MODELLING THE OPTIMAL GEOTECHNICAL MODEL OF THE CREST OF THE OTINJA EMBANKMENT DAM IN STIP

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ABSTRACT

The dam of the River Otinja will be established near the town Stip. Embankment will be locate in granites, or biotit adamelites, which are strong and very thick, but fairly fissured.
From the tectonical point of view, faults and fissures are situated in the accumulation area. In that regard, there are two faults with North – South general strike. Fissures occur in thick systems, so that certain systems may contain up to 30 cracks per meter.
According to engineering – geological classifications, the rock masses from the partition place and water reservoir area have been divided into strongly bounded, poorly bounded and unbound rock masses
Two kinds of rock masses have been found in the partition place and the accumulation area, which are of importance for the hydrology in the area: bound rock masses of cracked and fissure porosity and unbound sediments of inter-grained porosity.
When creating the technical part, several cross sections of manifested instability were analyzed when the current and newly created state for rehabilitation was analyzed. Analyses of the slope stability were made according the methods of Bishop and Spencer and GeoStudio 2004 software packet was used.
From the total filed investigations, 3D model was made in AutoCAD 2007software packet.

Key words: embankment dam, granites, accumulation basin, slope stability, models

1. Introduction

The accumulation area of the embankment dam on the River Otinja is situated along the Otinja valley. It is a 900 m long natural accumulation basin occupying an area of 3600 m^2 and volume being 1 500 000 m^3. The accumulation area above the water reservoir widens; the riverbed shortens and widens depending on the rocks.
The cross-section of the construction area is a natural canyon where the Otinja penetrates the granite rock massif. The water reservoir, according to the type, should be 30 meters high with drainage area of 30 km^2. The north-western border of the drainage area begins at peak 548 passing over Ciganski Rid towards Varena Glava, Vezir Tepe to peak 997 (Crni Vrv) from where it is goes further towards peak 666 and across Komarnik, Gjupski Rid and Kavaklija continues as far as Stip.

2. Method of work

Complex method of field investigation was applied including detailed engineering geologic mapping and field method of defining the composition and pattern of the place where the crest of the water reservoir is to be constructed. Special attention was paid to the foliation and level of fissuration, crack orientation and angles of slope.

3. Geological characteristics of the terrain

According to the geotectonic setting of the Republic of Macedonia the area is part of the Vardar Zone. It is part of the north-western portions of the Buchim tectonic block where mainly granitoids overlain by Upper Miocene and Quaternary sediments prevail (fig. 1).
Granites: The granites in the area are part of the Stip granitoid massif. The massif consists of three kinds of granitoids:

- Biotite adamelites (quartz monzonites),
- Biotite granites,
- Aplitoid granites.

The dam location and the accumulation area of the water reservoir are located in biotite adamelites.
Biotite adamelites (quartzmonzonites): The biotite adamelites extend south-east from Stip to Ljuboten and Ciflik. The adamelites are medium-grain sized, seldom coarse- and fine-grain sized with occasional 3 cm porphyroid grains of dark grey potassium feldspar.
Upper Eocene: Based on detailed investigations carried out by different research workers so far, the upper Eocene is divided into 4 groups:

- basal series - sandstones, marls and conglomerates,
- lower flysch zone - conglomerates, sandstones, slates - grey sandstones, violete slates,
- lower yellow sandstones, - yellow sandstones,
- upper flysch zone - sandstones, slates, marls, sandstones, slates.

Part of the accumulation area of the river is located in the basal series.
The basal series is composed of sandstones alternating with conglomerates as well as clayey and carbonate layers. Carbonate members are present as limestones and marls. Owing to the presence of higher or lower amount of limonite material, light or dark red layers alternate. The redder portions correspond to the sandstone and slaty members, less red ones to carbonates. The whole series is depilated, non homogenous, altered and irregularly coloured. Carbonate beds are broken and rocky, sandstones being in some places conglomerative.
Sand layers are 2 - 5 m thick, whereas carbonate ones are up to 10 m thick.
Sandstones are made up of quartz and broken feldspars. There are also pieces of hornfels, femic minerals, slaty pieces cemented with limonite and carbonate material. Sandstones are fine - to coarse - grained.
Marls contain carbonate material, finely mixed with large amount of clayey and limonite material.
Slates alternate sandstone and limestone layers. They are violet to brown-dark.
Limestones are least present. They can be coarse-crystal, sandy, marly and dolomite.
Conglomerates alternate sandstones and lumpy limestones located on the top most part of the series. They are made up of diabase boulders, less of cherts, limestones, gabbros, granites and amphiboles. The cement is limonite-sandstone.
Settling of such sandstone-carbonate material, non-homogenous, poorly bound, points out to near coastal medium of settling.
The basal series is 350 m thick. Quaternary: the dam and accumulation area consist of:

