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SEISMIC AND GEOELECTRIC TOMOGRAPHY RESULTS IN CONCRETE AND ROCKFILL DAMS IN ALBANIA

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Abstract

Results of seismic and geoelectric tomography in two large dams of Hydroelectro Power Plants in Albania are presented in the paper. These Hydroelectro Power Plants have an installed power 5 MW up to 600 MW. Their dams have a crest length up to 500 meters and maximum height of 165 meters. The dams have been in situ investigated by geophysical methods during the period 1995-1998. The results of these investigations and the technical data on the stability of the constructive materials and rocks will be used to apply the modern dynamic methods for re-estimation of the stability of the hydrotechnical construction.

1. Introduction

Albania has numerous and biggest dams belonging to the hydroelectric power system. These dams are made of concrete and/or rockfill with central clay core. Bigger hydrotechnical work in Albania, the Fierza Hydroelectro Power Plant, has an installed power of 500 MW. The volume of water in its artificial lake is 2.7 billion m^3 (Hydropower Plant Executive Projects, 1953-1988). This hydrotechnical work composed of several constructions. The rockfill with central clay core dam is the biggest assemblage therein. The dam has a crest length of 500 meters and maximum height of 165 meters. In Albania have been constructed also about 600 dams for the reservoirs of the irrigation system, constructed in a short period of about 30 years. The height of their clay dams varies among 10 and 40 meters, while the crest length of the dams goes up to 3 500 meters.

The exploitation of hydrotechnical work over the last 15 to 40 year has influenced the modification of their physical- mechanical properties and constructive structure. Under present conditions, the re-estimation of the stability of the hydrotechnical construction was necessary. In this case, the acquisition of geophysical data on the stability of the constructive materials and rocks was very important in order to apply the modern dynamic methods of such re-estimation. These data were extracted from the in-situ geophysical investigation, which had to go through the following steps (Frasheri A. et al., 1998):

1. Investigation of constructed material which the dam was build up:

1.1. The studies of the structure of the construction material,

1.2. The determination of its physical-mechanical properties.

1.3. The evaluation of the variation of these properties in times.

2. The estimation of slope stability and the study of landslides in the lakeside.

3. The investigation of the grout curtain under the dam in riverbed.

4. For the future is planned: the estimation of the remnant deformations of the dams, monitoring of the dams and the active landslides, the study of lake fillings with alluvium sediments.

Large number of case histories analyzed from various objects is analyzed in the paper.

1. Methods

A complex of geophysical methods was applied for in-situ investigation of the dams (Frasheri A. et al., 1998, Robert C. Benson et al. 1983). Seismic tomography of concrete along the galleries of the dam, and between the galleries and dam top surfaces was carried out. The tomography was combined with refraction seismic profiling of high frequencies on the top surfaces of the dam, and in galleries of the concrete dams as well. The quality of the grout curtain under the dam in the riverbed was investigated in situ on the gallery floor. Geophones lines with lengths from 0.5-43 meters, according to the object’s size and the required depth investigation were used for the seismic observation. Creation of the seismic waves was performed by mechanical source. A seismic 12-channel station ECHO-2 of Canadian Firm SCINTREX was used to make the recording. Records were made by the company's software package. According to the surveys' data the velocity of P-waves (Vp) and S- waves (Vs) were calculated, as well as the layer thickness. According to all the seismic data, the physical-mechanical properties were calculated for the soil, rocks and concrete of the dams such as Poisson coefficient, elasticity dynamic modulus of, Bulk modulus, rigidity modulus and module of compression volume strength.

Geoelectrical tomography to investigate the clay core of the dam's raw materials was carried out. Resistivity Realsection of the Geoelectric tomography were performed by multiple spacing gradient arrays, with maximal spacing up to AB = 360 m, which provided a survey depth of 50 to 70 m. Profiling was performed in four depth investigations, according to the required depth investigation for each object.

Alongside in the downstream area of raw materials, self-potential surveys were also carried out, in order to study the water filtering process through it.

3. **Discussion of the results**

The seismic and geoelectric tomography results presented in this paper was carried out for dams investigation of Ulza and Vau Dejes Hydroelectro Power Plants (Frasheri A. et al. 1998). Ulza Hydroelectro Power Plant, constructed in 1957, has an installed power 25.6 MW (Executive Project, 1953). The Ulza concrete dam has a crest length of 340 meters and maximum height of 131 meters (Photo 2). Vau Dejes Hydroelectro Power Plants, constructed in 1971, has an installed power 250 MW (Executive Project, 1967). Two sections compose Qyrsaqi dam in Vau Dejes: Concrete section (1) and gravelfill with central clay core section (2) (Photo 1). The dam has a crest length of 480 meters and maximum height of 79 meters. Geoelectric tomography was performed only in the raw materials section of this dam.

In-situ geophysical investigations were carried out in order to resolve a wide specter of duties in several objects.

Evaluation of the concrete physical-mechanical properties

Tomography data at 30 m and 53.5 m in the concrete section of the Qyrsaqi dam showed that, generally, the concrete has a characteristic wave velocities of greater than Vp=4000 m/sec and Vs=1900 m/sec (Fig. 1). But, at the left dam edge, an area where the Vp decreases to less than 4000 m/sec exists. The fact that, together with the P-waves velocities, the S-waves velocity decreases, shows that in this sector, the concrete has weaker physical and mechanical properties.

It is not enough to use only the seismic tomography among different galleries, because this leads to deficiencies in results and incorrectness in details. These results were compared with the supplementary seismic profiling on the concrete structure, especially in superficial spots. The concrete bottom of inspection galleries in Qyrsaqi dam also has good physical-mechanical properties. But in some sectors of the galleries, a superficial layer of some centimeters to 1 meter is attached, which mechanically is weak (Fig.2, 3, 4). The mechanically weak concrete layer shows that the concrete will deteriorate under the water's effect, or the cementing in these sectors was made by poor quality concrete. The surveys and tests we are going to develop further on will resolve this alternative.

