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TRANSFORMATIONAL FUNCTIONS FOR DISPLACEMENT COLUMNS PERFORMED IN COHESIVE LOW-BEARING-CAPACITY SOILS

FUNKCJE TRANSFORMACYJNE DLA KOLUMN PRZEMIESZCZENIOWYCH WYKONYWANYCH W SPOISTYCH GRUNTACH SŁABONOŚNYCH

A b s t r a c t

The paper presents the method of determining the total non-linear correlation of load settlement relationship for individual concrete displacement columns performed in cohesive low-bearing-capacity soils, gyttja in Żoliborz-Szczęśliwice glacial tunnel valley.

Keywords: gyttja, transformational function, settlement

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

W artykule przedstawiono metodę wyznaczenia globalnej nieliniowej zależności obciążenie-osiadanie dla pojedynczych kolumn przemieszczeniowych wykonywanych w spoistych gruntach słabonośnych, gytiach „Rynny Żoliborsko-Szczęśliwickiej".

Słowa kluczowe: gytia, funkcja transformacyjna, osiadanie

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1. Classification and mechanical characteristic of gyttja

In accordance with the Polish Standard PN-B-02480: 1986 concerning beside other classification of soils for engineering purposes, gyttja is described as ”mud with calcium carbonate content of more than 5%, which may change soil skeleton giving the nature of the rocky soil with low compressive strength values”.

According to Długaszek [1] gyttja are composed of lacustrine deposits containing more than 2% of organic matter, and includes the lacustrine chalk, the sediment containing more than 80% of the calcium carbonate content, organic matter may be less than 2%.

Specialists in natural and engineering sciences (i.e. agriculture, geology, geotechnics and construction sector, engineering geology, sedimentology, petrology, soil science, botany) are interested in lacustrine deposits, especially in gyttja. That wide range of scientific applications concerning this type of soil required the introduction of a number of definitions and classifications.

Since when in 1862 Hampus von Post has adapted the Swedish word “gyttja” literally meaning “slime” or “ooze” (Myślińska [5]) to determine a specific type of lake sediments, several dozens of organic soils’ classifications, including lacustrine sediments as well as gyttja have been created.

A simple classification by Długaszek [1], concerning only gyttja and a simplified classification by Okruszko [7] are according to the authors’ opinion the most appropriate engineering and geological classification of this type of soil for engineering purposes.

The most common types of gyttja described in the branch literature concerning engineering geology and geotechnics are based on classifications by Okruszko [7], Markowski and Ilnicki and present the percentage content of easily determined elements in the sediment (calcium carbonate, organic material and non-carbonate mineral grains and particles).

According to selected classification, the comparison of some types of gyttja presented in the Table 1 was made . The samples were collected from the terrain where the columns were installed.

Table 1

Comparison of several types of gyttja according to selected classification

calcium carbonate CaCO3 (%)	organic material Iom (%)	non-carbonate mineral grains and particles (%)	gyttja type by Długaszek	gyttja type by Okruszko	gyttja type by Ilnicki	gyttja type by Markowski
10	22	68	Mineral and organic low carbonate gyttja	clayey gyttja	organic and clayey gyttja	lacustrine mineral deposits
calcium carbonate CaCO3 (%)	organic material Iom (%)	non-carbonate mineral grains and particles (%)	gyttja type by Długaszek	gyttja type by Okruszko	gyttja type by Ilnicki	gyttja type by Markowski
50	22	28	mineral and organic high carbonate gyttja	calcareous/ lime gyttja	calcareous/ lime gyttja	calcareous/ lime gyttja

To expand the knowledge about the mechanical properties of gyttja and to use some common designing method for displacement columns based on in-situ tests, such tests (CPT and DMT tests) were made in six sites in Warsaw, located in Żoliborz-Szczęśliwice glacial tunnel valley. Macroscopic description and gradation tests classified the investigated soil as gyttja with particle size distribution typical for silts. The same conclusions gave Flat Dilatometer Tests (DMT) (68% of 559 readings by DMT were qualified as silts). Moreover, preliminary tests of Atterberg limits gave the same results to those obtained from CPT/CPTU. On the modified Casagrande plasticity chart (ASTM D 2487-93, BS EN ISO 14688-2:2006/Ap2:2012; Grabowska-Olszewska [2]) the results of the investigated gyttja were clustered in a very cohesive group, below the A line, separating soils CL (lean clay) and CH (fat clay) from soils ML (silt) and MH (elastic silt) or OH (organic clay). Basing on original Casagrande plasticity chart, the investigated gyttja with liquid limit WL>50% gave the results clustered in the group of high plasticity with the symbol OH. Using the extended group of plasticity (eg, according to the classificaytion form in conformity with the British Standards – BS 1377: Part 2:6,4; 1990), the tested soil was characterized by extremely high plasticity and therefore it may be marked by symbol OE.

Although the particle size distribution was typical for silts (done by laboratory tests and DMT), the results of CPT/CPTU clearly showed (more than 96% of 6566 readings of cone resistance and sleeve friction) that the investigated gyttja from Żoliborz-Szczęśliwice glacial tunnel valley revealed the characteristic properties of glacial tills (sandy clays) and clays. The classification was based on adaptation of Robertson profiling chart to Polish soils classification PN-B-04452: 2002. Such observations allows to treat gyttja like clays/sandy clays for estimating the bearing capacity of displacement columns.

2. Transformational functions

2.1. Recomended functions

According to the recommendations by Gwizdała [3] the load-settlement of column head can be determined with sufficient accuracy using hyperbolic function or power function. Their general form could be presented in the following formulas (1) and (2).

