Journal of Engineering Science *Vol. XXVII, no. 1 (2020), pp. 43 - 49*
Fascicle *Architecture, Civil and Environmental Engineering* *ISSN 2587-3474*
Topic *Civil Engineering and Management* *eISSN 2587-3482*

DOI: 10.5281/zenodo.3713364
CZU 524.131.5

GROUNDS STABILIZED WITH ORGANIC BINDERS

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Received: 02. 05. 2020
Accepted: 03. 22. 2020

Abstract. The paper presents the enzymatic stabilizers effect on grounds in the compaction process by vibration. It has been intended, by specific rheological modeling of the ground mixtures with organic additives, as well as by laboratory or "in situ" tests, to highlight the increased effect of elasticity longitudinal modulus and volumetric elasticity. Also, based on experiments it was determined the rheological evolution of the bulk modulus in relation to time up to the asymptotic stabilization specific to the final parametric values of the structure resistance and stability. The analytic assessment performed by modeling, as well as the experimental results significantly highlight the enzyme stabilizer effect. Thus, it is distinguished that by the pore size and the enzyme content modification, as a result of the recycled ground dynamic behavior, the Poisson's ratio increases considerably, reaching the value of 0.485. The experimental results confirm the possibility to increase the resistance and stability of ground road structures stabilized with enzymes. In this context, the compaction process by vibrations has to be performed in the optimal dynamic regime for the substantial modification of the material porosity.

Keywords: *Organic additives, longitudinal modulus of elasticity and volumetric elasticity, recycled ground dynamic behavior, enzyme stabilizer, Poisson's ratio.*

Introduction

As a rule, the Earth, as basic or actual building material, does not have the ideal form from the point of view of an engineer in the field. It is known, that this problem is exceeded through different specific procedures to improve soil quality, one of the most important and frequent actions on the soil is the densification being achieved by compaction.

For road structures, while using existing soils, additive materials are necessary, as well as appropriate technologies, in order to obtain the resistance and stability performances at the levels required by normative regulations. In this context, this paper highlights the effect of ground mixed with natural enzymes, mineral aggregates and additive materials. For certain categories of ground with large content of clay mixed with sand and mineral aggregates with an adequate treatment of enzyme stabilizers there were obtained remarkable experimental results.

Thus, the characteristics of the stabilized enzyme structures can be defined being based on mechanical strength σ_z of the vertically longitudinal elasticity modulus E_z, of the volumetric elasticity modulus E_v and rigidity coefficient *k* vertical direction [1].

The presence of enzymes in the mixture of material is remarked, under conditions of corresponding dosing, mixing and homogenization, by modifying the coefficient Poisson, noted with ʋ. In this case, by increasing values of u towards the maxim limit $ʋ_{max}$ = 0,5 it is found the increase of volumetric elasticity modulus, the increase of resistance as well as of the completed structure rigidity [2, 3].

The rigor of the processed stabilized ground structure

During the blending process, the mixture ground-mineral aggregates should assure the optimal dose of supply in atomized condition with enzymes or organic binders that would occupy the porous spaces by decreasing the water content from the natural porous network.

Present technologies with automatic control and computer monitoring are able to arrange a large variety of technical solutions [4, 14].

Therefore, the processed material in the form of stabilized earth with enzyme must have the porous network with high content of enzymes to expand Poisson coefficient and the rising resistance of freezing process (freezing-thaw).

In the field of elastic deformation for the vertically implemented road structure, as a consequence of compaction through vibration, rigidity can be measured as follows:

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

Where k is rigidity coefficient, in the elastic field, C_z is the coefficient of uniform elastic contraction matching to the area S of the contact rectangular surface; for the coefficient of uniform elastic contraction the following relation is implemented [5].

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

Where α is the form coefficient of the real surface, which is materialized through a contact board, with values within the range $0{,}8 \div 1{,}5$.

In regard to „in situ” experiments for a certain ground type, one can use „test plate” with a rectangular surface of area $S^{'}$, which permits the calculation of rigidity coefficient $k^{'}$ for the „test field” with the relation:

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

The rigidity coefficient k for the real surface S of rectangular shape (the contact spot) between the vibrating roller and the stabilized ground layer can be calculated using the formula:

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

From the relations (3) and (4) there can be measured the value of k in relation to the value of $k^{'}$determined experimentally, as follows

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

For the test plate with $S = 4500\, cm^2$ the rigidity coefficient $k^{'}$ for different field categories was experimentally determined under dynamic regime of vibrations of resonance.

