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Foam Concrete as New Material in Road Constructions

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Abstract

The article presents the possibilities of using lightweight concrete - foam concrete in road construction. Principles of sustainable development create the need to develop new building materials. Foam concrete is a type of lightweight concrete that has many advantages compared to conventional building materials, for example low density and thermal insulation characteristics. With current development level, any negatively influencing material features are constantly eliminated as well. This paper deals with the substitution of hydraulically bound mixtures by cement foam concrete Poroflow 17-5. The executed assessment is according to the methodology of assessing the existing asphalt pavements in Slovak Republic. The special calculation was used to estimate the modulus of foamed concrete Poroflow 17-5 based on the results of static load tests conducted using the experimental in-situ stand.

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1. The main advantages and examples of use of foam concrete

In this present day, lightweight concrete (foam concrete) represents a mixture of binder (usually cement), water, admixtures, additives and technical foam what makes concrete a building material with good mechanical strength, low thermal conductivity and with simple, yet highly technologically demanding processing.

The function of a filler in the mixture is to fulfil the air bubbles, making it appropriate to produce foam concrete directly on the construction site using special technological equipment intended for such production. If the foam

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concrete was mixed outside the site and transported there by mobile concrete mixers, it would cause a significant decrease of its volume followed by increased 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.
- 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-levelling.
- Good absorption properties - foam concrete has a fine cell structure, which allows it to absorb kinetic energy during compression or settlement of the upper construction, [1].
- 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 disturbing and less manipulation on site. Recycling is also very easy and energy efficient.
- Wide ranges of density, [2, 3] - usually bulk density varies from 300 to 1600 $kg.m^{-3}$.

Foam concrete [4], has been used in highway construction in the United Kingdom (UK) since 1970, yet it took about 10 years for foam concrete to become competitive as well as a recognized building material. The greatest construction suppliers using foam concrete technology in the UK are the Foam Concrete Ltd and The Pump Engineering Ltd. These companies are behind construction of the following constructions works.

- Foam concrete was used as a base material for roads in newly built **Hertfordshire (UK)** industrial zone. The original subbase consisted of peat that caused numerous floods in the area in combination with high phreatic surface. It was necessary to implement drainage before and during construction. It was not possible to use a common structure of the road because repeating wetting and drying of individual construction layers would subsequently damage already finished road structure [3].

Fig. 1. Views of preparation of the underlay, a poured layer of foam concrete, the pyramidal formwork and application of the last layer of foam concrete, [5].

- Another example is from Northwest Highway (Route 14) construction, were utilized over 13,000 cubic meters of density 590 and 410 kg/m^3 foam concrete. There were thickness up to 1. 20 m, were they installed to supplement pre-existing foam concrete to across soft soils in six areas along Route 14. Filled areas varied from 1 meter to 12 meters wide for both eastbound and westbound lanes, including areas to support new storm water drains. Several low areas were dewatered and carefully constructed to prevent floatation due to rain and groundwater. Upon completion of foam concrete in these low bearable areas, the hardened foam concrete was quickly covered with the designed layer of aggregate subgrade of thickness 300 mm. This layer was then covered with concrete pavement to finishing roadway, [5].
- The Central road, Schaumburg, Illinois overpass in length of 3 km, was reconstructed at full depth of a four-lane road with drainage improvements and installation of curb and gutters. At the east end of the project, the road was constructed over a marsh area with soft organic underlying soils (peat) located at depth of 3 m to 5 m under the surface. This project is typical for the construction of lightweight foam concrete road fills. Soft organic underlying soils with a low bearing capacity, can caused consolidation settlement when there is additional loading or stress change. The general contractor proposed a combination of a 900 mm thick layer of 400 kg/m^3 and 600 mm layer

of 500 kg/m^3 foam concrete in lieu of the EPS to construct the lightweight fill. The major benefits of the general contractor decision were in lower unit cost, less installation time, and higher quality of the material, [3].