In the Ulza Dam (Fig. 5, 6), results from the seismic tomography survey indicates that the concrete in general is also characterized by high velocities of the seismic waves propagation Vp= 4300-5035 m/sec and Vs= 2412-2429 m/sec. The elasticity dynamic modulus is (3.27-3.60)x10^5 kG/cm^2. According to the tomography data, it is noticed that at the upper levels of dam , the longitudinal wave velocities Vp are, on average, higher than the lower levels . At the same time, at both levels, the transversal wave velocities are equal. In addition to that, the average square deviation of transversal wave velocity is almost twice less than the longitudinal wave deviation. These facts are an argument that the decrease in velocity and high fluctuations in velocities impacts on water penetration into the concrete pores. The velocities (Vp) in the lowest levels are lower than in the upper levels, as a result of being under constant high water pressure. The concrete of lower levels also contains more water. The mechanical properties of this concrete are also weaker than the upper levels. Considering the concrete mark 250 for lower levels (Dzievanski J. et al., 1981), based on the calculated physical-mechanical properties, the upper levels have concrete of higher value than 250, because the elasticity dynamic modulus is 3.96 x 10^5 kG/cm^2. In the tomogram it is possible to define a sector which characterized with physical-mechanical properties lower than the surrounding environment. Within this sector, the main water filtering of the gallery of lower level is observed.

Even at the dam of Ulza the inner walls of the inspection gallery, as well as in dam surface, have a low elasticity dynamic module, up to 74.000 kG/cm^2 (Fig. 7). At this sector, several filtration of Lake Water are evidenced in the inner of dam. This state of concrete at the Ulza dam shows once more the impact of “ageing” phenomena on concrete

Evaluation of the soil and rocks physical-mechanical properties

The clay material has a lower resistivity at the center and western edge of Qyrsaqi dam than the eastern edge (Fig. 8, 9). The seismic wave velocity is lower in this sector, too. The water filtering into the clay’s core explains this.

The average electric resistivity of the dam’s core is about 100 Ohmm. However, in 5 sectors of the dam’s core, this resistivity decreases up to 25 Ohmm in spots. As it is shown at the Resistivity Realsection, these anomalous spots are located at 3 m depth to 45 m from the level of dam’s top surface (Fig. 4). It is evident that three of these anomalies coincide horizontally. The anomaly, which happens under the station ST. 20, initiates from 22 m depth and continues to 45 m, has a vertical extent, and dips toward the west.

The seismic tomography section shows that, beneath the superficial layer at the top of the dam, which has a thickness of 2–10 m and low velocities of seismic waves, (respectively V_p=1080 m/sec and V_s=550 m/sec), there is a second clay layer (Fig. 8). This layer of clay has a thickness of 4 – 21 m, increasing in thickness towards the west, where the ground dam meets the concrete part of the dam. The velocities of seismic waves are lower in western dam sector. The clay’s core, under the second layer, is characterized by higher seismic waves velocities (up to V_p=2200 m/sec and V_s=800 m/sec). The elasticity dynamic module, calculated according to Vs data, varies from (0.04-0.88)*10^5 kG/cm^2 for the second clay core. Based on the geophysical investigation results, shown above, the areas with a lower electric resistivity and lower velocities of seismic waves than the other part of the dam's core, are interpreted to be due to water filtering through the clay core. This interpretation does not exclude the possibility of heterogeneity of the clay's material during dam's construction .The increase of velocities of the seismic waves toward depth shows than the clay's core is compacted. The configuration of seismic waves velocity contours in the section shows normal bedding of core's material, with western dip. The study of these dangerous phenomena brings the necessity of monitoring the dam through geophysical methods, along with all other installed equipment from the Geologic-Technical Service of Hydropower Plant. Some periodic investigation over many years are necessary in order to observed the changes in time of electric resistivity and the seismic waves velocities.

4.Conclusions

1. Concrete used to build hydroelectric power plant dams in Albania has different physical-mechanical properties, thus diverse technical state from each other. The higher quality of concrete is found in Qyrsaqi dam of the Vau Dejes Hydroelectric Power Plant. The lowest quality concrete is observed in Ulza dam.
2. At the dams of Qyrsaqi and Ulza Hydroelectric Power Plants, the existence of superficial concrete layers, up to 1 meter thick, are observed. These have very poor physical-mechanical properties.
3. In the central and western part of the clay core at Qyrsaqi dam, there are observed some sectors with low values of electric resistivity and velocities of seismic waves, more than at the side parts of the dam. The increases in physical properties are interpreted to result from water infiltration to the clay's core

5. References

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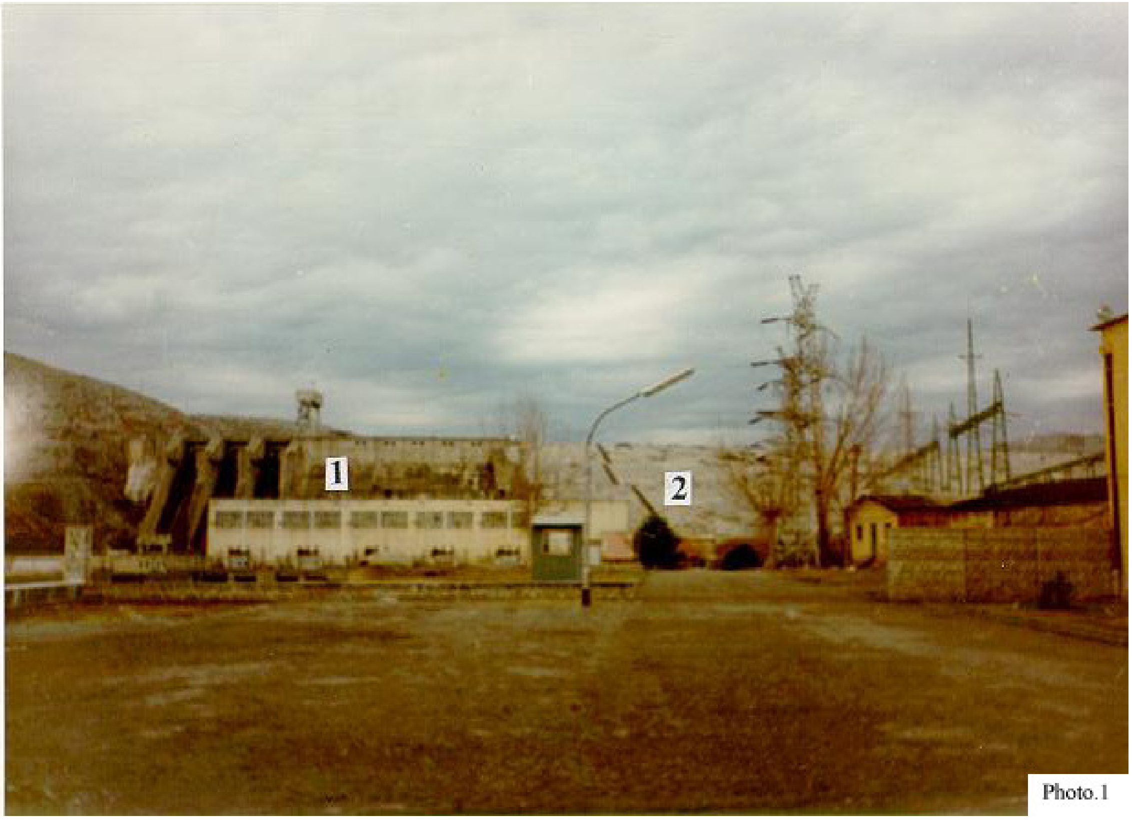