Table 1

Experimental values of rigidity k' with the dynamic teste plate

Nature of Stabilized Ground Layer	Rigidity Coefficient k' (MN/m)
Loose sandy soil Gravel (3 ÷ 7) mm with sand	44,0
Loose loamy fine sand Gravel (7 ÷ 15) mm with loamy sand	67,5
Medium grained and light loamy loose sand	90,0
Medium grained sand until the sea	95,6
Gravel (7 ÷ 15) mm with pre compacted ground Clay with compacted ground	120

Modulus of longitudinal elasticity

For a cylindrical sample derived from the stabilized/compacted layer, subjected to the uniaxial compression, according to the national standards the axial elastic modulus E_z is determined as follows:

$$E_z = \frac{4}{\pi}\frac{F_z}{d^2 - d_0^2}\frac{h_0}{\Delta h} \quad (6)$$

Where F_z is the axial force applied centrically;
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 - variation of height (compaction) of the sample under compression force, so that $\Delta h = h - h_0 < 0$

Accordingly, based on 1500 of samples collected from the ground layer stabilized with enzymes and compacted with a vibrating roller, there were determined the values of the modulusE_z.
Regulated by the amount of enzyme mass, reported to 100 kg of milling, mixed, compacted ground, that is at the percentage dose ε, %, were achieved the values of longitudinal elastic modulus E_z given within the Table 2.

Table 2

Modulus E_z depending on the ε

$\varepsilon, \%$	0,1	0,2	0,3	0,4	0,5	0,6
$E_z, MN/m^2$	5,81	6,50	7,80	8,78	9,15	10,21

Coefficient of Poisson

On condition of uniaxial compression under direction Z with the force F_z the process of axial deformation described through specific deformation $\varepsilon_z = \frac{h-h_0}{h_0} = \frac{\Delta h}{h_0}$ is logically accompanied by the transversal deformation from the median plan, expressed by $\varepsilon_y = \frac{d-d_0}{d_0} = \frac{\Delta d}{d_0}$, so that $\varepsilon_y = \nu\varepsilon_z$ [4, 6, 7]

Respectively, the coefficient of Poisson ν may be determined with the relation

$$\nu = \frac{h_0}{d_0}\frac{\Delta d}{|\Delta h|} \tag{7}$$

The experimental conclusions have shown ν values of between 0.42 and 0.485 for the 1500 samples collected „in situ”. Table 3 presents the values of the coefficient of Poisson depending on the percentage does ε of the enzyme stabilizer.

Table 3

Values of the coefficient of Poisson depending on the ε, %

ε, %	0,1	0,2	0,3	0,4	0,5	0,6
ν	0,421	0,442	0,453	0,465	0,475	0,485

Modulus of volumetric elasticity

For fields with large surfaces and wide spaces subjected to vibrations or undulating processed wave unidirectional propagation, the volumetric modulus E_v can be calculated as follows:

$$E_v = E_z \frac{1-\nu}{(1+\nu)(1-2\nu)} \tag{8}$$

It is demonstrated that by alteration the porosity and supply of voids with stable fluid like substances, the coefficient of Poisson rises until the limit value $\nu_{max} = 0{,}5$ (so that $\nu < \nu_{max}$) [1, 11].

Modulus of volumetric elasticity E_v during the module E_z and ν, determined experimentally is given in table 4.

Table 4

ModulusE_v depending on modulus E_z and ν

ν	0,421	0,442	0,453	0,465	0,475	0,485
$E_z, MN/m^2$	5,81	6,50	7,80	8,78	9,46	10,21
$E_v, MN/m^2$	14,96	21,83	31,25	45,86	67,26	117,80

The samples taken on layers of ground stabilized with enzymes within the dose $\varepsilon = 0{,}5$ % were used for the purpose of being followed in time. The volumetric elastic modulus dynamic (deformation) measured „in situ” at 35 m from the compaction source through vibration, at certain time intervals, is shown in the Table 5 [3, 8, 12]

Table 5

Volumetric elasticity modulus E_v in time

Time, hours	0	16	24	48	72
$E_v, MN/m^2$	67,5	70,5	96,3	101,8	109

The rheological evolution with regard to time points out a stable asymptotic, as results from the experimental data contained within Table 2. Therefore, the rheological law established by the authors of the present paper is under form [9].

$$E_v(t) = \frac{0877+15t}{0{,}13t+0{,}013} \tag{9}$$

With $E_v(0) = 67{,}46\ MN/m^2$ at the moment *t = 0*. The temporal variable t is expressed in hours.

For the results obtained experimentally, within Figure 1, it appears the curve of variation of the modulus $E_v(t)$ in relation to time.

