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The research of the operating mode of the concrete mixture plane depth compactor with a circular vibration exciter

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The paper proposes an essentially new design of a concrete mixture depth compactor made in the form of a vertical plate with a circular vibration exciter mounted on its upper part. A design diagram of the «plane depth compactor – concrete mixture» dynamic system is presented and the vertical plate movement equations describing its linear vibrations in the horizontal plane and torsional vibrations in relation to the center of gravity are provided. It has been determined the regularity of the vertical plate motion during the compaction of concrete mixtures. The provided results of the research enable the substantiation of the rational parameters of the plane depth compactor performing spatial vibrations and the efficient modes of the vibratory action on the concrete mixtures of different consistence.

Keywords: plane depth compactor, concrete mixture, vibration compaction.

Дослідження робочого режиму площинного глибинного ущільнювача бетонних сумішей з віброзбудувачем кругових коливань

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Запропонована принципово нова конструкція глибинного ущільнювача бетонних сумішей, що виконана у вигляді вертикальної влити, на верхній частині якої змонтовано віброзбуджувач кругових коливань. Описано принцип дії площинного глибинного ущільнювача бетонних сумішей. Складена розрахункова схема динамічної системи «площинний глибинний ущільнювач – бетонне середовище», в якій останнє представлено у вигляді наведеної маси і наведених коефіцієнтів непружного і пружного опорів. Знайдено момент інерції наведеної маси бетонної суміші щодо центру ваги системи, що коливається. Визначено інерційні, пружні і непружні сили опору бетонної суміші, які діють на вертикальну плиту в процесі їх спільних коливань. Складені рівняння руху вертикальної плити, яка контактує з бетонною сумішшю, що описують її прямолінійні коливання в горизонтальній площині і крутильні коливання відносно центру тяжіння. Рівняння руху враховують дію інерційних сил глибинного ущільнювача і ущільнюваної бетонної суміші, сил пружного і непружного опору бетонної суміші і сил тертя нижньої кромки вертикальної плити про бетонну суміш або основу. Встановлена закономірність руху робочої поверхні вертикальної плити, що взаємодіє з бетонною сумішшю в горизонтальному напрямку і викликає в цьому бетонному середовищі нормальні напруги. При цьому реалізується змінний амплітудно-частотний режим руху вертикальної плити, що викликає в ущільнювальному шарі поширення пружно-пластичних хвиль деформацій, які забезпечують створення імпульсного напружено-деформованого стану, що забезпечує ефективне ущільнення бетонних сумішей пластичних з осадкою конуса ОК-3,5 – 4 см сумішей, так і жорстких сумішей жорсткістю Ж=30 – 120 с Наведені результати досліджень дозволяють обґрунтувати раціональні параметри площинного глибинного ущільнювача, що здійснює просторові коливання, і ефективні режими вібраційної дії на бетонні суміші різної консистенції.

Ключові слова: площинний глибинний ущільнювач, бетонна суміш, вібраційне ущільнення.

Introduction

The depth (internal) vibration of concrete mixtures takes less energy than vibration compaction by other methods. Thus, it is topical to create simple, reliable and highly efficient vibration machines for depth compaction.

Review of research sources and publications

For internal vibration depth vibrators [1 - 4], equipped with circular tips of various diameters, submerged into the concrete mixture, is used. They have a small radius of concrete mixture working and are used for the compaction of plastic concrete mixtures. To improve the productivity it is used packaged depth vibrators with individual drives [5]. The design of these devices is rather complex and they are used for very big volumes of concreting. To improve the vibration efficiency the author of paper [6], proposed a plane depth compactor performed in the form of a vertical flat plate equipped with two depth vibrators, each with an individual drive. Big weight prevented this depth compactor from being used in construction industry as a manual mechanism. Moreover, all the depth vibrators are equipped with planetary vibration exciters that quickly break down [7].

Definition of unsolved aspects of the problem

In the process of the research it is necessary to substantiate the rational parameters of the plane depth compactor of a simple design, high reliability and provision of the compaction of concrete mixtures of different consistence.

Problem statement

The purpose of the paper consists in the development of a highly efficient plane depth vibration compactor for concrete mixtures of different consistence.

Basic material and results

The proposed plane depth compactor (Fig. 1) consists of a compacting plate made in the form of vertical plate 1 with stiffening rib 2, bracket 3, rigidly fixed to plate 1, and mounted on this bracket by means of threaded joints 4 of circular vibration exciter 5 with unbalance shaft 6.

The plane depth compactor operates in the following way.

The operator turns on the plane depth compactor and introduces vertical plate 1 into concrete mixture 7, spread as a smooth layer. Under the action of circular vibration exciter 5 the vertical plate performs complex motions, arousing in the compacted medium the resilient viscous plastic deformation waves with rather high frequency. These deformations cause ultimate destruction of the structural connections in the concrete mixture and transform it into thixotropic condition. They result in the intensive reorientation of the mineral particles, the displacement of the air and the formation of a more compact packing.

To determine the law of motion of the vertical plate interacting with the concrete mixture in the operating mode we consider the design model of the «plane depth compactor – concrete mixture» dynamic system (Fig. 1). The movements of the considered dynamic system under the action of the circular vibration exciter whose unbalance generate circular disturbing force Q have been analyzed. It has been decomposed this force into two components: horizontal $Q\sin\omega t$ and vertical $Q\cos\omega t$ forces.

