Journal of Engineering Science *Vol. XXVII, no. 2 (2020), pp. 135 - 144*
Fascicle *Architecture, Civil and Environmental Engineering* *ISSN 2587-3474*
Topic *Energy Efficiency and New Building Materials* *eISSN 2587-3482*

DOI: 10.5281/zenodo.3784366
CZU 624.138.22

ASPECTS REGARDING EVALUATION OF COMPACTING PROCESS BY VIBRATION OF ENZYME-STABILIZED SOILS

Eugeniu Braguța[1*], ORCID ID: 0000-0001-9579-1033,
Cornelia - Florentina Dobrescu[2], ORCID ID: 0000-0003-2713-7456

[1]*Technical University of Moldova, 168, Stefan cel Mare Bd., Chisinau, Republic of Moldova*
[2]*National Institute for Research and Development in Construction, Urban Planning and Sustainable Spatial Development, 266 Pantelimon Street, 021652, Bucharest, Romania,*
*Corresponding author: Eugeniu Braguța: *eugeniu.braguta@dmmc.utm.md*

Received: 04. 06. 2020
Accepted: 05. 08. 2020

Abstract. The paper presents, in synthesis, the outcomes of the research on the experimental methods of soil stabilization with ecological substances in order to achieve some stable and durable structures using technological processes of compacting by vibration. Based on laboratory and „*in situ*” tests, there were determined values of soil elasticity taking into account Poisson's coefficient change. Thus, as a result of the modification of the size and content of the enzyme pores in the process of atomized treatment of the soil treated by special mixing, significant variations of the elasticity modules (monoaxial and volume) are produced and of the stiffness coefficient varies in the normal direction of vibration at the soil compaction surface. The effect of unstable soils stabilization using enzymatic solutions is even more significant as the porosity index decreases, Poisson's ratio and the modulus of soil elasticity is increasing.

Keywords: *Rheological model, Elastic modulus, Monoaxial Compression, Enzymes, Stabilized Soil.*

Introduction

The realization of road systems based on stabilized soil, enzymes and natural adding materials is possible only on the basis of an appropriate research program aimed at highlighting the technological stages, the material resources and the dynamic compacting vibration equipment.

The output of the research should highlight consistent, efficient and reproducible results of an assessed method and technology leading to strength increase and stability of road structures.

In this context, this paper highlights the effect of enzymes mixed with natural soil, mineral aggregates and additives to achieve stable and durable structures. As a result, for certain categories of soil with significant and measurable content of clay, mixed with sand and mineral aggregates, with the appropriate treatment of enzyme stabilizers, remarkable experimental outcomes were obtained. Thus, the characteristics of the enzyme-stabilized structures can be defined on the basis of the mechanical strength σ_z of the longitudinal elastic modulus E_z, in the vertical direction, of the modulus of volume elasticity E_v and of the coefficient of stiffness k in the vertical direction [7, 8]. The treatment with atomized enzyme solutions is conditioned by the appropriate dosing, mixing and homogenization by modifying the Poisson's ratio, marked by ν. In this case, by increasing values of ν to the maximum limit $\nu_{max} = 0{,}5$, it is found the increase of the volume elasticity modulus, the increase of the strength and the increase of the rigidity of the achieved structure.

The evolution of the dynamic compaction parameters highlighted by the families of curves, reflects the efficiency of the compaction process of the stabilized soils [9].

Parametric Analyses of Enzyme-Stabilized Soils

Dynamic rigidity

The mineral-aggregate mixture must be provided with the optimal dose of atomized feed, with enzymes or poly-enzymes to occupy the porous spaces.

This reduces the water content of the natural porous network. In this case, the processed material, in the form of enzyme-stabilized soil, must have a porous network with significant enzyme content to increase the Poisson's coefficient and the resistance to the gelling process (freeze-thaw).

Taking into account the elastic deformations for the road structure put into operation at the static compaction, the rigidity can be established with the relation:

$$k = C_z \cdot S \tag{1}$$

Where k is the stiffness coefficient in the elastic domain, C_z the uniform elastic contraction coefficient, corresponding to the S- area of the rectangular contact surface.

