DETERMINATION OF THE COMPRESSION MODULUS WITH A DYNAMIC CIRCULAR PLATE

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Abstract

Geotechnical soil tests in order to achieve the best possible performance of new buildings or rehabilitation of existing buildings occupy one of the leading places in construction. Due to the lack of investigative work, a large number of buildings are exposed to danger. In order not to have bad effects on buildings in the future, it is necessary to minimize ground subsidence. Testing of the compressibility modulus / determination of the compressibility modulus is performed during the construction of roads, railways, buildings, parking lots and embankments, on the foundation soil, replacement layers, bedding and embankment layers and buffer. The purpose of the test is to ensure that, due to insufficiently compacted layers during installation, they do not settle after some time, as well as cracking of the floor in the building, deterioration of part of the building, deterioration of the pavement structure of roads and parking lots (potholes), etc. A circular plate is the name for an instrument used to test the compressibility module of a building's foundation. A dynamic test with a falling weight plate enables simpler and faster testing and immediate results.

Keywords: *geotechnical tests, compressibility modulus, dynamic circular plate, settlement.*

1 INTRODUCTION

It is essential to obtain accurate data on the condition of the soil before construction or before determining the method and use of the machines that will be used to compact the soil. It is certainly necessary to know the soil on which it is being built by carrying out geotechnical tests. One of the significant characteristics of the foundation soil is its compactness. During compaction, the soil particles are more densely packed, and the total porosity decreases. Compaction depends on many factors, primarily which compaction machine we use, the deformability of the substrate, water content, type of soil, and similar to that.

To shape / design a building according to the requirements of the investor, as well as according to the requirements of the profession, implies predicting the behavior of the building and the underlying soil, whereby it is necessary to clearly define permissible deformations and other conditions imposed by the use of the building, loads imposed by the location, the structure itself, the building and its use, conditions which enables the soil [10]. Regarding the above, geotechnical tests are being carried out.

They are used to assess the conditions in the underground levels of the land before starting the construction of a building on a certain land. During the test, the location of the object, features of the subsoil, as well as possible problems that may arise during the test or construction process must be taken into account. The duration of each geotechnical test should last until the underground conditions are fully established. Only after this has been determined, construction work can begin.

Laboratory and field investigations are always carried out as part of the investigation. The main goal and purpose of laboratory research work is to examine the physical properties of the soil on specific samples taken directly from the soil under investigation. The following standard laboratory tests are most often performed: oedometer compressibility test, test in a triaxial apparatus, tests for direct shear with controlled increase in deformation and force, screening of material, which determines the granulometric composition of the soil, and Proctor's test [4]. Field works include drilling, in situ tests, geophysical methods, penetration tests, test plate tests and similar to that. The goal of all of them is to determine the engineering-geological conditions in the underground soil and their characteristics at the locations of the research works, by direct inspection of the rocks or soil, by digging excavations or making boreholes from which samples are taken for laboratory tests, and by indirect inspection of the rocks, using insitu experiments and geophysical methods. The in situ experiments also include checks of the compressibility modulus with a static and dynamic circular plate [4].

2 PROPERTIES OF SOIL COMPACTION

One of the biggest safety factors is soil compaction. This is for the purpose of achieving a proper relationship between load capacity and deformations, which affects the usability of the building as well as its lifespan. In order to improve the characteristics of the bulk material, if we use the soil as a building material, the soil is subjected to compaction.

According to the definition, compaction is a procedure that increases the density of the soil, that is, the volume weight of the soil grains are packed closer to each other while reducing the air, while the amount of water in the soil does not change. If the compaction of the soil is higher, the binding strength is also higher, and the deformability of the soil is lower. Controlling the process by which soil and granular materials are compacted is important for all areas involved in construction. In this procedure, it is especially important to distinguish surface compaction in layers from deep compaction.

During the compaction process itself, soil particles are connected faster, structural aggregates are crushed, and overall porosity is reduced. The main goal of soil compaction is actually to improve the technical properties of the soil by reducing the pores in which there is air and often water. Due to the fact that the surface area decreases, the density increases and there is an increase in strength, and the compressibility and water permeability of such material decreases. Also, soil swelling is prevented by compacting the particles. Many factors affect the compaction of the soil, for example: it depends on which machine is used for compaction, what is the deformability of the substrate, what is the amount of water in the soil, what type of soil is it in general. Since all materials do not react equally to this process, the following factors have the greatest influence on soil compaction: the type of material being compacted, the moisture content of the material, the required compaction of the material and the use of machines. The process of compacting earth and other materials depends on the goal of compaction, compaction equipment, material properties, and based on this, we choose the compaction process itself.

