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Experimental studies on soil compaction using BOMAG BW 226 BVC-5 vibratory roller

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Abstract. Mathematical modelling is used to assess the influence of various factors on the result of soil compaction with a vibratory roller. Verification of the mathematical model is carried out by comparing it with the results of experimental studies. Expanding the list of roller models in the experimental studies allows expanding the range of conditions for verification of the mathematical model. The paper presents the results of experimental studies of soil compaction by a vibratory roller BOMAG BW 226 BVC-5. Data on the change in the value of the dynamic deformation modulus of the Evd soil were obtained in relation to the number of roller passes during the compaction of the sand-gravel mixture with a layer thickness of 0.5 m. The peculiarities are revealed, which is reasonable to consider when carrying out further experimental research. Experimental studies of the range of vertical movements of the drum, as well as vertical accelerations of the drum and its frame, were performed on a BOMAG BW 226 BVC-5 vibrating roller during compaction of the sand-gravel mixture. The compaction result after each pass was evaluated using the value of the dynamic deformation modulus Evd, measured using a ZORN ZFG 3.0 dynamic loading unit. In the experiment, the vertical movements of the vibrating roll were recorded using a BAUMER OADM 13U6480/S35A laser sensor. The accelerations of the vibrating roll and the roll frame were recorded using piezoelectric accelerometers of models AR2099-100 and AR99-100. When processing the readings of the sensors, digital signal processing technology was used - low-pass filters with the boundary frequency of 200 Hz. The research was carried out at two sites with different soil moisture conditions. The results obtained show that the oscillation range of the roll as well as the amplitude values of vertical accelerations of the roll and the frame of the roll increase slightly with increasing soil deformation modulus Evd. The results of this experiment correlate with the research conducted on roller models. The results of the experiment will help to further verify the mathematical model of the roller and to carry out experimental studies of a similar nature.

1 Introduction

The process of compaction is one of the most common technologies to improve the strength, bearing capacity and resistance to weather and climatic factors of all engineering structures erected on soils. Despite the large number of studies and expertise of domestic and foreign

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specialists, the issues of interaction of compaction machines with the ground are insufficiently studied, which leads to premature failure of roads of building structures erected on the ground.

To date, there are three main methods of compaction - static, vibratory and impact compaction. Vibratory compaction is most popular with the use of vibratory rollers. The vibratory compaction process causes the machine body to vibrate, and the vibrations are transferred to the layer to be compacted. During vibration, higher compaction densities and greater compaction depths are achieved, resulting in higher productivity. These advantages mean that vibratory machines currently account for around 70% of the market.

The main aim of the compaction process is to increase the number of contacts between the particles of the compacted material by displacing liquids and gases and redistributing the particles in the compacted volume of material. This results in a permanent deformation of the soil, which is an indication of the degree of compaction of the soil.

By way of schematic explanation, compaction can be thought of as a process in which more mineral particles come into contact with each other by redistributing them and allowing smaller particles to bridge the gaps between the larger particles by externally imposed compaction forces. At the same time the soil acquires a residual deformation which is estimated by the compaction coefficient defined in accordance with code of specification 34.13330.2012.

According to code of specification 34.13330.2021, the result of soil compaction is evaluated by the compaction coefficient. However, determining the compaction coefficient is associated with the influence of a large number of factors that reduce the reliability of the results. Besides, the compaction factor does not reflect the strength properties of the ground and its ability to accept mechanical loads [1, 2, 3, 4]. It is more perspective to use dynamic and static deformation modulus in accordance with GOST R 59866-2022 to estimate compaction results.

