ASSESSMENT OF THE DYNAMIC SOIL PROPERTIES FOR THE FEM MODEL OF THE LIULYAKOVITSA TAILINGS DAM

Nikolay Kerenchev, Nikolay Milev

Nikolay Kerenchev, Assist. Prof., Ph.D., Dipl.-Ing.; University of architecture, civil-engineering and geodesy – Sofia; Hr. Smirnenski 1; kerenchev@hotmail.com
Nikolay Milev, Assist. Prof., Ph.D., M. Sc.; University of architecture, civil-engineering and geodesy – Sofia; Hr. Smirnenski 1; n.milev@yoda-bg.com

Abstract: Liulyakovitsa tailings dam, located in the central part of Bulgaria is the largest in the Balkans region. The main dam of the facility is about 180 m above the terrain and has a slope of 15^0 on the free side. It is expected that the tailing dam will be build up with another 100 m. Dynamic analyses has been performed to determine the seismic behaviour of the facility. In this paper we concentrate on the soil properties that were need for the 2D dynamic FEM model. Based on data from field geophysical measurements and dynamic triaxial test, initial shear modulus G0, shear modulus reduction and hysteresis damping coefficient D (all as functions of shear deformations) are determined. All basic soil parameters e.g. friction angle, void ratio as well as E-modulus and others are also discussed.

Key words: dynamic soil properties, shear modulus, hysteresis damping, tailings dam

INTRODUCTION

This paper describes a small part of a more general topic related to the seismic reaction of one of the biggest tailings dam in Europe. Part of the topic was assigned to an academic team from the Bulgarian Academy of Sciences (BAS) and the University of Architecture, Civil Engineering and Geodesy (UACEG). Historic data could be found in [1]. For the seismic stability assessment, dynamic analysis should be performed. Such type of analyses is usually done with the help of FEM models. The physical soil properties used in the program solutions are often directly or indirectly obtained. Based on the tailings dam material specifics, such type of parameters are rarely described in scientific and technical literature. One of the parameters to obtain is the E50 Modulus. Other important soil properties are related to shear modulus and its reduction curve, hysteretic damping and its change with the increasing strains. This article will concentrate exclusively on these parameters and the standard physical parameters of the tailings material obtained in laboratory test, for the purpose of FEM modelling. More on the constitutive models parameters is given in [5] and [2]. Figure 1 shows the mixed picture of different layers, based mostly on deposits technology and on-going tests, while figure 2 shows the generalisation of the soil layers for the seismic analysis.

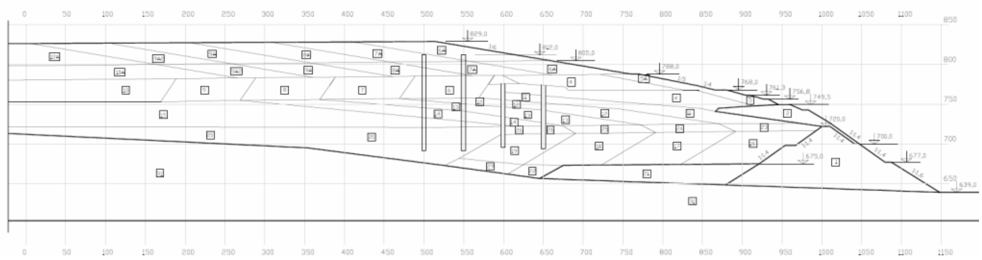

Fig. 1 Soil (tailings dam material) layers, based mostly on deposits technology and on-going tests

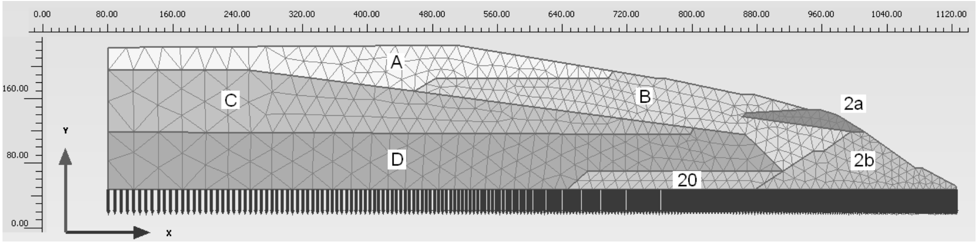

Fig. 2 Generalisation of the soil layers

SHEAR STRENGHT

The paper concentrate on the dynamic parameters, but since the shear strength is also part of the FEM models it is important to show the obtained test results and its implementation in the model. The results are based mostly on triaxial tests and direct shear tests, as well as insitu tests performed as on-going tests. Since the old geotechnical standards and the geologist involved does not treat the dynamic soil properties as important input data, most of the data are regular physical properties and shear tests. Those test are presented as graphs, based on the depth of the samples. Figure 3 shows the data for the friction angle based on the on-going tests.

