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ANALYTICAL AND COMPUTATIONAL ASSESSMENTS IN VIBRATORY COMPACTION PROCESS

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Abstract: *In this paper the author presents a computational model for simulation of the vibratory compaction technological process. The analysis of complex interaction between the vibratory technological equipment and the terrain layers assuming the large area of dynamic and rheological instances which appears within this system, frame the main objective of this study. Proposed model are based on both continuously and lumped elements which have been combined thus that it was supplied the capability of depth compaction provided by the equipment and also the capacity of terrain to enable and dignify deep inside consolidation phenomena. In respect with this hypothesis the computational results reveal an appropriate behavioral estimation comparative with in situ tests analysis. Fine reconfiguration of the model according with realistic database information and tuning of the essential parameters in respect with regular in situ investigations will convert this model into a scalable computational approach of vibratory compaction with serviceable application in real-time monitoring and leading this technological process.*
Keywords: *vibration, dynamics, rheology, computational analysis, compaction process.*

1. INTRODUCTION

A brief history of the technological process of vibrating compaction highlight both the importance, and the need for as complete as possible analysis of this issue. Thus, taking into account the completely complex technological systems and the various materials involved in the process are distinguishing some major directions for evaluation and analysis, as follows: main equipment, internal phenomena from compacted material and the complex interaction between working body and terrain.

Vibratory compaction equipments had benefited along time by a large interest and obviously by a great number of research papers. Mechanics of soils provides both the basic theory and the extended means for analytical and experimental analysis of compaction process, and also for vibration influences evaluation on consolidation of different type of materials [2,3,6,7,11-17].

Latest studies have been assuming the complex interaction between working equipment and base material. This paper briefly presents a set of analytical assessments with direct impact and scalable implementation on computational simulation of vibratory compaction process. These approaches contain support elements for machine schematization, and also for material gridding, but the main goal consist by a new scheme for modeling and simulation the machine – soil interactions. Hereby, this study have been fully framed by the last mentioned research direction.

2. ANALITICAL FORMULATION

The entire analyzed domain was dividing into a finite number of horizontal layers linked by the previous presented rheological models. The behavior of each layer was simulating using the Euler-Bernoulli beam on elastic foundation theory. The Winkler hypothesis was also uses. 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 [3,5].

In respect with last hypothesis it was compiled the general model, and the constitutive equations for the "i" layer have the expressions as follows [3]

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

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 follow formulation [3]

$$Q(x,t)=Q_{static}(x)+Q_{dinamic}(x,t)=$$
$$=Q_{static}(x)+Q_0(x)\cdot\sin(\omega t) \qquad (2)$$

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

In Fig. 1 is depicted a schematic section through entire analyzed domain with layers and rheological linkages representations. Additional symbols on Fig. 1 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 vibratory action, and $v(t)$ denotes the drum equipment horizontal velocity (supposing to have constant value during the entire simulation process).

The proposed theoretical model mainly follows the main direction which is the simulation of the realistic behaviour of the vibratory equipment on a deep and direct link with the material (e.g. the powerless terrain which will be reinforced by compaction).

Figure 2 depicted the schematic diagram of the proposed *conservative – dissipative - consolidate enabling* linkage model [10]. This is composed from two main groups. The first group is based on the *Hooke's* model parallel linked with the *Newton's* model. The other group is composed by the *Saint-Venant* model parallel linked as well with the other *Hooke* model. The both groups have succession type montage. Hereby, based on intuitive way it can be deduced that for the high values of deformation velocity, the stress on the first group will acquire the high values too, and the global instant displacement of the entire model will be given only by the second group. For the low values of the deformation velocity, the model wills entirety working [4,8,9,10].

