



Bottom Feed Vibro-replacement Application



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Development & Application of Vibroflotation

- Applied by Europ in 1930s with Vibro-compaction. Since 1970s vibro-replacement has been developing. In China, vibroflotation was launched in 1977 by BVEC company and developed rapidly in construction industry.
- Vibroflotation bring an effective good result to soft soil even it use simple, convinient and cheap equipment and material. Construction organization and construction process are simple. It is recognized to be **a practical application**





Development & Application of Vibroflotation

Vibroflotation's Remarkble Effect on the Following Properities of Subsoil

Bearing Capacity

Foundation Settlement

Drainage Consolidation

Eliminate Liquefaction

Vibroflotation Worikng Principle

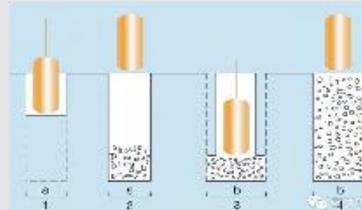
Vibrate to compact

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

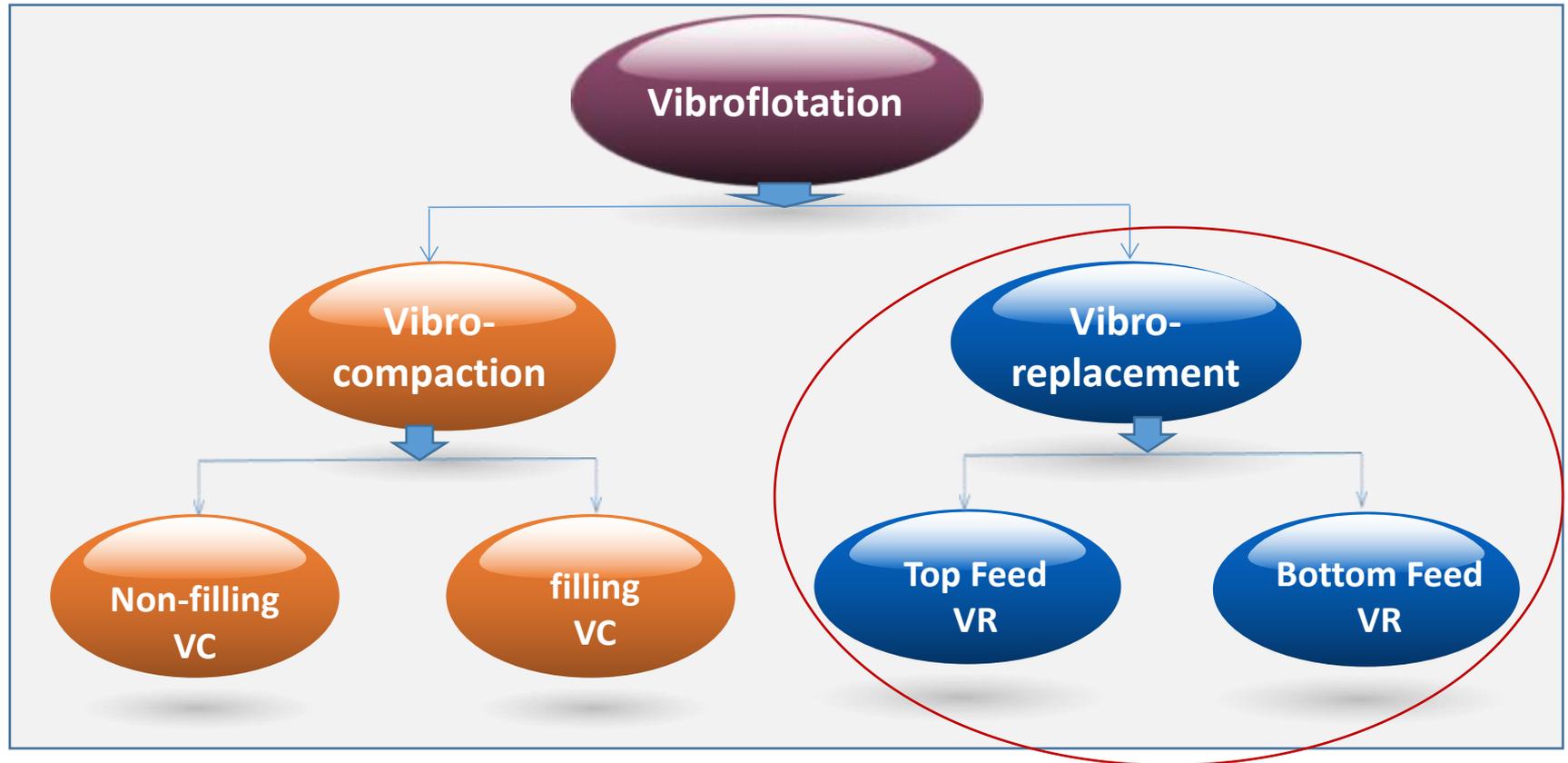
The formed gravel pile can works as drainage pipe insert in soil layer. The drainage situation of soil was improved





Development & Application of Vibroflotation

Vibroflotation Classification

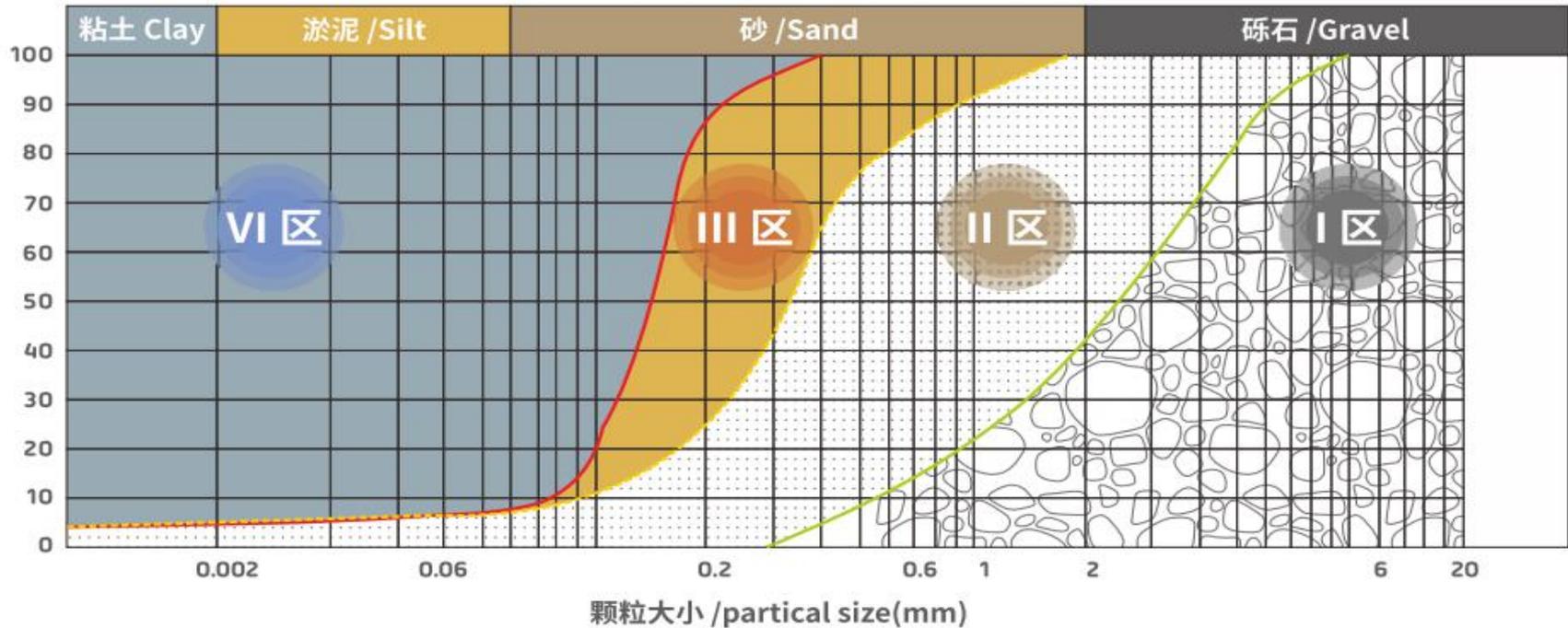


At present, the main application of vibroflotation in China are non-filling VC and top feed VR (it sometimes also is named top feed vibro-stone column)



