Sample Chapter

Special Deep Foundation – Compendium Volume II
Methods and Equipment – Drilling rigs and duty cycle crawler cranes
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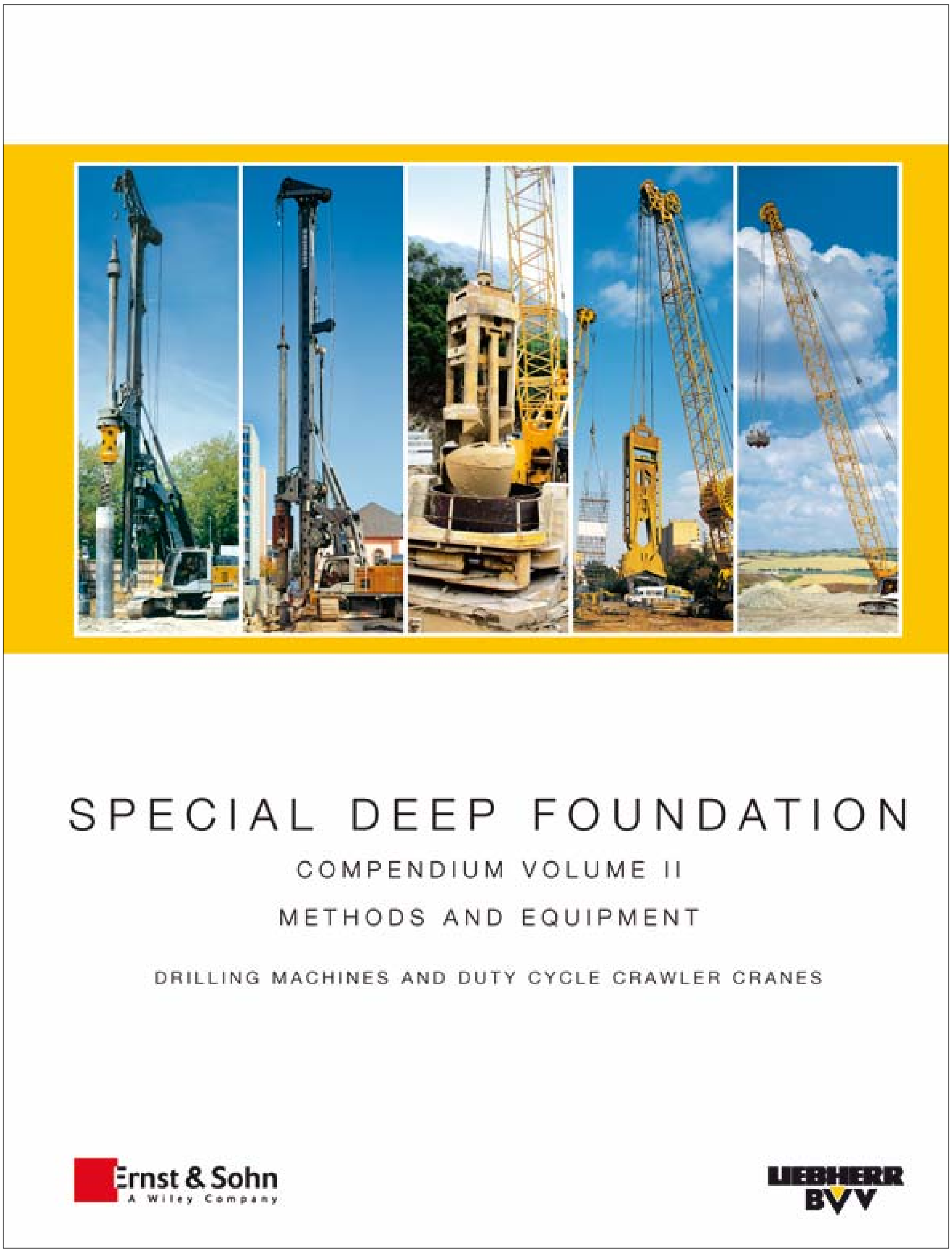

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Kelly drilling

1 General

Kelly drilling is a dry rotary drilling method for producing large diameter boreholes (minimum approx. 50 cm).
It is the most widely spread large diameter drilling method in special deep foundation. Using this method, cased and uncased drilling is carried out.

Thanks to their special torsion-resistant leaders the Liebherr LB drilling rigs are especially well suited for this method as high rotary forces (torques) can be applied to the drilling tool.

Kelly drilling is exclusively used for producing large diameter boreholes by rotary drilling, namely for the following applications (products):

- large diameter drilled piles
- boreholes for installing steel beam profiles and steel pipes
- boreholes for sand and gravel piles
- soil exchange drilling
- well drilling

The method gets its name from the use of a specially designed drilling rod, the **"Kelly bar"**. This is a specially moulded, multiple telescopic drilling rod, with the help of which the rotary movement (torque) of a **rotary drive** (single rotary drive) and the vertical movement and/or the crowd (crowd force) can be transferred to the drilling tool.

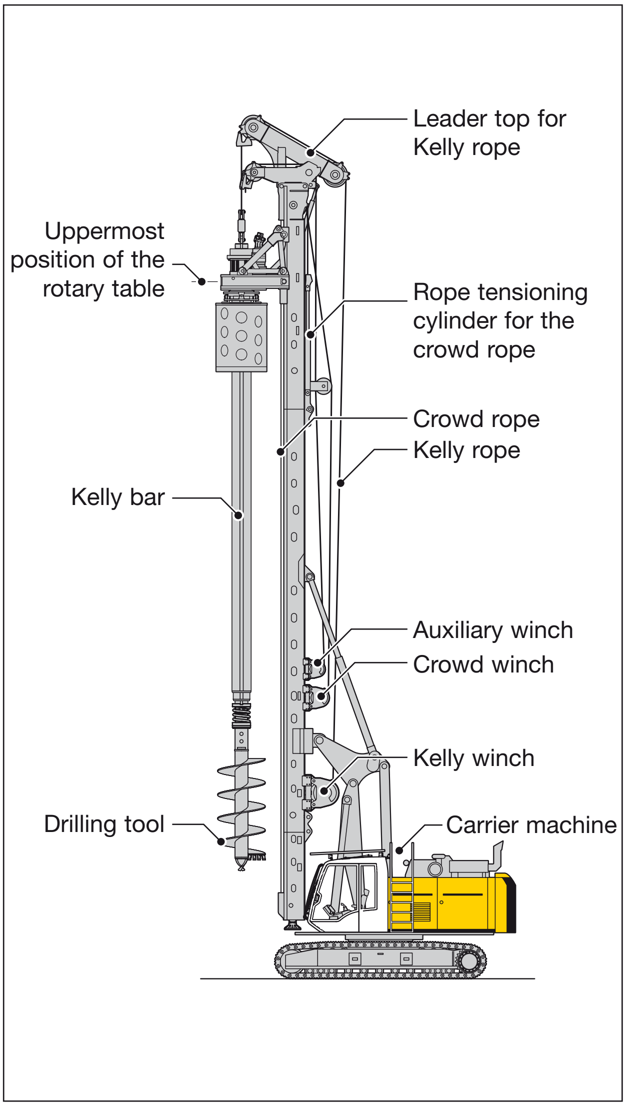
The rotary drive is fixed to a **rotary table (guide carriage)**, which is mounted on a **leader (drilling mast, drilling leader)** and can be slid vertically. This leader is firmly attached to the carrier machine. The carriage with the rotary drive is either pulled down by **rope crowd** or by a hydraulic crowd cylinder **(cylinder crowd)**.

Kelly drilling

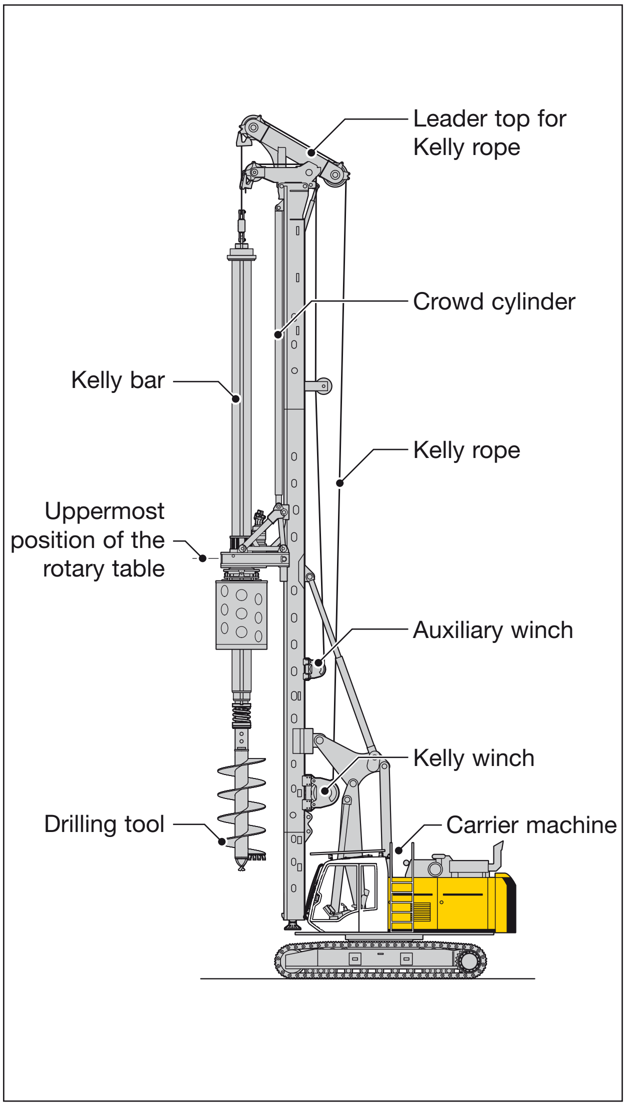
The Kelly bar is suspended on the **Kelly rope** which leads to a separate winch, the **Kelly winch**, via a short jib **(leader top for Kelly rope)**. The Kelly bar is always suspended on the Kelly rope via a swivel **(Kelly swivel)**.

The number of telescopic sections and the individual lengths of the Kelly bars determine the drilling depths that can be achieved with this method. Kelly bars may be 2-fold, 3-fold or 4-fold telescopic and drilling depths of more than 70 m can be achieved using them. When determining the drilling depth, the length (height) of the drilling tool as well as the lowest possible position of the rotary drive on the leader has to be taken into account.

