AGRAS H.E.P-MINIMIZING EMBANKMENT SETTLEMENTS TO PREVENT OVERTOPPING

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Abstract

The Agras Hydroelectric Project (H.E.P), situated in Northern Greece, was one of the first hydroelectric schemes in Greece and was constructed from 1951 – 1954.

In 1958, a 4.8 km. clay embankment, of approximately 1 - 2 m initial height, was constructed in the reservoir, in order to prevent excessive water losses through the karstic surrounding limestones.

Since the embankment foundation conditions were very poor, due to presence of peaty mud, the embankment suffered long term settlements of the order of few meters, resulting in frequent overtopping of it and in excessive compensation costs, not affordable when compared to the energy production profits of the scheme.

Raising of the clay embankment, in order to maintain the crest just above the maximum flood level imposed higher loads to the soft foundation resulting to further settlements in the long term [1].

In early 2010, a more permanent and effective solution to this problem came into consideration. This involved incorporating in the embankment light-weight expanded polysterine (E.P.S) instead of the heavier clay.

1. INTRODUCTION

Agras H.E.P consists of a 5m high earthfill dam on Vodas river, a reservoir of $3.8x10^6$ m^3 capacity (called Nission lake), and an approximately 1.5 km long power channel and 1.6 km long power tunnel conveying the water to a 50 MW Power Station.

After lake filling, a 4.8 km. long low clay embankment was constructed, in order to isolate the reservoir water from the karstic limestone outcropping at the north-eastern part of the lake, as well as for protecting the nearby cultivated area from flooding at high reservoir levels.

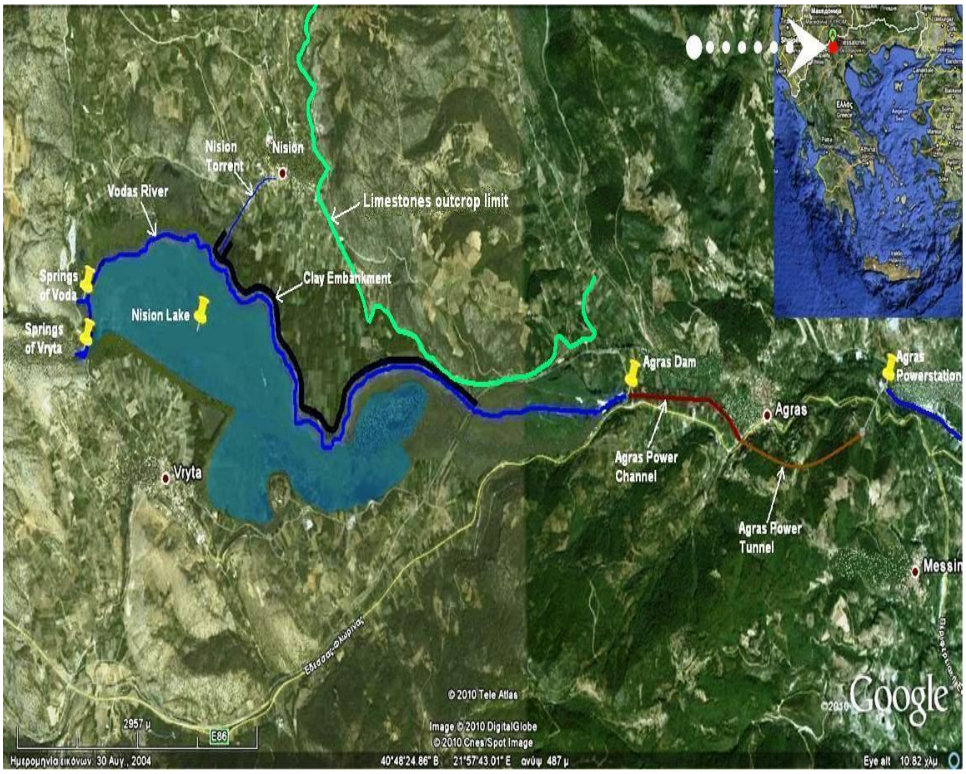

Fig. 1 Nission Lake Google Map

2. RESERVOIR - GEOLOGICAL LAYOUT

In the wider area of Nission lake, where the clay embankment was constructed, three main geological – geotechnical formations were established by borehole sampling, as follows ;

- The upper formation, consisting of peat and/or peaty muck.
- The intermediate formation, consisting of silty sands with clay.
- The deeper formation (bedrock), consisting of karstic limestone.

