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STUDY ON PARAMETRIC MODELING OF SOIL BEHAVIOR DURING DYNAMIC COMPACTION

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ABSTRACT

This research focuses on existing practices for soil improvement by developing and implementing mathematical and analytical simulations of the soil's dynamic response to dynamic loads during the vibro-compaction process. The results of parametric modeling using rheological models will enable a realistic assessment of soil behavior, considering the effects of the compaction process and controlling technological parameters through a predictive model. Experimental testing correlated with numerical tools can be applied to identify reliable solutions, both technically and economically, for compacted soils, thus ensuring high-quality engineering compaction works and improving design techniques.

KEYWORDS: vibro-compaction, behavior, rheological models, soil

1.INTRODUCTION

The dynamic effects transmitted to the ground are analyzed for each rheological model under stationary vibration conditions at a specific frequency of the perturbing force. A comparative analysis of the dynamic responses of two rheological models was conducted using the dynamic compaction model for viscous-elastic materials [1], [2]. This analysis focuses on bituminous mixtures utilized in road construction and enhancing the bearing capacity of foundation soils for buildings.

The compaction of bituminous mixtures and soils is achieved through dynamic rolling-compressing techniques, which involve the application of a cylindrical roller and the simultaneous transmission of a stationary harmonic vibration field. Accurately evaluate the compaction effect reflected in increased soil density and reduced porosity is essential for establishing a parametric correlation between vibratory compaction machines and the physical and mechanical properties of the soil [3], [4].

Several researchers and equipment manufacturers have developed compound rheological models to describe the dynamic behavior of various soil types.

These models, including viscous-elastic-plastic representations, demonstrate strong alignment between experimental results and theoretical predictions. Prominent examples include the Bathlet, Ephremides, Dvorak–Peter, Hartmann, Voigt-Kelvin, and Maxwell models [5].

In this context, two fundamental models were selected for analysis: Voigt-Kelvin and Maxwell viscous-elastic models. These models, with parameters varying dynamically to reflect real-time compaction processes, provide critical insights into the actual behavior of soils during dynamic compaction [6].

2.PARAMETRIC SIMULATION OF COMPACTING PROCESS

The study regarding parametric simulation of compaction process controlled by vibration technological factors in laboratory conditions is focused on emphasizing their influence on variation of soil compaction characteristics.

Compaction is a process to increase the density of soil by mechanical means, which usually involves rolling, vibrating, tamping, or a combination of these processes. In this process, particles are rearranged by the application of an external force and air in the voids is expelled. This external force is applied in the form of rolling, vibrating, tamping, or a combination of these processes[7].

In the study of the compaction process the following three categories of variables have to be considered: - parameters regarding the compacted material: initial density, granularity, material humidity etc.; machine parameters: the mass of the machine, the frequency and the amplitude of the vibrations that are generated and transmitted to the compacted material; compaction method (machine type, number of passes, speed of the vibratory compactor etc.)[8].

In this investigation, the effect of compaction energy on compaction characteristics was studied, as indicated in the curves illustrated in fig. 1. The number of hammer blows varied from 25 blows per layer to 30, 40, and 56 blows per layer, which in turn varied the compaction energy per unit volume applied to soil compacted in three layers from 594 to 713, 950, and 1331 kJ/m3. Maximum dry density and optimum water content were obtained for each set of compaction.

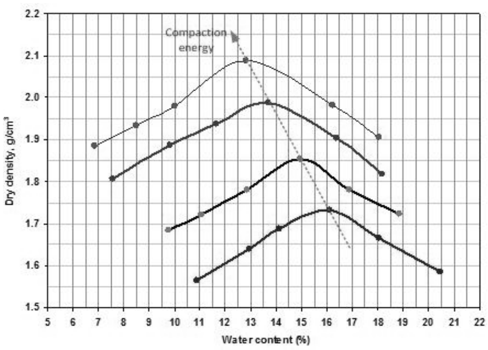

Figure 1. Effect of compaction energy on soil compaction characteristics

While the compaction energy increases, maximum dry density increases from 1,7 g/cm3 to 2,0 g/cm3, simultaneously to decrease of optimum water content from 16,0% to 13,0% as a result of changes manifested in soil structure by particles rearrangement and reducing of air voids due to high energy associated to vibration impulse on soil samples. It can be remarked that greater compaction energy can gradually improve the soil compaction characteristics up to 20%. This aspect reveals that compaction energy can significantly influence the efficiency of the compaction process by adjusting a number of technological parameters during the compaction process.

