SAFEGUARDING THE ARCHEOLOGICAL MONUMENTS OF PLATAMON CASTLE IN NORTHERN GREECE UNDER SEVERE VIBRATIONS REGIME. A GLOBAL SOLUTION TO THE PROBLEM.

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1. INTRODUCTION

The case study of an archeological monument's safeguarding is presented in this contribution. By the end of year 1997 the archeological area of Platamon, sited at the southeast foot of Mt. Olympus (Northern Greece) was found in the middle of intensive construction activity aiming to the upgrading of the main railway line Athens – Salonica. A severe regime of construction vibrations was produced mainly because of drill and blast excavation method used to open up a series of in line railway tunnels.

The Platamon Castle (photo 1) was one of the fortified Middle Byzantine cities (10^{th} – 11^{th} century) that were build on naturally fortified sites in order to control major communication routes. In the same area ancient sources and recent archeological finds locate the ancient Hellenic city of Herakleion dated to the 4^{th} century BC until the Early Christian Era. The Castle is well preserved and maintains the original polygonal walling, reinforced by eight four-sided external towers. There is an internal walled citadel on the southwest side with a higher octagonal tower that was the last defensive line. There are the remains of two Christian churches as well and more is expected to be revealed during the actual excavating program conducted by the 9^{th} Ephorate of Byzantine Antiquities of the Hellenic Ministry of Culture. Rescue restorations has been carried out between 1968 and 1973. A more systematic restoration of the castle's walls and towers and development of the interior area began in year 1990.

The upgrading project of the main railway line Athens – Salonica is part of the Hellenic Railways Organization's investment program for restructuring the national railways network. Within the geographic area of Platamon the project comprises the construction of a new high velocity double-line for 12 kilometers length with tunnel opening for 4,33 kilometers total length and ten bridges for 0,38 kilometers of total length. The project is performed by a joint venture of Greek and European contractors. The project's owner is the O.S.E Sa. (Hellenic Railways Organization) and the project management is conducted by ERGOSE Sa. (Hellenic Railways Organization's Projects).

The following topics will be presented in the next sections:

- The trial blasts program that anticipated the beginning of the main works.
- A short description of the tunnels' excavation method and damage criteria choice.
- Description of the instrumentation program for the monitoring of the castle's structure.
- The monument's structure behavior and response.
- Final conclusions.

2. TRIAL BLASTS PROGRAM

In year 1995 a geotechnical investigation program was ordered by the project's owner (O.S.E Sa. - Hellenic Railways Organization). In this frame SEISMOTER – Geophysics & Blasting conducted a trial blasts program in order to provide the local scaled distance model for the vibrations level prediction and for the safe planning of blasting. This model would be part of the tender issues, so that the future contractor could keep in count of the fact that the tunneling method should be controlled and not very fast in any case, because of the archeological monuments presence.

The scaled distance model was obtained through a sufficient number of trial blasts and induced vibrations monitoring in various points of the castle simultaneously (photo 2). The trial blasts were suitably planned and performed in shallow drillholes on the Platamon hill's northern slope and during the ''ad hoc'' opening of a short trial tunnel near the north access of the future railway tunnel.

After regression analysis of the data, the scaled distance model that came out, using the U.S.B.M. (United States Bureau of Mines) proposed formula was the folllowing:

$$\boxed{V_{max} = 176 \,.\, (R/W^{1/2})^{-1,416}}$$

where: V_{max} = peak particle velocity in mm/s
R = distance between the castle and blasting front
W = quantity of explosive material per firing interval

Using always the same formula the safe quantity of explosive material per firing interval is given by:

$$\boxed{W_{max} = R^2/(V/176)^{1,412}}$$

where: V is the hypothetical safe value in particles velocity.

This scaled distance model fully represented the real situation as it was verified afterwards during the railway tunnel's excavation.

3. TUNNEL’S EXCAVATION METHOD AND DAMAGE CRITERIA CHOICE

The N.A.T.M. (New Austrian Tunneling Method) was employed to open up the railway tunnel. A typical cross section is seen in figure 1.

Therefore drill and blast procedures were followed. After the preparation of the south portal area the excavation advanced in two phases. Phase ‘’A’’ consisted in top heading (arch) excavation and phase ‘’B’’ in bench excavation (figure 2). The advancing step in ‘’A’’ phase was of 2,5 meters. In ‘’B’’ phase the step was of 12 meters in the central part of the bench and of 3,6 meters in the two lateral parts. The temporary support system consisted of immediate shotcrete lining with steel ribs every two meters and rock bolts where necessary. Forepoling method with 12 meters poles was used where adverse rockmass conditions occurred. Generally in that parts drill and blast method was substituted by mechanical means (hydraulic hammer).