Photo.1

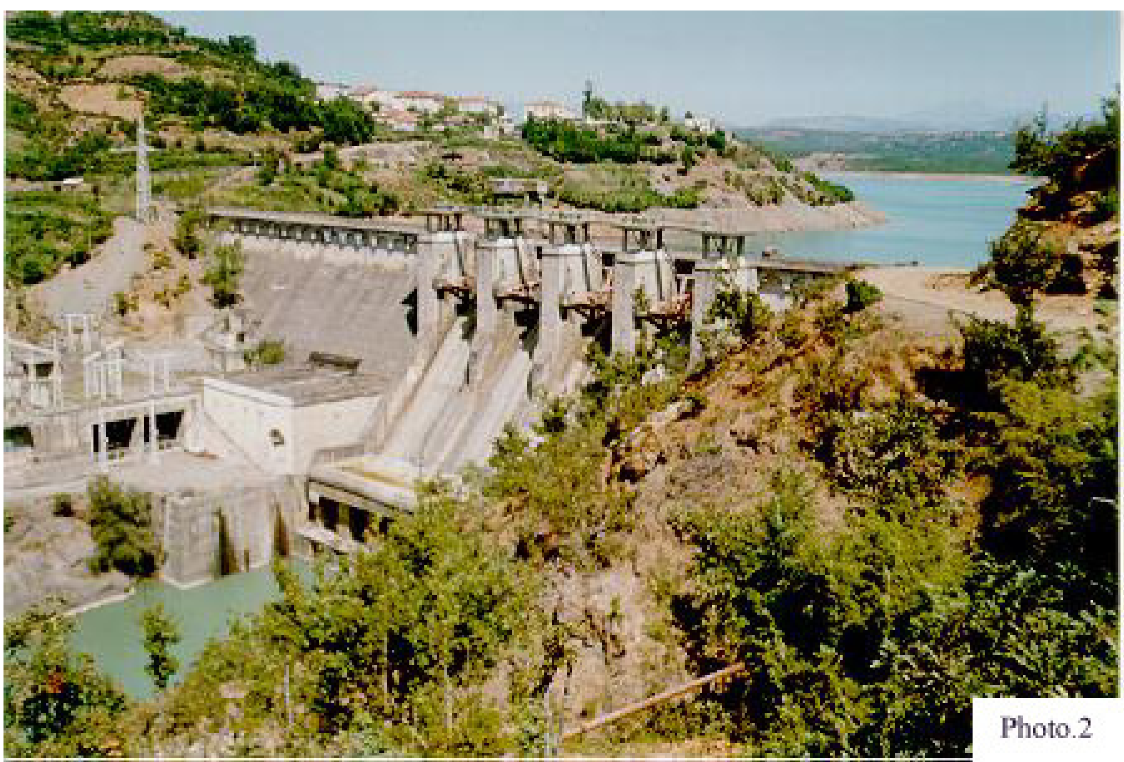


Photo.2

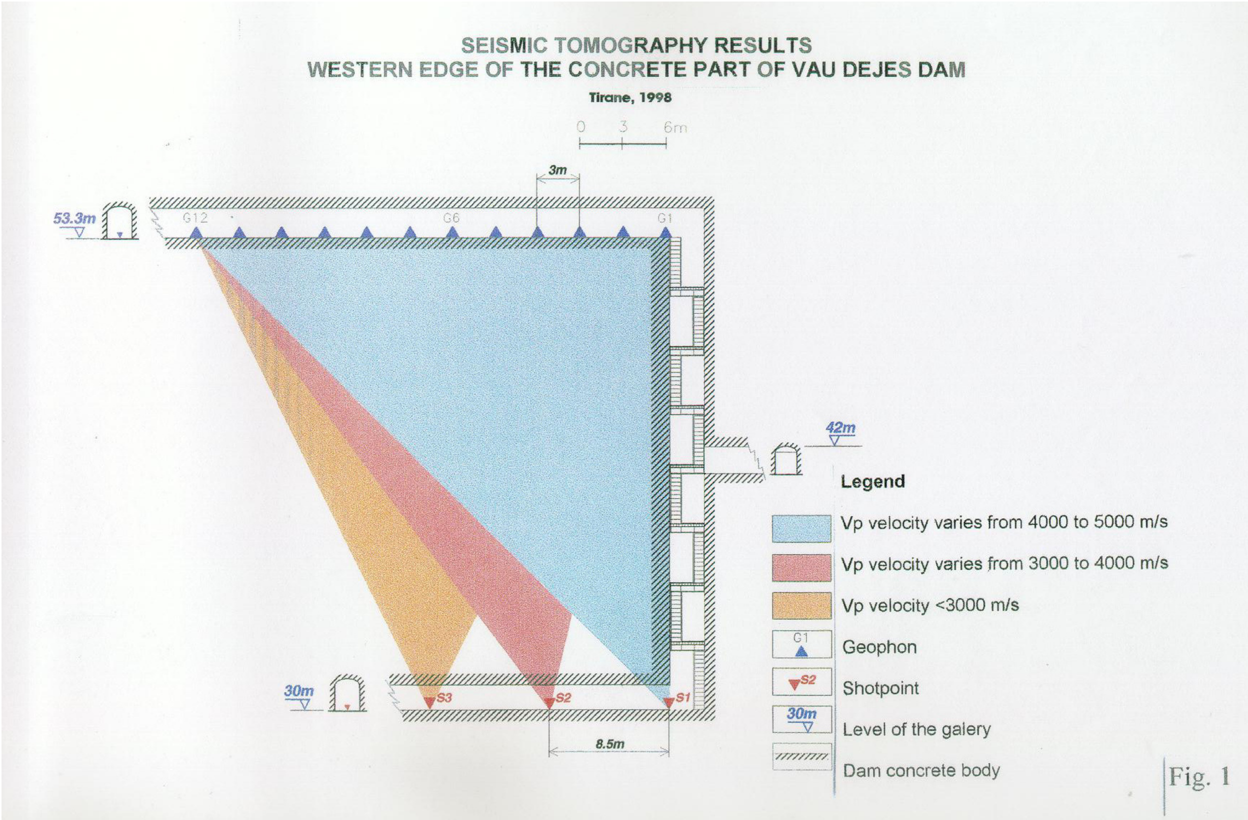

SEISMIC TOMOGRAPHY RESULTS
WESTERN EDGE OF THE CONCRETE PART OF VAU DEJES DAM
Tirane, 1998
0 3 6m
3m
53.3m
G12
G6
G1
42m
30m
S3
S2
S1
8.5m
Legend
Vp velocity varies from 4000 to 5000 m/s
Vp velocity varies from 3000 to 4000 m/s
Vp velocity <3000 m/s
Geophon
Shotpoint
Level of the galery
Dam concrete body

Fig. 1

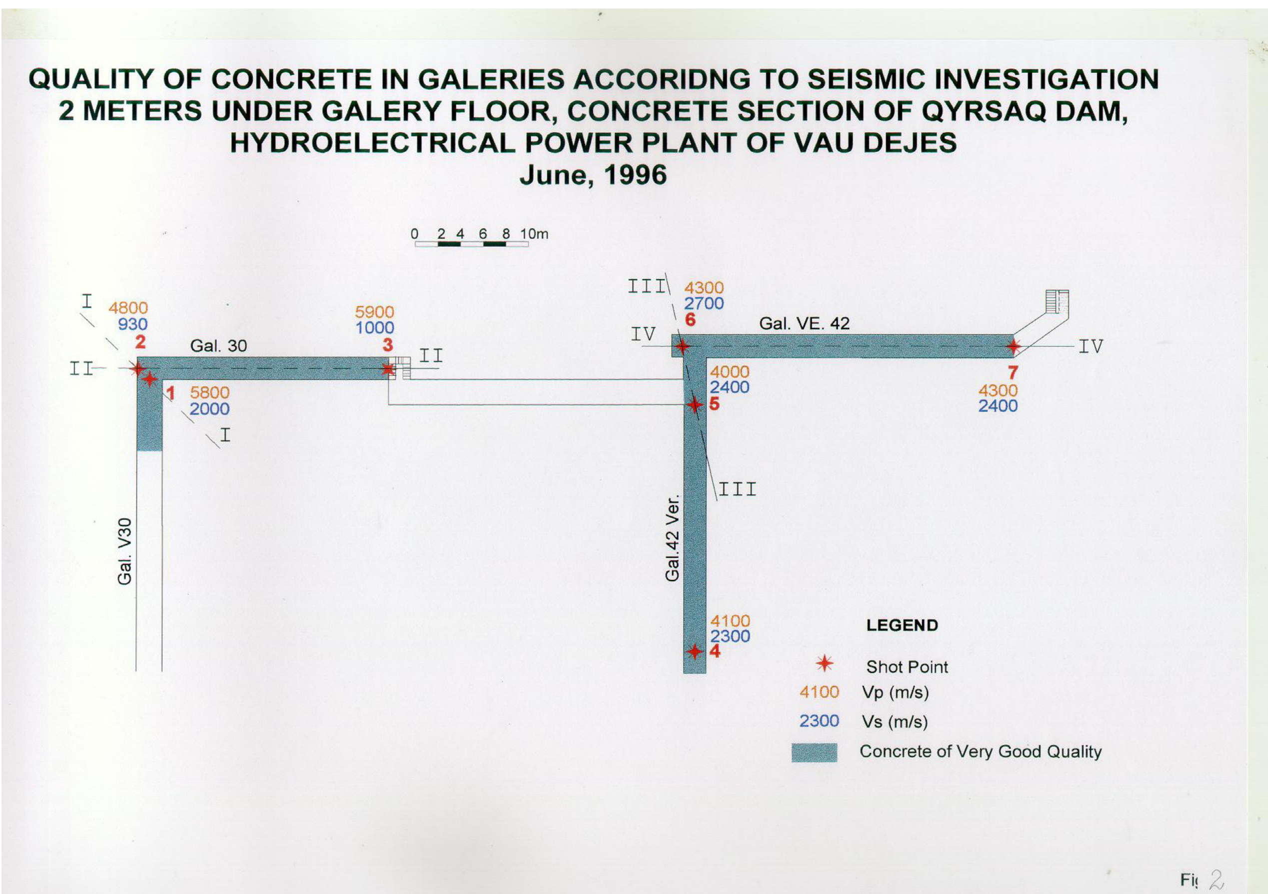

QUALITY OF CONCRETE IN GALERIES ACCORIDNG TO SEISMIC INVESTIGATION
2 METERS UNDER GALERY FLOOR, CONCRETE SECTION OF QYRSAQ DAM,
HYDROELECTRICAL POWER PLANT OF VAU DEJES
June, 1996
0 2 4 6 8 10m
I
4800
930
2
Gal. 30
II
1
5800
2000
I
5900
1000
3
II
III
4300
2700
6
IV
Gal. VE. 42
IV
4000
2400
5
7
4300
2400
III
Gal. V30
Gal.42 Ver.
4100
2300
4
LEGEND
Shot Point
4100 Vp (m/s)
2300 Vs (m/s)
Concrete of Very Good Quality

