Elasticity Modulus and Flexural Strength Assessment of Foam Concrete Layer of Poroflow

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Abstract. Nowadays, it is necessary to develop new building materials, which are in accordance to the principles of the following provisions of the Roads Act: The design of road is a subject that follows national technical standards, technical regulations and objectively established results of research and development for road infrastructure. Foam concrete, as a type of lightweight concrete, offers advantages such as low bulk density, thermal insulation and disadvantages that will be reduced by future development. The contribution focuses on identifying the major material characteristics of foam concrete named Poroflow 17-5, in order to replace cement-bound granular mixtures. The experimental measurements performed on test specimens were the subject of diploma thesis in 2015 and continuously of the dissertation thesis and grant research project. At the beginning of the contribution, an overview of the current use of foam concrete abroad is elaborated. Moreover, it aims to determine the flexural strength of test specimens Poroflow 17-5 in combination with various basis weights of the underlying geotextile. Another part of the article is devoted to back-calculation of indicative design modulus of Poroflow based layers based on the results of static plate load tests provided at in situ experimental stand of Faculty of Civil Engineering, University of Žilina (FCE Uniza). Testing stand has been created in order to solve problems related to research of road and railway structures. Concern to building construction presents a physical homomorphic model that is identical with the corresponding theory in all structural features. Based on the achieved material characteristics, the tensile strength in bending of previously used road construction materials was compared with innovative alternative of foam concrete and the suitability for the base layers of pavement roads was determined.

1. Introduction
Lightweight concrete (foam concrete) represents a mixture of binder (usually cement), water, admixtures, additives and technical foam, which make concrete as a building material with good mechanical strength, low thermal conductivity and with simple, yet highly technologically demanding processing. The function of the filler in the mixture is to produce the air bubbles, making it appropriate to produce foam concrete directly on the construction site using special technological equipment intended for such production, [1, 2]. If the foam concrete was mixed outside the site and transported
there by mobile concrete mixers, it would cause a significant decrease of its volume followed by increasing costs.

The main advantages of foam concrete structures include:

- Simple and quick pouring - with such pouring it is possible to produce and implement the installation of 400 - 600 cubic meters per day and to significantly reduce construction time and costs.
- Wide range of densities – the bulk density can range from 300 to 1600 kg/m³.
- Complete filling of cavities and pores without compaction - the advantage of foam concrete is that all cavities get filled, which means that it is also partly self-leveling.
- Good absorption properties - foam concrete has a fine cell structure, which allows it to absorb kinetic energy during compression or settlement of upper construction.
- Low failure rate - in contrast to some of the synthetically lightened materials, the foam concrete is not susceptible to failure due to the presence of hydrocarbons, bacteria or funguses.
- Environmentally friendly - the usage and manufacturing of the foam concrete directly on the construction site with a dosing device means less traffic disturbance and less manipulation on site. Recycling is also very easy and energy efficient.

According to [4], foam concrete has been used in highway construction in the United Kingdom (UK) since 1970, yet it took about 20 years for foam concrete to become competitive as well as a recognized building material. It has been also found examples of successful using of foam concrete technology in other countries, e.g. USA [5], and contemporary research continue [1, 2, 6, 7].

2. The in-situ experimental stand of FCE UNIZA

The in-situ experimental stand of Faculty of Civil Engineering at University of Žilina (FCE Uniza) has been designed to solve selected research problems of highway constructions. Experimental stand was built within years 2012 and 2015. During the research in collaboration with a Slovak foam concrete company iwtech Ltd., first engineering structure was built as seen in Figure 1. The building construction represents a physical homomorphic model that is identical to the corresponding theory in all structural features.

**Figure 1.** Structural composition of the underlay construction using Poroflow 17-5 (left) and view on the building construction (right)

Depicted structure is 6 m wide and 4 m long (Figure 2) in its ground plan. It is divided into three sections with a width of 2 m, in each section there are other types of geotextiles.
3. Verification of elasticity modulus on bulk density of Poroflow

Figure 3 presents the dependence of elasticity modulus $E$ of lightweight concrete type Poroflow on its bulk density discovered collectively under the leadership of iwtech Ltd in the laboratory. It is clear from chart that the increasing bulk density is followed by an increase of the elasticity modulus.

In situ verification of laboratory objectified correlation dependence was performed on a physical model of homomorphic. Interest verification was based on the results of static load test (PLT) measurements according to the principles of STN 73 6190 [8]. The edge of the board should be distanced from the counterweight supports at least 2.5 times the diameter of the board. Loading board is assembled to the smooth compact surface layer and with at least two rotations around the axis, small imperfections are adjusted.