The elastic contraction coefficient in static mode, shall be calculated as follows:

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

Where α is the shape coefficient of the contact rectangular surface ($\alpha = 0{,}8 \div 1{,}2$), E_z is modulus of longitudinal (monoaxial) elasticity of the soil, ν *is* Poisson's coefficient. The stiffness coefficient k_s, in static mode, for the real surface S, of rectangular shape (contact flat), between the compactor's roller and the ground (stabilized soil layer) can be calculated as:

$$k_s = \frac{\alpha E_z \sqrt{S}}{1-\nu^2} \tag{3}$$

In the dynamic one-directional vertical regime, at the action of the vibrations guided in the normal direction versus the compaction surface, the elastic volumetric reaction of the deformed soil is expressed by the volume elasticity model E_v, as follows:

$$E_v = E_z \frac{1-\nu}{(1+\nu)(1-2\nu)} \tag{4}$$

In this case, the uniform contraction coefficient in dynamic mode C_z^d, can be written down as:

$$C_z^d = \alpha \frac{E_z}{\sqrt{S}} \frac{1}{(1+\nu)(1-2\nu)} \tag{5}$$

The dynamic stiffness coefficient of the road structure of soil stabilized with enzymes in the technological vibration mode corresponding to the compaction process emerges as:

$$C_z^d = \alpha E_z \sqrt{S} \frac{1}{(1+\nu)^2(1-2\nu)} \quad (6)$$

It is noted that k_s^d parameter increases with respect to the increase of the E_z, S values as well as with the increase of $\nu \in (0,1 \dots 0,5)$.

Centric monoaxial longitudinal elastic modulus

The laboratory experiments are performed on cylindrical samples taken from the stabilized and compacted soil layer. The samples are subjected to quasi-static pressures of centric mono-axial compression at controlled deformation rates, according to the specialized normative documents. In this way, the E_z axial elastic modulus is determined as follows:

$$E_z = \frac{4}{\pi} \frac{F_z}{d^2 - d_0^2} \frac{h_0}{\Delta h} \quad (7)$$

Where F_z is the centrically applied axial force;
d_0 - initial diameter of uncompressed sample;
h_0 - initial height of uncompressed sample;
d - final diameter of the median transversal section after compression;
h - final height remained, of the sample, after compression;
Δh - the variation (compaction) of the sample height where compressive force so that
$\Delta h = h - h_0 < 0$

Thus, on the basis of a samples sufficient number taken from the enzyme-stabilized soil layer compacted with a vibrating roller, the values of the E_z modulus were determined. Depending on the amount of enzyme by mass relative to 100 kg of ground, mixed, compacted soil, that is to e, % percent dose and a clay content % of the total mass, there were obtained the values of the E_z longitudinal elasticity modulus values, presented in table 1.

Table 1

Elasticity modulus E_z, MPa

e, %	0,1	0,2	0,3	0,4	0,5	0,6
$a = 20$ %	5,81	6,50	7,80	8,78	9,15	10,21
$a = 45$ %	37,1	41,6	50,0	56,19	58,56	65,34

Coefficient of Poisson

In the case of the monoaxial compression in the vertical direction with the F_z force, the axial deformation process characterized by the specific deformation $\varepsilon_z = \frac{h-h_0}{h_0} = \frac{\Delta h}{h_0}$ is accompanied by the transverse deformation in the median plane, expressed by $\varepsilon_x = \frac{d-d_0}{d_0} = \frac{\Delta d}{d_0}$, so that $\varepsilon_x = \nu \varepsilon_z$ [4, 6, 7]

Consequently, Poisson's ratio ν may be determined by:

$$\nu = \frac{h_0}{d_0}\frac{\Delta d}{|\Delta h|} \quad (8)$$

The experimental results showed values of ν ranging from 0.400 and 0.485 for the 100 samples taken „in situ” for the specified parametric values of the clay and enzymes dosages specified in Table 1.

Viscous amortization of the enzyme stabilized soil

The c coefficient of viscosity specific to the linear viscous force proportional to the deformation velocity of soil, during the compacting process by vibration, determines the fraction of the critical ξ amortization, as follows:

$$\xi = \frac{c}{2\sqrt{km}} \quad (9)$$

Where: m is the vibrating mass of the compactor.