Applicable Scope of Vibroflotation

Vibroflotation Applicable Scope by Soil Classification



- I. **VC** can be proposed but big rocks may be suffered
- II. **Non-filling VC** can be applied
- III. **Both non-filling VC and filling VC** are the possible applicable solution
- IV. **VR (Stone column)** can be applied



Applicable Scope of Vibroflotation

Other Consideration for Vibroflotation Applicability

Water content
and strength
of clay soil

DL/T5214-2016

3.0.3 For the silt with strength less than 20KPa, the applicability need to be verified by field test

Constraction
feild

Offshore or land

For the offshore job, a reliable and feasible method is needed to guarantee the efficiency and quality of construction

Construction
water
usability

Water using

- Water using will be limited at place where water is lack
- Dry method is specified to avoid negative impact to soil by high pressure water

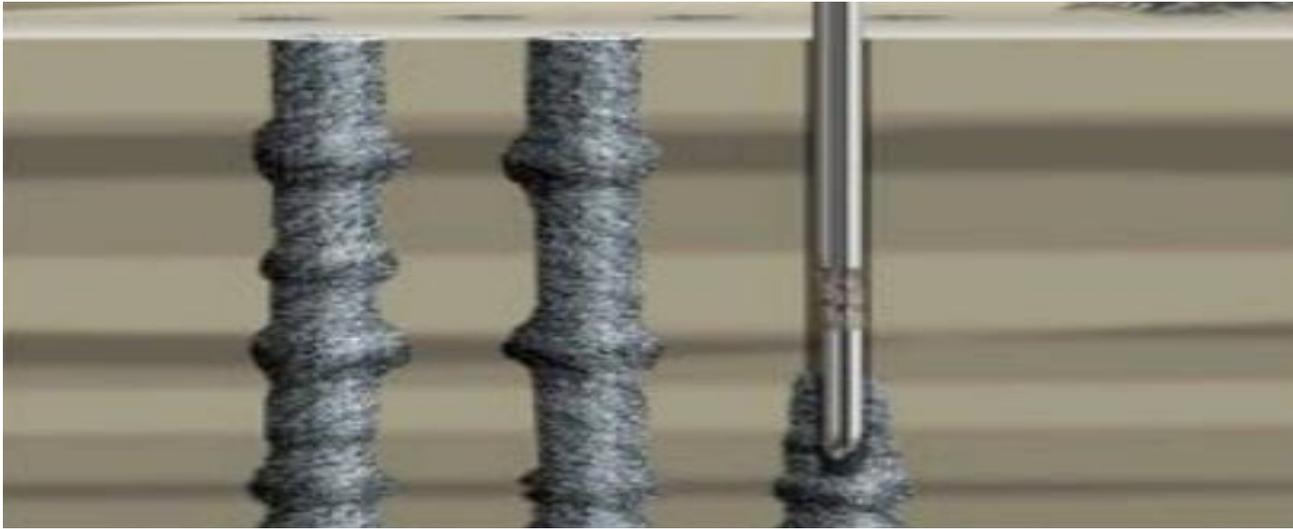
Limitation and
convinience of
Sewage
discharge

Environment factor

- Sewage discharge is prohibited
- No convinient area to receive sewage or high cost of discharge



Situational Pile Diameter in Vibro-Replacement



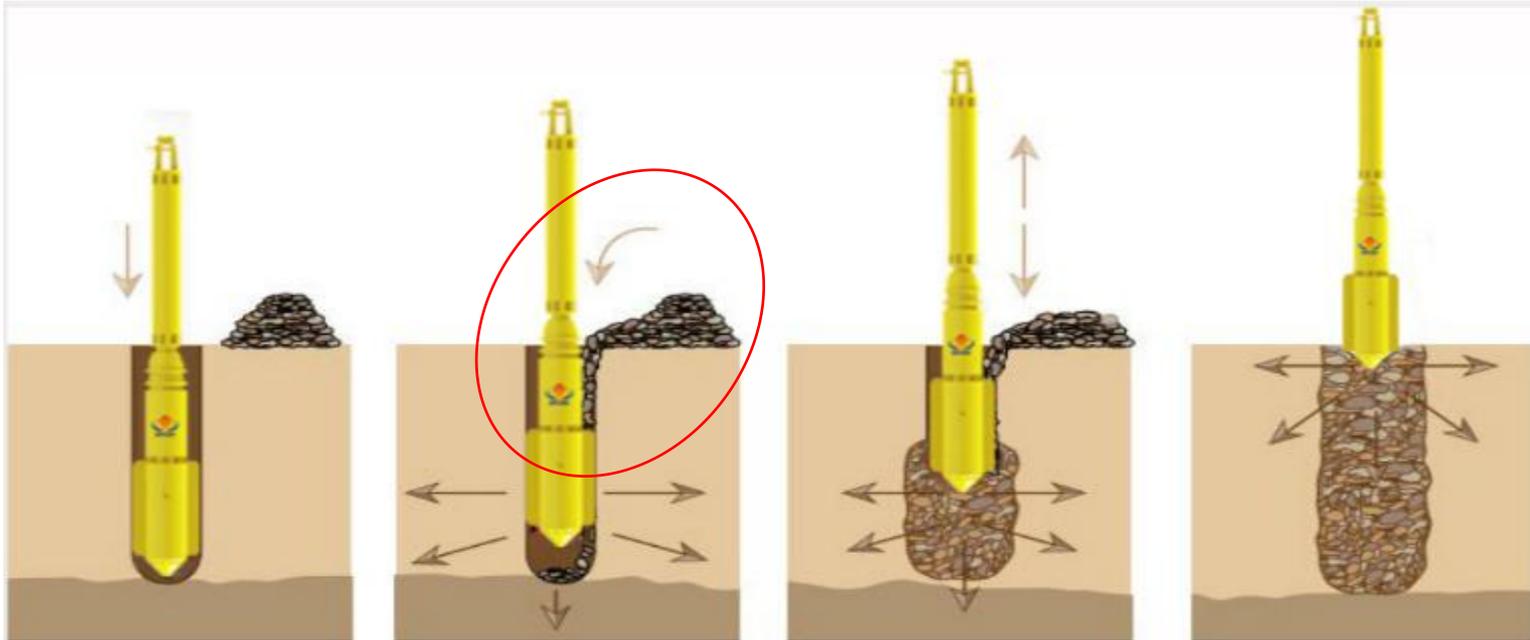
Stronger in weak and weaker in strong

1. Actual diameter changes in different soil layer with different hardness
2. Bigger diameter formed in soft soil layer and vice smaller diameter formed
3. The overall shape of stone column looks like a gourd
4. Diameter we usually say is a conception of **“average diameter”**



Applicable Scope of Vibroflotation-Control of Real-time pile diameter

TF VR Method Contro Diameter by “Average” Instead of “Real-time”



Example: We are making a 10 meters stone column. 1.5 m³ stone is put at top of borehole when vibroflot is working at 8m depth. We can say these volumn will contribute to the 10m column instead of the specified section from “-8m to -6m”

