ON NONLINEAR DYNAMICS OF VIBRATING COMPACTION
PROCESS OF CONSTRUCTION MATERIALS

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This paper deals with dynamic behavior analysis of construction materials subjected to technological actions in order to obtain a suitable compaction degree. Direct interaction between working body and materials both at the input point and at overall domain that acquire dynamic changes, frames the main objective of this study. We present a basic approach regarding nonlinear models intended for computational dynamics of vibratory compaction process in order to evaluate the consolidation level, taking into account the complex rheology of terrains and the relative variable dynamic load in time for each point inside the working area. Numerical simulations have developed for two nonlinear models that contain conservative and complex dissipative rheological elements representing the cohesive and non-cohesive ground. The results put into evidence the cumulative effect of the successive passes and the consolidation in depth all over the monitored area.

Keywords: vibratory compaction, dynamics, nonlinear analysis

1. Introduction

The technological process of vibratory compaction has a large area of application because many situations in construction technologies require preparation works such as foundation consolidation. These technologies imply a large range of natural terrains and asphalt mixtures. Putting into the evidence the ground response (based on stochastically approaches of the main material characteristics) as a result of dynamic action due to technological process of vibratory compaction it helps the deeply
understanding of the interaction between the working tool and the compacted material [1–5]. The main effect of this understanding supplies the technological optimization through the improvement of the functional performances of the dynamic compaction equipment.

In this paper the authors briefly present the results obtained with the help of computational models, which integrate the theoretical nonlinear approaches with experimental observations into a unitary ensemble. The analysis of the vibrating compaction process had based on two main types of terrain as follows: cohesive and non-cohesive [10,13]. It was evaluated the deformations of the surface layer, taking into account the contact area between the ground and vibratory drum of roller.

2. Dynamic model of vibratory roller - ground

Without taking into consideration about ground characteristics, a general vibratory roller – ground system dynamic model are shown in Fig. 1.

![Figure 1: Forces acting on drum during vibratory compaction process [9].](image)

The expression of the contact force between the vibratory drum of the roller and the ground can also be written like [7-9]

\[
F_s = F_e \cos(\Omega t) + \left( m_f + m_d \right) g - m_d \ddot{z}_d - m_f \ddot{z}_f,
\]

where: \( m_d \) represents the mass of the vibratory drum of roller [kg]; \( m_f \) – mass of frame roller [kg]; \( F_e \) – amplitude of vertical component of eccentric excitation force [N]; \( F_s \) – contact force between vibratory drum and the ground [N]; \( \Omega \) - excitation frequency [rad/s]; \( \ddot{z}_d \) and \( \ddot{z}_f \) – vertical acceleration of the drum and, respectively, frame of the roller [m]. The last two terms of Eq. (1) can be neglected because of small values of inertial forces created by drum and frame comparatively with other forces that acting during compaction process.

The force developed between the roller and the ground can also be written like

\[
F_s = k_s \, x_s + c_s \, \dot{x}_s,
\]

where \( k_s \) represents the ground stiffness; \( c_s \) – ground damping. In this paper, these parameters will be evaluated after each passes of the vibratory roller and their evolution has been considered as non-linear expressions. Also, the Eq. (2) is valid when \( x_s \geq 0 \), but for \( x_s < 0 \) the value of \( F_s \) becomes zero.

Soil stiffness (\( k_s \)) was calculated by using semi-infinite elastic cone model [10,11] and assuming the small settlements of the ground during compaction process [6] we can considered that

\[
k_s = \frac{G}{1-\nu} \left( 3.1 \, a^{0.75} \, b^{0.25} + 1.6 \, b \right),
\]

\[
c_s = 4ab \sqrt{\frac{2G(1-\rho)\rho \, \frac{1-\nu}{1-2\nu}}{E}}.
\]

\[
G = \frac{E}{2(1+\nu)},
\]
where $E$ represents the dynamic modulus of elasticity, $\nu$ is the Poisson's ratio, $a$ denotes half-width of the roller, $b$ is the footprint width, $p$ denotes moisture content and $\rho_d$ represents the soil bulk density. The values of $a$ and $b$ have been defined in literature [13,14].

