The Influence changes of moisture soils and rocks on the formation of landslides

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Abstract

Landslide and mud avalanches have been analysed in the paper. It is confirmed that a fundamental number of the slides occur in the weathered rock of the Carpathian Flysch. Rocks occurring in this area are of the sea origin and 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. The results of varied 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 present methodology proposals for researching these rocks. These investigations indicate how genetic and climatic variations occurring in other regions influence the strength parameters of the rocks. Some new research directions are possible owing to the methods applied. For example computer simulations performed with the program GEO-SLOPE are really helpful. Their aim is to search for the strength parameters on the landslide failure planes for which the coefficient of safety is close to one.

1. Introduction

A fundamental number of the landslides in one of the provinces in the south of Poland occur in weathered rock of the Carpathian Flysch. These formations are of the sea origin and, form a horizontal laminar system. Sedimentation of soils of marine origin, forming soft rocks is a very complicated processs. Such formations consisting of menilite shales, shale clays, sandstones, marls, limestones and their weathered products are treated as clayey mixtures (Jaremski, 1997; Zabuski and Thiel and Bober, 1999). These materials, especially when weathered, are characterized by unusual sensitivity to changes of water content strongly influencing their strength parameters.

A landslide characteristic of the area results from the geological structure, i.e. corrugated and deeply cracked laminar basal layers and the mineralogy, of the alternate sandstones and shales, which are extremely sensitive to changes of water content. As well, the internal friction angle is low. Landslide type is dependent on a ratio of the morphological form to the subsoil movements and its lithological formation (Bober and Zabuski, 1993).

A forecast of landslide dynamics and knowledge about the potential slide surface along which soil mass movement can be observed are also of a great importance.

In the landslide areas there are also fault and dislocation zones (Ksiazkiewicz, 1972). The mudstone series of flysch formations when occurring just below the surface or on the surface, especially on steeper hills, form landslide areas which can be dangerous. Unidentified zones of artesian water supply and temporary groundwater pressure increases after drought periods, increase tendencies for the formation of new landslides.

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This paper uses tests of representative flysch outcrops and analyses of chemical and mineralogical composition as well as their comparison with geotechnical parameters of sedimentary rocks occurring in other regions of the world (Bozinovic, 1993; Jaremski, 1997; Oteo and Sola, 1993). These parameters are comparable for similar water content. The rocks are of a marine origin and have a common diagenesis. Their mineralogical and chemical composition are similar and the changes are a result of qualitative and quantitative differences in their detritic material. The results of many different tests, for example microstructural tests done with a SEM, diffractometry and X-ray fluorescence, tests in situ and laboratory tests of prepared samples, can be helpful in preparation of test methods related to these rocks. The tests allow the determination of the influence of genetic or climate features. They should enable the determination of the best numerical values for geotechnical parameters (Jaremski, 1994b, 1997). These values can be treated as basic data for the determination of stability and for landslide protection design. The influence of particular, unique hydrogeological conditions occurring at the test area are also considered. While calculating stability, there are often difficulties in determining the ground-water conditions. Observation of the underground water level, especially water filtration and artesian water sources, seem to be very helpful. Such observation allows the determination of a preliminary phase of the landslide failure, a phase of catastrophic displacements, a phase of decaying displacements and establishment a time of no landslide movement.

Soft rock weathering takes place in soils subjected to permanent structural changes under the influence of external factors. It means that the landslide analyses can give often unreliable results; with some derived strength values too low (Jaremski, 1993a).

Modern geology tends to more and more precise forecasts of soil mass reactions to the results of human activity (Jaremski 2012). Landslide analysis methods have been described for examples with a stable structure of solid parts (Hancox and Perrin, 1994; Watts and Macfarlane, 1996).

