THE ANNALS OF “DUNAREA DE JOS” UNIVERSITY OF GALATI
FASCICLE XIV MECHANICAL ENGINEERING, ISSN 1224-5615
2008

ON THE RHEOLOGICAL BEHAVIOUR OF THE SOIL IN THE ARTIFICIAL COMPACTING PROCESS

Prof.dr.eng. Gheorghe OPROESCU
Lecturer dr.eng. Carmen DEBELEAC
Lecturer dr.eng. Adrian LEOPA
Lecturer dr.eng. Silviu NASTAC
"Dunarea de Jos" University of Galati

ABSTRACT

The artificial compacting of the soil is made mostly with machines with dynamical action such as vibrating plate, vibrating beater or vibrating drum. Their effect on the compacting process of the soil has two origins: the own weight of the machine and the unidirectional vibrating force generated from a specific device. A centrifugal vibrating generator is the frequently used device. In order to develop equipments with high performance, namely computer-aided machines, machines with active adaptation or alike, the physical and mathematical modeling of the soil behaviours are necessary. The previously developed models, based on the linear elastical behaviour of the soil and certain tricks used in the presentment of the soil properties in order to make easy an analytical solution of the movement equations, try to adapt a linear model to a nonlinear and nonelastical medium. This fact brings about very large approximations of the reality.Our work shows a new model of the soil, based on more properties such as elasticity, viscosity, plasticity and dry friction. This model is excited by a vibrating machine and the result concerning displacement, speed, acceleration or consumed power is possible to be obtained on computer. The modification of the properties of the compacted soil modifies the result of the model and therefore the compaction degree can be modeled by modifying the result of the developed model.

KEYWORDS: compacting of the soil, rheological behaviour, nonlinear properties, compaction degree, computer-aided equipment.

1. INTRODUCTION

A soil compactor like vibrating plate, vibrating beater or vibrating drum fig. 1 acts on the soil [4]. How does the soil behave under the combined action of the weight of the machine and of the dynamical periodical force, both on the vertical direction? An easy experiment, fig. 2, shows that the soil tolerates a certain deformation δ_1 under the external pressure F_1 and after the clearance of the action comes back only partial, $\delta_{1r} \neq 0$. A renewal of the experiment under greater force F_2 shows a greater deformation δ_2 and again a new partial recursion, $\delta_{2r} \neq 0$. After more repeated compressions and relaxations, the soil undergoes certain permanent deformations and a modified consistency. If the compression exceeds the maximal admissible values, dependent from the soil structure, the soil is destroyed and becomes fragile. This is the macroscopic behaviour of the soil at compaction and, finally, the designation of the compacting process, namely the conversion of a non-cohesive soil into a cohesive one. Microscopically, the soil consists of many particles of different form, dimension and origin, fluids with different viscosity and binding agent. Among all components appear cohesive forces, dry or lubricated friction forces, reciprocal actions and reactions.

The modeling of the behaviour of the soil is not easy because too many parameters appear and the soil is not homogeneous.

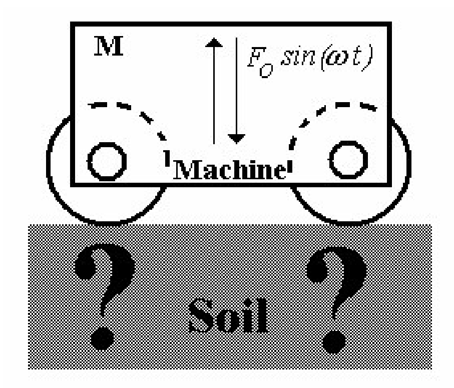

Figure 1. Vibrating drum and its action

The really dependence between the force F and displacement δ is not linear and not the same in different points on a certain area.

