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The Regularity of the Transmission of Vibroimpact-Peristaltic Effects on Concrete Mix and Concrete

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Abstract. It is accepted that as a result of the complex impact of vibration-impact forces on the elementary volume of the concrete mixture with section F, the sum of the three main forces acts (Fig. 1). This includes the gravity force of the molded product and the outer shape m, inertial forces I, and the shock load P from the vibration core pressing band.
The most difficult is determining the pressure from the impact of the shock load of the pressing band. Moreover, the use of a shock load resulting from the reciprocating movements of the outer shape and the concrete pipe being manufactured leads to a twisting shock. To determine the actual mechanical stress by the method of continuum mechanics, the following prerequisites were used:
- there is a directly proportional relationship between stress and deformation upon impact;
- the modulus of elasticity of the concrete mixture under static and shock loading is the same;
- the height of the core section with the pressing band is equal to the initial displacement of the column of a concrete mixture.

These prerequisites have been confirmed with a sufficient degree of accuracy by experiments. In this case, the system in which interactions are realized, representing the process of systematic collisions, is called a vibroimpact system. Naturally, these interactions have significant specificity in comparison with the act of a single impact. However, this is true if the frequency of forced collisions, as in the case under study, is comparable to the frequency of natural vibrations of the column of the compressed concrete mixture. In this situation, the collision of a pressing organ, for example, a bandage and a column of concrete mixture, occurs in an excited system with a certain reserve of energy, which can accumulate from impact to impact, causing the development of the process of hyperexposure of the mixture.

INTRODUCTIONS

Let us consider some aspects of the theory of the impact of a pressing element (band) on a column of concrete mixture, limiting ourselves to the presentation of only those issues that are necessary for a correct understanding of the processes occurring in a vibroimpact system, allowing to build a mathematical model of this process [4-10]. First of all, we will be interested in the change in the force and kinematic characteristics of the movement of the pressing band, colliding with the column of a concrete mixture. The impact is characterized by the appearance of a stressed state in the contact zone due to the transition of the kinetic energy of the relative motion of the contacting element into the deformation energy of the compacted column of the concrete mixture. As a result, energy is distributed over the entire volume of the column of concrete mixture, causing vibrations of their elements and being absorbed by it.

METHODS

For a preliminary identification of the factors affecting dewatering, consider the process of compacting a concrete mixture laid in a form representing a cylinder with a solid wall. Suppose the mixture is compressed by normal pressure applied to the piston. If the volume of cement slurry ($V_{ц.р.}$) present in the concrete mixture turns out

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to be less than the volume of pores (V_{pop}) between the grains of coarse aggregate, then normal pressure will be perceived only by the coarse aggregate, and the cement slurry will not perceive any pressure in this case ... The effect of vibro-impact-peristaltic pressing in these cases is likely to be negative since, under the action of normal force, cases of fragmentation of individual grains of a coarse fraction are possible, which leads to a decrease in the strength of concrete.

If $V_{ц.р.}$ = Vpore between grains of coarse aggregate, then normal pressure will be perceived by grains of all concrete mixture components. Under these conditions, the effect of vibro-impact-peristaltic pressing will be unstable.

If $V_{ц.р.}$is by a certain amount greater than V_{pop}, then the normal pressure will be perceived only by the cement slurry, and the effect of vibro-shock-peristaltic pressing will depend on the ability of the cement-sand slurry to deform. The mortar will deform if the amount of cement paste is greater than the pore volume of the fine aggregate. Under these conditions, the entire load must be absorbed by the cement paste. With an excess amount of water in the cement paste, the entire load will be absorbed by the water [11-15].

Thus, to improve the sealing efficiency by vibro-impact-peristaltic pressing, the cement paste must be a medium in which grains of coarse and fine aggregates are located.

