ISSN 2664-9969

UDC 624.1
DOI: 10.15587/2706-5448.2024.310802

Oleksii Vasyliev,
Andrii Yakovenko

DETERMINATION OF THE DENSITY OF THE SURFACE WHICH IS EXPOSED TO VARIOUS WORKING BODIES OF THE VIBRATION PLATE VP-10

The object of research is a vibrating plate with interchangeable working bodies developed by the authors. Vibrating plates are an integral part of small mechanization equipment and are mainly intended for layer-by-layer compaction of various materials, such as sand, gravel, bituminous mixtures, etc. Vibration compaction methods are widely used in the construction of road surfaces and other infrastructure facilities. Self-propelled vibrating slabs are also used effectively in other construction processes such as compaction, trench reinforcement, land work and laying paving slabs. They ensure effective compaction of materials due to vibration.

This paper is aimed at determining the optimal equipment for compaction of materials during the construction of small objects. Analyzing the characteristics of the machines that most affect the quality of compaction, it is also necessary to evaluate their influence in specific conditions. Studies show that for each type of material, a special working body should be selected, taking into account the specific conditions and requirements for compaction, to ensure optimal quality of work.

The authors seek to consider the selection of vibrating plates and their working bodies that best meet the requirements and needs of compaction of various materials on limited construction sites. The analysis of different types of working bodies for different surfaces helps to improve the compaction process and provides optimal conditions for different types of building materials, taking into account their unique properties.

The paper examines the influence of the working body on the processed environment, in particular, analyzes the ability of various factors to influence the quality of material compaction. Special attention is paid to the influence of the geometry and size of the contact area on the sealing efficiency of each material type. Overall, this analysis can significantly improve material compaction strategies in the construction industry, contributing to improved construction quality.

Keywords: *vibration, vibration installation, vibration amplitude, vibration exciter, mathematical analysis, vibration machine.*

Received date: 02.07.2024
Accepted date: 30.08.2024
Published date: 31.08.2024

How to cite
Vasyliev, O., Yakovenko, A. (2024). Determination of the density of the surface which is exposed to various working bodies of the vibration plate VP-10. Technology Audit and Production Reserves, 4 (1 (78)), 26–31. https://doi.org/10.15587/2706-5448.2024.310802

1. Introduction

Compaction of construction materials is an integral part of construction processes. Traditionally, this process was carried out using vibrating plates for vibration compaction of materials. Today, the market offers a wide range of vibrating plates with diesel, gasoline or electric engines. To achieve high compaction quality, it is important to consider the specifics of each type of material [1].

Self-propelled vibration plates are compact mechanized devices used for surface compaction of materials such as sand, gravel, bitumen and other mixtures in the process of roadworks, backfilling of trenches, improvement of territories, as well as laying of paving stones and paving slabs using the method of vibration tamping. These devices can move both forward and backward. They are equipped with a four-stroke gasoline engine for models weighing up to 160 kg, and for heavier models diesel and electric engines are used [2, 3].

When preparing a construction site for sand vibratory compaction, it is important to consider several key factors to ensure optimal results. First of all, sand is poured in a layer of up to 0.6 meters, which depends on the power and weight of the vibrating equipment. For better compaction and dust reduction, this layer must be evenly moistened. It is necessary to pass the vibrating plate over the moistened layer at least three times in order to achieve the required degree of compaction [4].

Compaction of crushed stone is not an easy task due to the variety of its fractions. Before starting work, it is necessary to determine the maximum permissible layer thickness for effective compaction. After four passes of the vibrating slab, crushed stone or gravel should be compacted by 95 % [5].

While laying paving slabs, special rubber or polyurethane linings are added to the working plate of vibration equipment. These actions are necessary to prevent damage and preserve the aesthetic integrity of the created coating.

It should be remembered that the vibration plate should have a small mass within 70 to 90 kilograms. Too much weight of the vibration plate can lead to a violation of the integrity of the paving slab. It is also necessary to monitor the power level of the vibration plate, an increased indicator is the cause of the destruction of the material [6, 7].

Therefore, *the aim of research* is to confirm the effectiveness of the proposed equipment for compacting materials during the construction of small objects. The main task is to prove the choice of vibration plates and their working bodies that would best meet the requirements and needs for compacting various materials on small construction sites.