The (9) relation enables the calculation of the amortization for the discreet variance of the k stiffness after each pass of the vibratory roller.

Parametric measures of the vibratory compactor –stabilized soil system

There are presented physical and mechanical values that define the Voigt-Kelvin rheological calculation model for the dynamic analysis of the compaction process.

Thus, for the $F(t) = m_0 r\omega^2$ perturbator force, the $m_0 r = 5\ Kgm$ and $\omega = (0 \dots 500)$ rad/s static moment assures the dynamic compaction level for a stabilized soil mix with 45 % clay percentage and 3 % enzyme dosage. In this case, the calculation parameters for the case study are presented in table 2.

Table 2

Experimental parameter values

No.	Parameter symbol	Experimental values			
1	$\nu, \%$	0,400	0,450	0,475	0,485
2	E_z, MPa	50	50	50	50
3	S, m^2	0,750	0,750	0,750	0,750
4	$k_z = 10^8\ N/m$	1	2	4	6
5	$\xi, \%$	25,00	17,00	12,50	10,80
6	$c = 10^5\ Ns/m$	5,090	5,000	5,09	5,10
7	$m, 10^3\ kg$	10	10	10	10

Analysis of the Dynamic Parameters of the Compaction Process

The Voigt-Kelvin rheological model is illustrated in Figure 1 and it means that the enzyme-stabilized soil in the dynamic compaction process can be analyzed in the linear viscoelastic domain for each successive step of repeatedly passing the vibrating equipment.

$$m\ddot{x} + c\dot{x} + kx = m_0 r\omega^2 \sin\omega t \quad (10)$$

Where: $x(t) = x$ means the instantaneous movement of the vibrating roller in permanent contact with the surface of the stabilized soil structure.

The differential equation of motion for the model in Figure 1 is:

The solution in stabilized regime, for the compaction technological vibrations, on vertical direction is:

$$x = A\sin(\omega t - \varphi) \quad (11)$$

Where: *A* is the amplitude of the instantaneous movement, φ - the phase shift between the instantaneous movement $x = x(t)$ and the excitation force $F(t) = m_0 r\omega^2 \sin \omega t$.

Out of the condition that the (11) condition is the solution of the (10) differential equation, *A* and φ emerge, as follows:

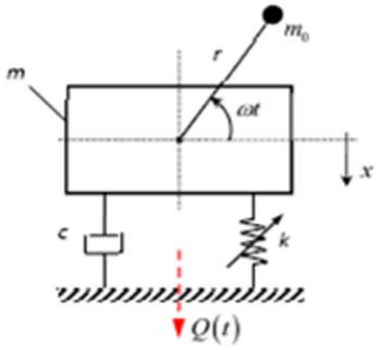

Figure 1. Dynamic calculation model.

$$A = m_0 r\omega^2 \frac{1}{\sqrt{(k - m\omega^2)^2 + c^2\omega^2}} \quad (12)$$

$$\varphi = arctg \frac{c}{k - m\omega^2} \quad (13)$$

The efficiency of the behavior may be considered by assuring the parameters that reflect the dimension of the $Q(t)$ force transmitted to the soil and of the dissipated energy by the W_d viscous component of the soil.

Dynamic force transmitted to soil

The dynamic transmitted force $Q(t)$ may be written down as:

$$Q(t) = kx + c\dot{x} \quad (14)$$

Where: $x = A\sin(\omega t - \varphi)$ and $\dot{x} = A\omega\cos(\omega t - \varphi)$ are inserted. Thus, it is obtained:

$$Q(t) = kA\sin(\omega t - \varphi) + cA\omega\cos(\omega t - \varphi) \quad (15)$$

Considering the (15) relation $Q(t)$ can also be written down as:

$$Q(t) = Q_0 \sin(\omega t - \theta) \quad (16)$$

Where: Q_0 is the force amplitude $Q(t)$, θ dephasing between $x = x(t)$ and $Q = Q(t)$

By identifying the (15) and (16) relations it emerges:

$$\begin{cases} Q_0 \sin\theta = -kA\sin\varphi + c\omega A\cos\varphi \\ Q_0 \cos\theta = kA\cos\varphi + c\omega A\sin\varphi \end{cases} \quad (17)$$