The Platamon hill area is built by carbonatic rocks characterized by low-medium grade of metamorphism, highly tectonization and mostly inhomogeneous as mechanical properties. A mass of alterated ultramafic rocks that lays in tectonic contact to the west, appears in some places creating the above mentioned adverse conditions.

Since the preliminary study it was thought to adopt the peak particle velocity as damage criteria for the protection of the monuments, using the safe values of velocity and frequency imposed by the German DIN4150/Part 3 standards (Structural vibrations in buildings – Effects on structures).

In March 1998 after the evaluation of the first blasts, SEISMOTER that in the mean time acted as special consultant of ERGOSE in construction vibrations matters, advanced the idea that peak particle velocity’s occasional monitoring only was not sufficient to safeguard the monuments.

Therefore SEISMOTER proposed to monitor continuously not only the induced vibrations to the castle’s structure and do all necessary to keep the vibrations all time under line 3 of the DIN4150/Part 3 regulation, but in the same time to monitor and study the dynamic response and the permanent deformations of the structure. In this way not only the cause (induced vibrations) is put under control, but the effects on the structure (dynamic response and permanent deformations) are observed and every possible damage is early detected and can be avoid.

4. MONITORING INSTRUMENTATION PROGRAM

ERGOSE 's special consultant (SEISMOTER) prepared a monitoring instrumentation program that was well accepted by the 9th Ephorate of Byzantine Antiquities and the technical committee of the Central Archeological Council (Hellenic Ministry of Culture). This technical committee is the supervising Authority.

SEISMOTER immediately actuated the instrumentation program (figure 3) comprising the monitoring of:

a. Induced vibrations in continuous basis

An MR2002 vibration recording system (photo 4) was installed in location V1 on the external wall and on the vertical line over the tunnel's axis. The MR2002 is equipped with dual mode recording, Autopage/Faxalert call back system in order to inform immediately all the interested parts in case of particle velocity's safe values exceedance and is also connected to an MC1 (GSM modem) remote access unit that is particularly useful and well appreciated. This MR2002 station completed the other seven seismographs units previously used by the Contractor in order to perform occasional vibrations monitoring. After the installation of the MR2002station these seismographs were used as control units in several locations (S locations in figure 3).

b. Dynamic response of the monuments' structure during the application of seismic load

Four dynamic crackmeters (photo 5) were placed in the locations DC1, DC2, DC3 and DC4 in order to monitor the relative displacement of two pre existing structural cracks along the horizontal transversal and the vertical axis during the 5,5 seconds, that a typical blast of twelve half-second electric caps used to last.

c. Permanent deformations of the structure

Ten 3D-jointmeters (photo 6) were placed in the locations SC1 to SC10 in order to monitor the plastic behavior of the structure along ten already existing cracks.

Five tiltmeters with electrolytic sensors (photo 7) were placed in the locations TL1 to TL5 in order to monitor the walls change of inclination as effect of the permanent deformations in five relatively high points on the walls.

The choice of the sensor locations was based on the previous experience in the same monument and the cooperation with the personnel of the (9th Ephorate of Byzantine Antiquities.

The amount of data collected from the instruments was processed by special software for each application, was correlated and suitably presented to ERGOSE, to the technical committee of Central Archeological Council and to the 9th Ephorate of Byzantine Antiquities.

The supervising Authority (technical committee of the Central Archeological Council) decided from time to time to intervene in basis of the monitoring instruments results and modify the blast design, changing mainly the maximum allowable quantity of explosive material per firing interval. In the same time the engineers of the 9th Ephorate of Byzantine Antiquities actuated a tempest and intensive structures' reinforcement program. They restored all the old and new major cracks by installing transversal reinforced-concrete beams (photo 8). All the expenses of the reinforcement program were afforded by ERGOSE, as the UNESCO's " Recommendation Concerning the Preservation of Cultural Property Endangered by Public Works" recommends in section 15.b

5. MONUMENT'S STRUCTURE BEHAVIOR AND RESPONCE

Blasting works were carried out for quite one year under the Platamon Castle. During this year the monuments' structure was constantly found under an induced vibrations regime, which in some times could be defined as severe vibrations regime considering the vulnerability of the monument's structure.

Maximum peak values of particles velocity never exceeded 10 mm/s with an average value of 2,5 mm/s. The range of main frequencies was from 30 to 35 Hz with the resonant frequency at 4 Hz.

The ''A'' phase of excavation broke through in March the 6th (photo 9) and ''B'' phase is expected to finish by the end of next month. There were no major structural failures and irreversible damages on the archeological monuments. Minor cracks appeared quite immediately after unusually strong blasts and old cracks enlarged. However the structure was under control and every tendency of motion to become a damage was early detected and blocked.