To improve technique and technology of soil compaction, it is necessary to develop a mathematical model of influence of loading modes and characteristics of a working body on the result of soil compaction in particular conditions. Traditionally, the rheological modeling methods, semi-empirical methods and methods based on the equations of continuum mechanics were used for modeling soil compaction processes. The analysis of works of various authors on mathematical modeling [5, 6, 7] has shown that a mathematical model of interaction of vibratory roller with compacted soil must describe features of vibrating elements of the vibratory roller (drum and drum frame). In addition, the mathematical model must describe the processes of changing the stress-strain state of the soil. Since the soil is a complex multiphase medium, and a vibrating roller is a multi-mass oscillating system with nonlinear relations, various assumptions are introduced to simplify the developed mathematical models. This leads to the necessity of subsequent verification of the mathematical model by comparing simulation results with experimental data. Experiments are preferably carried out in the field on commercially available machines during compaction of various construction materials. For verification, one can use characteristics of vibratory roller elements' vibrations (displacements and accelerations of roller and drum frame), stresses at different depths of soil, values of compaction coefficient and dynamic or static modulus of soil deformation. Having analyzed the existing results of experimental studies of soil compaction by vibratory roller [8, 9, 10], we concluded that, in most cases, researchers specify only the vibratory roller model, without specifying the drum mass, frame mass, number and characteristics of shock absorbers and other parameters required to verify the mathematical model. In this regard, it is necessary to expand the list of roller models and the range of conditions under which experimental studies are conducted.

In this article the results of experimental studies with a vibratory roller BOMAG BW 226 BVC-5 are presented. The experiment was carried out to verify mathematical models of interaction between vibratory roller and compacted soil.

2 Materials and Methods

Experimental studies were carried out in August 2022 on one of the construction sites in St. Petersburg. The experimental tests were carried out in August 2022 on a construction site in St. Petersburg.

The research involved a BOMAG BW 226 BVC-5 vibratory roller with the following specifications: operating weight 12830 kg; engine power 100 kW; vibrator frequency 27/37 Hz; compaction force 246/144 kN; drum static pressure 29.2 kg/cm; drum oscillation amplitude 1.9/0.8 mm; drum diameter/width 1504/2140 mm; AW 23. 1-26 12 PR; 14 drum dampers (BOMAG model BW 226 BVC-5) installed.

Fig. 1. Location of accelerometers: on the roller drum (left picture) and on the drum frame (right picture).

The compacted soil is a natural sand-gravel mixture (gravel content not less than 30%, clay particles 3...4%), poured as a layer 0.5 m thick at a specially designated area of the construction site.

Accelerations of drum and roller drum frame vibrations were recorded by means of piezoelectric accelerometers with built-in electronics model AR2099-100 (roller drum) and AR99-100 (roller drum frame). The sensors were attached using magnets with a force of 220 N. Considering the weight of the sensors (45 g) and the weight of the magnets (28 g), a secure fixing was ensured. The sensor was mounted directly to the frame of the roller and the vibrator was mounted on a bracket. Both sensors were mounted vertically in a plane passing through the longitudinal axis of rotation of the tumbler (Fig. 1).

The vertical movements of the vibrating roll were also measured in the experiment. These measurements were carried out with a BAUMER OADM 13U6480/S35A laser sensor with the following characteristics: measuring range 50 to 550 mm; resolution 0.01 to 1.1 mm; linear error ±0.08 to ±3.5 mm; response time <0.9 ms; linearity error in measuring range 100 to 150 mm from the upper point of the roll shell does not exceed 0.3 mm. During the measurement process, any encrusted soil was scraped off with a scraper to eliminate the influence of the soil on the measurement results.

Accelerometer and displacement sensor readings were recorded using a ZET 017-U8 spectrum analyzer manufactured by ZETLAB (Zelenograd, Russia). Measurements were taken at a sampling rate of 5000 Hz. All equipment, including the spectrum analyzer, was powered by an autonomous battery and was located in the roller operator's cabin.

During the tests, one pass of the roller was taken as a forward movement with the vibrator switched on. Reverse movements were carried out without vibration. During operation the BOMAG BW 226 BVC-5 roller used only one mode of operation with maximum force exerted.

The compaction result after each pass was evaluated using the ZORN ZFG 3.0 dynamic compaction unit.

