 https://doi.org/10.1051/e3sconf/202015706013

Laboratory and In situ Investigation of Modulus of Elasticity of Foam Concrete

Veronika Valašková[1*] and *Jozef* Vlček[1]

[1] University of Zilina, Faculty of Civil Engineering, Univerzitna 8215/1, Zilina, 010 2, Slovak Republic

Abstract. Foam concrete (FC) is a building material which consists of a combination of cement, water additives and technical foam. This material has some useful advantages such as low density, high stiffness and compression and flexural strength in comparison to the granular fill materials, good thermal resistance or damping potential. It's currently used as a levelling layer for floors or as a sub-base layer of the new pavements or industrial floors or at the road reconstructions and excavations. Because of utilization of the foam concrete is aimed at the horizontal slab-like structures, deformation characteristics such as modulus of elasticity are important for the design of such a layer. High porosity of the final material reaching almost 70% of the volume complicates the determination of the stiffness parameters. Its stiffness is higher in comparison with the conventional granular fill materials but when thin layer is proposed, membrane like behavior influenced by the local imperfections of the material and the geometry can affect the overall stiffness of the compound. This paper presents the firsts attempts to estimate the modulus of elasticity of foam concrete of dry bulk density of 400 kg·m-3 in laboratory and as a derived value from in situ load tests using SOJUZDORNII theory.

1 Introduction

Foam concrete (FC) is a building material which consists of a combination of cement, water additives and technical foam. The basic principle of production is well known for more than 40 years, but over the time, its formula has changed to match the new application requirements. His important component is closed void pores. This material has some useful advantages such as low density, high stiffness and compression and flexural strength in comparison to the granular fill materials, good thermal resistance or damping potential [1-3]. In engineering practice, it's currently used as a levelling layer for floors or as a sub-base layer of the new pavements or industrial floors or at the road reconstructions and excavations.

Research was aimed at the laboratory and in situ testing of the static modulus of elasticity for the selected FC dry bulk density of 400 $kg \cdot m^{-3}$.

* Corresponding author: stepevedy@yandex.ru

2 Compression modulus of elasticity *E* in labo

Static modulus of elasticity *E* is a quantity that describes resistance of an object or material to being deformed elastically when a stress is applied to system. The elastic modulus is defined as a slope of the stress–strain curve in the elastic deformation region. The modulus of elasticity can be calculated as follows:

$$E = \sigma / \varepsilon. \quad (1)$$

σ is a compression stress per unit area and is defined as $\sigma = F / A$. *F* is force and *A* is the cross-sectional area where the force is applied and ε is strain response to stress and is defined as $\varepsilon = \Delta l / l$. Δl is the change in length and *l* is the original length [4].

Overall, six samples were used to determine the modulus of elasticity in compression. Diameter of the samples were 150 mm with the length of 300 mm. For each sample, its weight and contact area were measured. For the testing, basic principles for determination of static modulus of elasticity in compression for concrete were adopted [5]. The middle third of the specimen was considered as an original length *l* (Fig. 1). Vertical displacement at 3 points around the upper and lower boundary of the base *l* was measured so final change Δl can be calculated as a difference in displacement of upper and lower points. Displacements were measured at the end of the loading stage at the moment of quick unloading.

Fig. 1. Compression test of modulus of elasticity.

The specimens were loaded with the vertical force up to 12 kN corresponding to the nominal vertical stress of 679 kPa. This value represents about 2/3 of the typical compression strength of about 1000 kPa. Modulus of elasticity was calculated for the particular loading stage of 3, 6, 9 and 12 kN (Fig. 2). Error values were excluded from the records. These values were caused by the failure of the bond between the measurement rings and the foam concrete walls.

