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Application of Horizontal Oscillation Vibratory Hammer in Offshore Wind Power Pile Sinking Equipment

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Abstract

In order to adapt to the rapid development of offshore wind power, Shanghai Zhenzhong Company innovated the pile sinking equipment and invented the horizontal oscillating vibratory hammer. Through the analysis of its working principle, the pile-soil dynamics model was created, and the equivalent stress cloud diagram and acceleration curve diagram of the soil were obtained by simulation using Ls-Dyna finite element software. The simulation data was processed by Matlab and collected in Shanghai Zhenzhong According to the experimental data, the results show that the new type of vibratory hammer has less impact on soil deformation and has a smaller vibration level than the traditional one. The horizontal oscillating vibratory hammer will surely stand out due to its small impact on soil deformation and low vibration, which is of great significance to the development of national offshore wind power.

Keywords

Horizontal Oscillating Vibrating Hammer, Pile Sinking at Sea, Ls-Dyna.

1. Introduction

With the introduction of carbon peak and carbon neutral targets, the development of clean energy has attracted the attention of countries all over the world[1]. As a clean and renewable energy, offshore wind energy has the advantages of saving land resources, stable wind energy, rich resources, and suitable for large-scale development. In recent years, its development and utilization technology has developed rapidly [2]. In order to adapt to the rapid development of offshore wind power, research on port and shipping equipment is essential. In the pile-sinking construction of offshore pile foundations, it includes the feeding stage, the self-sinking stage of the steel pile, the hammering and the hammering pile-sinking stage [3] . Among them, in the stage of hammering and hammering piles, the vibratory hammer plays a vital role. The magnitude of the exciting force generated by the vibratory hammer will affect the construction efficiency and construction quality.

This paper designs and studies a new type of horizontal oscillating vibratory hammer. Its principle is that the vibration exciter generates horizontal torsional force. Through the simulation analysis of Ls-Dyna finite element software and actual tests, it can be known that this vibratory hammer can effectively reduce the impact on the soil. The deformation and vibration pollution at the same time are very beneficial to the development of offshore wind power.

2. The Basic Principle of the New Horizontal Oscillating Vibratory Hammer

The structure of the horizontal oscillating vibratory pile hammer consists of five parts: a lifting device, a pressurized guide wheel, a vibration damping device, a vibrating box, and a pile gripper. The function of the lifting device is to tighten the wire rope by the hoist and then use the hook to lift the pile; the function of the pressurized guide wheel is to provide downward static pressure so that the pile can sink and penetrate into the soil; there are many damping devices The spring damper is used to reduce the vibration; the pile clamp is a device used to clamp the pile and fix the position of the pile to keep it straight when working; the vibrating box contains a power device and a vibrator, of which the power device It is a device that provides power to the vibrator and the pile gripper. The oscillating pile hammer is driven by a motor. The function of the vibrator is to generate an exciting force.

The vibrator is the core component of the vibratory pile hammer. Unlike the traditional exciter, the exciter used in the new piling mode no longer generates an exciting force perpendicular to the ground, but an exciting force parallel to the ground. The pile body presents a reciprocating oscillating movement along the circumference in the horizontal plane. The schematic diagram of the excitation device is shown in Figure 1.