- diluvial sediments,
- alluvial sediments.

Diluvial sediments are widespread and occur mainly in areas of developed Upper Eocene sediments. It is a decomposed, loose cover consisting mainly of 5 to 10 m thick Paleogene sediments.
Alluvial sediments are present along the river Otinja valley. They have been divided into:

- higher river terrace,
- lower river terrace,
- present day river detrituses.

Upper river terraces are present only on the left side of the river, mostly as loams with interlayers of pebbles of various thickness.
The lower river terraces are present on both sides of the riverbed. They are mainly 5 to 10 m thick loams, sands and pebbles. It is of note that in the layers of the lower river terrace boulders of host rock of variable composition can be found, of which metamorphic and magnetic varieties prevail.
Present day river layers. The river detritus in the River Otinja bed consists of pebble and sand. Pebble grains are variably thick, the most common being 2 to 5 cm in size. According to the lithological composition the most common are fragments of metamorphic and magmatic rocks. The tickness of the river layer does not exceed 15 m.

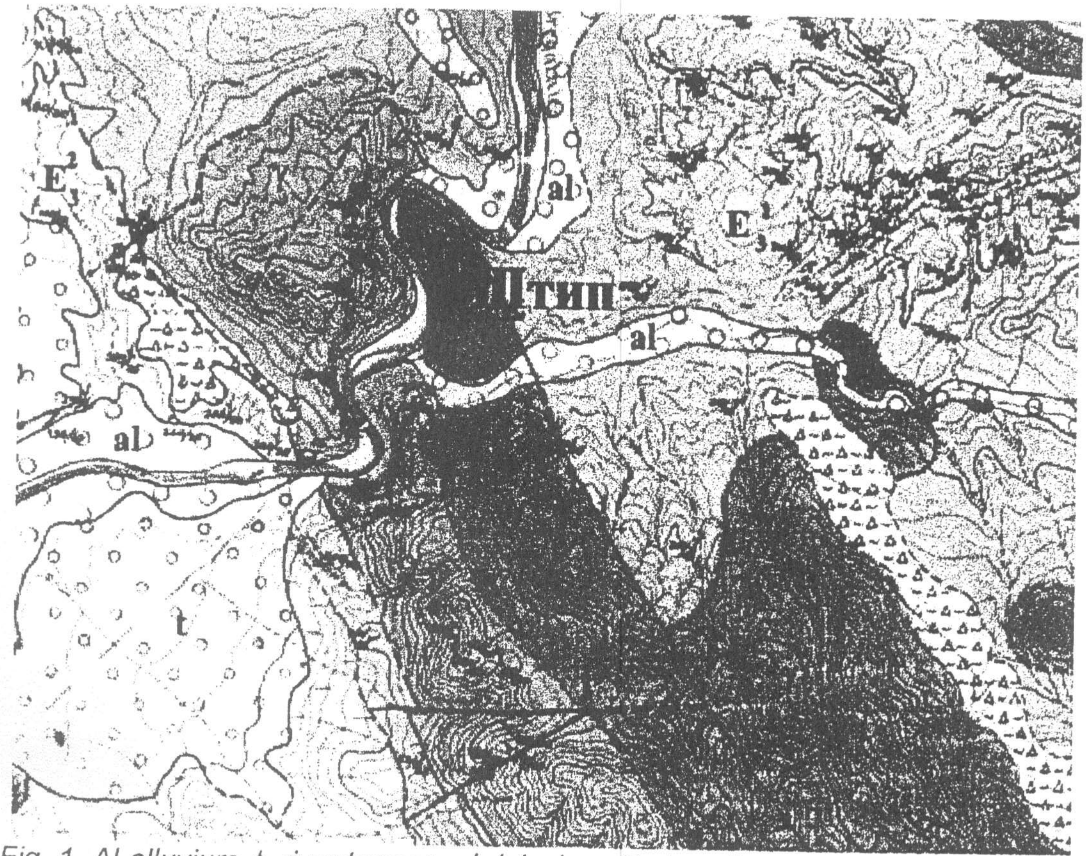

Fig. 1. Al-alluvium, t- river terrace, d-deluvium, E - basalt conglomerates, E – lower flysch zone, γ - adamelites and biotite granites, I- determined, overlain and supposed fault.

