Tunnelling and underground works in PPC hydro projects:
Contracting practices & construction management

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Public Power Corporation S. A.

a 49% privatized company with extensive experience on hydroelectric projects realization

Topic presented:

The practice used in PPC for contracting and executing underground works

Underground structures in a hydro project:

- diversion and power tunnels,
- tailrace and bottom outlet tunnels
- adits for grouting and drainage.
- power station caverns,

Hydro-Electric Projects completed in the last decades include:

- **Pigai Aoos** with tunnels and an underground power house complex in a depth of 400m,
- **Thissavros** HEP featuring an underground power plant, largest in Greece
- **Ilarion** HEP with spillway tunnels up to 12m diameter
- **Messochora** HEP with a 7, 5 km long power tunnel.

Thissavros HEP

PPC S.A.-Generation/Hydroelectric Generation Department organisation:

- 70s: foundation of the "Bureau" of Hydro projects design
- Upgraded in a branch of the company, the Hydroelectric Projects Development Department
- Nowadays, the activity is embedded in the Hydroelectric Generation Department

Design and construction branches included

Hydro scheme design and execution stages

Owner controlled procedure adopted for design, bidding, contract assignment, and supervision of works

Design branch tasks:

- Hydrology assessment,
- Hydro potential evaluation, feasibility studies, environmental assessment and permits issuing
- Surveying and expropriation.
- Geotechnical and geological studies for the dams and relative structures
- Civil works design
- Electromechanical design

Construction branch tasks:

- Preparing bidding documents
- Contract assignment
- Dealing with the questions-claims arising in the construction phase.
- Managing site offices

Site supervision units tasks:

- Managing the various contracts.
- Supervising timely and according to the specifications execution of works
- Deciding in a first stage on any question concerning contractual issues

The site office is very well organised with disciplines including engineers, geologists, technicians, foremen, administration support etc

Project stages

- **Feasibility Study**: evaluation of the site's potential + overall technical estimation of the conditions
- **Preliminary Design phase:** main questions are assessed and project's main data defined.

  -hydrology analysis

  -geotechnical investigation program

  Especially for underground works, extensive investigation is implemented with drilling and testing of cores.

  Rock mass classification is done and support measures assessment according to the NATM principles.

Project stages (cont.)

- **Design phase:** analysis of surface and underground structures, detailed drawings preparation, measurement of quantities and preparation of bidding documents.
- **Bidding procedure** for a project: this may include *multiple contracts* for civil and electromechanical works, depending on the timing for implementation and the specialization of the contractor.
- **Construction phase** in which the *contracts are activated in stages*, starting from the diversion tunnel works and progressing with dam and appurtenant structures construction, the implementation of the power tunnel and power house contracts. Supervision of works according to the specifications and coordination of the contractors is the task of *the site office*

Underground excavations:

Complex works with uncertainties arising from the difficulty of assessing precisely the actual ground conditions

Key contractual conditions in underground works:

The contractor

- Is fully aware of the results of the geotechnical investigations executed in the design.
- Is responsible for assuming rock mass properties and behavior and for choosing excavation means and effective support

In reality,

- Management of the underground works in PPC contracts endorses a comprehensive level of *flexibility*, while the *day by day collaboration* between both parts at site guarantees the smooth handling out of the job. So, *a fair risk sharing* between the owner and the contractor is practically achieved.

Key contractual conditions in underground works (cont.)

Detailed unit prices are provided for all tunneling items expected to be needed

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flexibility in adapting the job to the real conditions

- Payment is made for actual tunneling work

Key contractual conditions in underground works (cont.)

- **rock classification** and appropriate *support* type are decided at the tunnel face, with mutual agreement between owner's and contractor's engineers and geologists
- The decision is based on well defined **criteria** that, in the latest contracts are based on *rock type description*, *strength and fracturing evaluation, rock mass GSI rating results of in-situ inspections, hydro geological routine documentation, and geotechnical measurements.*
- Day by day evaluation and interpretation of such information helped in running the contracts without problems in most of the cases.

Key contractual conditions in underground works(cont.)

Alteration in ground conditions outside contract limits:

- Is practically tackled with extra support measures applied by the contractor and/or changes in the methodology.

  This may be done without the immediate approval from the supervision or the designer
- the advice of an outside tunneling expert is usually followed.

Contractual conditions in underground works (cont.)

In the case of no agreement, a **procedure for dealing with claims** is prescribed in the contract, that includes:

- Examination of the case from the site office upon submittal from the contractor of all the related documents within a period of 30 days
- If no agreement is achieved, the claim is transferred to the managing unit of PPC/HGD
- In the case of final non agreement, a procedure of *"amicable settlement"* can be triggered before the case arrives to court. The examination of the claim by an independent committee can be done and this gives the possibility to settle the matter in most cases.

Focus on specific projects
Pigai Aoos

- The project comprises a Main earthfill dam 80m high and 6 saddle dams, a 144,5x10^6 m^3 net storage reservoir, situated on a high elevation plateau, between el. 1300 and 1400m a.s.l.
- outflow from the power house ends down to the Metsovitiko river at el. 650m a.s.l.

Pigai Aoos

underground structures:

- diversion tunnel 0,65km long,
- headrace system (tunnel and penstock) 3,5km long,
- vertical shaft 440m high,
- underground 210 MW power house and
- tailrace tunnel 2,8km long.

3 main tunnelling contracts were implemented

NATM principles were not directly endorsed at that time in the technical specifications. and rock classes were not defined, work was practically done by estimating rock quality at the tunnel face by supervision geologists and the engineer in collaboration with the contractor and adjusting the support measures accordingly.

Pigai Aoos
Contract PAH-1

- Excavation of the 1,6km long access to the powerhouse tunnel and the 2,7km tailrace tunnel.
- Contractor: Norwegian firm SELMER-FURUHOLMEN
- Contractual cost $1,7x10^6$ euro (equivalent price 1981)

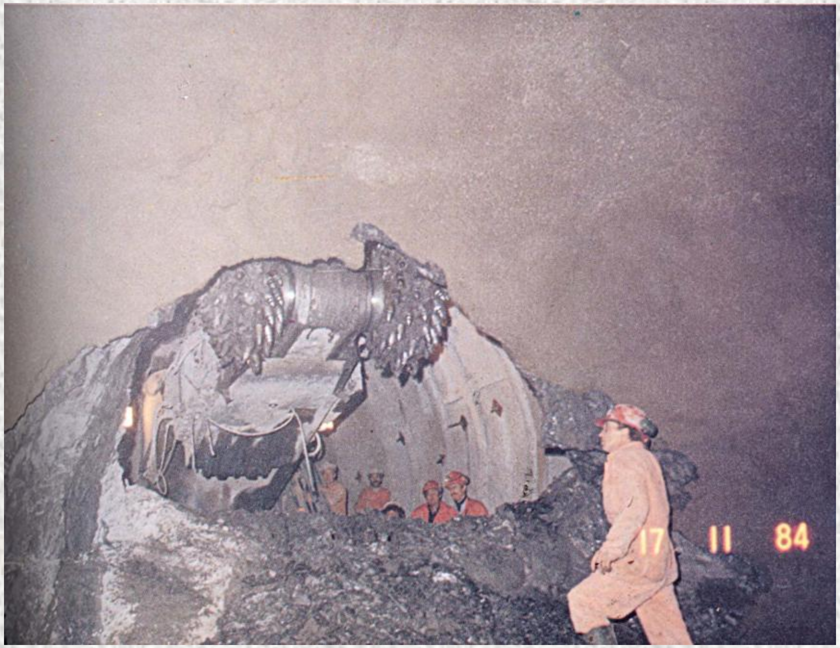
Pigai Aoos
Contract PAH-1

- Difficulties encountered mainly concerned poor *geological conditions of the tailrace drive* that was mainly mechanically bored, with a roadheader machine, through flysh formations, mostly folded, and fractured claystone.