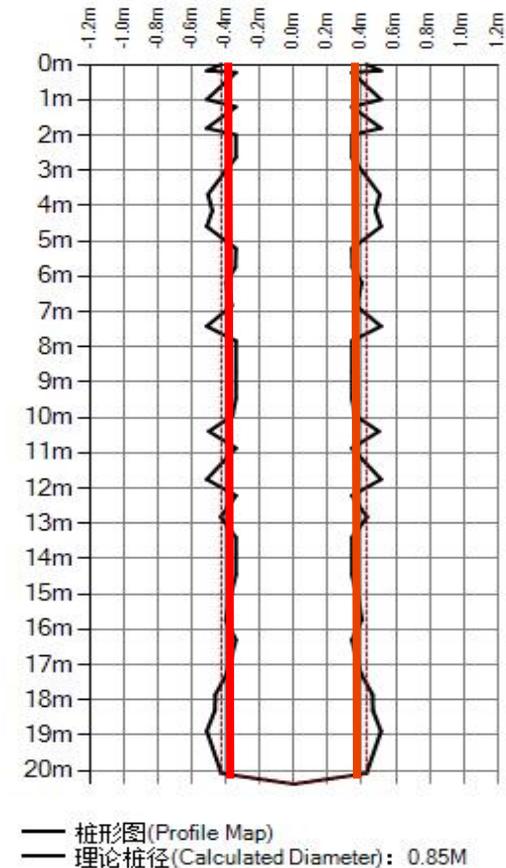


Applicable Scope of Vibroflotation-Control of Real-time pile diameter

The Significance of Controlling the Real-time Diameter of Stone Column

- Facilitate to estimate the hardness of soil layer and realize the optimization of construction technology
- Play the function of self-inspection, verify the rationality of the construction design scheme, and provide the data support for the optimization of the design scheme
- Obtain the relatively accurate real-time diameter of pile, can be used to calculate the replacement ratio(m) of different soil layer, contribute to a more accurate calculate of bearing capacity and settlement.
- To improve the degree of theorization of vibroflotation which is now staying at the status of “semi-empirical and semi-theoretical”

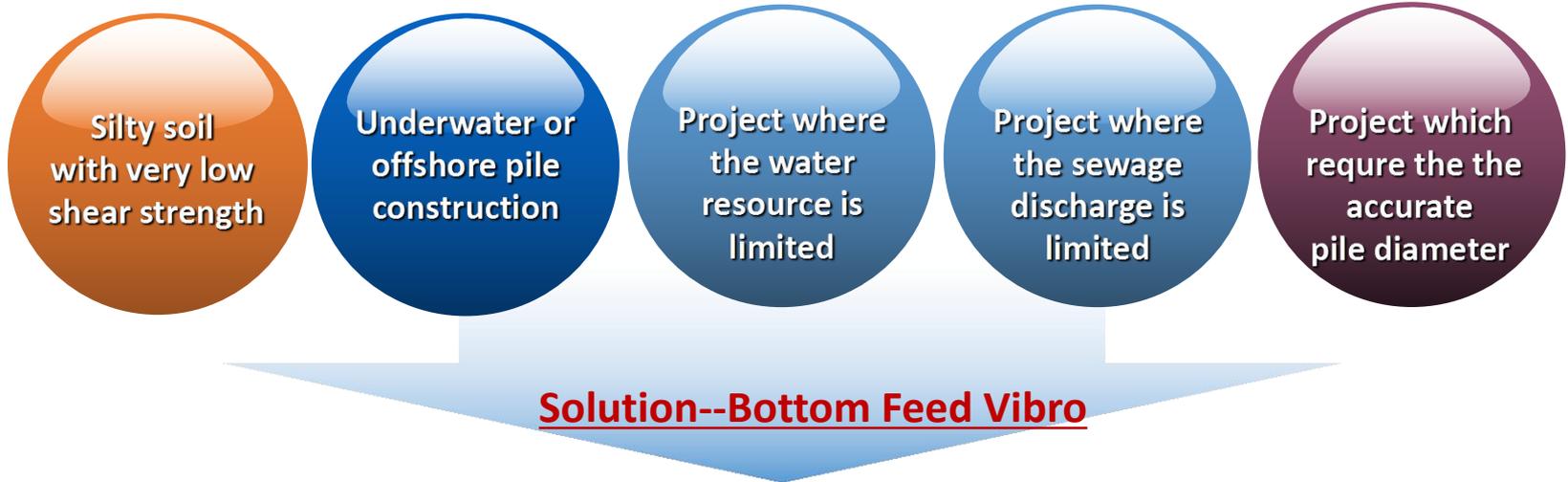
桩形图曲线(Profile Map)





Applicable Scope of Vibroflotation-Control of Real-time pile diameter

Limitation of Applicability to Top Feed Method



Vibro-bottom feed is an extension application of traditional vibroflotation to expand the applicable range of vibroflotation technology

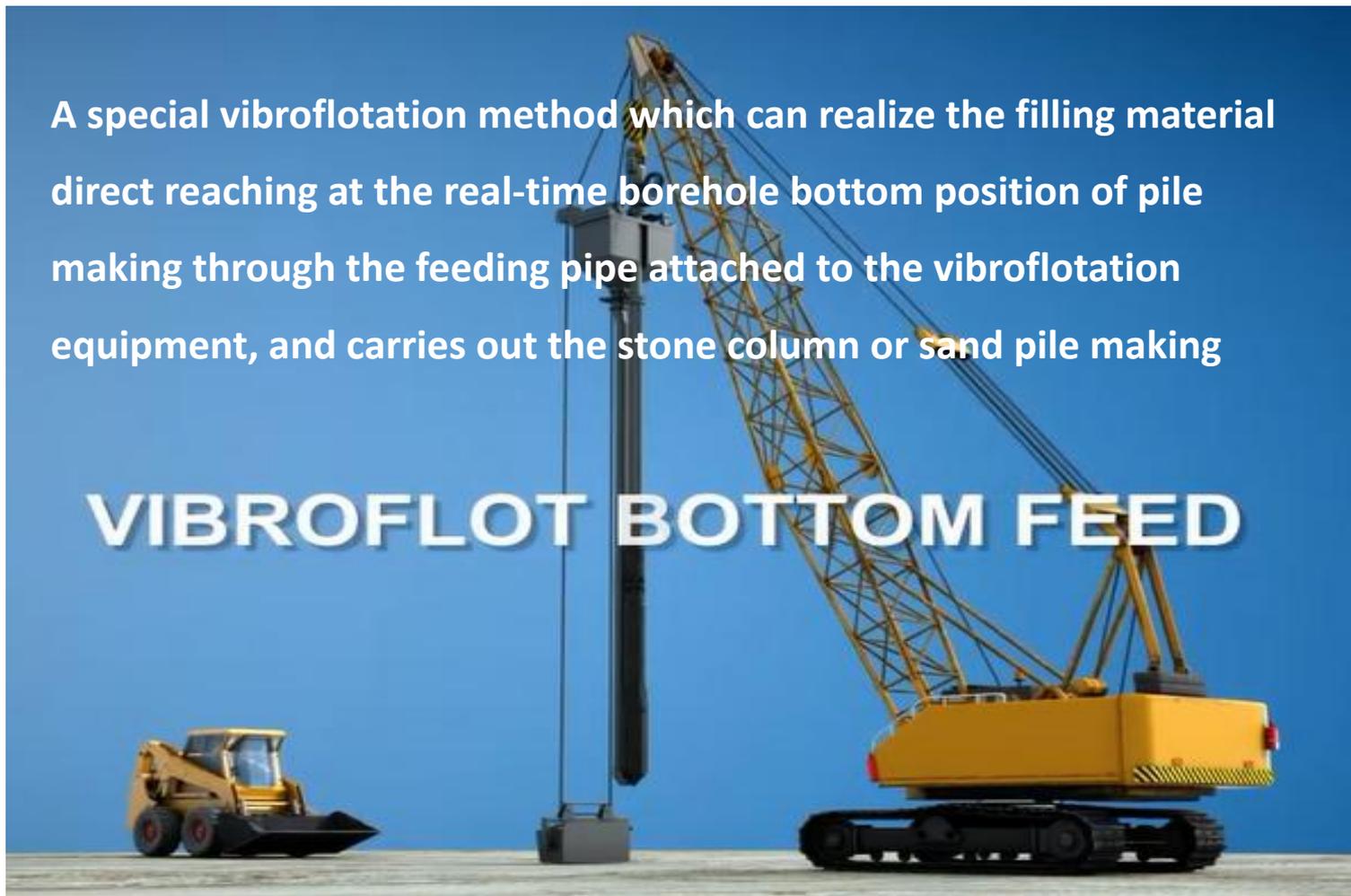


Conception of Bottom Feed Vibroflotation

What is Bottom Feed Vibroflotation

A special vibroflotation method which can realize the filling material direct reaching at the real-time borehole bottom position of pile making through the feeding pipe attached to the vibroflotation equipment, and carries out the stone column or sand pile making