4. Tectonic relationship between the dam and the accumulation areas

The most important tectonic structures occurring in the dam and the accumulation areas are faults and fissures.

There are two assumed faults in the area designated as construction site for the water reservoir - both being of north- south general strike. One fault is situated before the dam site extending on both banks. The second is on the south side within the accumulation area. A small stream flows through the fault. Both faults are part of the granite massif. In addition to the two faults there are several smaller faults without any specific importance. Fissures are essential structural element in the granitoid mass. The entire granitoid massif is strongly fissured, with visible cracks of 10 m in size (figs. 2 and 3).

Fissures occur in thick systems, so that certain systems may contain up to 30 cracks per meter. Such systems are of the following slope elements (SE), SE 112/86, 120/50, 210/36.

Fissures are from 1 to 5 mm wide, occasionally maximum 10 mm wide. Some fissures SE 122/42 and 60/77, are filled with parent material. Several maximums of fissures have been distinguished: SE 2/39, 40/41, 291/87 for the left bank, and SE 58/50, 202/71. 119/79, 83/22 for the right bank.

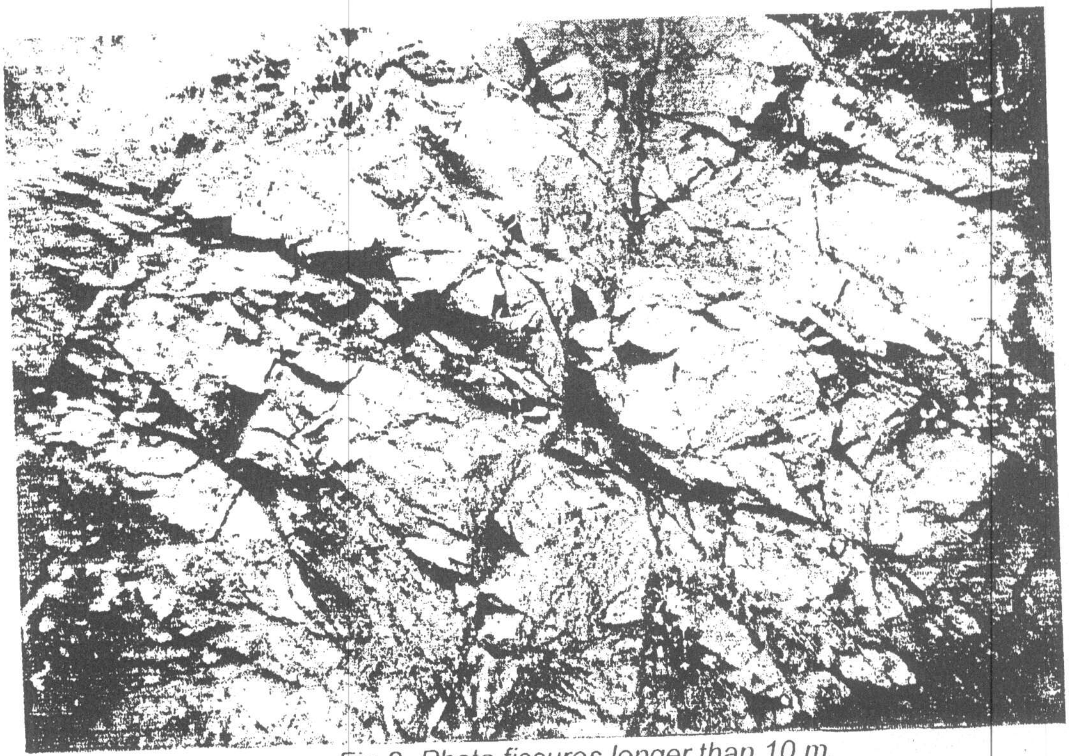

Fig.2 Photo fissures longer than 10 m.

