Causes of Instability in Plio-Quaternary Sediments, Near Zagreb - Croatia

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Abstract

The area of Vukomericke gorice, situated in the south peripheral region of the Croatian capital Zagreb, is formed of plio-quaternary sediments consisting of inter-layers of sands, mould, clay and gravel. In some parts, they are characterized by limonite concretions. In clays, remains of coal and peat are also found. These materials occur in the form of thin layers.

The litho-facial differentiation implies to the deposition of coarse-grained sediments the margins of the sedimentary basin, in the form of banks on the shore or directly by the water side, while the finer sediments are deposited in deeper parts of the basin. Engineering geological, hydro-geological and morphological factors, in combination with mechanical and permeability characteristics of soil layers, and structure-tectonic correlations represent the medium to be very submissive to the occurrences of instability.

The region is characterized by a series of landslides and creep areas. The article, describes the geotechnical medium, causes and mechanisms of sliding/ instability and the applicable methods of improvement.

Introduction

The Republic of Croatia belongs geographically to the south-east European region. Geologically, two geo-tectonic units can be generally outlined - Pannonian region in the north and Dynaric region in the south. Pannonian region is characterised with predominantly flattened terrain, built of unconsolidated and soft rocks of Neogene and Quaternary era, with isolated mountains built of Palaeozoic and Mesozoic rocks. In the South, mountains and coastal parts of Dynarides is built predominantly of carbonate rocks of Mesozoic era, rarely of Palaeozoic clastic rocks and of Palaeogene flysch (Fig. 1).

Mildly hilly, picturesque region of Vukomericke gorice, positioned south from Zagreb capital, belongs to the farthest south-west part of the Pannonian Tertiary basin, built of Plio-quaternary deposits (PL2,3Q1).

Terrain morphology and exchange of units with different engineering geological and hydro-geological properties, combined with structural-tectonic relations, is in great extent favourable to the evolution of instabilities on the slopes of Vukomericke gorice. The appearances of instabilities, such as landslides or creeps happen often in the zones of infrastructure objects and settlements, where the activation of instabilities is contributed by human factor also.

Based on the data from the interpretation of the Basic Geological Map of the Republic of Croatia, the general overview of geology and structural-tectonic relations in the region of Vukomericke gorice is given. Gathered data from the various geotechnical investigations of a series of landslides from the region of Vukomericke gorice, show that the geotechnical conditions of the soil as well as the causes and the mechanisms of land slide are generally of similar character on all the studied landslides. On the example of one such landslide, the display of engineering geological, hydrogeological, geotechnical

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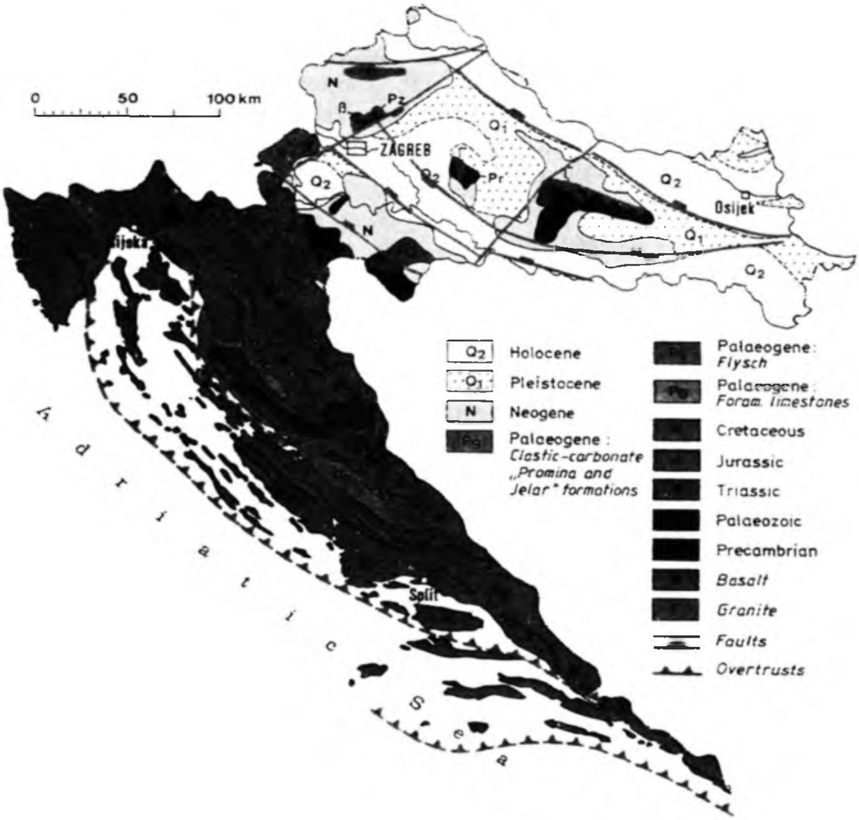