Drilling tool with rope crowd



Drilling tool with cylinder crowd



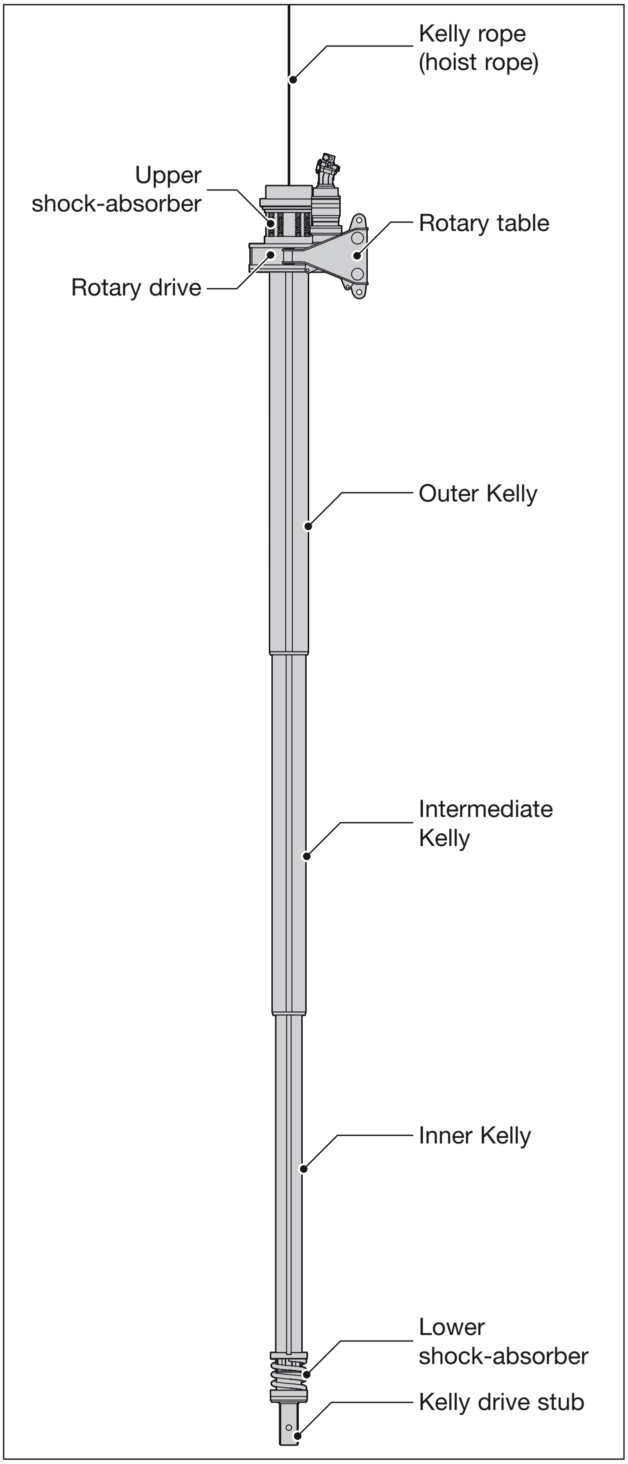
Kelly drilling

2 The Kelly bar

The Kelly drilling rod, which is also simply called Kelly bar or **Kelly**, consists of several, i.e. two to four, drilling rods inserted into each other. On the outside, these rods are fitted with continuous drive cams for torque transmission. Moreover, the drive cams are equipped with notches, serving to lock the rods against each other longitudinally and thus providing the transmission of the down-crowd force. Longitudinal locking of the drilling rods can be done with the single bars either retracted or extended. Thus, torque and crowd force are transferred with positive locking as with one single rigid drilling rig.

If a Kelly bar consists of three drilling rods inserted into each other, this is called a 3-fold Kelly bar. Such a “3-fold Kelly“ consists of three drilling rods, an “outer Kelly“, an “intermediate Kelly“ and an “inner Kelly“, which can be extended or retracted into each other.

Principle of the Kelly bars (e.g. 3-fold Kelly, extended)



Kelly drilling

When rigging-up the drilling rig the set of locked drilling rods, which are inserted into each other, is introduced into the rotary drive from above. Thereby, the hoist rope is fixed to the upper end of the inner Kelly via a special rope swivel, the Kelly swivel. The drive cams of the outer Kelly are fitted to the corresponding notches in the rotary drive.

Thus, the outer Kelly is inserted in the rotary drive and firmly locked with it at its upper end. In this way the rotary force can be transferred to the Kelly bar via the rotary drive and the crowd force via the rotary table.

The lower end of the inner Kelly is formed as square (connector square). This **“Kelly drive stub”** is slid into the **“Kelly box”** (a square bucket) which is situated at the upper end of the actual rotary drilling tool. It is secured with a pin and a safety catch. Thus, the force for the rotation and the force for the crowd can be transmitted from the Kelly bar to the drilling tool.

The vertical crowd force and/or pull force is either transmitted via line pull of the crowd winch and/or the pull winch or by a hydraulic crowd cylinder mounted on the leader.

During the process of lowering, the drilling rods, which have so far been inserted into each other, start to telescope as soon as the outer drilling rod contacts the rotary drive.

The impact of Kelly bars that might fall through is cushioned by a spring shock absorber at the upper end of the outer bar, by a shock absorber at the rotary drive or by rubber buffers and springs at the upper and lower end of the Kelly bar.

Kelly drilling

3 Kelly drilling

3.1 Drilling with outer casing (cased drilling)

Cased drilling is always required when the penetrated soil is not stable enough even when using a support fluid and if there is a danger of the borehole walls even partially caving in. Borehole casings are also used in order to limit the unavoidable breaking up of the soil around the borehole resulting from the drilling process (see also description under “Drilled pile”).

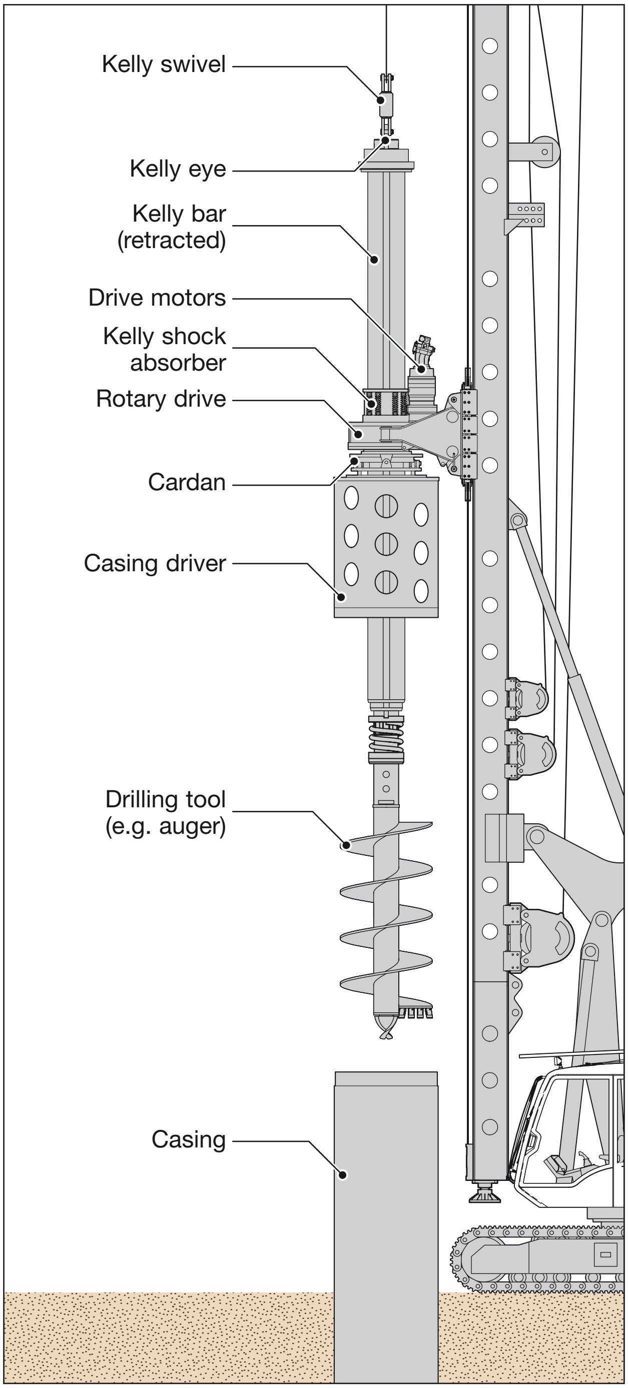
Installation of the casing (drill casing) is carried out directly with the rotary drive via a connecting element to the drill casings which is also called **casing driver**, **casing drive adapter** or **adapter plate**. This casing driver is a pipe - mostly with openings – with a diameter fitting the casings and which can be connected to the rotary drive and to the drill casings.

The process of cased Kelly drilling includes the following steps (see illustration of phases **1-10** on the following pages):

The first casing section with the cutting shoe at its lower end is connected to the casing driver and drilled into the ground until it is stable (**1**).

Another drill casing is connected to the first one with positive and friction locking and this casing section is drilled into the ground as deeply as possible. Next, the connection between drill casings and rotary drive is released and the emptying process starts. The drilling tool, a drilling auger or bucket, which is already mounted on the Kelly bar, is drilled into the soil within the casing using crowd and rotary drive and thus fills with ground material. Then the drilling tool is lifted again with the Kelly bar and emptied (**2**).

Rotary drive



Kelly drilling

This process is repeated as often as necessary before the next casing section is positioned and installed. In doing so it is important to observe that the casing is always deeper than the drilling tool in order to avoid breaking up of the soil below the casings (**3**).

After reaching the drilling depth corresponding to the first Kelly section, another casing section is positioned and drilled into the ground as deeply as possible (**4**).

Subsequently, the connection between casings and rotary drive is released again and the second Kelly section is extended as the rotary table simultaneously travels upwards (**5**).

When the drilling tool is in the casing, retracting and extending of the Kelly bar is effected with the rope of the Kelly winch. The whole telescoping process is controlled through this winch and by alternate turning of the inner Kelly bar to the right and left. The described processes (positioning of casing sections, installing, emptying, telescoping) are repeated until the projected drilling depth is reached (**6** to **10**).

Finally, the bottom of the borehole has to be cleaned using a drilling bucket (see description in chapter A, Drilled pile).

Thereafter, the designated fill material or structural element is inserted into the cased borehole.

For instance, when producing a pile the reinforcement and concrete are introduced into the casing.

The extraction of the casing is carried out step by step – one section after the other - using the casing driver, mostly by simultaneous oscillating and pulling.

Kelly drilling

Kelly drilling illustrated by cased drilling

1

Positioning and inserting of the first drill casing

2

Fitting the second drill casing, emptying it by drilling and removing the excavated spoil to the side (several times)