When the mold is completely sealed, the mixture is compacted only due to a slight decrease in the volume of entrained air, i.e., the effect of vibro-shock-peristaltic pressing will be insignificant. This effect will increase with an increase in the water permeability of the mold walls since, in the presence of filtration holes, free water under the action of the difference in pressure inside the mold and outside it will begin to move towards the filtration holes.

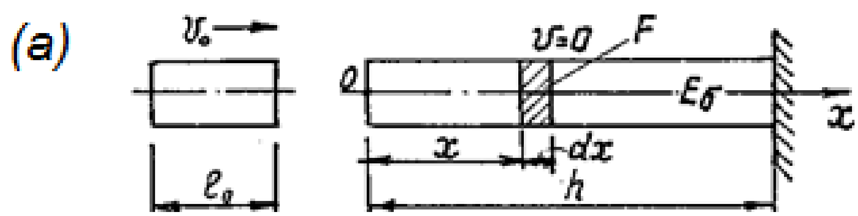
So, in the process of removing excess water and entrained air, the cement particles will begin to approach each other, which, in turn, will lead to the convergence of the grains of coarse and fine aggregates. Normal pressure transferred to water and causing it to be removed will facilitate the approach of particles until the external pressure is completely absorbed by the dispersed phase [16-18].

RESULTS AND DISCUSSION

Let us consider a longitudinal impact of a pressing band (Fig. 1) with a length of 1o, moving at a speed ϑ_o towards a column of a concrete mixture of length h, of the same section F, conditionally sealed at the right end of the formwork and at rest. The height of the concrete mixture column h is taken equal to the wall thickness of the concrete pipe is formed. At the moment of contact between the pressing band and the column of concrete mixture, interaction forces arise equal to the value of P and are directed inside the colliding bodies. These forces deform in an elementary time interval dt a section of a concrete column with a length dh. Greatness determines the speed of propagation of disturbances in the concrete mixture.

$$\gamma - \frac{dh}{dt} \tag{1}$$

Propagation of peristaltic shock waves of hyperelasticity along a column of concrete mix at successive times



BANDAGE Pillar of concrete mix

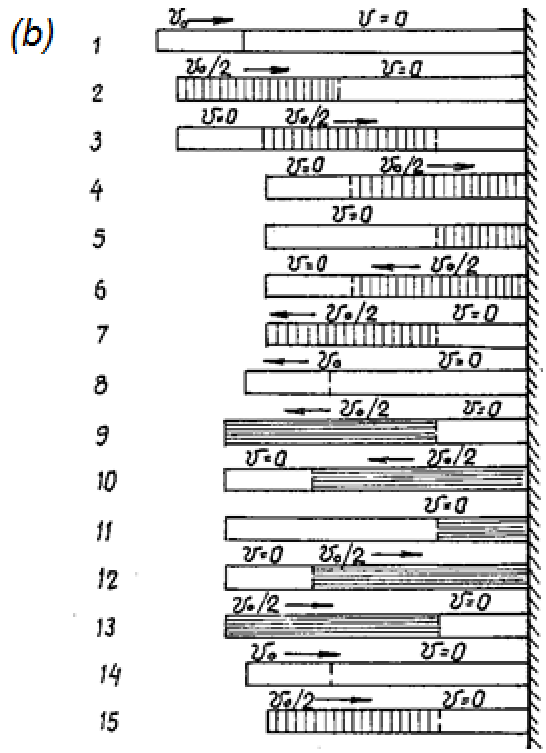


FIGURE 1. a) the original design scheme; b) propagation of waves of hyper exposure along the column of concrete mixture at successive times.

