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Original Research Article

DETERMINATION OF PEAT ELASTICITY MODULUS (CONSTRAINED MODULUS) BASED ON FIELD MEASUREMENT USING SIMPLIFIED CONSOLIDATION MODEL

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Abstract

The article presents methods to determine the peat elasticity modulus based on settlement measurement of the preloaded embankment. The author proposes two methods: the first does not take into consideration the strengthening of the soil as a result of the settlement and the second includes the strengthening process of soil related to the settlement. Based on the presented methods, computer simulations were performed in the first case for the assumed embankment in order to verify the methods and in the second case for the real conditions in the area of Szczecin, Poland.

Keywords: elastic modulus, peat parameter, embankment on organic soil, field measurement.

1. INTRODUCTION

Organic soils are resulting from the decomposition of dead organic substances i.e. remnants of plants and animals. The most frequently occurring type of organic soil is peat. Besides that there can be dy, gyttja or humus. The parameters of organic soils are quite different from mineral soils. The shear strengths of organic

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soils are usually lower than for mineral soils. The organic soils have very low stiffness. The compressibility of the peat is very high. Even for small external loads, the settlements are about the amount of more than half of the original thickness of the peat layer. Consequently a very important stiffness parameter of peat is elasticity modulus [2, 3, 4, 8].
The elasticity modulus is usually determined in an oedometer test. In this test, the sample is in a small metal ring. During the test, mainly the settlement of sample is measured. The sample has no direct measurement of pore fluid pressure or volume change. From the test results scaled-up to the field model. For organic soils, the elasticity modulus (constrained modulus) is low. Therefore for organic soil, it can lead to different values than reached in the field. Therefore, there is a need to estimate this parameter through field tests [2, 3, 4, 7].

2. MATEMATICAL DESCRIPTION

The author proposes to specify peat constrained modulus in the field throughout overloading the organic soil with embankment [1] and measure its settlement. Such embankments are used as a method of strengthening the soil [3, 4].
To define peat elasticity modulus, two methods can be used: first, that does not take into account the strengthening of the soil as a result of settlement and the second which takes soil strengthening into consideration.
Both methods assume a uniaxial state of stress and strain in the soil. Also, the mineral soil layer lying below the organic soil is undeformable. To determine a settlement, the stress field from the external load in the peat should be known.
In both methods, the embankment should be divided into small calculation areas. It is shown in figure 1.

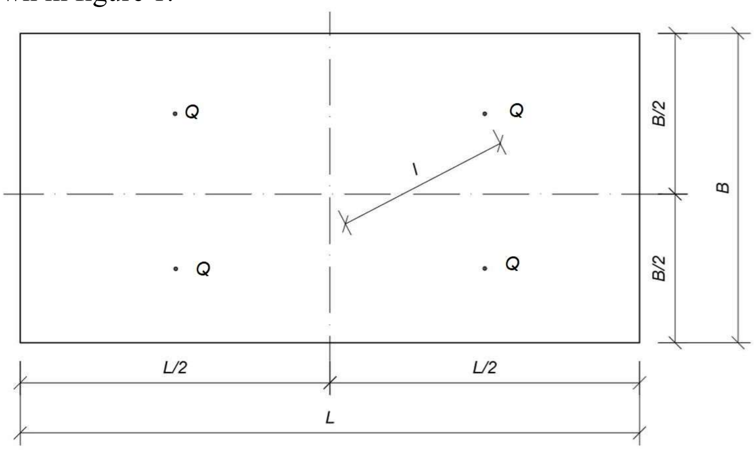


Fig. 1. Division of embankment into small calculation fields

For each calculation field, the load acting in the middle of the area can be determined. Then the stresses in the ground are calculated accordingly to the Boussinesq theory [9] and superposition principles. Calculations are done in junctions of the resulting mesh.
Each junction is considered separately, taking into account the calculations the impact of all calculation field and juctions.
The stress from the external load in the ground depends on its value, its area of operation and the place where it is determined. The model includes only the vertical component of the stress.
Under the embankment, the stress is determined on the basis of the Boussinesq theory and from the principle of superposition [9]. The value in each junction is calculated with formula (2.1).

