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Drainage Tunnels for Halting Landslides

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Abstract:-This research examines the possibility of stabilizing slopes which are sliding with the use of drainage channels. Inside those, draining boreholes are opened which drain the area inside the tunnels contributing substantially to the stability of these areas. We have researched and implemented those measures to a sliding area of Egnatia Highway where the drainage of the area is achieved through the use of the appropriate grid of the drainage boreholes inside the drainage channels. We have monitored their function and came to conclusion: the construction of drainage tunnels on landslide areas, where there is presence of high aquifer within these materials, decline of groundwater level, reduction of pore pressure that these cause, reduce ground movements with a view to stabilizing the region and to restore the balance.

Keywords: Drainage tunnels, drainage boreholes, disturbed materials, aquifer, halting landslides

I. INTRODUCTION

After the extensive description of the geological formations which are present in the area and the presence of surface water and groundwater in these, and their effect on mechanisms activating failures we look into the way in which the implementation of these drainage measures can cause reduction of the pore pressure, increase of the safety factor and inhibition of the ground motions resulting in halting landslide phenomena. Thus, by constructing drainage tunnels and within them opening drainage boreholes we can achieve the drainage of the landslide mass and the simultaneous channeling of the leachate inside the channels and not the drilling of drainage wells which results in channeling removal of the water to the ground surface by pumping, which is the usual practice. The channeling of the water and its removal inside the tunnels is done through uninhibited flow and not through pumping and is implemented when certain conditions are met. These conditions involve:

- Having loose landslide ground materials saturated with water combined with the absence of underlying permeable layer, in which case drainage if the landslide materials is needed for the restoration of the slope stability.
- Having an unconfined aquifer formation in landslide materials and thus presence of impermeable underlying formation.
- Having loose landslide ground materials combined with background of flysch (an alternation of sandstones and siltstones which means permeable and impermeable formations) and limestones (permeable formations) or underlying limestones and overlying flysch.

The results of the research have indicated that we can achieve the drainage of the slope and the stabilizations of the sliding mass at a satisfactory degree. [1]

II. INVESTIGATION DRAINAGE TECHNIQUES

A. The role of water in landslides and drainage as a remedial measure

Each design of a slope is a unique case because of the singularity of the nature of the ground and the geological environment in which the slopes are. But in all cases in order to achieve the prevention of landslides the stability or safety factor need to be estimated, that is the fraction of the forces of resistance to the forces which cause the movement along a possible fracture (Gedney – Weber, 1978). The fracture occurs when the safety factor is <1 while stability occurs when the safety factor is >1 or even better between 1,25 and 1,50. The basic principles of slope design in road construction include, among others, interventions which are aimed at reducing the forces which tend to cause the movement. These forces include, mainly, the gravity forces, because of the weight of the unstable mass and the weight of the water. The simplest way of reducing these forces and thus increasing the endurance of the materials, is by reducing the unstable mass by removing the underground water.

Layers with different natural and mechanical properties, that is alternations of permeable and impermeable formations and zones which are characterized by intense neotectonic activity are highly susceptible to landslide phenomena. In particular the formations of flysch, the neogenes and the clay rocks, because clay is soaked through water and becomes from elastic to viscous mass. Furthermore, when clay is located under permeable or semi-permeable formations, a sliding surface is created following the filtration of water, because of the increase of its placticity, which when it forms a favorable slope it facilitates the landslide of the overlying formations. This slide surface is likened to an imagined surface which separates permeable and impermeable formations. A deciding factor in the occurrence of this phenomenon is water with the saturation of the materials, the creation of hydrostatic pressure and the fluctuation of pore pressure. Inside the ground (in our case inside the disordered materials) the so called overall trends are developed as a result of its own weight and possible external loads. One part of these is received by the solid phase while the rest by the liquid phase. But, while on the one hand air does not receive normal and shear stresses, that is it does not indicate the slightest resistance to compression and shear, water, on the other hand, although it does not indicate the slightest resistance to compression either, it indicates immense resistance to compression (it is, practically considered uncompressed). [6]

In addition, the important role of water is indicated by Coulomb's law:

$T\alpha = c + \sigma' \tan\varphi$ (1.1)

Where in saturated soils the water in the gaps receives an important amount of the overall trends σ resulting in the development of pore pressure, that is trends σ towards all directions. Then the equation becomes:

$T\alpha = c + (\sigma - u) \tan\varphi$ (1.2)

'

In unsaturated soils, because of the presence of compressed air, a neutral trend is not developed and as a result the active trend is equaled with the overall trend.

From all the above we can conclude that the drainage of the area is the most suitable solution for the halting of the landslide phenomena. In particular, by implying τεχνική of the drainage of the area we can achieve the reduction of the pore pressure, the reduction of compressability and as a result the increase of strength and the bearing capacity thus facing the landslide problem.
[6, 9, 10]

B. Selection of the appropriate drainage measures

As stated above most movements of masses are caused mainly because of underground water and the most effective measures not only for the prevention but also for the remediation of most movements are those of underground drainage, in particular, the works which combine surface and underground drainage. These works depend on the type of project which is being constructed. The most common drainage techniques are the installation of horizontal and vertical drains, the drainage and pumped wells, the placing of drainage filters at the base of the slope and the construction of drainage tunnels. In our research we had a proven case of slide surface which meant that we had a safety factor <1. After careful examination of all the conditions and the criteria of the area we conclude in the selection of the most appropriate method of drainage measures.