2. Materials and Methods

The object of research is a vibrating plate with variable working bodies. This article examines the issue of the impact of the working body on the processed environment, in particular, analyzes the ability of various factors to affect the quality of material compaction in different ways.

During the performance of the work were used:
- method of three-factor experiment to determine the most significant parameters that affect the compaction;
- graphical study method for visualization and better presentation of results.

3. Results and Discussion

Based on theoretical studies and design developments, a vibration machine with a replaceable working tool for compacting the soil was created, which is shown in Fig. 1 [8].

The main feature of the created vibration device is its ability to easily move on a non-smooth surface under the influence of a small force.

To determine the type of soil and its degree of compaction in the theory of cutting and earthworks, the classification of soils according to the number of blows inflicted by the impact device is widely used, according to which all soils are divided into categories [9]. The impact device of DorNDI (State Enterprise «National Institute of Infrastructure Development», Ukraine) is used in road construction to assess the bearing capacity of dirt roads in order to determine the need for repair. The design of the impact mechanism is extremely simple and reliable in operation.

Fig. 1. Vibrating plate VP-10

In contrast to the traditional method of determining the type of soil using a DorNDI impact device, another approach can be used to determine the stage of soil compaction by analyzing the operating parameters of vibrations of a vibrating plate, the experimental setup is presented in Fig. 2 [10]. This method provides determination of optimal material compaction and guarantees high quality soil preparation before construction and other works.

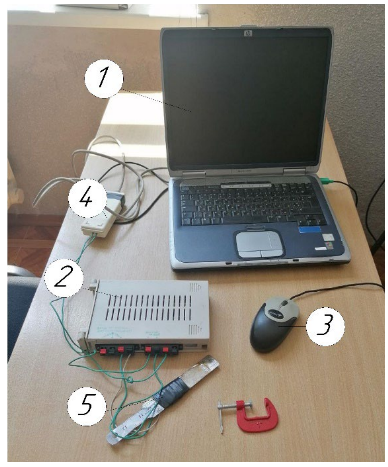
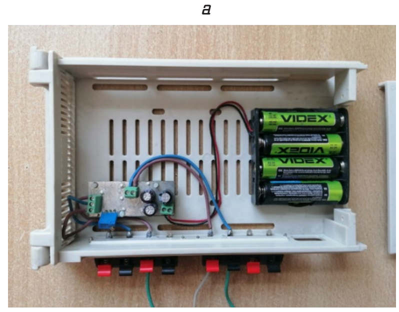


Fig. 2. Laboratory instrument and measuring complex:
1 – computer, 2 – analog-digital converter, 3 – computer mouse,
4 – COM adapter, 5 – strain gauge

The entire system is installed on a printed circuit board (Fig. 3). The connection is made via a DB9 cable with appropriate desoldering used as an extension cord.

a



b

Fig. 3. Analog-to-digital converter with TLC chip:
a – general view; *b* – arrangement of PCB and power supply

The basis of the method is the recording of data from the analog-digital converter during the operation of the vibrating plate, followed by their processing with the help of a computer and a specialized program. The data is displayed on the screen in the form of a diagram and can be saved to a text file for further analysis.

As a strain gauge, a fragment of a steel locksmith's line, which is shown in Fig. 4.

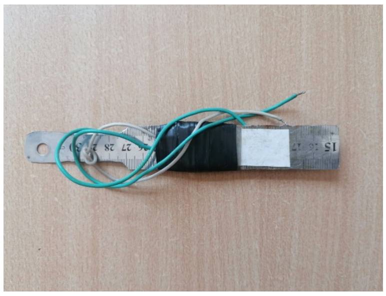


Fig. 4. Strain gauge

The strain gauge is fixed on the frame of the vibrating plate as shown in Fig. 5. When securing the sensor, the tightening force of the clamp screw must be taken into account so that the screw does not deform the strain gauge, as this can lead to inaccurate measurement results.

