Choosing the effective modes of compaction of hard concrete mixtures

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Abstract. In the manufacture of reinforced concrete products and structures, one of the main labor-intensive operations is the compaction of concrete mixtures. All the basic physical and mechanical properties of the molded products, such as density, strength, frost resistance and others, as well as the specified shapes and high-quality surfaces, depend on the quality of mixture compaction. A decrease in the density of a product after compacting concrete mixes by 1% leads to a decrease in the strength of hardened concrete by 5-7%, and when molding products from hard mixtures – up to 13%. The effectiveness of vibration molding of concrete and reinforced concrete products is largely determined by the methods and modes of compacting concrete mixtures in molds. These questions are especially relevant when compacting hard and very hard concrete mixes. The analysis of the existing modes of molding reinforced concrete products from hard concrete mixtures is carried out in this paper. The equipment used for molding reinforced concrete products applies different types of compaction: vibration, shock-vibration and shock. The main parameters of vibroforming machinery are frequency, amplitude and acceleration of the working body, which can be symmetric and asymmetric. The advantages of using asymmetric shock-vibration modes are shown, and a method for creating shock-free asymmetric vibrations is proposed. The results of theoretical and experimental studies are presented, which have shown the high efficiency of compaction of hard concrete mixtures in shock-free asymmetric modes.

1. Introduction
In the manufacture of reinforced concrete products and structures, one of the main labor-intensive operations is the compaction of concrete mixtures. All the basic physical and mechanical properties of the molded products, such as density, strength, frost resistance and others, as well as the specified shapes and high-quality surfaces, depend on the quality of mixture compaction. A decrease in the density of a product after compacting concrete mixes by 1% leads to a decrease in the strength of hardened concrete by 5-7%, and when molding products from hard mixtures – up to 13% [1, 2].

To increase the efficiency of shaping reinforced concrete products, especially from hard concrete mixtures, it is very important to rationally approach the choice of molding equipment and use the optimal modes of vibration on the compacted concrete mixture.

2. Materials and methods
The equipment used for molding reinforced concrete products applies different types of compaction: vibration, shock-vibration and shock. The main parameters of vibroforming machinery are frequency,
amplitude and acceleration of the working body, which can be symmetric and asymmetric [1-4].

Evaluation of the effectiveness of vibration impact on the concrete mix during the molding process is most often carried out according to the intensity $I$, which is determined by the acceleration of vibrations of the screed vibrator [5]:

$$I = A \omega^2,$$

where $A$ - amplitude of displacement; $\omega$ - circular vibration frequency.

3. Results and Discussion

Numerous works on the study of the processes of molding concrete products have convincingly shown that asymmetric shock-vibration modes are most effective for compacting hard concrete mixtures [1, 2, 4]. Comparison of the specific power of the screed vibrators during the compaction of concrete mixtures showed that the power of the vibrators functioning in asymmetric modes are about eight times higher than the capacities of the vibrators operating in the symmetric vibration mode [2].

When implementing asymmetric shock-vibration modes, two accelerations are recorded (depending on the position of the screed vibrator): top $A_{gh}$ and bottom acceleration $A_{gt}$. Moreover, $A_{gt}$ plays a primary role in molding, since maximum compaction forces develop in the concrete mixture during this period of time [1, 3].

The results of comparative experimental studies, showing the effectiveness of various modes of molding products from hard concrete mixtures, are presented in Table 1 [6]. In this case, the compaction time of concrete mixtures was used as a criterion.

| Concrete mixture stiffness (s) | Compaction mode | Compression ratio |
|-------------------------------|-----------------|------------------|
|                               | Symmetric $f = 50$ (Hz) $A_g = 3.5 g$ | Shock-vibration $f = 10$ (Hz) $A_{gh} = 2-2.5 g$, $A_{gt} = 5-7 g$ | |
| 20                            | 30              | 15               | 0.98 |
| 50                            | 150             | 50               | 0.98 |
| 70                            | 300             | 120              | 0.95 |

The data in Table 1 convincingly show that the asymmetric shock-vibration mode of compaction of concrete mixtures is more preferable in comparison with the standard mode of harmonic vibrations.

