

# **OLYMPIC TUNNELLING BLASTING - Facts and experiences from Hellenic projects regarding some 2004 Olympic Games infrastructures**

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## **Abstract**

This paper deals with cases of blasting projects that refer to road and rail tunnels. Among the case histories we had available from the Hellenic Territory, the most in number and also most characteristic examples of specific management, that we were required to deal with and implement, were in the wider area of Athens (Attica). That is so because the construction of many tunnels falls within the infrastructure civil works programme regarding the 2004 Olympic Games.

In those underground works excavation had to be performed through blasting, though there were archaeological finds and constructions (some of which were even older than 2300 years), road junctions and traffic in operation, settlements, industrial installations, fuel and natural gas networks or any other facilities on the surface.

Consequently, we had to pay particular attention and care to the damage risks that might occur. Also, we had to find ways of how to prevent them from happening; we had to care for the compliance with strict specifications and regulations, the conventional and contractual obligations, the vibration monitoring and PPV limits, the proper blast design and materialization of blastings, the selection and implementation of specific blasting techniques, the staff training and preparation, etc.

The facts, data and records concerning the above are presented through some of the case histories we faced and the experience we obtained while providing blast consulting and engineering services.

## **1 Introduction**

There are many tunnelling projects in Hellas that, some of which, have been accomplished and completed in the recent years or others that are in process and are about to be finished soon. An extensive and far – reaching programme of improving and updating the infrastructures of our country has caused and resulted in many construction projects of major importance, some of which include tunnelling, too. However, the needs and necessities for providing the infrastructures and the essential and proper facilities for the 2004 Olympic Games, in Athens, have dictated the construction of works based on tunnels. This paper mainly refers to road and rail tunnels. One case of hydraulic tunnel is also included.

The main, in common, characteristic of all these projects is blasting implementation for tunnelling based on the NATM method. What, however, makes them of particular interest (and is the main reason why it has been chosen and included in this paper) was the fact that blast design and materialization had to be performed in such a way that issues such as the damage risks, the fact that we had to care for the compliance with strict specifications and regulations, the conventional and contractual obligations, the vibration monitoring and PPV limits, etc. would be faced and dealt with effectively. These high damage risks came from data from the surrounding area and the particular parameter and risk requirements and subjects that we undertook to manage as consultants, as it is analysed below.

## **2 The tunnelling blasting projects**

We have selected and included 11 projects in this paper; we codified them beyond their brief names, as T1, T2, etc (see Table 1, classified in order of time of performance).

Most of them refer to twin road tunnels (T2, T3, T4, T5, T6) of big cross – section and rail tunnels (T1, T5, T7, T8, T9) of the new railway network. One hydraulic tunnel has also been included (T11), of a relatively small cross – section.

Table 1

TUNNEL BLASTING PROJECTS			Parameters and facts to manage											
Code	Name	Period	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12
T1	LIOSIA	9/94-3/97	↗											
T2	MAVRIORA	5/98-2/02					↗			↗		↗		↗earth
T3	IWPM "D"	6/98-12/99	↗							↗				
T4	KERATSINI	11/98-5/99			↗			↗		↗	↗		↗	
T5	KAKIA SKALA	11/99-2/02			↗	↗	↗						↗	
T6	IWPM "C"	5/00-10/02	↗	↗										↗age
T7	EYTAXIA	6-7/00			↗		↗						↗	
T8	PALASKA	2/02-in process	↗							↗				↗mil
T9	METRO PER.	2-7/02	↗	↗									↗	↗dec
T10	SKARAMAGKA	7/02- in process	↗				↗			↗	↗		↗	↗mil
T11	KOROPI	3/03- in process	↗	↗									↗	

Coding of parameters P1 – P12: see in the text, Chapter 3

Almost all projects presented here, belong to major big construction programs and basic infrastructure works that are now in process. For example:

- ATTIKI ODOS Motorway, the 70km new peripheral ring – road of Athens that crosses the Northern side of the Basin of the wider area of Athens (Attica), from the East (the New Athens International Airport) to the West side (where the No 2 National Highway comes to Athens from Corinth); it is also intersected by the No 1 National Highway from Athens to Northern Hellas. It is one of the largest in Europe Build – Operate – Transfer (B.O.T.) Highway Projects. This new Motorway includes the projects T2, T3, T6 and indirectly the T10 and T11 ones.

- The new railway network of the country (Hellenic Rail, known as OSE), for high-speed trains. This program includes also some projects in the wider area of Athens (T1, T5, T7 and T8).

- ATTIKO METRO, the new network and the extension of the Metro system of the wider area of Athens. The test blasting in a main Metro tunnel, of the project T9 belongs to this.

All the above projects, are placed and located in the wider area of Athens they belong to the program of works that deals with the construction and improvement of infrastructures and networks, in the framework of the preparation of the City for the 2004 Olympic Games.

We have considered it absolutely essential to present some concise technical data below and describe, in brief, the peculiarities and particularities or the risks we had to deal with and manage in each one of the 11 tunnelling blasting projects.

