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Comparative Efficiency Investigation of Various Types of Dynamic Influences on the Dipped Pile

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Abstract: This article investigates different types of dynamic influences on the steel pile dipped into solid water-resisting soil as the excavation fencing is constructed. In order to solve this task, an experiment is carried out on a construction site, with dipping a pile, with the following types of dynamic influences: driving in with a diesel, mechanical and hydraulic drop hammers (with the frequency, respectively, 50; 15-20; 100 hits per minute); by the method of vibrational immersion with the frequency of oscillation 1440 per minute and with the use of a vibrational pile driver with the frequency of 420 hits per minute. Vibrational-percussive pile driving was done with a free-falling springless vibrational pile driver weighing 4.7-6.7 tons and with the relation to the driving force from 0.25 to 0.36. Using these methods, 4-6 piles of flat profile and u-shape, with the length of 8-11 m were driven into the cushion. As a result of experiments aimed at finding the criterion of the maximum speed and depth of pile driving without significant deformation, the efficiency was estimated for percussive and vibrational-percussive methods with increased frequency of hits and a small height of dropping the hammer. Such result can be explained by the changing character or resistance in the solid soil against the pile entering it. With a higher frequency, fatigue loading of the soil takes place under the tip of the driven pile, which, in its turn, crushes the monolith body of the soil and decreases the point resistance against the pile.

Key words: Steel pile · Solid soil · Drop hammer · Vibrational pile driver · Frequency of oscillation and hits · Energy of hit

INTRODUCTION

In modern construction, deep excavations are widely used. With this in mind, special fencing for excavations are necessary, so as to serve as a water-and soil-resisting barrier and also have sufficient strength to withstand the active pressure of the neighboring soil caused by the movement of construction machinery, storage sites etc. The construction experience showed that this purpose is best achieved with the fencing made from steel piles with different cross-section profiles; this method is the most technological as compared to other methods (trench walls in the soil, fencing made from cutting or tangent bored piles, fixing the soil with the method of jet cementing etc.), judging by the criteria of cost, quickness of works and the area needed to install the technological equipment [1, 2].

The pile needs to be driven to the sufficient depth, so that the lower tip of the pile entered the layer of solid water-resisting soil, which is also needed to prevent the underground water into the excavation.

However, the experience of the previous experiments showed that the task of driving the piles into solid soils cannot be solved by using traditional methods [3]. Thus, using high-frequency vibrational pile driving and percussive methods used when driving high strength piles is not suitable; in the former case, it does not ensure the required driving depth, in the latter case, it causes deformation of the pile in the form of loss of longitudinal stability, breaking cushions, deformation of the fencing line etc.

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Table 1: Technical parameters of immersed piles

Pile profile	Designation	Cross-section size, mm Width (between cushions)	Height	Sheet thickness	Cross-section area, cm²	Weight of 1 m, kg
Flat	ShP-1	400	-	10	82	62.6
U-shaped	ShK-1	400	75	10	64	49.0
As above	L-IV	400	204.5	12-14.8	94.3	74.0
As above	L-V	420	196	15-21	127.6	100.0