Under the action of horizontal force $Q\sin\omega t$, the vertical plate interacting with the concrete mixture performs complex movements: linear movements in the direction of coordinate axis X, passing via the center of gravity C of the vibrating system and torsion vibrations about the center of gravity C.

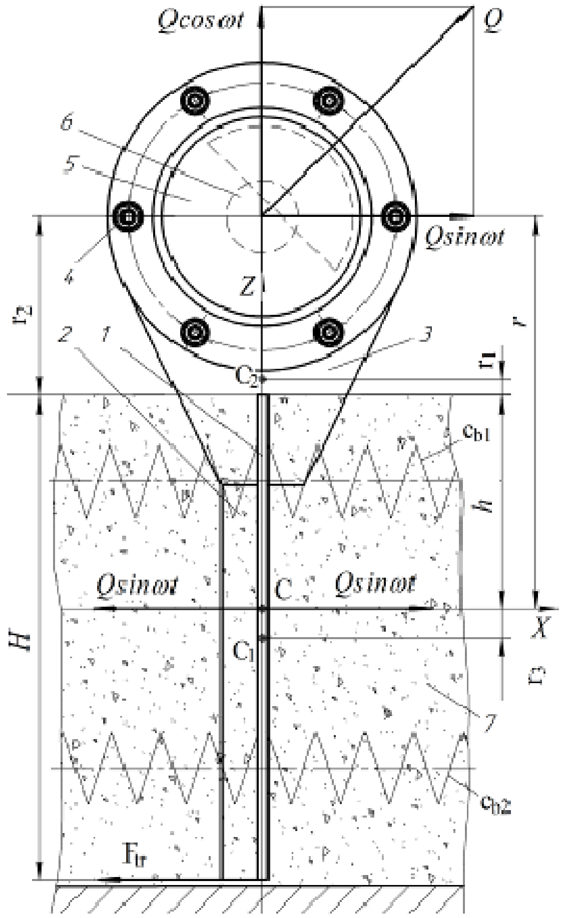

Figure 1 – The design diagram of the «plane depth compactor – concrete mixture» dynamic system

It is determined the vertical shift of the center of gravity C of the vibrating system in relation to the center of gravity of the concrete mixture O_1 from the following dependence

$$r_3 = \frac{m(0{,}5H \pm r_1)}{m + m_b}, \qquad (1)$$

where m – the mass of the plane depth compactor;

r_1 – the distance from the center of gravity of the plane depth compactor to the vertical plate upper edge coinciding with the surface of the compacted concrete mixture;

m_b – the modified mass of the concrete mixture determined depending on the method of vibration of the concrete mixture: in half-space [8] or in the form [9].

In expression (1) sign plus is taken in parentheses if the center of gravity of the plane depth compactor is over the upper edge of the vertical plate, and sign minus if it is below.

In this case the movement of the vertical plate contacting the concrete mixture can be described by the following equation system:

– the linear movement in the horizontal plane in the direction of coordinate axis X

$$(m+m_b)\frac{d^2x}{dt^2}+b_b\frac{dx}{dt}+c_bx\pm F_{tr}=Q\sin\omega t; \qquad (2)$$

– the angular shift about coordinate axis Y

$$(J+J_b)\frac{d^2\psi}{dt^2}+n_b\frac{d\psi}{dt}+k_b\psi\pm M_{tr}=Qr\sin\omega t; \quad (3)$$

where x – the linear movements of the vertical plate over the center of gravity of the vibrating system;

ψ – the angular movements of the vertical plate about coordinate axis Y, passing via the center of gravity of the vibrating system;

m_b, b_b, c_b – the values of the modified mass and modified coefficients of the concrete mixture elastic and non-elastic resistances, determined according to the method of the concrete mixture vibration: in half-space [8] or in a form [9];

F_{tr} – the force of friction of the vertical plate lower edge against the concrete mixture or the base,

$$F_{tr}=mg\cdot f_{tr}, \qquad (4)$$

f_{tr} – the coefficient of the friction of the vertical plate lower edge against the concrete mixture or the base;

J – the moment of inertia of the plane depth compactor against the center of gravity C of the vibrating mass,

$$J=J_y+m(0{,}5H-r_3+r_1)^2, \qquad (5)$$

J_y – the moment of inertia of the plane depth compactor against its own center of gravity O_2;

r –the distance from the axis of rotation of the unbalance shaft of the vibration exciter to the center of gravity of the vibrating system;

