ANALELE UNIVERSITĂȚII
"EFTIMIE MURGU" REȘIȚA
ANUL XX, NR. 3, 2013, ISSN 1453 - 7397

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Basic Approaches of Complex Interaction Drum-Terrain for Vibratory Compaction

In this paper the author tries to use a new method to evaluate and analyze the interaction between roller and terrain. The analysis is rheological approached, with a predominantly dynamic behaviour, so as to reveal the compatibility of the working body performances with the characteristics of the terrain. The basic idea shows that it must be assured the energy transfer maximization in the interaction between the two components of the system. The model must have permanent and continuous adjustments of the material characteristics so it can be evaluated the technological capability. The fulfilling of these objectives will be provided by using a complex model with both distributed and concentrated elements which can have rheology of elastic, dissipative and plastic types. The first conclusions of the presented study goes to the idea that the harmonization of the basic parameters of the model with the experimental values can lead to structural and functional optimizations of the entire technological system.

Keywords: *dynamic behavior, rheological evaluation, energy transfer maximization*

1. Introduction

A history of 80 years of research, development, and field experience takes about the vibratory compaction. Certainly, the compaction technique was a great win. Through this method it can be compacted efficiently unbound materials such as soil, aggregate materials, and basic materials. The first vibrating compaction appear in 1930 in Germany and it is implemented widely in the construction of a highway. In Europe, the vibratory compacting and vibrating equipment development took place after the Second World War. In 1950 many U.S. companies start using vibrating rollers compactors for the construction of highways. In 1970 they replace the static methods with vibrant methods.

In the same time with the increasing use of vibratory compaction rollers for unbound materials, several European countries have started using vibratory rollers for compaction of asphalt mixtures. Early reports indicate that dynamic force transmitted by the roller was too big for the concrete construction of asphalt. After several studies had concluded that the only way to reduce dynamic force was to reduce the frequency, this one increasing the impact distance. This required a decrease of speed rollers, which could not compensate enough for the increase of impact area and frequency [1,2,3,5,8,13,15,16,20].

Dynamic forces, performed through the drum, are produced by a rotary eccentric located in the drum. The rotating eccentric who takes place from the shaft produces a dynamic force that is directly proportional to the mass, velocity squared and eccentricity.

This brief history is important because highlight the need for a complete analysis of these issues. Thus, the complex technological systems and materials involved in the process reveal some directions for evaluation and analysis, as follows: main equipment, internal phenomena from compacted material and the complex interaction between working body and terrain [14,17-19,22].

In this paper is presented the vibratory roller - terrain interaction analysis. The analysis is made in the conditions of complex rheological approaches of a direct influence area of vibration on compacted domain material. The main goal of this study consists by a complex lumped-continuous model of terrain compaction and related machine-terrain interaction approaches. It was analyzed during the research a large area of rheological models. From these it was adopt for presentation a conservative - dissipative complete model that allows both Voigt-Kelvin and Maxwell formulations. Further will be detailed the theoretical approaches, which will underlie the numerical simulations and the final validations of initial hypothesis of this analysis. Based on classical elastic and dissipative models the author was build a multiple layer continuous-lumped system that is able to simulates the continuous phenomenon during each layer taking into account discrete linkages between adjacent layers.

2. Theoretical basics

The basic hypotheses for the analysis take into account the dynamic rheological behaviour of the terrain in the whole domain with direct influences to the vibratory drum equipment. Such as it was presented in the previous paragraphs, the author had finally adopted a conservative-dissipative complete model [4,6,7,9,10-12,21]. The Voigt-Kelvin model in derivation with the Maxwell one composes this model. In Fig.1 is described the schematic diagram of the proposed model. In respect with specific values for parameters set (k_i, c_i, i =1..2) the model is able to simulates a large palette of viscous-elastic behaviour, starting with classical linear models and continuing with any kind of non-linear approaches.

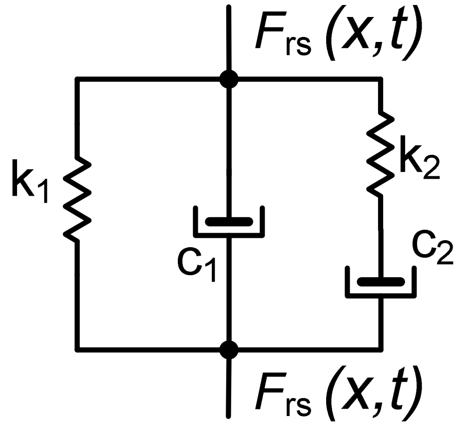

Figure 1. Diagram of complete conservative-dissipative rheological model

The constitutive equation of the model from Fig.1 was formulated in terms of external forces *$F_{rs}(x,t)$* and displacement *z(t)* as follows:

$$k_2 F_{rs} + c_2 \dot{F}_{rs} = (k_1\, k_2) z + (k_1 c_2 + k_2 c_1 + k_2 c_2)\dot{z} + (c_1 c_2)\ddot{z} \qquad (1)$$

where $k_{1,2}$ represent the rigidity parameters, $c_{1,2}$ represent the damping parameters. The independent variable *x* corresponds to the horizontal position lengthwise the longitudinal section of terrain. The displacement *z* will be replace into the final form of equations system with the deformation variable of the adjacent layers.