Figure 3. Correlation dependence of elastic modulus applications Poroflow on its bulk density

As long as smaller depressions remain under the board, they will be filled with smooth sand. With the exact determination of the deformation or elasticity, it is necessary to indicate from which loading cycle relevant modules were set. Calculation principle is evident from Figure 4. Based on this model, the bearing capacity of an earth structure can be characterized by [9]:

- modulus of elasticity $E$

$$E = \frac{\pi}{2} \left(1 - \mu^2\right) \frac{P \cdot a}{y_c}$$

- Modulus of deformation $E_{def}$

$$E_{def} = \frac{\pi}{2} \left(1 - \mu^2\right) \frac{P \cdot a}{y_c}$$

where:

$E$ – modulus of elasticity [MPa]
$E_{\text{def}}$ – earth structure’s modulus of deformation [MPa]
$\mu$ - Poisson's ratio [-]
$p$ – specific surface load on the earth structure’s surface [MPa]
$a$ – radius of circular loading area [m]
$y_e$ – elastic deformation on the earth structure surface [m]
$y_c$ – total elastic deformation on the earth structure surface [m].

Figure 4. The principle of calculation of the modulus of elasticity and deformation modulus [8]

For the theoretical calculations in highway construction, the elasticity modulus of individual construction layers needs to be known, therefore it was necessary to recalculate the equivalent elasticity modulus on the surface of construction system to the modulus of elasticity layer Poroflow 17-5. This recalculation was executed with the use of theory of 2-layers model. [10]. The calculation model is designed based on the equal deformation of the homogeneous road materials (attributes are the same as those of the subbase) and strain two-tier system of modules $E_i$ (top layer thickness $h_i$) and $E_p$ (elastic modulus of surface or subsoil). Two-layer system is loaded by a load ring with a diameter $d$. Equivalent module of the two-layer system $E_e$ is calculated as below [10, 11],

$$E_e = \frac{E_i}{E_p} \left[ 1 - \frac{2}{\pi} \left( 1 - \frac{1}{(E_i/E_p)^2} \right) \arctg \left( \frac{h_i}{d \sqrt{E_i/E_p}} \right) \right]$$

(3)

According to the fact that it was not possible to use the results of plate loading test (PLT) on surface of the drainage layer (aggregates f=8/16), interest resident modulus was ascertained by calculation from the measurement devices lightweight dynamic plate (LDD 100). Because the elasticity modulus determined from the first loading cycle PLT $E_i$ is practically identical to the deformation modulus from second gel loading cycle PLT $E_2$, difference of 1.4 % was detected in [2, 3], the elastic modulus will be referred to as $E$. Based on the above and the article [11, 12], the equation for determination of the modulus from $E_{\text{def}}, 2$ values appointed by LDD 100 equipment is obtained.

$$E = 0.164 \cdot E_{\text{def}, 2}^{1.663}$$

(4)

As an example of the elasticity modulus Poroflow 17-5 PLT calculation, the evaluation of the measuring position 3 is referred to. On the Poroflow surface, equivalent modulus $E_{S, P} = 26.0$ MPa was rated.
To determine the exact deformation modulus $E_{\text{Poroflow}}$ from in situ measurements, the modulus of the subbase system needs to be known, in this case it was the drainage layer of crushed stone 20 cm thickness, $f = 8/16$ mm on clayey subsoil. Results of PLT could not be used because of the aggregate sideways deflection, deformation of formwork or formwork decreases and declines in the measurement of frame. For this reason, with the help of LDD100 device, the value $E_{v,d} = 10.1$ MPa was assigned which was recalculated afterwards using the Equation (3) to the deformation modulus of the structural supporting layer Poroflow $E_{\text{podklad, Poroflow}} = 7.7$ MPa. From these values, the value rounded to 10 MPa $E_{\text{Poroflow}} = 1580$ MPa was determined with [10] method using the iterative application relationships 4 for the measured thickness of the drainage layer of 20 cm.

4. Determination of flexural strength

For the purposes of applying the foam concrete to road pavements as the substrate layer, it is necessary to know the flexural strength according to STN EN 12390-5 [13]. The principle of the test lies in exposing test specimens to the bending moment caused by load, which is transmitted by supporting’s of the upper and lower metal rollers (Figure 6). During the test, the maximum achieved load is recorded and subsequently, the flexural strength is calculated using formula (5).

![Figure 6](image_url)

**Figure 6.** The test specimen apparatus

It must be loaded with a constant load of speed in the range from 0.04 [MPa/s] (N.mm$^2$.s$^{-1}$) to 0.06 [MPa.s$^{-1}$]. After the initial loading, which cannot exceed approximately 20% of load of disruption, the test specimens are loaded uniformly and without hits and load increases continuously with a constant speed ± 10% up to achieve the maximum load.
The obtained results are used to determine the flexural strength from formula

\[
f_{ck} = \frac{F \cdot l}{d_1 \cdot d_2}
\]

where:  
- \( f_{ck} \) - present flexural strength [MPa/s];  
- \( F \) – present maximum load [N];  
- \( l \) – distance between supporting rollers [mm]  
- \( d_1 \) and \( d_2 \) – measurements of specimens’ cross sections [mm]

The reason for using the test specimens is to see the impact of geotextile on the values of the flexural strength. Using the test specimens verifies its functionality, accuracy and suitability for the specific type of construction.