$$\sigma_z = \frac{3Qz^3}{2\pi\left(l^2 + z^2\right)^{\frac{5}{2}}} \tag{2.1}$$

where: Q – force acting on the subsoil in the analyzed area [kN]; z – depth of the place considered [m]; l – distance of the force from the analyzed point in the the embankment [m] determined according to the formula (2.2):

$$l = \sqrt{(x - x_0)^2 + (y - y_0)^2} \tag{2.2}$$

where: x, y – coordinates of applying force in the plane of the embankment; x_0, y_0 – coordinates of analyzed point in the plane of the embankment.
To calculate the settlement of peat in each junction one should know the area of stress distribution. The stress distribution in peat layer is shown in figure 2.

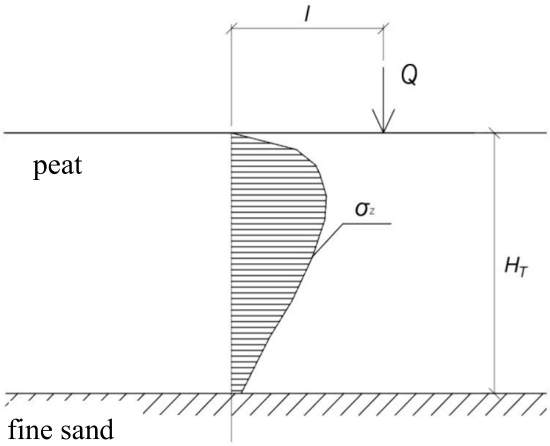


Fig. 2. Stress distribution in the distance l from the force Q by Boussinesq

The stress field from the external load in the peat layer below each junction may be calculated:

$$I_i = \int_0^{H_T} \sigma_z dz = \int_0^{H_T} \frac{3Qz^3}{2\pi(l^2+z^2)^{5/2}} dz = \frac{3Q}{2\pi} \cdot \left[\frac{2}{3l} - \frac{2l^2+3H_T^{\ 2}}{3\left(l^2+H_T^{\ 2}\right)^{3/2}} \right] \tag{2.3}$$

where: I_i is the stress field from the external load in the peat; Q is load from calculation area; H_T is thickness of peat.

3.1. First method: Determination of peat elasticity modulus based on field measurement without taking into account the strengthening of the soil as a result of settlement

The settlement can be calculated by equation (2.4) [8]:

$$s_{cal1} = \frac{\int_0^{H_T} \sigma_z dz}{M_0} = \frac{I_i}{M_0} \tag{2.4}$$

where: I_i is the stress field from the external load in the peat; s_{cal1} is calculated settlement in first method; M_0 is peat elasticity modulus (constrained modulus).

If the settlement of embankment is known, the external load affected in the peat and thickness of peat, the peat elasticity modulus (constrained modulus) may be calculated using the back analysis.

Next step, with known measured settlements of embankment, the peat elasticity modulus can be determined using the least squares method.

The calculations assume that the final settlement is constant (s=$const$) for analyzed "column" of peat under analyzed junction.

$$\sum_{i=1}^{n} \left(s_{meas} - s_{cal1}\right)^2 = \sum_{i=1}^{n} \left[s_{meas} - \frac{\sum_{i=1}^{i=n} \left\{ \frac{3Q}{2\pi} \left[\frac{2}{3l} - \frac{2l^2+3H_T^{\ 2}}{3\left(l^2+H_T^{\ 2}\right)^{3/2}} \right] \right\}}{M_0^{(1)}} \right]^2 = min \Rightarrow M_0^{(1)} \tag{2.5}$$

where: s_{meas} is measured settlement; s_{cal} is calculated settlement in first method; $M_0^{(1)}$ is peat elasticity modulus (constrained modulus) from first method.