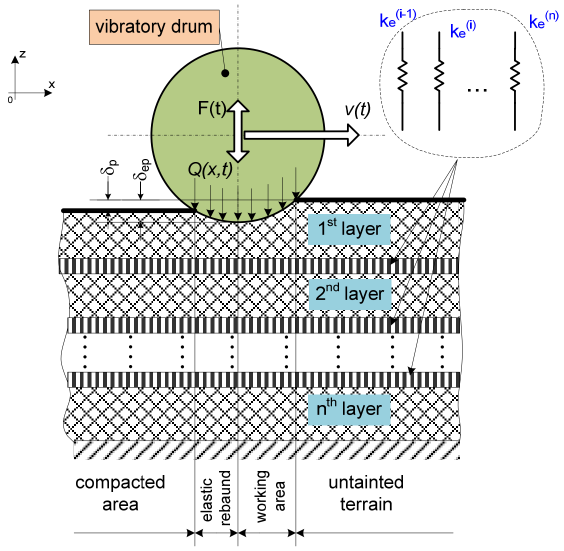

Fig. 1. Schematic diagram of multiple layer model based on complex continuous-lumped components

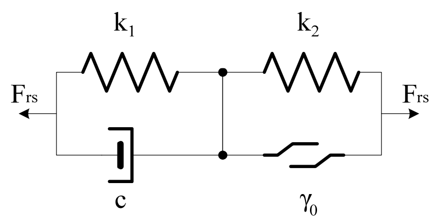

Fig. 2. The rheological model for behavior analysis of dynamical systems

It was supposed that for high speedy external loads, the material will acquire the plastic preponderant instant deformations; the viscous-elastic character will be present only for slow acting charges. In the last case, with low velocity, but high values charges, the material have elastic-viscous-plastic complex working characteristic.

The constitutive equation of the model in Fig. 2 [10], assuming excitation $F_{rs}(x,t)$ and displacement $\delta(t)$, can be written as follows

$$F_{rs}(k_1+k_2)+c\dot{F}_{rs}=k_1k_2\delta+k_2c\dot{\delta}+\gamma_0k_1 \qquad (3)$$

In Eqn. (3) the parameters k_1, k_2 denote the stiffnesses for the two elastic bodies; c is the damping parameter; γ_0 denote the limit stress of the plastic model (the plasticity threshold).

An impulsive haversine function with the expression [1]

$$F = F_0 hav(\omega t) \quad (4)$$

has assumed for an effective approach of transitory component of the excitation. The parameters in Eqn. (4) have the significations as follows: F_0 means the magnitude of the excitation and ω denotes the pulsation of the vibratory device.

For convenience it will assume that practical formulation of dynamical component of the excitation induced by the vibratory drum respects the following piecewise expression [1]

$$\begin{cases} F = \frac{F_0}{2}(1 - cos\omega t)\ for\ 0 < t < T \\ F = 0\ for\ anything\ else \end{cases} \quad (5)$$

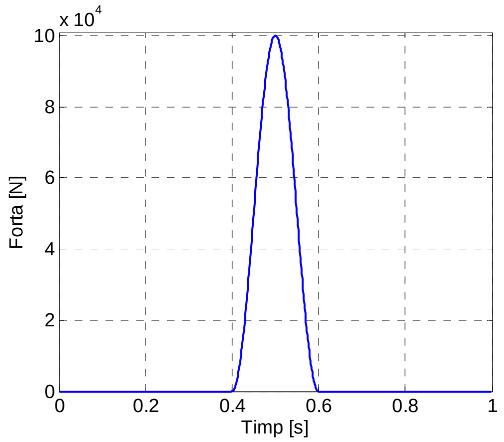

Fig. 3. Dynamic component as a singular haversine function [1]