Fig. 1: Geological map of the Republic of Croatia.

conditions and instability of slopes is given, with the review of possible landslide remediation measures.

Geology of the wider region of Vukomericke gorice

Geology

Region of Vukomericke gorice is elaborated on the Basic Geological Map of the Republic of Croatia, S 1:100000, sheets Sisak (M. Pikija, 1987.) and Zagreb (K. Sikic, O. Basch, A. Simunic, 1979.). According to the interpreters for those sheets, the region of Vukomericke gorice is built of Plioquaternary deposits from middle and upper Pliocene to lower Pleistocene (Pl2,3Q1). These are fresh water fluvio-glacial sediments, which lie discordantly on the older Tertiary deposits. Based on the lithological and faunal characteristics, they belong to the deposits known in literature as "paludinski deposits". Lithologically, "paludinski deposits" are represented by the sands, gravels, clays, silts, rarely by sandstones and conglomerates and in individual parts the beds of lignite and pit were found. The colour of these sediments depends on the content of limonite or organic substance. Sands are of various nuances of grey, brown, greenish grey, bluish grey and yellowish grey colour. They are sometimes laminated. Other structures noticed within the deposits are bedding, inclined and crossed beddings. Strong limonitization in the form of coatings, inter-beds of limonite concretions, crusting and sandstones with limonite cement, are manifested in the individual parts of these deposits. By the granulometric analyses, the fine grained Plio-quaternary sediments are determined as fine to coarse grained sands,

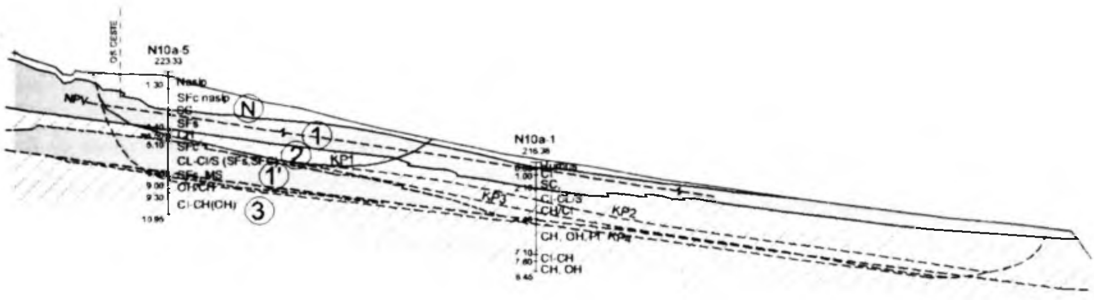

Fig. 2 : Engineering geological/ geotechnical cross-section of soil

gravelly sands, silty and clayey sands, silts, sandy and clayey-sandy silts, clays, silty and sandy clays. Gravels usually are well rounded class. The pebbles are predominantly of coloured quartz, usually up to 1 cm in diameter. Sandstones are usually in the forms of thin irregular inter-beds within the sands and they are usually limonitized. Cement is calcite/ carbonate rich. Fine grained conglomerates are present locally.

Such litho-facial differentiation leads to the conclusion that these deposits evolved on the margins of paleo-lakes. While the coarse grained sediments were deposited in the immediate vicinity of shores and partially probably on the land, and the fine grained sediments were deposited in the deep waters. The thickness of "paludinski deposits" is estimated to be 200-400 m.

