

## Variability of engineering geological parameters in flood facies sediments

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Flood-deposited, muds are characterised by considerable variability of their lithological characters. This variability reflects the development of the river forming the terrace, the geological setting of the drainage basin and the morphology of the flood plain. The lithological variability of the muds causes great vertical and lateral variability in the engineering geological parameters. Therefore all calculations based on mean values obtained from laboratory analyses are prove to error. The most reliable values of parameters are obtained from fieldwork “*in situ*”.

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### INTRODUCTION

The commonly applied lithological classification of flood facies sediments in river valleys into silty-sandy and loamy muds, followed by a genetic classification into muds of braided (wild) and meandering rivers (Leopold *et al.*, 1964; Falkowski, 1980; Myślińska, 1984; Bozzano *et al.*, 2000) is insufficiently for engineering geological purposes, as shown below precise. These subdivisions may suggest that, within the two main groups, the soils are not variable, have a similar lithology and possess similar physical and chemical parameters.

Data for muds from the Vistula River valley in the vicinity of Warsaw, given below, indicate that flood facies sediments are much more diverse, and that further subdivision is justified by their engineering geological parameters.

### ENGINEERING GEOLOGICAL PARAMETERS IN FLOOD FACIES SEDIMENTS

There is ever increasing data on the lithology and physical-mechanical parameters of muds. In general, the data justify the classification of flood facies sediments into two basic groups (silty-sandy muds series I, loamy muds series II). This basic subdivision can be observed during analyses of soil profiles, from both macroscopic analyses of deposits and quantitative data, i.e.

from statistical (CPT), dilatometric (DMT), and BAT soundings (Groundwater Monitoring System) (Figs. 1–3). BAT field investigations of the hydraulic conductivity ( $k_w$ ) indicated a high variability of this parameter (Fig. 1): for muds series II  $k_w = 1.3 \times 10^{-8}$  (Kaczyński, 1997, unpubl.)  $2.92 \times 10^{-9}$  m/s, at the saturation index ( $S_r$ ) below 100% (unsaturated soil). For saturated soils the filtration coefficient determined in the compressional permeameter GEONOR was  $1.4 \times 10^{-8}$  m/s.

However, compilation of data from a larger area shows subdivision to be less clear. Table 1, showing the physical properties of soils, indicates that the ranges obtained overlap in particular groups of sediments. It is also difficult to pinpoint a parameter linked with their identification. Similar conclusions can be drawn from the analysis of the engineering geological parameters (Tables 2 and 3), although the sub-division is more distinct in this case.

The large scatter of results of laboratory and field analyses points to the fact that soils of the flood facies include a large spectrum of soils characterised by different parameters, necessitating a more detailed engineering geological evaluation of the valley.

In general, the lithological succession of flood facies sediments of the Vistula River valley from the vicinity of Warsaw is as follows: 0.5–2.0 m of silty-sandy mud (silty sands and silts); followed by 1.0–2.5 m of thick loamy mud (loam to clay). The topmost part of the succession in urban areas is represented by anthropogenic soils (embankments). The thickness

