EVALUATION OF THE RESIDUAL LOAD-BEARING CAPACITY OF THE EXISTING ROAD USING PLATE LOADING TEST

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Abstract. In the last few years as the road construction budget has been decreasing in Latvia, the number of road construction reinforcement design and construction objects has been increasing. At the beginning of the project development of the existing road condition is assessed, taking into account various pavement evaluation criteria and it is determined on which road sections it is possible to reinforce the pavement and where full construction is required. The road pavement structure in Latvia is developed using "Recommendations for road design. Pavement" and inaccurately defining the bearing capacity of the existing foundation can significantly affect the service life of the designed structure. During the construction of the road, establishing that the bearing capacity of the existing foundation is lower than specified in the project incurs additional costs for the customer. Project changes are made, and special solutions are provided in order to achieve the bearing capacity on the mineral material layers defined in the project. One of the most accurate ways to determine the bearing capacity of existing road structural layers is the static plate test. However, the results of this test are also not 100% accurate and any of them may give unreasonable results due to various influencing factors. The aim of this work is to analyze the results of static plate test by determining the most important factors that affect the obtained load-bearing capacity values, identify biased / erroneous test results, and determine which results reflect the residual load-bearing capacity of the existing road structure.

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

Introduction

In Latvia significant funding for the road sector came from the European Union structural funds, but from 2018 it is decreased from 124 million euros to 63.2 million euros in 2019. It means that in the coming years, road construction and renovation will become increasingly dependent on the state budget. Europe has defined the goals for the next period, which do not actually include road construction and similar projects, however, the European Commission points out it is possible that Latvia could obtain a small amount of funding for roads. However, we cannot rely only on the European Union structural funds, and we need to think of another way to increase funding for Latvian roads. To keep the existing national road network in its current state by providing daily maintenance and road construction repairs around 600 million funding for the road sector every year would be needed (Latvian State Roads, December 2019).

According to statistics, 28% of main roads in Latvia are still in poor and very poor condition. Comparing to year 2012, proportion of regional roads in poor and very poor condition has decreased only by 7%, in 2020 a reduction of 50% was planned. Comparing year 2018 to 2012, proportion of regional roads with black pavement has increased only by 5.2%, but 80% were planned. In order to significantly improve the overall condition of the Latvian road network, it is necessary to increase funding for road reconstruction or to look for innovative and cheaper methods to reduce construction costs (Latvian State Roads, December 2019).

In recent years 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. Not realizing a full road construction, it is possible to significantly reduce the project costs, thus it is possible to optimize the available funds for road reconstruction. In order to perform a high-quality road construction reinforcement project, it is very important to analyze the load-bearing capacity and structural condition of the existing road structure and foundations with the help of geotechnical or another research. Incorrect assessment of the existing foundation 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 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. If in the road reconstruction or reinforcement project are specified requirements for the load-bearing capacity or compaction of the prepared soil layers, then the static plate test is considered to be one of the most accurate methods to estimate load-bearing capacity and degree of compaction. Due to the accuracy of the test results and the fast data processing, it is very often used to estimate the residual load-bearing capacity of the existing road base. However,

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we must take into account the fact that the static slab test must be carried out on a perfectly flat and unobstructed surface, either on the ground surface or at a certain depth at the bottom of the trench, thus significantly determining whether the results obtained are adequate and true.

1. Objectives

Inaccurately determining the residual load-bearing capacity of the foundations of the existing road structure can significantly affect the service life of the reconstructed road, increase construction costs by eliminating unforeseen problems, thus reducing the overall quality of the road network.

The aim of this work is to analyze the results of static plate test by determining the most important factors that affect the obtained load-bearing capacity values, identify biased / erroneous test results and determine which results reflect the residual load-bearing capacity of the existing road structure. As part of this work, the data of geotechnical research and construction work quality (load-bearing capacity indicators and compaction of the prepared layers) of the motorway A10 Riga-Ventspils 13.30 - 19.20 km section were analyzed.