Structure and Tectonic relations

According to the structural-tectonic districts division, the region of Vukomericke gorice belongs to structural unit Vukomericke gorice within the higher tectonic unit of so called Sava tertiary basin, on the ending southwest part of the Pannonian basin. Region of Vukomericke gorice represents the positive form with the dynaric strike that some investigators, due to the placement of "paludinski deposits" consider as the anticline. It is sure that from the beginning of the Quaternary era, this region represented the deepest part of the River Sava tertiary basin on the north-west, where in the residual fresh water depressions the "paludinski deposits" were deposited: clays, silts, sands, gravels and coal in exchange. The evolution of the positive structure form was conditioned by faults of the dynaric strike, which lie to the north-west and south-east of that form. It took place after the deposition of the mentioned sediments i.e. during the Quaternary era. In structural-tectonic sense, Vukomericke gorice generally show the form closest to the horst. Longitudinal faults with dynaric strike (NW-SE) are dominant, especially in the north-eastern part. Along those faults horst sinks step -like towards the River Sava depression. Transversal faults cross the above mentioned ones and along them the horizontal movements of blocks took place.

Landslides on the slopes of vukomericke gorice

In the region Vukomericke gorice that is built of Plio-quaternary sediments (Pl2,3Q1), a series of landslides that endanger the existing roads and/or housing and economic structures were investigated. The significant geotechnical data was acquired for the mentioned region, and all the gathered data and knowledge from the conducted investigations, as well as from the implemented remediation measures, are the good base and guidelines for studying and remediation of the new landslides and unstable areas.

The majority of landslides emerge on the mildly (10-17°) inclined parts of slopes. It is determined that their lithology is the sediment complex represented by the inter-layering of the cohesive (clays and silts) and cohesion less (mainly sands) layers of soil differentiated vertically and laterally. On the vast number of those landslides the layers/ inter-beds or irregular lenses of coal and peat were registered. Hydro-geologically such complex represents the interlayering of permeable and impermeable layers of soil. The layers are mostly inclined (dip slopes) in the same direction as the slope, with the same or lower inclination angle. More permeable, mostly sandy layers and layers of coal and pit have often limited strike either because of the sedimentation conditions or because of the tectonic disturbance of the previous sediment layers. In hydro-geologically unfavourable periods of the year, the permeable layers can be saturated with groundwater. Depending on the layer thickness, the significant hydrostatic pressures can be developed, which have unfavourable effect on the slope stability. Concentration of the emerged landslides is in the zones of roads and settlements, where the problem of unsolved drainage of the surface and waste waters is present. The inflow of the surface waters from the roads or the precipitation and waste waters from housings directly into the ground increases the water saturation degree of soil and it is often the cause for initiating the landslide. It has been shown that the sliding planes are activated along one or more planes of lower shear strength of clayey layers on the contact with the water bearing layers of sand, coal or peat.

Characteristic engineering geological and geotechnical model of typical landslide

Engineering geological and geotechnical model of the typical landslide from the region of Vukomericke gorice, presented in Fig. 2 describes majority of the landslides of this region

From the cross-section (Fig. 2) it is visible that the landslide developed on the mildly inclined slope, with the average inclination of 10° and that it directly endangers the existing road. On the downhill part the road is on the embankment and on its uphill parts, it is in the cutting or on the surface of the slope. The surface road drainage is not constructed, so the surface water flow into the embankment along the road and further down the slope. Besides that in this case the drainage of the waste water from the houses and commercial buildings, goes directly into the landslide area. Tensile crack that has the tendencies of widening, accompanied with the road subsidence, is clearly visible on the road. Tensile cracks on the road are the forerunners of the active sliding process.

Characteristic cross-section given in Fig. 2 gives the insight in the complex structure of Plio-quaternary deposits. The slope is built of layers or zones of material with different engineering geological, hydrogeological and geomechanical characteristics in exchange. Layer inclination is mostly smaller or accompanies the slope inclination. Clayey zones (marks 2 and 3 on the cross-section) are built of clays with distinctly increased plasticity indexes, of high and very high up to extreme high plasticity. Clays contain non permanent interbeds and irregular lenses of organic clays and pit. Due to the high plasticity indexes (and the fact that clayey material with higher indexes has lower shear strength), clayey zones have high potential to be failure zones. It has been shown that the residual values of the shear strength parameters of those clays are c=0, ?=9-11°. Sandy material zones (marks 1 and 1' on the cross-section) are represented with sands or sands with excessive content of clays and silts and sands bounded by clays or with sandy clays with the interbeds of sands and sands with excessive content of clays and silts. These deposits can laterally significantly differ according to the granulometry. On the characteristic cross-section (Fig. 2) sandy zone 1 spreads from the surface. Below that the clayey zone 2 and below that there is the sandy zone 1',