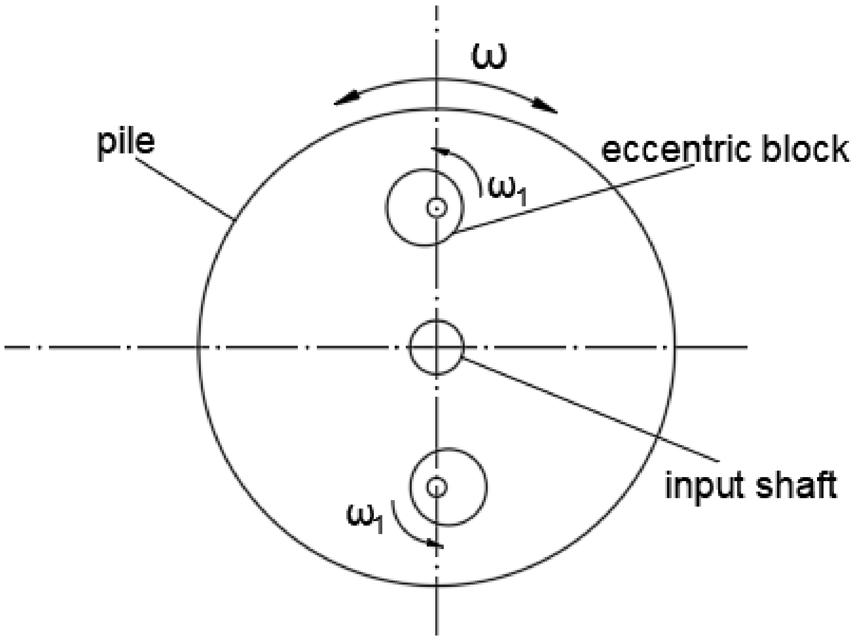


Figure 1. A schematic top view of the horizontal oscillating pile hammer working

3. Pile Sinking Simulation of Horizontal Oscillation Vibratory Hammer

3.1 Basic Assumptions of Pile-Soil Model

During the construction of a wind farm, the underground soil quality in the same sea area is not the same [4] and the main effect of the construction efficiency of the vibratory hammer is the soil layer under the sea water. Therefore, this paper ignores the influence of water and simplifies it as pile-soil The model makes the following assumptions:

(1) Ignoring the horizontal and vertical vibration of the frame on the upper part of the pile, it is considered that the pile is connected to the relatively stopped frame through elastic elements, so that the frame does not participate in the vibration system.

(2) The pile is only subjected to couple moments during the circular arc oscillation movement, and only rotates around its axis without radial displacement. The pile is regarded as a homogeneous solid cylinder with a mass equal to m, without vertical vibration.

(3) Simplify a thick soil around the pile body into a massless elastic damping body and connect it to a fixed soil body far away from the pile.

Therefore, the vibration dynamics model is shown in Figure 2.

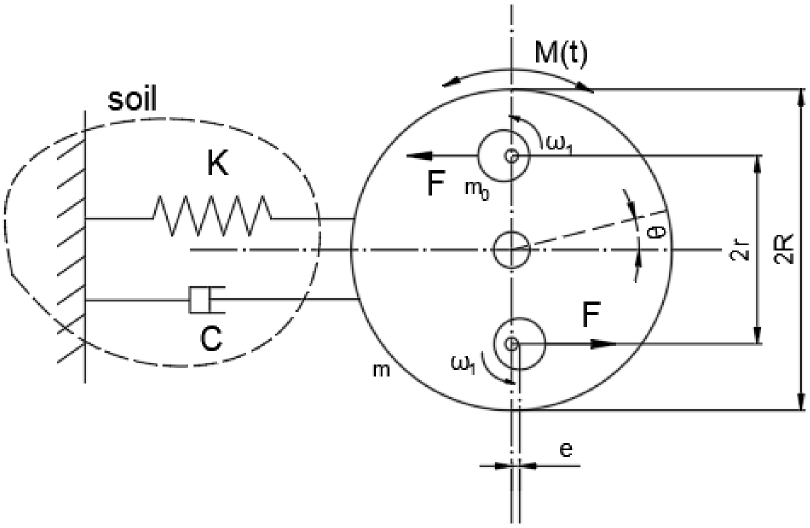


Figure 2. Pile-soil vibration dynamic model

From Figure. 2, the dynamic model is a single-degree-of-freedom forced vibration system. When the pile is oscillating in a circular arc around the center, the torsional vibration differential equation with the pile rotation angle θ as the degree of freedom can be listed according to the model[5]:

$$J\ddot{\theta} + CR^2\dot{\theta} + KR^2\theta = M(t) \tag{1}$$

Where: J--The moment of inertia of the pile around its center;

C--Equivalent damping of a certain thickness of soil around the pile;

R--Pile radius;

K--The equivalent stiffness of a certain thickness of soil around the pile;

M--exciting alternating moment of couple.

