2nd Eastern European Tunnelling Conference
"Tunnelling in a Challenging Environment"
Athens, 28 September – 01 October 2014

The Maliakos-Kleidi Motorway (MMK) Tunnels
Geotechnical Conditions and Construction Experience

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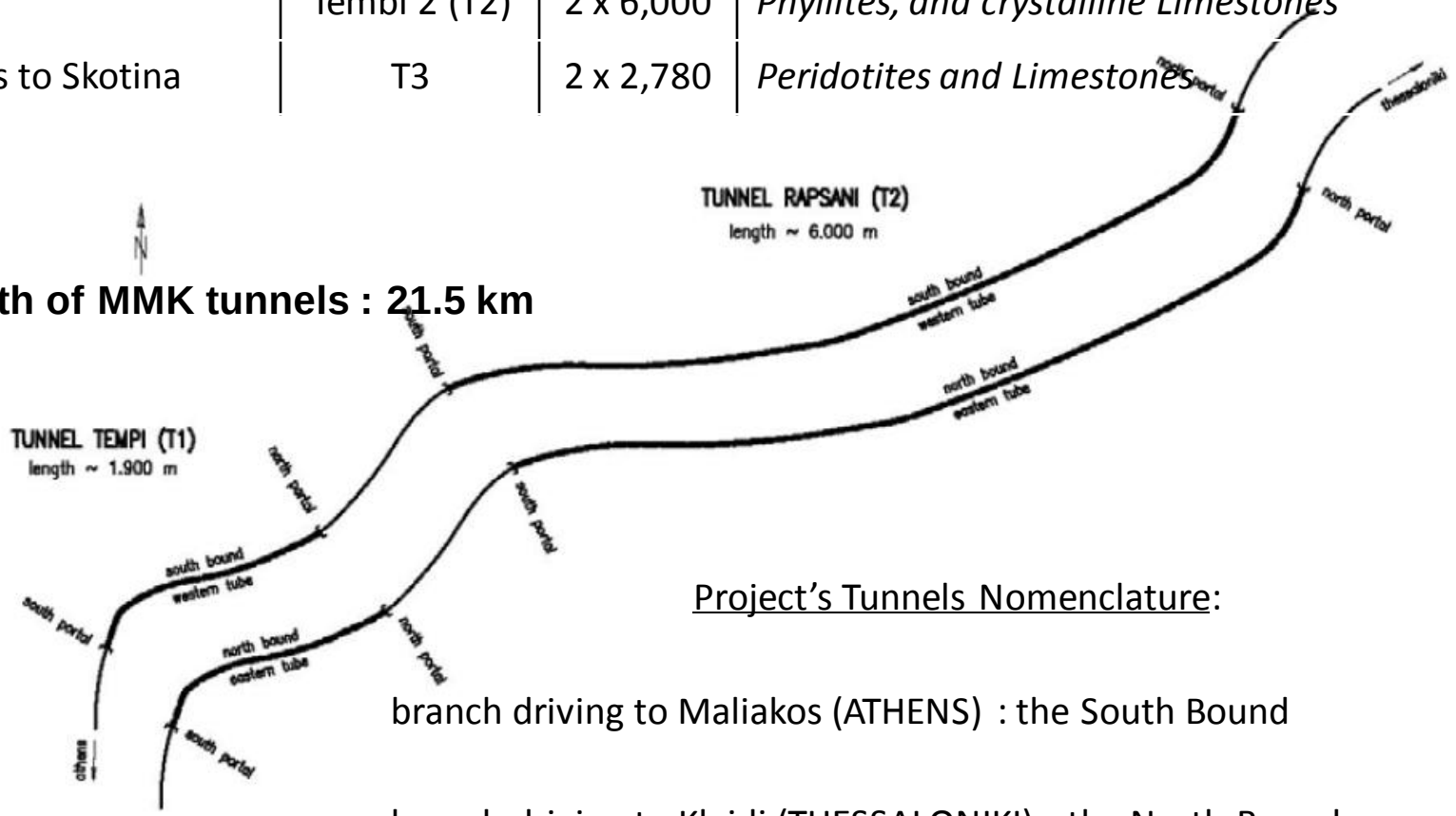
Project Section	Tunnel	L (m)	Geology
Evagelismos to Rapsani	Tembi 1 (T1)	2 x 2,000	*Amphibolies, Amphibolite Schists, Marbles, Phyllites*
	Tembi 2 (T2)	2 x 6,000	*Phyllites, and crystalline Limestones*
Platamonas to Skotina	T3	2 x 2,780	*Peridotites and Limestones*

Total Length of MMK tunnels : 21.5 km



Project's Tunnels Nomenclature:

branch driving to Maliakos (ATHENS) : the South Bound

branch driving to Kleidi (THESSALONIKI) : the North Bound

The presentation is structured to:

- present the key aspects of the MMK tunnels' design
- present the most striking cases from the tunnels' construction

Design of the MMK Tunnels

The Role of the Tunnel Design Consortium

(**ILF Austria, OK CONSULTING Greece, HOCHTIEF Consult Germany**)

- to elaborate **safe, competent and efficient designs** for the E&S, the Final Lining and the Fit out details of the MMK tunnels, which:

i. comply with the Contractual Requirements and the International Standards;

ii. fit to the time schedule of the MKC-JV (HOCHTIEF/AKTOR, J&P, VINCI, AEGEK, ATHENA);

iii. account for different tunneling approaches & equipment, on request by each of the construction firms;

iv. can be readily approved by the Supervising Authority (the Independent Engineer)

- to provide **continuous design consultation on Site during construction** (by continuous construction Follow Up) in updating the design to address unpredictable conditions;

Design of the MMK Tunnels

Tunnel Designs

i. The Preliminary Design for the 3-lane section

ii. The Geological Studies

iii. The geotechnical investigation campaign (to enhance the geological/geotechnical data basis along the tunnel stretches towards risk mitigation of unpredictable underground conditions)

iv. The Geotechnical Interpretation

v. The Final Designs (Portal & Portal structures, Excavation & Support, Final Lining, Hydraulic facilities and Fit-out details)

vi. Fast Track Designs (special designs ordered to speed up the start-up of tunnelling)

Design of the MMK Tunnels

Role of the Tunnel Designer

Fast Track Design, *an intermediate design phase agreed (MKC-JV and the IE) to precede the Final Design submissions (covering Construction drawings & Engineering Reports for the E&S – not detailed stability calculations) so as to allow for quick & safe start-up of the construction works; and be incorporated into the subsequent Final Designs.*

covered approx. 30% of 21.5 km:

2x400m for T1N (ATHENA), 2x800m for T2S (AEGEK), 2x500m T3S (J&P) & 2x1000m for T2N and 2x600m for T3N (OLYMPIA JV).

Main Aspects of the Safety Concept of the MMK Tunnels

(substantiated by Risk Analysis Study)

- cross passages between both tubes in a general distance of ≤ 300 m [reference is made to RABT]
- cross over between both tubes, designed as traffic bypasses each 900 m (maximum distance) for service and rescue vehicles
- Emergency niches each 150 m on the right hand side
- Closed road dewatering system with water intakes at the lower side of the carriageway connected with a main dewatering pipe and a separate basin outside the tunnels [reference is made to Project Specifications].
- All structural elements and components within the tunnel tubes have to have a fire resistance of 90 minutes [reference is made to Project Specifications].

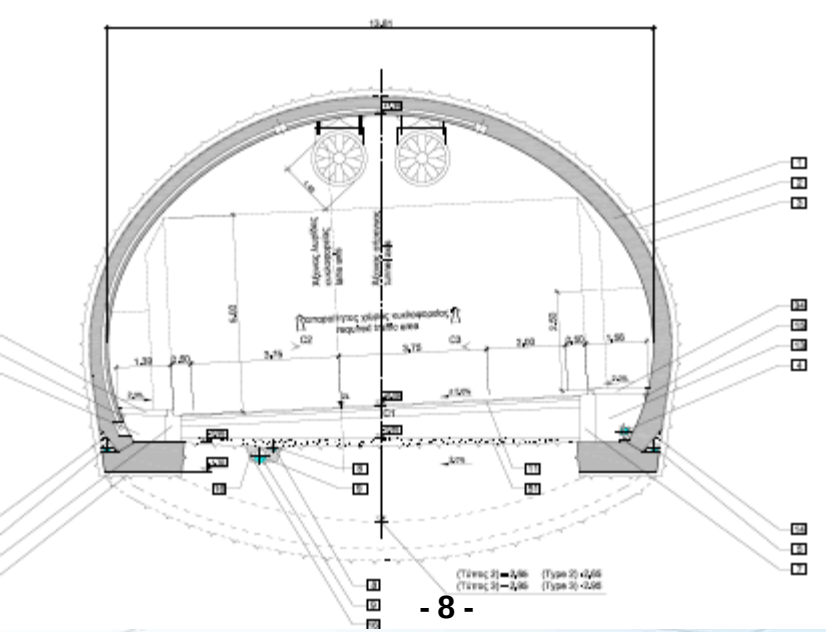
The Ventilation Concept for the MMK Tunnels

a) A **longitudinal ventilation system** with jet fans is initiated for operation phase.

b) Especially for tunnel Tembi 2 (~6.000km) **three (3) smoke extraction points** were also assigned to fit to the international regulations (requiring smoke extraction every 2km length for tunnels with length > 3.000m.

c) Connection of the transverse smoke extraction points onto Ventilation Crossings.

Type 1 with jet fans



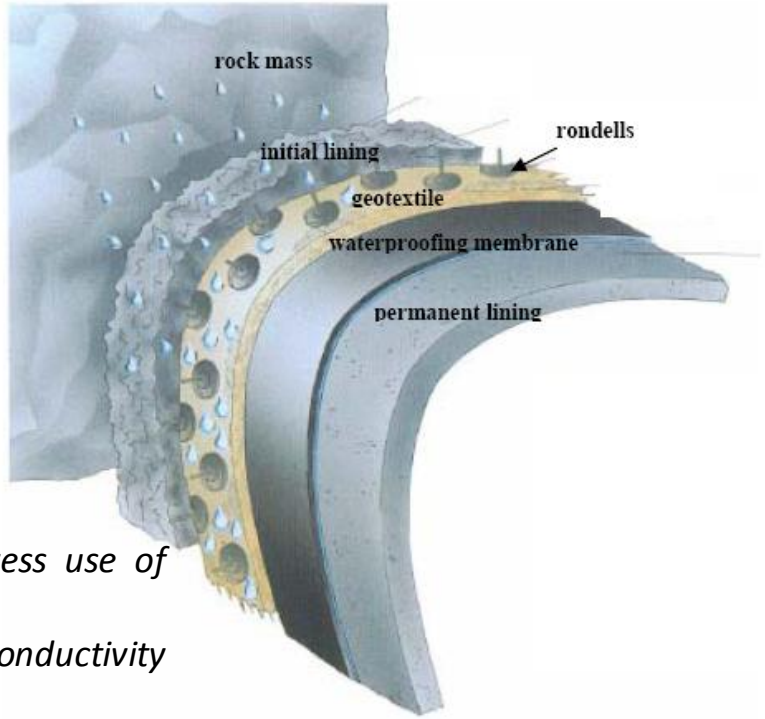
Structural Requirements for the MMK tunnels

- Application of the **NATM** for the excavation-support and final lining of the tunnels
- Minimum concrete quality for permanent structures and structure components **C30/37**
- Minimum thickness of permanent lining ≥40cm for the main tunnel sections
- Permanent lining **without reinforcement** depending on the rock mass conditions
- Crack width limitation at: 0.30mm in case of reinforced lining; 1.0mm for the unreinforced sections
- Shrinkage and creeping acc to DIN 1045-1
- Average construction temperature of 15^0C and a difference Δt of $\pm 10^0$C
- Consideration of impacts of explosion on the final lining
- Consideration of effect of fire to the final lining (use of increased cover of the reinforcement 60mm)

The New Austrian Tunnel Support Method - Tunnel Support Concept :

Dual support of the tunnel cavity, to comprise:

- an initial (primary) outer lining composite liner of sprayed concrete
- a permanent (inner) lining of cast in situ concrete C30/37 class (steel reinforced or unreinforced)

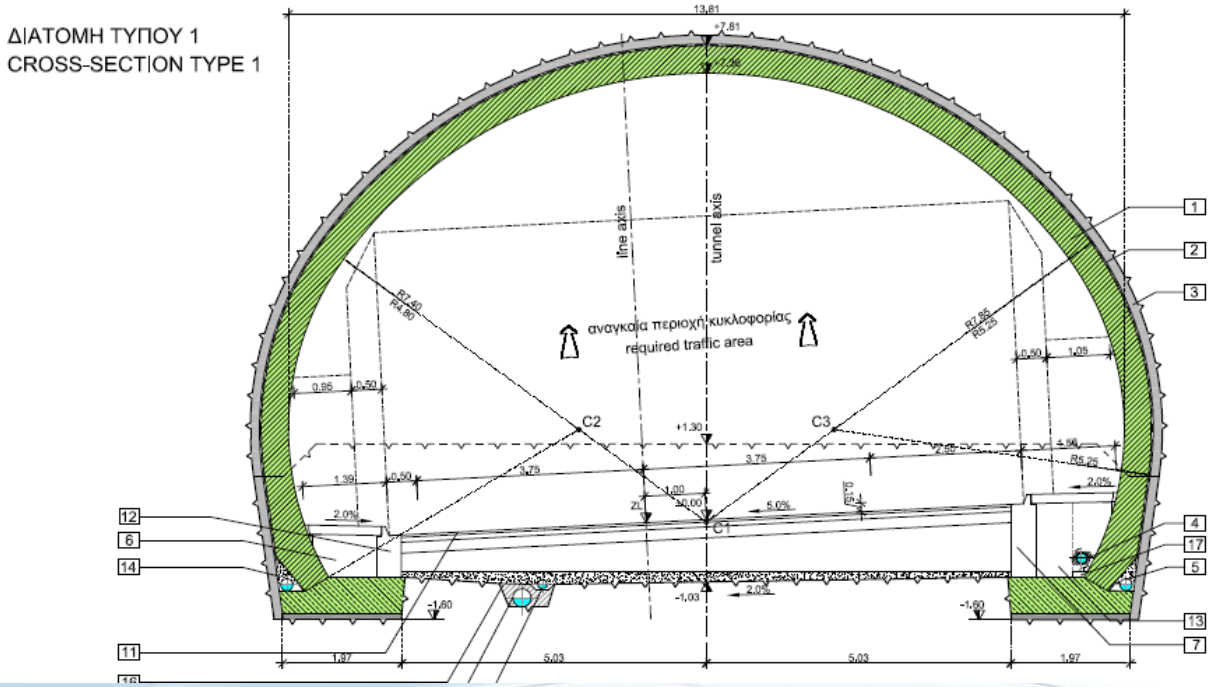


separated by

- a geotextile fleece ≥600g/m² (*in areas with high water ingress use of drainage geocomposite with increased discharge capacity / conductivity characteristics, such as the DOMODRAIN 1200*); and
- a PVC waterproof geomembrane (thickness > 2mm)

Geometrical Requirements – Clearance - Dimensions

- 2 traffic lanes (3.75 each) & emergency (safety) lane (2.50m)
- width of safety lane at left side of the carriageway 0.50m
- minimum width of the sidewalks 1.0m
- height of traffic area above the lanes 5.00m
- vertical clearance at the emergency walkway 2.50m



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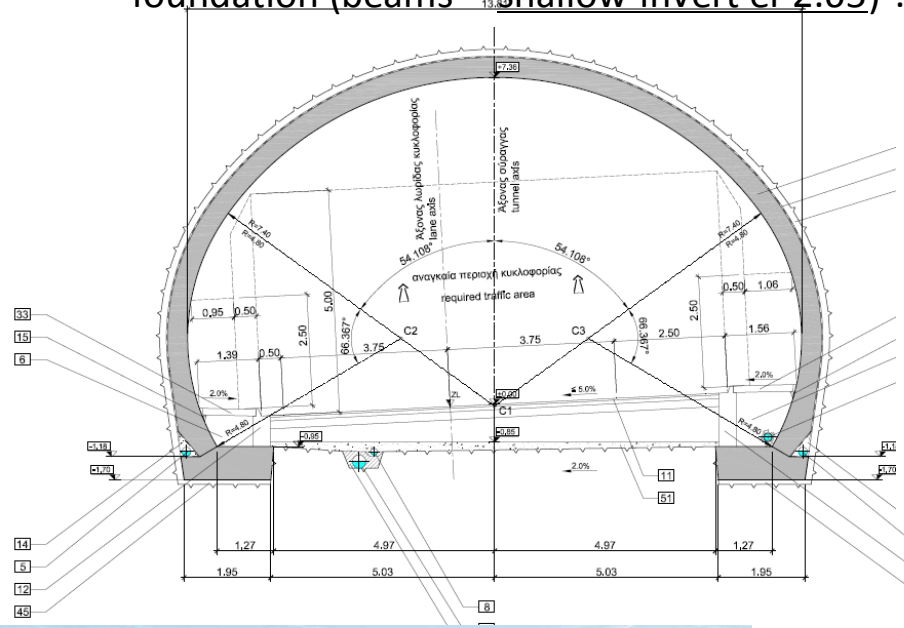
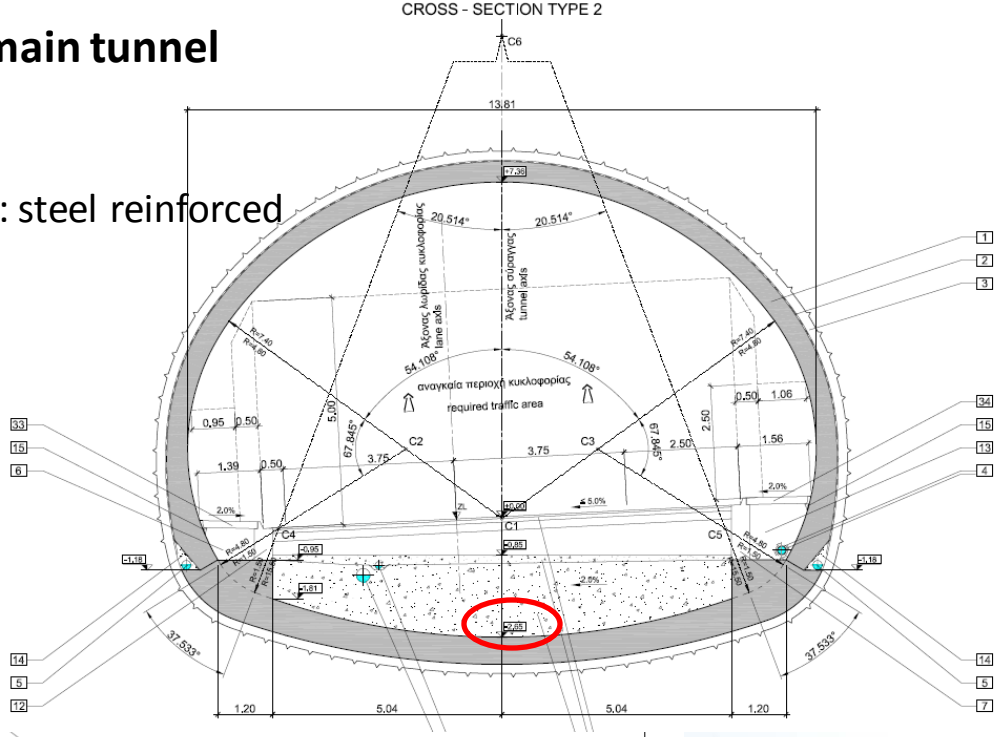
Three Basic Types of Final Lining (FL) – main tunnel

ΔΙΑΤΟΜΗ ΤΥΠΟΥ 1
CROSS - SECTION TYPE 1

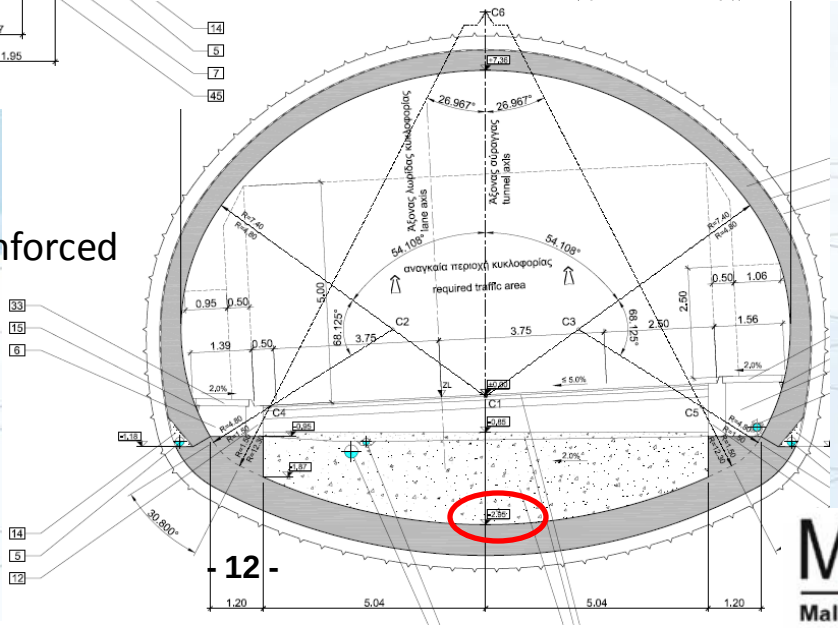
vault : steel reinforced / unreinforced
foundation (beams – shallow invert el-2.65) : steel reinforced