The main compactor parameters and, respectively, the values that characterize the initial state of the ground will be subjected to compaction process, useful for input data in the simulation model are shown in Table 1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$m_f$ [kg]</th>
<th>$m_d$ [kg]</th>
<th>$\Omega$ [rad/s]</th>
<th>$F_e$ [N]</th>
<th>$\rho_d$ [kg/m$^3$]</th>
<th>$\nu$ [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>4320</td>
<td>4000</td>
<td>314</td>
<td>6480</td>
<td>1400</td>
<td>0.5</td>
</tr>
</tbody>
</table>

The simulation was performed for 12 passes over the monitored area, with the mention that it was applied an accelerated regime in order to optimize the analysis duration.

3. Results and discussions

In Fig. 2.a was depicted the evolutions of the estimated consolidation of the non-cohesive material during vibratory compaction process. For evaluation of the ground rheological behaviour under dynamic action, it was analysed three distinct cycles taking into account the instantaneous deformation, and the results was presented as details in Fig. 3.a. These cycles was adopted thus that it represent the starting cycle, an intermediate cycle with 90% consolidation, and one of the last cycles with final consolidation value.

The detailed evolutions in Fig. 3.a reveal three types of transitory regimes as follows: the first case denotes great permanent deformations combined with intense dissipative and elastic behaviours; the second case presents both the viscous and elastic components with mainly contribution within global evolution, and the permanent characteristic but much more diminished comparative with the starting cycle; the third case that reveals a viscous and elastic transitions with small magnitudes overlapped by the maximum value of ground consolidation (obtained approximatively after ten passes).

![Figure 2: The evolutions of the estimated consolidation during the vibratory compaction process:](image)

(a) ![Figure 2: The evolutions of the estimated consolidation during the vibratory compaction process:](image)

(b) Figure 2: The evolutions of the estimated consolidation during the vibratory compaction process: a) for non-cohesive ground; b) for cohesive ground.

The diagram in Fig. 2.b presents the estimated values of the consolidation parameter in respect with numbers of passes of the vibratory roller that acts upon a cohesive ground.

Comparative analysis of the graphs in Fig. 3.b denotes the limit number of passes - eight passes for this case - that are able to assure a final value of consolidation parameter. After this, the dynamic response of the terrain contains only the dissipative and elastic components that generate an oscillating movement around the equilibrium position given by the final consolidation.

A comparative analysis between these cases dignifies that the different dissipative component had induced both qualitative and quantitative changes into the essential parameters evolutions. Neglecting the conservative component into the dynamic consolidation evolution can obtain the final state of compaction for every cycle with temporary changing of the local rigidity characteristic.
On the other hand, an important aspect it was represented by the spectrum frequency of the conservative and, respectively, dissipative components of instantaneous force developed at contact between ground-vibratory roller in technological process.

For time analysis of these signals, only one compaction cycle it was considered, but the frequency analysis has been performed for acquired signal entirely. In the case of non-cohesive ground, in the Fig. 4 it can observed the presence of the dominant spectral components around of 8,3Hz, 24,9Hz and 41,3Hz which means odd order harmonics.

These frequency values are found for all four evaluated signals, but the weight of the respective spectral components within each signal differs. It is noted that the major weight of the harmonic components in the global response of the ground is given by the dissipative component.

Also, in the case of cohesive ground, in Fig. 5 are shown the spectral displacement of the frequencies that appears during the process of ground consolidation until achieving the final value of this parameter. Removing conservative component (elastically recovery) of settlement that appears in dynamic forced regime contributes to the stabilization of the final consolidation state per cycle, with temporary changing of the local stiffness characteristic.

A comparative analysis of the excitation signal spectrograms, respectively of the ground response signal, it was observed the displacement of the frequencies in the direction of their increase.
4. Concluding remarks

The main concluding remark of this study frames the idea that a proper simulation of dynamic compaction using vibration requires a combination of technological equipment models, with advanced and realistic formulation of the ground rheology, and with specific element regarding the structure and the particularities of the technological process.

After the initial estimations of the ground response and the equipment capability, it have to be analysed the cumulative effect of the successive passes and the consolidation in depth all over the monitored area and using the real dynamics of the vibratory tool scanning the entire surface.

REFERENCES


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