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Research paper

Determination of the characteristic values of the undrained shear strength of organic soils according to Eurocode 7

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Abstract: The paper presents the methods of determining the characteristic value on the basis of the standards: PN-B-03020:1981, PN-EN 1997-1:2008, prEN 1997-1:2022-09 and Schneider formula. Determination of the characteristic value of the undrained shear strength τ_{fu} was carried out using statistical method on the basis of the prEN 1997-1:2022-09 standard and Schneider formula. The statistical calculations were based on the results of field vane tests carried out in organic subsoil of test embankment in Antoniny test site before loading and after the 2$^{\mathrm{nd}}$ embankment stage. In order to determine the undrained shear strength τ_{fu} of organic soils from field vane tests, the measured values of shear strength τ_{fv} were corrected using the average values of correction factors $\mu = \mu(\mathrm{lab})$ determined on the basis of triaxial compression, simple shear and triaxial extension tests. The analysis of the calculation results shows that with relatively numerous data sets, large values of the coefficient of variation V_x result in significantly lower characteristic values of τ_{fu} obtained according to prEN 1997-1:2022-09, compared to the values obtained according to the Schneider formula. In the case of few data sets, for which high values of the coefficient k_n are obtained, with high values of the coefficient of variation V_x, the comparison of the values according to prEN 1997-1:2022-09 with the values obtained according to the Schneider formula shows the greatest differences.

Keywords: characteristic value of the parameter, Eurocode 7, field vane test, organic soils, statistical procedure, undrained shear strength

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1. Introduction

The aim of the paper is to analyse and discuss the method of determining the characteristic values of geotechnical parameters according to the procedure proposed in the draft standard prEN 1997-1:2022-09 Eurocode 7 [6] on the example of results analysis of field tests for undrained shear strength of organic soils: peats and gyttja.

The basis for structure design using the limit state method are the characteristic values of geotechnical parameters, on which the design values of the parameters are determined. The appropriate characteristic value of the parameter to be used in the design is the one that affects the occurrence of considered limit state [17, 34, 36]. The selection of characteristic values of geotechnical parameters is very difficult, and the method of selecting characteristic values of parameters has changed in successive geotechnical standards [6, 16, 18].

The evaluation of characteristic values should take into account the spatial variability of soil parameters according the recommendations given in International standard ISO 2394:2015 Annex D [8]. It is also worth noting that suggestions for taking spatial variability into account were also discussed in Polish publications [23, 24].

The stages of determining the characteristic values of geotechnical parameters are as follows [34]: measurements as well as field and laboratory tests, possible determination of values derived on specific correlations from literature, standards and own (local [25, 29]), studies, determination of subsoil geotechnical model [30], i.e. division of the subsoil into geotechnical layers characterized by a set of parameters, selection of characteristic values (e.g. using statistical methods [15]) and determination of design parameter values by applying partial factors.

1.1. PN-B-03020:1981 Standard

According to the Polish standard PN-B-03020:1981 [16], the characteristic (standard) parameter value of a given subsoil layer in method A determining geotechnical parameters is calculated as the average value according to the Eq. (1.1). In method B, the characteristic value of the geotechnical parameter is determined on the basis of established correlation relationship between the searched parameter and the leading parameter determined by method A (usually: liquidity index I_L or degree of compaction I_D). In method C, the characteristic value of the searched parameter is determined on the basis of practical construction experience in similar areas, e.g. from archival materials. The design value of the searched parameter is obtained by multiplying the characteristic values by the material factor γ_m calculated according to the Eq. (1.2), where the limit values of the material factor of a given soil layer are $\gamma_m = 0.80$ or $\gamma_m = 1.25$. In method B or C, material coefficients can be taken as $\gamma_m = 0.90$ or $\gamma_m = 1.10$. In the standard [16], the characteristic values of geotechnical parameters, which are most often used to foundation design, are presented in tables and figures. These values can be treated as the results of comparable experiments [34].

$$x^{(n)} = \overline{x} = \frac{1}{n} \sum x_i \tag{1.1}$$

$$\gamma_m = 1 \pm \frac{1}{x^{(n)}} \left[\frac{1}{n} \cdot \sum \left(x_i - x^{(n)} \right)^2 \right]^{\frac{1}{2}} \tag{1.2}$$

where: $x^{(n)}$ – characteristic (standard) value of a geotechnical parameter, $\overline{x}$ – average value of a parameter, x_i – results of determination of the parameter concerned, n – number of determinations, γ_m – material coefficient.