ΔΙΑΤΟΜΗ ΤΥΠΟΥ 2
CROSS - SECTION TYPE 2



vault : steel reinforced
foundation (deep invert el-2.95) : steel reinforced



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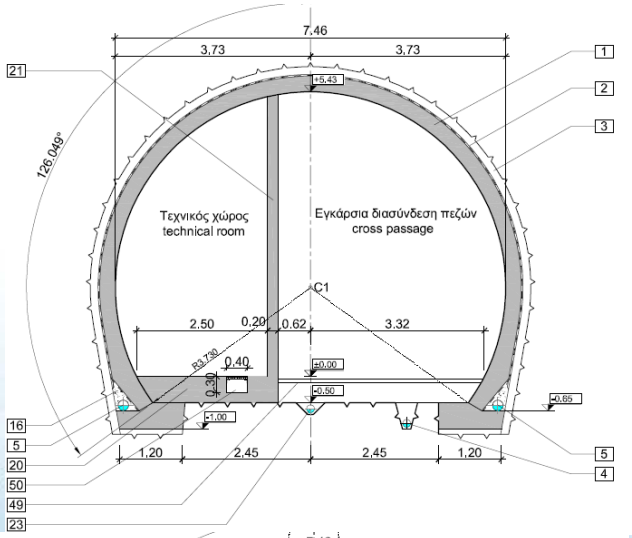
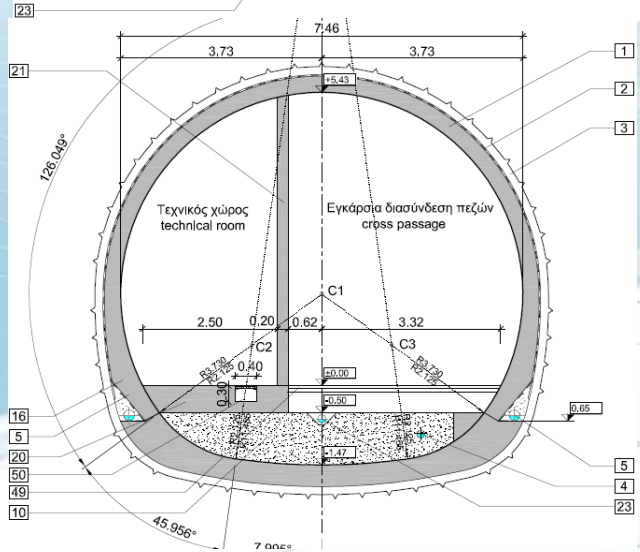
Two Basic Types of Final Lining (FL) - crossings

A. Cross Passages (XP)

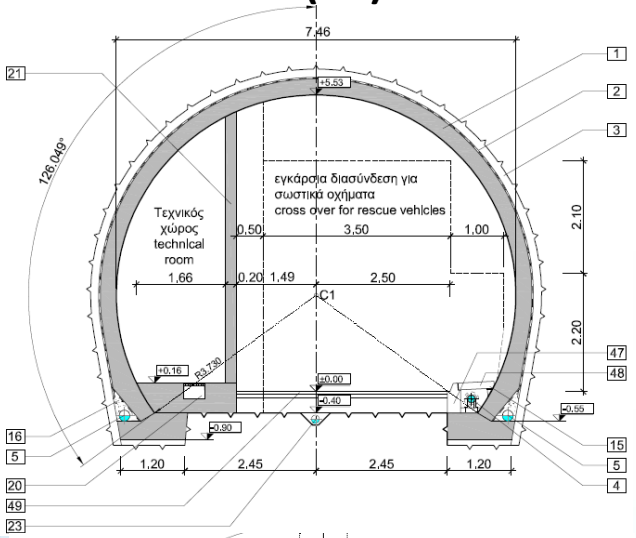


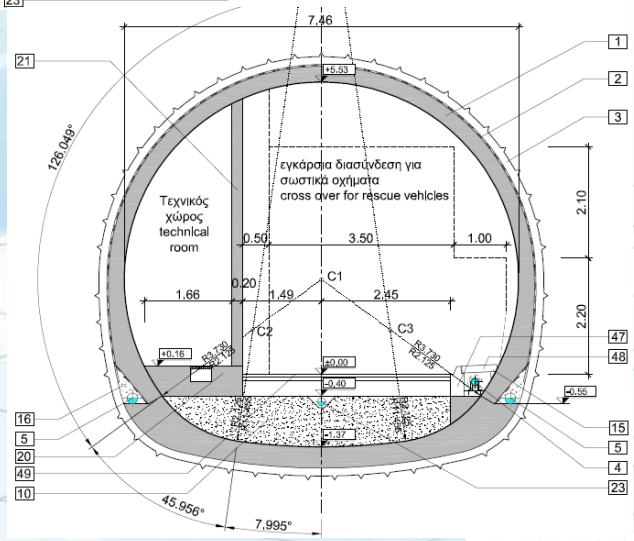
Type I



Type II

B. Cross Overs (X0)





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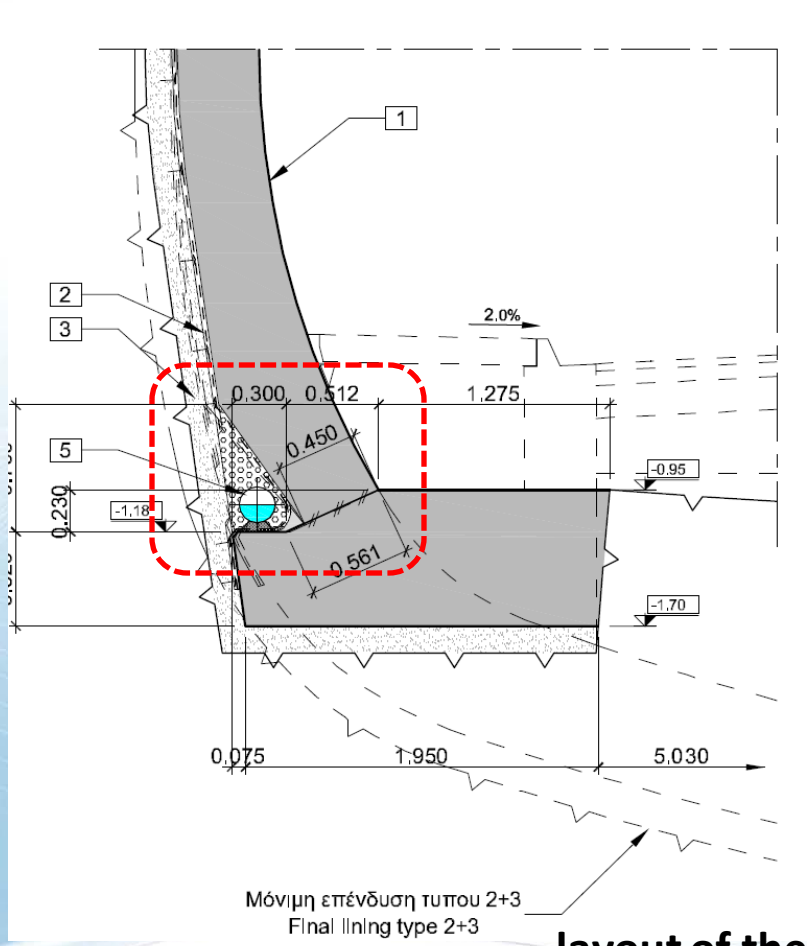
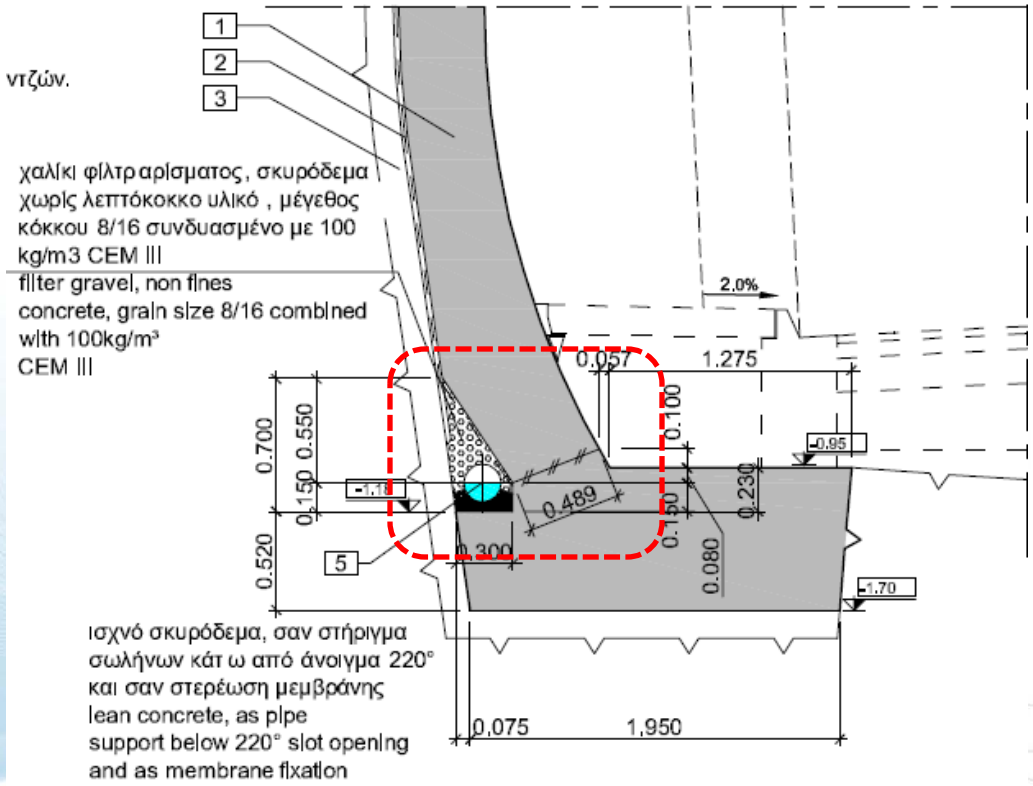
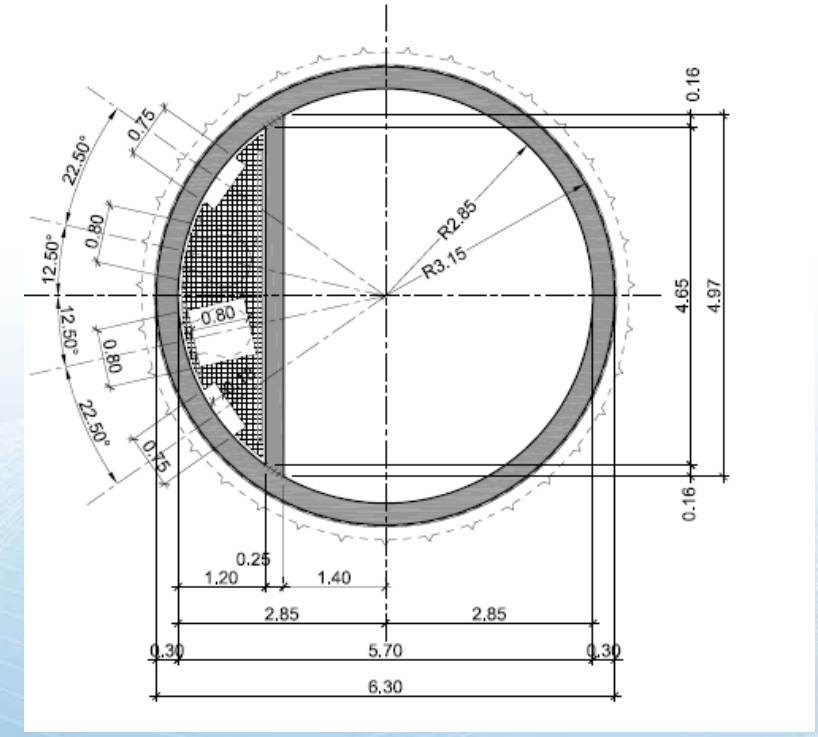
different construction solutions designed for the different construction companies



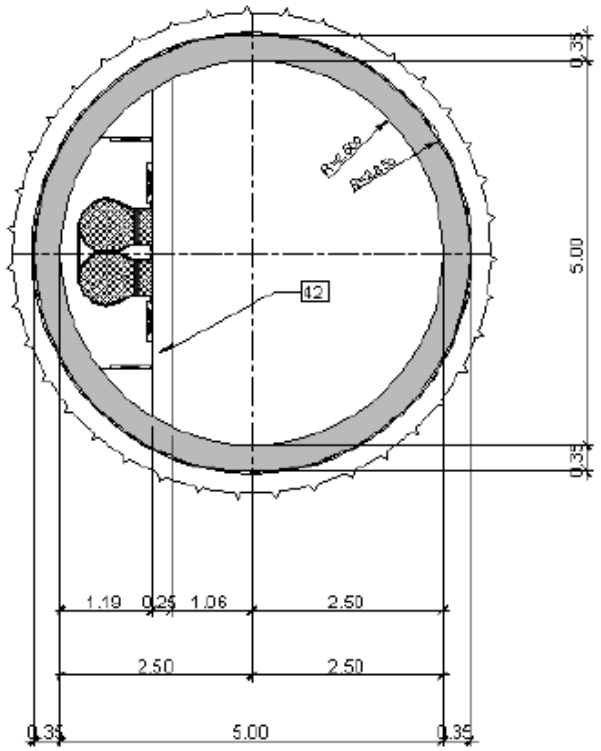


layout of the joint between vault and foundation

different construction solutions designed for the different construction companies



Shaft T2-N (AKTOR/HOCHTIEF)



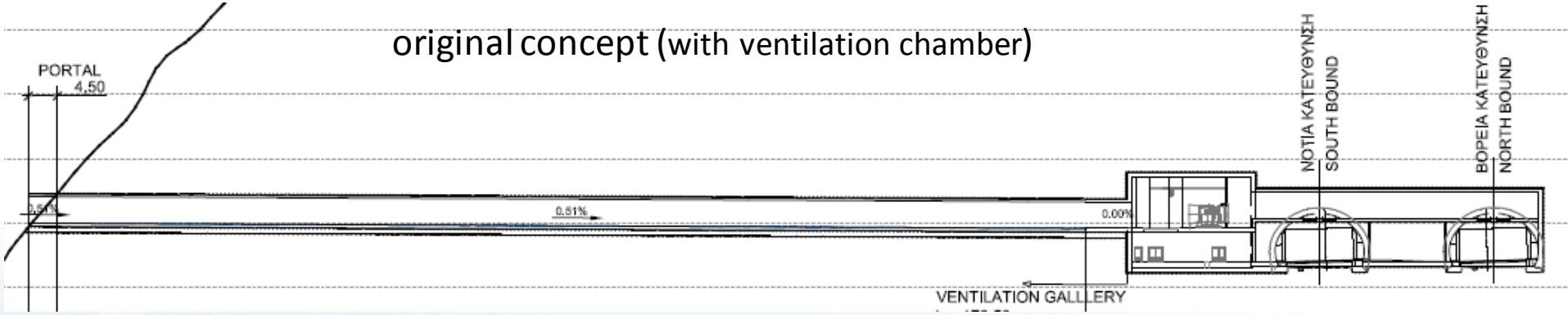
Shaft T2-S (AEGEK)

dimensions of the ventilation shafts

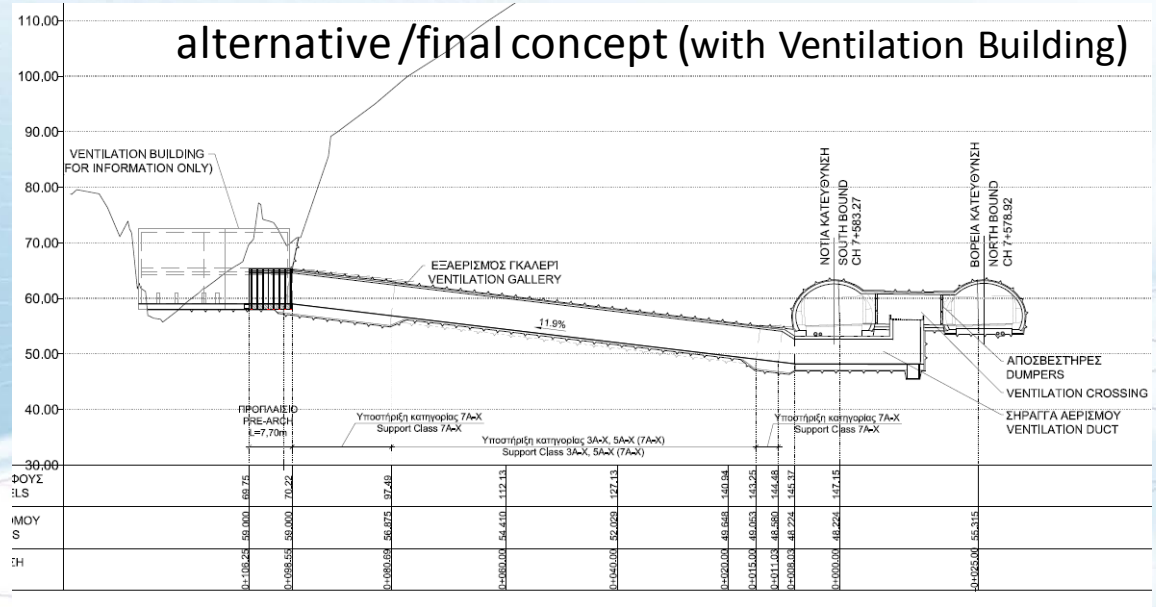
preparation of alternative designs to speed up the construction schedule:

The configuration of the Central Ventilation Facility

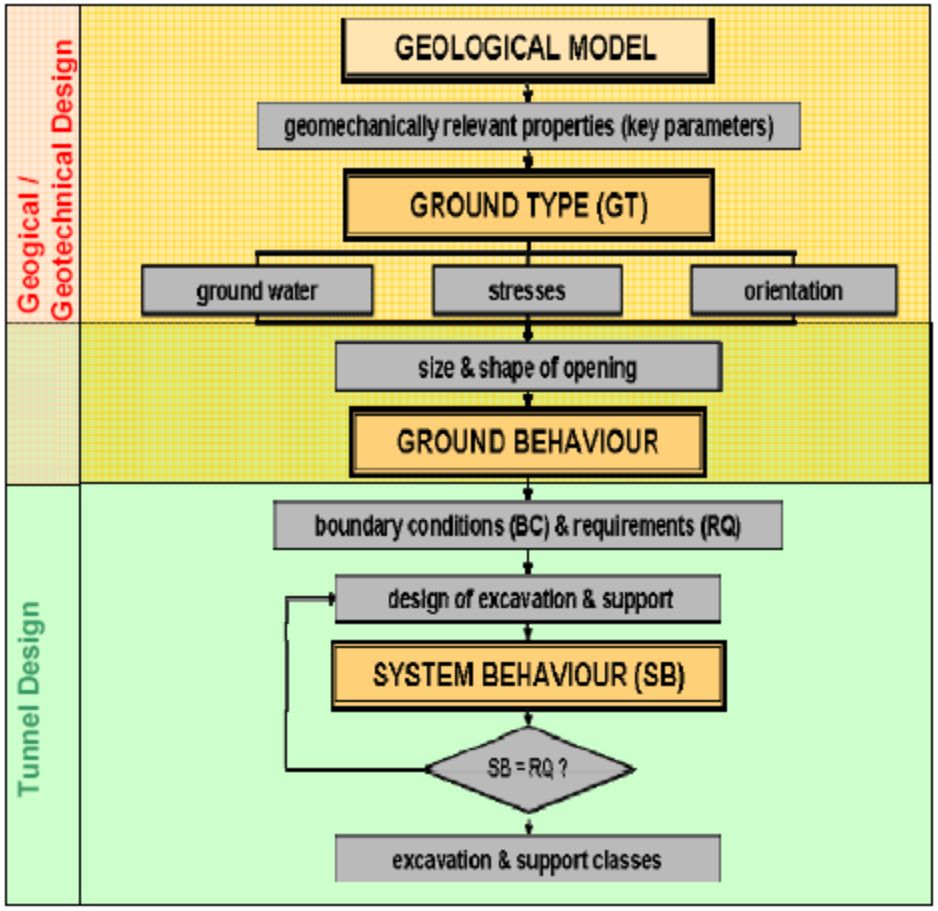
original concept (with ventilation chamber)