From where we have: $Q_0 = A\sqrt{k^2 + c^2\omega^2}$

or replacing A from the (12) relation, we obtain:

$$Q_0 = m_0 r\omega^2 \sqrt{\frac{k^2 + c^2\omega^2}{(k^2 - c^2\omega^2)^2 + c^2\omega^2}} \quad (18)$$

The de-phasing is obtained from the (17) relations system as:

$$tg\theta = \frac{\sin\theta}{\cos\theta} = \frac{-mc\omega^3}{k(k - m\omega^2) + c^2\omega^2} \tag{19}$$

Dissipated energy in the process of compaction by vibration

The dissipated energy may be calculated with the relation:

$$W_d = \pi c\omega A^2 \tag{20}$$

or considering the (12) relation we have:

$$W_d = \pi c(m_0 r)^2 \frac{\omega^5}{(k - m\omega^2)^2 + c^2\omega^2} \tag{21}$$

Hysteretic loops

The energy dissipated on the cycle is equal to the hysteretic loop area. For the linear Voigt-Kelvin viscoelastic model, the hysteretic loop is an ellipse whose own axis are rotated relative to the chosen reference system.

a) Equation of the *F – x ellipse*

For the forced excitation with $F(t) = F = F_0 \sin\omega t$ and the solution $x(t) = x = A\sin(\omega t - \varphi)$, the equation of the ellipse *F* - *x* is obtained by eliminating the time between function $x(t) = x$ and the trigonometric function $\sin\omega t = \frac{F}{F_0}$, taking into consideration $\cos\omega t = \pm\sqrt{1 - \frac{F^2}{F_0}}$

Thus, we have: $x = A\sin\omega t\cos\varphi - A\sin\varphi\cos\omega t$

Where there are inserted the $\sin\omega t$ and $\cos\omega t$ functions.

In this case, we obtain:

$$\Phi^2 - 2X\Phi\cos\varphi + X^2 - \sin^2\varphi = 0 \tag{22}$$

Where: $\Phi = \frac{F}{F_0}$ and $X = \frac{x}{A}$

From the (22) equation, it emerges $\Phi = \Phi(X)$ thus:

$$\Phi = X\cos\varphi \pm \sin\varphi\sqrt{1 - X^2} \tag{23}$$

Where: $\sin\varphi = c\omega\frac{A}{F_0}$; $\cos\varphi = (k - m\omega^2)\frac{A}{F}$; $\Phi = \frac{F}{F_0}$ and $X = \frac{x}{A}$, Thus by replacing it in the (23) relation we obtain:

$$F = x(k - m\omega^2) \pm c\omega\sqrt{A^2 - x^2} \tag{24}$$

Which represents the equation of the ellipse in the axis system *F- x*.

b) Equation of the *Q – x ellipse*

Force $Q(t) = kx + c\dot{x}$ may be written down as:

$$Q(t) = kx \pm c\omega A\cos(\omega t - \varphi) \tag{25}$$

Where: $\cos(\omega t - \varphi) = \pm\sqrt{1-\sin^2(\omega t - \varphi)} = \pm\sqrt{1-\frac{x^2}{A}}$. In this case, the (25) relation may be written down as:

$$Q(x) = kx \pm c\omega\sqrt{A^2 - x^2} \tag{26}$$

The dissipated energy on cycle is equal to that area of the hysteretic loops. In the case of the *F* - *x* and *Q* - *x* functions, which define the specific ellipses, areas are equal, as follows:

$$W_d = \int_0^T F(x)\dot{x}dt = \int_0^T (Q(x) + m\ddot{x})\dot{x}dt = \int_0^T Q(x)\dot{x}dt \tag{27}$$

because $\int_0^T m\ddot{x}\dot{x}dt = 0$ because $\dot{x}$ and $\ddot{x}$ are orthogonal functions.

Families of Curves Characteristic to the Dynamic Compaction Process

Based on the data from Table 2 and on the calculation relations, the parameterized curves families were drawn by the discreet variance of the dynamic rigidity in accordance with the discrete variance of Poisson's coefficient for the four values.

