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FRESHLY COMPACTED CONCRETE DYNAMIC RESPONSE TO HARMONIC VIBRATIONS IN PRECAST BRIDGE BEAMS

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Abstract: *When fresh concrete is poured into the metal patterns of the beams of approx. 40...42 m used in the construction of bridges and viaducts, external vibration is activated with inertial vibrators arranged along the length of the metal pattern. The paper presents the parametric analysis of the compaction of freshly poured concrete into molds with equipment with external inertial vibrators. The stiffness and damping values of the fresh concrete were determined according to its physical nature and composition, in steps of the degree of compaction with variations discrete stiffness and critical damping fraction based on the Voigt–Kelvin rheological model. In this context, the families of characteristic amplitude-frequency curves highlight the fact that the post-resonance regime is favorable to the compaction process.*

Key words: *forced vibration, concrete compaction, stiffness, critical damping fraction, precast beam.*

1. INTRODUCTION

The functional analysis of the outdoor vibrators equipping the elastic metal molds for concrete compaction must be established according to the mass of fresh concrete, the duration of vibration and the physical-mechanical characteristics of the entire mold – vibrator – concrete assembly. Equipping with outdoor vibrators increases the compaction effect through the undulating effect manifested in the mass of freshly placed concrete. In order to obtain a maximum effect of compaction and as high as possible homogenization of the concrete mass, it is necessary that the vibration regime transmitted to the concrete to be stable, controllable and at the parameters imposed by the work technology. During the compaction process, both the stiffness and the internal damping rate change simultaneously, which enables the dynamic analysis to be assessed through families of parameterized amplitude-frequency characteristic curves [1, 2, 3, 4].

2. RHEOLOGIC MODEL

For the calculation of the constructive and functional parameters of the outdoor vibrators with inertial disturbance force, several simplifying assumptions are introduced, namely:

- The vibrating system - clamping element is considered to be modeled as a system with a degree of freedom over a length of approximately 2 m as a radius of action from the length of the elastic metal mold;

- The vibrator is placed in the center of gravity of the elastic element that fulfills the role of a unitary segment with a length of 2m.

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The Voigt - Kelvin rheological model defines the dynamic calculation scheme for an elastic system with external vibrator with rotating disturbing force (centrifugal inertia force) generated by an eccentric mass in rotational motion. It is considered that the external vibrator 2 is located in the mass center of the element to be compacted 1 (mold, formwork) which will be called working organ. The presented model is characterized by the fact that the center of the elastic forces coincides with the center of the dissipative forces and with the application point of the centrifugal force of inertia that maintains the forced vibrations in a stabilized regime (Fig. 1) [5, 6, 7, 8].

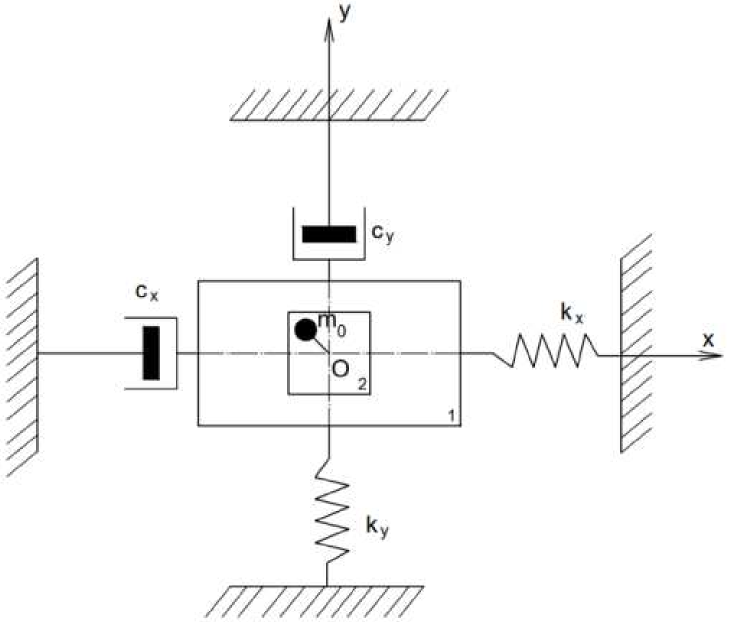

Fig 1. Schematization of the dynamic model

The differential equations of motion of the viscoelastic system, excited with a rotating perturbing force, are:

$$\begin{cases} m\ddot{x} + c_x\dot{x} + k_x x = m_0 r\omega^2 sin\omega t \\ m\ddot{y} + c_y\dot{y} + k_y y = m_0 r\omega^2 cos\omega t \end{cases} \quad (1)$$

where m_0 is the total mass of the eccentric; r – distance from mass center of the eccentric to the rotation axe (eccentricity); ω – angular speed of the eccentric mass or the pulsation of the disturbing force; k_x, k_y – equivalent stiffness coefficients of the elastic system, corresponding to directions x and y; c_x, c_y – equivalent coefficients of the dissipation forces proportional to speed $\dot{x}$ and $\dot{y}$.

