



Vibro Ground Improvement



Deep vibro techniques present flexible solutions for soil improvement. They are mainly used under foundations of structures that are to be constructed on soils of low bearing capacity or with liquefaction potential.

Keller developed the depth vibrator (patented in 1934), which was originally used to compact granular soils such as sand and gravel.

Today, throughout the world, Keller improves a variety of granular and cohesive soils employing a wide range of depth vibrator models and techniques.

Contents

- 3** Overview of deep vibro techniques
- 4** Vibro Compaction
- 6** Vibro Replacement
- 8** Structural Foundation Elements
- 10** Special Applications
- 11** Quality Control



OVERVIEW OF DEEP VIBRO TECHNIQUES

The subsoil

If the properties of the existing soil cannot fulfil the requirements set by the proposed loading conditions, bearing capacity, lateral stability and earthquake induced liquefaction potential, deep vibro techniques offer an economical solution for the ground improvement. They can be carried out to almost any depth.

The depth vibrator

The cylindrical depth vibrator is typically between 3m and 5m long and weighs approximately 2 tonnes. The core element of the vibrator is an electrically driven eccentric weight which induces the horizontal oscillation of the vibrator. The vibrator string is assembled with the vibrator and extension tubes to suit the improvement depth and suspended from a crane or mounted on a custom built base machine (such as the Keller Vibrocat).

The techniques

The depth vibrator is used for 3 distinct techniques which differ both in their soil improvement and in their load transfer mechanism. The foundation design is therefore frequently developed in close cooperation with both the consultant's geotechnical and structural engineers and Keller.

The **Vibro Compaction** technique compacts granular soils with negligible fines content by rearrangement of the soil particles into a denser state.

The **Vibro Replacement** technique builds load bearing columns made from gravel or crushed stone in cohesive soils and granular soils with high fines content.

The third technique creates **structural foundation elements** in the ground which will allow comparatively high loads to be safely carried by soils where no adequate lateral support for Vibro Replacement columns can be mobilized.

The execution

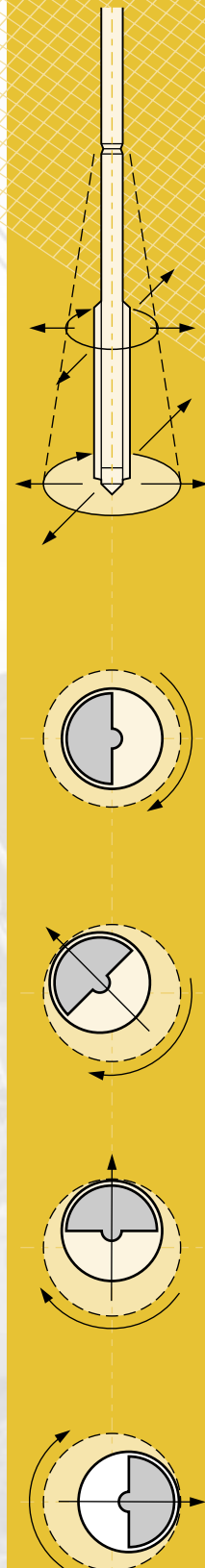
For all techniques the vibro process starts with the penetration of the oscillating vibrator into the ground to the required improvement depth. The soil treatment is carried out on extraction by either compacting the soil or by building a stone column or structural element from the bottom up.

The benefits

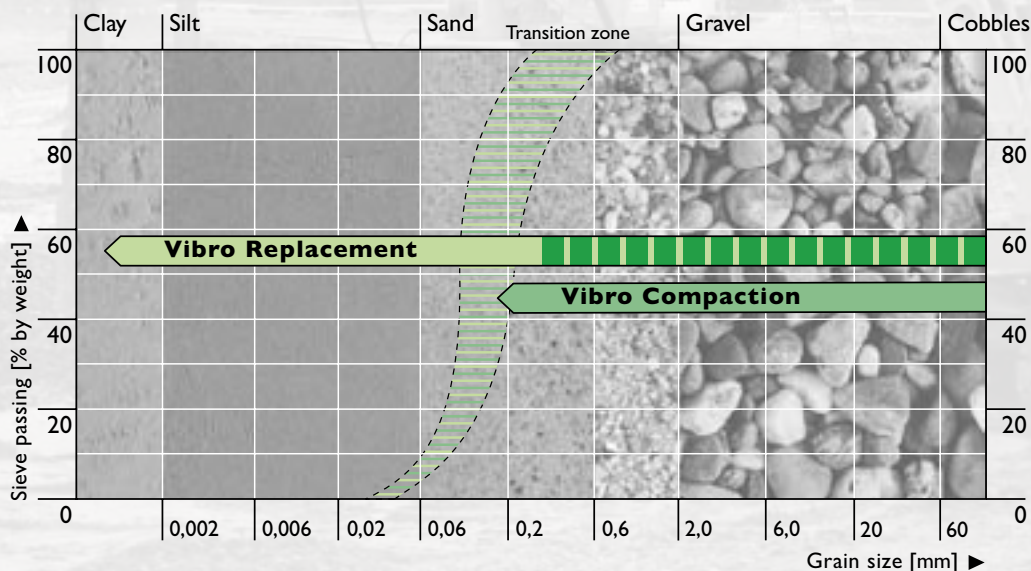
The deep vibro techniques provide a highly versatile ground improvement method that can be adjusted to a wide variety of ground conditions and foundation requirements. Its execution is comparatively fast even if large volumes of soil are to be improved and subsequent structural works can follow quickly. The soil improvement enables the contractor to utilise standard shallow footings or ground bearing slabs which, in turn, leads to additional savings compared to suspended floor options.

