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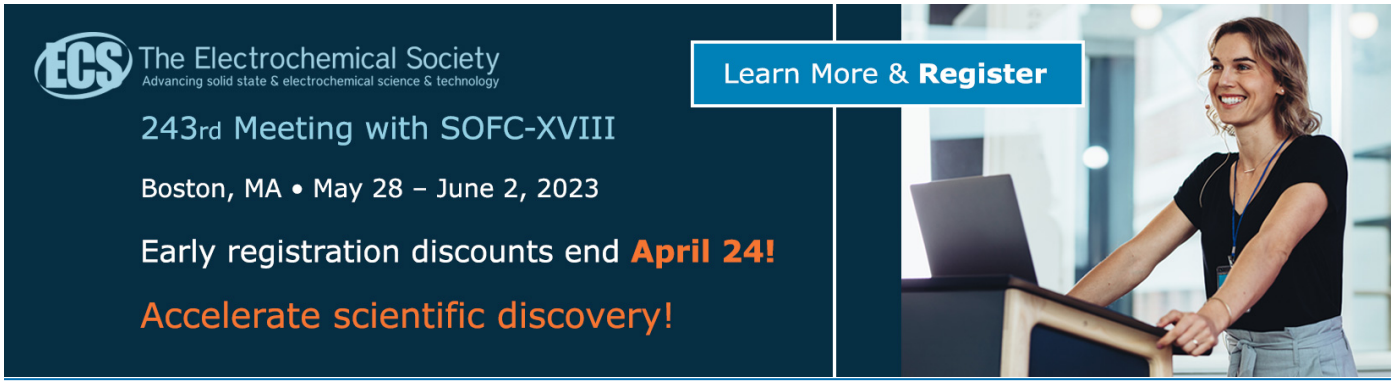

Development of a static plate test finite element calculation model

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Abstract. In the last few years as the budget for the road sector has been decreasing in Latvia, the number of road pavement structure reinforcement projects has been increasing. In order to ensure the long-term viability of the road it is necessary to assess the load-bearing capacity of the existing road structure and the subgrade. During the geotechnical research, the load-bearing capacity of the existing base layers is assessed using static plate test. However, the accuracy of the results is strongly influenced by the thickness of the existing asphalt layer and the size of the dismantled asphalt area. In order to determine the load-bearing capacity of the existing road base in the deeper layers, the engineer performs a subjective experience-based interpretation that is not based on mathematical calculations. With the development of geotechnical survey equipment and engineers' understanding of the bearing capacity of the subgrade, it is also possible to use other field research methods, such as probing and interpretation of their data. Various software's for soil calculations have been developed worldwide. With the help of software's, it is possible to evaluate the properties of soil layers, predict deformations and develop reinforcement solutions, however, the obtained results do not reflect the basic bearing capacity, which is expressed in MPa units. It is planned to develop a Finite Element Method simulation of static plate test based on the values of the soil layer parameters obtained from the interpretations of the probe data and to compare the results with the static plate test performed on site. The aim of the study is to determine whether the load-bearing capacity of the existing base can be accurately determined by finite element calculations - a simulation of a static plate test based on the physical-mechanical properties of the soil determined during the geotechnical survey.

Keywords. Road bearing capacity; Roads; Road construction; Soil reinforcement; Static plate load test;

1. Introduction

In Latvia significant funding for the road sector came from the European Union structural funds, but from year 2020, road construction and reconstruction had become dependent on the state budget. Because of decreasing road sector funding, the number of pavement reinforcement projects has increased significantly. By not envisaging a full pavement construction, it is possible to significantly reduce the project costs, thus it is possible to optimize the available funds for road reconstruction.

When designing the pavement reinforcement project (partial construction of the road structure), the most important thing is to accurately assess the bearing capacity of the existing pavement structure base layers. During the geotechnical investigation, the compaction and residual bearing capacity of the

existing pavement structure base layers is determined using the static plate test. The static plate test is also used during road construction to control the quality of the constructed pavement layers and the achieved bearing capacity.