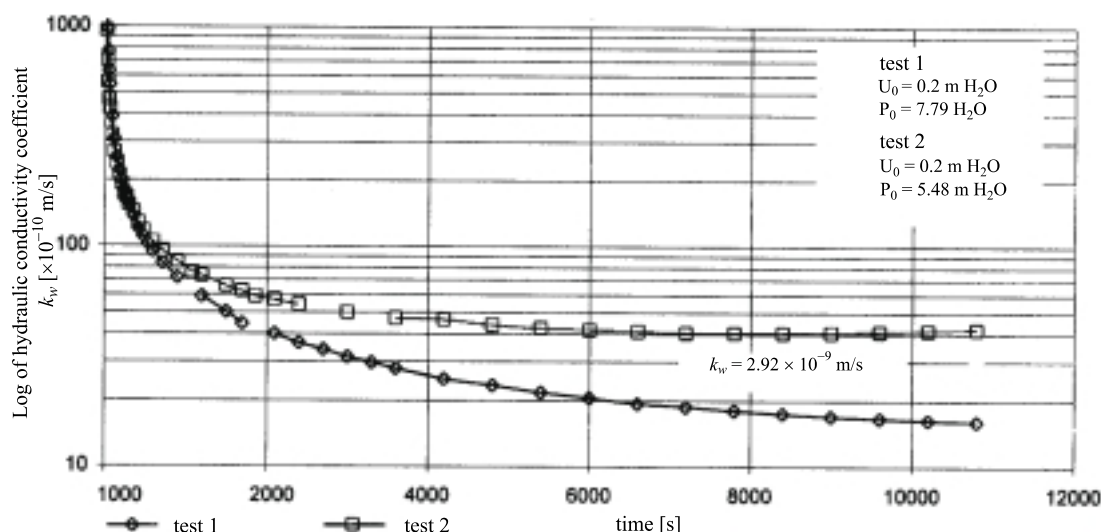


Fig. 1. The hydraulic conductivity coefficient ( $k_w$ ) for muds series II

$U_0$  — pore pressure (mH<sub>2</sub>O);  $P_0$  — gas pressure in permeameter (mH<sub>2</sub>O) at time  $t = 0$

of loamy muds increases from the riverbed towards the margin of the Pleistocene terrace, concordantly with the stratigraphic sequence of the Holocene river meanders.

#### THE LITHOLOGICAL-MECHANICAL PROPERTIES OF MUDS

The variability of muds formed in the same interval may be explained by the specific conditions, in which they were

formed. The factors influencing the formation of mud (Fig. 4) show local variability. This variability results from the interaction of three main factors: type of water level rise, quantity and type of the transported debris and the geomorphology of the flood area.

The type of water level rise and its characteristics. The rapid outflow of water from the river channel, flow rate, high water level, duration of water rise may differ in particular river sections. The retreat of floodwater into the river channel may also vary.

Table 1

Physical parameters of the Vistula River muds from the vicinity of Warsaw

Type of mud	Parameter	Myślińska (1984, unpubl.) Profile W-wa Świdry Małe	Szmidt (unpubl.) Profile W-wa Wilanów	Filipek (unpubl.) Profile W-wa Zawady
I Sandy silty muds	Granulometry [%]			
	Fraction sand	3.0–41.0	3.0–11.0	4.0–12.0
	silty	41.0–80.0	71.0–84.0	70.0–82.0
	clay	15.0–24.0	13.0–18.0	14.0–18.0
	Natural moisture content $W_n$ [%]	8.8–37.0	22.8–28.6	23.2–25.2
	Plasticity limit $w_p$ [%]	16.0–26.0	20.0–23.0	19.0–21.0
	Liquid limit $w_L$ [%] (Casagrande's method)	31.0–46.0	34.2–38.7	32.0–36.0
II Laomy muds	Plasticity index $I_p$ [%]	12.0–20.0	11.5–18.4	12.3–15.6
	Liquidity index $I_L$	–0.6–0.70	0.13–0.50	0.16–0.48
	Ignition loss [%]	1.9–9.0	–	–
	Granulometry [%]			
	Fraction sand	10.0–68.0	45.0–57.0	43.0–59.0
	silty	26.0–72.0	35.0–46.0	33.0–48.0
	clay	6.0–18.0	7.0–9.0	8.0–9.0
Natural moisture content $W_n$ [%]	6.5–25.4	12.1–15.3	12.8–15.2	
Plasticity limit $w_p$ [%]	21.0–24.0	15.0–18.0	17.0–18.0	
Liquid limit $w_L$ [%] (Casagrande's method)	24.0–41.0	22.0–26.0	25.0–26.0	
Plasticity index $I_p$ [%]	4.0–17.0	7.3–8.1	7.9–9.3	
Liquidity index $I_L$	–2.2–1.22	–0.5––0.27	–0.45––0.29	
Ignition loss [%]	1.6–9.3	–	–	