Fig. 2. Views of a typical “Two-stage” road fill project where steel sheeting is installed down the centreline of the roadway to support live traffic while excavation, placement of foam concrete, and pavement construction can be performed in the first stage, [6].

- At Chicago's O'Hare International Airport, a water retention reservoir project at the north airfield involved constructing a soil berm over an existing water supply with materials from the reservoir excavation. Due to the designed burial loading and present depth of the water level, only a minimal amount of additional loading could be excepted. PROVOTON foam concrete was used to construct a 28' wide, 10' thick spread footing and to provide the required load reduction over a 2900' long stretch of the water main to support a minimal amount of soil cover placed on top of the spread footing, [8].
- Richards Bay, a deep-water port was opened in 1976 primarily to export coal and by the early 1990s it was handling almost one-half of all cargo passing through South African ports. Since South Africa has no commercially navigable rivers, ocean shipping has long been a major feature of its transportation network. The port's five terminals handle approximately 1650 commercial ocean going vessels annually [7].

Fig. 3. South Africa’s busiest port, foam concrete being placed in 600 mm deep fills, [7].

2. The testing in-situ stand

The testing experimental stand has been built by Faculty of Civil Engineering at University of Žilina (FCE UNIZA), in order to provide selected research in topics of highway and railways constructions. Testing stand FCE Uniza was built in 2012-2015 (Fig.4).

2.1. Geological conditions at place of stand

The area of experimental testing stand is a typical for major construction sites, it is composed by layer of antropogenous soil from past excavation works of class of soil CI – clay of intermediate plasticity. At layer of subbase soil has been provided all kinds of geotechnical testing – like static plate load test, light falling weight deflectometer (LFWD) test, CBR in-situ tests by CLEGG device [9], CPT (cone penetration test). In situ testing was accompanied by laboratory testing for classifications, and technological parameters obtaining - like maximum bulk density of dry soil $\rho_{d,max}$ =1632 kg.m^{-3} and w_{opt} = 15.8 %.

Fig. 4. Testing experimental stand FCE UNIZA progress.

2.2. Parameters of used foam concrete

Thanks to research activities of iwtech LTd. it has been producing in certain volume homogenous and stiff foam concrete at desirable bulk density and desirable compressive strength. Code numbers after name Poroflow 17-5 means 1.7 MPa of compressive strength and bulk density 500 kg.m^{-3}.

2.3. In situ verification of equivalent elasticity modulus of layers with Poroflow

Laboratory testing of materials are useful for obtained material properties. In order to know interaction of new material in real structure behaviour, real physical model at scale 1:1 is the best solution. Inappropriate scale can have caused also inappropriate results; especially shear resistance of material is influenced by scale effect, [3, 12]. Therefore, in-situ experimental stand was used. Interesting verification was based on the results of the static plate load test's (PLT) measurements provided on the surface of foam concrete layer, at three places of different layer's composition of pavement structure and on foundation soil too, see Fig. 5.

Fig. 5. Executions of series of measurements at in experimental stand FCE Uniza.

For the theoretical calculations in road construction design, the modulus of elasticity of each construction layer is necessary to be known. Based on known parameters of multi-layered system there is possibility to recalculate the equivalent modulus of elasticity E_e of the multi-layered composition with foam concrete - Poroflow 17-5. This recalculation was executed by using an analytical theory Sojuzdornii [11]. The calculation model was designed based on the equal deformation of the road's homogeneous materials (attributes are same as those of the subbase) and strain two-layer's system of modulus E_1 (of top layer thickness of h_1) and E_{sub} (elastic modulus of surface layer of subsoil). Two-layer system's is loaded by the circular shape plate of diameter d. Equivalent modulus of the two-layer's system E_e is calculated as below,