Figure 2 shows the family of curves of amplitude depending on the continuous variation of the perturbation and the discreet variance of stiffness.Figure 3 shows the variation curves of the maximum force Q_0 transmitted to the stabilized soil layer. The variation curves of the dissipated energy are presented in figure 4.

Ellipses surfaces Q – x are in table 3.

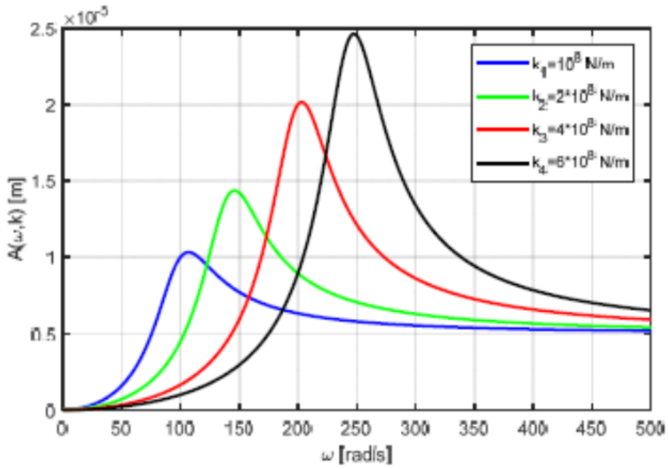

Figure 2. Amplitude variation in relation to ω and k.

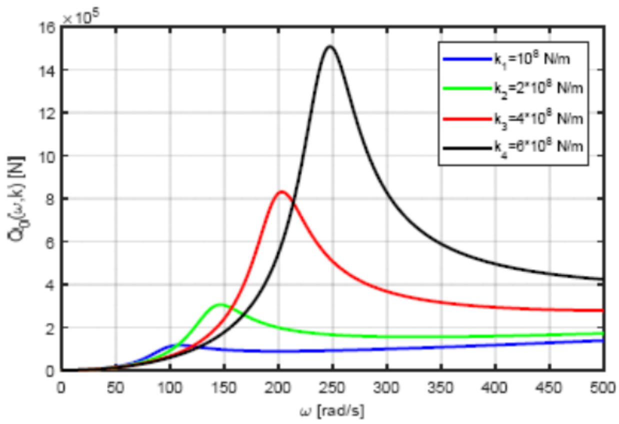

Figure 3. Variation of the maximum force transmitted in relation to ω and k.

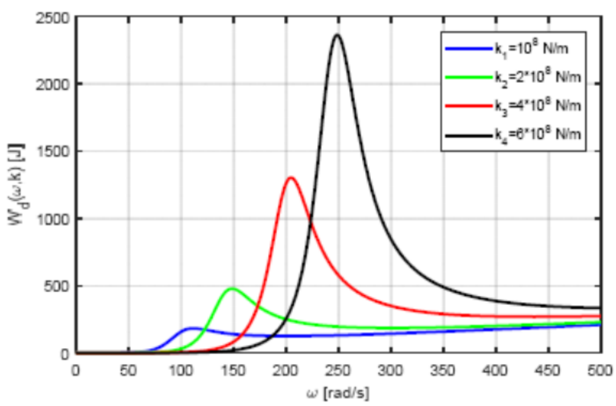

Figure 4. Variation of the dissipated energy in relation to ω and k.

Figure 5 shows the hysteretic *Q* - *x* ellipses for the four distinct situations of the excitation technological pulse.