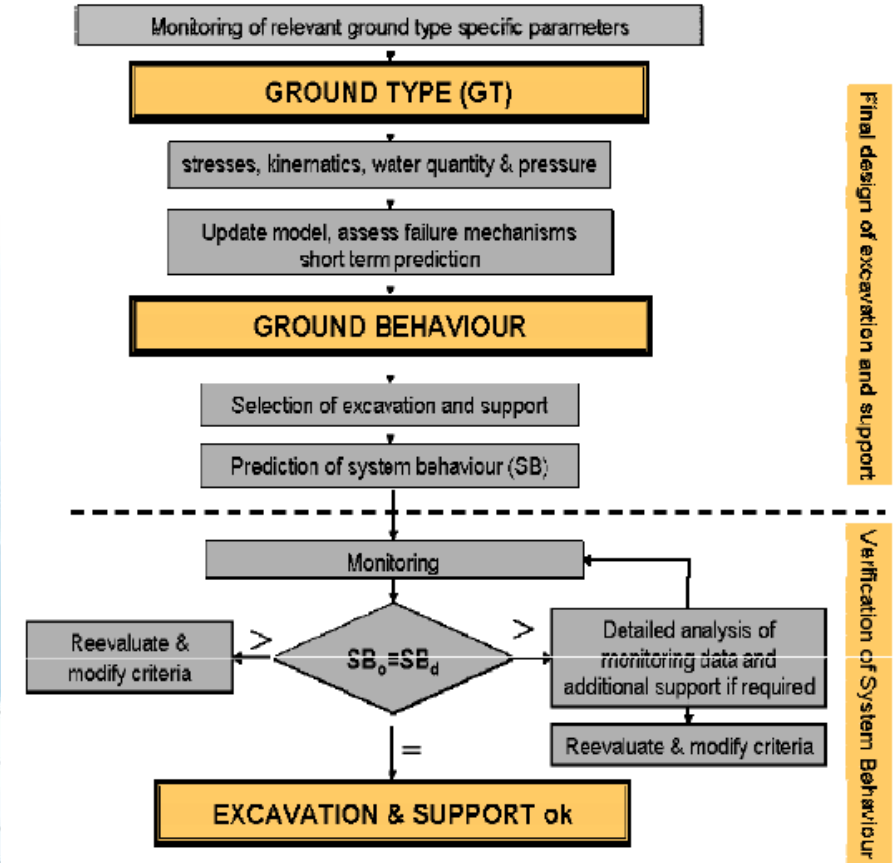


alternative /final concept (with Ventilation Building)



Application of the NATM procedures in design and construction:





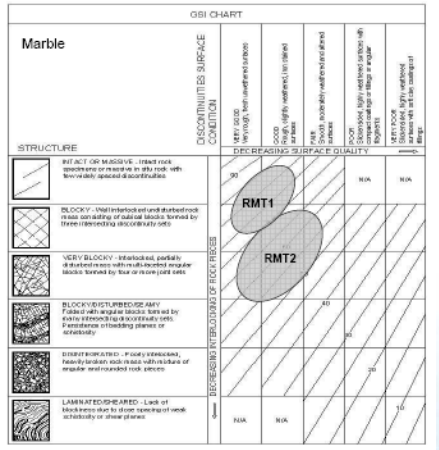
The Excavation & Support (E&S) Design must account for :

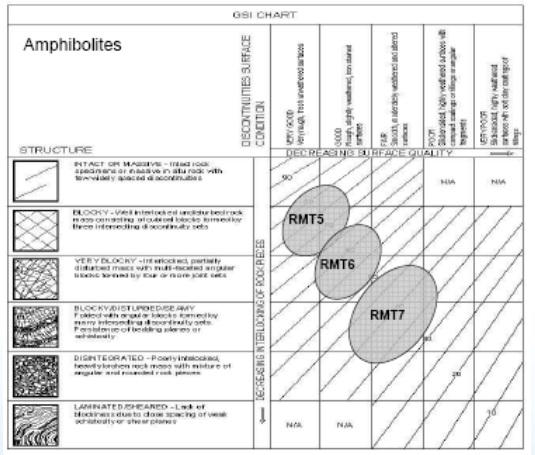
- the **variability** of the geotechnical conditions
- the **variability** of the stress conditions
- the **variability** in the groundwater conditions
- the **non-continuity** in the geotechnical information along the tunnel stretches, which requires interpolation towards the realistic prediction of the actual **geotechnical risks**;
- interaction with the **utilities** involved with the alignment (i.e. **Nat. Gas Pipeline**, influence to the **supply water springs** at the Platamon area)

Stages of the Excavation and Initial Support (E&S) Design

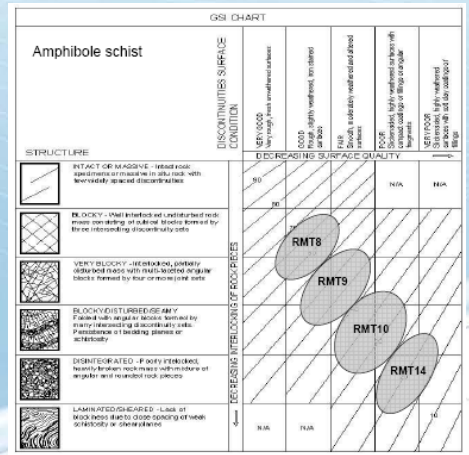
- interpretation of the geotechnical conditions (grouping in Rock Mass Types and Soil Types – RMTs & STs)
- combination with the overburden heights
- evaluation of the anticipated rock mass behaviour (Rock Mass Behaviour Types – RMBTs)
- grouping the E&S requirements for each RMBT – definition of E&S Classes
- establishment of Criteria for Application of each Support Class

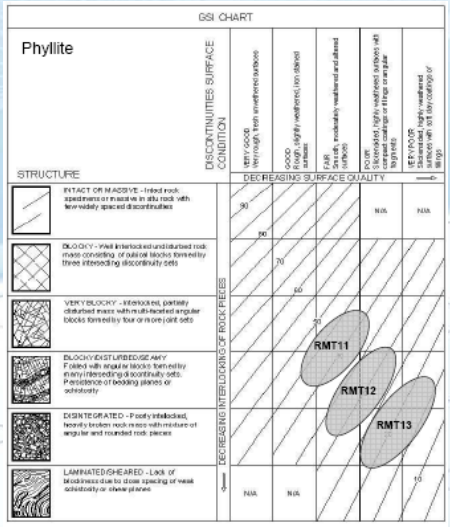
Rock Mass Conditions – Rock Mass Types – Tunnel T1



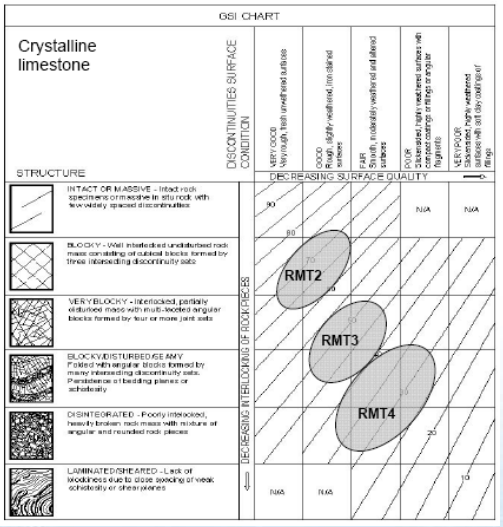


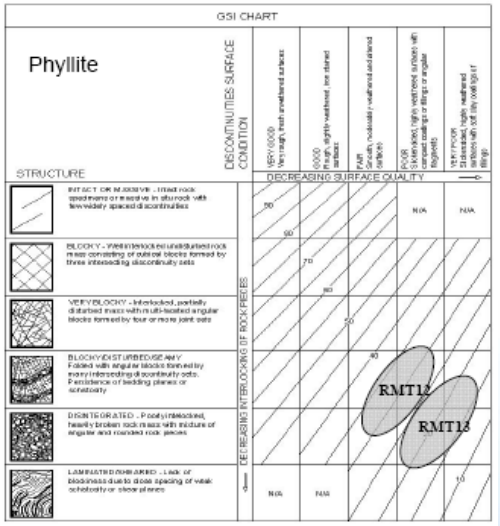
Significantly broad range of rock mass qualities





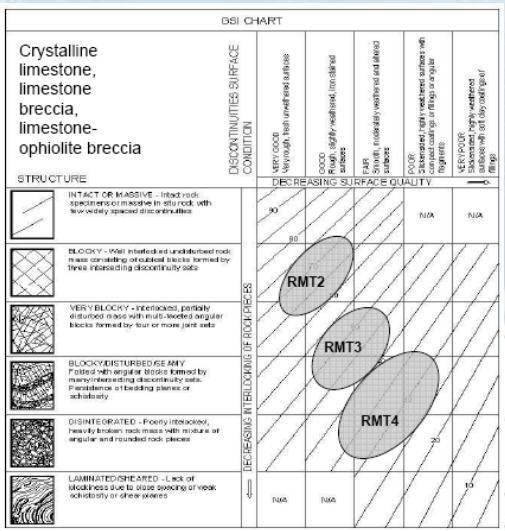
Rock Mass Conditions – Rock Mass Types – TunnelsT2 , T3

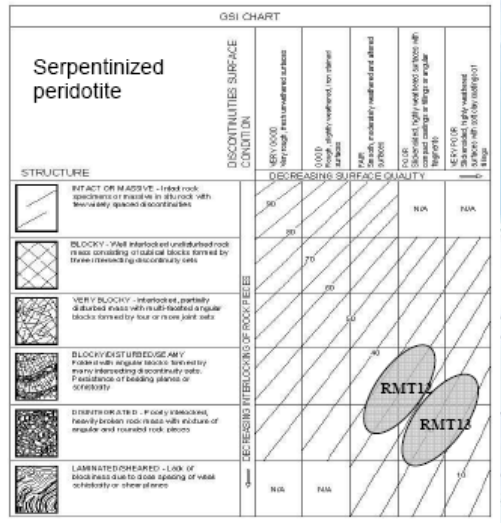




Tunnel T2

Significantly broad range of rock mass qualities





Tunnel T3

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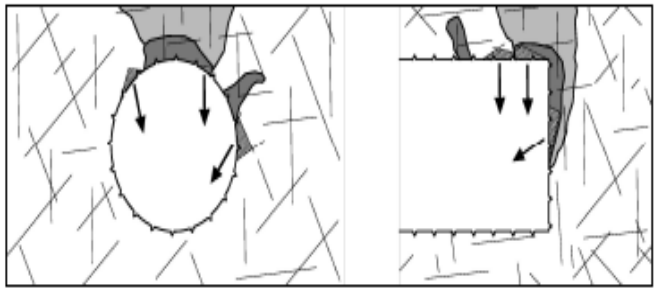
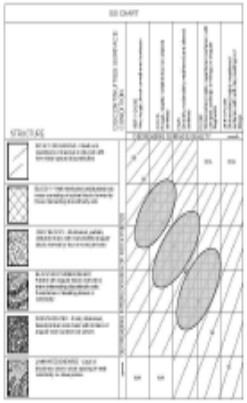
Rock Mass Behaviour Types (RMBT)

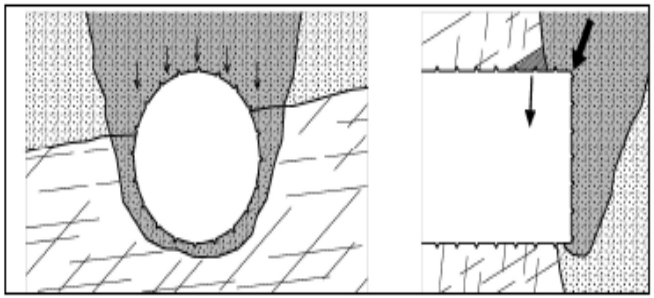
RMBT 11/2





Rock Mass Types	RMT 2, RMT 3, RMT 4
Discontinuity Parameters	b: 141/85, b: 328/75 b: rough - planar, j: rough - undulating
Persistence	s: 10-20m, j: 1-3m
Aperture, Infilling	s: 200-300mm, j: 500mm no infilling, slightly weathered and clay infilling
Short description of Geology	Crystalline limestones, limestone breccia, limestone-ophiolite breccia, slightly to fully fractured, karstified
Overburden	No impact
GSI	25-75
Water	possible water inflows
Rock Mass Behaviour	kinematical failures due to karstic voids and caves

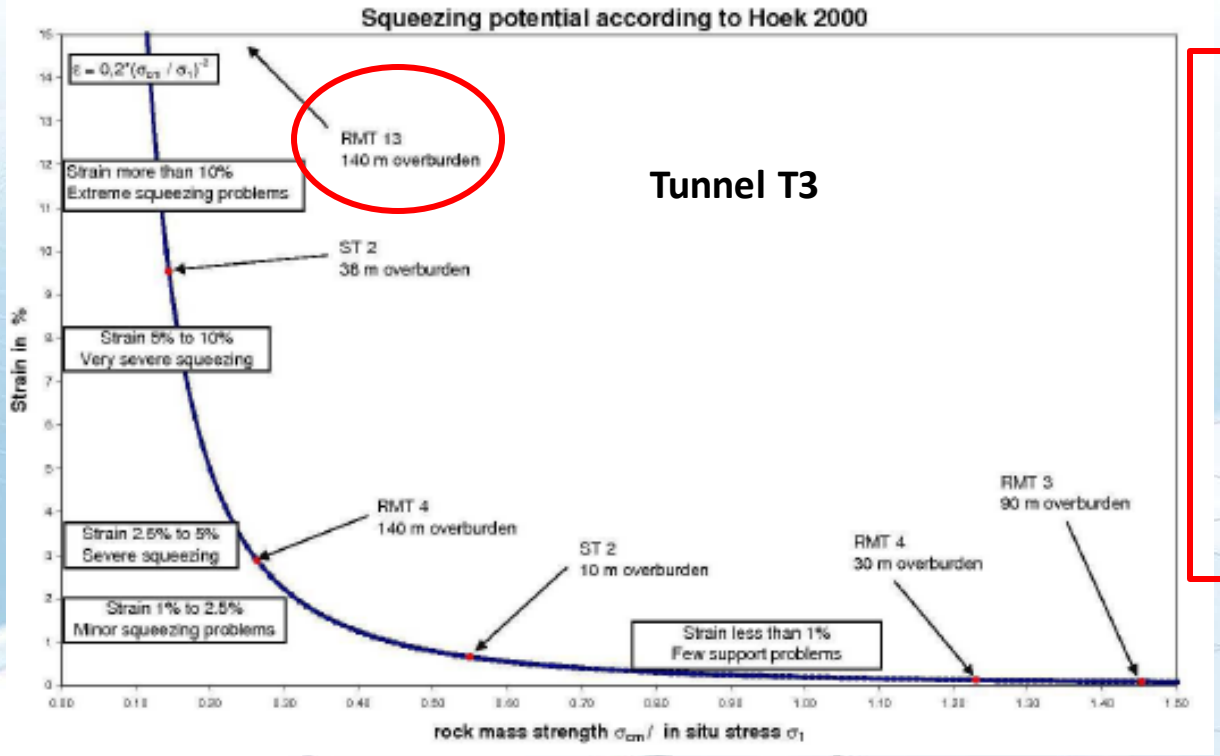
RMBT 7



Rock Mass Types	ST 1, ST 2
Discontinuity Parameters	disintegrated rock mass / soil
persistence	disintegrated rock mass / soil
aperture, infilling	disintegrated rock mass / soil
Short description of Geology	Alluvial deposits
Overburden	< 20 m
GSI	n. a.
Water	Minor water inflows possible
Rock Mass Behaviour	Potential for excessive downfall with progressive shear failure and the development of chimney type failure to the surface

Identified Geotechnical Risks:

- squeezing potential (in weak phylites and peridotites)
- cave-ins in the very low overburden areas
- karstic features in limestones
- high groundwater inflows and connection with the springs and aquifers at the Platamon area



PROJECT's KEY DECISION:

The high squeezing potential not to be addressed by using flexible support.

Instead, use of over-excavation concept in conjunction with dual primary support measures.

Mode of Application Criteria for the E&S

ROCK MASS TYPE - 2

ΤΕΧΝΙΚΟΓΕΩΛΟΓΙΚΗ ΕΝΟΤΗΤΑ - 2

D

ΓΕΩΤΕΧΝΙΚΕΣ ΣΥΝΘΗΚΕΣ – ΕΚΣΚΑΦΗ
GEOTECHNICAL CONDITIONS - EXCAVATION

1. ΠΕΡΙΓΡΑΦΗ ΒΡΑΧΟΜΑΖΑΣ / ROCK MASS DESCRIPTION

Crystalline limestone (k), grey coloured, crossed by several intersecting discontinuity sets, constituting a blocky to very blocky rock mass (small wedges are expected). Discontinuities are mainly rough, closed, low to moderately weathered. Some sandy filling is detected.

Small influence of underground water.

2. ΕΚΤΙΜΩΜΕΝΕΣ ΠΙΕΣΕΙΣ - ΠΑΡΑΜΟΡΦΩΣΕΙΣ / INDUCED PRESSURES - DEFORMATIONS

Negligible induced stresses around the excavation and negligible deformations. Rock mass strength higher than the induced tangential stresses around the tunnel. Zero plastic zones. Stable excavation faces. The behaviour is controlled by structurally induced instabilities. Frequent small wedges are expected to fall from the periphery of excavation, formed by unfavourably oriented discontinuities.

Maximum Overburden Heights H ≤ 150m.

3. ΜΕΘΟΔΟΛΟΓΙΑ - ΣΤΑΔΙΑ ΕΚΣΚΑΦΗΣ / METHODOLOGY - STAGES OF EXCAVATION

Underground excavation by employing careful blasting techniques and avoiding detrimental disturbance (loosening) of the surounding rock mass. Two independent excavation stages, i.e. top heading excavation (down to elevation +0.78m from the red line) advancing independent of the bench (down to -0.85 / -1.80m below the red line).

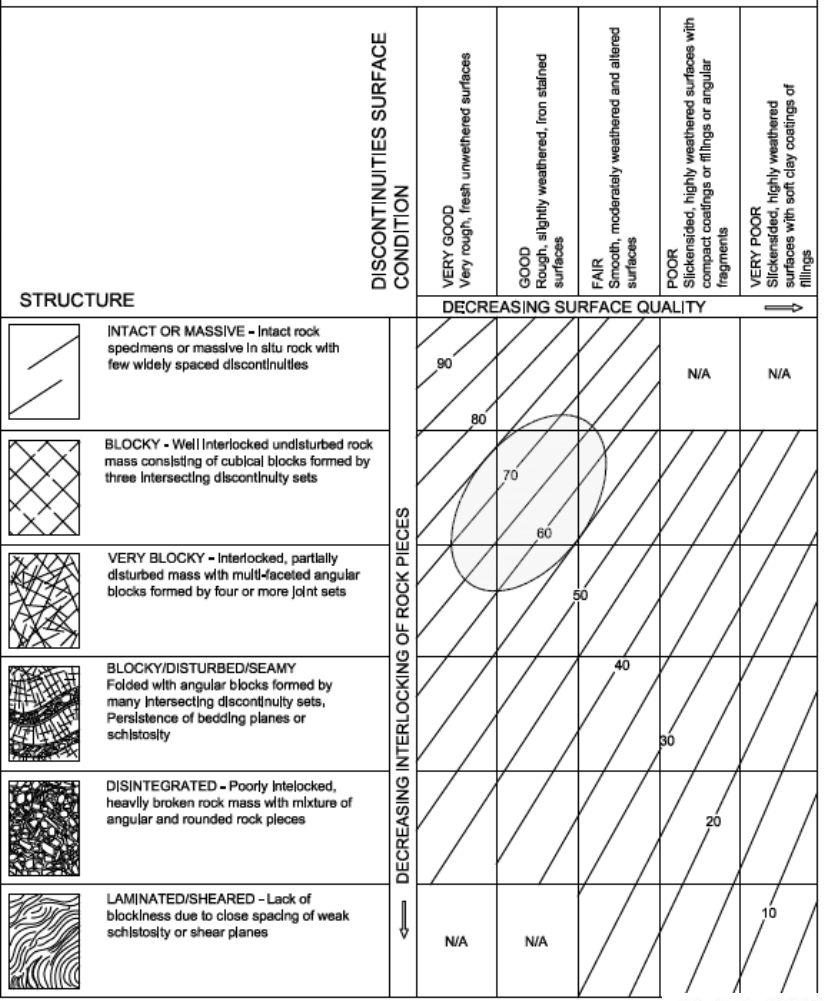
4. ΒΗΜΑ ΠΡΟΧΩΡΗΣΗΣ / ROUND LENGTHS

Round length up to 3.00m for the top heading, up to 6.00m for the bench.

5. ΚΡΙΤΗΡΙΑ ΕΦΑΡΜΟΓΗΣ / APPLICATION CRITERIA

Limestones of RMT - 2 at overburden heights H ≤ 150m.