The Evd values were measured after each pass, at three points on the drum track, transverse to the direction of movement (in the middle of the track and at a distance of 0.4 to 0.5 m from the right and left border of the track) and then averaged. Each series of measurements of Evd values was performed with a 1-2 m shift forward in relation to the area of previous measurements.

Sensor readings were recorded when the vibratory roller approached the experimental site a few metres away and stopped when the roller moved away from the test site.

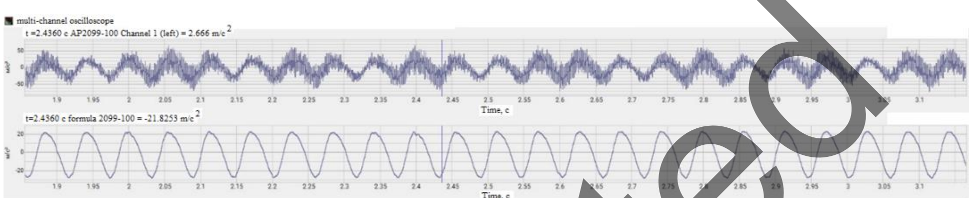

Fig. 2. Oscillograms of initial acceleration sensor readings of roller AP2099-100 and with the digital filtering of the signal.

Analysis of the sensor readings shows considerable noise, making it very difficult to determine the amplitude values of the signals (Fig. 2). Therefore, digital filtering of the sensor signals was applied. Fig. 2 shows an example of the results of processing the original vibration acceleration sensor signal using low-pass filters. The upper waveform (see Fig. 2) shows the signal from the AP2099-100 sensor. It can be seen that distorting noise is being applied to the signal. The sources of distortion can be various units of mechanisms and systems of the roller, as well as electrical interference to the recording equipment. From experience of previous studies [11, 12, 13, 14, 15] it was decided to use for digital signal processing a low-pass filter with boundary frequency 200 Hz in "Formula" tool of ZETLAB ANALIZ software package. In the Fig. below (see Fig. 2), the lower oscillogram shows the filtering result of the original signal.

3 Results

The experimental works were carried out at two sites with the same type of soil. At section 1, the work was carried out during heavy rain and on overwatered soil and at section 2 - on soil with humidity close to optimum.

This analysis showed an undulating pattern of changes in the dynamic strain modulus of soil E_{vd} at site No. 2 (Fig. 3). It was found that lower E_{vd} values were observed in the middle of the roller track, while at the edges the values increased. This phenomenon can be explained by additional compaction from pneumatic rollers.

At section 1, the values of soil deformation modulus E_{vd} were significantly lower and practically did not increase during all passes (see Fig. 3). It is connected with the fact that when the soil is too wet, no compaction is carried out. The results of measurements of vertical movements of BOMAG BW 226 BVC-5 tumbler during steady-state vibrations at section 1 are shown in Fig. 4.