2.1 DEEP COMPACTION

Deep compaction is a type of soil improvement in which the best results are achieved by vibro flotation (removal and replacement of material), strong compaction and deep blasting. These methods usually achieve results down to a depth of 10 to 20 m, depending on soil properties, compaction equipment and compaction energy. The soil can be improved to a depth of 40 m with the help of a "giga machine" for impact compaction (weight is 200 t, drop height 40 m), while with vibro flotation, improvements are made to a maximum depth of 60 m [1]. Deep compaction procedures are applied both to improve natural soil and to improve artificial embankments, especially when it is carried out as part of soil drying procedures. Our experience and tests in the field show that deep dynamic compaction significantly increases the resistance to liquefaction and seismic loading of soil and artificial embankments. We have a number of examples from today's everyday life where buildings based on such improved soil are significantly more resistant to seismic impacts than buildings standing on soil that was not improved by dynamic compaction/increase in soil density. This applies to both shallow and deep foundations.

2.2 SURFACE COMPACTION IN LAYERS

The main area of compaction of soil and granular materials in layers is certainly surface compaction. It is required for almost all types of construction, from roads, railways, airports to various types of embankments. In order to achieve the optimal value of compaction, the action of key factors that influence surface compaction, or compaction in layers, is important. These include material parameters, compaction roller parameters, process parameters, vibratory roller operating mode, and oscillating roller drum operating modes.

Following all of the above, we conclude that compaction is a complex process and that a large number of factors depend on its final outcome if one wants to achieve a suitably compacted surface. In addition to the degree of compaction, we must not forget the importance of uniform compaction of the particles.

3 COMPACTION CONTROL

In places where there is interaction between the structure and the soil, as well as on structures consisting of earth or similar granular material, on-site compaction control is important. The application of appropriate control is particularly important for achieving optimal compaction quality as well as for evaluating that quality. Although the application of traditional methods in soil mechanics is successful, it is important to note that it is based only on individual tests, that is, on tests of randomly selected locations. Due to increasingly strict requirements, which are insisted upon during the construction of engineering structures and embankments, today compaction is increasingly controlled continuously, from the beginning of the compaction process itself. This is made possible today by two non-destructive methods: - continuous compaction control (CCC) with a device located on the roller, - spectral analysis of surface waves (SASW) or continuous analysis of surface waves (CSW). However, unlike the CCC procedure, which is performed with a device already mounted on the roller, in the CSW procedure, the roller is used with special external testing equipment that should be placed on a flat ground surface, consisting of an electromagnetic vibrator that generates surface waves and a series of geophones that they receive these waves. Therefore, truly continuous compaction optimization (ie optimization during rolling) is not possible, and extensive calibrations should be performed for continuous compaction control. On the other hand, the advantage of the CSW procedure consists in the depth of penetration, which enables subsequent control of the entire construction [1]. When performing works on roads, embankments and other types of buildings, it is necessary to meet the minimum requirements for material quality. These requirements are prescribed by the general technical conditions (OTU) for certain types of works. Tests of the foundation soil include the determination of the degree of compaction in relation to the Proctor procedure (Sz) or the determination of the compressibility modulus (Ms) with a circular plate with a diameter of 30 cm [8,9].

Thus, we have the following types of materials and criteria for evaluating the quality of the foundation soil:

- Earth materials: (part of excavation category "C" materials - all clays of low to high plasticity and dusty soils)

a) compacted soils composed of coherent earth materials, and the designed embankment is not higher than 2.00 m Degree of compaction Sz(%) 97 Compressibility module (MN/m2) 20
b) compacted soils composed of coherent earth materials, and the designed embankment is higher than 2.00m Degree of compaction Sz(%) 95 Compressibility module (MN/m2) 20
c) Incoherent materials and mixed materials: (excavated materials of categories "A" and "B" and part of materials of category "C", stone materials, mixed stone and earth materials...)
d) compacted soils composed of coherent earth materials, and the designed embankment is not higher than 2.00 m Degree of compaction Sz(%) 100 Compressibility module (MN/m2) 25
e) compacted soils composed of coherent earth materials, and the designed embankment is higher than 2.00m Degree of compaction Sz(%) 95 Compressibility module (MN/m2) 25.