The most important factor, among those affecting the monument's integrity, was the total duration of blasting operations. It is obvious that the structure was stressed for one year and the fatigue effects were unavoidable. Comparing the particles displacement in the same station during two similar blasts, one of early date and one of late, it is clearly seen that the displacement amplitude ratio is 1 to 7. This fact is due only to the structures loosening at theat point over the time. In figures 12 vibrations parameters of early late blasts are represented. Figure 4 shows the cracks situation of the monument.

In figures 5, 6, 7 and 8 the 3-D jointmeters behavior is represented in four particular points. SC4 and SC6 lay on the northwest side of the wall, SC8 on the ''E'' tower and SC9 on the octagonal tower.

The tiltmeters behavior is shown in figure 9. Two typical recordings from dynamic crackmeters DC3 and DC4 are shown in figures 10 and 11.

CONCLUSIONS

The following conclusions came out of this case study:

a. The safeguarding of archeological monuments (and sensitive structures generally) under severe vibrations regime is a complex problem that requires a global solution. Vibrations monitoring and vibration regulations respect are not sufficient by themselves to prevent major damages. In the case of Platamon Castle peak particle velocities appeared to be within the regulations safe values before and during the manifestation of new structural cracks generated by construction vibrations.

b. Structure's behavior monitoring (through 3-D jointmeters, dynamic crackmeters and tiltmeters use) was a right decision, as it is a valuable tool, indicating in time to the investigators the structural motions and their probable trends. So in the end, it is the same monuments' structure to impose and regulate safe blasting operations for the tunnel's excavation.

c. Supervision of the works must be thorough all the time until the last blast's execution.

d. Monument's structure loosening after the tunnel's opening must be kept under control and it will be very useful to continue with structure's and vibrations monitoring even during the next construction steps, until the final use of the tunnel (monitoring of different types of trains crossing through the tunnel and evaluation of the effects on the monuments' structure).

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SISKIND et altr. “Structure response and damage produced by ground vibration from surface mine blasting” U.S. Bureau of Mines, RI8507 Washington D.C. 1980.

INTERNET RESOURCES

HELLENIC CULTURE MINISTRY: alexander.macedonia.culture.gr

ERGOSE sa (Hellenic Railways Organization Projects): www.ergose.gr

SEISMOTER - GEOPHYSICS & BLASTING: www.seismoter.com

CONSTRUCTION VIBRATIONS COMMUNITY: www.civil.nwu.edu/people/dowding/chdpage.html

INTERNATIONAL SOCIETY OF ROCK MECHANICS: leo.lnec.pt/~isrm

D.I.N. (DEUTSCHES INSTITUT FUR NORMUNG): www.din.de

U.S.B.M. (United States Bureau of Mines): www.usbm.gov

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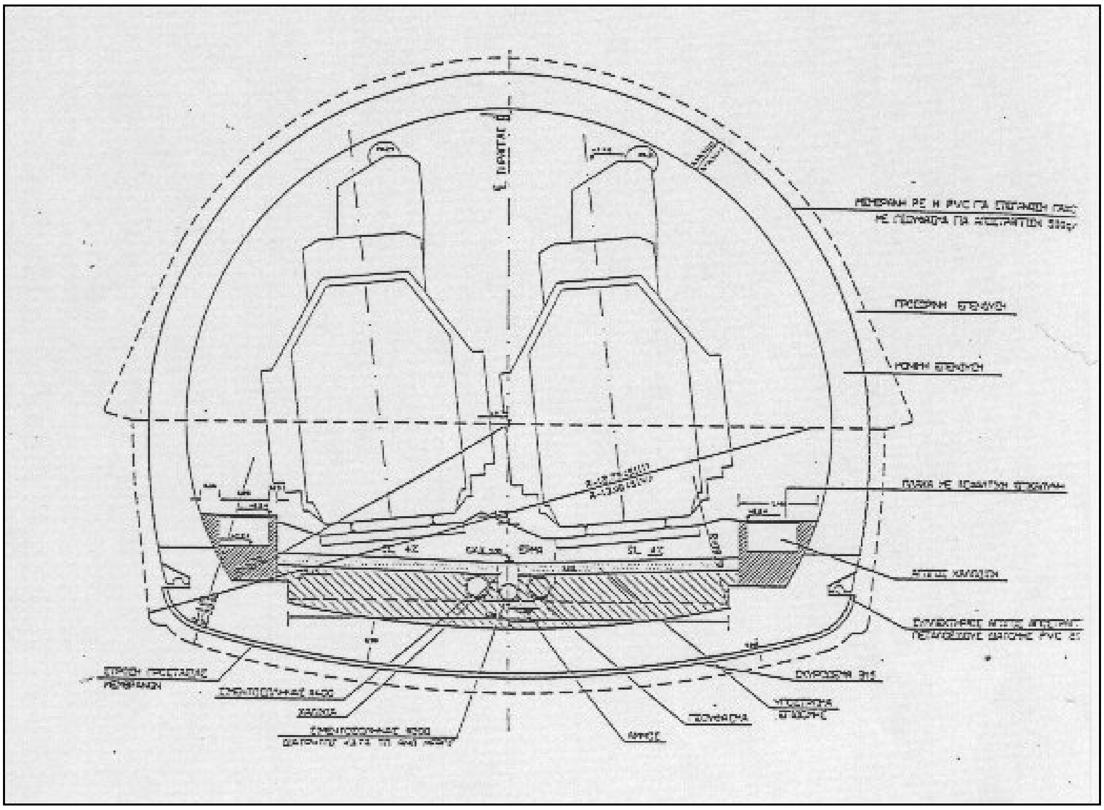