Fig. 3 Photo of characteristic system of fissures.

5. Engineering - geotechnical characteristics of the terrain

The rock masses in the partitian place and water reservoir area have been divided into strongly bound rock masses, which in tern have been divided into

- rocky,
- semi-rocky,
- poorly bound rock masses and
- unbound rock masses.

Strongly bound rock masses: Granites have been found as strongly bound rock masses (the crest of the water reservoir) in this engineering-geologic group. Granites are strong and fairly

fissured and very thick. In the surface part they are rather broken and under the influence of exogene factors are of rather poor engineering-geologic characteristics compared to those in the deeper part of the massif.
The masses are situated in a manner that they intersect the granite massif and are favorable to the construction of accumulation pool.
Semi-stone rock masses. The group consists mostly of Eocene sediments present as flysch sediments (slates, marls, sandstones and limestones), present along the river course and the accumulation area, particularly on the right side. Basal conglomerates of fragments of magmatic and metamorphic rocks are well bound being the footwall of flysch sediments. When the accumulation period is complete and the rocks become saturated with water their loosening ca be expect.
Poorly bound rock masses: the group includes diluvial sediments developed with decomposition of rock mass above the Eocene flysch. They are widespread on the slopes overlying the host rocks being not very thick. They posses variable granulometric composition, variable thickness and variable physic-mechanical properties. So, they have variable engineering-geological characteristics that depend on percentage presence of major factors in the mass. In conditions of form accumulation due to their small thickness, problems of their stability are not expected.
Unbound sediments: The group includes sediments of the higher and lower river terraces alluvial layer and arenite products. Two groups of sediments are distinguished:

- fine-grained,
- coarse-grained.

Fine-grained sediments: This group includes loams and slates, and sands and comprising the high and lower river terrace. Loams and slates have been found in the cross-section of the partitian place and accumulation area as interbeds and cherts in the higher and lower river terrace of the Otinja. They are of non-uniform mineral composition with occasional occurrences of dusty slaty sediments. Sands have been distinguished in the slaty material, whereas quartz material is absent. Sands are more common in the river detritus than in the higher or lower river terrace. Quartz and feldspar grains prevail in them transported from surrounding terrains being coarse- medium- or fine-grained fractions. Differentiation of granulometric composition is a precondition of the wide range in their properties. Sands can be classified based on their granulometric composition as coarse-medium and fine-grained with variable presence of slate substance. The slate substance is more common in the marginal part of terraces, whereas towards the riverbed the sand is much more common.
Coarse-grained sediments: This group of sediments consists of coarse-grained material of the river layer and its tributaries. Gravels can be found along the river and the tributaries along the detritus and, in part, in the slope of lower rive terrace. Gravel is 1 to 2 cm in size of variable mineralogical composition. Fragments of magmatic and metamorphic rock are the most common. Gravel is of clear shape, the grains of Eocene flysch being elongated. The gravel in the magmatic rocks is more round in shape. The coefficient of filtration and angle of natural slope of the crest depend on the mineral composition and the size of the gravel grains and the mineral composition.
Present day mineralogical processes such as erosion and denudation of the entire basin have been found in the whole area of the River Otinja valley. In general, pronounced intense present day geological occurrences have not been found in the area of the water reservoir area. There are no classical landslides in conditions of created accumulation. Filling the basin with water and variation of water level may result in small landslides in some areas. Such will be the areas of flysch diluvial layers being of little importance for the water reservoir. Such possible occurrences can be followed during water reservoir exploitation and occasionally rehabilitated with removal of the material.
Decomposition of rock masses and Eocene sediments in the place designated for crest construction and accumulation area. The intensity of fissuration of rocks may result in activation, acceleration and deepening of erosion process.
As the separation and accumulation area are made up of granite and Eocene sediments, decomposition depends on textural and structural properties of rock masses and their microtectonic damage. Climatic conditions and configuration also play an important role.