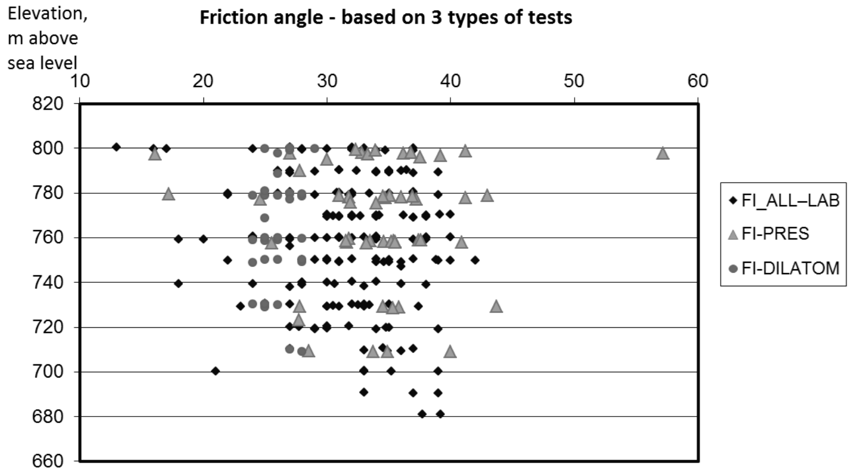

Fig. 3 Friction angle φ (^{0}) for the tailings dam material – laboratory tests, pressuremeter, dilatometer

It is clear that the data are scattered all over the graph. Some tendency for higher friction angle with the depth could be noticed. The scattered laboratory data could be explained with the technology of deposition of the tailings dam material, as well as different sample extraction, preparation and testing. The pressuremeter data have smaller standard deviation. The dilatometer data are always showing the same result. The depth independency could be explained based on the material type and relative equal grain size and consistency. Figure 4 shows the cohesion with depth based on laboratory test and its comparison to the insitu tests.

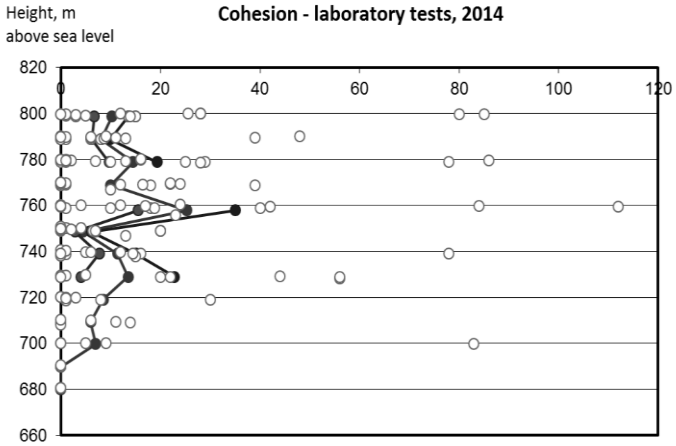

Fig. Cohesion for the tailings dam material – laboratory tests

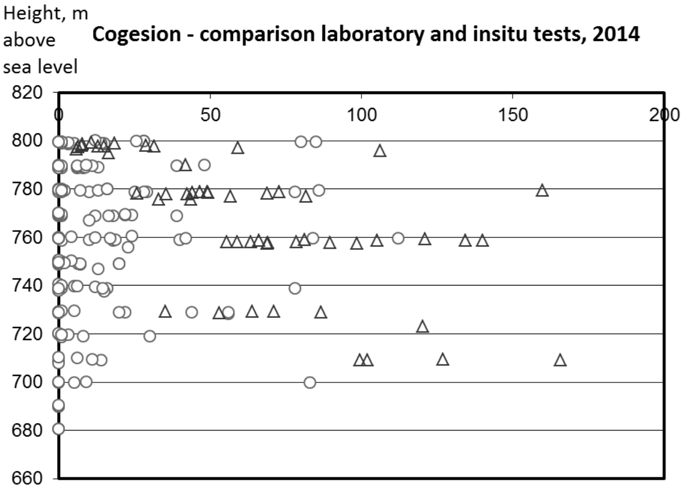

Fig. 5 Fig. Cohesion for the tailings dam material –comparison laboratory tests insitu tests

It is noticeable that the relevant cohesion values are under 20 kPa, based on the laboratory tests, and about 50 based on insitu tests. The insitu tests also shows relation between the cohesion and the depth, which is not the case with the laboratory tests.