GSI CHART (55 - 75)



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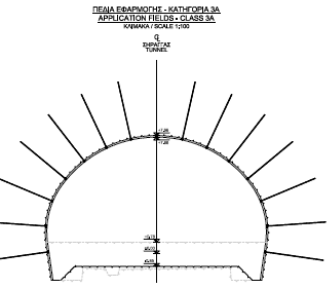
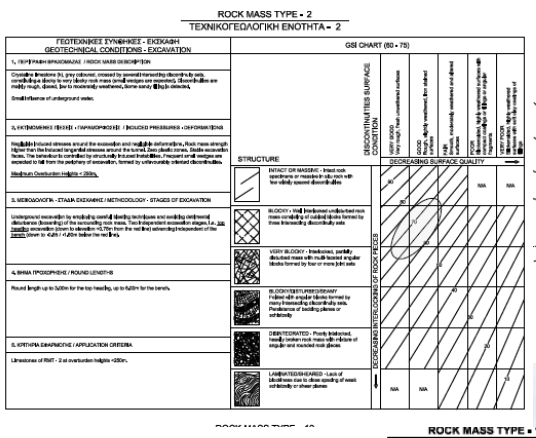
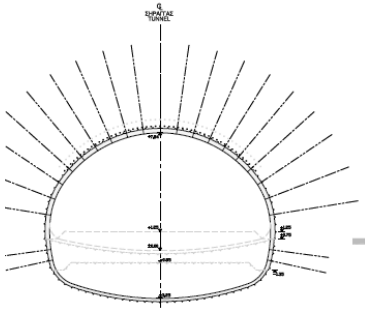
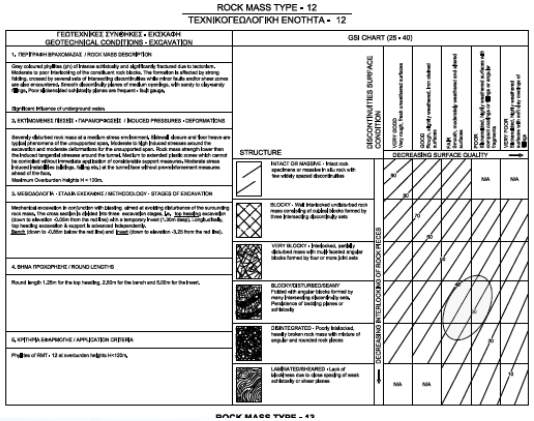
Support Classes – Application Criteria

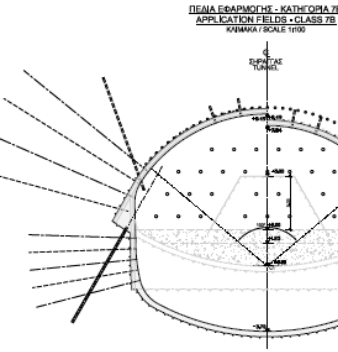
Type I	Type II	Type III ⇐ FL Types
3A, 4A,5A	5B, 6A	7A, 7B, 7C ⇐ E&S Class

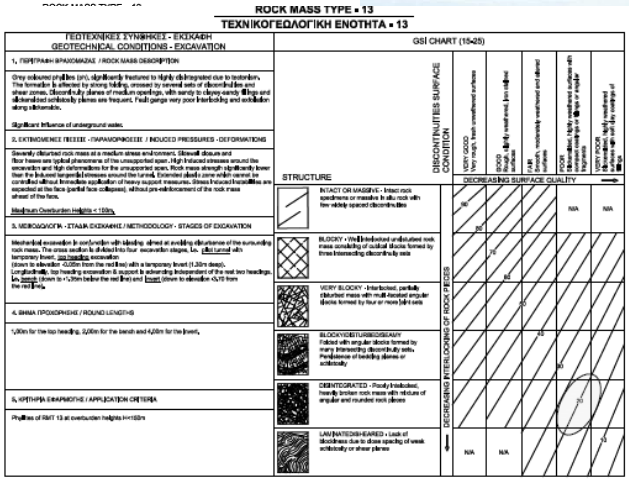


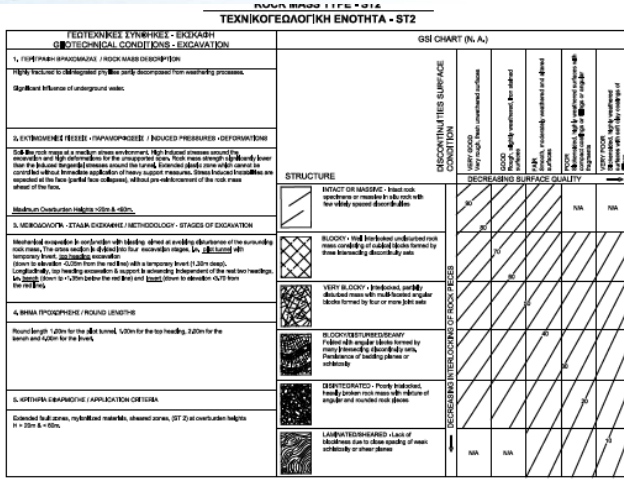












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Tunnel T3 - Excavation & Support Classes – Application Criteria

Lithology / Λιθολογία		Excavation and Support Class / Κατηγορία Εκσκαφής & Άμεσης Υποστήριξης								
RMT / ST	GSI	3A	4A	5A	5B	6A	7A-J	7A	7B	7C
RMT2	70-55	H<150m								
RMT3	55-40	n/a	H<150m							
RMT4	40-25		n/a	H<100m	100<H<150m					
RMT4	25-15			n/a	n/a		H< 60 m		60<H<150m	60<H<150m [1]
RMT12	40-25					H<120m		120<H<150m		
RMT13	25-15					n/a		H<80m		80<H<150m
ST1	<15								H<20m	
ST2	<15							H<25m	n/a	25<H< 150m [2]
ST3	<15						H<45m	n/a		

Notes:

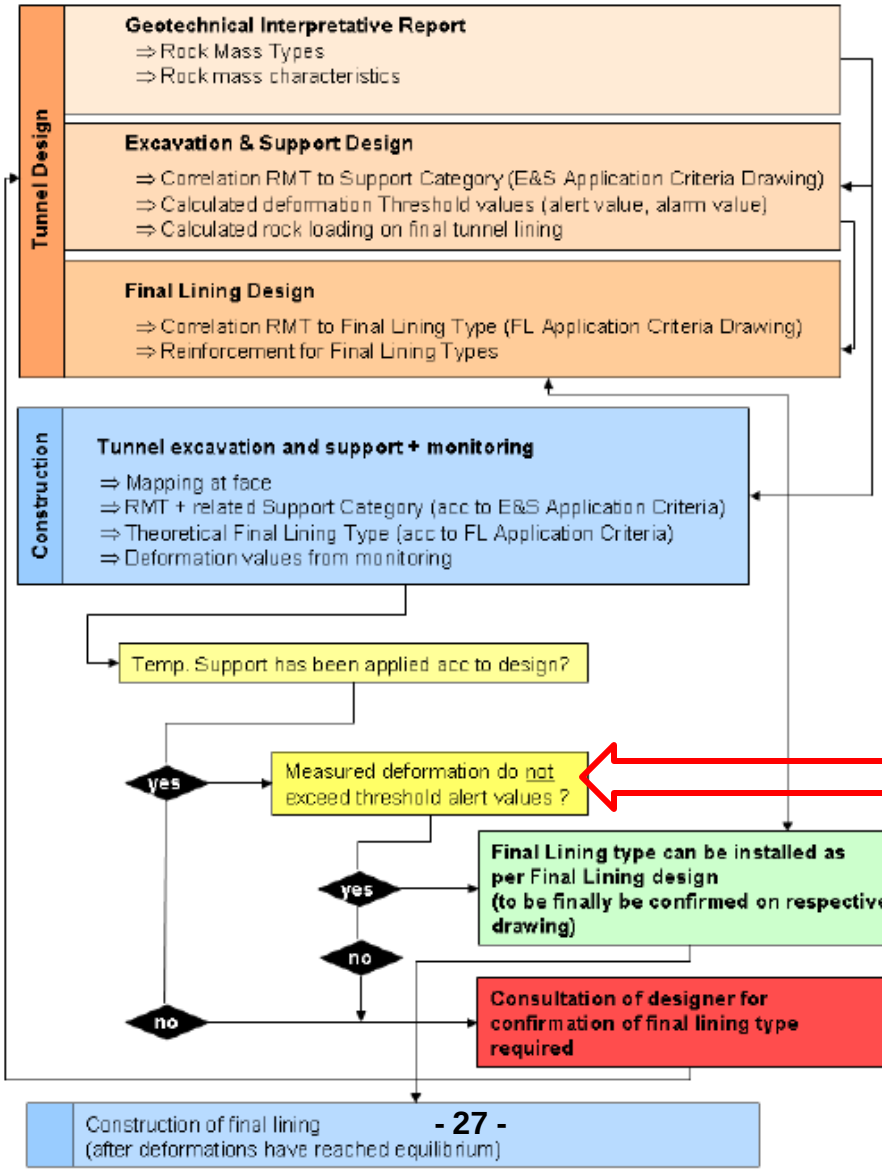
[1] in case face stability failure is predominant

[2] in case of highest overburden, the applicability is limited to a peridotite lense with an extension of 40 m along the tunnel stretch

n/a not applicable

Μη εφαρμόσιμη

Flow Chart for Final Lining Application



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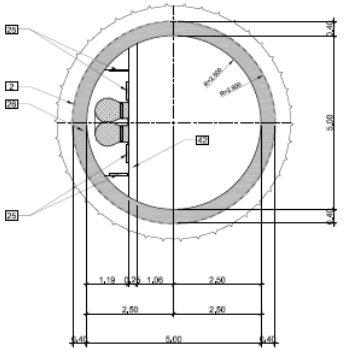
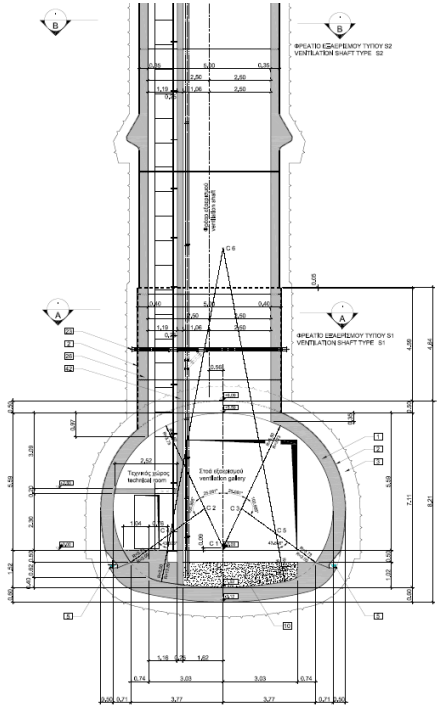
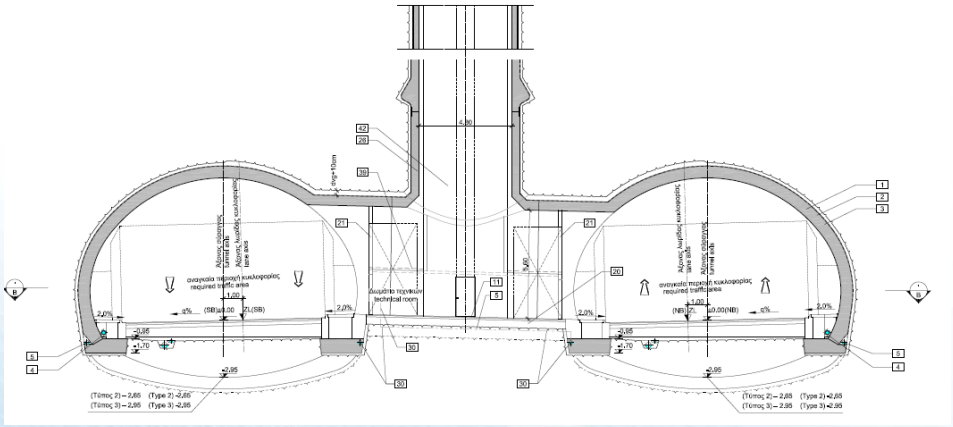
Tunnel T2 - Ventilation Shafts – Layout

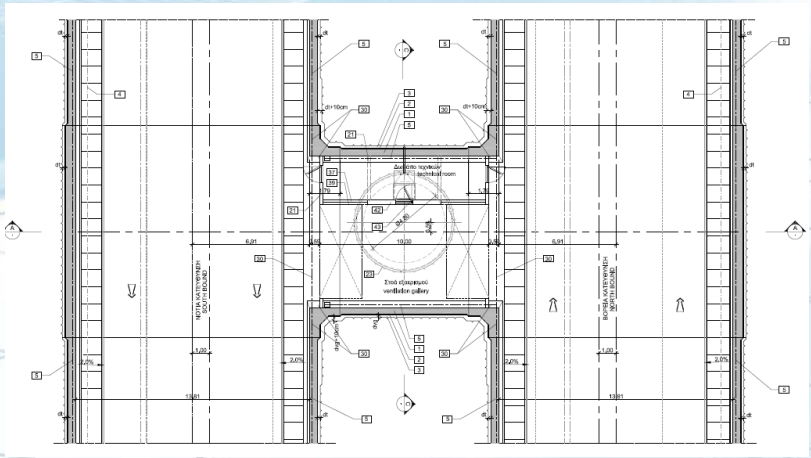


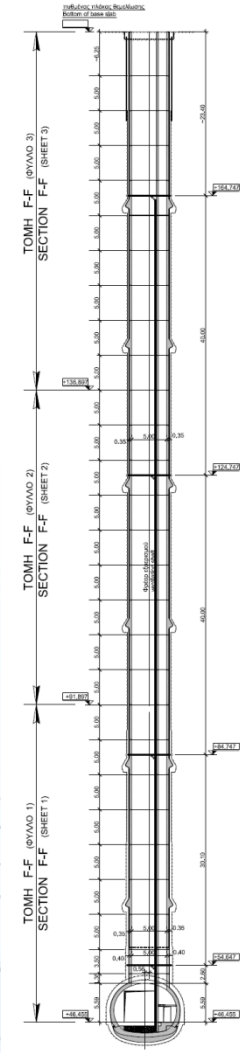
Shaft at CH.5+750 H=135m, in phyllites (GSI~40)

Shaft at CH.9+150 H=45m, in debris material & shattered limestones









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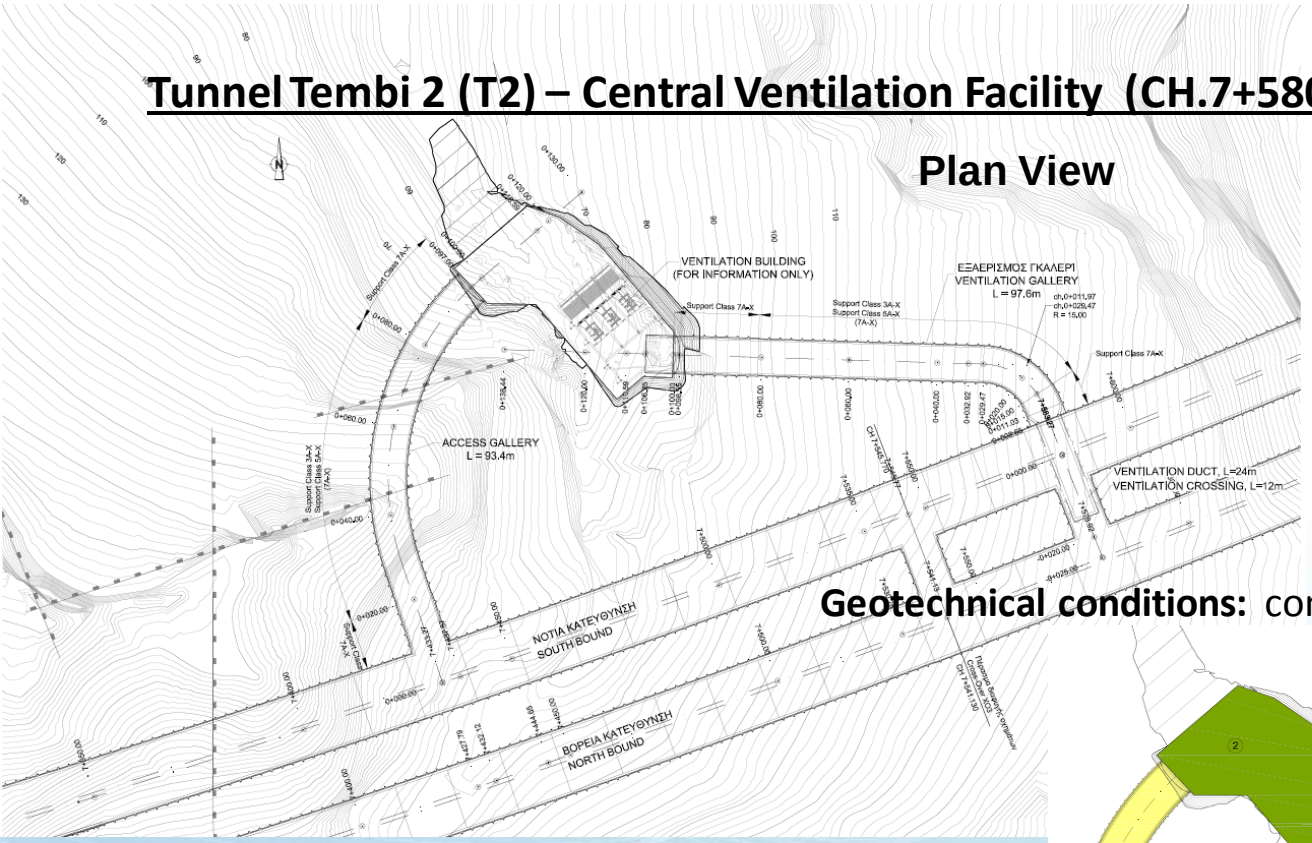
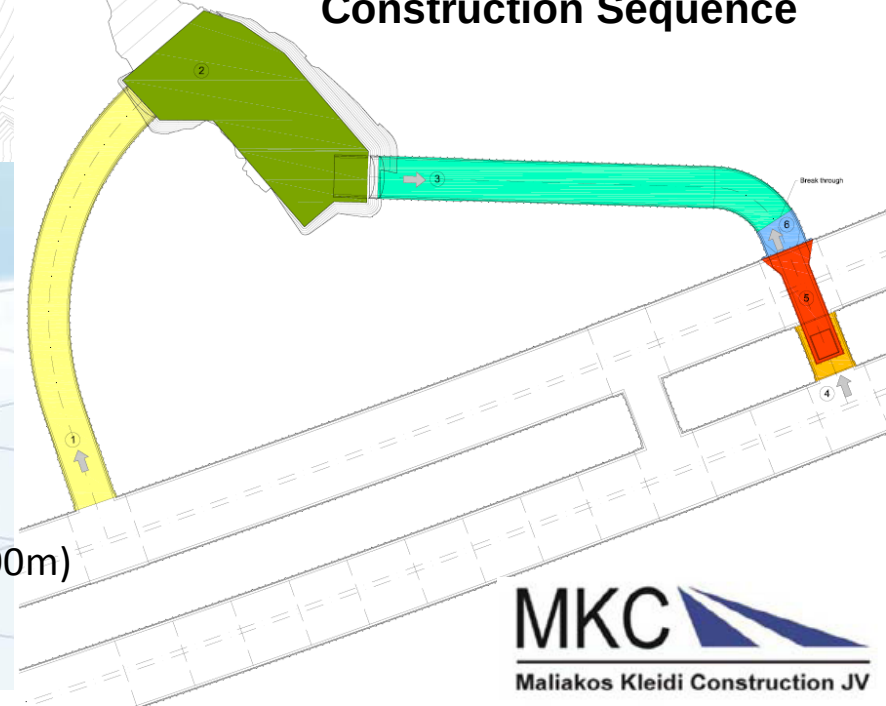
Tunnel Tembi 2 (T2) – Central Ventilation Facility (CH.7+580)

Plan View



Geotechnical conditions: competent limestones GSI 40- 55

Construction Sequence



- access gallery L=97m
- ventilation complex : ventilation crossing
  air duct
  ventilation gallery (L=100m)

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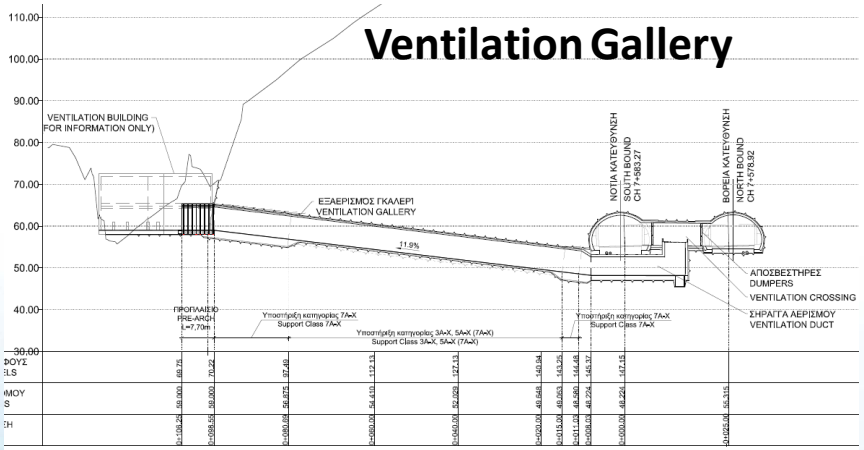
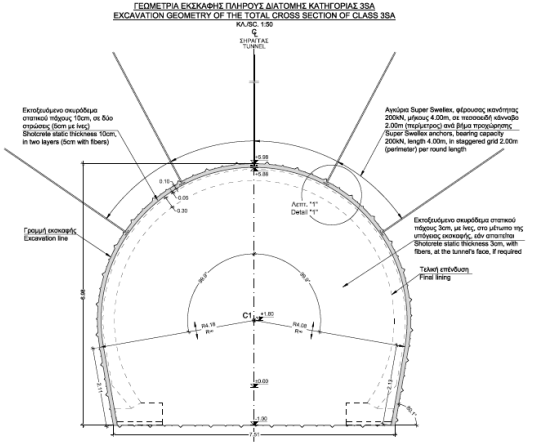
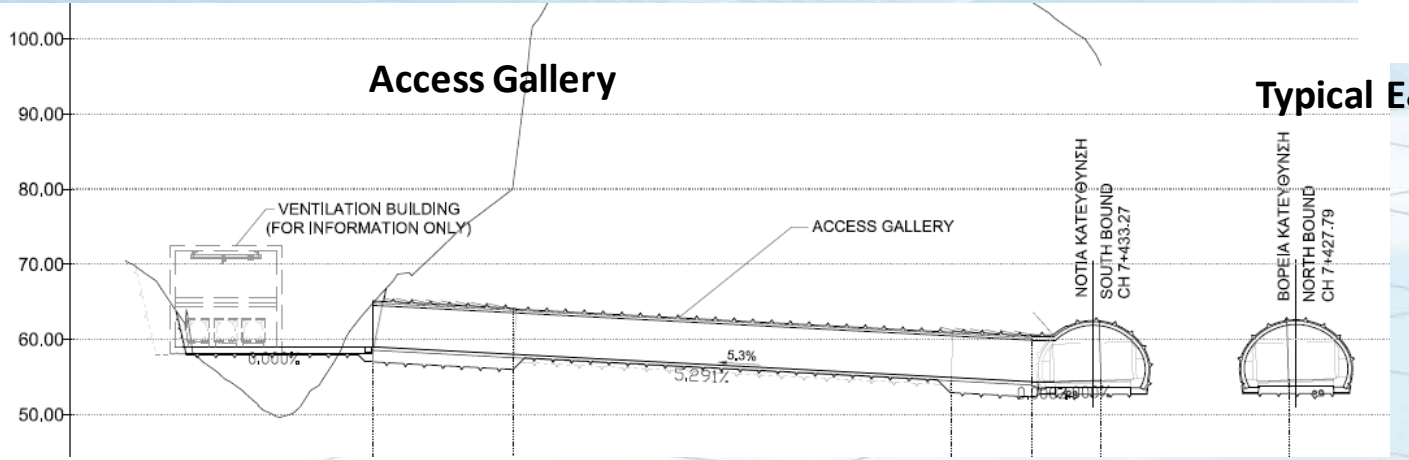
Tunnel Tembi 2 (T2) – Central Ventilation Facility (CH.7+580)