3.EXPERIMENTAL MODELING TO ESTIMATE DYNAMIC EFFECT OF VIBRO-COMPACTION PROCESS

The main elastic or viscous effects of the materials, arranged in layers, are highlighted in the layout of the two models of analysis. They are structurally distinct, and each of them can reveal the elastic or viscous effects [1]. The linear viscoelastic dynamic model is composed of a linear Voigt-Kelvin rheological system with elasticity parameters k, damping c, and mass m of the compacting vibratory roller, inertially excited with an eccentric mass m_0 of radius r rotating with angular velocity ω. For the present analysis, the Voigt-Kelvin and Maxwell rheological models were used to simulate a realistic soil response during the dynamic compaction process.

According to Voigt-Kelvin, the specific model elements and further the response parameters can be deduced (Figure 2), meaning the force transmitted to soil Q and amplitude A of technological vibrations.

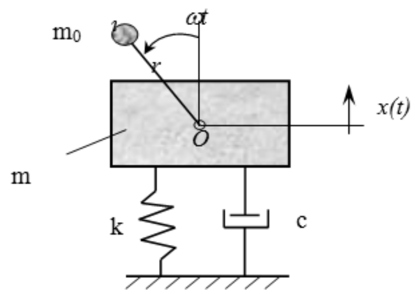

Figure 2. Scheme of Voigt-Kelvin model

The perturbing force has the following forms presented in equation (1) and (2):

$$F_0 = m_0 r \omega^2 \cos \omega t \quad (1)$$

$$F_0 = \frac{m_0 r}{m} k \Omega^2 \quad (2)$$

The transmitted force to soil is $Q = kx + c\dot{x} = Q_0 \cos(\omega t - \varphi)$ where in complex expression $\tilde{Q}$ has the forms shown in equation (3) and (4):

$$\tilde{Q} = \frac{1 + 2\zeta\Omega_j}{(1-\Omega^2) + 2\zeta\Omega_j}\Omega^2 F_0^{st} e^{j\omega t} \quad (3)$$

$$Q_0 = F_0^{st}\Omega^2 \sqrt{\frac{1+4\zeta^2\Omega^2}{(1-\Omega^2)^2 + 4\zeta^2\Omega^2}} \quad (4)$$

The motion amplitude is given by the following equation:

$$A = \frac{\Omega^2 A_{st}}{\sqrt{(1-\Omega^2)^2 + 4\zeta^2\Omega^2}} \quad (5)$$

To switch to the ω variable, the transformation $\Omega = \omega\sqrt{\frac{m}{k}}$ is applied.

According to Maxwell, the viscous model can be schematized as in Figure 3.

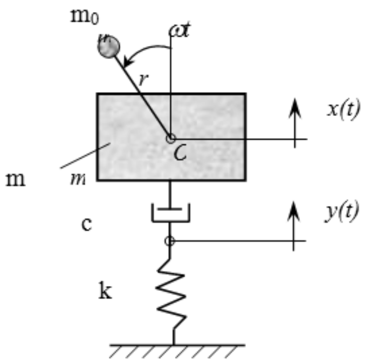

Figure 3. Scheme of Maxwell model

The transmitted force is $Q = ky = c(\dot{x} - \dot{y})$, where $\dot{x}$ and $\dot{y}$ are the absolute velocities of the absolute displacements x and y. The transmitted force has the form presented in equations (6) and (7):

$$Q_0 = |\tilde{Q}_0| = \sqrt{\frac{c^2\omega^2 k^2 F_0^2}{m^2\omega^4 k^2 + c^2\omega^2 (k - m\omega^2)^2}} \quad (6)$$

$$Q_0 = F_0^{st}\Omega^2 \frac{2\zeta\Omega}{\sqrt{\Omega^4 + 4\zeta^2\Omega^2(1-\Omega^2)^2}} \quad (7)$$

