TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 63, Issue III, Septembre, 2020

ANALYSIS OF THE MODIFICATION OF THE MODAL FREQUENCIES OF RESONANCE ACCORDING TO THE ELASTIC CHARACTERISTICS OF THE LAND AT VIBRATION COMPACTION FOR ROAD STRUCTURES

Cornelia – Florentina DOBRESCU

Abstract: *This paper presents the elastic characteristics of the composite road structures composed of proportionate mixtures of clay, gravel, sand with a direct influence on the resonant frequencies for the vibratory-land roller system. Thus, for four categories of land, defined by proportionate compositions, there has been determined the rigidity on a vibration-excited trial device. In this case, there have been determined the k* dynamic stiffnesses which were subsequently converted into dynamic stiffnesses k for the compactor vibrating roller.*
For a four degree of freedom compaction item of equipment, in the case of the CVA10 vibrating roller, there have been established the resonant frequencies related to the functional excitation frequency of the vibrator.
Key words: *resistance modulus, land dynamic rigidity, modal frequencies of vibration, vibration technological regime composite land*

.1. INTRODUCTION

The elastic characteristics of the land are determined with a trial dynamic device that has a 0.3 x 0.3 m contact plate and an electrodynamic exciter with variable frequency from zero to 500 Hz.

Based on the experimental conditions in the field, reaching the resonance regime, the dynamic rigidity k^* is determined corresponding to the contact surface with S^* area.

The value of the rigidity that corresponds to the vibrating roller in contact with the land for S area emerges based on the elastic deformations relations specific to the analyzed field.

In this context, four categories of soil (lands) were established for which the elastic parameters k and E were determined, corresponding to the vibrating roller system - land.

Based on the dynamic analysis of the CVA10 vibrating compactor, using the experimental elastic parameters, the resonance frequencies were established.

Eventually, assessments can be made on the modification of the four resonance frequencies of the own vibration modes, with practical conclusions necessary to establish the vibration regime. [1, 2, 3, 4]

2. THE PARAMETRIC VALUES OF THE ELASTIC CHARACTERISTICS OF THE LAND

In order to assess the elastic parametric dimensions of land it was taken into account the rheological behavior during vibration. Thus, the mechanical models analyzed and frequently used in the rheological analysis of the roller-vibrator land system highlight the following properties with major weight in the following order: elasticity, viscosity, plasticity and hysteretic amortization.

The complex models used in the analysis of the dynamic behavior of soils are: Voigt-Kelvin, Zener, Maxwell, Bathelt, Hartman, Bouc-Wen. [5, 6, 7, 8, 9]

The effective working pressure at the vibrator roller-land contact is within (0,5 ÷ 1,5) daN/cm^2 range of values and the technological vibrations with the amplitude of (0.25 ÷ 1.5) mm are the essential factors in achieving the dynamic compaction process.

Taking into account the behavior at reversible elastic deformations of the vibrating roller-land with the S contact surface (contact footprint), the k land rigidity can be written as follows:

$$k = SC_z \tag{1}$$

For the rectangular contact area assimilated with a rectangular plate, the C_z uniform elastic contraction coefficient can be expressed as:

$$C_z = \alpha \frac{E}{1-\nu^2} \frac{1}{\sqrt{S}} \tag{2}$$

where α is the influence coefficient of the geometry of the plane contact area;

E – the dynamic elasticity (resistance) modulus of soil;

S- the area of the contact surface between the roller and the soil;

ν – Poisson's coefficient.

Rigidity k^* is experimentally determined, corresponding to the S^* area contact surface, using the rectangular contact plate dynamic device, with dynamic resonance excitation, can be calculated as follows:

$$k^* = \alpha \frac{E}{1-\nu^2} \sqrt{S^*} \tag{3}$$

Rigidity k of the soil underneath the vibrating roller, corresponding to the S area real contact surface, in dynamic regime, is given by the relation

$$k = \alpha \frac{E}{1-\nu^2} \sqrt{S} \tag{4}$$

From relations (3) and (4) there emerges the calculating formula for the operational dynamic rigidity of the land (soil) under the compactor vibrating roller, as follows

$$k = k^* \sqrt{\frac{S}{S^*}} \tag{5}$$

The dynamic elasticity (resistance) modulus or the Young E modulus results from relation (4) as

$$E = k \frac{1-\nu^2}{\alpha\sqrt{S}} \tag{6}$$

For the dynamic trial device with the area S^*=0,09 m^2 and coefficient α = 0,95, as well as for the real roller-land contact surface S = 1 m^2 there were determined the elastic characteristics given in Table 1. Poisson's coefficients, for each category of land, are presented in table 1. [1, 2, 10, 11, 12, 13]

