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RESEARCH ON THE PROCESS OF VIBRATORY COMPACTION OF SUSTAINABLE ROADS

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Abstract: *The paper evidences preliminary research results on the process of vibratory compaction of soils for sustainable road construction. For an efficient process, one important aspect is that of determining soils characteristics, out of which compressibility behavior is relevant. An innovative loading device for the oedometer test has been designed so that to enable efficient loading of soil samples - with minimum effort and complex data processing of the results. Further, Kelvin-Vogt model of the viscoelastic rheological behavior of soil has been considered for in situ research. The obtained experimental data and their associated mathematical models, as well as the plotted graphs would be applied for optimum soil's vibratory compaction process. Related to the mentioned aspects, there has been conceived a Romanian fit control plan for sustainable road construction.*
Key words: *Soil compaction, Oedometer test, Vibratory roller, Vibration amplitude, Quality control plan.*

1. INTRODUCTION

Romania is situated in the south-eastern part of Europe, at the crossroad of international highroads. Its transport network is connected to similar networks of neighboring countries and to the ones of European and Asian countries. Romania's infrastrucure is far below needs. Out of almost 80 thousand kilometers, the percentage of its national roads does not exceed 20% and the highways network is about 850 km long.

The tremendous number of vehicles driven on the streets and the need of high traffic fluency stand for the main reasons of focusing attention on sustainbale road construction – with inegrated smart traffic. One real problem in Romania, is that in few months of exploitation there appear cracks, wholes and damaged zones on the roads. Of course, there are many factors that determine the failures, such as: improper materials in roads layers, inadequate technology and techniques of deposition, wrong exploitation, etc.

A very important factor that do influence the quality of roads is the degree of soil compaction and, therefore, research on this process has been done and presented further by the paper.

2. COMPACTION EVALUATION

The soil on which roads are going to be build is called road foundation while, the soils and other natural agregates used for embankment are generically called soils. The three main stages of investigting road embankment soils' behaviour are mentioned next:

- the geotechnical identification – enables correlation of estimated soil's behaviour to that of a certain known soil's type;
- the study of state characteristics – soil behaviour parameters are specific and have to be reported to the reference values, when moisture is considered;
- the evaluation of bearing capacity – done by conventional / standard tests.

Soil compaction is defined [1, 5, 6, 12, 13] as "the method of mechanically increasing the density of soil". If performed correctly, there will be not unnecessary maintenance costs or structure failure repairs.

Schematic representation of the soil compaction loading force type is shown in Figure 1.

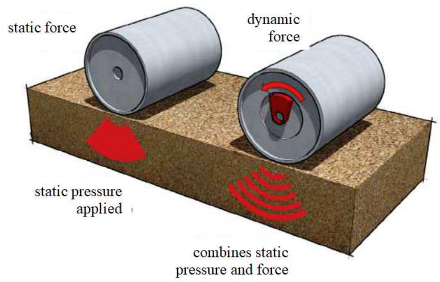


Fig. 1. Force type in compaction of soils.[1]

For an efficient soil compaction process and, further, sustainable road construction, the study of soil's compressibility characteristic has to be done. The oedometer test is standardized laboratory test consisting in successive loading of a soil sample (in a cell) and measuring the resulting deformation (soil compaction). This test has two main components: cell containing the soil sample; loading system – discreet (by weight) or continuous (pneumatic, hydraulic, electric) loading.

The standard values for discrete loading, as mentioned in STAS 8942 / 1-89 are: 2 kgf; 4 kgf; 8.25 kgf; 12.25 kgf; 16.5 kgf; 20.5 kgf; 24.5 kgf; 32.75 kgf; where 1 kgf is approximated to 9.81 N.

While investigating the characteristics of studied soils, there was a requirement (from a private accredited laboratory) for a device to enable the application of, both discrete and continuous loading in the oedometer test (consolidation test). This device should be friendly user, of affordable price and fit to the other equipment in that laboratory. This is why there has been designed and, further, manufactured a customized loading device whose main components are: linear actuator and universal load cell, S-type – see Figure 2.