VIBROFLOT BOTTOM FEED



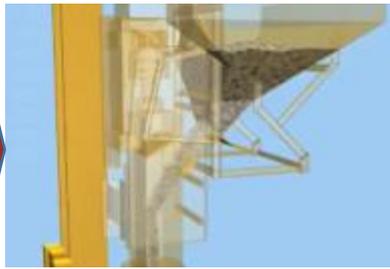


Conception of Bottom Feed Vibroflotation

Working Principle of Vibro-BF



Stone into the container



Stone transfer to feeding pipe



Compact to make pile



Stone go into soil from pipe





Conception of Bottom Feed Vibroflotation

Working Process of Vibro-BF





Construction Equipments of BF Vibroflotation

Composition of Vibro-BF Equipment System

➤ Vibroflot System

Vibroflot, damper, extension tube, cabinet

➤ Feeding Tube System

Feeding tube, Damper

➤ Stone Container System

Double cavity, single cavity, non-container

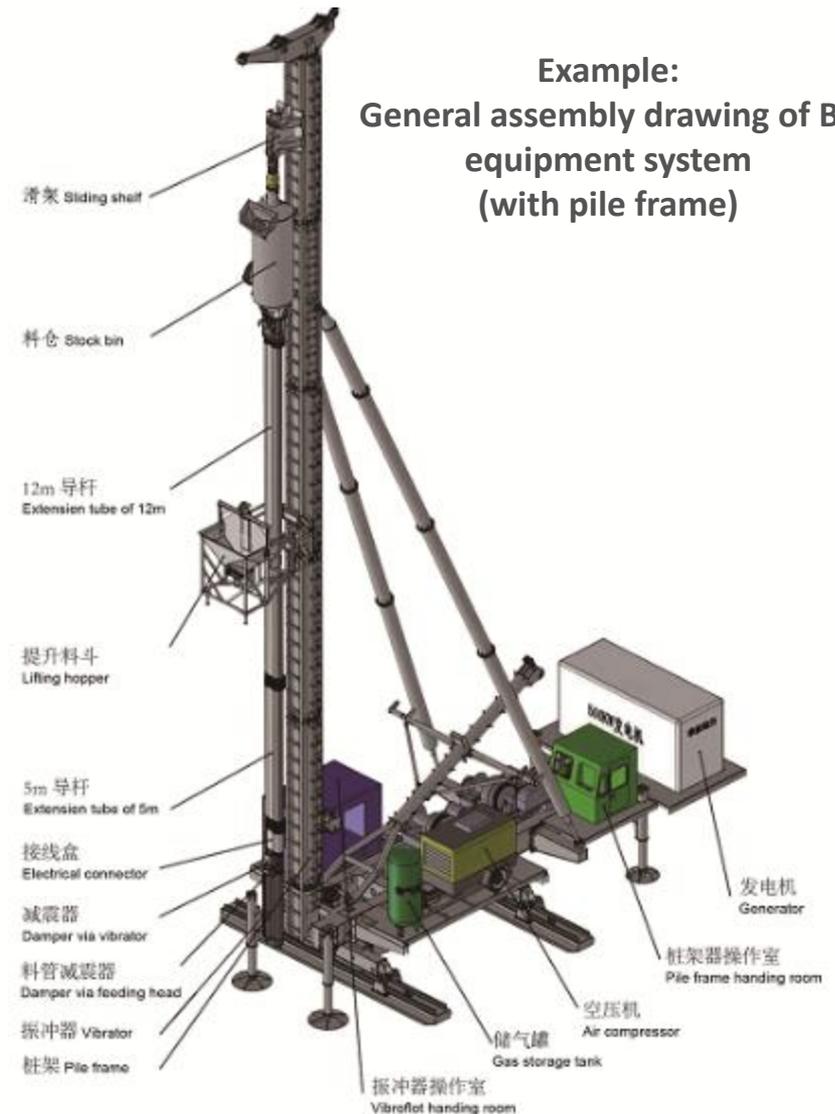
➤ Material Supply System

Wind-up type, lead-track type / Flip type, chute type

➤ Control System

Control of valve, air compressor and materail level

Example:
General assembly drawing of BF equipment system (with pile frame)

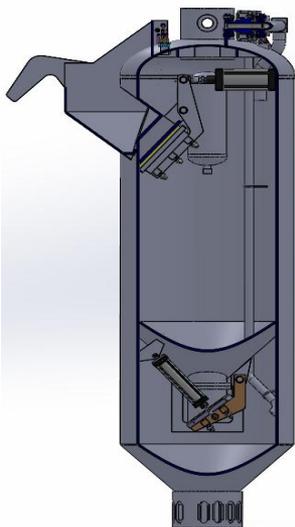




Construction Equipments of BF Vibroflotation

Material Container System Type

Double Cavity System



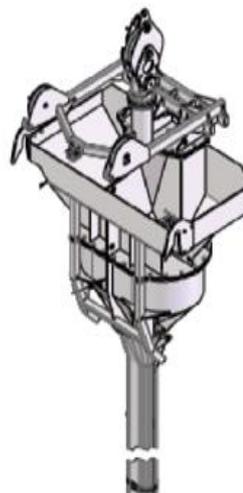
Characteristics

- With double-lock cavity
- Keep sustainable air pressure in feeding tube

Application

- Underwater(offshore) job
- Long pile job(>15m)

Single Cavity System



Characteristics

- With single cavity
- Circle transition of state between with-pressure and non-pressure

Application

- Land job
- Shallow pile(<15m)



Construction Equipments of BF Vibroflotation

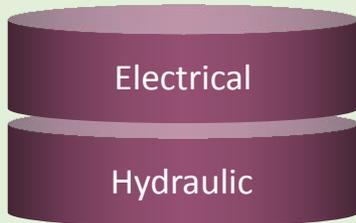
Customization of BF Equipment System

Modules of BF Equipment Components

Module 1



Vibroflot



Electrical

Hydraulic

Module 2



Feeding tube



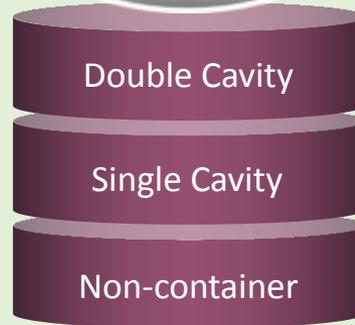
Bottom Feed

Waist Feed

Module 3



Materail
Container



Double Cavity

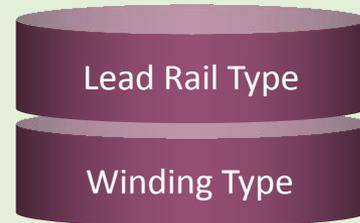
Single Cavity

Non-container

Module 4



Materail Supply



Lead Rail Type

Winding Type



Construction Equipments of BF Vibroflotation

Customization Application Case (1)



