

Classifications of bog peat sensitivity to anthropogenic impact (Western Siberia)

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Abstract. The article deals with strength parameters of peats in Western Siberia, evaluates their transformations under the anthropogenic mechanical impact, presents peat classification in terms of sensitivity allowing the forecast of strength loss when destructing their structure in the process of building roads, pipelines. Sensitivity classification also permits predicting roadability for construction design.

1. Introduction.

In the territory of Western Siberia soft soils, such as peat, silt, sapropel, quick clay, are widely distributed. They are rather sensitive to anthropogenic impact when developing wetland areas. Reliable impact forecast design would prevent serious problems and permit calculating properly a bearing capacity of structure base. Sensitivity indicator (S_r) is of particular interest as it characterizes peat properties, the structure of which has been destructed as a result of site stripping in oil field development, partial peat reclamation while building, chiselling and trimming polluted top layers with washing under hydraulic pressure, land remediation, transport passage (off-roaders, tractors, grubbers, dozers, etc.).

The purpose of the article is to study transformations of peat strength properties, their evaluation in remolded (c_{ud}) and undisturbed states (c_u), classification in terms of peat sensitivity to mechanical effects in peat lands as well as unnamed peat massifs in the oil-gas field sites of Tomsk Oblast and Khanty-Mansiysk Autonomous District. The tasks include studying engineering-geological conditions of the territory; processing the results of peat vane field test; investigation of changes in strength characteristics of peat formation – before and after structure deformation; revealing the relationships between depth and strength characteristics, peat classifications in terms of strength properties and sensitivity.

The study of peat shear strength characteristics and peaty soil was carried out in the works by Amaryan L.S., Yevgeniev I.Ye., Kazarnovsky V.D., Shaposhnikov M.A. as well as Kanmuri, H., Landva, A.O., Marachi, N. D., Mesri, G. Ogino, T., Oikawa, H., Tsushima, M., Mitachi, T., Miyakawa, I., Radforth, J., Sodha V.G., Helenelund K.V. [1-13]. Anthropogenic impact of oil pollution and its influence on soil physical properties are considered in the work [14]. Among the widely used classifications of strength properties according to the vane test defining the building type of soft soil in groundwork base are those by Shaposhnikov M.A., Yevgeniev I.Ye., Kazarnovsky V.D., et al [3, 11, 15], roadability classifications [1, 16], soft soil sensitivity classifications [17-21].



2. Methods

Within the problems being solved, the thickness of boggy deposits has been stated, the parameters of peat reaction has been studied at peat deposits Klukvennoye (upland and lowland deposits), Plotnikovskoye, Vasyugan (site 5, Gavrilovka), Chelbak-2, Tagan, Ust-Kandinskoye and others, the density (ρ), the density of the solids (ρ_s), the density of the dry soil (ρ_d), water content (w), the parameters of the state, such as the void ratio (e), porosity, saturated limit, ash content (D_{as}) and the degree of decomposition were obtained by the gravimetric method (D_{dp}). Work was carried out in accordance with the methods provided in the existing regulatory standards [22].

In boggy sites peat was tested by vane shear test apparatus in 0.5 m through the whole peat formation thickness according to GOST 20276-2012. The foreign analogue to the method of rotary cutter to determine soil undrained resistance is vane shear test [22]. Field tests for determining undrained shear strength of soil with natural (c_u) and remolded structure (c_{ud}), as well as sensitivity (S_t) were carried out using vane shear test, according to [23, analogues 24].

Vane shear test allows determining the peat natural strength in formation after destruction of its structural bonds by rotary blades of the vane tester. The natural maximum peat strength (c_u) is determined by dependence curve peak of test rotational moment on soil deformation, i.e. angle of vane rotation in the formation. After destruction of natural soil texture and its structural bonds by the vane tester the steady-state strength (c_{ud}) is left, which is conditioned by water-colloid bonds of particles. This strength characterizes residual shear strength with which soil can resist to load after its structural bond destruction by construction machinery.

The relationship of maximum natural and steady-state values, i.e. the so called sensitivity index ($S_t = c_u/c_{ud}$) and difference in values of maximum and steady-state strengths ($S_t' = c_u - c_{ud}$), characterizes relative and absolute strength of structural bonds (chemical, ion, covalent, etc.), composition properties, compression, and anthropogenic impact rate, as well as, indirectly, gives data on lithification rate of soft soils and their structures.

