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EVALUATING A VIBRATORY DRUM ROLLER'S PERFORMANCE AT ADJUSTABLE SETTINGS

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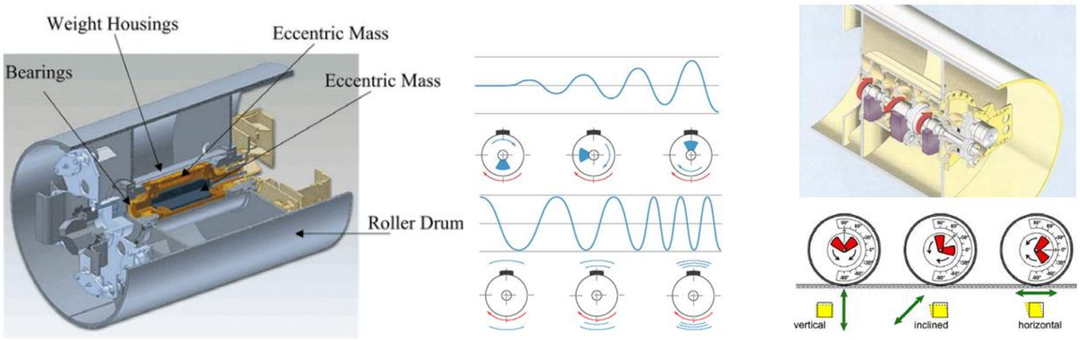
Abstract: *This study focuses on the development of a virtual model of a vibratory drum to perform a dynamic analysis of the behavior at adjustable settings of the static moment values in the two mounting configurations. The movement of the roller-ground system was studied on the 2DOF model in terms of the stability of the movement and the impact force transmitted to the soil when varying the frequency and amplitude of the vibrations.*

Keywords: *Vibratory roller, virtual model, simulation, operational performance, adjustable settings*

1. Introduction

The compaction process can be carried out in two operating cases, with vibrations and oscillations (when force is cyclically applied to the ground as the drum rotates), for dynamic and static compaction (when the weight of the machine itself provides a constant and vertical force). In vibratory compaction, one or two rotating eccentric masses create a force that generates the vertical motion needed to provide the high energy for soil densification. The eccentric masses are mounted on the shaft so that as the motor operates, these generate vibrations that are transferred to the machine drum assembly and into the soil, respectively. The eccentric weights are positioned in the compactor drum to generate different compaction effects by changing the working regime in terms of amplitude, frequency and force transmitted to the ground. To create vibrations, the weights are aligned in the same direction to result in a strong vertical force. To create oscillations, these weights are placed 180° out of phase to cancel the force in the vertical direction and create a horizontal, rocking movement that generates shear forces without impact (in which case, even if the compaction effect is deep, the structure of the material of which the layer is made will not be damaged). In compactor drums, the eccentric assembly is mounted inside the steel drum, supported by bearings and driven by a hydraulic or mechanical system. Some compactors allow adjustment of the eccentric masses or the position of the drive shaft to modify the frequency and force of vibrations, correlating the working regime according to different types of soil and applications.



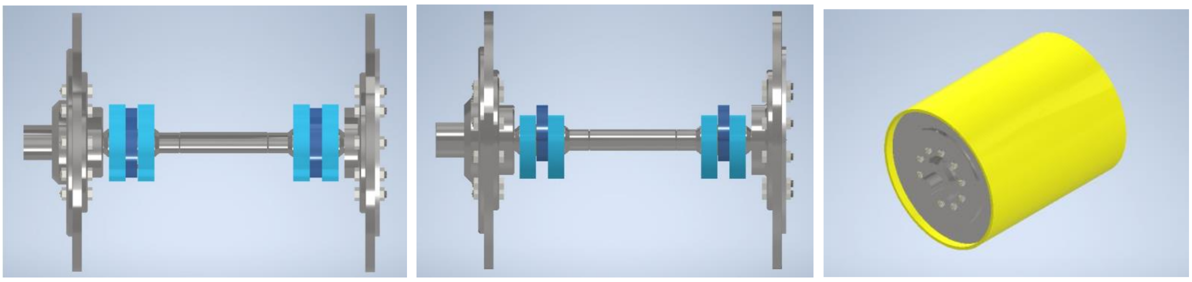
a) b)

Fig. 1. Schematization of vibratory drum compactor:
a) Ammann model [1]; b) Bomag model [2].

Of particular interest in the knowledge of the dynamic behavior of the compactor drum motion during the compaction process. This is influenced by three mechanical characteristics that will be presented below:
a) the inertial characteristics of the drum, which highlight the influence of the inertia phenomenon because of the mass distribution during the work process.
b) the kinetic characteristics of the drum, which characterize its motion from a dynamic point of view, influencing the work process by transforming the state of motion.
c) the dynamic characteristics of the drum are mechanical quantities that characterize its interactions with the surface of the terrain with which it comes into contact, highlighting the influence of these work tool - terrain type interactions on the evolution of the state of motion of the vibratory roller [3,4].