3

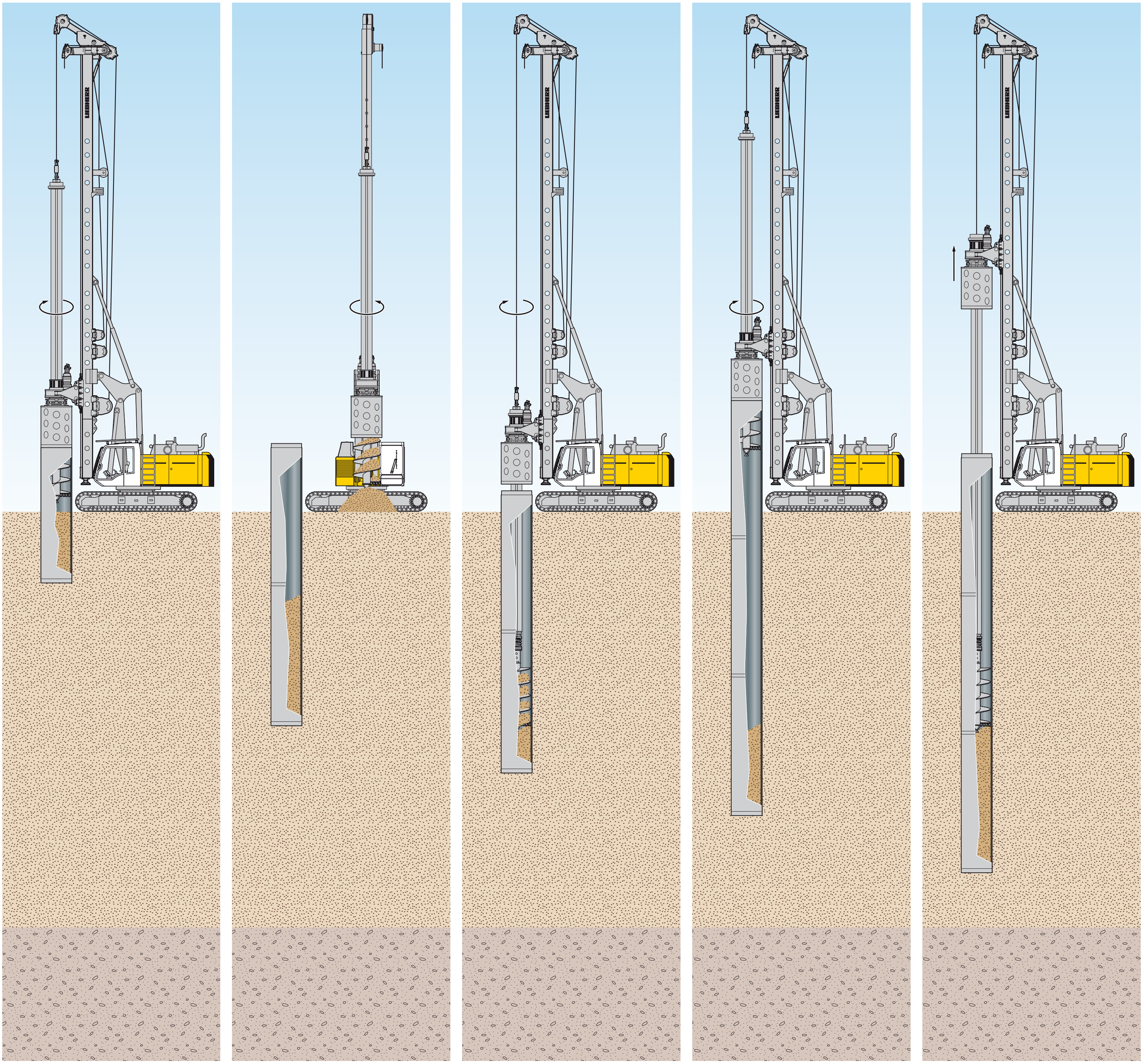
Drilling down until end of section 1

4

Inserting another casing

5

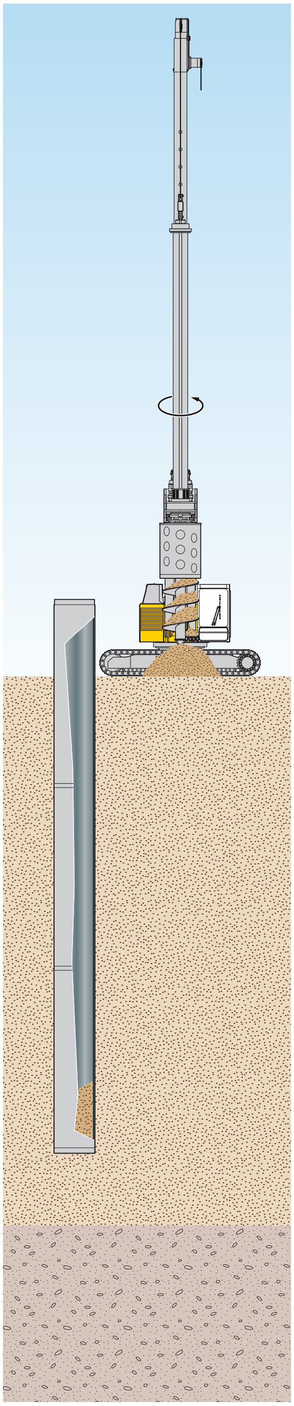
Extending section 2



Kelly drilling

6

Emptying by drilling, retracting the Kelly bar and removing the excavated spoil to the side (several times)



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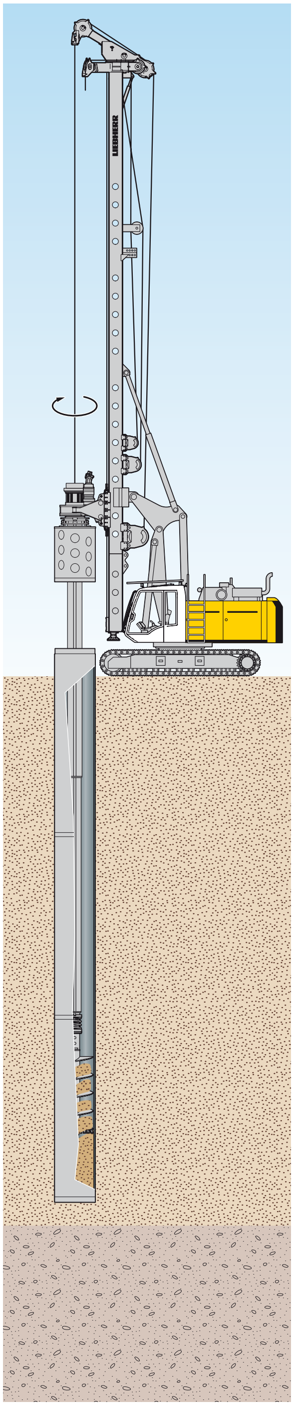
Drilling down until end of section 2



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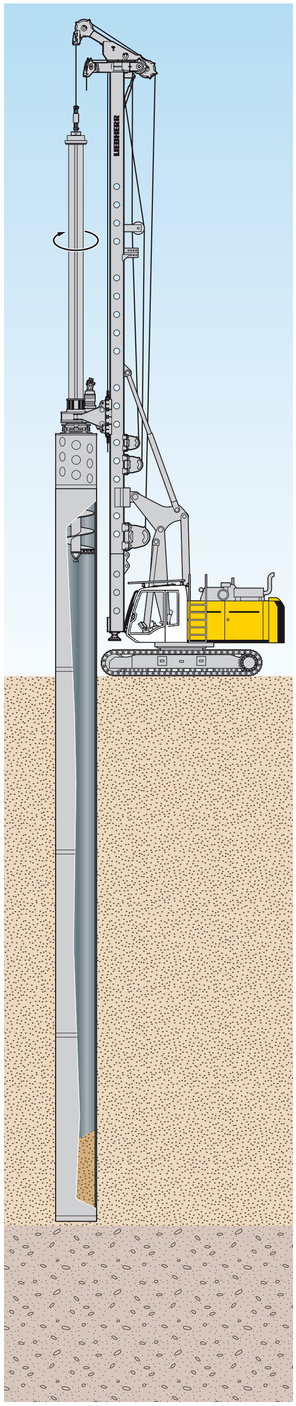
Fitting and inserting further casings



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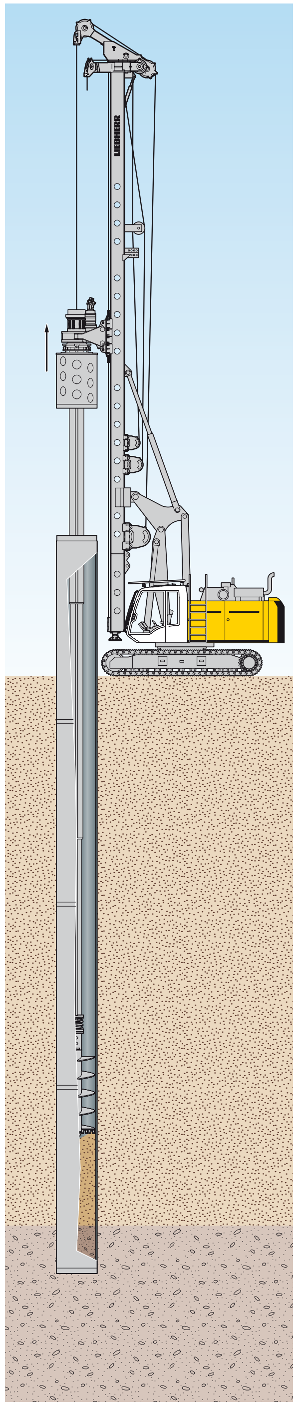
Extending section 3



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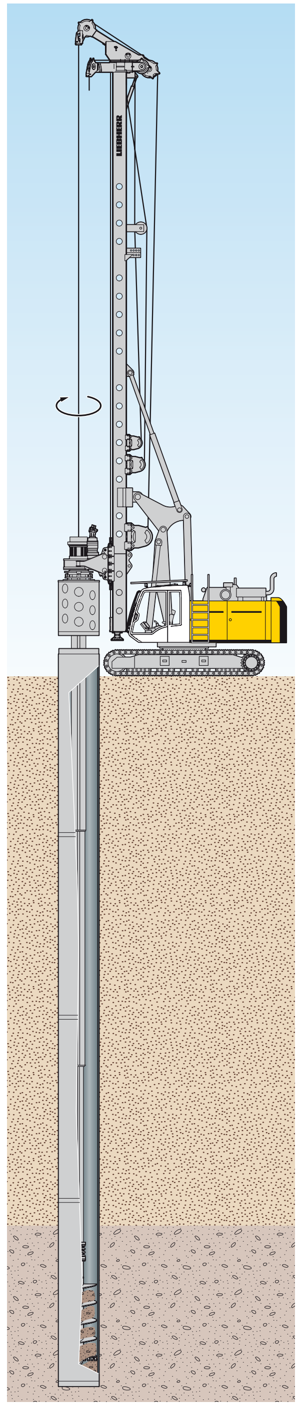
Drilling down to final depth (by repeatedly installing the casings and emptying them)



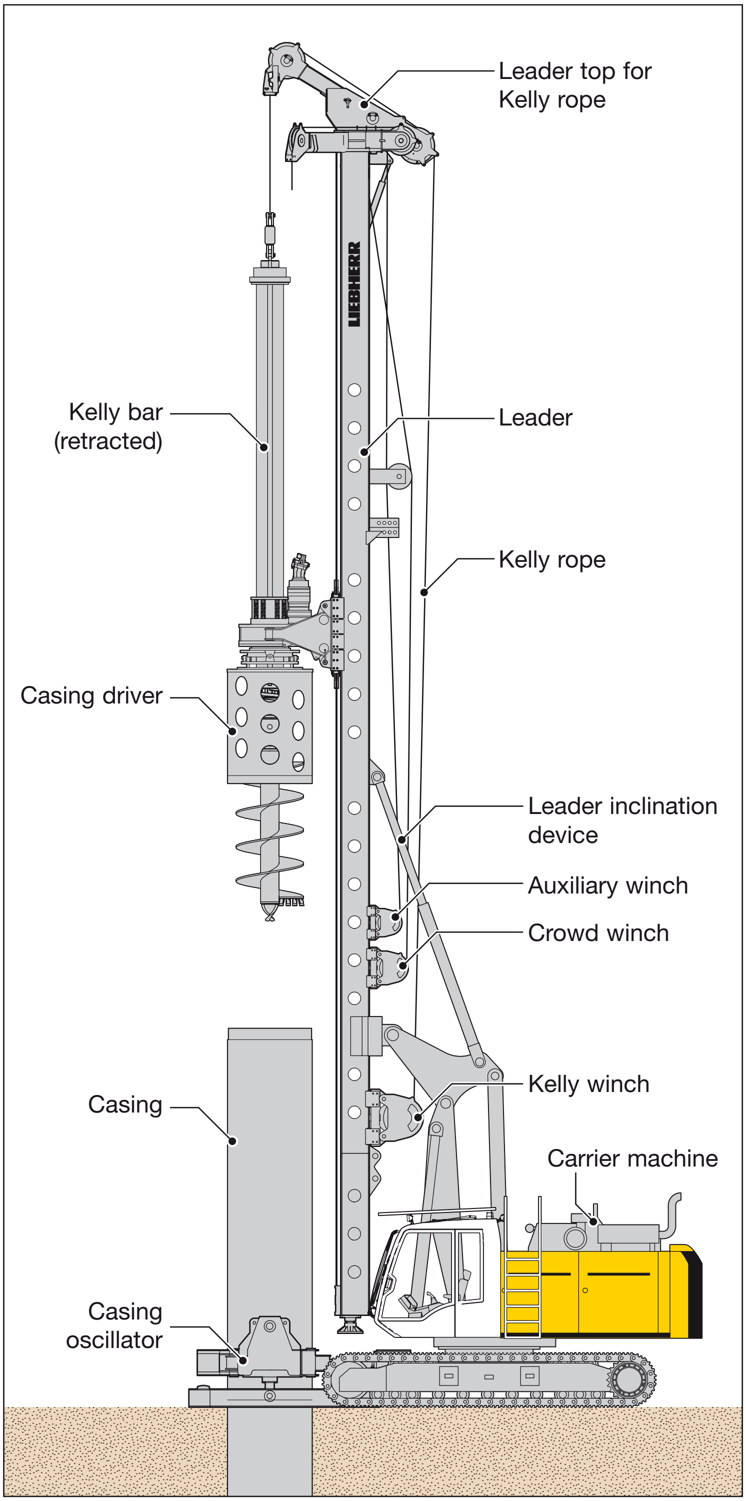
3.2 Drilling with outer casing and casing oscillator

In special situations the installation of the casings may require the additional use of a **casing oscillator**. This is the case if the torque of the rotary drive and the crowd force are not sufficient to overcome the skin friction between casing and soil, or if the casing cannot be extracted using only the rig's pull force. This can be due to the soil conditions, the drilling depth or the large drilling diameter.
The casing oscillator is able to hold the casings and to install and extract them again by turning.

