Geotechnical soil conditions and long term deformation- landslide phenomena of Mesochora village, Central Greece.

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ABSTRACT

Mesochora village is located in Central Greece, 3km upstream of the already constructed 150m high Mesochora concrete faced rockfill dam (C.F.R.D). The hydroelectric project of Mesochora, owned by P.P.C S.A (Public Power Corporation of Greece), has a total installed capacity of 161,6 MW.

The project design makes a provision for impounding the Acheloos river reservoir up to elevation +773 a.s.l. This means that the lower part – half of the Mesochora village – with population of approximately 400 inhabitants, will be submerged under the maximum reservoir level.

The village is situated on a flysch slope, partially consisting of a series of old-ancient landslides that currently are partly reactivated before impoundment as the up to date records of displacements of the geotechnical instrumentation installed verify.

The present paper makes an effort to introduce a deformation- landslide model of the Mesochora area stability as well as the stabilization measures examined for the remaining- over the maximum pool level- village.

Keywords: Landslides, deformation, displacements, deep creeping, stabilization.

1. INTRODUCTION

The Mesochora village has been for quite a long time a key issue for the completion of the homonymous hydroelectric project.

Human reactions concerning the project completion along with complicated geological-geotechnical conditions effected in an almost 10 years delay in the commissioning of the project. The area consists of old slide materials in the order of $6x10^6$ m^3,with half of this volume resting over the maximum elevation of the future reservoir. Long term deformation in the area ,in the form of deep creeping is clearly evident through subsidences and tensional cracking observed in the road passing through the village (photo 1) as well as from road walls cracking , tree trunks bending and morphological features of successive flat areas in the village slopes

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Photo 1 Subsidence-tensional cracking in Mesochora main road

1.1 *Engineering geological conditions*

Mesochora village belongs to the Pindus geotectonic zone that is considered an area of moderately seismicity in Greece. The prevailing lithological formation is flysch consisting of intercalations of sandstones, siltstones and less often limestones and cherts. The layering is dipping in general towards downslope , with a dip amount ranging from 30^0 to 70^0.

Geomorphologically the slope where the village is situated consists of a succesive serie of ridges and gullies along Vathirema tributary of Acheloos river. The prevailing formation in the ridges is sandstone being somehow more stable. In the gullies, flysch talus scree material has accumulated, been slided in the past, forming thus old landslides.

The depth of this material ranges from 5 to 30m, usually appearing a chaotic material of accumulated rock fragments within a soil like matrix.

At the interface with the bedrock a predetermined slickensided slide surface was usually encountered by the geotechnical investigation that has preceded. The *G.W.L* is in the most of the cases above the sliding surface and in a depth ranging from 5 to 15m.

The slide materials are partially unsaturated, possessing thus an additional unstabilizing effect in the case of saturation due to dam impoundment.

Some springs appear in the village area over and below the maximum future reservoir elevation and in the range of the 40 meters high draw down.

1.2 *Geotechnical conditions of unstable materials*

The old slide materials are classified after *U.S.C.S* as sandy or silty clay of low plasticity (*CL*). The fines passing the 2μm (clay fraction) is ranging from 6 to 40%.(table 1)

The natural water content (*w%)* of the samples range from 5 to 17% and in some cases it was lower than the plastic limit (*P.L*) meaning that some of them, were preloaded (overconsolidated).

The liquid limit (*L.L*) ranged from 25 to 42% classifying the material as of low plasticity and compressibility.

SPT - *N* value, ranged from 16 to 50 ,due to the presence of rock fragments, classifying the sample as stiff to very stiff.

The uniaxial unconstrained compressive strength (*qu*) ranged from 40 to 565 KPa.

The compression index (*Cc*) obtained by oedometer tests ranged from 0.10 to 0.14 classifying the material as low to moderate compressible.

From *C.U.P.P* lab test results ,the effective cohesion (*c'*) ranged from 15-110kPa while the effective angle of internal friction (*φ'*) from 12^0 to 28^0.

In addition, from ring shear testing ,that was performed to the old slide materials ,the residual friction angle *Φr* ranged from 10^0 to 30^0.

The permeability coefficient (*K*) ranges from 10^{-3} to 10^{-6} cm/sec.