Considering that the geotechnical investigation is carried out at the initial stage of the development of the road project, it is very difficult to define in which sections of the road it would be possible to envisage the construction of an incomplete pavement structure and at what depth it would be necessary to determine the residual bearing capacity of the existing foundation. In a previous study [1] (E. Virsis, A. Paeglitis and A. Zarins (2021)) it was determined that the results of the static plate test are significantly affected by trial test pit size because remaining asphalt layer affects the development of deformations in the base layer. The geotechnical research data do not give accurate results if a sufficiently large trial test pit area is not prepared, but taking into account the fact that it is not possible to create at least 1.5x1.5 m asphalt section during the research, then the engineer must estimate the approximate reduction in load-bearing capacity depending on the size of the trial test pit created during the geotechnical research. Therefore, during the geotechnical research, it is important to perform photo fixations when creating the trial test pits and performing the static plate tests, because with the help of photos it is possible to assess the test conditions.

In the road project, assuming the full construction of the road structure, a minimum bearing capacity of subgrade is 45 MPa. However, during construction, problems often arise to achieve the required load bearing capacity, thus additional costs arise to build additional solutions to ensure the load bearing capacity. Taking into account that during construction, the bearing capacity is determined with the help of a static plate test, it is necessary to analyze whether it is possible to simulate this test with the help of a finite element program. In this way, already during the development of the project determining the sections of the road where there might be problems in achieving the required bearing capacity.

Due to the considerations described above, it is important to analyze whether it is possible to simulate the static plate test in finite element calculation programs. In this way, it would be possible to significantly improve the quality of the analysis of the existing base bearing capacity and reduce the amount of unforeseen costs, as well as possible deformations of the road structure.

2. Objectives

Incorrect assessment of the existing pavement structure properties and residual load-bearing capacity can create significant risks of structural deformations in the new road structure. As a result, the road may lose load-bearing capacity and incur unforeseen costs.

The aim of this work is to analyze whether with the finite element calculation program, it is possible to simulate the static plate test to determine the bearing capacity of the existing foundation at the required depth. For FEM calculations was used the physical-mechanical properties of the soil layers determined during the geotechnical investigation. Using probe test interpretations was determined existing soil/pavement layer properties – unit weight, Poisson's ratio, young's modulus, cohesion, friction angle, dilation angle, void ratio. As part of this work, the data of geotechnical research of the roads P86 [2] (Serene-Kalniesi 33.59 - 37.87 km section) and A10 [3] (Riga-Ventspils 13.30 - 19.20 km section) were analyzed.

3. Static plate load test simulation

The static plate loading test is used to assess the deformation properties of the soil, the load-bearing capacity of the existing foundation, as well as the compaction of structural layers. This test can be performed on all types of dispersed (loose) soils, embankments and rocky soils, but is not normally used on very soft and fine-grained soils.

Plate load test is performed based on German standard DIN 18134. The loading of the plate must be carried out with a gradual increase in pressure. The loading test consists of three stages – the first-time loading when a pressure of 0.5 MPa is reached with at least 6 loading steps; unload (3 pressure reduction stages (50%, 25% and ~ 2% of maximum load)); followed by a second-time loading, during which the load must be increased to the pre-final load level of the first cycle [4] (DIN 18134:2012).

Finite element model and loading stages were made according to German standard DIN 18134 with three stages – loading, unloading and repeat loading. The physical and mechanical properties of the soil layers used in the calculations were obtained by performing static and dynamic probe interpretations. Using the photo fixations made during the geotechnical investigation, the size of each trial test pit area and the position of the static plate test were determined.

By evaluating all the initial data (thicknesses of the soil layers, physical-mechanical properties, loading cycles of the static plate test and other parameters), a finite element calculation model was developed. The static plate test simulation model is shown in Figure 1. The size of the trial test pit area (the area of removed asphalt) was 34cm in diameter and corresponded to the conditions that existed during the geotechnical investigation. The static plate test in figure 1 was carried out by loading the existing crushed stone base layer.