E MODULUS

The triaxial tests were conducted only for estimating the shear resistance of the material, based on the old geotechnical concepts. It is still not common in the country to estimate the E50 modulus. Later, more precise model of the material behaviour and the performance of the dam should be made. A team of geotechnical material model experts stepped in. Even that was not enough for precise model solution, but the expectations were reached. E50 modulus is obtained based on the well-known methodology [9] for determining the E50 modulus of the standard triaxial undrained and drained test. Figure 6 and 7 shows the E50 modulus correlation with void ratio and sand percentage.

One of the best-known relations of E50 modulus is the one with the void ratio. Tailings dam materials are not excluded. The logarithmic curve fits best on the scatter and it corresponds to the expectance. These results could be explained with the small strain stiffness nature and the particle distribution of the dense material. In general the value limits are 8000 – 15000 kPa.

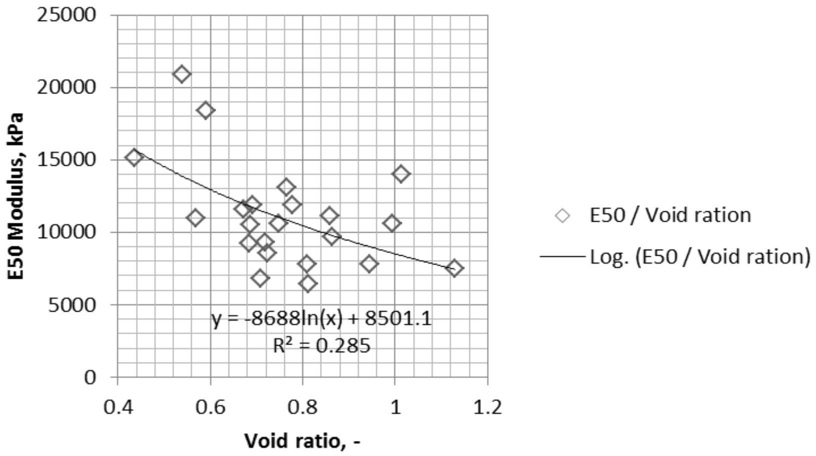

Fig. 6. E50 modulus vs void ratio.

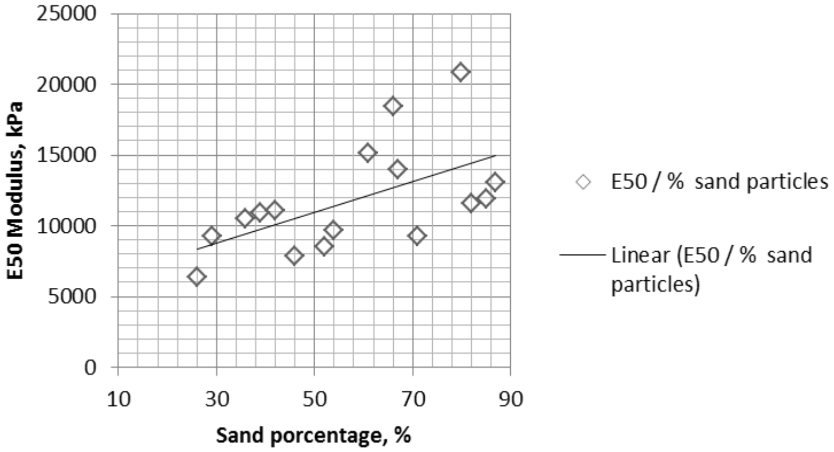

Fig. 7. E50 modulus in vs sand percentage.

It is common that the E50 modulus is important characteristic for granular material behavior and is highly dependent on sand and gravel content. Most of the samples are granular material and consist of sand and silt, whereas gravel and clay are not presented. More on E50 Modulus on tailings dam materials in [2].

DINAMIC PARAMETERS

Disturbed soil samples from the Liulyakovitsa tailings dam are tested in triaxial apparatus in Tokyo [6]. Its natural water content (saturated) is artificially recovered. The density index is recovered to the value of depth 12-33 meters [8]. Physical parameters of the dynamic soil samples are given in Table 1. And the sieving curve is shown on figure 8.