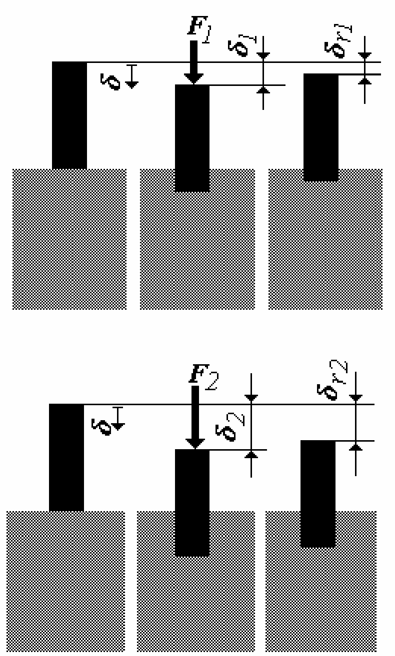

Figure 2. The deformation of the soil

The differential equations used in order to describe the compacting process in all its complexity are not possible to be solved on analytical way and therefore the mostly developed and available models are based on linear properties of the soil and linear differential equations with a few tricks in order to correct the difference from the reality [4].

2. AVAILABLE MODELS OF THE SOIL

All available models are based on a few basic easy models, fig. 3 [4].

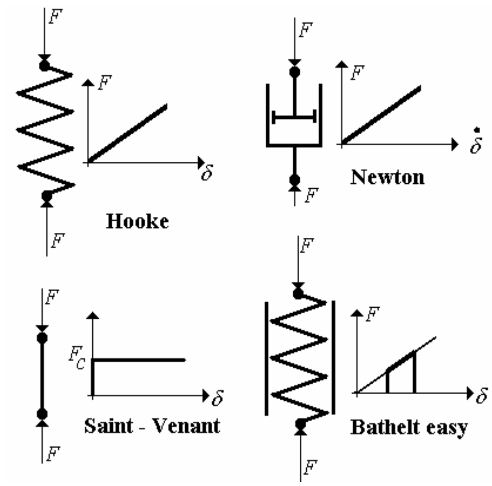

Figure 3. Basic models for different rheological media

Therefore are used Hooke model (linear pure elasticity), Newton (linear pure viscosity), Saint-Venant (pure plasticity for the forces over critical value F_c) and Bathelt easy. The last model combines Hooke model with two lateral catch pawls in order to block up the returning movement of the pure spring and substitutes the really behaviour of the elasticity and plasticity together. Experimentally it has been developed a composed model of the soil, fig. 4 and 5.

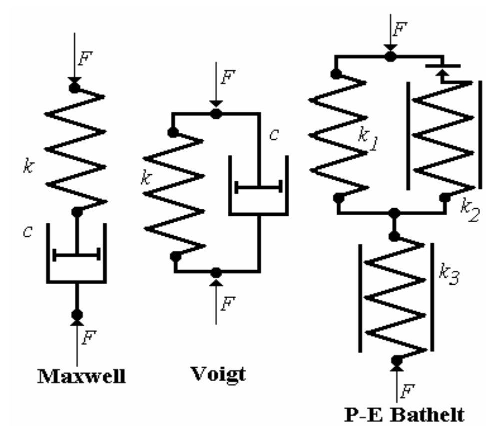

Figure 4. Composed models without dry friction

All composed models without dry friction contain only linear components, elasticity k and viscosity c, namely viscoelastical model [3]. The differential equations are easy on soluble analytical way for Maxwell and Voigt models. At P-E Bathelt model the differential equation is soluble stepwise only. At compression we have two different differential equations, the first equation contains the linear elasticity of the left upper spring k_1 up to contact with the spring k_2, the second equation contains the equivalent linear elasticity of springs k_1, k_2 and k_3 together and another differential equation with linear elasticity given from left upper spring k_1 at relaxation. The final solution of each differential equation becomes initial condition for the next equation.

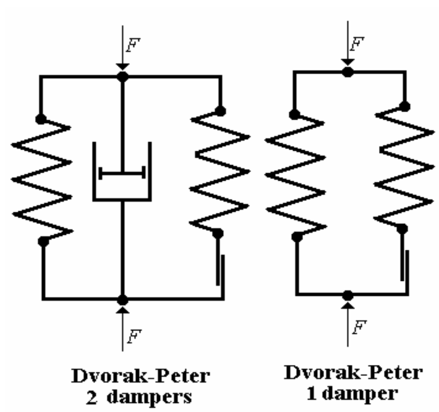

Figure 5. Composed models with dry friction

The Dvorak-Peter models from fig. 5 contain a linear spring, a damper with dry friction and facultative viscous dampers. The mathematical nonlinearity produced from dry friction is soluble stepwise too, with two or more differential equations on different phases of the movement determined from the direction of the momentary speed. These tricks permit an analytical solving but with certain errors and on toilsome way.