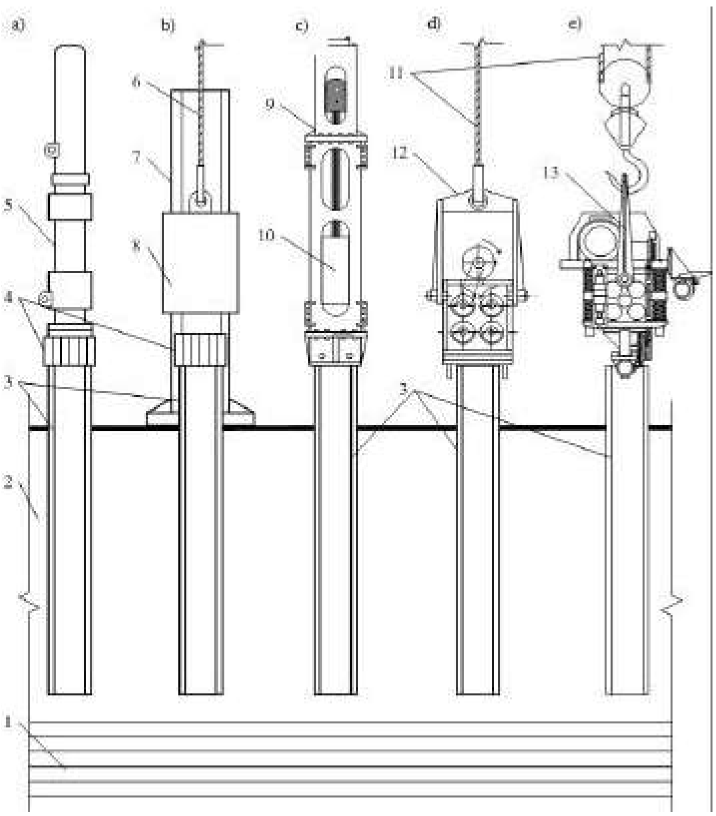


Fig. 1: Technological schemes of pile driving during experimental works: a, b, c-driving with, respectively, diesel, mechanical and hydraulic drop hammers; d, e-pile driving in the vibrational-percussive and vibrational modes, respectively; 1-solid water-resisting soil, 2-upper layer of soft soils, 3-pile, 4-cap block, 5-diesel drop hammer, 6-hammer winch cable, 7-hammer support, 8-free-falling mechanical drop hammer, 9-hydraulic drop hammer, 10-percussive element of the drop hammer, 11-crane hook, 12-free-falling springless vibrational pile driver, 13-vibrational pile driver.

In order to estimate the comparative efficiency of different types of dynamic influence, the article considers the results of the experiments that make it possible to select the optimal technology of driving piles into solid water-resisting soil.

Experimental works were carried out at the construction site on pile driving; steel piles of the following profiles were used: U-shaped Larsen-IV, Larsen-V, ShK-1 and flat ShP-1. Parameters of piles are presented in table 1.

Soils of the experimental site are represented with the following series: backfilled sand (0.0-2.0 m); peat (2.0-2.2 m); fine sand with gravel inclusions (2.2-3.0 m); moraine loams, solid and semi-solid, with gravel and rubble (from 3.0-4.0 m).

The purpose of the experiments was investigation of comparative efficiency of different types of dynamic influence when driving a pile into the layer of solid loams with the following physical-mechanical characteristics: solidity 2.72 g/cm³, consistency-0.22, module of deformation 36 MPa, filtration factor 0.05 m/day [4].

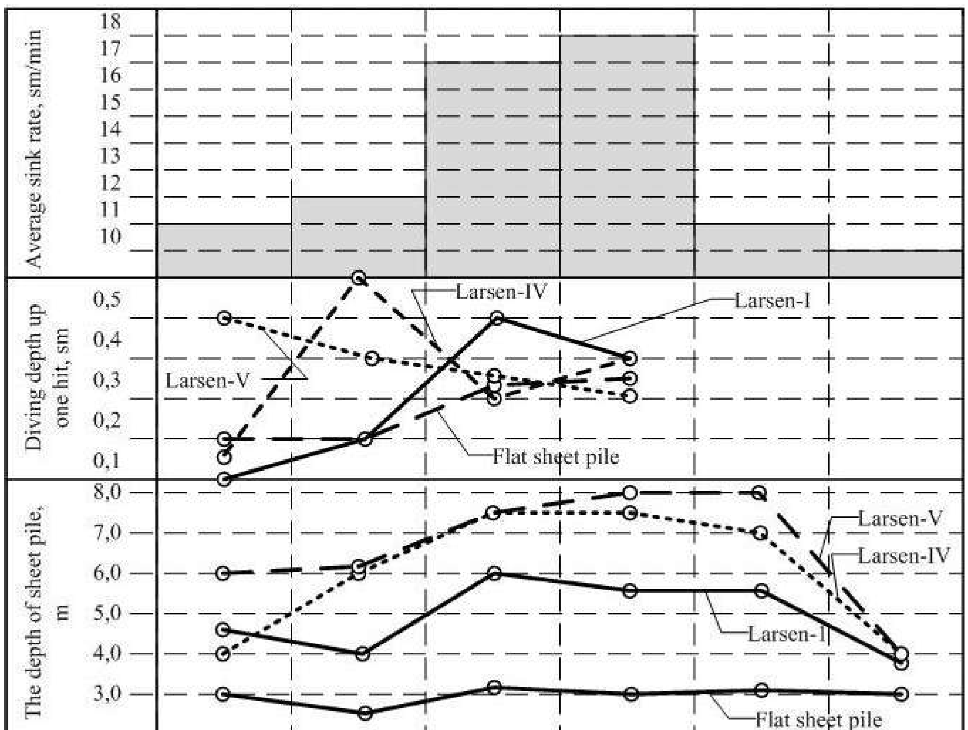
Table 2: Comparative results of pile driving

