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MODELING VIBRATORY COMPACTION OF SOILS AS A FUNCTION OF DISCRETE SETTLEMENT CHANGE

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Abstract: *The research results of dynamic analysis and its effect on natural or backfilling soil, for construction foundations have been obtained due to the optimization of achieving the value 98% for the degree of compaction. Basically, for the construction of national roads and highways in Romania, there have been carried out tests for the correlation of vibratory roller performances with dynamic loading of 150 and 250 kN, excitation frequencies of 25 and 50 Hz. The period of research was 2008-2021 and the focus was that of optimal correlating the dynamic parameters to the technological requirements for soils compaction, in order to achieve a minimum value of 98% for the degree of compaction. For soil compaction there is used trailed or self-propelled vibratory equipment. The mass M of vibratory roller is within the interval (3000 ... 5000) kg and the initial excitation forces are of amplitude (2 ... 5) G, where G is correlated to the mass values (G = 9.81M).*
This paper also analysis the variation curves for the amplitude of forced vibrations depending on the excitation pulsation, the force acting on the shaft of eccentric rotating masses and generating the dynamic force. The experimental results were determined „in situ”.
Key words: *technological vibrations, excitation force, dynamic model, compaction vibratory roller.*

1. INTRODUCTION

The analysis of dynamic response has been done for the vibration compaction equipment, made in Romania, CV10 type, in use for the road foundation compaction works, in Romania.

Basically, the considered dynamic model is that of a system with two mass and two degrees of freedom, with elastic links (see figure 1). The compaction soil has been modeled by Hooke model, due to the fact that the work regime in technological compaction by vibration is post-resonance one, where viscous damping does not have a significant influence. At this work regime, for frequencies values within the interval 10 Hz and 25 Hz, the resonance frequencies are about (1 … 3)Hz with dynamic excitation forces of (50 … 250) kN. [8,9,17]

The graphs for amplitude and pulsation variation depend on non-dimensional parameter, $\lambda_1 = \frac{k_1}{k_2}$, characterizing the increase of soil rigidity, k_1, after each pass of the compaction equipment over the same soil layer. The rigidity value, k_2 , of the link between the two masses, m_1 and m_2, is constant and have to perform dynamic isolation of, at least, 90%.

Further in this paper will be presented, by comparation, the parameters results determined both by calculi and experimentally.

The experimental tests enabled to set the work parameters of the compaction equipment by setting the dynamic regime for clay soils with 15% sand and humidity (6÷8)%. Depending on the amplitude – frequency dynamic regime and on the excitation inertial dynamic force there have been set the values for the degree of compaction measured „in situ”. [11, 12, 15]

2. VIBRATION AMPLITUDES

Based on the specific data in References, regarding the most efficient constructive and functional solutions for vibratory rollers used in soil compaction with post-resonance regime, it has been adopted the two degrees of freedom model.

This model consists in two masses with vertical instantaneous translation motion, so that

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the $\boldsymbol{m_1}$ mass of the vibratory roller to be in permanent contact with the soil modeled by the constant rigidity, $\boldsymbol{k_1}$. The mass $\boldsymbol{m_2}$ linked by the elastic system of $\boldsymbol{k_2}$ constant represents the specific parameter of the superior chasis, on which there are mounted the actuation module and other equipments. The vibrations transmitted from the technological regime vibratory mass $\boldsymbol{m_1}$ to the mass $\boldsymbol{m_2}$ must be dynamically isolated, so that the isolation degree values not to be less than 90%. [4,6,8,12,13,25] The dynamic scheme for modeling and calculation is shown in figure 1.

