 | | | 660 | 3080 | 426 | 3860 | 2000-2500 |

# How to select vibroflots




- Compaction/replacement
- Bearing capacity
- Liquefaction disappear

- Stregnth of original soil
- Drilling difficulty
- Soil layer

- Bottom feed
- Tranditional feed

- Diameter size
- space of piles

## Electric control system

The central system and the “general command”

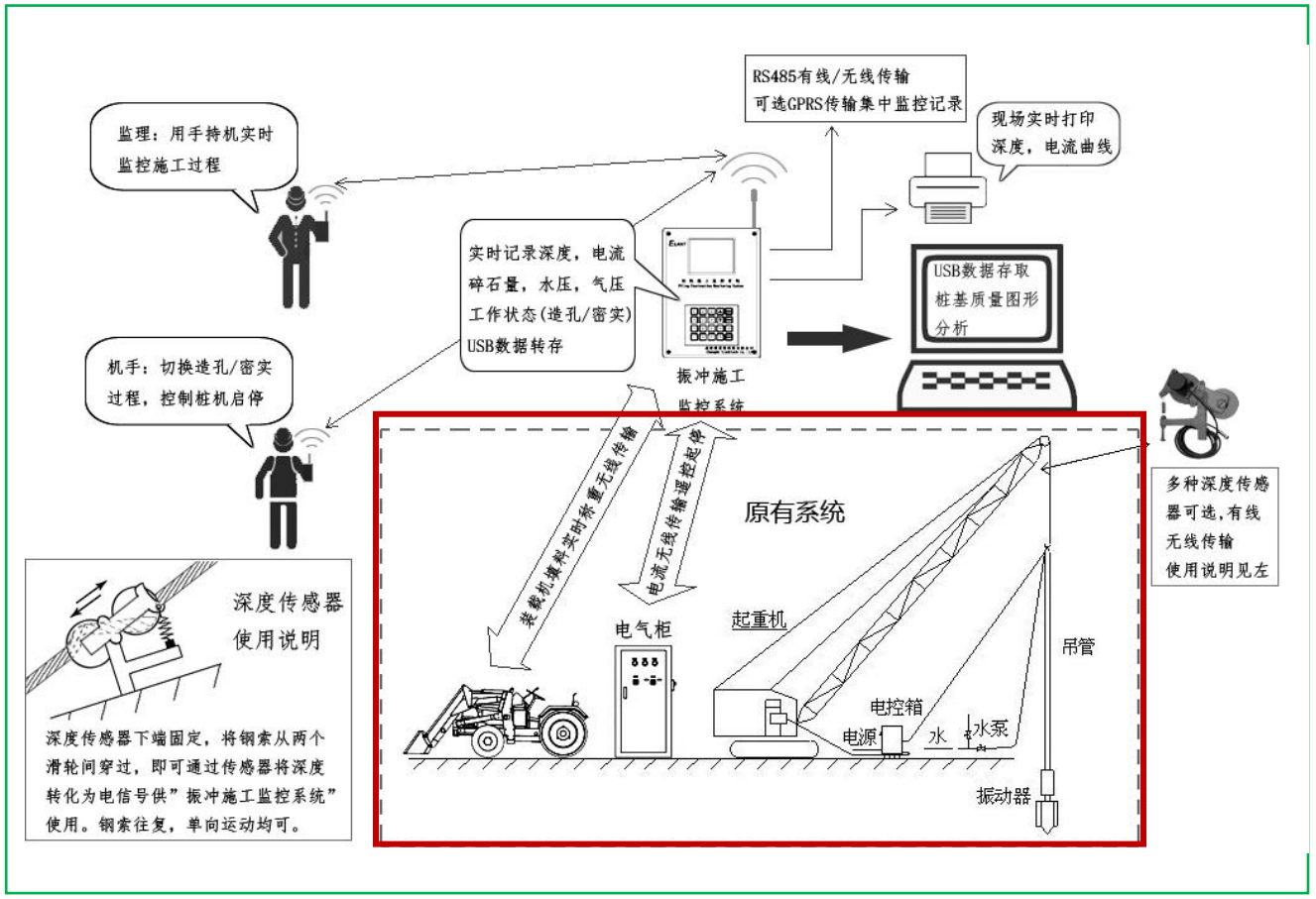
- Switch on and off the vibroflot and pump
- Pre-set, remind and alert working electric current.
- A real-time recording of working current and water pressure(air pressue of pump

## Advantage of BVEM electric control cabinet

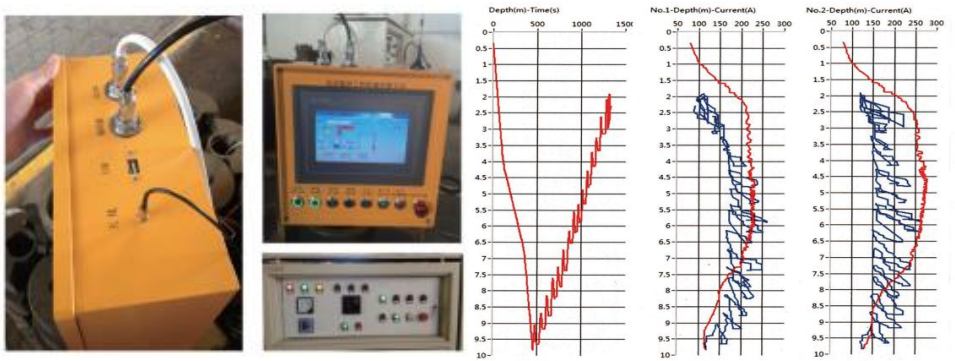
- Adopt high quality international standard accessories with 3C certification
- Assort with the switchs and power port of high-pressure pump, sewage pump and sinking pump. Increase the constrction convenience
- Reasonable overload of electric current protection  o prevent the time of overheat
- Equipped with a buzzer alarm device
- Can be compatible (hole, compaction, overload adjustable)