The removal of underground water in a direct way has a limited field of application as it depends on the various types of ground and the wear and tear of the pumping units and the pipes. An important problem in draining is the flowing of underground water through newly found routes. In those cases the newly found routes give underground water the ability of moving while consuming the minimum hydraulic load. This fact forces the rest of the water mass to be "waiting" for its entrance to these routes, which can cause lowering of the level of the water table which is the intended result. At the same time, it can cause the relocation of the materials of the solid phase, with possible consequences on the stability of the slopes and the surrounding area. In our case we wanted the removal of water to be achieved with the aid of a dense system of pipes in the wider surrounding area of the landslide and through the disturbed section force its level to drop a lot below the bottom of the excavation since we were faced with clay soils. Lowering the level of underground water successfully contributes to the reduction of buoyancy force and thus the increase of the phenomenon weight and the resulting solidification of both the ground layer which is being drained and the underlying layer which carries the additional load from the drainage of the overlying layer. [2, 6]

After careful consideration of all the above we have decided to proceed with the opening of drainage boreholes on the top and the sides of the tunnels, so as to achieve the drainage of the area surrounding the tunnels. Although generally opening drainage boreholes is difficult and cost effective if, on the other hand, these are incorporated in the original project and not implemented as a remedial measure after the construction, they are cost effective. In our case it was also the most effective method since it did not require the additional use of pumping mechanisms, given the seasonal fluctuations of the aquifer, as we will see in the next paragraphs.

C. Construction methodology of the drainage tunnels

The excavation and the temporary supporting of the tunnels will be held by applying the principles and construction methods of the New Australian Tunneling Method – NATM. The excavation is intended to be carried out with the use of mechanical means, except for category III where a limited use of explosives might be required. In that case emphasis should be placed on the planning and implementation of the controlled perimeter blasting techniques, in order to minimize vibrations and disturbance of the surrounding rocks in the sensitive sliding area.

The construction of tunneling sequence will be the following:

- Excavation of the whole section in one phase (head on).
- Placing of the first layer of thick shotcrete with fibers throughout the perimeter of the excavated section, including the reversed bottom (closed ring). On the reversed bottom in particular it is possible to implement all of the measures of direct supporting, that is shotcrete with fibers and the lattice girder so that immediately after the bottom can be recoated to facilitate worksite traffic.
- Placing the lattice girder throughout the perimeter of the excavation including the reversed bottom, if that has not been done during phase 2.
- Placing the second and final layer of thick shotcrete with fibers throughout the perimeter of the excavation including the reversed layer, if that has not been done during phase 2.
- Construction of drainage boreholes on the top and the slopes of the tunnels with the use of a special drill ring. [3]

III. DRAINAGE TUNNELS CONSTRUCTION AREA (SECTION 2.4. EGNATIA HIGHWAY, SECTION A – C.H 6+380 – 7+500)

A. General information

The category of major infrastructure projects comprises all major highways that cross Europe and Egnatia Highway is part of this trans-Europe transportations network. The Egnatia axis crosses all the geological formations and all the geotectonic zones which develop in the area of north Greece. A notable feature is the distinct geotechnical problems (landslide areas) which combined with the intense mountainous terrain further complicate the situation. [1]

One of these is the landslide of Peristeri (Area A΄, from C.H. 6+380 to C.H. 7+500), which is located in the section 2.4 of Egnatia Highway (Arachthos River – Peristeri) and which required immediate addressing of the problem and stabilization, so as to proceed with the construction of Egnatia Highway and to ensure the Highway's stabilization. The area in question is a riverside landslide area by Metsoviticos river which crosses the wider study area and is the most important morphogenetic event of the area.

B. Landslide of Peristeri (Area □', C.H. 6+380-7+500)

B.1 Geological structure and geotectonic framework of the landslide area

More than one factors interact for the occurrence of landslide including the geological substratum and the tectonic of an area combined with the presence of underground water. Our extended area of study includes the formations of the Ionian geotectonic zone and the formations of the geotectonic zone of Pindos which are obduct on the flysch formations of the Ionian zone. Especially the overthrust of the Pindos formations upon the flysch formations of the Ionian zone is the most important incident that characterizes the geological and tectonic structure of the area. According to data from the geological maps of IGME, of the above mentioned overthrust is found in the perimeter of the area under study and as a result the area under study is a "tectonic window". The geotectonic zone of Pindos comprises the formation of flysch and a wide range of limestone and hornstone formations together with magmatic andesitic and cave rocks. The Ionian geotectonic zone which is found in the area of study under the cover of the soil materials comprises flysch formations that include conglomerate lenses with pebbles from the rocks of the geotectonic zone of Pindus. [2]

Our area of study (area A of the Peristeri landslide), is an gradient that is slightly sloping towards the bed of Metsoviticos river and according to the mapping of Egnatia Highway it begins from the exit of tunnel T8 and includes the deep water body on the west of the exit of the existing tunnel in the area. It is a catchment area whose upstream part is arcuate and it is defined, where it meets the bedrock with the recent clastic formations. Upstream of area A, at the natural slope above the National Road, there are two water bodies on the background where it is estimated that a movement towards downstream has taken place in the form of mud flow of disordered materials which originating from upstream. These water bodies supply the disturbed materials with groundwater. (foto 1)

Photo 1: Area A (Fronts of Exit of the Tunnel T8 of Egnatia Highway).