Many products can form from the complex flysch formations. They are represented by weathering of diverse mineralogical structures and the content of minerals belonging to smectite, illite and kaolinite clay groups. Where the clayey fraction essentially consists of montmorillonite and illite, weathering is very sensitive to changes of water content, which in turn strongly influences the strength parameters. In soft rock weathering the water taking part in chemical reactions plays an important role. First of all, it causes changes at the microstructural level. Changes of weather conditions, which cause wetting or drying of the weathered materials, influence the water content and determine constraints on reconstruction at the microstructural level. Next, as these phenomena increase, microstructural changes can be observed and gaps or voids between the rocks chips become filled. When drying takes place, loss of water causes partial destruction of the water-colloidal constraints.

A stress state at any point in the weathered layer under variable loading depends on an actual loading state at a given point and the time of its action and physical and chemical processes occurring in both weathered material and the rock mass.

2. The Proposed Complementary Tests Methods

Microstructure test

From analyses of the causes of formation or periodic activation of landslides (occurring as mass movements), it appears that the landslides are caused by changes of water content of the weathered material in the culluvium. These water content changes usually takes place between the weathered material and the unweathered flysch rock.

It seems to be necessary to perform tests leading to the description of the changes of the fatigue parameters of weathered rock and the determination of their worst numerical strength values under the maximum possible moisture content, taking into account the occurring periodical self-hardening of the weathered material caused by cohesion reconstruction.

The subsoil occurring in the south of Poland is very complicated, so it is necessary to search for new test methods.

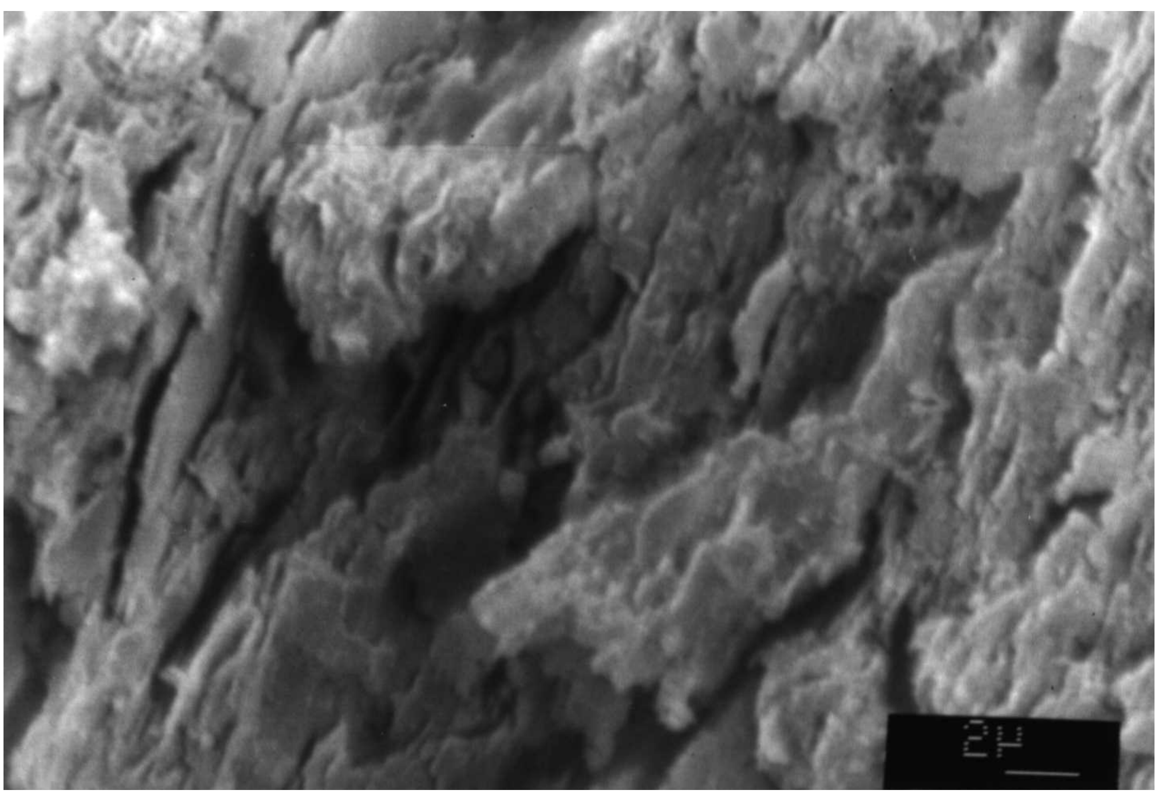
For the case of the complicated geological structure, hydrogeological conditions and variable geotechnical properties, many research workers think that each landslide should be considered separately. Moreover, even when a landslide is not complex, many tests are necessary and it is not easy to determine suitable reasons for the landslide formation – it is a typical example of a multicomponent analysis.