3. OUR PROPOSED MODEL

The difficult nonlinear differential equations are today possible to be solved by numerical way on computer. Based on the real deformation of the soil, fig. 2, we have imagined another model of the soil, fig. 6. The model contain an elastical device k, a viscous damper, a plastical device c_{pl} and a dry friction damper F_{df}. All four devices are considered parallelly connected because a certain deformation of the soil produces the same deformations to each device. The balance of the forces can be also written:

$$F = F_{el} \cdot \mathrm{sgn}(\delta) + \left(F_{vsc} + F_{pl} + F_{df}\right) \cdot \mathrm{sgn}(\dot{\delta}) \qquad (1)$$

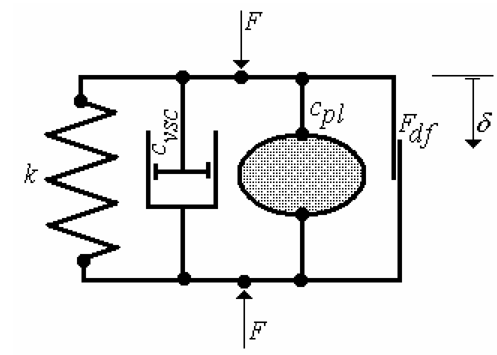

Figure 6. Proposed model of the soil

where

$$F_{el} = \begin{cases} f_1(|\delta|) \text{ if } \delta > 0 \\ f_2(|\delta|) \text{ if } \delta < 0 \end{cases}; \quad F_{vsc} = \begin{cases} g_1(|\dot{\delta}|) \text{ if } \dot{\delta} > 0 \\ g_2(|\dot{\delta}|) \text{ if } \dot{\delta} < 0 \end{cases};$$

$$F_{pl} = \begin{cases} p_1(|\delta|) \text{ if } \delta > 0 \\ p_2(|\delta|) \text{ if } \delta < 0 \end{cases}; \quad F_{df} = \begin{cases} F_{df1}(|\delta|) \text{ if } \dot{\delta} > 0 \\ F_{df2}(|\delta|) \text{ if } \dot{\delta} < 0 \end{cases}; \qquad (2)$$

The elastical, viscosity, plastical and dry friction forces appear in equation (1) with positive values only and the functions $sgn(\delta)$ or $sgn(\dot{\delta})$ apply the adequacy sign. These forces are calculated from equations (2). We have chosen this mode to write these forces in order to use different formulas, dependent from the displacement or speed direction; $f_1, f_2, g_1, g_2, p_1, p_2$ are functions, $F_{df}1, F_{df}2$ constant values or functions. Hereby can be described any physical model with linear or nonlinear, symmetrical or unsymmetrical forces.

A vibrating machine acts on the soil with these properties, namely a machine with mass M bears on a medium analogously composed with our proposed model of the soil, fig. 7.

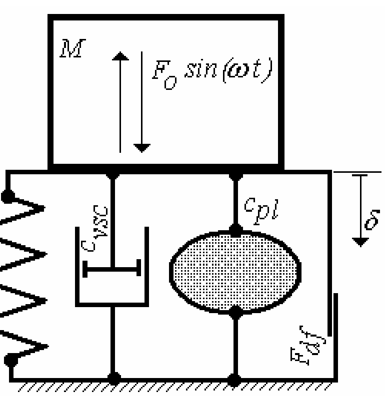

Figure 7. The machine on the soil

We use the following hypotheses: the machine has only a vibrating mass beard on the soil and the boundary effects around of the machine are negligible. The equation of the movement is [1],[2]

$$M \cdot \ddot{\delta} + F = F_0 \sin(\omega t) \qquad (3)$$

and can be integrated on the numerical way. We have used Runge-Kutta method from order IV programmed by us on a computer PENTIUM IV [5],[6].

4. RESULTS

We have chosen the single drum soil compactor CA134 from DYNAPAC [7], with following parameters: mass of the drum compactor $M = 1800\ kg$, vibration frequency = *35Hz* (*2100 rot/min,* $\omega = 220\, s^{-1}$), centrifugal force $F_0 = 89\ kN$.