J_b – the moment of inertia of the modified mass of the concrete mixture against the center of gravity of the vibrating system,

$$J_b=m_b\frac{H^2}{12}+m_br_3^2; \qquad (6)$$

k_b, n_b – the coefficients of torsional stiffness and non-elastic resistance of the compacted medium at the angular movements of the vibrating system against coordinate axis Y,

$$k_b=k_{b1}+k_{b2}; \quad n_b=n_{b1}+n_{b2}; \qquad (7)$$

k_{b1}, n_{b1} – the coefficients of torsional stiffness and non-elastic resistance of the compacted medium at the angular movements of the vibrating system against coordinate axis Y at the section of height $h = 0{,}5H–r_3$,

$$k_{b1}=\sum_{i=1}^{n_1}c_{by}F_iz_i^2; \quad n_{b1}=\sum_{i=1}^{n_1}b_{by}F_iz_i^2; \qquad (8)$$

k_{b2}, n_{b2} – the coefficients of torsional stiffness and non-elastic resistance of the compacted medium at the angular movements of the vibrating system against coordinate axis Y at the section of height $h_1 = 0{,}5H - r_3$,

$$k_{b2}=\sum_{i=1}^{n_2}c_{by}F_iz_i^2; \quad n_{b2}=\sum_{i=1}^{n_2}b_{by}F_iz_i^2; \qquad (9)$$

F_i – the area of equal elementary sections with the height division of the vertical plate,

$F_i = F / (n_1 + n_2)$;

n_1, n_2 – the number of the divisions of the vertical plate respectively in its upper part at the section of height h and its lower part at the section of height h_1;

Z_i – the vertical distance from the center of gravity of the vibrating system to the i-the marked element;

c_{by}, b_{by} – the values of the specific modified coefficients of the elastic and non-elastic resistances of the concrete mixture determined according to the method of the concrete mixture vibration: in half-space [8] or in a form [9];

M_{tr} – the moment of the forces of friction of the vertical plate lower edge against the concrete mixture or the base,

$$M_{tr}=mg(H-h)f_{tr}. \qquad (10)$$

Using the method of linearization of Coulomb friction [10], it is modified equations (2) and (3) to the following form:

$$(m+m_b)\frac{d^2x}{dt^2}+(b_b+b_s)\frac{dx}{dt}+c_bx=Q\sin\omega t; \quad (11)$$

$$(J+J_b)\frac{d^2\psi}{dt^2}+(n_b+n_s)\frac{d\psi}{dt}+k_b\psi=Qr\sin\omega t, \quad (12)$$

where b_s – the equivalent coefficient of viscous friction in the direction of coordinate axis X,

$$b_s=\frac{4F_{tr}}{\pi A\omega}=\frac{q_r}{A\omega}; \qquad (13)$$

n_s – the equivalent coefficient of viscous friction about horizontal axis Y;

$$n_s=\frac{4M_{tr}}{\pi\Phi\omega}=\frac{q_m}{\Phi\omega}; \qquad (14)$$

A – the amplitudes of the vertical plate vibrations in the horizontal direction about the center of gravity of the vibrating system;

Φ – the amplitude of the angular (torsion) vibrations of the vertical plate about horizontal axis Y;

$$q_r=\frac{4F_{tr}}{\pi}; \qquad (15)$$

$$q_m=\frac{4M_{tr}}{\pi}. \qquad (16)$$

Based on the known methods of the classical theory of vibrations [10, 11], it is found the solution to equations (13) and (14) in the following form:

$$x(t) = A\sin(\omega t - \varphi_1)\,; \qquad (17)$$

$$\psi(t) = \Phi\sin(\omega t - \varphi_2)\,, \qquad (18)$$

where φ_1 – the angle of phases shift between the amplitude of disturbing force Q and the movement along x;

φ_2 – the angle of phases shift between the amplitude of the moment of the disturbing forces and the amplitude of the angle movement;

$$A = \frac{Q}{\sqrt{[c_b - (m + m_b)\omega^2]^2 + (b_b + b_s)^2\omega^2}}\,; \qquad (19)$$

$$\Phi = \frac{Qr}{\sqrt{[k_b - (J + J_b)\omega^2]^2 + (n_b + n_s)^2\omega^2}}\,; \qquad (20)$$

$$\varphi_1 = arctg\frac{(b_b + b_s)\omega}{c_b - (m + m_b)\omega^2}\,; \qquad (21)$$

$$\varphi_2 = arctg\frac{(n_b + n_s)\omega}{k_b - (J + J_b)\omega^2}\,. \qquad (22)$$

Substituting dependences (13) and (14) respectively in expressions (19) and (20), we obtain equations for the determination of the amplitudes of the linear and torsion vibrations of the vertical plate in the following form:

$$A^2 + \frac{2Aq_r b_b\omega}{[c_b - (m + m_b)\omega^2]^2 + b_b^2\omega^2} - \frac{Q^2 - q_r^2}{[c_b - (m + m_b)\omega^2]^2 + b_b^2\omega^2} = 0; \qquad (23)$$

$$\Phi^2 + \frac{2\Phi q_m n_b\omega}{[k_b - (J + J_b)\omega^2]^2 + n_b^2\omega^2} - \frac{Q^2 r^2 - q_m^2}{[k_b - (J + J_b)\omega^2]^2 + n_b^2\omega^2} = 0; \qquad (24)$$