The slopes of the terrain upstream and in the middle section of the catchment area are gentle varying between 10 and 20 degrees. The presence of such gentle slopes on a mountainous zone indicates the accumulation of soft, loose materials, generally saturated, with local upwelling water. Area A is completely covered by disturbed materials originating from the upstream formation of flysch and are an assorted geological material that includes rocky items in a clayey sand mass.

The downstream limit of the catchment area is a morphological lifting with gradients of around 30 degrees towards the side of Metsoviticos river, which is a further indication of the fact that the catchment area originated from landslides. Furthermore, in the area there are levels, plateaus, which are the product of human activities (landscaping for cultivation), while the folded structures of the formations are a characteristic of the area. (photo 2). There are morphological indications of landslides on a smaller scale, near Metsoviticos river, which are affected by the erosion caused by the river. The huge armourstone which is found in the riverside zone protect the bottom of the slope from undercutting. [2]

In area A the following features are found: recent κλαστικοι formations such as scree, materials from the degradation of slopes and materials from landslides. They are mainly sandy clays with increased percentages of sands and grained materials at places. The tectonic formations *(mélange*) which are materials from overthrust are found mainly in the form of sandy clays and grained materials. There are also the materials from the background, that is the rocky formation of flysch which comprises alternations of siltstones, sandstones, breccia and conglomerates. The recent clastic and tectonic formations have different origins but similar natural and mechanical characteristics. They are examined as one formation and are called disordered materials. (photo 3)

Photo 2: Characteristic folded structure along the existing road

Photo 3 : Landslide materials area A.

The main cause of landslide phenomena is both the erosion caused by Metsoviticos river at the bottom of the non-stable slope and the overthrust. Also the deep and, possibly, quite fast erosion of the ridges of the valley combined with the tectonic stress caused mainly by overthrust and the dismemberment of area has caused instabilities, some of which are still active, on both ridges of the valley. The horizontal alignment of the area is shown on map 1. [4, 5, 8 & 9]

Map 1: Horizontal alignment of area A (6 + 380-6 + 700) Section 2.4 of the Egnatia Highway.

B.2 Hydraulic conditions of groundwaters and surface water indications

The estimation of the condition of the underground water was done using open type and Casagrande type piezometers which had been placed in boreholes as the geotechnical study suggested. During the geological mapping surface were observed of water events and so tests of liquid permeability were carried out mainly on disordered materials. All these combined with rainfall data show a sudden increases of the levels inside the most impermeable clay-silty materials, which may be caused by the most siliceous materials where there was some water flow. Based on this data there was an estimation of the level of underground water in the background and a rough estimation of the level on the loose and disordered materials above the background. The highest levels in the piezometric boreholes are between February and June, during and immediately after the high rain season.

The rocky formations of the background are semi-permeable to permeable. The flow of the water changes depending on the type of the formation and is allowed mainly through sandstones or conglomerate while the intervention of siltstone layers (impermeable formation) causes deviation or halting of the flow. The flow of underground water is facilitated by the discontinuities and the possible fractures in the formations. Regardless of the degree of permeability, in the places where the background formation meets the overlaying loose disordered materials there is flow of water. The level in the disordered materials is not even throughout the formation but it varies locally depending on the depth and thickness of the siliceous interventions.

The increased percentage of fine grains in the disordered materials inhibits the flow of underground water while the discontinuity of their mass (presence of boulders and rocks), and the presence of more siliceous layer of material favors the infiltration and the flow of underground water. As a result the filtered water is collected in various places which become underground aquifers whose water increases the pore pressure of the formation and can consequently increase the instability of the slope. According to research done on the site the disordered materials are saturated at places during the rain season since surfacing water concentrations is observed in flat areas in the loose materials. According to the geological study of the area there are two groups of surface water events.

- On the contour level 590÷595m. In this zone there is conglomerates in the flysch formation and a possible fracture and is possibly the zone that supplies the disordered materials with water from the background.
- On the contour level 560 ÷ 565m. In this zone discharges the mass of loose and disordered materials of the etching region by Metsovitiko River (level 590 ÷ 595m to level 560 ÷ 565m). [2]

C. Investigation and construction of deep drainage measures (Drainage tunnels and drainage boreholes therein)

Movements can occur anywhere in the mass of disordered-loose these materials. Based on the above we see that the pore pressure development during the wet season, and after heavy rains, and the corresponding reduction of active stresses in existing or new slide surfaces with unfavorable orientation is responsible for the destabilization of natural slope. All this stood occasion to look at the deep drainage solution with the construction of drainage tunnels and drainage boreholes therein.

For this purpose should be made before any other technical in the area A perimeter drainage ditch upstream of disordered materials. Thereby preventing the infiltration of surface water and the supply of the horizons developed in sliding materials. Then the solution was tested with three drainage tunnels and the analyzes showed that the structure thereof sufficient to stabilize the region regardless of activated possible sliding surface. The tunnel current flowing in the stream at the beginning of the alignment. Generally tunnels designed to drain the area and stopping the supply of underground water from upstream, to the extent possible. By draining the slope crossing achieved humility underground horizon and therefore increase the safety factor against shear failure at acceptable prices. Note that according to the results of geotechnical studies the slopes of the area A is slowly evolving positions instabilities landslide type (creep). To improve the drainage of the slope, the tunnels will be constructed drainage holes length of 200 meters in the fan assembly.