## LIOSIA

### Tunnel blasting project T1 - data sheet

1. Project title and area: OSE Railway line, between Liosia Station and Thriasion Pedion (Western Attica)
2. Contractor: TECHNODOMI - MIC. TRAVLOS BROS. SA
3. Tunnel type and use: Rail tunnel
4. Geological formation: Limestones
5. Length (m): 860
6. Width x Height (m): 12.6 x 10.1
7. Total cross section (m<sup>2</sup>): 94
8. Excavation stages (m<sup>2</sup> per stage): 1<sup>st</sup> stage (upper part): 53 - 2<sup>nd</sup> stage: 41

This project regarded the construction of a railway tunnel underneath the Ancient Wall “DEMA”, of the 4<sup>th</sup> century B.C., at Ano Liosia, West Attica. The Ancient Wall concerns the outer fortifications of the wider region of Ancient Athens. Some parts of the tunnel are about 50 – 70 m from the base of the Ancient Wall.

We suggested and it was accepted that the maximum permitted vibration velocity should be the maximum, provided one by the DIN4150 criterion (line L3), for the frequency area (over 50Hz), as it was established by the initial monitoring. This means 10mm/sec.

Several sequential blasting scenarios were examined, based on the usage of electric caps (non – electric caps were not in use in Hellas, at that time) but the 4 – circuits firing scenario was selected as the most appropriate, which was relatively the simplest and the most applicable, too. It has been designed, tested and applied. It was the first implementation of the Sequential Blasting technique in tunnelling, both in Hellas and perhaps in Europe, too.

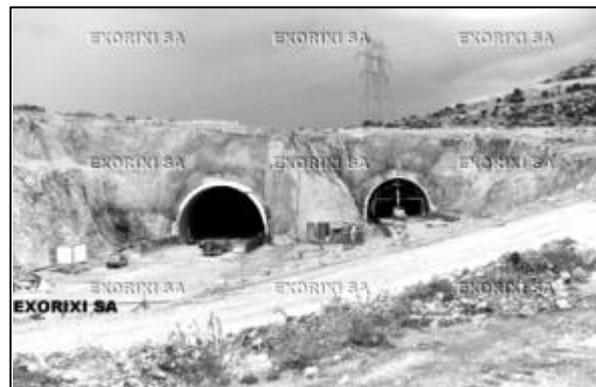
The vibration monitoring programme was carried out by 1 – 3 monitors.



## MAVRI ORA

### Tunnel blasting project T2 - data sheet

1. Project title and area: Tunnels in the area of “MAVRI ORA” Liosia (Attiki Odos Motorway – West section)
2. Contractor: TEB SA (ATTIKI ODOS J/V)
3. Tunnel type and use: Road - 2 parallel tunnels (twin tunnels)
4. Geological formation: Limestones
5. Length (m): 371.20 + 358.50
6. Width x Height (m): 16.0 x 10.3
7. Total cross section of each tunnel (m<sup>2</sup>): 140
8. Excavation stages (m<sup>2</sup> per stage): 1<sup>st</sup> stage (upper part): 44 - 2<sup>nd</sup> stage: 96



This project (along with the T3 and T6 ones) is a part of the major project ATTIKI ODOS Motorway. Thus, the annotations that are mentioned further down in the project T3 are valid and in force regarding the specifications and the permitted PPV limits.

The twin tunnels of this project (which included surface blastings, as well) were too close to the main water supplying canal of Athens (Momos Water Canal), exactly underneath the main natural gas distribution network and very close the Ancient Wall "DEMA" (this project is located in the area of project T1, where the protection of this particular ancient construction had also been faced and dealt with). Part of the project (mainly surface excavations – blastings) was close to buildings that had been damaged or affected by the earthquake in West Attica (September 1999).

There had been used a network of 2 - 3 vibration monitors.

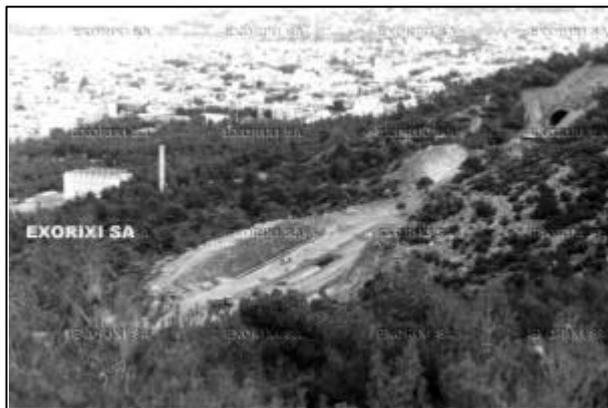
IWPM "D"

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#### Tunnel blasting project T3 - data sheet

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1. Project title and area: Imittos Western Peripheral Motorway - "DEMOCRITUS" area tunnels (part of Attiki Odos Motorway)
  2. Contractor: AKTOR – ATTIKAT – TEB J/V (ATTIKI ODOS J/V)
  3. Tunnel type and use: Road - 2 parallel tunnels
  4. Geological formation: Limestones and Schists
  5. Length (m): 193 + 208
  6. Width x Height (m): 15.20 x 9.85
  7. Total cross section of each tunnel (m<sup>2</sup>): 127
  8. Excavation stages (m<sup>2</sup> per stage): 1<sup>st</sup> stage (upper part): 66 - 2<sup>nd</sup> stage: 61
- 



The twin tunnels T3 and those of T6, belong to the same project, which is part of the ATTIKI ODOS Motorway project. This section of the Motorway is exactly on the eastern boundaries of the wider urban area of Athens.