Another advantage is the environmental friendliness of the deep vibro techniques, as natural and in situ materials are used and a comparatively small quantity of soil is removed in the process.

The principle of the vibro process



Limits of application for deep vibro techniques



THE VIBRO COMPACTION PROCESS

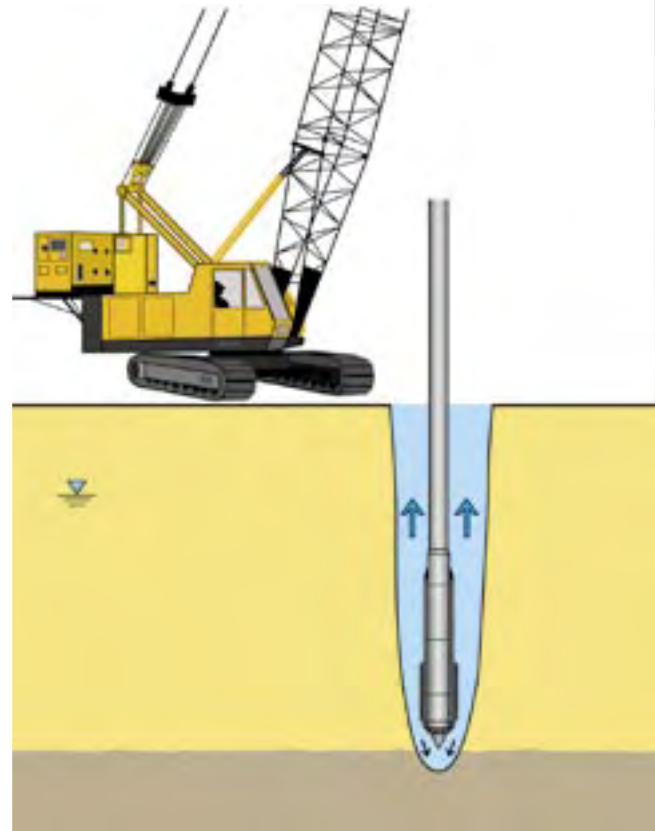
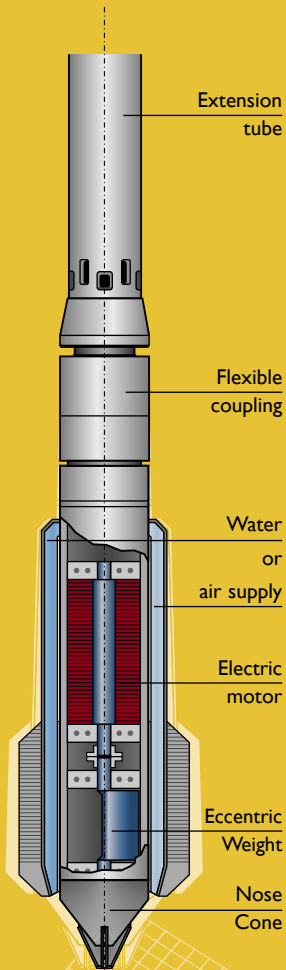
The vibro compaction process is used in granular soils with limited fines content.

Equipment and execution

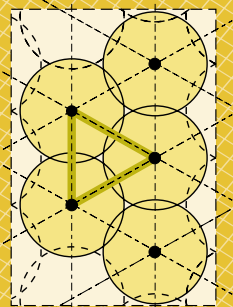
The compaction of granular soils is most economically attained with vibrators oscillating at a comparatively low frequency to achieve optimum compaction of the soil particles. The penetration of the vibrator and, to a certain extent also the compaction process, is aided by water flushing with jets of variable pressure. The pressure pipes and jets form an integral part of the vibrator string. The compaction is carried out from the bottom of penetration upwards in predetermined pull out steps and compaction intervals. The compaction result is dependant on the effectiveness of the vibrator and the soil conditions.