Finally, X ray diffraction tests (*X.R.D*) ,in the slide surface material, revealed the presence of swelling clay minerals in the order of 5% while the total amount of clay minerals in the samples ranged from 35% to 50% (Anastasopoulos and Lambropoulos,2004 and 2005)

Geotechnical properties of materials	***USCS***	***W %***	***LL***	***SPT***	***c'(KPa)***	***φ΄ deg***	***φr deg***	***Cc***	***qu (KPa)***	***K (cm/sec)***
Old slides material	CL	6-40	25-42	16-50	13-108	12-18		0.10-0.40	40-565	10^{-3}-10^{-6}
Slide surface							10-30			10^{-3}-10^{-6}
Bedrock									3000-9000	10^{-4}-10^{-6}

Table 1. Geotechnical properties of materials

1.3 Deformation-Landslide model

According to both visual and geotechnical instrumented observations in the area, the most prevailing deformation-landslide model in the wider area of Mesochora village is that of a long term deformation of old slide material, especially along the gullies where the loose material has accumulated (fig.1)

The sandstone ridges- being also laterally squeezed (deformed)- separate different slow landslide and or deep creeping that occur along the gullies. Along the maximum slope inclination, the model of retrogressive sliding is the most probable to occur in the future either as new activations or as reactivations of old slides.

Nowadays the prevailing motion is that of old slides reactivations in the form of deep creeping, especially after heavy winter periods.

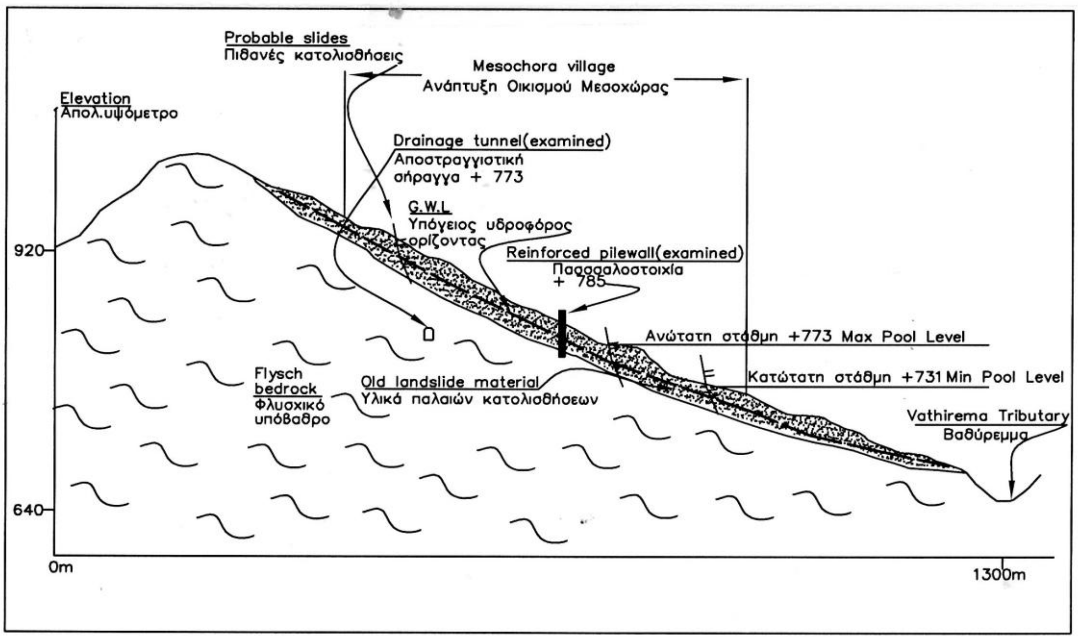

Figure 1. Landslide model and examined stabilization measures at sector D

1.4 Soil displacements data

P.P.C S.A in order to monitor the ground motions in the area of the village before impoundment, established a geodetical survey system consisting of surface monuments(fig.2), along with a network of inclinometers. Most of the instrumentation showed displacements during the last 15 years and 8 inclinometers were sheared. (figs 2,3,4)

