THE ANNALS OF "DUNAREA DE JOS" UNIVERSITY OF GALATI
FASCICLE XIV MECHANICAL ENGINEERING, ISSN 1224-5615
2010

ON THE EFFICIENCY OF COMPACTING EQUIPMENT

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ABSTRACT

In this paper, the efficiency of vibratory rammer during compaction is examined. A three-degree-of-freedom model has been established for analytical representation of the soil-rammer interaction. In the first approach, it was considered only the vertical rammer movement. The soil is characterised as linear model taking into account the influence of the next properties: elasticity, plasticity and viscosity. A programme in Matlab/Simulink 7 was developed to solve the system of differential equations, which describe the rammer movement. The simulation results are presented as diagrams of displacement and acceleration of the main parts of the system.

KEYWORDS: efficiency, compacting, modelling, soil, rammer, vibrations, dynamics.

1. INTRODUCTION

In general, there are two different types of compaction force: static and vibratory. The static force is developed by the weight of the machine applying downward force on the soil surface, compressing the soil particles. The vibratory force is developed with the help of the vibrating mechanism, which has a rotating eccentric weight, in case of vibratory compactors, or piston/spring combination, in case of rammers (tampers).

In practice, there are many types of equipment for compaction, each with specific applications, function of the material that needs compaction, as it can be seen in Tabel 1.

Soil compaction is the consolidation of disturbed soil by applying mechanical energy and in this work was used a rammer equipment which delivered a high impact force making them an excellent choice for cohesive and semi-cohesive soils. Usually, the frequency range is of 500 to 850 blows per minute.

Rammers get compaction force from a small gasoline or diesel engine powering a large piston set with two sets of springs. The rammer is inclined at a forward angle to allow forward travel as the machine jumps.

Table 1. Equipments applications [9]

Material / Compacting equipment	 Vibratory plate	 *Vibratory rammer*	 Vibratory roller
Granular soils	Best application	Not recommended	Not recommended
Sand and clay	Recommended	*Recommended*	Best application
Cohesive clay	Not recommended	*Best application*	Recommended
Asphalt	Best application	Not recommended	Best application

2. SOIL MODELLING

For compaction purposes, soil can be classified into three basic groups: cohesive, granular and organic. The modelling of the behavior of the soil is not easy because too many parameters appear and the soil is not homogeneous. If it is supposed that rammer develops in soil a stress σ, when this was removed at a certain level as shown in Figure 1, the strain did not wholly return to the initial point. If only the elastic strain component was returned, it would be possible to calculate the plastic strain by deducting it from the total strain at the time point of stress removal.

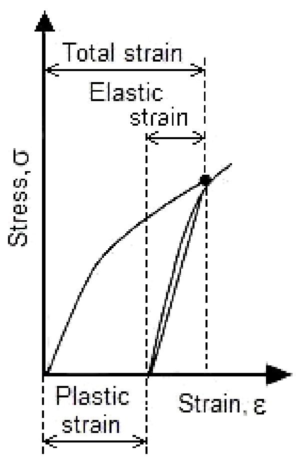

Fig. 1. Separation of two components: elastic and plastic strain

In the literature, a new parameter was introduced, called the plasticity parameter ε, which is defined as [1]:

$$\varepsilon = \frac{k_e + k_p}{k_p} \quad (1)$$

where k_e/k_p represent elastic/plastic constants of the material that are needed to be compacted.

The plasticity parameter ε, varies from 0 to 1 because the soil has a various behaviour from entirely plastic to perfectly elastic state, as it can be seen in Figure 2.

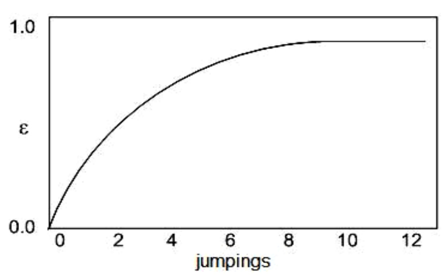

Fig. 2. Value of plasticity parameter

All available models for soils are based on a few basic models: Hooke (linear pure elasticity), Newton (linear pure viscosity), P-E Bathelt, Maxweel, Voigt, etc. [4].

In this paper, for simplifying the mathematic model for the soil, the author adopted a model obtained by serial by connecting a Hooke model with a simple Bathelt model and by paralel connecting it with a viscous device, such as in Figure 3.

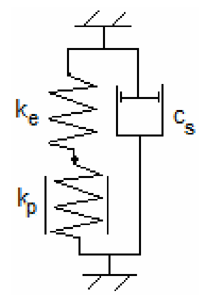

Fig. 3. Model of soil

Under the action of a vibratory force developed by rammer against the soil modelled like in figure 3, the behaviour has two stages:

- the deformation of the elastic system at the continuous increasing of the force, period in which it is considered the rigidity k_{eq};

$$k_{eq} = \frac{k_e k_p}{k_e + k_p} \quad (2)$$

- at the force decreasing, the elastic device with k_p rigidity remains blocked and only the elastic device k_e works.