The T3 tunnels have been designed at the section where the Motorway is close to the area where the National Research and Physical Sciences Centre nuclear reactor is located. It is known as "DEMOCRITUS". It is a reactor used for research and medicine. Just before the project started there had been a study regarding the safety of the reactor because of the blasting vibrations; the permitted PPV limit had been set at 13 mm/sec. We had never, of course, reached this limit, since, even in much lower PPV values, the scientists of the research Institutes were anxious about damage risk effects on their electronic equipment and their sensitive laboratory systems.

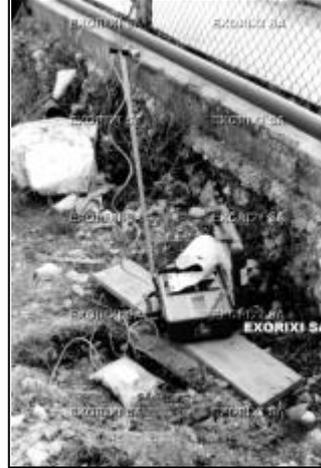
The caused vibrations monitoring, using 3 - 4 vibration monitors each time, was a sophisticated process, since we had to select the closest and most sensitive installation. However, the reporting itself was quite demanding, since it was addressed to scientists who understand quite a lot regarding the monitoring procedure, they follow and check its reliability, they demand correlations and parallel monitoring, etc.

The 13 mm/sec value had been adopted at the approval of the environmental terms time period, as the permitted PPV value regarding the whole great project of ATTIKI ODOS Motorway. This created serious questioning and speculation in the beginning of the project, since, there were blasting areas located too close to urban areas or historical monuments (T6). Consequently, a process of revision and re-examination of the permitted PPV values started; it was set and restricted at 6mm/sec, for the urban areas, along with the parallel usage and application of the DIN4150 specification.

## KERATSINI

### Tunnel blasting project T4 - data sheet

1. Project title and area: Peripheral Motorway of Piraeus, Section from St.Nicolaus Bay to Ichthioskala – KERATSINI tunnels
2. Contractor: ABAJ – ROYTSIS J/V
3. Tunnel type and use: Road - 2 parallel tunnels
4. Geological formation: Limestones - Conglomerate
5. Length (m): 366.5 + 360.14
6. Width x Height (m): 10.5 x 7.5
7. Total cross section of each tunnel (m<sup>2</sup>): 66
8. Excavation stages (m<sup>2</sup> per stage): 1<sup>st</sup> stage (upper part): 46 (in 2 – 4 steps) - 2<sup>nd</sup> stage (the rest part): 20



This project was a part of the new Peripheral Avenue in the area of Piraeus Sea-Port. The two tunnels of the project were cut underneath the “Aghios Georgios” Power Plant, in Keratsini. The biggest part of the tunnels is located in the area of the installations and systems that manage and distribute electric power; also close to the main generator unit buildings (which use oil and natural gas, as their fuel). The tunnels are also very close to “Aghios Georgios Mills” cluster of buildings that include old –scheduled buildings, too.

At some places the overburden (depth) of the tunnel is just 3.50m thick, whereas the minimum distance from the buildings on the surface is 12.0m.

We implemented a vibration monitoring programme of 7 tunnel blastings, installing up to 7 vibration monitors each time; we did so in order to evaluate both the parameters and the damage risk of the surface installations. The minimum distance of the monitoring station from the blasting was 11.0m.

We used the DIN4150 specifications. The permitted PPV values, that were suggested and accepted, were 15mm/sec for common constructions and buildings and 40mm/sec for heavy structures.

After the whole programme was completed we implemented a long – term continuous monitoring programme. We achieved doing so by installing a vibration monitor where the old – scheduled buildings of the Mills were located.

## KAKIA SKALA

### Tunnel blasting project T5 - data sheet

1. Project title and area: Highway and Railway in the area of KAKIA SKALA (West of Attica)
2. Contractor: METON-AKTOR-TEB-AEGEK-ALTE J/V
3. Tunnel type and use: a. Road twin tunnel, b. Rail tunnel
4. Geological formation: Limestones (mainly)
5. Length (m): a. for road tunnels (280+840) + (270 + 1650) + 1090 = 4130  
b. for rail tunnels 450 + 1450 +1412 = 3312
6. Width x Height (m): a. 20.0 x 13.0 b. 13.0 x 10.45
7. Total cross section (m<sup>2</sup>): a. 200 b. 110

8. Excavation stages (m<sup>2</sup> per stage): a. 1<sup>st</sup> stage (upper part): 110 - 2<sup>nd</sup> stage: 90  
b. 1<sup>st</sup> stage (upper part): 56 - 2<sup>nd</sup> stage: 54
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The phrase “Kakia Skala” means rough or dangerous road or passage, in Hellenic. Because of that, the area where this project is located has been well known. Many legends and tales have been created due to the roughness of the particular territory, since the ancient times. That is because of the rough and steep rock relief of the area that makes the cutting and opening up or any other surface works quite difficult.