3.2. Second method: Determination of peat elasticity modulus based on field measurement taking into account the strengthening of the soil as a result of settlement

One-dimensional, non-linear consolidation model of organic soils has been developed in the Section of Geotechnics of the West Pomeranian University of Technology Szczecin. The settlement of peat results from the decrease of its porosity due to the applied load.

The settling of the consolidated peat layer taking into account the effect of the decrease in porosity can be determined according to the formula (2.6) given by Meyer [5,6,7] Using this method was assumed $\frac{\partial M(s)}{\partial z} = 0$.

$$s = \eta_0 H \left[1 - \left(1 + \frac{\kappa - 1}{\eta_0} \frac{q}{M_0} \right)^{\frac{-1}{\kappa - 1}} \right] \tag{2.6}$$

where: s is settlement; M_0 is oedometer elasticity modulus (constrained modulus); H_T is thickness of peat; n_0 is virgin porosity of peat; κ is dimensionless ratio from oedometer test, q is load of the embankment.

The values of κ and η_0 can be calculated from the following empirical relations [6]:

$$\eta_0 = 1 - \frac{1}{12} \sigma_{con}^{\frac{1}{3}} \tag{2.7}$$

$$\kappa = 2{,}2 \sigma_{con}^{\left(-\frac{1}{18} \right)} \tag{2.8}$$

where: σ_{con} - stresses in the contact surface of the embankment with organic soil [kPa]

The formula for the elasticity modulus considering strengthening of the peat as a result of subsidence was defined by Meyer [5, 6] with formula (2.9).

$$M(s) = M_0 \left[1 - \frac{s}{n_0 H_T} \right]^{-\kappa} \tag{2.9}$$

where: s is settlement; M_0 is oedometer elasticity modulus (constrained modulus); H_T is thickness of peat; n_0 is virgin porosity of peat; κ is dimensionless ratio from oedometer test.

Using formula (2.9), the settlement of embankment with the strengthening of the soil as a result of settlement can be calculated:

$$s_{cal2} = \frac{\int_0^{H_T} \sigma_z dz}{M(s)} = \frac{I_i}{M_0\left[1 - \frac{s}{n_0 H_T}\right]^{-\kappa}} \tag{2.10}$$

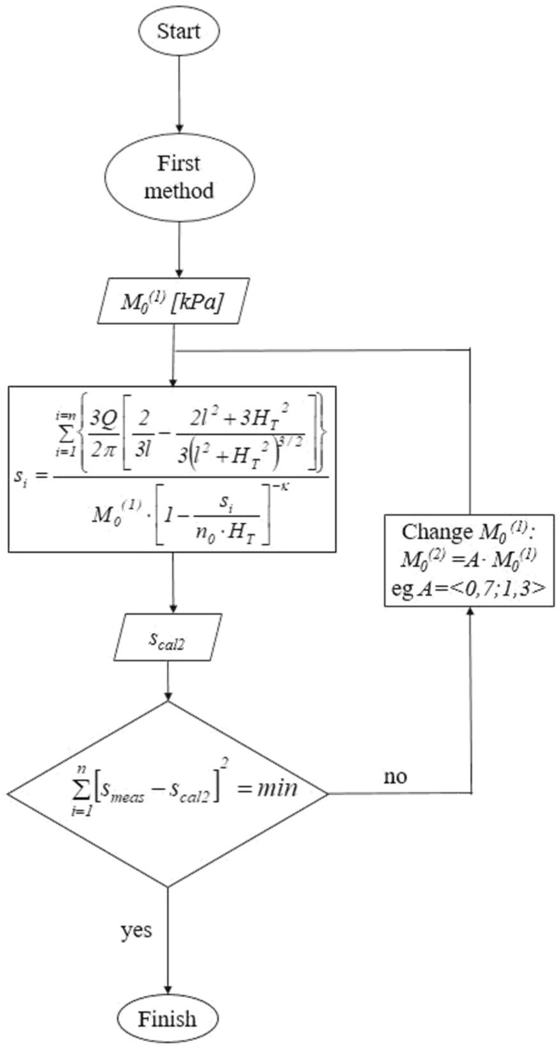


Fig. 3. The calculation algorithm of the second method

Like in the first method, the peat elasticity modulus in this method can be calculated using the least squares method. To calculate the value the minimum of peat elasticity modulus from second method the parameter $M_0^{(1)}$ has to change for example from 0,7 to 1,3 with parameter A (fig. 3)

