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Source / Izvornik: **Archives of Civil Engineering, 2021, 67, 181 - 194**

Journal article, Published version
Rad u časopisu, Objavljena verzija rada (izdavačev PDF)

https://doi.org/10.24425/ace.2021.137162

WARSAW UNIVERSITY OF TECHNOLOGY Index 351733
FACULTY OF CIVIL ENGINEERING
COMMITTEE FOR CIVIL AND WATER ENGINEERING
POLISH ACADEMY OF SCIENCES ISSN 1230-2945

DOI: 10.24425/ace.2021.137162

ARCHIVES OF CIVIL ENGINEERING

Vol. LXVII ISSUE 2 2021

s. 181–194

Research paper

Liquid consistency of organic soils under the bridge construction

G. Kacprzak[1], P. Pietrzykowski[2], Ž. Veinović[3]

Abstract: The paper presents the case study of geotechnical investigations reporting connected with expert's opinion on undrained shear strength of organic sediments in the river valley at the north of Poland according to reinforcement methodology of c.a. 0,7 km highway embankment. Diversification of primary results caused additional research which revealed and confirmed liquid consistency of organic soils – several meters of organic and calcareous sediments – gyttja under the thin cover of peat. The main goal of the paper is a discussion on standardization of consistency of organic soils itself and additionally to point out very rare possibility of liquid consistency, finally not pointed in International Standards ISO 14688. The application of Atterberg limits in organic sediments is moot but even organic soil with water content higher than liquid limit can't be classified and interpreted as very soft with description as soil which exudes between the fingers when squeezed in the hand. Such identification is practically impossible when it's hard to squeeze because of gravitationally leaking through the fingers.

Keywords: gyttja, consistency, organic sediments, geotechnics, standards

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1. Introduction and background of discussion

At the phase of choosing soil reinforcement technique the update of geotechnical report [3] revealed diversification in consistency of soils strictly connected with the key parameter – undrained shear strength cu. At the first stage of geotechnical reporting the consistency index which should be determined then according to ISO 14688-2:2004 [8] only for silts and clays, for definitely organic soils (described as peats and muds) was I_C = 0,50. This value was extrapolated for generalized whole layer of organic sediments (Fig. 1) from values of liquidity index I_L = 0,5 (I_C = 1 – I_L) determined in one of drilled boreholes in the area of river channel at different depths as shown on the picture below (Fig. 2).

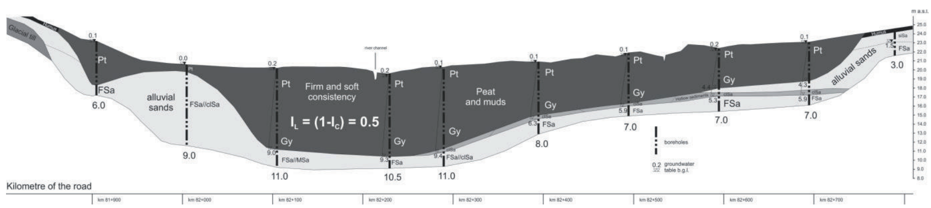

Fig. 1. The simplified geological cross-section of river valley filled by tested organic sediments from Ground Investigation Report [3]

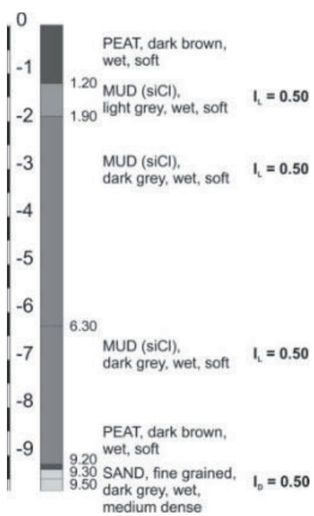

Fig. 2. The example of engineering log-borehole with determined consistency parameters for organic sediments in geotechnical report on tested area [3]

Another report [2] with verification of geological model exposed irrelevant differences in layers and geotechnical parameters. Organic layers were described as "soft" with parameters of liquidity index IL as presented on Fig. 3. It has to be constantly remembered that consistency index (or liquidity index) should be determined according to ISO 14688-2 only for silts and clays, so determination of consistency parameters for organic soils seems to be professionally improper at the beginning. Correctness of such procedure will be discussed later in the paper.