### Table 1 Flexural strength of the test specimens

| Sample name            | Sample number | Force [N] | Strength \( F_{ck} \) [MPa/s] | Specimen |
|------------------------|---------------|-----------|-------------------------------|----------|
| PRF 17-5 - PE-foil     | 11.1          | 803.61    | 0.2                           |          |
| PRF 17-5 - PE-foil     | 11.2          | 397.55    | 0.1                           |          |
| PRF 17-5 - PE-foil     | 11.3          | 0         | 0.0                           |          |
| PRF 17-5 - PE-foil     | 13.1          | 857.42    | 0.3                           |          |
| PRF 17-5 - PE-foil     | 13.2          | 828.07    | 0.2                           |          |
| PRF 17-5 - PE-foil     | 13.3          | 812.17    | 0.2                           |          |
| PRF 17-5 - GTX 200     | 4.1           | 1532.55   | 0.5                           |          |
| PRF 17-5 - GTX 200     | 4.2           | 1283.05   | 0.4                           |          |
| PRF 17-5 - GTX 200     | 4.3           | 1154.62   | 0.3                           |          |
| PRF 17-5 - GTX 200     | 5.1           | 940.59    | 0.3                           |          |
| PRF 17-5 - GTX 200     | 5.2           | 998.07    | 0.3                           |          |
| PRF 17-5 - GTX 200     | 5.3           | 1361.32   | 0.4                           |          |
| PRF 17-5 - GTX 500     | 8.1           | 1462.84   | 0.4                           |          |
| PRF 17-5 - GTX 500     | 8.2           | 1527.66   | 0.5                           |          |
| PRF 17-5 - GTX 500     | 8.3           | 1185.20   | 0.4                           |          |
| PRF 17-5 - GTX 500     | 9.1           | 930.80    | 0.3                           |          |
| PRF 17-5 - GTX 500     | 9.2           | 1136.28   | 0.3                           |          |
| PRF 17-5 - GTX 500     | 9.3           | 978.50    | 0.3                           |          |
5. Conclusions
The article describes the latest research activities carried out by FCE UNIZA in cooperation with iwtech Ltd. for the field of possibilities of using foam concrete in road construction. Specifically, outputs in situ verification in lab objectified correlation dependence of elasticity modulus of foam concrete Poroflow on its bulk density [2]. It was done assessment of laboratory results of Poroflow layer elasticity modulus dependence on the bulk density (Figure 3), which was proved for bulk density of 500 kg/m³ and extrapolated value of modulus $E_{\text{Poroflow}}$ done in laboratory at value 1300 MPa.

Results of the resident modulus Poroflow 17-5 determined from recalculations of results of static and dynamic load tests measurements on all layers of the experimental design for the transportation structures are presented in Table 2. The average value when rounded to tens of MPa reached $E_{\text{Poroflow}}$ 17-5, in-situ = 1720 MPa. Increase of $E_{\text{Poroflow}}$ 17-5, in-situ compared to $E_{\text{Poroflow}}$ 17-5, in lab is explained by the effect of reinforcing geotextiles. Based on objectively observed research results presented in Table 1, it was confirmed that the geotextile substrate increases flexural strength of the test specimens and positively affects the strength of the material, which allows its variable use in the construction of road pavements and paved areas. Currently, the research activities are in progress trying to optimize the structural composition for civil engineering works, including the selection of the optimal type of geotextile using which would reach the highest values of interest of mechanical characteristics and particularly the resident modulus and tensile strength in bending.

Table 2. Values of modulus of elasticity of Poroflow 17-5 detected by reversal calculation from equivalent modulus of elasticity measured by the SZS on the surface of Poroflow and elastic modulus of the underlay system $E_{\text{sub-base, Poroflow}}$

| Construction                        | Modulus of elasticity $E$ [MPa] | Tensile strength in bending $R$ [MPa] | Material         | Modulus of elasticity $E$ [MPa] | Tensile strength in bending $R$ [MPa] |
|------------------------------------|-------------------------------|-------------------------------------|-----------------|-------------------------------|-------------------------------------|
| Poroflow 17-5 15 [cm]              |                               |                                     | HBBM G1 C5/6    | 1 200                         | 0.5                                 |
| Geotextile 250 g/m²                |                               |                                     | HBBM G1 C6/8    | 1 600                         | 0.65                                |
| Crushed stones f=8/16 20 [cm]      | 1770                          | 0.4                                 | CBGM C8/10      | 2 000                         | 0.8                                 |
| Geotextile 250 g/m²                |                               |                                     | CBGM C12/15     | 2 500                         | 1.0                                 |
| Poroflow 17-5 15 [cm] Separation   |                               |                                     |                 |                               |                                     |
| foil                               |                               |                                     |                 |                               |                                     |
| Crushed stones f=8/16 20 [cm]      | 1450                          | 0.2                                 |                 |                               |                                     |
| Geotextile 250 g/m²                |                               |                                     |                 |                               |                                     |
| MS 2                               |                               |                                     |                 |                               |                                     |
| Poroflow 17-5 15 [cm]              |                               |                                     |                 |                               |                                     |
| Geotextile 500 g/m²                |                               |                                     |                 |                               |                                     |
| Crushed stones f=8/16 20 [cm]      | 1950                          | 0.4                                 |                 |                               |                                     |
| Geotextile 250 g/m²                |                               |                                     |                 |                               |                                     |

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