3. Results and discussion

The results obtained have shown that the value of shear strength in natural state changes from 4.2 to 44.6 kPa, in remolded state from 0.01 to 16.1 kPa (fig. 1). The minimal values of S_t are of greatest interest as they define mechanical cohesion of peat particles – the less the value, the better the cohesion. The minimal difference of it is found in fuscum, magellanicum peat, and cottongrass-sphagnum, which indicates high cohesion of peat particles with sponge texture even in remolded state. Being more decomposed, small size particles of other peats loose most of their bonds after their natural structure destruction, long fibers of sphagnum moss often remain undisturbed. The results of correlation analysis show that there are the closest significant relationships between S_t and porosity coefficient e (correlation coefficient $r = -60$) that demonstrates low cohesiveness of peat particles with low porosity ($e < 12-13$) containing high amount of decomposed elements: sedge, woody-sedge, wood. The minimal values of S_t are observed for sphagnum peat with porosity coefficients ranging from 16–17 to 20, but at higher porosity coefficients the values of S_t grow again, as c_u and c_{ud} decrease, and the number of contacts among the peat particles is likely to decrease when destructing the peat structure. The changes of S_t with the increase of ρ_s are closely connected with variations of ρ_s in peats of different botanical composition. The increase in S_t after 1.70 g/cm³ is connected with the decrease in c_{ud} with growth of D_{as} .

According to the strength properties classification [3], the study peats are referred to I and II construction types, in remolded state they are mainly referred to II–III types. In site stripping, tree and bush roots serving as reinforcement for improved roadability are removed. For example, after peat structure destruction, cross-country capability of peat deposits Klukvennoye and Chelbak-2 are referred to heavy ones in terms of the Amaryan classification [1], whereas that of rest deposits – to particular ones. Those aspects are necessary to take into account at wetland operation performance to avoid heavy traffic and long transport stops in such sites.

As has been noted, soil classification is performed separately in terms of the following indicators c_u and S_t . When soft soils lose their strength in the remolded state, the classification including strength and sensibility can be used to group them. It may be the classification models combining c_u and S_t or c_u and

S_t' [1, 3, 11, 15-21] in different ways. They are intended for site investigation of linear structure construction.

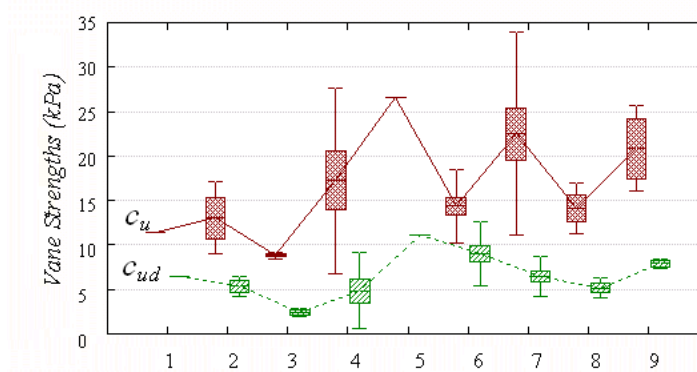


Fig. 1. Distribution of shear strength of different peat types: 1 – cottongrass-sphagnum, 2 – magellanicum, 3 – sphagnum-ridge, 4 – sedge, 5 – grass, 6 – fuscum, 7 – woody-sedge, 8 – sedge-hypnaceous, 9 – hypnaceous.

“Boxes” denote standard errors, dotted line – standard deviations, lines – average values of c_u and c_{ud}

Let us consider the examples of peat classifications using the results of vane test (fig. 2) obtained from peat deposits in landscaping development of Mamontov oil field. In terms of their inflow regime and location the bog are referred to moss type confined by flow runnels and topographic lows. The bog deposits include low-ash peats of different decomposition degree. As a result of geological survey, the peat deposit thickness is established: least decomposed peat 0.3-1.5 m, medium decomposed peat 0.2-3.8 m, and fibrous one 1.2-2.2 m. The least decomposed peat has organic matter content 94.8%, degree of decomposition – 15.8 %, water content – 9.1 u.f. (unit fraction), deformation modulus – 0.11 MPa, shear strength from 3 to 9 kPa; medium decomposed peat contains 92.2% of organic matter, degree of decomposition – 32.5 %, average water content – 6.8 u.f., density 1.05-1.08 g/cm³, density of the solids – 1.47 g/cm³, deformation modulus – 0.23 MPa, shear strength from 7.3 to 7.5 kPa; fibrous peat makes up 8.6% of organic matter content, degree of decomposition – 51.3 %, average water content – 4.2 u. f., density 1.20-1.28 g/cm³, density of the solids – 1.81 g/cm³, deformation modulus – 0.25 MPa, shear strength from 11.1 to 11.5 kPa. With depth water content decreases, whereas degree of decomposition, ash content, density, deformation modulus and shear strength increase.