Geotechnical aspects

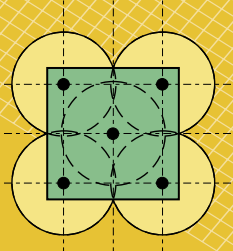
Under the influence of the induced vibration, the soil particles within the zone of influence are rearranged and compacted. The range of this zone depends on the vibrator used, the soil and the method employed. The volume reduction of the compacted soil can reach values in the order of 10% depending on the soil conditions and the intensity of the compaction effort.



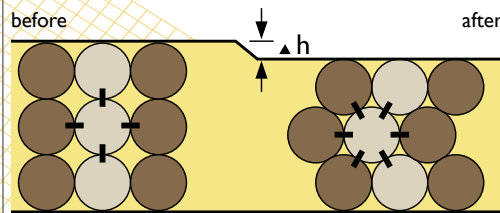
Compaction below raft footings



Compaction below single footings



Density of the soil



The foundation concept

The extent of compaction for an individual point is governed by several parameters. Keller is able to draw upon a wealth of experience to propose a suitable foundation concept. The optimum arrangement of the vibro compaction points is usually best achieved by an on-site trial, where different compaction grids and methods can be tested and evaluated. After compaction, high loads can be safely carried and can reach foundation pressures up to 1MN/m².

I Penetration

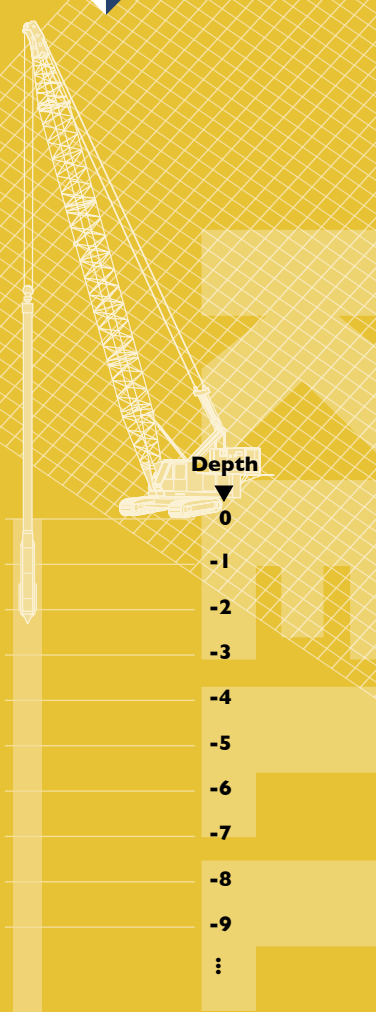
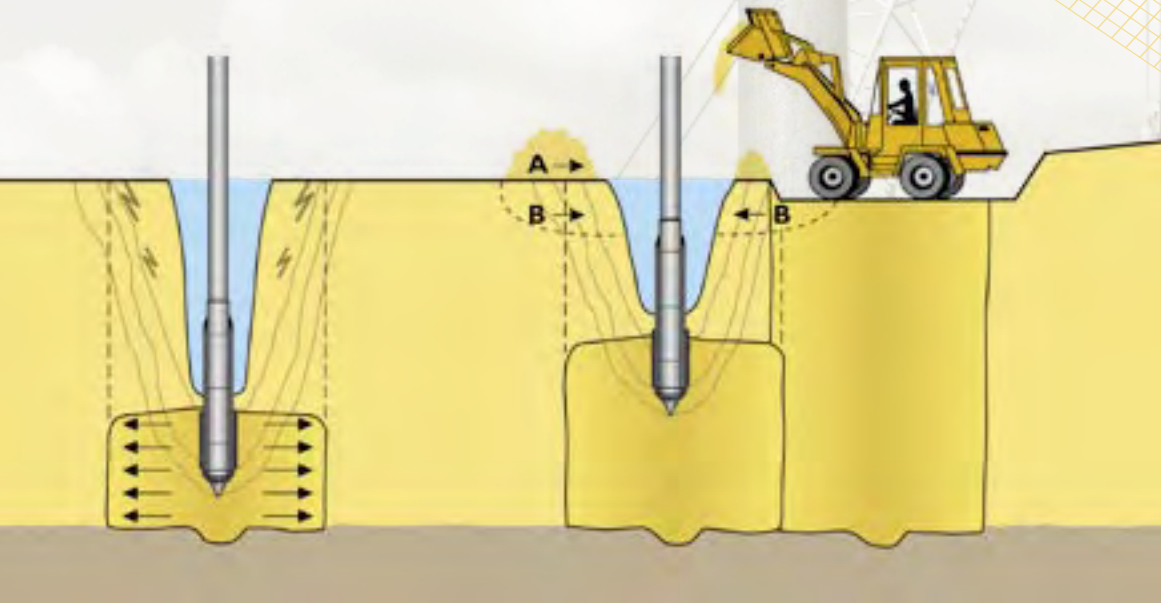
The process

At full water pressure the oscillating vibrator penetrates to the design depth and is surged up and down as necessary to agitate the sand, remove fines and form an annular gap around the vibrator. When at full depth the water flow is reduced or stopped.

