Influence of fen soils moisture changes on the strength parameters and applied foundation solutions

JAN JAREMSKI, KRZYSZTOF WILK

Rzeszow University of Technology.(e-mail: jjaremsk@prz.rzeszow.pl)
Rzeszow University of Technology.(e-mail: kwilk@prz.rzeszow.pl)

Abstract: The influence of flood state causes moisture content of fen soils to increase as a result of vertical and horizontal infiltration. In this paper the decrease in the strength of soil parameters is analysed. Influence in the changes of river water states on groundwater levels depends on geological structure, coefficient of permeability, height and speed of shaping of flood wave etc. Fen soils are commonly acknowledged as ground that has a low bearing capacity. These grounds are characterised by relatively low strength. Sites where they occur are the youngest sediment and it is very difficult to obtain samples that are undisturbed. The determination of the usefulness of such samples is very significant because fen soils are present in many areas of towns and housing estates.

Fundamental investigations of the soils physical properties and strength parameters, taking into account pore water pressure influences on effective values of the angle of internal friction and the cohesion, have been carried out with use of the advanced apparatus of GDS Instruments Ltd. This apparatus makes the testing of rheological properties (tests taking time into consideration) possible. Laboratory tests were performed, with samples of simulated moisture contents, to allow for the extreme bearing capacity conditions to be simulated. The need for such test results from building condition surveys on flood sites. In many of the cases studied it would have been sufficient to displace the founding object by a few meters as this would have prevented ground movements occurring between water receiver and object.

Resume: Le travail contient une analyse de l'influence des états de crues – influant sur l'augmentation de l'humidité des fonds suite à une infiltration verticale et horizontale – sur la diminution de leurs paramètres de résistance. L'influence des changements des niveaux d'eau dans la rivière sur le niveau d'eaux souterraines dépend de la structure géologique, du coefficient d'infiltration, de la hauteur et de la rapidité avec laquelle se forme l'onde du flux, etc. Les sols alluviaux, considérés généralement comme des sols de petite capacité de charge, se caractérisent par une relativement petite résistance. Les terrains sur lesquels ils apparaissent sont constitués du sédiment le plus jeune et il y est difficile de prélever des échantillons sans détruire leur structure. La définition de leur utilité semble pourtant très importante étant donné que les sols alluviaux dans de nombreuses villes et quartiers n'ont été utilisés qu'avec prudence pour la fondation des objets, compte tenu des difficulté ci-mentionnées. Ces terrains sont généralement pleinement viabilisés en infrastructure.

Les analyses de base des propriétés physiques des fonds et des paramètres de résistance ont été effectuées avec l'utilisation des outils de la société GDS Instruments Ltd, modernes et fort avancées du point de vue technologique, avec une prise en compte de l'influence de la pression poreuse sur les vraies valeurs de l'ongle du frottement interne f et de la cohérence c. Une attention particulière a été portée également sur le problème de la pose du fondement et sur la nécessité de reconnaissance précise du fond sur les terrains des terrasses soumis aux flux, y compris les analyses des échantillons des fonds dans les conditions de l'humidité simulée.

Keywords: alluvium, engineering properties, floods, permeability.

INTRODUCTION

Due to the development of towns and housing estates on areas of river flood plains and uncertainties in relation to the condition of flood defence systems and river regulations, a problem exists for the protection of existing buildings as well as new construction.

In this study, the influence of floodwater flow conditions on the geotechnical properties of flood plain soils caused by the consequence of floodwaters running and temporary flooding some parts of the area has been analysed. Particular attention has been paid to the effects of these conditions on the increase in the plasticity of fen soils that typically consist of silty clay and silt and frequently form the foundation stratum for existing buildings and also new developments. This type of cohesive soil is exceptionally sensitive to changes in moisture content that in turn give rise to marked variations in plasticity (Jaremski 1974).

The principal subsoils beneath layers of fen soil usually comprise fluvioglacial sand or gravel or mixtures of sand and gravel. Defining the influence of changes of floodwater conditions on groundwater is extremely difficult because the changes of such conditions are irregular and associated with a large number of factors and so the levels of groundwater are also characterised by irregularity. The influence of changes in water conditions in a river on the right changes of groundwater conditions mainly depends on the geological structure, filtration factor, height and speed of a flood wave development. Having analysed many works, it has been accepted that in the case of the Vistula valley in the study area, the speed would equal up to 150 m/day, Wieczysty (1982). Many authors claim that the speed of passing the level of groundwater perpendicularly to the river axis is so big that can not be linked to the river water flow only on the ground, Jaremski (1974). In addition, rainwater from the study areas is usually channelled along open ditches to a sewer or to an old river bed. The high river level is usually accompanied by intensive atmospheric rainfall, which also contributes to their level rise as well as the increase of passing the changes of groundwater level. The speed of passing the level of the cross section of Nowa Wies is provided in the theses by Wieczysty (1982). According to this research, for a 5 m damming up of water, at the distance of 200 m groundwater table increases by 4 m, at the distance of 400 m by 2 m and at 1000 m by 1.8 m.

The period of low flood levels over recent years resulted in a hydrological drought and many researches connected with establishing computational numerical value of geotechnical parameters. The binding norms connected with the location of buildings give values depending on the ground conditions. The predictions of groundwater changes and flood levels during which horizontal infiltration occurs as well as vertical infiltration have failed to take into account the flows which result from flooding of the areas of flood plain.

