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Opponent's Report of the Habilitation Thesis

Ing. Jozef Vlček, PhD.

within the field of habilitation and inauguration procedure in Civil Engineering and Transport Structures at the Faculty of Civil Engineering, University of Žilina

Title of the Habilitation thesis: *Application of Foam Concrete in Subbase Layers*
(*Aplikácia penobetónu v podkladových vrstvách*)

This habilitation thesis is devoted to the study of practical use of foamed concrete in the subbase layers of industrial floors and parking places or subbase layers of floors of single-family houses, using knowledge of its physical and mechanical properties. The topic falls within the field of engineering structures and transport structures. The author presents the results of his own experimental research (laboratory and field) and numerical analyses conducted at the Department of Geotechnics, Faculty of Civil Engineering, UNIZA. The thesis is divided into six main chapters, each with its own subchapters, with 80 references demonstrates a very good level of formal merit, and meets the criteria for a habilitation thesis.

1. Relevance of the analyzed topic

Although the technology for producing foamed concrete has been known for appr. 100 years, foamed concrete has not been effectively implemented. The area of research into the use of foamed concrete as a subbase layers of industrial floors, presented by Ing. Jozef Vlček, PhD., is still relevant and necessary. This is evidenced by the growing interest in foamed concrete among scientists from many foreign research institutions and the demand in civil engineering. This demand is related to the search for new ecological solutions in industrial, residential, and road construction. The use of foamed concrete is consistent with the goal of reducing the use of natural resources and lowering energy consumption, thus reducing CO₂ emissions.

A crucial prerequisite for the proper design of solutions using foamed concrete is detailed knowledge of its properties, construction technology, and behavior in situ. Furthermore, the effective implementation of foamed concrete in geotechnics requires the ability to evaluate such solutions using foamed concrete after construction, which has not been well understood to date. This knowledge is further enhanced by analyses of field test

results of actual structures conducted at the Faculty of Civil Engineering UNIZA, which were presented in this habilitation thesis. Furthermore, it should be emphasized that Ing. Jozef Vlček, PhD., analyzes foamed concrete reinforced with geotextiles and meshes, both monolithically constructed and precast. The number of publications and research conducted in this area is limited. I believe that reinforcing foamed concrete with geotextiles and/or meshes is an effective way to improve the properties of layers constructed using foamed concrete.

In summary, I conclude that the topic analyzed in the habilitation thesis is relevant. However, the effects of the presented solutions have practical and applied value.

2. Method of processing and documenting the results

In the introduction to the habilitation thesis, traditional methods of soil reinforcement were presented. The use of foamed concrete in the subbase layer was indicated as an alternative to these methods. This is the underlying goal of the habilitation thesis. The aim of the dissertation is to analyze the practical application of foamed concrete in subbase layers of industrial and parking floors or subbase layers of floors of single-family houses, using knowledge of its physical and mechanical properties.

Chapter 1 presents a description of foamed concrete, including its components, production method, and application. This chapter also highlights the advantages of foamed concrete. The habilitation candidate highlights the experience of the University of Žilina in collaborating with partners in producing foamed concrete with various dry densities (primarily 300, 400, 500, 600, and 700 kg/m³).

The preparation of precast foamed concrete slabs (panels) is presented in Subsection 2.3. The purpose of this procedure is to assess the feasibility of delivering prefabricated foamed concrete slabs to the construction site. This subchapter justifies the choice of foamed concrete density and the dimensions of the foamed concrete slabs. Twelve foamed concrete slabs with a dry density of 600 kg/m³ were fabricated. For selected slabs, strain gauges were installed on the basalt reinforcement before pouring the foamed concrete into the mold to measure the deformation of the reinforcement in two mutually perpendicular directions.

Laboratory testing is presented in Chapter 3. Laboratory testing of foamed concrete included tests to determine the following properties: compressive strength, flexural strength, modulus of elasticity, Poisson's ratio, thermal conductivity coefficient, and dynamic parameters. The flexural strength was determined for beams and slabs. Selected results, which I consider the most interesting, are presented below. Compressive strength was determined for foamed concrete with dry densities of 500, 600, and 700 kg/m³. The compressive strength of the foamed concrete increased over time. The 3-day compressive strength was shown to be 40% of the 28-day compressive strength.