Note that the second term in the Eq. (1.2) is just the standard deviation. So, practically the design value is mean value plus or minus one population standard deviation.

1.2. PN-EN 1997-1:2008 Standard

The PN-EN 1997-1:2008 standard [18] recommends that the characteristic value of the geotechnical parameter X_k should be chosen as a conservative estimation of the value determining the occurrence of the limit state, i.e. the most probable value of a given parameter at which the considered limit state will occur. The conservative estimation of the mean value involves selecting the average value from a limited set of geotechnical parameter values, with 95% confidence level, while in case of considering local failure, the conservative estimation of the lower value corresponding to the 5% fractile. A 5% fractile is a parameter value that divides the dataset so that 5% of the cases in the set are less than or equal to the fractile, and the remaining 95% of the result values are greater than the fractile.

The characteristic value of the parameter shall be chosen on the basis of values derived from laboratory or field tests, taking into account the results of generally recognized experiments (from correlations and formulas from the literature, from standards or own research – with the source provided), in accordance with the expert's decision.

Design values of the parameter should be calculated according to the Eq. (1.3), using material partial factors, which values should be taken according to PN-EN 1997-1:2008 (Appendix A) [18] and the National Annex PN-EN 1997-1:2008/Ap2: 2010 [19].

$$X_d = \frac{X_k}{\gamma_M} \tag{1.3}$$

where: X_d – design value of the parameter, X_k – characteristic value of the parameter, γ_M – material partial factor for the given parameter.

Measure of parameter variability in a given soil layer is the coefficient of variation V_x, calculated according to the Eq. (1.4) or the CV_x coefficient of variation calculated in % according to the Eq. (1.5):

$$V_x = \frac{S_x}{\overline{\overline{X}}} \tag{1.4}$$

$$CV_x = \frac{S_x}{\overline{\overline{X}}} \cdot 100\ [\%] \tag{1.5}$$

where: S_x – standard deviation, most often from a sample – in the case of a limited number of test results.

The standard deviation from the sample S_x is expressed by the Eq. (1.6):

$$S_x = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \overline{x})^2}{n-1}} \tag{1.6}$$

Lists of coefficients values of variation CV_x from tests of various geotechnical parameters can be found in the literature [14, 27, 34] and in the standard [6].

It is always recommended to compare the assumed values of geotechnical parameters with the existing (local, national) experience [19, 34].

Due to the lack of clear guidelines in the standard [18] on the use of the statistical method to determine the characteristic value of geotechnical parameters, many examples of the use of various calculation procedures can be found in the literature as part of the discussion [3, 15, 22, 30] and comparisons of various statistical approaches [4, 9, 13, 25, 35, 36].

As part of this discussion, taking into account the need for careful estimation of geotechnical parameters, Schneider [26, 28] proposed the Eq. (1.7) for the assessment of the characteristic parameter value, which was recognized by specialists [34]:

$$X_k = \overline{X} - 0,5 \cdot S_x \tag{1.7}$$

1.3. prEN 1997-1:2022-09 Standard

The draft standard prEN 1997-1:2022-09 [6] recommends the use of design value of geotechnical parameters X_d, determined according to the Eq. (1.8):

$$X_d = \frac{X_{\mathrm{rep}}}{\gamma_M} \tag{1.8}$$

where: X_{rep} – representative value of the ground properties, γ_M – material partial factor.

The representative values X_{rep} of the ground properties are the specific geotechnical properties of a given subsoil layer. If the checked limit state of the ground is insensitive to the spatial variability of the given ground property in the volume of the involved soil (case A) – then the representative value of the given parameter is its nominal value X_{nom} (i.e. the average, i.e. 50% fractile), in accordance with Eq (1.9). If a given limit state is sensitive to the spatial variability of the ground (case B), then the representative value of the parameter is its characteristic value X_k, according to Eq. (1.10).

$$X_{\mathrm{rep}} = X_{\mathrm{nom}} \tag{1.9}$$

$$X_{\mathrm{rep}} = X_k \tag{1.10}$$

Draft Eurocode 7-1 [6] (Annex A) describes the statistical procedure for determining the characteristic value of the geotechnical parameter X_k taken as an estimate of:

- Case A: mean value,
- Case B: lower value (5% fractile, when the lower value of the ground parameter is unfavourable) or higher (95% fractile, when the higher value of the parameter is unfavourable).

