New Data on the Application of Vibratory Machinery to Foundation Operations

Perfectionnements récents dans l'emploi des vibrateurs pour les constructions de fondations

by Doctor O. A. SAVINOV (All-Union Scientific-Research Institute of Hydrotechnics and Sanitary Engineering, 50-b Sadovaja str., Leningrad, USSR)

Summary

The author presents new data on the application of vibratory machinery to foundation and other building operations. The information was obtained during the period between the last Conference and the present one.

The author describes methods proposed by Soviet engineers for sinking large precast reinforced concrete cylinders, ways of laying pipes without trenches ; as well as methods of excavation and of pumping water from boreholes.

At the Forth International Conference D. D. Barkan, presented a paper on a method of driving piles by vibration ; the problem of further development of this method is discussed by the present author.

Sommaire

Dans ce rapport sont indiqués les résultats de recherches expérimentales sur l'emploi des vibrateurs dans les travaux de fondations et de construction. Ces recherches ont été effectuées en U.R.S.S. depuis le Quatrième Congrès International de la Mécanique des Sols et Travaux de Fondations.

Un court aperçu est donné sur les méthodes élaborées par les spécialistes soviétiques pour foncer des puits en grands diamètres à parois minces, placer des canalisations sans avoir à faire de tranchées, excaver les sols, pomper l'eau dans les forages etc., et aussi sur les vibrateurs employés pour ces travaux.

Le rapport reprend ensuite la question de l'enfoncement des pieux par vibration qui avait déjà fait l'objet d'un rapport de D. D. Barkan au Quatrième Congrès.

Soviet engineers have experimented with vibration methods over a wide field. They have proposed new vibro-methods and vibrator units for driving large thin-shelled reinforced concrete cylinders, laying pipes without trenches ; excavating pits for isolated foundations, for loosening soil during excavation ; for mechanical loading of rock soils ; for placing concrete plates for road and other prefabricated constructions, and for pumping water out of boreholes.

In addition to pile driving by vibration, soil compaction and hole drilling have made considerable advances.

The method of sinking thin-shelled concrete cylinders of from 1·5 — 6 m diameter under bridge-piers is a very interesting development. At present over 20 large bridges are under construction and some have already been completed in the U.S.S.R. ; for example bridges accross the Volga, the Ural, the North Dvina, the Don, the Ob, etc. Over 12·000 m of cylinders have been sunk within the last few years.

Vibratory machinery in bridge building is very effective. For example : 73 supports for bridges of 20 m long prefabricated shelled cylinders were erected within four months. Vibrator units were also used for driving cylinders for bridge piers across the Jangtse River with the help of Soviet engineers. The maximum length of bridge is 3 km, and the foundations have been sunk to depths ranging from 36 to 76 metres ; all these bridges were built within a year.

Different types of low-frequency vibrators are used for driving shelled cylinders in bridge building in the U.S.S.R. The shelled cylinders are driven to a depth of 10 — 15 m by a vibrator only ; depths of 20 to 25 m are achieved by periodical removal of the soil from the pit ; and below 25 m the same procedure is followed, with allowance for scour.

Researches undertaken by D.D. Barkan, Ju. I. Nejmark, A.S. Golovatchjoff and by the author have made it possible to increase the capacity of the vibrator by using the resonance effect. The most powerful vibrators — V.P.-160, V.P.-250 (designed by A.D. Prokhorov and K.S. Silin) and V.D.D. — 3 now under construction (designed by M.G. Tceitlin), — are equipped with a device for changing the vibration frequency and the unbalanced moment. B.P. Tatarnikov designed an experimental resonant vibrator unit N.V.P.-56, with a constant frequency of vibration, for driving cylinders of 3 m diameter into soil, having a depth of from 20 to 25 m. The vibration frequency was selected for particular soils (a thick layer of loose clay soil). It had to be a little lower than the oscillation frequency of cylinder itself, considered as a solid body within a flexible environment. (See vibrator N.V.P.-56 in Fig. 1).

Tests showed that at a disturbing force of only 50 tons the vibrator can drive 60-ton shells into loose water-saturated clay soil to a depth of 20-25 m without previous excavation. Extensive research is now under way to improve the mechanical setting up of low-frequency vibrators at the most effective (resonant) conditions in the process of operation.

