

# LOESSES NEAR KRAKÓW IN LIGHT OF GEOLOGICAL-ENGINEERING RESEARCH

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**Abstract:** This work is only a preliminary study on the evaluation of geological engineering properties of loess area of Kraków. It has been expanded to include field tests (CPTU, DMT), which is an alternative to expensive and time-consuming laboratory tests. The field tests allow enough detail to track the variability of physical and mechanical properties of soils, but in many cases, provide too much information, because their interpretation is often based only on a qualitative analysis. Laboratory and field tests are complementary and should be continued in order to determine best the correlation between the measured values of the resistance probes (CPTU, DMT) and the results obtained from laboratory tests. This will provide new calculation formulas for the evaluation of geotechnical parameters of loess in situ.

## 1. INTRODUCTION

The fast pace of building development in recent years is the reason for occupying new areas and using them for housing, service or industrial construction. More than often, they are lands which are characterized by unstable structure. One of them are loess soils, which are regarded as *unstable lands* in engineering geology.

The current research conducted on loess deposits is restricted mainly to petrographic assessment or the origin, while less space is devoted to their geotechnical properties (Kolasa 1963, Malinowski 1971, Frankowski 1991).

The results of the research presented in the paper concern a preliminary analysis of the materials gathered and the most characteristic physical and mechanical properties of loess deposits near Kraków, obtained through the laboratory and field research.

## 2. LOCATION OF THE AREA OF RESEARCH

The area of research comprises two macroregions, a basin, Niecka Nidziańska and a valley, Kotlina Sandomierska. Two of the four test facilities have been situated in the south-western part of an upland, Wyżyna Miechowska, in Michałowice, another one in the southern part of a plateau, Płaskowyż Proszowicki in Sulechów and the fourth one in Targowisko, a western part of foothills, Pogórze Bocheńskie, which is a western part of Kotlina Sandomierska.

The major part of the area of Wyżyna Miechowska, Płaskowyż Proszowicki and Pogórze Brzeskie is covered with substantial loess deposits of varied thickness ranging from several to a dozen or so metres, reaching the dimension of twenty or some-

thing metres at times and they generally form a dense layer. They are cut through by the river valleys, namely, left-bank tributaries of the Vistula, such as Dłubnia, Szreniawa, Nidzica, and Raba, and a mesh of ravines, the density of which is about  $0.5 \text{ km/km}^2$  on average (Józefciuk and Józefciuk 1999).

The loess samples taken from the areas of Wyżyna Miechowska and Płaskowyż Proszowicki have been categorised as eolian formations, which are accumulations of a plateau type, lying 180–350/400 metres above sea level, while the ones taken from the area of Pogórze Brzeskie as eolian formations of a foreland and mountain type (Łanczont and Wojtanowicz 1999, Maruszczak 2000), and as interfluvial and interfluvial-slope loesses in respect of relief (Maruszczak 1991).

About 40 samples taken from boreholes have been subject to the research and the comparative analyses were extended by the tests conducted by Kolasa (1963) in the sixties of the last century, which concerned the loesses of Niecka Nidziańska – Płaskowyż Proszowicki and Wyżyna Miechowska and Wyżyna Krakowsko-Częstochowska – Wyżyna Olkuska.

### 3. GEOLOGICAL-ENGINEERING PROPERTIES OF LOESSES

Both laboratory and field research, chiefly, the CPTU static probe and dilatometer tests, have been used to specify the physical and mechanical parameters of loesses. The range of research conducted made it possible to determine the basic physical properties of loess, i.e., granulometric composition, moisture and soil consistency, as well as mechanical properties, i.e., undrained shear strength, compression modulus and lateral earth pressure. Additionally, the mineralogical composition of the samples has been determined using XRD.

### 4. ANALYSIS OF THE RESULTS

The research of the granulometric composition of loess has been carried out by means of aerometric method (PN-B-04481:1988, PKN-CEN ISO/TS 17892-4:2009). Two standards have been used to classify the soils, so-called old one PN-B-02480:1986 and a new one PN-EN ISO 14688-2:2006. Both of them differ, which causes complications in using the archive materials. The differences result not only from the changes in the names of the soils, but also from the changes in size range of silt fraction (0.002–0.05 mm – PN-B-02480:1986, 0.002–0.063 mm – PN-EN ISO 14688-2:2006) and sand fraction. Thus, it was difficult to rely only on numeral quantities found in the literature, which might be misinterpreted in many cases, and without the access to a graphical presentation of the particle distribution. Therefore, the new standard was applied to classify only the soils checked by the author in terms of granulation (Fig. 3).