# BVEM remote control recorder of vibro construction

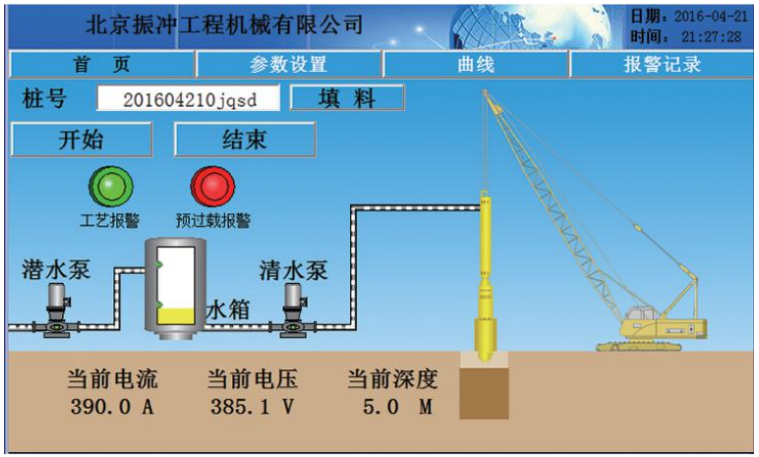
- Remote control the switch on /off of equipments by different persons in jobsite
- Improve construction efficiency
- More Convenience for construction management and monitor
- Real-time recording of current, water air pressure, position of vibroflot and stuffing volume
- Simplify the construction team member to reduce staff cost

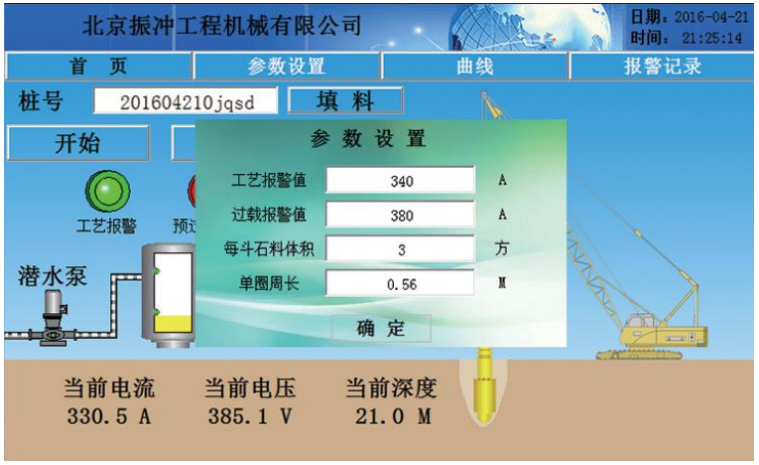


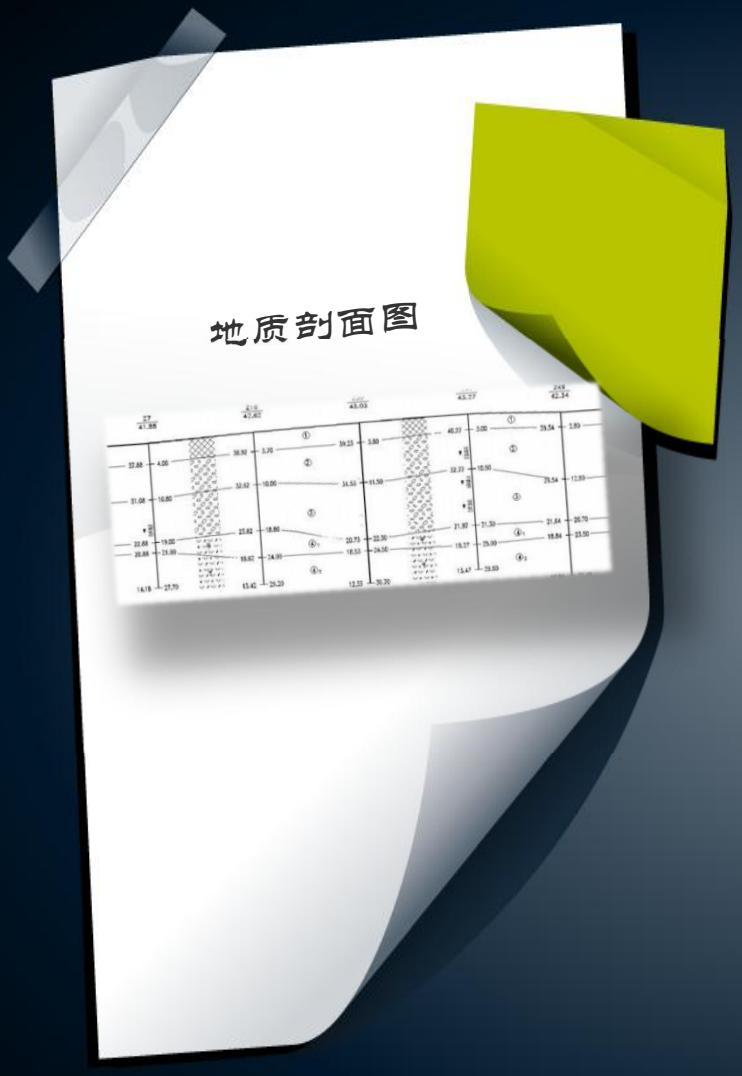
# BVEM remote control recorder of vibro construction




