
Modeling the Dynamic Interaction between a Vibratory-Compactor and Ground

Sergiu BEJAN

Technical University of Moldova, Department of Roads, Material, Machines for Construction. Faculty of Urbanism and Architecture, Dacia bd, 39, No 9, Chisinau, Republic of Moldova. sergiu.bejan@dmmc.utm.md

Heriberto PEREZ-ACEBO

University of the Basque Country UPV/EHU. Mechanical Engineering Department, Faculty of Engineering Bilbao, P^o Rafael Moreno "Pitxitxi", 2, Bilbao. Spain, heriberto.perez@ehu.eus

Abstract: - There have been proposed various models for the structural analysis of vibratory compactors, with different degrees of freedom, in order to know the dynamic response of the road compaction process. In the same way, many rheological models for the materials of the soils have been developed so as to represent the behavior of the ground, usually based on characteristic parameters which describe the compaction process of the soil.

Based on experimental measurements, this paper aims to establish the connection between the actions of the vibratory-compactors and the effect of those actions in the ground during the compaction process and to predict the effects of a conducted action under known conditions. Better understanding the compaction process will lead to better qualities in embankments, and, consequently, pavement deterioration will be delayed, particularly rutting, and structural parameters of roads will deteriorate more slowly.

Keywords: - vibratory compactor, dynamic analysis, rheological models, pavement management

1. INTRODUCTION

In order to develop a mathematical model to simulate the performance of a real process from some real data, steps shown in Figure 1 must be followed [1].

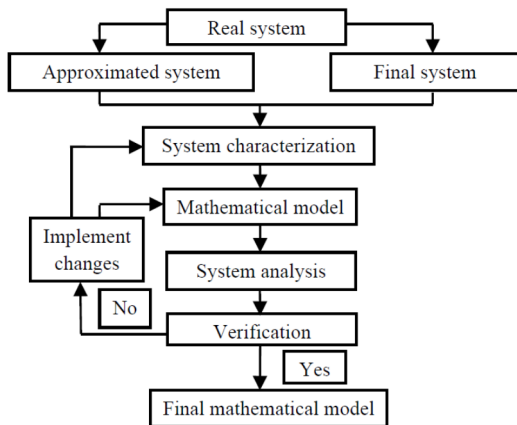


Figure 1. Steps for developing a mathematical model of a mechanical system.

Various dynamic models have been proposed for vibratory compactors. They are necessary since the results are a useful baseline for the dynamic analysis of compaction process. This includes the study of the mechanical system motions elements under the action of external forces applied, taking into account the

forces and the moments of inertia occurred as a result of the movement system. The purpose of this study is to determine the forces and the deformations of the components of the mechanical systems occurred during its movement [1]. The system's response is also influenced by its mechanical characteristics and the excitation parameters. The problems of dynamic systems consist in linking excitation and the dynamic characteristics of the mechanical system and analyze the results [2]. The simplest dynamic model of the performance of a self-propelled compactor is a single vibrator roller with a unique degree of freedom, resulted in the displacement of vibrating roll vertically, denoted by x_r and shown in Figure 2. More sophisticated models for vibrating compactors include 2, 3 or 4 degrees of freedom.

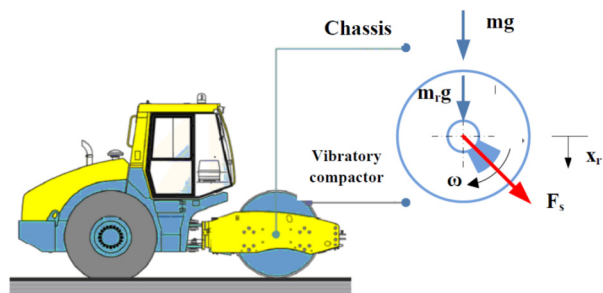


Figure 2. Dynamic model of vibratory compactor with a unique degree of freedom.

On the other hand, it is compulsory to obtain a model that represents the behavior of the ground. For the compaction study, the land is considered to be semi-infinite, homogeneous and isotropic and the limit of elasticity is infinitely large [3,4]. The fundamental mechanical properties of the land are elasticity, viscosity and plasticity. When only one of this properties is considered dominant and the rest are neglected, simple mechanical models of the land are obtained, made of one single element: Hooke, Newton, Saint-Venant and simple Barhelt. Due to its behavior, the ground cannot be rendered with sufficient approximation by simple mechanical models and, therefore, composite mechanical models of the land were created, combining in series, parallel or mixed, from two to six elements, considering at the same time, two or all the three fundamental mechanical properties of the land [5].