Table 1. Sieving curve of the tailings dam material used for the triaxial dynamic tests

Spec. density	Dry density	Void Ratio	Max. void ratio	Min. void ratio	Density index	Av. Part. Diame-ter	Part. smaller than 75 µm	Uniformity coefficient	Friction angle
ρ_s	ρ_d	e	e_{max}	e_{min}	D_r	D_{50}	F_C	C_U	ϕ
[g/cm^3]	[g/cm^3]	[-]	[-]	[-]	[%]	[mm]	[%]	[-]	[°]
2.73	1.79	0.527	1.200	0.501	96	0.17	7.62	1.89	22.00

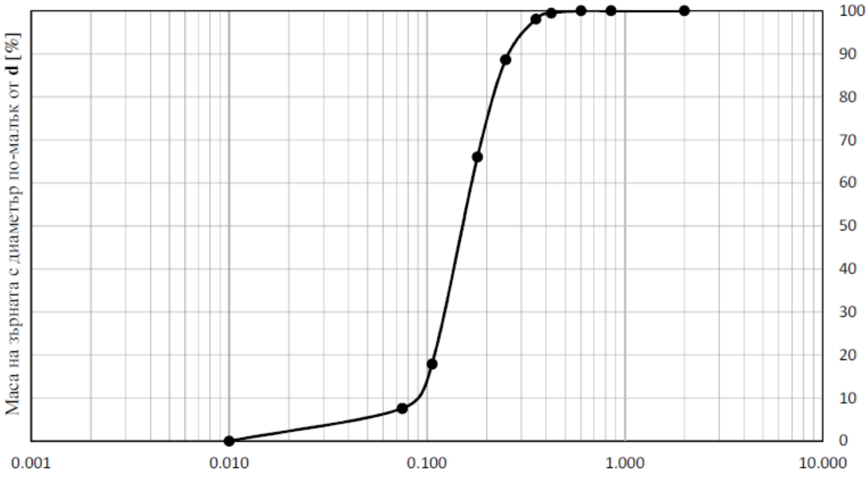

Fig. 8. Sieving curve of the tailings dam material used for the triaxial dynamic tests

INITIAL SHEAR MODULUS AND SHEAR MODULUS REDUCTION CURVE

Determining the initial shear modulus also known as maximal shear modulus is based on trigger and bender elements. The shear reduction curve in the shear deformation zone between 10^{-6} and 10^{-3} are obtained based on the internal deformation transducer and the zone above 10^{-3} based on external displacement transducer. Using the described technique, the apparatus could obtain the shear modulus and the shear modulus reduction curve related to the shear deformation in much wider zone compared to other apparatus. Figure 9 shows the obtained data based on several detection technique.

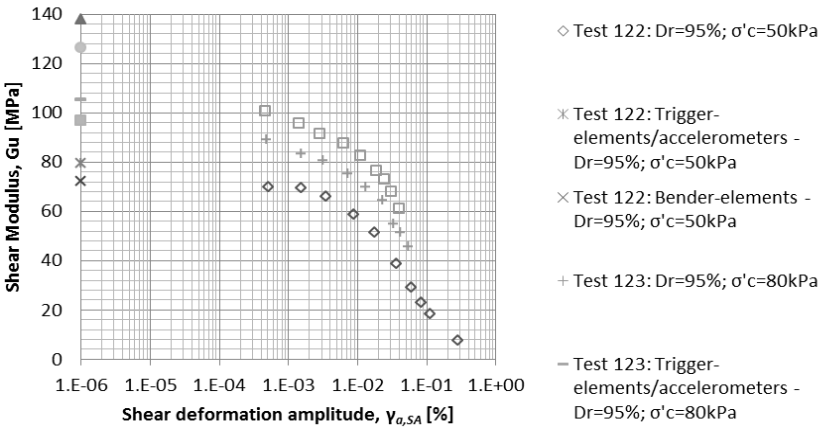

Fig. 9. Initial shear modulus and shear reduction curve

Based on the apparatus "Komaba" for depth between 5-10m the initial shear modulus is G_u = 75-125 MPa for shear deformation $\gamma = 10^{-6}$ %.; G_u = 70 -100 MPa for $\gamma = 10^{-3}$ % and down to G = 20 MPa for $\gamma = 10^{-1}$ %.