- The effective control distance is 100 meters, the accurate detection of the current, the pile depth, the stuffing volume, better control the construction quality
- The high reliability LCD touch screen can be used to set parameters and data input easily
- Chinese and English language interface

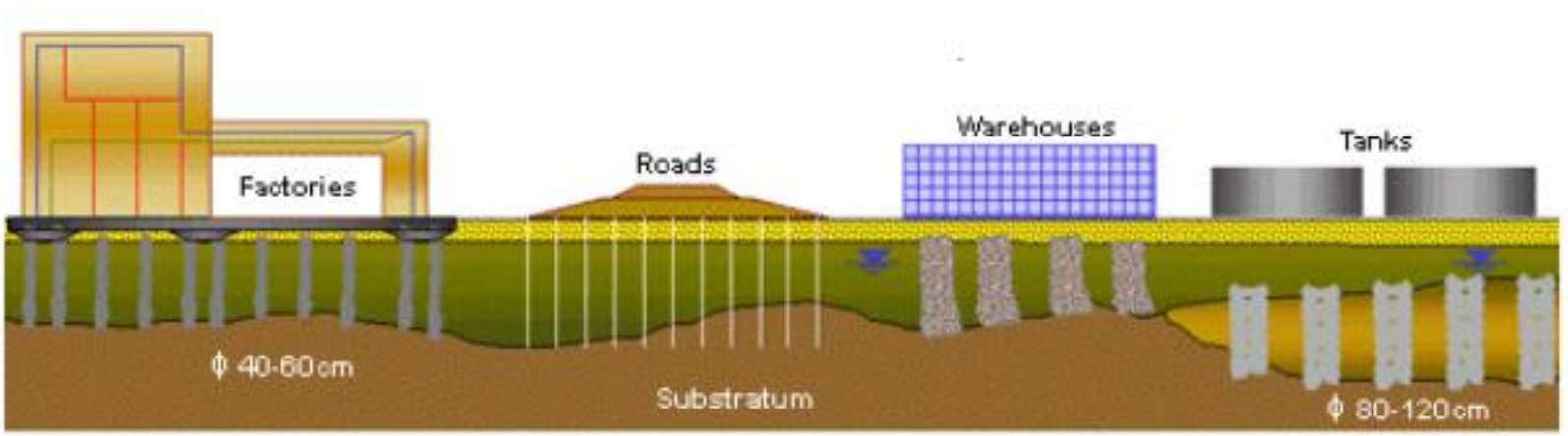





# Design of vibroflotation

## Engineering requirement and geological condition determined Vibro-pile design




**The design include: caculation of bearing capacity and settlement, diameter and depth of pile, palcement of pile and detailing requirement of construction, etc.**

## Design standard of vibroflotion



《Technical specification for building foundation treatment》（JGJ79-2012）

《Technical specification of foundation treatment for hydraulic engineering vibroflotation method》（DL/T5214-2005）

## Basic information needed for the design of vibroflotation

### Information of original soil

- Geological investigation report
- Borehole section
- Physical and mechanical index of soil 标