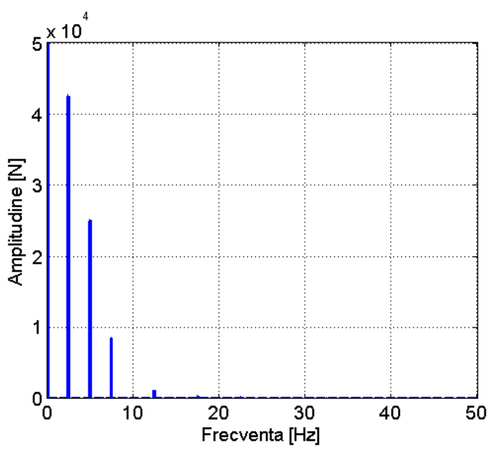

Fig. 4. The spectral composition representation of dynamic component [1]

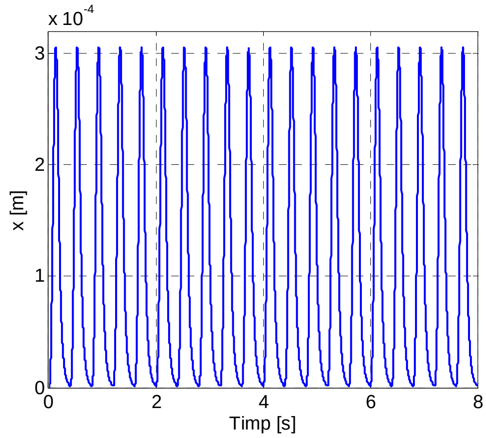

Fig. 5. The system response in time-displacement coordinates for a SDOF model [1]

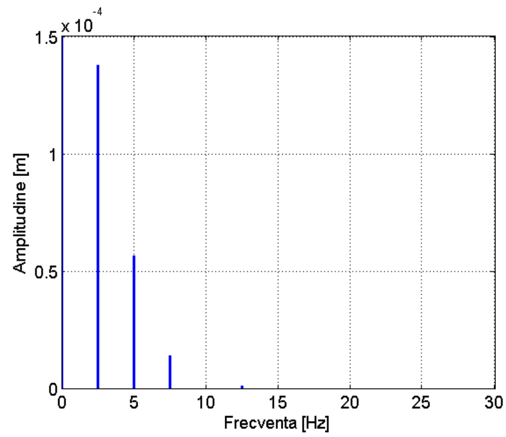

Fig. 6. The system response in frequency-displacement coordinates for a SDOF model [1]

A graphical representation of the haversine expression - Eqn. (5) is depicted in Fig. 3 with a spectral composition showed in Fig. 4. The diagrams in Fig. 5, and Fig. 6 respectively, presents timed evolution and spectral composition of a single degree of freedom (SDOF) system charged by a have sine input.

3. SIMULATION AND DISSCUSSIONS

Taking into account the Eqn. (1) and supposing the diagram in Fig. 1 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.

One basic hypothesis of this study supposes the constant velocity of technological equipments and the constant parameters of vibration generated by the drum [3,5].