With the proposed tests, it is possible to identify chemical and mineralogical structures of the weathered material, and the mechanical parameters for the threshold humidity under which the weathered reaches its minimum strength.

Strength parameters of the weathered flysch formations are dependent on the mineralogical structure and, fineness and degree of plasticity. Mineralogical structure strongly influences the degree of plasticity, swelling ability and shrinkage ability. Weatherings where the clayey fraction in its basic part consists of smectite and illite is extremely sensitive to humidity changes, influencing the strength parameters.

Thus, it is suggested to identify the illite minerals by tests using a scanning microscope, analyses of composition by X-ray fluorescence and diffractometry and tests of swelling ability using the method proposed by Jaremski, (1993a, 2010). The results for the most common flysch rocks of the tested area are shown in Figure 1.

The tests performed by such methods allow the determination of the fractions of particular minerals in the tested weathered material for which strength tests are performed. The obtained results are comparable with values of the strength parameters for weathered materials of marine origin occurring in other regions of the world (Jaremski, 1997).



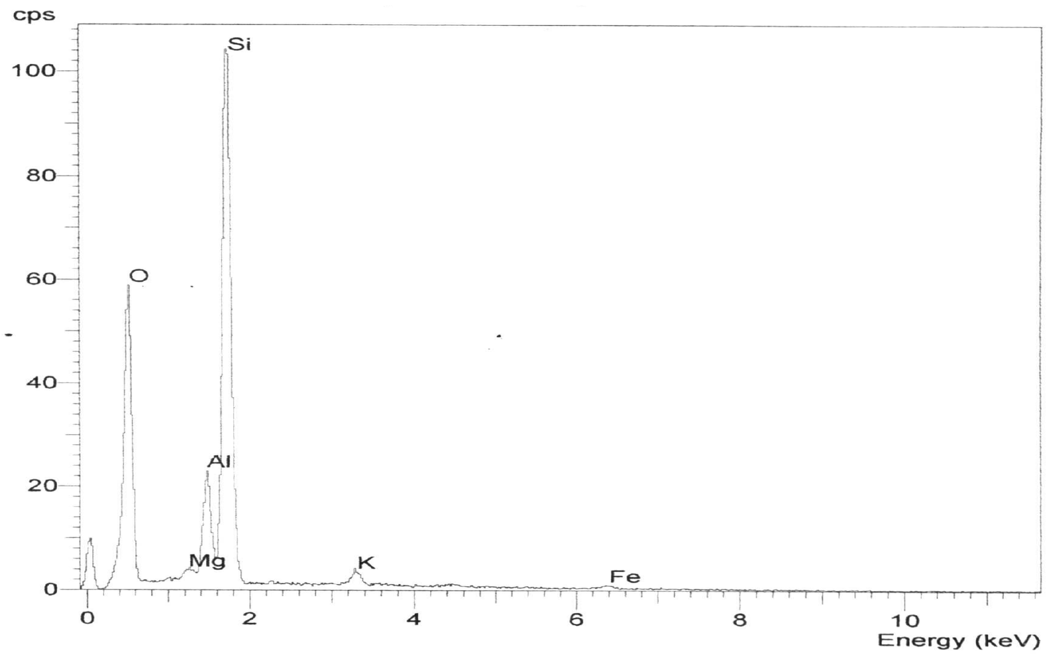


Figure 1: Microstructure surface of shale clays observed in SEM and analysis of their chemical composition with use of X-ray fluorescence (Oxford LINK ISIS-EDS).