2. Plate load test (PLT)

Plate load test is a field test which is commonly adopted to determine the bearing capacity and settlement of soil under a given condition of loading as well as the quality of the compaction works performed on shallow foundations. This test can be performed on all types of dispersed (loose) soils, embankments, and crushed stone layers, but is generally not used in very soft and fine-grained soils. Testing of shallow foundation with a plate must be performed on a flat and smooth surface - either on the surface of the ground or at the foundation of the excavation at a certain depth. If the construction design specifies requirements for the bearing capacity or compaction of the prepared soil layer (ledge), the static plate method is one of the most accurate methods for determining this load-bearing capacity and compaction degree. It should be noted that with a standard stamp of Ø 300 mm the soil is tested at a depth of about 60 cm (x2 stamp diameter). Therefore, in cases where a compaction test of a thicker embankment layer is required, the tests should be carried out gradually when the corresponding embankment layer is heaped up and compacted (Ģeo eksperts, 5 March 2021).

Plate load test is performed based on German standard DIN 18134 (Testing procedures and testing equipment – Plate-loading test). The loading of the stamp must be carried out with a gradual increase in pressure. The pressure recommended by DIN 18134 for the standard stamp of Ø 300 mm, which must be achieved by loading, is 0.5 MN/m2 (or 0.5 MPa). The load shall be increased in not less than six stages or steps approximately of the same degree until the aforementioned maximum pressure is reached. Each change of load (from step to step) must be completed within one minute. The loading test consists of three stages – the first-time loading when a pressure of 0.5 MN/m2 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 (so that a full load of 0.5 MPa would not be achieved).

After performing the test at the site, the data obtained are processed and the results are evaluated in the office. Based on the recommendations given in DIN 18134, calculations can be done manually based on the calculation formulas provided by this standard but can also be done using special computer software designed for this purpose. As a result of the static plate-loading test, the following main parameters are obtained: EV1 (after first-time loading results) and EV2 (after second time loading results) deformation modules as well as the ratio of these modules EV2/EV1. In the construction practice, the value EV2 and the ratio EV2/EV1 are mainly used. The value EV2 shows the bearing capacity and deformation properties of the tested soil, but the ratio EV2/EV1 indicates the degree of compaction of the particular soil type (Ģeo eksperts, 5 March 2021).

3. Geotechnical research

During road reinforcement and reconstruction projects, geotechnical research of the existing soil and road surface is always performed. Depending on the road category and the traffic intensity of the vehicles, the design task defines the minimum requirements for geotechnical research, which includes soil drilling, various soil in situ tests, static loading plate, laboratory tests of soil samples and other studies.

Justification of geotechnical research - to provide the customer with the necessary information to ensure the development of a full-fledged road pavement reinforcement (reconstruction) project. To provide the information necessary for road engineers about the existing roadway pavement structure, road embankment and natural subsoils including the structural layer of the road surface the composition, properties and distribution of the soil layers, both in section and in direction. The task of geotechnical research is to obtain information on the structure of the road surface, the properties of the road pavement structural layers and the characteristic values of the geotechnical parameters of the natural subsoil by installing exploration wells and removing soil samples, as well as performing in-situ tests and laboratory tests. (Ceļuprojekts, 2018).

Geotechnical research on the state main highway A10 Riga-Ventspils 13.30 - 19.20 km section was performed by the Geology Department of AS "Ceļuprojekts" (see Figure 1). During the geotechnical research, a total amount of 170 survey points was made on the road section: 34 boreholes next to the road slope foot (borehole depth 1.0… 3.0 m) and 136 boreholes on the roadway part, as well as on the roadside (borehole depth average 1.0 m). The total volume of drilling works was 228.6 m. In order to determine the physical and mechanical properties of the road structural layer and natural soils, dynamic probing was performed at a depth of 3.0 m at 15 research points. The total volume of dynamic probing was 45.0 m. In order to determine the deformation and strength properties of the existing base layer of the road, static plate loading test were performed at 34 points in the carriageway part. During the drilling works, 68 samples of pavement asphalt concrete were taken from the exploration boreholes to determine the binder content, granulometric composition, penetration and softening temperature; 34 samples of structural layers of the road with disturbed structure for determination of granulometric composition; and 25 samples of lying natural soils with disturbed structure for soil type determination. (Ceļuprojekts, 2018).

Figure 1. Geotechnical research on the state main highway A10 Riga-Ventspils 13.30 - 19.20 km

The base of unbound mineral materials in the exploration site of the existing road base is mostly variable in composition and thickness, it consists of dolomite crushed stone with gravel or gravel with pebbles. But the base sub-layer consists of gravel with pebbles or gravel with a mixture of pebbles and dolomite chips. The total thickness of the road base layer varies from 0.22 to 0.55 m, average 0.35 m. The deformation modulus/ bearing capacity (Ev2) of the existing base layer in the research phase was significant and indicates a high degree of compaction of the base layer. The modulus of deformation Ev2 varies from 161 to 374 MPa. In road kilometer 15,8km (SKT-51 / PLT-15) Ev2 was relatively lower and reached 121 MPa. The parameter ratio Ev2 / Ev1 characterizing the degree of compaction varies from 1.07 to 5.00. (Ceļuprojekts, 2018).

