The Influence of The Rigidity of The Compacted Soil on The Dynamic Regime of The Vibrating Rollers for Road Works

Cornelia – Florentina DOBRESCU
NIRD URBAN – INCERC, Bucharest, Romania; corneliadobrescu@yahoo.com

Abstract: - This paper presents the modification of the technological vibration regime when compacting composite road structures. These are mixtures of clay, gravel and sand with direct influence on the resonance frequencies for the vibratory roller -ground system. In this context, the dynamic rigidity was determined "in situ" for four categories of land, defined by distinct dosages. For a 10t mass compaction equipment and a 2t vibrating roller, the resonance frequencies and the excitation frequency of the vibrator were set as technological parameter.

Keywords: - dynamic rigidity, composite soils, resonance frequencies, technological vibrations

1. INTRODUCTION

The elastic characteristics of composite soils for roads are measured under experimental conditions in the field, reaching the resonance regime. The value of stiffness corresponding to the vibrating roller in contact with the ground is experimentally established based on the elastic deformations in resonance regime.

In this context, four categories of soils were analyzed for which the elastic parameters *k* and *E* were determined, corresponding to the vibrating roller - ground system, using the experimental elastic parameters, in resonance regime.

Thus, assessments can be made on the resonance frequency for the technological vibration regime. [1, 2, 3, 4]

2. THE EXPERIMENTAL ELASTIC CHARACTERISTICS OF THE SOIL

The assessment of the elastic parametric quantities of the soils was made based on the rheological behavior. The dynamic models analyzed and frequently used in the rheological analysis of the of the vibrating-roller – ground system points out the following properties: elasticity, viscosity, plasticity and hysteretic amortization. The following models are used in the analysis of the dynamic behavior of soils: Voigt-Kelvin, Zener, Maxwell, Bouc-Wen. [5, 6, 7, 8, 9]

At the vibrating roller – ground contact, pressure is within the range of values (0.5÷1.5) daN/cm^2, and the technological vibrations with the amplitude of (0.25÷1.5) mm determine the dynamic compaction process.

The behavior at reversible elastic deformations of the vibrating roller-ground with the contact surface *S*, determines the rigidity of the soil as:

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

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

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

E – soil dynamic elasticity modulus (resistance);

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

ν – Poisson's coefficient.

The experimentally determined rigidity *k**, corresponding to the contact surface with the *S** area using the dynamic experimental field device with rectangular contact plate, with dynamic excitation in resonance is determined in the form:

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

Rigidity *k* of the dynamic ground-vibrating roller system, corresponding to the real contact surface with the *S* area, in dynamic regime, is calculated in the formula

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

Relations (3) and (4) trigger the land rigidity (soil) underneath the compactor vibrating roller, as follows

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

The dynamic elasticity modulus or the Young E modulus emerges from relation (4) in the form

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

For the dynamic trial device with the area S^*=0.09 m^2 and the coefficient α = 0.95, as well as for the real roller-ground contact surface S = 1 m^2 the elastic characteristics shown in table 1 were determined. Poisson's coefficients, for each category of land, they are presented in table 1. [1, 2, 10, 11, 12, 13]

Table 1

No.	Composite soil	Elastic parameters: Rigidity, MN/m		Elastic parameters: Dynamic resistance modulus MPa	Poisson' s coefficient
		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. FUNCTIONAL RESONANCE FREQUENCY FOR THE ROLLER VIBRATOR-LAND SYSTEM

The case study was performed on a 10t mass vibrating roller and the maximum rotating disturbing 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 the equipment is a multibody system with four degrees of dynamic freedom, the inertial, elastic and amortization characteristics being presented in the paper.