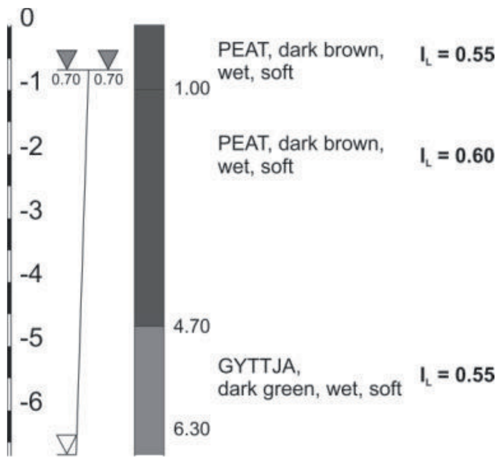

Fig. 3. Borehole example with the profile of organic sediments at verification of geological model stage I [3]

Surprisingly, another report [4] for the same construction site revealed significantly different values of consistency parameters (Fig. 4). There were no numbers for upper peats but lower gyttjas were split for lower sublayer with liquidity index values I_L = 0,70 – 0,95 and upper sublayer with values I_L > 1. Separately from differences from past reports, this suggests that the geotechnical parameter water content w of upper gyttja is higher than liquid limit LL and on the other hand according to international standards it should be described only as "very soft" as the soil with consistency index I_C < 0,25 (I_L > 0,75).

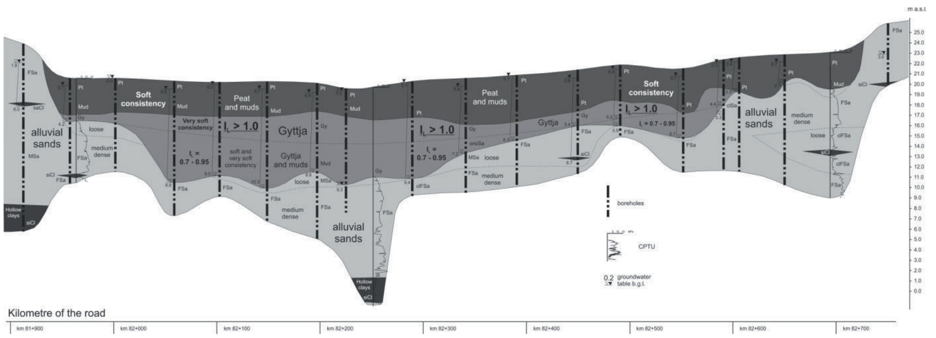

Fig. 4. Verified geological model on cross-section with layers of peat and gyttja on eastern lane of highway (verification of geological model stage II – 2016) [4]

Authors' research was focused on verification of geological model and confirmation of problematic organic soils' consistency parameters.

2. Field investigations

Numerous boreholes and penetration tests were carried out on the site. The cross-section presented above on figure 4 presents only a few of them – boreholes and penetration tests used for visualization of geological model for eastern road lane in the report for whole 0,7 km of the highway embankment. Figure 5 presents fair example of whole reliable recognition on the c.a. 100 m section of the road with 30 boreholes and 3 penetration tests.

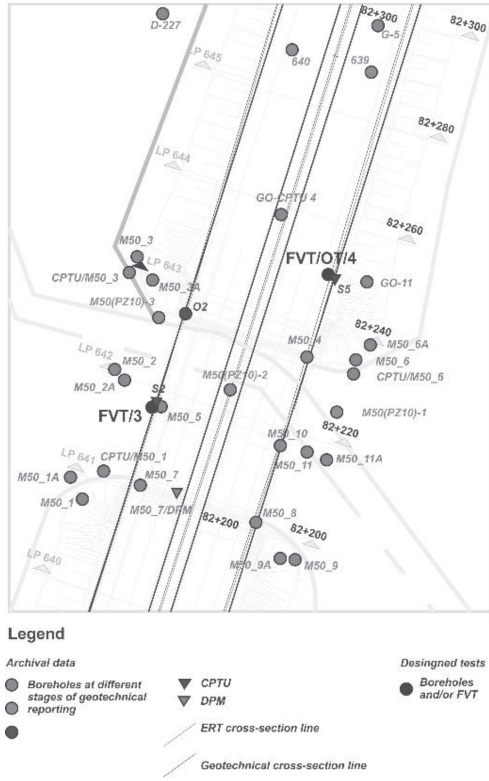

Fig. 5. Maximum concentration of research points on 100 m section in the area of designed bridge over the river on the technical background of the road elements