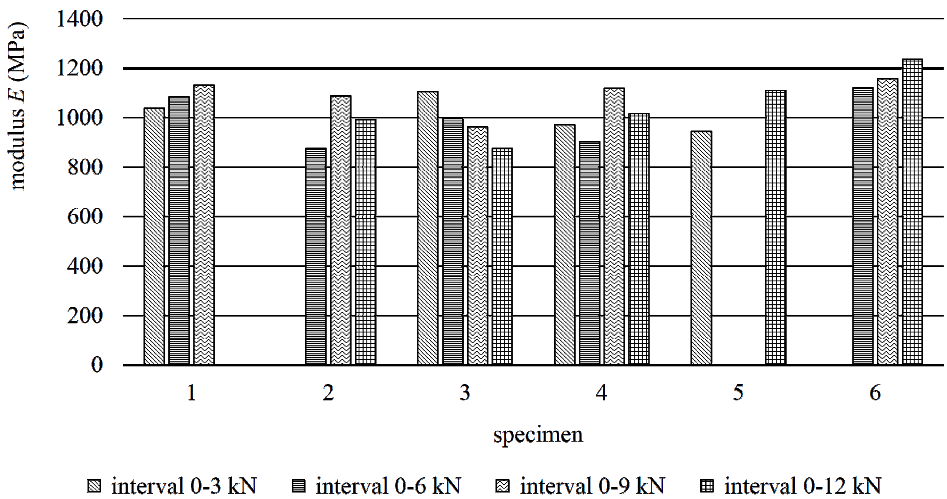

Fig. 2. Results of testing of modulus of elasticity in labo.

Some dispersion of the results can be seen but overall trend is clearly visible when results oscillate around 1000 MPa level. The values that exceed the 20% interval around the average value of 1073 MPa were excluded from the chart 2. Average value of modulus of elasticity from the chart 2 is then 1038 MPa.

3 Modulus of elasticity *E* in situ

A physical modelling at the experimental field was selected as a verified and reliable method for observation of behavior of the examined structure. Together with the computational simulation, it represents the powerful tool not only for research but also for designing of these structures [6,7].

The experimental field represents the sub-base structure of the foundation or industrial floor. Observations are realized at known boundary conditions what allows to acquire relevant outputs. Geometric disposition is plotted in the Figure 3. The subsoil of the field was formed by the clay of intermediate plasticity and firm consistency. This soil type is often present in the subsoil of such structures. The surface of the subsoil was levelled and covered by the separation geotextile with the planar weight of 200 $g \cdot m^{-2}$. Two layers of the foam concrete was then constructed and the tests were realized on both of the FC layers and on the subsoil.

Series of observations of the real scale physical model in the test field were proposed to estimate the stiffness of the final compound. The observations consisted of static plate load tests (PLT) realized on the clayey subsoil and on the foam concrete layers. This test is commonly used to determine the modulus of elasticity of the subgrade and the sub-base [8,9]. The foam concrete was created in two layers to describe the increase of the sub-base stiffness with increasing thickness of the foam concrete [10].

Static modulus of elasticity *E* is calculated using the output of the plate load test:

$$E = \frac{\pi}{2} \cdot \left(1 - \upsilon^2\right) \cdot \frac{p \cdot r}{s_e} \quad \text{(MPa)}, \tag{2}$$

where υ is Poisson's ratio of the tested layer (= 0.25 for the foam concrete),
p contact stress under the loading plate (MPa),
r loading plate radius (= 0.1785 m),

s_e average elastic plate settlement (m).

Because of higher stiffness of foam concrete layer, deflection radius under the loading plate is larger and can affect the legs of the standard measurement beam for PLT testing. Therefore, a larger beam stabilized outside the foam concrete plate was constructed (Fig. 4).