Fig. 5. Fixing the strain gauge on the frame of the vibration plate

The proposed design of the vibration plate (Fig. 6), with replaceable working bodies (Fig. 7), developed on the basis of theoretical research and design developments, allows choosing the optimal working body for each type of material to be sealed. This significantly improves the quality of soil compaction.

In order to study the action of each working body of the proposed design, experimental measurements of the impact of the vibration plate on the treated medium were made (Fig. 8) and statistical processing and analysis of the obtained experimental data was performed (Fig. 9) [11].

To obtain a reliable mathematical model of the influence of the working body on the material during experimental research, methods of mathematical planning and mathematical statistics were applied.

Fig. 6. Vibration plate with replaceable working elements

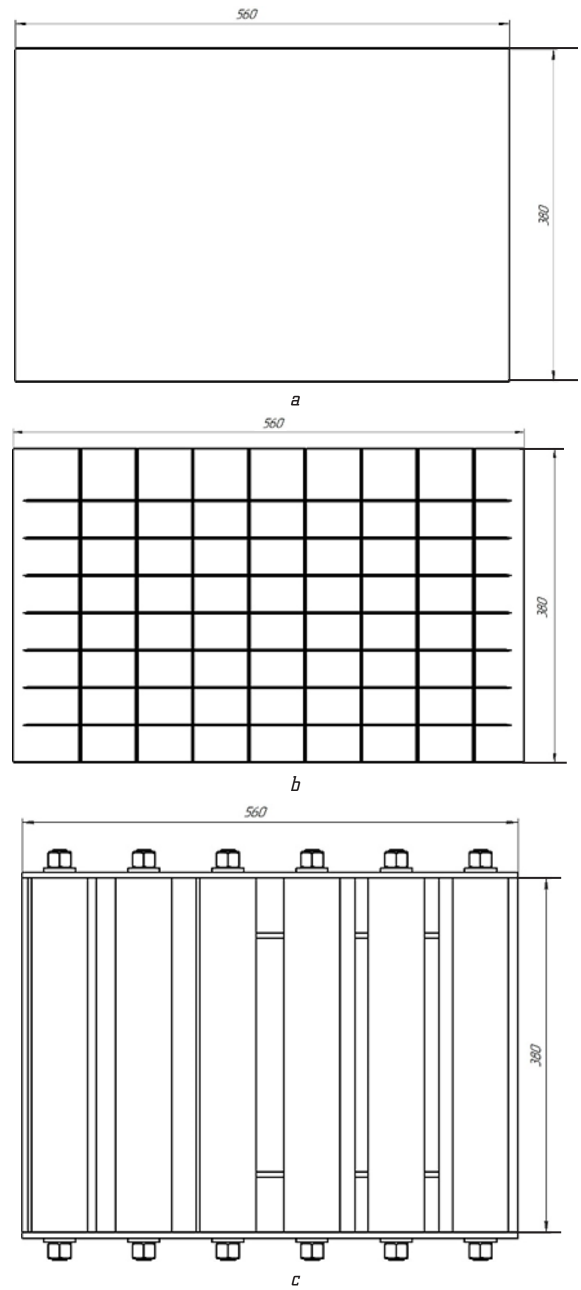
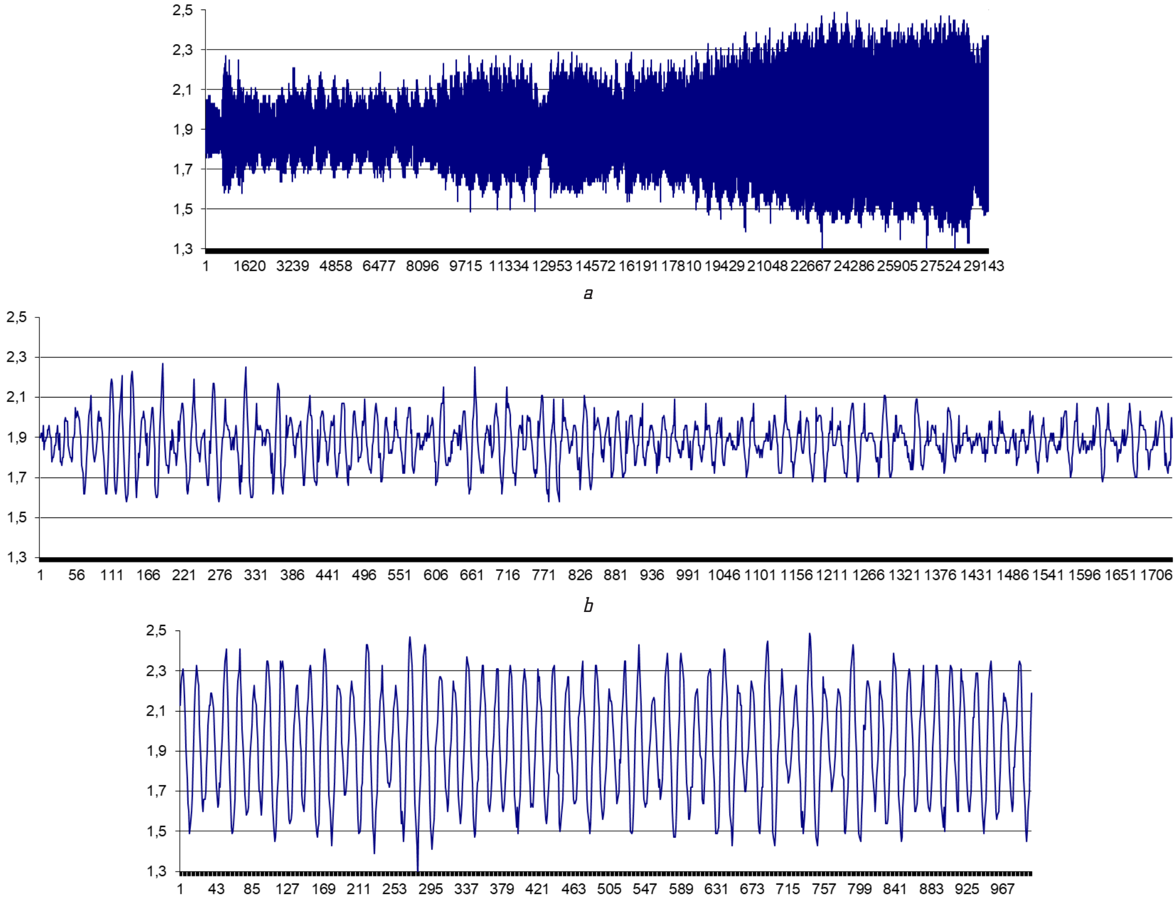