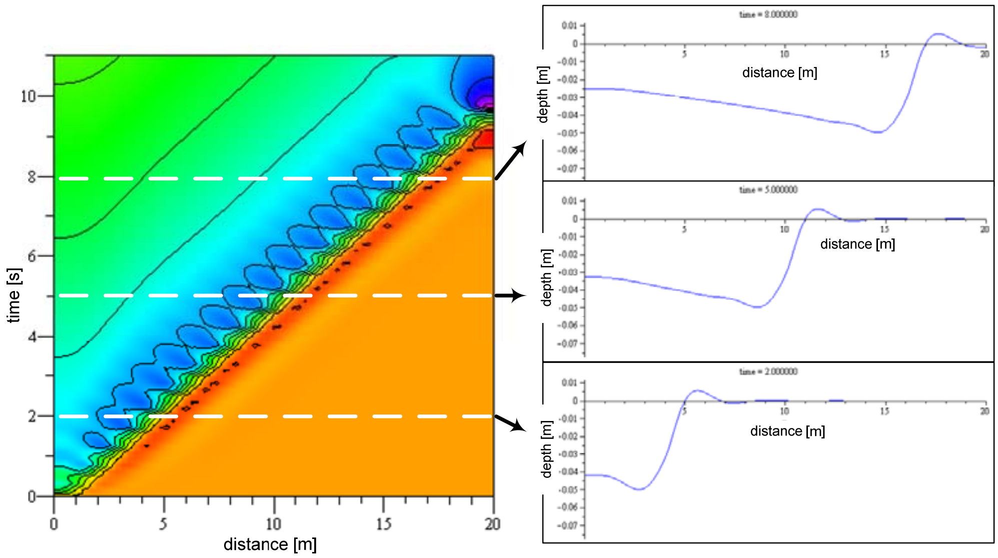

Fig. 7. Timed evolution of compaction level inside the first layer (see text for details) [3]

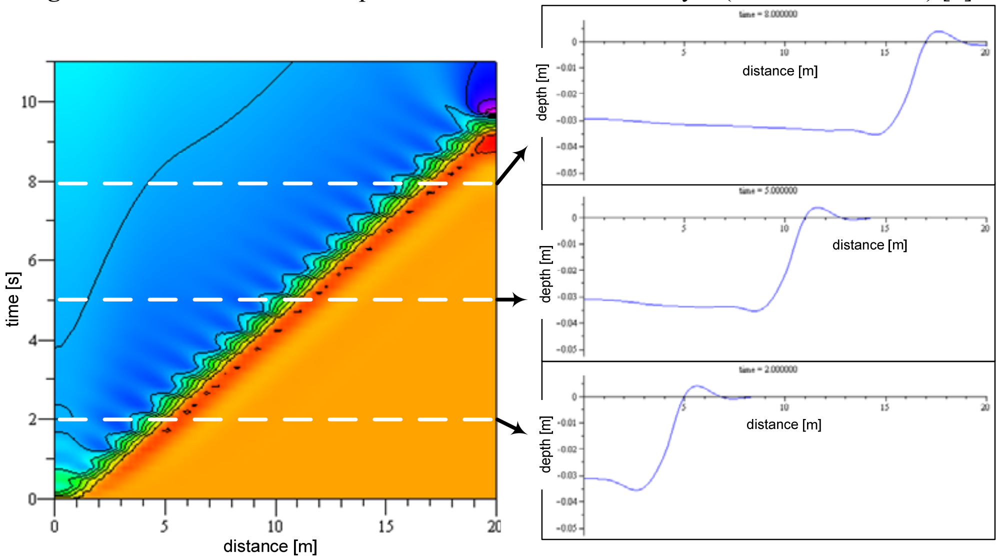

Fig. 8. Timed evolution of compaction level inside the second layer (see text for details) [3]