In the dynamic equation, the excitation $M(t)$ changes in a cosine cycle, and the magnitude is controlled by the separation distance between the eccentric force F. The magnitude of the eccentric force F and the expression of the excitation $M(t)$ are:

$$\begin{cases} F = m_0\omega_1^2 e\cos(\omega_1 t) \\ M(t) = 2Fr = 2rm_0\omega_1^2 e\cos(\omega_1 t) \end{cases} \tag{2}$$

Where: m_0 --the quality of the eccentric wheel;

ω_1 --The angular velocity of the eccentric shaft ;

e--The eccentricity of the centroid of the eccentric wheel to its axis;

r--The distance from the axis of the eccentric shaft to the axis of the input shaft;

$\omega_1 t$ -Angular displacement of the eccentric wheel.

3.2 Ls-Dyna Simulation Environment Construction

The pre-processing software uses TrueGrid to establish the model and divide the grid. The pile part adopts Lagrangian grid, and the soil part adopts ALE grid. After the grid is divided, it is imported into lsprepost for analysis. Now the divided unit is given. The quarter model after the grid is shown in Figure 3.

Volume 8 Issue 1, 2022
DOI: 10.6919/ICJE.202201_8(1).0052

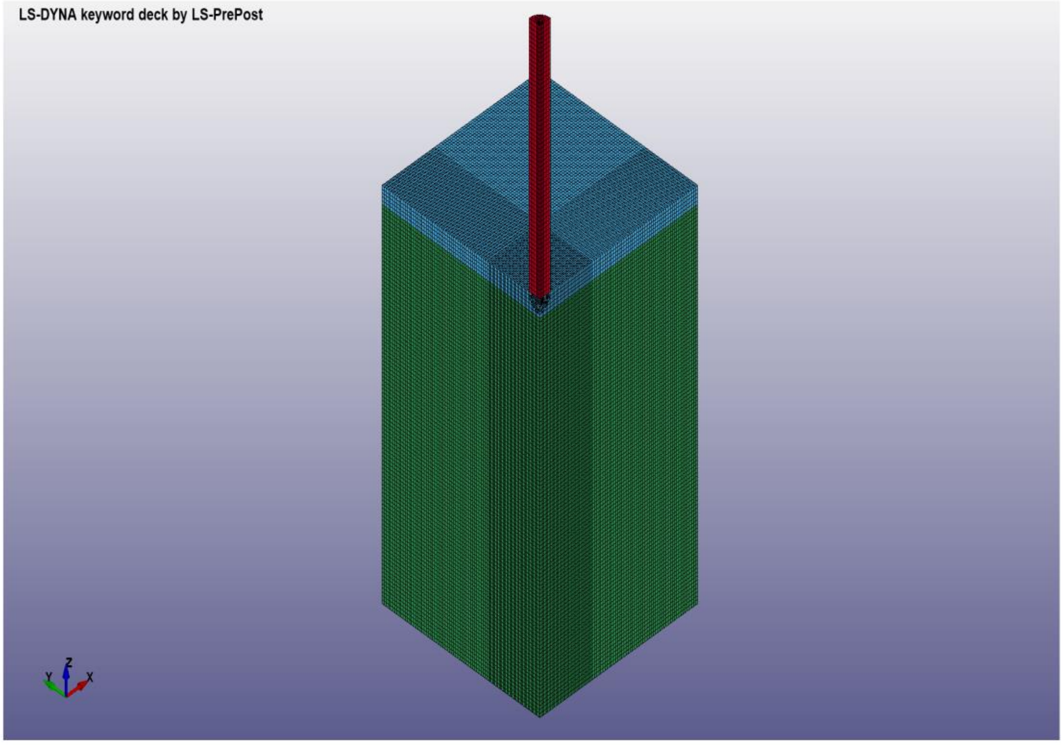


Figure 3. Quarter-pile-soil finite element model

This study does not consider the impact of the vibratory hammer on the pile, so the pile is regarded as a rigid body.Due to the anisotropy, dilatancy, elastoplasticity, pore water pressure and other characteristics of the soil itself, it is quite difficult to completely simulate the material parameters of the soil in the simulation environment. According to research experiments by some scholars[6] *MAT_SOIL_AND_FOAM among the built-in material options of Ls-Dyna can approximate the properties of soil materials, and is usually called MAT005 material model. The material parameters of this soil model are listed in Table 1 according to references.