2. Methods and materials

The virtual modeling for a drum compactor begins with structural design using Computer-Aided Design (CAD) techniques to create a 3D digital representation of all components that will be imported in different software environments for advanced analysis. In Figure 2 the eccentric masses ensembles (developed with Inventor software) are connected in two positions by shaft for different compaction effects.



a) b) c)

Fig. 2. Assembly with eccentric masses into the drum:
a) in the same direction (case 1); b) in opposite directions (case 2); c) general view of the drum.

The static moment (M_{st}) of eccentric masses is calculated as the product of the unbalance mass (m_0) and its eccentricity (r) using the formula $M_{st} = m_0 r$. The resulting force amplitude F_0 is given by $F_0 = m_0 r \omega^2$, where ω is the angular velocity. To modify different operating modes (e.g. different vibration characteristics or transmitted forces), the vibrating device can have a different mechanical configuration because of combinations of eccentric masses. A dynamic rheological model with 2DOF (Figure 3) can be developed by using lumped parameters like springs and dampers to represent the material's behavior, where changing the working regime can be simulated by altering the model's parameters, such as stiffness and damping coefficients.

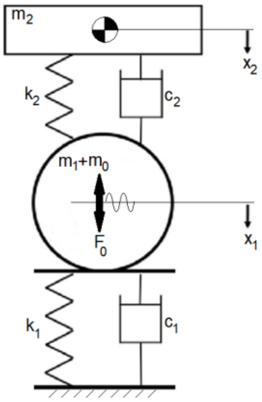


Fig. 3. Rheologic dynamic model of the vibratory roller

Adopting Newton's second law, the steady-state dynamic behavior of the vibratory roller during vibration due to the centrifugal force applied to the drum via rotating eccentric mass can be written as below [5]:

$$\begin{cases} (m_1 + m_0)\ddot{x}_1 + c_1\dot{x}_1 + k_1 x_1 + c_2(\dot{x}_1 - \dot{x}_2) + k_2(x_1 - x_2) = m_0 r \omega^2 sin\omega t \\ m_2\ddot{x}_2 - c_2(\dot{x}_1 - \dot{x}_2) - k_2(x_1 - x_2) = 0 \end{cases} \quad (1)$$

where m_1 – chassis mass; m_2 – drum mass; m_0 – eccentric mases; k_1 – soil stiffness; k_2 – suspension stiffness; c_1 – damping soil; c_2 - damping suspension. The expression for the contact force that arises as a result of the interaction between the roller and the soil has the following expression [6]:

$$F_s = k_1 x_1 + c_1 \dot{x}_2, \quad (2)$$

which is applicable only if the condition $x_1 > 0$ is met, and if $x_1 < 0$ then the value of the force F_s is zero. The following data and information (Table 1) were used to create the case scenario for next analyses: terrain type: sandy soil; viscous-elastic characteristics of the soil: k_1 = 35x10^7 N/m; c_1 = 10 Ns/m; drum mass: m_1 = 1158,7 kg; chassis mass: m_2 = 2500 kg; viscous-elastic characteristics of the suspension: k_2 = 45x10^5 N/m; c_2 = 5 Ns/m; static moment: 7,5-10 kgm; frequency: f = 15-25 Hz

Table 1: Technical details for two operating regimes of the roller compactor

Constructive variants	Case 1	Case 2
Static moment of eccentric masses (M_{st})	7.5 kgm	10 kgm
Drum mass moment (I_Z)	111.005 kgm^2	111.026 kgm^2
Center of gravity (C_Z)	0.470 m	0.472 m

We implemented in MATLAB/Simulink a work scheme to illustrate roller movement by modeling a vibrator's eccentric masses, in two positions, and to put into evidence how changes to its parameters affect the vibration amplitude and impact force.

3. Simulation results

The results of simulations and plots showing how the roller's motion (in form of its vertical displacement) is influenced by the vibrator's operational settings. In this regard, the following graphs will be represented: the variation of the contact force that arises at the roller-ground interface (Figure 4), drum amplitude vs work frequency (Figure 5) and the movement in the phase plane (Figure 6).

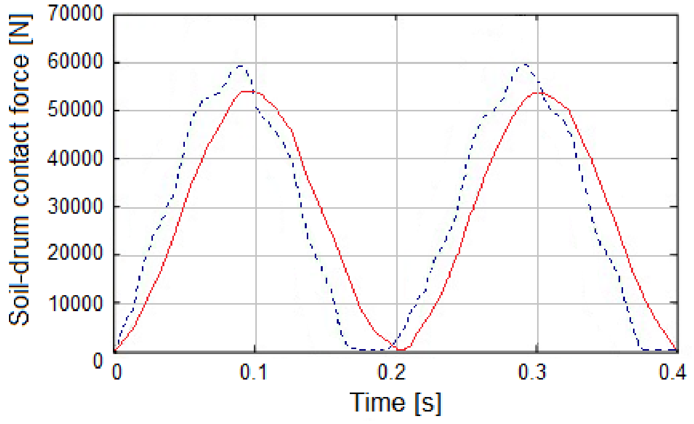


Fig. 4. Behavior of contact force between soil and vibratory drum on different work regimes: Red line – simulation case 1; Blue line – simulation case 2.