Double cavity + Pile frame +
Hopper with lead rail



Double cavity + Crane + Winding
hopper

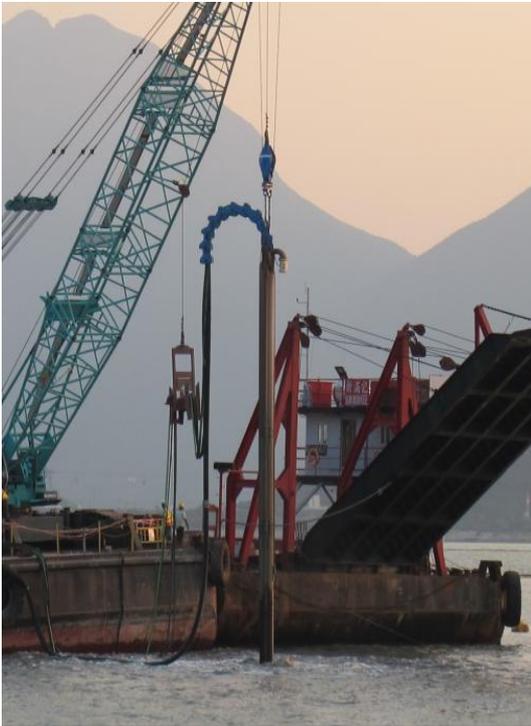


Double cavity + Vessel + Lead rail



Construction Equipments of BF Vibroflotation

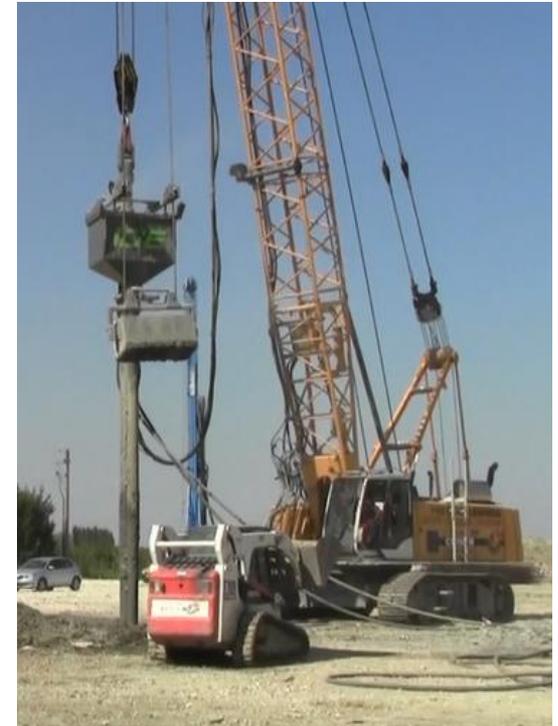
Customization Application Case (2)



Non-container + Hoist + Pressure piping system



Hydraulic Vibroflot + Single cavity + Rig + Non-hopper



Single cavity + Crane + Winding hopper



Comparison Between Vibro-BF and Vibro-TF

Points in Common

The mechanism and effect of soil improvement

- **Vibro-stone column principle**

Soil improvement realized by means of pillar,, subcrust and drainage effect of stone colimn

Design principle and method

- **Principle of composite foundation**

Calculate and design according to composition foundation principle of stone column

Inspection and test method

- **Inspection and test method for effect of stone column job**

Inspect and test according to the standard of stone column



Comparison Between Vibro-BF and Vibro-TF

Difference between Vibro-BF and Vibro-TF

1

Construction Devices

- Additional stone supply system
- Multiple construction method(Dry, water and linkage)

2

Construction Technology

- Control real-time pile diameter
- Feasibility of **Suspension construction method** for silty soil

3

Penetrating Capacity

- Bigger section area of device
- No power giving from feeding tube

4

Construction Efficiency

- More complex construction process
- More control points



Comparison Between Vibro-BF and Vibro-TF

Stone Material Saving

Top Feed



Bottom Feed



BF method reduces the waste of stone and improves the usage ratio of stone. Facilitate to lower cost and better field appearance



Comparison Between Vibro-BF and Vibro-TF

Selection between BF and TF

Vibro-TF

- 
- General vibro job
 - Simple device need and easy to organize
 - Simple operation and high efficiency
 - Strongger penetrating capacity
 - Lower cost of device and construction

Vibro-BF

- 
- Can be applied for offshore job
 - Dry, water and linkage method can be offered
 - Controllable to real-time diameter
 - Lower penetrating capacity
 - More complex of operation and lower efficiency of construction

Commonly, BF will **not be recommended** in following situation

- Non-packing vibro-compaction job
- Vibroflotation job for shallow stone column (less than 10m)
- Project without bottom feed requirement, or project with high construction efficiency requirment



Comparison Between Vibro-BF and Vibro-TF

Situation of BF Applying

- BF avoid the phenomenon of stone sticking due to shrinkage cavity
- Suspension construction method can be applied to avoid the failure of pile formation due to too small confining pressure of the bore-hole wall

**Silty soil with
Cu value
less than 20 Kpa**

Geological

Quality control

Accurate Diameter

- Compatibility with data recorder improved
- Available real-time diameter

- Possibility of feeding stone in accuracy and efficiency in offshore job

Under-water job

Field condition

Environment/Resource

Dry method specified

- No need for big amount of water
- No big amount of waste water producing

BF is an **extension application** of TF, instead of replacement



Comparison Between Vibro-BF and Tube-sinking Stone Column

Points in Common

Working Mechanism

Vibratory compaction and composite foundation principle

- Compact soil by means of external vibration giving
- Formed stone column work together with soil to bear external load
- Drainable stone column facilitate the solidification of high water content soil
- Improve the anti-seismic ability via density increasing of liquefiable soil by compaction

Feeding Type

Bottom feed method

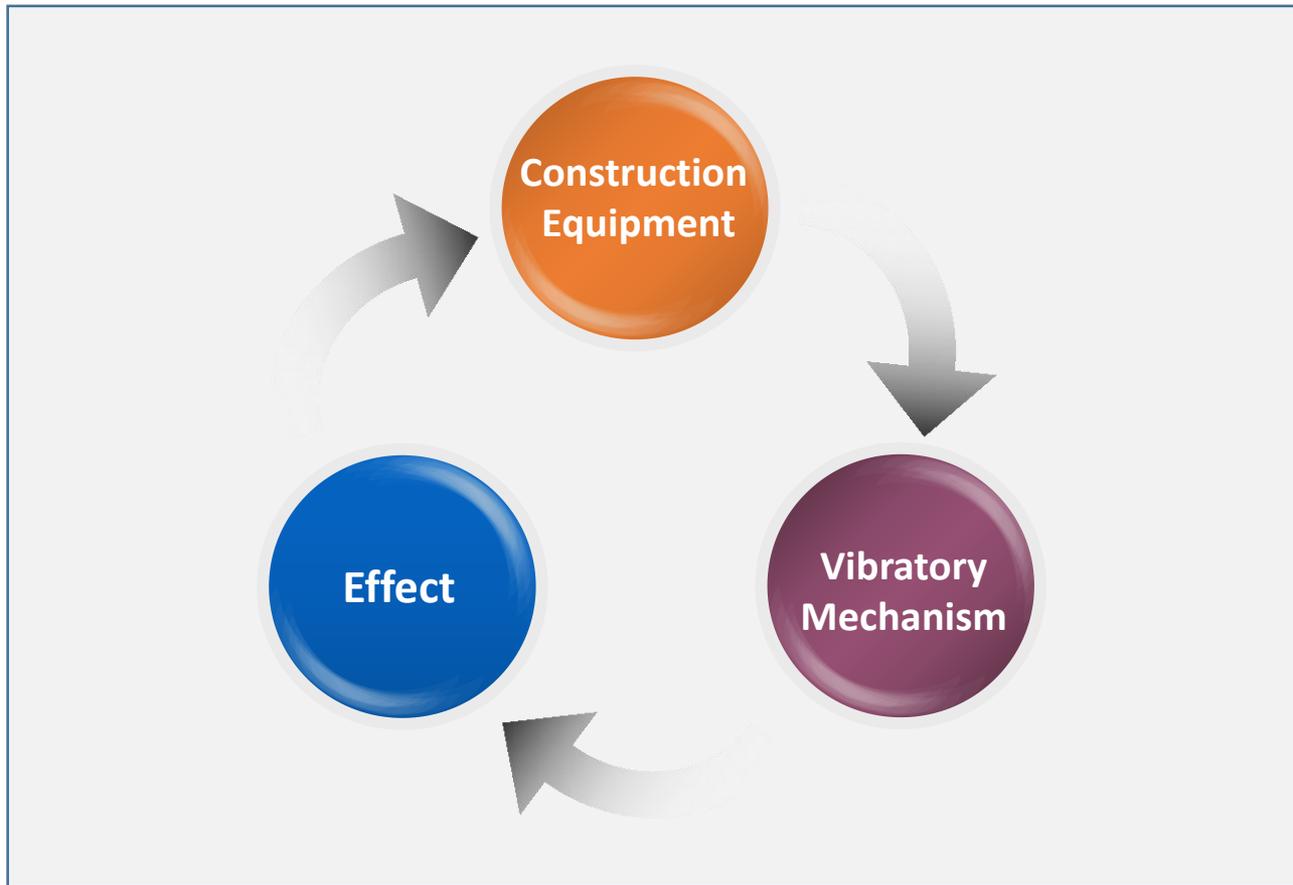
- BF feed stone to bottom through bypass tube
- T-S feed stone through the model tube
- Realize the real-time pile diameter controlling
- Can applied for offshore job and construction for silty soil