The Proposed Strength Parameters Tests

In order to determine the stability of a slope or for the design application of coluvia a purposes of reinforced soilbank, it is necessary to perform basic laboratory tests. They allow the observatione of the processes caused by moisture changes, such as the effects of cohesion reconstruction, recrystallisation, and the effects of changes of chemical and mineralogical compositions (Jaremski, 1994a, 1994b).

Laboratory tests for determining the internal friction angle and cohesion should use samples with undisturbed structure and moisture, obtained in situ or from exploratory bore-holes in the areas where a preliminary phase of mass movement occurs. Also prepared samples of standard moisture are recommended (Chandler, 1969; Jaremski, 1993a, 2000).For laboratory tests, the GDS Instruments Ltd. triaxial apparatus system is very good.

For more precise determination of strength parameters, tests in situ are recommended to verify the other strength parameter values. Such strength parameters can be precisely determined, with the soil-wedge extrusion method presented in a previous papers by Jaremski, (1993a).

3. Computer-Aided Determination of the Strength Parameters

Standard tests of strength parameters for flysch rocks and their weathered materials are very expensive.

The author has been engaged in determination of the strength parameters for weathered marl for many years. The tests performed allow qualification of these weathered materials as a foundation in one of the cities in southern Poland where marl weathering has occurred under a humus layer and the correct properties had not been applied to foundations (Jaremski, 1991, 1993b, 1994a, 1994c). Foundations on piles or on introduced fill soil instead of the weathered material was an alternative solution.

All the slope stability calculation methods lead to calculations of the most unfavourable factors of safety for the assumed slide surfaces.

The computer-aided calculations are very precise, but introduction of incorrect strength parameters gives results directly dependent on the assumed values. The author suggests an extension of computer simulation which could be used especially at the preliminary phase of the landslide study, by introducing the strength parameters from the model tests existing landslides for which their failure planes are applied and for which the strength parameters occurring in the soil mass at the existing limit state are calculated. The determined strength parameters, also from the slopes tested at the preliminary stage for the simulated planes of the landslides, should be compared with strength tests performed under the actual conditions in the landslide area.

Some new directions for research works are possible due to the methods applied. For example computer simulations performed with the program GEO-SLOPE are really helpful. The aim is to search for the strength parameters on the represented planes of the landslide for which the coefficient of safety is close to one.

Simulation calculations were perfomed for the most unfavourable geotechnical parameters usinge the computer program SLOPE/W DEFINE Version 5.13 made by GEO-SLOPE International Ltd. The program allows one to assume many possible failure planes for the landslide. It was possible to determine numerical values of the strength parameters for the limit state. The results are shown in Figures 2 and 3.

Because of the use of computer analysis of slope stability, with the assumption that the limit state takes place, information about numerical values of the strength parameters existing at the moment of the landslide formation are obtained. Next, the performed simulation was applied to analyse the occurring symptoms such as water effusion, periodical dislocation of the surface, demonstrating the preliminary landslide phase , and so on.