Ventilation Gallery





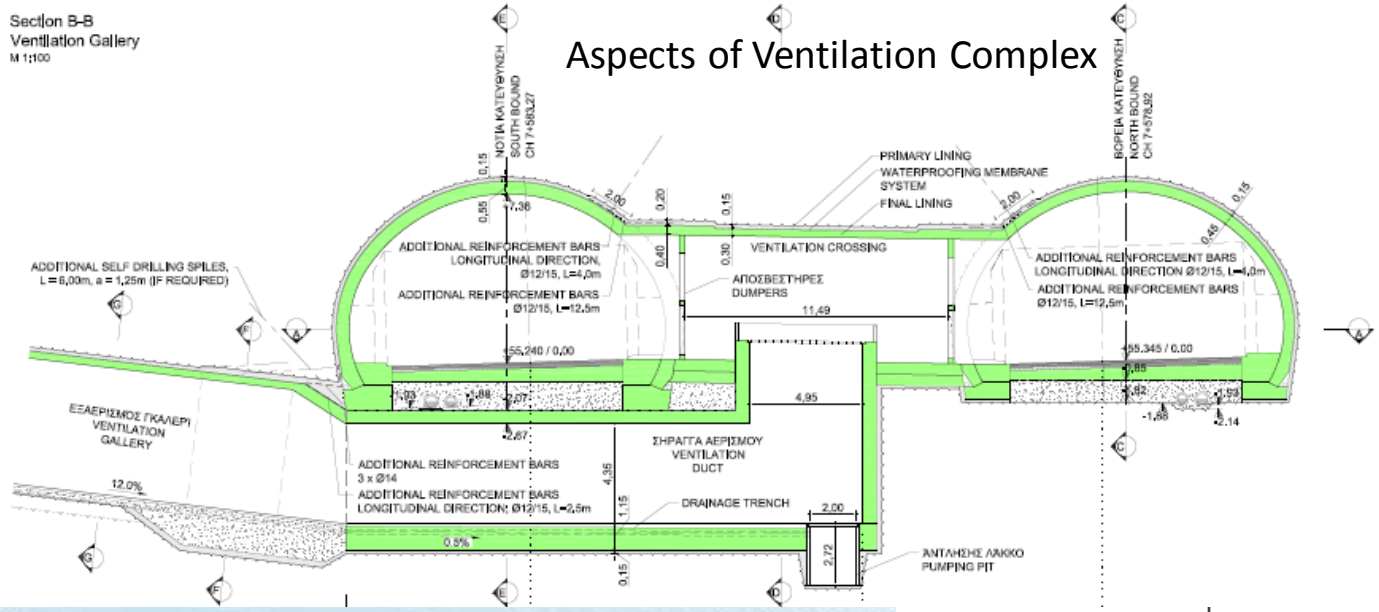
Access Gallery

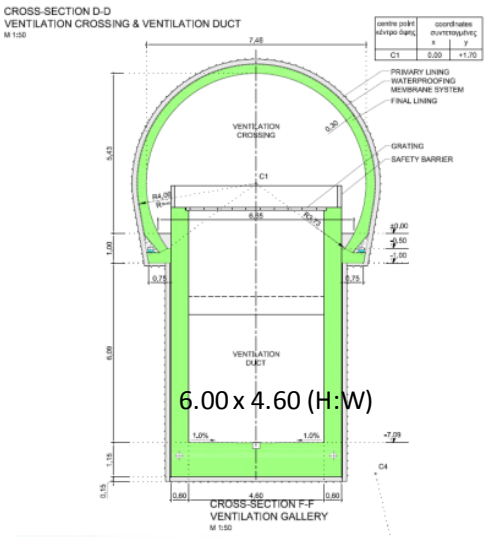


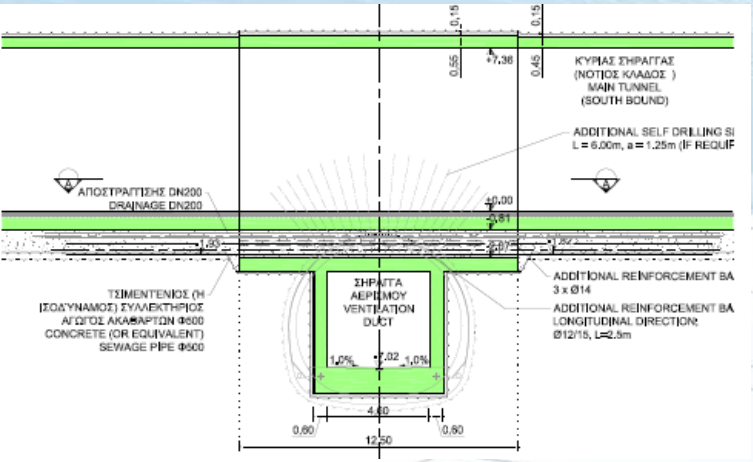
Typical E&S class for both adits

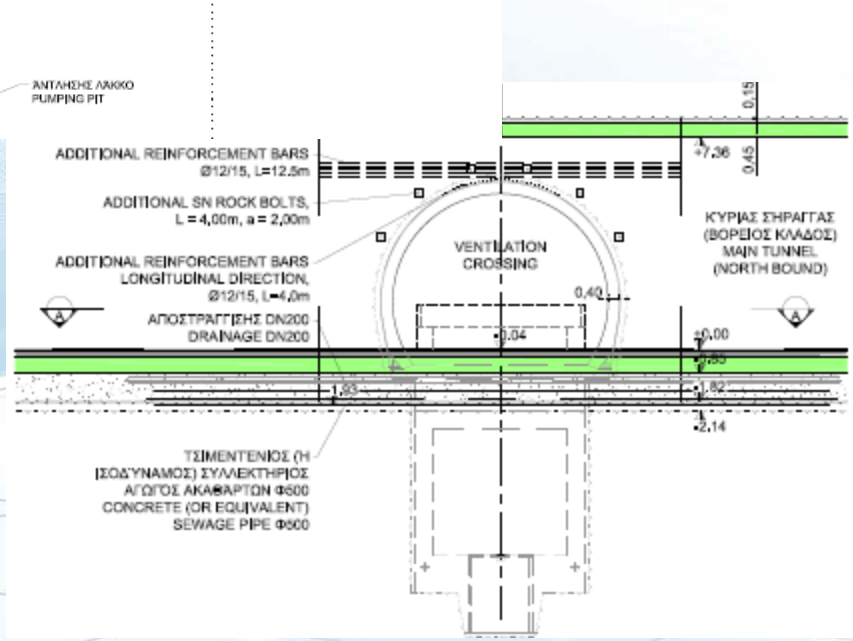
Tunnel Tembi 2 (T2) – Central Ventilation Facility (CH.7+580)

Aspects of Ventilation Complex









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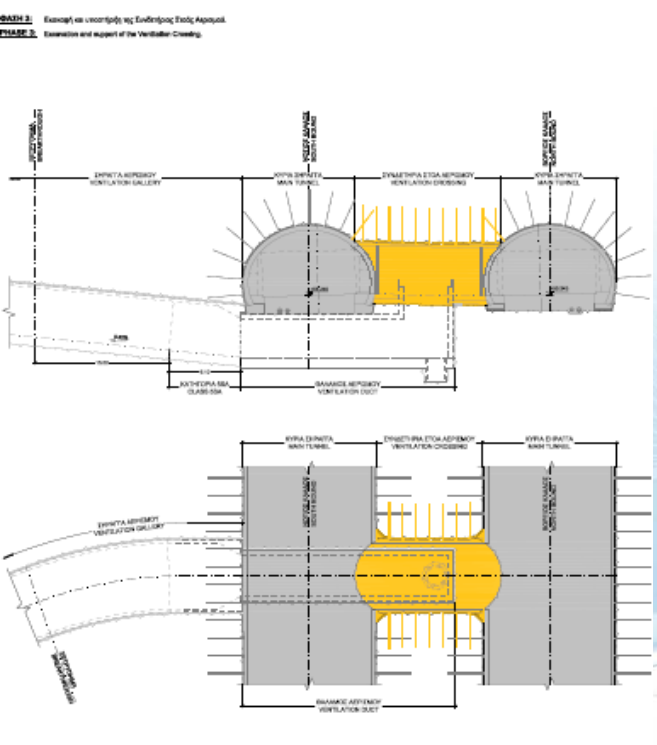
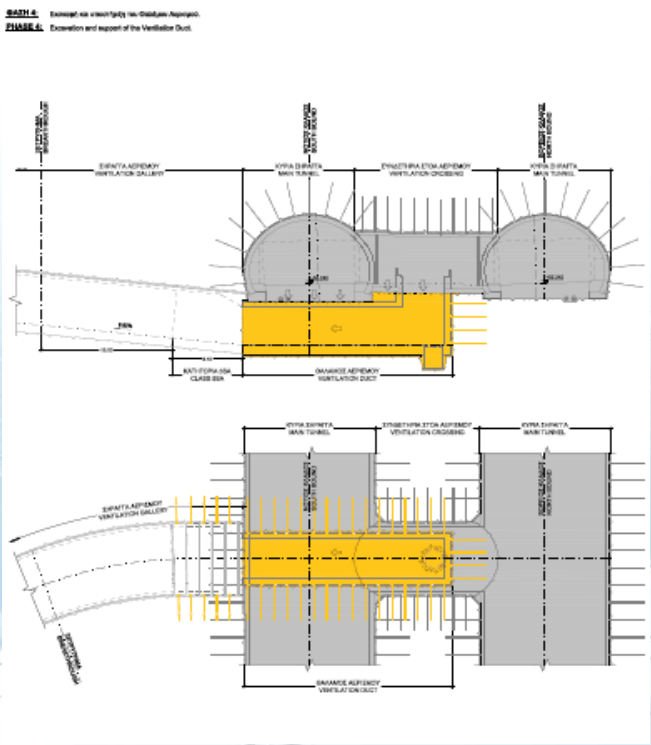
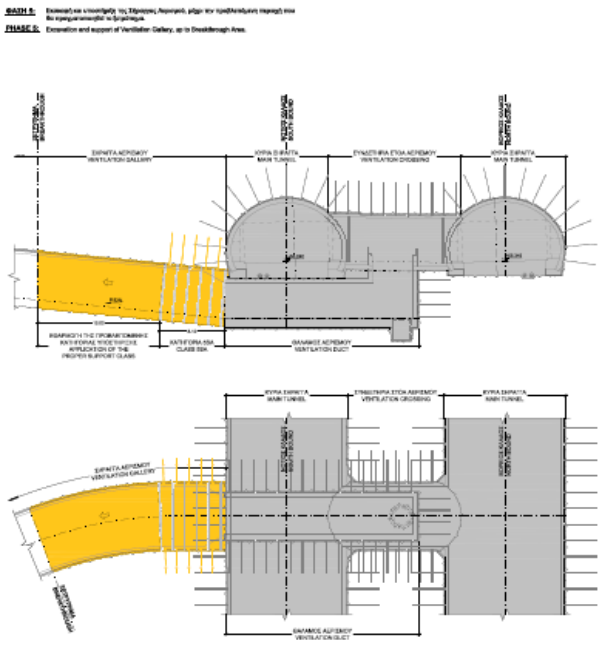
Tunnel Tembi 2 (T2) – Central Ventilation Facility (CH.7+580)

Excavation sequence of the Ventilation complex (ventilation crossing & duct)

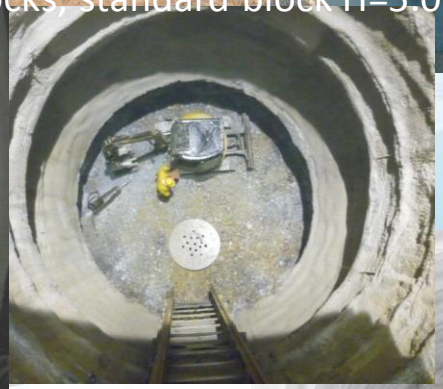






Tunnel Tembi 2 (T2) – Ventilation Shaft H=135m (CH.5+750, Φ5000)

- excavation from top to down
- raise boring (Φ1000mm)
- material feeding from the top - spoil removal from the bottom
- competent phyllites (GSI~40)
- time for E&S : 6 months
- time for concreting: [illegible]27 blocks, standard block H=5.00m)



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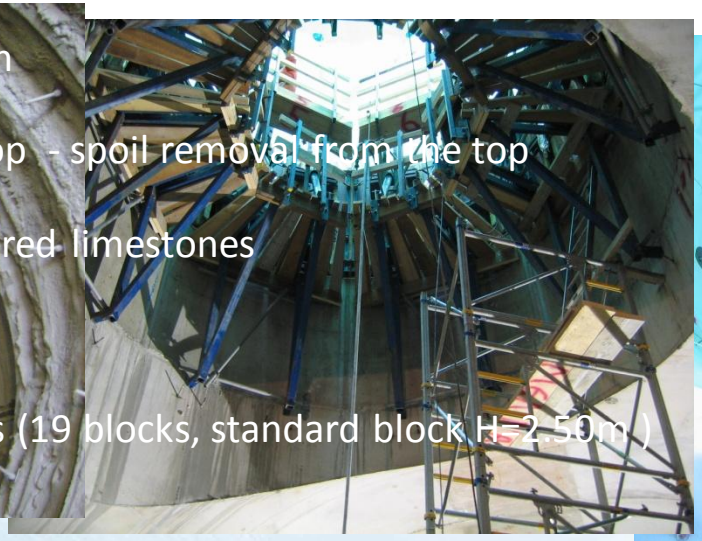
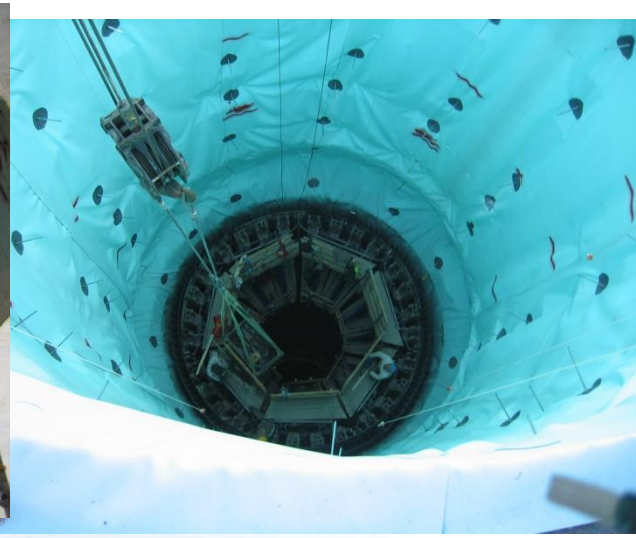
Tunnel Tembi 2 (T2) – Ventilation Shaft H= 45m (CH.9+150, Φ5700)

- excavation from top to down
- material feeding from the top - spoil removal from the top
- Limestone debris and shattered limestones
- time for E&S : 4 weeks
- time for concreting: 5 weeks (19 blocks, standard block H=2.50m)





Tunnel Tembi 2 (T2) – Ventilation Facility (CH.7+580)


duct ceiling


Vent crossing / duct


Access gallery – portal


Duct bottom plate


Vent. gallery portal


duct below the SB

UNREINFORCED FINAL LINING

Principles of designing the unreinforced lining in the MMK tunnels:

Unreinforced in the **main tunnel** sections (**depending on rock mass conditions**), however in blocks with niches (drainage & EDP) where an unreinforced lining is applied , the **area around the niche** is steel reinforced

Steel reinforced lining adopted in:

- the crossings
- the intersection blocks of the main tunnel
- the shafts and complex underground spaces
- sections susceptible to seismic forces (*i.e. for the C&C structures, low overburden areas*)

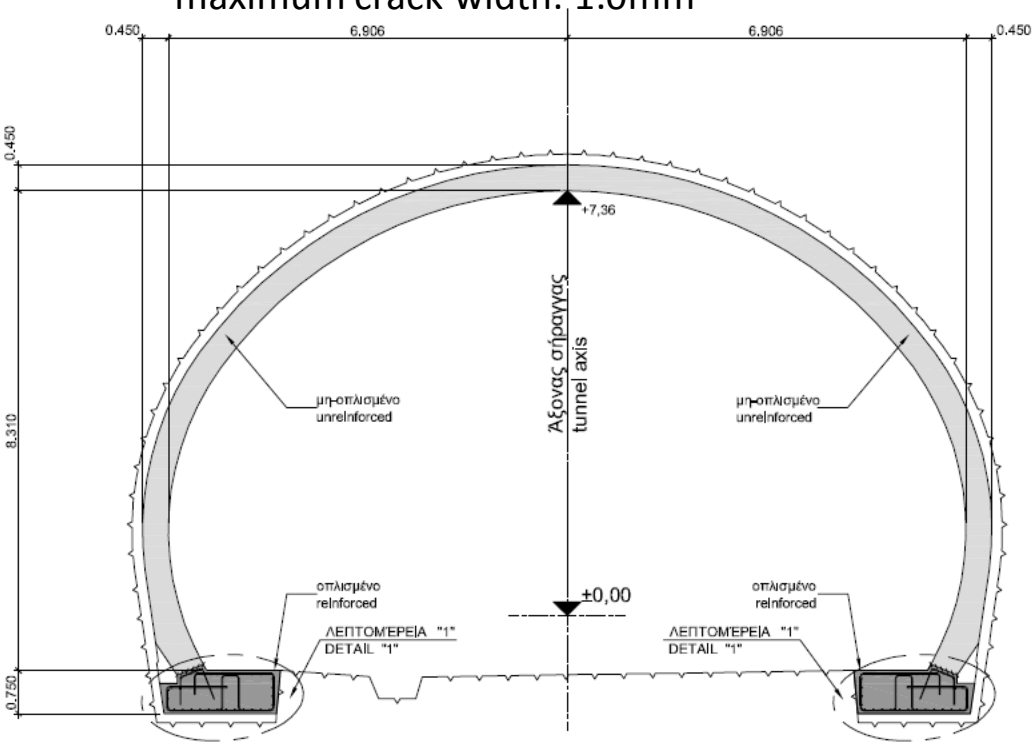
UNREINFORCED FINAL LINING

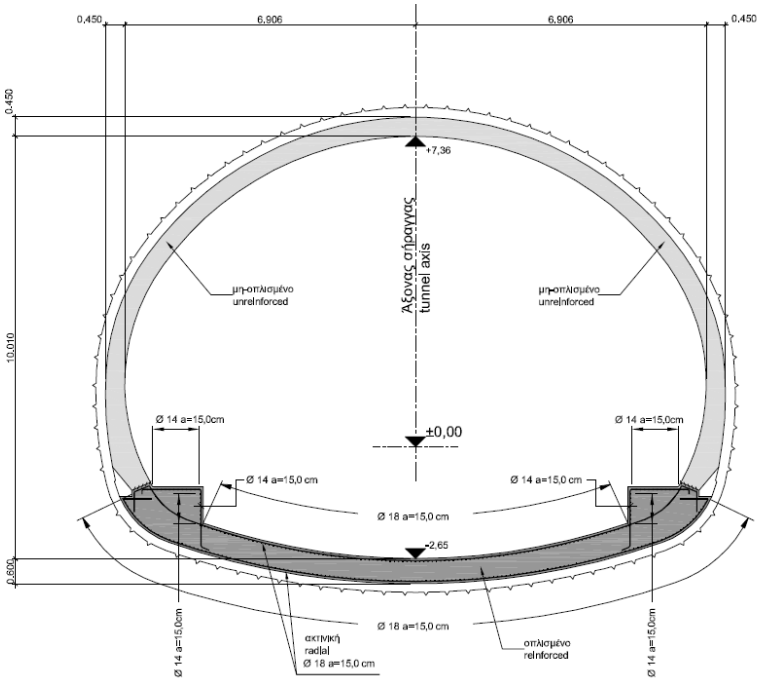
concrete quality C30/37; de-moulding concrete strength >2MPa

min thickness of vault 45cm

application in competent rock mass with E>1GPa

maximum crack width: 1.0mm



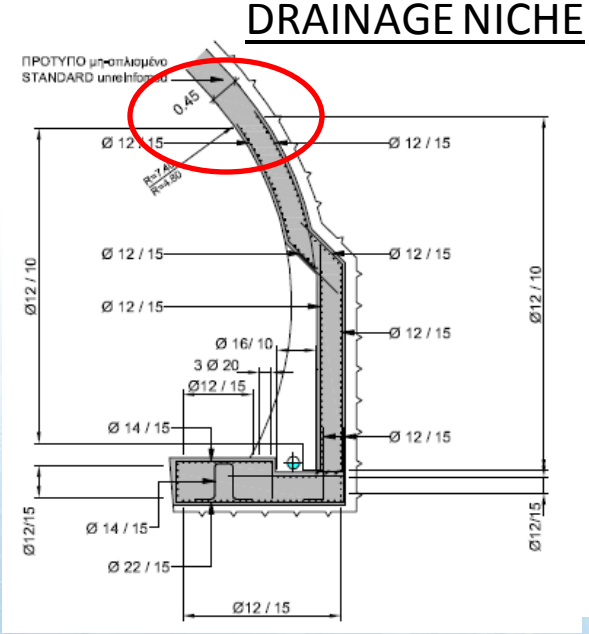


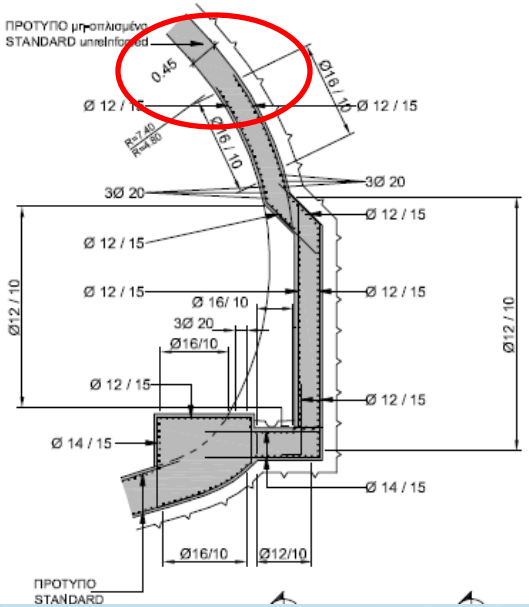
Unreinforced lining designated only for the FL types 1 and 2 (NOT for Type 3)