An important precondition is that the casing oscillator has to be firmly mounted on the carrier machine.

The casing oscillator is usually positioned on the working level exactly at right angles to the drilling axis. For raked boreholes it is therefore required to create a raked plane. The casing oscillator encloses and clamps the casing projecting above the ground. A clamping collar and hydraulic locking cylinders are clamped round the whole circumference of the casing. This clamping collar can be turned alternately to the left and right by two hydraulic cylinders (oscillation cylinders) acting at an angle, while two vertical hydraulic cylinders (hoist cylinders) can press the whole clamping and turning equipment up or down. In this way the casings are installed by simultaneous turning to the left and right (oscillating) and pressing down.

Kelly drilling system with casing oscillator

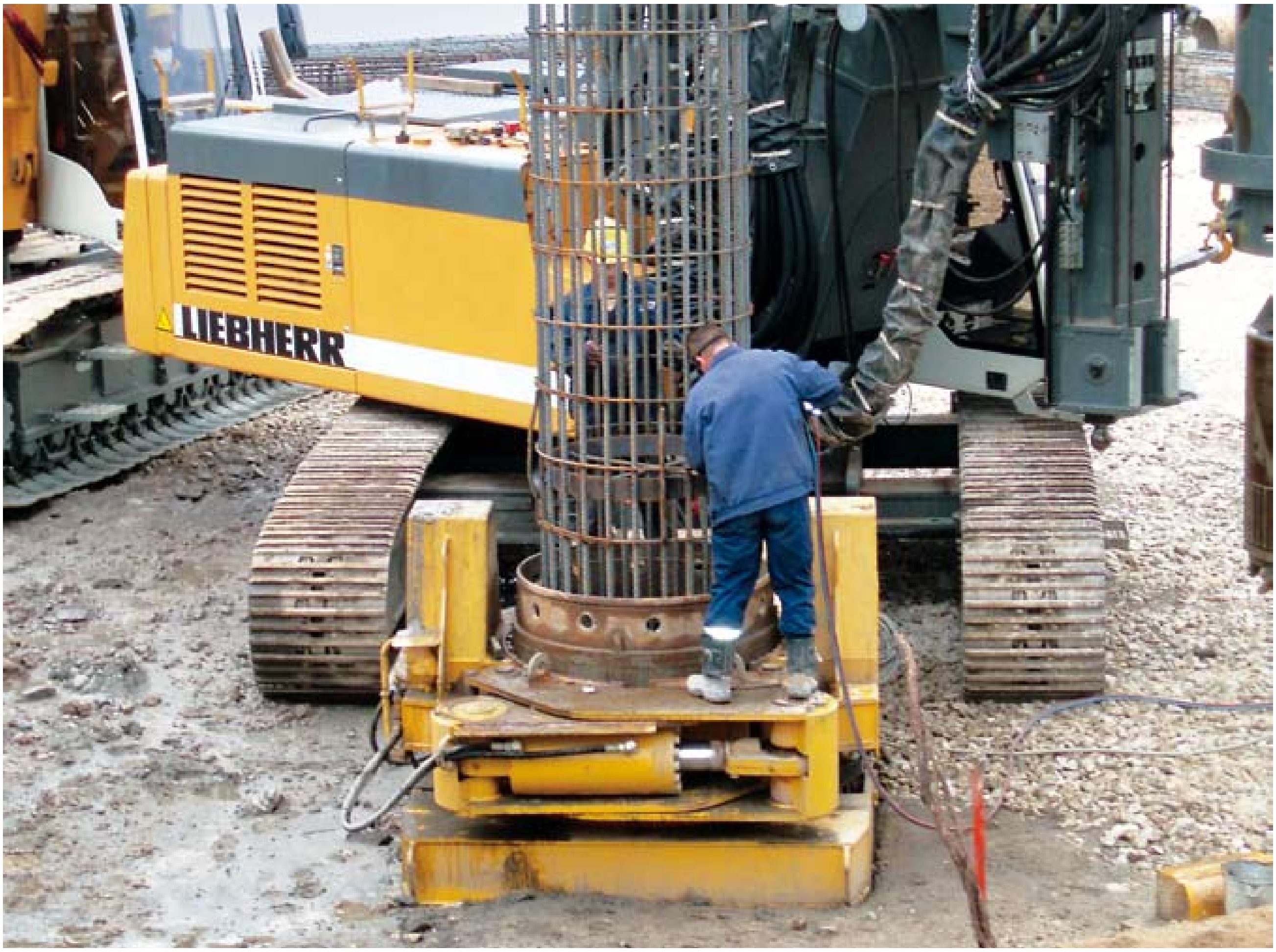


Kelly drilling

The casing oscillator is driven directly from the hydraulic system of the carrier machine. Thus, it is possible to simultaneously operate the rotary drive and the casing oscillator, allowing for synchronous drilling and casing installation. When combined with the Kelly drilling method the rotary drive of the rig is mainly used for rotating the drilling tool with the Kelly bar.

The drilling process for emptying the casings is carried out in the same way as for cased drilling without casing oscillator.

Casing oscillator at work



3.3 Drilling without outer casing (uncased drilling)

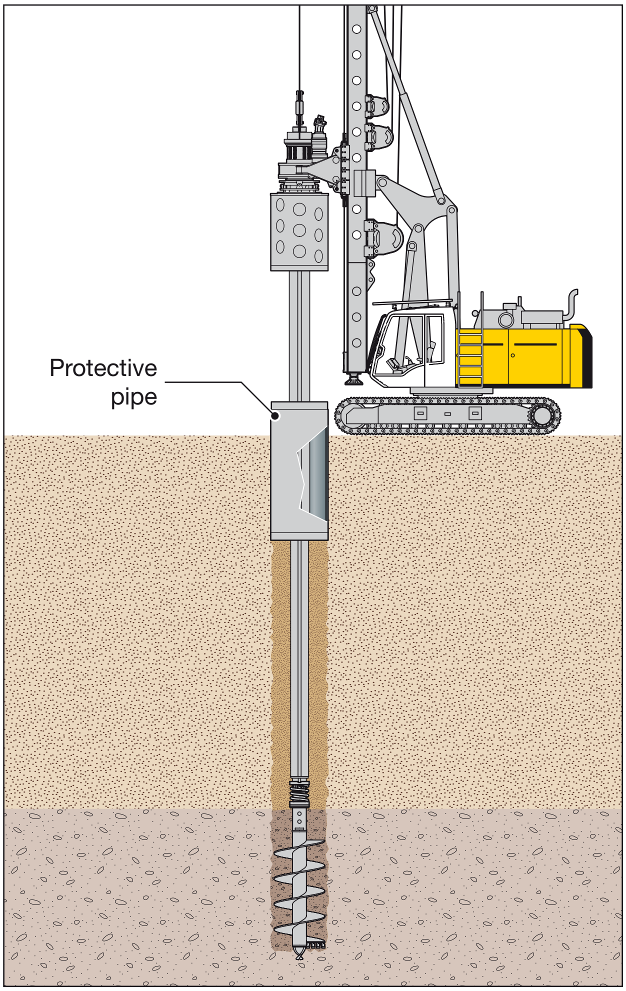
With suitable soil conditions the Kelly drilling method can also be applied for the production of uncased boreholes. The most frequently used drilling tools are a short auger and/or a drilling bucket. The application of a core barrel and a roller bit (e.g. in rock) is also possible.

a) Drilling without support fluid

For drilling without support fluid, the soil must be free of water, the borehole must be stable throughout its entire length and it must be certain that there is no danger of the borehole wall even partially caving in. Raked boreholes should on no account be produced without a continuous casing.

The upper part of the borehole must be secured with a protective pipe of at least 2 m length. Its purpose is to guide the drilling tool during insertion and extraction as well as to secure the borehole against possible caving in caused by any outside influences of the drilling work.

The drilling process is carried out in the same way as with cased drilling.



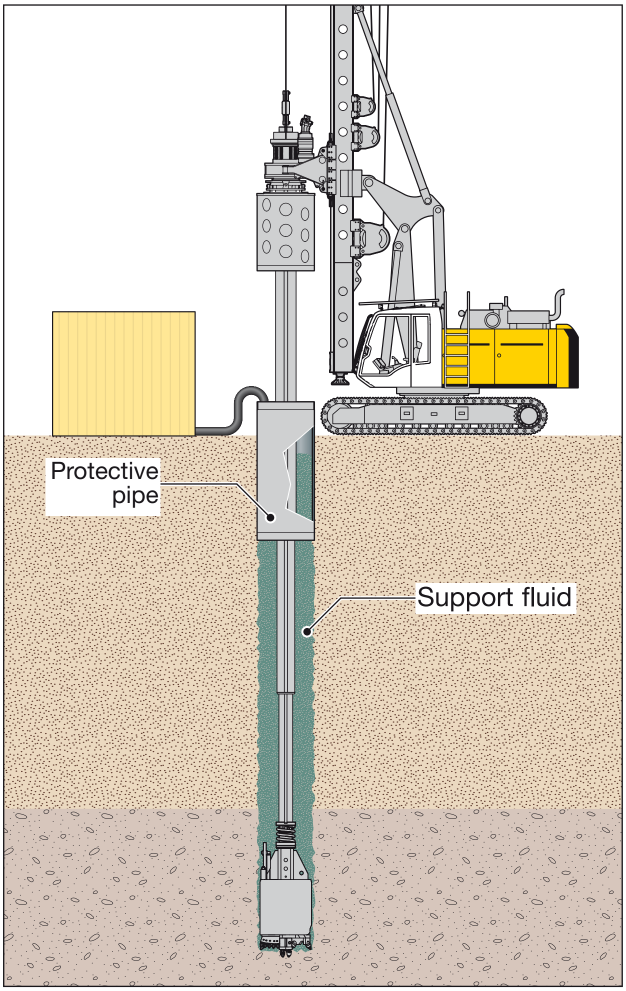
b) Drilling with support fluid

Another variant of Kelly drilling without borehole casing is drilling with a borehole supported by fluid. The upper part of the borehole must be secured with a protective pipe of at least 2 m length.

This method secures the borehole wall in unstable soil layers against caving in through excess fluid pressure. The support fluid generally used is a clay or bentonite suspension or a polymer suspension. It is important to observe that during the whole drilling process and also during installation, of e.g. concrete (when producing a pile), the level of support fluid in the borehole never sinks below the lower edge of the protective pipe.

The support fluid emerging up again when pumping in concrete or inserting another installation material has to be pumped off. It is either harmlessly disposed of or, most often, delivered to a regeneration plant where it is recycled to be reused.

Regarding its composition, the clay or bentonite suspension equates to the support fluid used during the production of cast-in-place slurry walls. Detailed data hereto can be found, among others, in the German standard DIN 4126 (EN 1538). See also the description in the chapters “Slurry wall installation“ and Slurry wall (K).