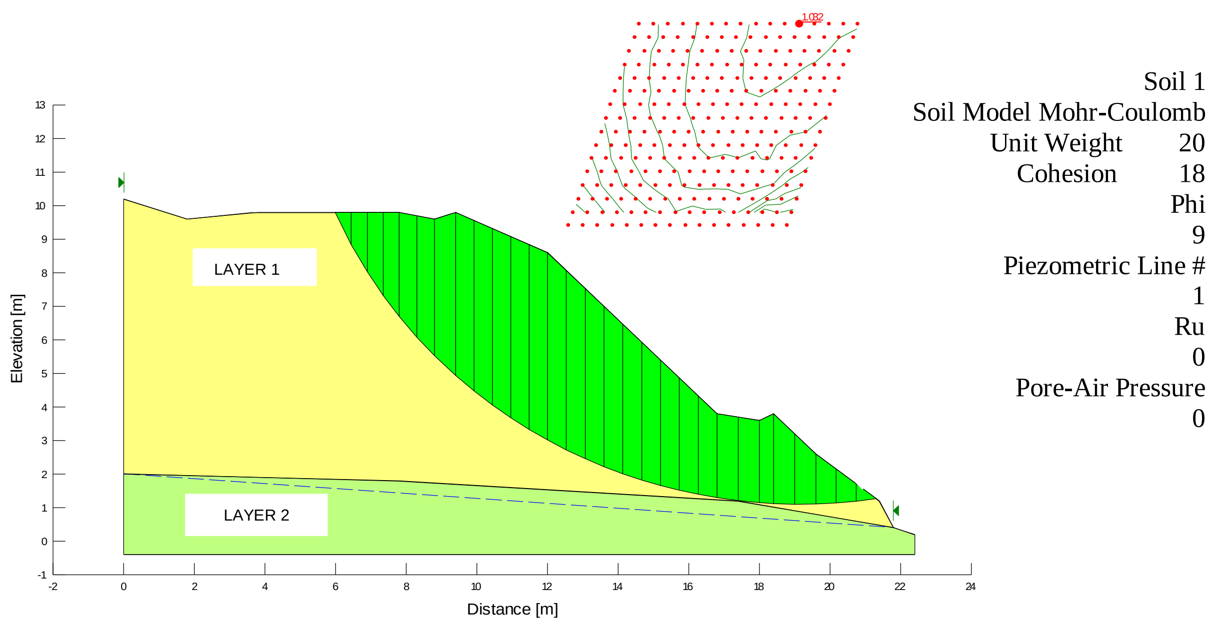


Figure 2: The example printout of calculations results from SLOPE/W DEFINE Version 5.13 program.

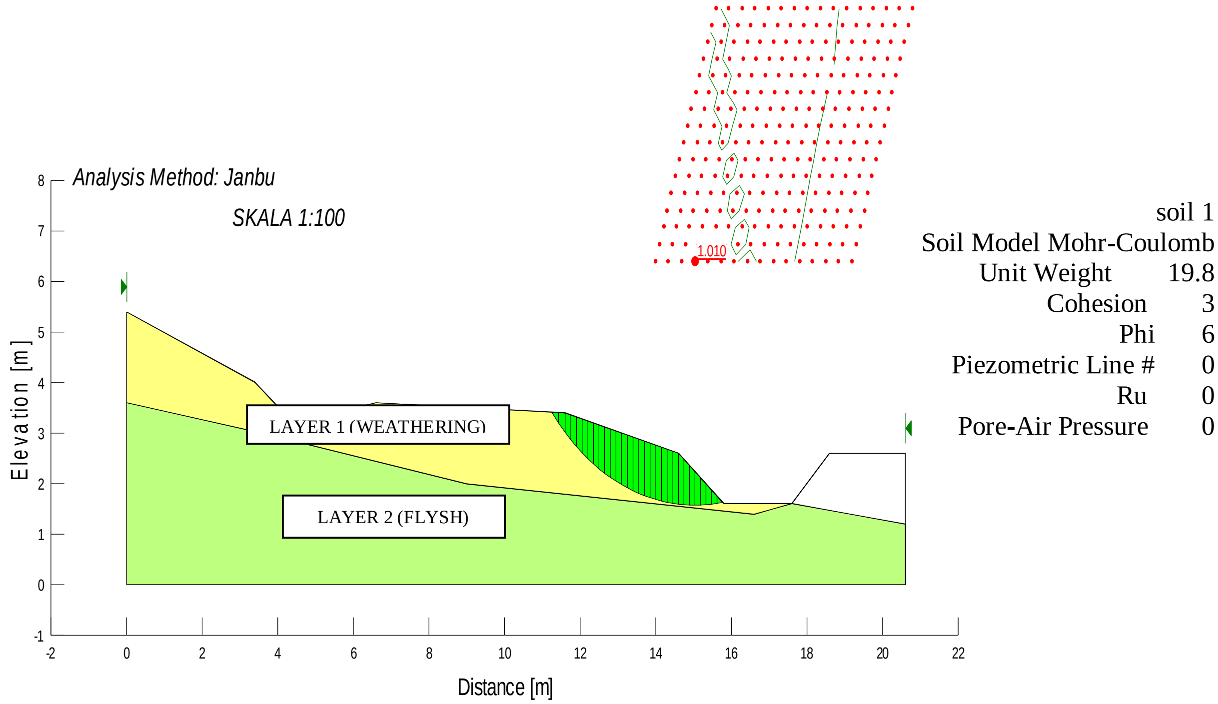


Figure 3: The example printout of calculations results from SLOPE/W DEFINE Version 5.13 program.

