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INFLUENCE OF MOISTURE CHANGES ON PHYSICO-CHEMICAL PROCESSES AND GEOTECHNICAL PARAMETERS IN SOFT ROCKS

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Abstract: A comparative analysis of weathered marls and flysch, silty soils, illite and baidelite clays leads to the determination of a common feature of these grounds, namely the exceptional sensitivity to changes of the moisture content. From the tests performed we can state that this common characteristic is due to the presence of illite and smectite in these media. In the paper, a methodology of the swelling ability test has been proposed as a method of identification of such clay minerals. Investigation of the eluvium geotechnical parameters by "in situ" methods has also been proposed.

1. INTRODUCTION

The author has been working on determination of strength parameters of marl eluvia for many years. The tests carried out enabled him to qualify these eluvia as building foundations in a city in the south of Poland, where marl eluvia occurred below the humus layer and they had not been used for foundations before.

In the paper, preliminary investigations of Carpathian Flysch rocks have been described with reference to many years' standing laboratory and "in situ" tests of weathered marls in Opole – a city in the south of Poland. The marls exemplify the grounds being mixtures of calcite-clayey minerals and other minerals in which calcite is a binding agent.

The Opole marls include: solid (fresh) rock, slightly weathered rock, moderately weathered rock, highly weathered rock and completely weathered rock which lies just under the humus. Opole marls occupy almost the whole area just under the soil layer and in contrast to other regions where commonly above marls there occurs a covering of clayey weathering or clay. This decides on the exceptional sensitivity of weathered marls to changes of moisture content caused by precipitation. The structure of these grounds changes under the influence of external factors. During droughts the weathered marls are typical rock debris. On the other hand, during a long period of precipitation, this ground becomes similar to a typical cohesive soil. Among practicing engineers a common view is that the weathered Opole marls are nonbearing subsoil and should be removed. Because of this buildings were mostly founded on the ground changed in the place of weathering, i.e. on loose ground.

A wide programme of laboratory tests and investigations "in situ" was carried out and results had been collected successively for many years [7], [8], [9]. In search for answers to the doubts which appeared at particular stages of investigations it was necessary to conduct some subsidiary research which brought about the determination of geotechnical properties and permitted making use of the Opole marl eluvium as the construction subsoil of a good bearing capacity [6].

Since marls and their weathering can be classified as calcite-clayey mixtures [2], [3], geotechnical parameters of the marls occurring in various parts of the world can be compared. Some practical problems of the analysis of physical and chemical processes occurring in Opole marls and Carpathian Flysch and their influence on geotechnical parameters have been shown. The test methods proposed by the author could be applied in practice and would allow us to classify weathered rocks as well as foundations strata used and describe properties of marls occurring in different regions. The tested parameters of soft rocks are very important for engineers designing various building structures.

2. RESEARCH CONNECTED WITH EXPLANATION OF PROCESSES CAUSING EXTREME VALUES OF THE STRENGTH PARAMETERS

Dumbleton compared red clays in Kenya and Keuper Marls in South Wales. The author of this paper, inspired by Dumbleton's works [3], compared Opole marl eluvia with rock weathering of the Carpathian Flysch and silts of flysch being the sediments of river terraces occurring in the Podkarpacie region, with loess massif, and illite and baidelite clays. The comparative analysis of these ground media leads to assertion of their common feature, that is special sensitivity to moisture changes.

Weathered marls like flysch weathering occurring in landslides sliding surfaces, silty (cohesive) soils of the river terraces investigated, soils of loess massif, illite and baidelite clays reveal the threshold moistures in condition of loss of their strength [15]. Based on the tests executed it has been stated that existence of clay minerals (illite and smectite) was the reason of this common characteristic. These minerals, occurring only as vestigial amount, influence combinations of elementary minerals such as, for example, calcite in marls or quartz in loess. The existence of those minerals brings about the occurrence of shrinkage and swelling [4], [17], integrally connected with moisture content of soil medium being analysed. The first investigations which led to the above conclusions were carried out for the Opole marls.

3. RESEARCH OF SWELLING

The author has been occupied with getting to know the processes occurring in weathered Opole marls during their transition from rock rubble into typical cohesive soil. Explanation of these extreme states of weathering, integrally connected with shrinkage and swelling [6], [11], was a very important direction of research.

The phenomenon of swelling under conditions "in situ" was observed and it was the result of the presence of clay minerals of the illite group, found in mineralogical tests, that showed the ability to swelling under certain conditions. To accept such a statement as the right one it should be proved that the phenomenon of swelling occurred in the marl eluvium. Therefore, the problem of determination of this phenomenon appeared. However, from the data collected from the source materials, being the result of investigations carried out for the needs of geological and engineering documentation, and from the laboratory tests made by other researchers it appeared that in the Opole marl eluvium the swelling had not been registered at all. The author's own tests of swelling, carried out according to the accepted standards and to the successively-collected methods given in literature, did not permit us to register the phenomenon of swelling in the medium discussed. These negative results confused the problems because in the absence of swelling effects it was impossible to explain the following processes occurring in the deposit:

- changes in fissibility accepted as the characteristic feature for the medium considered,
- reconstruction of structural bonds,
- intensive weathering,
- reconstruction of cohesion.