The frost-resistant layer was found during the field work at all research points, just below the base layer. The frost-resistant layer consists of fine-grained, dense to medium-dense sand. The thickness of the layer varies from 0.20 to 0.60 m, the average thickness is 0.30 m. In some places, the frost-resistant sandy mixture contains pebbles or crushed stone. The content of clay particles (particle size <0.063 mm) varies in the range from 2.0 to 5.6%. The organic matter content in the round is <2%.

Using the results of the geotechnical research of the static plate test, a summary of the basic load-bearing capacities of the existing structure has been developed (see Figure 2).

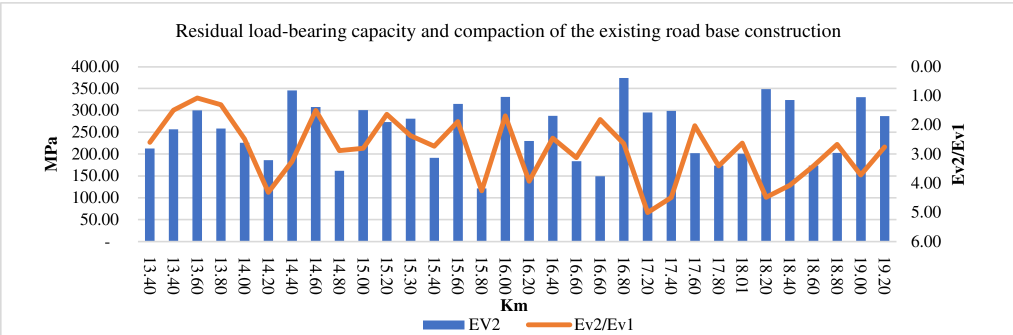

Figure 2. Residual load-bearing capacity and compaction of the existing road base construction

The Figure 2. shows the load-bearing capacity and the compaction of the existing base. Obtained result analyze proved, that it is possible to observe the correlation between compaction and load-bearing capacity. As the compaction of the base layer is increasing, its bearing capacity also increases. In the obtained results there are some sections in which this correlation is not observed, for example, in the section from 16.8 -17.4km, 18.2-18.4km and 19.0-19.2km. To make sure, why these sections, have such a high load-bearing capacity, considering low degree of compaction, the relationship between the load-bearing capacity and the existing crushed stone / gravel base thickness must be compared (see Figure 3).

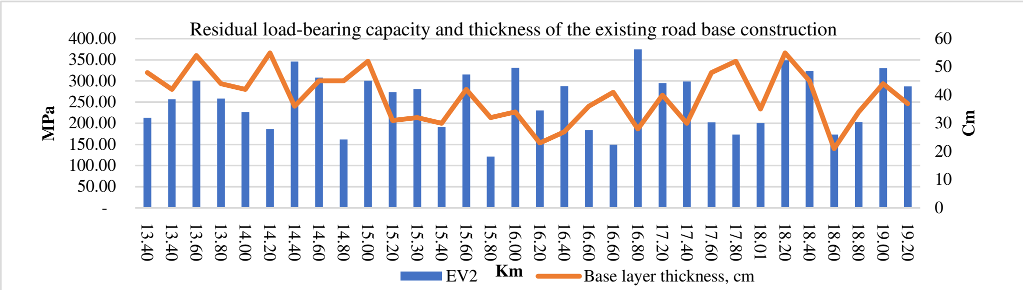

Figure 3. Residual load-bearing capacity and thickness of the existing road base construction

The Figure 3. shows the load-bearing capacity of the existing foundation depending on the thickness of the base layer. There is no unambiguous correlation in the obtained results and it is possible to conclude that the compaction of the structure has a much more significant effect on the load-bearing capacity of the existing foundation. In the previously determined sections from 16.8 -17.4 km, 18.2-18.4 km and 19.0-19.2 km, it can be observed that the thickness of the basic structure varies in the range from 30 to 55 cm. In the previously determined sections from 16.8 -17.4 km, 18.2-18.4 km and 19.0-19.2 km, it can be observed that the thickness of the basic structure varies in the range from 30 to 55 cm. In the section from 18.2-18.4 km and 19.0-19.2 km the thickness of the existing base is larger than in the adjacent sections and it is possible that a high load-bearing capacity of the existing base structure was achieved here despite the low degree of layer compaction. The high load-bearing capacity of the section 16.8-17.4 km with the base thickness and compaction cannot be justified.