Both can be classified to Bottom Feed Method



Comparison Between Vibro-BF and Tube-sinking Stone Column

Difference Between Vibro-BF and T-S





Comparison Between Vibro-BF and Tube-sinking Stone Column

Applying Equipments



T-S Stone Column

Power equipment: **Vibro-hammer**
Boring equipment: **Model tube**
Vibratory device : **Model tube**
Lifting device : **Pile frame**
Stone supply : **Loader**

Power equipment: **Vibrator**
Boring equipment: **Vibrator**
Vibratory device : **Vibrator**
Lifting device : **Variety**
Stone supply : **Variety**

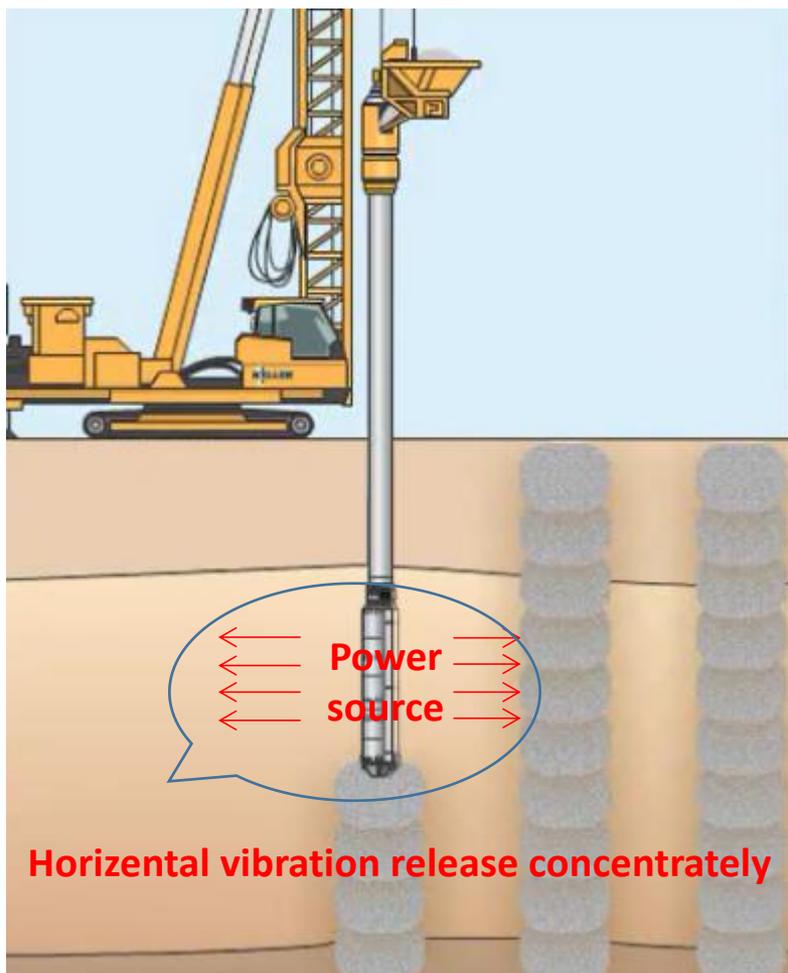
Vibro-BF





Comparison Between Vibro-BF and Tube-sinking Stone Column

Vibro-BF Vibratory Mechanism



- Vibrator produce the horizontal force and ACTS directly on the soil
- All horizontal force concentrate at vibrator and power is released concentrately
- Vibrator is not only the releasing power source but also the penetrating and leading device
- Compacting soil by section, the maximum released energy can be obtained by each section of soil

| | |
|------------------------------------|----------|
| Pile Depth (m) | 40以上 |
| Pile Diameter (m) | 700-1500 |
| Penetrating Ability SPT (blows) | 30以上 |
| Dia. Scope of applicable stone(mm) | 20-50 |

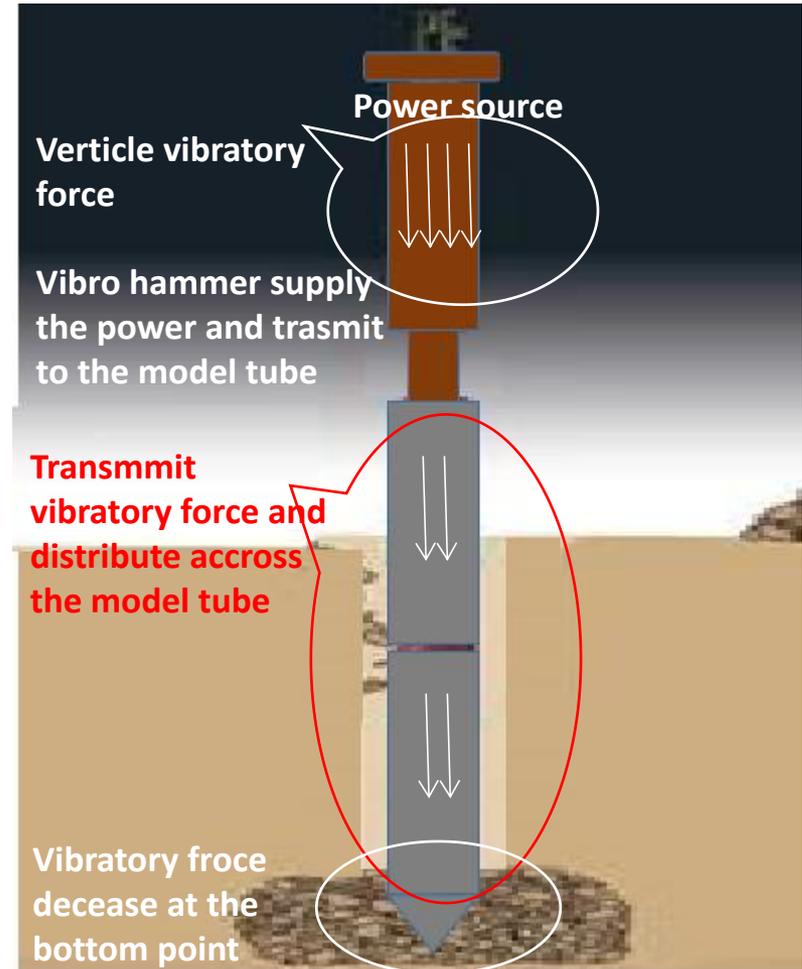


Comparison Between Vibro-BF and Tube-sinking Stone Column

T-S Method Vibratory Mechanism

- Vibro hammer produce verticle vibration force and **transmit** to model tube
- Verticle vibratory force distribute across the model tube and **decreased at the bottom point** where the pile is being made
- Model tube play the function of leading boring and force transmitting, pore-forming capacity is limited
- Pile diameter is greatly affected by the power of vibro hammer

| | |
|------------------------------------|----------|
| Pile Depth (m) | 30以下 |
| Pile Diameter (m) | 400-1000 |
| Penetrating Ability SPT (blows) | 15 |
| Dia. Scope of applicable stone(mm) | 40以下 |