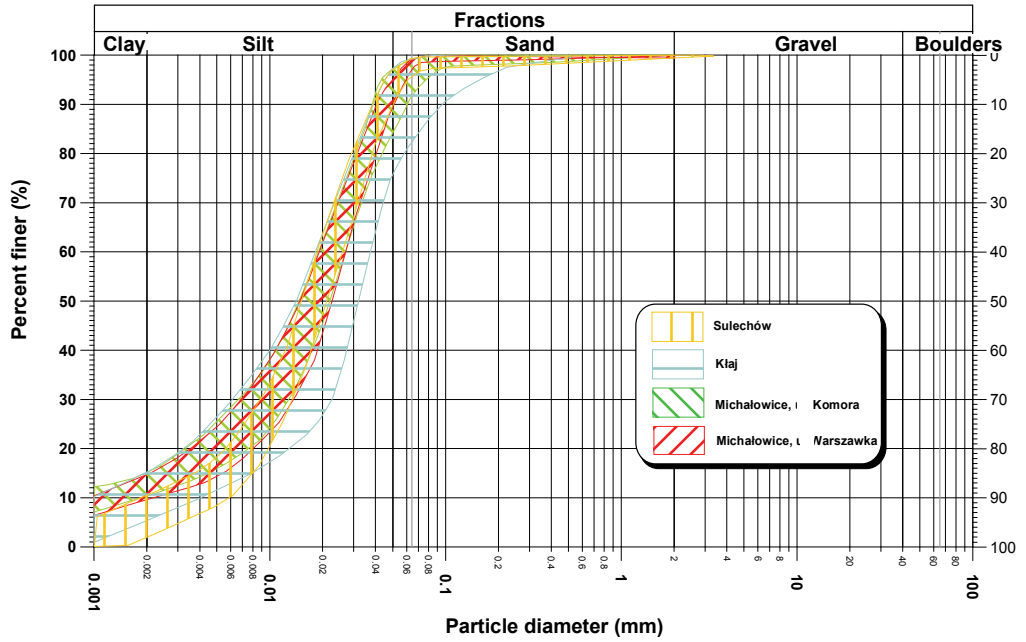


Fig. 1. The granulometric composition of loess

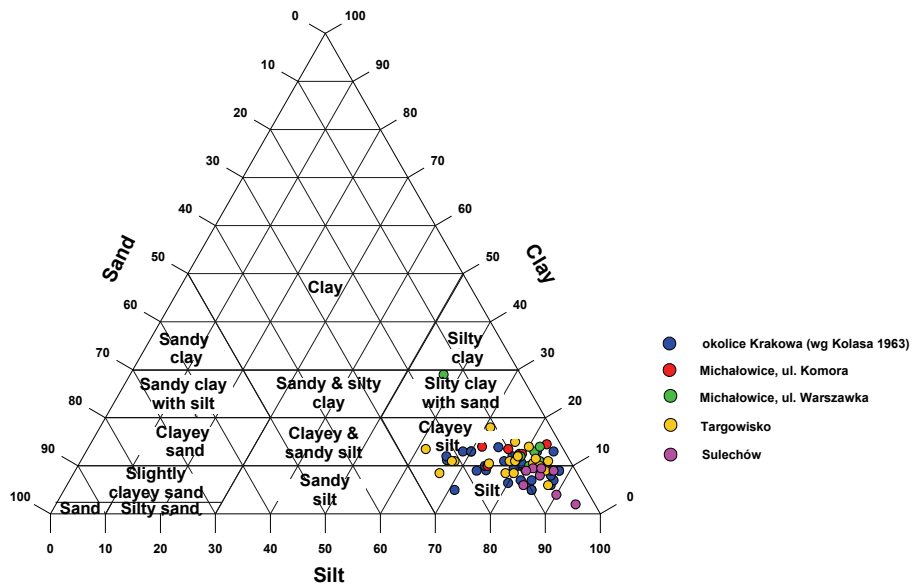


Fig. 2. Granulometric classification of loess according to PN-B-02480:1986

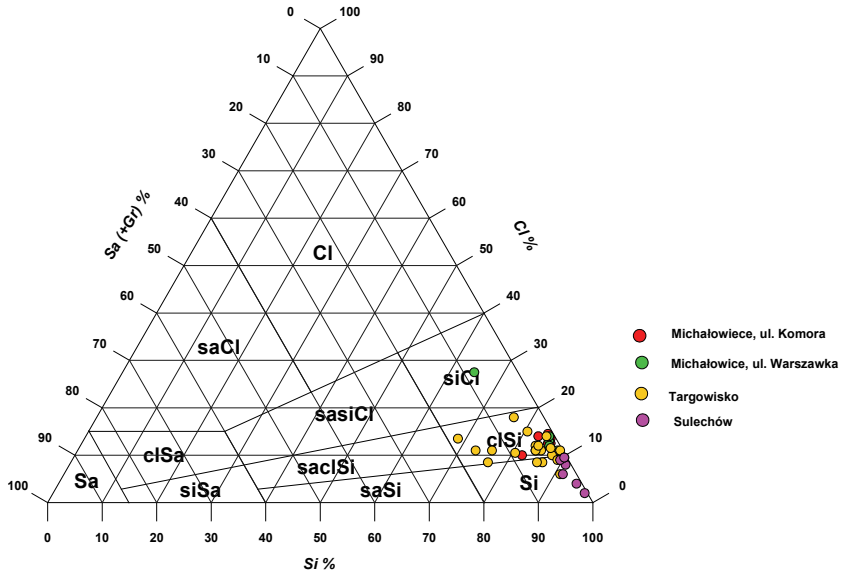


Fig. 3. Granulometric classification of loess according to PN-EN ISO 14688-2:2006

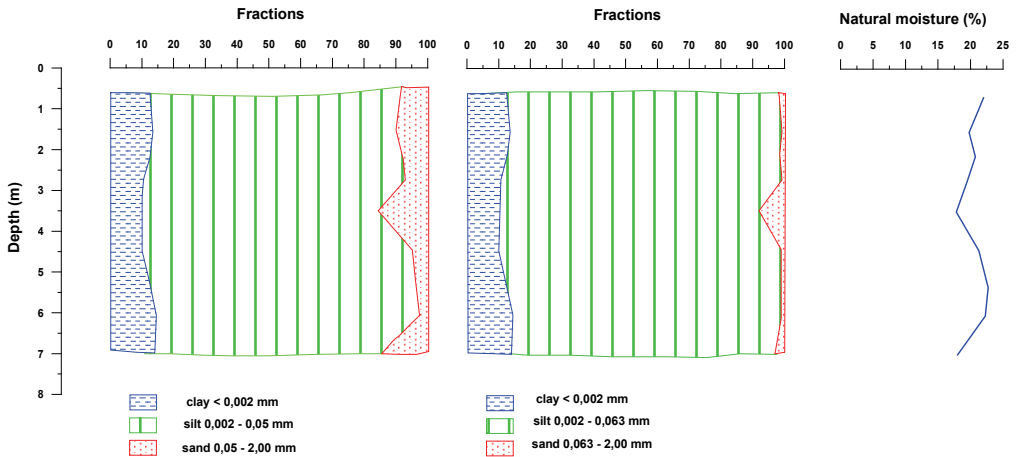


Fig. 4. The layered structure of particular fractions (according to PN-B-02480:1986, PN-EN ISO 14688-2:2006) and moisture of loess in the depth profile in Michałowice, ul. Komora

In terms of granulometric composition, the soils tested were classified as loam and silt, about 99% of the whole population, and occasionally there is compacted loam

(Figs. 1–2), according to the new standard as silt and silt loam – considering only the results of the author (Fig. 3).

Table 1

A list of the mean values of fractions

Fractions	Michałowice ul. Komora	Michałowice ul. Warszawka	Targowisko	Sulechów
Sand Sa [weight %]	9 (2)	5 (2)	12 (6)	7(1)
Silt Si [weight %]	79 (86)	83 (87)	81 (87)	86 (92)
Clay Cl [weight %]	12	11	11	7

The dominant part in the particle distribution of the loess tested is silt fraction (about 79÷86% – PN-B-02480:1986, about 88% – PN-EN ISO 14688-2:2006), which constitutes about 80% of so-called loess fraction 0.01–0.05 mm. Other fractions are of minor importance (Table 1). The differences in the content of particular ranges of the fractions are considerable at times and equal from 2.5% to 25.0% (0.5÷18.0%) for sand fraction, from 61.5% to 87.5% (73÷91%) for silt fraction and from 9% to 14.5% for clay fraction (Figs. 5–9). Therefore, the loess is not characterized by homogeneous granulation. However, the differences disappear when the mean values are used for particular profiles (Table 1) and they parallel those obtained by Kolasa (1963) and Frankowski (1991).