4. SEM MICROSTRUCTURAL ANALYSIS

Photographs showing the microstructural surface were taken with a scanning electron microscope (SEM). They were taken in order to investigate three-dimensional packing of calcium carbonate and clay minerals as well as to explain change of marl properties influenced by variable humidification and drying. The material under investigation originated from the testing ground on which "in situ" examinations were made, and from the samples which were used for laboratory tests. The microstructure image of solid chip marl and filling fissures and binder from prepared weathering were subjected to examinations of their microstructure with the use of a scanning electron microscope. The microstructural image of solid marl chips of prepared eluvium is shown in figure 1.

After the analysis of photographs of various samples it has been found that marl microstructure creates a spatial configuration, rich in calcite from which the sediment is mainly composed and it is of an organic origin. The empty spaces between the visible calcite forms can be packed by air of calcium carbonate in a fine-crystalline amorphous form. One should emphasize that calcite crystals are characterized by rich forms and originate from fractional precipitation or mechanical grinding of calcareous chips. At any rate, part of the sediment is built from decomposed, to a greater extent, skeletons of calcareous invertebrates, chiefly foraminiferas mixed to various degrees with fine-grained material, which contains many plankton algae from coccolithe group. There are also robdolits, compact silice needles, scarse sponge needles, etc. Beside the chips of organisms, terragenic mineral there occurs a binder of rock background character or packing mass. This rock background or packing mass present a meshy

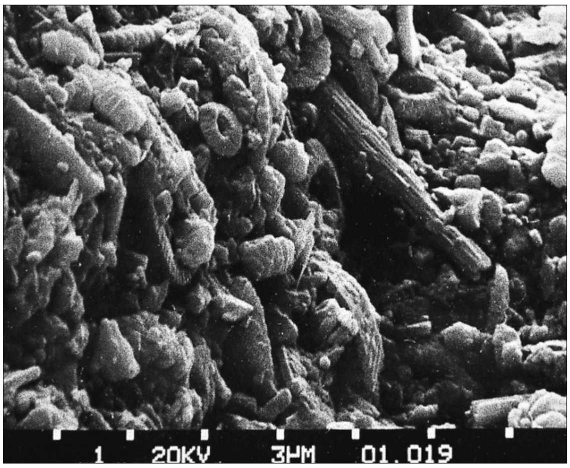


Fig. 1. Microstructural surface of solid chip from marl eluvium observed in SEM, scale 3000:1

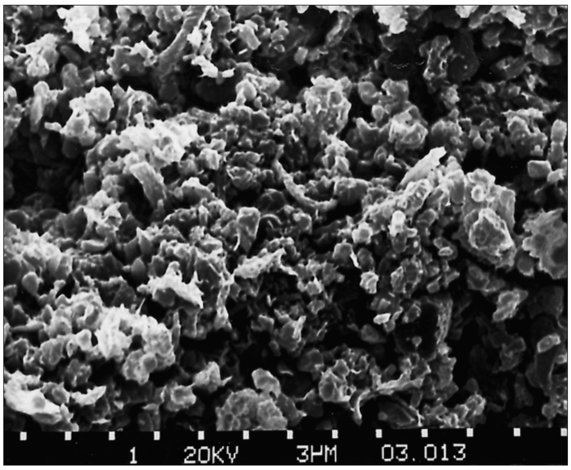


Fig. 2. Microstructural surface of binder of marl eluvium observed in SEM, scale 3000:1

mosaic of calcite grains which originated due to chemical recrystallization of precipitated calcareous slime. The fine grained mass is partly mixed with colloidal clay substance. Usually, the terragenic material is the fine grain in carbonate rocks. Therefore, it can be recognized in the carbonate mass only by great magnification. Calcite elimination is very instrumental by means of disodium versenate. The marl presents such a type of rock in which its organic skeletons are not the main rock elements but some attention should be paid to the fact that during the formation of the deposit those organisms could indirectly cooperate in the formation of rock causing fractional precipitation of calcium carbonate from the solution together with illite minerals which occur here considering the specific conditions as flatten illite visible in many photographs. For comparison purposes, some additional examinations were made on samples taken from solid marl from several places and from recrystallization material which is the binder of rock spalls (figure 2).

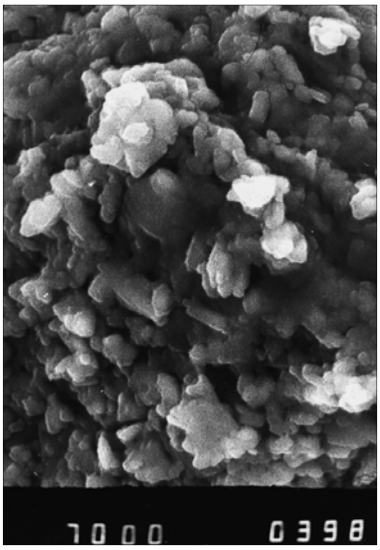


Fig. 3. Microstructural surface of binder taken from laboratory samples of granulated marl eluvium after recrystallization of calcite observed in SEM, scale 4200:1

Microstructural images obtained were compared pointing to the existence of fragments of fossil in the compact material in contrast to the binder. The compact samples contain a well preserved microfauna which proves that the rock has not been recrystallized. The samples of the second type containing no microfauna are characterized by a great number of empty spacers. This does not exclude the occurrence of amorphic, fine dispersed calcium carbonate and clay minerals. It was proved by microstructural photographs of marl eluvium which was granulated in the laboratory, saturated with water and dried, and after its solidification the samples were taken from the compact material and the binder aiming at SEM analysis (figure 3).