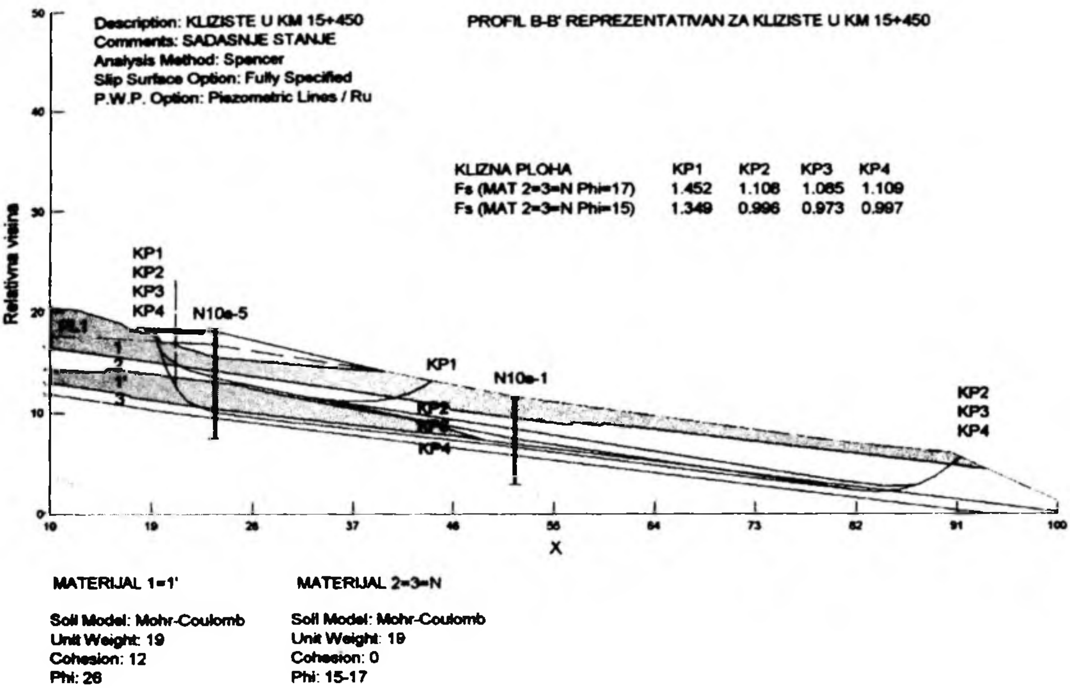

Fig. 3 : Stability analyses for the existing state

which is in the lower part of the slope, inclined into the clayey zone 2 and into the clayey zone 3 that lies in the footwall of the zone 1'. It has been seen that the wedging out of the sandy zones downhill is often so in the lower parts of slope, where they are closed with clayey deposits. This creates the conditions for sub-artesian aquifers and increased hydrostatic pressures in the lower part of the slope. Monitoring of the piezometric wells and dug wells in the region shows constant presence of the groundwater in the soil. Mostly high groundwater levels were recorded in extreme conditions with long lasting and intense precipitations. The groundwater level is close to the surface. High pore pressures in the soil are additionally permanently supported by the constant inflow of surface and waste water into the landslide area.

Described characteristic package of Plio-quaternary deposits of Vukomericke gorice, with inter-layered sequence of permeable and impermeable zones, in combination with the groundwater, are ideal conditions for the landslides. Low shear strength parameters of clayey materials combined with the groundwater flow/ uplift pressures, lead to destabilization of the terrain in the form of creep and sliding.

In the initial phases the sliding starts most commonly in the lowest parts of the slope, where the pore pressures on the sliding planes are the highest. After that the sliding advances uphill due to the loss of foothold in the lower parts of the slope. Sliding planes can be formed on multiple levels, according to the expected failure planes along the clayey zones of low shear strength. On the presented cross-section (Fig. 2) the sliding along the planes formed in clayey zones 2 and 3 was presumed, which was confirmed by measurements of inclination.