4. Road reconstruction

According to the data of geotechnical research, during the design the load-bearing capacity of the existing foundation is analyzed and the calculation of the road pavement structure is developed. There are no common assumptions about how to accurately determine the remaining load-bearing capacity of an existing foundation, so it is the engineer's responsibility and duty to carefully analyze the available information to develop a quality project. Inaccurately determining the remaining load-bearing capacity of the existing foundation may affect the course of construction, and during the construction of the real situation, it may be necessary to develop special solutions for strengthening the existing foundation or significantly change the design of the intended pavement structure.

In the project was designed the construction of a pavement reinforcement solution consisting of an existing foundation, a 20 cm thick layer of recycled material and three layers of asphalt (see Figure 4). On the existing base layer, was defined that it is necessary to achieve a load capacity of 90MPa. Such load-bearing capacity indicators were determined by performing calculations using the "Road Design Recommendations Road Pavement" methodology. Using this calculation methodology, we obtain the theoretical values of the bearing capacity of the layers. Based on the data of the realized road projects, it can be stated that there is a correlation between the theoretical bearing capacity calculation values Eekv and the static plate test values Ev2, therefore the value obtained in the calculation of the ICP methodology was determined as the remaining load-bearing capacity of the existing base.

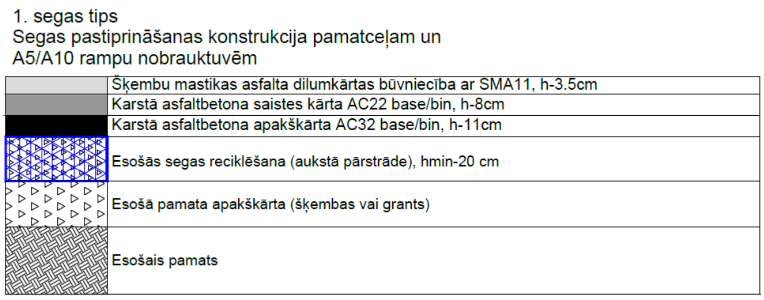

Figure 4. Designed road construction

The static plate test measurements were made on the existing road base layer during the reconstruction to make sure about the possible implementation of the developed solution and about the estimated load-bearing capacity of the existing road base. Initially, the old asphalt concrete structure was milled and the test was performed on the existing foundation under it.

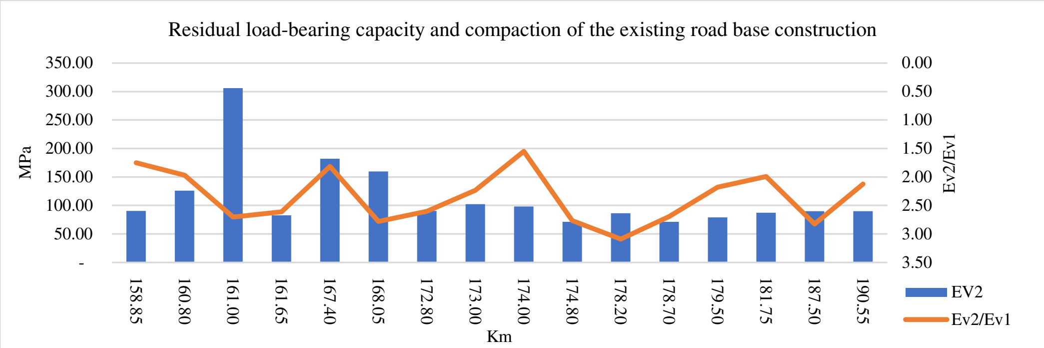

Figure 5. Residual load-bearing capacity and compaction of the existing road base construction

The Figure 5. summarizes the load-bearing capacity indicators of the existing foundation determined during construction. According to the obtained results, it can be seen that the average load-bearing capacity of the existing base is about 90MPa, therefore it can be concluded that the load-bearing capacity of the existing base has been determined accurately. Compared to the results obtained during the geotechnical survey, there is no clear correlation between the basic compaction and the changes in bearing capacity.