Table 1

No.	**Composite soil**	**Elastic parameters**		**Poisson' s coefficient**
		Rigidity, MN/m		**Dynamic resistance**
		k*	***k***	***E***	***ν***
1.	Slightly cohesive soil (40%) containing sand (30%) sorted gravel (3 ÷ 7) mm (30%)	13.2	44.00	37.00	0.450
2.	Slightly cohesive soil (30%), fine clayey sand (20%), sorted gravel (7 ÷15) m, m (50%)	20,25	67,50	55,30	0.458
3.	Greasy clay (30%), sorted gravel (7÷15) mm (30%), clayey fine sand (40%)	27.00	90.00	74.70	0.460
4.	Greasy clay (30%), sorted gravel (7÷15) mm (30%), clayey fine sand (10%)	36.00	120.00	97.80	0.475

3. MODAL FREQUENCIES FOR THE VIBRATING ROLLER IN INTERACTION WITH THE COMPACTION SOIL

The case study was conducted on a vibrating roller with a mass of 10 t and the maximum rotating disturbance force $F_0 = m_0 r \omega^2$, with the value of 100 kN at the excitation frequency of 50 Hz. The static moment of the vibration system is $m_0 r$ = 1 kgm.

The dynamic structure of equipment is a multibody system with four degrees of dynamic freedom, the inertial, elastic and amortization characteristics being presented in the paper.

Using the dedicated calculation program for RV (Roller Vibration) compactor vibrating rollers where the Table 1 soil rigidity values were used, there were determined the frequencies presented in Table 2. [14, 15, 16, 17, 18, 19]

Table 2

No.	Rigidity k, MN/m	Own frequency (modal), Hz			
1	44.00	2.458	19.369	20.682	26.491
2	67.50	2.468	19.413	22.442	32.341
3	90.00	2.470	19.536	25.195	37.419
4	120.00	2.471	19.428	28.818	42.733

The analysis of the data in table 2 shows that the discrete variation of rigidity, on distinct categories of land, keeps unchanged the first two modal frequencies f_1 and f_2, leading to a slightly increasing variation of the modal frequency f_3 and to a consistent variation of the modal frequency $f_4 > f_3 > f_2 > f_1$.

These values of the (own) modal frequencies are particularly important for the positioning of the compaction technological regime in post-resonance with the excitation frequency $f = \frac{\omega}{2\pi} > f_4$.

4. CONCLUSIONS

The assessment on experimental bases of soil rigidity for road structures emphasizes the influence of proportions (dosages) of the component materials (clay, gravel, sand) and Poisson's coefficient on the dynamic resistance modulus and on the dynamic rigidity of the soil layer subjected to the compaction process.

a) In the process of dynamic compacting with vibrating rollers, the dynamic resistance modulus and the dynamic rigidity changes after each pass, so that after a number of 4-6 passages, the variation of the specified parameters is significant with relative increases from 10% up to 80% of the initial values. [20, 21, 22, 23]

b) The research carried out on layers with a thickness of 0.4-0.5 m, from four categories of mixed soils, with controlled dosages, showed that the modulus of resistance and rigidity are dependent both on the composition of the soil, on the Poisson's coefficient as well as the area of the contact surface between the vibrating roller and the land. [24, 25, 26]

c) Based on the experimental values as well as on the parameters of the vibrating roller, table 1 presents the modulus of resistance and the rigidity of the soils for four distinct categories. It is found that the higher the percentage of clay, and the quantity of the gravel has a significant weight, the dynamic rigidity increases significantly.

d) The discrete variation of the dynamic rigidity, according to the data in table 1, enabled the assessment of the modal resonance frequencies for a vibrating roller with four degrees of freedom. [27, 28, 29]

Thus, it is found that in table 2 the own modal frequencies of the first and second order, that is f_1 and f_2 remain unchanged at the discrete variation of rigidity, while the modal own frequencies of the third and fourth order that is f_3 and f_4 change significantly.

In this case, it results that the assurance of the technological vibration regime in post resonance is conditioned by the discrete variation of rigidity.