The solutions of the decoupled differential equations according to the rectangular axes Ox and Oy are given in the stabilized working regime, as:

$$\begin{cases} x = A_x \sin(\omega t - \varphi_x) \\ y = A_y \cos(\omega t - \varphi_y) \end{cases} \quad (2)$$

where A_x is the movement amplitude on axe x;
A_y – movement amplitude on axe y.

The amplitude of movements according to axes x and y are given by the relations:

$$A_x = \frac{m_0 r\omega^2}{(m_1 + m_0)\sqrt{(p_x^2 - \omega^2)^2 + 4h_x^2\omega^2}} \quad (3)$$

$$A_y = \frac{m_0 r \omega^2}{(m_1 + m_0)\sqrt{(p_y^2 - \omega^2)^2 + 4h_y^2\omega^2}}$$

where the following notes were used:

- phase shifts φ_x and φ_y with expression:

$$\varphi_x = arctg\frac{2h_x\omega}{p_x^2 - \omega^2}$$
$$\varphi_y = arctg\frac{2h_y\omega}{p_y^2 - \omega^2} \tag{4}$$

- own pulsations p_x and p_y as:

$$\begin{cases} p_x = \sqrt{\frac{k_x}{m}} \\ p_y = \sqrt{\frac{k_y}{m}} \end{cases} \tag{5}$$

- damping factors h_x and h_y:

$$\begin{cases} h_x = \frac{c_x}{2m} \\ h_y = \frac{c_y}{2m} \end{cases} \tag{6}$$

For the case where dissipation is so small that it can be neglected, the calculation relations can be applied in the form:

$$A_x = \frac{m_0 r \omega^2}{(m_1 + m_0)|p_x^2 - \omega^2|}$$
$$A_y = \frac{m_0 r \omega^2}{(m_1 + m_0)|p_y^2 - \omega^2|} \tag{7}$$

And phase shifts φ_x and φ_y can be:

$$\begin{Bmatrix} \varphi_x = 0, pentru\, p_x > \omega \\ \varphi_x = \pi, pentru\, p_x < \omega \end{Bmatrix}$$
$$\begin{Bmatrix} \varphi_y = 0, pentru\, p_y > \omega \\ \varphi_y = \pi, pentru\, p_y < \omega \end{Bmatrix} \tag{8}$$

The analysis of the amplitude-frequency characteristic is done on the basis of the graphical representation of the amplitude of the movements along axes x and y, given by relations (3) when the stiffness and the damping rate change with the increase in the degree of compaction [10, 11, 12, 13, 14].

3. AMPLITUDE-FREQUENCY CHARACTERISTIC

For a 42 m length beam, it is necessary to use a metal mold also of 42 m so that for the entire beam-mold system, 24 exterior vibrators placed at a distance of 2 m between them, by mechanical fixation, will be needed [15, 16, 17, 18, 19].

In this case, for freshly poured concrete with density $\rho = 2500kg/m^3$ and volume dimensions of the mold of 0.25 m x 1.0 m x 2 m, the physical and mechanical measures of rigidity and damping in two directions have the following values:

- mass of vibrated concrete m = 2000 kg;
- discretely variable bidirectional rigidities k_x, k_y depending on the degree of compaction;
- viscous dampings $c_x = 4 \cdot 10^4$ Ns/m; $c_y = 2 \cdot 10^4$ Ns/m;
- total static moment of an exterior vibrator is $m_0 r$ = 0,5 kgm
- excitation pulsation or the angular speed of rotation of the eccentric masses is ω=157 rad/s;
- post-resonance regime amplitude is $A_0 = \frac{m_0 r}{m}$=0,25 $\cdot 10^{-3}$=0,25mm

The graphical representation of amplitudes A_x and A_y according to the current variable ω=0...400 rad/s and the discrete variable of rigidity k_x and k_y shall be made based on the relations below:

$$A_x = \frac{m_0 r \omega^2}{\sqrt{(k_x - m\omega^2)^2 + 4\zeta_x^2 m\omega^2 k_x}} \qquad (9)$$

$$A_y = \frac{m_0 r \omega^2}{\sqrt{(k_y - m\omega^2)^2 + 4\zeta_y^2 m\omega^2 k_y}} \qquad (10)$$

where k_x = (3, 5, 8, 10)· 10^6 N/m and k_y = (5, 8, 12, 20)· 10^5 N/m, and $\zeta_x = \frac{c_x}{2\sqrt{k_x m}}$ and $\zeta_y = \frac{c_y}{2\sqrt{k_y m}}$,

Fig. 2 presents the curve family for $A_x(\omega, k_x)$, and figure 3 shows the curves for $A_y(\omega, k_y)$.