This is the construction of three drainage tunnels of 1A, 2A and 3A. Specifically the 1A, located in the upstream area, 321m length, a depth 20 ÷ 30 from the surface, tilt gradients that ~ 1.5% and the level located above the Metsovitikos river flood level. Drilled into the bedrock of the Ionian flysch zone. (Photo 4) The 2A is opened in the downstream area, 349.50m length, to a depth of 40m in particular abnormal materials (disintegrated background flysch of Ionian zone) and bedrock flysch of Ionian zone in order to achieve the best drainage and stability of the region. The gradients is ~ 4% and the level located above the Metsovitikos river flood level. Then after the relegation control resource pressures and the stability of the region and made the third tunnel (downstream) 3A, 330m length at 42m depth in disordered materials and local meets the siltstone / sandstone background. The gradients of the third tunnel is ~ 4.65%, while the level is located above the Metsovitikos river, flood level. [2]

Photo 4: Drainage tunnel 1A.

The internal effective width of the tunnels ranging from 2.70 to 6m and height 2.50 to 4m in axis, so as to facilitate excavation work, collection of the excavation materials, water controls, construction of temporary and permanent supporting and permanent lining and can they are made from the inside, the drainage holes. They are also "blind or without exit " and contain dimensions well ~ 4,50m x 6,00m, at the end, while their investment (temporary and permanent) made with prefabricated components reinforced concrete. The final height after the final lining of the tunnel does not exceed 2m. (Photos 5 & 6)

Photos 5 and 6: Drainage Tunnel 1A (before and after the final coating).

To drain the surrounding rock mass manufactured drainage holes (boreholes) diameter F76mm from inside the tunnel length of the tunnel ~ 20m by placing each plastic perforated tube minimum internal diameter F50mm. Also provided six (6) drainage holes to drain the soil-rock mass environment, set up radially in the dome by ~ 6m. The area is especially Geotechnical problems such as the stability of the slopes of trenches, which greatly affected by high levels of underground water so be built and other special drainage measures and stabilization particular concern drains construction (construction open coated drainage ditch at the foot of embankment) and the construction of stabilizing walls of gabions.

The area is ongoing geotechnical measurements and observations with a view to controlling the behavior of underground excavation and ambient rock and soil surface in positions relative sensitivity to ensure firstly the stability of the project, and further more safety and satisfactory function of project. Should the supply of the problem area with underground water from upstream and lighten the overall situation to some extent must be first drilled upstream tunnel as starting stabilization area (pre-measure), since in this way prevented, thereby making it safer and opening of the remaining tunnels.

In the area of the riverbank Metsovitikos are blocks of limestone, significant dimensions, which prevent corrosion to some extent. However, the third downstream tunnel, helps to stabilize the area along the river and prevents loss of material by erosion of the river that is destabilizing the entire region. The effectiveness of the solution with three tunnels controlled by systematic measurements in piezometers and inclinometers and accordingly decided to thicken or not the drainage holes. [2]

C.1 **Categories of rock mass and description of the Engineering - Geological Conditions of the tunnels**
Depending on the Engineering - Geological Conditions of the transit area of the tunnel the rock mass is classified into three categories: I, II and III and the temporary retaining measures are as follows:

Preamplifier dome drilling and placement of slight type beams spilling D25/20, 4m length (pieces 24) will be applied per second step advancement ie eight in total, systematically for upstream under 15m and where required for upstream over 15m, for all classes.
Step excavation whole section of the tunnel (A' and B' phase together) CAT. I: 1m, CAT. II & CAT. III: 1.5m-2m.

Front retaining measures implementing fiber-reinforced shotcrete thickness 5cm and fix anchors front D25 - S500s, 12 pieces, 8m long by 4 meters excavation, systematically for upstream under 15m and where required for upstream over 15m, for all categories.

Excavation retaining measures implementing fiber-reinforced shotcrete C25 / 30, KAT. I: static thickness 15cm in one layer, CAT. II: static thickness 10cm in two layers and CAT. III: static thickness 15cm in two layers and two welded steel mesh T188. Inserting metal lattice frame Lattice Girder, type LG115 / 20-30 / 165, per step advancement. **Placing five drainage** holes, 4-10m length (systemic). **Excavation** using mechanical means.

Drainage Tunnel 1A (321m) - Section from CH 0 + 009.50 to CH 0 + 330.50:

Geologically appears conglomerate with medium size of pebbles 5-10 cm and sporadic appearances intercalations of sandstones and siltstones. The state of the rock mass varies from conglomerate coherent sandstone binder and GSI 44-48 to siltstone recommendation binder, less coherent with GSI 36-40. Low upstream (up to 11m). It is the bedrock flysch of the Ionian zone in the orifices area with low upstream and subsequent prevalence of conglomerate. Humidity was also observed in some places small continuous flow on forehead. The category of rock is III.

Drainage Tunnel 2A (349,50m) - Section from CH 0.15 CH 48.15 and 139.65 to 349.65:

Appears siltstone dark grey, strongly sheared, soft pieces of sandstone and maroon colored clay layers. Also met in places unattached exchanges with well bonded conglomerate with medium size pebbles 2-5 cm. The GSI of rock mass ranging from 10 to 15 and the upstream from 5 to 25m. This is wathering background flysch Ionian area, and especially in the first part with low upstream, this soil. Humidity was also observed in some places small continuous flow The category of rock is I.