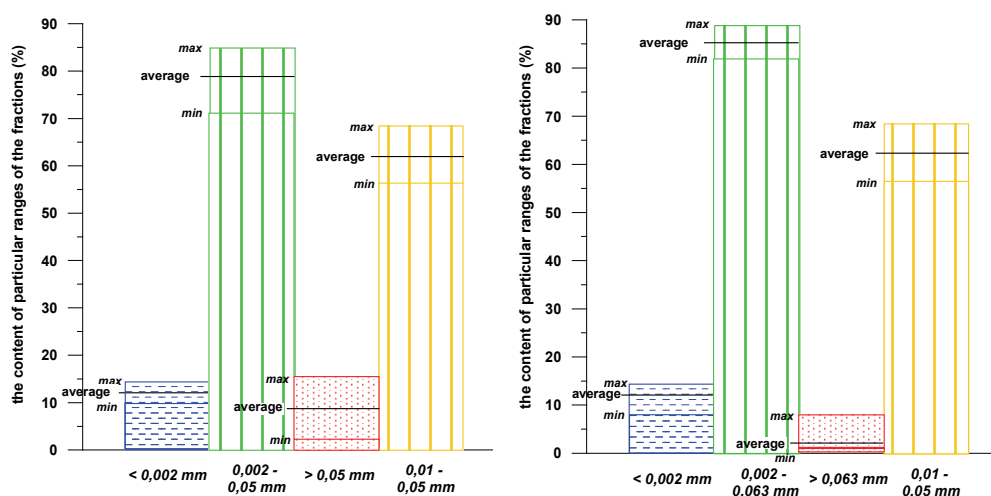


Fig. 5. The layered structure of particular loess fractions taken from the borehole in Michałowice, ul. Komora (according to PN-B-02480:1986, PN-EN ISO 14688-2:2006)

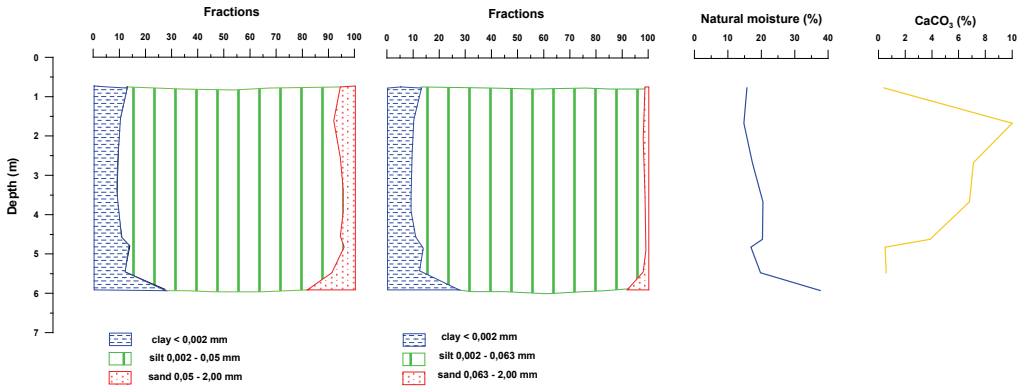


Fig. 6. The layered structure of particular fractions (according to PN-B-02480:1986, PN-EN ISO 14688-2:2006), the moisture and CaCO<sub>3</sub> of loesses in the depth profile in Michałowice, ul. Warszawa

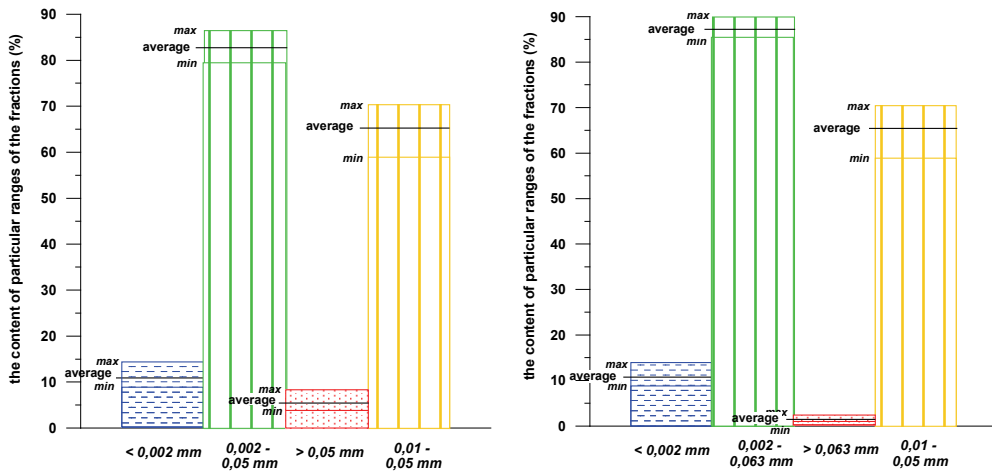


Fig. 7. The layered structure of particular loess fractions taken from the borehole in Michałowice, ul. Warszawa (according to PN-B-02480:1986, PN-EN ISO 14688-2:2006)

A certain regularity has been observed in the case of loess from Targowisko and Sulechów, which is a fall in percentage of sand fraction while the depth is increasing and a rise in silt fraction. Probably, it is the effect of the movement of fine soil fractions caused by rainwater infiltration into the subsoil – suffusive secondary stratification (Figs. 8, 9).