Laboratory research, including the investigation of soil samples of simulated moisture content, gives results for the loss of the substratum capacity and the findings are confirmed by the condition of buildings on the areas of flood plain. Identifying the area leads to working out guidelines on the basis of which such areas as those bordered with ditches canalling water, old river beds, etc should be abandoned in the land development plans. In many of the analysed cases it would be enough to move the location of a building by a short distance (several meters), which would eliminate the cause of ground mass movements occurring between the water receiver and the building.

Fen soil is widely considered to be of low carrying capacity and it is characterised by a relatively small strength. Typically it is found in areas associated with the youngest sediment. Accordingly, collecting samples of undisturbed structure is problematic and so their usefulness is crucial because fen soils in many cities and estates have been unwillingly used for localisations because of listed difficulties. These areas are most often equipped with full infrastructure.

In the reaction of fen substratum on the forces caused by human activity and changeable environment conditions, the most frequent processes occurring under the influence of the changes of water conditions play a decisive role. The level of complexity, development of more and more precise calculating methods and the importance of geotechnical tasks in such complex conditions, also requires the development of methods determining geotechnical parameters of ground centre.

One of the authors was inspired by research works of Dumbleton (1967) who compared the red clay in Kenya with Keuper's Marls in South Wales. This approach was used to compare the silts of weathered Opole marls with the weathered Carpatian flysh and also to the silts being a sediment for river terrace of Podkarpacie (Jaremski 2003, 2004). Research on setting strength parameters of weathered marls, previously described by Jaremski (1990, 1994), allowed to qualify this weathered marls as a building foundation for one of the cities of southern Poland where they are formed under the layer of humus and they haven't been used for localisation. The chosen solution was the situation on stilts or on the ground which replaced the weathered material.

Basic research of ground physical property and strength parameters with the use of modern advanced unit for ground research by GDS Instruments Ltd. has been carried out, taking into account the influence of porous pressure on effective values of internal friction angle ϕ and cohesion c. The machine enables research of rheological value, that is, taking the time factor into account. Carried out laboratory research, including the research of soil samples of simulated humidity, allows us to get to know the extreme conditions of load – bearing capacity of the ground. The need for this kind of research results from the estimated condition of buildings on flood territory.

Attention has also been paid to foundation problems and the necessity of proper recognition of soil ground on floodland areas, including the research of soil samples of simulated moisture content.

THE CHARACTERISTICS OF FLOODLAND GROUNDS

The soils of river valleys deposited during flood conditions differ significantly from other types of soils formed by normal sedimentation and many features and parameters are the result of the manner of their formation. On the basis of many years experience and research work to establish the engineering geological characteristics of alluvial ground, it can be confirmed the complexity of factors influences their significant change, Frankowski (1980), Myślińska (1990), Myślińska, Hoffman, Kulesza-Wiewióra (1982). The most important and influential as far as physical – mechanical properties of flood deposits are concerned, is their lithology, which comprises also other sedimentation and post-sedimentation factors. Lithological diversification of fen soil is a result of the history of development of a river valley and also the way of river channel development and geological – lithological character of alimentation areas of particular parts of the valley, Myślińska (1984).

The majority of mature free river valleys two series of alluvial deposits set on fine-grained channel sand are differentiated Myślińska (1990), Myślińska, Hoffman, Kulesza-Wiewióra (1982). These are clay fen, meandering river deposits and sandy-silty fen, wild river deposits.

The origin of the formation of alluvial ground, from which their principal stratum results, over-strata among which one can differentiate sandy, silty, clayey fractions often including organic parts, classifies them between other weak grounds. It needs to be emphasised that these grounds have never undergone significant consolidation load within centuries. A small consolidation occurred only under its own load of these grounds or under a brief load of flood water. The lack of ground consolidation has a significant influence on the change in time under the external factors of fen soil properties. Among others, the filtration process, humidity changes take place much faster than in other grounds that may be granulometrically similar, but undergoing consolidation.

The characteristics of fen grounds in Zalesie Gorzyckie

Within the works on the subject the consequences of flood in Zalesie Gorzyckie have been analysed. This locality is situated a few kilometers east of Sandomierz and on the right bank of the Vistula River, in its pravalley, between the mouths of Łeg i Trzesniowka river, in Gorzyce province. On this area typical arrangement of alluvial deposits have been recognised.

For soils of this region, research has been carried out on the behaviour of geotechnical parameters in relation to changes in moisture contents. In the substratum silty clay of a light brown colour lies at the depth of 0.5÷1.5 m, below this layer at the depth of 2.5 m there is silty clay of grey colour. Deeper, under this clay, the strata are silts and non-cohesive grounds, fine and medium sand. The thickness of Quaternary substratum reaches 14÷16 m.

The findings of the research showed a clear dependence of strength parameters on moisture contents. Ground moisture varies as a result of vertical and horizontal infiltration along selected paths of filtration and infiltration (close neighbourhood of ditches and old river beds) led to uneven sinking and loss of strength.

It is assumed that many building damages on the analysed territory result from such a change of parameters of building foundations.

In the area of the village Zalesie Gorzyckie there are a few erosion valleys, both the Vistula as well as its tributaries - Łeg and Trzesniowka. The main buildings of this village go along one of these valleys. There are heterogenous soils of limited carrying capacity, in the form of sandy silts, fine and medium silty sands and muds. In a part of these valleys there have been created containers of still water. The valleys of the old river beds reach significant depth even 4.0÷5.0 m below the ground level, reaching the layer of fine and medium sand, and the escarpments of their banks show in places a significant bending. Such a situation may be a reason for horizontal movement of soil masses which might slide down to these valleys also because of the property changes and ground parameters caused by the rise in moisture content. Shaping the foundation to the condition in which movement and slide in the ground is possible, leads to the creation of landslides causing damage to the building construction. Such slides have been observed in Zalesie Gorzyckie. An example section through erosion valley running through the discussed place has been shown on Figure 1.