Section from CH 48.15 to CH 139.65:

Siltstone dark grey color in places strongly sheared, with sandstone pieces and maroon colored clay layers. Also met in places unattached exchanges with well bonded conglomerate with medium size pebbles 2-5 cm. The GSI of rock mass ranging from 15 to 25 and the upstream of 15 to 25m. It is the bedrock of flysch of the Ionian zone and category of rock is II. Humidity is also seen in places with a small continuous flow.

Drainage Tunnel 3A (330m) - Section from CH 24.20 to CH 76.20 and 184.20 to 354.20:

Siltstone dark grey color strongly sheared, soft pieces of sandstone and maroon colored clay layers. Also met in places unattached exchanges with well bonded conglomerate with medium size pebbles 2-5 cm. The GSI of rock mass ranging from 10 to 15 and the upstream from 5 to 25m. This is the background disintegrated flysch of Ionian zone and mainly for soil. The category of rock is I. Humidity is also seen in places small continuous flow.

Section from CH 76.20 to CH 184.20:

Siltstone dark grey color in places strongly sheared with sandstone pieces and maroon colored clay layers. Also met in places unattached exchanges with well bonded conglomerate with medium size pebbles 2-5 cm. The GSI of rock mass ranging from 15 to 25 and the supernatants of 15 to 25m. It is the bedrock of flysch of Ionian zone and category of rock is II. Humidity is also seen in places with a small continuous flow.

C.2 Drainage boreholes (holes) that drain in the drainage tunnels.

For the drainage of the surrounding area of the drainage tunnels, are construted drainage boreholes from the inside of the tunnels. The boreholes also relate to the three drainage tunnels A. Also, while initially projected six (6) drainage holes for the drainage of the surrounding rock mass, arranged radially in the dome by ~ 6m, but after checking the measurements in piezometers and inclinometers in the region and the finding of inadequate drainage indications is condensation drainage holes per 3m. The boreholes drilled radially in the dome, with a diameter of 76mm and a length of 20.0m each. In places their length increased up to ~ 40m. (Photo 8). Internally fitted plastic perforated pierced pipe of minimum internal diameter 50mm, wrapped geotextile (200g / m2), which is anchored in the lining of the tunnel with mortar shrinkage after affixed with wooden peg. The geotextile enveloping tube completely with sufficient coating along the perimeter of the pipe and secured in position using adhesive tape. (Photo 9)

Photo 8: Drilling drainage holes in the drainage tunnel.

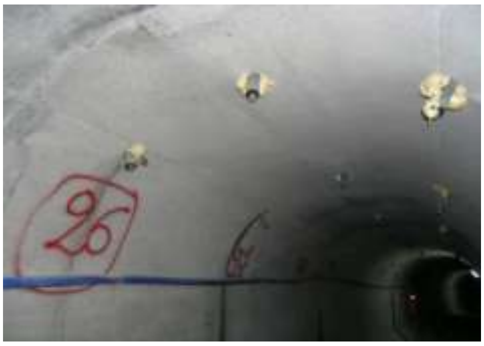

Photo 9: Inserting plastic tube into the drainage holes.

Alternatively it may be mounted perforated plastic minimum inner diameter of tube 1 ½, which is anchored in the lining of the tunnel with mortar shrinkage after affixed with wooden peg. The drilling is made upwardly through tubes of fitted in the concrete of the final coating for this purpose. [3]

D. Results of the construction of drainage tunnels and wells in landslide area Of our research, we watched the evolution of the phenomenon of the landslide, through continuous monitoring and evaluation of the measurements the piezometers and inclinometers for many years. While the construction of the above drainage started in 11th of 2006 and was completed in late 2007, measurements of geotechnical instruments continue to this day (last measurement 3^o of 2016) and some of them require a lot of years monitoring. In this way, investigating the success of the drainage project, the control of ground water level, while we watched the reduction of ground motions from measurements of inclinometers. More specifically the evaluation of these measurements, we find the following:

Based on the level measurement of open type piezometers (boreholes: □**1,** □**3,** □ □ □**1,** □**9**) into the background and (drilling: □ □**3,** □**5,** □ □**6,** borehole **N4**), the disturbed materials and Casagrande type (boreholes: **B2 ', B3' , B4 ', B6' B7 'BN1' BE1** ') in disordered materials - background limits, estimated that the underground water level is within the loose-disordered materials of the background, above the bedrock. In addition to borehole □ □ □**1** artesian occurred when drilling encountered background. In drilling B3 'also made artesian, from the substratum, during the month of November. While high levels of B1piezometer, located on the upstream area, in March near the surface, at 0,56m depth, we conclude that the region A is supplied with water from upstream. Also as mentioned above, higher levels in piezometers are observed during the period of rainfall. Also during the tunnel construction work placed and new piezometers as A5-2, A5-4 (type Casagrande) and DT9-2, ZΠ1 and ZΠ2 (open-ended).