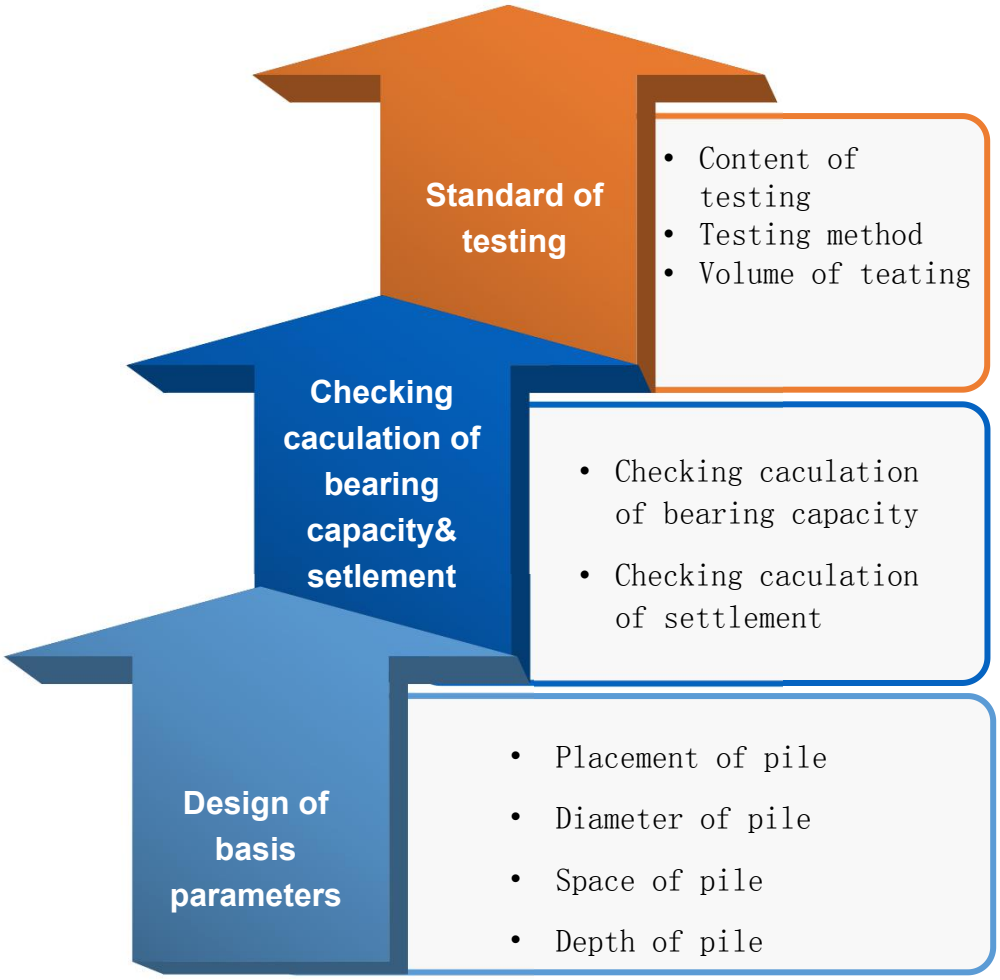
### Information of engineering

- Grade of engineering
- Grade of building
- Types of foudation, load and grade of anti-seismic

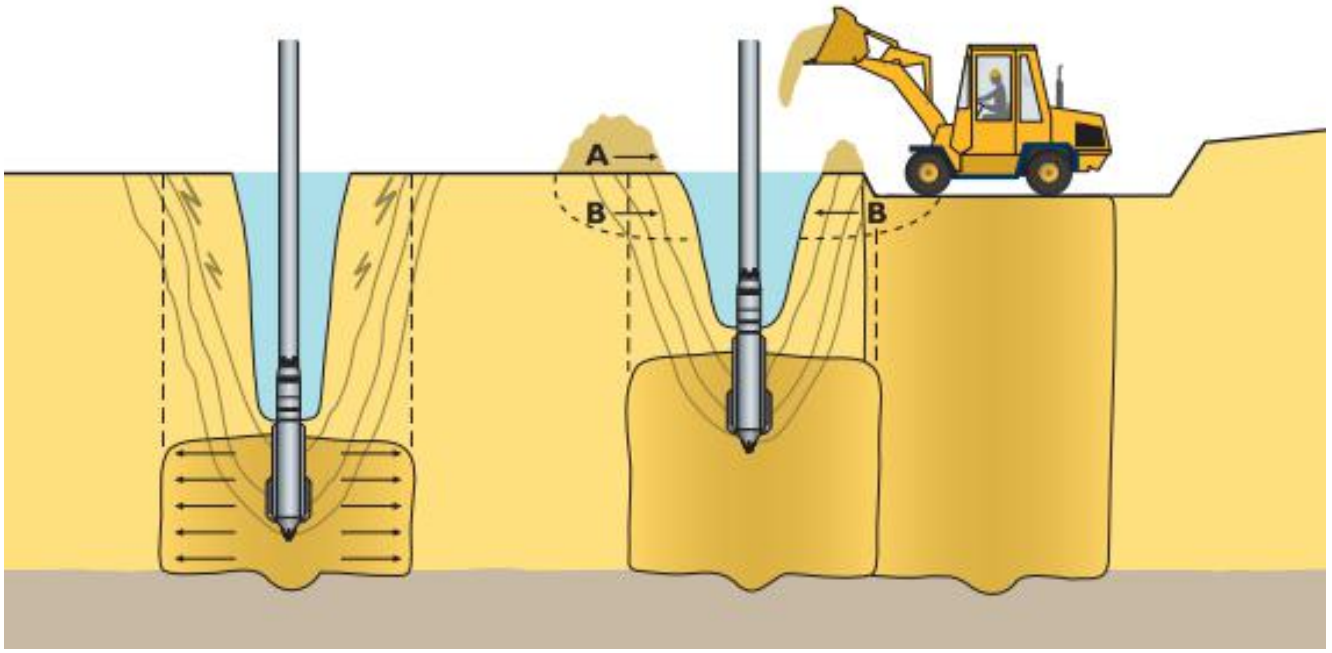
### Physical and mechanical requirement of soil

- Bearig capacity of composite foudation
- Settlement
- Index of shearing resistance

## Design content of vibroflotation




# Design of vibro-compaction



## Placement of compaction pile

**Scope of layout:**

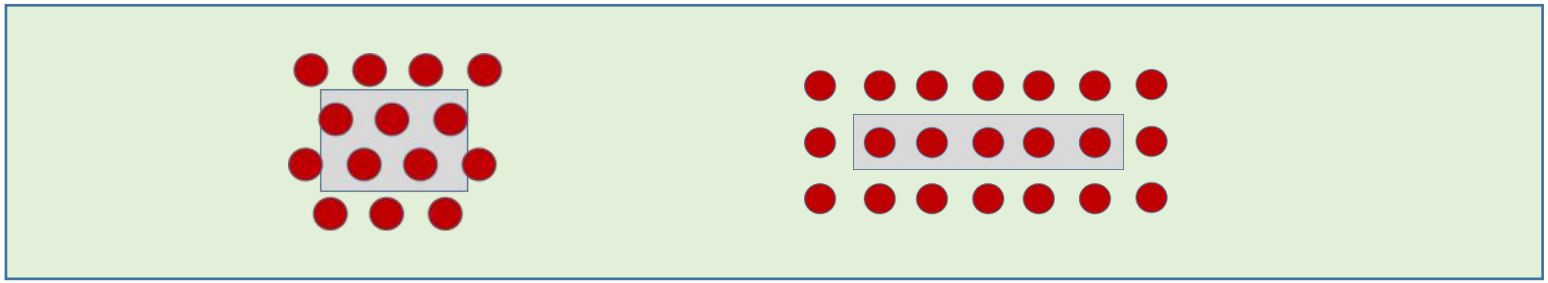
1、High-rise or multi-storey building foundation needs 1-3 row retaining piles o base outer edge