For a quality compaction there must be correlated the discrete variation of rigidity with the last modal frequency so that $f_4 < \frac{\omega}{2\pi}$, where ω is the pulsation of the disturbing force with harmonic excitation of the vibrating roller. [13,14,16,18,19,20,21]

5. REFERENCES

[1] Bratu, P., *Evaluation of the dissipated energy for viscoelastic and hysteretic soil systems for road works.* Test Report for Bechtel company – „Transilvania Highway" Romania.

[2] Bratu, P., *The behavior of nonlinear viscoelastic systems subjected to harmonic dynamic excitation*, The 9th International Congress on Sound and Vibration, University of Central Florida Orlando, Florida, 8 – 11 July, (2002)

[3] Bratu, P., *Dynamic analysis in case of compaction vibrating rollers intended for road works*, The 17tg International Congress on Sound& Vibration, ICSV, Cairo, 18-22 July, (2010)

[4] Bratu, P., Stuparu A., Popa S., Iacob N., Voicu O., *The assessment of the dynamic response to seismic excitation for constructions equipped with base isolation systems according to the Newton-Voigt-Kelvin model*, Acta Tehnica Napocensis, series: Applied Mathematics, and Engineering, Vol 60, Issue IV, November, pp. 459-464, (2017)

[5] Bratu, P., *Dynamic Stress Dissipated Energy Rating of Materials with Maxwell Rheological Behaviour*. Applied Mechanics and Materials Vol 801 (2015) pp 115-121, Doi:10.4028 wwwscientific.net/AMM.801-115

[6] Bratu, P., *Dynamic response of nonlinear systems under stationary harmonic excitation*, Non-linear acoustics and vibration, 11th International Congress on Sound and Vibration, 2767-2770, St. Petersburg, 5 - 8 July, (2004)

[7] Bratu, P., Stuparu A., Leopa A., Popa S., *The dynamic analyses of a construction with the base insulation consisting in anti-seismic devices modeled as a Hooke-Voigt-Kelvin linear rheological system*, Acta Tehnica Napocensis, series: Applied Mathematics, and Engineering Vol 60, Issue IV, pp. 465-472, November (2018)

[8] Bratu, P., Stuparu A., Popa S., Iacob N., Voicu O., Iacob N., Spanu G., *The dynamic isolation performances analysis of the vibrating equipment with elastic links to a fixed base*, Acta Tehnica Napocensis, series: Applied Mathematics, and Engineering Vol 61, Issue I, March, pp. 23-28, 2018;

[9] Bratu, P., *Hysteretic Loops in Correlation with the Maximum Dissipated Energy, for Linear Dynamic Systems*, Symmetry 2019, 11, 315; doi:10.3390/sym11030315

[10] Bratu, P., Dobrescu, C. F., *Dynamic Response of Zener-Modelled Linearly Viscoelastic Systems under Harmonic Excitation*, Symmetry **2019**, 11, 1050; doi:10.3390/sym11081050

[11] Bratu, P., *Dynamic Stress Dissipated Energy Rating of Materials with Maxwell Rheological Behavior, Applied Mechanics and Materials*, Vol.801, pp 115-121, DOI: 10.4028/www.scientific.net/AMM.801.1 15, (2015)

[12] *Test report for laboratory and "in situ" tests. Transylvania Highway, Bechtel Romania*, 2008. Developed and issued by ICECON Bucharest

[13] *Test report for laboratory and "in situ" tests for the Lugoj-Deva highway*, 2015. Developed and issued by ICECON Bucharest

[14] Bratu P., Buruga A., Chilari O., Ciocodeiu A., I., Oprea I., *Evaluation of the Linear Viscoelastic Force for a Dynamic System (m, c, k) Excited with a Rotating Force*, RJAV vol 16 issue 1/2019

[15] Dobrescu C., F., *Analysis of the dynamic regime of forced vibrations in the dynamic compacting process with vibrating roller*, Acta Technica Napocensis - Applied Mathematics, Mechanics and Engineering, Vol 62, No 1 (2019)

[16] Dobrescu C. F., *Highlighting the Change of the Dynamic Response to Discrete Variation of Soil Stiffness in the Process of Dynamic Compaction with Roller Compactors Based on Linear Rheological Modeling*, in: Herisanu N., Marinca V. (Editors), Applied Mechanics and Materials, vol. 801: Acoustics & Vibration of Mechanical Structures II, 350

page., (ISBN 978-3-03835-628-8), page. 242-248, [ISI Web of Science (WoS)], disponible at doi: 10.4028/www.scientific.net/AMM.801.242, (2015)

[17] Dobrescu C.F., Brăguţă E., *Optimization of Vibro-Compaction Technological Process Considering Rheological Properties*, Proceedings of the 14th AVMS Conference, Timisoara, Romania, May 25–26, 2017, Springer Proceedings in Physics 198, Nicolae Herisanu, Vasile Marinca Editors, pp 287-293, ISSN 0930-8989 ISSN 1867-4941 (electronic) Springer Proceedings in Physics ISBN 978-3-319-69822-9 ISBN 978-3-319-69823-6 (eBook) https://doi.org/10.1007/978-3-319-69823-6.