The upper formation has a mean thickness of 10m and a dark brown to black color. According to chemical analyses, the organic content of the peat ranges from 25-85% with mean value of 65%,that classifies the formation according to the L.G.S- Luisiana classification system (Kearns et al, 1992) as peaty muck or mud.

The intermediate formation, with mean thickness of 25m, consists mainly of sands and silty clays with occasional limestone fragments and thin peat intercalations and is of lacustrine origin [4].

Finally, the limestone is medium bedded and fractured. It is white to grey-black, dipping with 30^o towards Northeast. Karst features, such as small holes, wide opened joints with calcite coatings etc., are present in the limestone, as detected from borehole cores.

3. GEOTECHNICAL CONDITIONS OF THE FOUNDATION

The upper formation (peaty muck), has very small uniaxial compressive strength (mean value of uniaxial compressive strength q_u =50 kPa), a mean S.P.T value of 1 (characterizing the formation as very loose to very soft) a low specific gravity of 1.84 due to its high porosity and a compression index Cc in the order of 0.18-0.24.

The high liquid limit (110%) along with an average plasticity index of 105,classifies the material as of high plasticity. The mean permeability value is rather high, of the order of 1.7 x 10^{-5} m/sec.

The intermediate formation is somewhat stiffer, having a mean S.P.T value of 20 and a mean uniaxial compressive strength q_u =200 Kpa. The specific gravity Gs of the formation is 2.60 and has a natural water content of 56%. The permeability value is of the order of 5 x 10^{-6} m/sec, indicative of a medium to high permeability of the formation. The c' and φ' values were determined from laboratory testing, as 50 kPa and 30^0 respectively.

Finally, the lower formation posses a high mean permeability value (of the order of 3 x 10^{-4} m/sec), due to the karstification and fragmentation of the rockmass.

4. PAST TREATMENT OF THE FOUNDATION PROBLEM

The protective clay embankment of Nission lake constructed during 1958, was founded on the upper peat formation. The initial dimensions of the embankment were: height 0.5m- 4m, width 3m and length 4790m.

The last 20 years a geodetical survey conducted along the embankment revealed large settlements along it, in the range of 0.5 to 4m, as well as a maximum settlement rate of the order of 20cm/year.

During this period and in order to maintain the crest of the embankment above the maximum flood level, more clay was dumped and compacted on the crest, increasing thus the imposed loads to the foundation and therefore worsening the long term settlement problems.

Fig.2 Twenty years observed settlements along clay embankment.

5. PRESENT TREATMENT

In order to control the excessive settlement problems some other alternatives were recently examined in order to confront the settlement problems.

Initially, the use for embankment raising of peaty mud, that was plentiful available in situ, was considered, since this is a somehow (30%) lighter material than the pure clay used in the past for embankment raising. (G_s clay = 2.75, G_s peaty muck = 1.84).However, the peaty mud could not be used without improvement of its properties to become more stable, impermeable and workable. These would necessitate lowering of the moisture content, adding a soil stabilizer or fly ash to the material etc [3].

The solution was abandoned as it was considered that it would not drastically reduce the settlements.

Another alternative examined was the improvement of the peaty material by foundation improvement methods, such as the soil displacement method. This would effect in the reinforcement of the peat layer by a grid of cement based micropiles (Φ25cm) in a grid pattern, that would transfer the embankment load on the sandy silt formation underneath the peat. The cost estimate for the application of this method resulted to approximately 700 - 800 Euro/m of treated embankment.

This solution was abandoned mainly due to cost limitation reasons.

Last but not least, the alternative of replacing the heavier clay material with a light weight material, like E.P.S. (expanded polysterine) with a nominal density of 30 kg/m^3, was examined and came out to be both economical (with an estimated cost of 450 Euro/m) and technically appropriate.

Utilization of the very light weighed EPS is anticipate to significantly decrease settlements (both absolute values and rates)[6], due to the significant reduction of the loads imposed to the foundation, compared to all other materials that were considered as alternatives for reinstating the embankment at the level requested for flood protection.