As a result of using vibration, it has been possible to eliminate heavy pier footings almost entirely.

Thin-shelled reinforced concrete cylinders are widely used in hydraulic and industrial engineering.

A new interesting method of laying pipes without trenches has been worked out by A. Ja. Luskin, based on the application of axial vibrations to a tube.

The vibrator unit (Fig. 2) consists of a vibrator (1) with central hole and clamps for inserting and fixing the pipes ; the carriage 2 supports the vibrator unit on a spring damper ; the frame 3 and the winch transmitting a piercing force to pipe 5 through wire ropes 4 attached to the carriage.

The first model of the machine was designed for laying pipes 30 m long and 200 mm in diameter having a maximum weight of half a ton.

Fields tests of vibrator units, carried out in different types

Fig. 1 The vibrator unit NVP-56 (designed by B. P. Tatarnikov).
Vibrateur NVP-56 (étudié par B. P. Tatarnikov).

Fig. 2 The vibrator unit for laying pipes (designed by A. Ja. Luskin).
Vibrateur pour mettre en place les tuyaux (étudié par A. Ja. Luskin).

of soils, showed good results. The average penetration speed reached 0·5-0·7 m per min, the piercing force varying from 2·5 to 2·8 tons.

A more powerful unit is now being tested with the help of which it will be possible to lay pipes of 400 mm diameter weighing up to 2·5 t.

With the help of D.D. Barcan, P.S. Shkurenko investigated the use of excavating hoppers with vibrating cutters; she proved it to be effective. In these tests the vibrating cutters were connected to the excavating hopper of 0·75 cub. m capacity.

The tests proved that the depth of cutting through frozen soil was 18 cm as compared with only 3·6 cm when the work was done without vibration. Satisfactory results were obtained in the mining of soft rock soils. The average consumption of electric energy was 25·3 kW/cm when excavating the soil without vibration, and 9·3 kW/cm when using vibration.

A modification of a vibro-grab has been designed for excavating holes 4 m deep and 630 mm diameter, by A.S. Golovachjoff and B.U. Chernjaev. A general view of this, mounted on a mobile crane is shown in Fig. 3. It consists of the frame 1, equipped with screw outriggers 2, vibrating hammer 3 and tube vibrograbs 4. After exhaustive tests a design of vibrograb was developed which facilitated the excavation of both solid soils such as clay and frozen ground as well as loose waterlogged sand. The vibrating hammer is equipped with two 14 kW electric-motors, the weight of its impact component reaching 590 kg.

The complete cycle of the operation of excavating a 1·2

Fig. 3 The vibro-grab unit for excavating trenches (designed by A. S. Golovatchjoff, V. I. Chernjajeva and others).
Vibrateur à bêches pour creuser des tranchées (étudié par A. S. Golovatchev, V. I. Tcherniaiev et autres).

cub. m trench with this vibro-grab takes 7-10 min. in sand soils and 12-15 min. in loam.

In recent years methods of soil compaction by vibration have been widely developed.

A series of new designs of vibro-rollers (Fig. 4) of powerful depth hydro-vibrators, pneumatic-pulsating compressors (Fig. 5) and other machines have been constructed. These units were successfully employed on large water power schemes. On the construction of the Stalingrad hydroelectric station the amount of soil compacted by vibration was about 12 mln. cubic metres.

Fig. 4 The vibro-roller PVK-25 (designed by A. A. Smoljar and V. J. Somov).
Roulette vibrante PVK étudiée par A. A. Smoliar et V. J. Somov).

Fig. 5 Compressed air machine for compacting (designed by D. A. Trifonov-Jakovlev).
1. piston pulsator; 2) pipes; 3) flexible hose.
Compacteur pneumooscillant (étudié par D. A. Trifonov-Jakovlev).
1) piston oscillant; 2) tuyaux $d = 1{\cdot}5''$; 3) tuyaux flexibles.

Vibrator units have been widely employed in civil engineering. For example, V.M. Usakowskji developed a vibro-pump comprising a pipe with a reversible valve at its lower end, and a vibrator imparting axial movement at its upper end.