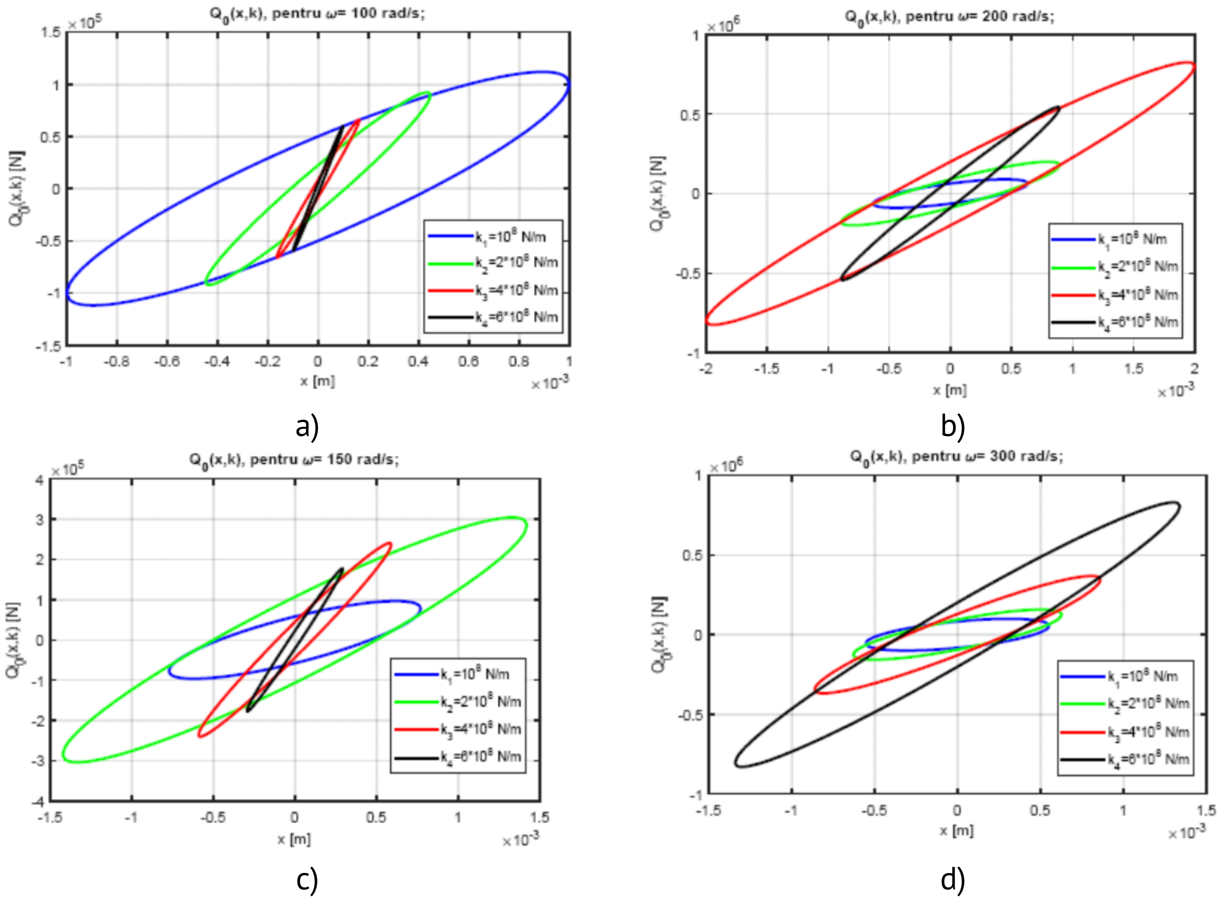

Figure 5. *Q* – *x* Hysteretic Ellipse

a) ω =100rad/s; b) ω =150rad/s; c) ω =200rad/s; d) ω =300rad/s.

Table 3

Experimental parameter values

k [N/m] / ω [rad/s]	10^8	$2\cdot10^8$	$4\cdot10^8$	$6\cdot10^8$
100	157.020408	31.404082	4.243795	1.554658
150	140.279262	476.949489	82.232671	20.382457
200	125.616326	251.232653	1256.163264	251.232653
300	143.984752	196.126630	350.054671	847.910203

After each passing of the compactor in dynamic conditions, the proportionality between compaction degree and dissipated energy corresponding to the increase of hysteretic loop surface while increasing soil stiffness and reducing settlement of the compacted layer has been noted.

Conclusions

The research results revealed the correlation between the degree of compaction for every equipment passing and energy proportionally dissipated with hysteretic loop when the soil is stabilized with natural enzymes brought in atomized state using an ejection system (nozzles) with micrometric level during mixing process.

The effect of unstable soils stabilization using enzymatic solutions is even more significant as the porosity index decreases, Poisson's ratio increase while the modulus of soil elasticity is increasing. In this case, the proper soil stiffness for layer stabilization evidenced by compaction degree increase and settlement decrease is ensured.

Numerical simulation performed in the study by considering Voigt-Kelvin rheological model has conducted to a realistic assessment of soil dynamic response during vibro-compaction process, which can be considered as an important tool to be applied to provide a high quality of engineering compaction works and improvement of design techniques.