2、The foudation outer edge processing width is not less than 1/2 of the thickness of the liquefaction soil layer, not less than 5m

**Style of placementi**

1、Large area foudation should adopt triangular lauout

2、Independent and strip foundation could adopt triangular, square, rectangular or mixed layout



## Design of pile diameter

- Normal diameter: 08m-1.2m
- Diameter of non-filler piles determined by size of vibroflot,power and property of soil layer

## Design of pile space

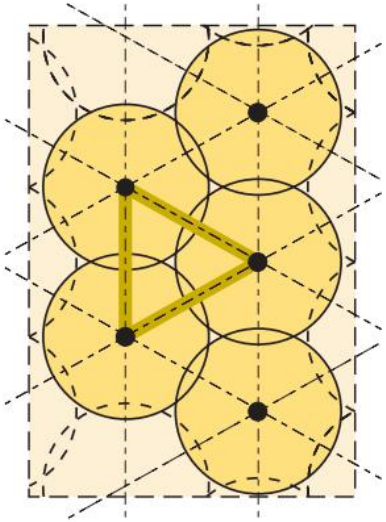
- Following factors influence space of pile：

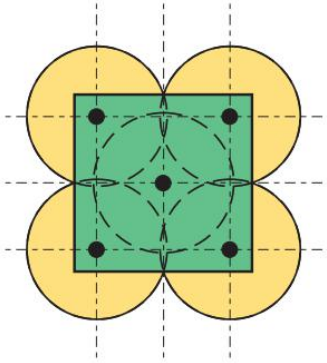
1、Soil condition、2、Grade of engineering、3、Power of vibroflot

- 1.5-3m space can be adopted for 75KW or bigger vibroflot
- Small space should be adoped for large load or small soil partical condition. Conversely, large space should be adopted

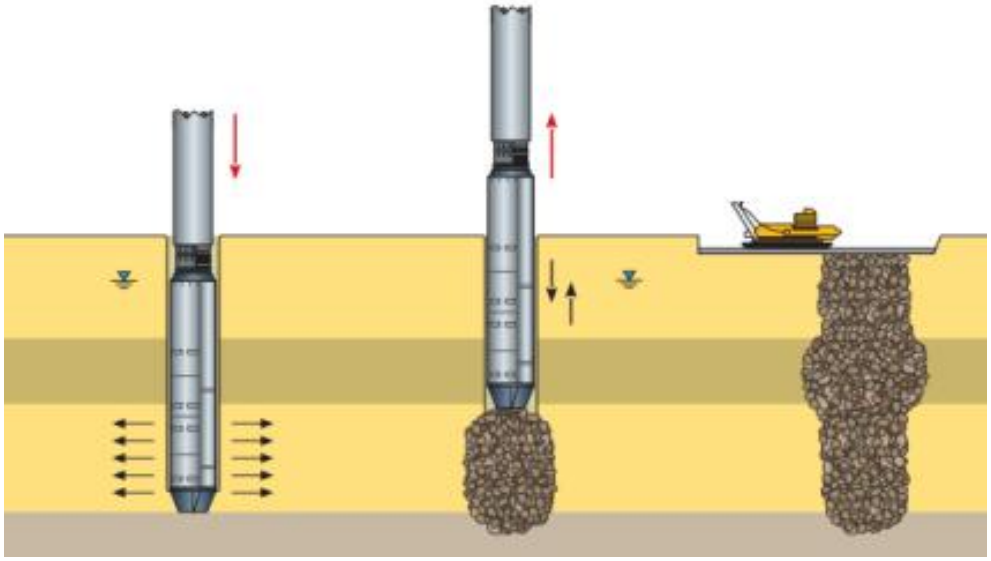
## Design of pile depth

- When the hard layer is not buried deep, it is determined according to the relative hard layer
- Conversely, it is determined by allowable settlement
- For liquefiable soil layer, it is determined by anti-seismic treatment depth





# Design of vibro-replacement



## Layout of gravel pile

**Scope of layout:**

1、Determined by caculation of settlement and stability

2、Place the pile in range of foundation, meanwhile 1-2 rows of retaining piles iareneeded at foundation outer edge

3、For independent,strip foundation, piles can be placed in range of foundation. when soil is clay, 1-2 rows of retaining piles should be placed at outer edge of foundation