It should be stressed that there occurs a distinct similarity of microstructures between the sample taken from greater solid parts of marl eluvium and the one which is a binding agent and filling subjected to repeated moisture and recrystallization. The microstructural similarity of samples taken from solid parts and binder is probably the result of phenomena caused by the changes of moisture content and recrystallization and it also proves the correctness of conclusions which state that these processes occur under deposit conditions and the binder petrifaction is part of their action.

5. DESCRIPTION OF PHYSICO-CHEMICAL PHENOMENA OCCURRING IN MARL ELUVIUM

Marl eluvium consists of debris (rock pieces) and filling which determine the most weathered marl. This marl is found in the form of fine fraction, filling partially or completely gaps and free spaces. In respect of mineralogy the marl and its eluvium consists of calcite and clay minerals from the illite group and their chemical composition $CaCO_3$, CaO, Al_2O_3, SiO_2, MgO, F_2O_3 prevail and cations K^+, Na^+, Mg^+, SO_4 also occur. Under conditions of the deposit the processes described in the previous chapter, in principle, act simultaneously but the participation of these processes, considering variable outer conditions may be accepted as random and dependent on many agents. The scale of recognition of the processes permits the author to describe the model of physicochemical phenomena occurring in the marl eluvium with regard to their interaction and the results of the strength and deformation ability of weathering. The description of the conditions of these phenomena, with extreme values of the geotechnical quality of marl eluvium, is very important because it allows us to arrive at the correct interpretation of the results obtained in many examinations and this leads to the evaluation of geotechnical parameters.

6. DESCRIPTION OF PHENOMENA OCCURRING UNDER ATMOSPHERIC CONDITIONS CAUSING THE PROCESSES OF MAXIMUM WEATHERING EXSICCATION

During the time without atmospheric falls, when the temperature outside the deposit is high, as a consequence of heat transport to the non-uniform distribution of humidity, flowing continually from the more wet zones to less wet ones, the liquid relocation from the inside to outside occurs. The condition of humidity is the result of not only the external effects but also the weathering ability to the moisture content fixation during binder hardening. The structural constraints which came into being through the absorption of water by eluvium, as a result of the formation of gel, are weak and can be easily upset by evaporation. The kinetics of water drying begins, first of all, from high pores and capillars by the upset of physicochemical constraints and by expelling free water (dependent on the gravitation action). Then water evaporates from micropores and microcapillars, the state of capillary pressure appears, which creates deformation through shrinkage. After evaporating the capillary water, the water connected structurally and packed in colloidal water, begins to expel. The humidity shrinkage comes into being, that is to say, together with the change of water content, the changes of structure and volume are joined. As a consequence of drying and the processes of reclystallization, which will be described later on, there must occur the terminal humidity, bringing about the tendency towards the formation of scratches and cracks in the binder. The scratches are magnified by the occurrence of stresses or by the concentration of local stresses. They transmit the formation of cracks on the external strata of pieces developing the microstructural situation in the inflow heat zone during drying and reclystallization which can be presented as soft material of a grid in highly reinforced interior consisting of well-formed calcite which can be seen in the photographs of scanning electron microscopy. The cracking formation must be connected with strong local deformation of the vicinity of these limits. The interclystalline fracture overcomes small cavities (empty spaces bigger or smaller which may also be seen in the microstructural photographs) packed by perlite or non-crystallized calcite coming from chemical reactions or by illite molecules and in these areas between granules and packing there are plastic displacements proceeding to scratches and cracks. Besides, as a consequence of heat growing in the coarse-grained area of the beat interaction zone there appear cracks along grain limits between monolithic and chip parts. Crack growing is also possible as a result of the formation of calcite nuclei of recrystallization from the bigger saturation of calcium carbonate. Each change in the decrease in the concentration of CO_2, dissolved in water, may be the cause of calcium carbonate precipitation. Calcium carbonate can be precipitated by the evaporation of water containing acid calcium carbonate. This precipitated calcium carbonate can form nuclei of recrystallization in scratches, holes and empty spaces which appeared among chips before. The speed of creating nuclei of recrystallization and their growing may be accelerated by the segregation of cations of other minerals on the separation surface of original particles and on free surface of holes. The total deformations achieved as a result of the connected deformation mechanism are sufficient for the internal stress reduction.

In such a situation, a further heat influx can be observed. It causes water evaporation from capillaries where the gravitational water inflows. This leads to cracks and shrinkage. Thus, heat reaches larger and larger surface of the particles and, as a consequence, evaporation of electrostatically bound water can be observed. This water occurs as dipoles in colloidal micelles; it cauases rapid increases of moisture shrinkage and determines formation of new cracks on larger areas – surface filled with smaller and smaller fractions. Finally, even big chips crumble. At the same time further moisture inflow may occur through the evaporation from the underlaid strata as a result of the decrease in underground water and the transition of the intensity area of moisture contraction to the lower strata. The evaporated water sometimes enriched qualitatively even by small precipitation may be absorbed in the newly created cracks and empty spaces bringing about the processes of calcite dissolution joining partly the swelling with chips and unfractional eluvium which makes it possible to recreate the calcite recrystallization processes which join together loosely composed streak chips or punctually fill fissures increasing the strength of eluvium. During the decrease in moisture and the processes of drying intensive cracking occurs and under the state of total drying the crumbling occurs. In the packing between granules as well as in partly packed fissures where part of evaporated water coming from the underlaid strata condensates, some new connections are created from calcite recrystallization which integrate chip walls where that process is more intensive in consideration of less moisture sorption by chip surfaces.