During the passage of the stress wave along the column of the concrete mixture during the time dt, its deformed section will decrease by the value $du = \varepsilon \cdot dh$, where ε is the relative deformation. As a result, the column of concrete mixture involved in the wave process will move at a speed

$$\vartheta = \frac{du}{dt} = \varepsilon \frac{dh}{dt} - \varepsilon \cdot \gamma \tag{2}$$

or, assuming that the deformation is elastic,

$$\vartheta = \frac{\delta \cdot \gamma}{E_\delta} \tag{3}$$

where δ = P / F is the voltage in the disturbed section of the concrete mixture column;
$E_\delta$is the modulus of elasticity of the concrete mixture.
For the mass of the deformed section dm, from the theorem on the change in the momentum

$$\vartheta \cdot dm = \vartheta \cdot \rho_\delta \cdot v_\delta = \vartheta \cdot \rho_\delta \cdot F \cdot dh \tag{4}$$

and using Newton's second law, P = ma, we get:

$$\vartheta \cdot \rho_\delta \cdot Fdh = Pdt \tag{5}$$

where ρ_δ is the density of the concrete mixture.
Equating equations (3) and (4), we find:

$$\gamma = \sqrt{\frac{E_\delta}{\rho_\delta}} (6)$$

The modulus of elasticity of the concrete mixture ranges from 3 to 7 MPa.

Considering that the density of the concrete mixture fluctuates in a very narrow range of γ- 2400 ... 2450 kg / m3, we find γ_{cp}- 2425 kg / m3.

Using these data, according to formula (2), it is possible to estimate the movement speed of the particles of the column of concrete mixture ϑ, at which its plastic flow begins. To do this, it is sufficient to substitute the ultimate elastic deformation of the column of the concrete mixture $\varepsilon = {}^{u}/_{h}$into equation (2).

In the process under consideration, the movement of the particles of the column of the concrete mixture occurred in the direction of the passage of the waves; therefore, such waves are called longitudinal or expansion waves. Such waves arise due to the elastic resistance of the material to a change in its volume. In cases where the transverse dimensions of the column of the concrete mixture (waveguide) are comparable to or greater than the length of the longitudinal wave, its speed increases due to the additional resistance of the material to expansion in the transverse direction and becomes equal to

$$\sqrt{\frac{E_\delta\,(1-\mu)}{(1+\mu)\cdot(1-2\mu)\cdot\rho_\delta}},$$

where μ is the Poisson ratio of the concrete mixture.

Resistance of the material of solids to change in shape generates in them another type of wave, in which particles of the material move perpendicular to the propagation of shock waves. These are shear waves or shear waves that are very important for compaction of the mixture, having a velocity equal to

$$\sqrt{\frac{G_\delta}{\rho_\delta}}$$

where G_δ is the shear modulus of the concrete mixture.

Recall that the quantities E_δ, G_δ and μ are related by the relation adopted in the theory of elasticity:

$$G_\delta = \frac{E_\delta}{2(1+\mu)}$$

The waves predicted by Rayleigh usually appear on the surfaces of solids. They generate particle trajectories close to circular, located in a plane normal to the surface and coinciding with the direction of propagation of waves. The amplitudes of surface waves exponentially decrease with depth, and the speed of their passage is approximately 90% of the speed of shear waves [7]. These types determine the general picture of the propagation of perturbations in solids, which can be obtained within the framework of models of the theory of elasticity [19-25]. Let us consider the interaction between the pressing band and the column of the concrete mixture upon impact (Fig. 1 a). By directing the X-axis along the column of the concrete mixture, we will match the origin with the position of the interacting sections at the moment of the beginning of the impact t = 0. We will describe the absolute displacements of arbitrary sections by functions u (x, t), and the longitudinal forces arising in them will be denoted by P (x, t).