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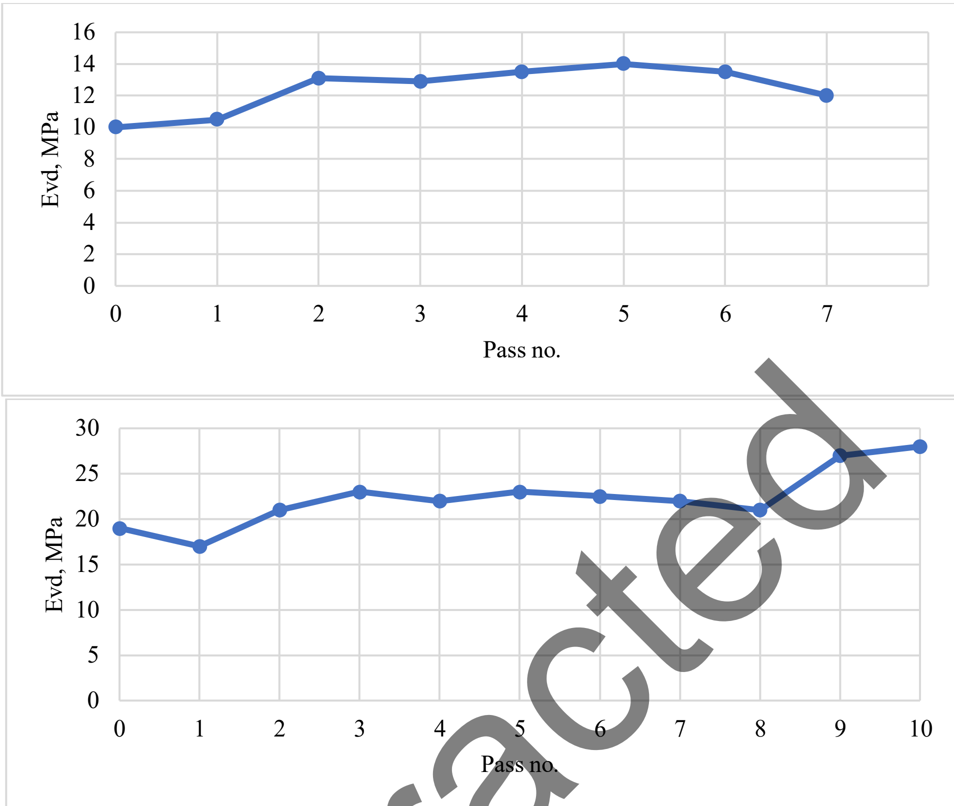

Fig. 3. Diagrams of the dynamic ground deformation modulus Evd by passage of a BOMAG BW 226 BVC-5 roller: a - in section 1; b - in section 2.

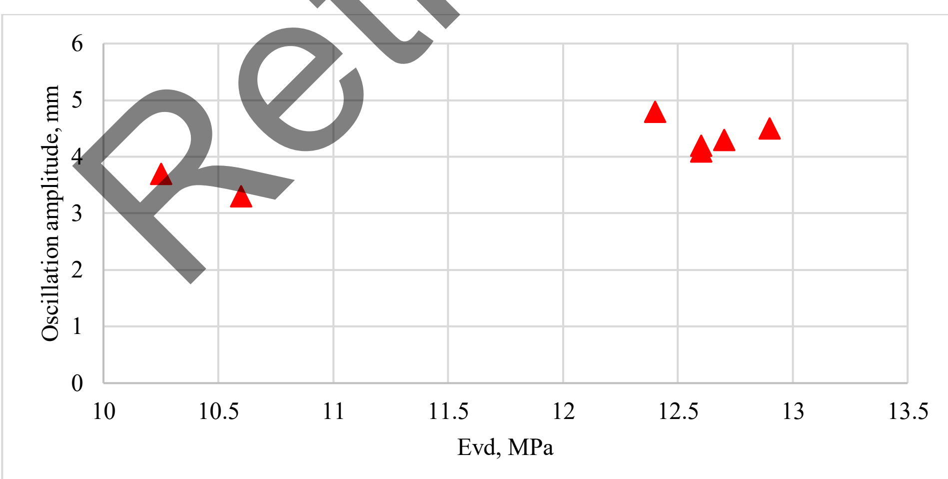

Fig. 4. Results of measuring the vertical oscillation range of a BOMAG BW 226 BVC-5 roller during steady-state vibration during compaction of soil section 1.

The results of measuring the vertical accelerations of the vibrator drum and the vertical accelerations of the BOMAG BW 226 BVC-5 roller frame during soil compaction in section 1, while driving with steady vibration, are shown in Fig.s 5, 6.