As the interaction between the described models is important so as to obtain an embankment with the required quality, this paper aims to present dynamic models of the interaction between ground and compaction equipment. A better knowledge about the compaction process will induce the construction of embankments with better qualities in shorter time. As a consequence, compaction machinery will be used more efficiently and pavement deterioration process will be delayed. Structural parameters of pavement management systems are related to structural capacity of all the layers of the pavement as well as the condition of the subgrade [6]. So that, pavement management should include this compaction process optimization in order to prolong pavement structural capacity.

2. DYNAMIC MODEL FOR THE INTERACTION GROUND-ROLLER

The simplest model for shaping the dynamic interaction of ground and a roll, a single compactor roller, is shown in Figure 3. The model has a single degree of freedom, resulted in the displacement of vibrating roll vertical direction [7].

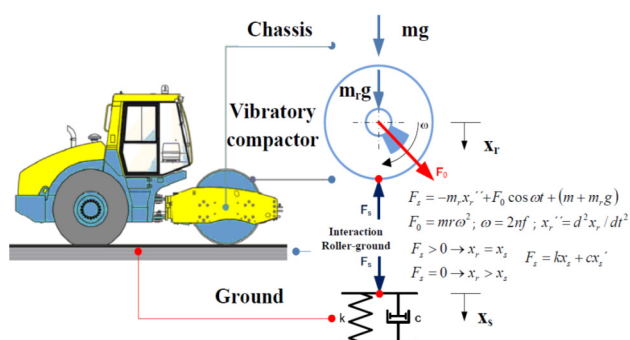


Figure 3. Dynamic model of interaction roller-ground with a vibratory compactor with a degree of freedom.

The equation of motion of the dynamic system shown in Figure 3 is:

$$m_r \ddot{x}_r = (m + m_r)g + m_0 r \omega^2 \cos(\omega \cdot t) - F_s \quad (1)$$

Where m_r is the mass of the vibrator roller, m the mass of the chassis, $m_0 r$ is the static moment of eccentric pieces, ω is the pulsation of disturbing force, x_r is the vertical moment of the chassis and F_s is the contact force between the roll and the ground.

The expression of the force of contact between the roll and the ground can be written as:

$$F_s = kx_s + c\dot{x}_s \quad (2)$$

Where k is the stiffness coefficient of the ground, c is the damping coefficient of the ground. Equation (2) applies to $x_s \geq 0$, and for $x_s < 0$, the F_s force value is zero.

2.1. Influence of stiffness variation of the layer of soil on dynamic parameters

The behavior of the most used natural soils, stabilized soils (lime, bitumen, cement) or organic products (enzymes, polienzimes) is described by two models, namely, the Voigt-Kelvin model and Maxwell model.

In this paper, models with discrete variable stiffness will developed. For each pass of the vibrator roll on the same layer of soil, there will be a certain rigidity, so that after n passes, n values for stiffness will be achieved, k_1, k_2, \dots, k_n .

The dynamic response will be given by the following parameters: instantaneous displacement amplitude vibration, denoted by A (Ω, ξ). Thus, for each model, it is demonstrated the influence of the growing rigidity on the parametric values.

A complete study for the same vibrator roll and the two rheological models is presented.

2.2. Voigt – Kelvin (E | V) model

The Voigt – Kelvin model used to represent the soil is represented in Figure 4. For the dynamic model is considered following initial data: $m = 4000kg$; $c = 4 \cdot 10^5 Ns / m$; $m_0 r = 20kgm$; $\xi = \xi(k) = c / (2\sqrt{km})$; $k = (1,2,3,4) \cdot 10^8 N / m$; $\Omega = \omega\sqrt{m/k}$; $\omega = 0 \dots 500Hz$. The amplitude is given by Equation (3) and represented in Figure 5.

$$A^{V-K}(\Omega, \xi) = \frac{m_0 r}{m} \cdot \frac{\Omega^2}{\sqrt{(1 - \Omega^2)^2 + 4\Omega^2 \xi^2}} \quad (3)$$

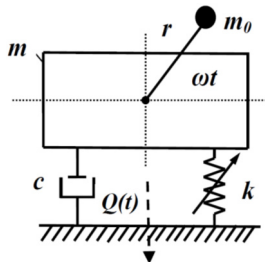


Figure 4. Voight-Kelvin rheological model.

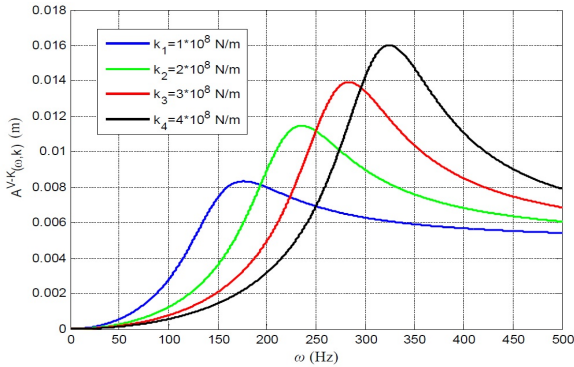


Figure 5. Amplitude variation depending on the stiffness and pulsation, Voight-Kelvin model.