The characteristic value of the geotechnical parameter X_k shall be calculated according to the Eq. (1.11):

$$X_k = X_{\text{mean}}\left[1 \mp k_n V_x\right] = X_{\text{mean}}\left[1 \mp \frac{k_n S_x}{X_{\text{mean}}}\right] \tag{1.11}$$

where: X_{mean} – average value of the soil parameter X from the n number of parameter values, calculated according to the Eq. (1.1), V_x – coefficient of variation of the X parameter, calculated according to the Eq. (1.4), k_n – factor depending on the number n, $\mp$ means that $k_n V_X$ should be subtracted when the lower value of X_k is required or added when its upper value is required, S_x – standard deviation of the X parameter from the sample, calculated according to the Eq. (1.6).

The assumptions for the Eq. (1.11) are as follows: the X values are in accordance with the normal distribution and the mean value X_{mean} of the parameter under consideration is unknown. Formulas for other distributions of parameters are given in FprEN 1990:2022-09 (Annex D) [5]. The standard [6] allows the use of other statistical procedures, e.g. Bayesian statistics, the application of which has been shown in works [13, 25].

The coefficient of variation V_x of the value of the observed geotechnical parameter includes coefficients of variation of test results due to various sources of uncertainty [1–3, 11, 33] resulting from: natural variability of the substrate, variability of the measurement error (and the quality of the samples taken), transformation variability (when the value of a parameter is not measured directly, but determined on another measure).

The standard procedure [6] can be used in three different cases:
- Case 1: when V_x is known (from previous studies in comparable situations),
- Case 2: when V_x is taken by the designer as indicative values for the ground parameters from Table A.2 [21] or for the test parameters from Table A.3 [6],
- Case 3: when V_x is unknown – then V_x is calculated according to the Eq. (1.4) and the sample standard deviation is calculated according to the Eq. (1.6).

The formulas for calculating the factor k_n are given in Table A.1 [6] depending on the selected case A or B and one of the cases 1–3. Tables A.4–A.7 contain the calculated values of the coefficient k_n for all combinations of cases, which consider the number of measurements in the range of n = 2–100 measurements.

In this paper, the calculations of the characteristic values of undrained shear strength τ_{fu} of organic soil layers were carried out using the procedure from the draft standard prEN 1997-1:2022-09 and Schneider proposal Eq. (1.7).

2. Characteristics of test site

The Antoniny test site is located in north-western Poland in the valley of the Noteć river, where the Department of Geotechnical Engineering of the Warsaw University of Life Sciences in cooperation with the Swedish Geotechnical Institute conducted extensive field and laboratory tests during the construction of levees [7, 12, 31, 32]. Two test embankments (with and without vertical prefabricated drains) were constructed between 1983 and 1987. The embankment without vertical drains constructed in three stages was then brought to failure by successively increasing height of embankment [12, 31]. The height of the embankment was 1.2 m in the first stage, 2.5 m in the second stage and 3.9 m in the third stage, and 7.95 m at the loss of stability. The organic subsoil consisted of peat and gyttja layers underlain with a layer of fine sand. The organic subsoil, 7.8 m thick, consisted of a layer of peat 3.1 m thick and gyttja 4.7 m thick. Based on the origin and index properties, the peat layer was divided into two layers: the first one is fibrous peat from the ground surface to a depth of about 1.0 m, and the second – amorphous peat from 1.0 m to a depth of 3.1 m. In the layer of amorphous peat, the natural water content ranges from 310% to 340%, and the content of organic matter from 65% to 75%. The gyttja layer was divided into three layers, the first of which is calcareous-organic gyttja lying from 3.1 m to 4.5 m below ground level, and the second and third are calcareous gyttja layers from 4.5 m to 6.8 m and below, respectively 6.8 m below ground level. Gyttja layers are characterized by natural water content of 110% to 140%, organic matter content of 8% to 20% and calcium carbonate content $CaCO_3$ of 70% to 90%.