The relationship between capacity, frequency and amplitude of oscillation is shown in Fig. 6. The curves show that doubling of the rotational speed at a constant amplitude increases the capacity by 30-50 per cent; but doubling of the amplitude to a constant number of revolutions increases the capacity by 70-150 per cent. Consequently, in order to increase the capacity of the pump it is necessary to increase the amplitude of oscillation.

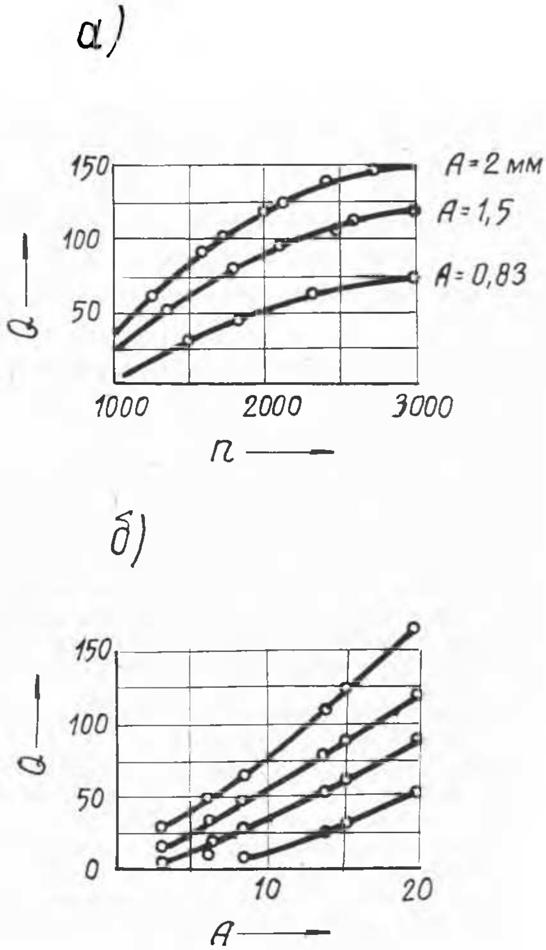

Fig. 6 The efficiency Q of a vibro-pump (mm/sec) in relation to speed of the vibrator and amplitude of the pipe oscillation.
Relation entre la productivité (q l/sec) d'une vibro-pompe :
(a) le nombre (n/min) d'oscillations ; (b) et l'amplitude (D mm) de l'oscillation du tuyau).

It has been proved that 50 per cent of the energy used during water-lifting is lost in the vibrator itself. This proves that it is possible to obtain a considerable increase of efficiency.

A vibro-pump for water-lifting from the depth up to 200 mm has been designed and is undergoing tests at present.

Improvement of vibratory methods of driving piles are mainly directed towards increasing the efficiency and durability of vibrator units.

Research by Soviet engineers has proved that during recent times vibratory machinery has been successfully used for a very wide range of civil engineering work.

One important method of increasing efficiency is by using resonance when determining the vibrating parameter.

The correct choice of static pressure is also very important. It can be seen in Fig. 7.

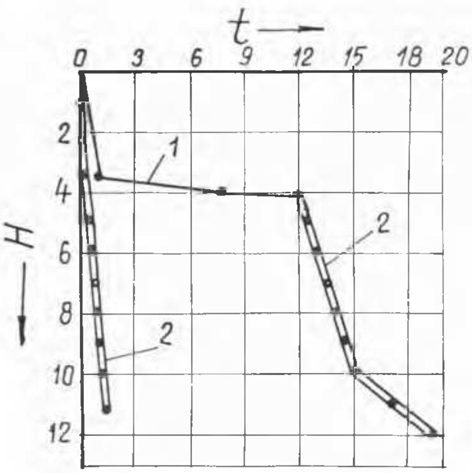

Fig. 7 Relationship between depth of driving a pile and the time of driving.
1) without a load; 2) with a load.
Relation entre la profondeur (Hm) des pieux et le temps (t/min).
1) sans charge; 2) avec charge.