Evaluating all the evidence indicates that the background 'involved' in the underground hydraulic with the pore pressure development in contact with the overlying "disordered" materials throughout area A, which corresponds to a single hydraulic grade surface the levels of which they are within the abnormal materials. Also placing the position and depth of movement from measurements of inclinometers, into territorial sections of the area bounded by the sliding surface. So taking the sections A2 and A5 (Figures 1 and 2 respectively) showing these movements, it is found that there are at least two major failure surfaces that actually these surfaces can be and surrounding surfaces of the individual successive or consecutive slides. Also in these sections are divided and the positions of the drainage tunnel in relation to failure surfaces.

After the construction of drainage measures a decrease in the level, so the above piezometers and a previously installed and piezometers (B30, B33, VP34, B37, B38, N17, N18 and B42) in the region. The level drop of the water table starts from small reduce and continued throughout the years performed measurements. Indicatively drop level by 5m. to 15m. depth (B3), from 6m to 9m (B5), from 7m to 5,5m (VP6), from 22m to 29 m (DT9-2), from 10m to 13m (ZP1), while we also had greater reductions as the piezometer B’6 that the level from 17m fell to 35m depth, and while we simultaneously reduce pore pressure as this pressure piezometer are open type and Casagrande. Also in B1 the water level fell to 5 meters depth, but unfortunately the head of piezometeer was destroyed, in 2012 and no longer performed measurements. There piezometers placed after the construction of tunnels (2009), such as ZΠ2 maintaining the level of water in low water level 30m, during all these years until today (3rd / 2016).

Section 2.4. Area A - Cross section A2

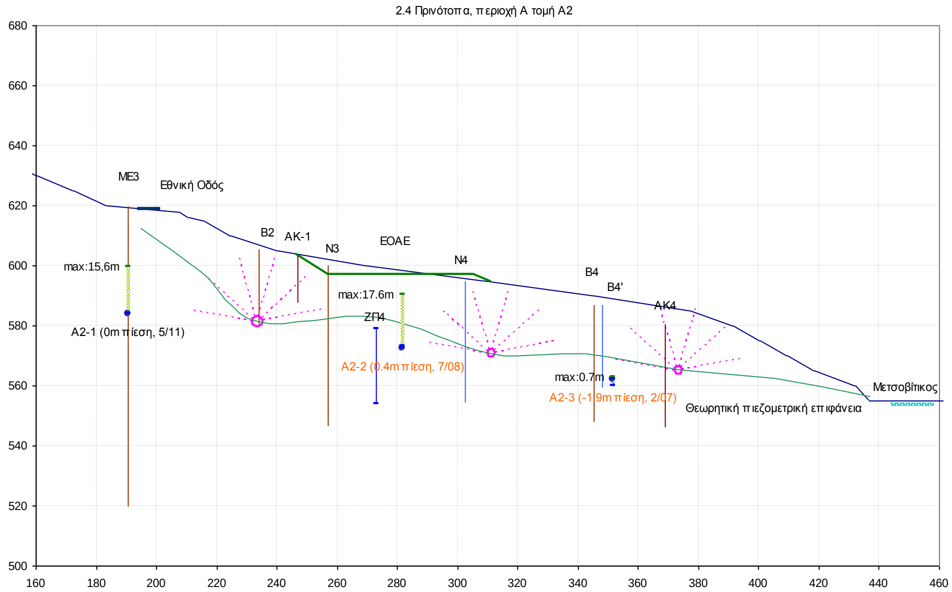

Figure 1: Cross section A2 designed the first major failure surface penetrating and three drainage tunnels.

Section 2.4. Area A - Cross section A5

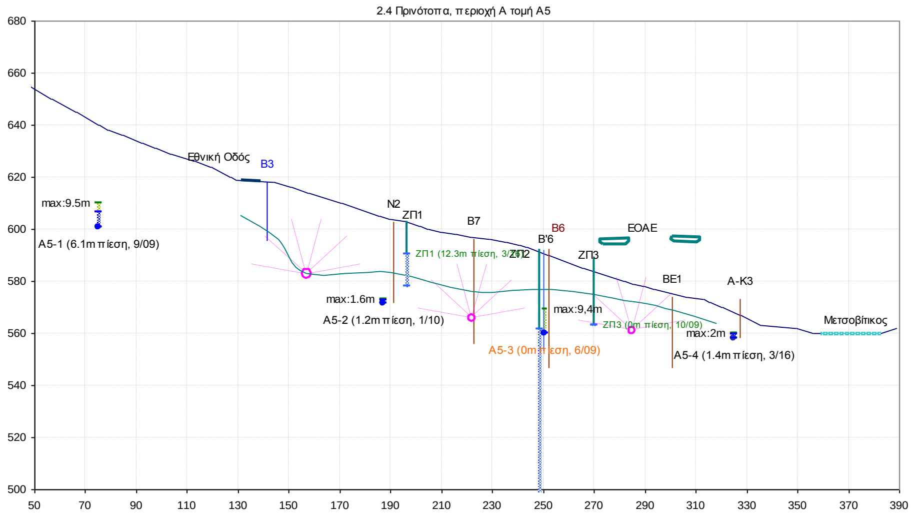

Figure 2: Cross section A5 planned second main fault surface above tunnels 2A and 3A, intersecting 1A

We emphasize that even when the level is not reduced enough, never reached their original level, even winter or rainy months of spring (March-April), eg piezometer B1. Also from the resource pressures measurements at Casagrande piezometers, we have reductions of 50% (piezometer A5-2) and the order of 44% (A5-4) from 2006 to the 3rd of 2016.