$$\sum_{i=1}^{n}\left(s_{meas}-s_{cal2}\right)^2=\sum_{i=1}^{n}\left(s_{meas}-\frac{\sum_{i=1}^{i=n}\left\{\frac{3Q}{2\pi}\left[\frac{2}{3l}-\frac{2l^2+3H_T^{\,2}}{3\left(l^2+H_T^{\,2}\right)^{3/2}}\right]\right\}}{M_0^{(1)}\cdot\left[1-\frac{s_i}{n_0\cdot H_T}\right]^{-\kappa}}\right)^2=min\Rightarrow M_0^{(2)} \quad (2.11)$$

where: s_{meas} is measured settlement; s_{cal2} is calculated settlement in second method; $M_0^{(2)}$ is peat elasticity modulus (constrained modulus) from second method.

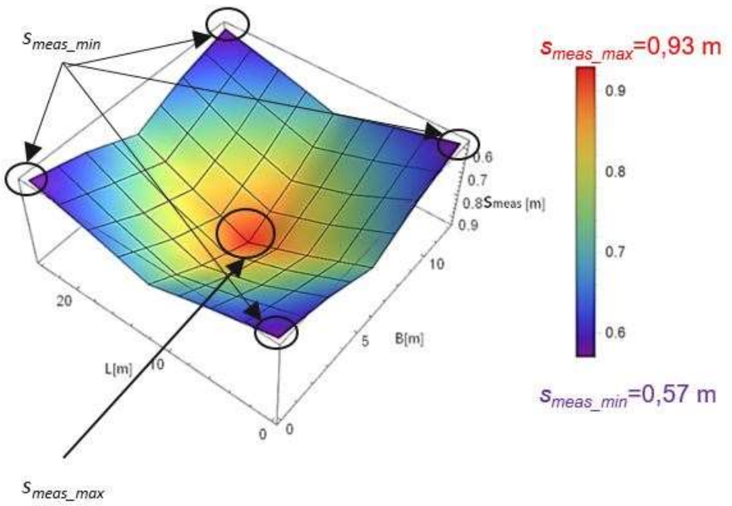
To calculate peat elasticity modulus from second method you shoud use an algoritm. The algoritm is shown in figure 3.

Fig. 4. Embankment at Wyspa Okrętowa in Szczecin (Poland)

3. DATA AND ANALYSIS

Calculations were performed within both methods for two cases.

First case was a simulation model. This case was executed for the verification of meters long. It was given 46,6 kPa load. Under the embankment there was a peat layer 9-meter thick. The embankment was divided the embankment into 144 the methods. It was an embankment built of medium sand, 12 meters wide and 24



