SUMMARY

The dissertation entitled *'Establishing own correlation between the results of in situ tests and soil parameters which include both CPTU and DMT results'* focuses on problems of correlation of soil parameters with the results of CPTU (Cone Penetration Test) and DMT (Dilatometer Test) field tests using MLP (Multilayer Perceptron) and LSTM (Long Short-Term Memory) neural networks. The dissertation discusses in detail the architecture, hyperparameters and algorithm of selected neural network models. The dissertation uses the author's transformation method, which allows the correlation models to take into account the natural variability of the geotechnical parameter within the soil layer. The dissertation analyzed ground investigations conducted for 15 subjects located in Poland. The research data provided the basis for verification of existing correlation models as well as allowed to design their own.

The dissertation consists of 8 sections and appendices.

In Section **1**, the author presents the theoretical introduction of the subject matter undertaken, the motivation for writing the dissertation, as well as the problematic and main objectives of the work. The author focuses on the importance of soil investigations for the design and construction of structures. The author highlights the complex nature of soil as a material and the flexibility of the current regulations on the scope of geotechnical investigations, which often leads to incomplete and inaccurate recognition of the conditions of the subsoil. The aim of the dissertation is to analyze the various field and laboratory testing methods used in the study of the subsoil and to identify best practices in this field. The author focuses on CPTU and DMT soundings, which he considers particularly effective and efficient. The author presents the main objectives of the work, which include the analysis and preparation of large amounts of ground investigation data from various locations in Poland, verification of existing correlation solutions for CPTU and DMT soundings, and an attempt to create our own correlations using artificial neural networks.

Section **2** deals with the importance and specificity of ground investigation, especially in the context of Polish regulations. According to them, the subsoil is is categorized by its complexity, which has a direct impact on geotechnical categories of buildings. This makes it possible to determine the scope of geotechnical investigations required by law. The research involves defining the layers of the subsoil, ground water levels and geotechnical parameters. The results

of these studies provide the data needed to properly design the facility, that is, taking into account the structural stability, functionality and economy of the building. In addition, the section includes a discussion of the boundary condition concept used in the Eurocodes. The author highlights the complex nature of soil as a material and presents sources of uncertainty in the recognition of soil parameters and gives their measures of uncertainty based on data from the literature.

In section **3**, the technique of performing CPTU and DMT static sounding is described and various components of these devices are presented. The author highlights the applicable regulations for these tests and the potential risks of the testing procedure. The section presents sample records of CPTU and DMT test results. The author emphasizes the widespread use of CPTU and DMT soundings in investigations of the subsoil of civil engineering structures due to their advantages, such as automatic data recording, mechanized in-situ testing procedure, high quantity and accuracy of measurements, and low interference with the subsoil.

In section **4**, the author discusses some methods, existing in the literature, for interpreting the results of CPTU and DMT soundings in order to calculate geotechnical parameters of the soil. These methods are based on various correlations, which need to be confirmed with the results of drilling and laboratory examination of the collected samples, as recommended by Eurocode 7. The correlations use the basic parameters of CPTU soundings, which are used to classify the type of soil and determine the geotechnical parameters of the soil. The section also highlights the usefulness of CPTU soundings for determining selected strength parameters of the subsoil, such as friction angle, cohesion, undrained shear strength, compressibility modulus, and material parameters such as liquidity index and relative density. The author also presented relevant models for interpreting DMT test results. He emphasizes that the selection of an appropriate interpretation method is a challenging task that requires verification with the results of local experiments.

In section **5**, the author focuses on the analysis of investigation data obtained from infrastructure projects, which the author co-authored, together with the Geological and Engineering Studio from Lodz. The data relates to the construction of road and railroad infrastructure, multi-family housing, and service and commercial developments. Information was obtained from geotechnical cross-sections, documentation maps, cards with results of

field and laboratory tests. The scope of work performed to document subsoil conditions included drilling to determine geological and engineering conditions, mapping to identify geological risks, and conducting field and laboratory tests on collected samples. The work was carried out at test points. The author, out of 136 completed research topics, selected 15 to achieve the aims of the dissertation. The criteria for selection was the appropriate amount of research conducted for the topics. In the section, the author presents the location of the selected topics on a map of Poland and the scope of work performed for each topic. In addition to this, the author in the section presents the applied methods for interpreting the results of CPTU and DMT soundings, which are based on models established by specialists of the field. At the end of the chapter, the author compares the results of the interpreted soil parameters with the correlations presented in section 4 with the results of the same parameters, but for parallel laboratory tests conducted.

In section **6**, the author discusses the topic of artificial neural networks (ANNs), which are part of artificial intelligence. ANNs are comprehensive approximation systems capable of modeling multidimensional problems in various scientific fields. The process of learning neural networks involves minimizing the cost function as a result of an algorithm for optimizing the weights of connections between neurons. The author distinguishes and discusses types of neural networks. Attention is focused on classical MLP-type networks and extended LSTM-type networks. The author highlights the advantages of LSTM networks, which take into account the time factor in data analysis and, thanks to the gating system, eliminate the problem of vanishing and exploding gradient occurring in large MLP networks. The author discusses the hyperparameters of the network, which have a significant impact on the model's prediction performance. In addition, the section discusses the procedure for building correlations between sounding results and soil parameters, using an artificial neural network. Test points with the highest data saturation were selected, including CPTU, DMT, boreholes and soil samples. Points were selected for 10 different soil types, for which efforts were made to select data with the widest range of geotechnical parameter values. The section notes the problem of an unreal constant distribution of geotechnical parameters within a layer based on laboratory test results. The section presents the author's own transformation method that allows the correlation models to take into account the natural variability of the geotechnical

parameter. Database preparation procedure is presented. The database is intended to provide a high-quality, representative basis for creating the author's own correlations.

In section **7**, three correlation models for the results of CPTU and DMT probings with the parameters of the soil using MLP and LSTM type neural networks are presented. The three presented models differ in the structure and content of the input data set. The first model uses only the results of CPTU sounding, the second model additionally takes into account the type of soil, and the third model additionally uses the results of DMT sounding. For each model, the output layer was the geotechnical parameter after applying the author's transformation method. Thanks to this, an increase in network predictions efficiency of up to 50% is achieved. The exception was the correlation for liquidity index, for which the transformation was unsuccessful. The network hyperparameters were the same for all correlations, and the number of epochs was adjusted individually. The network's prediction results were presented on a test set, and the learning process continued until the smallest error was reached for this set. Thus, the quality of the obtained results was compared with soil parameters from different regions of Poland. In general, the proposed correlation models have good quality in predicting soil type, liquidity index, friction angle, cohesion, undrained shear strength and compressibility modulus from the results of CPTU and DMT soundings. The effectiveness of prediction differed depending on the correlation model, while the most favorable results were similar for both types of neural network.

Section **8** summarizes the results of the dissertation and presents prospects for future research. The author notes that the results can easily be verified or updated with additional research data. In the longer term, new models should be created that will include additional data from other soil investigations as input to the network. Using the proposed models, an attempt can also be made to interpret other geotechnical parameters. The author notes that automation of certain network-building processes could make it possible to find better fitting network predictions. This would have a particularly great impact on improving the final results of the LSTM network, due to its very complex structure. Another pespective of the LSTM network is that it can be used in predicting geotechnical parameters for unexplored areas.

At the end of the paper there are appendices, which contain the full results of the designed networks considering both training and test datasets, graphs of the learning process of these datasets in function of epochs, and a summary of the layers selected for creating correlations.

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