Parameter designation	Method of pile driving: Driving with mechanical drop hammer, with the weight, tons: 3.5	5.65	Driving with diesel drop hammer	Driving with hydraulic drop hammer, m	Vibrational pile driving V-402	Vibrational-percussive pile driving VP-1
1	2	3	4	5	6	7
A. U-shaped piles: Larsen-IV						
Max. depth of pile driving, m	4.13	6.0	7.5	7.5	4.0	7.0
As above into the layer of loam	1.13	3.0	4.5	4.5	1.0	4.0
Terminal failure, cm	0.1-0.2	0.5-0.6	0.3	0.4	-	-
Speed of pile driving, cm/minutes	11-12	12-13	17	17-20	8-13	10
Pile driving: Larsen-V						
Max. depth of pile driving, m	6.1	6.2	7.5	8.0	3.7	7.0-8.0
As above into the layer of loam	3.1	3.2	4.5	5.0	0.7	2.5-3.0
Terminal failure, cm	0.4-0.6	0.2-0.6	0.2-0.5	0.3	-	-
Speed of pile driving, cm/minutes	12	12-15	17	17-20	8-13	10
Pile driving: ShK-1						
Max. depth of pile driving, m	4.66	4.0	6.0	5.5	3.7	5.5-6.0
As above into the layer of loam	1.66	1.0	3.0	2.5	0.7	2.5-3.0
Terminal failure, cm	0.1	0.2	0.5-0.6	0.4	-	-
Speed of pile driving, cm/minutes	10	11-12	14-15	16	8-13	9-11
B. Flat pile ShP-1						
Max. depth of pile driving, m	3.0	2.5	3.2	3.0	3.0	3.0-3.2
As above into the layer of loam	0	0	0.2	0	0	0-0.2
Terminal failure, cm	0.2	0.2	0.3-0.4	0.4	-	-
Speed of pile driving, cm/minutes	10	11-12	14-15	16	8-13	9-11

Pile driving was carried out by the following methods:

- mechanical driving with a free-falling drop hammer weighing 3.5 tons and 3.65 tf with the frequency of drops 15-20 minute^{-1}. The energy of hit 17.5 kJ and 18.2 kJ. The amount of energy applied onto the end of the immersed pile a per minute was 350 and 364 kJ;
- driving with the use of a tube diesel drop hammer with the frequency of drops 50 minute^{-1} and the mass of the percussive element 1.8 tons, the total weight of the drop hammer 3.65. The height of drop of the percussive element 3 m. The energy of hit 48 kJ. The amount of energy applied onto the end of the immersed pile a per minute was 2400 kJ;
- driving with the use of a hydraulic single-action hammer with the mass of the percussive element 4.0 tons (the total weight of the drop hammer 6.2 tons) with the frequency of drops 100 minutes^{-1}. The height of drop of the percussive element drop 0.1-0.8 m. The energy of hit 20 kJ. The amount of energy applied onto the end of the immersed pile per minute was 2000 kJ;
- vibrational pile driving with the pile driver V-402 weighing 2.74 tons, operating in the vibrational mode with the frequency of oscillation 1440 minutes^{-1} and the amplitude 25 mm. Such mode means solid fixation of the vibro-exciter to the pile with the help of a hydraulic clamp;
- vibrational-percussive pile driving with a vibrational pile driver VP-1 weighing 4.7 tons, rigged for operating in the mode of free-falling springless vibrational pile driving with the frequency of hits 420 minutes^{-1} and amplitude of oscillations 20.6 mm. During the experiments, the weight of the vibrational pile driver was gradually increased to 6.7 tons. The energy of hit against the butt of the immersed pile was 1.4 kJ. The amount of energy applied onto the end of the immersed pile per minute was 588 kJ. Such vibrational-percussive method of pile driving does not mean solid fixation of the vibro-excited with the immersed element and is similar to the operational mode of modern hydraulic pile drivers. Technological schemes for experimental pile driving are shown in fig. 1.