The force transmitted in relation with the relative pulsation, $\Omega = \omega/p = \omega\sqrt{m/k}$, and the damping is expressed in Equation (4) and shown in Figure 6.

$$Q_0^{V-K}(\Omega, \xi) = \frac{m_0 r \cdot k \cdot \Omega^2}{m} \sqrt{\frac{1 + 4\Omega^2 \xi^2}{(1 - \Omega^2)^2 + 4\Omega^2 \xi^2}} \quad (4)$$

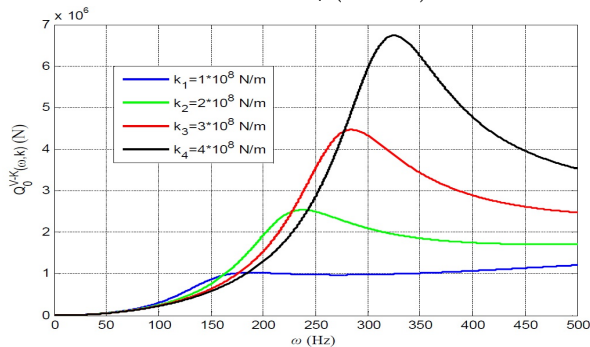


Figure 6. Transmitted force variation depending on the pulsation, Voight-Kelvin model.

It is found that the force transmitted is dependent on the static moment of vibrator roll mass, stiffness of the ground layer after compaction, pulsation and amortization. So that, it is demonstrated that transmissibility is only dependant on stiffness and damping of ground. Dynamic transmissibility is given by Equation (5) (Figure 7).

$$T^{V-K}(\Omega, \xi) = \sqrt{\frac{1 + 4\Omega^2 \xi^2}{(1 - \Omega^2)^2 + 4\Omega^2 \xi^2}} \quad (5)$$

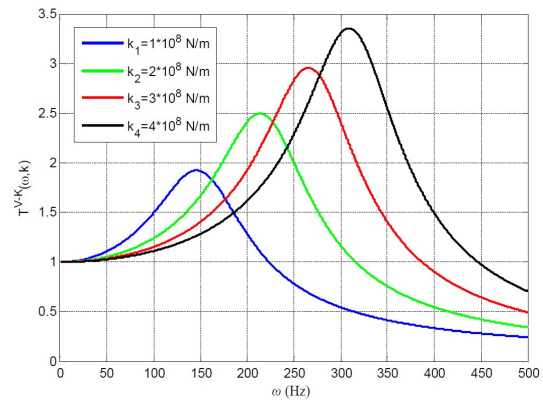


Figure 7. Dynamic transmissibility depending on the pulsation, Voight-Kelvin model.

2.3. Maxwell model (E-V)

The Maxwell rheological model is represented in Figure 8. It is composed of two rheological simple parts, k and c in series. In this case, the variable stiffness entails the amendment of relative pulse and a fraction of critical damping. The amplitude is expressed by Equation (6) and shown in Figure 9:

$$A^M(\Omega, \xi) = \frac{m_0 r \cdot \Omega^2}{m} \sqrt{\frac{1 + 4\Omega^2 \xi^2}{\Omega^4 + 4\Omega^2 \xi^2 (1 - \Omega^2)^2}} \quad (6)$$

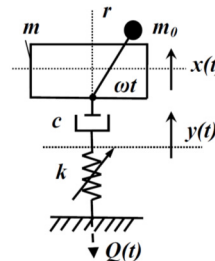


Figure 8. Maxwell rheological model.

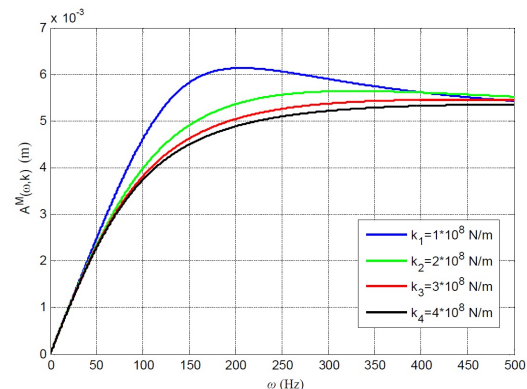


Figure 9. Amplitude variation depending on the pulsation, Maxwell model.