Flexural strength was determined by a 4-point bending test on foamed concrete beams with dry densities of 300, 400, 500, 600, and 700 kg/m³. The 3-day flexural strength was shown to be approximately 50% of the 28-day flexural strength of the foamed concrete without and with reinforcement (Figs. 3.7 and 3.8).

Based on the results of the bending test of reinforced foamed concrete in various configurations (Fig. 3.10), it was shown that the 200 g/m² geotextile is almost comparable, and heavier geotextiles in terms of their effect on flexural strength. Based on the analysis of the results, the reinforcement was selected and subsequently used in field tests.

Flexural strength tests were conducted on two reinforced foamed concrete slabs with a density of 600 kg/m^3 and dimensions of $1.0 \times 1.0 \times 0.15 \text{ m}$, where additional force and deflection sensors and strain gauges were installed. The slab failure mechanism was similar to that of the beam reinforced with reinforcing mesh during the bending test.

Based on laboratory tests of dynamic parameters and numerical analyses using the finite element method (FEM), it was demonstrated that the estimated values of the Rayleigh coefficients α and β indicate good damping potential of foamed concrete at lower frequencies. This may be an advantage for roads or railways in built-up areas.

Chapter 4 presents a description of in-situ tests of foamed concrete. In the following subsections, a detailed description of the experimental site, subsoil preparation, and the construction of the foamed concrete layer (monolithic and precast) is presented. The postdoctoral researcher presented field tests constructed at the Faculty of Civil Engineering, University of Žilina, using foamed concrete of varying dry densities and various layer configurations placed on a subsoil of varying stiffness. The field tests were designed to reflect the actual conditions of foamed concrete application in in subbase layers of industrial and parking floors or subbase layers of floors of single-family houses

Two were constructed using monolithic technology (experimental layers A and B) and one using precast technology. Furthermore, experimental layer A, containing foamed concrete with a dry density of 500 kg/m^3 , was placed on a subsoil of two stiffnesses. For each subsoil stiffness, two types of foamed concrete reinforcement were used (reinforcement using only geotextile and additionally basalt mesh). In test area B, foamed concrete with a dry density of 400 kg/m^3 and similar strength to the foamed concrete in test area A was used. Foamed concrete reinforced with geotextile was used. The results of the static plate load test (SZS) and the dynamic test using a lightweight dynamic plate (LDD) are presented. Based on the results of the in-situ tests in test area A, it was found that:

- a smaller dispersion of the obtained moduli was demonstrated,
- the use of a reinforcing mesh increased the deformation modulus and improved the uniformity of the finished layer and the entire system,
- the obtained modulus values for foamed concrete reinforced with geotextile and reinforcing mesh meet the requirements for the analyzed applications.

Based on the results of the tests conducted in test area B, it was shown that the deformation modulus (Table 4.4) and static modulus (Table 4.5) determined for the foamed concrete layer are higher compared to the subsoil, with the modulus determined for the second foamed concrete layer being higher than for the first. The maximum values are comparable to the elastic modulus determined in the laboratory (Fig. 4.20). The moduli determined on the second foamed concrete layer after the winter period were higher.

The relationships between the static deformation modulus from the second loading cycle E_{V2} and the dynamic deformation modulus E_{vd} before the winter period were determined for foamed concrete layers 1 and 2 (Fig. 4.22). Furthermore, these relationships were determined for the second foamed concrete layer before and after the winter period (Fig. 4.23).

Ing. Jozef Vlček, PhD., developed relationships between the thickness of the foamed concrete layer and the secondary and primary deformation moduli and deformation determined on the surface of the foamed concrete layer. These relationships can be used when designing a monolithic foamed concrete substructure for given soil conditions and a specific structure (Figs. 4.24 to 4.27).

In the final section of this chapter, the results of in-situ tests of precast foamed concrete slabs placed on the ground in a field test are presented. A static plate load test and a dynamic test using a lightweight dynamic plate (LDD) were conducted on the ground beneath the slabs and on the surface of the slabs in various positions. Furthermore, conclusions from the analysis of the results were presented. It was shown that:

- The effect of the foamed concrete layer was demonstrated. However, lower secondary deformation moduli were obtained than for the monolithic layer.
- The highest values of the deformation modulus E_{vd} were obtained in the central part of the tested slabs; these values are higher than the values of the deformation modulus E_{v2} . However, the values of the E_{vd} modulus at the slab interface were lower. The effect of expansion joints at the interface between foamed concrete slabs was demonstrated.