The layout of the compactions points can be adjusted in such a manner that soil volumes of any size are compacted.

The achieved degree of compaction can be easily and economically verified using a range of different tests.

Natural or man made deposits of sand and gravel are frequently not dense enough or are too inhomogeneous to allow a proposed structure to be safely and reliably founded. With Keller's depth vibrators the soil density can be increased and homogenized independent of the depth of the groundwater table.



2 Compaction

The compaction is carried out in steps from the maximum depth of penetration upwards. It encompasses a cylindrical soil body of up to 5m diameter. The increase in density is indicated by an increased power consumption of the vibrator.

3 Backfilling

Around the vibrator a crater develops which is backfilled with sand, which is either imported (A) or taken from the existing soil (B). For this purpose a volume of up to 10% of the treated soil volume is required.

4 Finishing

After completion of the compaction, the surface is re-levelled and, if required, compacted with a surface vibratory roller.

As early as 1939 a compaction depth of 35 m was reached on a site in Berlin. Nowadays maximum compaction depths beyond 50m can be achieved.

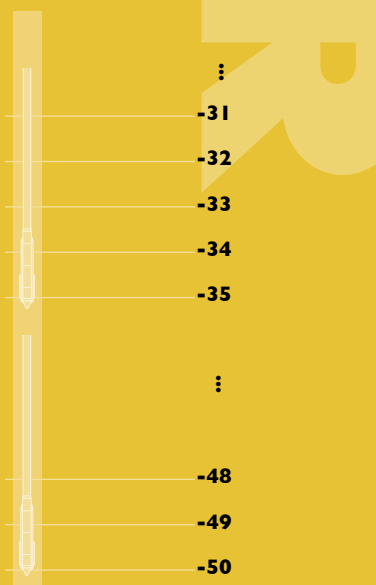


Vibrator in a compaction crater

Special applications

With depth vibrators, slender elements such as dolphins, soil anchors or steel profiles can be sunk into sandy soils and securely anchored.

A further field of application is the densification of wall zones and excavation bases to reduce their permeability.



VIBRO REPLACEMENT

The Vibro Replacement method is used in granular soils with high fines contents and in cohesive soils.

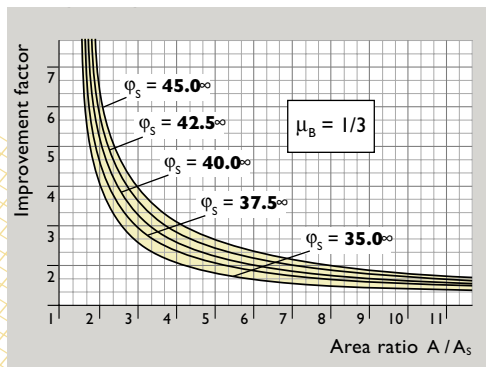
Equipment and execution

For the construction of Vibro Replacement columns the bottom or top feed processes can be employed. The bottom feed method introduces coarse granular material to the tip of the vibrator with the aid of pressurized air. To optimize the performance of this process and to accommodate the specialized equipment, Keller has developed the Vibrocat base unit which guides the vibrator on its leader and allows the exertion of an additional pull-down pressure during penetration and compaction. The Vibro Replacement process consists of alternating steps. During the retraction step, gravel runs from the vibrator tip into the annular space created and is then compacted and pressed into the surrounding soil during the following re-penetration step. In this manner stone columns are created from the bottom up, which act as a composite with the surrounding soil under load.

Geotechnical aspects

The Vibro Replacement process, does not assume any compaction in the surrounding soil. The improvement relies on the higher stiffness and higher shear strength of the stone column.