Solving equations (23) and (24), we find the final values of the amplitudes of the vertical plate vibrations taking into account the values of the equivalent coefficients of viscous friction b_s, and n_s

$$A = \frac{1}{[c_b - (m + m_b)\omega^2]^2 + b_b^2\omega^2}\left\langle -q_r b_b\omega + \sqrt{q_r^2 b_b^2\omega^2 + M_1\{[c_b - (m + m_b)\omega^2]^2 + b_b^2\omega^2\}}\right\rangle; \qquad (25)$$

$$\Phi = \frac{1}{[k_b - (J + J_b)\omega^2]^2 + n_b^2\omega^2}\left\langle -q_m n_b\omega + \sqrt{q_m^2 n_b^2\omega^2 + M_2\{[k_b - (J + J_b)\omega^2]^2 + n_b^2\omega^2\}}\right\rangle, \qquad (26)$$

where

$$M_1 = Q^2 - q_r^2\,;\ M_2 = Q^2 r^2 - q_m^2\,.$$

We can represent the law of movement of the vertical plate working surface interacting with the concrete mixture in the direction of coordinate axis X, and causing normal stresses in this concrete medium, based on expressions (17) and (18), taking into account expressions (25) and (26), in the form of the following functions

$$X_n(z,t) = x(t) + z\varphi(t) \text{ at } -(H-h) \le z \le h\,. \qquad (27)$$

Substituting the values of functions $x(t)$ (17) and $\varphi(t)$ (18) into expression (27) it is obtained the dependence for the description of the law of the movement of the vertical plate working surface contacting with the concrete mixture in the following form

$$X_n(z,t) = A(z)\sin[\omega t + \varphi(z)] \text{ at } -(H-h) \le z \le h\,, \qquad (28)$$

where $A(z)$ – the amplitude of the movement of the vertical plate working surface interacting with the concrete mixture, depending on coordinate z,

$$A(z) = \sqrt{A^2 + \Phi^2 z^2 + 2A\Phi z\cos(\varphi_1 - \varphi_2)}\,; \qquad (29)$$

$\varphi(z)$ – the angle of phases shift between the amplitude of the disturbing load and the amplitude of a certain point movement on the vertical plate with coordinate z,

$$\varphi(z) = arctg\frac{A\sin\varphi_1 + \Phi z\sin\varphi_2}{A\cos\varphi_1 + \Phi z\cos\varphi_2}\,. \qquad (30)$$

Considering expressions (13) and (14), it is modified dependences (21) and (22) to the following form:

$$\varphi_1 = arctg\frac{b_b\omega + q_r/A}{c_b - (m + m_b)\omega^2}\,; \qquad (31)$$

$$\varphi_2 = arctg\frac{n_b\omega + q_m/\Phi}{k_b - (J + J_b)\omega^2}\,. \qquad (32)$$

The analysis of expressions (28 – 30) reveals that the vertical plate of the proposed plane depth vibration compactor performs spatial vibrations during its operation. It provides efficient compaction of the concrete mixture due to alternating amplitude-frequency action. This vibratory action causes normal stresses in the compacted medium in the horizontal plane. They determine the destruction of the structural connections and result in the transformation of the concrete mixture into the thixotropic condition. In this case the forces of internal friction in the mixture sharply decrease due to the release of water, acting as lubrication, into the inter-grain space. The air is displaced out of the compacted mixture, the mineral particles reorient and approach each other forming a more compacted packing.

The obtained dependences used for the functional dependences determination of the concrete mixture compacting process represented in the form of a half-space is analyzed.

Fig. 2 shows the variation of the vertical plate vibrations amplitude of the depth vibration compactor A and stresses σ, occurring in the concrete medium of different consistence at the place of the concrete mixture contact with the vertical plate along its height, i.e. from the upper edge of the vertical plate to its lower edge. In Fig. 2 the origin of coordinates along the height of the vertical plate superposes its upper edge.

The data were obtained at the use of the above given theoretical dependences for the depth plane compactor with the following basic parameters: the depth compactor mass – m = 4.93 kg; the amplitude of the disturbing force of the vibration exciter – Q = 0.981 kN (100 kg); the angular frequency of the forced vibration – ω = 292 rad/s; the distance from the center of gravity of the depth vibration exciter O_2 to the upper edge of the vertical plate – r_1 = 2.85 cm; the moment of inertia of the depth vibration compactor against the axis passing through the center of gravity O_2 – J_y = 0.0365 kg·m^2; the height of the vertical plate – H = 20 cm; the width of the vertical plate – B = 20 cm; the area of the vertical plate surface interacting with the concrete mixture (at the bilateral contact) – F = 800 cm^2.