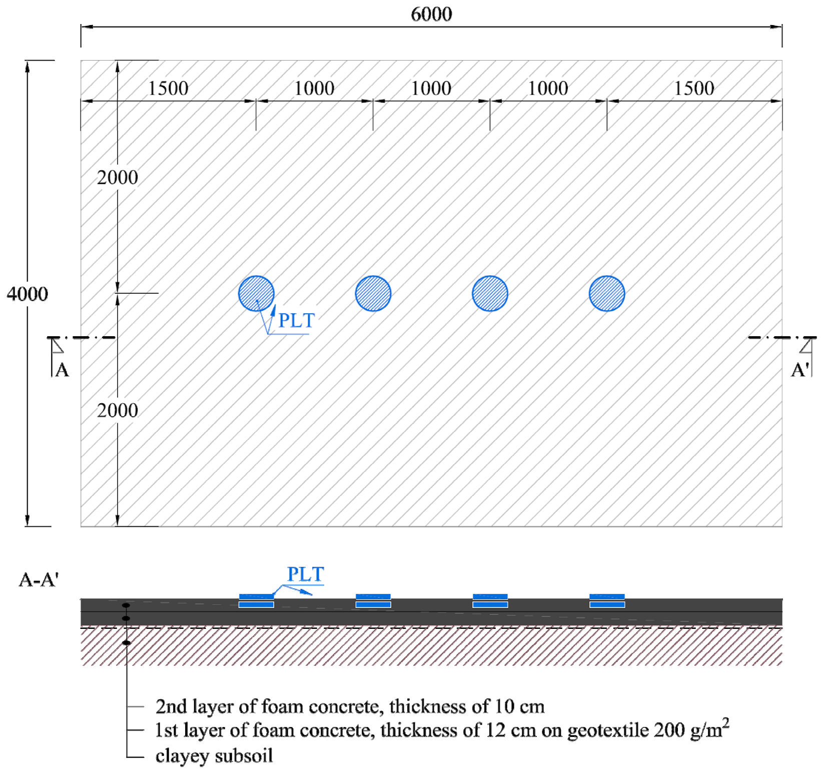

Fig. 3. Experimental field scheme for the tests on the foam concrete (dimensions in mm).

Fig. 4. Measurement apparatus for PLT testing.

Calculated values of modulus of elasticity for particular layer in the experimental field are in Table 1. Testing was carried out before and after winter season on the second FC layer. Due to the repeated loading and some consolidation process in the subsoil, the E values are slightly higher after winter season.

Table 1. Static modulus of elasticity E from in situ testing (MPa)

Position	Measured interval	Average value
clayey subsoil	17.4 – 21.4	19.7
1st FC layer	32.6 – 55.5	43.8
2nd FC layer	73.0 – 94.6	86.5
2nd FC layer – testing after winter season	102.1 – 113.1	106.4

4 Comparison of laboratory and in situ *E* modulus

Calculation model for bi-layered system based on SOJUZDORNII theory considers the modulus of the upper layer E_1 with the thickness h_1 and the modulus of the subgrade E_p. If the system is loaded with the circular loading with the diameter d (in this case PLT loading plate), equivalent elastic modulus of the system E_e can be calculated as follows:

$$E_e \frac{E_1}{n^{2.5} \cdot \left[1 - \frac{2}{\pi} \cdot \left(1 - \frac{1}{n^{3.5}}\right) \cdot arctg\left(\frac{h_1}{d} \cdot n\right)\right]}, \tag{3}$$

where:

$$n = \sqrt[2.5]{\frac{E_1}{E_p}}. \tag{4}$$

If the equivalent or apparent modulus E_e from PLT testing is known, the modulus of elasticity of the FC layer E_1 can be calculated following the Eq. 3. For the loading plate of diameter d = 0.357 m and E_p = 19.7 MPa, comparison of the E modulus of elasticity from laboratory and in situ testing is plotted in Figure 5. Minimum and maximum in situ E values are related to the actual E modulus of the FC layer corresponded to the minimum and maximum E values for overall compound from Table 1.