FIGURE 1: TYPICAL CROSS SECTION OF THE TUNNEL

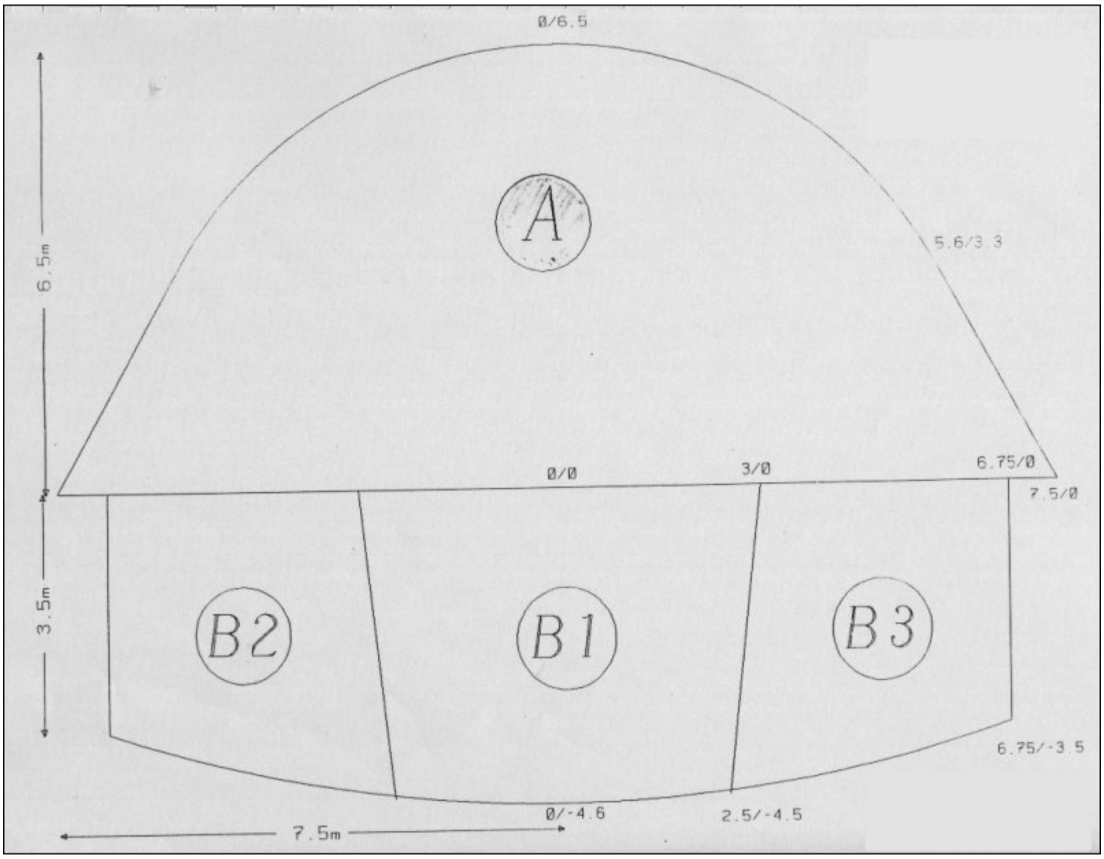
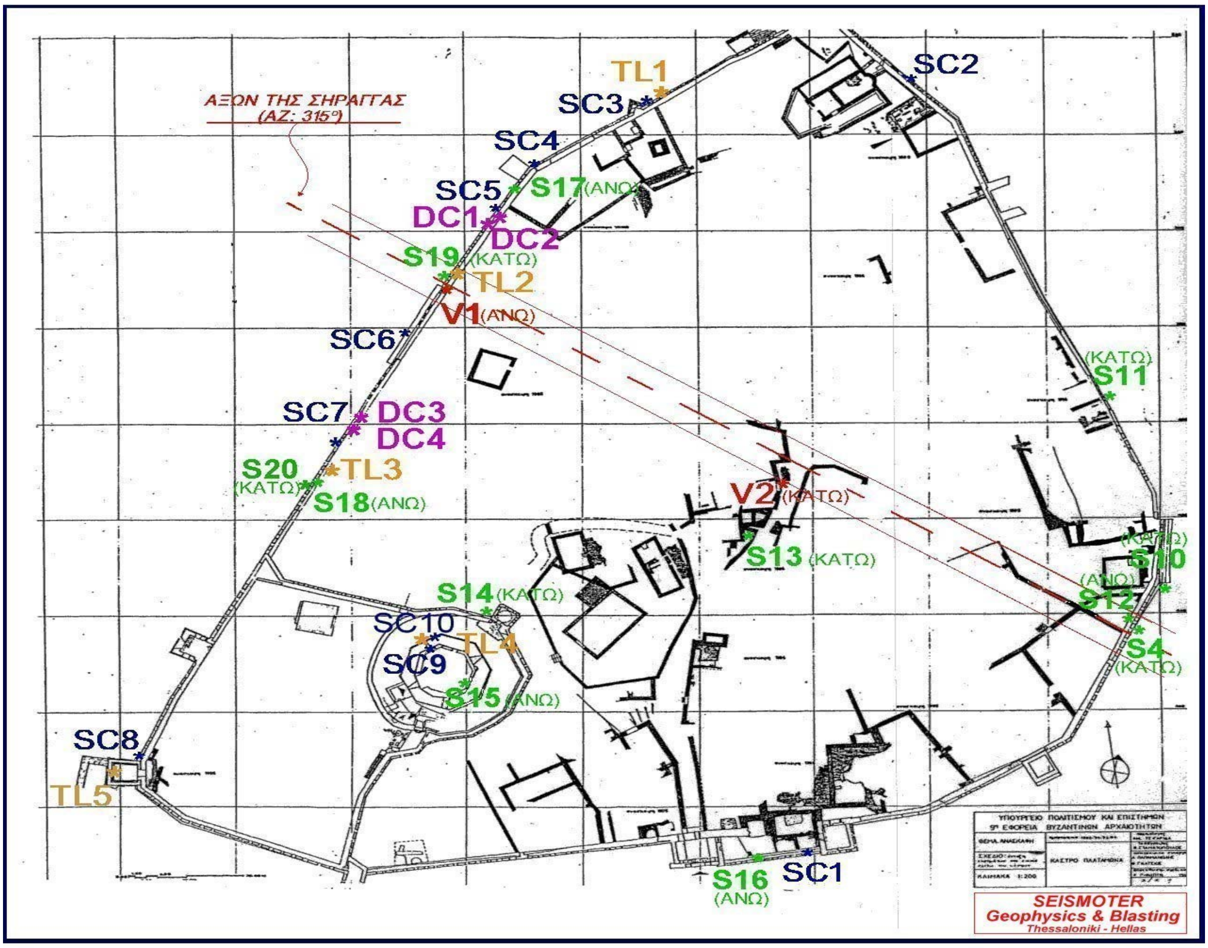