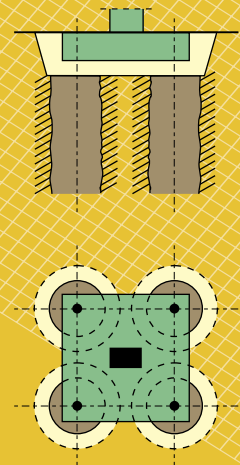
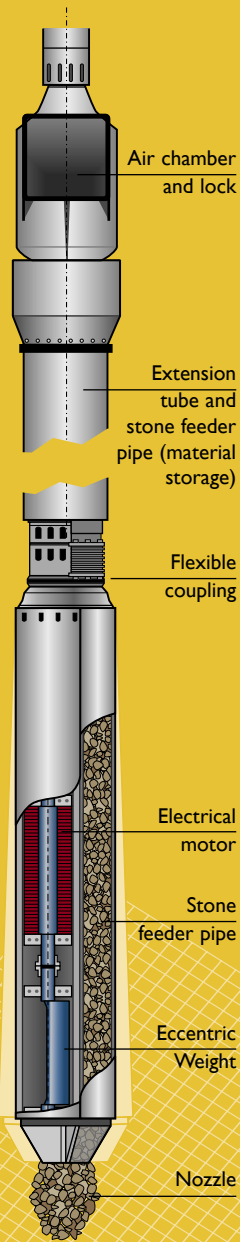
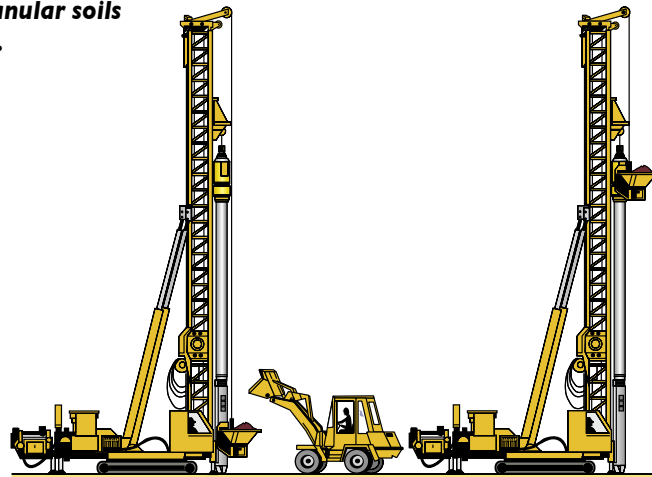
Design diagram for Vibro Replacement



The foundation concept

While the compaction of the surrounding soil can be easily verified by soundings, the improvement effect of the Vibro Replacement can best be checked by in situ load tests. Keller has developed a reliable design method which uses the geometry of the columns and the friction angle of the column material as input parameters.

For the foundation design, the improved ground is treated as a normal subsoil. The allowable bearing pressure that is achieved after the improvement is typically in the range of 150 to 400 kPa.

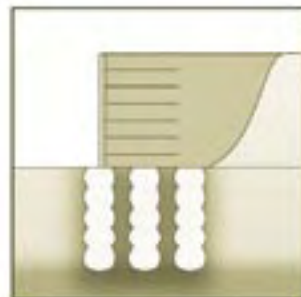
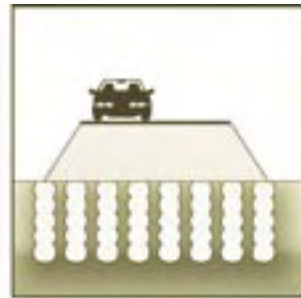


	1 Preparation	2 Charging
The process	The Vibrocat positions the vibrator over the required location of the compaction point and stabilises itself using hydraulic supports. A wheel loader fills the skip with aggregate.	The skip is lifted and empties its contents into the air chamber. Once the air lock is closed, the material flow towards the vibrator tip assisted by pressurized air.