3. RAMMER MODELLING

The tamping machine presented in Figure 4 consists of three main parts: the tamping foot, the piston and the engine. The motions of mass m_1, m_2 and m_3 are measured by coordinates x_1, x_2 and x_3, and only vertical tamping movements are assumed.

Applying Newton's second law on the masses in Figure 4 results a system with three differential equations which describe the non-linear dynamic behaviour of this equipment.

$$\begin{cases} m_1\ddot{x}_1 = -F_{soil} + c_f(\dot{x}_2 - \dot{x}_3) + k_f(x_2 - x_1) + \\ \qquad + k_s x_0 + m_1 g \\ m_2\ddot{x}_2 = F - c_f(\dot{x}_2 - \dot{x}_1) - k_f(x_2 - x_1) + m_2 g \\ m_3\ddot{x}_3 = m_3 g - F \end{cases} \quad (3)$$

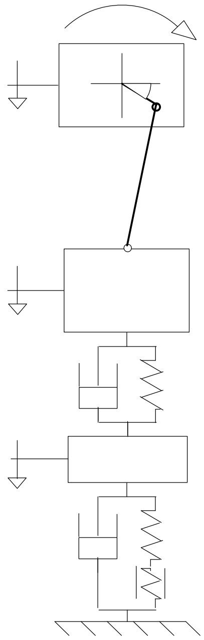

Fig. 4. Model of rammer equipment

The equation of engine torque is given by:

$$J\ddot{\theta} = M - Fr\cos\theta \qquad (4)$$

Under the action of vibratory rammer, the soil will be compacted, over a cycle time, with x_1 displacement.

The static deformation of the soil because of rammer weight action is given by the expression:

$$x_0 = \frac{(m_1 + m_2 + m_3)g}{k_e}. \qquad (5)$$

Between the displacements of masses m_2 and m_3 exists the following relation

$$x_2 = x_3 - r(1-\cos\theta) \qquad (6)$$

and through deriving in time it is obtained the velocity and the acceleration of mass m_2.

$$\dot{x}_2 = \dot{x}_3 - r\dot{\theta}\sin\theta \qquad (7)$$

$$\ddot{x}_2 = \ddot{x}_3 - r\ddot{\theta}\sin\theta - r\dot{\theta}^2\cos\theta \qquad (8)$$

By replacing of $x_2, \dot{x}_2, \ddot{x}_2$ from Eq.(6-8), and force F from Eq. (4) with Eq.(3), the final expressions of the differential equations of rammer motions can be written as follows:

$$\begin{aligned}
&m_1\ddot{x}_1 = -F_{soil} + c_f(\dot{x}_3 - \dot{x}_1) + k_f(x_3 - x_1) + c_f\dot{\theta}r\sin\theta + \\
&\quad + k_f r - k_f r\cos\theta - k_s x_0 + m_1 g \\
&m_2\ddot{x}_3 + \left(m_2 r\sin\theta + \frac{J}{r\cos\theta}\right)\ddot{\theta} = c_f(\dot{x}_1 - \dot{x}_3) + k_f(x_1 - x_3) - \\
&\quad - m_2 r\dot{\theta}^2\sin\theta - c_f r\dot{\theta}\sin\theta - k_f r\cos\theta + \\
&\quad + \frac{M}{r\cos\theta} - k_f r + m_2 g \\
&m_3\ddot{x}_3 - \frac{J}{r\cos\theta}\ddot{\theta} = m_3 g - \frac{M}{r\cos\theta}
\end{aligned} \qquad (9)$$

F_{soil} represents the force exerted by the earth against the rammer foot. This force has various expressions in different stages of the motion rammer, defined by Eq.(10)

$$F_{soil} = \begin{cases} 0, \text{ for jumping} \\ \frac{k_e k_p}{k_e + k_p}x_1 + c_s\dot{x}_1, \text{ for compaction} \\ k_e(x_1 - \delta) + c_s(\dot{x}_1 - \dot{\delta}), \text{ for elasticrecovery} \end{cases} \qquad (10)$$

where δ represents the soil plastic deformation.

At the end of the compaction stage, the foot speed becomes zero and results the total deformation x_1 and the plastic deformation δ of the soil. In this case, δ is defined by the following expression:

$$\delta = \frac{k_{eq}}{k_p}x_1 \qquad (11)$$

Taking into account the eq.(1), the plastic deformation results:

$$\delta = x_1(1-\varepsilon) \qquad (12)$$

It is necessary to write the conditions for the machine being in contact with the soil:

$$F_{soil} \geq 0 \text{ and } x_1 \geq 0 \qquad (13)$$

else F_{soil} becomes zero.