[18] Morariu-Gligor R., M., Crisan A., V., Şerdean F., M., *Optimal design of a one-way plate compactor*, Acta Technica Napocensis Series: Applied Mathematics, Mechanics, and Engineering Vol. 60, Issue IV, pp. 557-564, November (2017)

[19] Mooney, M.A., Rinehart, R.V. *Field Monitoring of Roller Vibration During Compaction of Subgrade Soil*, Journal of Geotechnical and Geo environmental Engineering, ASCE, Vol. 133, No. 3, pp. 257–265, (2007)

[20] Mooney, M.A., Rinehart, R.V., *In-Situ Soil Response to Vibratory Loading and Its Relationship to Roller-Measured Soil Stiffness*, Journal of Geotechnical and Geo environmental Engineering, ASCE, Vol. 135, No. 8, pp. 1022–1031, (2009)

[21] Vucetic, M., Dobry, R., *Effect of Soil Elasticity on Cyclic Response,* Journal of Geotechnical engineering, Vol.117, No. 1, pp. 89 – 107, (1991)

[22] Wersäll, C., Larsson, S., Bodare, A., *Dynamic Response of Vertically Oscillating Foundation at Large Strain*, Proceedings of the 14th International Conference of the International Association for Computer Methods and Advances in Geomechanics, Kyoto, Japan, pp. 643 – 647, 22 – 25 September (2014)

[23] Wersäll, C., Larsson, S., Ryden, N., Nordfeld, I., *Frequency Variable Surface Compaction of Sand Using Rotating Mass Oscillators*, Geotechnical Testing Journal, Vol. 38, No. 2, pp 1 – 10, (2015)

[24] *Test report for laboratory and "in situ" tests for the Timişoara-Lugoj highway*, 2016. Developed and issued by ICECON Bucharest

[25] Bratu, P. *Elastic systems vibrations*, Ed. Tehnică, Bucharest, Romania, 2000

[26] Bratu, P.*, Elastic structures analysis*, Ed Impuls, Bucharest, Romania, 2011

[27] Wersäll, C., Nordfeld, I., Larsson, S.*, Soil Compaction by Vibratory Roller with Variable Frequency*, Submitted to Geotechnics for Sustainable Infrastructure Development – Geotec Hanoi (2016)

[28] Yoo, T – S., Selig, E., T., Dynamics of Vibratory Roller Compaction, Journal of the Geotechnical Engineering Division, Vol. 105, No.10, pp, 1211 – 1231, (1979)

[29] *Test report for laboratory and "in situ" tests performed on the road layers of the Bucureşti-Constanța highway*, 2004. Developed and issued by ICECON Bucharest

Analiza modificării frecvențelor modale de rezonanță în funcție de caracteristicile elastice ale terenului la compactarea prin vibrare pentru structuri de drumuri

Rezumat: În lucrare se prezintă caracterisitcile elastice ale structurilor rutiere compozite alcătuite din amestecuri proporționate din argilă, pietriș, nisip cu influență directă asupra frecvențelor de rezonanță pentru sistemul rulou vibrator-teren.

Astfel, pentru patru categorii de teren, definite prin compoziții proporționate a fost determinată rigiditatea pe un dispozitiv de probă excitat în regim de vibrații. În acest caz, au fost determinate rigiditățile dinamice k^* care apoi au fost convertite în rigidități dinamice k pentru rulou vibrator compactor.

Pentru un echipament de compactare cu patru grade de libertate, în cazul ruloului vibrator CVA10, au fost stabilite frecvențele de rezonanță raportate la frecvența funcțională de excitație a vibratorului.

Cornelia – Florentina DOBRESCU, Eng., PhD, NIRD URBAN—INCERC, Research and Testing for Geotechnics and Construction Foundations Department, icecon@icecon.ro, Bucharest, Romania