At the stage before author’s verification, summarizing, 87 boreholes and 8 penetration tests were done for geological model description of 700 metres of road. So accurate recognition and access to raw data of the field tests required only additional investigations connected with undrained shear strength cu determination and several boreholes connected with them and with probing for consistency tests. Finally, seven shear vane tests (field vane tests – FVT) and four checking boreholes were conducted [13], and results were compared with cone penetration tests for empirical cone factor Nk estimation and verification of cu results interpreted from CPTU tests in geotechnical reports.

Geological model was confirmed. Layers and sublayers of peat and gyttja were recognized and results of field vane tests confirmed low values of cu. Exemplary comparison of archival data and verification results with additional FVT measurements is presented on figure 6

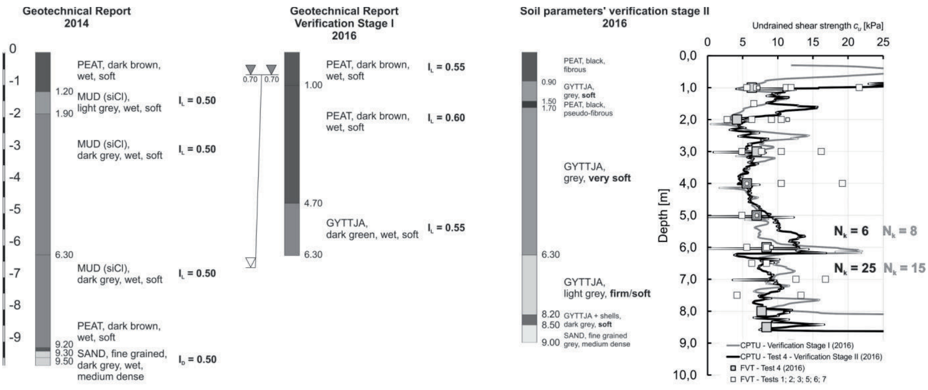

Fig. 6. Comparison of boreholes logs and geotechnical tests results in the area of river

Basing on plasticity and liquidity tests, appropriate correction factors μ for determination of undrained shear strength cu were calculated [1]; [6]; [11] (Fig. 7). It is worth to point out that correction factor was initially used only for cohesive soils [1] but afterwards it has been successfully used for organic soils as well i.e. μ = 0,5 for highly organic clays [12] or μ = 0,65 for sulphide organic silts or organic clays in Sweden [14].

Simplifying results from 18 tests (Table 1), correction factors were estimated μ = 0,7 for 5 FVT profiles (FVT: 1–5) and μ = 0,6 for 2 FVT profiles (FVT: 6–7). This is shown on the figure 6 that all measurements of undrained shear strength cu including simplified correction factors μ are significantly lower than 15 kPa in the area located directly next to the river and most of other measurement points do not exceed that value. As well as confirmation of low bearing capacity, analyses revealed differences between two types of used cones for CPTU tests (black and gray line). The compliance of the measuring profiles is clearly visible, which confirms correctness, but only with the use of appropriate (but different) cone factors N_k for different devices. The observed differences in q_c values with the same measurement trend indicate the measurement inaccuracy and/or the lack of proper calibration of the device during the tests, combined with factory differences, which should not be the case especially in such low bearing capacity soils. The derived large spread of the N_k coefficient, adapted to direct FVT measurements, clearly confirms the thesis derived above. Such low values confirms thesis about extremely low values of shearing resistance of tested soils. The calibration of derived N_k factors based always on the nearest testing points FVT vs CPTU and Fig. 6 presents the most representative CPTU plot. Values of shear strength presented on Fig. 6 at first glance seem to be highly diverse but obtained by field vane tests in 7 (seven) locations range mostly between 5 – 15 kPa with local measurements c.a. 20 kPa.