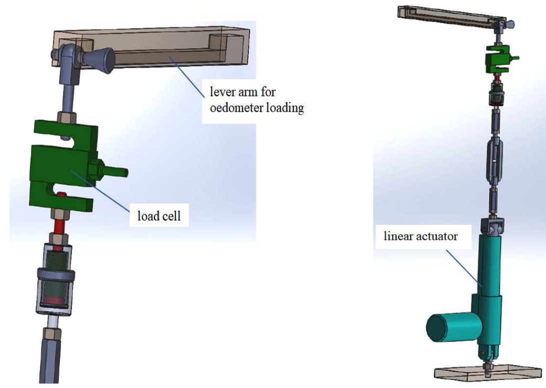


Fig. 2. Customized loading device for the oedometer test.

3. VOIGT- KELVIN MODEL FOR THE VIBRATORY COMPACTION PROCESS

Compaction of soil is a physical-mechanical process that results in the rearrangement and redistribution of solid particles in soil, by partially elimination of air and water from its pores.

This is why, due to the increase in density and reducing of voids, the mechanical characteristics (shear strength, load bearing capacity) of soils are improving and, finally, the embankment stability for sustainable road construction is to be achieved. [5, 6, 12]

Depending on the type of loading force for compaction, the process would be static, or dynamic (see Figure 1). In roller vibratory compaction process, the vibrations produced by the rotation of an eccentric weight are transmitted to soil generating relative displacement of soil's particles and much more compact arrangement. [2, 3, 4, 12, 13]

As the compaction process is very complex, there are rheological models for simulating soil's behavior, such as: Hooke (elastic material); Newton (viscous material); Saint-Venant (plastic material); Voigt-Kelvin / Maxwell / Zener (viscoelastic material). [5, 6, 7, 8, 9]

In the research presented by this paper, it has been considered the Voigt-Kelvin rheological model for soil, more specifically, the soil is a linear viscoelastic material, with both elasticity and viscosity behavior. The schematic representation of vibratory roller – soil interaction (spring and damper parallel connected) is shown in Figure 3.

The mathematical analysis and characterization of the phenomena specific to the vibration compaction process are evaluated by the adopted model [2,5,6,7,8,9,10,12,13,16].

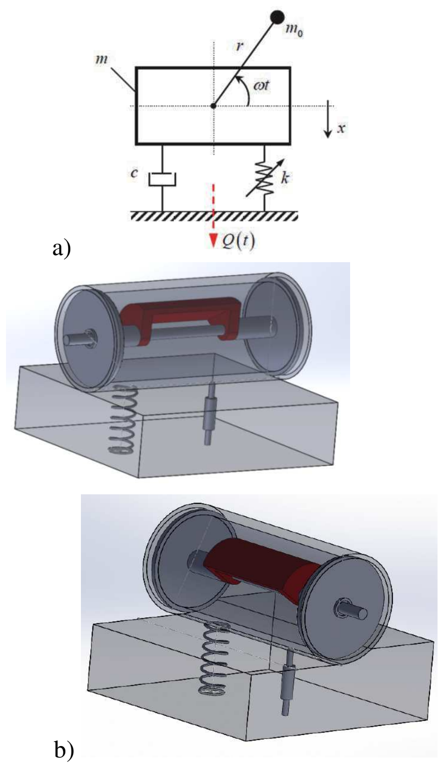


Fig. 3. Schematical representation of the dynamic interraction.
a) linear rheological Voigt-Kelvin model
b) vibration system

The vibratory roller has dynamical compaction effect only by its vertical motion, as described by equation (1):

$$x = x(t) = A\sin(\omega t + \varphi) \qquad (1)$$

The viscoelastic behavior of soil is defined by the coefficient of viscosity, c [Ns/m] and the coefficient of elasticity, k [N/m] – at one pass of the vibratory roller, over the same layer.

Vibrations are determined by the rotation of eccentric weight, m_0, positioned at r distance with respect to the rotational axis of the roller.