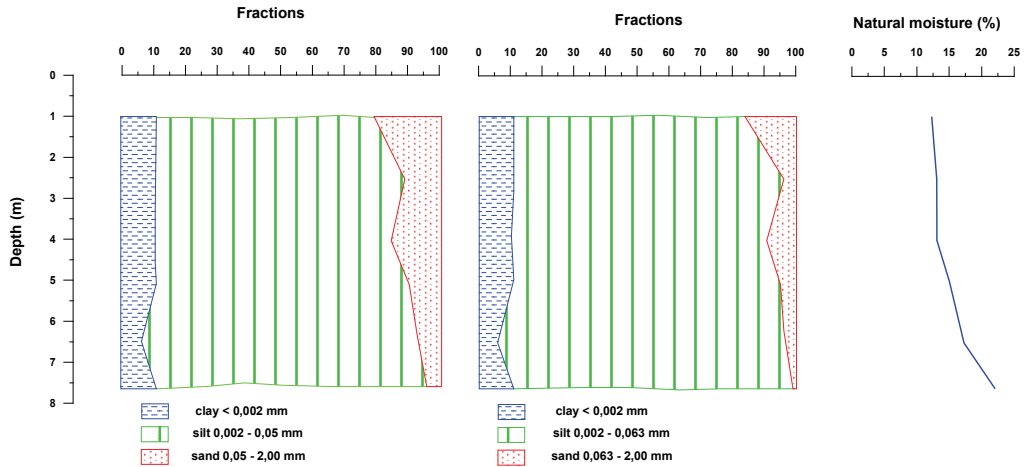


Fig. 8. The layered structure of particular fractions (according to PN-B-02480:1986, PN-EN ISO 14688-2:2006) and the moisture of loesses in the depth profile in Targowisko

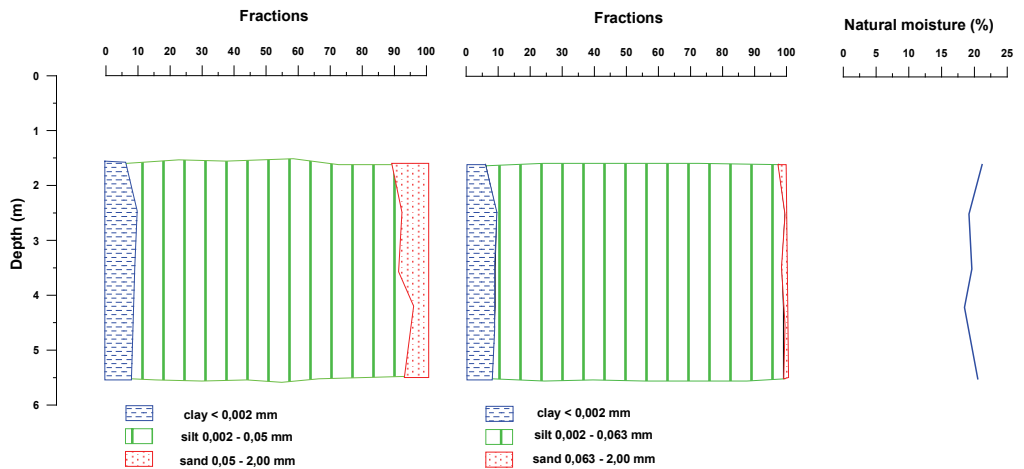


Fig. 9. The layered structure of particular fractions (according to PN-B-02480:1986, PN-EN ISO 14688-2:2006) and the moisture of loesses in the depth profile in Sulechów

The moisture has a significant impact on the properties of loess. In the case of the loesses under investigation, it changes from 10.3% to 22.7%, amounting to 18.4% on average, but the samples from Michałowice, ul. Komora and Sulechów reach the highest percentage (Table 2, Figs. 4, 9).

No considerable jumps in the moisture when the depth is increasing have been observed, and the moisture fluctuations amount to only several percent, give or take, as compared to the mean values. In the case of the profile in ul. Warszawka, a sudden rise in the moisture at the depth of about 6 metres below the ground level is the result of a change in the soil type, to compacted loam – silty clay, and the presence of a rubble of late Cretaceous marls and gaizes.

Table 2

A list of the physical parameters of loess near Kraków

Parameters	Michałowice ul. Komora	Michałowice ul. Warszawka	Targowisko	Sulechów
Natural moisture $w_n$ [weight %]	$\frac{18.00 \div 22.72}{20.45}$	$\frac{14.18 \div 20.49}{17.81}$	$\frac{10.30 \div 22.01}{15.89}$	$\frac{16.97 \div 21.99}{19.49}$
Plastic limit $w_p$ [weight %]	$\frac{20.05 \div 21.47}{20.78}$	$\frac{19.16 \div 21.10}{20.15}$	$\frac{20.36 \div 22.56}{21.44}$	$\frac{18.66 \div 22.28}{20.65}$
Liquid limit $w_L$ [weight %]	$\frac{26.40 \div 36.91}{30.71}$	$\frac{26.17 \div 31.79}{29.33}$	$\frac{26.59 \div 36.25}{28.65}$	$\frac{31.80 \div 44.31}{37.62}$
Plasticity index $I_p$ [weight %]	$\frac{6.21 \div 16.60}{9.93}$	$\frac{5.51 \div 12.46}{9.18}$	$\frac{5.22 \div 14.96}{7.53}$	$\frac{11.30 \div 23.86}{16.98}$
Liquidity index $I_L$ [-]	$\frac{-0.35 \div 0.13}{-0.09}$	$\frac{-1.18 \div 0.09}{-0.34}$	$\frac{-2.15 \div 0.09}{-0.95}$	$\frac{-0.31 \div 0.12}{-0.09}$
CaCO <sub>3</sub> content [%]	–	$\frac{0.41 \div 10.01}{4.18}$		

The moisture is one of the criteria to evaluate the stability of loess structure against water. The high levels of moisture obtained during the research, approximately 18.4%, show that the loess has a stable structure (Grabowska-Olszewska 1966, 1988), and it is not subject to collapse settlement under the impact of water saturation. It should be indicated that in the case of the loess from Targowisko there is a real risk of additional settlements due to water retention in soils as the average moisture is about 13% at the depth of 4 metres below the ground level. Moreover, the susceptibility of the loess to collapse settlement should not be associated strictly with moistures of soil, but also with its internal structure, i.e., a type of structural connections and CaCO<sub>3</sub> content (Grabowska-Olszewska 1998, Myślińska 1984), which is changeable in the case of the samples tested (Table 3, Fig. 6).



The properties of plasticity of the loess in question are similar in general. In terms of soil consistency, it has been classified as brittle solid, occasionally semi-solid. On the basis of Atterberg limits (Table 2), it has been determined that an average plastic limit of the loess is 20.6% and an average liquid limit is 31.6%, thus it falls into the category of low plasticity and medium plasticity soils, less often of high plasticity soils ( $I_p = 6 \div 23.5\%$ ). Low values of the plasticity index, in the range of 5–15%, even with a small increase of moisture, cause a quick change in the loess consistency, from brittle solid to plastic. Further increase of moisture may lead to the liquefaction of loess, which results in mud-flow and surface landslides in the areas marked by slopes and loess escarpments.

On the basis of the Casagrande plasticity chart, the loess near Kraków could be classified as cohesive soil of low – 70% of the population, or medium plasticity (Fig. 10).