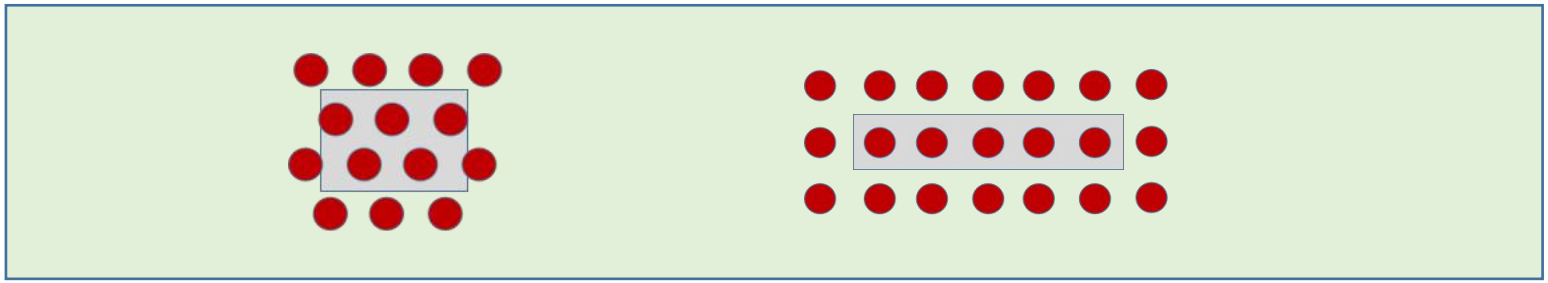
4、Foundation outer edge proccessing width is not less than 1/2 of treating depth of under foundation for liquefiable soil

**Style of pile layout:**

1、Large area foundation can adopt triangular, square and rectangular layout

2、Strip foundation can place pile along central line of foundation. Multiple row pile can be adopted when single row can not meet requirement.

3、For independent foundation, triangullar, square , rectangular and mixed style can be adopted

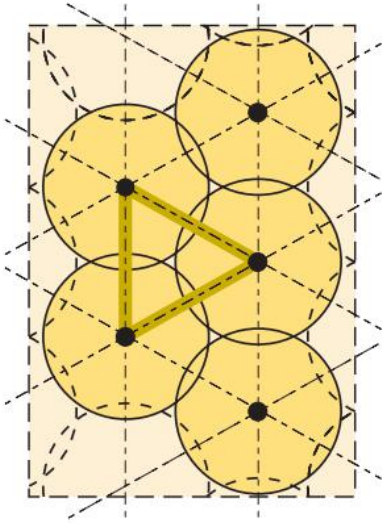


## Design of gravel pile diameter

- Requirement of bearing capacity and settlement to get the minimum replacement ratio
- Normally set by 0.8m-1.2m
- formula $d_0 = 2\sqrt{\eta V_m / \pi}$

$V_m$——每延米桩体平均填料量，$m^3/m$；

$\eta$ ——密实系数，一般为 0.7～0.8。

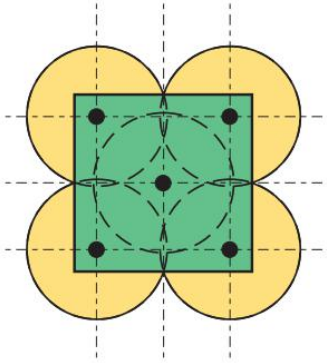


## Design of pile space

- Following factors influence space of pile：

1、Soil condition、2、Grade of engineering、3、Power of vibroflot

- 1.5-3m space can be adopted



## Design of pile depth

- Requirement of bearing capacity and settlement
- Stability against sliding treatment should under more than 1.0m depth of the sliding surface
- Checking caculation of bed rock should be adopted when pile achieve bed rock depth
- For liquefiable soil layer, could adopt according to standard of GB50011 and DL5073

## Caculation of the characteristic value of bearing capacity of composite foundation

| Testing method can be found in appendix A of standard | $f_{spk}=mf_{pk}+(1-m)f_{sk}$ <br> $m=\frac{d_0^2}{d_e^2}$ <br> $f_{pk}$ ——桩体单位截面积承载力特征值，kPa； <br> $f_{sk}$ ——桩间土承载力特征值，kPa； <br> $m$ ——面积置换率； <br> $d_0$——桩长范围内的平均桩径，m； <br> $d_e$——单桩等效影响圆直径，m。 | $f_{spk}=[1+m(n-1)]f_{sk}$ <br> $f_{sk}$ ——桩间土承载力特征值（对于非可加密土，取其天然地基承载力特征值；对于可加密土，取其加密后的地基承载力特征值），kPa； <br> $n$ ——桩土应力比，无实测资料时取 2～4，桩间土强度低时取大值、高时取小值。 |
|---|---|---|
| Determined by pre-loading testing on composite foundation | Determined by seperate pre-loading test on piles and soil | Determined by caculation |
| Accurate | More exact | estimate |