Kelly drilling

4 Advantages of the Kelly drilling method

- The telescopic Kelly bar allows for great drilling depths with limited leader height without extension of the drilling rod.
- The borehole wall can be supported with drill casings or with support fluid.
- With borehole casing, the process can be carried out in virtually any soil.
- Very flexible adaptation to various soil conditions through the use of various drilling tools.
- Quick and simple change of the drilling tool thanks to standardised connections.
- Possible application in all soil types, including rock.
- When using special drilling tools obstacles of any kind, even wood, reinforced concrete and steel can be penetrated.



Kelly drilling

5 Application limits

The limits arise on the one hand from the maximum possible drilling depths that can be achieved with the drilling diameters used and the drilling tools applied based on the soil conditions, and on the other hand from the size (length, width, height) of the equipment used and the pull force of the carrier machine as well as the achievable torque.

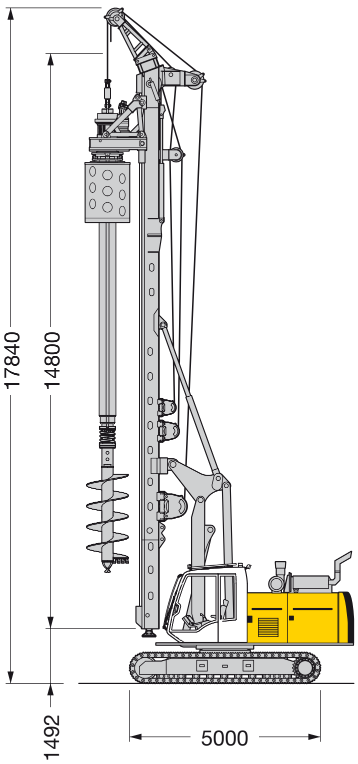
Drilling rig	Drilling depth up to	Maximum drilling diameter	
		uncased	cased
LB 16 with rotary drive BA 160 from Kelly MD 15/2/16 to Kelly MD 15/3/27	14 m 25 m	900 mm	750 mm
LB 20 with rotary drive BA 200 from Kelly MD 28/3/24 to Kelly MD 28/3/33	22 m 31 m	1,900 mm	1,500 mm
LB 24 with rotary drive BA 240 from Kelly MD 28/3/24 to Kelly MD 28/4/42	22 m 40 m	1,900 mm	1,500 mm
LB 28 with rotary drive BA 280 from Kelly MD 28/3/24 to Kelly MD 28/4/54	22 m 52 m	1,900 mm	1,500 mm
LB 36 with rotary drive BA 360 from Kelly MD 36/3/30 to Kelly MD 36/4/60	28 m 58 m	2,300 mm	2,000 mm

Kelly drilling

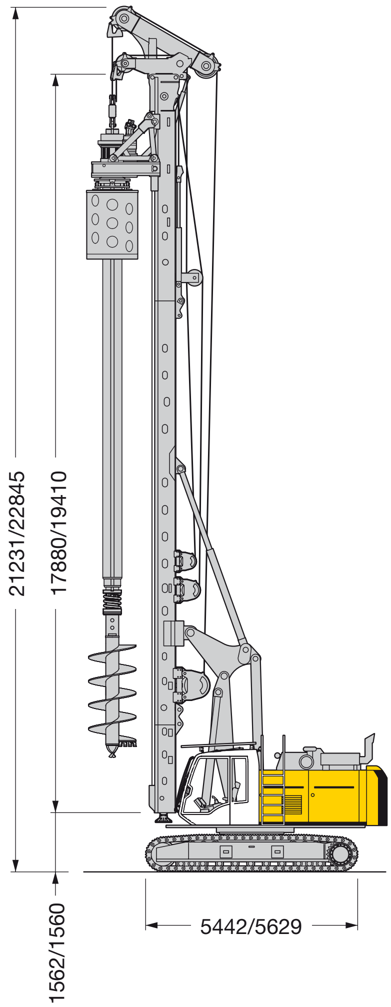
6 Machine diagrams showing equipment

6.1 Carrier machines with Kelly drilling equipment (rope crowd)

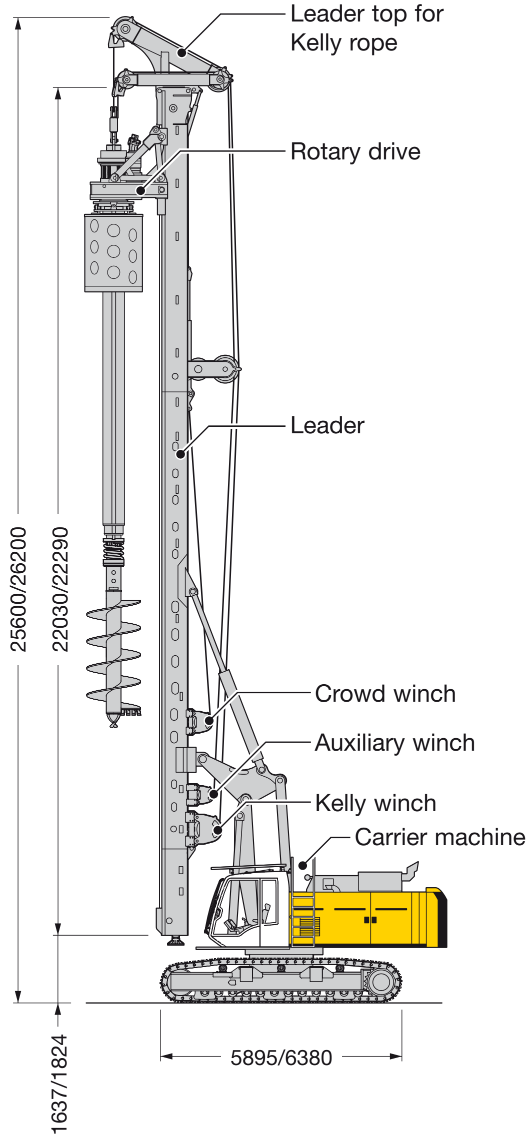
LB 16



LB 20/LB 24



LB 28/LB 36

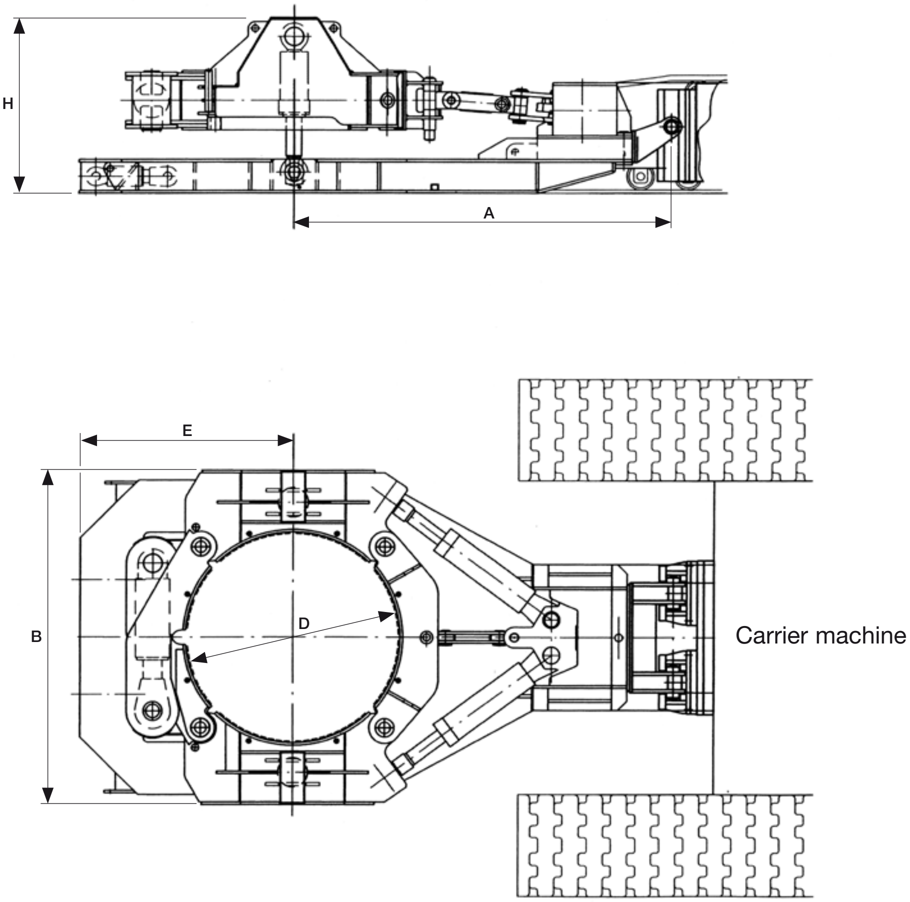


Kelly drilling

If required an additional hydraulic casing oscillator is used which has to be firmly mounted on the carrier machine.

The hydraulic supply is generally provided by the carrier machine.

Overview of selected hydraulic casing oscillators (flat design)



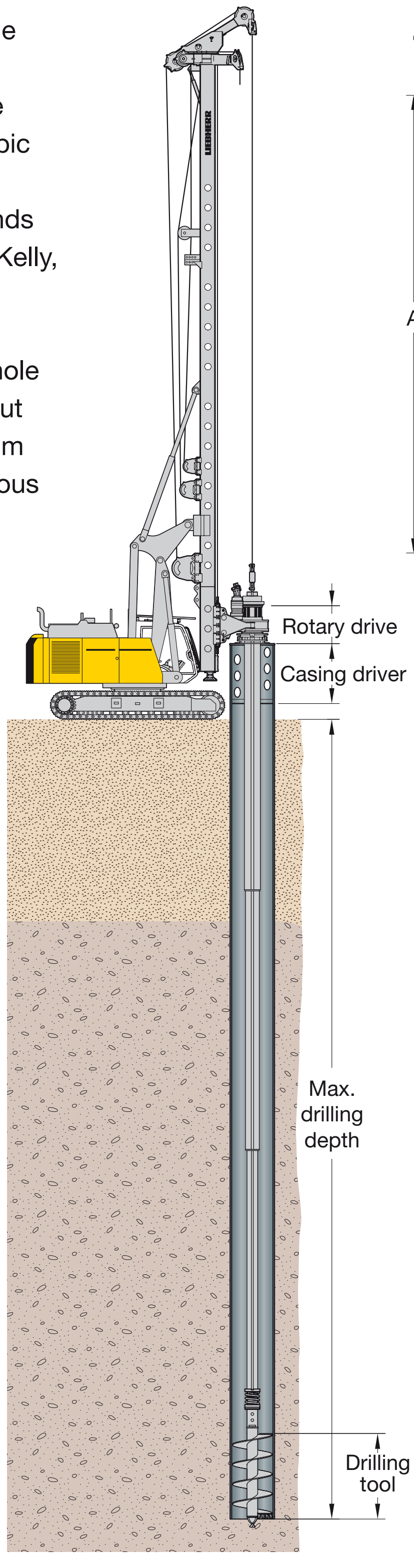
Designation	Distance drilling axis to carrier connection A	Distance drilling axis to front edge E	Suitable for casings with external diameter up to D	Height H	Width B
VRM 118 KL	2,270 mm	1,000 mm	880 mm	1,485 mm	2,050 mm
VRM 120 KL	2,270 mm	1,000 mm	1,200 mm	1,485 mm	2,050 mm
VRM 150 KL	2,800 mm	1,420 mm	1,500 mm	1,600 mm	2,500 mm
VRM 200 KL	3,545 mm	2,015 mm	2,000 mm	1,685 mm	3,220 mm
VRM 250 KL	3,715 mm	2,265 mm	2,500 mm	1,855 mm	4,000 mm