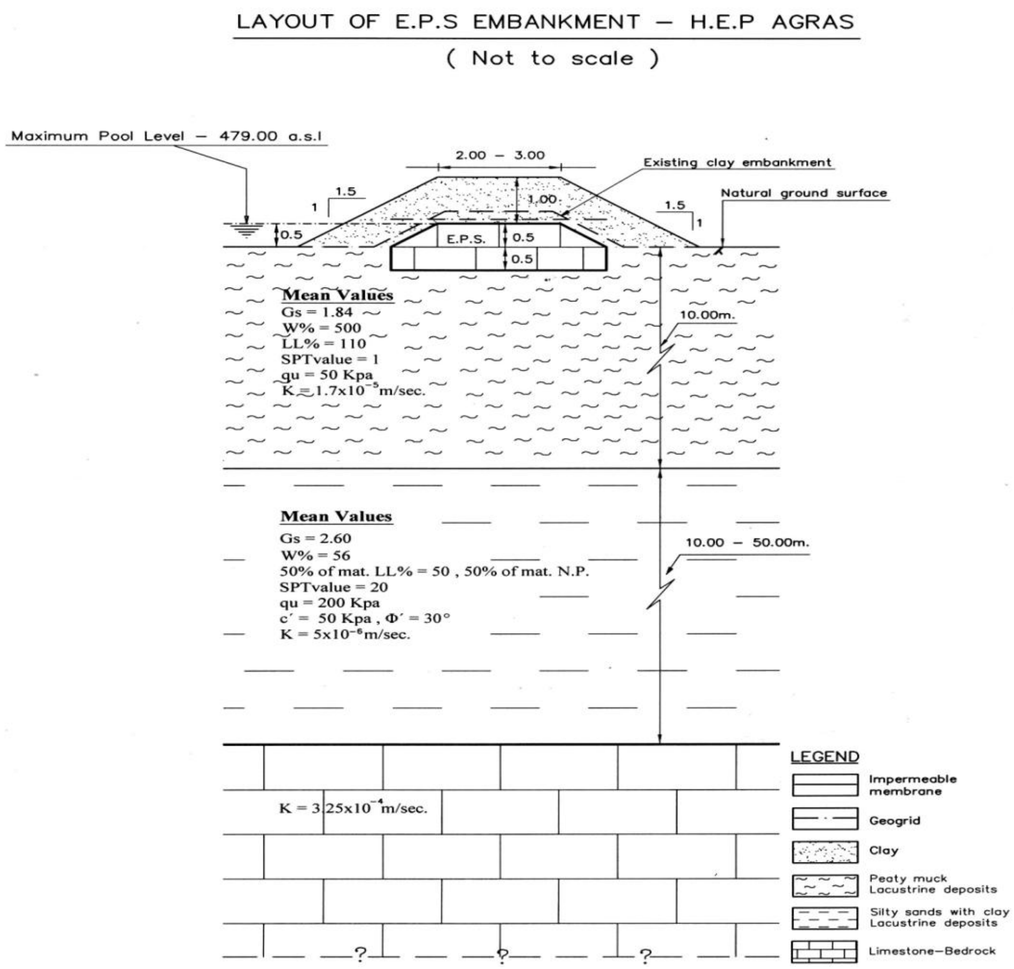

Fig.3 Geotechnical section along E.P.S embankment

The thickness of the E.P.S. as well as the of clay layer on top were determined by the requirement for an acceptable safety factor against uplift at max flood level.

In order to verify the adequacy of the construction method envisaged as well as performance of the structure, a test embankment with E.P.S was constructed in the most critical section, on December 2010.

5. CONCLUSIONS

The use of E.P.S. (expanded polysterine) light weighted material can be a very effective material in reducing settlements in poor natural soil conditions such as the peaty muck foundation of the Nission embankment. Application of this method proved to be very simple and cost effective compared with all other alternatives examined. Also appears to be a permanent solution for the long term flood control in the embankment area.

Since the above method was used for the first time for flood control, the long term behavior of the structure has to be monitored in order to verify its adequacy in the long term.

6. ACKNOWLEDGEMENTS

The author wish to thank Public Power Corporation of Greece for providing valuable data and Mr. K. Anastasopoulos, President of the Greek National Committee on Large Dams for valuable discussions on the paper.

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