The network of tunnels that has been designed and is now being materialized will drastically change the traffic both in the motorway from Athens to the West and the railway network, as well.

This network of twin road tunnels in a row, the railway tunnels being at a lower level, over new structures, cut and cover tunnels, bridges, etc, constitute a very complex project. The carrying out of this project faces the roughness of the particular relief, on the one hand, and on the other the fact that it should not prevent the regular road and railway traffic or cause dangers of any kind.

Consequently, even the construction of accesses and the inlet sections of the tunnels should be considered as a great accomplishment. Particularly those that were too close to roads and facilities in use.

We were asked to manage and monitor the following issues regarding the tunnel blastings of the area: basic design and technical support of the blasting operations; minimize the blast vibrations caused so that we would minimize the danger of shifting and displacement of massive rock relief volumes; blast vibration monitoring and evaluation regarding neighbouring tunnels; blast vibration monitoring and damage risk prevention concerning buildings and structures of the surrounding area; massive surface blast design and materialization in tunnel mouths; evaluation – suggestions regarding massive tunnelling blastings at the 2<sup>nd</sup> stage.

#### IWPM “C”

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##### Tunnel blasting project T6 - data sheet

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1. Project title and area: Imittos Western Peripheral Motorway - “COLLEGE” area tunnels (part of ATTIKI ODOS Motorway)
  2. Contractor: AKTOR – ATTIKAT – TEB J/V (ATTIKI ODOS J/V)
  3. Tunnel type and use: Road - 2 parallel tunnels
  4. Geological formation: Limestones and Schists
  5. Length (m): 426 + 354
  6. Width x Height (m): 19.68 x 11.55
  7. Total cross section for each tunnel (m<sup>2</sup>): 181
  8. Excavation stages (m<sup>2</sup> per stage): 1<sup>st</sup> stage (upper part): 91- 2<sup>nd</sup> stage: 90
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The twin tunnels were cut under the «St. Joannis the Hunter» Monastery, at the Eastern side of Athens. There is a Byzantine Temple among the cluster of buildings of the Monastery, which is almost 850 years old. This temple, apart from the damage caused by time, has suffered certain human interventions at different time periods that make it impossible, even for experts, to know its strength and static behaviour.

The minimum tunnel overburden (depth) is 30m and the minimum distance between the tunnelling faces and the temple is approximately 78m.

The Central Archaeological Council that was asked to give their consent to the tunnelling blasting set a committee of experts. The committee gave their consent to the majority of tunnelling via blastings. They selected the monitored data from a network of vibration monitors and suggested the temporary supporting of the Temple.

However, no one took the responsibility to suggest, officially, the permitted PPV value. We proposed the value of 3 mm/sec. In the end, however, we saw that the maximum PPV value would not go beyond 1.5 mm/sec at the rocky foundation of the Temple; the most often met value was 0.70 mm/sec; the 78% of PPV values was between 0.5 and 0.9 mm/sec.

Tunnelling blastings seemed to be unacceptable, in some parts of the tunnels because of the expected PPV values. A piece of machinery with a rotating cutting head was used there.

Eight vibration monitoring stations had been installed in different parts of the Byzantine Temple. The communication infrastructure had been secured and a centre of collecting and transmitting the monitoring data via tel modems had been created. We collected and evaluated all the monitoring data, in our office, immediately after every blast so that we would provide the guidelines for the preparation of every blast that would follow.

At the same time we had installed six 2D and three 3D crack-meters on the outer walls of the Temple. Most of these crack-meters had been installed long before they approached by the blasting faces.

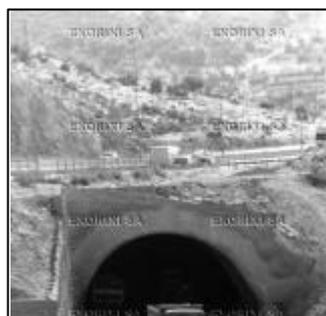
## EYTAXIA

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### Tunnel blasting project T7 - data sheet

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1. Project title and area: OSE new Railway line between Athens and Corinth, area from EYTAXIA up to N. PERAMOS crossing - West of Attica.  
Special subject, passing EYTAXIA tunnel underneath the Highway from Athens to Corinth
  2. Contractor: THE EYTAXIA TUNNEL J/V
  3. Tunnel type and use: Rail tunnel
  4. Geological formation: Limestones
  5. Length (m): 1700 (170m underneath the Highway)
  6. Width x Height (m): 14.4 x 6.5 (1<sup>st</sup> stage)
  7. Total cross section (m<sup>2</sup>): 105
  8. Excavation stages (m<sup>2</sup> per stage): 1<sup>st</sup> stage: 60 - 2<sup>nd</sup> stage: 45
- 



In this project we had the chance to work on the basic blast design and support, on blastings regarding the two accesses - inlets of tunnel and the surface blastings of an excavation site close to a settlement. The most challenging part of the project, though, was tunnelling underneath the National Highway from Athens to the West; its length was about 170m. The overburden depth was just 3 – 5 m from the roof of the tunnel, which also included the aggregate layers of the existing National Highway. This Highway is the only way in and out of the Western side of the wider area of Athens, so the traffic is quite heavy. Consequently, we had to see that there would be no effects or damages of any kind to the Highway because of the tunnelling blasting.