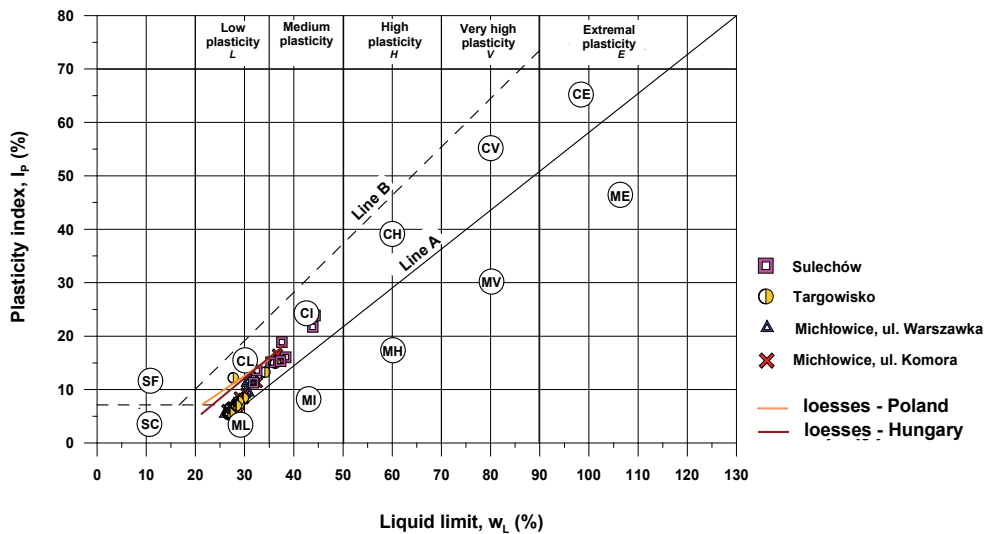


Fig. 10. An evaluation of the plasticity of loess (Casagrande plasticity chart according to Head (Myślińska 1998))

To indicate the qualitative mineral composition of the samples tested, the powder (Debye-Scherer, XRD) method has been applied. The roentgenograms of all samples have been recorded by an x-ray diffractometer DRON-3.0. The tests of particular samples demonstrate a similarity in the mineral composition. The main element is quartz although there are also some feldspars and clay minerals, such as illite, smectite and some trace elements of kaolinite. From the standpoint of research on loess deposits, the presence of carbonates, i.e., calcite and dolomite (Table 3) is essential as they affect the settlement of loess.

Table 3

A list of the qualitative mineral composition  
of the samples of loess deposits near Kraków

Targowisko 0–3 1.0 m	quartz, plagioclase feldspar, potassic feldspar, illite, Ca,Mg-smectite dioctaedric (Sm), amorphous phases and trace elements of kaolinite
Targowisko 0–3 2.5 m	quartz, plagioclase feldspar, potassic feldspar, illite, Ca,Mg-smectite dioctaedric (Sm), amorphous phases and trace elements of kaolinite
Targowisko 0–3 4.0 m	quartz, plagioclase feldspar, potassic feldspar, illite, calcite, dolomite, Ca,Mg-smectite dioctaedric (Sm), amorphous phases and trace elements of kaolinite
Targowisko 0–3 7.6 m	quartz, plagioclase feldspar, potassic feldspar, illite, calcite, dolomite, Ca,Mg-smectite dioctaedric (Sm), amorphous phases and trace elements of kaolinite
Sulechów 0–1 1.6 m	quartz, plagioclase feldspar, potassic feldspar, illite, Ca,Mg-smectite dioctaedric (Sm), amorphous phases and trace elements of kaolinite
Sulechów 0–4 3.5 m	quartz, plagioclase feldspar, potassic feldspar, illite, Ca,Mg-smectite dioctaedric (Sm), amorphous phases and trace elements of kaolinite
Sulechów 0–2 5.5 m	quartz, plagioclase feldspar, potassic feldspar, illite, Ca,Mg-smectite dioctaedric (Sm), amorphous phases and trace elements of kaolinite
Michałowice ul. Komora 1.4÷1.7 m	quartz, plagioclase feldspar, potassic feldspar, illite, Ca,Mg-smectite dioctaedric (Sm), amorphous phases and trace elements of kaolinite
Michałowice ul. Komora 3.35÷3.6 m	quartz, plagioclase feldspar, potassic feldspar, illite, calcite, dolomite, Ca,Mg-smectite dioctaedric (Sm), amorphous phases and trace elements of kaolinite
Michałowice ul. Komora 5.8÷6.2 m	quartz, plagioclase feldspar, potassic feldspar, illite (26-911), Ca,Mg-smectite dioctaedric (Sm), amorphous phases and trace elements of kaolinite
Michałowice ul. Warszawka 1.5÷1.8 m	quartz, plagioclase feldspar, potassic feldspar, illite, calcite, dolomite, Ca,Mg-smectite dioctaedric (Sm), amorphous phases and trace elements of kaolinite
Michałowice ul. Warszawka 3.5÷3.8 m	quartz, plagioclase feldspar, potassic feldspar, illite, calcite, dolomite, Ca,Mg-smectite dioctaedric (Sm), amorphous phases and trace elements of kaolinite
Michałowice ul. Warszawka 5.4÷5.5 m	quartz, plagioclase feldspar, potassic feldspar, illite, Ca,Mg-smectite dioctaedric (Sm), amorphous phases and trace elements of kaolinite
Michałowice ul. Warszawka 5.8 m	Ca,Mg-smectite dioctaedric (Sm), quartz, opal, plagioclase feldspar, potassic feldspar, illite, amorphous phases and trace elements of kaolinite