Large deformations were locally observed and a wide range of support measures, including steel sets in the 20% of the total length of the tunnel, had to be applied.

Pigai Aoos
Contract PAH-1

- Outside international arbitrage has been implemented, as it was foreseen in the contractual documents, in resolving main questions and claims focused on geological conditions of the tailrace tunnel.
- A 2,5 years period was necessary to complete the excavation and lining with cost overrun for the contract approximately at 26% , which was fully justified taking into account the conditions



Pigai Aoos
Contract PAH-2SA

- Excavation & concreting of the 3,2 km long power tunnel, ending at the surge shaft, and the upper valve chamber. Contractor “ODON & ODOSTROMATON”
- In good rock conditions, mainly in sandstone formations requiring bolting and shotcrete support.

- duration of the contract: 3 years
- 21% cost overrun on the 4,2 equivalent million euro contract (prices 1981)
- Very small amount of cost increase in the tunnel.
- No major claims were made by the contractor.

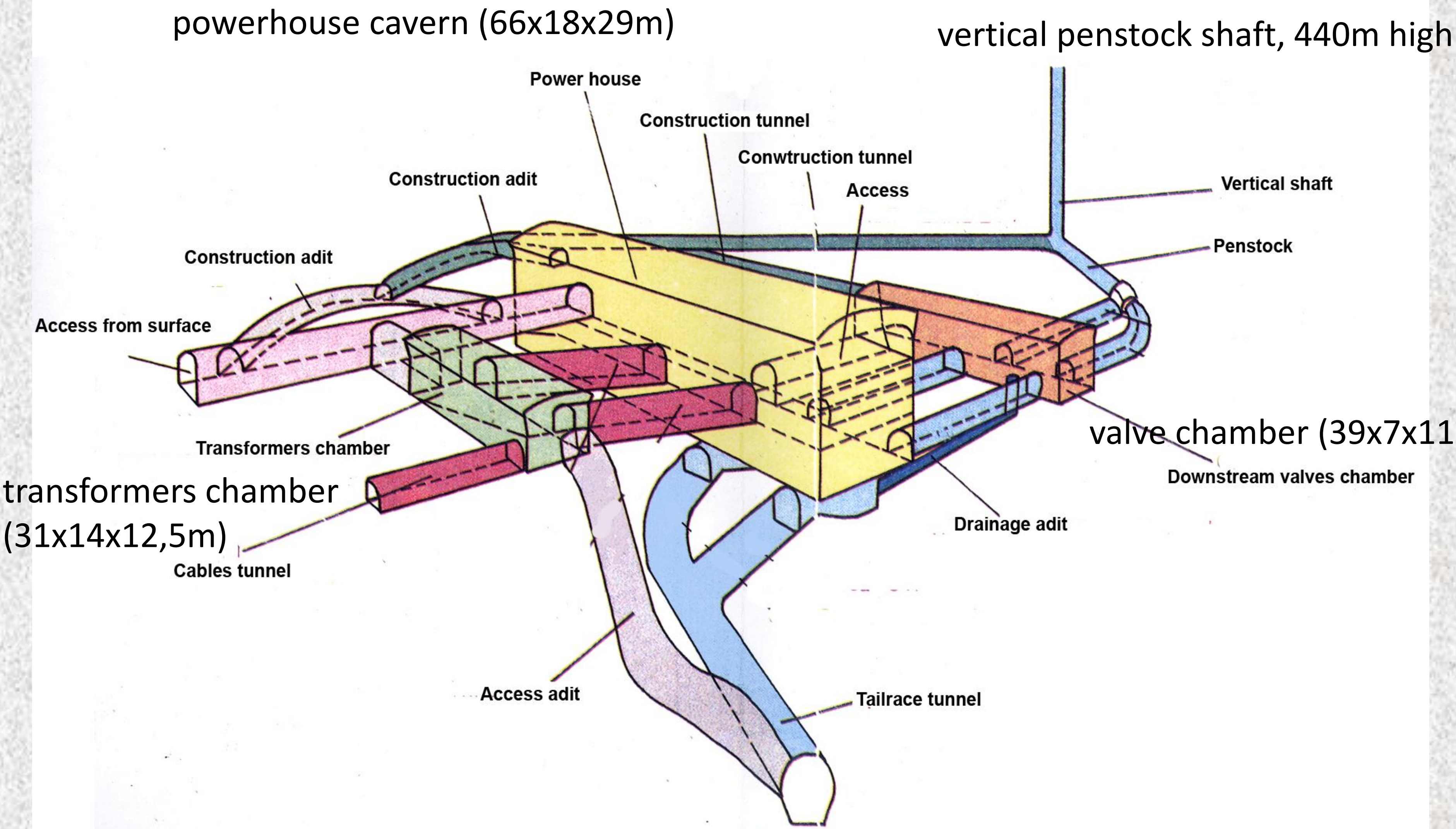
Pigai Aoos
Contract PAH-2SB

excavation of the

- powerhouse cavern (66x18x29m)
- valve chamber (39x7x11), the
- transformers chamber (31x14x12,5m)
- vertical penstock shaft, 440m high, down to the power house.
- A number of access galleries were included in the contractor’s methodology (Norwegian firm NOCON).

Contractual cost: 2,25 million euro (equivalent price, 1981)