We simulate hereinafter some properties of the soil in order to demonstrate the influence of the compaction degree of the soil on the variation of the operating parameters of the vibratory device during and after compaction. Hereby we chose as initial values: elasticity $k = 100000 N/m$, plasticity $c_{pl} = 50000 N/m$, viscosity $c_{vsc} = 5000 Ns/m$, dry friction $F_{df} = 5000N$.

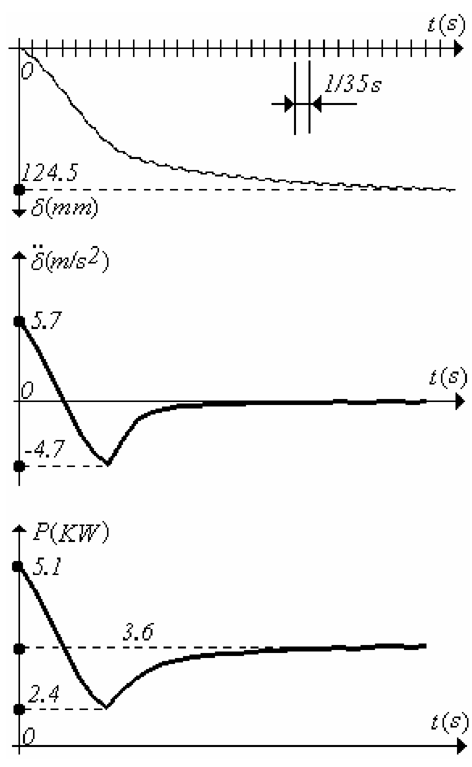

Figure 8. Variation of the operating parameters

The variation of the soil properties is dependent from the compaction degree, namely from the values of δ. We have chosen the following values:

$$F_{el} = \begin{cases} 100000 \cdot |\delta| + 50000 \cdot \delta^2 \text{ if } \delta > 0 \\ 0 \text{ if } \delta \le 0 \end{cases};$$

$$F_{vsc} = \begin{cases} 5000 \cdot |\dot{\delta}| + 50000 \cdot \dot{\delta}^2 \text{ if } \delta > 0 \\ 0 \text{ if } \delta \le 0 \end{cases};$$

$$F_{pl} = \begin{cases} 50000 \cdot |\delta| + 30000 \cdot \delta^2 \text{ if } \delta > 0 \\ 0 \text{ if } \delta \le 0 \end{cases};$$

$$F_{df} = \begin{cases} 5000 + 30000 \cdot \delta \text{ if } \delta > 0, \dot{\delta} \ne 0 \\ 0 \text{ if } \delta \le 0 \end{cases};$$

We remenber again, these values serve only to simulate the behaviour of the soil but its form can be allied to real soils. The dry friction forces are considered symetrical, its values are not dependent from the speed or speed direction.

The absorbed average power of the vibratory device or the average acceleration of the vibrations of the machine can be a good indicator of the compaction degree, see fig. 7. Its form is the same and goes after the form of the compaction δ.

The length of the simulation covers 30 periods from 1/35 second of the vibrator.

If the soil parameters are constant or have another variation law, the evolution of the compaction degree, average power or average acceleration is similar to fig. 7.

REFERENCES

[1] **Bratu P.** *Vibratiile sistemelor elastice*, Editura Tehnica, Bucuresti, 2000, ISBN ISBN 973-31-1418-9
[2] **Cauteş Gh, Oproescu Gh.** - *Dinamica sistemelor mecanice neliniare*. Editura CEPROHART, Brăila, 2003, ISBN 973-7909-03-8.
[3] **Kecs W.** *Elasticitate si viscoelasticitate*, Editura Tehnica, Bucuresti, 1986
[4] **Mihailescu St., Vlasiu Gh.** *Masini de constructii si procedee de lucru*, Vol. 2, Editura Didactica si Pedagogica, Bucuresti, 1973
[5] **Oproescu Gh.** *Um den Grundsatz und das Grundprinzip in Zahlenrechnung.* The VI-th International Conference on Precision Mechanics and Mechatronics, The Romanian Rewiew of Precision Mechanics, Optics and Mechatronics, Vol. 2-20b, 10-12 October 2002, Braşov, România, ISSN 1220-6830, pg. 349-352.
[6] **Oproescu Gh., Cautes** *Metode numerice si aplicatii***,** Ed. Tehnica, Chisinau, 2005
[7] ***Dynapac company website. URL: http://www.dynapac.com