The process of drying, apparently destructive, leads to indissoluble chip-wall connections where in consideration of small precipitation the processes of recrystallization occur. The above-mentioned reactions occur continually consolidating the weathering and bring about relatively high values of the internal friction angle and little deformability which is documented by the "in situ" measurements, presented in the author's another paper. The geotechnical parameters of eluvium, occurring under the humus stratum, achieve the maximum values during long-lasting droughts and when the underground water level is the lowest. Then the marl eluvium achieves the greatest thickness and stores the maximum quantity of heat coming from the atmosphere as a result of ventilation and it is the typical stone debris and its geotechnical characteristics are more favourable than the values achieved by the eluvium deposited in the zone of capillary ascent, e.g. 6÷7 m below the ground.

7. DESCRIPTION OF PHENOMENA OCCURRING UNDER ATMOSPHERIC CONDITIONS BRINGING ABOUT MAXIMUM MOISTURE CONTENT OF ELUVIUM

If it is possible that after long-lasting drought there are long-lasting rainfalls, then water dissolving CO_2 as well as CaO (calcium oxide) cations and anions becomes a chemical solution which is a carrier of the processes described in earlier chapters. Calcium oxide dissolving in water shows in a theoretical way solubility product L_{CaCO3} = $[Ca^{2+}] \times [CO_3^{2-}]$. If water contains the dissolved CO_2, H_2CO_3 (carbonic acid) dissociates according to the equation:

$$\frac{[H^+]\times[HCO_3^-]}{[H_2CO_3]} = L_1$$

H^+ ions join with CO_3 ions from calcium carbonate to HCO_3 ions, which are a little dissociated by the equation:

$$\frac{[H^+]\times[HCO_3^{2-}]}{[H_2CO_2^-]} = L_2$$

L, L_1, L_2 denote some constant values here. Joining H^+ ions with CO_3^{2-} ions causes the loss of balance. Calcium carbonate is dissolved for so long time as a result of Ca^{2+} ions concentration increase, the state of the system returns to the primary values of solubility product and calcium carbonate precipitates again when H^+ ions are carried off from the solution:

$$Ca(HCO_3)_2 = CaCO_3 + CO_2 + H_2O.$$

The most important factor for calcium carbonate solubility is the concentration of CO_2 which is dissolved in the form of gas in water. As a result of hydration process CaO contained in marl in excess of water passes into $Ca(OH)_2$:

$$CaO + H_2O = Ca(OH)_2.$$

As a result of the changes of water condition and evaporation of gravitational water as well as separation of crystals of hydrated calcium as a consequence of CO_2 the crystallization occurs:

$$Ca(OH)_2 + 2\ H_2O + CO_2 = CaCO_3 + (n + 1)\ H_2O.$$

This creates a difficult microstructural situation. In the first phase of moistness, all the above-mentioned reactions occur, but what is important is that only part of them also occur in the reverse direction as a result of changes of the concentration of dissolved CO_2 and precipitation reactions. Water, apart from solubility reactions, in addition, cools granules of tiny fractions forming thermal stresses in granules and capillary cracks from which as a result of granules hydrophilly (containing calcite and illite minerals) water extrudes air and surrounds granules separating one from another. Illite minerals as a consequence of accumulated heat quantity become the paste of processes creating colloidal bonds. Water penetrates deeply into capillary cracks and causes their expansion which helps the hydrolysis and hydration reactions. In consequence, the volume of crystals nets becomes greater which results from electrostatic moulding leading to the bigger and bigger packing of water dipoles. This swelling of surface strata of crystals nets creates mutual approach of colloidal micelles which brings about the bigger packing and the same phenomena occur on the surfaces of less or more weathered chips. This process of colloidal water binding also promotes an increase in the concentration of Ca^{2+} ions, the state of the system may sometimes return to the primary solubility values after partial calcite precipitation, which at that moment starts to influence, with a restraining effect, the growth of colloid. Water progressively enters the interior of weathered granules and chips or less weathered thicker parts of surfaces and crack surfaces. This creates bigger water absorption to the interior through bigger surfaces of colloidal particles arranging greater quantity of water dipoles which causes the compacting of particles and uncreating micelles approach each other and as a result of coagulation the micelles connect into bigger aggregates and the formation of the stage of microstructures begins.

When such formation is finished, swelling begins to end. Moisture close to the plasticity limit corresponds to such a state, and since the minimum amount of gravitational water remains, the maximum concentration of Ca^{++} as well as calcite recrystallization can be observed. It leads to the end of swelling. For the maximum swelling, the maximum possible amount of water dipoles is settled and it enters the composition of colloidal micelles. The expanded eluvium resembles cohesive soil, the amount of gravitational water in which solubling processes may occur is minimal. The amounts of calcium and potassium and different cations at the maximum degree are equalized by the electrostatic influence of micelles, the state of the system returns to the primary values of the solubility product. A part of acid carbonate becomes to precipitate in $CaCO_3$ and the relative state of equilibrium is achieved. To sum up, the formation of coagulation structure is finished and the process of intensity of recrystallization starts. It is accompanied by the high level of underground water which creates the biggest difference of water level between the Turonian level with respect to the tense level of Cenoman water as well as Triassic water.