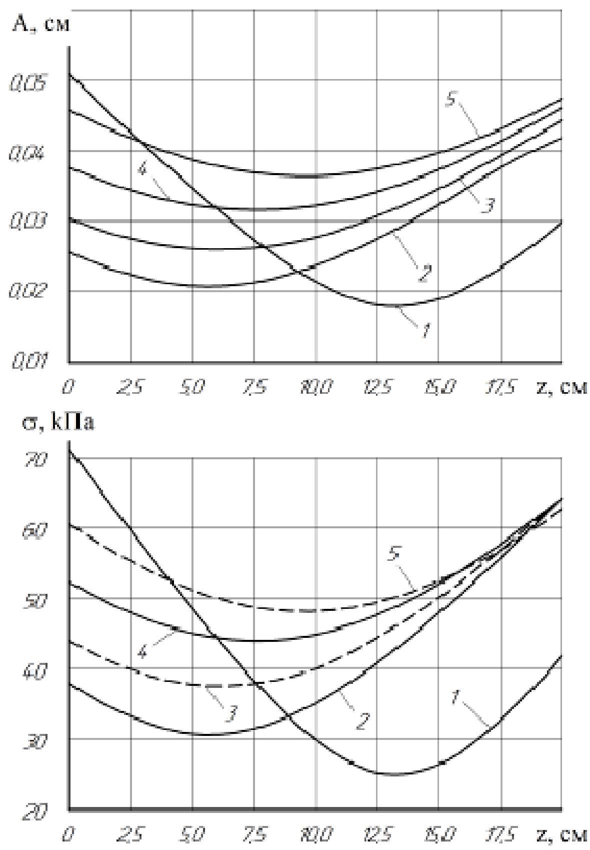

Figure 2 – The variations of the amplitudes of movements A and stresses σ, occurring in the concrete medium of different consistence at the place of its contact with the plane depth vibration compactor depending on the coordinate along the height of the vertical plate:
1 – at the slump of 3.5 – 4 cm;
2 – at mixture hardness H = 30 s;
3 – at H = 60 s; 4 – at H = 90 s; 5 – at H = 120 s

The analysis of the given data (Fig. 2), obtained for the final process of compacting, i.e. at complete compaction ρ_k, reveals that during the process of vibratory compacting by the proposed plane compactor the concrete mixture is subject to the action of the alternating amplitude-frequency vibration along the height.

This vibratory action results from simultaneous linear and torsion vibrations of the vertical plate. The amplitudes change of the vibrations and stresses during the compacting process depending on the mixture relative deformation ε is also continuous. By way of example, Fig. 3 shows the typical change of the amplitudes of vibrations and stresses occurring in the concrete mixture of the hardness of 60 s at the place of its contact with the vertical vibration plate, depending on relative density ε. The farther the vibration source is the lower and smoother the amplitudes of the vibrations in the compacted medium and stresses in it are (Fig. 4).

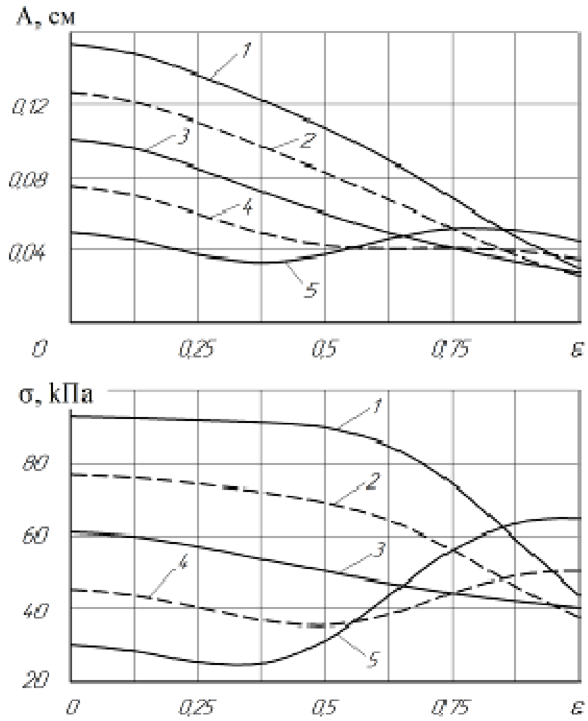

Figure 3 – The variations of the amplitudes of movements A and stresses σ, occurring in the concrete mixture of hardness 60 s at the place of its contact with the plane depth vibration compactor depending on the concrete mixture relative density ε and coordinate z along the height of the vertical plate beginning with its vertical edge:
1 – at z = 0; 2 – at z = 5 cm; 3 – at z = 10 cm;
4 – at z = 15 cm; 5 – at z = 20 cm

It is this ambiguous character of the vibration action on the concrete medium that contributes to the efficient destruction of the internal connections in the concrete mixture, the reorientation of the mineral particles and air displacement with the formation of a more compact packing. The obtained indices determine the amount of the energy put into the concrete medium by the depth plane vibration compactor and enable the determination of the law of the increase of the concrete medium density during the process of its compacting by the vibration action. They also enable the determination of the necessary duration of the vibration action depending on the average values of the amplitudes of vibrations and stresses in the concrete medium, the consistence of the concrete mixture and the distance of the propagation of the resilient-plastic deformation waves providing the required compactness.

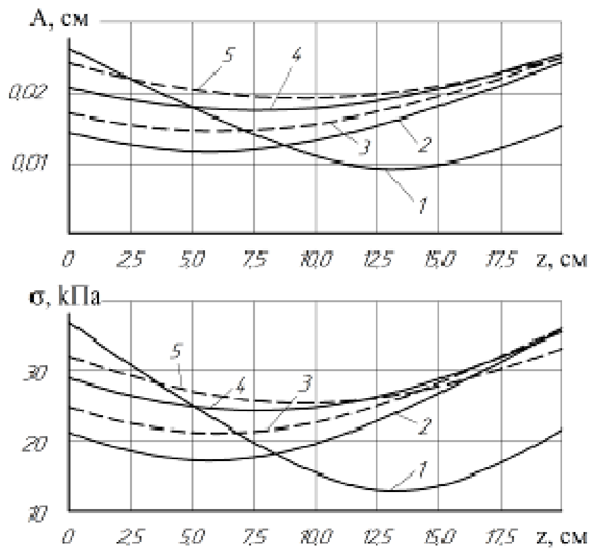

Figure 4 – The amplitudes variations of movements *A* and stresses *σ*, occurring in the concrete medium of different consistence at the distance of *x* = 80 cm from the source of vibration depending on the coordinate along the height of the vertical plate beginning from its vertical edge:
1 – at the slump of 3.5 – 4 cm;
2 – at the mixture hardness H = 30 s;
3 – at H = 60 s; 4 – at H = 90 s; 5 – at H = 120 s