WATERTABLE m 5.2

Reduction formulae according to Marchetti, ASCE Geot.Jnl.,Mar. 1980, Vol.109, 299-321  
 NOTE : OCR = ''relative OCR''. OCR below often reasonable. Accuracy can be improved if precise OCR values are available. Then factorize all OCR below by the ratio OCRreference/OCR

										INTERPRETED GEOTECHNICAL PARAMETERS							
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Po	= Corrected A reading									Ko = In situ earth press. coeff. by Lunne <i>et al.</i> (1997)							
P1	= Corrected B reading									Ocr= Overconsolidation ratio by Lunne <i>et al.</i> (1997)							
Gamma	= Bulk unit weight/GammaH2O									q = Eroded overburden above g.s.						bar	
Sigma'	= Effective overb. stress									M = Constrained modulus (at Sigma')						bar	
U	= Pore pressure									Cu = Undrained shear strength						bar	
Id	= Material Index																
Kd	= Horizontal stress index																
Ed	= Dilatometer modulus																
Z (m)	Po	P1	Gamma	Sigma'	U	Id	Kd	Ed	Ko	Ocr	q	M	Cu	DESCRIPTION	Ko	Ocr	
0.80	0.7	2.7	1.70	0.14	0.00	3.14	4.8	71					132	SILTY SAND			
1.00	0.7	2.7	1.70	0.17	0.00	3.14	3.8	71					118	SILTY SAND			
1.20	0.9	4.3	1.70	0.20	0.00	3.85	4.3	118					210	SAND			
1.40	1.2	4.8	1.80	0.24	0.00	3.08	5.0	126					238	SILTY SAND			
1.60	1.2	4.5	1.80	0.27	0.00	2.77	4.4	115					203	SILTY SAND			
1.80	1.2	4.5	1.80	0.31	0.00	2.77	3.9	115					191	SILTY SAND			
2.00	1.3	5.0	1.80	0.34	0.00	2.93	3.7	129					211	SILTY SAND			
2.20	1.2	4.4	1.80	0.38	0.00	2.67	3.2	111					164	SILTY SAND			
2.40	1.3	4.3	1.80	0.41	0.00	2.43	3.0	106					150	SILTY SAND			
2.60	1.3	2.5	1.60	0.45	0.00	0.93	2.9	42	0.76	1.8	0.3	52	0.16	SILT	0.60	1.0	
2.80	1.4	2.4	1.60	0.48	0.00	0.71	2.9	35	0.77	1.8	0.4	43	0.17	CLAYEY SILT	0.61	1.1	