This creates conditions for the maximum filtration through numerous faults occurring here. After a long-lasting precipitation, water evaporates upwards and its filtering off occurs downwards which under these conditions leads to a very quick decrease in the underground water level.

8. RECAPITULATION OF MARLS ELUVIUM RESEARCH

The examinations, made by means of a scanning electron microscope, gave the image of geometry of space configuration at the microstructural level. The similarity of the microstructure of samples taken from solid parts, binder filling and from recrystallization material, being the packing of rock chips in moulded samples, is the result of the phenomena caused by the variations in humidity, drying and recrystallization. This proves the correctness of conclusions worked out in the analysis of the processes of deposit formation in a sedimentation basin. The processes occurring in the deposit and presented in the description are comparable with those occurring during the formation of marl sediment. Obviously, under those conditions the seawater concentration differed as a result of the processes of strophy and the development of various sea organisms. The dynamics of processes depended on the intensity of biological life and the amount of detritial material which flowed into the sedimentation basin as a result of the processes of weathering and erosion from subsidiary river basins. It decided on the participation of chemical calcite in packing between skeletons of organisms and the amount of illite minerals and others. From the investigations carried out on the marl eluvium we have found out that under present temperature and moisture deposit conditions, the processes occurring in the deposit are renewed at the macro- and microstructural levels. The participation of these processes is random and their intensity determines the level of moisture and quantity of accumulated heat.

The intensive swelling, occurring under the critical moisture (when the weathering becomes similar to the cohesive soil), is the provision against the loss of strength, which is observed on the surface and in excavations (of the construction sites) as a result of soaking and distribution as well as excessive moistening at the contact of debris pieces. In the course of investigations the author has found that the most favourable state of weathering under conditions of deposit is accompanied only by a decrease in the values of geotechnical characteristics which result from the investigations "in situ". The loss of strength was registered only during laboratory tests on samples with big moisture content in which the processes occurring under conditions of deposit were not simulated. The values described above correspond to the conditions of the model.

In natural conditions the natural water content of 24% has been registered in which the marl eluvium has maintained its strength. The author's long-lasting research has resulted in the application of marl eluvium as a safe basement for architectural objects founded in new areas of Opole city. The condition of the slopes of already exploited quarries in the Opole city confirms also the results presented before. The walls are vertical and they display the absence of massive movements, i.e. no failures or slips even in the neighbourhood of a busy highway.

The author compared mechanical properties of rocks and their eluvia deeply located. The results obtained from the experimental loading of piles were compared with the parameters of eluvia and marl rocks at their outcrops. The silty sediment was compared with silty eluvia of the flysch. Unfortunately, it is difficult to collect samples of disarranged structures from silty soils – this is easier in the terraces.

9. DESCRIPTION OF PHENOMENA OCCURRING IN WEATHERED ROCKS (SOFT ROCKS) OF THE CARPATHIAN FLYSCH

In reaction of the flysch massif to the effects of man's activities and variable natural conditions, processes taking place in the eluvia play usually the most important role. People making studies in such complicated conditions use more and more precise measuring methods, new tools for strength estimation [12], etc. Methods of geotechnical parameter determination for the soil medium considered must be still developed. Determination of the most disadvantageous numerical values of geotechnical parameters, which can occur in the slope's real conditions, plays a very important role in slope stability analysis and also in selecting a method of protection against a landslide [1], [13], [16].

The problems of landslides occurring in the area of one of the provinces of southern Poland have been analysed in the paper. It has been affirmed that the fundamental part of the landslides occurs in the weathered rock of the Carpathian Flysch [10], [18]. Rocks occurring in this area are of the marine origin and they are calcite-clayey mixtures. These mixtures, especially when weathered, are characterized by exceptional sensitivity to changes of water content which decidedly influences their strength parameters.

Having analysed the results of the research concerning the chemical and mineralogical composition as well as geotechnical parameters of sedimentary rocks occurring in other parts of the world, it may be affirmed that these parameters are similar for comparable water content. The rocks are of marine origin and have a common diagenesis. Their chemical and mineralogical composition is similar and the registered changes are due to the qualitative and quantitative differences in their detritic material. The analysis of physical and chemical processes [14], which occur during formation of sediments in the sedimentation basin, proves that these processes added to the strength properties in response to the continual changes caused by the weathering processes.

The processes taking place during formation of sedimentary soils in the sedimentation basin are comparable to processes occurring during weathering and they are subject to the continual changes caused by the atmospheric conditions as well as the change of ground water level. In earlier works the author made an attempt to describe the physical and chemical processes occurring in the marls weathered under the influence of moisture changes. The aim of the analysis was to predict the maximal decrease of eluvium parameter value in the case of a deposit under the maximal water content conditions.

To recapitulate, the results of the various research, including microstructural tests carried out by means of the SEM, X-ray diffractometry, X-ray fluorescence, in situ investigations and laboratory tests on prepared samples, can lead to present methodology proposals for conducting research into these rocks. Such investigations indicate how genetic and climatic variations occurring in other regions influence the strength parameters of the rocks. The research methodology of the eluvium geotechnical parameters by in situ methods has been proposed and the necessity to conduct widened laboratory investigations has been pointed out in the paper.