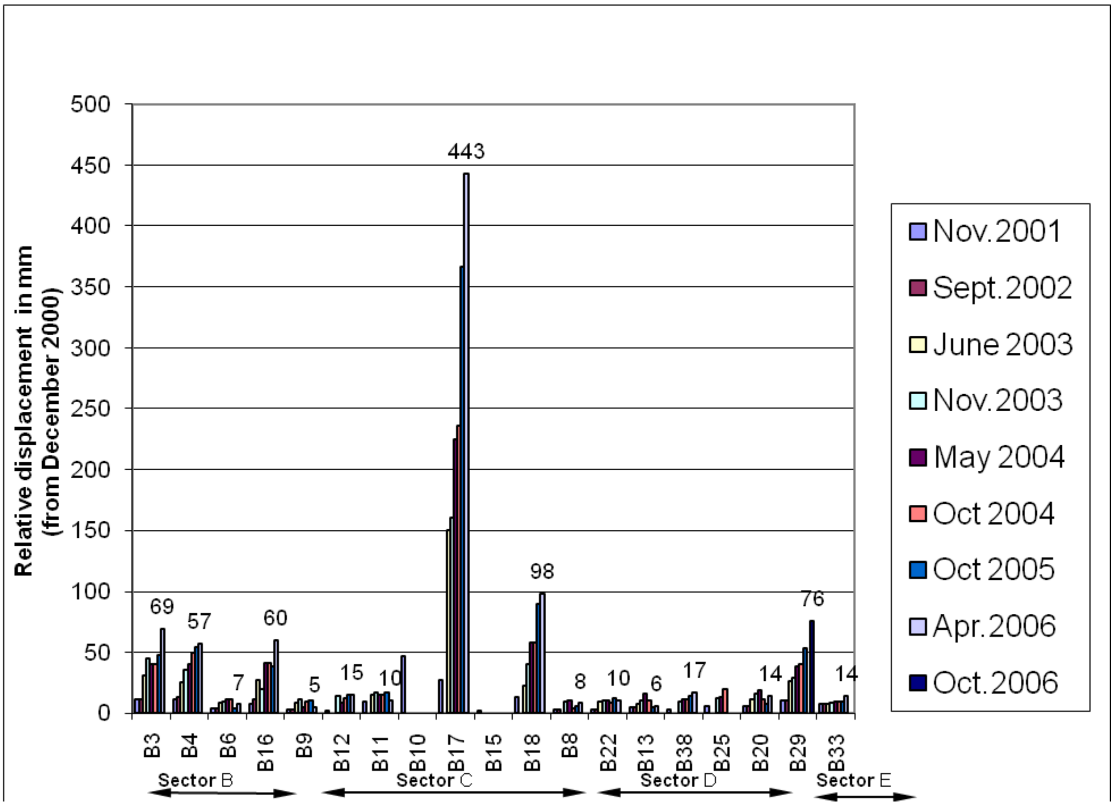

Figure 2. Surface monument displacements versus time in various areas of the village

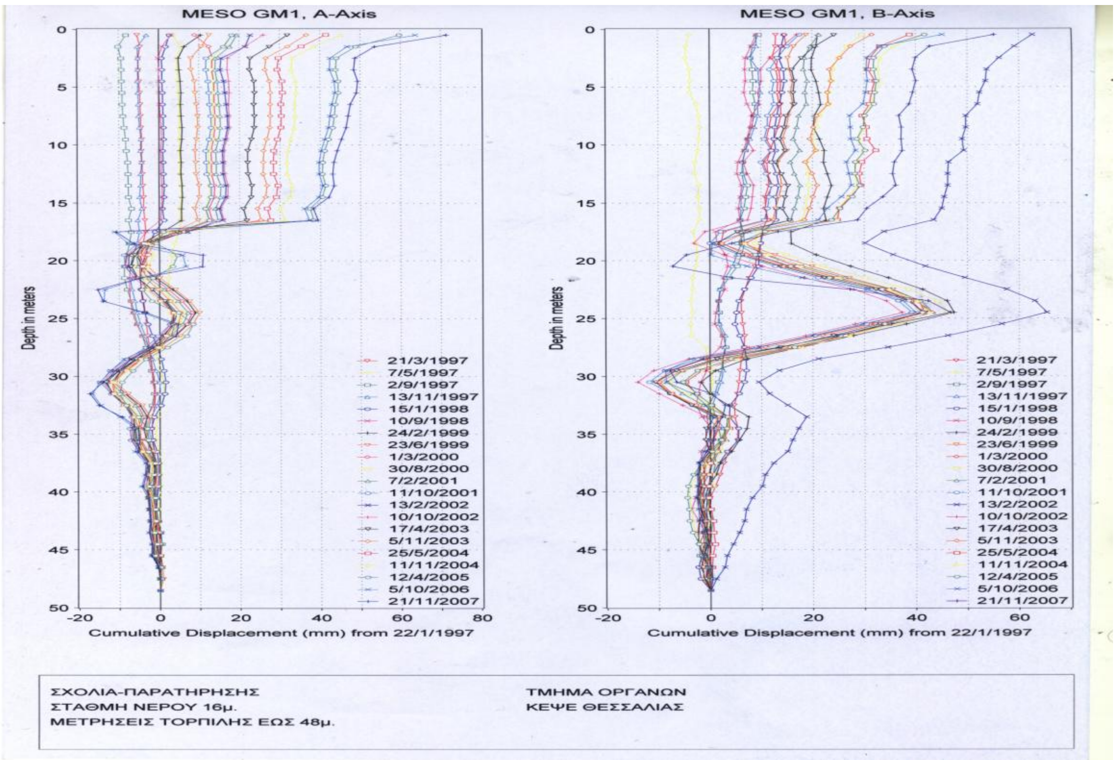

Figure 3. Mesochora village sheared inclinometer (sector B)