Such phenomena are manifested as 5 m thick arenite zone in the upper parts of the water reservoir.

6. Hydrogeological characteristics obtained with previous investigations

Two kinds of rock masses have been found in the partition place and the accumulation area, which are of importance for the hydrology in the area:

- bound rock masses of cracked and fissure porosity, and
- unbound sediments of inter-grained porosity.

Bound rock masses of cracked and fissure porosity is the place where several complexes can be distinguished: a complex of water permeable and impermeable rocks and sediments and complexes of poorly water permeable masses.

- The complex of water permeable and water impermeable rocks and sediments includes rock masses of Eocene flysch sediments very common in the areas of the accumulation area. They are present as water permeable carbonate rocks and sandstones. Since they are not very frequent they have little influence on the permeability of the rock masses in the flysch complex.

- Another type of rocks in the flysch sediments (water impermeable, insulators) is the clays and marls through which ground water can not flow except through some cracks and faults. As flysch sediments rhythmically alternate, there are no water impermeable parts in them.

- The complexes of poor water permeable rock masses include granites. These are poorly water permeable rocks, but owing to fissuration, occasionally water permeability is intense.

- The type of unbound sediments of inter-granular porosity includes:
  a. a complex of water permeable sediments,
  b. a complex of water impermeable sediments.

Complex of water permeable sediments: The complex includes the sediments of the lower river terrace and river detritus of the Otinja. They are mostly gravels and sands with high possibility of ground water filtration and accumulation. Filtration coefficient k amounts to 10^{-4} (m/s). In thicker sediments, better granulometric composition and coarser-grained fractions there are possibilities of accumulation of larger amounts of ground water. Ground water originates from atmospheric precipitation and from the river when it is of higher water level and when ground water movement and river coincide.
The complex of water impermeable sediments in the water impermeable sediments consists of diluvial slaty sediments. In the type and characteristics of porosity are such as they do not allow accumulation of ground waters or filtration through them is impossible. Based on their position in the terrain, they have a positive effect on the water runoff from future reservoir.

7. Analysis of the location for the construction of the water reservoir crest

When creating the technical part, several cross sections of manifested instability were analyzed when the current and newly created state for rehabilitation was analyzed.
All investigations were taken in consideration with regard to defining the crest, the plain of landslide, fault zone, granite foliation, lithological pattern were analyzed using the Method of Bishop. Analysis of the stability of this method was carried out for specific possible circle-cylindrical sliding plains.
Safety coefficients are determined according to the expression:

$$F = \frac{1}{\sum W \cdot \sin\alpha} \sum \left[c' \cdot b + W(1 - r_u)\tan\varphi' \right] \frac{\sec\alpha}{1 + \frac{\tan\alpha \cdot \tan\varphi'}{F}}$$

When pore pressures are determined based on the level of ground water, safety coefficient is determined according to the expression:

$$F = \frac{1}{\sum W \cdot \sin\alpha} \sum \left[c' \cdot b + (W - u \cdot b)\tan\varphi' \right] \frac{\sec\alpha}{1 + \dfrac{\tan\alpha \cdot \tan\varphi'}{F}}$$

Where:
W - is the strip weight,
A - drip of strip base towards the horizontal,
H - strip height,
B - base of the strip,
φ' - Angle of internal friction,
C - cohesion,
Ru - coefficient of pore pressure,
U - pore pressure calculated from the ground water level to the base of strip.