At the landslides, changes of soil water content caused by infiltration of run-off and superficial waters cause their plasticization or even fluidization. The sructure of flysch formations is very complicated and there are many difficulties encountered in determining the strength parameters of such soils.

10. CHARACTERISTICS OF THE CARPATHIAN FLYSCH CONSIDERED

A great part of the landslides forms in the eluvia or in the area between the eluvium and the flysch solid rock. An increase of water content accompanies landslide formation. The behaviour of the flysch massif is influenced by the strength of eluvia or layers of the cracked flysch being the weakest element. In the surface layer, these eluvia usually occur in the form of silts or silty clays. The external part of the massif is formed of flysch formations, i.e. sandstones, shales, mudstones.

Generally speaking, flysch water-bearing capacity is connected with its fissuring – it results from a low porosity of the flysch, i.e. from 0.02 to 0.1. In the interporous space, the flow is made difficult because of the small dimensions of the pores. Moreover, the pores are filled with the weathered clayey fraction, very sensitive to shrinkage and swelling. It reduces the flysch water storage capacity, even to zero. The water storage capacity gets worse with the depth of layer deposits.

(a)

(b)

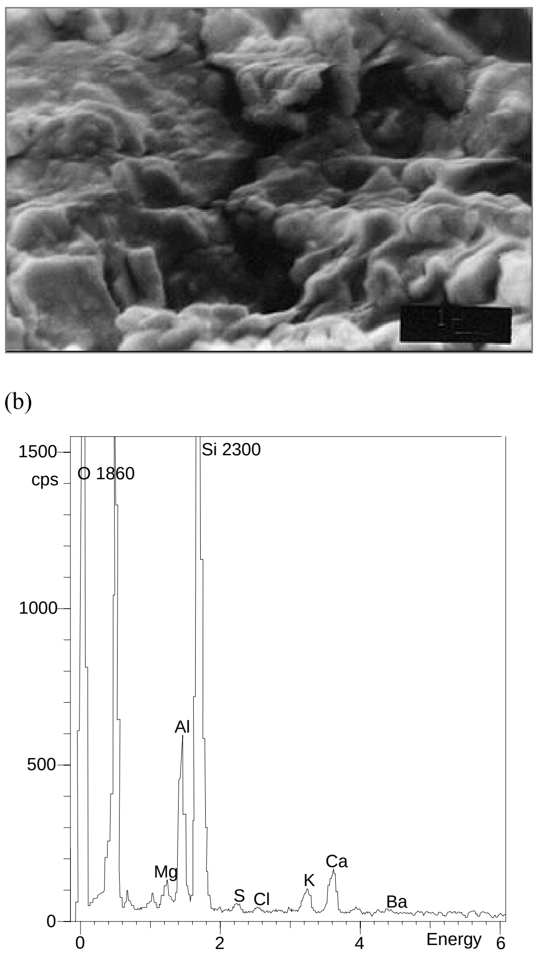


Fig. 4 (a) An example of microstructure surface of river terrace clays observed in SEM (scale 10000:1), and (b) analysis of their chemical composition with the use of X-ray fluorescence (Oxford LINK ISIS-EDS)

Abundance of ground waters is minimal, there is a lack of water-bearing layers. Water is stopped and occurs only in the cracked rocks. Thus, precipitation waters can easily flow to water courses, drifting the weathering products. Large run-offs transported the weathering products during floods, forming Holocene deposits of river terraces. The accumulated sediment was compared with the eluvia deposited in the places of their formation. It was found that they were comparable (in practice, the same) – silts, silty clays of similar chemical and mineralogical compositions and similar strength parameters. This was proved by microstructural tests using SEM, tests of chemical composition using fluorescence, etc. (figures 4 through 6).

Tests of silty soils from eolian and water accumulations in the Polish Carpathian region have been performed for many years [5]. The researchers try to explain the reasons of settlement formation a long time after the object foundation as well as test silty soils formed from typical loess after their macroporosity loss. The settlements cause scratches and cracks of the buildings. The test results were also applied for explanation of reasons of cracks in the buildings existing on typical loess.

Landslides occurring on the river terrace slopes formed of silty soils, and landslides existing in railway and road embankments located on the loess massif slopes were also taken into account [10].

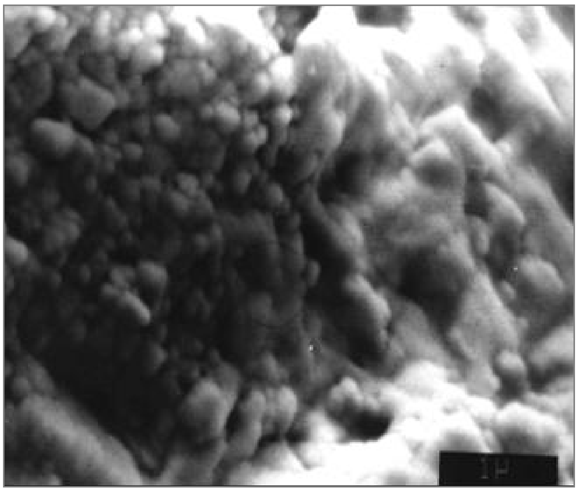
11. ADDITIONAL TESTS

All the phenomena occurring in nature can be explained with the use of suitably chosen simple mechanisms. The author considered some landslides searching causal connections and assumed that chemical and mineralogical compositions of the tested medium strongly influences landslide movements in the eluvium, in layers of shales, clay shales, etc.