The entire analyzed domain was dividing into a finite number of horizontal layers linked by the previous presented rheological models. The behaviour of each layer was simulating using the Euler-Bernoulli beam on elastic foundation theory. The Winkler hypothesis was also used. Hereby, the beam approach denotes the continuous aspect of the global model, while the rheological linkages between adjacent layers correspond to the lumped component of the global model.

In respect with last hypothesis it was compiled the general model and the constitutive equations for the "i" layer. They have the expressions as follows:

$$E\,I \frac{\partial^4 v_i(x,t)}{\partial x^4} + c_b \frac{\partial v_i(x,t)}{\partial x} + \rho A \frac{\partial^2 v_i(x,t)}{\partial t^2} + F_{rs}(x,t)\big|_i - F_{rs}(x,t)\big|_{i-1} = Q(x,t)\big|_i \qquad (2)$$

where $v(x,t)$ denotes the vertical deflection, EI, ρA, c_b denotes flexural stiffness, unit mass and a specific shape parameter of the terrain layer. The index i denotes current layer, whereas the index i-1 denotes upside layer. The external load $Q(x,t)$ usually acts on the top layer (i=1) and have the following expression:

$$Q(x,t) = Q_{static}(x) + Q_{dynamic}(x,t) = Q_{static}(x) + Q_o(x) \cdot \sin(\omega t) \qquad (3)$$

In equation (3) the independent parameter x is related to the horizontal position on the longitudinal axis of the layer and helps to simulates static and dynamic components of the external load. The author has using the harmonic evolution of the dynamic component with respect to regular vibratory equipment mounted into compaction drums.

In Fig. 2 is described a schematic section through entire analyzed domain with layers and rheological linkages representations. Additional symbols on Fig. 2 has the following means: δ_p, δ_{ep} denotes permanent, respectively total instant deformations of the top layer, *F(t)* is the dynamic force due to the vibratory action, and *v(t)* denotes the drum equipment horizontal velocity (supposing to be constant during the entire simulation process).

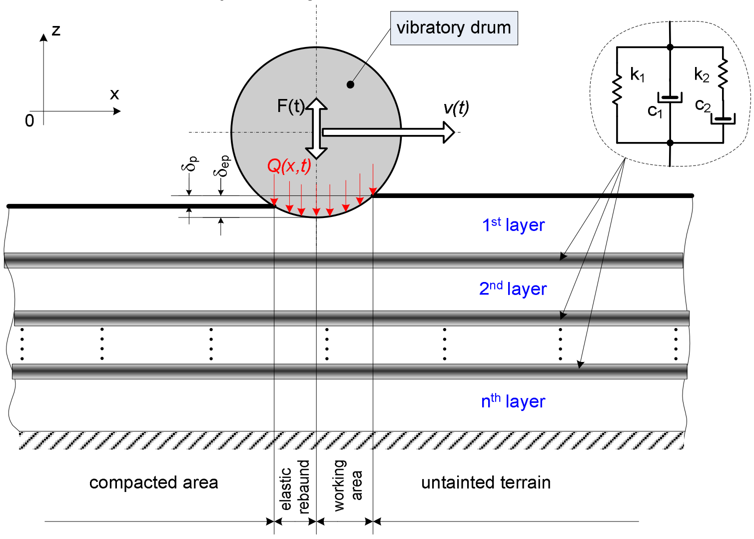

Figure 2. Schematic diagram of multiple layer model based on combined continuous-lumped components

3. Simulation results and discussions

Taking into account the equation (2) and supposing the diagram from Fig. 2 results that on the top layer (i=1) acts only the bottom linkages with elastic and dissipative resistant forces. In addition, the external loads are acting only on the top layer.

For this study the basic hypothesis were: a) the velocity of technological equipments was constant; b) the parameters of vibration generated by the drum were constant; c) the parameters values for the entire layer were constant; only the variation with layer number was accepted, and a linear law was adopted for this simulation.

For the presentation was choosed the first three layers behaviour during the vibratory compaction process. The simulation time of 11 seconds was performed, but because of the mathematical unsteadies states both at starting, and at final of numerical computations it was considered that the proper time period for analysis is t = (2..8) seconds. Hereby, in Figs. 3, 4 and 5 it was described the evolution of the compaction level for the first, the second and the third layer. On each diagrams it was revealed three time moments (using thick white dashed line) as follows: 2, 5 and 8 seconds from process started, and in respect with these moments it was presented an appropriate diagrams of depth vs. distance. Horizontal distance supposed as independent parameter denotes total length of the terrain area, which was involved into the analysis. The technological equipment scans the entire length from the left (x = 0 m) to the right (x = 20 m) side.