Organic soils are preconsolidated, with a overconsolidation ratio OCR that decreases from 5 to 2 with depth. In the first stage, the vertical effective stress was less than the pre-consolidation pressure. During the staged construction, the vertical effective stress exceeded the pre-consolidation pressure several times. Due to consolidation, the undrained shear strength of the organic subsoil was significantly increased, as evidenced by the fact that the loss of stability of the embankment without strengthening the organic subsoil would occur at the embankment height of 1.70 m, and after consolidation of the subsoil, it occurred at the embankment height of 7.95 m.

3. Results of field vane tests

Field investigation, which were carried out on the test embankment without vertical drains, included among others field vane tests FVT [10–12, 21]. In order to determine the undrained shear strength τ_{fu} of organic soils from field vane tests [20], the measured values of shear strength τ_{fv} were corrected using the correction factor μ according to the Eq. (3.1):

$$\tau_{\mathrm{fu}} = \mu\tau_{fv} \tag{3.1}$$

In the paper, the average values of the correction factors $\mu = \mu(\mathrm{lab})$ were determined on the basis of the following laboratory tests: triaxial compression, simple shear and triaxial extension were used [12], which are presented in Table 1. The location of the examined test points P5-P19 are shown in Fig. 1.

The organic subsoil of tests embankment was tested with the field vane test FVT before embankment loading and after each of the 3 stages of embankment loading (Fig. 1). The values of the undrained shear strength τ_{fu} of organic soils in the subsoil, which were corrected according to the Eq. (3.1) before loading and after the 2$^{\mathrm{nd}}$ stage of embankment, are presented in Table 2 and Table 3.

Table 1. Correction factors $\mu = \mu(\text{lab})$ to the shear strength measured with a field vane test of organic soils from Antoniny

Soil type (layer passage)	μ(lab)
peat (0–3.1 m)	0.51
gyttja 1 (3.1–4.5 m)	0.56
gyttja 2 and 3 (4.5–7.8 m)	0.61

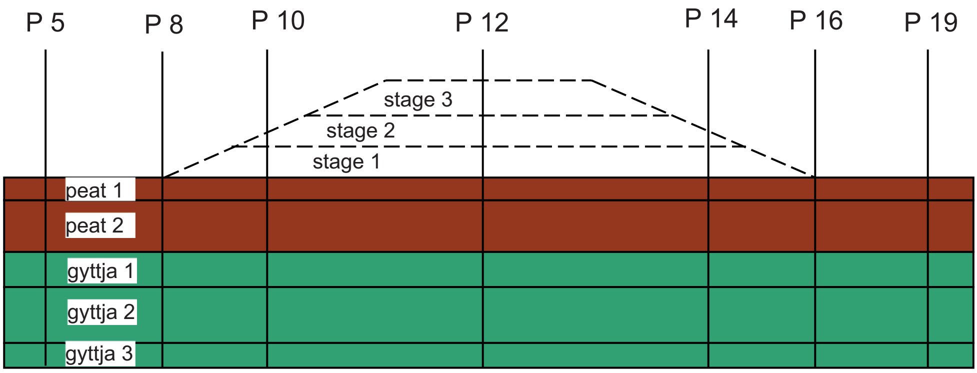

Fig. 1. Location of test points of organic subsoil with field vane test in Antoniny

Table 2. Values of undrained shear strength τ_{fu} of organic soils before embankment loading

Depth below initial ground level	Profile No.						
	P5	P8	P10	P12	P14	P16	P19
	τ_{fu}	τ_{fu}	τ_{fu}	τ_{fu}	τ_{fu}	τ_{fu}	τ_{fu}
[m]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]
peat 1: 0.50	13.72	17.41	10.44	10.96	13.09	10.96	12.89
peat 2: 1.00	6.57	6.13	6.45	6.71	7.22	6.77	7.22
peat 2: 1.50	5.74	6.32	5.48	5.67	5.35	5.09	6.38
peat 2: 2.00	5.22	6.32	5.67	5.67	5.09	5.67	5.16
peat 2: 2.50	6.45	6.90	6.71	6.51	7.09	7.09	6.45
peat 2: 3.00	6.64	7.42	6.51	6.91	6.64	6.57	7.74
gyttja 1: 3.50	8.14	7.78	7.78	7.22	7.43	7.64	6.73
gyttja 1: 4.00	9.77	9.49	8.64	8.71	8.50	9.34	5.02
gyttja 1: 4.50	7.08	7.22	7.08	7.22	6.73	6.73	8.36
gyttja 2: 5.00	7.86	7.56	6.94	6.86	7.17	7.09	7.33