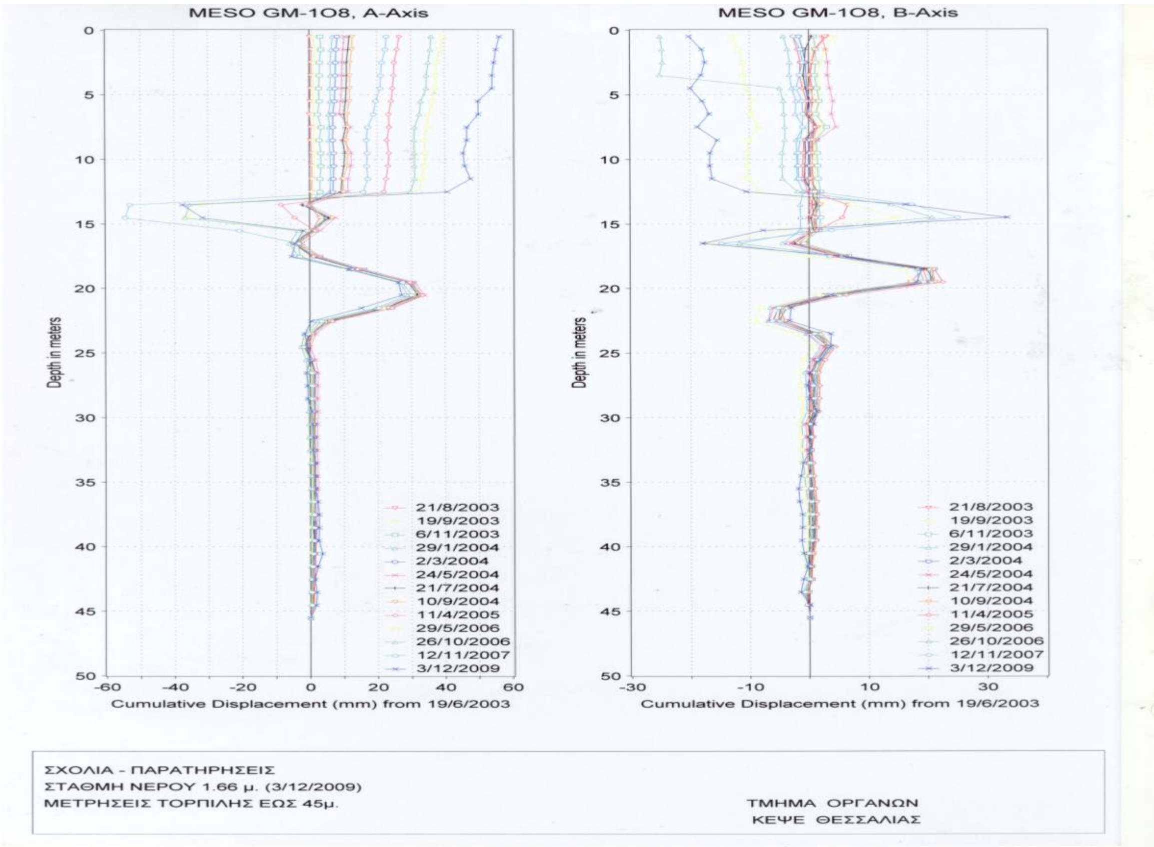

Figure 4 . Mesochora village sheared inclinometer (sector D)

The rate of displacements that have been established from the geotechnical instrumentation of the data collected are presented in Table 2 for the different sectors of the village (Anastasopoulos and Lambropoulos, 2011) :

Sector	Mean rate of displacement (mm/yr)
B	1 - 15
C	20 – 90
D	3 – 10
E	3 - 15

Table 2. Mean rate of displacements.

The above rates of displacements classify these landslide movements as very slow (Cruden and Varnes, 1996)

1.5 Stability analyses and examined stabilization measures.

In sector B, rapid draw down conditions reduce the *FOS* by 15-20% (Anastasopoulos;Lambropoulos;Papa-hantzaki,2004).

Improvement of the factor of safety by means of drainage through construction of an approximately 1km long gallery, serving that purpose, was considered. However, stability of Sectors C and D, even with the drainage tunnel, could not be guaranteed, since in sector D failure occured in the case of rapid draw down, whereas in sector C, where the stability conditions are less favorable, failure occured even while impounding to maximum pool level (Imperial College London Consultants,2003).