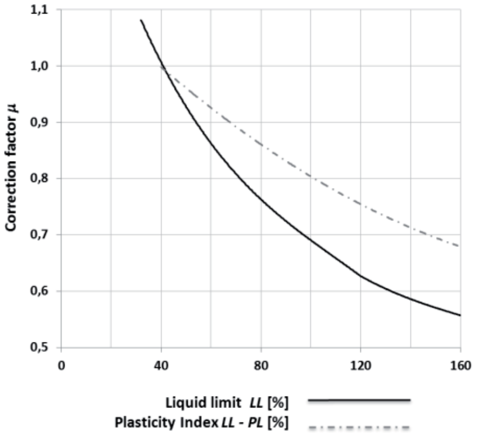

Fig. 7. The example of correction factors determination basing on liquidity and plasticity parameters of soils [6]

Table 1. The results of correction factors basing on Atterberg limits

Probe number	Liquid limit LL [%]	Correction factor μ	Plasticity index LL-PL [%]	Correction factor μ	Derived value of correction factor μ
2/3,0	117	0,65	59	0,75	0,70
2/6,0	81	0,75	37	0,85	0,80
2/8,0	128	0,60	65	0,75	0,70
4/1,1	251	0,50	179	0,50	0,60
4/3,2	119	0,65	61	0,75	0,70
4/5,5	99	0,68	46	0,82	0,70
4/7,0	137	0,60	78	0,70	0,65
5/5,5-6,0	81	0,75	32	0,90	0,80
6/2,3	1660	0,50	1290	0,50	0,50

3. Laboratory tests

Apart from classification measurements, which completely confirmed organic genesis of tested soils, final determination of consistency was examined. Determination of the Atterberg limits is not limited to mineral soils and such tests can be done in organic soils [5, 12]. Values of liquid limit and plastic limit in gyttja are commonly used for classification or for further correlations with physical [5,14] or mechanical [14] geotechnical parameters. Comparing the values of liquid limit [I_L = 80 – 140% from 7 tests (in other 2 tests values reached 250 and 1700%) and plasticity index [I_P = 30 – 80% from 7 tests (in other 2 tests values reached 180 and 1300%) with values reached by Goławska et al. [5] it's claearly shown that gyttja is characterized by very high (MV) or extremely high (ME) plasticity.

Apart from Atterberg limits the use of the parameter of consistency for organic soils is still debatable, what the authors undertake in this chapter. In manual tests, as pointed in ISO 14688-1:2002 [7], the consistency of cohesive soils, shall be identified as very soft, soft, firm, stiff and very stiff. Same terms were indicated in ISO 14688-2:2004 [8] for the designation of consistency index IC of silts and clays depending on the value of this parameter. Important problematic guidelines coming from recalled standards were:

- description and table presented in ISO standards about consistency of soils is designed for cohesive sediments (silts and clays) separately from organic soils,
- the most non-bearing soil consistency shall be described as very soft, even when the liquid limit value is exceeded; authors are aware that this is nearly impossible but the results coming from the current case threw new light on discussion about consistency of not only organic soils.

It is very important to mention that in recalled ISO 14688-1:2002 [7] the chart for the identification and description of soils (Fig. 8) instructed then using consistency description for organic soils as complementary properties.