Pigai Aoos



PIGAI AOOS UNDERGROUND POWER HOUSE COMPLEX

Pigai Aoos
Contract PAH-2SB

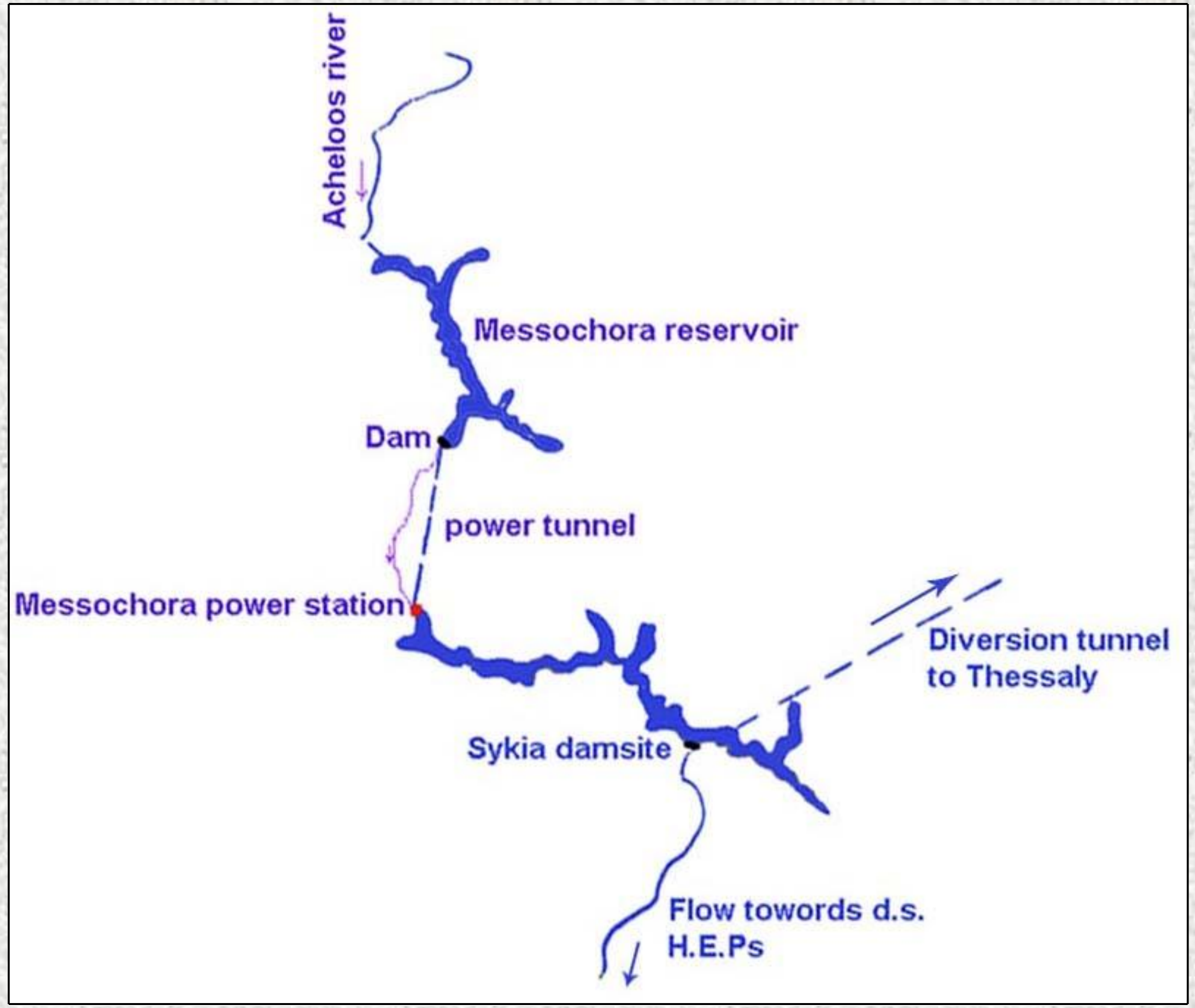
- Good rock conditions were encountered, mainly sandstone units, in the power house area. Support measures consisted of bolting and shotcrete.

Pigai Aoos
Contract PAH-2SB

Prestressed anchors and concreting of the arch at the powerhouse cavern roof.

Duration of the contract was 3,5 years, including concreting.
Cost overrun was about 6%. No major claims were made.

Messochora Hydroelectric project,
first upsteam project in the course of Acheloos



The Messochora HEP

Dam

- ✓ Type : Concrete faced rockfill dam (CFRD)
- ✓ Height : 150 m
- ✓ Concrete slab area : 52.000 m^2
- ✓ Dam crest elevation : 775,00m a.s.l.
- ✓ Reservoir live storage volume $288x10^6$ m^3

The Messochora HEP

Spillway

Type : open with gates , inclined channel, ski jump, and plunge pool

- ✓ Openings 2x14 m
- ✓ Radial gates 22,5 x 12,5 m
- ✓ Q_{max} 3.300 m^3/sec

The Messochora HEP

Intake

Power tunnel

- ✓ L = 7.500 m
- ✓ D = 5,30 m

The Messochora HEP

Surge shaft

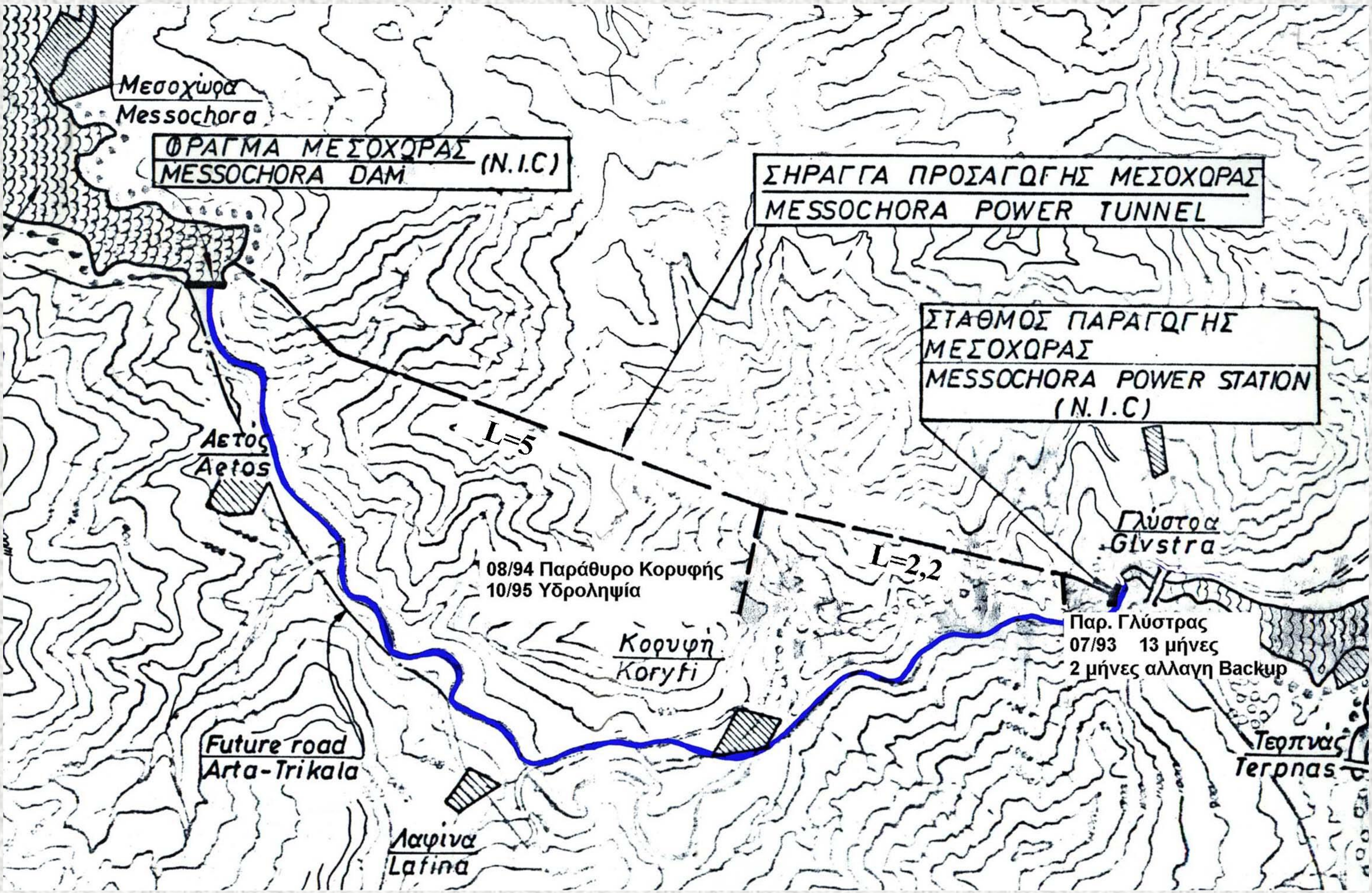
- ✓ H = 130 m
- ✓ D = 12,50 m

The Messochora HEP

Power station

- ✓ Type : open air
- ✓ 2 Francis turbines of vertical axis
- ✓ Nominal Capacity 2x82,6 MW