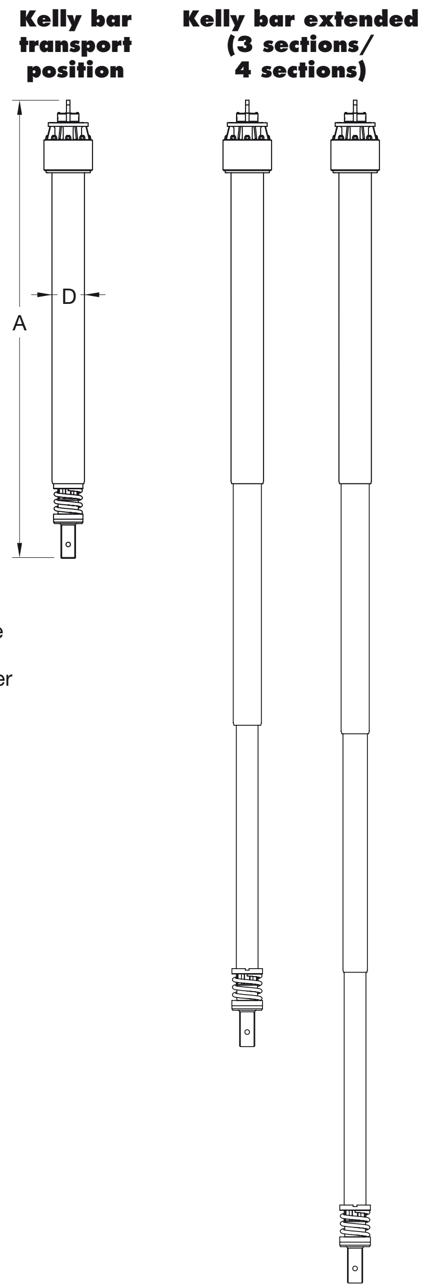
Kelly drilling

6.2 Tool system

The **Kelly bar** transfers the torque and the crowd force to the drilling tool. The type designation refers to the max. admissible torque, the number of integrated telescopic drilling rods and the maximum nominal drilling depth (e.g. MD 28/3/30 corresponds to admissible torque of 280 kNm, 3-fold Kelly, max. drilling depth 30 m). The actually achievable drilling depth depends on the applied drilling tool and the type of borehole casing. In case of cased boreholes without casing oscillator it is approx. 0.5 m – 0.9 m less. The Kelly bars are designed for various (absorbable) torques.

Each Kelly bar has a Kelly eye and a Kelly swivel with swivel protection at its upper end. The lower end is equipped with a shock-absorber, consisting of a coil spring (up to 7 t) or disc springs (over 7 t) depending on the weight of the Kelly bar.





Kelly drilling

Kelly bars (examples)					
Type	Number of drilling rods	Max. admissible torque (kNm)	Diameter of outer bar (mm) **D** =	Max. drilling depth (m)	Length (retracted) (mm) **A** =
MD 28/3/24 MD 28/3/27 MD 28/3/30 MD 28/3/33 MD 28/3/36	3	280	419	22 25 28 31 34	9,880 10,880 11,880 12,880 13,880
MD 28/4/36 MD 28/4/42 MD 28/4/48 MD 28/4/54	4	280	419	34 40 46 52	11,130 12,630 14,130 15,630
MD 36/3/30 MD 36/3/36	3	360	470	28 34	12,000 14,000
MD 36/4/42 MD 36/4/48 MD 36/4/54 MD 36/4/60	4	360	470	40 46 52 58	13,000 14,500 16,000 17,500

Note: The listed Kelly bars are adapted for use with the described LB drilling rigs.

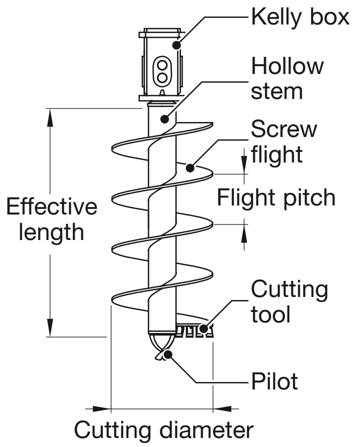
Kelly drilling

Possible **drilling tools** are short **augers**, **drilling buckets** and **core barrels**. The outer diameter of these drilling tools matches the inner diameter of the drill casings applied. The augers feature an effective length of 1.5 m. The upper end holds the Kelly box. For drilling in various soil types, single-start augers, double-start augers and so-called tapered augers with special bits are available. Augers are usually fitted with a pilot.

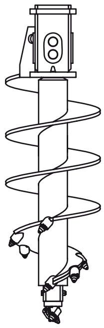
Drilling buckets are designed for drilling in sandy, loose soil types as well as for drilling in all types of loose soils in groundwater or for cleaning the bottom of the borehole. They are equipped with a hinged swivel bottom plate. They can be of the single-start or double-start type with or without a pilot. For rock of high workability there are special rock drilling buckets. The effective length is 1.2 m.

For drilling in rock up to medium strength and in non-reinforced concrete **core barrels** are used. They can be fitted with **cutting bits**, with **round shank bits** or with **roller bits**. The drilling cuttings produced with core barrels always have to be extracted alternately with a drilling bucket. The effective length is 1.5 m.

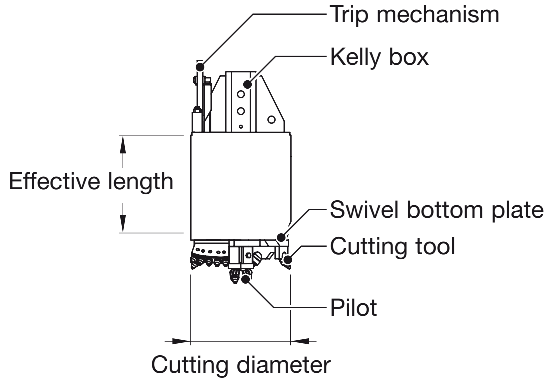
Auger



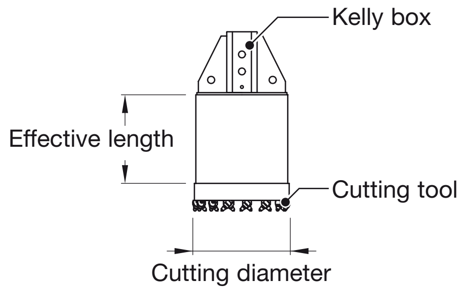
Tapered auger



Drilling bucket



Core barrel



Kelly drilling

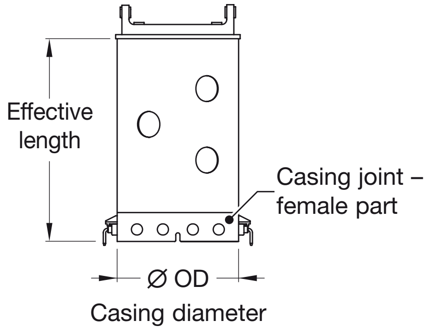
As borehole casings mainly double wall casings are used. For drilling diameters of minimum 150 cm single wall casings are also applied. The individual casing sections are connected to each other via welded-on **casing joints** (male and female part). The casing joints are coupled with conical bolts. Drill casings are produced in effective lengths between 1 m and 6 m. The total number of casing sections assembled for a cased borehole is also called **casing string**.

For cased boreholes produced using the Kelly drilling method casings with an outer diameter between 600 mm and 1,800 mm are used.

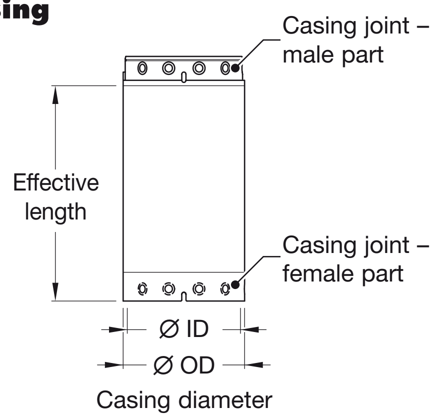
The first (bottom) section of a casing string is fitted with a **cutting shoe** (also called **pipe shoe** or **casing shoe**). It can also be equipped with a welded-on **cutting ring**. Depending on the type of application and on the soil type, the cutting shoes and cutting rings are equipped with armoured **cutting blocks**, carbide tipped **weld-on teeth**, carbide tipped teeth or bits.

The casing driver is mounted between the rotary drive and the casing. It is coupled with the rotary drive in such a way as to ensure co-rotation and that tensile and compression strengths are transmitted. The casing driver is a pipe mostly designed with openings with a diameter fitting the casings. At the lower end a casing joint is welded on. Casing drivers must be able to absorb the maximum torque of the rotary drive. They are designed for torques of up to 150 kNm and up to 400 kNm. Their standard length is 1.9 m or 2.2 m.

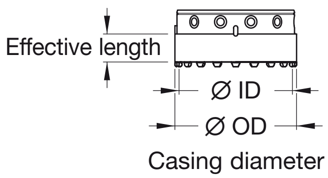
Casing driver



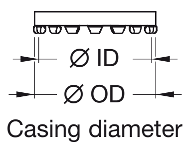
Casing



Cutting shoe



Cutting ring



Deep compaction

1 General

In deep foundation and construction engineering various methods are used. Their purpose is to modify the natural properties of the soil in such a way that it meets with the demands of the construction purposes projected for the area. This includes methods which only serve to improve soil with insufficient load-bearing capacity, so it can be used to accommodate construction loads. In foundation engineering these methods are summarised in the term **building ground improvement** (also called **soil improvement**).

Building ground improvement means making positive changes to the natural properties of a soil with a view to construction, through treatment and/or the addition of other materials. The aim of the building ground improvement process is to increase the natural load-bearing capacity of the soil in order to accommodate loads from building works or embankments and/or to reduce the compressibility (settlement) of the soil. The methods used can be divided into the following systems:

- Ground improvement through input of energy
- Ground improvement through the addition of materials
- Ground improvement through the removal of water

The replacement of soil (soil exchange) with a ground material of another "better" type is not ground improvement in this sense.

The many different methods of building ground improvement can be divided into three groups:

1. Methods where specific energy is input, e.g. during execution of vibratory compaction on the surface. This near-surface ground improvement through energy input can be achieved using tamping or vibrating machines. Such methods are diversely applied in road construction and earth-moving work, but are not described here. In foundation engineering, however, methods reaching deeper down into the subsoil are applied in order to improve the building ground. One of these methods is **deep compaction**, which is used above all for compacting mainly non-cohesive soils (also gravel and sand and mixtures of them, with only little silt content) through energy input. This method is also known as **vibro-flotation**. It is exclusively carried out using deep vibrators hanging freely on the rope of a crane or an excavator. LIEBHERR duty cycle crawler cranes with lattice boom are especially suitable for this application.

Deep compaction

2. Methods in which soil is displaced and material is added in addition to the input of energy. This is the case, for example, when carrying out **vibro-replacement** or when producing **vibration columns**. These methods are further developed variants of the deep compaction method, where a so-called **bottom-feed vibrator** (horizontal vibrator) is used to produce load dissipating columns of gravel and sand in soil which is only slightly or not compactable. Instead of gravel and sand, a gravel-sand mixture blended with cement in a dry mixing process can be installed. Vibration columns produced in this way are called **grouted vibro-replacement columns**.
   Thereby, the vibrator is always guided on a leader. For this purpose, a LIEBHERR LRH piling rig – a HS duty cycle crawler crane with lattice boom and a leader fixed to the boom top (called **fixed leader**) – can be used.

3. Methods, achieving better water drainage or an increase in load-bearing capacity or better workability for subsequent construction techniques through the extraction of soil by drilling and the installation of a soil replacement material. This includes the sand and gravel piles described in chapter D as well as soil exchange drilling.

A further method of producing vibration columns by installing a specially designed vibration pipe is described in the **compendium volume I, Piling and drilling rigs, LRB series**.