From the analysis of chemical composition and tests of microstructure of many outcrops of the Carpathian Flysch and sediments from river terraces containing the transported weathered silts as well as eluvia it results that all of them contain minerals of illite and smectite.

These minerals are characterized by diversified absorption capacity, for example, absorption capacity of monmorillonite reaches 700%, and absorption capacity of kaolinite is 90%. These minerals strongly influence minimum and maximum geotechnical parameters. They influence their extreme sensitivity to water content changes caused by variable water conditions. These minerals cause the following mechanism of landslide plane formation resulting from contraction. During hydrogeological drought, the extreme sensitivity of illite-smectite minerals to contraction causes formation of cracks and slots and, in consequence, disintegration of layers of clays and clay shales forming ways of infiltration of water from the rains. Thus, humid slide surfaces are formed in the flysch layers. This can be proved by the structure of menilite shales occurring in the flysch area considered. Landslide movements are not registered at the slopes of the shales. The shales contain mainly quartz and they do not contain illite nor smectite.

(a)



(b)

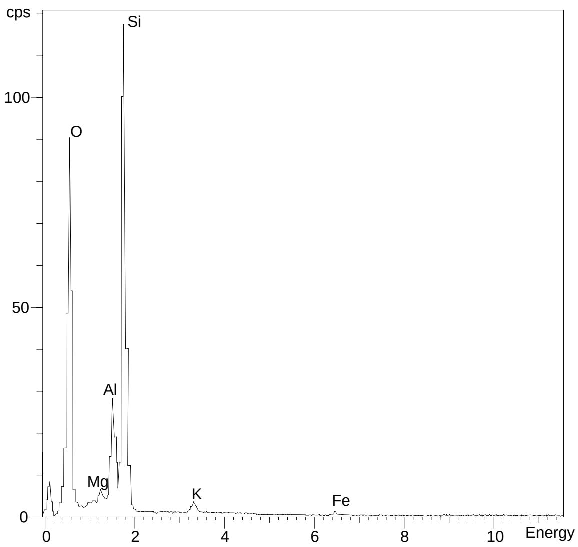
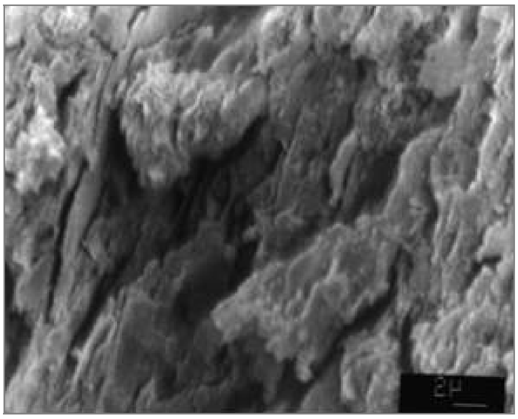


Fig. 5 (a) An example of microstructure surface of weathered clay shales observed in SEM (scale 10000:1), and (b) analysis of their chemical composition with use of X-ray fluorescence (Oxford LINK ISIS-EDS)

(a)



(b)

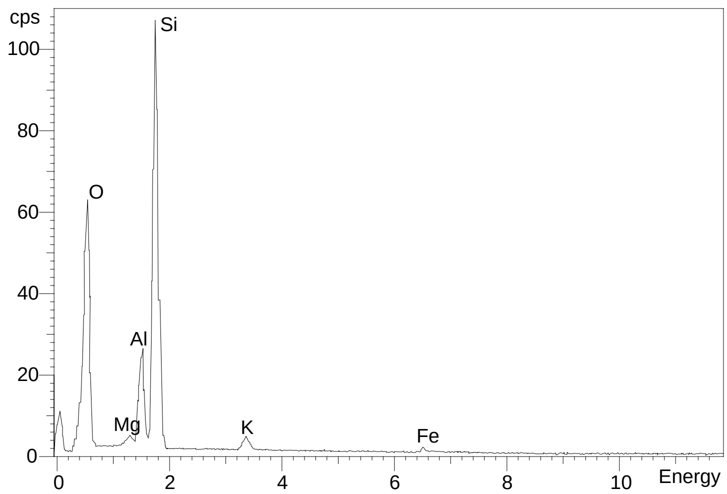


Fig. 6. (a) An example of microstructure surface of clay shales observed in SEM (scale 10000:1), and (b) analysis of their chemical composition with use of X-ray fluorescence (Oxford LINK ISIS-EDS)

Many tests were done, for example, microstructural tests performed with the use of a scanning microscope, and X-ray fluorescence, "in situ" tests and laboratory tests on the samples prepared. Their structure and composition are shown in figures 5 and 6. New test methods can be proposed for such a kind of rocks [7]. The tests enable determination of genetic or climatic singularities. They should be helpful in determination of the worst geotechnical parameters [9].

The tests were performed in the representative flysch outcrops. Chemical and mineralogical composition was tested and the strength parameters were compared with parameters of sedimentary rocks occurring in other regions of the world. For similar moisture content, these parameters are comparable. They are the rocks of marine origin. Their chemical and mineralogical composition is similar, and the registered changes result from diversified detritic material.

12. THE PROPOSED ADDITIONAL TESTS OF SWELLING ABILITY

The basic part of the landslides under study formed in a zone of weathered silty soils. In identification of such soils, traditional geotechnics includes particle diameters and their fraction in percentage terms. Mineralogical composition and fraction of particular clayey minerals often strongly influence strength parameters, and in the case of eluvia in the area considered causes extreme sensitivity to water content changes.