UNREINFORCED FINAL LINING

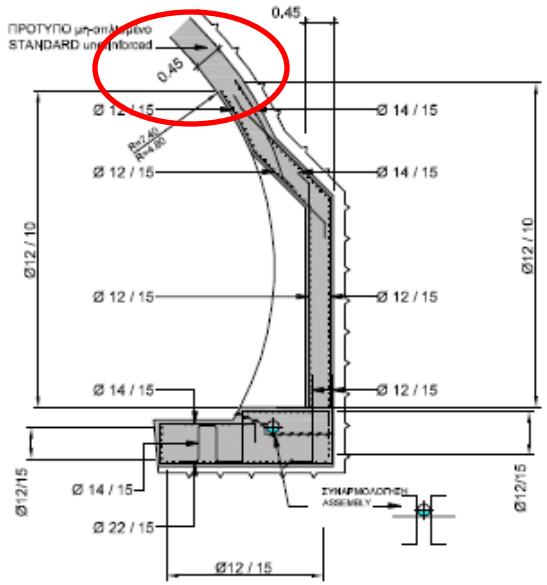
- Application in blocks with a niche

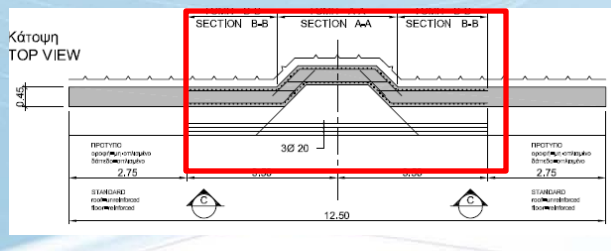
DRAINAGE NICHE

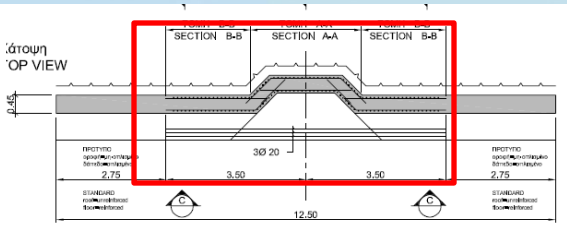


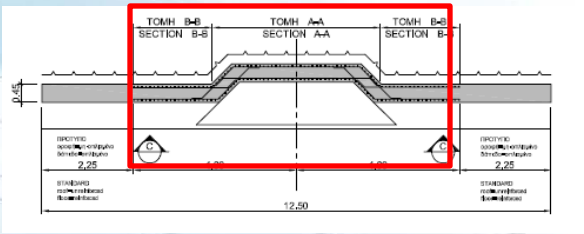


EMERGENCY (EDP) NICHE

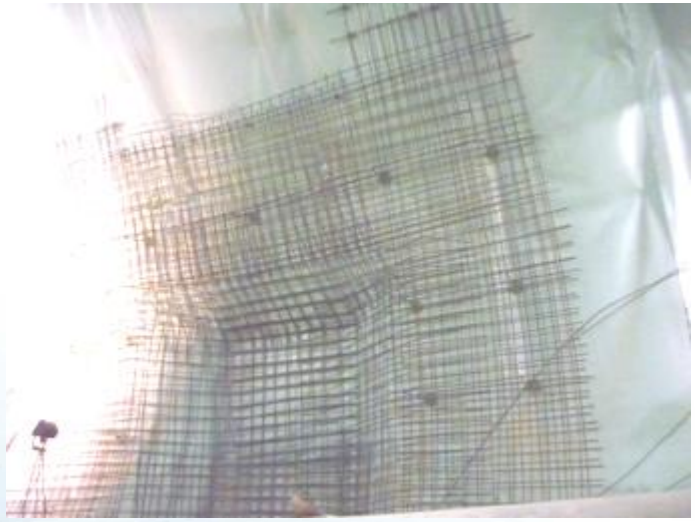








UNREINFORCED FINAL LINING



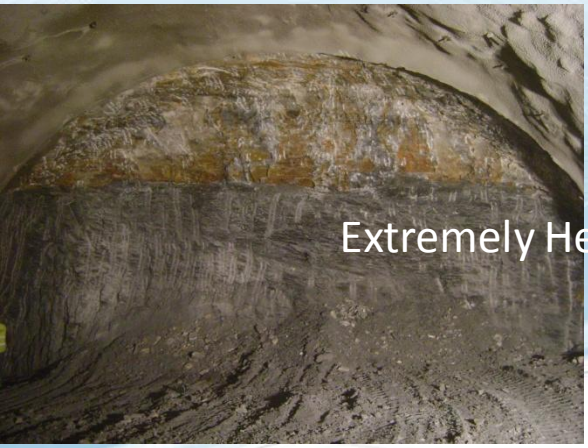
Application ~ 20% of the project

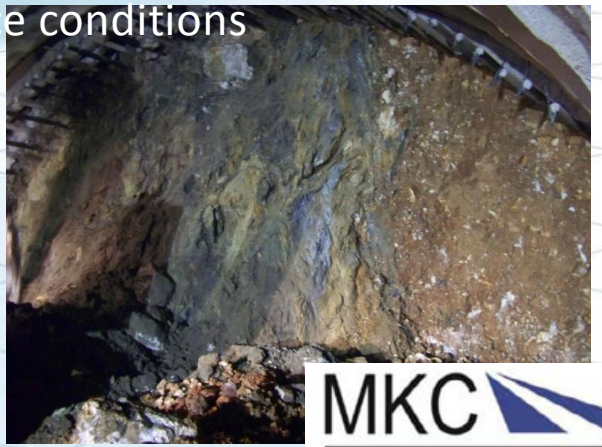
- **Tunnel T1:** 1.46 km out of 3.85 km
- **Tunnel T2:** 3.37 km out of 11.94 km
- **Tunnel T3:** 0

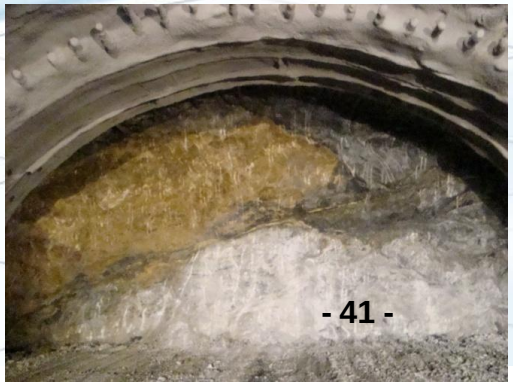
SPECIAL CONDITIONS ENCOUNTERED IN THE EXCAVATION & SUPPORT

- ✓tunnelling under low overburden (as low as 6m)
- ✓tunnelling under high overburden (T2 >250m, T3 ~150m)
- ✓formation of complex underground spaces for the ventilation facilities
- ✓extremely heterogeneous masses and mixed face conditions
- ✓unprecedented face instabilities
- ✓high convergence rates / delayed deformations – need for rehabilitation works
- ✓significant groundwater inflows (75l/s)

SPECIAL CONDITIONS ENCOUNTERED IN THE EXCAVATION & SUPPORT







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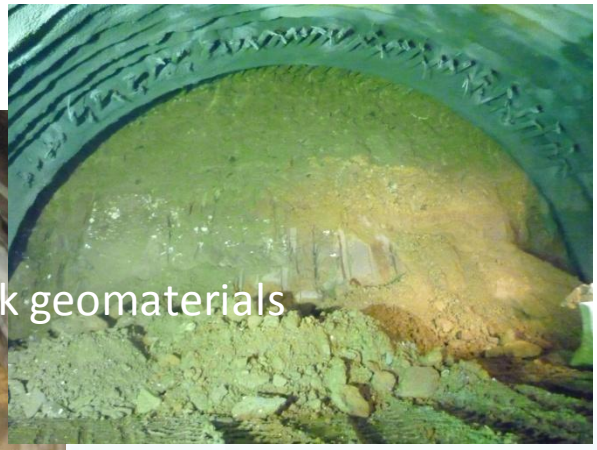
SPECIAL CONDITIONS ENCOUNTERED IN THE EXCAVATION & SUPPORT



SPECIAL CONDITIONS ENCOUNTERED IN THE EXCAVATION & SUPPORT

Most hazardous situations were linked with the tunnels passing through long zones of weak to very weak geomaterials, esp. in

tunnels T2 (Tembi 2 / phyllites) and

T3 (Platamon / peridotites)

SPECIAL CONDITIONS IN TUNNEL TEMBI TUNNEL 2 (T2)

The "short pilot" tunnel method

Description of tunnel troublesome situation:

- Top heading excavation in shattered phyllites GSI~10
- medium overburden 70m
- Severe face instabilities (impossible to address with standard methods, such as: face buttress, intense fiberglass face bolting etc)
- Adverse stress environment
- inability to timely implement the support measures for the cavity
- early development of high convergences evidence of interaction between the SB and NB

under-performance of the initial lining (overstressing) – tunnel under-profile

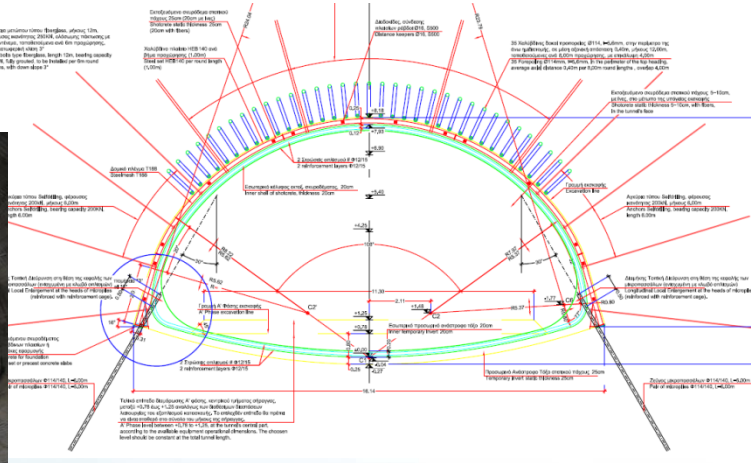
Sections affected: 35m for the SB (leading tunnel) and 25m for the NB (lagging tunnel)

Need for : **contingency measures design for immediate tunnel stabilization** and **upgrading the safety standards in E&S to advance the tunnels**

SPECIAL CONDITIONS IN TUNNEL T2 -Tunnelling in CH.10+730 – The "short pilot" tunnel method

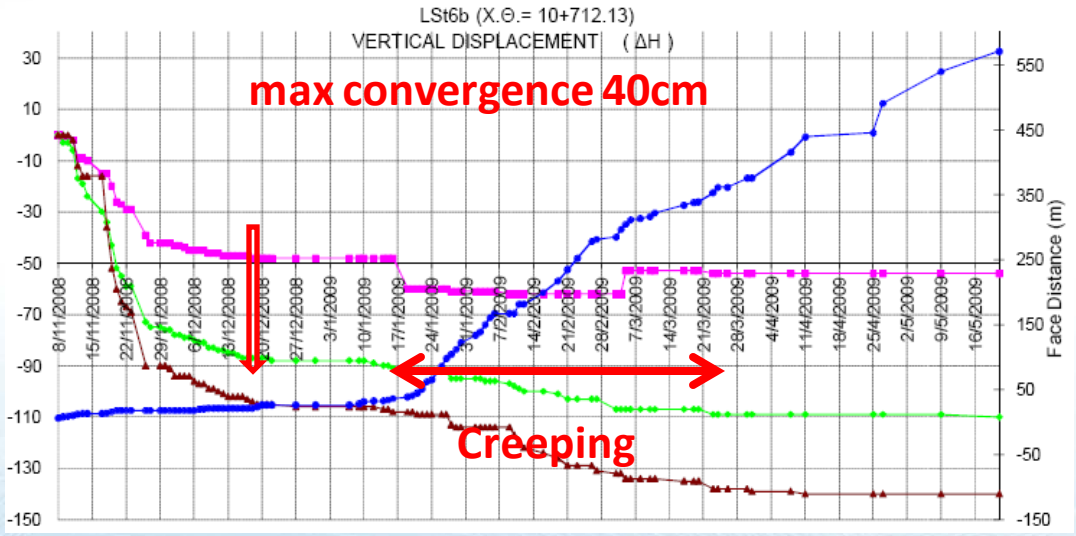
❑Tunnel Stabilization

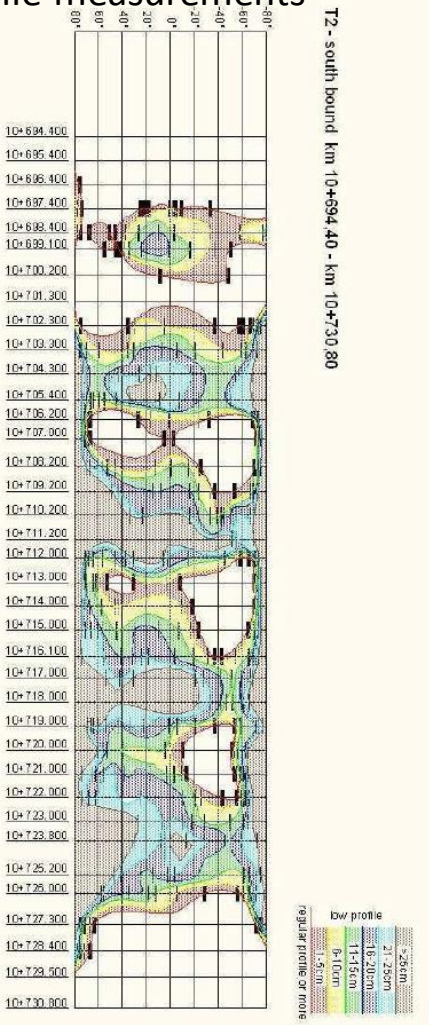
Application of 30cm inner shell of sprayed concrete reinforced with 2#Φ12/15 steel grids



SPECIAL CONDITIONS IN TUNNEL T2 -Tunnelling in CH.10+730 – The "short pilot" tunnel method

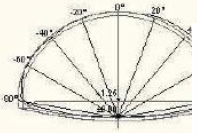
Captured convergence – profile measurements






face instabilities


phyllites in shear zone



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SPECIAL CONDITIONS IN TUNNEL T2 -The "short pilot" tunnel method

Side drifts were rejected (requiring different equipment)

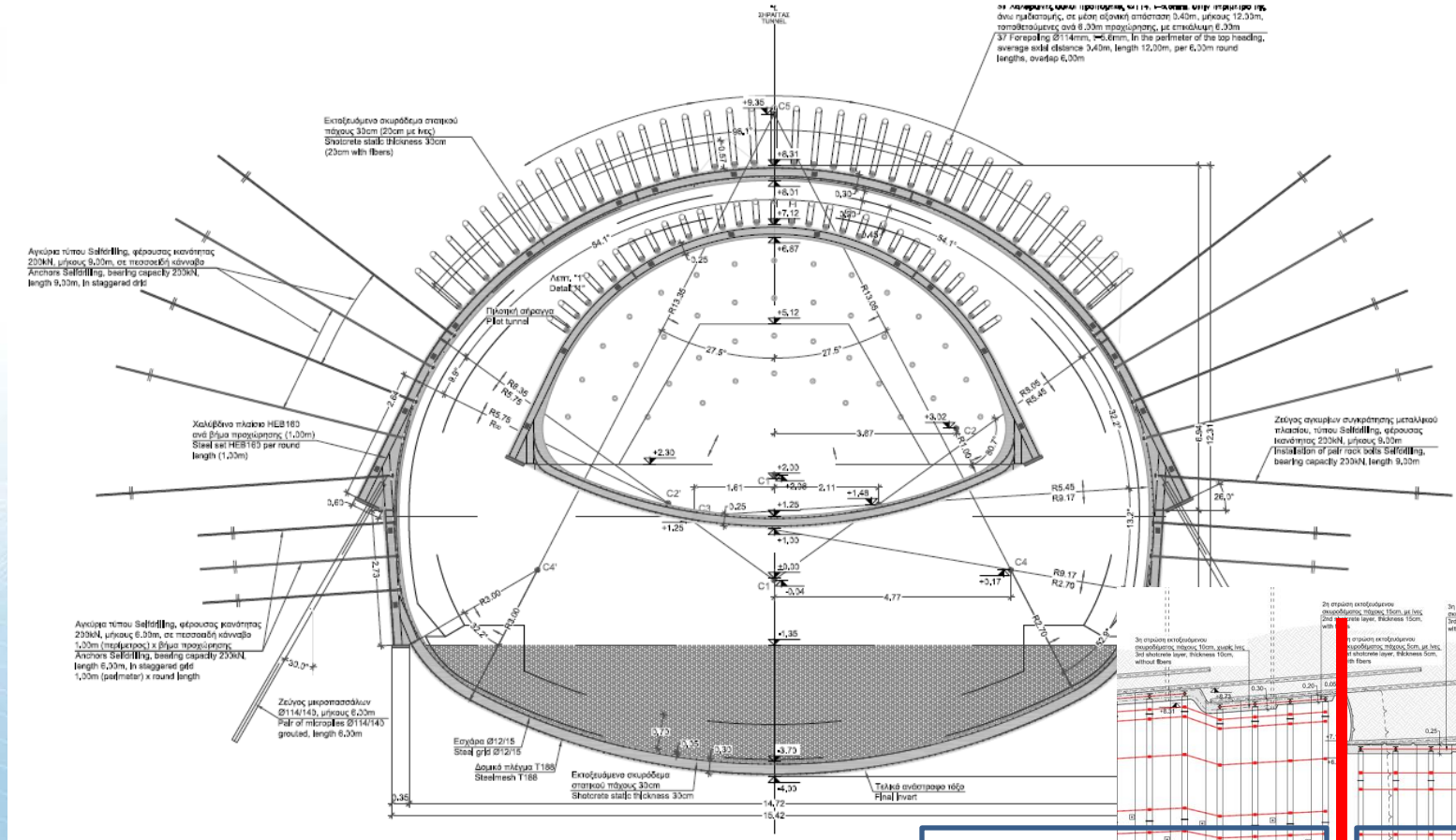
Grout strengthening also rejected (low permeability of the sheared phyllites)