Table 1. Soil material parameters

parameter name	Parameter symbol	value	unit
Material density	RO	2350	kg/m^3
Shear modulus	G	3.447E+7	Pa
Unloading bulk modulus	KUN	1.502E+7	Pa
Yield function constant	A0	1E+6	Pa2
Yield function constant	A1	1500	Pa
Yield function constant	A2	0.152	/
Cut-off pressure	PC	0	Pa
Volume fragmentation option	VCR	0	/
Hydrostatic pressure initialization option	REF	0	/
Logarithmic form of volumetric strain	ESP(1-10)	0.08	/
Pressure corresponding to volumetric strain	P(1-10)	0.4	MPa

3.3 Analysis of Ls-Dyna simulation results

The horizontal oscillating vibratory hammer has a unique oscillating rotation curve. Because the drawn curve is too dense, only the part of 0-2s is shown here. 2-8s is the same as before, as shown in Figure 4.

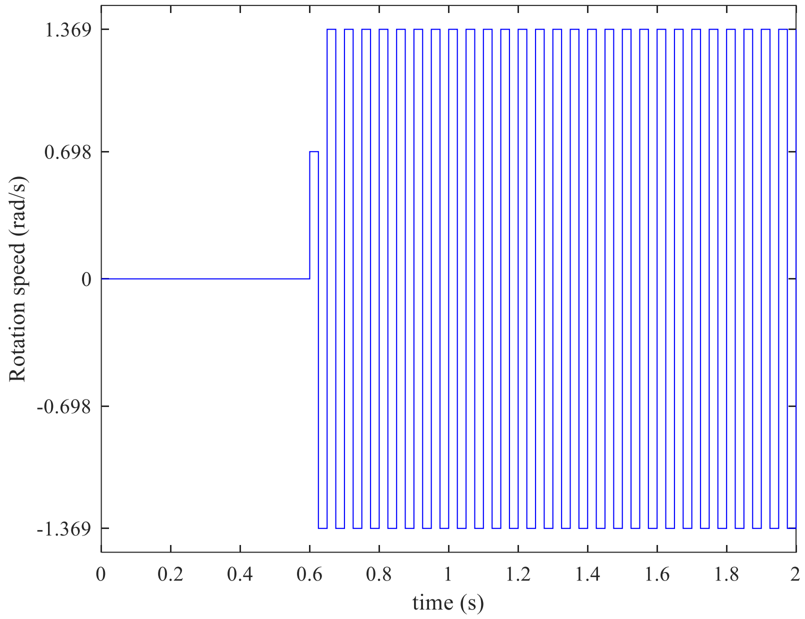
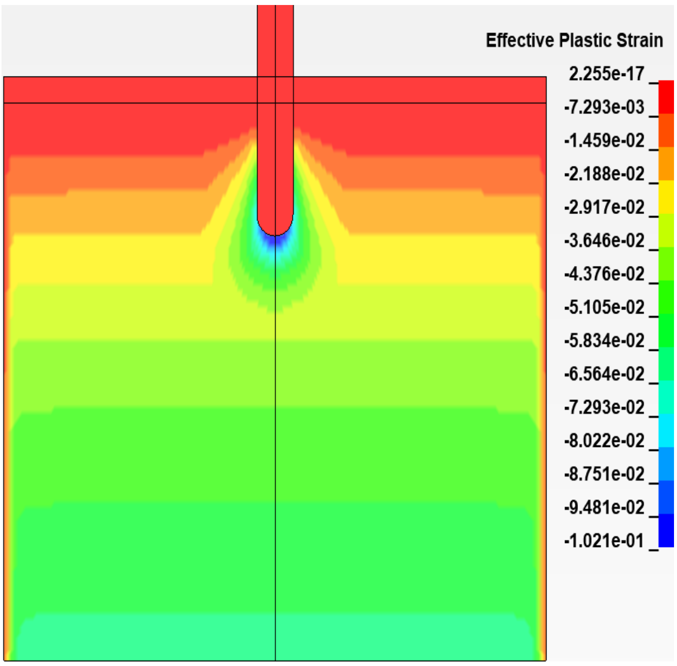
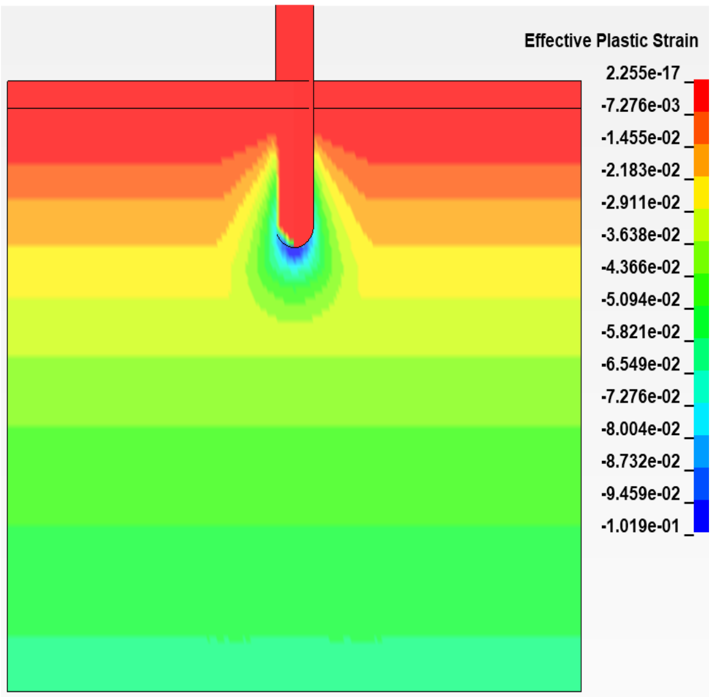