Using the calculation program dedicated for compacting vibrating rollers RV (Roller Vibration) where there were used the values of land rigidity in table 1, the functional post-resonance frequency in table 2 was determined. [14, 15, 16, 17, 18, 19]

Table 2

No.	Rigidity k, MN/m	Resonance frequency f_r, Hz
1.	44.00	26.491
2.	67.50	32.341
3.	90.00	37.419
4.	120.00	42.733

From the analysis of the data in table 2 it is found that the discrete variation of rigidity, on distinct land categories, highlights a significant variation of the modal resonance frequency f_r. These values of the resonance frequencies are particularly important for the positioning of the technological compaction regime, with the technological excitation frequency $f = \frac{\omega}{2\pi} > f_4$ so that $f > f_r$, where r=1,2,3,4 is a position in Table 2.

4. ANALYSIS OF THE RESONANCE CIRCULAR FREQUENCY MODIFICATION FOR VIBRATORY ROLLERS USED IN ROAD CONSTRUCTION.

For the vibratory rollers type RV5 and type RV10, with a mass of 5t and 10t, respectively, there were performed field tests for four structures categories and there were determined the resonance circular frequencies. It is mentioned that the two vibrating rollers are modelled as dynamic systems with four degrees of freedom so that both analytically and instrumentally, four values of resonance circular frequencies were determined.

In Table no.3 there are presented the values for the vibratory roller type RV5.

Table 3

Stiffness MN/m	Resonance circular frequency, rad/s computational / experimental			
	ω_{n1}	ω_{n2}	ω_{n3}	ω_{n4}
20	24,13	62,22	132,76	161,89
	26,08	63,45	134,15	163,24
30	24,45	62,66	162,29	194,71
	25,82	64,12	163,87	195,86
40	24,61	62,87	187,23	222,82
	26,72	63,92	189,41	225,94
50	24,72	63,01	213,36	352,48
	26,54	64,14	215,41	354,26

In Table no.4 there are presented the values for the vibratory roller type RV10.

The values in both tables are within the limit of 10%, which leads to the fact that the experimental evaluation of the dynamic stiffness in the field corresponds to the accuracy degree required by this category of construction works.

Table 4

Stiffness MN/m	Resonance circular frequency, rad/s computational / experimental			
	ω_{n1}	ω_{n2}	ω_{n3}	ω_{n4}
44,00	15,32	121,70	129,95	166,45
	16,12	123,14	131,25	168,20
67,50	15,46	121,98	141,01	203,25
	16,92	123,56	142,61	205,42
90,00	15,52	122,75	158,31	233,42
	16,98	123,86	159,42	235,26
120,00	15,57	122,07	181,07	268,50
	17,04	123,62	182,91	269,83

5. CONCLUSIONS

Based on the experimental trials of soil rigidity for road structures, it is emphasized the influence of the component materials dosages (clay, gravel, sand) and of Poisson's coefficient on the dynamic resistance modulus and the dynamic rigidity of the soil layer subjected to the compaction process.

a) The dynamic resistance modulus and the dynamic rigidity modify after each pass, so that after a number of 4-6 passes the variation of the mentioned parameters is significant with relative increases from 10% to 80% of the initial values, in the dynamic compaction process. [20, 21, 22, 23]

b) The experimental research carried out on 0.4-0.5 m thick layers, from four categories of soils prepared in mixture, with controlled dosages, highlighted that the resistance modulus and rigidity are dependent on both the composition of the soil, Poisson’s coefficient as well as on the area of the contact surface between the vibrating roller and the ground. [24, 25, 26]

c) The experimental values present the resistance modulus and the rigidity of the soils for four categories of soil.

d) The variation of the dynamic rigidity based on the field trails enabled the assessment of the resonance frequencies for a 10t vibrating roller. [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 own modal frequencies of the third and fourth order, that is f_3 and f_4 change significantly.

It emerges that ensuring the technological vibrations regime in post resonance is conditioned by the discrete variation of rigidity. For a quality compaction the discrete variation of rigidity must be correlated with f_r resonance frequency so that $f_r < \frac{\omega}{2\pi}$, where ω is the pulsation of the disturbing force with harmonic excitation of the vibrating roller for the four categories of soil, that is for r = 1,2,3,4 [13,14,16,18,19,20,21].

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.801.115, (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-Constanţa highway*, 2004. Developed and issued by ICECON Bucharest.