3.00	1.5	3.1	1.60	0.51	0.00	1.03	3.0	55	0.78	1.9	0.4	71	0.19	SILT	0.61	1.1	
3.20	1.6	3.9	1.70	0.54	0.00	1.45	2.9	80					105	SANDY SILT			
3.40	1.8	3.1	1.60	0.58	0.00	0.73	3.1	46	0.81	2.0	0.6	60	0.22	CLAYEY SILT	0.63	1.1	
3.60	1.5	2.7	1.60	0.61	0.00	0.75	2.5	40	0.68	1.5	0.3	44	0.18	CLAYEY SILT	0.56	0.9	
3.80	1.5	2.7	1.60	0.64	0.00	0.75	2.4	40	0.65	1.3	0.2	42	0.18	CLAYEY SILT	0.55	0.8	
4.00	1.9	2.9	1.60	0.67	0.00	0.55	2.8	36	0.75	1.7	0.5	44	0.23	SILTY CLAY	0.60	1.0	
4.20	1.8	2.3	1.60	0.70	0.00	0.30	2.5	18	0.68	1.4	0.3	20	0.21	CLAY	0.56	0.9	
4.40	1.8	2.5	1.60	0.73	0.00	0.42	2.4	26	0.65	1.3	0.2	27	0.20	SILTY CLAY	0.55	0.8	
4.60	1.4	6.1	1.80	0.77	0.00	3.27	1.9	162					169	SILTY SAND			
4.80	1.4	3.3	1.70	0.80	0.00	1.43	1.7	67					57	SANDY SILT			
5.00	2.6	14.7	1.90	0.83	0.00	4.71	3.1	421					622	SAND			
5.20	3.0	16.4	1.90	0.87	0.00	4.44	3.5	465					733	SAND			
5.40	2.2	15.0	1.90	0.89	0.02	5.74	2.5	443					574	SAND			
5.60	2.9	16.2	1.90	0.91	0.04	4.61	3.2	461					693	SAND			
5.80	1.6	9.6	1.80	0.92	0.06	5.32	1.6	279					258	SAND			
6.00	2.2	12.1	1.90	0.94	0.08	4.73	2.2	344					412	SAND			
6.20	1.7	8.3	1.80	0.96	0.10	4.17	1.7	230					216	SAND			
6.40	2.4	14.2	1.90	0.97	0.12	5.20	2.3	410					506	SAND			
6.60	2.4	14.2	1.90	0.99	0.14	5.25	2.3	410					497	SAND			
6.80	1.6	10.2	1.80	1.01	0.16	5.76	1.5	297					252	SAND			
7.00	2.0	12.7	1.90	1.02	0.18	5.71	1.8	370					378	SAND			
7.20	2.0	12.2	1.90	1.04	0.20	5.60	1.7	353					348	SAND			
7.40	2.4	14.5	1.90	1.06	0.22	5.62	2.0	421					470	SAND			
7.60	1.8	10.3	1.90	1.08	0.24	5.24	1.5	293					249	SAND			
7.80	1.7	13.0	1.90	1.09	0.26	7.74	1.3	392					333	SAND			
8.00	1.8	12.2	1.90	1.11	0.27	7.07	1.3	363					308	SAND			
8.20	1.6	19.2	1.90	1.13	0.29	13.34	1.2	610					519	SAND			