Table 1 contains the values of the required duration of compacting the concrete mixtures of different consistence at the vibration processing length of $x = 80$ cm. The total length of the vibration processing is 160 cm, as vibration processing is performed simultaneously by both the front and the end wall of the plane vibration compactor.

The comparison of the data given in paper [8] and Table 1 reveals that at the equal disturbing force the proposed plane vibration depth compactor, performing simultaneously linear and torsion vibrations, is more efficient than the plane vibration depth compactor performing only linear vibrations. The use of linear and torsion vibrations enables to improve the productivity of the plane depth vibration compactor by 1.62 – 2.32 times at compacting plastic and moderately hard concrete mixtures and by 1.35 – 1.38 times at compacting hard concrete mixtures of the hardness of 60 – 90 s.

Table 2 contains the values of the required duration of compacting the concrete mixtures of different consistence at the length of the vibration processing of $x = 60$ cm and the vibration plate width increased by 1.5 times – $B = 30$ cm, i.e. at somewhat changed parameters of the vibration depth compactor: the mass of the depth compactor – $m = 5.57$ kg; the distance from the center of gravity of the depth vibration compactor to the upper edge of the vertical plate – $r_1 = 0.05$ cm; the moment of inertia of the depth vibration compactor against the axis passing across the center of gravity – J_y = 0.0486 kg·m^2; the area of the vertical plate surface interacting with the concrete mixture (at bilateral contact) – F = 1200 cm^2.

Table 1 – The values of the required duration of the vibration process of compacting t_v concrete mixtures of different consistence at the vibratory processing length *x* = 80 cm

Concrete mixture consistence	Slump= 3.5–4 cm	H= 30 s	H= 60 s	H= 90 s	H= 120 s
Compacting required time, s	17.0	31.5	41.6	48.7	53.8

Table 2 – The values of the required duration of the vibration process of compacting t_v concrete mixtures of different consistence at the vibration plate width *B* = 30 cm and the vibratory processing length *x* = 60 cm

Concrete mixture consistence	Slump= 3.5–4 cm	H= 30 s	H= 60 s	H= 90 s	H= 120 s
Compacting required time, s	29.5	60.1	79.2	92.0	100.0

The analysis of the data given in Table 2 reveals that the increase of the area of the interaction of the plane depth vibration compactor by 1.5 times due to the increase of the vibration plate width without the growth of the amplitude of the disturbing force does not result in a significant improvement of the productivity. In this case it is possible to consider admissible (Table 2) plastic concrete mixtures compacting with the slump S = 3.5 – 4 cm and hard concrete mixtures compacting of hardness 30 – 90 s.

Fig. 5 shows the change of the amplitude of the vibrations of the vertical plate of the depth vibration compactor *A* and stresses *σ*, occurring in the concrete medium of different consistence at the place of the concrete mixture contact with the vertical plate along its height at somewhat changed parameters of the vibration depth compactor: the mass of the depth compactor – m = 5.57 kg; the distance from the center of gravity of the depth vibration compactor O_2 to the upper edge of the vertical plate – r_1 = 0; the moment of inertia of the depth vibration compactor against the axis passing across the center of gravity O_2 – J_y = 0.0803 kg·m^2 ; the area of the vertical plate surface interacting with the concrete mixture (at bilateral contact) – F = 1200 cm^2; the height of the vertical plate – H = 30 cm.

The data (Fig. 5) of the change of the amplitude and stresses, occurring at the place of the vertical vibration plate contact with the concrete mixtures of different consistence, are given for the final stage of the compacting vibration process when hardness ρ_k is achieved. Fig. 6 shows the change of the stresses occurring in the concrete mixture at the distance of 60 and 80 cm from the vibration source.

tic concrete mixtures with the slump S = 3.5 – 4 cm, and of hard concrete mixtures of hardness 30 – 90 s at the processing length 60 cm and 30 – 60 s at the processing length of 80 cm. To reduce the duration of the vibration process at the increased area of the vertical plate interaction with the concrete mixture it is reasonable to increase the amplitude of the disturbing force of the vibration exciter.