b) Real object

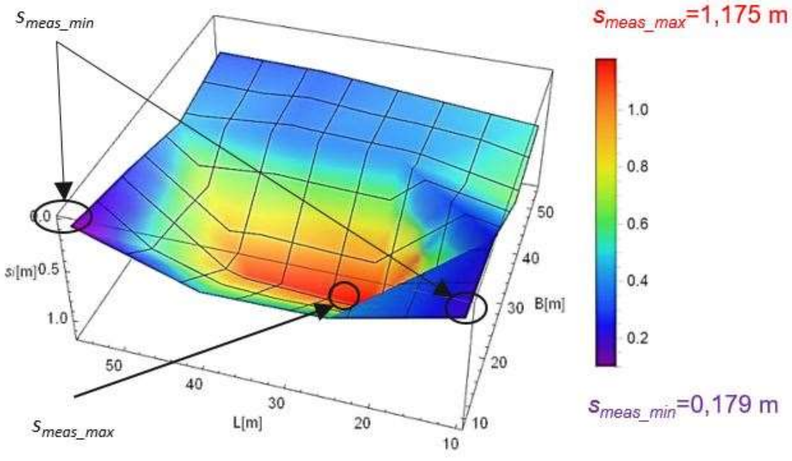


Fig. 5. The measured settlement: a) for simulation model; b) for real model

calculating fields, and the calculations were performed in 169 nodes. In order to verify the model, assumed a measured settlement (fig. 5a).

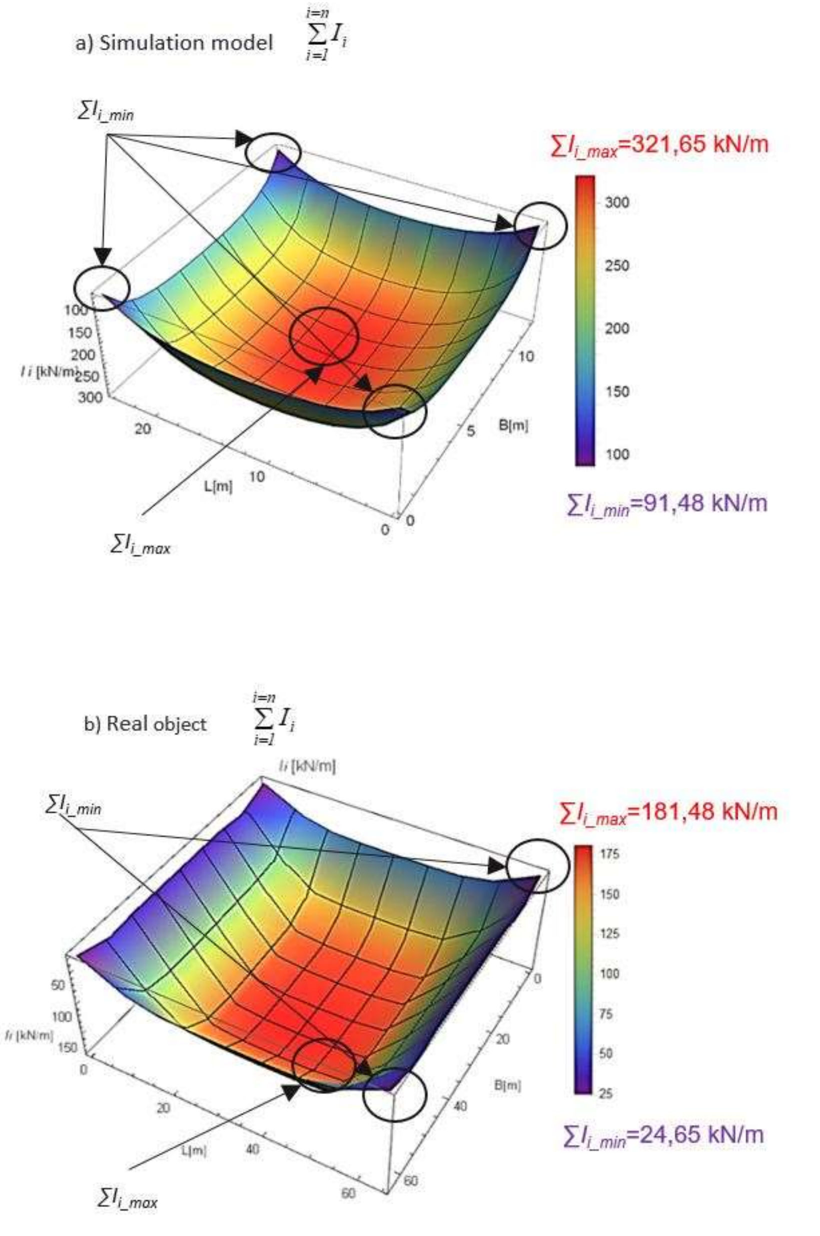


Fig. 6. The stress field from the external load in the peat: a) for simulation model; b) for real model

Second case was a real object. Located in Szczecin, Poland (fig. 4) It was an embankment built of medium sand 63.56 meters wide and 64.75 meters long.