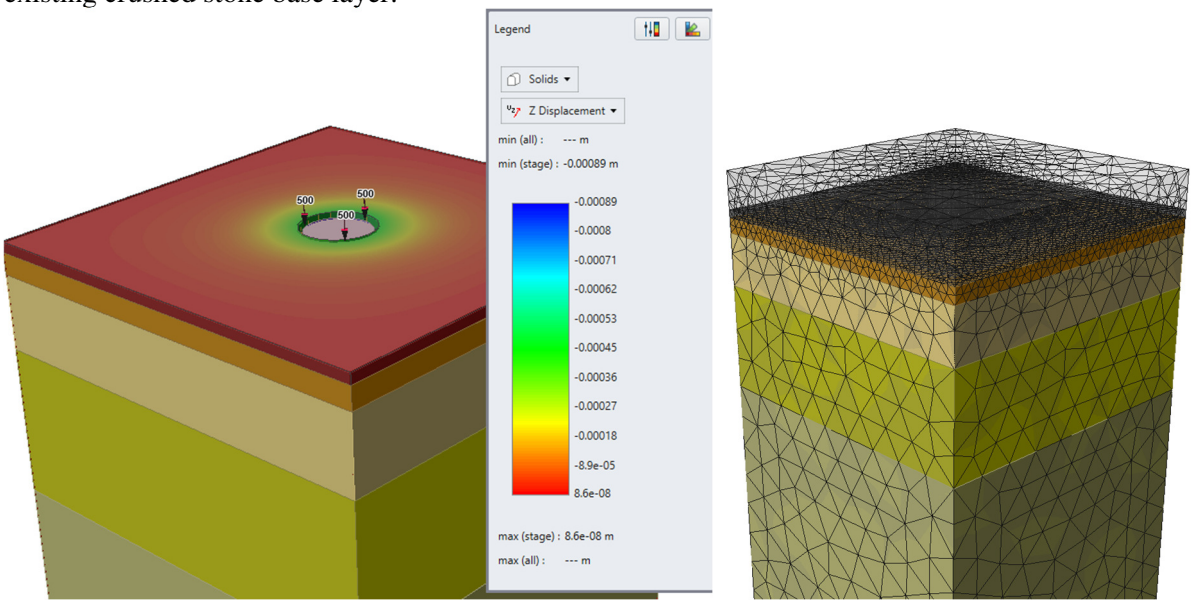

Figure 1. Static plate test simulation model

In the static plate simulation, the load was applied according to DIN 18134 with 6 loading stages in first loading cycle, 3 unloading stages and 5 loading stages in second loading cycle. At each of the loading stages, the vertical deformation of the static plate was determined and the collected data was processed to obtain a graph of the static plate test (see figure 2.) from which was expressed the bearing capacity values Ev1 (first loading cycle) and Ev2 (second loading cycle) of the existing foundation.