Fig. 2. Dilatometer test DMT

Quantity and type of material transported by the high water. This factor varies in relation to the geological setting of the drainage basin and the transport conditions in particular sections of the river.

Geomorphology of the flood area. The flood area contains many forms of different origin, influencing the high water flow and thus the sedimentation conditions of the transported debris.

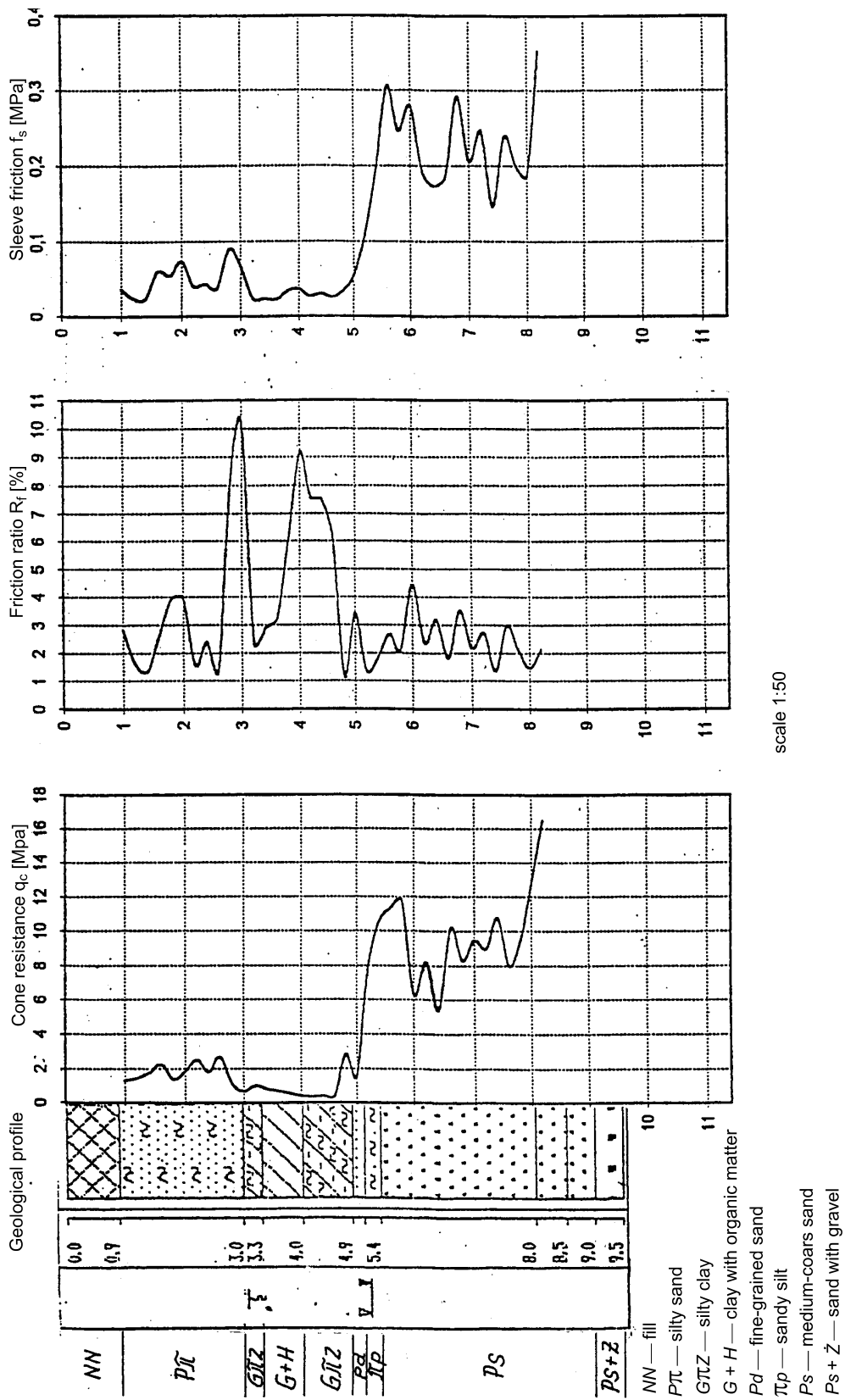
In engineering geological mapping it is essential to distinguish sub-regions within the flood plain, differing in the type of the flood facies sediment. They include:

— zones of flow channels; forms with a visible morphology and possessing lithological successions different to those other parts of the flood plain.

— zones with hampered flow and outflow of the high waters through e.g. dune zones; in this case fine sediment accumulates, which is enriched in organic matter.

CONCLUSIONS

1. The analysis of lithological and geotechnical data for flood facies sediments in the Vistula River valley in the vicinity of Warsaw indicates that they are much more diverse than may be concluded from the commonly used subdivision into two general groups (braided river muds and meandering river muds).



scale 1:50

Fig. 3. CPT profile from Warsaw, Belgijska 21, 83.6 m a.s.l.