The soil strength in both remolded and undisturbed states increases with depth (fig. 2), the most sensitive to structure destruction are peats of up to 2-3 meters deep, the index values become stabilized ($S_t=2\div3$) deeper than 4 meters. The close relationships of strength properties and test depth are reflected in the correlation equations:

$$\begin{aligned}
 S_t &= 3.77 - 1.36 \log_{10}(h) \quad (r=-60); \\
 c_u &= 2.07 + 2.10h - 0.087h^2 \quad (r=93); \\
 c_{ud} &= 0.28 + 0.83h - 0.02h^2 \quad (r=90).
 \end{aligned}$$

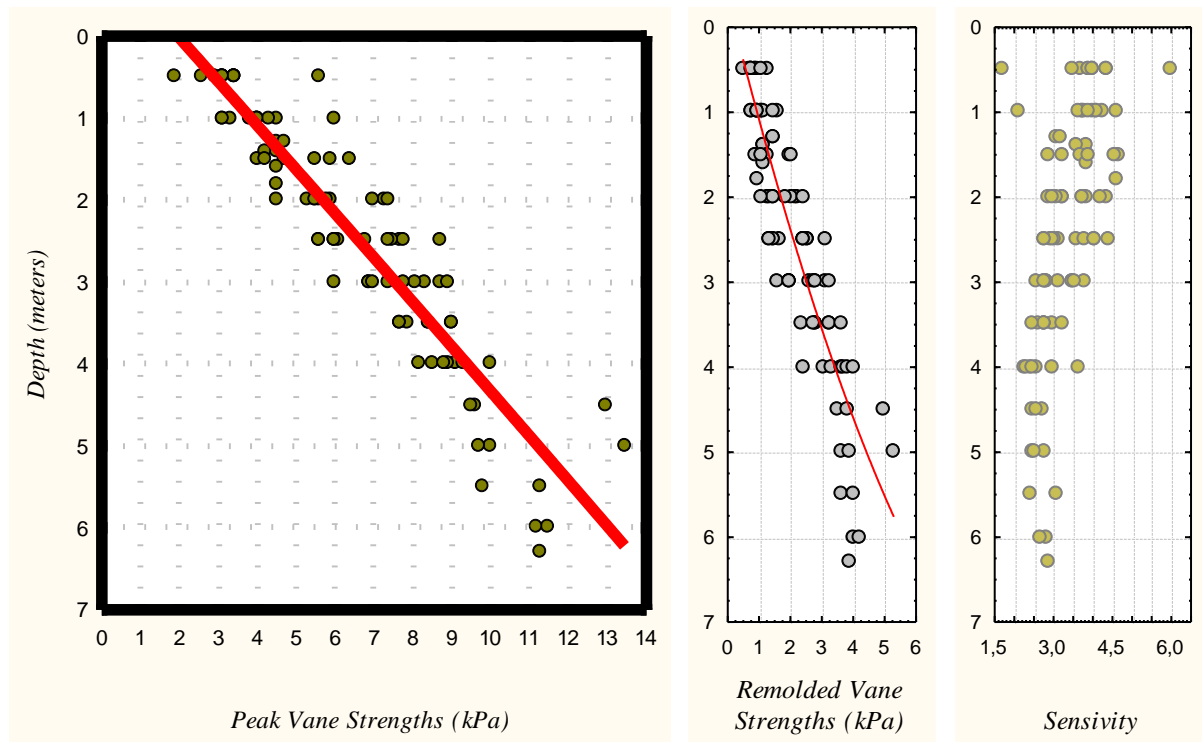


Fig. 2. Undrained shear strength profile of peat

In authors' opinion, to evaluate sensitivity to peat structure destruction in an integrated manner, the most conclusive and simplest classifications are those uniting indexes c_u and c_{ud} (tables 1-3). As the first example, the classification of soft soils in terms of road construction types is used from [26]. It should be reminded that 1 type includes peat that is not squeezed out under stress from loading, 2 type – squeezed out only under rapid stress, 3 type – always squeezed, 1,2 type requires additional consolidation tests to verify it. Hence, in the proposed classification of the same type are designated by the letters A (type 1), B (1, type 2), C (2 types), and D (3 types). According to table 1 and fig. 2 in the section of up to the depth of 2 m 2D type prevails, lower – 2C type up to 3-4 m, some points from the depth of 4.5-6.3 m can be referred to 1, 2 C types. Consequently, in the upper part of the bog soils with remolded structure would be squeezed out at any speed of filling.

Table 1. Peat types in terms of sensitivity according to road construction classification [26]

No sample	Peat type Peak strength	Remolded strength Undrained shear strength, kPa	A (1) >20	B (1,2) 20-10	C (2) 10-3	D (3) <3
1	1	>20	1A	1B	1C	1D
2	1, 2	20-10	-	1.2B	1.2C	1.2D
3	2	10-3	-	-	2C	2D
4	3	<3	-	-	-	3D

To classify peat in terms of its sensitivity, let us consider table 2 using another classification for pipeline construction [15]. According to Industry-Specific Construction Standards (ISCS), 51-3-85 peat types are determined depending on maximum shear strength c_u : 1 type – $c_u=10$ kPa, bogs are entirely filled with dense peat up to its mineral bed, which is a reliable foundation for pipelines; 2 type – $c_u=5-10$ kPa, bogs are filled with peats of stable structure with water layers and peat formation thickness of more than 2 pipeline diameters between them up to its mineral bed; such peat can be used as a bearing