4. The Proposed Test methods for weathered Silt

Weathering occurring in the considered area and formed from the rock matrix (of some shales, sandston), which can qualify as silts, is very complicated and, their behaviour can be variable.

The strength properties of weathered silts are close to those of loess. The most important difficulty is in obtaining undisturbed samples (Kronieger, 1990). Water content changes in the soils are caused by changes in weather conditions, variable underground waters levels, and waters coming from thaws and itense precipitations. These sometimes cause soil changes from semi-compact to the plastic state, or even to slightly plastic silts which are very sensitive to changes of water content. Under a low water content they demonstrate high strength parameter value. From the testing it appears that under threshold moisture (about 24 %) silts lose their load capacity and their internal friction angle and cohesion are close to zero.

Tests of prepared samples are very important for the analysis of mass movements in weathered silts and they allow the development of landslide protection works. Especially, the methods increasing and stabilizing the water content of weathered silt and in the reconstruction of cohesion are preferred. For testing the physical and chemical processes leading to cohesion reconstruction, samples of different moisture content were prepared. The samples were subjected to shearing in a standard direct shearing device and the rate or time was taken into account (after 1,2,3,5 and more days from moment of wetting).

In the case of silts the illite minerals fraction must also be determined- during their transition from a typical silt at the threshold water content to a cohesive soil. The importance of that problem is proved by testing the microstructure with a scanning microscope, tests of the endothermic maximum with use of derivatographic analysis, and tests of chemical composition with use of fluorescence – they prove occurrence of illite and smectite groups (Jaremski, 2000).

Based on experiences from the previous tests with sample preparation and on consolidation tests, it was possible to start testing suitable samples with variable moisture content in a typical cylinder used for obtaining undisturbed samples. Some samples were prepared in a Proctor apparatus and were air dried. These samples were subjected to compression strength testing - in a machine (MEGA 3-3000-100 made by FORM+TEST), to determine their compressive strength (from 500 kPa to 1670 kPa). These results are especially important for determination of the strength parameters of soils on slope, to be stabilised.

The shear planes of the samples are tested with a laser profilograph (TALYSKAN 150 made by TALOR-HOPSON) and the separated fractal dimensions on these planes are determined by a French program MAUNTAIN-MAP.

In the author’s opinion, application of a profilograph for tests of flysch formations gives new and promising possibilities.