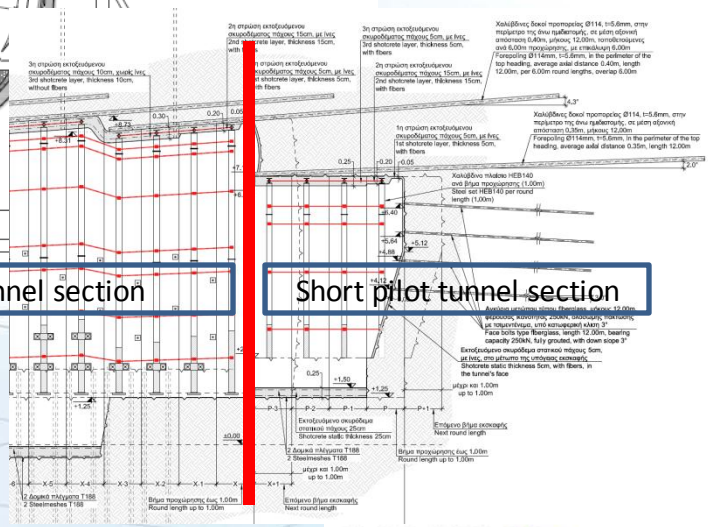
A central short drift in advance of the main tunnel

was selected to provide the confinement of the weak phyllites below the forepoling umbrella

- excavation is executed from the main tunnel, while the section is demolished on advancement of the main tunnel
- effective to deal with face instabilities in practically cohesionless geomaterials – where the standard measures (intense face bolting, shotcrete, forepolling) proved ineffective
- allowance for timely and safe application of the support measures of the cavity (as close to the face as possible)
- constructed with the same equipment deployed for the main tunnel

SPECIAL CONDITIONS IN TUNNEL T2 -Tunnelling in CH.10+730 – The "short pilot" tunnel method





Main tunnel section | Short pilot tunnel section

Specifics of the short pilot

- max advance 5m
- 29 pieces of 12m/4m long forepoles Φ114/140
- round length 1.0m
- 25cm thick shell of f.r. sprayed concrete
- HEB140 embedded
- no rockbolting

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SPECIAL CONDITIONS IN TUNNEL T2 – The "short pilot" tunnel method

Application of the "short pilot" tunnel method in the MMK tunnels

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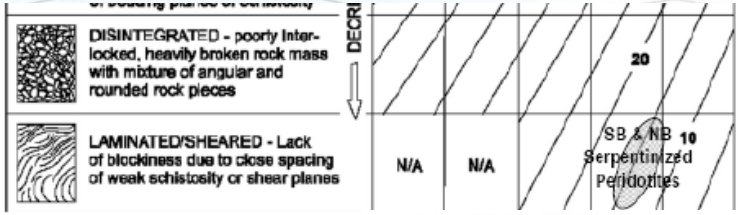
SPECIAL CONDITIONS IN TUNNEL T3

Tunnelling in CH.12+400 – Tunnel Rehabilitation

Cave in failure of the NB tunnel at ch.12+425

(*top heading excavation in very weak slickensided peridotites GSI~15, low overburden area~20m from the crown*)

- NB tunnel failed for 40m
- surface crater – surface subsidence impact as broad as 6 acres
- Nat. Gas Pipeline inside the settlement trough
- contingency actions to secure the SB tunnel – backfilling
- installation of surface monuments
- identification of site conditions by detailed site investigation
- rehabilitation Design



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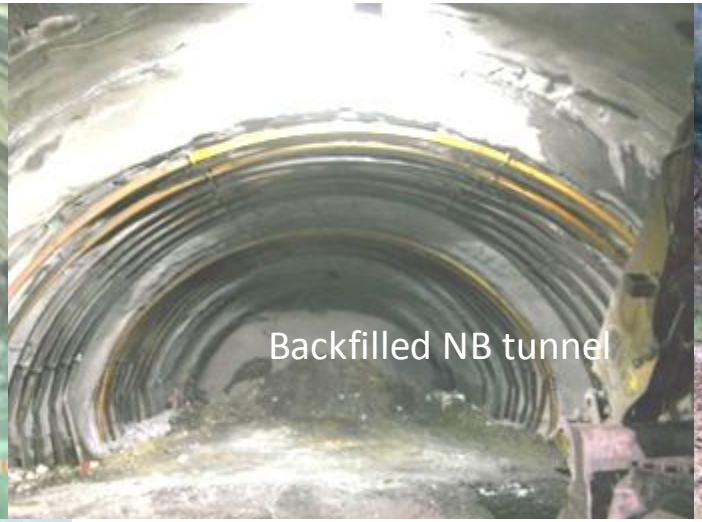
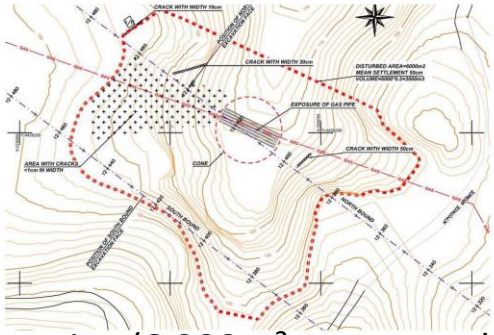
SPECIAL CONDITIONS IN TUNNEL T3

Tunnelling in CH.12+400 – Tunnel Rehabilitation





Surface subsidence footprint (6.000m^2, mean settlement 0.50m)

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SPECIAL CONDITIONS IN TUNNEL T3

Tunnelling in CH.12+400 – Tunnel Rehabilitation

- A **pilot tunnel** to get through the collapsed zone
- **no ground improvement** unless voids are detected into the collapsed area
- Subsequent **re-instatement** of the tunnel section by demolition of the pilot tunnel
- **Dimensions** of the pilot to be served by the equipment for the main tunnel (*forepoling, backhoe etc*)
- **Robust design** for the primary support shell (stiff and capable to sustain all dead loading) for both tunnels
- Excavation under successive and **overlapping forepoling umbrellas**
- well **calibrated numerical modeling** for checks of adequacy of the tunnel linings

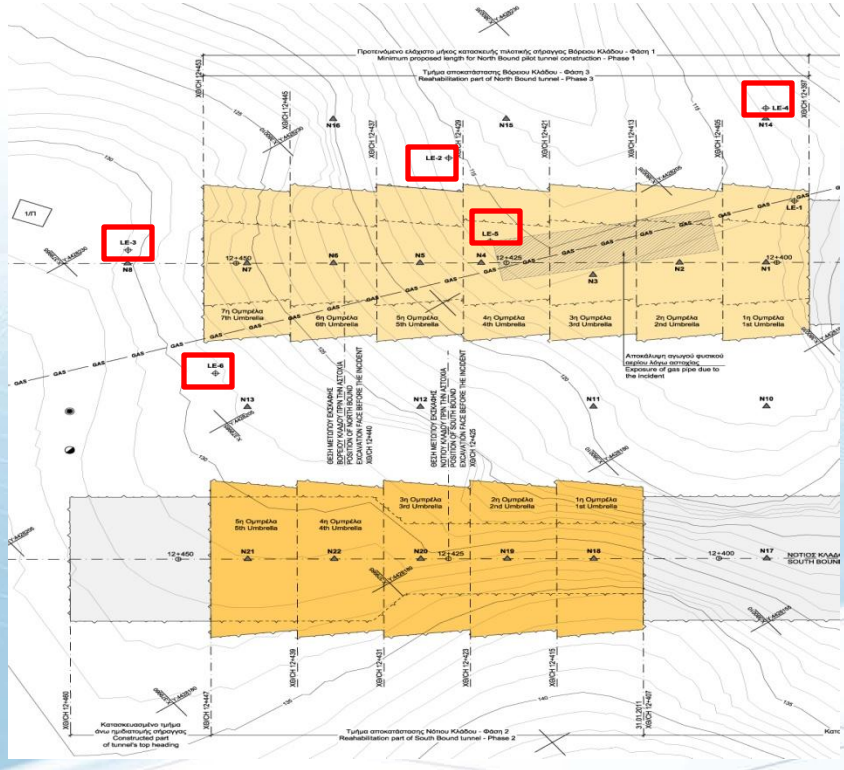
Restrictions:

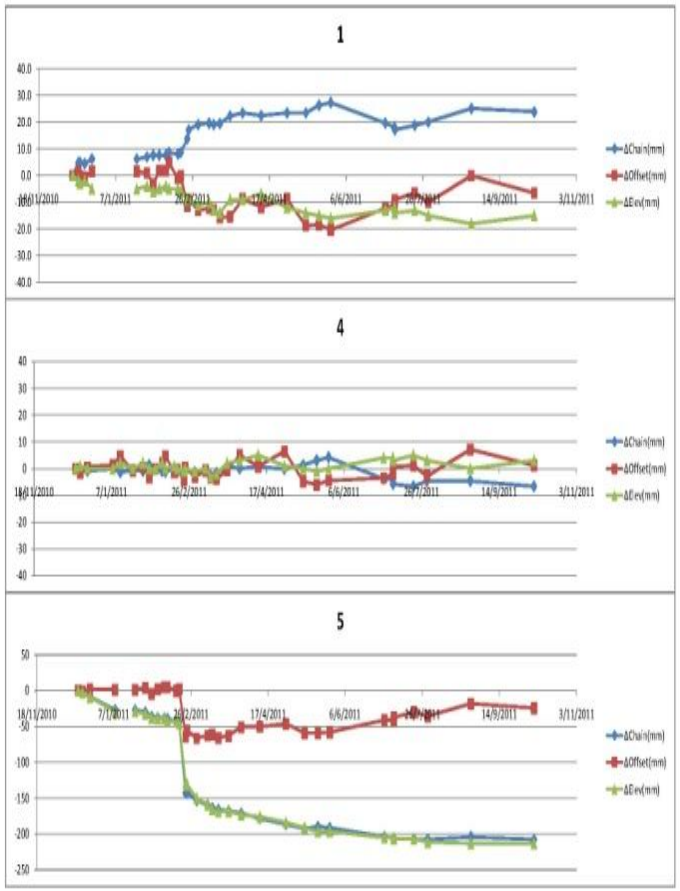
Very limited deformations on the NG pipeline

very strict **alert levels** for movements and well defined contingency actions

Tunnelling in CH.12+400 – Tunnel Rehabilitation

Surface monitoring – design phase





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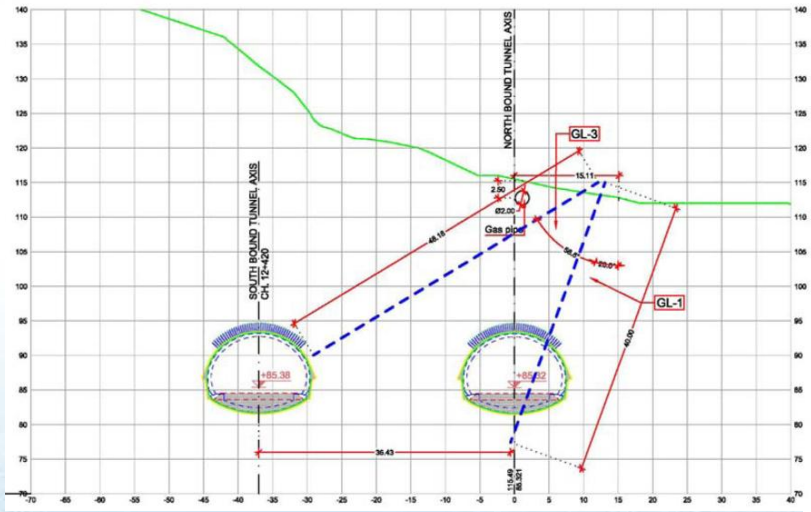
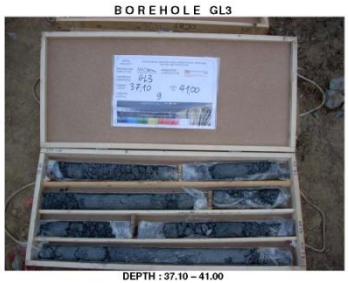
Tunnelling in CH.12+400 – Tunnel Rehabilitation

❑Site investigation phase





BOREHOLE	DEPTH (m)		LITHOLOGICAL DESCRIPTION	GEOLOGICAL FORMATION	ST/RMT
	From	To			
GL-1	0.00	1.50	Artificial Deposits	na	-
	1.50	4.00	White Limestones	k-br	RMT-4
	4.00	26.10	Completely disintegrated peridotites	ct	ST-2
	26.10	28.50	Muckpile - Tunnel collapse materials	n-a	-
	28.50	46.00	Peridotites	ct	ST-2
GL-2	0.00	0.80	Artificial Desposits	na	-
	0.80	7.00	Brown weathered peridotites	ct	ST-2
	7.00	18.00	Brown weathered peridotites with limestones	ct	ST-2
	18.00	25.30	Dark grey Peridotites, completely disintegrated	ct	ST-2
	25.30	30.70	Muckpile - Tunnel collapse materials	na	-
	30.70	46.50	Dark grey Peridotites, completely disintegrated	ct	ST-2
GL-3	0.00	3.80	Artificial Deposits	na	-
	3.80	6.20	Limestone, completely shattered	k-br	RMT-4
	6.20	30.70	Dark grey Peridotites, completely disintegrated	ct	ST-2
	30.70	48.20	Dark grey Peridotites, completely disintegrated	ct	ST-2
GL-4	0.00	25.20	White Limestones	k-br	RMT-4
	25.20	42.60	Dark grey Peridotites, completely disintegrated	ct	ST-2
	42.60	51.90	Limestone Breccia	ct	ST-2
	51.90	58.20	Grey Limestones	ct	ST-2

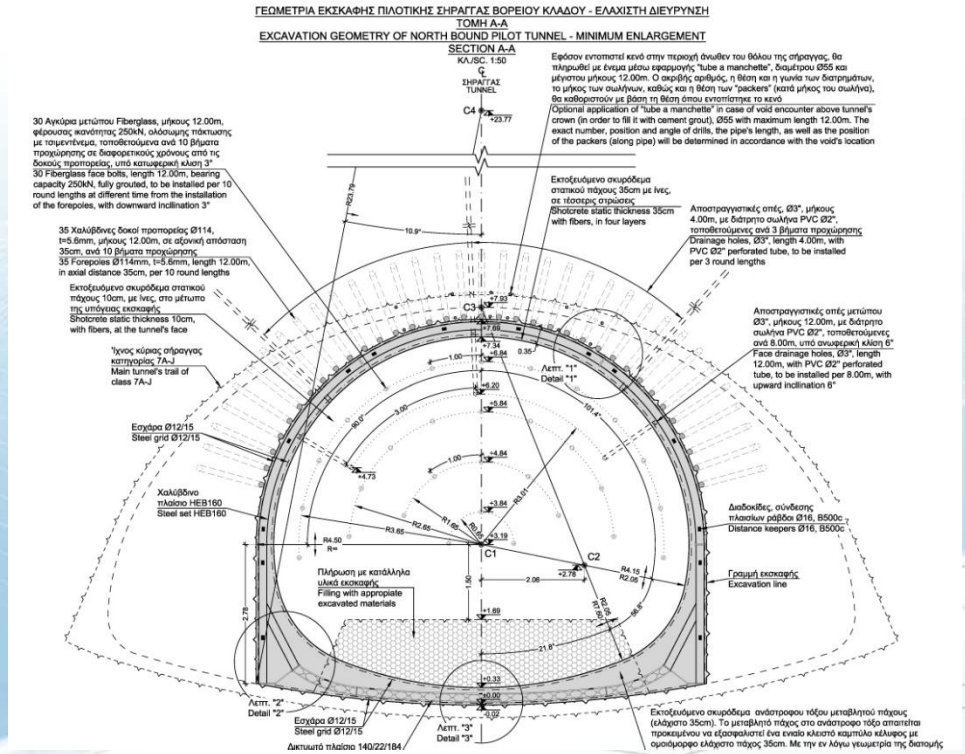
k (m/sec) ≈ 10^{-7} – not groutable

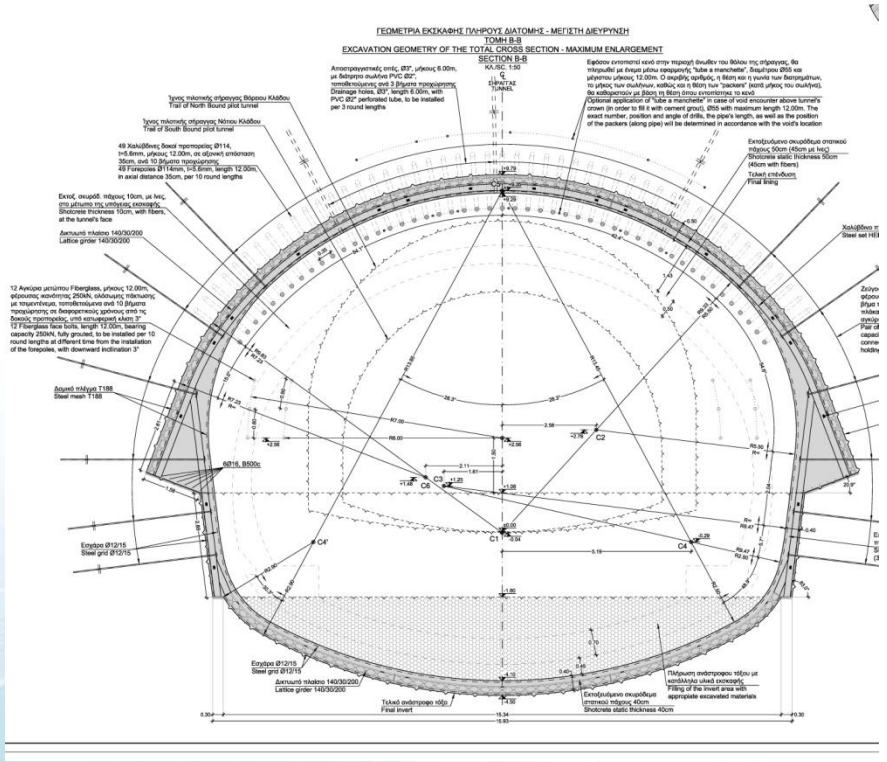
N0	Borehole	Depth	Water table	Permeability (cm/sec)	Test Type	Comments
1	GL-1	5.00-5.20	37.4	$9x10^{-5}$	Maag	Peridotites
2		12.00-12.20		$1.2 x10^{-5}$	Maag	Peridotites
3		18.50-18.80		$1.7 x10^{-5}$	Maag	Peridotites
4	GL-2	4.80-5.00	9.00	$3.7x10^{-4}$	Maag	Peridotites
5		11.00-11.20		$1.4x10^{-3}$	Maag	Peridotites
6		17.80-18.00		$1.5x10^{-5}$	Maag	Peridotites
7		27.00-27.20		-	Lefranc	Tunnel
8		31.00-31.40		$1.6x10^{-5}$	Maag	Peridotites
9		37.50-37.80		$7.9x10^{-6}$	Maag	Peridotites

Tunnelling in CH.12+400 – Tunnel Rehabilitation

- Designed tunnel sections

the pilot tunnel section





the section for widening

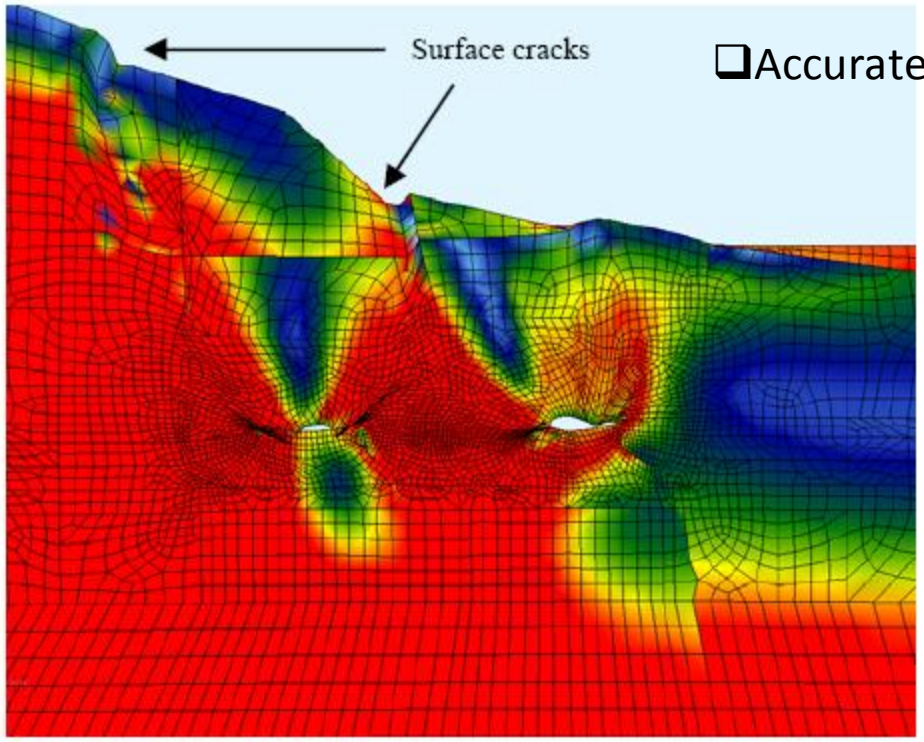
Tunnelling in CH.12+400 – Tunnel Rehabilitation