Comparison Between Vibro-BF and Tube-sinking Stone Column

BF Combines the Advantages of both Vibroflotation and T-S

Advantage from Vibroflotation



- Strong penetrating capacity
- Better compaction result
- Bigger diameter and depth
- Larger applicable scope of soil type
- Larger scope of applicable stone diameter

Advantage from Both



- Principle of Composite foundation
- Forming stone column
- Pillar, subcrust and drainage function

Advantage from T-S



- Environmental and green dry method construction
- No water using, no loss of soil particle
- Control real-time diameter
- Applicable for offshore jo and silty soil layer

Dry, water, and air-water linkage method can be adopted according need



Vibro-BF Application for Silty Soil Layer

Problems Existing in Vibro-TF Treatment of Silty Soil

DL/T5214-2016 article

3.0.3 For the undrained shear strength of less than 20% of the silt, silt soil and such soil artificial fill foundation, due to the field test to determine their applicability

主要问题

Feeding Problem

Shrinkage cavity of silt or silty soil cause the stone accumulate in the middle of the course and the stone can not fall to the bottom of the hole

Pile Forming Problem

1. A large amount of soil particle are brought out of ground due to the erosion of high-pressure water
2. Difficulty of pile forming and uncontroing of diameter due to the insufficient surrounding soil pressure



Vibro-BF Application for Silty Soil Layer

BF Solution for Silt Soil Vibroflotation Construction

Feeding Problem:

The stone is directly transported to the pile making position by the bypass pipe of the equipment, and the shrinkage hole in the silt layer will not affect the patency of the falling stone



Pile Foring Problem:

- Dry method of pile forming will not bring soil particle out of ground which make large amount of foundation soil are replaced
- **Suspension method adopting** avoid too big diameter of pile forming, or entire replacement of soft soil

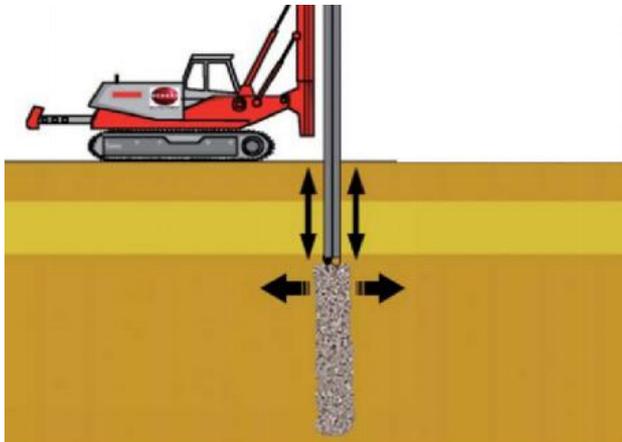




Vibro-BF Application for Silty Soil Layer

BF Suspension Construction Technology

Vibro Suspension Construction Method: In the process of making vibro stone column, the vibroflot is in the state of “hanging in the air” when the lifting equipment is loaded. It does not apply the downward force (reverse thrust force) generated by the dead weight to the bottom soil layer, but directly vibrates and compacts the stone through the vibratory force, and forms the stone column. Suspension Method usually controls the construction quality by packing quantity



In the construction of dry vibro-suspension method, because:

- 1、 Soil particle will not be brought out of ground to make the bore hole larger
- 2、 No excessive lateral extrusion force to make the pile diameter unlimited increase

These make the possibility of stone column making in silt soil and the composite foundation achieving available



Vibro-BF Application for Silty Soil Layer

Suspension Method Theory of BF Construction

Calculate of bearing capacity characteristic value of composite foundation:

$$f_{spk} = mf_{pk} + (1-m)f_{sk}$$

Working process controlling by filling amount

- To avoid limitless replacement of foundation soil
- Garrantee the required pile diameter achiving

To make sure replacement ratio-- m meet the design requirement

Solidifiction acceleration due to the drainage of pile

- The original silt transfer to non-silt soil
- Improved original soil facilitate to improvement of the properties of pile

Solidification of silt soil by drainage of pile significantly increase f_{pk} and f_{sk} value



Vibro-BF Application for Offshore Construction

Problem Existing in Under-water Construction



Against land job

Costly

Low Efficiency



Vibro-BF Application for Offshore Construction

Limitation of Vibro-TF in Under-water Construction

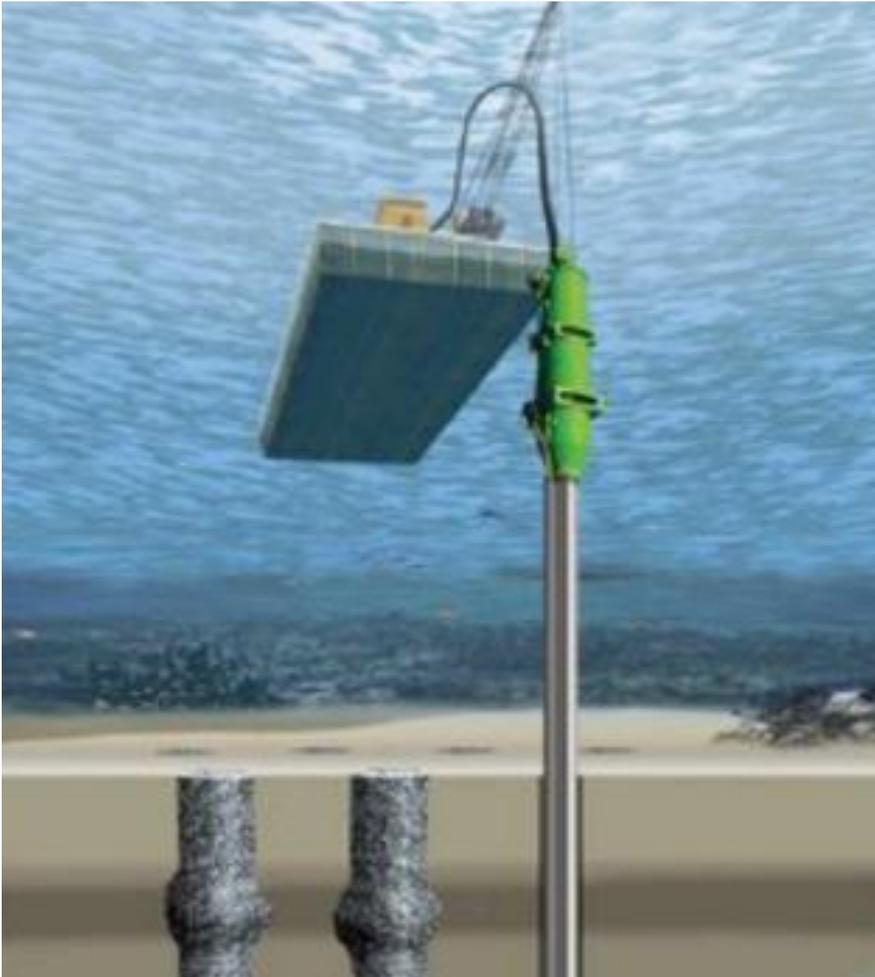
- Difficulty of hole boring
- Complex filling course
- Difficulty of filling amount controlling
- Serious waste of stone
- Difficulty of pile quality controlling
- Low construction efficiency