From the above evaluation of the measurements, we find that the level of groundwater is affected by the implementation of drainage measures, in the region A and in particular their application causes sinking of groundwater.

In the sections A2 and A5 illustrate the sliding surfaces, where the background is relatively close to the surface, the active sliding surfaces passing through the interface of the abnormal materials. However, when the background is more deeply the failure surfaces and passing through the mass of disordered materials. For the measurement of these detected movements entered in earlier investigations gradiometers phase in drilling N1, N2, N3. According to these measurements we observe reduction of ground movement after the construction of drainage measures. Specifically in almost all inclinometers of the drilling (AK1, AK2, AK-3, AK4, ZK1, ZK2, ZK3, B2, B4, B6, B7, BE-1, N1) before the construction of drainage tunnels, movements were recorded (ie once they placed by the end of 2007 - early 2008), but after the construction of drainage measures significantly reduced, tending to zero. Figure 3 shows quite clearly where the speed is shown in mm / month of inclinometer, during all these years. Ditto observe from Figure 4 illustrating their maximum movement over the years. More detail:

Starting with the oldest located, inclinometers, we have the borehole N1 destruction of the instrument shortly after the installation so no sense of the measurements. In borehole N2 clear signs of movement occurred at a depth of ~ 16,5m. The overall movement is of the order of 10 to 11mm over from 18/07/02 to 09/02/04 and the estimated annual movement in this position is of the order of 4-5mm. However, after the works at the exit of the tunnel have been significant movements in the order of ~ 10mm in just four months, from 25/11/04 to 03/09/05. The consisting measured movement today (3th/2016) is the order of 41,78mm, of which the first 40 mm occurred up to the end of 2007 and the remaining 1,78 from 2007 to today(3th/2016), meaning 0,2mm / year, so it is obvious reducing travel.

In borehole N3 also emerged clear signs of movement in depth ~ 6,5m. The overall movement is here of the order of 10 to 11mm, in a period from 18/07/02 to 02/09/04, and the annual movement estimated in the same order of magnitude as that of borehole N2. However after interventions at the exit of the tunnel there were very significant global movements of around 10cm over from 25/11/04 to 09/03/05 to the destruction of the institution in 2005. Before the last drilling range (B) the boreholes N2 and N3 gave an image of movement only in the upstream of the Egnatia Highway area and because the information was insufficient to estimate movements throughout the region, placed new inclinometer in boreholes B2, B4, B6, B7 and BE1the summer of 2004. Initially, until the end of October 2004 to early November 2004, there were no clear indications movements, only a vague ~ 7m in the borehole B2. Then, however, the damage to the area observed the following movements clearly define sliding surfaces. More detail:

In borehole B2 verified and strengthened displacement indications at ~ 6 to 7m. The instrument was blocked at this depth, the 9th / 2005 which was observed shear deformation in previous measurements (09/02/04 to 25/11/04). In borehole B4 the instrument found in clogged at the depth of 20,30m, in 2009, due to shear movement growth in this depth. But by then exhibited displacement of the order of 5 to 6mm in about 1.5 years, from 11/03/04 to 03/10/2005 at a depth of 10,5 to 11,0m. These measurements also delimit two sliding surfaces which are in agreement with the observed movement in the borehole N1. However, after the construction of the works, the movement was reduced from 6,87 mm / year or 1,76mm / month by 2009 with destroyed. In drilling B6, although initially no movements occurred, appeared movement of about 7-8mm in period from 25/11/04 to 09/03/05 in considerable depth (25m) which rapidly progresses to the last period. After there are no measurements apparently destroyed.

In borehole B7 although initially no deviations occurred, occurred here move in the range of 6 to 7mm in depth of 19m, as in drilling B6. But the instrument was destroyed in 2008. However overall movement by then, was the order of 41,69mm, of which the first 40 mm occurred up to the end of 2007 and the rest 1,69mm, at the 2009 witch destroyed, so it had obviously started the decline of the movement. In borehole BE1 movements appeared in over 7m but have particular important development zone from 3,5m to 7m. It was destroyed in 2005.

Then placed and new inclinometers:

AK-3: First measurement 14/11/2006 and last end of 03/23/2016. Originally from 2006 to 2008 we had total consisting piece 16mm, the depth of 11,5-12m followed so far, the rest had other 2mm total resultant movement. **AK-4:** First measurement 14/11/2006 and last end of 2011, we noticed movement in depth 7,5-8m with total resultant movement 7,66mm, at the depth of 11,5-12m, where 6,5mm occurred by the end of 2007 and since then we had other 1,16mm for the remaining period until 2011 that broke the head and not made measurements.

K2N: placed in 2009 and until the 3rd / 2016 have total resultant 21,24mm movement, at the motion zone 11-11.5 meters, of which the first 18mm occurred during installation and then have the rest 3,24mm since up to now (3rd/2016), which means about 0,5mm / year. Also the same happens in inclinometer **K4** which was placed in 2009 and until the 3rd / 2016 have total resultant 11,50mm movement, in the depth of 9 meters, ie surface and so may be due to surface creep. However the first 7mm occurred during the first measurement and then have the rest 4,50mm since until the 3rd / 2016, meaning around 1mm / year.