Table 2

**Selected engineering geological parameters of the Vistula muds from the vicinity of Warsaw**

Type of mud	Parameter	Myślińska (1984, unpubl.) Profile W-wa Świdry Małe	Szmidt (unpubl.) Profile W-wa Wilanów	Filipek (unpubl.) Profile W-wa Zawady	Kaczyński and Krauzlis (unpubl.)* Profile W-wa Saska Kępa
I Sandy silt mud	Bulk density $\rho$ [Mg/m <sup>3</sup> ]	1.53–1.90	1.75–1.77	1.75–1.76	1.70–1.90
	Angle of internal friction $\Phi$ [°]	13.5–27.0***	20.3**	23.7**	29.7–31.3
	Cohesion $c_u$ [kPa]	10.0–51.0***	40.6**	41.2**	–
	Undrained shear strength $\tau$ [kPa]	–	78.7** $\sigma_n = 100$ kPa	80.4** $\sigma_n = 100$ kPa	38.0–183
	Modulus of compressibility $M_o$ [MPa]	2.30–4.50 $\sigma_n = 0–200$ kPa	5.28–5.39 $\sigma_n = 0–200$ kPa	5.29–5.38 $\sigma_n = 0–200$ kPa	4.30–23.8
	Cone resistance CPT $q$ [MPa]	–	–	–	1.1–2.7
II Loamy mud	Bulk density $\rho$ [Mg/m <sup>3</sup> ]	1.82–1.95	1.80–1.89	1.80–1.89	1.60–2.00
	Angle of internal friction $\Phi$ [°]	3.0–24.0	14.2	16.3	9.1–15.5
	Cohesion $c_u$ [kPa]	10.0–72.0	19.0	15.4	12.0–23.0
	Undrained shear strength $\tau$ [kPa]	–	46.4 $\sigma_n = 100$ kPa	44.4 $\sigma_n = 100$ kPa	38.0–121.0
	Modulus of compressibility $M_o$ [MPa]	1.40–3.30	4.07–4.63	4.08–4.55	2.0–11.1
	Cone resistance CPT $q$ [MPa]	–	–	–	0.35–2.05

\* — Parameters obtained from fieldwork “*in situ*” (CPT, Dilatometer DMT, SLVT sounding); \*\* — parameters obtained from direct shear apparatus; \*\*\* — parameters obtained from triaxial apparatus

Table 3

**Selected engineering geological parameters of the Vistula muds (undivided) from the vicinity of Warsaw**

Types of mud	Parameter	Frankowski and Wysokiński (unpubl.) Profiles W-wa Zawady, Tarchomin, Goław, Saska Kępa	Lipińska (unpubl.) Profile W-wa Saska Kępa
I+II Undivided mud	Plasticity index $I_p$ [%]	8.6–56.2	–
	Liquidity index $I_L$	0.05–0.82	0.15–0.92
	Bulk density $\rho$ [Mg/m <sup>3</sup> ]	1.64–2.06	1.68–2.02
	Angle of internal friction $\Phi$ [°]	1.3–15.0	1.0–12.0***
	Cohesion $c_u$ [kPa]	10.0–100.0	10.0–50.0***
	Modulus of compressibility $M_o$ [MPa]	–	0.5–11.5

For explanations see Table 2

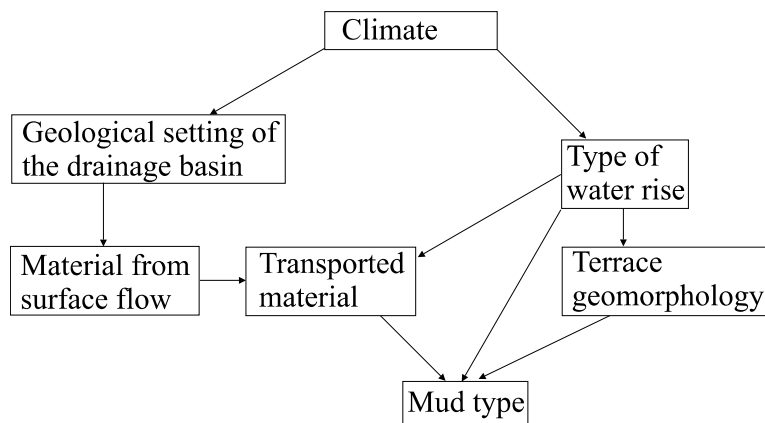


Fig. 4. Factors determining the lithology of the flood facies sediments

2. The distinct lithological variability of muds and their engineering geological parameters justifies the distinguishing of sub-regions differing in lithology and physical-mechanical parameters within the flood plain during cartographic work.

3. The high variability of the soils analysed requires field analyses, including static, dilatometric and BAT analyses to determine the engineering geological parameters.

4. For unconsolidated soils (e.g. muds), the best reliable method of characterising  $M_o$  (modulus of compressibility) is DMT sounding (Lunne *et al.*, 1997; Marchetti, 1999; Kaczyński and Krauzlis, 2000, unpubl.).

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