Fig. 7. Vibration plate with replaceable working elements: *a* – flat surface; *b* – grooved surface; *c* – slab with rollers

Fig. 8. Measurement of vibration plate effect on the treated medium

Measurements of the compaction of the material were taken within the change of the initial factors described above, the numerical values of which are given in Table 1.



c

Fig. 9. Graph of vertical vibrations of vibrating equipment: *a* – general vibrogram; *b* – beginning of the vibrogram; *c* – end of vibrogram

Table 1

Ranges of change of initial factors

No.	Factor values	Dimensionality	Designation	Upper level (+)	Main level (0)	Lower level (–)	Variation interval
X_1	Exposure time	c	t	150	90	30	60
X_2	Frequency of rotation	rpm	n	3000	2250	1500	750
X_3	Humidity	%	φ	17	11	5	6

The implementation of this experiment and the processing of the data obtained, allow to obtain a mathematical model of the action of the working body on the material in the form of a regression equation:

$$y_i = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2 + \\ + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3, \quad (1)$$

where y – base compaction; b_0, b_1, b_2, b_3 – regression equation coefficients.

The calculated values of the regression coefficients were tested for significance using the Student's test and found that they are all significant.

Therefore, the regression equation is:

$$y_i = 25.748 + 6.3x_1 + 0.7x_2 + 1.4x_3 - \\ - 2.799x_1^2 - 0.799x_2^2 - 0.299x_3^2 + \\ + 0.125x_1x_2 + 0.625x_1x_3 + 0.375x_2x_3. \quad (2)$$

The resulting equation establishes the dependence of the compaction of the material on the change in the external load on it of the working element of the vibration plate.