Messochora power tunnel

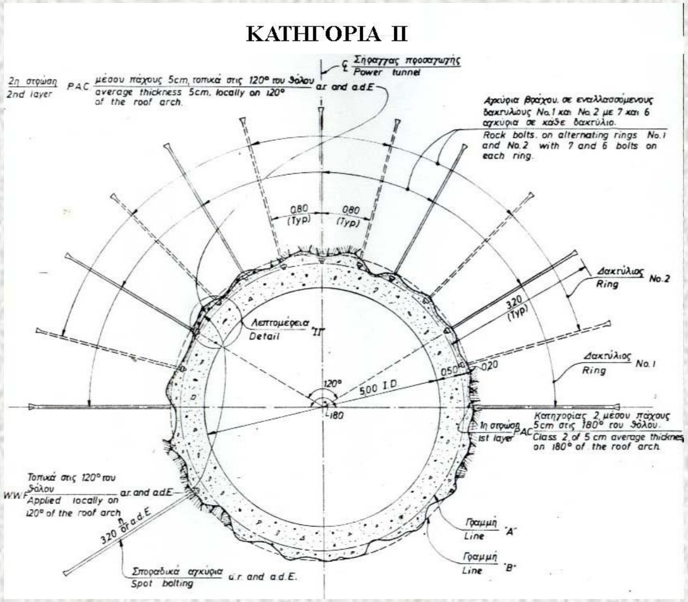


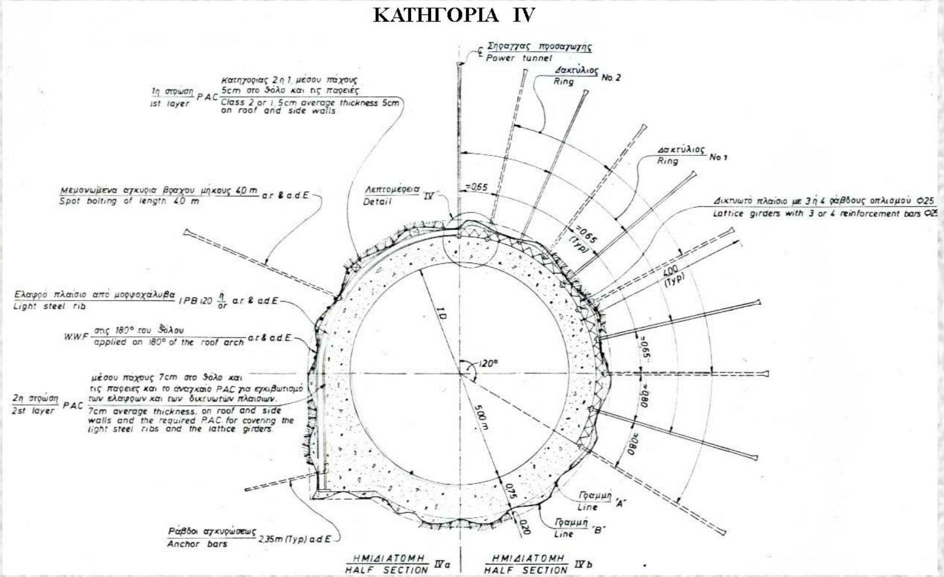
Messochora power tunnel

- The 7,5m long power tunnel was constructed under the contract MEH 2T. Contractual cost 17,8x10^6 equivalent Euros, 1990 prices
- The tender provided the use of the drill & blast method for the tunnel excavation, but also allowed as an alternative the use of the TBM method.
- NATM principles were endorsed for the drill & blast option, with five rock classes described and corresponding support measures defined. Rock classification at the face would be done in collaboration of supervision and contractor's geologists and engineers, following criteria based on geological data and deformation monitoring.

Messochora power tunnel

- The contractor was responsible for the "temporary" support measures, whereas "permanent" support measures would be defined by the engineer.
- In practice, this differentiation of support measures type was not clearly applied and payment was finally done for the totality of the support applied.