Figure 4. Partial time history diagram of the time curve of oscillating rotation speed

Run the simulation model to get the equivalent strain cloud diagram of the two to the soil as shown in Figure 5. By comparing the figures (a) and (b), it can be seen that under the same conditions, the strain generated by the oscillation mode at the left and right boundaries of the soil block is smaller than the static pressure pile driving method, and the deformation on the soil is smaller, so the pile driving effect is better.



(a) Static pressure pile hammer 2.5m



(b) Horizontal oscillating vibration hammer 2.5m

Figure 5. Equivalent strain cloud diagrams of the two types of piles

Select A2 (1.500, 0.100, -0.205), B2 (3.200, 0.100, -0.205), C2 (4.400, 0.100, -0.205), D2 (5.600, 0.100, -0.205) as the research objects. The simulation diagram is shown in Figure 6 Show.

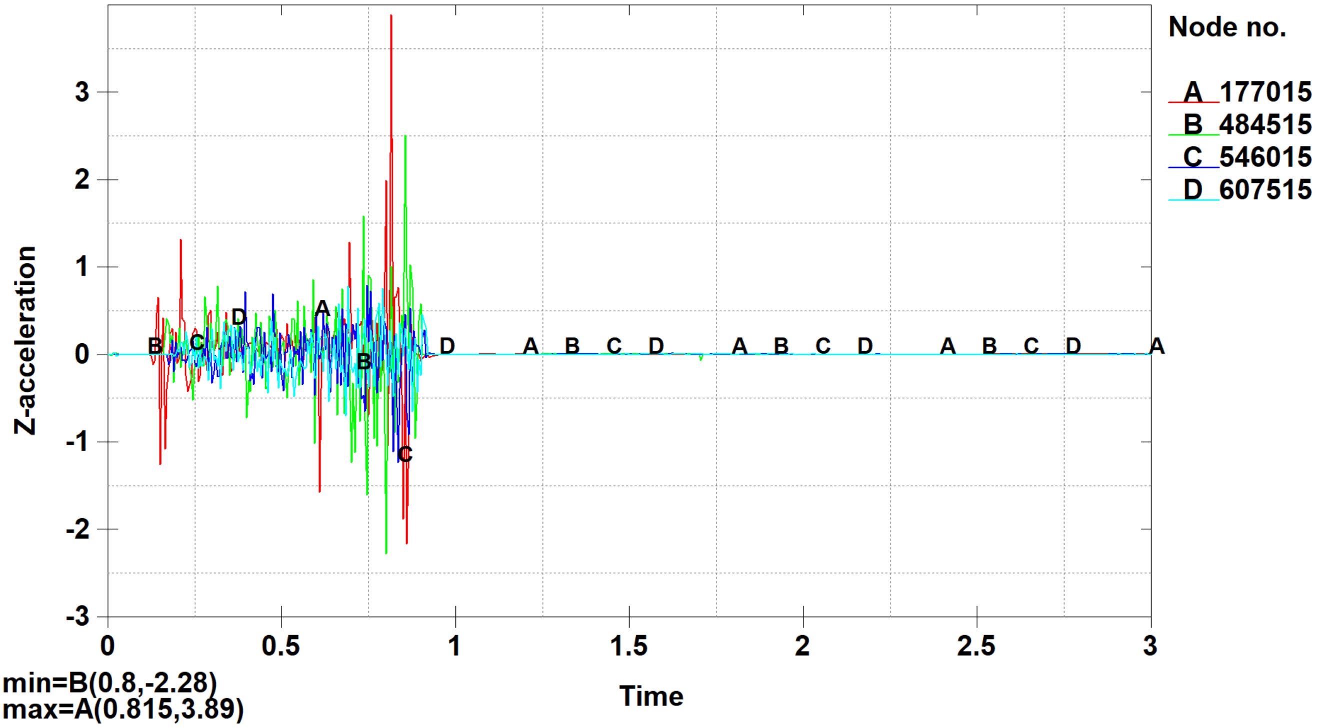


Figure 6. The Z-direction acceleration curve of horizontal oscillating piles A_2, B_2, C_2, and D_2 at the lsprepost interface

The result of processing the data in the lsprepost interface by Matlab is shown in Figure 7.

Volume 8 Issue 1, 2022
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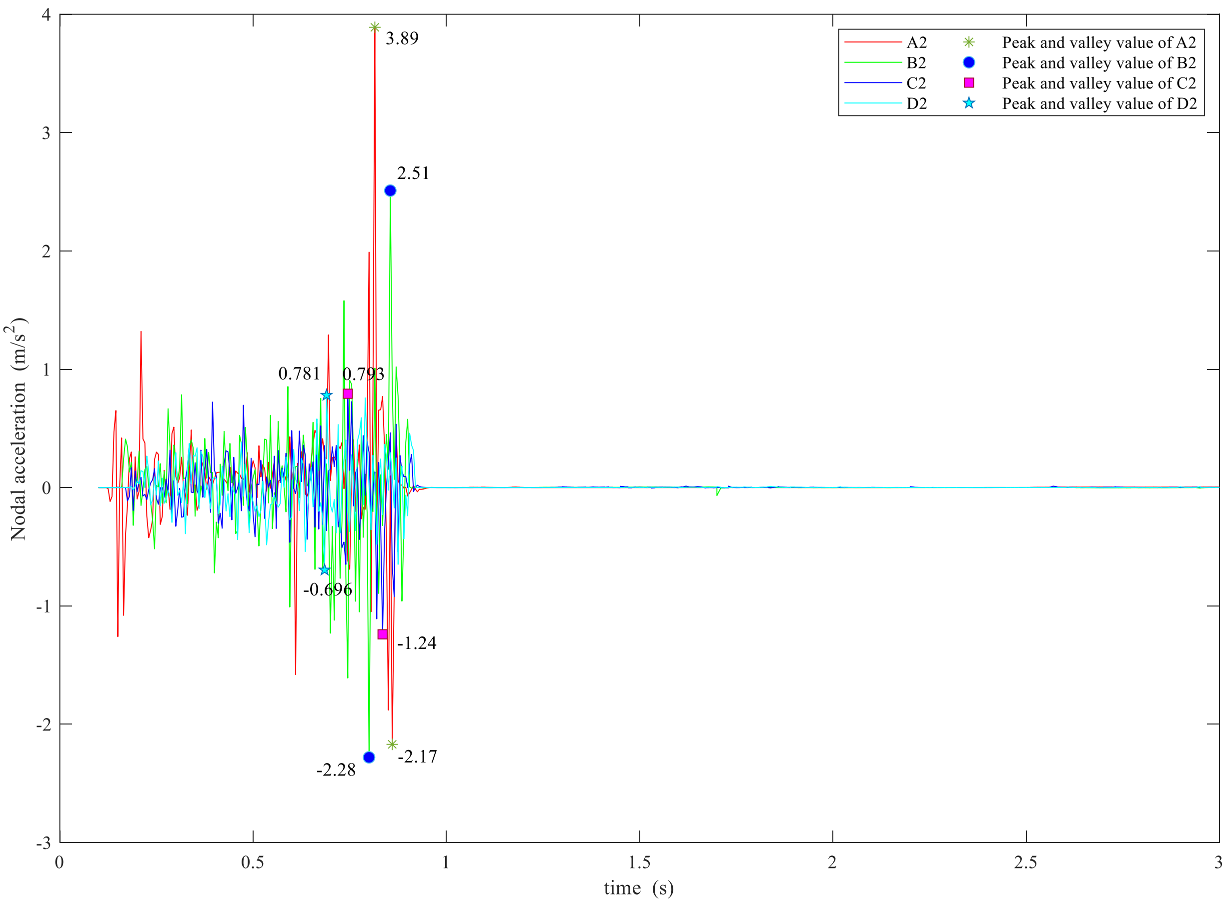