The general form of hyperbolic function is as follows:

$$q = \frac{z}{a_1 + \frac{z}{\alpha_1 q_f}} \quad \text{for} \quad z \le z_f \tag{1}$$

where:

- α_1 – correction factor for hyperbolic function (1,25 by Det Norske Veritas according to [3]),
- a_1 – initial slope of the curve,
- q_f – shaft (t_{max}) or bottom resistance (q_f) of the column [kPa],
- z – settlement of column head [m],
- z_f – column head displacement required to mobilize resistance along the shaft (z_v) or in the bottom of the pile (z_f) [m].

The general form of power function:

$$q = q_f \left(\frac{z}{z_f} \right)^{\beta} \quad \text{for} \quad z \le z_f$$

where:

- β – selected on the basis of the calculation to get the best compatibility with the field test results,
- q_f – shaft (t_{max}) or bottom resistance (q_f) of the column [kPa],
- z – settlement of column head [m],
- z_f – column head displacement required to mobilize resistance along the shaft (z_v) or in the bottom of the pile (z_f) [m].

2.2. Column shaft or column bottom resistance based on CPT test results

In order to determine the unit column shaft (t_{max}) or column bottom resistance (q_f) modified Bustamante and Gianeselli method was used (for details see [6]) treating gyttja as clay, according to CPT test results presented in chapter 1.

2.3. Full mobilization criteria

The international study on column head displacement needed to mobilize the column shaft or bottom of column resistance presented by Gwizdała [3] show that the threshold of 2–5% column diameter D and 10% D must be reached respectively. Preliminary study on interpretation of column load test made in gyttja indicated that the mobilization of column shaft resistance responds similarly to the mobilization of bottom resistance, requiring the column head displacement of 0.1 D. Finally, to determine the proper transformation function for all columns, $z_f = z_v = 0.1$ D were adopted.

2.4. Determination of transformation functions

To determine the key parameters initial values for the transformation function of shaft as well as column bottom (hyperbolic and power function, see Tab. 2), two column field load tests were performed in standard way with additional measurements of axial force distribution along column cores using a chain of connected, retrievable extensometers (the construction and operating principles of the extensometers was described in detail, see for example Krasinski [4]).

Table 2

Initial range of estimated parameters for transformational functions

		Column no. 255	Column no. 273
β (for power f.)	bottom of column	0.5494	0.5892
	column shaft	0.5325	0.5805
a_1 (for hyperbolic f.)	bottom of column	0.0035	0.0034
	column shaft	0.0492	0.0564

The next step was to use appropriate Curve Fitting method and with previously obtained parameters scope, which resulted in determining precise values β and a_1 for the transformation function of column shaft and column toe, see Tab. 3. The key parameters were found using all available test load results for the global function, The fitting was done separately for each column to obtain the local function. Fig. 1 and Fig. 2 present histograms of local and global fitting for respectively hyperbolic and power function being the sum of transformation function of shaft and toe of column.

Table 3

Parameters for local and global functions

		Local function	Global function
β (for power f.)	bottom of column	<0.2879–1.0000>	0.6447
	column shaft	<0.4670–1.0000>	0.6326
a_1 (for hyperbolic f.)	bottom of column	0.00355	0.00355
	column shaft	<0.0350–0.2000>	0.1162

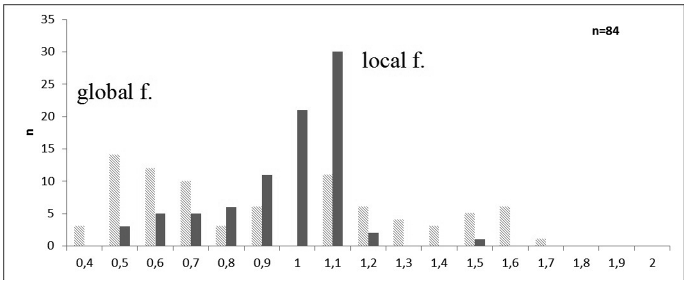

Fig. 1. Frequency bar chart of compliance for hyperbolic function

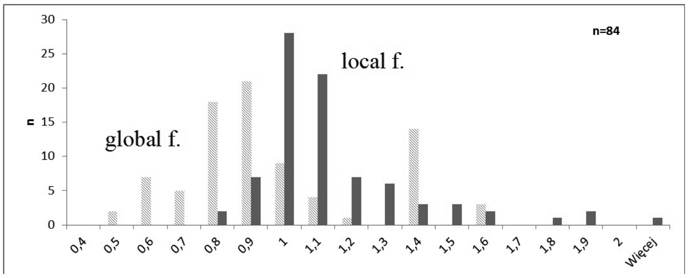

Fig. 2. Frequency bar chart of compliance for power function

Because unique parameters of transformation function are needed i.e. for the global function, better compatibility is attained for power function. These results in the vast majority have better compatibility factor (< 1). The results for which compatibility factors are greater than 1 are observed in the initial stage of the load-settlement ratio during the load test (see details in [6]).

The result of all the performed tests and their analysis allowed to create new transformation power functions for bottom (3) and shaft of column (4) respectively.

$$q = q_f \left(\frac{z}{z_f} \right)^{0.6447} \tag{3}$$

$$t = t_{\max} \left(\frac{z}{z_v} \right)^{0.6326} \tag{4}$$

3. Summary

In order to determine the transformation function of shaft and bottom of column, a series of 19 in-situ static load tests of concrete displacement column with diameter of 40 cm in gyttja and based on stiff clay were performed. Authors compared the field results with those estimated using power and hyperbolic function. Analysis of all obtained results shows that power function with found key parameter $\beta = 0.6326$ and $\beta = 0.6447$ for shaft and bottom of column respectively, can be used in the sufficient estimation of load-displacement relation for separately working column in a cohesive low-bearing-capacity soil (gyttjas of "Rynna Żoliborska").

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