Theory substantiating the effectiveness of using shock-vibration while molding reinforced concrete products in comparison with symmetric harmonic vibrations is presented in [7]. It was found that in the case of impact of harmonic vibrations on the concrete mixture, the particles of the mixture vibrate with the frequency of the generated vibration action. In the case of shock-vibration impact, the displacement of concrete particles during the propagation of a shock wave is directed against the direction of wave propagation, thereby providing a compaction effect. The intensity of compaction process for concrete mixtures in real conditions is also influenced by the shape and spectrum of impulses of shock-vibration effects.

One of the ways to reduce the time of vibration compaction of concrete mixtures is to use screed vibrators with a free (without fixation) form installed on the vibration table, which creates conditions for the form to collide with the table surface [2, 4]. As a result, the processes of vibration compaction of mixtures occur more intensively, since at the moment of impact a wide spectrum of frequencies, containing a large number of high energy components, is generated [3].

In shock-vibration modes, the maximum value of the bottom acceleration $A_{gt}$ (when the working body collides with the limiter) largely determines the magnitude of the dynamic stresses and the strength characteristics of the screed vibrator. Since the value $A_{gt}$ reaches 100 m/s$^2$ and more, this
leads to frequent crashes and breakdowns of vibration equipment [2, 4]. In addition to reducing the reliability and durability of equipment, the permissible noise and vibration levels are also exceeded.

As shown in [8], one of the effective modes of compaction of hard concrete mixtures is the use of the so-called asymmetric shock-free vibrations, to a large extent imitating the shock-vibration mode and differing from the latter in the absence of collisions of the vibrator with the balancing frame.

Asymmetric shock-free vibrations are achieved by combining two harmonic vibrations of the same amplitude, differing in frequency by two times. For the practical implementation of asymmetric vibrations, a system of inertial vibrators is required, containing two pairs of eccentric weights, synchronously rotating in opposite directions, and the circular frequency of rotation of the extreme weights \( \omega_1 \) should be twice the rotation frequency of internal weights \( \omega_2 \) (Figure 1).

![Figure 1. Inertial vibrator system. 1, 2, 3, 4 - eccentric shafts; \( \omega_1 = 2 \omega_2 \).](image)

To obtain the maximum asymmetry of the resulting vibration, it is necessary that, with equal eccentricities of the weights, the ratio of the eccentric mass of the external weights \( m_1 \) to the internal \( m_2 \) was 1:4 [8]. Taking into account these recommendations, the screed vibrator was developed and created with the following technical characteristics: lifting capacity - 1.5 t, vibration frequency - 7...32 Hz, vibration amplitude - 0.3...3.5 mm, electric motor power – 11 kW.

Researching the process of vibration compaction of hard concrete mixtures by asymmetric vibrations showed that the efficiency of compaction is determined not only by the absolute values of accelerations \( A_{g1} \) and \( A_{g2} \), but also depends on the duration of action of the bottom compaction acceleration \( A_{g1} \) [8].

Figure 2 shows oscillograms of displacements of a mold with a concrete mixture under shock-vibration and in asymmetric shock-free modes of molding with the same values of the frequency \( f \) and the amplitude of the lower acceleration \( A_{gf} \).

![Figure 2. Oscillograms of concrete mixture mold displacements in the process of shaping by shock-vibration (a) and in asymmetric shock-free mode (b).](image)

Let us determine the work performed by vibrators at the time interval during which the concrete mixture is affected by the compaction accelerations \( A_{gf} \). The work done by the screed vibrator with
shock-vibration (Figure 2a) is simplified by the area of a triangle, limited by the moments of time \( t_1, t_2 \) and the amplitude of the vibration \( A \).

Work \( A_p \), performed by a vibrator with asymmetric shock-free vibrations over a period of time from \( t_1 \) to \( t_2 \), that is, over a period of \( T_2 \) (Figure 2b) can be represented as:

\[
A_p = \int_{x_1}^{x_2} Fdx = \int_{t_1}^{t_2} Fvdt.
\]

where \( F \) and \( v \) are the force and speed of the impact of the screed vibrator working body;

\( x_1, x_2 \) and \( t_1, t_2 \) are the start and end coordinates of the point and their time values.