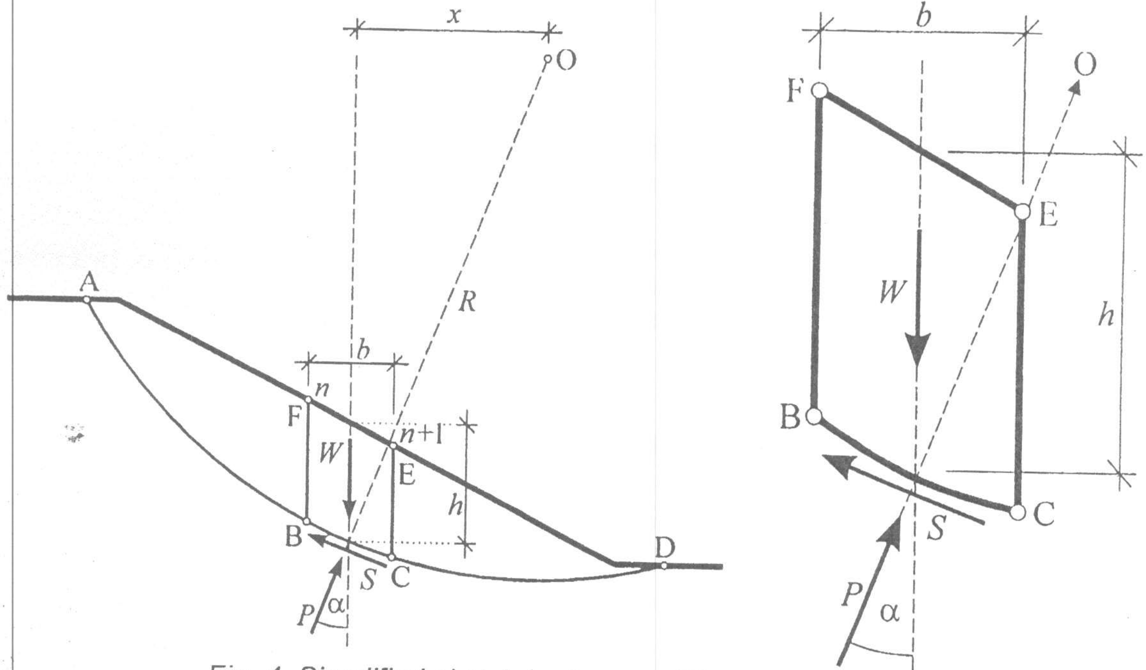

Fig. 4. Simplified sketch for the conditions and members used in the expressions of Bishop's method.

Method of Spencer. Calculation of stability by this method is similar to the one by Bishop, the difference being that this method takes into account the effects of interstrip forces that exert influence under some dip along strip height. This method makes it possible to analyze potential plains of sliding with arbitrary geometric shape. In this case, safety coefficient reflects the relationship between shearing strength S_m:

$$F = \frac{S}{S_m}$$

The result of inter strip forces is determined according to the expressions:

$$Q = \frac{\dfrac{c' \cdot b}{F}\sec\alpha + \dfrac{\tan\varphi'}{F}(W \cdot \cos\alpha - u \cdot b \cdot \sec\alpha) - W \cdot \sin\alpha}{\cos(\alpha - \theta)\left[1 + \dfrac{\tan\varphi'}{F}\tan(\alpha - \theta)\right]}$$

and it must meet the conditions of forces of balance in x, or in y direction:

$$\sum[Q \cdot \cos\theta] = 0; \quad \sum[Q \cdot \sin\theta] = 0;$$

and the balance condition of the moments around pole O:

$$\sum[Q \cdot R \cdot \cos(\alpha - \theta)] = 0$$

In this, safety coefficient F and the inter strip dip 0 are selected or calculated so that all balance conditions can be satisfied.