Assessments and proposals as to which method of ground improvement is appropriate to achieve the desired result are normally made by consultants and geotechnical engineers from institutes and engineering consultants specializing in this area.

Another deep compaction method is **impact compaction**, also known as **dynamic deep compaction** or **dynamic intensive compaction** (see description in chapter P).

Deep compaction

2 Production (see also "Vibrating"), applications

2.1 Vibro-flotation

Soil compaction using deep vibrators, i.e. vibro-flotation or vibro-compaction, is one of the oldest deep compaction methods. It was developed and made ready for implementation in Germany in the 1930's. Today it is applied more and more often throughout the world.

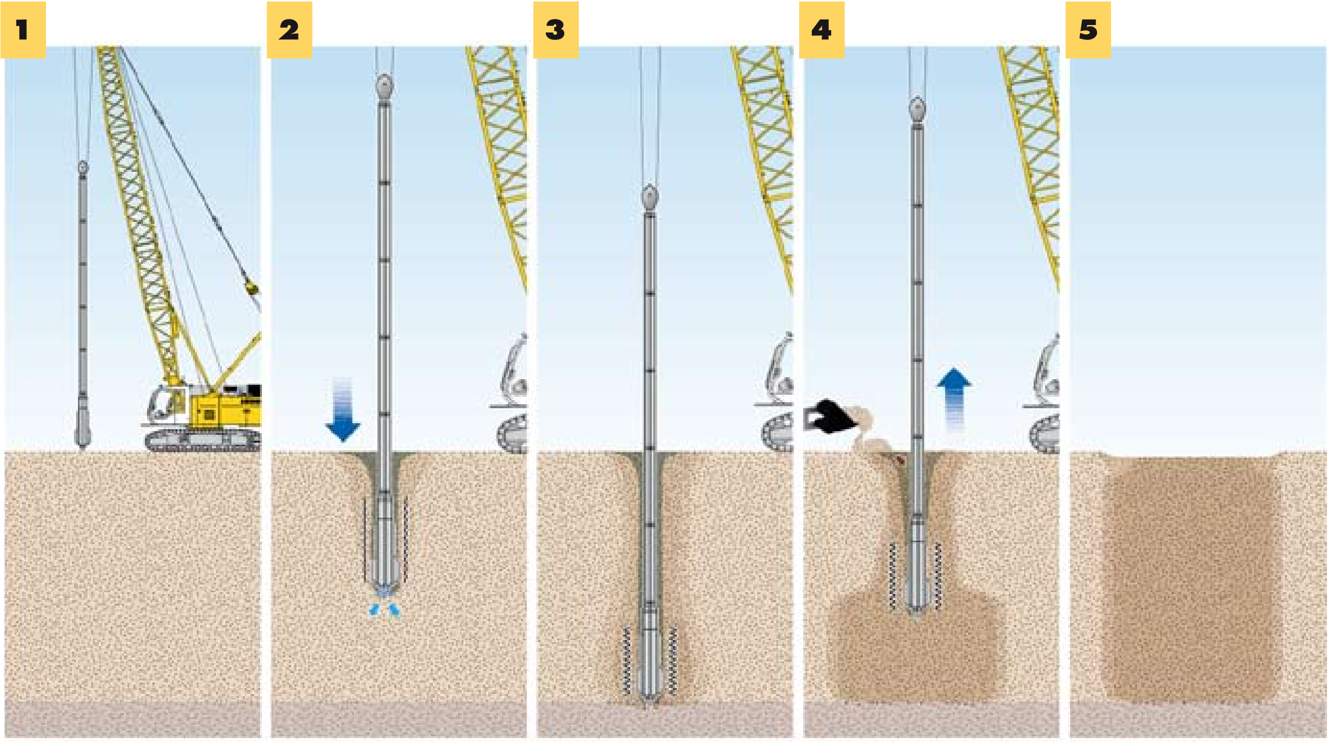
With a deep vibrator the soil is compacted through a cylindrical vibrator in which the eccentric weight rotates around a vertical drive shaft (horizontal vibrator, see description under "Vibrating").

The vibrator is situated at the lower end of a heavy pipe which is suspended on the rope of a crane or a HS duty cycle crawler crane. Vibrator and pipe together with the extension pipes feature a length at least as long as the projected penetration depth of the vibrator.

In foundation engineering it is known that non-cohesive (granular) soil is compressed if exposed to construction loads and thus, settlement occurs. During this process, the soil grains are rearranged from their original position (loosely layered with large pore volume) to a more compact position (more densely layered with smaller pore volume), i.e. the soil is compacted. The application of vibro-flotation is based on the fact that this rearrangement of the soil grains also occurs due to the influence of vibrations, i.e. the soil is compacted. If this compaction is effected before the construction loads are applied, the possibility of subsequent settlements of the soil are prevented to a large extent. Thus, a deep vibrator is used to improve the soil for construction purposes.

Deep compaction

The process of vibro-flotation includes the following steps:



The vibrator (out of operation) is hoisted on the rope, brought into the projected position and placed on the ground (**1**).

As vibration is switched on, the rope is slowly lowered. In order to support penetration, water emerging from the vibrator tip is added under pressure. In this way the deep vibrator penetrates the ground due to its own weight and the jetting force of the pressurised water. In most cases the vibrator is sunk into the building ground in one working step (**2**).

After the projected depth is reached, water jetting is reduced or completely switched off and the vibrator, which remains in operation, is pulled up step by step (**3**).

Thus, a compacted soil structure of cylindrical shape is created around the vibrator. Extraction of the vibrator is executed in predetermined hoisting steps and intervals. The reduction of the pore volume in the soil due to vibration leads to a funnel-shaped settlement around the vibrator. This is compensated by adding gravel or sand or adjacent soil material (**4**) (**5**).

Deep compaction

The combination and appropriate arrangement of the vibration points allows to compact soil structures of any size and depth in various geometrical shapes. Thus, the building ground can be exactly compacted as required for punctiform loads, line or stripe loads as well as for areal loads.

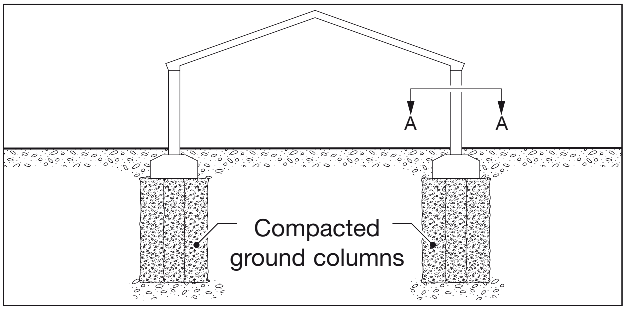
Vibro-flotation is mainly applied for improving loose sands and gravels as well as artificial fills. This method is predominantly used for improving building ground which is intended to be exposed to large-area loads (e.g. fuel depots, road embankments, stock grounds, airport runways, industrial sites). Another possible application is the compaction (reduction in volume) of slag heaps and mine dumps.

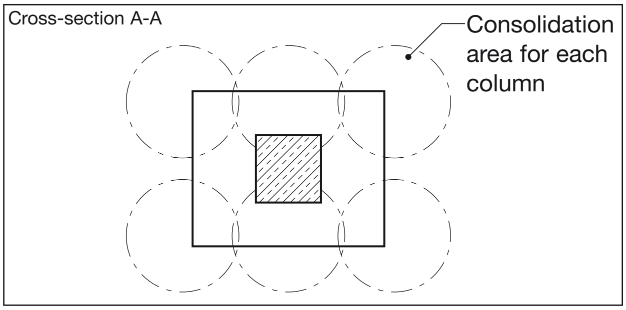
The diameter of the compacted soil column depends largely on the original soil structure and the vibration energy applied. It can be as much as 4 m.

The distance between the compaction points for producing a continuous area-wide compaction is between 2.5 m and 4.0 m.

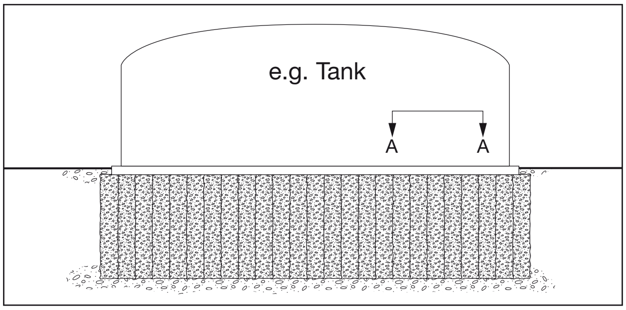
HS carrier machines from LIEBHERR are particularly well suited and cost-effective in the case of vibro-flotation applications where it is required to go to great depths. Installation depths of up to 30 m can easily be achieved using the HS 885 carrier machine.

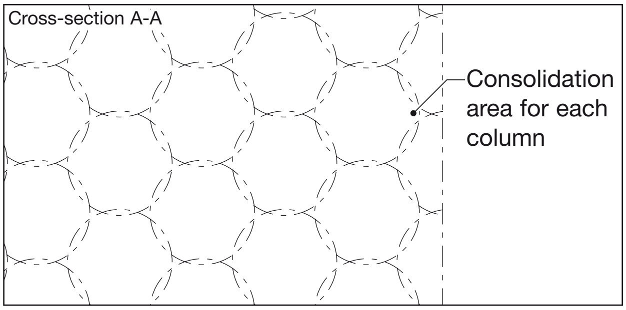
Compaction under foundations





Compaction under areal loads



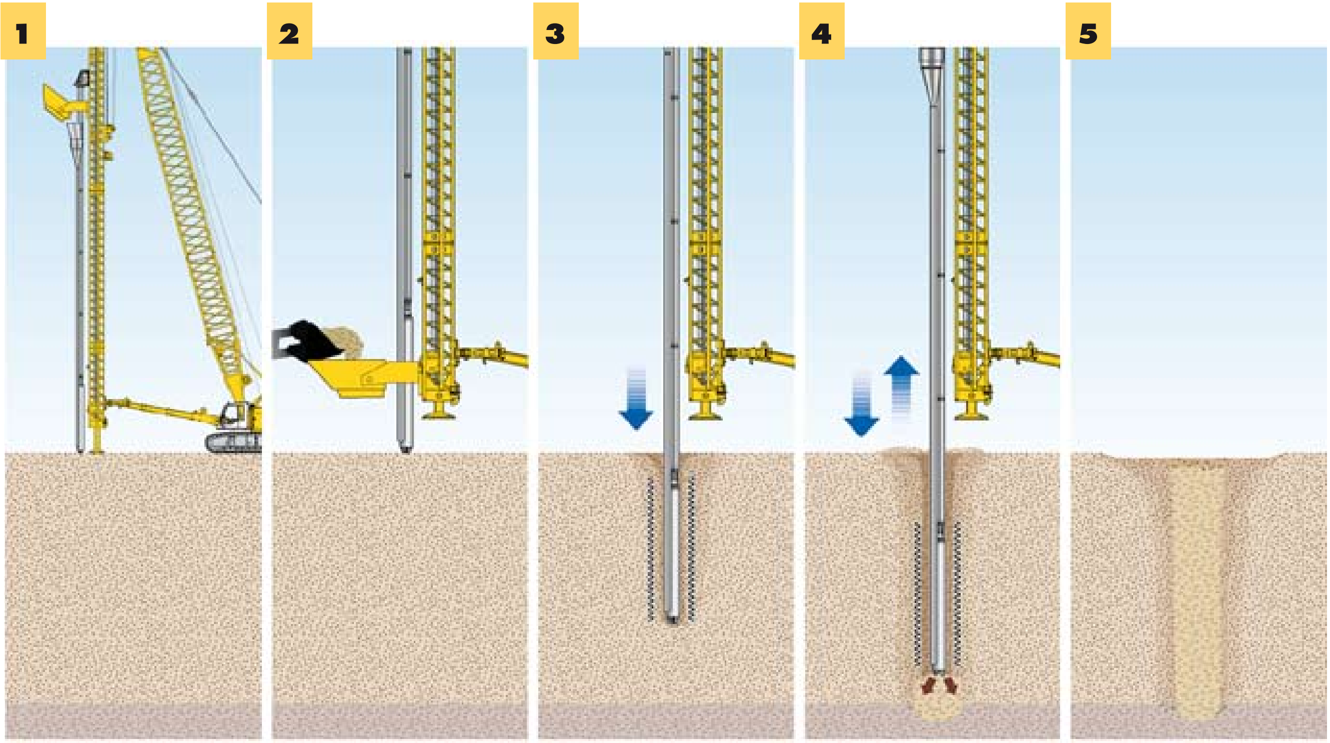


Deep compaction

2.2 Vibro-replacement

For these methods a deep vibrator with a device for adding material, a so-called **bottom feed vibrator** (horizontal vibrator), is vibrated into a non-compactable, fine grained soil, whereby the soil is displaced to the side. Thereby, the vibrator is always guided on a leader. For this purpose, a LIEBHERR HS duty cycle crawler crane with lattice boom and a leader fixed to the boom top (called **fixed leader**) can be used.