3.1 CONTROL OF COMPACTION IN EMBANKMENTS

In order to protect against large rockfalls, avalanches and mudflows, engineering constructions made of earthen material are used more and more today as high embankments. Protective embankments are mainly affected by dynamic impact loads that are superimposed on static loads, with occasional occurrences of excessive pore water pressure. The degree of particle compaction directly affects the internal and external stability of such embankments. Critical zones are reinforced with geosynthetic material. Since intense compaction increases the joint protective effect, and thus the overall impact resistance of the structure, it is clear why compaction is extremely important. In the design phase, certain properties of excavated materials for installation in embankments are tested, and in the construction phase, their quality is monitored and controlled, as well as the sizes prescribed by the technical conditions.

The project foresees [8]:

- which features of the installed materials and to what extent should be controlled,
- permissible deviation limits that meet the average prescribed value,
- methods of testing and measuring the achieved properties in the laboratory and in situ,
- systematization and analysis of the obtained results.

The quality control of the material incorporated in the embankment by field tests includes all the properties prescribed by the technical conditions of the project. The properties that will be checked depend on the design solutions for the construction of the embankment, the type and purpose of the building, the type and method of installation of materials in the embankment, etc. For road embankments, the most important are strength and compressibility, while for defense embankments and embankments, in addition to the properties listed for traffic embankments, water permeability is also important [8]. The analysis of the results obtained by the control measurement is performed on the basis of all collected laboratory and field data. Usually, for one embankment or dam, there are several individual measurements of various material properties, and it is convenient to perform their processing by statistical analysis, based on the normal Gaussian distribution, and evaluate them with statistical parameters (mean value, standard deviation, coefficient of variation, asymmetry of the curve, etc.).

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The quality of the installation is also controlled through the stiffness of the layer, by an experiment with a loaded circular plate according to EC7/3 (Plate loading test). This type of test is often used to test the compaction of road materials. We can say that this type of test is applied wherever it is desired to check the compressibility of the soil or the compaction effects of soil materials. The aforementioned is usually tested on the spot with a circular plate of standard dimensions. As already mentioned, this test is most often carried out in road construction, in the construction of airports, embankments for various purposes, etc., in such a way as to first determine the bearing capacity of the subsoil and individual parts of the structure, whereby certain criteria and sizes are prescribed that must be satisfied.

5 TESTING WITH A DYNAMIC CIRCULAR PLATE

If the investor wants to be sure that the soil is sufficiently compacted, a fast, simple and financially profitable test method with a dynamic plate will serve. By testing with a dynamic plate, it is possible to obtain information on the dynamic modulus of deformation (Evd) in the field in a short period of time, from which the static compressibility modulus (Ms) can be obtained by simple recalculation. The dynamic modulus of compressibility Evd is obtained through the following expression where:

r = Radius of the loading plate = Load under the plate (N/mm2)
s = deformation amplitude (mm)
1.5 = a factor that includes a number of laws that must be taken into account when loading the soil with a circular plate
The correlation between Evd and Ev2 depends on the type of soil. Ev2 = (1.5-3.0) Evd

Given the large range of the correlation coefficient, it is recommended to perform a parallel test with a static and dynamic plate before starting construction and determine the dependence of the deformation modules. The following correlation relations of the dynamic modulus of deformation (Evd) and the static compressibility modulus (Ms) are used:

for fine-grained soil – Evd ≤ 30 Mpa – Ms = 1.75 (Evd – 10)
for coarse-grained soil – Evd ≤ 30 Mpa – Ms = 1.16 Evd
– Evd > 30 Mpa – Ms = 1,42 (Evd – 30) + 35

The dynamic plate is used as an easily portable alternative to the standard static plate, where the device does not need to be specially fixed and additionally loaded on the vehicle, but the test is completely performed using the weight located on the device itself. Current control testing is recommended during the construction of embankments, replacement of the foundation soil, arrangement of bedding in installations, etc. Static tests, in other words traditional tests with a test panel, cannot be carried out if there is not enough space for them. This is the case, for example, when filling narrow ditches or filling supporting structures. In these cases, therefore, dynamic testing with a test plate or testing with a deflectometer with a falling load is increasingly applied. This test can be done very quickly and does not require a counterweight, as in a static test with a test plate. The dynamic plate measurement process itself is completely digitized. The equipment for testing the dynamic modulus of compressibility of the substrate consists of a light deflectometer and instruments for measuring elastic settlement. The results obtained after the measurement are displayed on the connected result display device. The obtained data actually show the characteristics of the bearing capacity and degree of soil compaction, and based on this, the methods by which this can be improved are determined later. Up to 10 measurements can be taken at one location in a 30-minute period. The measurement results can be obtained immediately (printed on a field printer) and a more detailed report can be created (in the office) with recommendations.