Continued on next page

Table 2 – *Continued from previous page*

Depth below initial ground level	Profile No.						
	P5	P8	P10	P12	P14	P16	P19
	τ_{fu}	τ_{fu}	τ_{fu}	τ_{fu}	τ_{fu}	τ_{fu}	τ_{fu}
[m]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]
gyttja 2: 5.50	7.56	7.71	6.86	6.78	6.78	6.17	6.94
gyttja 2: 6.00	7.09	6.32	6.17	7.17	7.63	7.17	7.56
gyttja 2: 6.50	7.17	6.17	6.17	6.94	6.78	7.2	7.33
gyttja 3: 7.00	6.78	6.40	6.86	6.94	6.63	6.17	7.02
gyttja 3: 7.50	6.78	9.02	5.40	6.94	7.71	6.1	10.95

Table 3. Values of undrained shear strength τ_{fu} of organic soils after the 2nd stage of embankment loading

Profile under embankment slope P10		Profile under embankment crest P12	
Depth below initial ground level [m]	τ_{fu} [kPa]	Depth below initial ground level [m]	τ_{fu} [kPa]
peat 1	–	peat 1	–
peat 2	–	peat 2: 1.65	21.98
peat 2	–	peat 2: 2.15	20.04
peat 2: 2.45	13.57	peat 2: 2.65	16.73
peat 2: 2.95	14.18	peat 2: 3.15	15.45
gyttja 1: 3.45	11.48	gyttja 1: 3.65	12.77
gyttja 1: 3.95	12.04	gyttja 1: 4.15	13.10
gyttja 1: 4.45	9.58	gyttja 1	–
gyttja 2: 4.95	9.27	gyttja 2: 4.65	10.80
gyttja 2: 5.45	8.48	gyttja 2: 5.15	10.13
gyttja 2: 5.95	8.72	gytjja 2: 5.65	10.00
gyttja 2: 6.45	8.48	gyttja 2: 6.15	10.31
gyttja 2	–	gyttja 2: 6.65	10.80
gyttja 3: 6.95	8.85	gyttja 3: 7.15	12.44

In the calculations of the characteristic values of the undrained shear strength τ_{fu} of the organic soils after the 2nd stage of embankment loading, peat layer 1 was not included due to the lack of data.

4. Statistical analysis

Calculations of the characteristic values of undrained shear strength of organic soil layers before loading and after the 2nd stage were made according to the statistical procedure recommended in prEN 1997-1:2022-09 [6], using the following assumptions:

– Case B: estimation of the smaller value of the parameter (5% fractile) and
– Case 2: "V_x unknown", taking into account the variability of organic soil parameters.

Therefore, the coefficient k_n in accordance with Table A.1 [6] should be calculated according to the Eq. (4.1):

$$k_n = t_{95,n-1}\sqrt{1 + \frac{1}{n}} \tag{4.1}$$

where: $t_{95,n-1}$ – Student's t-distribution, estimated for a 95% confidence level and n–1 degrees of freedom, where n is the number of measurements.

Subsequently, the following calculations were performed in individual data sets for selected soil layers:

– It was assumed that the variable τ_{fu} has a normal distribution,
– X_{mean} was calculated according to the Eq. (1.1),
– Standard deviations from the S_x from a sample were calculated according to the Eq. (1.6),
– The coefficient of variation V_x was calculated according to the Eq. (1.4),
– Values of the coefficient k_n were read from Table A.7 [6] for the respective numbers of n,
– It was assumed that the ultimate limit state is sensitive to the spatial variability of the subsoil in terms of undrained shear strength, therefore, according to the Eq. (1.10), the representative value of the parameter τ_{fu} is its lower characteristic value X_k calculated according to the Eq. (1.11).