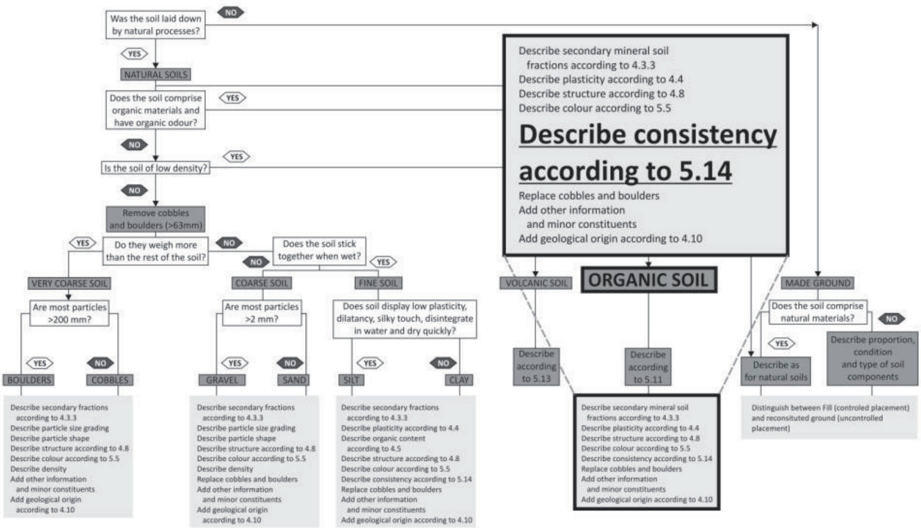

Fig. 8. Flow chart for identification and description of soils with underlined procedure concerning consistency of organic soils [7, changed]

Verified geological model in geotechnical report indicated upper sublayer of gyttja with the value of liquidity index $I_L > 1,0$ which definitely means that liquidity limit was exceeded. Observations from borehole logging presented on the picture below (Fig. 9) confirms that the consistency of sampled soil is softer than "…exuding between the fingers when squeezed in hand". Water from the ground drained gravitationally and there was no force of squeezing necessary to exude the soil in the hand. Archival results and manual observations were independently confirmed by certified laboratory [13] where Atterberg limits and water content were measured.

For five (of 6) tests of Atterberg limits of upper gyttja, the values of consistency index I_C of three samples were below 0,25 (0,24 0,14; 0,08) (where $I_C = 1 - I_L$) and another two of them exceeded the value $I_C = 0$ (-0,05; -0,06) (Table 2), what clearly confirms that consistency of organic soil may be liquid and complies with very low values of undrained shear strength from field tests. Those values confirmed as well the results from verification stage presented on the figure 4. Consent for using consistency parameters for organic soils, which were reserved for, however, cohesive non-organic soils (clays and silts), might come from flow chart for identification and description of soils (ISO 14688-1:2002). Consistency describing was clearly pointed as a part of procedure of manual description of organic soils

Table 2. Consistency result of upper gyttja

Probe number	Consistency Index $I_C = 1 - I_L$ [-]	Consistency description
2/3,0	0,08	Very soft
2/6,0	0,24	Very soft
4/1,1	0,42	Soft
4/3,2	– 0,06	Very soft*
4/5,5	0,14	Very soft
5/5,5-6,0	– 0,05	Very soft*

**natural water content exceeds liquid limit LL*

Fig. 9. Liquid gyttja sampled from one of the boreholes (Fot. P. Pietrzykowski)

4. International standards 14688:2017

Basing on reporting experience the newest adaptation (Fig. 10) of standards for identification and description of soil presented on the flowchart in ISO 14688-1:2017 [9] has been slightly but substantially changed by Technical Committee on the subject.

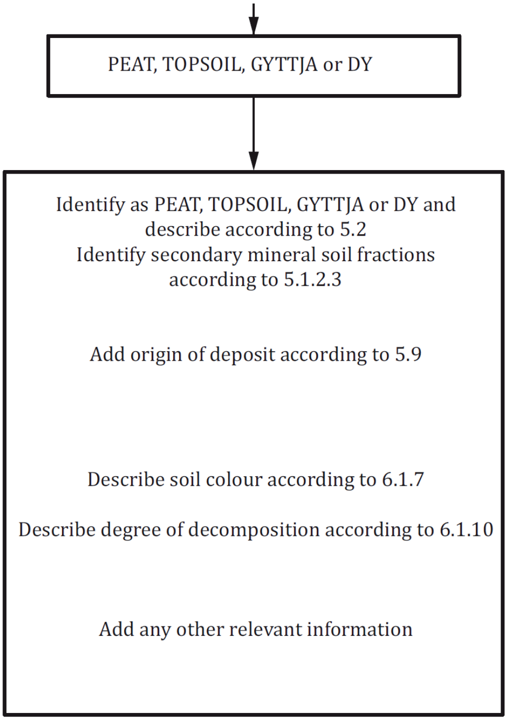

Fig. 10. The fragment of updated flowchart for the identification and description of soils [9]

Comparing it with previous version of standards there are no more suggestion to describe consistency of reported organic soils (peats, gyttja, dy and topsoil) [9]. Unintelligible disregarding about other relevant information (including consistency) was further enhanced on the revised Cassagrande's plasticity chart (Fig. 11) [10] where only silts and clays with different plasticity were pointed.