Fig 2

QUALITY OF CONCRETE IN GALERIES ACCORIDNG TO SEISMIC INVESTIGATION 0.5 METERS UNDER GALERY FLOOR, CONCRETE SECTION OF QYRSAQ DAM, HYDROELECTRICAL POWER PLANT OF VAU DEJES

June, 1996

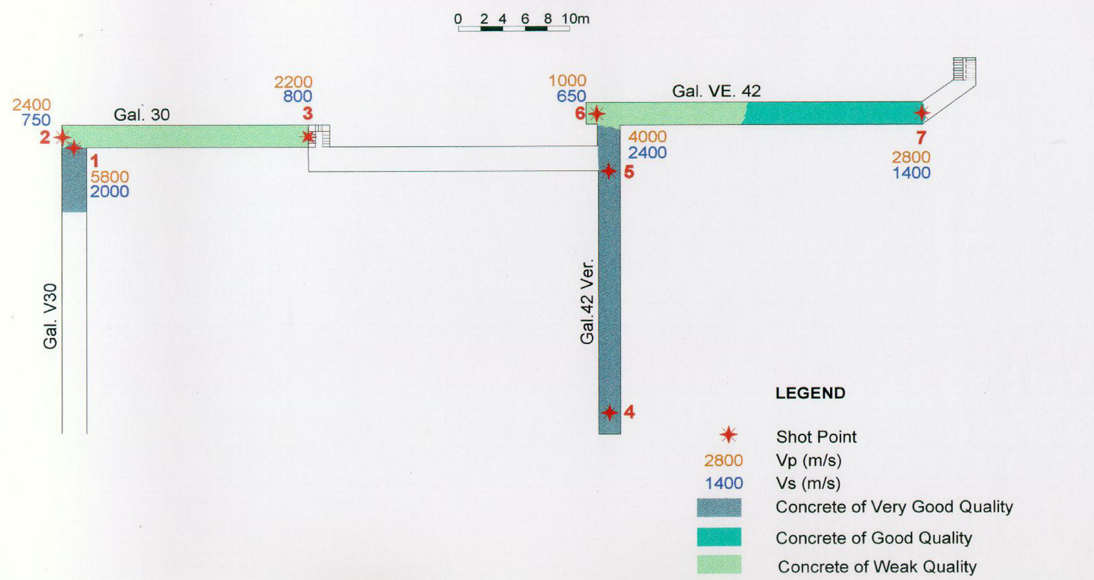
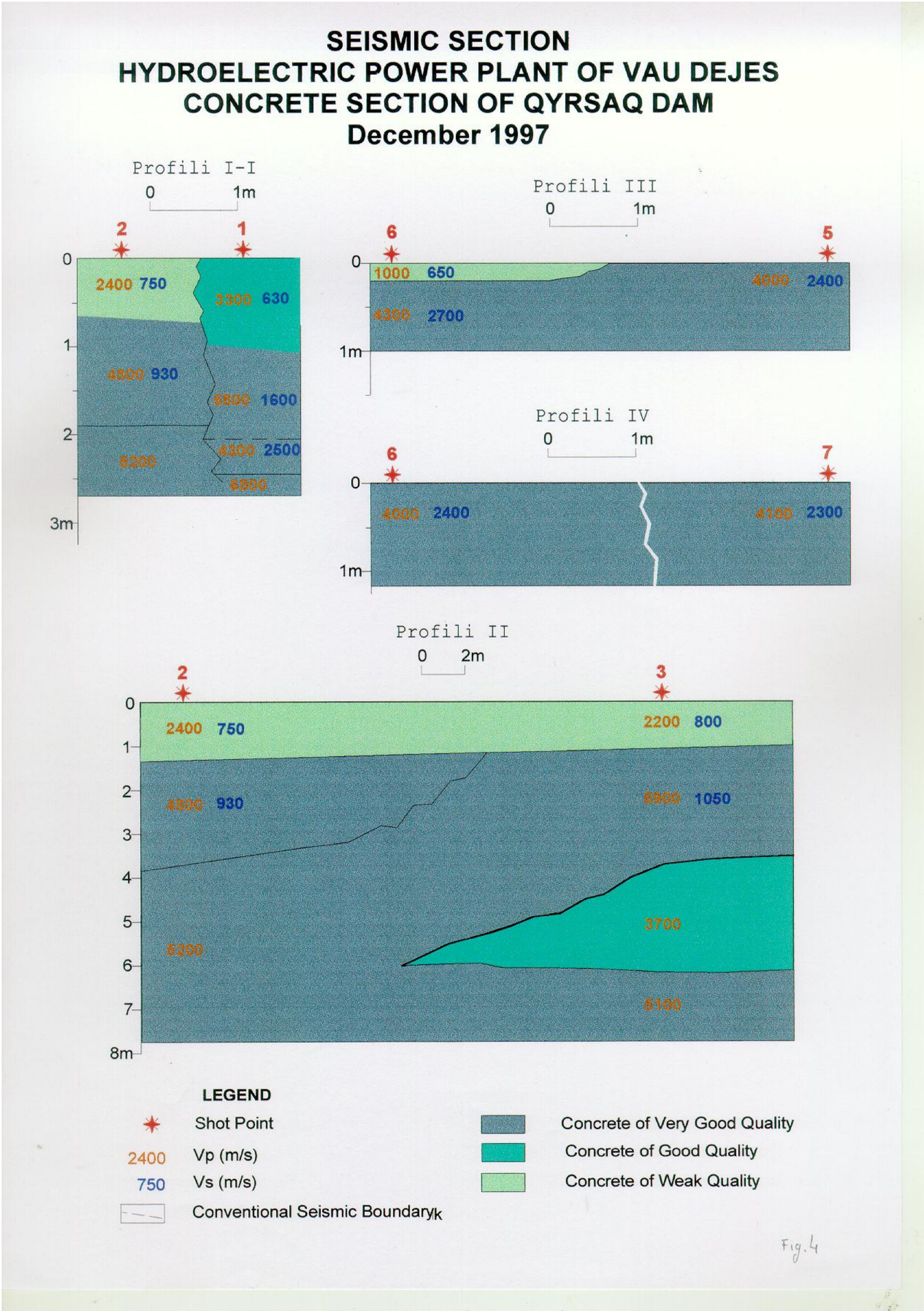
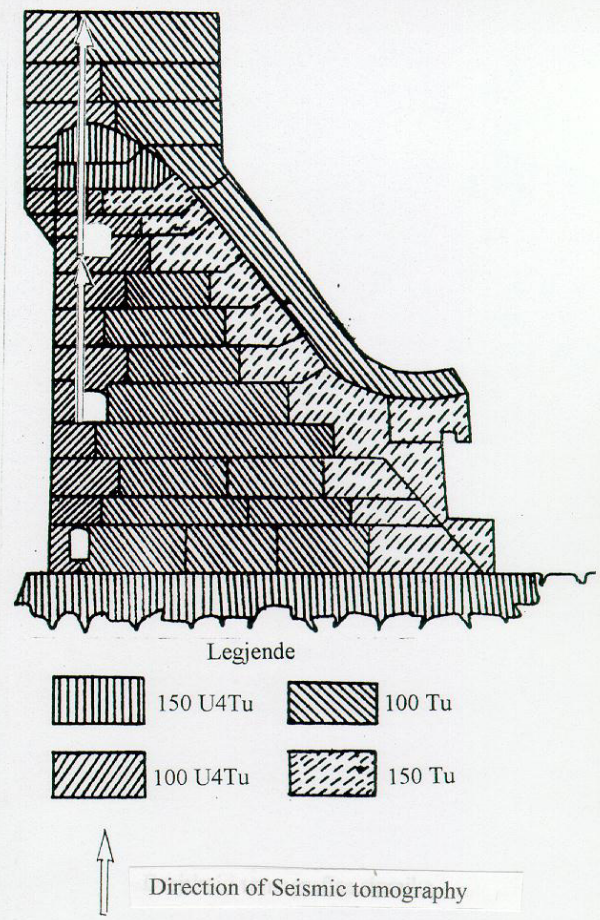