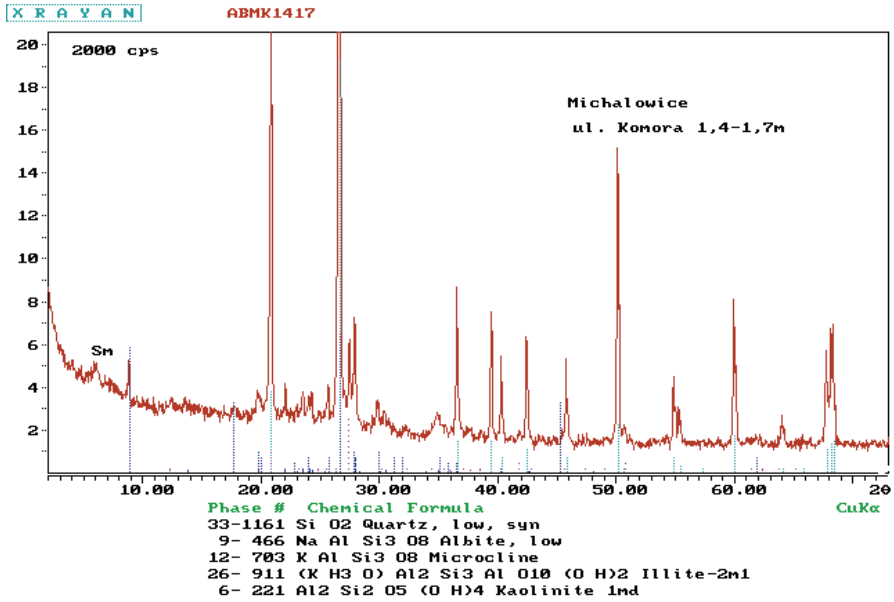


Fig. 11. A model of an X-ray diffraction of loess from Michałowice, ul. Komora

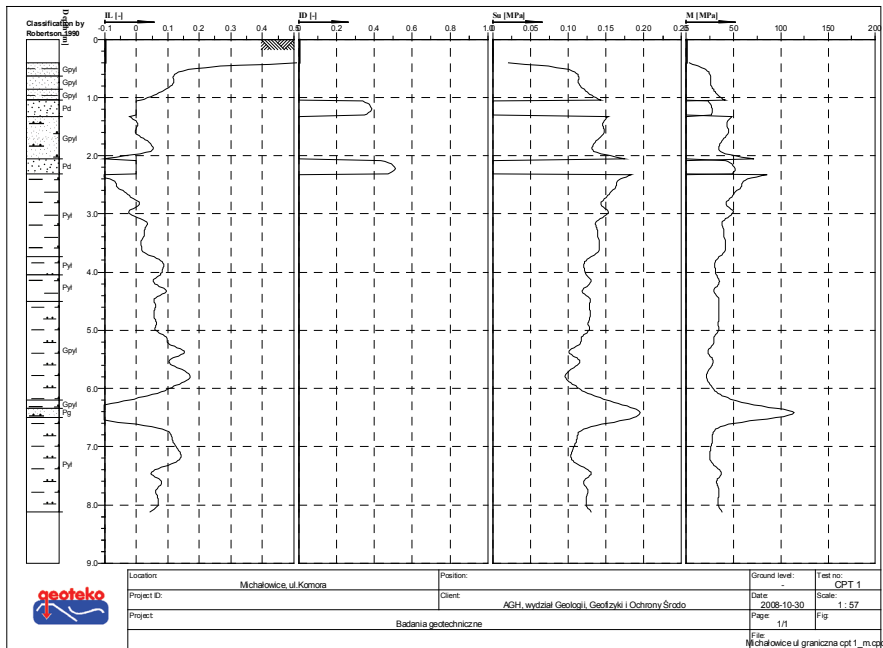


Fig. 12. The CPTU static probe – Michałowice, ul. Komora

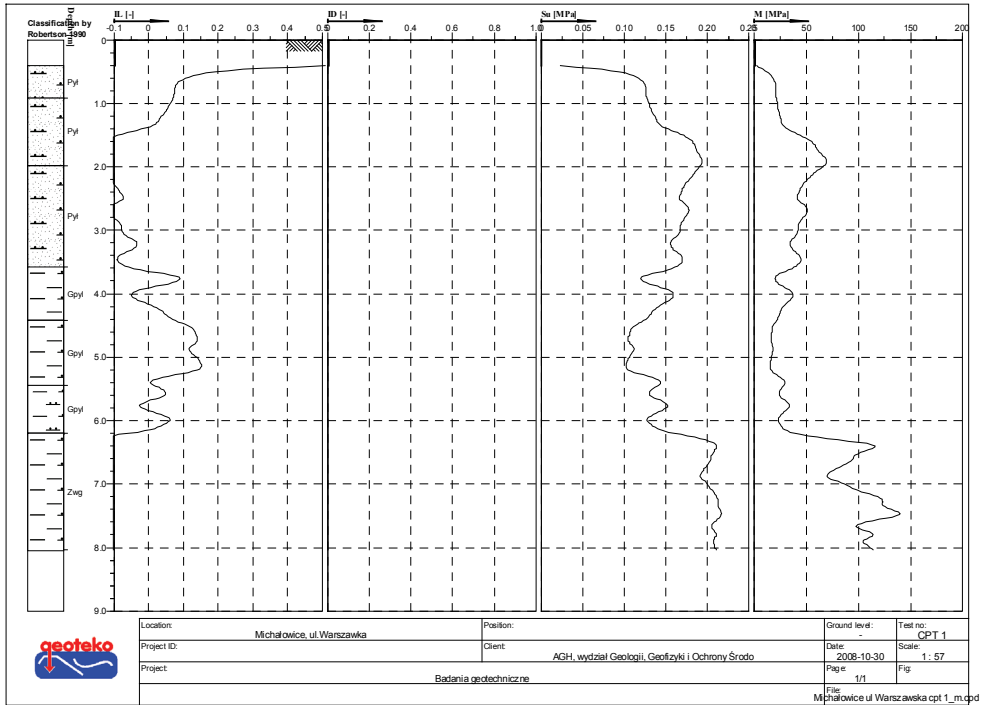


Fig. 13. The CPTU static probe – Michałowice, ul. Warszawska

The advantage of research conducted in situ is that it is done in the conditions of a normal stress of soil. Therefore, the CPTU static probe and Marchetti Dilatometer DMT have been used, where the former has been operated on three sites, i.e., Michałowice and Targowisko and the latter only in Michałowice (Figs. 12 and 13).

The basic parameters derived from dilatometer tests are the material index  $I_D(I_{DMT})$  – used to determine the type of soil, the horizontal stress index  $K_D(K_{DMT})$  and the dilatometer modulus (Figs. 14a, 15a). A knowledge of the data gives an opportunity to analyse the type of soil, constrained moduli, stress history and undrained shear strength (Figs. 14b, 15b).

The basis for interpretation of the penetration performance, CPTU and DMT, are the regional dependencies for particular types of soils. However, if there is no information of them, there are dependencies and functions provided in the literature (Lunne et al. 1997, Mayne et al. 1995, Młynarek et al. 2003, Sikora 2006, Totoni et al. 2001), bearing in mind that not every method of interpretation could be applied in the Polish conditions (origin, load history, etc.).