FIGURE 2: EXCAVATION PHASES

PLATAMON CASTLE - LOCATION OF MONITORING INSTRUMENTS



LEGEND	SC : 3-D JOINTMETERS	TL : TILTMETERS
SCALE 1:840	S : SEISMOGRAPHS V : MR2002 STATION	DC: DYNAMIC CRACKMETERS

GEOPHYSICS - BLASTING - CONSTRUCTION VIBRATIONS CONTROL - CONSULTING SERVICES

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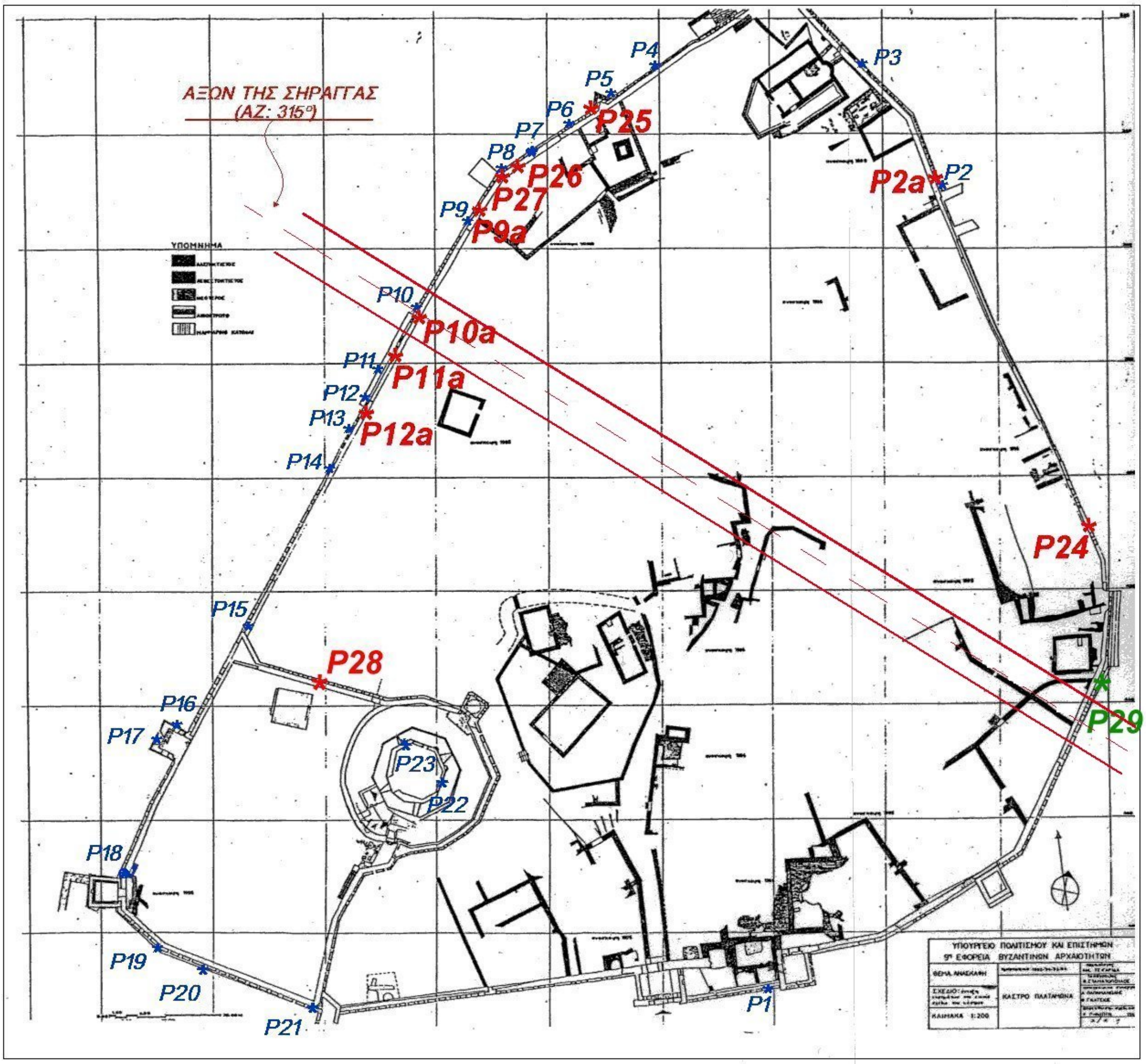
Internet: http://www.seismoter.com **email**: vibrations@seismoter.com

FIGURE 3: PLATAMON CASTLE – LOCATION OF MONITORING INSTRUMENTS

PLATAMON CASTLE - CRACKS SITUATION



P1: CRACKS ON 25.05.98
P24: CRACKS ON 01.03.99
P9α: CRACKS ENLARGED BETWEEN 25.05.98 & 02.03.99
P29: CRACKS AFTER 02.03.99

SCALE 1:1170

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FIGURE 4: PLATAMON CASTLE – CRACKS SITUATION