## Caculation for shearing resistance index

$$\mathrm{tg}\phi_{sp}=m\mu_p\mathrm{tg}\phi_p+(1-m\mu_p)\,\mathrm{tg}\phi_s$$

$$c_{sp}=(1-m\mu_p)\,c_s$$

$$\mu_p=\frac{n}{1+m(n-1)}$$

式中：

$\phi_{sp}$——复合土体的等效内摩擦角，（°）；

$\phi_p$——桩体材料的内摩擦角，（°）；

$\phi_s$——桩间土体内摩擦角，（°）；

$c_{sp}$——复合土体的等效黏聚力，kPa；

$c_s$——桩间土黏聚力，kPa；

$\mu_p$——应力集中系数。

## Caculation for settlement

1 复合土体的压缩模量：

$$E_{sp}=[1+m(n-1)]\,E_s$$

式中：

$E_{sp}$——复合土体的压缩模量，MPa；

$E_s$——桩间土压缩模量（非可加密土取其天然土的压缩模量，可加密土应取其加密后的压缩模量），MPa。

2 复合土体的变形模量：

1）通过复合地基载荷试验确定。

2）通过单桩和桩间土载荷试验按下式计算确定：

$$E_{op}=mE_p+(1-m)\,E_o$$

3）当现场仅做桩或桩间土载荷试验时可按下式计算确定：

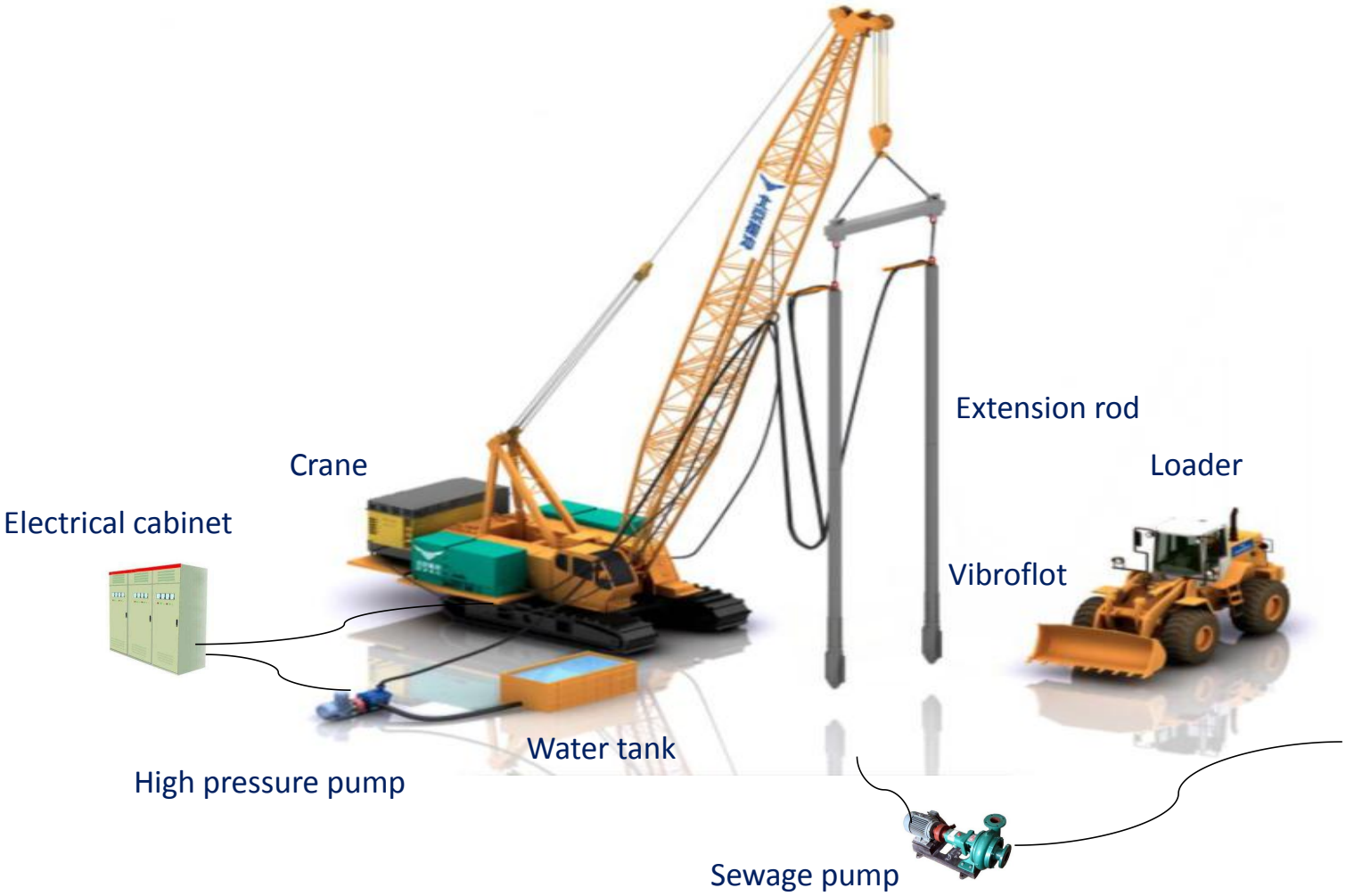
$$E_{op}=[1+m(n-1)]\,E_p/n \qquad (5.0.6\text{-}3)$$

$$E_{op}=[1+m(n-1)]\,E_o \qquad (5.0.6\text{-}4)$$

## Other key point of design

| | |
|---|---|
| Enhance of head of pile | The pile of high more 10m-1.5m of effective pile head should be enhanced |
| Treatment of top of pile | 0.2m-0.5m thickness gravel cusion should be put on the top of pile |
| Filler requirement | Partical of stone(gravel, grait, grail, gravelly sand,slag)should be in range of 20mm-150mm and with less than 5% of silt content |