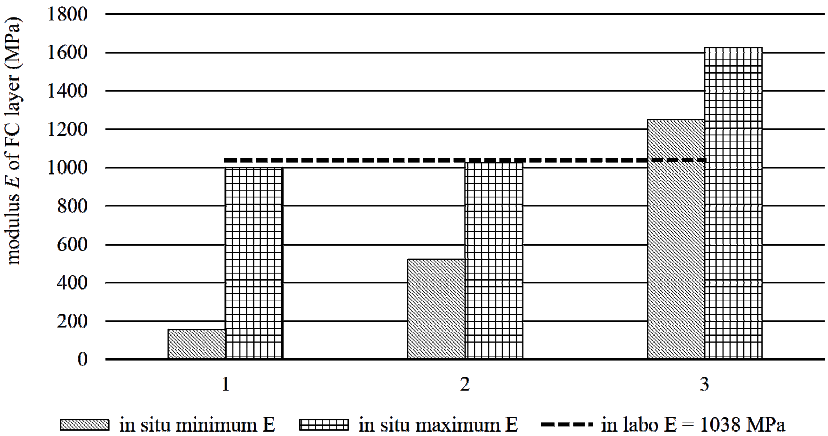

Fig. 5. Comparison of laboratory and in situ E modulus 1 – 1st FC layer, 2 – 2nd FC layer, 3 – 2nd FC layer after winter season.

SOJUZDORNII theory is very sensitive to the input parameters. Especially upper layer of FC has very large dispersion in input *E* value to achieve required global E_e modulus. This dispersion is lower with increasing stiffness of the final compound. With increasing total stiffness, modulus of elasticity from in situ testing better meets the in labo values. Maximum *E* values better coincide with the laboratory results. This is caused by the boundary conditions of the analytical theory where infinite half-space is considered. Because the dimensions of the experimental field are limited, obtained *E* values are probably underestimated. Results could be closer to the maximum values with larger FC slab with restricted influence of the slab edges.

Generally, this method is suitable for designing of the FC layer considering the in labo *E* values and the required global stiffness on the top of the foam concrete but detailed examination of both of the laboratory and in situ outputs should be carried out.

5 Conclusions

Results show good potential in combination of laboratory determined *E* values and analytical approach for designing of the sub-grade layers for various structures. Thinner FC layer should be more carefully analyzed because of membrane like behavior where imperfections in the geometry and the material characteristics of foam concrete and subsoil have larger influence in the overall stiffness of the compound. The sensitivity to the input of the analytical design using SOJUZDORNII theory is lower with increasing global stiffness or thickness of FC layer. Laboratory determined values of modulus of elasticity then better coincide with the values estimated from the experimental field.

More accurate determining of the *E* modulus in labo is required because of larger spread of the obtained values. The method for estimation of the modulus of elasticity usually used for conventional concrete is still usable but very porous structure of the foam concrete with almost 70% of air pores makes the testing complicated and much larger data set should be prepared in comparison with the standard concrete.

References

1. S.R. Abdullah, A.I. Riwayat, A.S.M. Abdul Awal, M. Hossain Zakaria, Int. J. of GEOMATE. **13** 129-134 (2017).
2. M. Decky et. el, *Proc. Engineering*. **161** (2016).
3. M. Drusa, A. Knoppik-Wrobel, R. Rudisin, W. Scherfel, *Proc. of XXI RSP Seminar*. 523-530 (2012).
4. M. Decky, M. Drusa, L. Pepucha, K. Zgutova, (Harlow, Pearson, 2013).
5. M. Hajek, M. Decky, M. Drusa, L. Orininova, *IOP conference series: Earth and environmental science* **44** (2016).
6. M. Kadela, M. Kozlowski, *Proc. Engineering*. **161** 468-476 (2016).
7. M. Kadela, Bulletin of the Polish Academia of Sciences. **64** 751-762 (2016).
8. M. Decky, E. Remisova, M. Mecar, L. Bartuska, J. Lizbetinec, I. Dreveny, Jour. Proc. Earth and Planetary Science. 11-18 (2016).
9. K. Zgutova, M. Decky, J. Sramek, I. Dreveny, J. Proc. Earth and Planetary Science. 263-270 (2015).
10. M. Hajek, M. Decky, W. Scherfel, Journal CEE. **12,** 55-62 (2016).