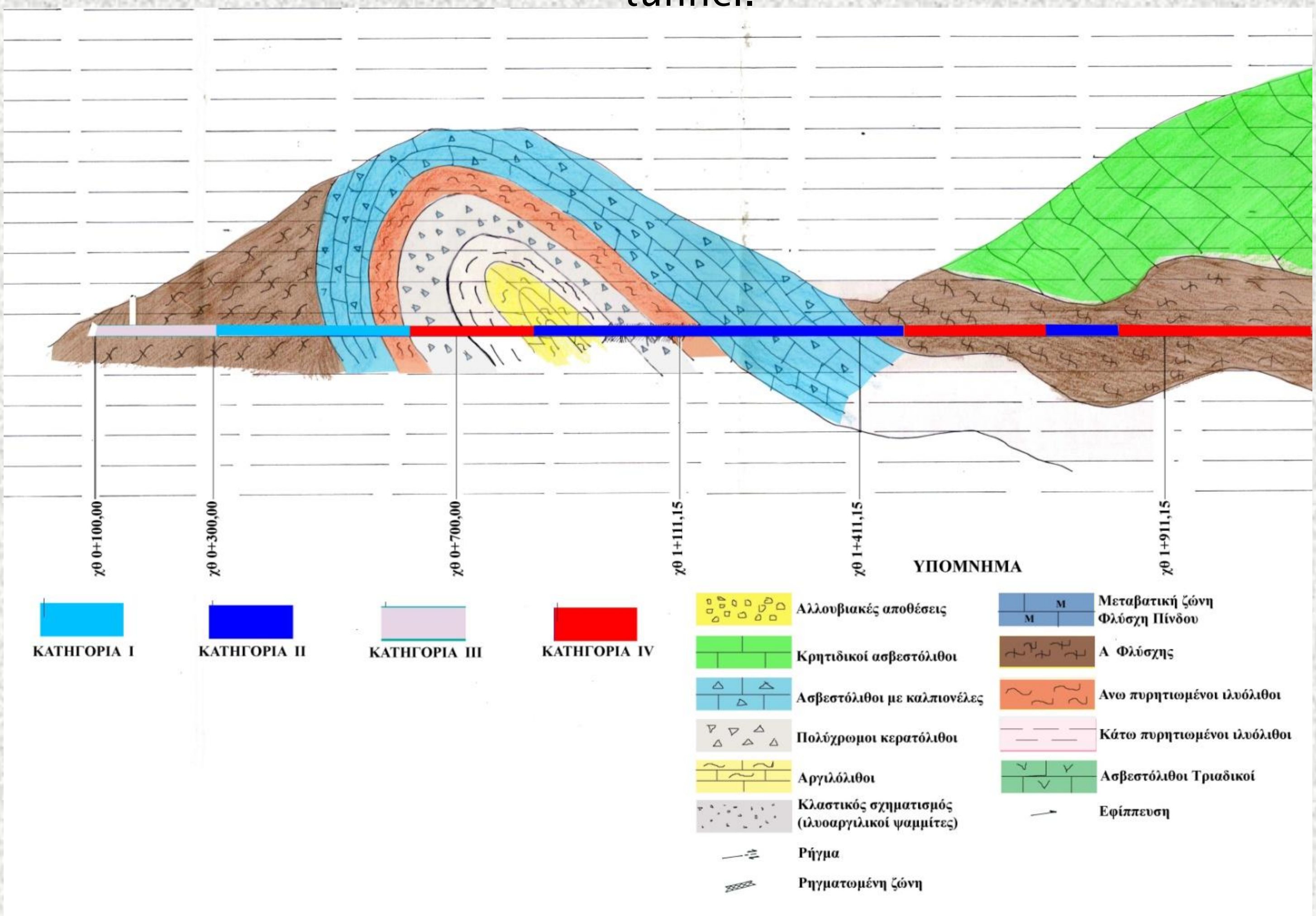


Support for rock class II and IV in the drill & blast option

Messochora power tunnel

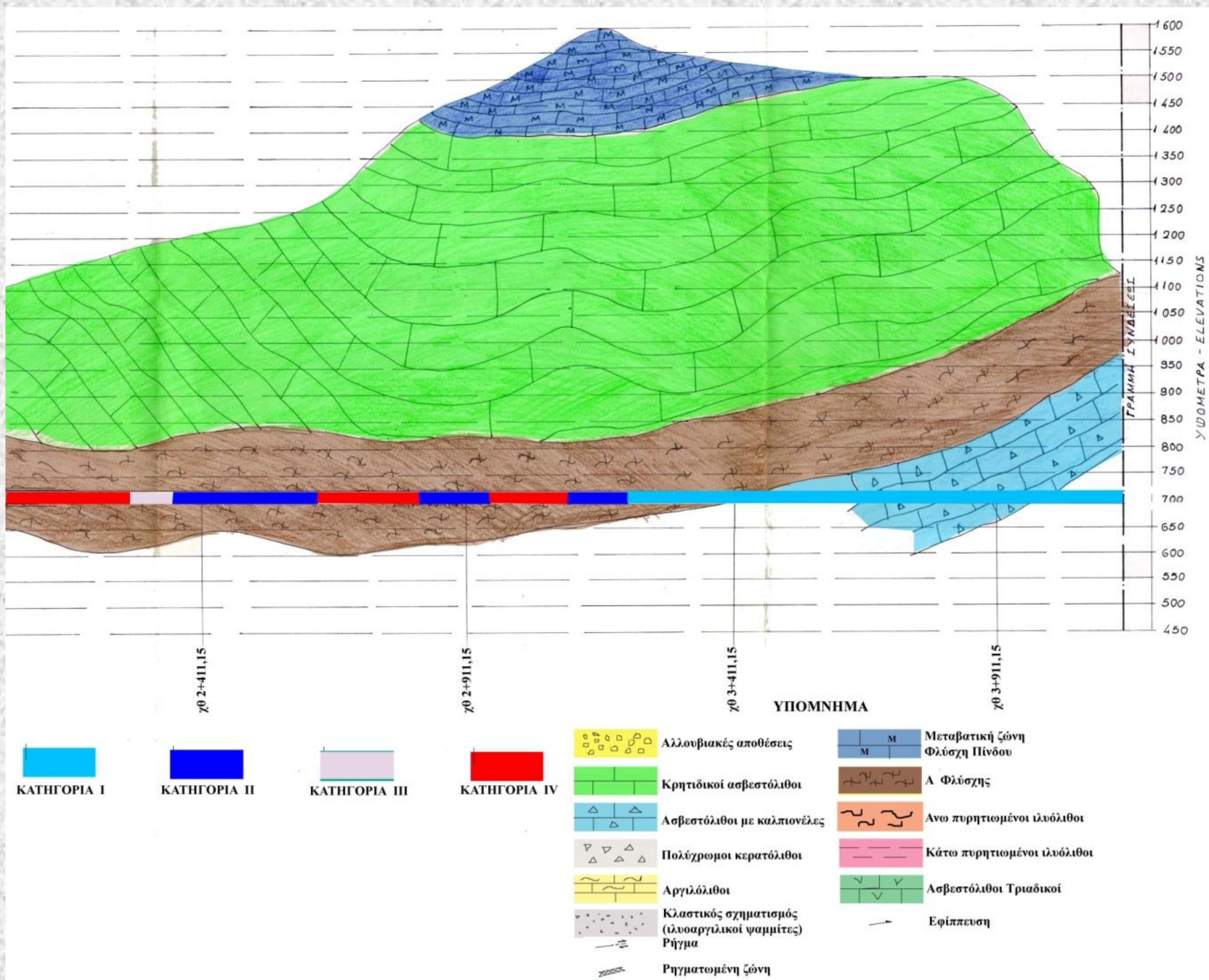
Geology along the tunnel route

Pindos sedimentary formations, with a cover up to 800m for 1/3 of tunnel's length, are encountered along the drive with limestone and flysh series intercalated with transition zone rock formations. The weaker flysh zones, been tectonised, were expected to show very poor rock quality for a portion of the tunnel.