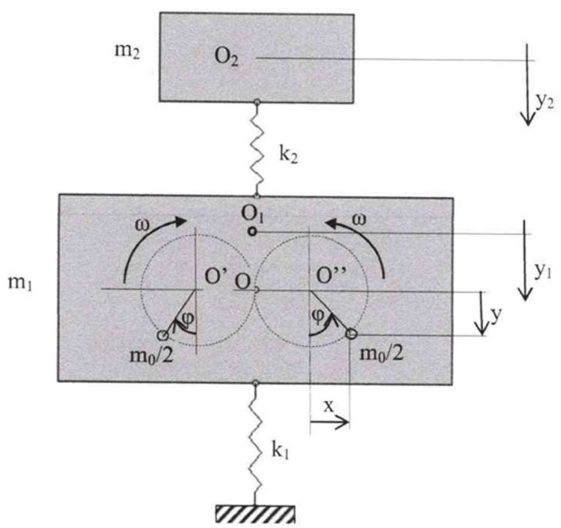


Fig 1. Dynamic scheme for calculation

The mass $\boldsymbol{m_1}$ of the vibratory roller has inside it a vibratory system made of two eccentric masses $\boldsymbol{m_0/_2}$ for dynamic imbalance, positioned to eccentric distance r, when referred to the center O. These eccentric masses have rotational synchronic and synphasic motion, with angular speed ω so that the vertical unidirectional excitation dynamic force, whose axis goes through O center, can be written as: $F(t) = m_0 r\omega^2 sin\omega t$ where $F_0 = m_0 r\omega^2$ represents the amplitude, or maximum excitation force.

The instantaneous coordinates defining the degrees of freedom for masses m_1, m_2 and m_0 are y_1, y_2 and, respectively, $\boldsymbol{\varphi}$ [1,3,4,7,12,16]

The differential equations for motion of thedynamic system are given by relation [5] (1)

$$\begin{cases} (m_0+m_1)\ddot{y}_1 - m_0 r\ddot{\varphi}\sin\varphi - m_0 r\dot{\varphi}^2\cos\varphi + \\ \quad k_1 y_1 + k_2(y_1-y_2) = 0 \\ m_2 r\ddot{y}_2 - k_2(y_1-y_2) = 0 \\ \quad -m_0 r\ddot{y}_1 \sin\varphi + (J_o + m_0 r^2)\ddot{\varphi} + \\ \quad m_0 g r\sin\varphi = M \end{cases} \tag{1}$$

where: J_0 is the total moment of inertia for the vibratory motor shaft;

M – moment of the actuation torque for the vibratory motor shaft.

The study of the stabilization regime in post-resonance for the compaction technological process is characterized by constant value for pulsation $\dot{\varphi} = \omega = const$ and, therefore, $\varphi = \omega t$ so that relation (1) turns into:

$$\begin{cases} (m_0+m_1)\ddot{y}_1 + k_1 y_1 + k_2(y_1-y_2) = \\ \quad = m_0 r\omega^2\cos\omega t \\ m_2\ddot{y}_2 - k_2(y_1-y_2) = 0 \\ -m_0 r\ddot{y}_1\sin\omega t + m_0 g r\sin\omega t = M \end{cases} \tag{2}$$

By solving the equations in the system (2), there results two vibration modes with two natural pulsation p_1 and p_2 given by relation:

$$p_{1,2} = \frac{\upsilon_2}{\sqrt{2}}\left[\frac{\alpha+\beta+1}{\beta} \pm \frac{1}{\beta}\sqrt{(\alpha+\beta+1)^2 - 4\frac{\alpha}{\beta}}\right]^{1/2} \tag{3}$$

where the notations stand for:

$$\upsilon_2 = \sqrt{\frac{k_2}{m_2}};\ \alpha = \frac{k_1}{k_2};\ \beta = \frac{m_1+m_0}{m_2};\ \upsilon_1 = \upsilon_2\sqrt{\frac{\alpha}{\beta}}$$

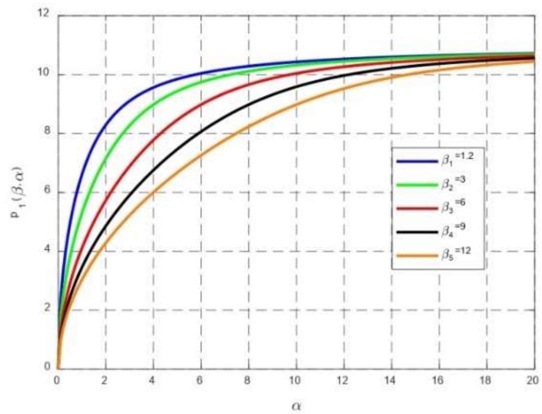
The displacements $y_1(t)$ and $y_2(t)$, in harmonic regime, have amplitudes A_1 and, respectively, A_2, as in relation (4)

$$\begin{cases} y_1 = y_1(t) = A_1\cos\omega t \\ y_2 = y_2(t) = A_2\cos\omega t \end{cases} \tag{4}$$