The chart was drawn from experimental data obtained while driving 12-13 m timber piles with an average diameter of 27 cm into flexible clay soils. At first the 1·5 ton vibrator without load was mounted in pile 1, with the help of this vibrator the pile was driven to a depth of 4 m within 8 min. Then the vibrator was switched off, and an additional weight of 4 tons was transmitted to the vibrator through a spring damper, which enabled the pile to be driven to its full depth in 7 1/2 minutes.

After that piles were driven by vibrators under load to a depth of 12 m within 1·25-1·5 minutes.

Thus, if the periodic force exerted by the vibrator is correctly chosen, sufficient static load will be transmitted to the pile, and it can be driven very quickly under any soil conditions. Yet tests proved that when sinking structures of relatively large cross section this load must be very large.

The author together with A.Ja. Luskin proposes to use a part of the pile driver or crane as load and include it in the operation with the help of a winch. According to these principles mobile units V.V.P.S. 20/11 and V.V.P.S. 32/19 for driving concrete piles with a cross section equal 40 × 40 cm and length of 6 to 10 m were designed for constructing the pile supports for transmission towers; one such vibrator unit is shown in Fig. 8.

These units are constructed in the following way.

The boom of the pile driver is mounted on a tractor with the help of a changeable frame; when the tractor is running the boom is turned to a horizontal position.

The generator is installed on the frame and is powered by the tractor motor. Above the generator there is a two-drum winch, with the help of which vibrator and pile are lifted, and pushing force is transmitted to the pile. The value of the force in the vibrator units V.V.P.S. 20/11 is 11 t and in vibrator units V.V.P.S. 32/19-19 t. The pushing force is transmitted to the vibrator through a spring system. The application of

Fig. 8 The unit VVPS-20/11 (designed by B. S. Malkov, G. Je. Metta, Ju. I. Smilovitskii and others).
Unité VVPS-20/11 (étudiée par B. S. Malkov, G. E. Mett, I. I. Smilovitzky et autres).

vibro-pushing installations under different soil conditions turned out to be very effective. At present these vibrator units are in mass production. In vibrating hammers the vibrator is not connected with the driven body but the hammer strikes the body during its movement.

There are many different designs of vibrating hammers but only two of them are being employed in URSS.

The first design is the simplest one, an ordinary vibrator loosely resting upon the driven body. The second design consists of a cap fixed on the driven body and the vibrator itself is connected with the cap through springs; one such vibrating hammer is shown in Fig. 9.

Vibrating hammers have two advantages in comparison with vibratory machinery — their driving capacity is higher and they require less power for their work. But they drive piles slower than vibratory machinery. In Fig. 10 the curves show the change of driving speed of a concrete pile 35 × 35 cm in section and 12 m in length into compact waterlogged sand with the same low-frequency vibrator, but one was fixed to the pile (curve 1) while the other rested upon it (curve 2). These curves prove that the average driving speed is nearly twice as great where the vibrator is fixed to the pile, but at the same time the depth of sinking does not exceed 8 m, whereas if the vibrator simply rests upon the pile the sinking depth is more than 12 m. The necessary power in the first case is 80 per cent higher than the second.

Methods of construction that have a low end resistance such as sheet piling, driven into loose soils, concrete pile-shells, driven with previous soil excavation out of the trench etc. should be driven by vibrators of a higher capacity, and structures with relatively large cross section should be driven by vibrating hammers.