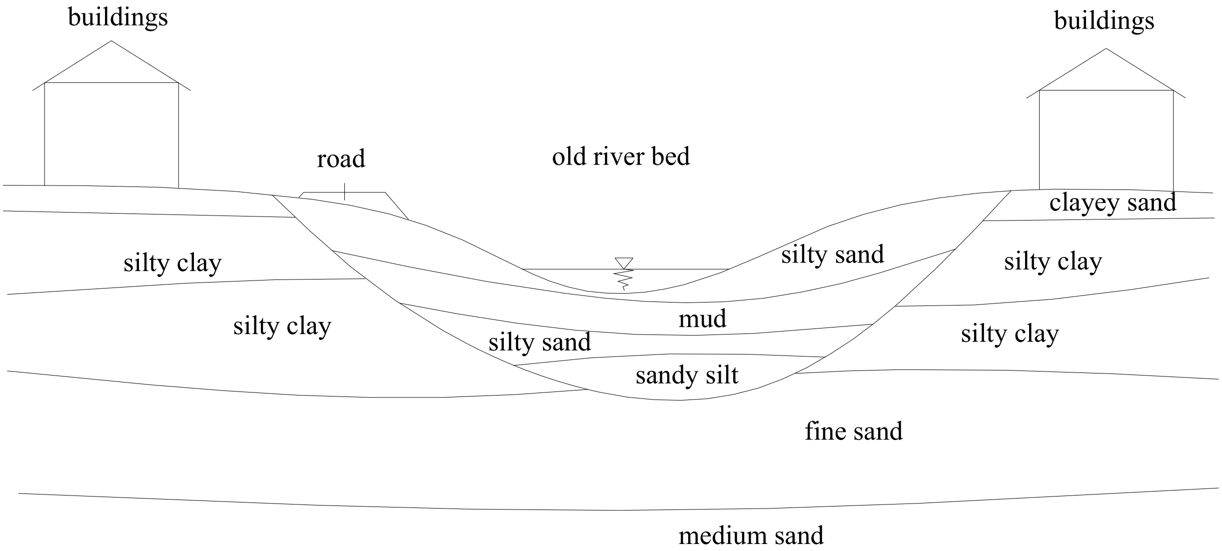

Figure 1. Characteristic geotechnical profile across old Vistula River bed valley in Zalesie Gorzyckie

The research of fen grounds in the area of Opole-Zaodrze

The aim of defining physical and mechanical properties of fen grounds in the area of the residential district Opole-Zaodrze laboratory research has been carried out connected with taking samples from the excavation along the line of one street. The area covered by the research programme is a Holocene channel of the Odra river. Within this part of the channel there are two old river beds. In the foundation there are early Cretaceous marls covered by a layer of Holocene river deposits at the depth of 5.5 to 9.5 m and they are covered by a layer of river sand deposits, gravel and fen, with thickness varying from 0.5 to 4.5 m. The level of ground water on the worked out area depends on the changes of the water level in the river and the amount of rainfall and ground penetrability. Water fluctuation reaches up to about 1 m.

In this region, the fen soils are mainly represented by silty clays, sometimes sandy clays, clayey sands and silts. The level of plasticity of these soils varies depending on the moisture content from 0 to 0.25, in some place even up to 0.35. The natural moisture content ranges from 13.52% to 22.65%. Volume density ranges from 1.83 g/cm^3 to 2.09 g/cm^3 and oedometric modulus ranges from 740 to 4300 kPa. The angle of internal friction varied, according to the research, in direct shear apparatus from 13^o and cohesion 8 kPa to 9^o and cohesion 28 kPa. The research in direct shear apparatus was carried out on samples of disturbed structure. The friction angle tested on samples of undisturbed structure in a unit of triple axis compact changed from 7^{o} with cohesion of 58 kPa to 10^{o} with cohesion 100 kPa. For the characterised above fen soil of the Odra river the results of ground research have been given for natural moisture content.

THE CHARACTERISTICS OF FEN GROUND OCCURRING ON THE ASSUMPTIONED TESTING GROUND

The majority of research work presented previously was carried out on samples taken from ground investigations at Lisia Gora in Rzeszow and within the area of the flood plain of the Wislok river. The findings were compared with the results of ground investigations from the floodlands of the Wisloka river from places: Pilzno, Podole and Przeclaw and the Wislok river near Siemienskiego and Bulwarowa streets in Rzeszow.

Preliminary drilling carried out on floodlands of Wislok and Wisloka river within the border of Dolina Sandomierska and Pogorze Podkarpackie showed significant lithological diversification both vertical and horizontal of ground layers in sections of neighbouring inlets distant from each other sometimes only a few meters (Jaremski & Wilk 2002, 2004a).

River sedimentation grounds observed in the area of Lisia Gora in Rzeszow are a classic example of fen grounds. Up to the depth of 3.5÷6 m almost only cohesive grounds occur, differing from each other by the properties and below medium and coarse sand. In this foundation the levels of water hung locally in cohesive grounds and proper tight water table of ground water in water carrying sand layer have been observed. Because of a low bank and shallow, in relation to the level of research area, normal localization of water table in the Wislok, the level of water in research inlets rose up to this height. The research inlets were made in the distance of 20÷80 m from the river bank line.