4. SIMULATION RESULTS

In the following figures, the autor presents the simulation results for compaction equipment type Petrol-tamper LT 70 equipment, from Svedala Compaction Equipment AB, Sweden. The values are determined according to Borg [2] and Broman [3]. The parameters used are: m_1=19.7 kg, m_2=3.9 kg, m_3=46.5 kg, M=43 Nm, J=0.6 kgm^2, k_f=77000 N/m, c_f=500 Ns/m, k_s=17000 N/m, c_s=50 Ns/m, r=0.0275 m. All parameters remain constant through the simulations.

The differential equations of the model are solved by using numerical methods [4], [6], [7] that are implemented in MATLAB 7 software. The results of the simulation are shown in Figure 5.

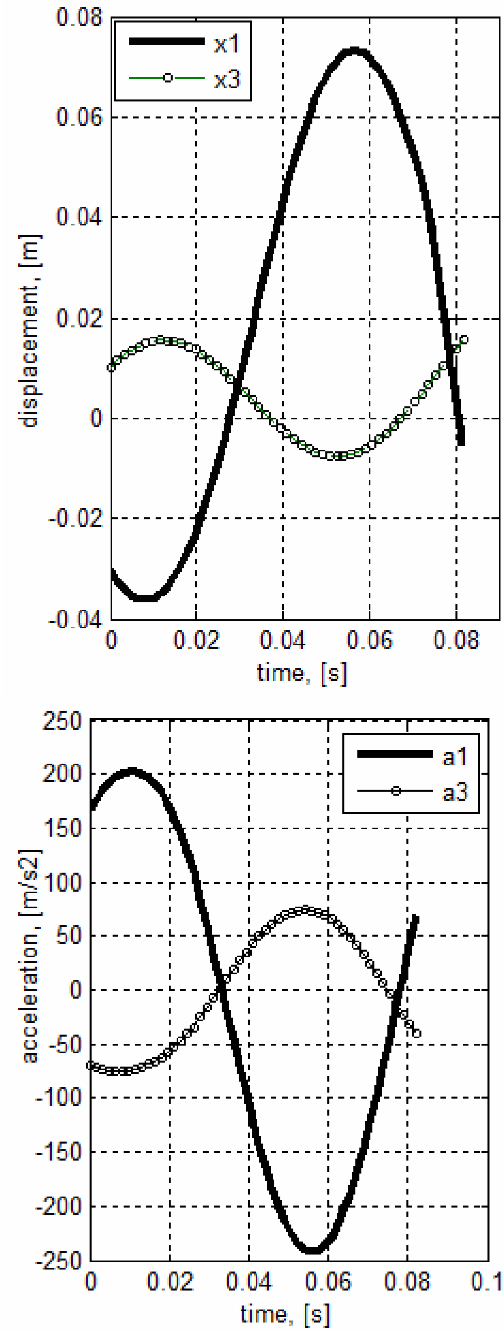

Fig. 5. Results of simulation dynamics rammer

It is important to known the conditions under which the rammer works with maximal efficiency. This thing can be investigated by running simulations for a large number of frequencies of vibratory rammer and plotting the results as diagram amplitude of displacement x_1 function of frequency, such as in figure 6.

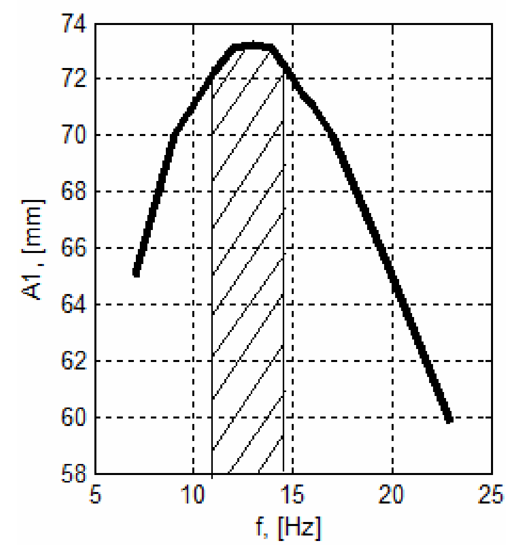

Fig. 6. Rammer efficiency

When the analised rammer works with frequency in range of 11...14 Hz, the maximum amplitudes of motion is obtained, that means the obtaining of maximal compaction degree of ground with this equipment.When the frequency rammer increases or decreases face to optimal domain, instabilities appear, motion becomes chaotic and periodic loss of contact (rammer-ground) may be possible.

In a future work, the author will study the behaviour of contact force between tamper-ground for different working conditions.

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