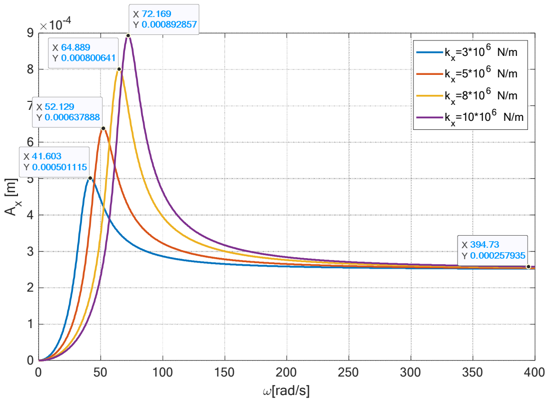

Fig 2. Amplitude-frequency characteristics on axe x

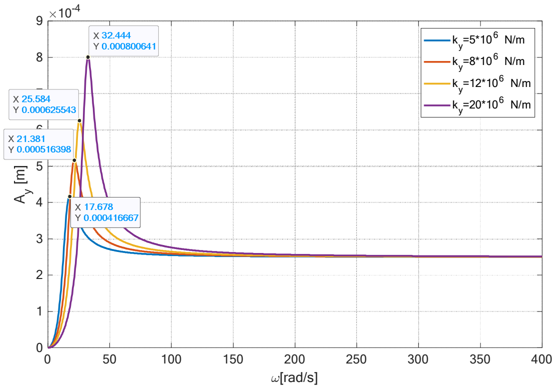

Fig. 3. Amplitude-frequency characteristics on axe y

4. CONCLUSIONS

The evaluation of the process of compaction by vibration of the fresh concrete in molds as well as on the basis of the research carried out, of the in-situ results obtained when making the 42 m long beams, by the road construction companies in Romania, the following conclusions can be reached:

a) The rigidity and damping parameters of the freshly poured concrete in the vibratory mold established on the basis of the fresh concrete recipes change during the compaction process. Discretely variable values correspond to the achievement of certain degrees of compaction [19];

b) The post-resonance vibration mode provides stability and ensures constant amplitude independent of rigidity and damping. In this case, one can count on the technological amplitude $A_0 = \frac{m_0 r}{m}$ [20] ;

c) The increasing variation of the rigidity, as a result of the variability of the concrete composition, leads to the change of the damping rate and to the increasing values of the resonance amplitude [21];

d) The geometric location of the peak points of the resonance amplitudes is a curve characteristic of the increase in the fresh concrete degree of compaction.

e) The author's contributions are essential in that the areas of technological vibration under optimal compaction conditions have been established. The results have been validated in the fabrication of concrete beams for bridges and tests carried out by the author in ICECON SA.

f) The original results consist in the fact that on the basis of the adopted dynamic model the optimal amplitude-frequency range for the designed behaviour can be highlighted.

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Răspunsul dinamic al betonului proaspăt compactat la acțiunea vibrațiilor armonice în cazul grinzilor prefabricate, pentru poduri

Rezumat: La turnarea betonului proaspăt în tiparele metalice ale grinzilor de cca 40…42 m utilizate la constructia podurilor si viaductelor, se activează vibrarea exterioară cu vibratoare inerțiale dispuse pe lungimea tiparului metalic.

In lucrare se prezinta analiza parametrică a compactării betonului proaspăt turnat în tipare cu echipamente dotate cu vibratoare inerțiale de exterior.Valorile de rigiditate și amortizare ale betonului proaspăt au fost stabilite în funcție de natura fizică și compoziția acestuia, pe trepte ale gradului de compactare cu variații discrete ale rigidității și fracțiunii din amortizarea critică, pe baza modelului reologic Voigt – Kelvin.

În acest context, familiile de curbe caracteristice amplitudine – frecvență evidențiază faptul că regimul postrezonanță este favorabil procesului de compactare.

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