All the above-listed methods were used to drive 4-6 piles of each profile with the length 8-11 m into the cushion. Comparative results are presented in table 2.



The mass of the striker hammer, t	3,5	5,65	1,8 (3,65)	4,0 (6,2)	4,7-6,7	2,71
Type the hammer	Power hammer		Diesel hammer	Hydraulic hammer	Vibrator BP-1	Vibrator BP-402
Impact frequency, min^{-1}	15-20	15-20	50	100	420	1440
The impact energy, kJ	17,5	18,2	48,0	20,0	1,4	–
The impact energy min, kJ	350	364	2400	2000	588	–
Method of driving	Driving with a low incidence of stroke				Vibro drop with a low frequency	Vibration at high frequency

Fig. 2: Diagrams of parameters of the experimental pile driving.

The results of the experiments in the form of diagrams of depth change, speed change and failures of experimental pile driving are shown in fig. 2.

The criterion to stop driving were deformations of the top end of the pile, loss of longitudinal stability or settling from one hit (failure) 1-2 mm [5]. The necessity to stop works is related to the fact that when such events take place in solid soils, the lower zones of the pile become deformed, cushions break and fencing loses integrity [6, 7].

RESULTS

As a result of the experiments, it is estimated that the maximum depth of driving U-shaped piles Larsen-IV, Larsen-V and ShK-1 with a mechanical drop hammer was 5.5-6.2 m, including the thickness of the moraine loams by 2.5-3.2 m. Increasing the weight of the drop hammer caused significant deformations of the top end of the pile without increasing the depth of pile driving. In some experiments, with the weight of the drop hammer 5.65 tons and a relatively low height of drop 0.3-0.5 m, by the end of the pile driving period, the deformations of the top of the pile were so high that the experiment could only be carried on if the deformed part of the pile was cut away.

Driving piles of any profile with the vibrational pile driver V-402 in the non-percussive mode ensured preservation of the driven elements without any deformations. However, as the pile reached the roof of moraine loams, or, sometimes, as the pile immersed into such soils by 0.1-0.5 m, the pile could be driven no longer.

The oscillograph showed that the amplitude of oscillation of the pile during penetration into the loam was 6-8 mm, which was enough to overcome the lateral friction and did not ensure overcoming the point resistance of solid loams.

As the vibrational pile driving did not ensure the acceptable results, additional experiments were carried out on vibrational-percussive pile driving with the unit VP-1 in the free-falling springless mode. In order to estimate the efficient and stable operation mode, the weight of the vibrational pile driver was sequentially set to 4.7; 5.7 and 6.7 tons. Each step was characterized by the relation to the driving force, respectively, 0.25; 0.1 and 0.36.

Such settings made it possible to drive the U-shaped pile by 2.5-4.0 m into loams at the speed 10 cm/minutes without critical deformations. Increasing the weight of the vibrational pile driver ensured improved stability and prevented swaying. Among those methods that were tested, the mode of pile driving with a hammer weighing 6.7 tons was the most optimal. In this mode a flat pile ShP-1 was driven. Similarly to the case with the percussive driving, in that mode the pile was only driven to the roof of the loam and then deformation started.

CONCLUSIONS

As a result of the experimental works, we can state about the efficiency of the percussive and vibrational-percussive method of the dynamic influence on the U-shaped piles with enough strength (Larsen-IV and Larsen-V) in solid soils layers. The character of depth and speed of the pile shows that it is optimal to use percussive modes with the frequency above 100 hits per minute with the summed energy of hit at least 2000 kJ per minute and vibrational-percussive modes with the frequency of hits above 420 per minute with the ratio of the total weight of the hammer to the driving force-0.4. These modes of dynamic influence have relatively low energy of single hits and increased frequency, which prevents damage of the driven pile, whereas reasonable speed is maintained.

The obtained result can be explained by the change in the character of solid soil layers resistance as the pile is driven into it. At higher frequency of hits, the fatigue load of soil takes place under the tip of the immersed pile, which, in its turn, crushes the monolith body of the soil and decreases the point resistance against the pile. Practical use of the results of experimental investigations carried out by the author will make it possible for the designers to select the most optimal types of dynamic influences on the immersed steel pile for each particular case of engineering-geological conditions and select the most efficient operational modes of pile drivers [8-10].

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