In sector D ,where is the main village portion, the drainage of the slope by a drainage gallery along with a reinforced concrete pile wall -of depth ranging between 10 to 30m- considered to be constructed 10 m higher of the maximum power pool level.(figs 1,5)

Implying the above stabilization measures an improvement of the factor of safety of the order of 20% was achieved (Maronikolakis et al., 2004; Poulos, 2004).

However, although the overall stability of the village is somehow improved, the application of the above stabilization measures could not provide adequate-guaranteed protection against local and/or surficial sliding phenomena in the overlying slopes that could potentially jeopardize housing and human lives.

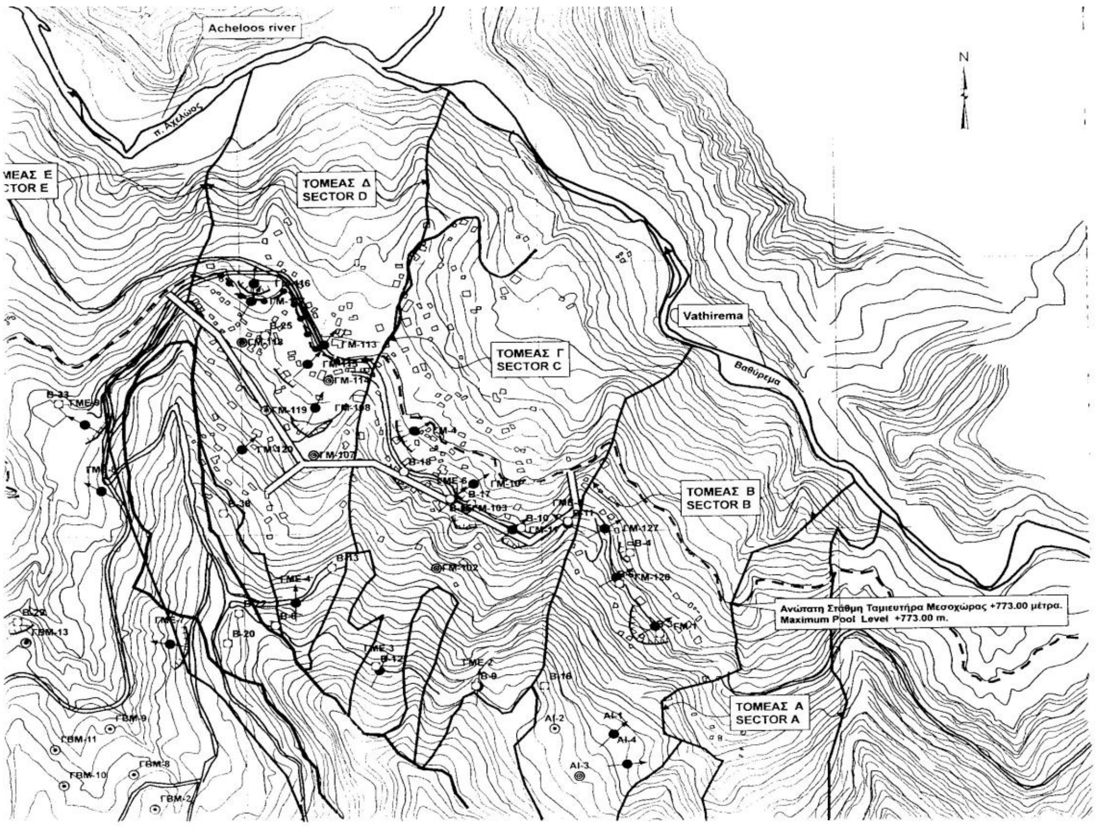

Figure 5. Mesochora village instrumentation-examined stabilization measures-scale 1:10000

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Conclusions

Slow rate deformation phenomena, in a form of deep creeping, do exist nowadays ,before impoundment, in the area of the Mesochora village.

Deterioration of these phenomena with probable activation of the existing landslides or the occurrence of new ones is expected due to either draw down conditions of the future reservoir (which is in the order of 40m) and/or due to a seismic event in the wider area after reservoir filling.

The confrontation of these phenomena that is of vital importance to be considered before impoundment , appears to be a complicated and difficult task due to both adverse soil conditions and human reactions concerning the project's completion.

For these reasons the relocation of the entire village in a safe-stable area, on higher elevations and remote enough from the planned reservoir was judged to be the most appropriate solution both for inhabitants and project integrity. (Anastasopoulos and Lambropoulos 2003,. Marinos ,2011)

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