# Complete equipment of vibro-construction



## Construction process

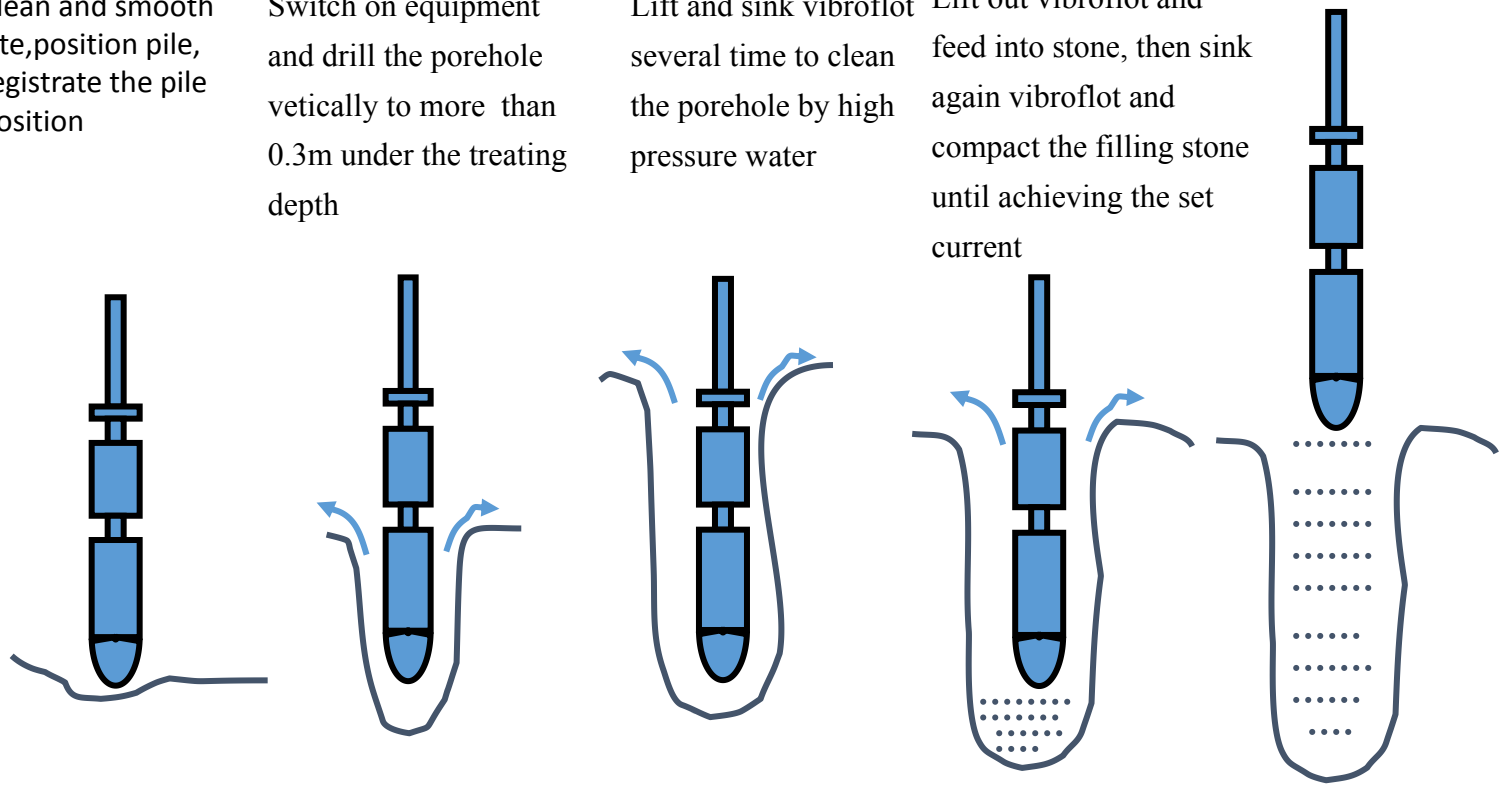
**Positioning** → **drilling** → **Borehole cleaning** → **feeding** → **Section pile fromed**

Clean and smooth site,position pile, registrate the pile position

Switch on equipment and drill the porehole vetically to more than 0.3m under the treating depth

Lift and sink vibroflot several time to clean the porehole by high pressure water

Lift out vibroflot and feed into stone, then sink again vibroflot and compact the filling stone until achieving the set current



# Key point of construction quality control

1

Benchmarke：
Compacting current, sectional compacting time, sectional thickness filler volume

2

The pile body compaction should start from the bottom of the pile, and should be moved up and out by section . Packing method can be used by forced , continuous and intermittent packing method

3

Electrical current,water pressure, compacting time and filler colume should be recorded. if there is big defferent with required filler volume, solution should be adopted

The filling coefficient is defined as the ratio of the actual filling volume of the gravel pile to the volume of pile which was determined by size of the pile diameter and pile length. The standard of gravel pile code suggested that the filling coefficient is 1.1 to 1.2

## Self-inspection

- Filler inspection
- The compactness of pile body can be tested by using heavy dynamic contact test
- The test of heavy dynamic contact test or standard penetration test caould be carried out for the compaction effect of the pile

## Inspection by the third party

- Pile position, quantity, diameter, density, soil treatment effect, composite foundation bearing capacity and deformation modulus should meet the requirements of design and specification
- Pile compactness can be tested by heavy dynamic penetration test, soil compactness canbe tested by dynamic penetration test and standard penetration test
- Static load test should accord with standrad

# Application case of vibroflotation

Macao road cotai building materials landfill levees construction project

The hong kong-zhuhai-macao bridge, bottom feed vibro-construction

Dalian changxing island north breakwater project

Caofeidian crude oil terminal and supporting facilities 1 #, 6# can projec

Construction of engineering foundation of no.2 artificial island in jidong oilfield no. 2

vibration construction of power plant in wulushan power plant in Inner Mongolia