Comparative analysis of the three sets of diagrams highlights the compaction level evolution inside the whole area. Hereby, the total deformations decrease with respect in global depth of the studied domain. In addition, the elastic recovery value decreases and the elastic recovery time period increases respectively with the depth. According to the fact that stiffness and damping parameters growing up with the depth, and the shape influence coefficient of each layer also increases in the same time, the previous observations was correct. Because of last two remarks, the permanent deformation of each layer acquires a relative increasing/random evolution during the whole simulation. For long periods of the simulation time was shows that compaction level in the terms of permanent vertical deformations clearly decreases with the depth of the analyzed area.

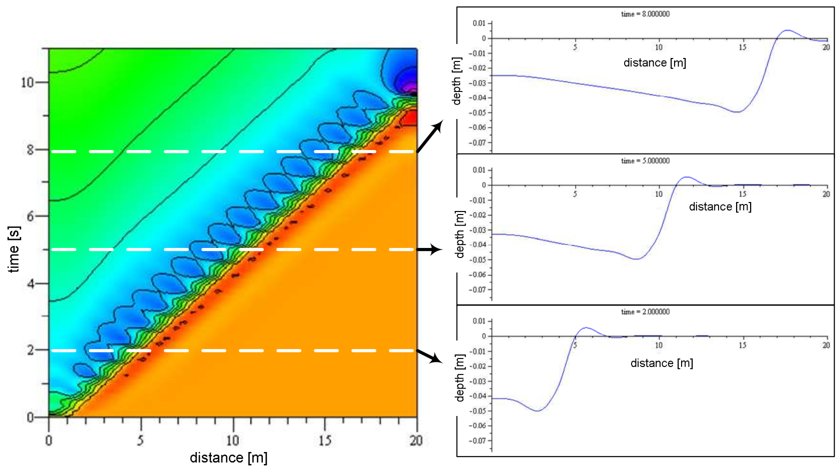

Figure 3. Timed evolution of compaction level inside the first layer (see text for details)

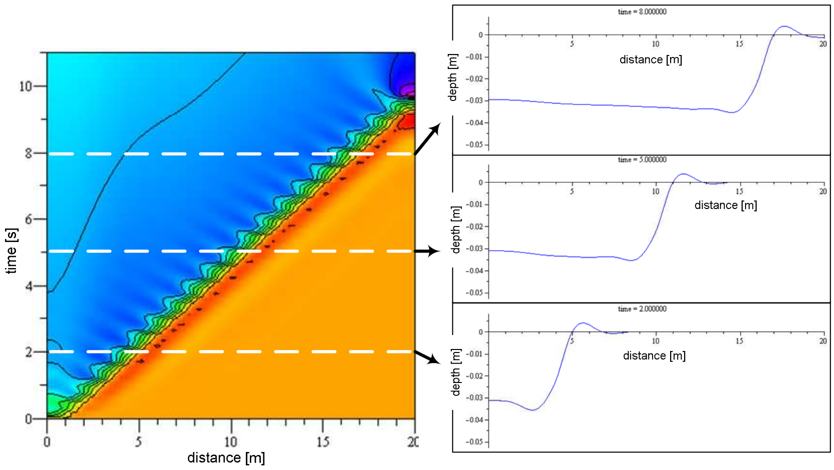

Figure 4. Timed evolution of compaction level inside the second layer (see text for details)

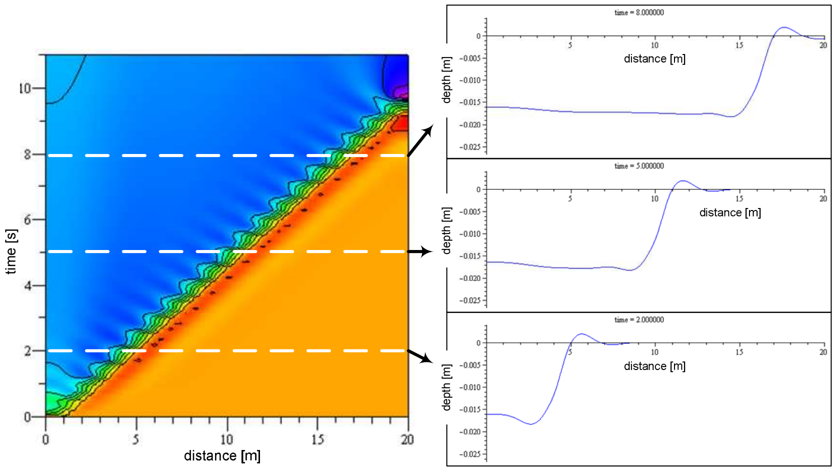

Figure 5. Timed evolution of compaction level inside the third layer (see text for details)

4. Concluding remarks

Computational analysis was revealed an appropriate evaluations of partial or final data with the experimental observations performed during the vibratory compaction technological process. The continuous - lumped model presented and used in this analysis provides an advantage of simplicity versus finite element approaches, and another advantage of powerfully versus classical lumped models. Future developments related to elastic, dissipative and especially plastic components and theirs participation into the resistant force between layers, in addition with full continuous model supplied for each layer will represent the next steps of this research.

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