stratum for pipelines; 3 type – $c_u = 5\text{kPa}$, bogs are filled with fibrous peat or water with organic remains, with water layers and peat formation thickness of not less than 2 pipeline diameters between them up to its mineral bed; such peat cannot be used as a pipeline foundation.

Table 2. Peat types in terms of sensitivity according to the classification for pipeline construction [25]

№ sample	Peat type Peak strength	Remolded strength Undrained shear strength, kPa	A (1) >10	B (2) 5-10	C (3) <5
1	1	>10	1A	1B	1C
2	2	5-10	-	2B	2C
3	3	<5	-	-	3C

According to table 2 and fig. 2 up to the depth of 2 m in the study areas 3C type prevails, lower there is 2C type, some points from the depth of 4.5-6.3 m can be referred to 1C type. Thus, independently on their initial strength, all peats are included in C category and, hence, such conditions are not acceptable for pipeline construction.

Table 3. Peat types in terms of radability [1]

№ sample	Peat type Peak strength	Remolded strength Undrained shear strength, kPa	A (1) >18	B(2) 12-18	C(3) 8-12	D(4) <8
1	(easy conditions)	>18	1A	1B	1C	1D
2	(medium conditions)	12-18	-	2B	2C	2D
3	(heavy conditions)	8-12	-	-	3C	3D
4	(particular conditions)	<8	-	-	-	4D

In terms of roadability (table 3) the peats under consideration can be taken from “heavy conditions” to “particular” ones – type 4D. Such bogs are suitable for passage of floating track machines or vehicles with arch tires, as well as passage in winter with the exception of warm winters.

The presented classifications (tables 1-3) and fig. 1 allow evaluating the behavior of different peats in a construction base. In terms of strength properties and sensitivity the most favorable peats are sphagnum – fuscum and magellanicum, other types are rather sensitive to structure destruction. On the other hand, the classifications do not consider deformation properties, whereas sphagnum peat compressibility can exceed 80% of bed thickness.

Conclusion

As a result of the research performed the peat strength properties of some peat formations have been characterized, the dependencies of peat strength properties parameters on the depth of occurrence have been revealed. They can be used to evaluate peats as a construction foundation. Based on the suggested classifications the most appropriate sites for transport and construction have been revealed. The suggested approach to evaluation of peat soil sensitivity by means of well-known and reliable classifications allows researchers and engineers to apply peat strength properties more carefully and consider soft soils attentively when prospecting, constructing, and using facilities.

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