Fig.3



SEISMIC SECTION
HYDROELECTRIC POWER PLANT OF VAU DEJES
CONCRETE SECTION OF QYRSAQ DAM
December 1997
Profili I-I
0 1m
2 1
2400 750
3300 630
4800 930
5800 1600
4300 2500
5200
6800
0 1 2 3m
Profili III
0 1m
6 5
1000 650
4000 2400
4300 2700
0 1m
Profili IV
0 1m
6 7
4000 2400
4100 2300
0 1m
Profili II
0 2m
2 3
2400 750
2200 800
4800 930
5900 1050
3700
5200
5100
0 1 2 3 4 5 6 7 8m
LEGEND
Shot Point
2400 Vp (m/s)
750 Vs (m/s)
Conventional Seismic Boundaryk
Concrete of Very Good Quality
Concrete of Good Quality
Concrete of Weak Quality
Fig. 4



CONCRETE BLOCKS WITH DIFFERENT QUALITY OF ULZA DAM

Fig.5

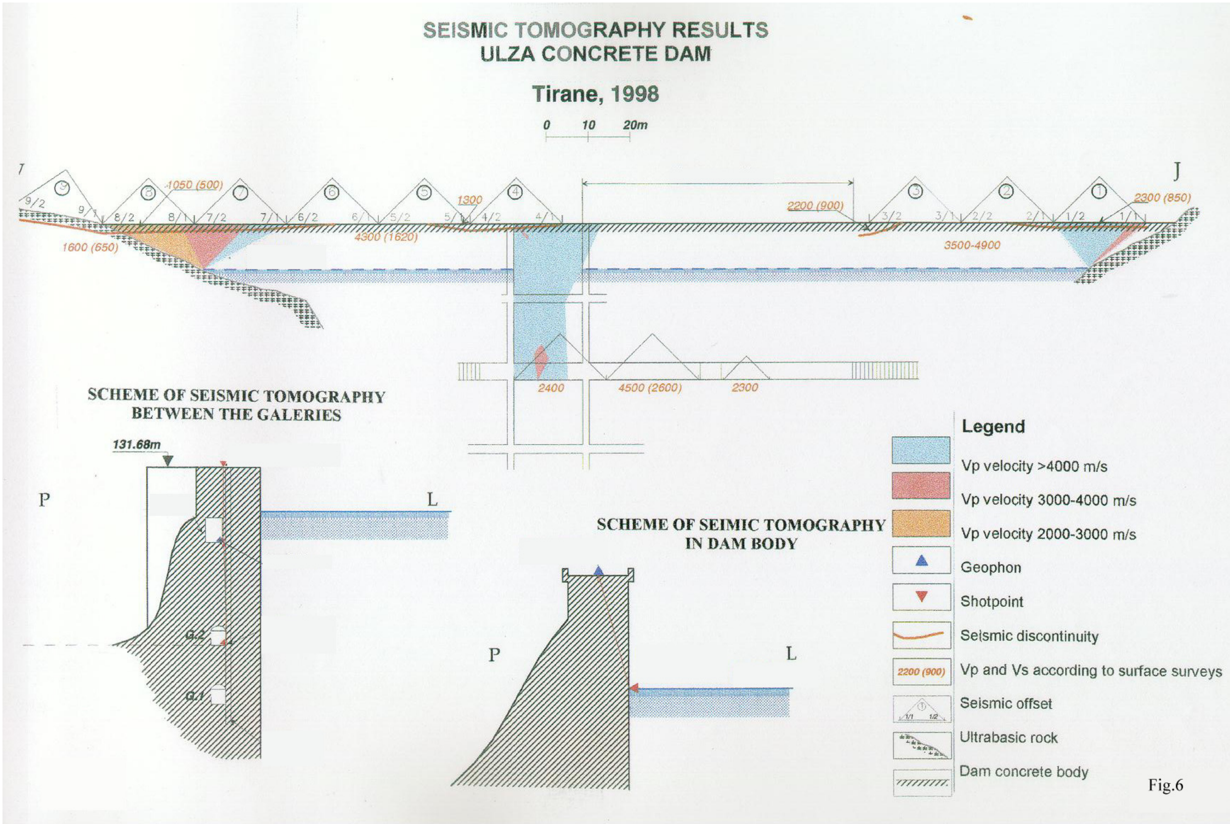

SEISMIC TOMOGRAPHY RESULTS
ULZA CONCRETE DAM
Tirane, 1998
0 10 20m
1050 (500)
1300
2200 (900)
2300 (850)
1600 (650)
4300 (1620)
3500-4900
2400
4500 (2600)
2300