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

where in addition to the already explained symbols is:

$$n = \sqrt[2.5]{E_1 / E_{sub}} \tag{2}$$

According to the fact, that it was not possible to use the results of PLT on surface of the drainage layer (crushed stones f- 8/16 was not stable due to small height of layer and poorly graded granulometry), interesting deformation modulus was ascertained by the empirical relations from the measurements of light falling weight deflectometer (LFWD) device type LDD 100. Because deformation modulus was determined from the first loading cycle of PLT E_1 is practically identical to the modulus from second loading cycle of PLT E_2, according to [13] a difference 1.4 % was not significant. Based on the above, this yields the equation for determination of the deformation modulus from $E_{def,2}$ values from LDD 100 equipment (E_{vd}), can be at this case used for determination of the elastic modulus referred as E, [1]:

$$E = 0.164 \cdot E_{vd}^{1,663} \tag{3}$$

It has been done also laboratory tests to ensure deformation characteristics of layer of Poroflow 17-5 material. On the Fig. 6 there is the dependence of elasticity modulus E on bulk density of Poroflow, [2, 14, 15]. It is expected, that the increasing bulk density of Poroflow is followed by an increase of the elasticity modulus. This characteristic is mostly required at design of road pavements. It can be used for continuing numerical verifications of structures with this new material and is numerically similar to equivalent modulus of certain multi-layered structures on standard subsoil bearing capacity.

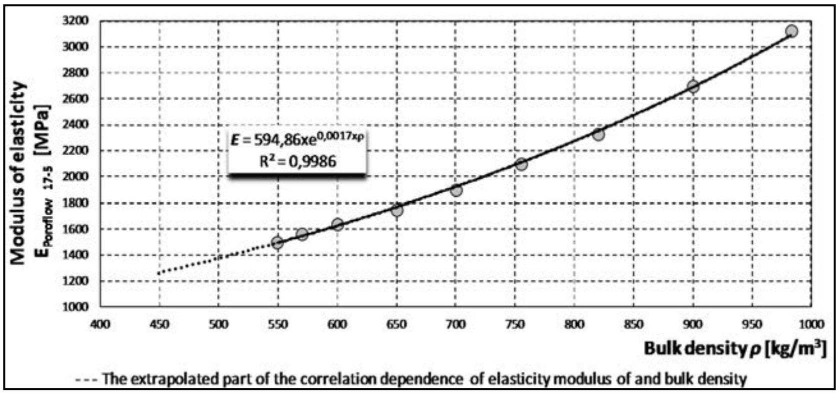

Fig. 6. Correlation dependence of elastic modulus on bulk density of Poroflow 17-5, [13].

At the final, values of equivalent modulus of elasticity of three Poroflow layers composition in certain geological conditions is presented in Tab.1. Comparing the results of modulus can be seen influence of PVC separation foil in composition II and tensile stiffness of geotextile at layer's composition III, where highest modulus was derived.

Tab 1. Values of equivalent modulus of elasticity of Poroflow layers detected by reversal calculation for measured modulus of subbase $E_{sub.}$

Layer's composition I.	$\mathbf{E_e}$ [MPa] (E_{sub})	Layer's composition II.	$\mathbf{E_e}$ [MPa] (E_{sub})	Layer's composition III.	$\mathbf{E_e}$ [MPa] (E_{sub})
Poroflow 17-5 15 cm Geotextile 250 g/m^2	**1 770**	Poroflow 17-5 15 cm Separation foil	**1 450**	Poroflow 17-5 15 cm Geotextile 500 g/m^2	**1 950**
Crushed stones f-8/16 20 cm Geotextile 250 g/m^2	(22.7)	Crushed stones f-8/16 20 cm Geotextile 250 g/m^2	(21.3)	Crushed stones f-8/16 20 cm Geotextile 250 g/m^2	(23.6)

4. Conclusions

The article describes the latest research activities carried out in experimental in-situ stand of FCE UNIZA in cooperation with iwtech LTd. It has been presented simple solution how to determined equivalent modulus of subgrade layers' composition with foamed concrete. Different testing method and different correlations was used in order to receive quit realistic values of the most important design characteristic. For objectification of methodology, series of 3D FEM numerical models was created. Currently, the research activities continuing at optimization of the structure composition, including the selection of the optimal type of geotextile and combined geosynthetics with drainage function, in order to achieve the highest values of deformations parameters and reliability of structure during lifetime.

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