It was given 35 kPa load. Under the embankment there was a peat layer 9-meter thick [1]. Final settlement of the embankment is shown in figure 5b.
For both cases, the average oedometer elasticity modulus was defined for peat layer. For the first case, it was 400 kPa and for the second 320 kPa. The virgin porosity of peat n_0 for the first case was 0,7 and for the second 0,73. The dimensionless ratio from oedometer test κ for the first case was 1,78 and for the second 1,81.
Then the stress field from the external load in the peat was calculated. The results are shown in fig. 6 for both cases. One can see that the highest values are in the middle of the embankment.
In both cases, the maximum value of I_i from external load in the peat is in the middle of embankment area. For the first case, the maximum value is 321,65 kN/m and for the second is 181,48 kN/m.
For both cases, an elastic modulus for peat layer without taking into account the strengthening of the soil was calculated as a result of settlement (the first method). The results are shown in figure 7.

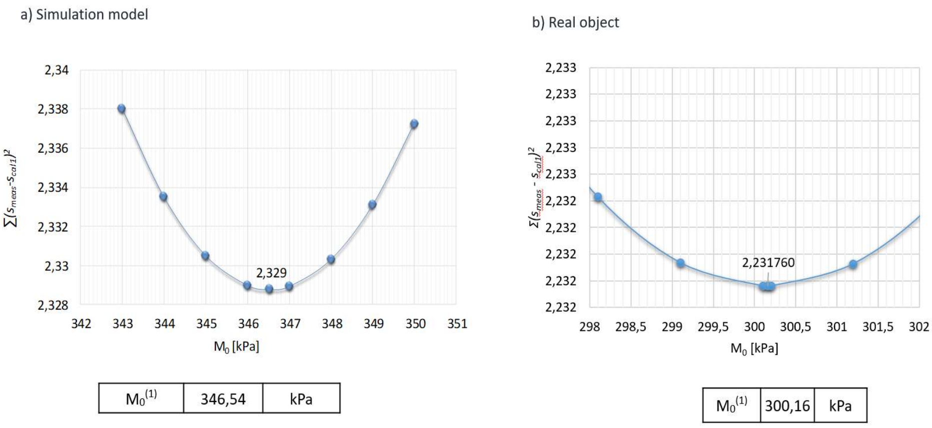


Fig. 7. Results of peat elasticity modulus (constrained modulus) from first method: a) for simulation model; b) for real model

Using the first method, I calculated peat elasticity modulus. In the first case, modulus has value 346,54 kPa and in the second 300,16 kPa.
For both cases, I calculated an elastic modulus for peat layer with taking into account the strengthening of the soil as a result of settlement (the second method). The results are shown in figure 8.

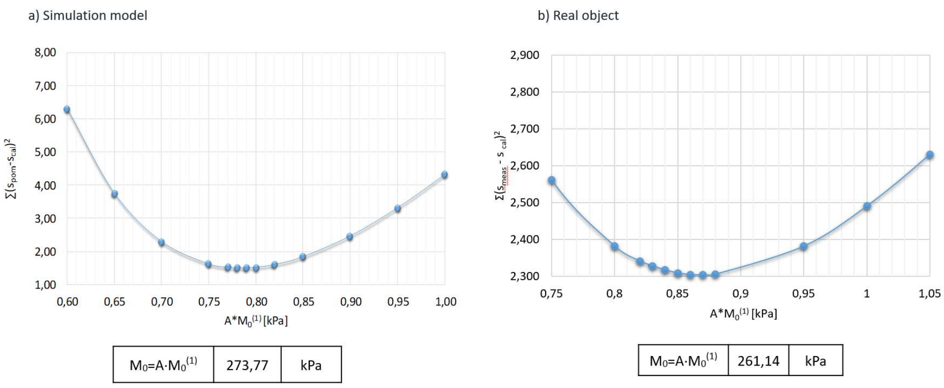


Fig. 8. Results of peat elasticity modulus (constrained modulus) from second method: a) for simulation model; b) for real model

Using the second method, I calculated peat elasticity modulus. In the first case, modulus has value 273,77 kPa and in the second 261,14 kPa.