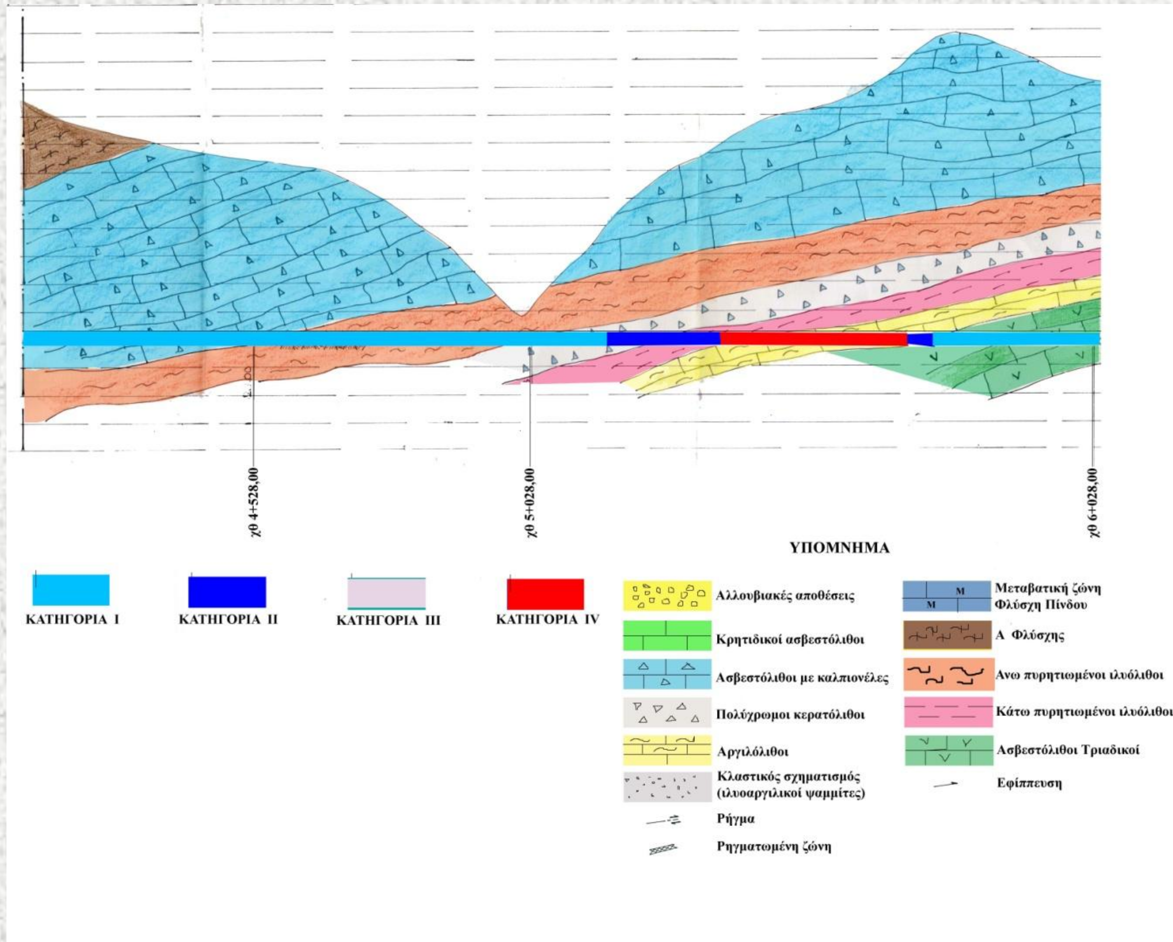
Messochora power tunnel

Geology along the tunnel route



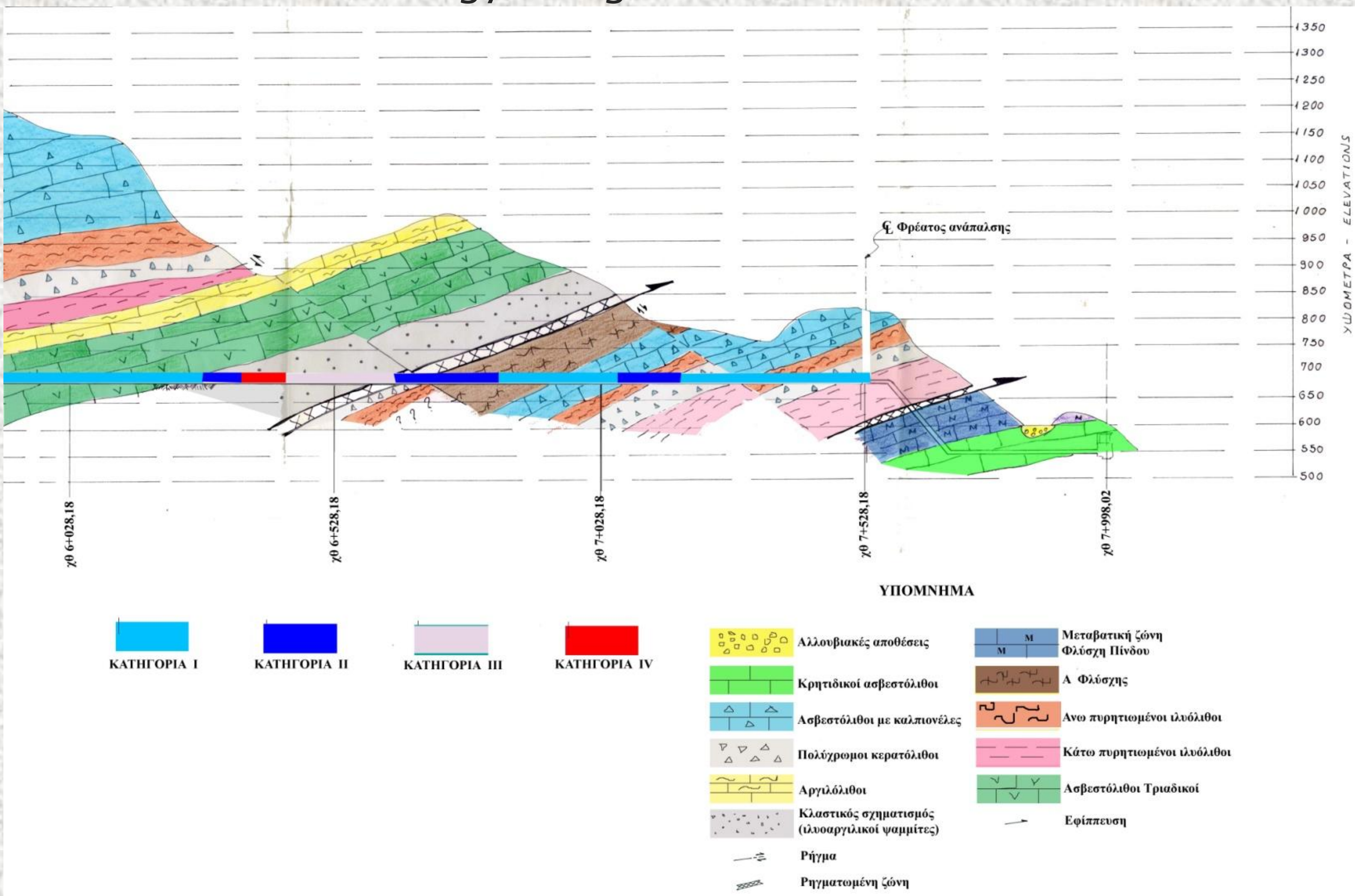
Messochora power tunnel

Geology along the tunnel route



Messochora power tunnel

Geology along the tunnel route



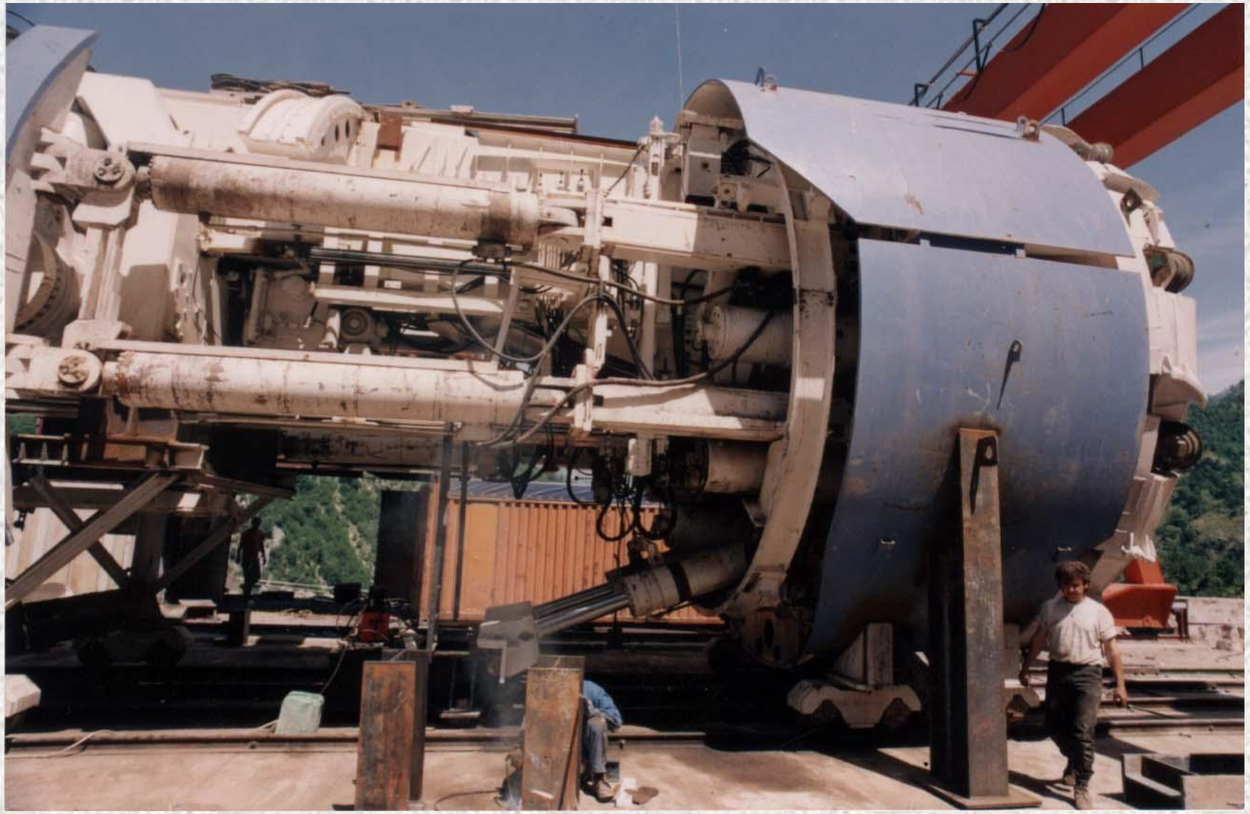
TBM alternative

- The contractor proposed the use of a hard rock TBM as an alternative for the excavation of the tunnel, while for the concrete lining to use precast concrete segments for the invert and conventional concrete for the rest part of the lining, that would be poured later on after completion of the excavation works.
- The advice of an expert has been used in order to adopt this choice.

TBM alternative

TBM alternative

Length of TBM 20m+backup 205m,
Shield at 3,80m from face,
Gripper surface 4m²



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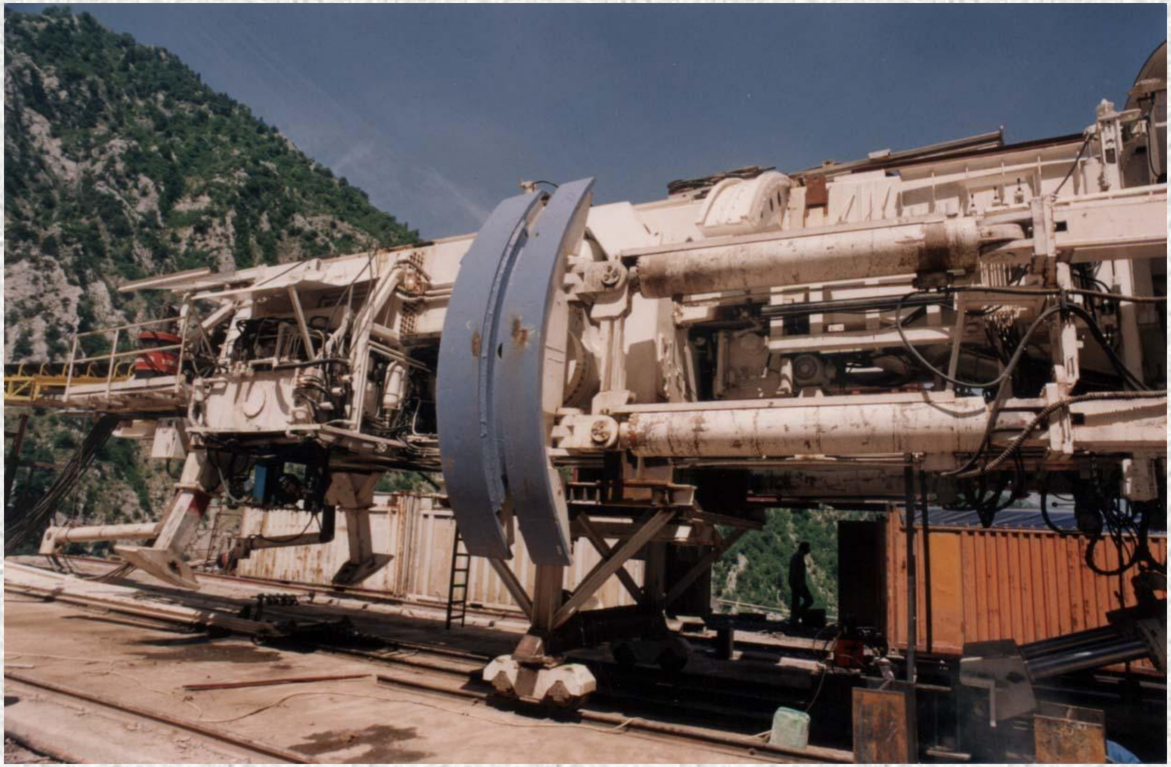
The main problems in this type of hard rock TBMs:

difficulty of spraying shotcrete near the face and the capability of placing permanent, fully grouted, rock bolts only at a 30~35m distance from the excavation face so, for immediate support at the face one had to rely to swellex type bolting, with steel beams and mesh.



Messochora power tunnel

New rock classification was adopted and support measures were adapted to the machine's capabilities. Four rock classes were defined ranging from local support of wedges for the best category, to systematic bolting, steel sets and shotcrete for the worst category.

Messochora power tunnel

class I

Rock type: Triassic limestones or alterations with cherts

Support: mesh + swellex bolts.

class II

Rock type: cherts in alteration with limestones. Fractured rock, SW to MW

Support to a wider area in the roof

Also placement of epoxy resin anchors

Messochora power tunnel

class III

Alternations of cherts, siltstones siliceous shales, first flysh

Support down to 240^0

class IV

Sheared first flysh, siltstones and claystones
Thrust zones

Support down to 360^0 with steel sets

Percentages of as build rock classes were:

- 45,9% for class I,
- 29,4% for class II,
- 6,2% for class III and
- 18,5% for class IV.

Messochora power tunnel

Execution of works

The excavation of the power tunnel was done in 32 months and another 18 months interval was necessary for the concreting.