5. Residual load-bearing capacity analysis

During the development and implementation of each road project, a geotechnical research is carried out. With the help of geotechnical research engineers try to determine the properties of the existing soil layers and road construction parameters. During construction, the quality of the constructed layers is monitored by determining the load-bearing capacity and compaction of the layer. It is safe to say that the static plate test is performed during the design and construction of each road, so it is important to understand the interrelationships that could be used to determine the load-bearing capacity of an existing foundation. The Figure 6. compares the load-bearing capacity of the existing foundation found during geotechnical research and construction.

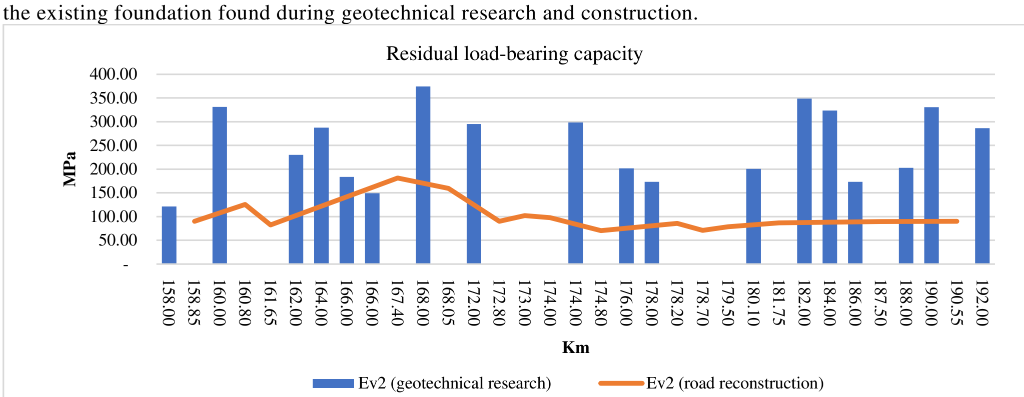

Figure 6. Residual load-bearing capacity

Comparing the load-bearing capacity determined during the project development and construction, it can be concluded that the results obtained in the geotechnical research are about 1.8 times, or by 80% higher than those determined during construction. Such a reduction in load-bearing capacity may create risks that an inexperienced engineer in the project will define the load-bearing capacity of the existing foundation based only on the results of the static plate test results obtained during the geotechnical research. The actual basic load-bearing capacity are influenced by other parameters of soil properties and, of course, there are other factors (heterogeneity of the geological situation, self-weight of asphalt concrete and geotechnical research results and others) that can significantly affect the results achieved.

One of the most important factors influencing the results could be the different static plate test loading conditions. During the geotechnical research, a small area of asphalt concrete is cut out to form a trial site pit in order to be able to get to the existing foundation structure, perform a static plate test and determine which soil layers are in the road structure and ground. During construction, the static plate test is performed when there is no other material on top of the tested layer that could affect the static plate test results. In order to ascertain how much the load-bearing capacity values of the existing base change taking into account different test conditions, a theoretical finite element calculation was performed (see Figure 7) by simulating a static plate test based on geotechnical research interpretations of soil layers and layer thicknesses. The calculation was based on the test procedure described in DIN 18134 (Testing procedures and testing equipment - Plate-loading test).

Name	Colour	Initial Element Loading	Unit Weight (kN/m3)	Peak Cohesion (kPa)	Peak Friction Angle (°)	Peak Tensile Strength (kPa)	Residual Cohesion (kPa)	Residual Friction Angle (°)	Residual Tensile Strength (kPa)	Dilation Angle (°)	Young's Modulus (kPa)
Skembas		Field Stress & Body Force	19	0	35	0	0	35	0	0	260000
SMILTS, smalka, blīva		Field Stress & Body Force	21	0	36.45	0	0	32	0	4	34690
SMILTS, smalka, vidēji blīva,		Field Stress & Body Force	19.7	0	33.85	0	0	31	0	3	25160
metals		Field Stress & Body Force	78	0	90	350000					200000000
Asfaltbetons		Field Stress & Body Force	22	400	45	0	200	40	0	0	2000000