The results of the calculations are presented in Tables 4–6.

For organic subsoil before embankment loading according to prEN 1997-1:2022-09 [6], the following characteristic values of the parameter τ_{fu} were obtained: for peat 1 $X_k = 7.78$ kPa, for peat 2 $X_k = 5.12$ kPa, for layers of gyttja 1 and 2 $X_k = 5.78$ kPa and $X_k = 6.12$ kPa, and for gyttja 3 $X_k = 4.58$ kPa. According to the Schneider formula [26, 28], correspondingly higher values were obtained: $X_k = 11.58$ kPa, $X_k = 5.98$ kPa, $X_k = 7.18$ kPa, $X_k = 6.76$ kPa and $X_k = 6.42$ kPa. The value of the coefficient of variation V_x for peat 1 and 2 was 0.188 and 0.112, and for the gyttja layers 1, 2 and 3 it was 0.114, 0.069 and 0.194, respectively. With relatively numerous data, the values of the coefficient k_n for peat 1 and 2 are 2.08 and 1.71, and for gyttja layers 1.76, 1.83 and 1.83, respectively. The analysis of results shows that for large values of the standard deviation S_x, and therefore large values of the coefficient of variation V_x, and with similar values of the coefficient k_n, significantly lower characteristic values of the parameter τ_{fu} were obtained according to prEN 1997-1:2022-09 compared to the values obtained according to the Schneider formula. In case of peat 1 and gyttja 3, for which the values of the coefficient of variation V_x were the highest, the greatest differences were obtained. These soils are characterized by the smallest values of the coefficient $[1 - k_n V_x]$ in the Eq. (1.11) of 0.609 and 0.645, which is used to calculate the characteristic value X_k based on the value X_{mean} (Table 4).

Table 4. Calculation of the characteristic value of undrained shear strength $X_k = \tau_{fu}$ of organic soils before embankment loading

Soil type (layer passage) [m]	Calculation according to							
	prEN 1997-1:2022-09 [6]							Schneider [26, 28]
	n [numbers]	X_{mean} [kPa]	S_x [kPa]	V_x [–]	kn [–]	$[1 - knV_x]$* [–]	Xk [kPa]	X_k [kPa]
peat 1 (0.0–1.0)	7	12.78	2.40	0.188	2.08	0.609	7.78	11.58
peat 2 (1.0–3.1)	35	6.33	0.71	0.112	1.71	0.808	**5.12**	5.98
gyttja 1 (3.1–4.5)	21	7.74	1.12	0.144	1.76	0.747	**5.78**	7.18
gyttja 2 (4.5–6.5)	14	7.01	0.49	0.069	1.83	0.874	**6.12**	6.76
gyttja 3 (6.5–7.8)	14	7.11	1.38	0.194	1.83	0.645	**4.58**	6.42

Note: *$[1 - k_n V_x]$ – the value of the coefficient by which X_{mean} is multiplied in Eq. (1.11)

For organic subsoil after the 2nd stage according to prEN 1997-1:2022-09 [6], the following characteristic values of the parameter τ_{fu} were obtained in the subsoil under the slope of the embankment: for peat 2 $X_k = 10.56$ kPa, for layers of gyttja 1 and 2 $X_k = 6.68$ kPa and $X_k = 7.75$ kPa, and for gyttja 3 there was only one measurement of $X = 8.85$ kPa, therefore the statistical method of evaluating the result is not applicable here. According to the Schneider formula [26, 28], respectively higher values were obtained: $X_k = 13.66$ kPa, $X_k = 10.39$ kPa and $X_k = 8.55$ kPa. The value of the coefficient of variation V_x for peat 2 was 0.031, and for gyttja layers 1 and 2 was 0.117 and 0.043, respectively. With few datasets, the value of the coefficient k_n for peat 2 was 7.73, and for gyttja layers 1 and 2 was 3.37 and 2.63, respectively. The analysis of results shows that in case of less numerous sets, a large value of the coefficient k_n with similar values of the coefficient of variation V_x results in significantly lower characteristic values of the parameter τ_{fu} obtained according to prEN 1997-1:2022-09 compared to the values obtained according to the Schneider formula. In case of gyttja 1, for which the value of the coefficient of variation V_x was the highest, the largest difference was obtained. This soil is characterized by the lowest coefficient $[1–k_n V_x]$ value of 0.606 (Table 5).