Along with the contractor's technical staff we examined and tried to apply and evaluate some alternative scenarios long before the blasting face came underneath the National Highway. It was a pilot blasting excavation that provided the best results and it was thus implemented throughout the tunnel cutting. This pilot excavation was in the centre of the face of the 1<sup>st</sup> stage (1<sup>st</sup> step) and after that there was a thorough excavation of the peripheral zone (2<sup>nd</sup> step).

All the above were combined with the appropriate adaptation of the blast design, in order to achieve blast vibration minimization, and also to prevent the transmission towards the tunnel roof, both the caused vibration and the extension of the fracturing zone.

We used the sequential blasting technique properly, applying up to 3 electric cap circuits, in the 1<sup>st</sup> step and up to 4 electric cap circuits in the 2<sup>nd</sup> step. The blast design was particularly easy and proved to be very efficient in order to get at the aim we pursued.

After careful and diligent searching and evaluating, of the permitted PPV values, we set that the blast vibrations at the National Highway monitoring stations above of the blast face should not be more than 150 – 180 mm/sec. We installed 2 –3 vibration monitors in all blasts. We, also, experimentally applied the usage of high – frequency geophones.

## PALASKA

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### Tunnel blasting project T8 - data sheet

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1. Project title and area: OSE – Railway link-up of N. IKONIO trade Sea-Port (Western side of Piraeus Sea-Port), with the main Rail network
  2. Contractor: THE IKONIO TUNNEL J/V (EYKLIDES – POLITECHNIKI J/V)
  3. Tunnel type and use: Rail Tunnel (merchant trains network)
  4. Geological formation: Limestones and Schists
  5. Length (m): 3500
  6. Width x Height (m): 8.70 x 8.50
  7. Total cross section (m<sup>2</sup>): 66
  8. Excavation stages (m<sup>2</sup> per stage): 1<sup>st</sup> stage (upper part): 46 - 2<sup>nd</sup> stage: 20
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This particular rail tunnel is designed for the merchant trains and the transport of containers from the Western section of Piraeus sea-port (the area of Ikonio, where the inlet of the tunnel is), towards the main rail network and the new central railway station in Western Attica.

The tunnelling was first performed at the side where its exit is, which is located within the military deployment called “Palaska” (base, military – Naval training area and support facilities of the Hellenic Navy).

So, apart from the basic blasts design of the tunnel, the technical support and the programme of improvements that we do materialize, we have to face and deal with the caused vibrations monitoring, the damage risk effect prevention and the management of complaints and annoyance of the military deployment staff.

What is more, the shaping of the access to the outlet of the tunnel means surface blasting close to the main distributing network of natural gas. The permitted vibration limit that is set for the safety of the pipeline is PPV=12mm/sec.

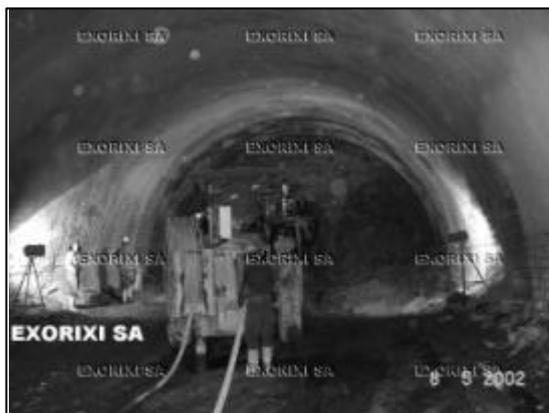
The tunnel blasting faces are expected to be quite close to this natural gas network.



## METRO PERISTERI

### Tunnel blasting project T9 - data sheet

1. Project title and area: ATTIKOMETRO – Athen’s Metro – Extension of line 2,  
Tunnel from Sepolia to Thivon
2. Contractor: METRO PERISTERI J/V
3. Tunnel type and use: Metro - double track tunnel
4. Geological formation: Limestones, Marbles and Conglomerate
5. Length (m): various sections
6. Width x Height (m): 11.33 x 8.44
7. Total cross section (m<sup>2</sup>): 87
8. Excavation stages (m<sup>2</sup> per stage): 1<sup>st</sup> stage: 53 (11.33 x 5.15) - 2<sup>nd</sup> stage: 34 (11.33 x 2.79)



The expansion of the Athens Metro network (this big project is known as ATTIKO METRO) is mainly carried out via TBM systems. Its extension Westwards includes tunnelling through hard conglomerates

and limestone formations – marbles. The NATM method and the usage of mechanical means of excavation that had to be implemented there, were problematic, doubtful and time consuming.