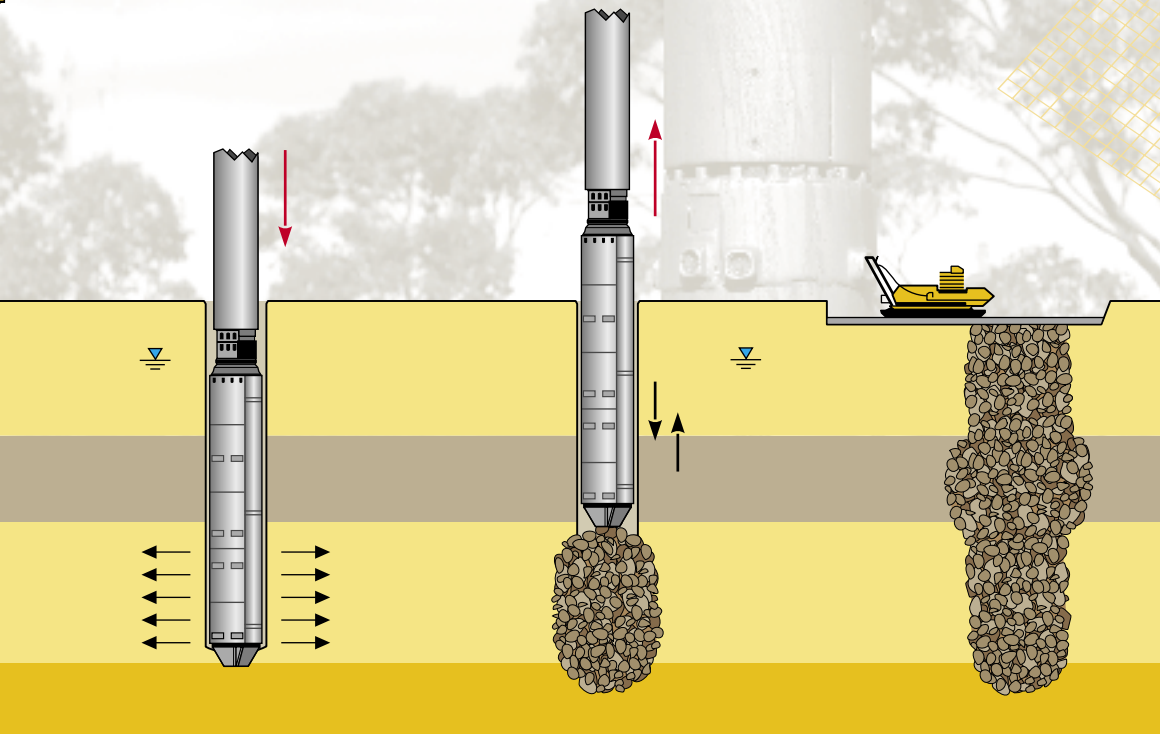
Applications of



View of the cut off level after Vibro Replacement



Mixed grained and fine grained soils frequently do not possess a sufficient bearing capacity. For fines content in excess of 10% to 15% the soils cannot be effectively compacted without the introduction of additional material. For these cases the Vibro Replacement technique is a viable option. This technique is also suitable for the treatment of coarse fills such as rubble, building debris and slag heaps.



3 Penetration

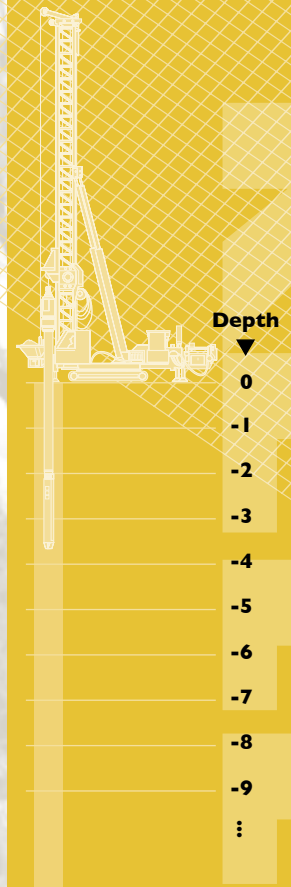
The vibrator displaces the soil and is lowered to the designed depth, aided by the compressed air and by the vibrocat's pull-down.

4 Compaction

After reaching the maximum depth the vibrator is pulled up slightly, causing the aggregate to fill the cavity so created. During re-penetration the aggregate is compacted and pressed into the surrounding soil.

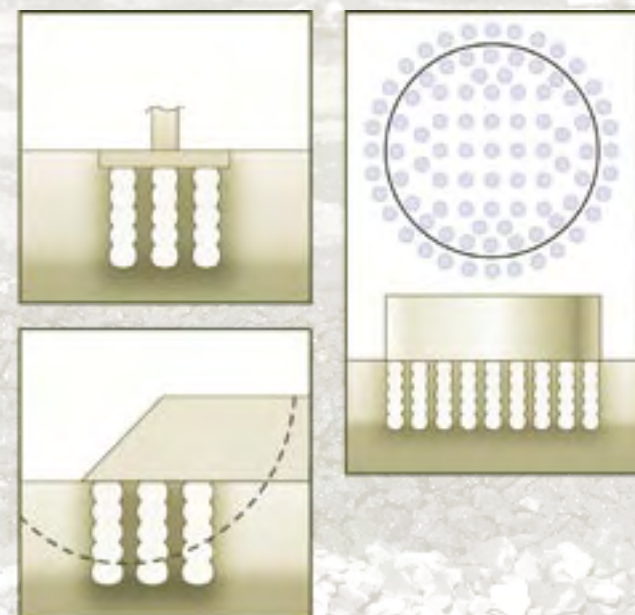
5 Finishing

The stone column is built up in alternating steps up to the designed level. During the final levelling, the surface requires to be re-compacted or alternatively a blinding layer is provided.



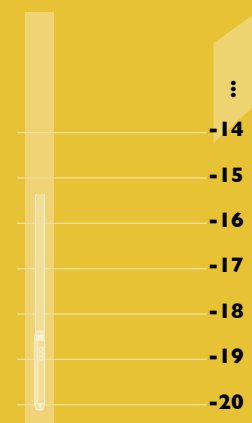
The Vibro Replacement technique was developed in the late 1950s. Without any special modifications the bottom feed setup the vibrocat can install columns up to 20 m depth.

Vibro Replacement



Benefits of working with the bottom feed vibrator:

- The aggregate is always fed directly to the tip of the vibrator, creating a continuous column.
- Only a single penetration is required.
- The collapse of the hole is not possible even in critical soils.
- The leader ensures the verticality of the columns.
- No water is required, eliminating the necessity to dispose of any mud otherwise created.



These methods are generally under high load conditions.