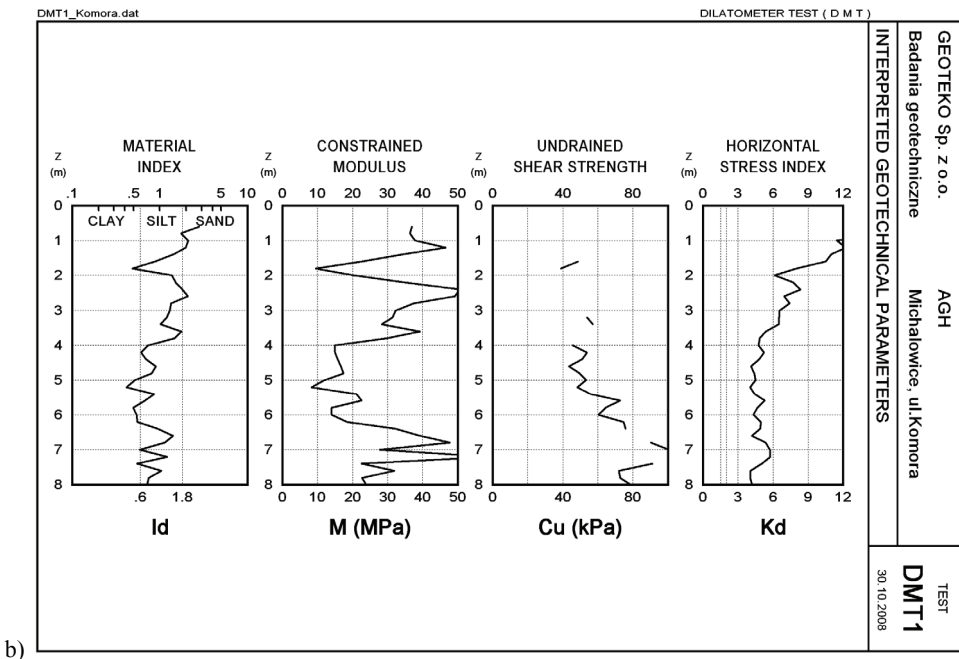
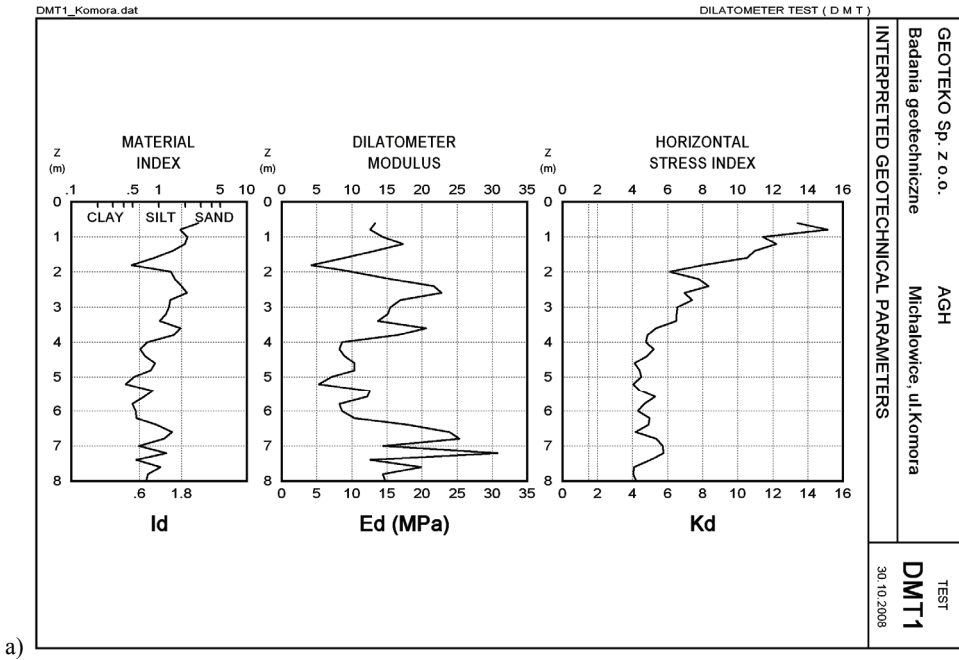


Fig. 14. The basic parameters derived from dilatometer tests – Michałowice, ul. Komora