Based on the graph above and the well know elasticity formula:

$$G_u = G' = \frac{E_u}{2(1+\nu)} \approx \frac{E_u}{3}, \tag{1}$$

where:

G_u – shear modulus; E_u - modulus of deformation, ν – poisons coefficient;

we could also obtain the E modulus reduction curve, Figure 10.

Base on the ultrasound seismoscope the initial (maximal) shear modulus is about 500 MPa -1400 MPa which even doesn't corresponds to the well-known factor of 2, for the shear modulus investigation based on insitu tests.

DAMPING RATIO

Since the damping ratio is one of the most important parameters for dynamic calculation, some tests are performed. Based on thhose tests the damping ratio for the lower level of shear deformation could not be estimated. Here could help another part of this apparatus or a resonant column tests [3]. Literature data could also be used. We could obtain the lower limit of dampis between 3 and 6 %. Figure 11 show the dampig ratio obtained from the dynimic triaxial tests for the tailings dam material.

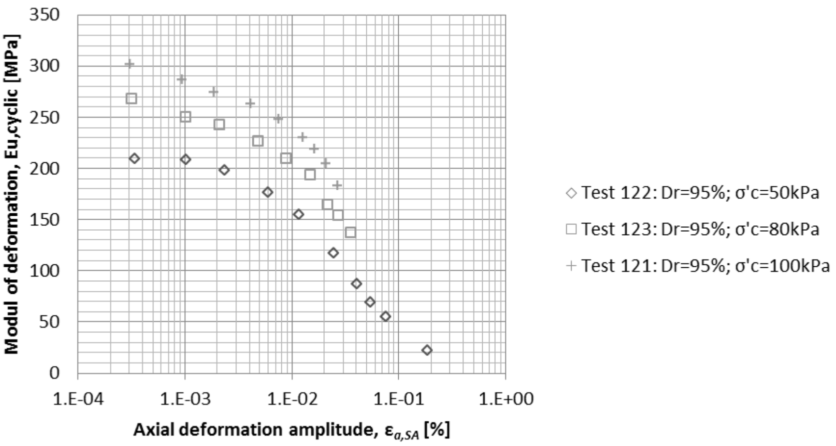

Fig. 10. Modulus of deformation and its reduction curve in respect to axial deformations

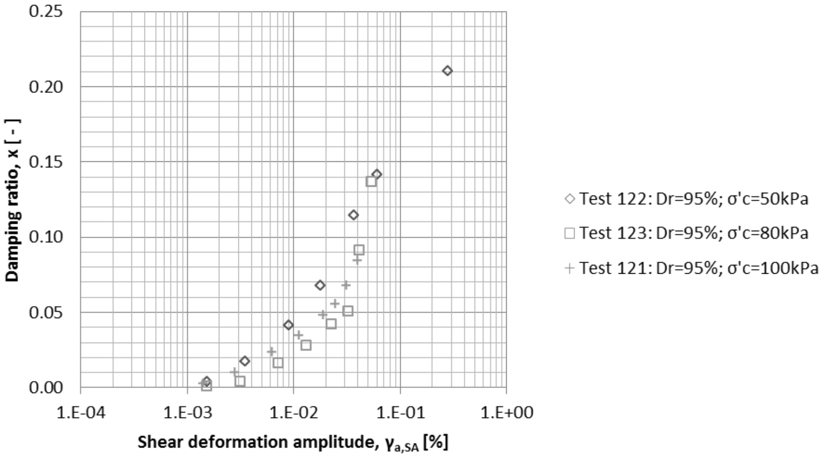

Fig. 11. Damping ration and its values in respect to shear deformations

CORRELATIONS AND DISCUSSION

Based on this data, as well as many standard physical parameters many correlations for the dynamic material properties of the tailings dam are made. Well known correlation is that of Ishibashi & Zhang (1993) [3] ,[4].

$$\frac{G}{G_{\max}} = K\left(\gamma, PI\right)\left(\sigma'_0\right)^{m(\gamma,PI)-m_0} \qquad (2)$$

where:

$$K\left(\gamma, PI\right) = 0,5\left(1 + \tanh\left(\ln\left(\frac{0.000102 + n(\mathrm{PI})}{\gamma}\right)^{0,4}\right)\right),$$

$$m\left(\gamma, PI\right) - m_0 = 0,272\left(1 + \tanh\left(\ln\left(\frac{0,000556}{\gamma}\right)^{0,4}\right)\right).\exp\left(0,0145.PI^{1.3}\right)$$

There is also many other graphical correlation curves for assessing the shear modulus reduction curve. One of the most used is that from [10]. After applying all those relations we obtain the initial shear modulus given in table 3.