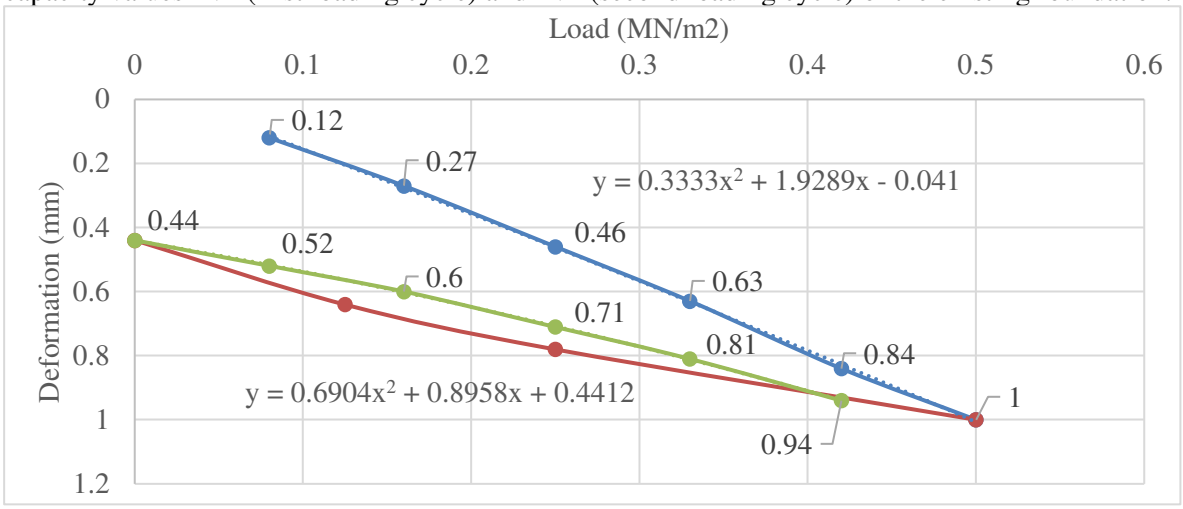

Figure 2. Static plate test simulation result graph

4. Data analysis of geotechnical research of road P86

As part of this work, the data of geotechnical research of the road P86 (Serene – Kalniesi) were analyzed. In order to determine the deformation and strength properties of the existing base layers of the road, static plate loading tests (PLT), static probing tests (CPT) and dynamic probing tests (DPT) were duplicated at 4 points in the carriageway part (Celuprojekts (2022)) [2].

In order to determine which of the geotechnical research methods (static probe or dynamic probe) provides more appropriate soil parameters, static plate test simulations for road P86 were performed using the data interpretations of both probing methods. The results of the calculations made with the finite element method were compared with the result of the static plate test, which was carried out on the road section during the geotechnical investigation. Although the most important goal of the study is to analyze whether it is possible to accurately determine the residual bearing capacity of the existing foundation (see figure 4.) with the simulation of the static plate test, a comparison of the bearing capacity of the first loading cycle was also carried out (see figure 3.).

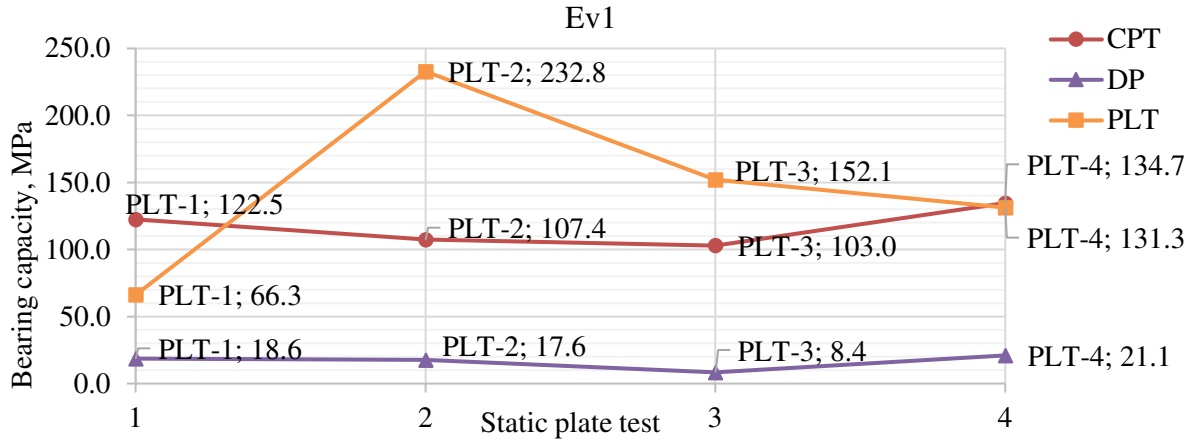

Figure 3. Residual load-bearing capacity of the existing base of the first loading cycle

In figure 3. shown results and estimated values from static plate first loading cycle. As can be seen from the obtained finite element calculation results static plate simulations using dynamic probing data gives low Ev1 values. The results were about 10 times smaller compared to the other two calculations.