Geological profiles worked out on the basis of research inlets, mainly from the areas of Lisia Gora are characterised by significant diversification, although all drillings and research earthworks were made at short distances apart, that is, 10÷200m. Not only layer mixing has been observed, but also ground that does not occur in other profiles.

Water carrying sandy layer occurring at the depth of 4 m has a water table of tight water, sub-artesian causing the rise of the level of the water table at the height of about 2÷3 m below the area level. The indirect local ground hung water levels have been observed much lower, at the depth of from 1.2 m below the area level. The sub-artesian level of water in the water carrying layer results from the location of the area within the territory of the influence of water in a flow, additionally intensified by the existence of a water dam, within the area of its influence. Rising the tight table is tantamount to the water level in the river.

THE FLOW OF WATER IN FEN GROUNDS

In spite of the tight water table at the depth of about 2.6÷5.5 m, it has been noticed especially in research earthworks partly soaks and water seeps from the depth of 1m that is the depth corresponding with the level of water in a river. It proves the existence of preferential paths for water filtration in the fen grounds. Stratum floodland ground build is in favour of the existence of such paths being a result of the way of their creation. Some accumulated strata deposited and accumulated during larger and more rapid river swelling are built of grounds containing greater amount of sandy fraction than neighbouring ones, therefore there is a higher rate of hydraulic transmission.

The preferential paths of filtration occur in grounds of floodlands and are a very disadvantageous phenomenon for their carrying capacity and possibility of use as a building foundation. Water seeping through those paths may change the degree of ground humidity and at the same time the value of its parameters. The phenomenon is especially noticeable and dangerous during water swelling and flood conditions. A steeper hydraulic gradient increases the pressure, speed and amount of flowing water in the grounds. The increase of water in the ground rapidly leads to the increase of ground humidity at the beginning in the neighbourhood of preferential paths of filtration and then over progressively larger areas. Increasing humidity of cohesive soil causes loss of its bearing capacity. There is also a danger of sufosion occurrence phenomena and creation of caverns in some less cohesive soils of river accumulation.

During flood alerts there can be the restraint of seepage water inflow in soil from the areas above the receiver and accumulation of it, concentrating in the ground. There is also a possibility of rising tide direction change, turning away the direction of water filtration and its diffuse penetration through the soil. The excess of water retained then in the ground increases the level of adaptability and weakens the endurance of soil. Because of the fact that cohesive soils of river accumulation contain different amount of sandy fraction and organic parts, and above all because of big heterogeneity of layering of such ground, moistness and ground adaptability of terrace floodland can run on different level in different places of such ground.

In relation to the coefficient of fen soil ground filtration, research was carried out using the GDS Instruments Ltd equipment. This allowed the measurement of characteristic flow sizes such as inflow pressure, low tide pressure, brought in water volume and channelled from the ground samples and also the water pressure in chamber $\sigma 3$. The water flow is extorted by two pressure collectors, one of them forces with the higher pressure the water inflow into the specimen and the other with the appropriately lower pressure takes water which was filtered by the specimen.

The advanced system for ground research allows investigation of the coefficient filtration factor by the use of two methods: Constant Head and Constant Flow. The Constant Head method consists in extorting the constant pressure value between the both ends of ground samples and fixing the water flow value (constant value of the water volume) in time. In Constant Flow method there is a constant value of water flow imposed (water volume) in time and the low tide pressure, but the value of inflow pressure is subjected to arrangement during the research.

The research work was performed on samples of soil with natural, untouched structure taken from the pit on the Wislok river terrace in the area of Lisia Gora in Rzeszow. The samples in the shape of the cylinder used in research, were placed in rubber covers and then fixed in the apparatus chamber and loaded with the water pressure σ_3 similarly to standard triaxial testing. Cylindrical samples used in testing were 38 mm and 50 mm in diameter and 76 ÷ 80 and 100 ÷ 110 mm in height.

They were cut in soils vertically and horizontally. During the test programme, low values were obtained for the coefficient of permeability (k) in the 10^{-7}÷10^{-9} m/s range and the average value was 10^{-8} m/s (see Tables 1 & 2). No significant differences in the constant value Darcy (k) were noticed during the tests on the samples cut from the soil vertically or horizontally. Convergence of received results, on one hand confirms the accuracy of carried out testing and on the other the difficulties in characterising filtration in fen soils which are built up in layers.

Table 1. Value coefficient of permeability k (m/s) for samples ϕ50 mm sampling horizontally

Number of order test		1	2	3	4	5	6
Type of test		CH	CF	CH	CF	CH	CF
Cell pressure (kPa)		30	30	50	50	100	100
Max. back pressure (kPa)		20	20	20	20	30	30
Max. base pressure (kPa)		10	10	10	10	20	20
Coefficient of permeability k (m/s)	sample 1	$3{,}86*10^{-9}$	$5{,}46*10^{-9}$	$3{,}63*10^{-9}$	$3{,}64*10^{-9}$	$3{,}60*10^{-9}$	$3{,}38*10^{-9}$
	sample 2	$1{,}24*10^{-8}$	$3{,}22*10^{-8}$	$7{,}95*10^{-9}$	$7{,}68*10^{-9}$	$4{,}11*10^{-9}$	$3{,}18*10^{-9}$
	sample 3	$3{,}86*10^{-9}$	$9{,}44*10^{-9}$	$3{,}71*10^{-9}$	$3{,}98*10^{-9}$	$1{,}72*10^{-9}$	$1{,}99*10^{-9}$
	sample 4	$5{,}45*10^{-8}$	$1{,}71*10^{-7}$	$3{,}21*10^{-8}$	$1{,}71*10^{-8}$	$1{,}13*10^{-8}$	$9{,}48*10^{-9}$
	sample 5	$1{,}67*10^{-7}$	$1{,}64*10^{-7}$	$1{,}83*10^{-8}$	$2{,}56*10^{-8}$	$7{,}69*10^{-9}$	$6{,}77*10^{-9}$