Peat compressibility parameters are strengthened as a result of embankment overloading. By the second method, the value of the constrained modulus can be determined before the load test, but taking into account the improvement of the parameter.

The results of average elastic modulus for peat layer for both cases are shown in figure 9.

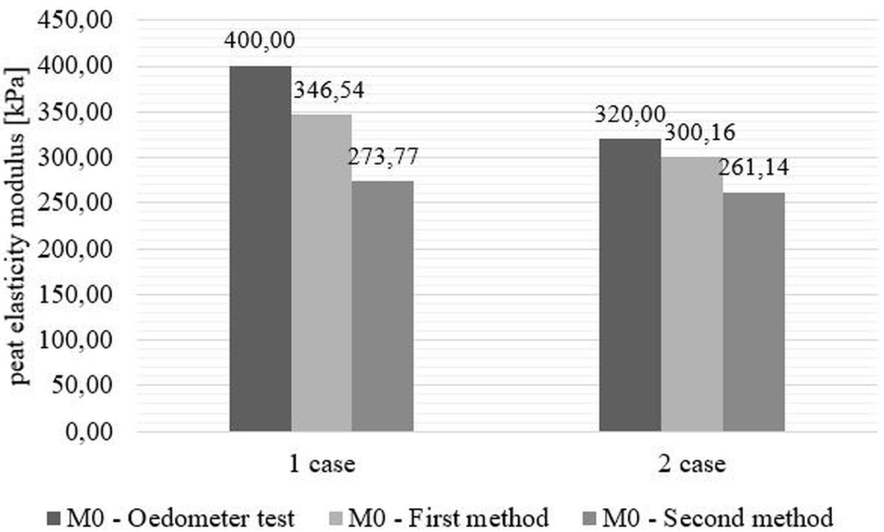


Fig. 9. Results of peat elasticity modulus (constrained modulus) for two cases

4. CONCLUSIONS

Mathematical model was proposed to determine peat elasticity modulus without (method 1) and with (method 2) consideration of the strengthening of the soil as a settlement results of overloaded embankment.
Peat elasticity modulus in both presented methods reached lower values than modules in traditional oedometer test.
It can be observed that values of peat elasticity modules (constrained modulus) in first method are higher than values in second method. This is caused by taking into consideration soil strengthening in the second method.
By assuming uniaxial state of strain and deformation, peat elasticity modules determined by both methods differs from parameter reached in oedometer test. Modulus in described methods combines triaxal state of strain and heterogeneity of organic soil. It will be the subject of further research.

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OKREŚLENIE MODUŁU ŚCIŚLIWOŚCI TORFU NA PODSTAWIE BADAŃ TERENOWYCH W OPARCIU O UPROSZCZONY MODEL KONSOLIDACJI

S t r e s z c z e n i e

W artykule przedstawiono metody wyznaczania modułu ściśliwości torfu w oparciu o pomiar osiadania nasypu przeciążającego. Autorka proponuje dwie metody: pierwszą, która nie uwzględnia wzmocnienia gruntów organicznych w wyniku osiadania oraz drugą uwzględniającą proces wzmocnienia. W oparciu o przedstawione metody określono moduł ściśliwości torfu na podstawie symulacji komputerowej, dla pierwszego przypadku w celu weryfikacji metod oraz drugiego przypadku dla warunków rzeczywistych w rejonie Szczecina w Polsce.

Słowa kluczowe: moduł ściśliwości, parametry torfu, nasyp na gruntach organicznych, badania terenowe

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