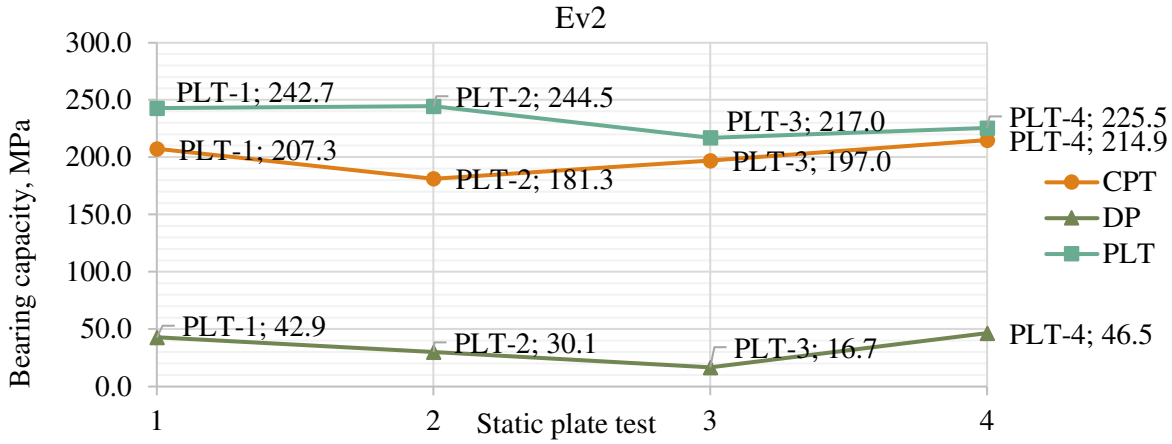

Figure 4. Residual load-bearing capacity of the existing foundation

In figure 4. shown the bearing capacity of the existing base. Finite element simulation using static probing test (CPT) data provide relatively accurate results compared to the static plate test (PLT) performed during geotechnical investigation. Calculations using dynamic probing data (DPT) interpretations gives a much lower bearing capacity of the existing foundation, so it is not possible to

use these data for static plate test simulation. Considering the large differences in results, only the results of the CPT and PLT are compared in figure 5.

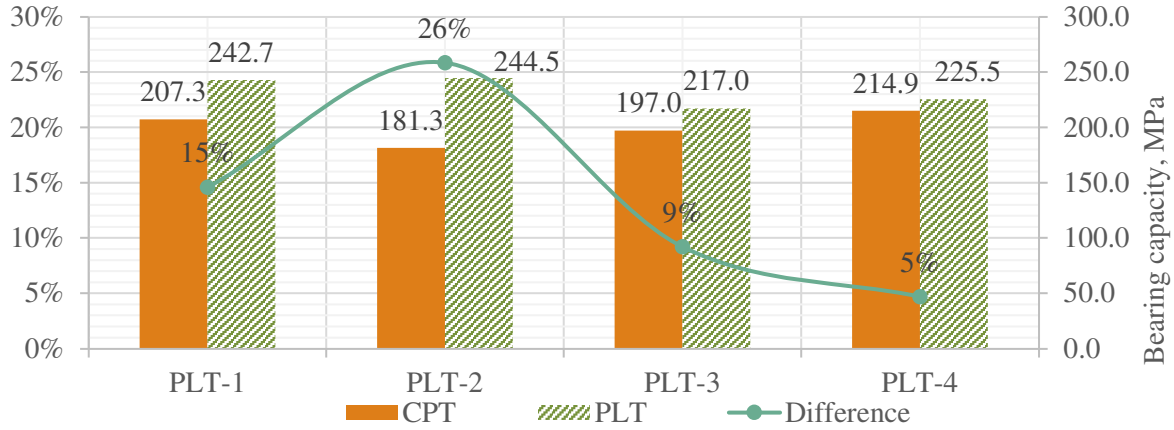

Figure 5. Comparison of the obtained results

In figure 5. shown the comparison of bearing capacity obtained with static probing data simulations and static plate tests done during geotechnical research. Biggest difference in results was 26 percent, but closest results was within 5 percent. The biggest differences in the obtained results may have arisen as a result of the existing asphalt layer. During geotechnical research is made trial test pit for plate test removing only small part of asphalt layer. The remaining asphalt affects the development of deformations in the base layer and therefore affects obtained results.