Table 2. Value coefficient of permeability k (m/s) for samples ϕ50 mm sampling vertically

Number of order test		1	2	3	4	5	6
Type of test		CH	CF	CH	CF	CH	CF
Cell pressure (kPa)		30	30	50	50	100	100
Max. back pressure (kPa)		20	20	20	20	30	30
Max. base pressure (kPa)		10	10	10	10	20	20
Coefficient of permeability k (m/s)	sample 1	$4{,}34*10^{-9}$		$1{,}81*10^{-8}$	$1{,}03*10^{-8}$	$4{,}72*10^{-9}$	$4{,}10*10^{-9}$
	sample 2	$1{,}03*10^{-7}$	$5{,}13*10^{-7}$	$6{,}45*10^{-8}$	$2{,}17*10^{-8}$	$4{,}07*10^{-9}$	$2{,}70*10^{-9}$
	sample 3	$1{,}70*10^{-7}$		$9{,}38*10^{-8}$	$6{,}98*10^{-8}$	$8{,}58*10^{-9}$	$6{,}01*10^{-9}$
	sample 4	$1{,}81*10^{-7}$	$3{,}53*10^{-7}$	$7{,}28*10^{-8}$	$5{,}00*10^{-8}$	$2{,}74*10^{-8}$	$2{,}52*10^{-8}$
	sample 5	$7{,}26*10^{-8}$	$5{,}67*10^{-7}$	$4{,}32*10^{-8}$	$2{,}69*10^{-8}$	$7{,}00*10^{-9}$	$5{,}51*10^{-9}$

CH – Constant Head test
CF – Constant Flow test

Low values of coefficient of permeability (k) suggest the minimal permeability of fen soil. The testing concerned only the chosen ground places. Those were not the places of ground water soakage that were observed in terrain pits. Taking samples from such places, preferential filtration is very difficult because of flowing water and the possibility of untouched ground structure damage.

LABORATORY RESEARCH

As well as test drilling that provided samples for observations on the stratification and measurements of the physical properties of fen soils, several trial pits were also excavated for samples for strength testing.

Conducting the multipurpose research was possible because of using the set for ground research GDS Instruments Ltd that allows to conduct many kinds of strength testing research, abilities of strain and hydraulic conductivity of soils (see Figure 2). The samples in the shape of the cylinder 38 mm and 50 mm in diameter used in research, were protected with rubber covers and then fixed in the apparatus chamber where the outer water pressure σ_3 operates as during the triaxial testing. The direct measurement of the axial force value working on the ground sample with the help of proper force sensor placed in the chamber is a kind of innovation. There can be the direct strain measurements Hall done in the chamber, with the use of electromagnetic sensors stuck on the sample (two sensors for height changes measurement and one for sample diameter changes). Apart from that the chamber has the independent, outer electronic measurement of sample height changes. All data taken from these measurements are collected in an in-box and send to a PC computer, then they are processed and saved in files on hard disk. The computer equipped with the proper card and software GDSLAB, apart from collecting and processing data is a device controlling the testing parameters by the group of three pressure collectors. These devices directly control, producing the proper water pressure with the use of stepper motors by such values as: pressure and water value in the chamber $\sigma 3$, changes of vertical strains, water pressure in ground pores, water flow through the ground sample and changes of these values in time. Collectors allow control either directly or by a computer. Planning of individual tests with the use of PC computer gives the chances and is less complicated on the grounds of compatibility of GDSLAB software and Windows.

Figure 2. Advanced apparatus of GDS Instruments Ltd.

Figure 3. Destroyed sample ϕ50 mm in cell

The basic testing of soil physical properties and strength parameters have been conducted in an advanced set for soil research of GDS Instruments Ltd. This apparatus is considered to be the most modern in the world (see Jaremski & Straż 2004) and measures the pore pressure on the effective values of friction angle ϕ and cohesion c (Figure 3). The test results provide an outlook on low parameters of river soils of terraced floodland. Maximum strength of these soils was obtained with the significant axial strains 11÷20%.

Wider differences in soil strength testing results were observed during the research, excluding the pore pressure. In the same tests including the pore pressure, the differences are smaller. Comparing the results with the values in norm, PN-81/B-03020 (1981), high cohesion values have been achieved as for non-consolidated grounds. Moreover, for the internal friction angle, the test results are different from the norm values and are smaller.

An example of the laboratory research results obtained for a series of samples of fen soils are presented in Table 3. These results show the diversity among similar soils of river sedimentation and reinforces the need for greater precision in the description and characterization of fen soils with the location on such investment land, even with the less importance and lower ground load.