This equation is checked for adequacy by Fisher's criterion:

$$F_p < F_{table}, 12.94 < 19.3. \quad (3)$$

It was found that the difference between the corresponding values of the experimental data and those calculated by the regression equation does not exceed the permissible limits and the regression equation with sufficient accuracy reflects the real process of the working body.

Using MathCad software, graphs were constructed showing the effect of three main factors – time, humidity and rotation frequency – on the quality of material compaction.

Graphs of the dependence of the compaction value of the material on the external load on the working tool of the vibration plate are shown Fig. 10–12.

These graphs (Fig. 10–12) allow to analyze in detail how the quality of the seal changes when each of these factors varies, which is extremely important for optimizing the seal process in production conditions.

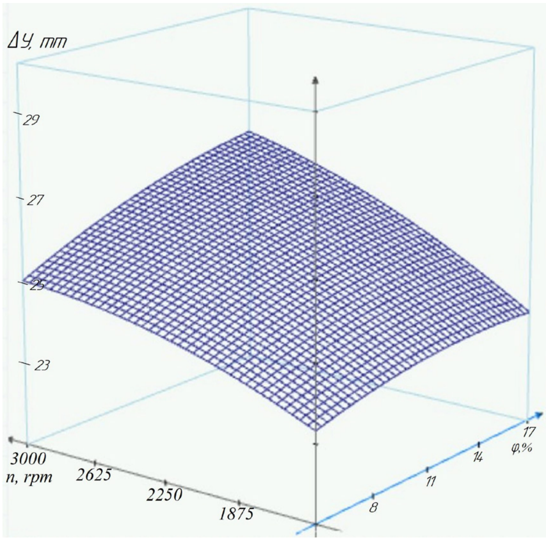


Fig. 10. Graph of the dependence of material shrinkage ΔY at a fixed time $t=90$ s in the range of rotation frequency $n=1500$–3000 rpm and humidity $\varphi=5$–17 %

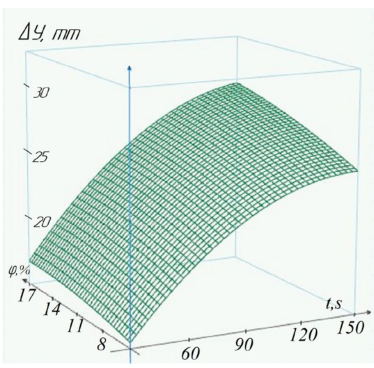


Fig. 11. Graph of the dependence of material shrinkage ΔY at a fixed rotation frequency $n=2250$ in the humidity range $\varphi=5$–17 % and time $t=30$–150 s

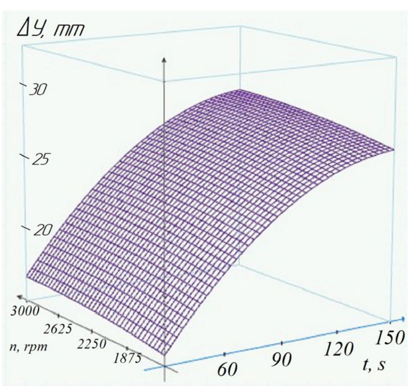


Fig. 12. Graph of the dependence of material shrinkage ΔY at a fixed humidity $\varphi=11$ % in the range of rotation frequency $n=1500$–3000 rpm and time $t=30$–150 s

The practical significance of this study lies in the possibility of using different types of working bodies in conditions of limited space. This research can be especially useful for small enterprises that specialize in the compaction of small-sized plots in conditions of dense construction.

Limitations of the study: The research was carried out under the conditions of material humidity in the range of $\varphi=5$–17 %, the frequency of rotation of the vibration motor $n=1500$–3000 rpm, and the time during which the vibrating plate compacted the material $t=30$–150 s. It is important to note that the developed mathematical model is valid precisely under the conditions under which the research was conducted.

The conditions of martial law in Ukraine complicated the study due to frequent power outages, which affected the duration of the study.

Prospects for further research are to study the processes occurring in the zone of interaction of the working body with the compacted material. Research in this direction will allow a deeper understanding of the mechanisms of the influence of the working body on the material, optimize the parameters of the sealing process, and improve the efficiency of equipment in various operating conditions.