Then according to Hooke's law

$$P(x,t) = E_\delta \cdot \varepsilon \cdot F = E_\delta \cdot F \cdot \frac{\partial u(x,t)}{\partial x} \tag{7}$$

The change in the longitudinal force on the elementary section dx will be equal to:

$$P(x+dx,t) - P(x,t) = E_\delta \cdot F \cdot \frac{\partial^2 u(x,t)}{\partial x^2} \cdot dx \tag{8}$$

The force difference gives the mass of an elementary section of the concrete mixture $\rho_\delta \cdot F \cdot dx$ acceleration $\frac{\partial^2 u(x,t)}{\partial t^2}$

Based on Newton's second law, we have

$$\rho_\delta \cdot F \cdot dx \cdot \frac{\partial^2 u(x,t)}{\partial t^2} = E_\delta \cdot F \cdot \frac{\partial^2 u(x,t)}{\partial x^2} \cdot dx \quad (9)$$

Reducing (9) by Fdx and considering (6), we obtain the differential equation of longitudinal vibrations of concrete mixture particles under the impact action of the pressing band in the form:

$$\frac{\partial^2 u(x,t)}{\partial t^2} = \gamma^2 \cdot \frac{\partial^2 u(x,t)}{\partial x^2} \quad (10)$$

By integrating this equation, we find its solution:

$$u(x,t) = \varphi \cdot (\gamma \cdot t - x) + \psi \cdot (\gamma \cdot t + x), \quad (11)$$

where φ and ψ are arbitrary twice differentiable functions.

These functions reflect the shape of deformation waves moving to the right and left along the column of concrete mixture with a speed of y.

Immediately after the impact, the compression wave along the column of the concrete mixture moves to the right of the contact zone and with theoretical separation of the pressing band from the contact zone - to the left. The waveform is determined by the nature of the interaction forces between the pressing band's contacting sections and the concrete mixture's column.

Since these forces are equal in magnitude, they form waves in such a way that the wave propagating along the column of the concrete mixture has the form $\varphi \cdot (\gamma \cdot t - x)$, and the wave in the pressing band $\psi \cdot (\gamma \cdot t + x)$.

The first wave draws successive sections of the concrete column into motion

$$u_1^I(x,t) = \varphi \cdot (\gamma \cdot t - x), (0 \leq x \leq h) \quad (12)$$

The second wave, on the contrary, causes deceleration of the corresponding sections of the pressing band according to the dependence

$$u_1^{II}(x,t) = \vartheta_0 \cdot t - \omega \cdot (\gamma \cdot t + x), (-lo < x < 0). \quad (13)$$

Here the superscript indicates the number of the pressing band and the column of concrete mixture; the lower one is the number of the considered time interval.

The relationship between the shape of the generated wave $\varphi \cdot (\gamma \cdot t - x)$ and the impact force P(t) is found from the following dependence for longitudinal forces in the zero section of the column of a concrete mixture:

$$-P(t) = E_\delta \cdot F_\delta \cdot \frac{\partial u^I(x,t)}{\partial x} | x = 0 \quad (14)$$

The minus sign indicates the compressive action of the force. Substituting (12) in (14), we have:

$$\varphi'(\gamma \cdot t) = \frac{P(t)}{(E_\delta \cdot F_\delta)} \quad (15)$$

Here, the prime means differentiation by argument.

Denoting the argument through α and integrating (15), considering$\varphi \cdot (0) = 0$, since at t = 0 the section x = 0 was motionless, we obtain

$$\varphi(\alpha) = \frac{1}{E_\delta \cdot F_\delta} \int_0^\alpha P \cdot (\frac{\alpha}{\gamma}) \cdot dx \quad (16)$$

For the colliding pressing band and the column of the concrete mixture (Fig. 1 "a"), we determine the value of the velocity ϑ of displacement of the sections involved in the wave process. According to the law of conservation of momentum, we have

$$\vartheta_0 \cdot dm = 2 \cdot \vartheta \cdot dm \tag{17}$$

Whence the speed of movement of the sections of the column of a concrete mixture is equal to half the speed of the impacting band

$$\vartheta = \vartheta_0/2 \tag{18}$$

Comparing (18) with (19), we find

$$P = \frac{E_\delta \cdot F \cdot \vartheta_0}{(2 \cdot \gamma)} \tag{19}$$

Substituting (19) into (16), we obtain after integration for $\alpha = \gamma \cdot t - x$:

$$\varphi \cdot (\gamma \cdot t - x) = \frac{\vartheta_0}{2} \quad (t - \frac{x}{\gamma}) \tag{20}$$