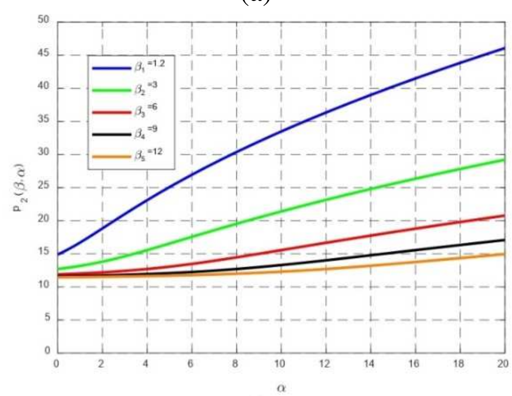
and the calculi relations for amplitude values are:

$$\begin{cases} A_1 = \dfrac{m_0 r}{m_2}\cdot\dfrac{\omega^2(\upsilon_2^2-\omega^2)}{(\alpha\upsilon_2^2-\beta\omega^2)(\upsilon_2^2-\omega^2)-\upsilon_2^2\omega^2} \\ A_2 = \dfrac{m_0 r}{m_2}\cdot\dfrac{\upsilon_2^2\omega^2}{(\alpha\upsilon_2^2-\beta\omega^2)(\upsilon_2^2-\omega^2)-\upsilon_2^2\omega^2} \end{cases} \tag{5}$$

The graphs for variation of pulsations p_1 and p_2 function of current variable α and discrete variable β are shown in figure 2.



(a)



(b)

Fig. 2 Graphs for variation of natural pulsations p_1 and p_2 (a) variation of pulsation p_1 function of variable α and parameter β; b) variation of pulsation p_2 function of variable α and parameter β

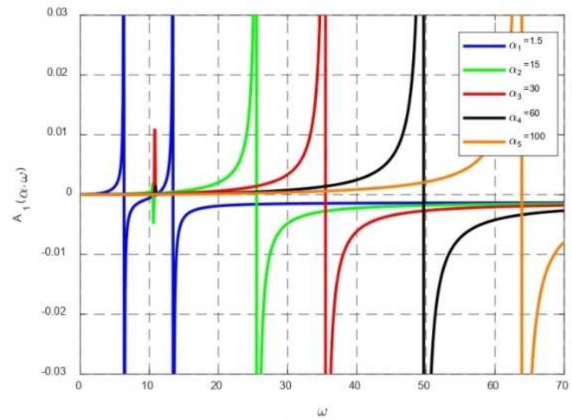
The graphs for variation of amplitudes A_1 and A_2 are shown in figure 3, considering the assumption that $m_0 r = 9,49\,kgm.$

The moment of the actuation torque results by considering the instantaneous displacement $y_1(t)$ from relation (4), calculating its acceleration as $\ddot{y}_1 = -\omega^2 A_1 \cos\omega t$, and introduction in relation (2). It finally results:

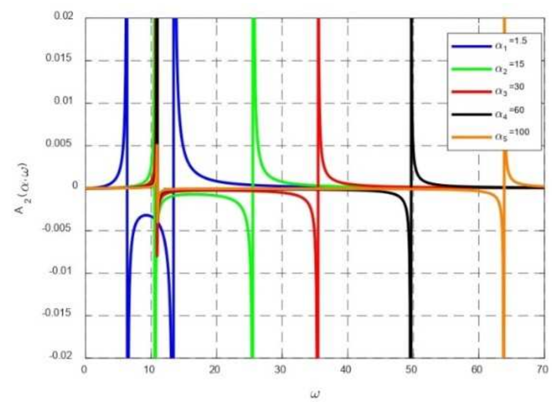
$$M(t) = \frac{1}{2} m_0 r(\omega^2 A_1 \sin 2\omega t + 2g \sin \omega t) \qquad (6)$$