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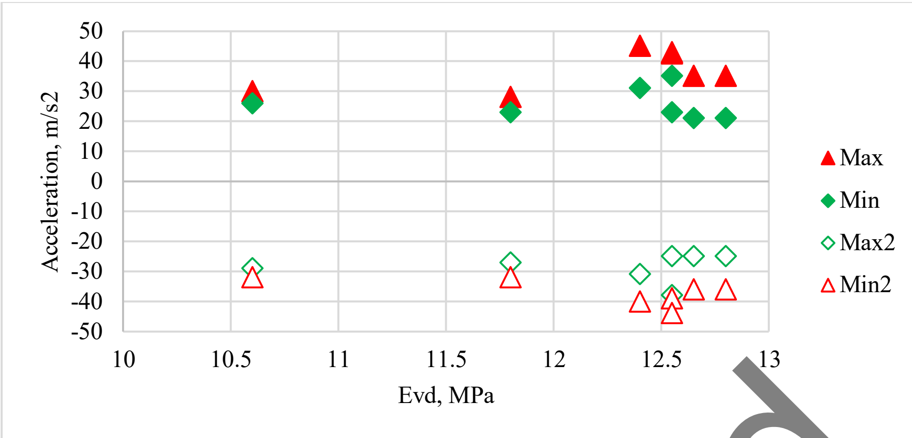

Fig. 5. Measurement results of amplitude values of vertical accelerations of vibratory roller BOMAG BW 226 BVC-5 during steady-state vibration during compaction of section 1.

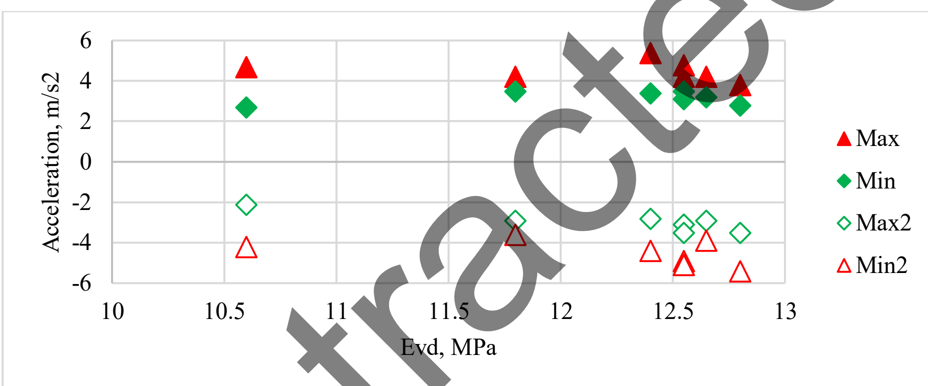

Fig. 6. Measurement results of amplitude values of vertical accelerations of the roller drum frame of the BOMAG BW 226 BVC-5 during steady vibration during compaction in section 1.

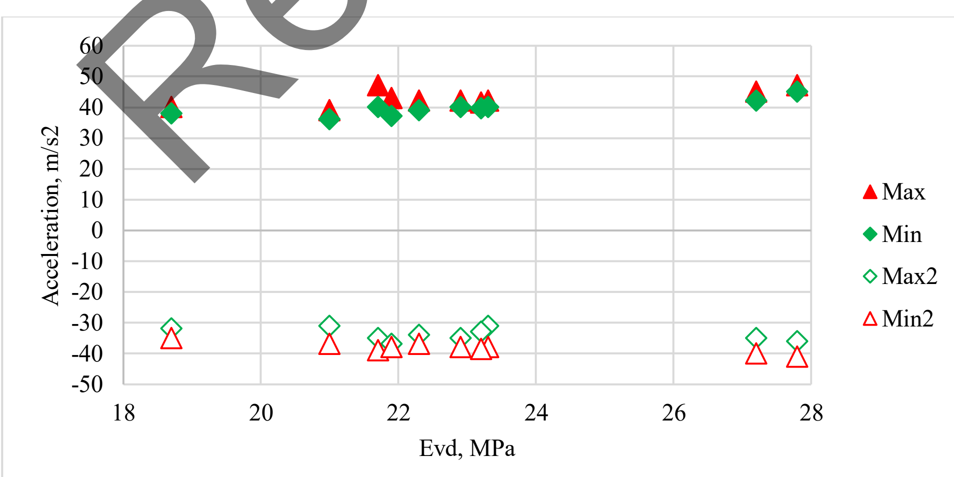

Fig. 7. Measurement results of amplitude values of vertical accelerations of vibratory drum roller BOMAG BW 226 BVC-5 during steady-state vibration during compaction of section 2.