The final results revealed the necessary conditions to set a rapid method to be used in verification of in-situ compaction parameters by a proper calibration of the technological tools system so that the hysteresis loop area can directly indicate the degree of compaction, the stiffness of the compacted layer in real time and the energy required in the compaction process.

The methodology will contribute to development of technical applications in compaction of bioactive stabilized soils used in road systems by ensuring durability and greening of performed works.

Reference

1. Al -Tabbaa A., Evans W.C., Stabilization-Solidification Treatment and Remediation: Part I: Binders and Technologies-Basic Principal, Proceedings of the International Conference on Stabilization/Solidification Treatment and Remediation, pp. 367-385, Cambridge, UK: Balkerma, 2005.
2. Andrei S., Introductory remarks: Soil Stabilization, Proceedings of 8th ECSMFE, Helsinki, vol. 3, 1288 pp, 1983.
3. Bejan S., The roller-ground dynamic interaction in the compaction process through vibrations for road construction, Romanian Journal of Transport Infrastructure, Vol. 5, 2016, No. 2, 9p.
4. Bratu P.P., Vasile O., Spanu, G.C., The Analysis of Insulation Systems Based on Hooke-Voigt Kelvin Dynamic Rhelogical Model, Journal of Vibration Engineering & Technologies, Volume 5, pp. 255-26, June 2017.
5. Bratu P., Dynamic parameters optimization for the vibrating siev with two granular material sizing units, working in resonance, Revista de Chimie, 2011, 62 (8), 832.
6. Bratu P., Căpăţână, G., The Linear Viscoelastic Behavior of the Asphalt Mixture to the Haversine Impulsive Dynamic Actions Specific in Road Traffic, RJAV, vol.VII Nr.1, pp.63-65, 2010.
7. Debeleac C., Nastac S., On Non-linear Characteristics Evaluation of Vibratory Tool and Terrain Interaction for Embankment Works, PAMM, Proceedings in Applied Mathematics and Mechanics, Volume 12, Issue 1, pp. 605–606, 2012.
8. Dobrescu C.F., Study concerning bearing assessment of natural and stabilized soils using binders with ecological benefits based on parametric correlations, Romanian Journal of Materials, pp. 296 - 302, 2017.
9. Dobrescu C. F., Braguța E., - Optimization of Vibro-Compaction Technological Process Considering Rheological Properties, Acoustics and Vibration of Mechanical Structures—AVMS-2017, Proceedings of the 14th AVMS Conference, Timisoara, Romania, ISBN 978-3-319-69822-9, ISSN 0930-8989.
10. Fan H., Fan Z., Lu Y., Identification of rheological constitutive relation of engineering material based on overlayer model, Chinese Journal of Rock Mechanics and Engineering, 24(5):768-773, 2005.
11. Ghanbari E., Hamidi A., Improvement parameters in dynamic compaction adiacent to the slopes, Journal of Rock Mechanics and Geotechnical Engineering 7, 2015, pp 233-236.
12. Khan T. A., Taha M. R., Effect of Three Bioenzymes on Compaction, Consistency Limits, and Strength Characteristics of a Sedimentary Residual Soil, Advances in Materials Science and Engineering, 2015.
13. Lewandowski, R., Chorążyczewski, B., Identification of the parameters of the Kelvin–Voigt and the Maxwell fractional models, used to modeling of viscoelastic dampers Computers & Structures, Volume 88, Issues 1–2, January 2010, Pages 1-17.
14. Mainardi F., Spada G., Creep, Relaxation and Viscosity Properties for Basic Fractional Models in Rheology" The European Physical Journal, Special Topics, Vol. 193, pp. 133–160, 2011
15. Marasteanu M. O., Hozalski R., Clyne T. R., Velasquez, R., Preliminary laboratory investigation of enzyme solutions as a soil stabilizer, Minnesota Department of Transportation, Research Services, USA, 2005.