The results of the stability analyses (carried out by using the program package GEO-SLOPE, program Slope/W) show that the studied slopes are in the state of liable equilibrium (Fs $\approx$ 1) in the state of high piezometric pressures (groundwater level is close to the surface) and with the residual

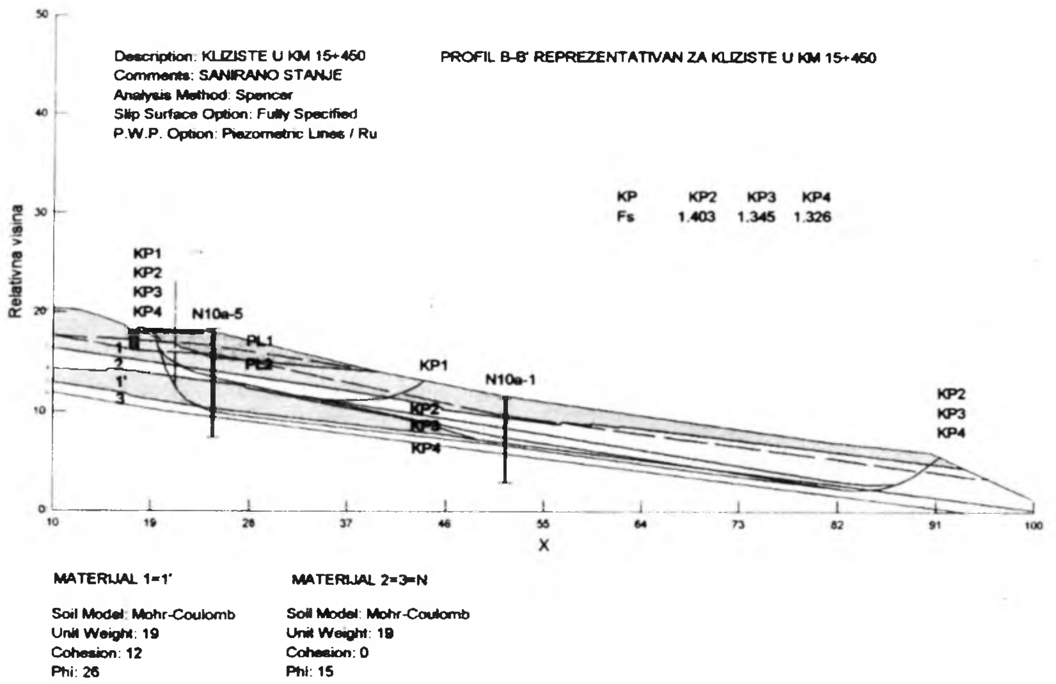

Fig. 4 : Stability analyses - remediation by draining the slope

values of the c and ϕ parameters of high plastic clays. In the concrete case of the geotechnical cross-section from Fig. 2, low safety factor was acquired for the shallower and for the deeper sliding planes, which confirms the presumption of sliding along the sliding planes formed in the shallower or deeper clayey material zone (Fig. 3).

It has been shown that the landslides can in majority be remediated by draining the slope. That is pointed at by stability analyses that analysed the influence of decreasing the piezometric pressures by lowering the piezometric line in the computing model. In the concrete case (Fig. 4), this resulted in improvement of the stability degree in respect to the initially analysed state (Fig. 3), where safety factors of $Fs \geq 1.3$ are considered as the satisfactory effect of drainage.

Review of applicable technical solutions/remediation

Based on the conducted geotechnical investigations on the series of landslides in the region of Vukomericke gorice, the data on an insight of the terrain, lithology, hydrogeological conditions of soil and geomechanical properties of individual layers were acquired, for a qualitative assessment of the causes of sliding and their remediation.

The two main factors influencing the landslides are:

- The natural conditions, represented by the geotechnical properties of the medium (engineering geological, hydro geological, geo-mechanical properties)
- The human factors which in most cases refers to unsolved drainage of surface and waste waters and uncontrolled deposition of material on the unstable parts of the slopes.

In the natural state, the stability factor for destabilization is low (1.0<FoS<1.3) so sometimes even minor changes leads to destabilization of the terrain.