The vibrations amplitude, A, of vibrations is given by (2):

$$A = X_0(\omega, k) = \frac{m_0 r w^2}{\sqrt{(k - m w^2)^2 + c^2 w^2}} \qquad (2)$$

The resonance frequency is expressed by (3):

$$\omega_n = \sqrt{\frac{k}{m}} \qquad (3)$$

The dynamic force transmitted to soil, evidences the efficiency of the vibratory compaction process and its amplitude is defined by equation (4):

$$F = Q_0(\omega, k) = m_0 r \omega^2 \sqrt{\frac{k^2 + c^2\omega^2}{(k - m\omega^2)^2 + c^2\omega^2}} \qquad (4)$$

Considering the issues mentioned above, and in cooperation with a famous private research institute (ICECON SA), experiments have been carried out “in situ”, with BOMAG single drum roller (Figure 4). [10,11,12,13,14,15].

Fig. 4. Bomag roller in experiments.

Input data for the analysis of dynamic answer are as follows:

- m = 2000 kg and $m_0 r$ = 1 kg·m;
- c = $0.5\cdot10^5$ [Ns/m];
- k = $2.5\cdot10^6$; $5\cdot10^6$; $7.5\cdot10^6$; 10^7 ; $2.5\cdot10^7$; $5\cdot10^7$ [N/m];
- ω = 0 ÷ 500 [rad/s]

By relation (2) and MATLAB software there have been plotted family of curves for the vibration amplitude, as evidenced by Figure 5.

Similarly, with input data values, for discrete variations of the c parameter values, as follows:

- m = 2000 kg şi $m_0 r$ = 1 kg·m;
- k = $5\cdot10^6$ [N/m];
- c = $0.5\cdot10^5$; 10^5 ; $2\cdot10^5$; $3\cdot10^5$; $4\cdot10^5$; $5\cdot10^5$ [Ns/m];
- ω = 0 ÷ 500 [rad/s]

and relation (2), the graphs of vibration amplitude are shown in Figure 6.

One can notice that, the higher the values for elasticity coefficient, k, for the same value of viscosity coefficient, c, the amplitude resonance values show a significant increase.

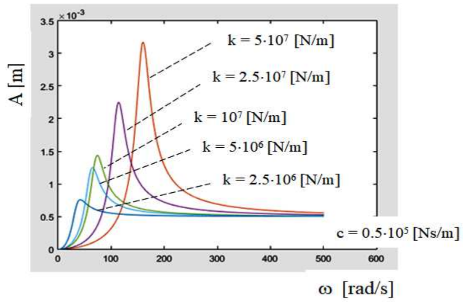


Fig. 5. Graph of vibration amplitude – for different values of the elasticity coefficient.

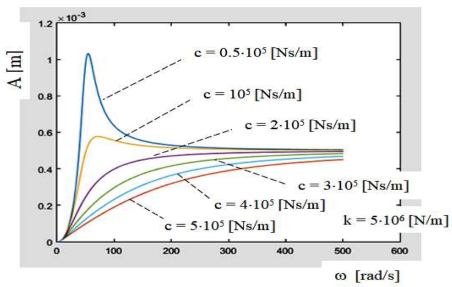
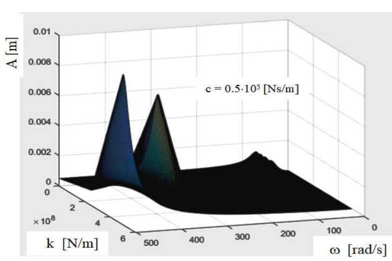


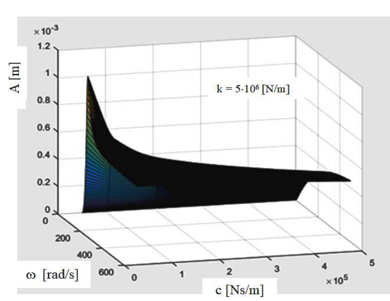
Fig. 6. Graph of vibration amplitude – for different values of the viscosity coefficient.

The response surface of vibration amplitude, relation (2) – for constant viscous damping is presented in Figure 7. When there is a discrete change in viscous damping, c, for constant elasticity (rigidity), k, the response surface is as shown in Figure 8.



A = A(ω, k) for c = const

Fig. 7. The 3D surface of vibration amplitude, for constant viscous damping.