For organic subsoil after the 2nd stage according to prEN 1997-1:2022-09 [6], the following characteristic values of the parameter τ_{fu} were obtained in the subsoil under the embankment crest: for peat 2 $X_k = 10.65$ kPa, for layers of gyttja 1 and 2 $X_k = 11.14$ kPa and $X_k = 9.53$ kPa, and for gyttja 3 there was only one measurement of $X = 12.44$ kPa, therefore the statistical method of result evaluating is not applicable here. According to Schneider formula [26, 28], higher values were obtained, respectively: $X_k = 17.05$ kPa, $X_k = 12.82$ kPa and $X_k = 10.22$ kPa. The value of the coefficient of variation V_x for peat 2 was 0.162, and for gyttja layers 1 and 2 was 0.018 and 0.036, respectively. With a small number of data, the value of the coefficient k_n for peat 2 was 2.63, and for gyttja layers 1 and 2 was 7.73 and 2.34, respectively. In case of peat 2, for which the value of the coefficient of variation V_x was the highest, the greatest difference was obtained. This soil is characterized by the lowest value of the coefficient $[1 - k_n V_x]$ of 0.574 (Table 6).

Table 5. Calculation of the characteristic value of undrained shear strength $X_k = \tau_{\text{fu}}$ of organic soil layers under embankment slope after the 2^{nd} stage

Soil type (layer passage) [m]	Calculation according to							
	prEN 1997-1:2022-09 [6]							Schneider [26, 28]
	n [numbers]	X_{mean} [kPa]	S_x [kPa]	V_x [–]	k_n [–]	$[1 - k_n V_x]$* [–]	X_k [kPa]	X_k [kPa]
peat 2 (1.0–3.1)	2	13.88	0.431	0.031	7.73	0.760	10.56	13.66
gyttja 1 (3.1–4.5)	3	11.03	1.289	0.117	3.37	0.606	6.68	10.39
gyttja 2 (4.5–6.5)	4	8.74	0.373	0.043	2.63	0.887	7.75	8.55
gyttja 3 (6.5–7.8)	1	8.85	?	–	–	–	**?**	?

Note: *$[1 - k_n V_x]$ – the value of the coefficient by which X_{mean} is multiplied in Eq. (1.11)

Table 6. Calculation of the characteristic value of undrained shear strength $X_k = \tau_{\text{fu}}$ layers of organic soils under the embankment crest after the 2^{nd} stage

Soil type (layer passage) [m]	Calculation according to							
	prEN 1997-1:2022-09 [6]							Schneider [26, 28]
	n [numbers]	X_{mean} [kPa]	S_x [kPa]	V_x [–]	k_n [–]	$[1 - k_n V_x]$* [–]	X_k [kPa]	X_k [kPa]
peat 2 (1.0–3.1)	4	18.55	2.995	0.162	2.63	0.574	**10.65**	17.05
gyttja 1 (3.1–4.5)	2	12.94	0.233	0.018	7.73	0.861	**11.14**	12.82
gyttja 2 (4.5–6.5)	5	10.41	0.374	0.036	2.34	0.916	**9.53**	10.22
gyttja 3 (6.5–7.8)	1	12.44	–	–	–	-	**?**	?

Note: *$[1 - k_n V_x]$ – the value of the coefficient by which X_{mean} is multiplied in Eq. (1.11)

5. Conclusions

The methods of determining the characteristic value of a geotechnical parameter based on the following standards: PN-B-03020:1981, PN-EN 1997-1:2008, prEN 1997-1:2022-09 and the Schneider formula are shown. The statistical calculations of the characteristic values of the parameter were carried out on the basis of the procedure from the draft standard prEN 1997-1:2022-09 and Schneider proposal. The statistical calculations were based on the results of field vane tests carried out in the organic subsoil of the test embankment before loading and after the 2^{nd} embankment stage. In order to determine the undrained shear strength τ_{fu} of organic soils from field vane tests, the measured values of shear strength τ_{fv} were corrected using the average values of the correction factors $\mu = \mu(\text{lab})$ determined on the basis of triaxial compression, simple shear and triaxial extension tests.