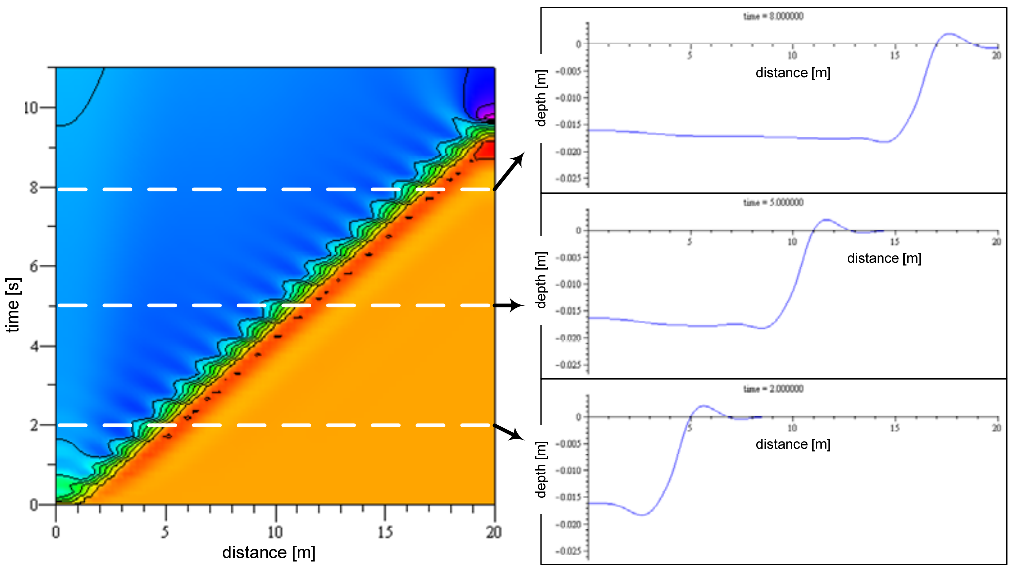

Fig. 9. Timed evolution of compaction level inside the third layer (see text for details) [3]

Another hypothesis consists by the constant parameters values for the entire layer. Only the variation with depth (with layer number) has accepted, and a linear law was adopting for this simulation.

For presentation the first three layers behaviour during the vibratory compaction process has choose. 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. 7…9 it has depicted the evolution of the compaction level for the first, the second and the third layers. Each diagram has dignified 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 has involved into the analysis. Technological equipment scans the entire length from the left (x = 0 m) to the right (x = 20 m) sides.

Comparative analysis of the three sets of diagrams put into the evidence the evolution of the compaction level inside the whole area. Hereby, the total deformations decrease with respect in layer number or, with the other words, 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. Supposing that stiffness and damping parameters growing up with the depth, and the shape influence coefficient of each layer also increase, the previous observations was correct. Thus, the permanent deformation of each layer acquires a relative increasing / random evolution during the whole simulation. However, for long periods of the simulation time results that compaction level in the terms of permanent vertical deformations clearly decreases with the depth of the analyzed area.

4. CONCLUSIONS

Utilization of the proposed conservative – dissipative – consolidate enabled model was mainly based on the experimental tests results, and provide a suitable tool for comparative analysis between the real data and the computer simulations with various mathematical approaches. This complex rheological model also enables smaller errors than others used for the vibratory compaction process analysis. The impulsive effect simulated by the periodic haven sine excitation reveals the additional spectral components, experimental validated, enabling a realistic simulation approach.

Computational analysis has dignified an appropriate fitting of the results with the experimental observations performed during the vibratory compaction technological process.

Finally it has to be noted that this model is also usefulness for analysis and optimization of the different working regimes for the technological equipments, to design a new equipments and technologies, to improve the global performances of used machines and technologies.

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CONSIDERAȚII ANALITICE ŞI ABORDĂRI NUMERICE DESPRE PROCESUL DE COMPACTARE PRIN VIBRARE

Rezumat: *În această lucrare autorul prezintă un model matematic util în simularea procesului tehnologic de compactare prin vibrare. Analiza interacțiunilor complexe dintre echipamentul tehnologic vibrator şi straturile de pamânt, analiză ce presupune o paletă largă de elemente dinamice şi reologice cu particularizări specifice, formează obiectivul central al acestui studiu. Modelul propus este format atât din elemente discrete, cât şi din modele ale mediului continuu, combinate astfel încât să ofere capabilitatea de modelare a compactării în adâncime specifică echipamentului, respectiv capacitatea terenului de a permite şi de a evidenția fenomenul de consolidare în adâncime. Ținând cont de această ipoteză rezultatele numerice pun în evidență comportări corespunzătoare cu cele obținute prin încercări experimentale. Reconfigurarea modelului în concordanță cu datele reale prin acordarea valorilor parametrilor esențiali în funcție de rezultatele obținute prin măsurări in-situ transformă acest model într-un simulator numeric scalabil pentru întreaga gamă de procese tehnologice de compactare prin vibrare cu aplicații practice în monitorizarea şi conducerea în timp real a echipamentelor tehnologice implicate.*

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