5. Data analysis of geotechnical research of road A10

As part of this work, the data of geotechnical research and construction work quality of the road A10 (Riga-Ventspils) were analyzed. During road construction was made test section where 5 static plate tests (PLT) and 5 static probing tests (CPT) was duplicated on unbound pavement structures (Celuprojekts (2018)) [3].

The results of the calculations made with the finite element method were compared with the result of the static plate test, which was carried out on the road section. Although the most important goal of the study is to analyze whether it is possible to accurately determine the residual bearing capacity of the existing foundation (see figure 7.) with the simulation of the static plate test, a comparison of the bearing capacity of the first loading cycle was also carried out (see figure 6.).

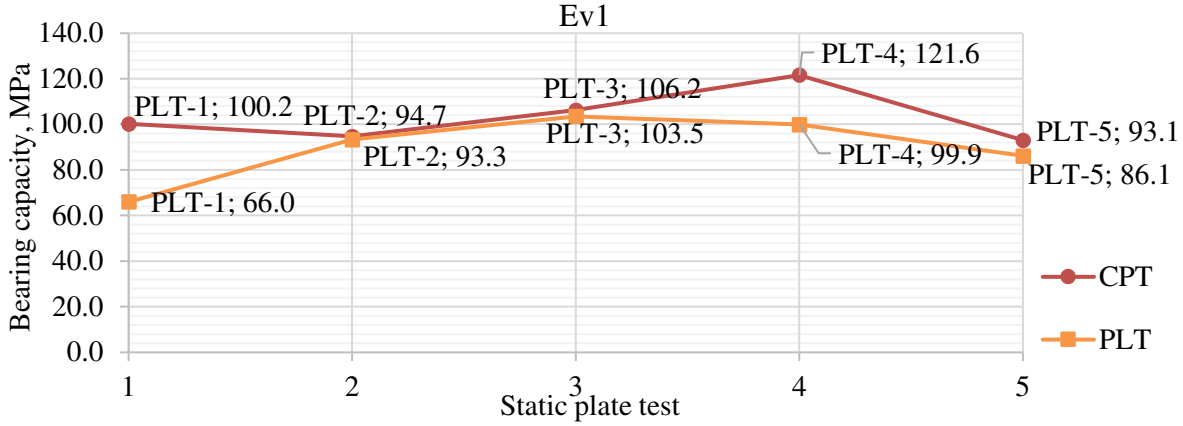

Figure 6. Residual load-bearing capacity of the existing base of the first loading cycle

As can be seen from the figure 6. the results obtained by static plate test simulation and static plate test done on the road section are equivalent. At some points, the differences are slightly greater, but the main goal of research was to compare the load-bearing capacity of the existing foundation.