16. Louay N., Mohammad Shadi S., Performance Evaluation of Stabilized Base and Subgase Material, Geosustainability and Geohazard Mitigation, Proceedings of Sessions of Geocongress, pp 1073-1080, 2008.
17. Pințoi R., Bordos R., Braguța E., - Vibration Effects in the Process of Dynamic Compaction of Fresh Concrete. and Stabilized Earth, Journal of Vibration Engineering & Technologies – Vol. 5, No.3, June 2017.
18. Ramasubbarao G.V., Siva Sankar G., Predicting soaked CBR value of fine grained soils using index and compaction characteristics, Jordan Journal of Civil Engineering, 7(3): 354-360, 2013.
19. Rios S., Viana da Fonseca, A., Bangaru, S.S., Silty Sand Stabilized with Different Binders, Procedia Engineering Advances in Transportation Geotechnics 3, The 3rd, International Conference on Transportation Geotechnics, Volume 143, 2016, pp 187–195.
20. Shankar, A., A., Rai, H.K., Mithanthaya, R., Bio-enzyme stabilized lateritic soil as a highway material," Indian Roads Congress Journal, vol. 70, no.2, 2009.
21. Sureka N., Gangadhara, S., Properties of Bio-enzyme Treated Expansive soil, International Journal of Engineering Studies, Volume 2, Number 2, pp. 155-159, 2010.
22. Taha M. R., Taha O.M.E., Influence of nano-material on the expansive and shrinkage soil behavior, Journal of Nanoparticle Research, vol. 14, article 1190, 2012.
23. Ter-Martirsyan Z.G., Ter-Martirsyan A.Z., Sobolev E.S., Vibration of Embedded Foundation at Multi-layered Base Taking into Account Non-linear and Rheological Properties of Soils, Procedia Engineering, vol. 153, pp. 747-753, 2016.
24. Velasquez R.A., Marasteanu M.O., Hozalski R.M., Investigation of the effectiveness and mechanisms of enzyme products for sub-grade stabilization, International Journal of Pavement Engineering, 7:3, 213-220, 2006.
25. Venkatasubramanian C., Dhinakaran G.: Effect of bio-enzymatic soil stabilization on unconfined compressive strength and California Bearing Ratio, Journal of Engineering and Applied Sciences, vol. 6 (5), pp. 295-298, 2011.
26. Vijay R., Suneet K., A review on stabilization of soil using bio-enzyme, International Journal of Research in Engineering and Technology, Volume 3, pp. 75-78, January 2014.
27. Zheng C., Liu, L., Structural Response of Asphalt Pavement under Dynamic Loadings, Journal of the Eastern Asia Society for Transportation Studies, Volume 5, pp. 999-1006, 2003.
28. White D., Thompson, M., Relationships Between In Situ and Roller-Integrated Compaction Measurements for Granular Soils, Journal of Geotechnical and Geoenvironmental Engineering, ASCE, Vol. 134, No. 12, pp. 1763–1770, 2008.
29. Braguța E. The dynamic compaction through vibration of road structures from stabilized soil with organic binders: Ph.D. Thesis. Galati (Romania): Dunarea de Jos" University from Galati, 2018.
30. Bratu P., Braguța E., - Performanțe de rezistență a pământurilor stabilizate cu enzime, în procesul de compactare prin vibrații, CONSILOX - 12, "Știința materialelor oxidice în slujba dezvoltării durabile" 16-20 septembrie 2016, Sinaia, Romania.
31. Dobrescu C. F., Braguța E., - Evaluation of strength and deformation parameters of soil based on laboratory tests, Multi-Conference on Systems & Structures (SysStruc 17) din Universitatea Eftimie Murgu din Reșița 9-11 noiembrie 2017.
32. Rahman, F., Hossain, M. and Romanoski, S. A., Soil stiffness evaluation for compaction control cohesionless embankments, *Geotechnical Testing Journal*, Vol. 31, No. S, pp. 442–451, 2008.
33. Rolling M. P. and Rolling R. R., Geotechnical materials in construction, McGraw – Hill, 1996.
34. Nicolescu, L., Technology of stabilizing grounds, Publishing House Ceres, Bucharest, 1980
35. Nicoară S. V., Contributions to the compaction of porous media in construction retention. PhD thesis. University Politehnica, Timisoara, 2003.
36. Braguta E. Grounds stabilized with organic binders. Journal of Engineering Science, 2020.