Table 3. Examples of the average laboratory results of parameters fen soils

Sampling place	Rzeszow – Lisia Gora					Pilzno	Przeclaw	Podole
	Excavation 1	Excavation 2	Excavation 3	Excavation 4	Excavation 5			
Depth (m)	1,0	0,9	1,2	1,4	1,3	0,9	1,7	1,3
Type of soil	sandy silt	sandy silt	sandy silt	clayey sand	sandy silt	clay	mud	clay
clayey (%) fraction	9,5	4,5	9,5	4,5	9		11	22,5
silty (%) fraction	40,5	34	39	20,5	31		75	45
sandy (%) fraction	49	61,5	48,5	74	57		14	32,5
Density (g/cm^3)		1,94	1,98	2,21	2,09	1,89	1,81	2,08
Humidity (%)	19,82	23,78	23,29	17,58	19,37	31,91	26,67	21,28
Plastic limit (%)	16,53	23,78	23,29	17,58	19,37		24,02	15,30
Liquid limit (%)	30,0	33,5	41,0	21,0	30,0		57,5	39,5
Liquidity index	0,24	0,30	0,22	0,40	0,10		0,08	0,25
Friction angle (°)		3,5	4,4	11,54	12,0	4,9	12,08	5,18
Cohesion (kPa)		36,2	44,2	13,6	50,8	34,67	85,4	64,8
Effecive friction angle (°)		22,16	16,4	28,3	22,7	25,33	15,46	10,3
Effective cohesion (kPa)		20,4	35,4	14,0	39,6	14,17	81,2	58,2

Apart from the samples of an undisturbed, natural structure, the prepared samples of variable moistness, thickened as in Proctor's apparatus have been tested. We can follow the influence of soil moistness on the strength parameter values such as internal friction angle and cohesion (see Table 4).

Table 4. Variability of strength parameters of fen soils prepared samples (average results)

Series of prepared samples	Humidity (%)	Density (g/cm^3)	Friction angle (°)	Cohesion (kPa)	Effective friction angle (°)	Effective cohesion (kPa)
1	15,59	2,19	12,6	117,0	13,0	120,0
2	18,77	2,17	4,62	31,0	11,5	27,0
3	22,43	2,06	2,23	10,0	20,8	3,89
NNS	21,28	2,08	5,18	64,8	10,3	58,2

NNS – natural undisturbed structure of samples

The results demonstrate the significant influence of consolidated ground on strength properties. Despite the fact that the fen soils should be categorised as non-consolidated, the strength of samples with an untouched, natural structure is obviously greater than prepared samples with similar moisture content.

The substantial problem and obstacle in treatment of ground terrace floodlands, as the base of building is their ability for significant strains. The high deformation of this ground is connected with the history of its formation and lack of consolidating load. The smaller part is played in case of grounds within this analysis, the content of organic parts fluctuates in 0÷5% range.

The test results of ground compressibility conducted in oedometers gave the values of oedometer modules 2000÷10000 kPa. These are small values, close to values for organic grounds.

CREEP PROPERTIES RESEARCH

Within the work on the subject, additional research has been carried out on the beneficial treatment of fen soils (Jaremski & Wilk 2004b). One of the most important involves research on creep properties.

Changes of soil moisture content on the ancient valleys and river valleys areas, made by the outflow and surface water infiltration, cause their adaptability and sometimes liquification. Unusually complex building on fen soil formations and the variability of strength parameters of such grounds requires the use of new testing methods. One way of meeting this requirement is setting the strength parameters with computer-aided tools.

Geotechnical soil diagnosis and defining the most disadvantageous parameters that can appear in time, needs the application of increasingly precise testing methods. The research work involved describing geotechnical parameters of soils that were present during the testing and taking samples. Setting the strength parameters and describing the range of their changes in buildings exploitation is particularly difficult for silty soils.

In conducted laboratory research the fen soil strain was observed to be highly dependent on moisture content and time. For the description of rheological features of tested centre the creep test was conducted using the GDS apparatus, that is adapted to the measurements of surface changes of sample diameter and it allows the installed measurement with the use of Hall effect. This measurement is a basic function of this apparatus and allows to provide the creep process record of tested grounds with the use of creep curves considering the moisture influence on the course of the tested process. The behaviour of the sample subjected to constant loading in time has been observed. The research has been made for soils with an undisturbed structure. The sample diameter was 38 mm, height about 80 mm. There has been the creep properties research done on the prepared samples.

During testing the pressure in the chamber σ_3 for all research was constant and amounted to 100 kPa. The value of vertical load was selected in a way to receive the complex value of tension intensity. The vertical strains were registered with the use of the sensor in the chamber. This is an innovation of GDS apparatus in comparison with traditional devices. This apparatus allows for the triggering in the sample the stress deviator state that causes the process of creep. Registered process needs the measurement of height changes and perimeter size that allows for the fulfilling of the condition of constant tension intensity within the testing time. The results obtained from the testing were processed and then creep curves were drawn for different tension intensities. This work resulted in a series of families of curves. On the basis of already conducted research we can state that they are comparable with marl eluvium creep properties research previously reported by Jaremski (1991). For example, for the samples NNS of fen soil clay from Podole with the moisture content of about 21%, that matches the level of adaptability I_L=0.25, with the tension intensity 86 and 98 kPa curves aim at horizontal asymptote, and with the intensity 115 kPa the curve aims at vertical asymptote (see Figures 4, 5 & 6). It was found that the creep curves go through all stages, that is the elastic state of creep to progressive state of creep, registered only in the first phase because of device limitation. In the state of progressive creep, the samples were characterised with high increase of strain, and it led to their destruction. It was observed that immediately before the destruction, strain increased with the intensity that was not able to register because of device limitation.