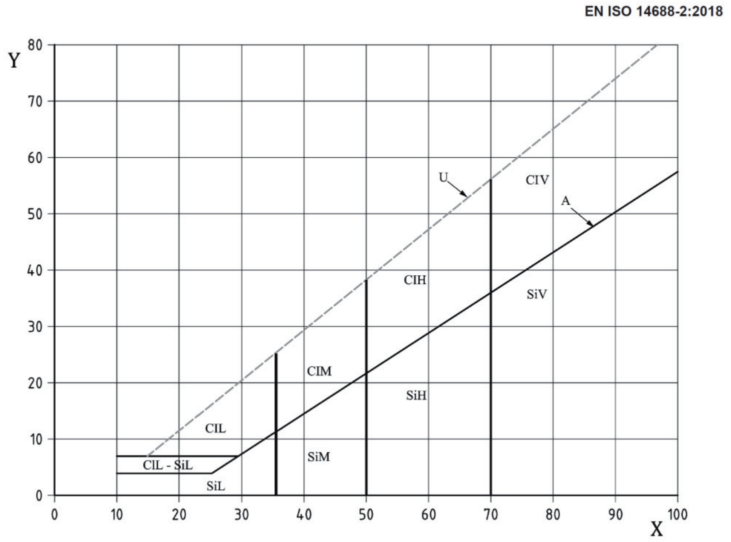

Fig. 11. Standardized plasticity chart [10]

This case study briefly presents that such simple geotechnical parameter like consistency is not clearly standardized and can be misunderstood for organic soils with extremely low values of undrained shear strength. Fortunately, the problem is scientifically and practically noticeable in the branch literature [5], where the authors consciously analyzed the distribution of their gyttja samples on the same Casagrande's plasticity chart diagram that does not take into account organic soils.

5. Conclusions

- Basing on experience of authors, consistency parameters should be still used for description of organic soils. It is definitely possible for silty organic sediments to gather so much water in the structure of soil to cross the liquid limit LL;
- There should be a legible permission in international standards for this procedure, but hitherto good practice excluded very soft, soft, firm, stiff and very stiff consistencies from organic soils;
- Apart from permission of using consistency parameters for organic sediments, it should be standardized possibility for authors of geotechnical reports for using liquid consistency when it is considered as appropriate.

6. Acknowledgments

Authors would like to thank Polish Geological Institute – NRI for permission of using the results of tests and archival data.

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Płynna konsystencja gruntów organicznych pod projektowanym mostem drogi ekspresowej

Słowa kluczowe*: gytie, grunty organiczne, konsystencja gruntu, stan gruntu, Polskie Normy*

Streszczenie:

Artykuł przedstawia analizę przypadku, w której podjęto się weryfikacji warunków gruntowych podłoża projektowanej budowy drogi ekspresowej w północnej Polsce. Zadanie projektowe utrudniła istotna rozbieżność w modelu geologicznym i parametryzacji geotechnicznej udokumentowanych gruntów organicznych w dolinie rzecznej na odcinku ok. 700 m, uwzględniającym posadowienie mostu w centralnym odcinku doliny. Rozpoznane w podłożu torfy i namuły w stanie na granicy plastycznego i miękkoplastycznego z kolejnymi etapami weryfikacji rozszerzono w modelu

geologicznym o wydzieloną niezależnie warstwę gytii. Przypisywane gytiom parametry stanu aktualizowano na miękkoplastyczny i bardzo miękkoplastyczny aż do wartości stopnia plastyczności IL>1,0 (w świetle nomenklatury bieżących standardów klasyfikacyjnych wskaźnika konsystencji IC<0,0), co świadczy o wilgotności naturalnej gruntu przekraczającej wartość procentową wilgotności granicy płynności według Atterberga.