A = A(ω, c) for k = const

Fig. 8. The 3D surface of vibration amplitude, for constant rigidity

4. QUALITY CONTROL OF SUSTAINABLE ROADS

In order to carry out the process of laying the layers of the road structure in optimal conditions, a quality control plan was designed. This plan is based on the activities mentioned in Figure 9. [1,14,15,16]

Fig. 9. Scheme of the quality control

A1. Verification of the preparatory technological conditions – consisting in the steps that follow.

- checking the existence of plans for levelling the works and the surface of the support layer;
- verification of the existence of certificates of conformity for products issued by the certification body for stabilized soil, asphalt and component materials;
- verification of the existence of technical inspection reports issued by an accredited third-party body;

A2. Quality control of road construction works in mixtures

The activities carried out for the control of the quality of the works of execution of the road layers in mixtures are:

- quality control of the component materials, the technological process of preparation and transport of the asphalt mixture and the quality of the surface preparation of the support layer;
- control of the technological process of commissioning of asphalt mixtures;
- quality control of road layers of asphalt mixtures.

A3. Quality control of component materials

- the quality control of the materials is performed during the execution of the works, the verifications being performed by the contractor's laboratory, on each batch of supplied materials: natural aggregates, bitumen, filling, additives;

- control of the technological process of preparation of the asphalt mixture (control and regulation of the installation of preparation of the asphalt mixture);
- control of the transport of the asphalt mixture (checking the technical condition of the means of transport (cleaning, technical condition, tarpaulins, solvent treatment of the useful surface of the trailer before the first stroke, tilting module);

A4. Quality control of the technological equipment for laying the asphalt mixture

- the verification of the finishing equipment is performed according to the maintenance plan and is performed by the specialized personnel of the technological equipment owner.
- checking the technological parameters aims to maintain the quality of the mixture and obtain the productivity required by the technological process;
- quality control, in the efficient release of the hot bituminous mixture layer, is performed on specific phases of execution;

A5. Quality control on the operation of technological equipment for compaction of asphalt mixing layer

Checks and tests on the operation of technological equipment for compacting the asphalt mixing layer consist of checking the mixing temperatures in the layer; verification of compliance with the compaction technology established by the experimental sector.

5. CONCLUSION

The research carried on point out toward the conclusions that follow.

a) Rheological characteristics of the materials for roads (stabilized soils, asphalt mixtures) have to be validated by, both, adequate laboratory devices / instruments (oedometer) and “in situ” sampling.

b) Adequate rheological modeling for large variety of layer by layer soil’s compaction roads, in stabilized regime of forced vibrations is linear viscoelastic, Voigt-Kelvin.

c) The vibration amplitude curves, for soil compaction by changing rigidity at each pass on the same layer, evidence the compaction rate that directly depends on the increase of technological amplitude once the resonance frequency do increase.

d) The family of curves, amplitude – frequency for constant rigidity and discrete variable damping, points out that each dynamic compaction pass on the same road layer generates an increase of damping while the compaction rate gets higher, for constant rigidity limited by the type of soil.

Comparing to all the above mentioned, the overall conclusion is that the parametric analysis of the vibratory roller – road’s soil interaction, in the process of dynamic compaction process evidences significant rheological behaviors with high impact on final results of sustainable road construction.

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CERCETĂRI ASUPRA PROCESULUI DE COMPACTARE PRIN VIBRARE A STRUCTURILOR RUTIERE

Rezumat: *Articolul evidenţiază rezultate preliminare ale cercetărilor asupra procesului de compactare prin vibrare a pământurilor pentru realzarea de structuri rutiere sustenabile. Pentru ca acest proces să fie eficient, trebuie determinate apriori caracteristicile pământului de compactat iar, în acest sens, compresibilitatea este una dinre caracteristicile fundamentale. A fost proiectat un dispozitiv inovativ pentru aplicarea sarcinilor de încărcare la încercarea în edometru, dispozitiv care permite încărcarea probelor cu minim de efort şi prelucrarea complexă a rezultatelor. Cercetările efectuate in situ au considerat pământul având comportare reologică tip viscoelastic, căreia i se asociază modelul Kelvin-Voigt. Datele experimentale au fost prelucrate, iar rezultatele obţinute pot fi utilizate pentru realizarea unui proces optim de compactare prin vibrare. În scopul construirii de structuri rutiere durabile s-a realizat un plan de control adecvat pentru România.*

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