The analysis of the calculation results shows that in case of determining the characteristic values of the undrained shear strength $X_k = \tau_{\text{fu}}$ of peat and gyttja layers before the embankment loading with relatively numerous data sets at high values of the coefficient of variation V_x with similar values of the coefficient k_n, significantly lower characteristic values of the parameter τ_{fu} were obtained according to prEN 1997-1:2022-09 compared to the values obtained according to the Schneider formula. In case of determining the characteristic values of undrained shear strength τ_{fu} of peat and gyttja layers under the slope and under the embankment crest after the 2^{nd} embankment stage, with few data sets (for which high values of the coefficient k_n are obtained), with high values of the coefficient of variation V_x, a comparison of the values according to prEN 1997-1:2022-09 with the values obtained according to the Schneider formula shows the greatest differences.

The characteristic value of the geotechnical parameter is significantly influenced by the parameter k_n, which considers the size of the measurements set. The large dispersion of test results, which is expressed by the coefficient of variation V_x, also significantly reduces the characteristic value of the geotechnical parameter.

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Wyznaczenie charakterystycznych wartości wytrzymałości na ścinanie bez odpływu gruntów organicznych według Eurokodu 7

Słowa kluczowe: Eurokod 7, grunty organiczne, polowa sonda krzyżakowa, procedura statystyczna, wartość charakterystyczna parametru, wytrzymałość na ścinanie bez odpływu

Streszczenie:

W artykule opisano sposób wyznaczenia wartości charakterystycznych parametru geotechnicznego na podstawie norm: PN-B-03020:1981, PN-EN 1997-1:2008, prEN 1997-1:2022-09 oraz wzoru Schneidera. Obliczenia metodą statystyczną wartości charakterystycznych wytrzymałości na ścinanie bez odpływu τ_{fu} przeprowadzono na podstawie projektu normy prEN 1997-1:2022-09 oraz propozycji Schneidera. W obliczeniach wykorzystano wyniki badań polową sondą krzyżakową przeprowadzone w podłożu organicznym nasypu doświadczalnego przed obciążeniem podłoża nasypem oraz po 2. etapie obciążenia podłoża nasypem. W celu wyznaczenia wytrzymałości na ścinanie bez odpływu τ_{fu} gruntów organicznych z badań polową sondą krzyżakową pomierzone wartości wytrzymałości na ścinanie τ_{fv} skorygowano za pomocą średnich wartości współczynników poprawkowych $\mu = \mu(\mathrm{lab})$ wyznaczonych na podstawie badań trójosiowego ściskania, prostego ścinania i trójosiowego rozciągania. Analiza wyników obliczeń wskazuje, że w przypadku wyznaczenia wartości charakterystycznych wytrzymałości na ścinanie bez odpływu $X_k = \tau_{\mathrm{fu}}$ warstw torfu i gytii przed obciążeniem nasypem, ze stosunkowo licznymi zbiorami danych przy dużych wartościach wskaźnika zmienności V_x przy podobnych wartościach współczynnika k_n znacznie mniejsze wartości charakterystyczne parametru τ_{fu} uzyskano według prEN 1997-1:2022-09 w porównaniu z wartościami otrzymanymi według wzoru Schneidera. W przypadku wyznaczenia wartości charakterystycznych wytrzymałości na ścinanie bez odpływu τ_{fu} warstw torfu i gytii po skarpą i pod koroną nasypu po 2. etapie obciążenia podłoża nasypem, przy nielicznych zbiorach danych (dla których uzyskuje się duże wartości współczynnika k_n), przy dużych wartościach wskaźnika zmienności V_x porównanie wartości według prEN 1997-1:2022-09 z wartościami otrzymanymi według wzoru Schneidera wskazuje na największe różnice. Zatem na wartość charakterystyczną parametru geotechnicznego ma znaczny wpływ współczynnik k_n, który uwzględnia liczebność zbioru pomiarów. Duży rozrzut wyników badań, który jest wyrażony za pomocą wskaźnika zmienności V_x także zdecydowanie obniża wartość charakterystyczną parametru geotechnicznego.

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