Grouted Stone Columns

Equipment and execution

These foundation elements are built in the same manner as described for the Vibro Replacement process. For grouted stone columns, the gravel is fed into the ground and during the same process mixed in-situ with cement grout, to provide a solid column.

For premixed grouted stone columns, a special coarse grained concrete mix typically ranging between strengths of 15MPa to 20MPa is installed. It behaves identically to the stone material, allowing the same compaction and displacement effects in the surrounding soil.

Geotechnical aspects

The load bearing behaviour of the structural foundation elements is similar to the behaviour of piles.

The foundation concept

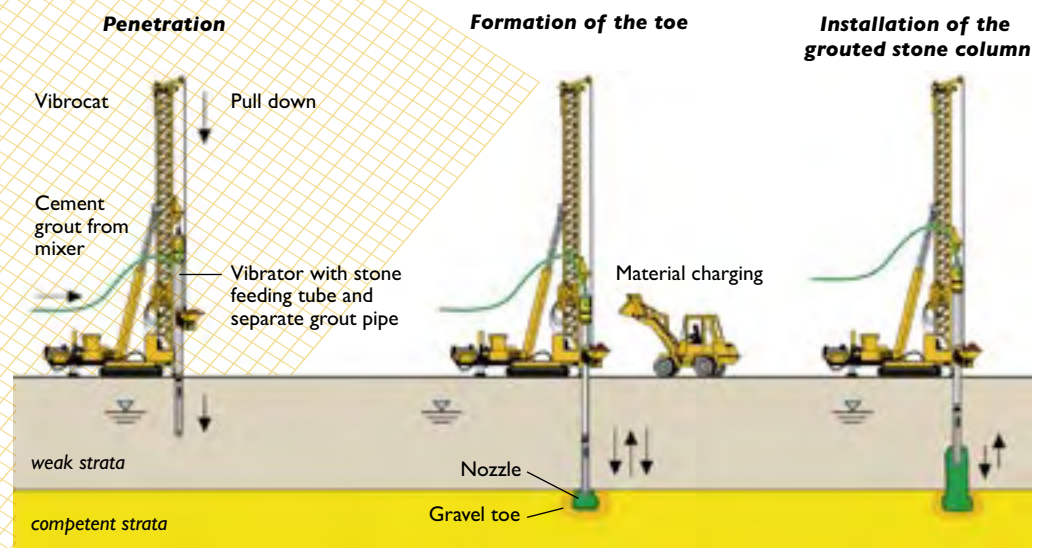
Depending on the soil conditions and the materials used, working loads of up to 600 kN can be achieved. Grouted stone columns can be easily combined with the normal Vibro Replacement method by eliminating the use of grout in the upper or lower section of the column as required, thus creating a buffer for the rigid grouted columns. These columns are called Partially Grouted Stone Columns.



Installation of grouted stone columns with in-situ grouting using cement slurry



Excavated grouted stone column



Vibro Concrete Columns



Excavated Vibro Concrete Columns

Equipment and Execution

Vibro Concrete Columns consist typically of pumpable concrete, grade 25MPa. The toe of the column is enlarged by repeated retraction and re-penetration of the vibrator, however the shaft is built in a single pull due to the high internal strength of the concrete.

Geotechnical aspects

During the installation of Vibro Concrete Columns a high degree of improvement can be achieved at the toe of the column, thus attaining a particularly high capacity and low deformations under load.

The foundation concept

Vibro Concrete Columns are generally more slender compared to other structural foundation elements. Typical shaft diameters range between 40 cm and 60cm. The capacity under working load reaches up to 800kN depending on the ground conditions and on the possibility to enlarge the toe.