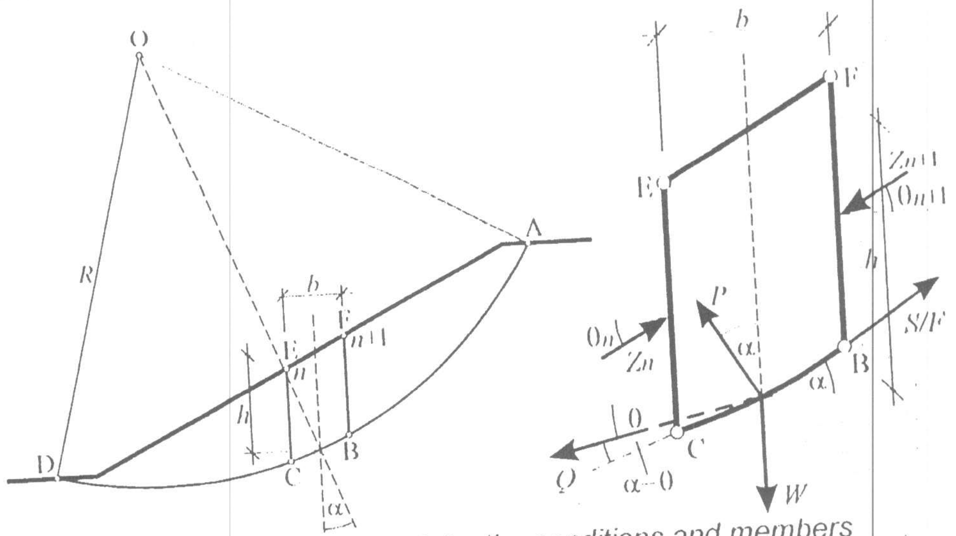

Fig. 5. Simplified sketch for the conditions and members used in the expressions of Spencer's method.

The methods of Bishop and Spencer with special software package GeoStudio 2004 were used to make several cross-sections of slope for field stability or where the most optimal location for the crest of the Otinja water reservoir would be (fig. 6).

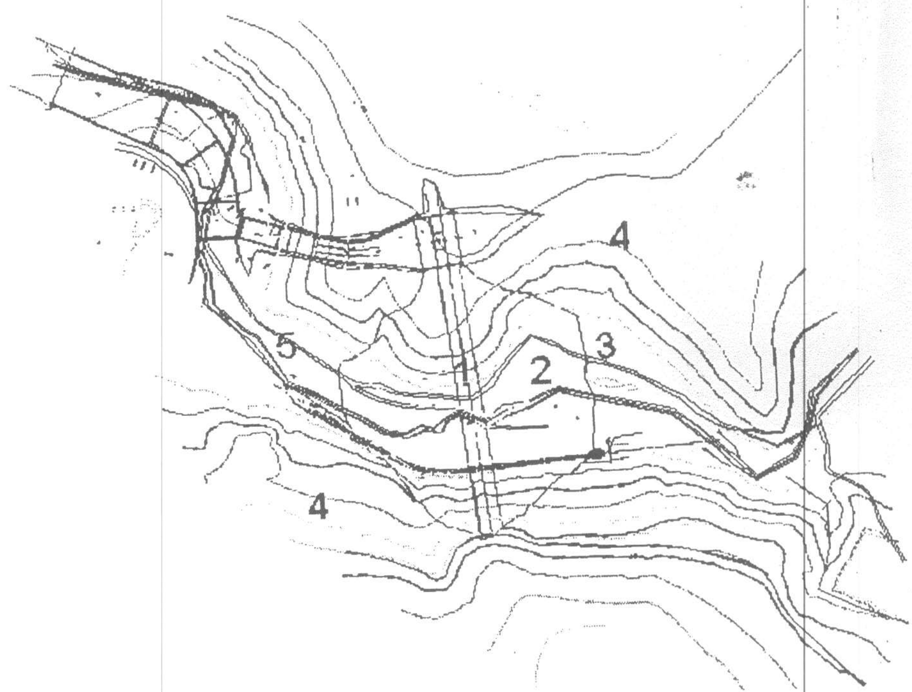

Fig. 6 – 1 - Dam crest, 2 - upper river terrace, 3 - lower river terrace, 4 - granite rock mass, 5 - River Otinja.

From Fig. 6 and the cross section calculated is obvious that the optimal place for the partitioning of the basin of river Otinja is the granite series on both margins of the river. Fig 7 gives the cross section that is further analyzed with the two above mentioned methods for field stability. The results are given in table 2, table 1, give the input data of the geomechnaical characteristics for the field according to Hoek and Brown.
The lowest peak, bedrock of the river, is 300. In the field, on the right side it rises to peak 357, on the left side to peak 368.

Zones marked with no.5 are zones, which according to optimal solutions, of possible landslic
and should be rehabilitated on time, so that construction work can be completed for the cres
the river Otinja.

Stability mode on the right side of the cross section is 3.259, and on the left side of the cr
section it amounts to 2.316.