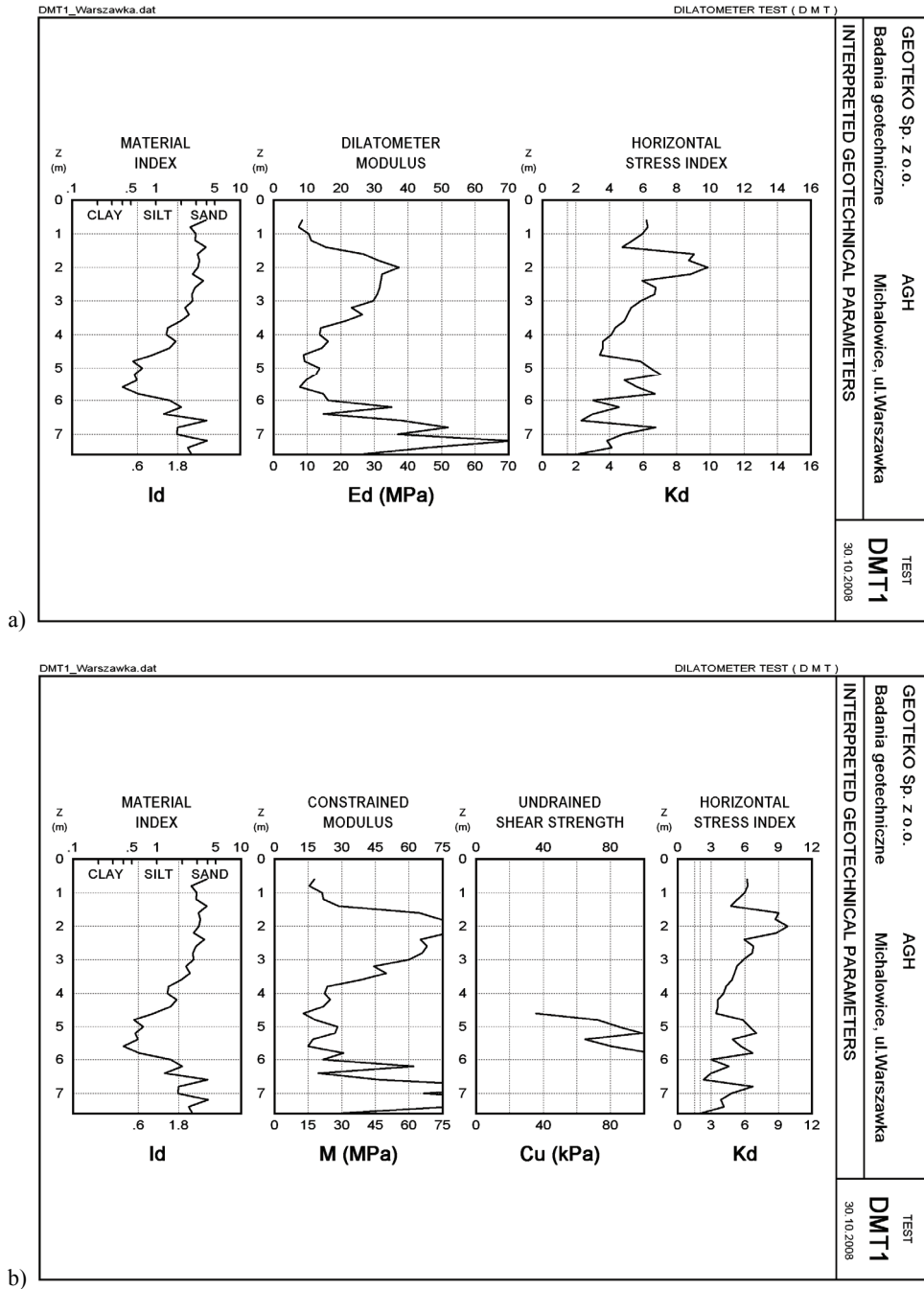


Fig. 15. The basic parameters derived from dilatometer tests – Michałowice, ul. Warszawa

To classify and evaluate the type of loesses near Kraków on the basis of penetration performance obtained during the static probing CPTU, the best known Robertson profiling chart (1990) has been used, (Figs. 12, 13). The results show that the loess tested is silt and loam in terms of granulometric composition, which proves that the computational formula correlates with the results obtained from the laboratory tests (Fig. 2).

A bit weaker correlation has been established from dilatometer tests (Figs. 14, 15). This mainly concerns the research conducted in ul. Warszawka, where it has been determined that there are sand soils at the depth up to 3 metres below the ground level while actually there is silt. This could be the result of the high soil condensation caused by human impact, e.g., heavy farming equipment, or a wrongly selected computational procedure not adapted to the local conditions.

The field methods create an opportunity to observe the changeability of the physical and mechanical properties of soils. However, a quantitative analysis of the data obtained is most difficult. It is much easier to perform a qualitative analysis, which makes it possible to determine zones in the substratum, characterized by weaker geotechnical parameters, which play an important role in designing the foundation of various engineering buildings.

The paths of curves obtained from both research methods, CPTU and DMT, which illustrate the changes of compression moduli of loess with the depth are comparable in terms of quality. The differences relate to quantity values only. This results mainly from using various computational formulas for a particular research procedure and the means of gaining the measured data. The average values for the compression moduli (M) from CPTU performance amount to about 40 MPa, from DMT about 30 MPa (ul. Komora) and 45 MPa (ul. Warszawka). A characteristic increase of the moduli at the depth of 6 metres below the ground level from probing in ul. Warszawka should be associated with the presence of 2-centimetre angular crumbs of saprolites of late Cretaceous marls and gaizes.

The obtained values of the undrained shear strength ( $s_u$ ) change from 0.1 to 0.2 MPa, amounting to about 0.15 MPa (Figs. 12, 13). Yet, two zones could be distinguished, the upper one, from 1 m below the ground level to 3÷3.5 m below the ground level, where higher values of  $s_u$  have been recorded in the range of 0.15÷0.17 MPa and the lower ones, where there is a decrease in the shear strength of about 0.11 MPa. However, it has not been observed that there are considerable jumps in the values of strength when the depth is increasing. They are comparable in the whole depth profile and the fluctuations of values amount to  $\pm 0.05$  MPa regarding the average values. Moreover, they can correspond to the values obtained for loesses near Kazimierz Dolny, the FVT rotational probe (Borowczak and Frankowski 1979, Frankowski and Grabowski 2006). A characteristic increase of the strength at the depth of 6 metres below the ground level from probing in ul. Warszawka should be associated with the presence of 2-centimetre angular crumbs of saprolites of late Cretaceous marls and gaizes.

The values of the plasticity index are a bit raised as compared to the results obtained during the laboratory research. In the future, consideration will be given to making corrections to the current computational formula used during the interpretation of the probing results.

The results from the dilatometer research have not been considered due to certain limitations in the conversion formulas used.

Special attention should be drawn to the fact that the obtained values of both physical and mechanical parameters may be subject to a noticeable change for more unfavourable ones, especially in the conditions of improper drainage of escarpments and slopes, wrong water management in urbanized areas, wrong construction of the storm drain system and sewer infrastructure, and inappropriate channelling of water from a home sewage treatment plant, etc.

## 5. SUMMARY

The loess deposits near Kraków mainly belong to silt and loam (silt and silt loam), sporadically to compacted loam.

Generally, there are soils characterized by brittle solid and semi-solid consistency and moisture amounting to 18.4%. So, high values of moisture obtained during the research demonstrate that the loesses have a stable structure and they are not subject to collapse settlement under the impact of water saturation, as it happened in the case of loess near Sandomierz, Kłodzko and Kazimierz Dolny. However, it should be pointed that in the case of loess in the area of Targowisko there is a real risk of additional settlements resulting from the water retention in soil, as an average moisture amounts to about 13% to the depth of 4 metres below the ground level.

The compression modulus of loesses fluctuates in the range of 30÷45 MPa and the undrained shear strength is 0.15 MPa on average.

The results of research presented in the paper are only the preliminary tests to the analysis of the geological-engineering properties of loesses near Kraków. They have been extended by field research (CPTU, DMT), which is an alternative to expensive and time-consuming laboratory research. The field research creates an opportunity for a meticulous tracking of the changeability of physical and mechanical properties of soils. However, in many cases they provide too much information and therefore their interpretation is often based on the qualitative analysis.

The laboratory and field research complement each other and should be continued in order to establish the best correlation dependencies between the measured values of probing resistivity (CPTU, DMT) and the results obtained from the laboratory research. This will make it possible to create new computational formulas for the evaluation of geotechnical parameters of loess in the in situ conditions.



The results obtained are essential information which could be used to generate land development plans as well as create a geological-engineering map of Kraków and its region.

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