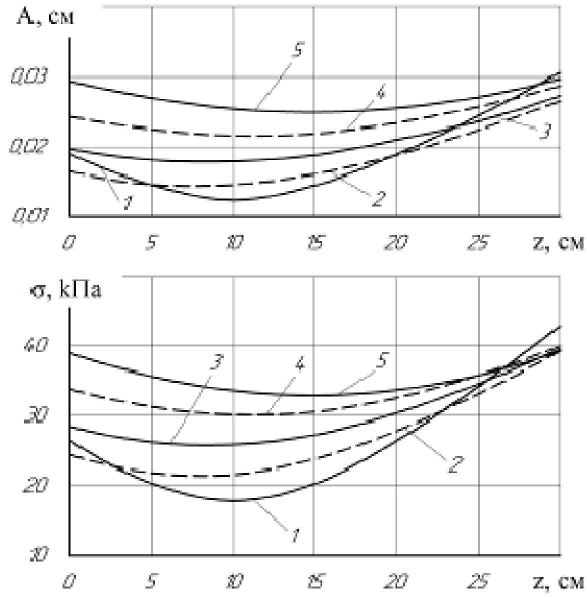

Figure 5 – The variations of the amplitudes of movements *A* and stresses *σ*, occurring in the concrete medium of different consistence at the place of its contact with the depth vibration compactor vertical plate depending on the coordinate along the height of the vertical plate from 0 to 30 cm:
1 – at the slump 3.5 – 4 cm;
2 – at the mixture hardness H = 30 s;
3 – at H = 60 s; 4 – at H = 90 s; 5 – at H = 120 s

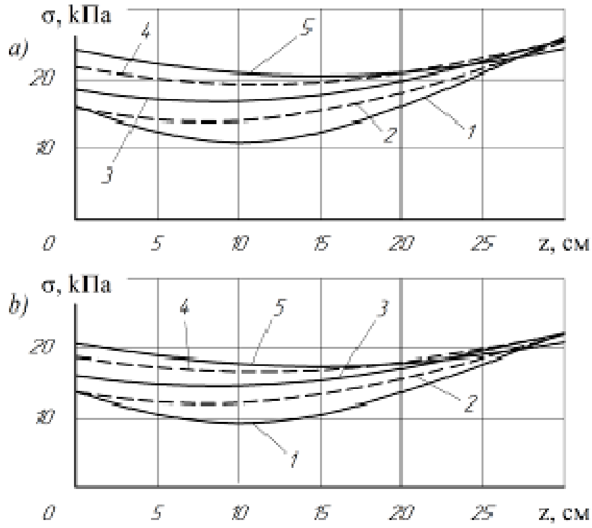

Figure 6 – The variation of the amplitudes of stresses *σ*, occurring in the concrete mixtures of different consistence at the distance of *x* = 60 cm (a) and *x* = 80 cm (b) from the source of vibration depending on the coordinate along the height of the vertical plate beginning from its vertical edge:
1 – at the slump 3.5 – 4 cm;
2 – at mixture hardness H = 30 s;
3 – at H = 60 s; 4 – at H = 90 s; 5 – at H = 120 s

The analysis of the data given in Figs. 5 and 6 reveals that the 1.5-time increase of the area of the vertical plate interaction with the concrete mixture due to the increase of the height changes the character of the variation of the amplitudes and stresses to some degree in comparison with other data stated above. The farther the vibration source is the essentially lower and somewhat smoother the amplitudes of the stresses in the compacted medium are.

Table 3 contains the values of the required durability of compacting the concrete mixtures of different consistence at the vibratory processing length of x = 60 cm and x = 80 cm, and at the vibration plate height increased by 1.5 times – H = 30 cm.

It follows from Table 3 that the growth of the area of the interaction of the plane depth vibration compactor by 1.5 times due to the increase of the vibration plate height without the growth of the amplitude of the disturbing force does not result in significant improvement of the productivity. In this case, it is possible to consider admissible (Table 3) the compaction of plas-

Table 3 − The values of the required duration of the vibration process of compacting t_v concrete mixtures of different consistence at the vibration plate height *H* = 30 cm and the vibratory processing length *x* = 60 cm and *x* = 80 cm

Concrete mixture consistence	Slump= 3.5–4 cm	H= 30 s	H= 60 s	H= 90 s	H= 120 s
Compacting required time, s	33 / 39	65 / 76	83 / 96	96 / 111	104 / 122
Note 1. The numerator contains the data obtained at the vibratory processing length x = 60 cm, and the denominator contains the data obtained at x = 80 cm.					

Thus, it has been determined that the use of the plane depth vibration compactor, simultaneously accepting linear and torsion vibrations, provides the efficient compaction of concrete mixtures.

Conclusions

It has been proposed a fundamentally new design of a plane depth concrete mixture compactor made in the form of a vertical plate equipped with a circular vibration exciter in its upper part. It has been presented a design diagram of the «plane depth compactor – concrete mixture» dynamic system and determined the regularity of the movement of the vertical plate contacting with the compacted concrete mixture in the operating mode. The obtained analytical dependences enable to determine the efficient modes of the vibratory action on the compacted medium in the form of an alternating amplitude-frequency deformation of the compacted medium. The presented research results enable the substantiation of the rational parameters of the plane depth compactor, performing spatial vibrations, and the modes of vibratory action on the concrete mixtures of different consistence.

References

1. Juradin, S., Baloević, G. & Harapin, A. (2014). Impact of Vibrations on the Final Characteristics of Normal and Self-compacting Concrete. *Journal of Materials Research,* 17(1), 178-185.