Taking into account (20), we have from (12), (13)

$$u_1^I(x,t) = \frac{\vartheta_0}{2}\left(t - \frac{x}{\gamma}\right), \quad (0 \le x \le h) \tag{21}$$

$$u_1^{II}(x,t) = \vartheta_0 t - \frac{\vartheta_0}{2}\left(t + \frac{x}{\gamma}\right), \quad (-l_0 < x < 0) \tag{22}$$

Since the impact on the column of concrete mix can be considered to be applied by an absolutely solid body (pressing band) having the mass Mo * (Mass Mo also includes 1/3 of the mass of the vibrocore of the installation *) and the speed ϑ_0, then, assuming that after the impact, the pressing band moves together with the end of the column of concrete mixture x = 0, we have according to (14)

$$-P(t) = -Mo \cdot \frac{\partial^2 u^I(x,t)}{dt^2}\Big|_{x\,=\,0} \quad = \quad E_\delta \cdot F_\delta \cdot \frac{\partial u^1(x,t)}{\partial x}\Big|_{x\,=\,0}$$

or introducing the designation for the ratio of the masses of the concrete mixture column and the pressing band $m = \rho_\delta \cdot F \cdot h/Mo$, and, taking into account (6), we obtain

$$\left[\frac{\partial^2 u^I(x,t)}{dt^2} - m\frac{\gamma^2}{h} \cdot \frac{\partial u^1(x,t)}{\partial x}\right]_{x\,=\,0} = 0 \tag{23}$$

Substituting (12) in (13), we arrive at the following equation to determine the waveform propagating after the impact

$$\varphi''(\alpha) + \left(\frac{m}{h}\right) \cdot \varphi'(\alpha) = 0$$

Integrating the last equation, we find

$$\varphi'(\alpha) = C \exp\ (-m \cdot \alpha/h),$$

where C is an arbitrary constant of integration.

Let us define an arbitrary constant of integration C from the conditions: at the initial impact time t = 0, the cross-section of the concrete mixture column x = 0 has a velocity $\partial u(0,t)/\partial t = \vartheta_0$, that is, it is equal to the speed of the impacting band. From here, taking into account (12), we find the value of the constant C:

$$C = \varphi'(0) = \vartheta_0/\gamma$$

In this way,

$$\varphi'(\alpha) = {}^{\vartheta_0}/_{\gamma} \exp\ (-m \cdot \alpha/h) \tag{24}$$

Integrating (24) with the initial condition φ (0) = 0, we find

$$\varphi(\alpha) = \frac{\vartheta_0 h}{\gamma \cdot m}\left[1 - \exp(-\frac{m \cdot \alpha}{h})\right].$$

With $\alpha = \gamma \cdot t - x$, we obtain the final equation for determining the displacements of arbitrary sections of the concrete column:

$$u_1^I(x,t) = \frac{\vartheta_0 h}{\gamma \cdot m}\left\{1 - exp\left[-\frac{m \cdot \alpha}{h}\left(t - \frac{x}{\gamma}\right)\right]\right\}, \tag{25}$$
$$(0, x < h).$$

Shock waves are reflected at the ends of the pressing band and the concrete column. For the final section of the column of concrete mixture $(x - h)$, according to (11), we have

$$u(h,t) = \varphi(\gamma \cdot t - h) + \psi(\gamma \cdot t + h) \approx 0$$

from where

$$\psi(\gamma \cdot t + h) = -\varphi(\gamma \cdot t - h) \tag{26}$$

As a result of the reflection of the shock wave from the final section in the column of concrete mixture, an additional wave appears, similar to incident one and propagating towards the opposite phase. Taking into account (26), expression (11) takes the form

$$u_2^I(x,t) = \varphi(\gamma \cdot t - x) - \psi(\gamma \cdot t + x - 2h) \tag{27}$$