Specifying the trajectory of motion of a point on the vibrating table surface by the expression \( x = A \sin \omega t \), taking the change in force over time as a function \( F = f \cos \omega t \), a speed change \( v = \frac{dx}{dt} = A \omega \cos \omega t \), work force for the period of vibration from \( t_1 \) to \( t_2 \) will have the form:

\[
A_p = \int fA\omega \int_0^{T_2} \cos^2 \omega t dt.
\]

Having chosen the initial moment \( t_1 = 0, x_1 = 0 \) and the final moment \( t_2 = \pi/2, x_2 = 0 \) and substituting these values into the equation (3), after some transformations we get:

\[
A_p = \frac{\pi}{2} A^2 f^2.
\]

These results are in good agreement with the criterion for evaluating the effectiveness of vibration impact on the mixture, which is determined by the acceleration of vibrations of the screed vibrator [5].

Comparing the operation of vibrators during compaction of concrete mixtures by shock-vibration (Figure 2a) and asymmetric shock-free mode (Figure 2b) with the same values of amplitude, vibration frequency and accelerations, it can be seen that the exposure time of asymmetric shock-free vibrations \( T_2 \) is longer than shock \( T_1 \) value. Therefore, the work performed by asymmetric shock-free vibrations is greater than the work in the shock-vibration mode.

The results of experimental studies of the kinetics of compaction of hard concrete mixtures, specifically by lowering the surface of the mixture in the process of vibration by various vibration effects, are shown in Figure 3 [8].

![Figure 3](image)

**Figure 3.** Dependence of the height of \( H \) layer on the compaction time \( t \) for hard concrete mixtures with hardness values of 1, 3 - 35s; 2, 4 - 60s at different vibration modes:

- - - - - - asymmetric shock-free mode;

- - - - - - - - - - - - - shock-vibration mode

As graphs in Figure 3 show, the time of compaction of concrete mixtures in the asymmetric shock-free mode is approximately 3.5-5 times less compared to the shock-vibration mode with a higher degree of compaction. Consequently, the asymmetric shock-free vibration mode is more effective than the shock-vibration mode.
4. Conclusion

The analysis of the existing modes of molding reinforced concrete products from hard concrete mixtures is carried out. The performed set of experimental studies has shown the high efficiency of compaction of hard concrete mixtures (hardness index of 30...80s according to a technical viscometer) when using asymmetric shock-free modes in comparison with shock-vibration and symmetrical vibrations. This makes it possible to reduce the overall molding cycle to 60...100s and increase the strength of concrete by 12...20%, depending on the vibration frequency, acceleration and hardness of the concrete mixture.

References

[1] Gusev B V and Zazimko V G 1991 Vibration Technology of Concrete (Kiev: Budivelnik)
[2] Savinov O A and Lavrinovich E V 1986 Vibration Technology of Compaction and Formation of Concrete Mixtures (Moscow: Striyizdat)
[3] Gusev B V, Deminov A D, Kryukov B I et al 1982 Shock-Vibration Technology of Compaction of Concrete Mixes (Moscow: Striyizdat)
[4] Shmigalsky V N 1968 Forming Products on Vibroplatforms (Moscow: Striyizdat)
[5] Gusev B V, Axelrod E Z, Zvezdov A I et al 1988 Manual on the Technology of Molding Reinforced Concrete Products (Moscow: Striyizdat)
[6] Sinyaeva E A 1982 Influence of the Parameters of Vertical-Directional Symmetric and Asymmetric Vibrations on the Compaction of the Concrete Mix: dissertation abstract (Moscow: NIIZHB)
[7] Vasiliev V G 2017 The Choice of Parameters of Vibration Effects in the Molding of Concrete Products J. Mech. of const. 11 21-25
[8] Vasiliev V G 2017 Block Vibration Platforms with Shockless Asymmetric Vibrations J. Mech. of const. 7 14-16