BN6: Placed 5th / 2011 and from then until the 3rd / 2016 does not show any movement. **K1:** Placed on 15/05/2011 and the last 3rd / 2016 infinitesimal movement in the zone of 12-13 meters, the range of 0,86mm overall movement throughout all these years, an average annual rate 0,18mm / year . Finally the borehole **ZK2** the inclinometer was placed in 2011 and until the 3rd / 2016 have total resultant 1.99mm movement, at the motion zone 16 to 16.5 meters, which is about 0.45mm / year, infinitesimal movement.

Monthly movements mm/month

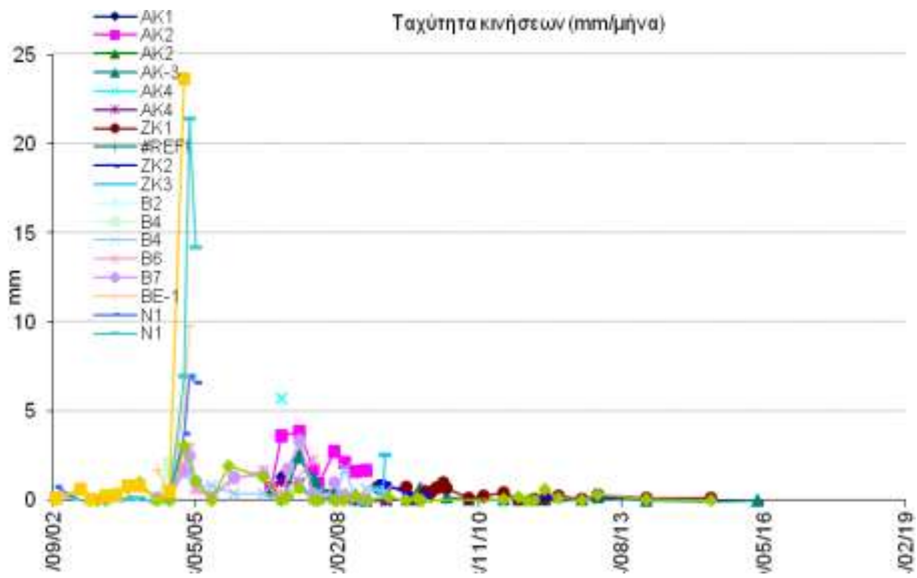

Figure 3: Depicting speed of monthly movements from 2002 to 3rd / 2016.

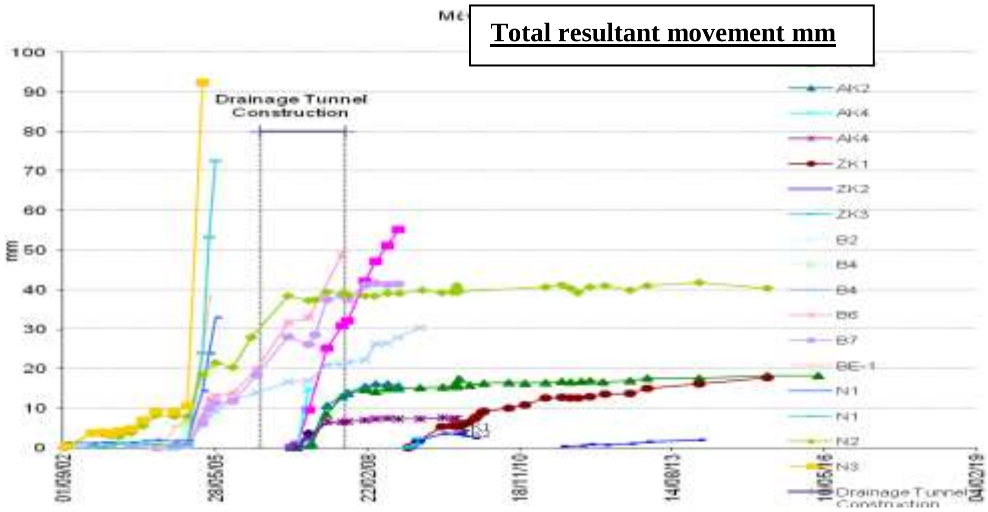

Figure 4: Depicting total resultant movement of inclinometers from 2002 to 3rd / 2016.

So all measurements of instruments established show quite clearly that: there were ground movements before the construction of drainage, exacerbation of these movements during their manufacture, the logical result of interventions and worksite operations and finally reduction to the zeroing (in some of these). So we emphasize that the monitoring and evaluation of measurements, for several years, confirmed that the construction of drainage tunnels with their boreholes manage to drain the landslide material, resulting in fall of water table and reduce rate of ground movement, so stabilizing the landslide area.

II. CONCLUSIONS

Finally in conclusion to mention that:

The drainage tunnels with drainage boreholes therein, is to increase the shear strength on the sliding surface, by falling levels of groundwater, and consequently the reduction - to zero - of pore pressure and therefore a corresponding increase of active trends. Therefore the drainage tunnels placed at great depth, greater slip zone, while remaining elevation above the level of any adjacent River, to ensure runoff drained into those waters by gravity. Otherwise there is no nearby river, should the exit tunnel be proper arrangements in order to collect the water of the drainage tunnels and removed from the area of the landslide.

Built three tunnels:

- the first (1A) tunnel to the upstream part of the landslide and extending into the background,
- the second (2A) and third (3A) at a downstream portion of the landslide, mainly within disordered materials, while (3A) local meets and bedrock of flysch of Ionian zone, in order to achieve the best drainage and stability area concerned.

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