(Index 2 numbers the time intervals after wave reflection). The reflection of the wave of the initial section of the column of concrete mixture in the absence of a longitudinal force: $E_\delta \cdot F \cdot \frac{\partial u}{\partial t} = 0$, occurs with the same phase; therefore, for the pressing band after reflection, we will have:

$$u_2^{II}(x,t) = \vartheta_0 t - \psi(\gamma \cdot t + x) - \varphi(\gamma \cdot t + x - 2lo) \tag{28}$$

Bearing in mind (20), from (28), we find

$$u_2^{II}(x,t) = \vartheta_0 t - \frac{\vartheta_0}{2}\left(t + \frac{x}{\gamma}\right) - \frac{\vartheta_0}{2}\left(t - \frac{x - 2lo}{\gamma}\right) = const.$$

Thus, the primary shock wave of compression, having reached the left end of the pressing band, will be reflected in the form of an expansion wave moving to the right and unloading the section of the column of the concrete mixture and the pressing element from the deformed state.

The process of passage of such waves is given a graphical interpretation, shown in Figure 1 b. Shown here is the propagation of waves along with a pressing band and a column of the concrete mixture at successive times. Cross-hatching means compressed areas, longitudinal - stretched. The absence of shading means that the corresponding areas are not deformed.

After the expansion wave has passed through the contact zone (position 3, Fig. 1 b), the pressing band is completely unloaded, and all of its energy is converted into the energy of waves moving along the column of the concrete mixture. At the same time, the contact between the pressing band and the column of a concrete mixture is maintained until the return of the wave reflected from the end embedded in the outer form. The periodicity of this process was characterized by us as peristaltic propagation of compaction waves [20,21,22].

The duration of the impact τ is usually characterized by the time during which the stressed state is maintained in the contact zone. In our case, $\tau = 2 \cdot lo/\gamma$.

If, after the end of the impact, the pressing bandage is removed, then the wave (21) or (25), having reached the outer shape and reflected following (27), will circulate along the column of the concrete mixture, causing oscillations of its sections with a period of $4 \cdot h/\gamma$(Fig. 1 b).

The periodicity of the process is a consequence of idealization, which does not take into account the real imperfection of the concrete mixture as an elastoplastic medium, which manifests itself in the absorption of energy due to internal friction in the mixture. The concept of internal friction unites several processes that are different in their mechanism, leading, in particular, to the existence of a hysteresis loop in the stress-strain curve during cyclic deformation of the material. The influence on the energy dissipation of hereditary factors due to the creep of the mixture and the relaxation of stresses in it does not allow, in principle, to obtain an expression for the dissipative forces in terms of the current values of deformation. The use of integro-differential equations to describe the evolution of a concrete mixture significantly complicates the study of the process of peristaltic hyperexposure.

The experiments carried out have established that with periodic deformation of the concrete mixture according to the harmonic law, the area of the hysteresis loop, which characterizes the degree of energy absorption and compaction, depends on the deformation amplitude and does not depend on the frequency. Therefore, in the study of the peristaltic hyperextension of a concrete mixture, we introduced an equivalent force proportional to the deformation rate. In this case, the coefficient of the equivalent force is chosen so that the usual dissipative effect of energy absorption in the concrete mixture corresponds to the experimental data. As a result, equation (10), which describes the effect of periodic vibrations of the pressing band and the column of concrete mixture, is written in the form:

$$\frac{\partial^2 u(x,t)}{\partial t^2} - \gamma^2 \frac{\partial^2 u(x,t)}{\partial x^2} - b\frac{\partial^3 u(x,t)}{\partial x^2 \partial t} = 0 \qquad (29)$$

where $b = \gamma^2 \cdot Kp/(2 \cdot \pi \cdot \omega)$is the linearized coefficient of internal friction forces in the concrete mixture;

$\omega$is the frequency of vertical action of vibration of the vibrating core;

Kp is the absorption coefficient found from the experimental data as the ratio of the energy dissipated in one cycle (proportional to the hysteresis loop area) to the total strain energy.