The force transmitted to the ground is given by Equation (7) and directly depends on the relative pulsation and the stiffness, as it is represented in Figure 10.

$$Q_0^M(\Omega, \xi) = \frac{m_0 r \cdot k \Omega^2}{m} \frac{2\xi}{\sqrt{\Omega^2 + 4\xi^2(1 - \Omega^2)^2}} \quad (7)$$

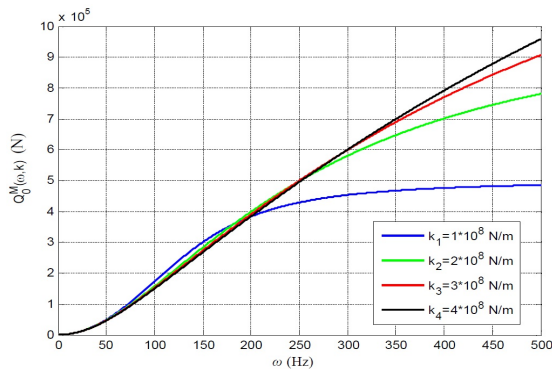


Figure 10. Transmitted force variation depending on the pulsation, Maxwell model.

This indicates that the damping factor is decisive. So, if $c = 0$ and $\xi = 0$, transmissibility is canceled.

Dynamic transmissibility is expressed by equation (8) and shown in Figure 11.

$$T^M(\Omega, \xi) = \frac{2\xi}{\sqrt{\Omega^2 + 4\xi^2(1 - \Omega^2)^2}} \quad (8)$$

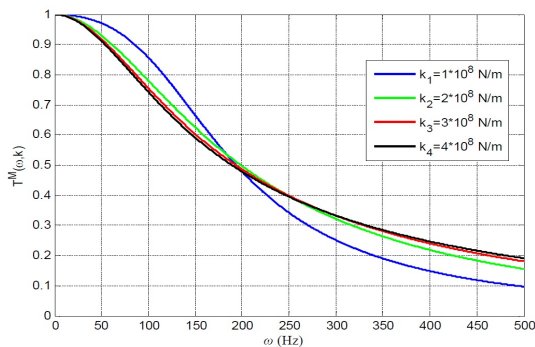


Figure 11. Dynamic transmissibility depending on the pulsation, Maxwell model.

Based on Figures 9, 10, 11, it is demonstrated that effect of the force transmission is very low to high pulse vibration. As a result, weak cohesive lands and sandy lands with plenty of water in the structural content are hard or almost impossible to compact. Their behavior can be modified introducing a chemical or organic stabilizer.

3. CONCLUSIONS

Models and systems analysis can be realized with numerical information, with the coherent integration of evolution of key parameters that characterize the process of dynamic vibration compaction. Response

field under the dynamic action produced by the vibrator roll, together with rheological components of composite materials, with elastic, dissipative and plastic type complex behavior; helps to understand the specific phenomenology of equipment - land interaction and facilitates technological optimization process, improving functional performance of dynamic compaction specific technological equipment. The ultimate goal of this optimization is to achieve higher values of compaction, which will lead to a slower deterioration of pavement roads.

Thus, it is necessary to analyze the process of compaction dynamic vibration through the combined use of equipment models with the advances on rheology field (optimization of specific parameters typology of the work area) and specific work elements (implementing technological structure of approach to dynamic compaction). That requires a pre-assessment of the ground response and requested equipment status, followed by simulation of complex cumulative effect caused by successive passages and evaluation in depth of the degree of compaction over the entire area of interest to simulate real dynamic action in the monitored area.

ACKNOWLEDGMENTS

The authors would like to thank ACTIVE – Atlantic Caucasus Technical universities Initiative for Valuable Education Erasmus Mundus Action 2 programme for making possible to research together in the area of Pavement Design and Management

REFERENCES

- [1] Ganciu, T. *Identificarea sistemelor*, Editura Nord-Est, Iasi, Romania, 1995.
- [2] Legendi, A., Bausic, F. Pavel, C. Panaitescu, L., *Elemente de mecanica teoretica si analitica*, Editura Matrix Rom, Bucuresti, 2012.
- [3] Feng, Z., Fan, H., Study on numerical simulation of rheological test of soft soil in Shanghai, *Journal of Tongji University*, Vol. 31, No. 4, 2003, pp. 379-382.
- [4] Năstac, S., Model reologic pentru analiza stării de tensiuni și deformații în solurile supuse procesului tehnologic de compactare, *Al II-lea Colocviu Național Tehnic Interdisciplinar, Facultatea de Inginerie Brăila*, 1997, pp. 181-184.
- [5] Bejan, S., Rheological Models of the Materials for the Road System in the Compaction Process, *Romanian Journal of Acoustics and Vibration*, Vol. 11, No.2, pp. 167-171.
- [6] Bryce, J. Flintsch, G. Katicha, S., Diefenderfer, B., Enhancing Network-Level Decision Making Through the Use of a Structural Capacity Index, *Transportation Research Record*, Vol. 2366, 2013, pp. 64-70.
- [7] White, D., Thompson, M., Relationships Between In Situ and Roller-Integrated Compaction Measurements for Granular Soils, *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 134, No. 12, 2008, pp. 1763-17