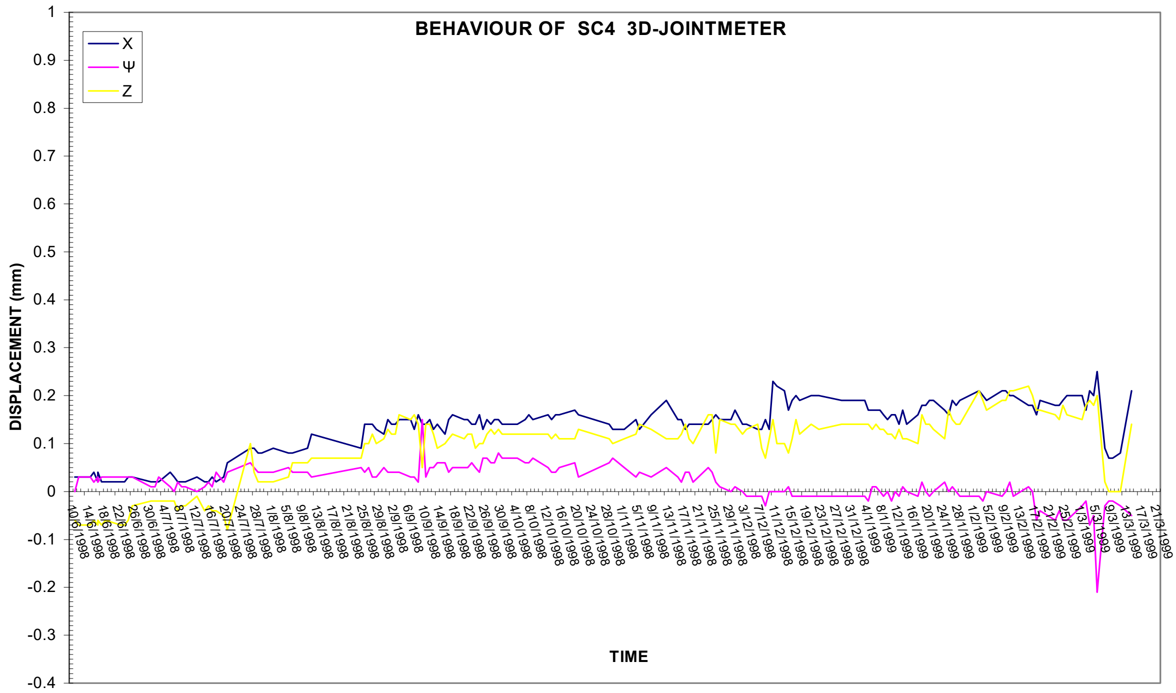


FIGURE 5: SC4 3-D JOINTMETER'S BEHAVIOR

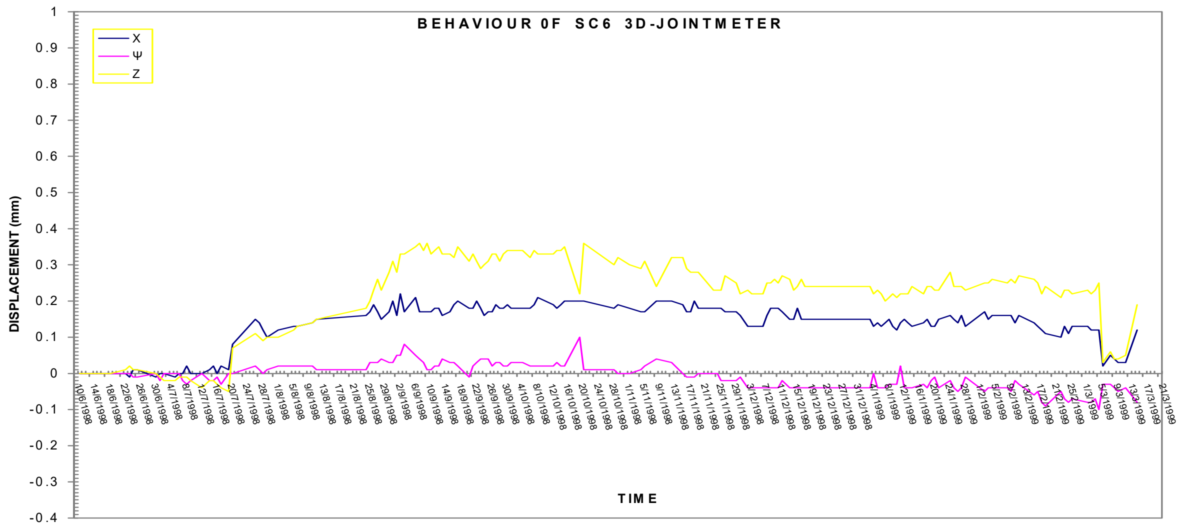


FIGURE 6: SC6 3-D JOINTMETER'S BEHAVIOR

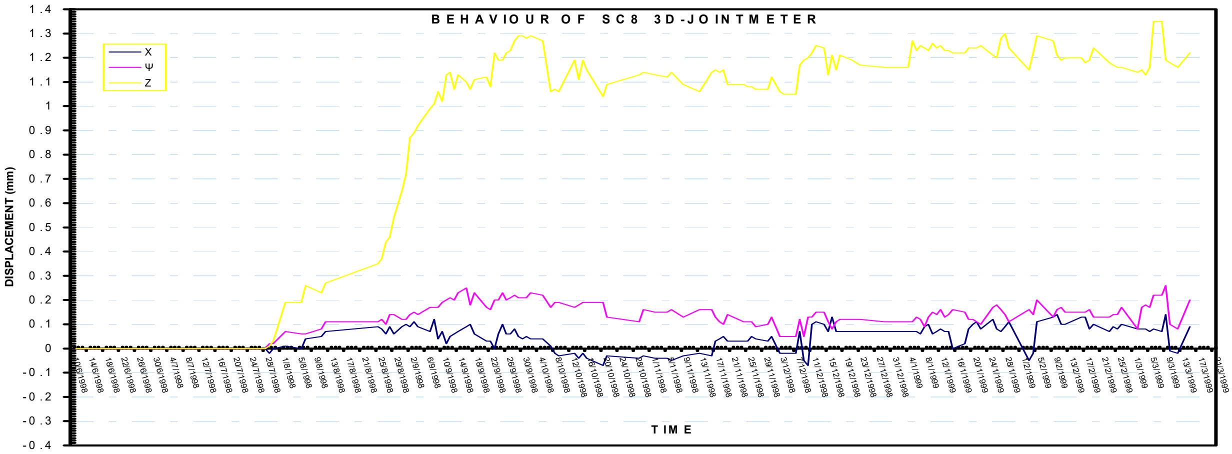