SCHEME OF SEISMIC TOMOGRAPHY BETWEEN THE GALERIES
131.68m
P
L
SCHEME OF SEIMIC TOMOGRAPHY IN DAM BODY
P
L
Legend
Vp velocity >4000 m/s
Vp velocity 3000-4000 m/s
Vp velocity 2000-3000 m/s
Geophon
Shotpoint
Seismic discontinuity
Vp and Vs according to surface surveys
Seismic offset
Ultrabasic rock
Dam concrete body

Fig.6

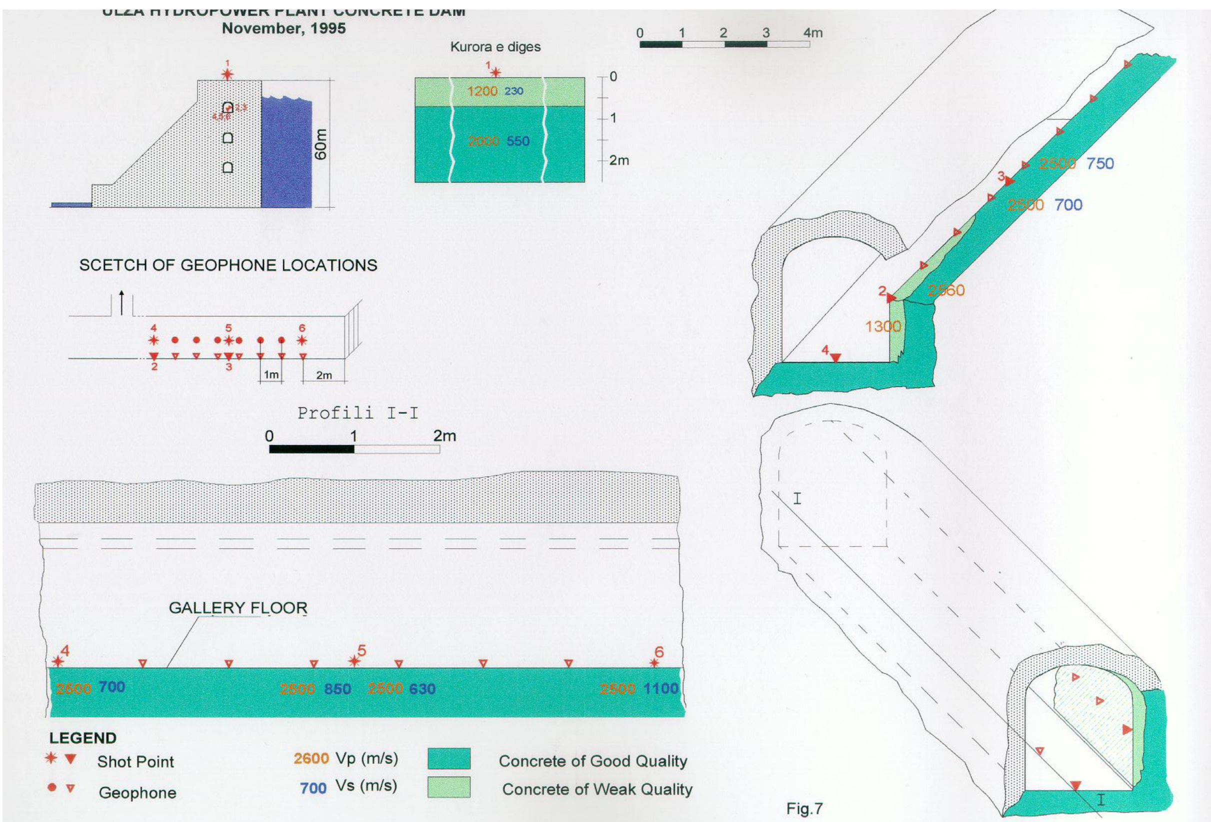

November, 1995
Kurora e diges
1200 230
2600 550
0
1
2m
60m
0 1 2 3 4m
2500 750
2500 700
2560
1300
SCETCH OF GEOPHONE LOCATIONS
1m
2m
Profili I-I
0 1 2m
GALLERY FLOOR
2600 700
2500 850
2500 630
2500 1100
LEGEND
Shot Point
Geophone
2600 Vp (m/s)
700 Vs (m/s)
Concrete of Good Quality
Concrete of Weak Quality

Fig.7

ELEKTRICAL RESISTIVITY REAL SECTION AND SEISMIC SECTIONS OF HEAD REFRACTION WAVE VELOCITIES Vp dhe Vs
VAU DEJES HYDROPOWER PLANT
RAW MATERIAL DAM
Tirane, 1998