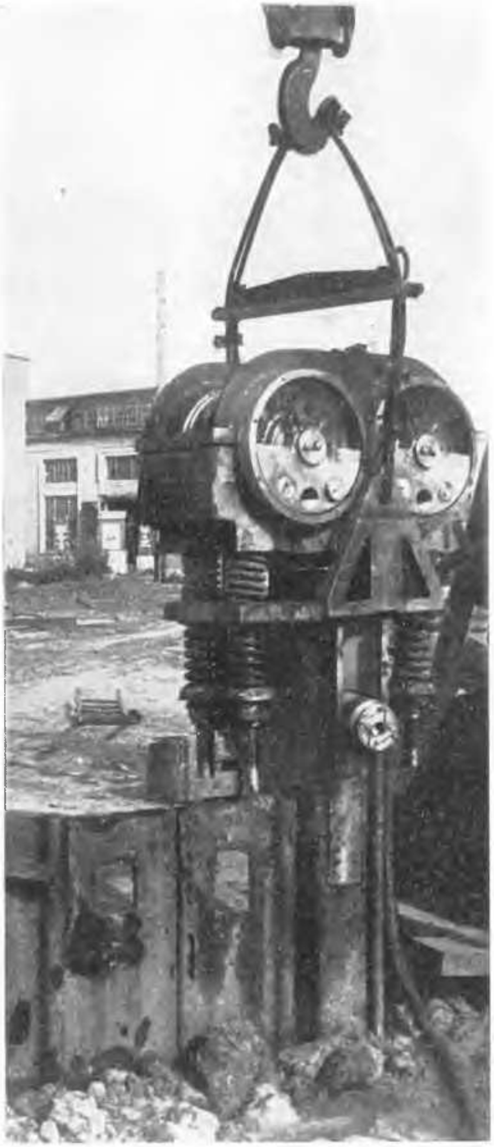

Fig. 9 Vibro-hammer VMC-3A (designed by S. A. Tsaplin). Vibromarteau VMU-3A (étudié par S. A. Tsaplin).

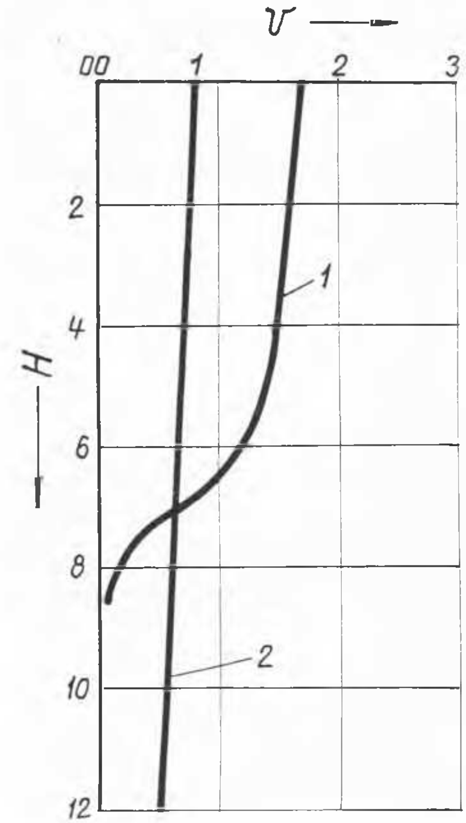

Fig. 10 Change of pile driving speed with time (data obtained by O. A. Savinov and S. A. Osmakov).
1) at vibro-driving; 2) at vibro-impact driving.
Variation de la vitesse (vm) de battage avec le temps (t/sec) (expériences de O. A. Savinov et S. A. Osmakov).
1) battage par vibrateur; 2) battage par vibrateur et marteau.

References

[1] Barkan D. D. (1959). Vibro-method in construction.

[2] Golovatshjoff A. S., Pchelin I. K., Chernjajev V. I. (1960). Experimental research in driving constructions into soil by vibrating hammers. *All-Union Scientific Research Inst. of Transport Construction.*

[3] Kuznetsov A. Ja., Smoliar A. A. (1959). Vibratory machinery used at the construction of the Stalingrad hydroelectric station. *Mechanizatsija Stroit.* N. 3.

[4] Savinov O. A., Luskin A. Ja. Vibratory method of pile driving and its application in different construction operations.

[5] Silin K. S., Glotov N. M., Gretsov A. P., Karpinskii V. I., Prokhorov A. D. Precast reinforced concrete shells for bridge piers.

[6] Tatarnikov B. P. (1959). A low-frequency (resonance) vibrator N.V.P.-56 for driving thin-shelled reinforced concrete cylinders into soil.

[7] Tsaplin S. A. (1959). The theory and application of vibrating hammers. *Proc. of the Inst. of Building Machines.* V. XXIV.

[8] Tseitlin M. G. (1958). The application of rotating and screw oscillation for pile-shells driving. *Proc. of the V.N.I.I.G.S.*, No. 10.