4. Conclusions

It was described the method of determining the compaction of the material using an analog-digital converter during the operation of the vibrating plate, with further analysis of the obtained data using a computer system and specialized software.

Experimental dependences were obtained to determine the compaction of the material when the three main factors – time, humidity and rotation frequency affect the quality of material compaction.

Analysis of the dependence graphs showed that the key factors affecting the process of compacting the material are the time of action of the vibration plate and the humidity of the material. The rational time of action is 120 seconds, or three passes with a vibrating plate, which ensures maximum sealing efficiency, and the moisture content of the material plays a decisive role, and its optimal value is 15 %. There is a direct proportional relationship between the level of humidity and the quality of the seal: with an increase in humidity from 5 % to 17 %, the quality of the seal is significantly improved. However, the efficiency of the time factor decreases and after reaching 150 seconds it has almost no effect on the subsequent compaction of the material, approaching zero.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Financing

The research was performed without financial support.

Data availability

The manuscript has no associated data.

Use of artificial intelligence

The authors confirm they did not use artificial intelligence technologies when creating the presented work.

References

1. Nazarenko, I. I. (2007). *Vibratsiini mashyny i protsesy budivelnoi industrii.* Kyiv: KNUBA, 230.

2. Nesterenko, M. P., Chebotarov, P. M. (2012). Analiz konstruktyvnykh osoblyvostei vibratsiinykh mashyn, yak peredumovy stvorennia kerovanoi vibratsiinoi ustanovky dlia poverkhnevoho ushchilnennia betonnykh sumishei. *Haluzeve mashynobuduvannia, budivnytstvo, 1 (31),* 267–275.
3. Lyutenko, V., Orysenko, O., Nadobko, V. (2018). Mathematical Model for the Manual Vibration Roller Drive Mechanism Investigation. *International Journal of Engineering & Technology, 7 (3.2),* 232–235. https://doi.org/10.14419/ijet.v7i3.2.14409
4. Lanets, O. S. (2008). *Vysokoefektyvni vibratsiini mashyny z elektromahnitnym pryvodom (Teoretychni osnovy ta praktyka stvorennia).* Lviv: Vyd-vo NU «Lvivska politekhnika», 324.
5. Maslov, A. G., Salenko, Y. S., Maslova, N. A. (2011). Study of the interaction between a vibrating plate with cement concrete mixture. *Transactions of Kremenchuk Mykhailo Ostrohradskyi National University, 67*, 93–98.
6. Gutiérrez, J., Ruiz, E., Trochu, F. (2013). High-frequency vibrations on the compaction of dry fibrous reinforcements. *Advanced Composite Materials, 22 (1),* 13–27. https://doi.org/10.1080/09243046.2013.764778
7. Itkin, A. F. (2009). *Vibratsionnyie mashinyi dlya formovaniya betonnyih izdeliy «Les MP».* Kyiv.
8. Vasyliev, A., Yakovenko, A. (2023). Vibrating machine for surface preparation and sealing. *Technical sciences and technologies, 4 (34),* 52–60. https://doi.org/10.25140/2411-5363-2023-4(34)-52-60
9. Zelenin, A. N. (1975). *Mashiny dlia zemlianykh rabot.* Mashinostroenie, 422.
10. Krot, O. Yu., Korobko, B. O., Krot, O. P., Virchenko, V. V. (2023). *Eksperymentalni metody doslidzhen.* Poltava: NUPP, 192.
11. Batsaikhan, Zh. (2015). Study of the interaction of the vibration plate working body with sealed medium. *Transactions of Kremenchuk Mykhailo Ostrohradskyi National University, 90,* 92–97.

✉***Andrii Yakovenko,*** *PhD Student, Department of Branch Machinery and Mechatronics, National University «Yuri Kondratyuk Poltava Polytechnic», Poltava, Ukraine, e-mail: andrii.yakovenko95@gmail.com, ORCID: https://orcid.org/0000-0003-0818-6332*

Oleksii Vasyliev, *PhD, Assistant Professor, Department of Branch Machinery and Mechatronics, National University «Yuri Kondratyuk Poltava Polytechnic», Poltava, Ukraine, ORCID: https://orcid.org/0000-0002-9914-5482*

✉*Corresponding author*