Figure 7. Z-direction acceleration curve of A_2, B_2, C_2, D_2

Table 2. A_2, B_2, C_2, D_2 acceleration effective value and decibel conversion value

Node number	Acceleration effective value(m/s2)	Z vibration level decibel value(dB)
A_2	0.2887	109.21
B_2	0.2730	108.72
C_2	0.1587	104.01
D_2	0.1310	102.34

From Figure 7 and Table 2, it can be seen that when the width and depth of the soil particle node are the same, the farther the node is from the length of the pile, the smaller the peak and valley value of vibration acceleration, the smaller the effective value of acceleration, and the Z vibration level in decibels. The smaller the number is, it means that the soil near the pile has a stronger disturbance effect, and the effect will decline as the distance increases, showing a state of attenuation of the vibration wave.

4. Analysis of Results

The pile sinking test was selected on the site of Shanghai Zhenzhong Company. The experimental equipment is shown in Figure 8 and Figure 9.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202201_8(1).0052

Figure 8. Pile driver prototype

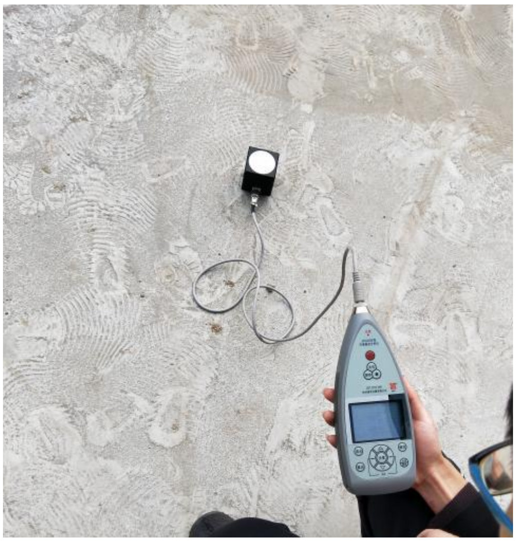

Figure 9. AWA6256B+ environmental vibration analyzer

The experimental data analysis is shown in Table 3 and Figure 10. The Z vibration level generated by the new type of vibratory hammer decays continuously with the increase of the pile distance, and the VLz in each measuring point meets the urban area environmental vibration level standard.