We were asked to survey the feasibility and conditions of tunnelling blasting, in an area where the main double track tunnel, of the section “Extension of Line 2, Sepolia to Thivon Tunnel”, passed underneath a densely – built urban area, with 10 – 14m depth of overburden. We have to say that, there have never been used blasting methods for tunnelling, for the extension of the Athens Metro. The State Services considered it to be prohibitive to implement tunnelling blastings in the urban area of Athens.

We had to work hard and spend much time on surveying, discussing and presenting our ideas and suggestions in order to achieve the changes we desired, regarding the conventional specifications and the permitted PPV values. The specifications that were finally accepted, were the DIN4150 (line L2) ones, in the framework of a test blastings programme; its implementation was put on due to the responsibility and the initiative taken by the contractor.

We designed and carried out a test – pilot blasting on 8/5/2002. This was the first blast ever performed for tunnelling for the Metro of Athens.

We used a network of 7 vibration monitors for the blast vibration monitoring. The one closest to the blasting face was installed in the basement of a small industry building which was just above of the tunnel blasting face. The distance was approximately 14m and the monitored PPV was 4.87mm/sec (at 85Hz). The blast result was particularly good and the vibration that was caused, even to the closest monitor station, was safe; even for the line L3 structures of the DIN4150 specifications.

Nevertheless, the Master of the project forbade the contractor to continue the blasting for tunnelling.

## SKARAMAGKA

### Tunnel blasting project T10 - data sheet

1. Project title and area: Aegaleo Western Peripheral Motorway South Connection – Skaramaga Junction (Western side of Attica)
2. Contractor: PANTECHNIKI SA
3. Tunnel type and use: Road Tunnel
4. Geological formation: Limestones
5. Length (m): 24
6. Width x Height (m): 28 x 7
7. Total cross section (m<sup>2</sup>): 196
8. Excavation stages: 1 (side extension steps)



This short in length tunnel is an underground passage on the New Peripheral Motorway of Aegaleo. This tunnel has been designed because of the findings that are on the surface, just 7m over the excavation roof: part – remains of an ancient road (“Sacred Road” is more than 2.300 years old), a distributing natural gas main and a network of distributing fuel pipelines (an oil refinery and military facilities of fuel storing are located close to the project).

After performing some test blastings and the evaluation of both the blasting parameters and the caused vibrations, we designed and implemented a method of tunnelling blasting, based on charging the blast-holes with detonating cord of heavy type.

We used a network of 3 – 4 vibration monitors in every blasting.

A programme of twin tunnels in the near-by area of the same project is going to be completed soon.

## KOROPI

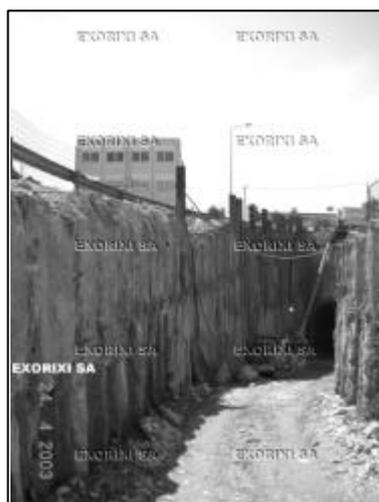
### Tunnel blasting project T11 - data sheet

1. Project title and area: Tunnel of Bari – Koropi Motorway (East side of Attica)
2. Contractor: EDRASIS – C. PSALLIDAS SA.
3. Tunnel type and use: Hydraulic tunnel - Draining network
4. Geological formation: Limestones
5. Length (m): 400
6. Width x Height (m): 4.10x4.40
7. Total cross section (m<sup>2</sup>): 15

This tunnel is part of the surface waters draining network of a new arterial road that is constructed at the area West of the New Athens Airport.

Tunnel construction was imposed to be chosen since the excavation of an open trench would be infeasible for the particular area. The tunnel passes underneath roads with heavy traffic and buildings (small industries and warehouses). Its overburden depth is 4 – 6m.

What is asked for here is that the blast vibrations would not cause, any damages or any harmful effects on the surface structures or works. A network of 2 –3 vibration monitors is used (during the first blastings there were up to 8), for the monitoring of all blastings. The DIN4150 specifications are in use.



### 3 Parameters and facts to manage while dealing with the tunnelling blasting

In Table 1, there was an attempt to organise in groups and classify the most common parameters and risk subjects that we were asked to manage and deal with while working on the 11 tunnelling projects that have been presented above.

We codified as P1, P2, P3, etc, every single one of the 12 parameters and risk subjects, that we found worth distinguishing and presenting, in order to make the topic more easily presentable.

A noteworthy feature is the fact that, in most of the projects, we had to deal with more than one parameters and risk subjects. There also many more projects that similar risks were faced and dealt with efficiently.

#### Underneath or too close to an urban area (code P1)

The continuous rise in demand for infrastructure expansion and better facilities in big cities, leads to the fact that many more road and rail tunnels should be cut open, so that some urban areas would be bypassed. This has taken place in the wider area of Athens, in the latest years (this is strongly connected with the providing infrastructures programme for the 2004 Olympic Games), in the projects T3, T4, T6, and T9. An other hydraulic tunnel had to pass underneath urban areas (T11).