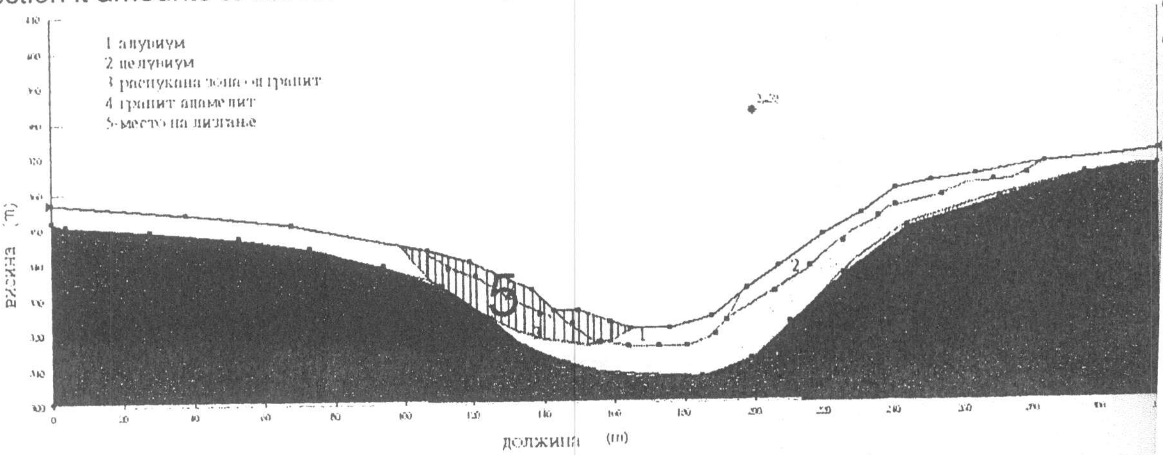

Fig. 9.

From the total filed investigations, geological, geomorphologic, hydro geological and optimal cross sections made for the construction of the partition dam crest, 3D model made in AutoCAD software packet 2007 shown in fig. 10

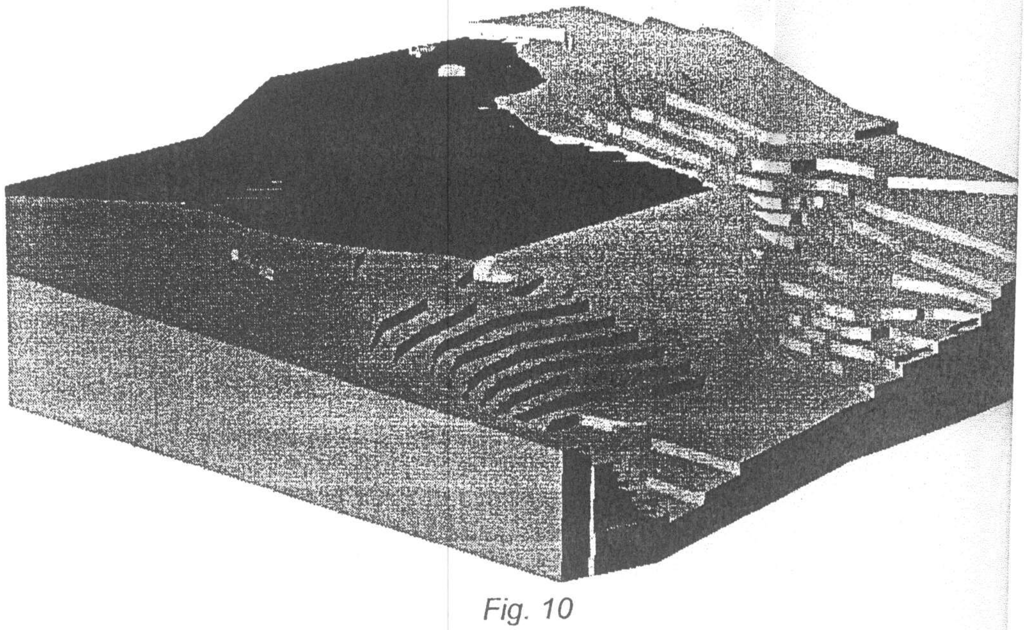

Fig. 10

Conclusion

From the field investigations obtained and the parameters obtained by software pa optimal safety model was obtained for the crest of the embankment dam on the Otinja.

The dam, which has been planned for construction for a long time, would be a good sol the improvement of the quality of human living in terms of water supply, improve climatic conditions in the region of Stip and the wider vicinity as well as improvemen environment.