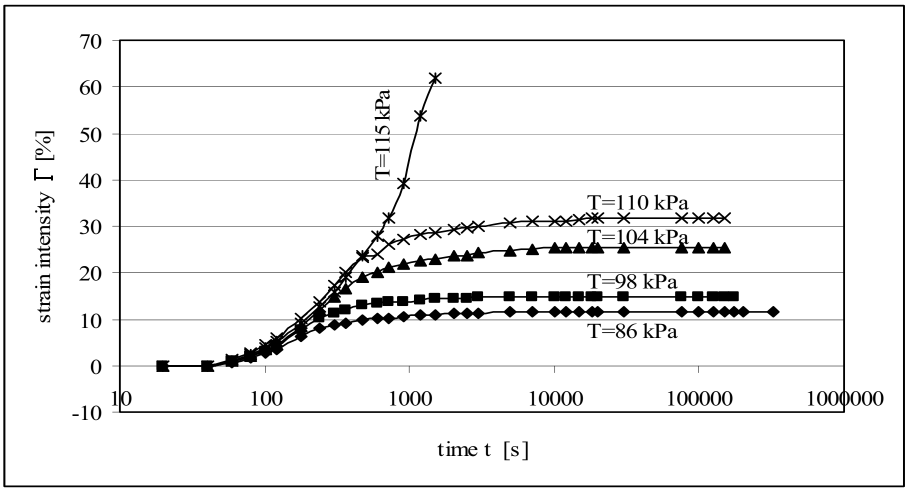

Figure 4. Logarithmic diagram of intensity strain of soil samples versus time.

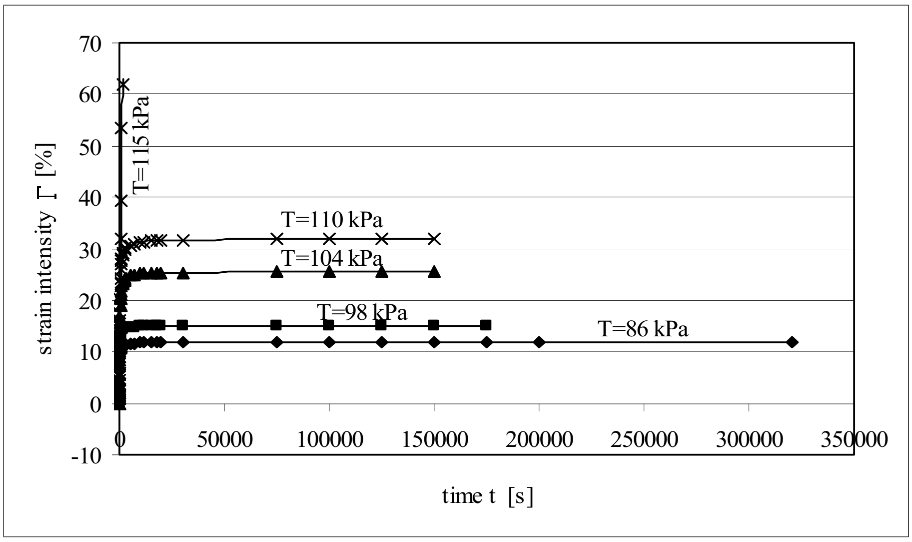

Figure 5. Linear diagram of intensity strain of soil samples versus time.

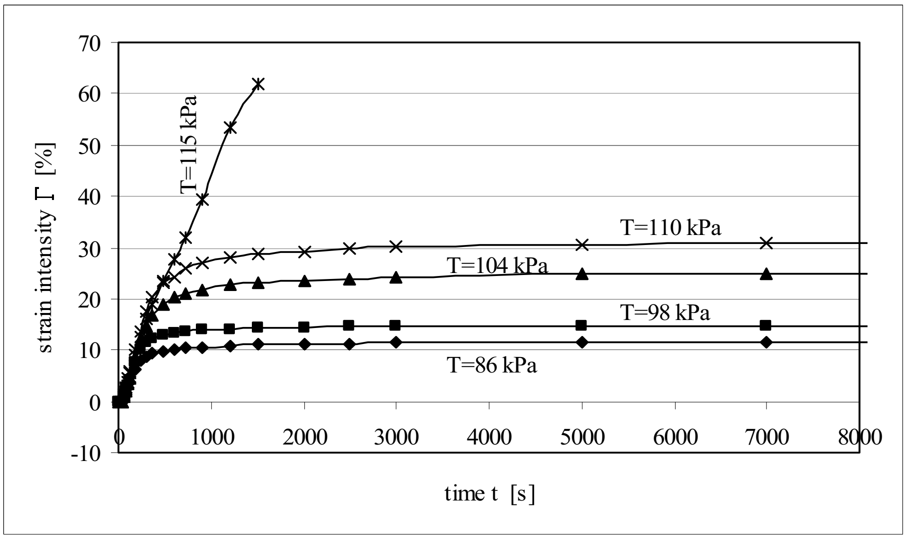

Figure 6. Linear diagram of intensity strain of soil samples in initial time of tests

Further work has been carried out on creep testing of prepared samples. Preparation of these samples involved batchwise thickening, similarly to the Proctor's apparatus, to the density close to natural conditions (see Figures 7 & 8).