Analizę przypadku przeprowadzono dwutorowo, w pierwszej kolejności sprawdzając udokumentowane archiwalnie istotne rozbieżności. W drugim przypadku podniesiono kwestie klasyfikacyjne gruntów organicznych. Badania terenowe sondą ścinającą FVT potwierdziły ekstremalnie małe wartości wytrzymałości na ścinanie w warunkach bez odpływu, nieprzekraczające często 15 kPa. Na podstawie badań granic konsystencji wyprowadzono także normowe i/lub literaturowe współczynniki korekcyjne redukujące mierzone wartości. Współczynnik korekcyjny μ wahał się w granicach od 0,5 do 0,8 przy uśrednionej wartości $\mu = 0,7$. Pomiary parametrów granic konsystencji wykorzystano dalej do klasyfikacji stanu gruntów na podstawie pomiarów wilgotności naturalnej.

Podejście klasyfikacyjne do gruntów organicznych nie zakładało przez wiele lat zgodnie z systemem normalizacyjnym oceny stanu/konsystencji gruntów organicznych zarezerwowanej wyłącznie dla gruntów spoistych/drobnoziarnistych (pyłów, iłów, glin). Zawartość substancji organicznej w gruncie istotnie zaburzała wyniki, co sztucznie osłabiało rozpoznawany stan gruntów. W praktyce inżynierskiej zgodnie z normalizacją nie stosowano zatem parametrów stanu/konsystencji gruntów organicznych z uwagi na niewiarygodne oznaczenia granic konsystencji. Z drugiej strony granice konsystencji gruntów organicznych były wyznaczane celem wyprowadzenia m.in. współczynnika korekcyjnego μ do redukcji wartości wytrzymałości na ścinanie w warunkach bez odpływu oznaczanej metodami niszczącymi. Polskie Normy klasyfikacyjne 14688-2, stowarzyszone z Eurokodem 7 przez okres ok. 15 lat zmieniały podejście w tym zakresie do gruntów organicznych, co wprowadziło niejednoznaczności w dokumentowaniu gruntów organicznych. W opisie makroskopowym norma 14688-1 zakładała opis makroskopowy konsystencji dla gruntów organicznych maksymalnie dopuszczając stan miękkoplastyczny z tłumaczenia oryginalnego (ang. very soft). Tymczasem norma klasyfikacyjna 14688-2 po 2 niejednoznacznych tłumaczeniach ostatecznie założyła klasyfikowanie gruntów (ang. very soft) jako gruntów maksymalnie bardzo miękkoplastycznych przy wskaźniku konsystencji IC<0,25 (IL>0,75) przy utrzymaniu konsystencji maksymalnie plastycznej dla opisu makroskopowego. Aktualizacja norm 14688-1 i 14688-2 w roku 2017 (oryginał) i 2018 (polskie tłumaczenia) utrzymały wcześniejszy podział oceny konsystencji, który nie pozwala na laboratoryjną weryfikację opisu makroskopowego. Przedstawiona analiza przypadku, gdzie grunty organiczne charakteryzują się wilgotnością naturalną przewyższającą granicę płynności, zgodnie z aktualnym systemem normalizacyjnym zdaniem autorów wprowadza odbiorcę wyników (projektanta) w błąd. Makroskopowo należałoby udokumentowane grunty opisać jako grunt miękkoplastyczny zaś sklasyfikować jako grunt bardzo miękkoplastyczny. W incydentalnych przypadkach, jak opisany w artykule, należy zdaniem autorów w sprzeczności z normami, jednoznacznie opisywać grunt jako płynny, co potwierdzają badania wilgotności w odniesieniu do granic konsystencji. System normalizacyjny w zakresie parametryzacji konsystencji gruntów organicznych wymaga dopracowania lub dopuszczenia swobody oceny przy ich dokumentowaniu.

Received: 07.10.2020, Revised: 02.03.2021