VIBRATORY HAMMERS FOR PILE DRIVING

By Kaj Balsborg

INTRODUCTION

The capability and versatility of hydraulic vibratory pile driving hammers are often underestimated. For many installations vibratory hammers are better alternatives to impact hammers and for other installations an important and cost-effective complementary tool to impact hammers.

Hydraulic vibratory hammers are in general faster and more economical than impact hammers, especially for installing sheet piles, cast-in-situ piles, H-beams (anchor piles) and steel pipe piles. Besides, they are superior to other equipment for extraction of installed piles.

For temporary installations of sheet piles the hydraulic vibratory hammers are unsurpassable by being fast for both driving and extraction. Besides, vibratory hammers seldom cause damage to the piles. As a result, sheet piles installed with vibrators can often be used again and again.

THE PRINCIPLE OF A VIBRATORY HAMMER

The major components of a vibratory hammer are:

- an even number of shafts – 2, 4, 6 or 8 - each with an eccentric weight.
- a vibratory case (oscillator) containing the shafts with eccentrics, gears and hydraulic motor(s).
- a vibrator head (suppresser) to hold and support the vibratory case.
- a single or a set of hydraulic pile clamps.

Eccentrics are mounted on each pair of shafts opposite each other and synchronously counter rotated by one or more hydraulic motors via a gear system. The horizontal components of the centrifugal forces then eliminate each other, and the vertical components add.

The rotational speed is 1200 - 3000 rpm (20-50 Hz). Hammers with a speed from 1200 to 2000 are generally characterized as normal-frequency hammers (although speeds less than 1600 rather should be considered low-frequency) and hammers with rotational speeds from 2000 to 3000 as high-frequency hammers.

The vibrator head is mounted to the vibratory case with high-effective vibration absorbers. The top is provided with an arrangement for rig and crane suspension or an attachment for mounting to an excavator.

Hydraulic clamp(s) are mounted under the vibratory case and ensure fixed and secure attachment to the pile driven or extracted. A clamp contains two gripping jaws - one fixed and one movable. The clamp cylinder is operated with a handheld remotely controlled block with two switches - closing and opening. It is provided with a check valve to protect the clamp from loosing the grip in case the hydraulic pressure drops – as an example in case of damage to a hydraulic hose.

The hydraulics of vibrator and clamp(s) are driven by a separate, hydraulic power pack or by the hydraulic system of the rig or excavator. The operating frequency of the hammer can be regulated by the speed of the diesel engine. A handheld block is normally used for remote operation of the hammer and powerpack.

The hydraulic hoses consist characteristically of a set of 5 hoses:

- a pressure and a return line for the hydraulic motors.
- a drain hose for the hydraulic motors.
- a pressure and a return line for the pile clamp(s).

HOW THE VIBRATORY HAMMER FUNCTIONS IN THE SOIL

The generated vertical forces are transferred to the pile via the clamp(s), resulting in oscillating pile movements with amplitudes being a function of the total operating eccentric moment and the total dynamic weight of hammer and pile (explained below).

The continuously transferred energy impulses propagates to the soil, travels away form the pile surface and tip and forms three different types of stress waves:

- Compression waves (P-waves) associated with changes in volume.
- Shear waves (S-waves) inducing distortion of the soil without change in volume.
- Raleigh waves (R-waves) radiating cylindrical away from the point of excitation.

The three waves propagate with different velocities through the soil and will thereby temporarly or lasting change its stress-strain behaviour and other characteristics.

Sand and gravel are especially suited for vibrating and the amplitude of the vibratory hammer/pile during the installation is important. The centrifugal force is less important.

In clay the centrifugal force is important and the amplitude less important. However, clay with firm consistence is less suited for vibrating and the available amplitude must as a thumb rule be at least 3 mm.

Please refer to our special review, "HOW TO SELECT THE RIGHT VIBRATORY HAMMER".

Soil damping

Normally the soil has a dampening effect on the amplitude of the vibratory motion. Only in exceedingly rare cases a complete fluidization of the soil and thereby no damping occurs. The degree of damping depends on the soil type and the embedded length of the pile. From the description above it appears, that the damping in cohesive soil is considerable higher than in granular soil.