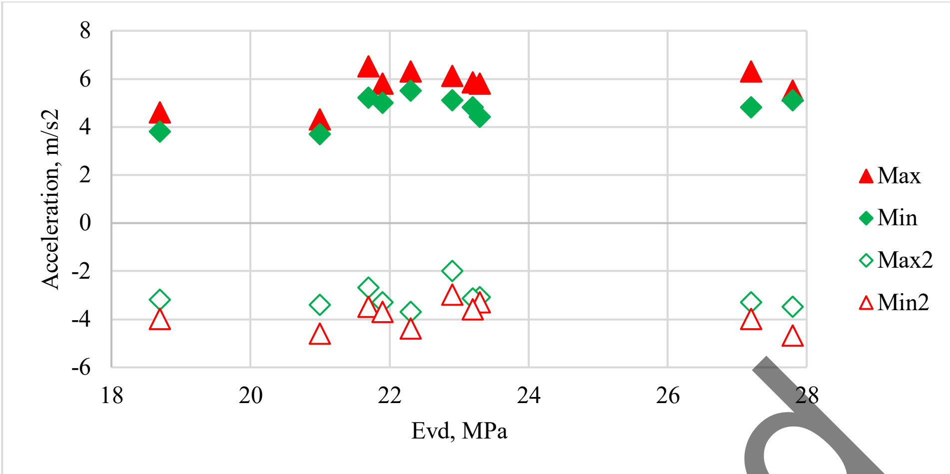

Fig. 8. Measurement results of amplitude values of vertical accelerations of the roller drum frame of the BOMAG BW 226 BVC-5 during steady-state vibration during compaction of section 2.

The obtained results show that the oscillation amplitude and amplitude values of vertical accelerations of vibrating roller and roller drum frame slightly increase with increasing soil deformation modulus E_{vd}. The results of the experiment correlate with the studies conducted on other roller models.

When measuring E_{vd} values in one cross-section the difference between measured values along the axis of roller movement and on the trail of pneumatic wheels could reach 30%, so in further studies it is advisable to measure E_{vd} values not on the trail of pneumatic wheels of rollers. Additional compaction of the ground by pneumatic wheels will in this case work into the load-bearing capacity of the ground. The dynamic modulus of deformation of the soil in over-wetted soil was in the range E_{vd} = 10...13 MPa, and with the soil of optimum moisture E_{vd} = 18...28 MPa. The range of vertical movements of the vibrating roller during compaction of the overwetted soil was 3.3 to 4.8 mm. Vertical accelerations of vibrating roller during compaction of overwet ground ranged from +20...+45 to -25...-43 m/s^2, and in optimal wet ground +36...+48 to -35...-40 m/s^2. When compacting over-wetted soil, the vertical accelerations of the drum frame range from +2.5...+5 to -2...-5 m/s^2, and for optimum wet soil +3.5...+6 to -2...-4.5 m/s^2.

4 Conclusion

Considering these results, it should be noted that in the experiment the actual frequency was 18 Hz and not 27 Hz as stated in the technical data of the BOMAG BW 226 BVC-5 roller. With this reduction in frequency, the oscillating force will be reduced by a factor of approximately 2.25. In the following work, it is advisable to first check that the machine is operating correctly and at the correct oscillation frequency before carrying out the experiment.

The results obtained can be used to verify the mathematical model of interaction between vibratory roller and compacted soil and to conduct experimental studies of a similar nature.

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