#### Archaeological findings and constructions (code P2)

In two cases (projects T1 and T10 in the Western side of Athens) the tunnels had to be cut underneath ancient constructions of about 2300 years old. In an other case (T6) a Byzantine monument, of at least 850 years old, had to be protected too.

#### Underneath roads with heavy traffic (code P3)

In three projects (T4, T9 and T11) the tunnelling was performed underneath roads of urban areas. In two other projects (?5 ?a? ?7), the tunnelling was carried out under the National Highway from Athens to the West.

The T7 project is of particular interest since there was low depth of overburden (code P11).

#### Simultaneous neighbouring tunnels cutting (code P4)

It is the case of the T5 group of projects. Road and rail tunnels had to be cut in the same area and at the same time period.

#### Intervention or movements and alterations risks on the surface relief (code P5)

In some projects the micro-movements risks and the alterations on the surface were very serious and had to be anticipated, since they could also combine the protection of archaeological findings (T10), road networks (?5, ?7) and other constructions (?2). The case of the T5 project is quite characteristic. Its relief could create fall risks and big or even small rock pieces movements.

#### Underneath an electric power plant (code P6)

It was the ?4 project case, in the West side of Athens. A twin road tunnel had to be cut underneath a power plant, with a very low depth of overburden.

#### Close to a nuclear reactor (code P7)

A part of the new ring – road of Athens (ATTIKI ODOS Motorway) passes close to the only existing reactor in Hellas. A twin tunnel was decided to be cut at the location, where the road is close to the reactor area.

#### Underneath or close to a distributing natural gas main (code P8)

Some tunnelling projects were found underneath or very close to the distributing natural gas main of the wider area of Athens. There is an Authority responsible for the managing and safeguarding of the network and we had to submit our monitoring data for the vibrations caused in the pipeline zone, to them.

#### Underneath or close to fuel pipelines (code P9)

A tunnel (T4) was underneath the fuel pipelines of a power plant. Another one (?10) is in the wider area of an oil refinery and is also close to a military fuel provision deployment we had to open up a tunnel underneath a fuel pipeline network.

#### Close to a central water canal (code P10)

The twin road tunnels of the T2 project had to be cut quite close to the main water supply Canal of Athens.

#### Very low depth of overburden (code P11)

We dealt with many tunnelling cases (?4, ?5, ?7, ?9, T10, ?11), where the depth of overburden was no more than 10 – 12m. We had to estimate and evaluate some other parameters, and risks, too (P6, P5, P3, P1, P8, P1 respectively), at the same time. The most characteristic case was the one regarding

the project ?7, in which tunnelling was successfully performed underneath the main highway, having 3 – 5m depth of overburden.

#### Encounter with other damages or existing risks (code P12)

In some projects, certain additional data or risks had to be estimated and evaluated along with the parameters that have been analysed above. We have sorted out and codified the most characteristic cases as follows:

age – Tunnel cutting in a project (?6) was performed underneath of an important Byzantine monument which – because of its old age – had damages and static problems and its strength could neither be evaluated or anticipated.

earthquake – The Eastern tunnel inlets, of the T2 project were very close to the area where there were extensive damages on buildings because of the September 1999 earthquake.

mil- Two projects (?8, ?10) were within or too close to military deployment areas. Consequently, we had to meet additional requirements, particular safety rules, reporting and exact time schedule, without sometimes been given any explanations regarding what is in danger or under threat because of blast vibrations.

dec- In the case of the project ?9, the first and the only, blasting was performed in a tunnel of the Athens Metro (new extensions to the West); it was carried out serving as a means to show the Authorities and convince them that blastings can also be put into practice for this tunnelling project.

## **4 Tools and rules for effective blast consulting and risk management**

Every single project, of the ones that were presented above, has its own particularities and peculiarities. Each time we have to “encounter” something that “differs” from any case projects we previously faced and dealt with.

A common “recipe” or a flat management, that would provide solutions to all problems and that would anticipate all risks would not be, of course, suitable for all the tunnelling blasting projects.

On the other hand, however, there are – and we see that we make the most of them - some common implements or uniform steps and rules that contribute to the effective supply of blast consulting services and thus make the risk management secure and reliable.

Some of these above-mentioned ones, classified in order of the time when we evaluate and deal with them, in a tunnelling blasting project, and not because of their importance and weight, are the following:

- Software and computer support. We have developed and use our own software (we call it BLAS-Tun1) and we go through the calculating and the presentation of instructions and quantitative data for blast tunnelling, the investigation and search for alternative scenarios, the cost parameters evaluation, etc. At the same time, we have developed the appropriate digital drawing applications.

- Training and on the spot attendance of the blasting staffs. We believe that studies and nice drawings alone, cannot carry out and achieve successful and not without problems blastings. The blasters (even the project engineers in some cases) may not have the ability, the level of knowledge or the willingness to learn what is right and proposed by our printed documents. That is why we stand by them in order to support, explain and help them while applying or sometimes, work along with them until we are sure that everything is crystal clear. We have established and we are soon going to systematically develop training courses and lectures. We are in constant search of the available technology and know-how and try to make the most of it. Our purpose is to bring to worksite all useful, usable and applicable information along with the scientific knowledge.