Table 3. Initial shear modulus of the tailings dam material used for the model

Layer	**γ_n (γ_r) (kN/m^3)**	**$\sigma'_{m,cp}$ (kPa)**	**$\sigma'_{v,cp}$ (kPa)**	**υ**	**G_0 (kPa)**	**$G_{0,ref}$ (100 kPa) (kPa)**	**φ (°)**	**c (kPa)**
A	19,4 (-)	265,1	410,0	0,35	128 269	78 780	25	10
B	19,5 (-)	477,9	739,0	0,32	206 772	94 575	32	12
C	19,6 (20,4)	730,9	1130,3	0,35	285 725	105 679	27	15
D	20,4 (21,5)	1125,8	1741,4	0,33	403 498	120 246	30	17
2a	20,0	117,0	204,0	0,26	355 035	328 230	38	22
2b	20,0	444,8	778,5	0,26	692 402	328 230	40	22
20	22,0	1043,0	1818,3	0,26	1 060 036	328 230	40	22

Comparison of the values for the shear modulus reduction curve from laboratory tests and correlation based on literature data are shown on figure 12.

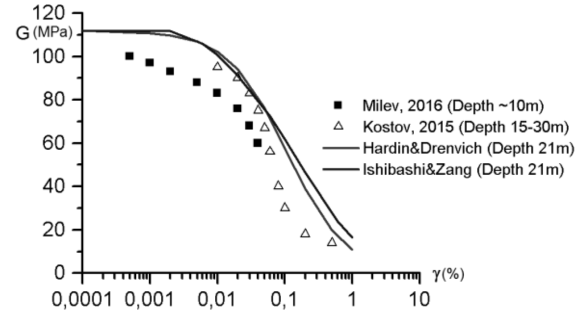

Fig. 12. Verification of the shear modulus - comparison - laboratory tests and correlation layer A

CONCLUSION

Since that was a huge project many other test were also performed. Most oft them not relevant to the actual models calculation. The parameters are used to help estimate the dynamic soil properties for the FEM models.

REFERENCES

[1] *Germanov T.*, MS 1 – Co-report. Limit states (stability, deformation, erosion..), Proc. XIII ECSMGE, Vanicek et al. (eds). CGtS Prague, ISBN 80-86769-02-X, (Vol. 3).

[2] *Kerenchev, N* (2019). ON THE E50 MODULUS OF TAILINGS DAM MATERIALS, 19th International Multidisciplinary Scientific GeoConference SGEM 2019, vol 19, 1.2, Page 399-404, DOI: 10.5593/sgem2019/1.2/S02.051

[3] *Kerenchev, N.* (2015). Analysis of seismic slope stability and deformations. *PhD Thesis (in Bulgarian)*. UACEG, University of Architecture, Civil Engineering and Geodesy, Sofia.

[4] *Kramer, St.,* (1996). Geotechnical Earthquake Engineering, Prentice-Hall

[5] *Mihova, L., Tanev, T.,* (2015). Elastic and elasto-plastic constitutive models in soil mechanics. Annual of the University of Architecture, Civil Engineering and Geodesy, Fascicule IV, Vol. XLVII, Sofia.

[6] *Milev N., Koseki J.*, (2018) STATIC AND DYNAMIC EVALUATION OF ELASTIC PROPERTIES OF SOFIA SAND AND TOYOURA SAND BY SOPHISTICATED TRIAXIAL TESTS, BUILDING MATERIALS AND STRUCTURES 61 (2018) 1 (47-61.

[7] *Milev, N.,* (2019). Experimental Evaluation of Shear Wave Velocity Change Induced by Repeated Liquefaction of Sofia Sand by Undrained Cyclic Triaxial Tests - International Conference on Earthquake Geotechnical Engineering (ICEGE 2019), Rome (Italy).

[8] *Milev, N.,* (2016). *Soil structure interaction – PhD Thesis (in Bulgarian)*. Sofia: UACEG.

[9] *Schanz T., Vermeer P.A.* (2000), The hardening soil model: Formulation and verification Beyond 2000 in Computational Geotechnics – 10 Years of PLAXIS © 1999 Balkema, Rotterdam, ISBN 90 5809 040 X,

[10] *Vucetic, M., Dobry, R.,* (1991). Effect of soil plasticity on cyclic response. Journal of Geotechnical Engineering, ASCE, Vol. 117. No. 1.