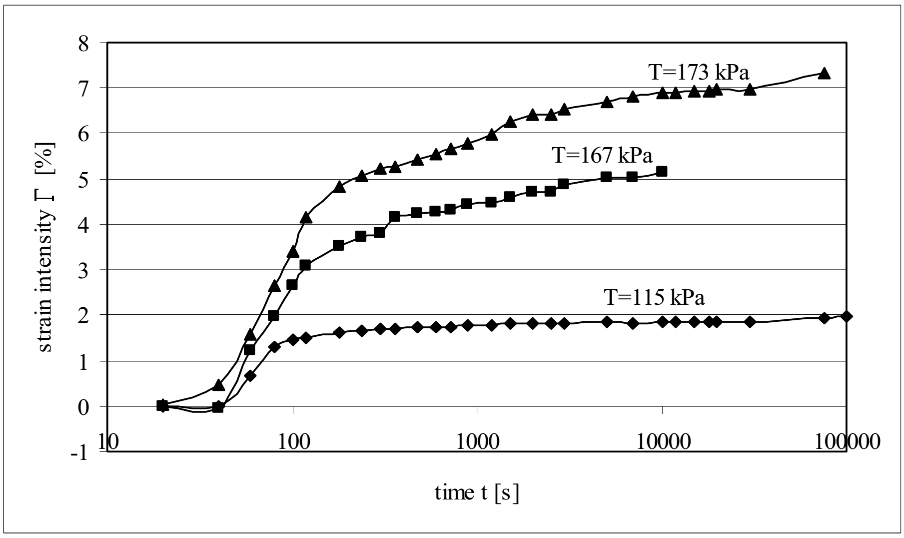

Figure 7. Logarithmic diagram of intensity strain of prepared soil samples versus time.

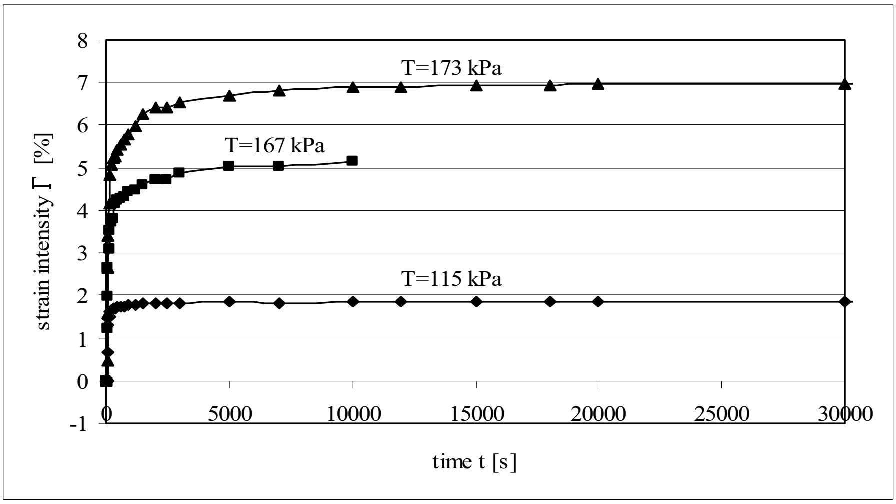

Figure 8. Linear diagram of intensity strain of prepared soil samples in time.

The research of strain abilities conducted in apparatus GDS Instruments Ltd. showed high values of Poisson's ratio ν, order 0.3÷0.5.

SUMMARY AND CONCLUSIONS

Areas of river floodplains threatened with flooding require detailed geotechnical investigations. There is a need for isolation of the land on which soils are extremely sensitive to disadvantageous changes of geotechnical parameters because of increases in moisture content. This need is connected with the risk of damage to buildings and infrastructure in these areas. An understanding of the changes in the geotechnical parameter will allow designers to optimize foundation solutions.

Total exclusion of buildings from certain parts of areas of flood plain appears unavoidable. These areas are where the changes of soil strength features exclude the shallow foundation and also the areas of previous erosional valleys and its neighbourhood. The knowledge of arrangement, bending of geotechnical layers and their features also indicate potential sites at risk of landslides. These landslides can be caused not only by the terrain height differences. In the case of escarpment of old river bed valleys, even filled with already brought ground batches, usually weak, with slight load, it is a real danger.

This geotechnical research is of considerable interest to administrative and self-government units for planning purposes. Appropriately prepared maps of areas of flood plain can show zones of "high risk" and thereby prevent the damage of many buildings and constructions in the future. The damage of buildings caused by the loss of foundation load is connected with their construction damage. This may disqualify these objects from further use and they may need to be demolished.

At the present time, it is not possible to retreat from areas of flood plain because of the existing infrastructure. However, a new planning permission should apply to these areas made conditional on fulfilling the number of conditions increasing the building safety, and even forbid to build new objects. New building development of districts should be planned in places where the ground parameters despite the moistness increase, change in the limited, safe range.

We should pay attention to circum-flooded terrains, where the loss of the load by the ground is likely because of horizontal infiltration of water in the ground. Also the areas of escarpments and hills which basis are at risk of moistness changes, create the danger of landslide and furthermore the significant material losses and life risk.

Foundation work on the ground shaped by the river accumulation is a very difficult task. It is confirmed by the low strength value parameters taken during the ground floodland terrace research, and by the diversity and complexity of lithological construction of fen soil.

The necessity of wide geotechnical ground parameter research on the areas threatened with flood is very important. Better knowledge of ground foundation will allow the use of the optimal solutions of building foundations by the designers, and also the construction itself.

There is a problem of working out methods of damaged foundation strengthening, increasing the ground load under these foundations after flood alerts to solve.

Another problem, in which the geotechnics participation can influence the cost reduction, is the grounds evaluation that are under the floodbanks, describing the tightness, choosing the methods of making and depth of anti-filter screens and so on.

This research programme has indicated the complex nature of the lithology of fen soils and the difficulties in providing a useful description of the basic ground strength parameters.

The research presented aim at the statement that the geotechnical parameters of different soils should be known in details and on the knowledge of their features we can predict the numerical values treating the mechanic apparatus as a tool.

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