Pilot Tunnel section - Support Measures

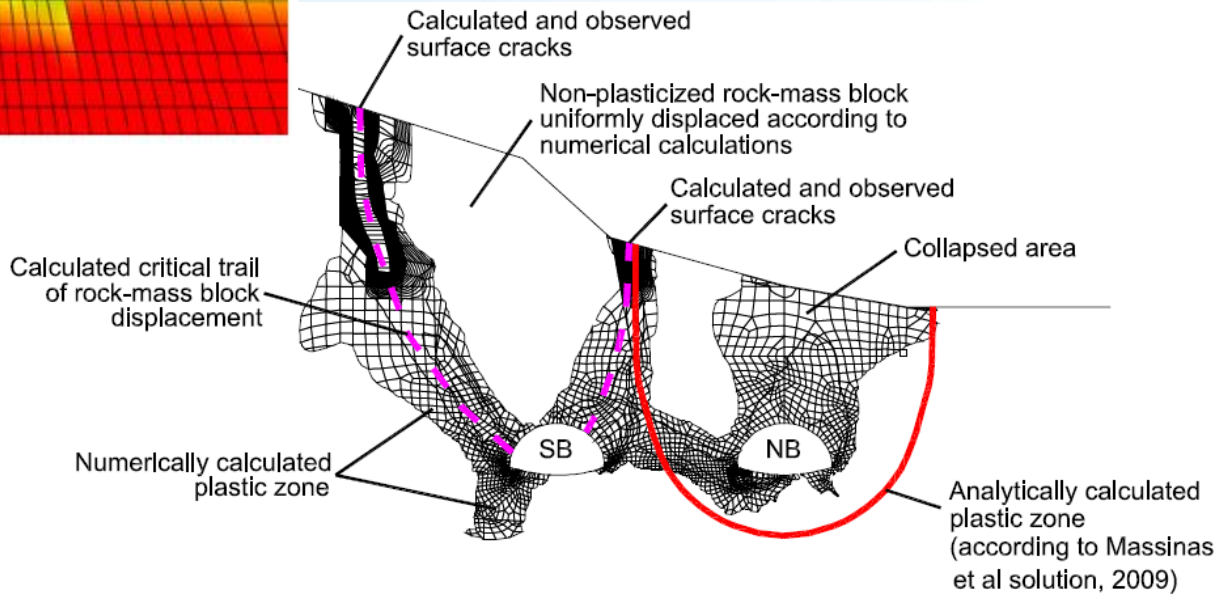
- 35 forepoles Φ114/140, 12m overlapping 4m
- 2 headings (vault and invert)
- excavation round 0.80m
- 35cm thick shotcrete shell (HEB160) + 2#12/15 steel grids
- no rockbolts
- 35cm thick shotcrete invert (LG140/30/200)+ 2#12/15 steel grids
- "tube a manchette" grouting for filling voids around the canopy (optional)

Widening Section - Support Measures

- 49 forepoles Φ114/140, 12m overlapping 4m
- 3 headings (top – bench – invert)
- Excavation/pilot demolition round 0.80m
- 50cm thick shotcrete double shell in top heading (outer shell LG140/30/200 – inner shell HEB180) +
- 30cm thick shotcrete shell in bench & invert (LG140/30/200)
- 6m self drilling rockbolts pairs
- Ring closure every 8m rounds



❑Accurate Model Calibration based on available data



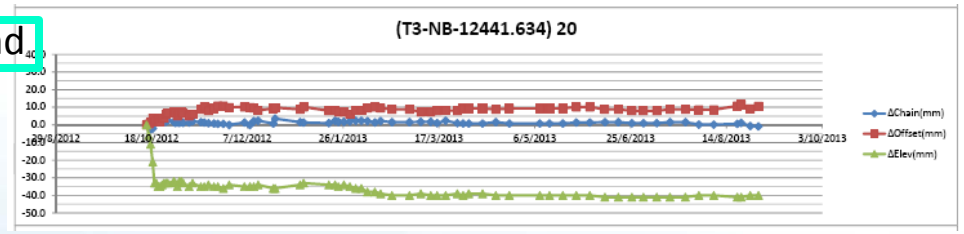
Tunnelling in CH.12+400 – Tunnel Rehabilitation

Rehabilitation works with strict monitoring of the NG pipeline and ground surface :

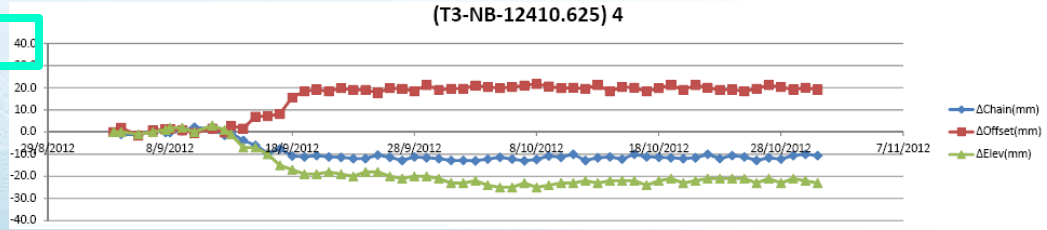
The involved part of the pipeline was exposed and backfilled only on the completion of the works

pilot tunnel phase - max convergence

underground

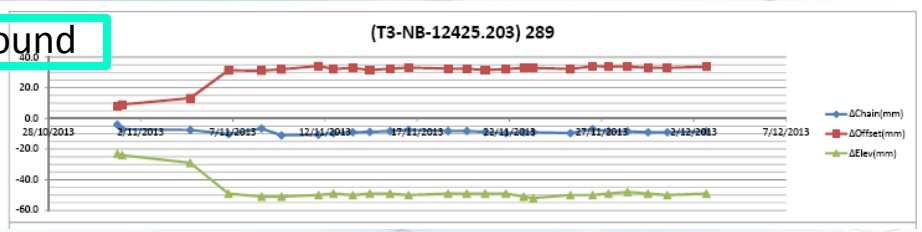


surface



widening phase - max convergence

underground



❑Pilot Tunnel Advance Phase

Duration of the pilot tunnel phase: 3 months

❑Pilot Tunnel Demolition & Section Widening Phase

Duration of the tunnel widening phase: 3 months

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SPECIAL CONDITIONS IN TUNNEL T3

Tunnelling in CH.13+500 – Tunnel severe Under-profile - Tunnel Rehabilitation

Description of tunnel troublesome situation:

✓top heading excavation of the NB tunnel in very weak sheared peridotites GSI~15 (*with floating megablocks of limestones and peridotites*)

✓overburden 70m

✓variable excavation conditions (homogeneous vs. significantly heterogeneous excavation faces)

✓different modes of deformation (uniform sinking vs. differential movement of the shell foundation)

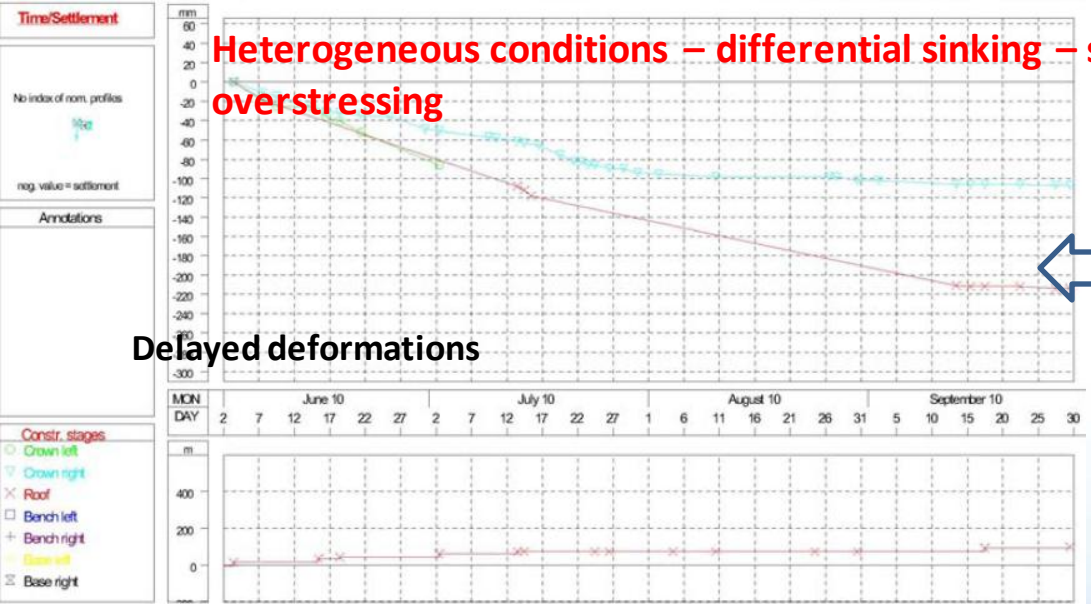
✓early development of high convergences and

✓under-performance of the initial lining (overstressing of the support elements) – tunnel under-profile

Sections affected: **50m**

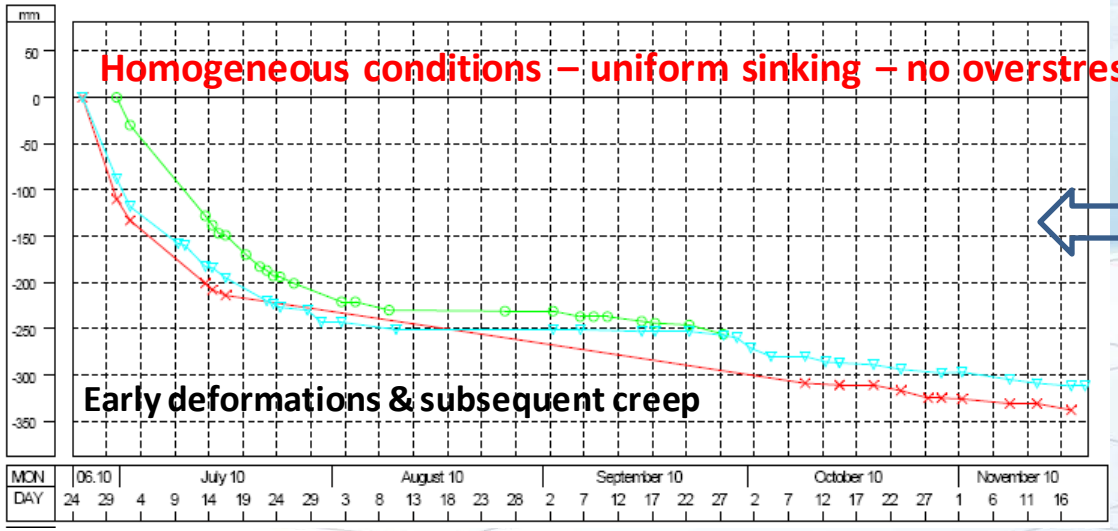
Need for : **special rehabilitation design to re-instate the under-profiled section**

SPECIAL CONDITIONS IN TUNNEL T3 -Tunnelling in CH.13+500 –Tunnel Rehabilitation



Heterogeneous conditions – differential sinking – shell overstressing

Delayed deformations



Homogeneous conditions – uniform sinking – no overstressing

Early deformations & subsequent creep

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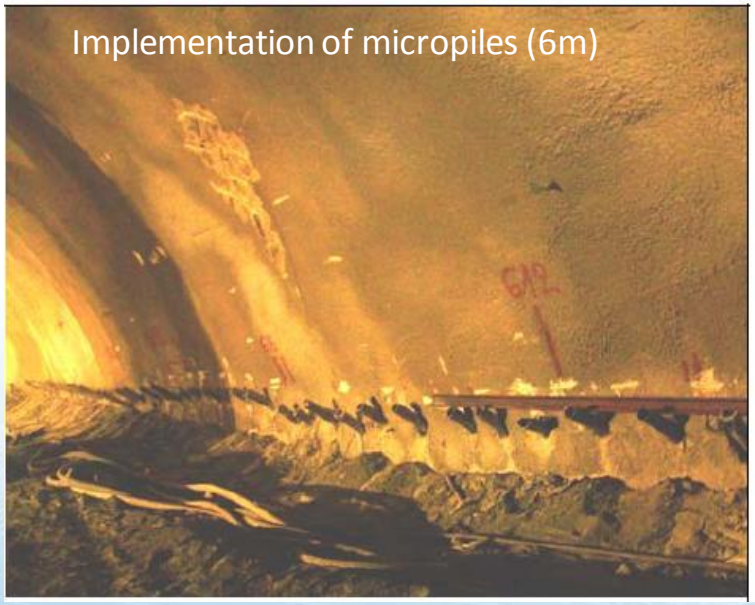
SPECIAL CONDITIONS IN TUNNEL T3 -Tunnelling in CH.13+500 –Tunnel Rehabilitation

Contingency measures to address severe deformation:



- use of micropiles – very limited effect
- use of pre-stressed anchors halted the convergence gradients, but not the creep effect

SPECIAL CONDITIONS IN TUNNEL T3 -Tunnelling in CH.13+500 –Tunnel Rehabilitation

Requirements for the design of the Rehabilitation section:

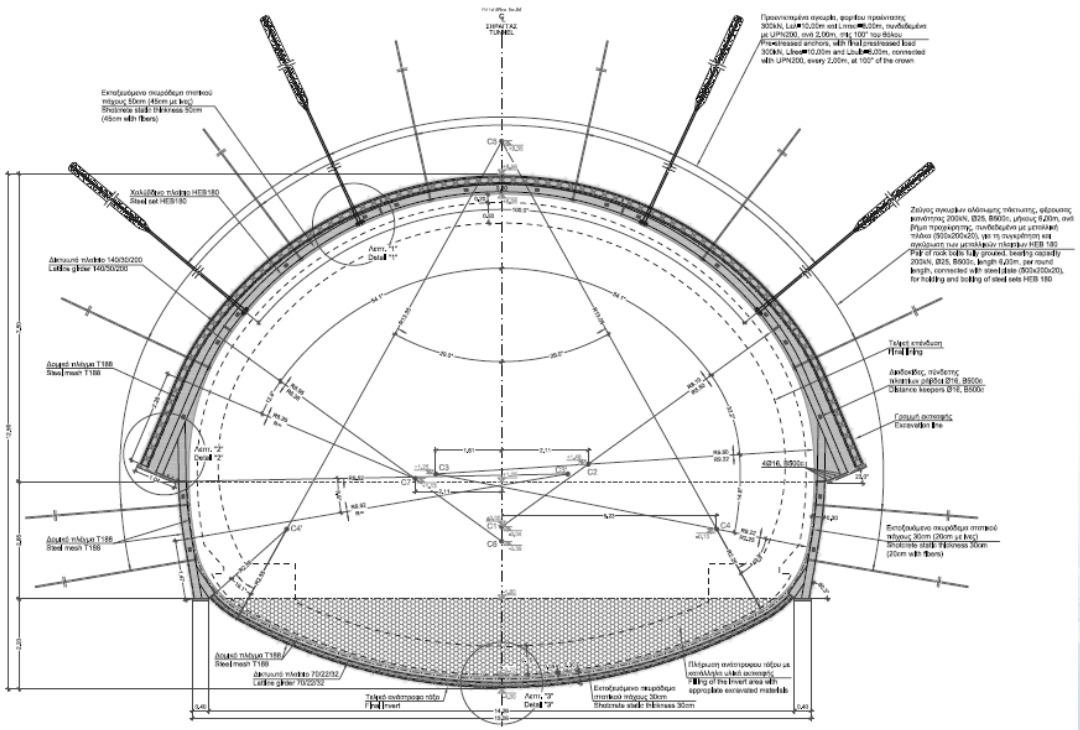
i. a **stiff and robust support** in top heading (implemented by combination of outer + inner sprayed concrete composite shells);

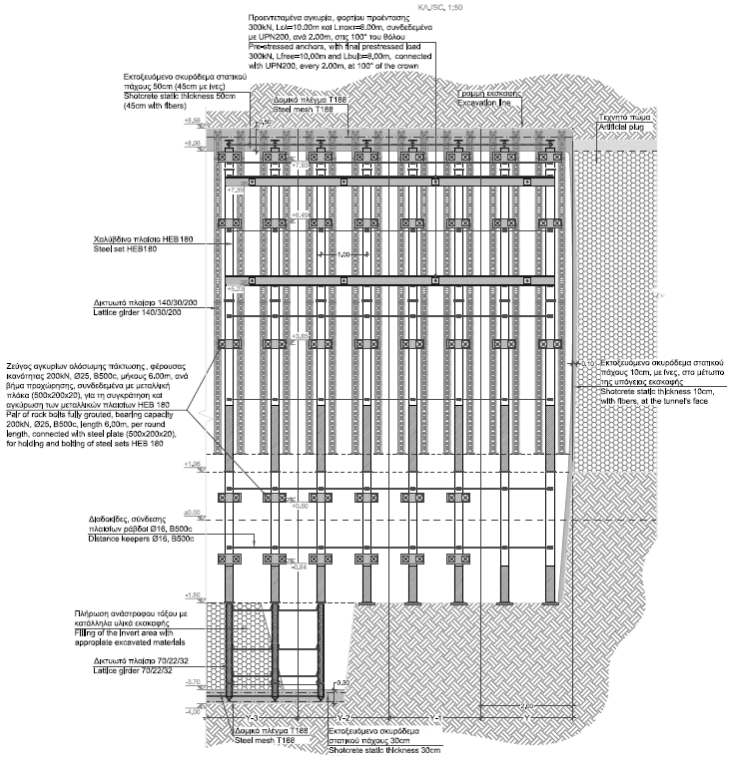
ii. **no forepoling** umbrella (since the converged section would provide the required confinement around the cavity);

iii. **ring closure in 8m rounds** to result in favourable re-distribution of loads around the cavity and catch up the tendency of early deformations;

iv. use of **pre-stressed anchors** (40tons, 18m long) to deal with the risk of creeping due to rockmass relaxation overtime (and effect from the SB excavation)

SPECIAL CONDITIONS IN TUNNEL T3 -Tunnelling in CH.13+500 –Tunnel Rehabilitation





ΣΤΑΤΙΚΟ ΠΑΧΟΣ ΤΕΛΙΚΗΣ ΕΠΕΝΔΥΣΗΣ STATIC THICKNESS OF THE FINAL LINING	d1	50cm 70cm
ΣΥΓΚΛΙΣΗ ΚΑΙ ΚΑΤΑΣΚΕΥΑΣΤΙΚΕΣ ΑΝΟΧΕΣ CONVERGENCE AND CONSTRUCTION TOLERANCES	d2	20cm 5cm
ΣΤΑΤΙΚΟ ΠΑΧΟΣ ΑΜΕΣΗΣ ΥΠΟΣΤΗΡΙΞΗΣ 1ου ΚΕΛΥΦΟΥΣ STATIC THICKNESS OF THE INITIAL SUPPORT 1st SHOTCRETE SHELL	d3-a	25cm
ΣΤΑΤΙΚΟ ΠΑΧΟΣ ΑΜΕΣΗΣ ΥΠΟΣΤΗΡΙΞΗΣ 2ου ΚΕΛΥΦΟΥΣ STATIC THICKNESS OF THE INITIAL SUPPORT 2st SHOTCRETE SHELL	d3-b	25cm
ΣΤΑΤΙΚΟ ΠΑΧΟΣ ΑΜΕΣΗΣ ΥΠΟΣΤΗΡΙΞΗΣ (ΒΑΘΜΙΔΑ) STATIC THICKNESS OF THE INITIAL SUPPORT (BENCH)	d3-c	30cm

Initial lining at the vault comprised:

- **an outer shell**, a composite sprayed concrete lining 25cm thick with LG140/30/200 embedded per 0.50m rounds
- **an inner shell**, a composite sprayed concrete lining 25cm with HEB180 arches embedded, in 1m rounds

SPECIAL CONDITIONS IN TUNNEL T3 -Tunnelling in CH.13+500 –Tunnel Rehabilitation

amount of convergence

SPECIAL CONDITIONS ENCOUNTERED IN THE EXCAVATION & SUPPORT

Significant experiences from NATM boring the **3-lane sections** through **weak geomaterials**:

- Tunnelling was linked with significant face instabilities and the "short pilot tunnel" method proved a viable solution to control.
- The wide top heading sections proved very unfavourable in terms of the attracted rock loading, which resulted in early deformations and extremely high convergence rates;
- Standard techniques suitable for normal tunnel sections (micropiles, temporary invert) proved ineffective – use of pre-stress anchoring proved very effective, instead.
- Independently advanced drifts (top, bench and invert) did not prove effective towards loads' redistribution around the cavity, unless the bench & invert drifts are kept as close as possible to the advancing top heading.

CONCLUSIONS:

- *The construction of MMK Tunnels represents the application of the NATM principles in a significantly variable and very demanding hydro-geological and geotechnical environment;*

- *Tunnel Designers had to elaborate competent and efficient designs for the Excavation and Support and the Final Lining of the involved underground spaces.*

- *Despite the relatively satisfactory level of the geotechnical investigation and executed comprehensive risk assessment, several hazardous situations were unfolded in the 21.6 km tunnelling;*

- *Close collaboration between the Designers and the Construction JV resulted in quick adaptation of the E&S methodology , processing of efficient solutions and modifications so as to successfully address the increased geotechnical hazards.*

- ✓ *Tunnelling started in August 2008 (Tunnel T2)*
- ✓ *For tunnels T1 and T2 the civil works are fully completed*
- ✓ *Significant delays were noticed due to works suspension period of two years*
- ✓ *For Tunnel T3 E&S was recently completed (end of July 2014) and civil works are nearing to complete*

THANK YOU FOR YOUR ATTENTION