Installation of Vibro Concrete Columns

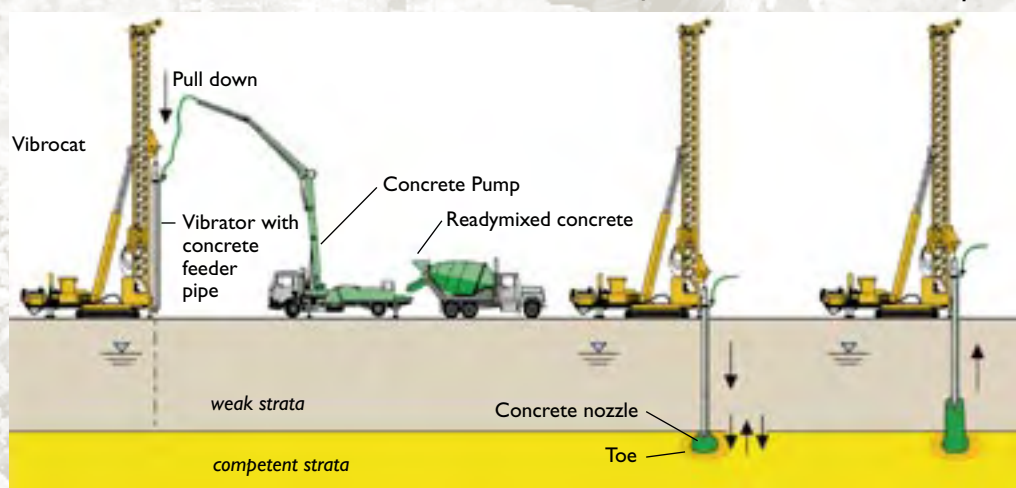


Cross Section of a Vibro Concrete Column

Preparation

Penetration and toe formation

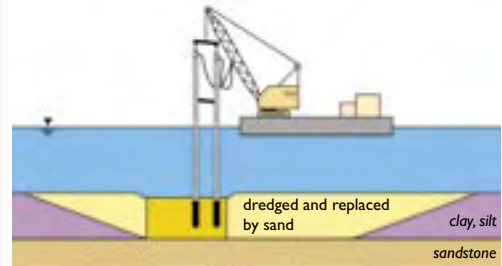
Installation of the shaft





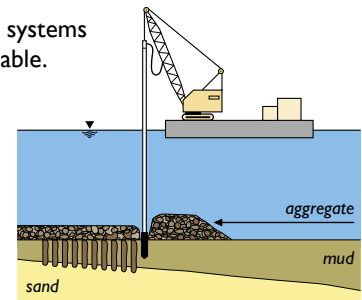
Multiple Vibrators and Offshore Compaction

Vibro Compaction of large areas both onshore and offshore can be carried out with multiple vibrator assemblies.



For Vibro Replacement offshore, such as for quay walls and bridge pillars, a gravel blanket can be placed which is then installed into the ground.

Bottom feed systems are also available.



Vibro Replacement – Top Feed Method

In suitable ground conditions the Vibro Replacement process can be performed using crane hung vibrators similar to the Vibro Compaction setup. In this case water or air flushing is used. The flushing medium assists rapid penetration into the ground and stabilizes the annular around the vibrator. It also can be used to increase the column diameter by flushing.



For all vibro techniques, electronic measuring devices are employed to ensure and record constant high quality workmanship.

The measuring device

To control the process, monitor the quality and for production records, the relevant construction parameters for each compaction probe can be measured, saved and printed as proof of production and quantities.

The measurement device consists of

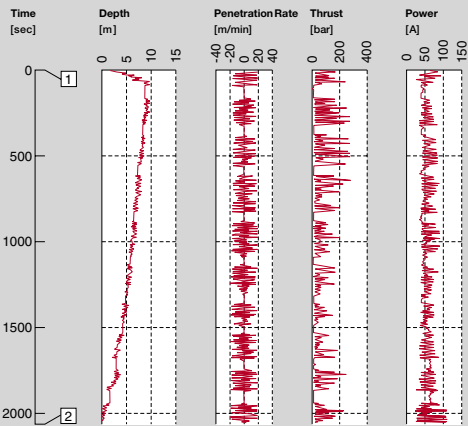
- The display unit in the operator's cabin,
- The CPU with data storage,
- PC with printer at the site office,
- Printer mounted on the base unit for real time printout (optional).



Display unit and CPU of the M4 measuring device



Process:	Vibration Process (3.0.0)					 Dep.: Consulting and Development
Inventory:	9130517	Site:	1234173	Ref. No.:	15	
Lot:	0	Point:	241	Interval:	4 sek	
Date:	15.09.04	Time:	05:10:47			
Weight:	1.5 kN/m ³					
Legend:						



Event No.	Type	Description	Time hh:mm:ss	Depth [m]	Electrical Energy [kWh]	Susp. Point [cbm]	Net Weight [Ton]	Total Weight [Ton]	Inclination Right/Left [Deg]	Inclination For/Back [Deg]
01	09	Point Start	05:10:47	0.1	0.00	0.00	2.98	2.98	-0.2	+0.3
02	10	Point End	05:45:08	0.1	21.03	0.00	2.79	5.77	-0.4	+0.2

Total Time:	34.33 min	Max. depth:	10.00 m	Rel. weight:	0.58 Ton/m
--------------------	-----------	--------------------	---------	---------------------	------------

The measurement results

During compaction a number of different site and production parameters are automatically recorded. Values such as time, depth, penetration/pullout speed, pull-down force and current drawn can be graphically displayed and printed.



Load tests are a suitable option to verify the improvement of the soil





**Keller
Ground
Engineering
Pty Ltd**

**AUSTRALIA
NEW ZEALAND
PACIFIC ISLANDS
INDONESIA**

Enquiries to:
PO Box 7974
Baulkham Hills NSW 1755

Level 1, 4 Burbank Place
Baulkham Hills NSW 2153
Australia
t: (02) 8866 1155
f: (02) 8866 1151
e: info@kellerge.com.au