TECHNICAL FORMULAS

When choosing a vibratory hammer for a project, the eccentric moment, centrifugal force and amplitude are important figures. These values are in general specified for hammers by the manufacturer - the amplitude, however, without pile weight. To make a better basis for understanding the fundamentals and to make it possible to calculate specific jobs, the formulas for calculating these values are shown below:

The eccentric moment: $\mathbf{M_{ecc} = \sum mr}$ [kgm]

Here **m** is the mass of the excenter on each shaft and **r** the distance from the axis of each rotating shaft to the centre of gravity of the mass. $\sum$ tells that the product **mr** must be summed up for the shafts in the vibrator. The symbols in bracket [ ] is the dimension - here kgm - used in the equation.

The centrifugal force: $F_c = M_{ecc}\,\omega^2 = M_{ecc}\,(2\Pi f)^2$ [N]

Here ω is the angular speed of the hammer and f the number of revolutions per <u>second</u>. If n symbolises revolutions per <u>minute</u>, we have:

The centrifugal force $\mathbf{F_c = M_{ecc}\,(2\Pi\, n/60)^2}$ [N]

The amplitude is calculated from the formula:

The amplitude: $\mathbf{A = 2000\, M_{ecc}/M_{dyn}}$ [mm]

Here M_{dyn} is the total vibrated mass, i.e., the total weight of all oscillating parts, e.g., the weight of the vibratory head, the clamp(s) and the pile.

Note that the amplitude (A) in practical foundations is the total oscillation distance and thereby twice the amplitude (a) as used in mathematics.

CRITICAL FREQUENCIES OF SOIL

Every flexible body - also soil - has a critical frequency, also called natural frequency. When soil is superimposed with vibrations in its natural frequency area, it will start to oscillate with high amplitudes. The body is said to be in resonance.

Oscillations will propagate to the surrounding area with amplitudes and to an extend depending on the soil damping. The lower damping the higher amplitude and extend. The result is major or minor disturbances in form of cracks and dislocations of the ground and often damage to nearby buildings.

Most soil has a natural frequency of 15 to 20 HZ (vibrations per minute) corresponding to the rotational speed of a vibrator of 900 to 1200 rpm. As a result, the max. rotational speed of a chosen vibratory hammer should be well above 1200.

HYDRAULIC POWER – VIBRATOR/HYDRAULIC POWER STATION

By using a power pack designated by a manufacturer to a vibratory hammer the hydraulic power will match the need of the hammer. However, if a vibratory hammer must be driven by the hydraulics from a rig, a crane, or an excavator, it is important to secure that the supplied hydraulic power matches the need of the vibrator. Otherwise, the full capacity of the vibrator cannot be utilized.

The hydraulic power of the Vibrator is normally indicated in the vibrator specifications. If not, it can be calculated from the following formula:

Calculation of Hydraulic Power

Flow [l/min] x pressure [bar]/600 = Hydraulic Power [kW]

When driven by an excavator, it is important to bear in mind that only 70 % of the engine power of the excavator is available for the vibrator. The rest goes to cooling, stick movements etc. So, the engine power of the excavator must be at least 1.4 times the hydraulic power of the vibrator.

DRIVING AIDS

In difficult soils some techniques can facilitate the pile installation.

Water jetting

When driving in sand the purpose is to concentrate water at the tip of the pile. This will loosen up the soil and reduce the toe resistance. When driving in clay the purpose is to create a film of water along the surface of the pile to reduce the skin friction.

The efficiency of water jetting depends on the density of the soil and the applied water pressure and the flow. High pressure jetting (350-500 bar) with low water flow (20 l/min) is normally preferred from low pressure jetting (10-20 Bar) with high water flow (200-500 l/min). High water volume will change the soil characteristics and give way to settlements. Therefore, water jetting is not always allowed.

Added Weight

By adding weight, the static weight of the vibratory hammer is increased. The static weight is the thereby the weight of hammer head and extra weight. Especially in firm clay this will result in deeper and faster penetration.

In sand added weight is less effective as the resistance under the pile must be overcome by the centrifugal force while in clay the friction must be reduced by the amplitude. The added weight supports the amplitude.

In general, unfavourable conditions arise in sand, when the total static weight exceeds the dynamic weight.

Predrilling

Predrilling can be necessary under certain soil conditions to enable installation. Besides, predrilling can be an advantage to avoid damage to piles.

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