Table 3. VLz of each measurement point on the horizontal oscillating pile driving site

number	Distance (m)	First (dB)	Second (dB)	Third (dB)	Fourth (dB)	Fifth (dB)	Mean (dB)
1	5.0	73.21	70.75	71.40	71.06	70.26	71.34
2	9.5	67.27	68.65	66.32	63.91	66.02	66.43
3	14.0	66.95	65.87	62.02	61.84	63.58	64.05
4	18.5	62.61	58.35	59.71	62.04	62.16	60.97
5	23.0	63.69	59.73	62.16	58.19	59.16	60.58

 Volume 8 Issue 1, 2022
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6	27.5	62.34	58.08	59.73	57.08	54.30	58.31

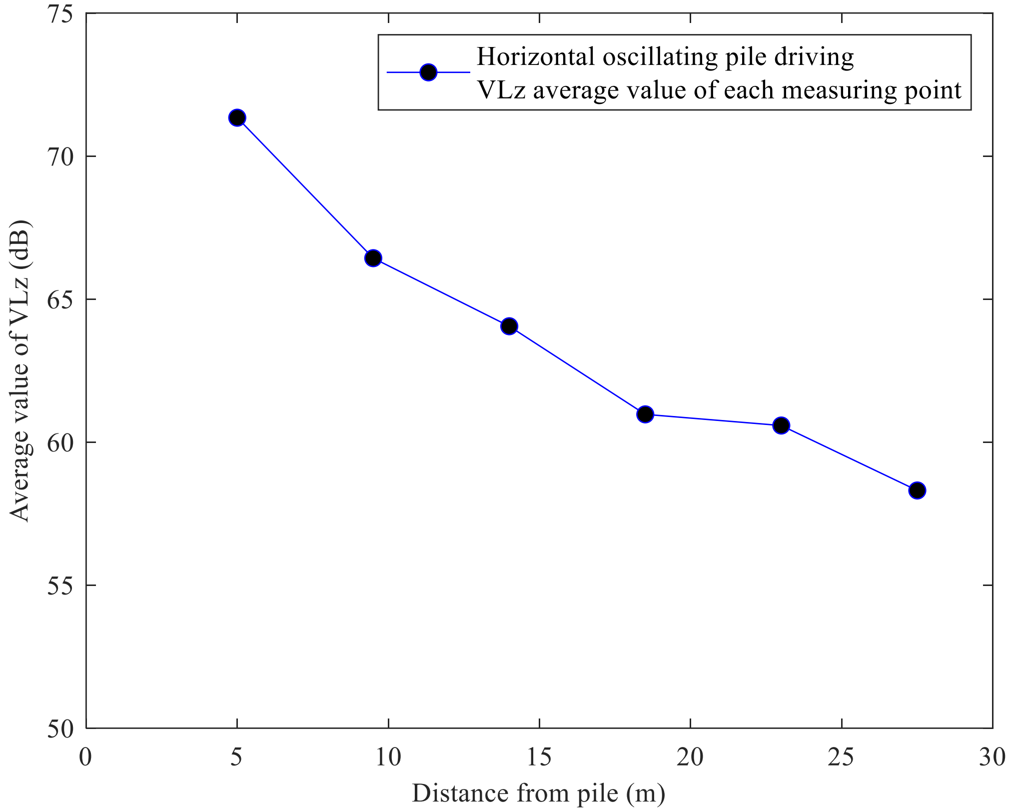

Figure 10. Line graph of VLz average value of each measuring point

5. Conclusion

1) A new type of horizontal vibration oscillating hammer is proposed, and its working principle is explained in detail. Its unique vibration exciter can not only provide a large sinking force, but also bring a small vibration effect.

2) The dynamic model of the pile-soil vibration system during the operation of the oscillating pile was established, and the simulation was carried out with Ls-Dyna software, and the experiment was done in Shanghai Zhenzhong Company. According to the equivalent stress cloud map of the ground, the new type of vibratory hammer has a smaller impact on the deformation of the soil than the traditional one. According to the acceleration curve and experimental data, it can be seen that the vibration generated by the new type of vibratory hammer during pile sinking is attenuated and conforms to National environmental vibration level standards.

In summary, the horizontal oscillating vibratory hammer can play an important role in offshore wind power pile sinking. Under the general situation of the country's advocacy of green environmental protection, it will surely stand out by virtue of its advantages such as small impact on soil deformation and low vibration. The development of wind power is of great significance.

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