Remediation Measure

For the majority of landslides it has been noticed that the basic remediation measure

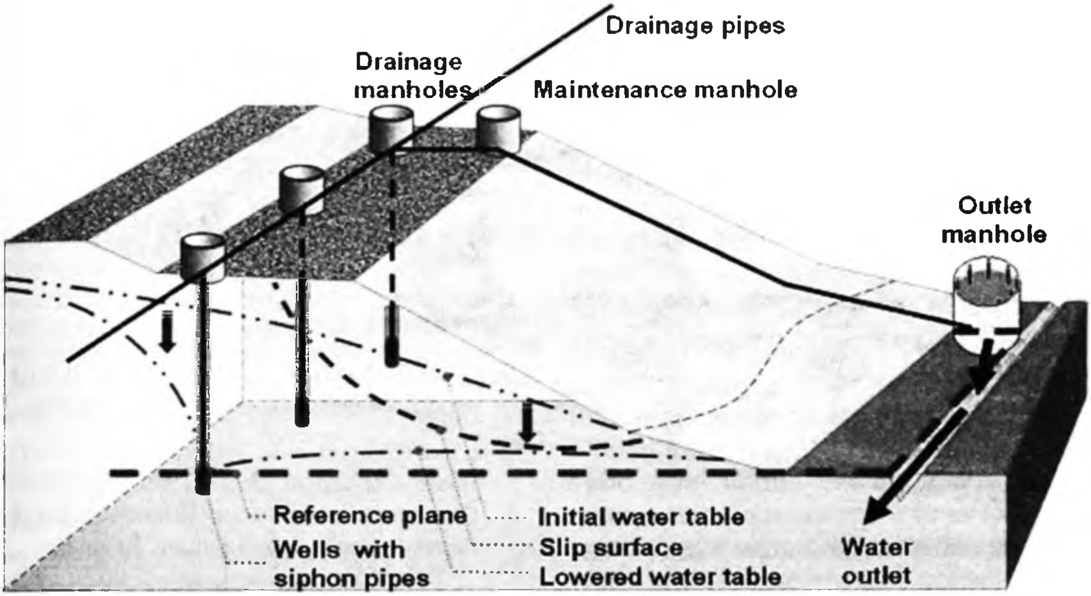

Fig. 5 : Siphon drains arrangement

is draining the slope, rarely in combination with supporting construction, arrangement of surface drainage, fixing and cleaning existing channels, closing the septic tanks and constructing proper sewer systems. Depending on the depth of sliding planes and the depth of permeable materials, that act as natural drainage, along which sliding most often occurs, the appropriate drainage solution is chosen.

Vertical drains

In the case of landslides along shallower planes (up to 4-5 m), the slope drainage could be successfully implemented with vertical drains. The depth of the excavated drains enables sufficient lowering of the piezometric line, which increases the safety factor along the shallower sliding planes. The trench drains of 60 to 120 cm width are constructed with machinery. Depending on the expected quantity of water, spacing between the drains the diameter of drainage pipes are chosen. The excavation is done with bracing (for example KRINGS formwork or similar) for the preservation of excavation from falling, as well as for the protection of workers. If the terrain conditions allow, it is sometimes possible to construct partly the drains with gentle slopes and the rest of the excavation up to the drain bottom with bracings. After the excavation, a layer of thin concrete is laid on the bottom of the drain and then the drainage pipe is installed with the protective geotextile layer or it is placed in the layer of sand. The gravelly drainage material is then carefully filled up and the impermeable clayey plug with a thickness of about 50 cm is laid on the top.

Trench drains: In the case of instability along deeper sliding planes, the slope drainage with trench drains are preferred. The construction of deep vertical drains or wells is tough and is not effective. The drilling of horizontal drains is not feasible because of significant drilling length (slopes and layers mostly gently inclined), insufficient efficiency of drains and the complicated construction procedures.

Vacum drains

The latest considerations, related to solutions of drainage along the deeper instability planes, are directed towards the innovative methods of drainage with the vacuum drains. For instabilities up to 10 m depth, the siphon system of drainage is considered the most effective. The system is gravity driven and uses the principle of siphons through the vertical boreholes. The system consists of a series of vertically drilled drainage wells, installed with drainage pipes. Every borehole is covered with drainage shaft. Drainage pipes from the vertical boreholes lead to the gathering/ exit shaft located near the bottom of the slope. Gathered water flows out into the appropriate canals and/or outflow pipes (Fig.5).

In the case of instabilities along deeper sliding planes (> 10 to 40 m) the drainage is solved similar to the earlier mentioned system of vertical drainage boreholes/ wells, equipped with electrical pumps, with drainage shaft at the top. The system is applicable for high discharges of water.

Conclusions

The data acquired from out gone investigations on the landslides in the studied region present a rich fund of geotechnical data that can be suitable for remediation/ solutions in some future landslides or existing ones, but not yet investigated and remediated.

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