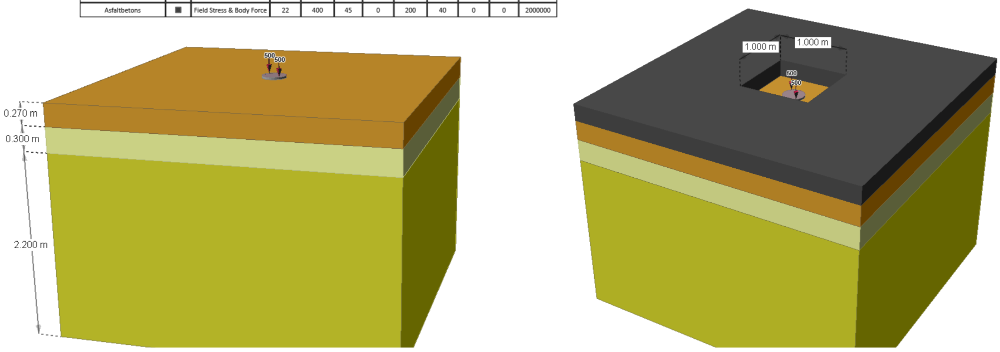

Figure 7. Finite element calculation model

The developed finite element calculation was based on the dynamic probe test DPM-62 (16.4 km). The left side of the Figure 7 shows the static plate loading scheme during construction, and the right side shows the approximate loading conditions during the geotechnical survey. In limited traffic conditions, much smaller trial site pits are often made during geotechnical research, but a 1x1m viewport is assumed for analytical calculation. The diameter of the static slab is assumed to be 0.3 m and the first load cycle is performed in 7 steps until the maximum load is reached, but the second cycle is performed in 6 steps (see Figure 8). At each loading stage, the achieved deformation is recorded and, similarly to the static plate test equipment, deformation curves have been developed.

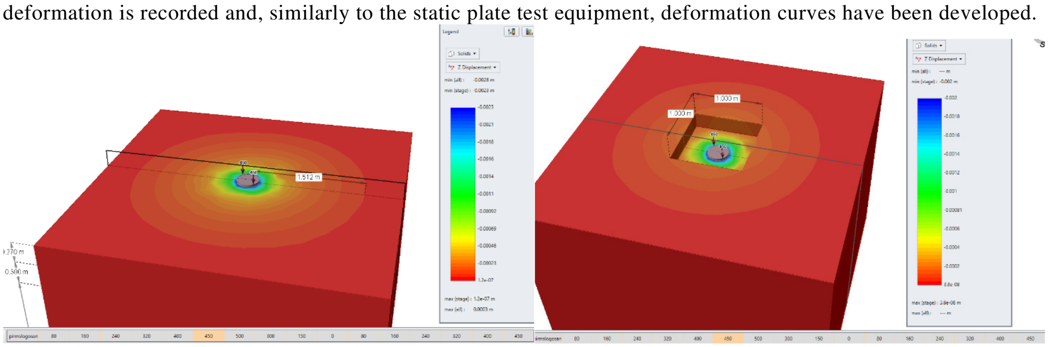

Figure 8. Finite element calculation results

According to the finite element calculation model, it was determined that the applied load spreads within a radius of approximately 1.5 m from the loading center. If the old asphalt concrete is above the existing base layer structure, the soil layer deformations during static plate test is slightly smaller (maximum deformation without asphalt layer - 2.8 mm, but with asphalt layer - 2.3 mm). It’s because the base layer cannot deform sideways and up, because the asphalt layer does not allow it.

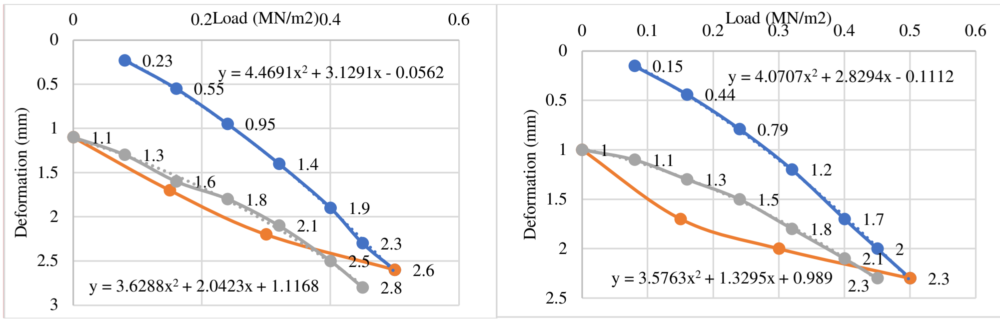

Figure 9. Finite element model load-bearing capacity calculation

Significant differences in the results were obtained in the calculated theoretical load-bearing capacity of the existing base (see Figure 9). The diagram on the left shows the load curve for a foundation without an asphalt concrete structure, but on the right considering the construction of the trial test pit. The following results were obtained:

- Construction without asphalt concrete surface (road construction) – Ev1=105,97MPa; Ev2=152,58MPa; Ev2/Ev1=1,43,
- Construction with asphalt concrete surface (geotechnical research) – Ev1=117,26MPa; Ev2=203,39MPa; Ev2/Ev1=1,73.