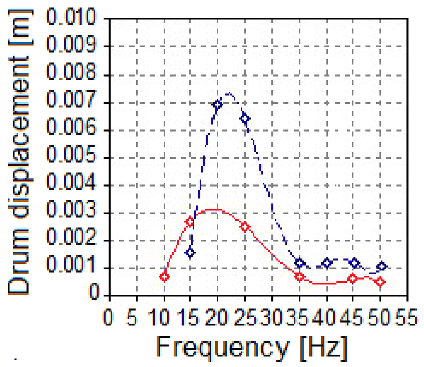


Fig. 5. Dependence of the amplitude of the drum vertical motion on the frequency: Red line – simulation case 1; Blue line – simulation case 2.

We have shown that the amplitude of the vertical motion of the vibratory drum increases with increasing frequency and is directly influenced by the static moment of the eccentric masses, which creates a larger impact force transmitted into the soil. For different static moments, the relationship between amplitude and frequency shows a unique curve, peaking at the resonant frequency of the system before decreasing again. Higher static moments lead to larger peak amplitudes and shift the resonant frequency to a higher value. The phase plane analysis for the roller motion shows the state of the system interpreted based on the velocity versus vertical position plot, focusing on the analysis of its sensitivity and stability over time. Thus, we can see how the phase plane trajectories diverge, indicating the sensitivity to the initial conditions and other parameters (frequency and eccentric masses), which can be visualized by changes in the shape of the phase plane, as shown in Figure 6. In addition, it is observed that the stable system has trajectories that converge towards a curve limit (cyclic), while the unstable system has trajectories that diverge or exhibit chaotic behavior.

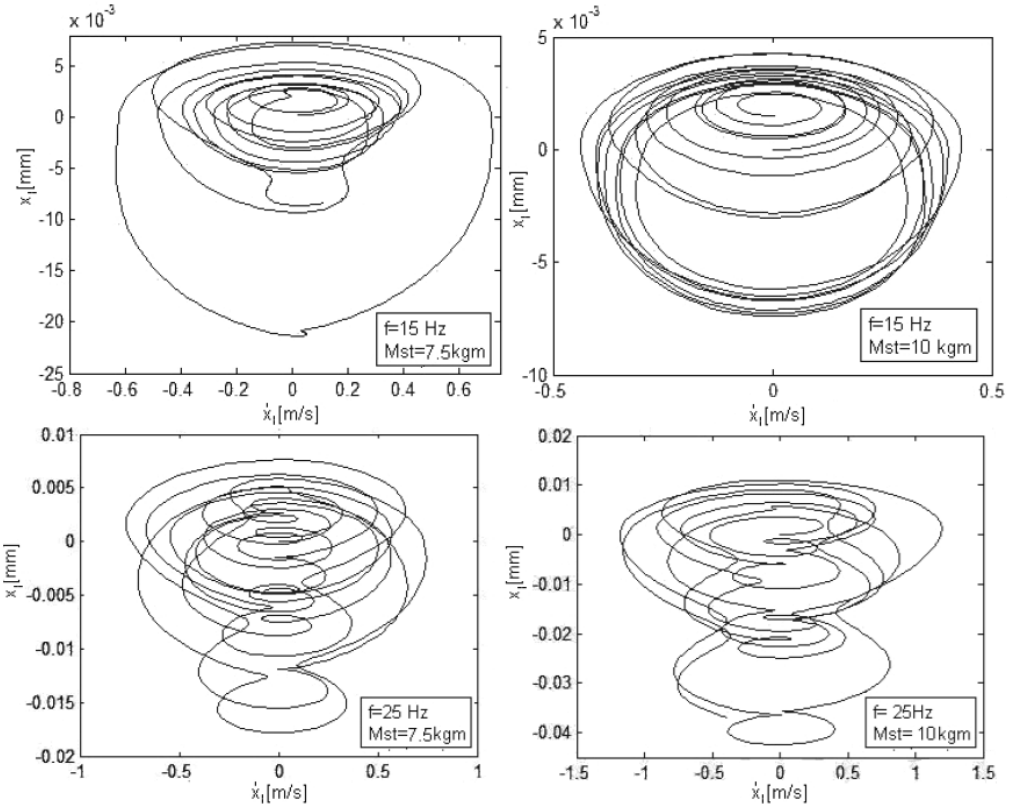


Fig. 6. Phase-plane representation for evaluating of stability motion of vibratory drum

4. Conclusions

Nonlinear dynamic behavior of the eccentric mass variation in vibratory roller compactors has been analyzed, revealing that it can lead to complex behaviors such as decoupling from the soil and different operating modes depending on factors like excitation amplitude and frequency. These analyses are supplied for understanding the roller's effectiveness and are based on models that include the coupling between the drum, frame, and soil, using lumped parameters.

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