3. CONCLUSION

The obtained research results highlight the fact that, after each pass of the compactor on the



(a)



(b)

Fig. 3 Graphs for variation of amplitudes A_1 and A_2 – with the assumption $m_0 r = 9,49\,kgm$ (a) variation of amplitude vibration A1 function of variable ω and parameters α, β ; (b) variation of amplitude vibration A2 function of variable ω and parameters α , β

same layer, the resonance regime for each individual case moves in the increasing direction of the excitation pulsation ω. In this case, it is useful to know the way of variation of the dynamic regime in the compaction process, because a post-resonance adjustment must be able to be correlated with the displacement of the resonances so that at the last pass the equipment must work in the post-resonance, to avoid the unstable regime and uncontrollable of technological vibrations.

In this context, the method of verifying the displacement of resonances in the field of technological pulsations has been applied, it is original and represents progress in the field of vibration compaction machines for the characteristic of the technological process in dynamic regime.

The research in this article highlights a particularly important aspect, analyzed for the first time in the specialized literature, namely the fact that the first natural pulsation, i.e., the mode I resonance regime, remains at a constant value regardless of the number of passes on the same layer (Fig. .2a). In the same vein, the second own pulsation defines the dynamic regime of resonance for degree II, it changes in relation to the number of passes (Fig.2b).

For the linear dynamic model of the vibratory roller, have been set p_1 and p_2 parameters that define the resonance for the two modes, amplitudes in stable regime for different values of discrete increase in rigidity k_1 and of vibratory roller mass m_1.

Relevant conclusion can be synthetized as mentioned next:

a) variation of natural pulsation evidence that starting from a certain value of parameter α, discrete changes of parameter β determine different changes in pulsation values, meaning one of the pulsations tends to be of constant value, while the other pulsation gets significant value changes;

b) amplitudes have two resonance values (points) – it is to be pointed out post-resonance A_1 getting stable to $\frac{m_0 r}{m_1}$, corresponding to $\omega > p_2$; chassis amplitude A_2 tends toward zero values in post-resonance.

Compared to the above, it follows that the method of evaluating the parameters expressed by the proper pulsations p_1 and p_2 as well as the proper amplitudes A_1 and A_2 constitutes a technological design procedure based on which the stable post-resonance compaction regimes can be established for terrain layers and the number of passes set as optimal.

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MODELAREA COMPACTĂRII PRIN VIBRARE A PĂMÂNTURILOR ÎN FUNCȚIE DE MODIFICARE DISCRETĂ A TASĂRII

Rezumat: Rezultatele cercetărilor de analiză dinamică corelate cu efectul asupra pământului natural sau în umplutură destinat fundațiilor de construcții au fost obținute ca urmare a optimizării atingerii gradului de compactare la nivelul de 98%. În esență, pentru lucrările de drumuri naționale și autostrăzi din România au fost efectuate încercări de corelare a performanțelor rulourilor vibratoare cu forțe dinamice cuprinse între 150 și 250 kN la frecvențe de excitație cuprinse între 25 și 50 Hz [1,8,11,13]. Perioada de lucru corespunde anilor 2008-2021 contând în armonizarea parametrilor dinamici cu cerințele tehnologice de compactare a pământurilor în vederea atingerii gradului de compactare de minim 98%. Lucrările menționate au fost realizate pentru autostrăzile din România pe următoarele tronsoane: Sibiu-Sebeș, Sibiu-Deva, Deva-Timişoara, Sebeș -Turda, Turda-Cluj Napoca și Craiova-Pitești. [9,10] La compactarea pământurilor se utilizează mașini vibratoare tractate sau autopropulsate. Acestea au masa ruloului vibrator cuprinsă în domeniul (3000 ... 5000) kg cu forțe de excitație inițiale care au amplitudinea cuprinsă în intervalul (2 ... 5) G unde G este greutatea ruloului. În prezentul studiu vor fi analizate curbele de variație a amplitudinilor vibrațiilor forțate în funcție de variația pulsației de excitație, forța ce acționează asupra arborelui masei excentrice în mişcare de rotație și care generează forța dinamică, cât și rezultatele experimentale pe baza încercărilor efectuate „in situ”

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