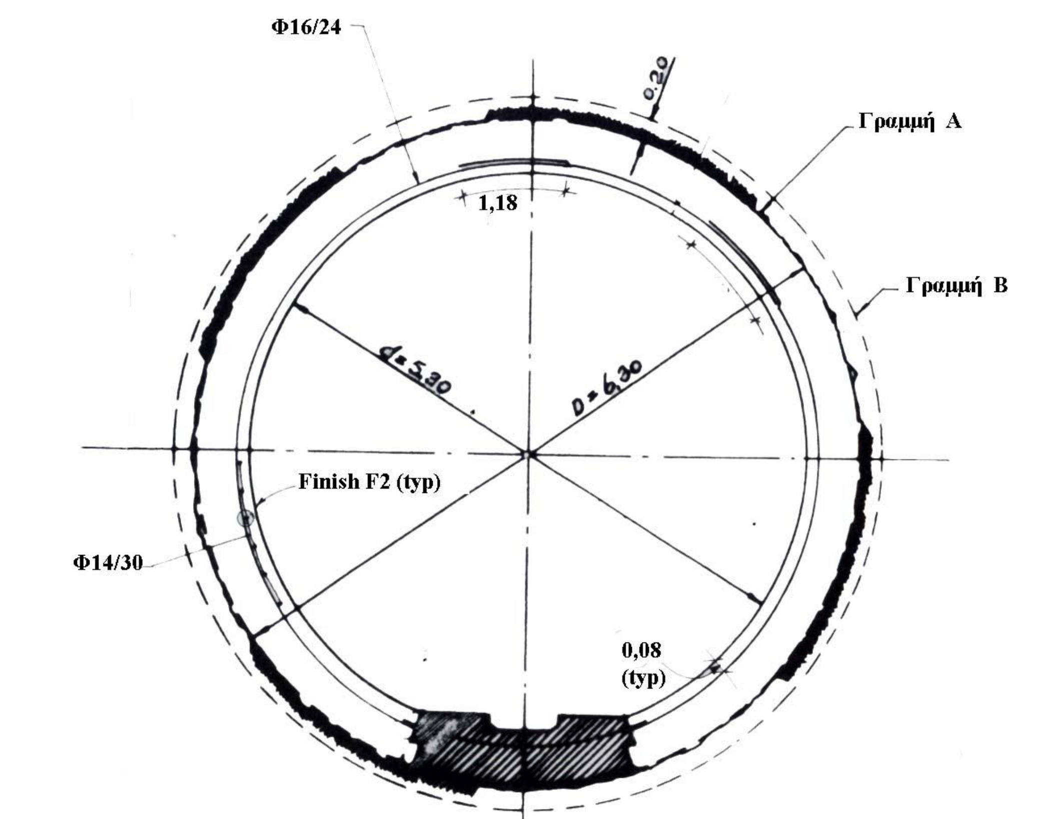
ROCK CLASS	AVERAGE EXCAVATION SPEED
I	20m (15 ~ 24)
II	
III	
IV	8m (4 ~ 11)

Messochora power tunnel

- segments placement after in the invert

Messochora power tunnel

Typical section of the lined tunnel
rock classes I & II



ΤΥΠΙΚΗ ΔΙΑΤΟΜΗ (Κατηγορία βράχου I &II

Messochora power tunnel

Contractor's claims

Messochora power tunnel

Claims focused on:

-Cutters wear in a hard rock formation of cherts,
-Clogging of the muck evacuating system in a clayey material that was overheated from cutting
-Segments uplift at an area of clayey material

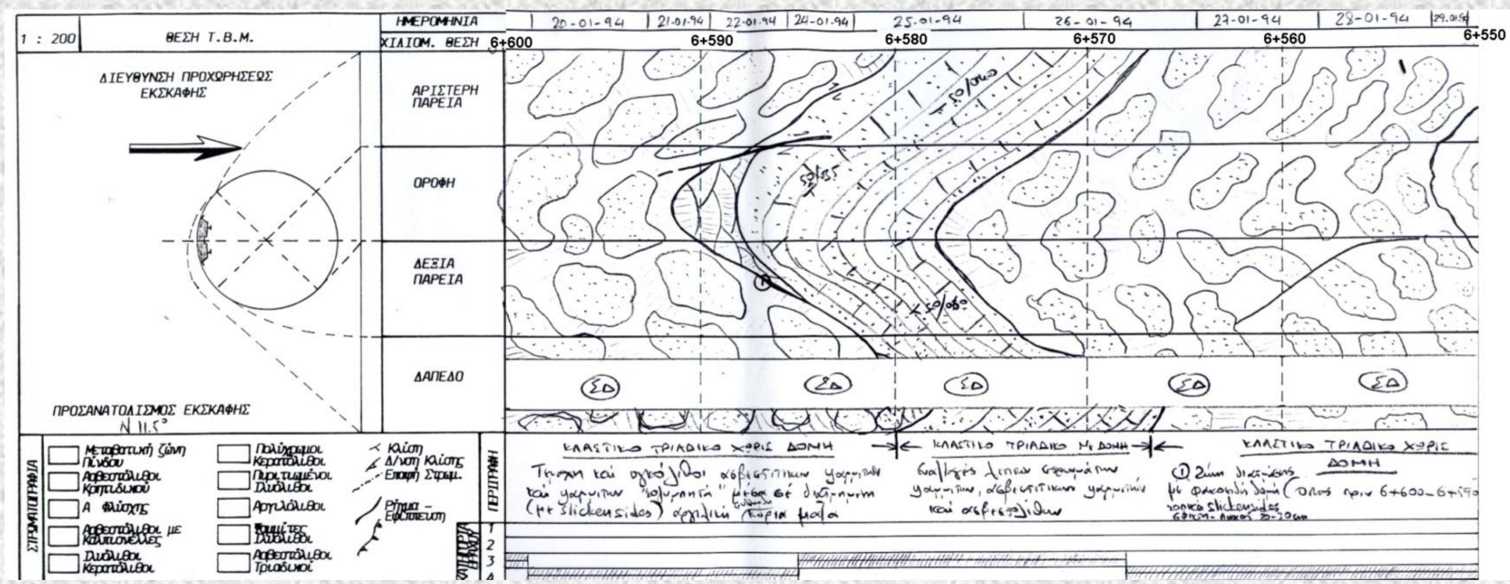
sta 5+290 to 5+050

more than 300% increase in cutting wheels wear

Messochora power tunnel

claims

Increased difficulties in the excavation were met in the area between sta. 6+600 and sta. 6+400 where, the presence of a formation of intensely fractured silty-clayey sanstone in the vicinity of a fault zone, provoked the deformation of the invert with some 20cm uplift of the segments.



Messochora power tunnel

All claims were settled within the contract and practically a less than 15% cost overrun can be attributed to the tunnel and auxiliary construction access adits, roads etc.

Conclusions

Strong points of the procedure adopted by PPC in managing tunnelling contracts can be summarized as follows:

- Well prepared contracts by an experienced PPC team, helped in satisfactorily anticipating ground conditions.
- Supervision by well manned with a variety of disciplines site teams, responsible for adapting the design and resolving day by day the arising problems, contributed positively in successfully carrying out the underground work.

Conclusions
(cont.)

- Flexibility in facing the situation due to changing conditions and ability to respond to difficult situations, which were assured with the support of the managing direction of hydroelectric development department and external expert's advice when necessary, allowed in handling the contract within the company.

- Overall acceptable progress of the works and avoidance of contract stoppage was the rule.

Conclusions
(cont.)

Weaknesses and negative aspects would include

- Cost overruns, although relatively limited
- Extension of construction time that maybe could be avoided in another form of contract

Thank you for your attention

- I would like also to thank PPC/DHP colleagues for their help in collecting and processing information from the presented projects