Eluvia of soft rocks change their structure under the influence of external factors. Soils of complex structures form from the flysch formations, then eluvia of diversified mineralogical composition and content of smectite, illite and kaolinite occur. The suggested method includes singular properties of the minerals, for example, illite swells after previous induction of heat energy and the following wetting. This method makes use of the presence of endothermic maxima.

The flysch rocks considered are mixtures of illite minerals and quartz, calcium and so on. In the solid part, tests of their swelling ability are proposed. Thus, a solid sample of disturbed structure should be powdered in the ball mill, next it should be dampened and formed as the plastic mass – a macroscopic test in the surface rolling should show its cracking at the first or second instant. From such soil we cut off a specimen as for a standard swelling test (previously it should be dried at the temperatures of endothermic maxima, i.e. up to 200 degrees).

13. THE PROPOSED METHOD OF EXAMINATION OF CLAY MINERALS

Application of the method of swelling ability test, given in the author's earlier works [9], [6], was proposed as method of determining the content of illite and smectite minerals. It has been proved so far that it is just these minerals that are responsible for moisture changes, extreme strength parameters and processes of petrification and maximum moisturizing.

Tests were carried out on the material taken from the deposit of different breakups, and samples were grouped in accordance with the diameter of sieve meshes. With the method of successive trials, it has been found that the most stable and real results are obtained by conducting the tests in the following way:

• the material undergoes a preliminary air-drying in the case of water content so that in can be sifted through the sieve of $\phi = 0.76$ mm,

• the material thus prepared is subjected to moisture content near to the plasticity limit (during the trial of roller bursts at the first or second instant) and is subjected to working (just like a typical "dough"),

• forming the material into the "cake"-like shape of 10 mm in height,

• then, samples with the diameter of ϕ = 50 mm and 65 mm and the height of 10 mm and 20 mm are cut by means of a ring,

• the samples thus prepared are weighed and dried in a drier at a temperature of 200 °C for the period from two hours until reaching constant weight,

• after drying and cooling the samples are weighed to determine their water content,

• the samples are subjected to the examination of swelling minerals in the apparatus testing unbounded swelling,

• after swelling has been defined the final moisture is determined.

The method of examination of clay minerals (smectite and illite) is presented in figure 7.

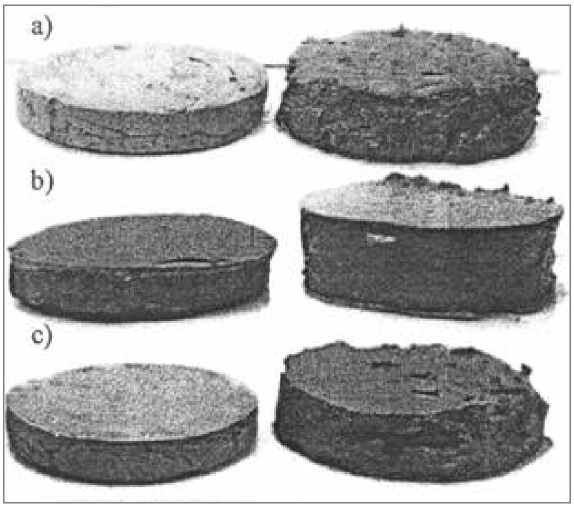


Fig. 7. Examples of soil samples with smectite and illite minerals after the investigation

14. CONCLUSIONS

The author tried to determine numerical values of geotechnical parameters of flysch formations formed at the moment of occurrence of the limit state of the landslides under study. Computer simulations were used, assuming the limit equilibrium state of the slope. The worst numerical values determined of the strength parameters, proved by the proposed additional tests, can be applied to calculations of stability and design of protections. The costs of the proposed methods of determination of necessary parameters for calculating the stability and protection of slopes are much lower than the costs of standard test methods.

A way of drainage of precipitation and thawing waters, efficiency of devices or difficult service often cause slope falls. The waters infiltrating into the coluvium mass influence the increase of moisture content and select the soil grains, wash out their small fractions and soluble minerals from the bottom of coluvium zone.

Many researchers think that each landslide should be considered independently because of its complex geological structure, hydrogeological conditions and variable geotechnical properties. Moreover, even in the case of simple landslides it is difficult to determine proper reasons of the landslide formation – it is a typical example of multicomponent analysis.

Weathered marls like flysch weathering occurring in the landslide sliding surfaces and the clay soils reveal the threshold moistures in condition of loss of their strength. From the tests performed we could state that the existence of clay minerals (illite and smectite) was a reason of this common characteristic.

The proposed method of testing volume changes in rock eluvia and clays with the so-called hidden swelling parameter allows us to describe the real state of these media and determine swelling registered under in situ conditions, and not registered with the conventional methods.

Three categories of difficulty were proposed in order to determine the minimum requirements for the test range for the swelling media and operating data allowing us to precise a degree of importance.

Determination of swelling in marl eluvia makes it possible to test the physico-chemical processes in the eluvium during its transition into cohesive soil. The tests of swelling give an additional parameter for identification of weathering ability.

Application of the method of swelling ability test was proposed for determining the content of illite and smectite minerals. These minerals are responsible for moisture changes, extreme strength parameters and processes of petrification and maximum moisturizing.

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