Vibro-BF Application for Offshore Construction

BF's High efficiency in Offshore Construction



- Both ocean platform and vessel are applicable
- Parallel operation of multiple equipments are available
- Simple construction devices need
- Breaking up the pile formation into parts by feeding stone in batches
- Directly sending stone to bottom of bore hole
- Accurately control the filling amount and diameter
- Small waste of stone
- High efficiency of construction



Vibro-BF Application for Offshore Construction

Case 1: Hongkong-Zhuhai-Macao Bridge Project

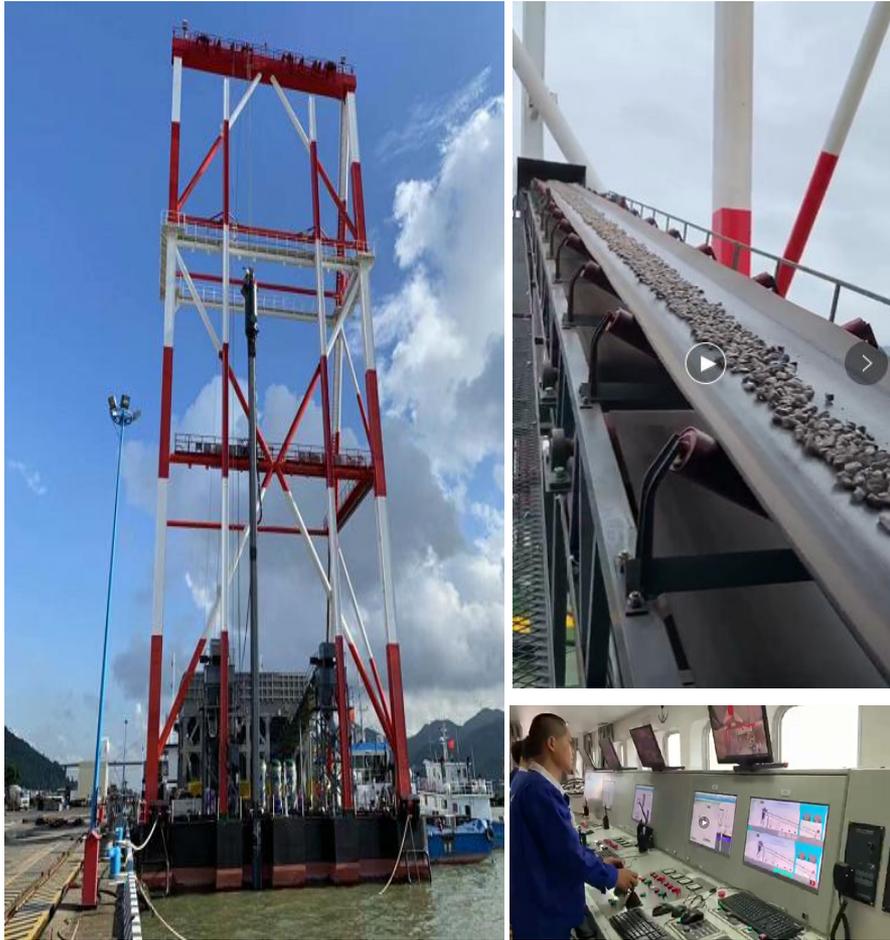


- 5 vessels were applied on which 4 sets of bottom feed vibroflots were parallelly equipped
- According to the average high water level at high tide, the average water depth is 5-14 meters
- The maximum length of pile is 33.5 meters, and the average length of pile is 23 meters
- RTK offshore surveying and positioning system was used to accurately determine the pile position
- Adopted the whole process data recorder system to control construction quality
- The total number of piles is 46,000. with total 1.1 million linear meters



Vibro-BF Application for Offshore Construction

Case 2: Tiba Bay New Container Port Project at Dili, Timor Leste



- The first case to do the vibro-BF construction by using of automatic construction system equipped on vessels
- Two vessels were used, on which 7 sets of bottom vibroflots were parallelly equipped
- The maximum length of pile is 35 meters
- RTK offshore surveying and positioning system was used to accurately determine the pile position
- Adopt the whole process automatic feeding system
- Adopt the whole process data recorder to control the construction quality



Vibro-BF Application for Offshore Construction

Construction Case of Offshore Application: Ashdod Port Project, Israel



- Construction on Ocean platform
- Non-container adopted, stone was sent by belt conveyor and pressure pipeline system





Real-time Diameter Control of Vibro-BF



Accurate measurement of feeding amount



Sending Stone directly to the real-time position

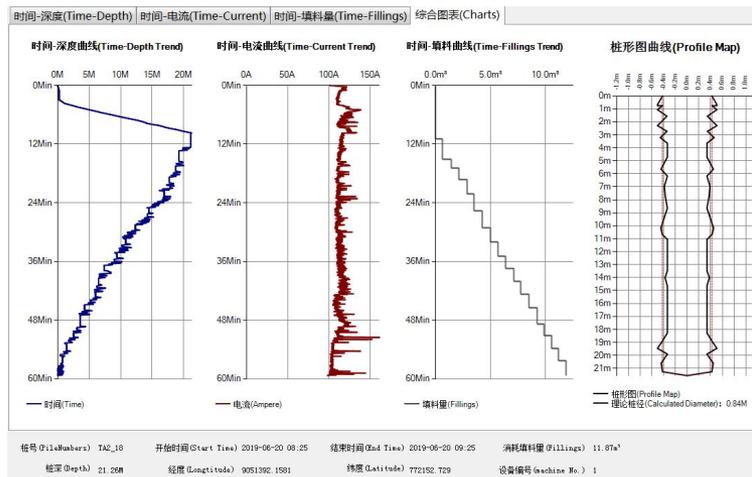
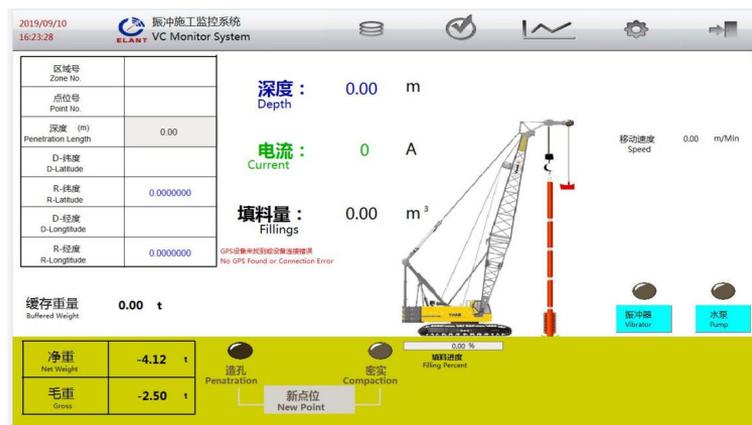


Whole process data record



Data correction for top plie position

Realization of Real-time diameter Controlling





Dry, Water and Water & Air Linkage Application of Vibro BF

Dry, Water and Air & Water Linkage Method of BF Construction



Dry Method:

- Lack of water resource
- Sewage discharge limited
- Dry method specification (no waste of soil particle or less clay bring into pile)



Water Method:

- usable water resource
- Available sewage discharging
- Very hard soil, difficult to penetrate



Air&Water Linkage Method:

- Limited water resource
- Limited sewage discharging
- Specify dry method but soil is very hard to penetrate

With multi-pipe system, the BF equipment can also realize the construction of pulverized stone column and further extend the application scope.



Summarization of Vibro-BF Technology

Characteristics



- ◆ Extend the applicable scope of vibroflotation, Can be used for silt soil improvement, offshore construction, dry method construction and project that require accurately control diameter
- ◆ According to condition, customized equipment can be realized to execute construction under different situation
- ◆ Whole process construction data record and automatic construction can be realized
- ◆ Facilitate to reduce the waste of stone and carry out environmental and green construction
- ◆ Dry, water and linkage of air&water method can be realized
- ◆ Can realize pulverized stone column construction