Chapter 5 presents the use of foamed concrete in the subbase layers of industrial floors and parking places or subbase layers of floors of single-family houses, presents the load-bearing capacity requirements of the subbase with a foamed concrete layer (Fig. 5.1) and the structural requirements for the floor structure laid on the foamed concrete subbase (Fig. 5.2, formula 5.1), as well as thermal insulation and technological aspects. Based on research and practical implementation, the principles for the construction and quality control of monolithic foamed concrete layers were established. Experience with the use of foamed concrete in three real-world buildings is presented in Chapter 6. In the first case, an industrial floor was considered using foamed concrete reinforced with geotextile (a structure 240 mm thinner than the baseline solution) and geotextile and basalt mesh (270 mm thinner than the baseline solution) due to static and thermal loads as well as economic analysis. In the second case, the use of foamed concrete reinforced with geotextile in the floor structure of an underground parking lot of a multi-family building was considered due to the low-temperature construction technology (air temperature down to -6°C and a subfloor temperature of -1°C under the foamed concrete). The third case study presented the use of foamed concrete in the floor structure of a distribution and warehouse hall, where weather conditions were variable during the individual stages, with temperatures ranging from 10 to 25°C . Technological guidelines were formulated. Furthermore, a method for repairing the foamed concrete layer was presented.

The habilitation thesis concluded with coherent conclusions, including the advantages of foamed concrete as a substructure for industrial floors. The thesis was supplemented with a table of contents, a list of figures and tables, abbreviations and symbols used, and a list of publications.

3. Evaluation of the habilitation dissertation and comments regarding the dissertation

I highly value the applicant's contribution to the habilitation thesis and the potential for its application. I highly value the comprehensive approach to the issue analyzed in the thesis, including laboratory and in-situ tests, design-stage analysis, and technological guidelines, as well as the comparison of laboratory and field test results. The Habilitation candidate's achievements, which I have mentioned above, constitute a significant contribution to the development of foamed concrete and its use as a subbase layers of industrial floors.

I would like to emphasize that the analyzed issues of determining deformation moduli and the technological recommendations have a specific practical aspect and have not been

analyzed in the literature to date (apart from the Habilitation candidate's co-authored publications). However, they do provide a basis for the widespread implementation of foamed concrete in construction.

The habilitation thesis was developed to a high standard. The author possesses extensive knowledge of the subject matter, both from a scientific and practical perspective. The thesis is clear and understandable. I have no critical comments about the habilitation thesis submitted for review. However, several issues require clarification or clarification. However, these do not affect my assessment of the habilitation thesis.

Questions for the habilitation thesis:

- What are the standard deviations for the properties of foamed concrete analyzed in the habilitation thesis?
- Please provide a correlation for the relationship between the modulus of elasticity of foamed concrete and its density (Fig. 3.19). Could you describe the research method used to determine the thermal conductivity coefficient (Chapter 3.7)?
- Can the author compare the results of the in-situ tests after the winter (Fig. 4.20) with the results of the frost resistance test for foamed concrete?
- The obtained relationships between the static and dynamic modulus for foamed concrete layers 1 and 2 (Fig. 4.22) were characterized by a low correlation coefficient. In Fig. 4.23, the author did not provide the equation for these relationships for foamed concrete before the winter. Please comment.
- In Fig. 5.1, the relationships are presented, but the vertical axis is missing a caption. Please discuss the relationships presented and describe the numerical model (model structure, constitutive relationships used, assumed parameters). Are the obtained results universal or specific to specific mix compositions and specific foamed concrete layer thicknesses?
- The habilitation thesis presents selected methods for strengthening foamed concrete. Are the relationships determined by the Habilitation Candidate universal? If not, what should be considered when using a different type of reinforcement?
- Please provide recommendations for further research on foamed concrete.

4. Conclusions

The submitted habilitation thesis fully meets the requirements for a habilitation thesis.

In his habilitation thesis, Ing. Jozef Vlček, PhD, presented new scientific knowledge. At the same time, he demonstrated that he possesses the skills and competencies to perform research and teaching as an associate professor.

Considering the above, I recommend awarding Ing. Jozef Vlček, PhD, the academic and teaching title of associated professor in the habilitation process in the field of civil engineering and transportation structures.