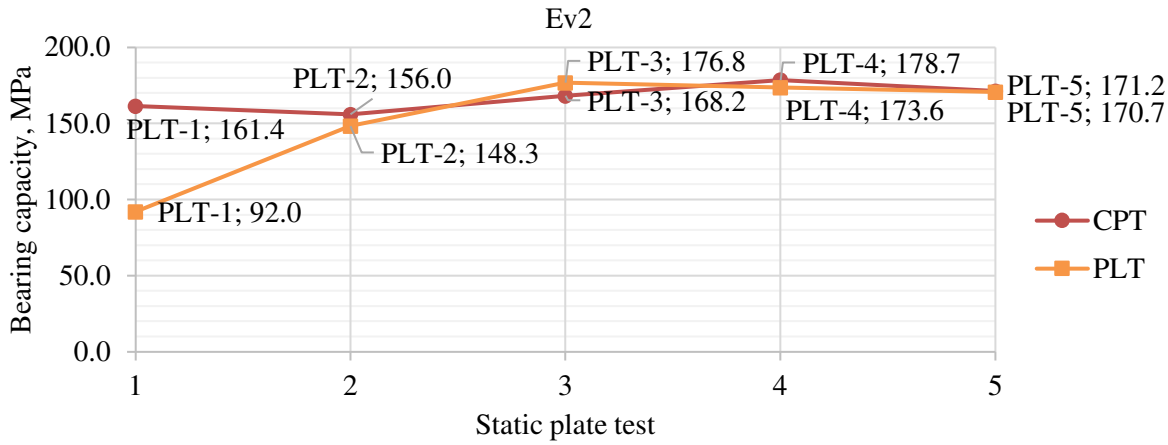

Figure 7. Residual load-bearing capacity of the existing foundation

In figure 7. shown the bearing capacity of constructed base layer. The results obtained are very accurate. The bearing capacity of foundation determined during geotechnical research at 1st point is relatively much lower than determined in other 4 points. Therefore, the static plate loading test performed on site may have been incomplete and the data obtained have been inaccurate. Obtained results difference of the CPT and PLT are compared in figure 8.

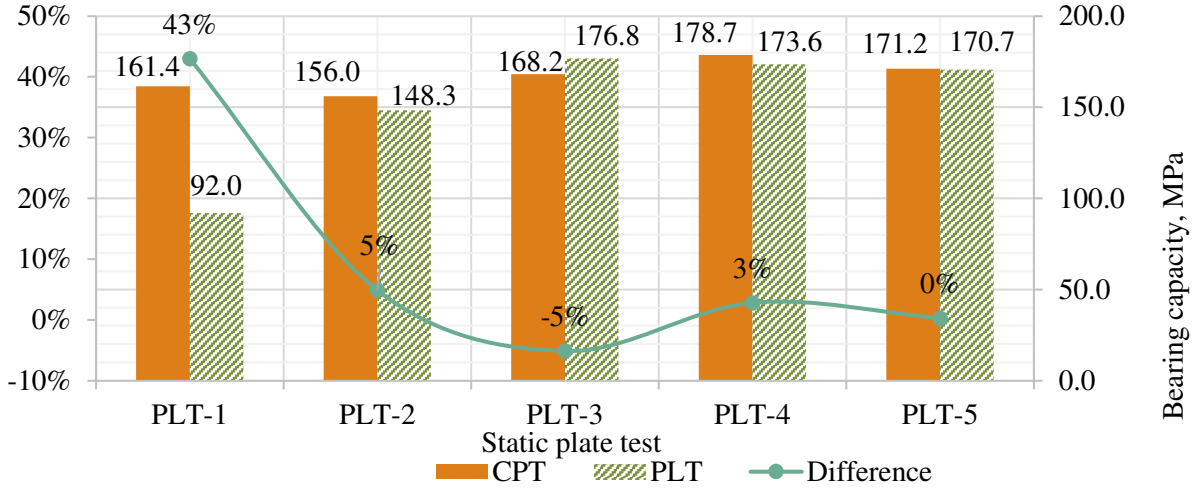

Figure 8. Comparison of the obtained results

As can be seen from the figure 8., the average difference in results is within 3 percent. It is possible to conclude that the residual bearing capacity of the existing foundation can be determined using the finite element method by simulating the static plate test, using the physical-mechanical properties of the soil obtained from the interpretations of the static probing test.

The existing bearing capacity of the foundation determined by the static plate test at the first point is relatively much lower than at other locations, so the test may have been incomplete and the data obtained are inaccurate.

6. Conclusions

The bearing capacity of the existing foundation can be evaluated by performing static plate test simulations using static probe data interpretations.

It is not possible to use the interpretations of the dynamic probe for the simulation of the static plate test, because the obtained results show a significantly lower bearing capacity.

Calculations performed on unbound pavement structures provide very accurate results.

During the geotechnical research, it is important to perform photo fixations when creating the trial test pits and performing the static plate tests, because with the help of photos it is possible to assess the test conditions.

It is necessary to continue the research by analyzing the bearing capacity of the existing ground surface.

Acknowledgements

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