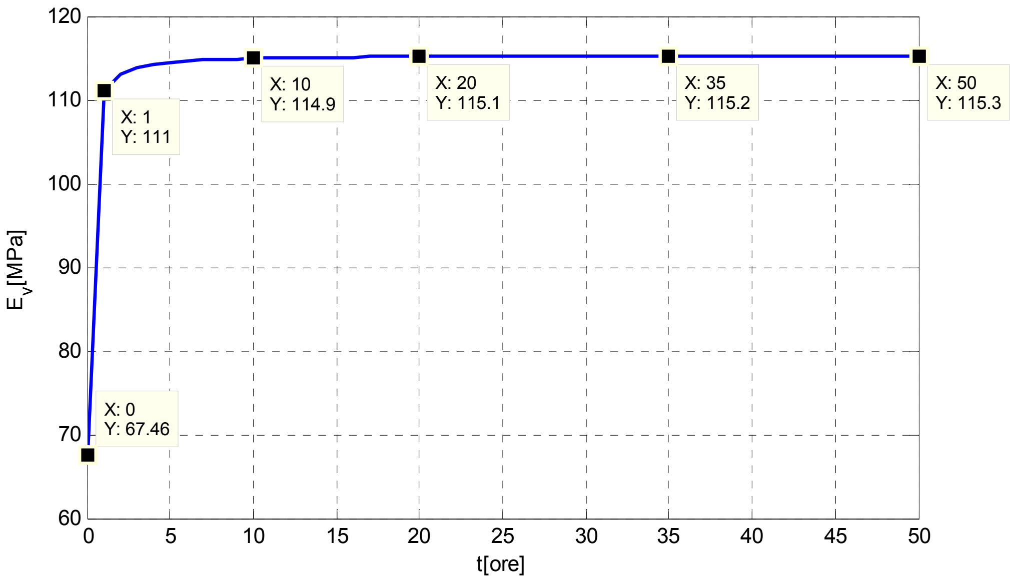

Figure 1. Variation of volumetric elasticity modulus in relation to time.

Californian index CBR

The Californian index of bearing capacity is indicated under the form of $\mathrm{CBR} = \frac{F_p}{F_s}$ for the depth of penetration Δp, where F_p is the effective penetration force, and F_s is the standard force relating to the values Δp =2,5 mm and Δp =5 mm.

For grounds stabilized with enzymes there were obtained the values from Table 6 [8 - 15].

Table 6

Index CBR, % for stabilized ground

Sample Lot	Average Value of the Effective Penetration Force	$CBR_{2,5}$, Δp = 2, 5 mm F_s = 13, 2 KN	CBR_5, Δp = 5 mm F_s = 20, 0 KN
I	8,3	63	-
	11,0	-	53
II	7,5	56	-
	9,2	-	46
III	7,8	58	-
			Continuation Table 6
	9,3	-	46
IV	9,45	71,5	-
	13,11	-	66
V	Index CBR, % for untreated ground		
	3,11	23,55	-
	3,86	-	19,32

Interpretation of experimental results

The experiments performed not only „in situ", but also in the laboratory, aimed to highlight the modification of the parameters of deformability, elasticity and resistance of grounds stabilized with enzymes, based on a permanent procedure, being compared to the same grounds untreated with enzyme stabilizers, that is in the natural state.

a) The modulus of longitudinal elasticity E_z determined at the request of axial compression, corresponding to relation 6, for stabilized grounds, it was evaluated for 1500 samples collected from the layer of stabilized ground for six mass doses ε of stabilizer, as results from Table 2. It is found that as the percentage quantity of stabilizer ε increases, also increases the modulus E_z.
b) The coefficient of Poisson, which experimentally was determined based on relation 7, for stabilized grounds, in the percentage quantities ε of the stabilizer, it is found to be increasing according to Table 3.
c) The volumetric modulus E_v depends not only on the coefficient of Poisson, but also on the modulus E_z Therefore, as the modulus of Poison and the dosage of stabilizer increases, it is found a pronounced increase of the volumetric modulus, according to the date from Table 4.
d) The Californian index CBR, with the experimental results from Table 6, points out values correlated with the volumetric modulus E_v, being mentioned the fact that the values for the ground stabilized are 3 - 4 greater than the case of ground untreated with enzyme solutions.

Conclusions

The issue of stabilizing grounds with enzymes is an efficient opportunity to achieve the road structures by processing „in situ" local grounds, which are made better with mineral aggregates and treated with organic substances.

In this context, it is also inscribed the present work shows not only the theoretical aspect to modify the elasticity modulus by increasing the coefficient of Poisson, depending on the dose of stabilizer, as well as the experimental results obtained „in situ" on the polygon testing and in the laboratory. It is specified the fact that there were accomplished experimental stages „in situ" with equipment of milling, mixture and stabilizer atomization, the deposit of unprocessed ground layers as well as the dynamic compaction through vibration. The experiments consisted to sample the natural ground and the layers of stabilized ground. As well, the dynamic charges from the field permitted the determination of the elastic moduli and rigidities. The capacity of road structure resistance was measured „in situ" by determining the Californian index CBR:

Based on analytical and experimental results the following conclusions can be summarized:

- ✓ The enzyme stabilizers in atomized and homogenous mixture with the natural ground determine the significant modification of resistance, volumetric elastic modulus, coefficient of Poisson and Californian index CBR;
- ✓ The presence of stabilizer with enzymes in the porous structure of grounds leads to significant increases of modulus and Californian index.

As a conclusion, the ecological treatment with enzymes to earth assures the road layers accomplishment from ground with special performances.

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