According to the finite element calculation models, the load-bearing capacity of the existing basic structure shows a difference of 50MPa, or 30%. In fact, by reducing the trial test pit area, this difference only increases, and to make sure of this, a third calculation model was developed, the trial test pit area was formed in a circular shape with a diameter of 34 cm. The shape and size of such a trial site pit correspond to the specific geotechnical survey point of the A10 motorway (see Figure 10).

Figure 10. Geotechnical research trial test pit at section 16.4km

The developed third finite element calculation model was based on the same existing soil properties from the dynamic probe test DPM-62. By creating such a small trial test pit, the conformity of the obtained results is significantly reduced in comparison with the real situation during construction, because in addition to the load caused by the static plate test, the self-weight load of the asphalt layer also works on existing foundation structure and asphalt layer limits the deformations of the existing base layer.

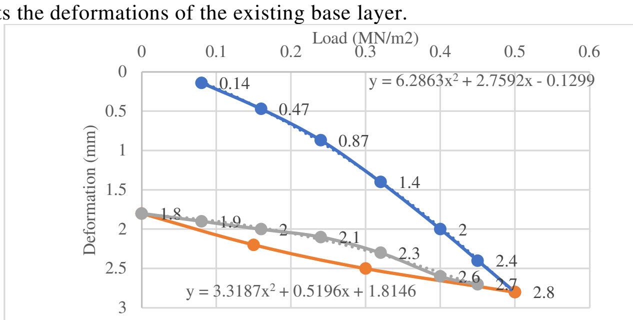

Figure 11. Finite element model load-bearing capacity calculation

The following results were obtained for circular trial test pit (see Figure 11) – Ev1=103,91MPa; Ev2=333,70MPa; Ev2/Ev1=3,21. Comparing the theoretically obtained load-bearing capacities of the existing base with the data of the static plate test results, we can see that during the geotechnical research on section 16.4 km load-bearing capacity determined Ev2=287,1 MPa, but the finite element calculation results showed Ev2 = 333.70 MPa load capacity. The difference of the obtained results is 16% and we can assume that the developed finite element calculation model provides relatively accurate results from which we can conclude the most significant correlations.

All three developed finite element calculation models are based on the same theoretical material properties, but each model has different loading conditions. After analyzing the data, we can conclude that the greatest influence on the test results of the static plate test is provided by the loading conditions, or the fact whether another layer is built above the test layer, which could affect the accuracy of the results. By reducing the trial test pit area from 1x1m to 0.34m in diameter, the value of Ev2 increased by 64%, but comparing to the structure without asphalt, the change in the value of Ev2 is 119%. These indicators give a clear idea that 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.

Conclusions

The actual basic load-bearing capacity are influenced by various parameters of soil properties and there are other factors (heterogeneity of the geological situation, impact of asphalt concrete self-weight on the results of geotechnical research and others) that can significantly affect the achieved results.

The basic bearing capacity determined during geotechnical research can be up to 3 times higher than that found during construction works, therefore it is very important to analyze not only static plate test results, but also soil sample laboratory data, field research data.

Different test conditions have the greatest impact on the load-bearing capacity of the existing base. The existing asphalt concrete or other type of structure located above the test layer prevents obtaining appropriate results, because the created trial site pit has too small area and the base layer cannot deform sideways and upwards, thus achieving higher load-bearing capacity of the existing base than they actually are.

According to the static plate test results, it is possible to observe the correlation that as the compaction of the base layer increases, its bearing capacity also increases. Therefore, in case the existing foundation is not sufficiently dense or the existing foundation layers are made of loose or soft ground the load-bearing capacity will be significantly lower and solutions should be sought during the project development to compact the loose or soft ground so that full road construction does not have to be rebuilt.

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.

Reducing the trial test pit size increases difference between load bearing capacity results comparing the geotechnical research and road construction work conditions.

Acknowledgements

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