The amplitude A is given by the equation (8):

$$A = A_{st}\Omega^2 \sqrt{\frac{1+4\zeta^2\Omega^2}{\Omega^4 + 4\zeta^2\Omega^2(1-\Omega^2)^2}} \quad (8)$$

Voigt-Kelvin and Maxwell rheological models used in the present analysis, for which the parametric families to identify the ability to work under vibration regime, are presented. The evolution study during vibro-compaction process of different cohesive and cohesionless soils is achieved by tracking the change of stiffness of the compacted layer after each passing of the vibrating roll. Consequently, the discrete variable parameter will be the soil stiffness, k, with increasing values and excitation pulsation ω is the current variable with values ranging between (50 ... 500) rad/s. In case of considered models, the parameters k and ζ were modified in order to be consistent with the depreciation of soil stiffness, as a consequence of the compaction process [6]. Thus, it has been taken into account the fact that for each new value of k a new value of ζ was set, with limit $\zeta \le 0{,}7$, meaning the relation $c = 2\zeta\sqrt{km}$ is valid. The resulting family curves based on the simulation of Voigt-Kelvin (as seen in Figure 4) and Maxwell (as seen in Figure 5).

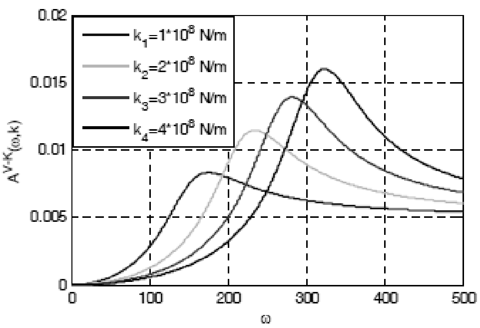

Figure 4. Amplitude curves of variation $A_p^{v-k}(k,\omega)$ depending on pulsation ω and stiffness parameter k (Voigt-Kelvin model curves)

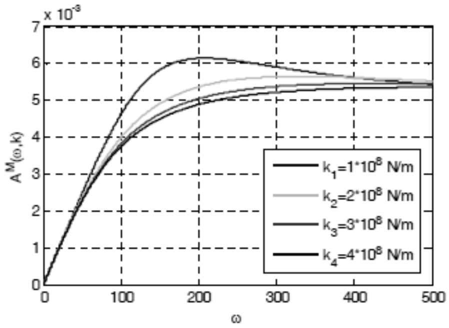

Figure 5. Amplitude curves of variation $A_p^{v-k}(k,\omega)$ depending on pulsation ω and stiffness parameter k (Maxwell model curves)

4.CONCLUSION

The viscous-elastic rheological modeling of soils can be applied by using Voigt-Kelvin and Maxwell models, depending on both k and c soil parameters and the field of vibration in anti-resonance or post-resonance regime, with ensured parametric stability. Based on the results gathered from simulation of rheological models used for assessing dynamic response of vibro-compaction process according to different soil categories, it can be highlighted the mainly elastic behavior of Voigt-Kelvin system, the significant viscous behavior of Maxwell system and also the ratio of excitation and physical and mechanical parameters, which can lead to unstable resonant values and insignificant effects. The correlation between the vibratory roller and the compaction layer is achieved using the parameters m, k, depending on the material and vibration regime. Numerical simulation performed in the study by considering Voigt-Kelvin and Maxwell rheological models has led to a realistic assessment of soil dynamic response during the vibro-compaction process, which can be considered as an important tool to be applied for providing a high quality of engineering compaction works and improvement of design techniques.

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