For the steel of the bandage Kp≈ 0.015, for the concrete mixture, it is equal to Kp = 0.27 ... 0.33.

Due to internal friction, the periodic process of compaction of the concrete mixture is established as a result of the regular inflow of additional energy from the periodic action of the vibro-core of the installation of the additional energy current [1, 23].

With periodic excitation, due to the superposition of direct and reflected waves, stationary wave fields (standing waves) are formed in our system, the intensity of which significantly exceeds the amplitudes of the generated waves. For the contact force $P(t) = \alpha_p \cdot \sin \omega \cdot t$ from (16), we find

$$\varphi(\alpha) = \frac{a_p}{E_\delta \cdot F}\int_0^L \sin\frac{\omega \cdot \alpha}{\gamma} \cdot d \cdot \alpha = \frac{a_p}{\omega \cdot E_\delta \cdot F} \cdot cos\frac{\omega \cdot \alpha}{\gamma}.$$

Thus, a direct wave is generated along the concrete column

$$\varphi(\gamma t - x) = -\frac{a_p \cdot \gamma}{\omega \cdot E_\delta \cdot F} \cdot cos\omega\left(t - \frac{x}{\gamma}\right) = \frac{a_p \cdot \gamma}{\omega \cdot E_\delta \cdot F} \cdot cos\left(\omega t - \frac{x\omega}{\gamma}\right).$$

The amplitude "a" of the standing wave, formed as a result of multiple reflections of the generated wave from the initial and final sections of the column of concrete mixture, according to (27) (the superposition of direct and reflected waves, satisfying the condition of fixing the right end), will take the form:

$$u^I(x,t) = a \cdot \cos\left(\omega t - \frac{x\omega}{\gamma}\right) - a \cdot \cos(\omega t + (x - 2h) \cdot \frac{\omega}{\gamma})$$

or using the well-known trigonometric formula

$$\cos\alpha - \cos\beta = 2 \cdot \sin\frac{\alpha + \beta}{2} \cdot \sin\frac{\beta - \alpha}{2}$$

we obtain the standing wave equation

$$u^I(x,t) = 2a \cdot sin\frac{\omega}{\gamma}(h-x) \cdot sin\omega(t-\frac{h}{\gamma}) \quad (30)$$

Introducing the phase ψ into the disturbing force P (t),

$$P(t) = a_p \cdot \sin(\omega t - \psi) \quad (31)$$

and, subjecting (30) and (31) to the condition on the initial section of the column of the concrete mixture (14), we have:

$$2a\frac{\omega}{h}E_\delta \cdot F \cdot cos\frac{\omega h}{\gamma} \cdot \sin\left(\omega t - \frac{\omega h}{\gamma}\right) = a_p \cdot \sin(\omega t - \psi), (32)$$

whence the amplitude of forced vibrations of the concrete mixture is equal to:

$$a = \frac{a_p \cdot \gamma}{2 \cdot \omega \cdot E_\delta \cdot F \cdot \cos(\frac{\omega h}{\gamma})} (33)$$

As a result, near the values

$$\omega = \frac{\pi \cdot \gamma}{2h} \cdot (2m-1), \qquad (m = 1,2 \dots n)$$

the amplitude of the standing wave increases indefinitely, i.e. the process of hyperexposure occurs, which we observed in all our experiments. As a rule, peristaltic hyperexposure led to a mixture compaction coefficient of at least 0.98.

CONCLUSIONS

1. A system of patterns of vibro-shock-peristaltic action on a concrete mixture has been obtained, which has revealed essential differences in the compaction process from a single impact and vibration compaction.

2. The emergence of high-intensity compression and tension zones in the column of the compacted concrete mixture, alternately changing in time, was proved, and quantitative characteristics were obtained to determine the compaction parameters.

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