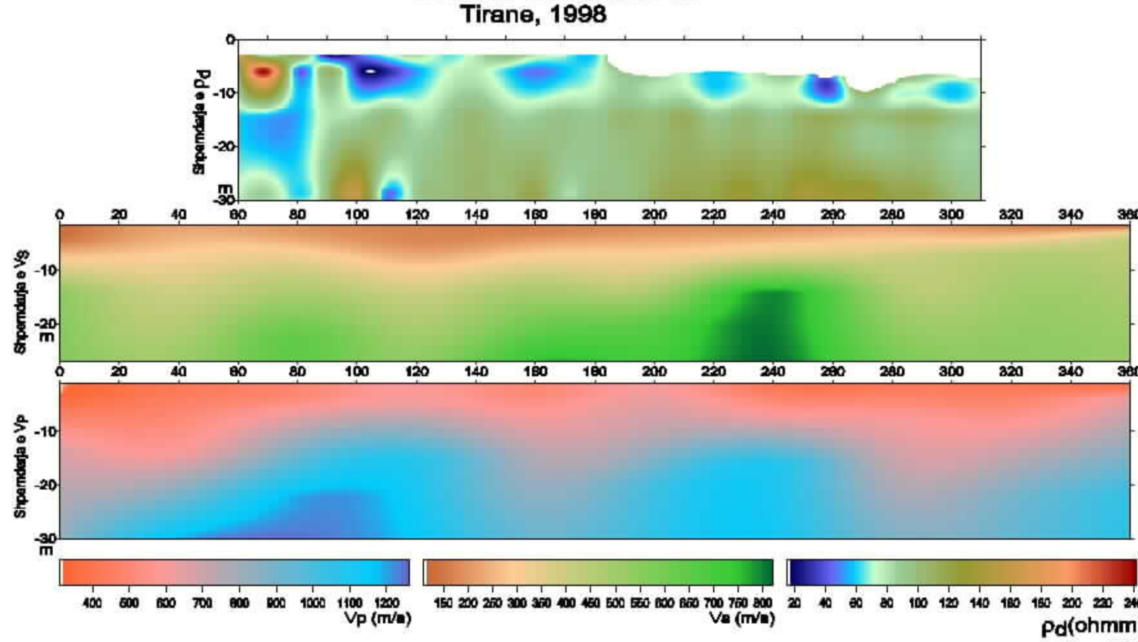


Fig.8

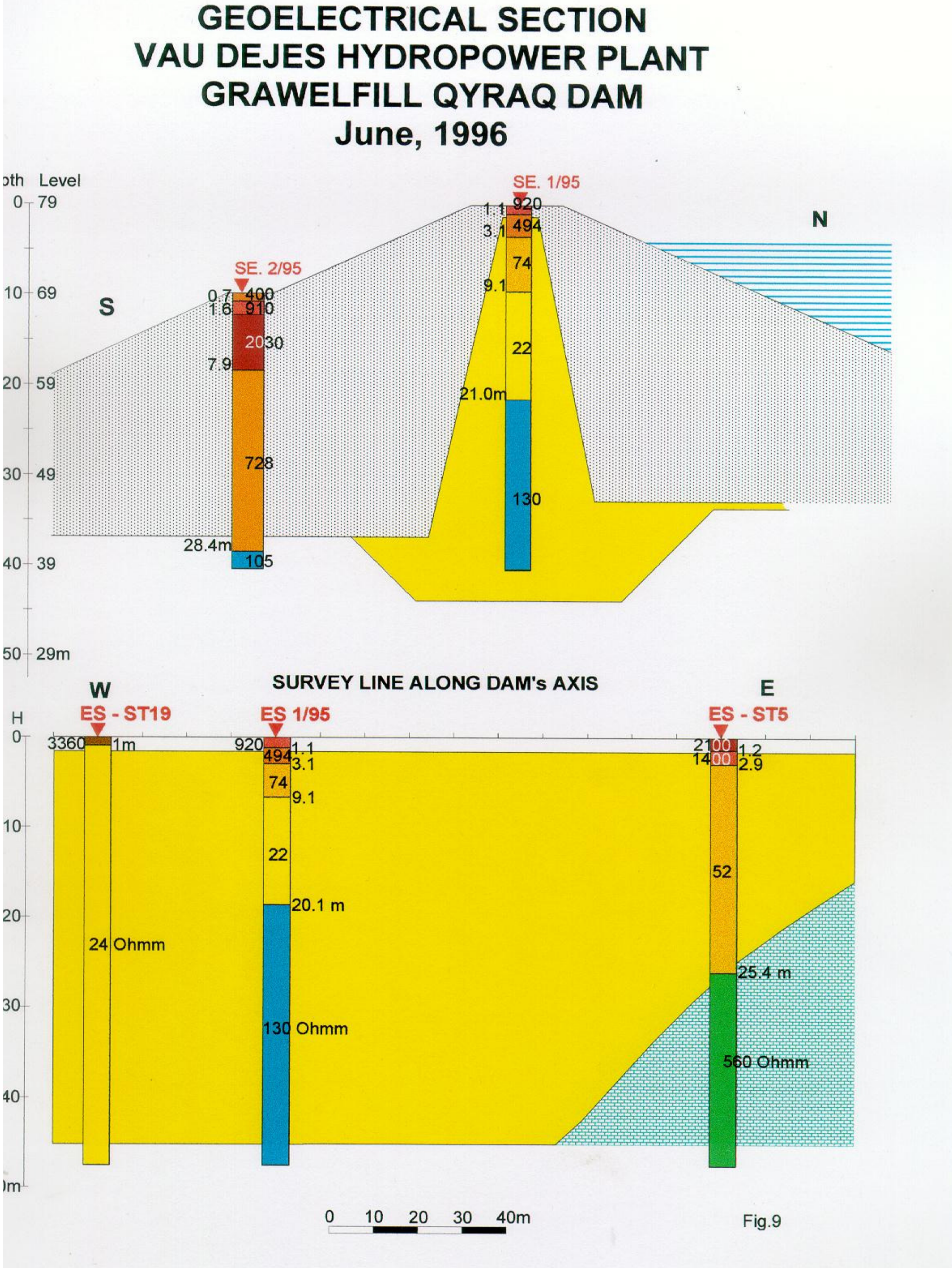

GEOELECTRICAL SECTION
VAU DEJES HYDROPOWER PLANT
GRAWELFILL QYRAQ DAM
June, 1996
Level
SE. 1/95
SE. 2/95
S
N
SURVEY LINE ALONG DAM's AXIS
W
E
ES - ST19
ES 1/95
ES - ST5
24 Ohmm
130 Ohmm
560 Ohmm
0 10 20 30 40m

Fig.9