- Close attendance and management of all the problems and issues that come up. There is no such a project in process that does not face questions and various technical problems. When it is about blasting implementations, we do think that such issues cannot simply be faced with drawing up and submitting a study. For this reason our contact with the project and the work-associates, that deal with the project, is constant.

In blastings there is always time and field for improvement, for alternative solutions, for interventions that aim at prevention or anticipation of things.

- Vibration monitoring. The vibration monitors are our essential great tools. They are our means to provide documented and improved blastings, harmful effects prevention, the conventional obligations control and the compliance with the specifications. There is a lack of official modern regulations and specifications regarding blast vibration monitoring in our country. Rarely do we start a blasting project with a view to designing or adjusting our ways to “eponymous” and modern specifications. Nevertheless, we have managed to import and use more than 60 advanced digital vibration monitors, with their advanced, potential, upgrading software, in Hellas (\*). We have introduced and set criteria regarding vibration evaluation in major and “widely-known” projects, even, at least, as a means of communication, reference and annotation.

- Constant reporting and annotation. All the above demand constant contact and communication with the staffs of the projects. We see that our reporting express our views and speculations; our comments aim at restoring or altering a situation, at spotting or stressing some particular danger of harmful effects. Submitting the typical out-put of a monitor has neither been sufficient nor good enough. Besides, we believe in “scripta manent” and, that is what makes a consultant more responsible and careful about what he writes and suggests; on the other hand, this is how he strengthens, consolidates, documents and states the submission of his suggestions and viewpoints.

- Development of the experience, obtained from the surface blasting of the project. A tunnelling project is usually accompanied with or followed by a surface blasting programme. The experience that is obtained, the blasters’ and staffs’ evaluation and attitude, the vibration monitoring data, the reaction and annoyance of the residents of the area and the opinions of the State Services involved are valuable data that we take under serious consideration when we start to study and propose the corresponding tunnelling blasting scenarios and the methodology of the project. Even from our engagement with the inlet shaping of a tunnel, we try to develop as many data as possible for the sake of the blast itself.

## **5 Blast consulting and engineering: essential condition for effective risk parameters and facts management**

We have analysed, above the case histories of 11 tunnelling blasting projects. In all of them we had to cope with and manage high risks and strict safety demands. The parameters we had to face are classified into, at least, 12 groups.

Most of the projects have already been successfully completed. The rest of them are now in process and are soon to be completed, too.

We believe, and it has been proved to be so through practice, that the blast consulting and engineering services have played a major role and were of essential contribution to pursuing and accomplishing effective blasting and risk management. Of course, the contractor’s attitude and approach to seek, pursue, engage and develop the most advanced services of this kind, contributed greatly to the positive outcome.

\*: Note

We insist on using Hellas – Hellenic, instead of Greece – Greek

## **6 References**

1. E.K. BALIKTSIS: ‘Blast vibration control using sequential techniques at a railway tunnelling project’, *proceedings of the International Symposium on Engineering Geology and the Environment*, 1997 Athens, Balkema, 2607 – 2612.

2. E.K. BALIKTSIS: “Construction blasting in the City of 2004 Olympic Games”, *proceedings of the 1<sup>st</sup> World Conference on Blasting Technique*, 9/2000 Munich, Germany, Balkema, 441 – 450.
3. E.K. BALIKTSIS: “Blasting activity and blast vibration control in major construction projects”, *proceedings of the 3<sup>rd</sup> Mineral Wealth Congress*, 11/2000 Athens, Hellas, 419-428
4. E.K. BALIKTSIS and P.D. KATSABANIS: “Explosives – Blasting technology and know-how. International developments and Hellenic reality”, *proceedings of the 3<sup>rd</sup> Mineral Wealth Congress*, 11/2000 Athens, Hellas, 457-466
5. E.K. BALIKTSIS, D. KALIAMBAKOS and D. DAMIGOS: “Blasting vibration limits to prevent human annoyance. Remarks from some case studies”, *Mineral Resources Engineering*, 2001, 10 (1), 71-82
6. E.K. BALIKTSIS: “Blasting technology and know-how offer ways to make mining – quarrying – extractive activities more effective and environmentally friendly. Our Hellenic reality”, *proceedings of the 2<sup>nd</sup> International Conference about Modern Management of Mine producing, Geology and Environmental Protection, SGEM 2002*, 6/2002 Varna, Bulgaria, 117-130
7. E.K. BALIKTSIS: “Blast vibration monument protection”, a Lecture regarding interfaculty post-graduate studies of National Technical University of Athens, on “Monuments Protection”, 2/2003 Athens, Hellas
8. E.K. BALIKTSIS and M. FRAGOULIS: “Effective blasting management through consulting and engineering. Facts, ideas and case histories”, *proceedings of the 3<sup>rd</sup> International Conference about Modern Management of Mine producing, Geology and Environmental Protection, SGEM 2003*, 6/2003 Varna, Bulgaria
9. EXORIXI SA, “Unpublished studies, surveys and reports on various projects”, 1996 – 2003