After several years of testing, the following results were obtained:

- Reliable test results can be obtained by sufficiently sensitive measurement of soil settlement.
- This is achieved with dynamic testing devices,
- The properties of the spring or damper must be unchanged in the range from 0 to 40 degrees Celsius, because the tests are often performed in very difficult field conditions.

5.1 EXAMINATION TECHNIQUE

The testing process itself consists of several steps:

1. A load (ring) of a certain mass, through the center of which a rod passes, is allowed to fall so that it hits the spring connected to the plate, which causes the acceleration of the middle part of the plate, which is measured by a special sensor located in that part. The displacement of the plate is calculated from this acceleration.
2. The experiment is carried out after preparing the base with sand and

repeating the previous release of the load three times, as preparation of the base.

3. The mean displacement from the three drop trials is then calculated. Experience in experiment implementation and an analyzer for experiment interpretation are required. The experiment lasts a short time, about 5 minutes.
4. A rigid steel plate with a diameter of 30 cm is loaded by the impact of a weight weighing 10 kg, which, lifted by hand, falls freely from a calibrated height onto a package of disc springs, thereby achieving the highest pressure on the ground p = 100 kPa, while an additional electronic device connected to the plate by a cable the device measures its largest settlement (s), through which, from the expression as for Ev1, the dynamic modulus of deformation is obtained [11]
5. The modulus is read and adopted directly from the settlement measuring device, as the mean value of three measured points, on the soil prepared with a fine leveling contact layer and three preload shocks.
6. According to the above, the dynamic modulus of deformation is obtained for a short-term load (18 ms), without the possibility of soil consolidation - which is achieved by prescribed, long enough loading during static action, so its value could be close to the value of the modulus at the corresponding multiple repeated (dynamic) load and soil relief in the range of 0-100 kPa.

5.2 ADVANTAGES OF DYNAMIC PLATE TESTING

The most significant advantages of this test are:

- Voice instructions when conducting the test, simply follow the voice instructions
- The test takes 2-5 minutes
- The first choice for tests in the execution of earthworks, canals, and construction of pipelines, in landscaping and landscaping
- Complete equipment with waterproof electronic measuring box with all accessories
- Android APP sending results to smartphones and tablets in real time, directly from the construction site, permanent proof of tested compaction
- Measurements ready to be sent to the office and to the client in real time, all measurements are automatically stored in the GPS System
- Precise accelerometer
- Sensor equipment built for heavy duty easy connection - sturdy plugs and sockets perfect for use on the construction site,
- The plate equipped with handles for easier testing enables easy handling
- Electro-nickeled material surface
- Electronic Box – the electronics are placed inside a solid case with an external start button
- Highly resistant material surface to the negative impacts expected on the construction site
- It is also recommended for smaller, private facilities.

CONCLUSION

Granulometric composition is one of the most important characteristics of any material. For a particular soil sample, this composition represents the relationship (ratio) of all classes of grain diameters and percentages of their masses. In order to achieve demanding engineering parameters such as density, permeability, strength, compressibility, etc., soil compaction techniques are used. In addition to the degree of compaction and density control, proving the success of soil compaction is tested using the circular plate method. These tests are especially important when determining the compressibility modulus, and the final result must be in accordance with all project requirements. The compressibility module reflects the bearing capacity of the soil in a certain way, but it is not directly applied in the methods for dimensioning traffic structures, but more for defining the bearing capacity and controlling the construction of the bedding. In this paper, dynamic plate test procedures are covered through preparation, performance technique and interpretation of results with a special reference to the norms that define the method of implementation. Advantages and disadvantages of the test are given. The aim of the compaction test with a dynamic circular plate is to ensure that after some time there is no subsidence of the ground, cracking of the floor in the building or even the collapse of part of the building. Individual tests should not exclude each other, but should complement each other. After the completed measurements and data analysis, conclusions are reached as to what steps need to be taken in order to achieve the final goal, which is a stable and safe built facility. So, after conducting tests with a dynamic plate, the investor can be sure because he knows exactly how compacted the foundation soil is, and continue with the construction to the satisfaction of all participants in the process.

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