2. Sudarshan, N.M. & Chandrashekar, R.T. (2017). Vibration Impact on Fresh Concrete of Conventional and UHPFRC. *International Journal of Applied Engineering Research*, 12, 1683-1690.

3. Koh, H.B., Yeoh, D. & Shahidan, S. (2017), Effect of re-vibration on the compressive strength and surface hardness of concrete. *IOP Conf. Series: Materials Science and Engineering*, 271, 012057

4. Gutierrez, J., Ruiz, E. & Trochu, F. (2013), High-frequency vibrations on the compaction of dry fibrous reinforcements. *Journal of Advanced Composite Materials*, 22(1).

5. Волков, С.А., Евтюхов, С.А. (2012), *Строительные машины*. С-Пб: "DNK".

6. Стасенко, А.С. (2010), *Технология каменных работ в строительстве*. Минск: Выш.школа.

7. Gerasimov, M.D. & Gerasimov, D.M. (2013). Determination of the law of motion, speed and acceleration of the center of mass of the planetary vibration exciter. *Intern. Journal of applied and fundamental research,* 12, 8-11.

8. Maslov, A., Batsaikhan, J., Puzyr, R., & Salenko, Y. (2018). The Determination of the Parameters of a Vibration Machinef the Internal Compaction of Concrete Mixtures. *Intern. Journal of Engineering & Technology*, 7(4.3), 12-19. http://dx.doi.org/10.14419/ijet.v7i4.3.19545

9. Maslov, O., Batsaikhan, J., & Salenko, Y. (2018). The Theory of Concrete Mixture Vibratory Compacting. *Intern. Journal of Engineering & Technology*, 7(3.2), 239-244. http://dx.doi.org/10.14419/ijet.v7i3.2.14411

10. Nesterenko, M., Maslov, A., & Salenko, J. (2018). Investigation of Vibration Machine Interaction With Compacted Concrete Mixture. *Intern. Journal of Engineering & Technology y*, 7(3.2), 260-264. http://dx.doi.org/10.14419/ijet.v7i3.2.14416

11. Maslov, A. & Batsaikhan, J. (2018). The research of the parameters of a vibration machine for composite materials compaction. *J. MATEC Web of Conf.,* 224, 02099.

12. Maslov, A., Batsaikhan, J., Nesterenko, M. & Nesterenko, T. (2018). Deep compactor with a concrete mixture laid in a form interaction process investigation. *Intern. Journal of Engineering & Technology*, 7(4.8), 306-311. http://dx.doi.org/10.14419/ijet.v7i4.8.27261

1. Juradin, S., Baloević, G. & Harapin, A. (2014). Impact of Vibrations on the Final Characteristics of Normal and Self-compacting Concrete. *Journal of Materials Research,* 17(1), 178-185.

2. Sudarshan, N.M. & Chandrashekar, R.T. (2017). Vibration Impact on Fresh Concrete of Conventional and UHPFRC. *International Journal of Applied Engineering Research*, 12, 1683-1690.

3. Koh, H.B., Yeoh, D. & Shahidan, S. (2017), Effect of re-vibration on the compressive strength and surface hardness of concrete. *IOP Conf. Series: Materials Science and Engineering*, 271, 012057

4. Gutierrez, J., Ruiz, E. & Trochu, F. (2013), High-frequency vibrations on the compaction of dry fibrous reinforcements. *Journal of Advanced Composite Materials*, 22(1).

5. Volkov, S.A. & Evtyukov, S.A. (2012). *Construction machinery*. SPb: "DNK".

6. Stacenko, A.S. (2010). *Technology of stone works in construction.* Minsk: Vysh. shk..

7. Gerasimov, M.D. & Gerasimov, D.M. (2013). Determination of the law of motion, speed and acceleration of the center of mass of the planetary vibration exciter. *Intern. Journal of applied and fundamental research,* 12, 8-11.

8. Maslov, A., Batsaikhan, J., Puzyr, R., & Salenko, Y. (2018). The Determination of the Parameters of a Vibration Machinef the Internal Compaction of Concrete Mixtures. *Intern. Journal of Engineering & Technology*, 7(4.3), 12-19. http://dx.doi.org/10.14419/ijet.v7i4.3.19545

9. Maslov, O., Batsaikhan, J., & Salenko, Y. (2018). The Theory of Concrete Mixture Vibratory Compacting. *Intern. Journal of Engineering & Technology*, 7(3.2), 239-244. http://dx.doi.org/10.14419/ijet.v7i3.2.14411

10. Nesterenko, M., Maslov, A., & Salenko, J. (2018). Investigation of Vibration Machine Interaction With Compacted Concrete Mixture. *Intern. Journal of Engineering & Technology y*, 7(3.2), 260-264. http://dx.doi.org/10.14419/ijet.v7i3.2.14416

11. Maslov, A. & Batsaikhan, J. (2018). The research of the parameters of a vibration machine for composite materials compaction. *J. MATEC Web of Conf.,* 224, 02099.

12. Maslov, A., Batsaikhan, J., Nesterenko, M. & Nesterenko, T. (2018). Deep compactor with a concrete mixture laid in a form interaction process investigation. *Intern. Journal of Engineering & Technology*, 7(4.8), 306-311. http://dx.doi.org/10.14419/ijet.v7i4.8.27261