The process of vibro-replacement includes the following steps:



The bottom-feed vibrator which is guided on the leader is brought into the projected position and placed on the ground (**1**).

Via a material bucket the feeder pipe is filled with the intended installation material (**2**).

The vibrator is then put into operation and penetrates the ground down to the projected depth using rope crowd force and supported by compressed air emerging from the vibrator tip (**3**). During penetration the soil is displaced to the side.

The vibrator, which is still in operation, is pulled up a little and the installation material is filled into the created cavity with the help of compressed air. The vibrator is alternately extracted by the same predetermined distance, then pressed in again with the down-crowd force of the vibrator by approx. 1/3 of the extraction distance while continuing to vibrate. Thus, the filling material is also “stuffed”, i.e. compacted. It has to be constantly added. This procedure is referred to as **“compaction regime”** (**4**).

The result is a **vibro-replacement column** (or simply called **vibration column** or **stone column**). The “stuffing” process leads to better interlocking with the surrounding soil and gives the vibration column a higher load-bearing capacity (**5**).

3 Characteristics, special features

In comparison to other special deep foundation methods such as drilled piles or impacted piles, the methods of vibro-flotation and vibro-replacement offer many technical advantages in terms of the process. The high degree of geometric flexibility allows the process to be optimally adapted to the given conditions. The ability to produce variable structural forms allows the process to be matched to the particular construction task.

As the achievable improvement of the soil's load-bearing capacity is very high, settlements caused by subsequent loading or by dynamic stress can be disregarded, as they have already been effectuated by the vibration.

Compared to other deep foundation methods these methods excel in their short execution time and are therefore very cost-efficient. This is above all due to the vibrator being installed in one single step.

Subsequent building work can be carried out after a short period of time and within close vicinity of the ongoing improvement of the subsoil. The building ground, which has been compacted area-wide, is immediately ready for subsequent building work as in the case of a common shallow foundation.

The compaction is equally effective above and below the groundwater table. The success of the compaction is neither affected by flowing groundwater nor by tides. Soil improvement using vibro-flotation and vibro-replacement is permanent and can not be disturbed even through aggressive groundwater.

As no soil is extracted with this method, the compaction of contaminated soils does not produce any additional costs for soil disposal.

To cope with changing soil conditions, the installation pattern can be changed immediately without interrupting the serial installation process.

Not only the pattern of the compaction points but also the compaction depths can be easily adapted to the loads from the building and/or the building work without changing equipment.

4 Application limits

Where obstacles are encountered in the soil, the installation process normally has to be aborted and the vibrator inserted again in a different location.

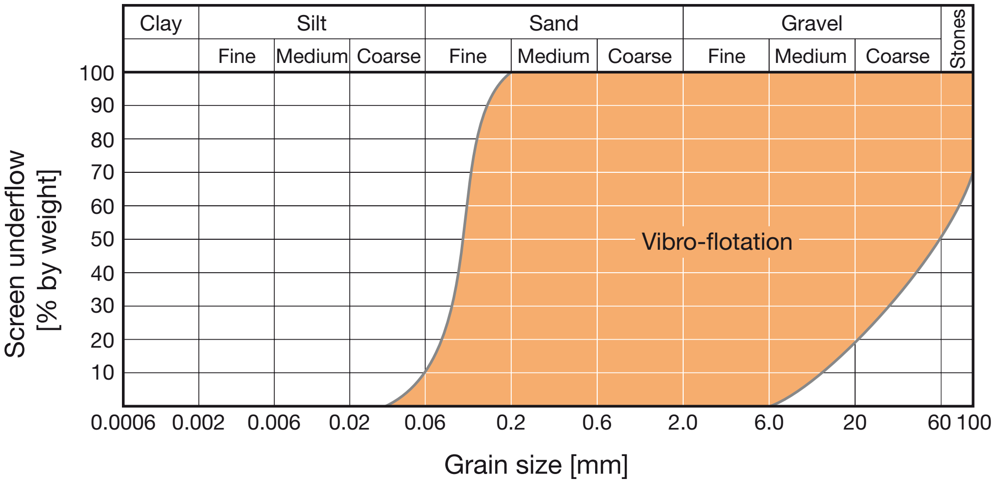
The application is limited to the compaction of non-cohesive soils with a low silt content (less than 5%).

Special measurements need to be taken if the compaction is to be carried out next to buildings with shallow or deep foundation.

Application limits are also given in terms of vibration emissions generated in the process.

Due to the stress during extraction the weight of the vibrator should not exceed 40% of the admissible hook load. The applied pull force has to be less than admissible for the vibrator.

Limiting grading curves

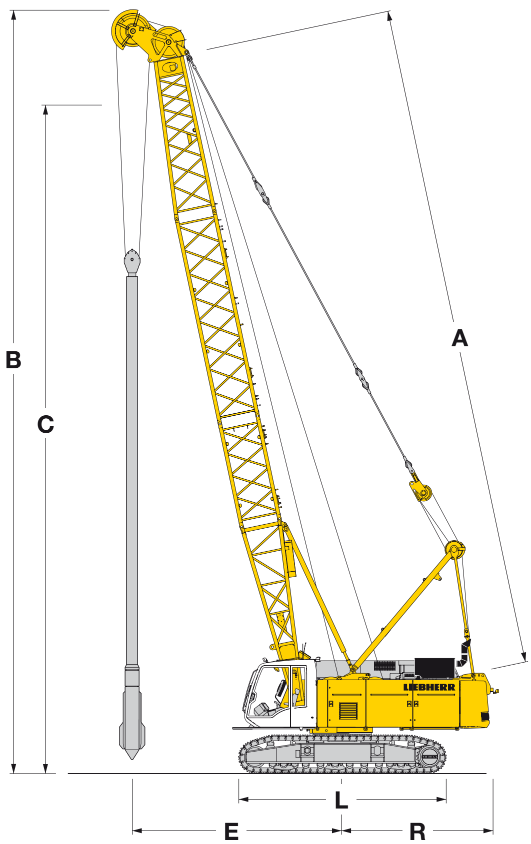


Deep compaction

5 Machine diagrams showing equipment

5.1 HS duty cycle crawler crane with deep vibrator

For this application the carrier machines HS 845 to HS 885 are predominantly used.

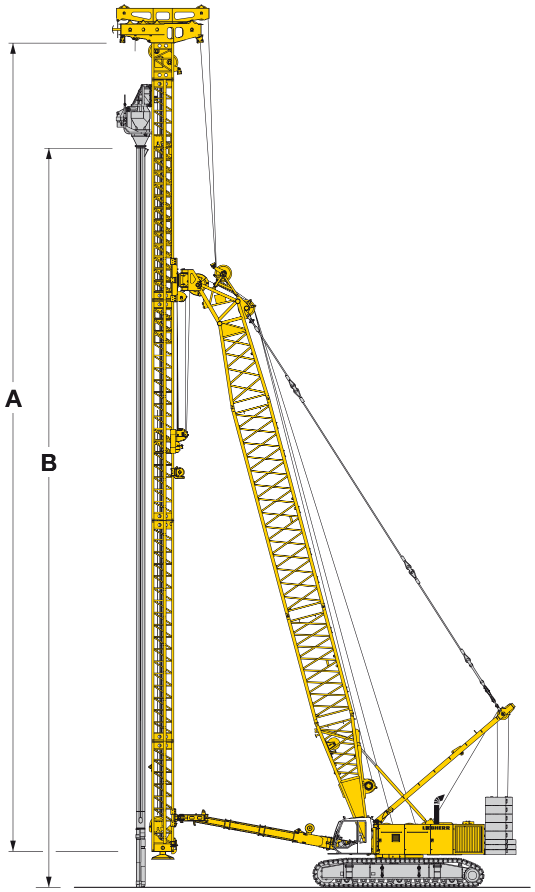


Dimensions for deep compaction application; selected examples

Duty cycle crawler crane	Boom length (mm) **A** =	Total height at approx. 75° (mm) **B** =	Max. effective height (mm) **C** =	Distance of vibration point (mm) **E** =	Length of crawler side frame (mm) **L** =	Swing radius (mm) **R** =	Max. load on hook (t)
HS 845	32,000	33,600	32,000	10,000	8,960	4,570	12
HS 855	35,000	36,600	35,000	10,000	6,460	4,700	23
HS 875	38,400	39,200	37,200	11,000	6,445	5,510	26
HS 885	41,000	42,200	40,200	12,000	6,750	5,510	28

Note: Further variants with longer/shorter lattice boom are possible.

5.2 LRH with bottom feed vibrator (vibro-replacement)



The following combinations of equipment can be applied			
	LRH 200	LRH 400	LRH 600
Carrier machine	HS 845 HS 855	HS 855 HS 875 HS 885	HS 895
Max. leader length **A** =	33 m	42 m	50 m
Max. capacity Max. pull / push force	20 t 40 t	35 t 60 t	65 t 80 t
Max. effective length* **B** =	approx. 28 m	approx. 37 m	approx. 44 m

* Depending on the applied type of bottom feed vibrator

6 Quality assurance

The optimum pattern of the compaction points is chosen from experience or according to tests previously carried out.

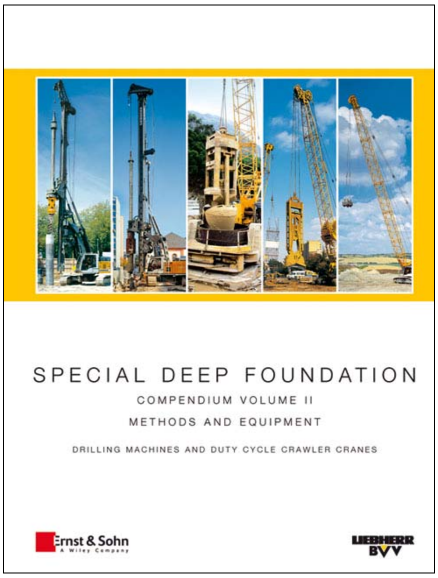
The following production parameters need to be monitored and recorded on data recording systems throughout the entire production process of vibro-flotation:

- The penetration depth of the vibrator from the working level downward
- The duration of the compaction process
- The energy input (e.g. oil pressure) of the vibrator
- Pressure and quantity of the jetting water
- The distance between the compaction points (grid dimension)
- The amount of material added for filling the vibrating hopper

The following controls are recommended after completion of the compaction works:

- Large-area levelling in order to determine the effected settlements
- Determination of the compacted soil's density via static and dynamic penetration tests
- Determination of the new strength properties of the soil through test loadings (load tests or plate load tests)

Book Recommendation



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