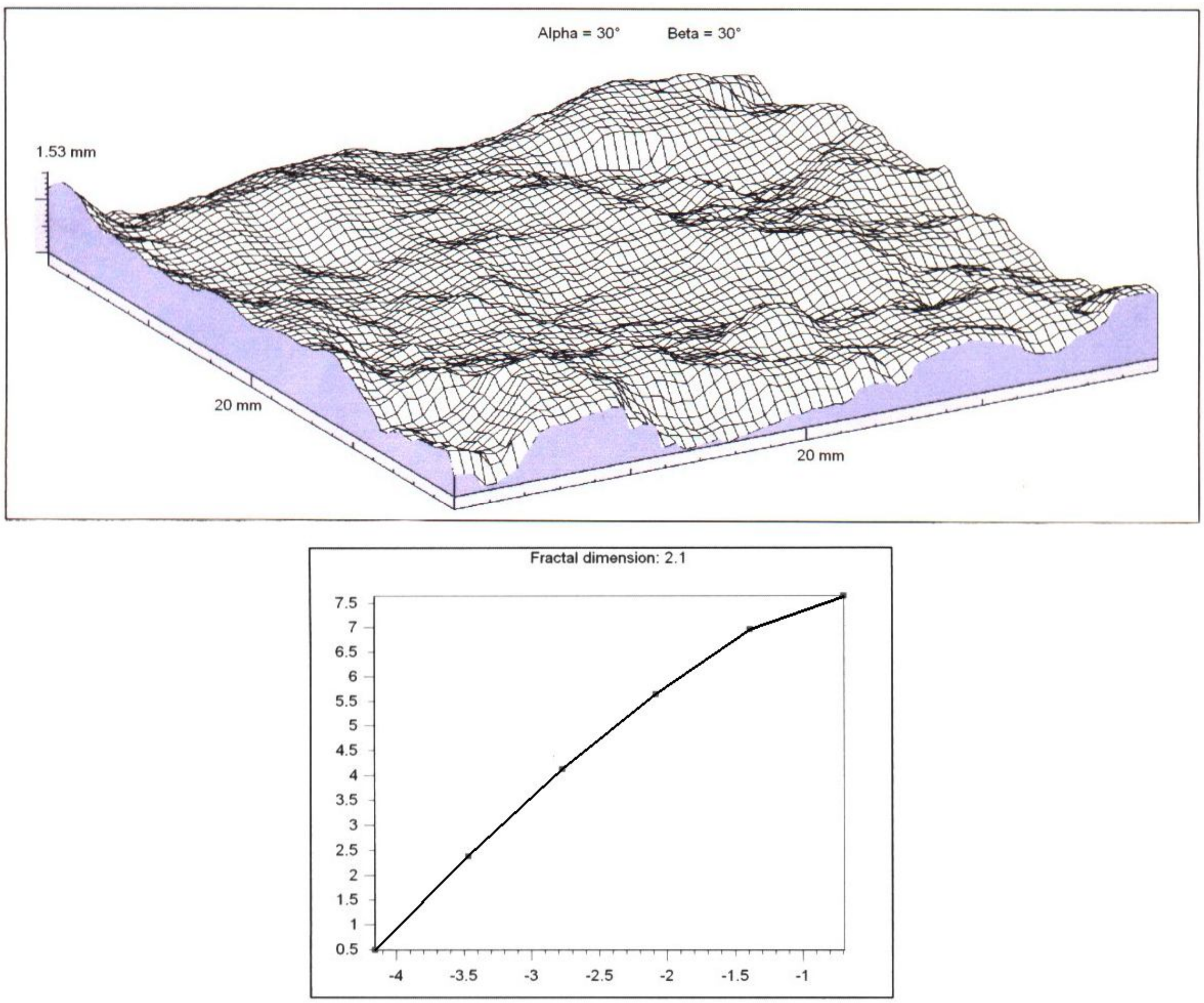


Figure 4: The printout of shear plane mapping and the received fractal dimension of that plane made with a laser profilograph for a sample of 1670 kPa crushing strength.

5. Summary and Conclusions

1. From analyses of chemical and mineralogical compositions and the strength parameters of flysch formations occurring in different regions of the world, it appears that the strength parameters are comparable.
2. Physical and chemical processes occurring during formation of sediments in their basins are similar. They are rocks of marine origin and of common diagenesis. Their chemical and mineralogical compositions are similar and the noted changes are a result of a diversified tetragenic material.
3. The author has analysed the results of many different tests and in his opinion the tests described can be regarded as a proposal of test methods to be applied to these rocks.
4. The paper includes numerical values of geotechnical parameters for the flysch formation which- occur at the moment that limit state occurs in the landslides. Computer simulations were used on the assumption of the slope being limit state equilibrium.
5. The proposed methods for obtaining the necessary parameters for stability calculations and for slope stabilisation are cheaper than standard test methods.
6. The flysch areas, where the landslides are found to be just at the slopes angle of inclination degrees are very complex. Thus, it is necessary to search for new test methods. Even preliminary information about the landslides lead to the conclusion that tests tending to the determination of the most unfavourable strength properties must be developed. The proposed methods can be useful while analysing the preliminary landslide phase and they allow the determination of the formation of a dangerous landslide caused by human activities changing the slope.

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