FIGURE 7: SC8 3-D JOINTMETER'S BEHAVIOR

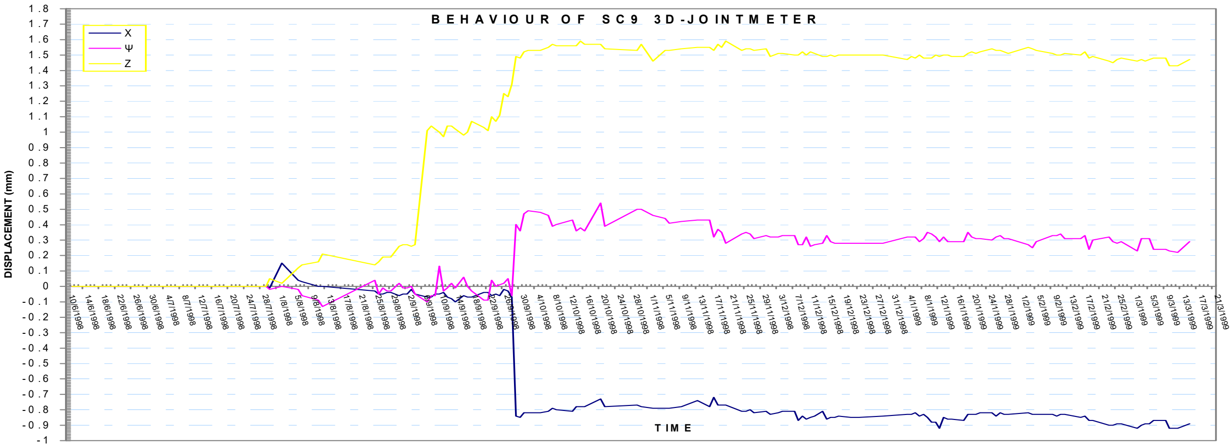


FIGURE 8: SC9 3-D JOINTMETER'S BEHAVIOR

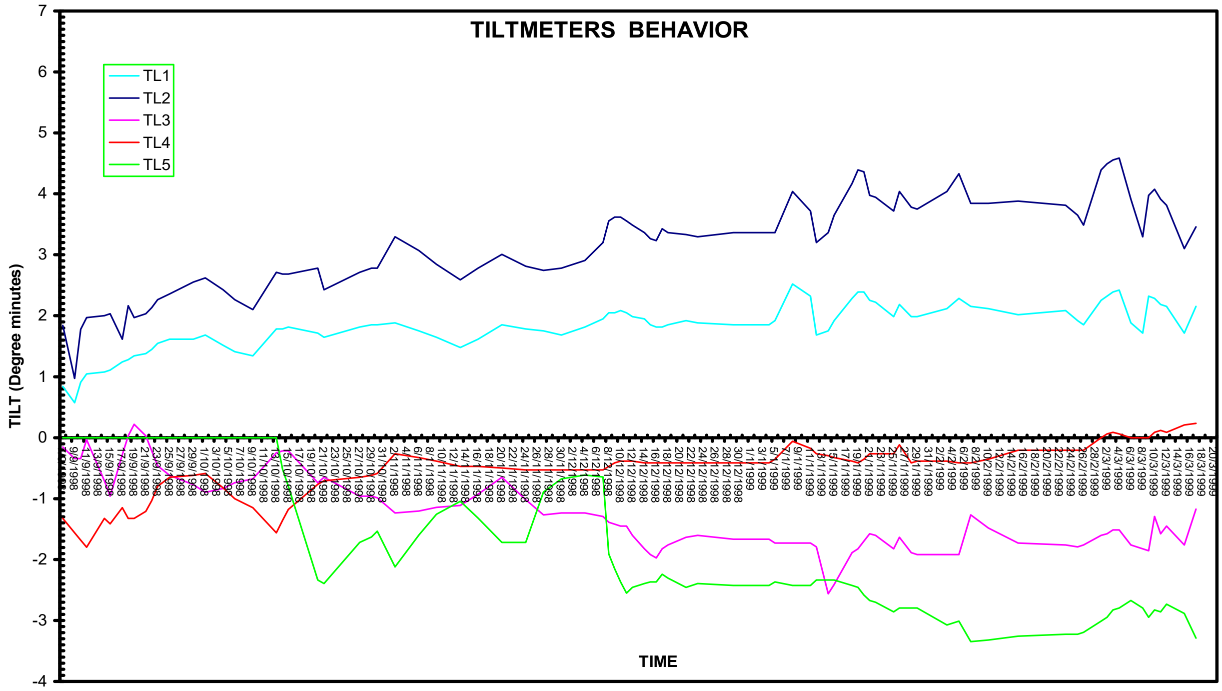


FIGURE 9: TILTMETERS BEHAVIOR

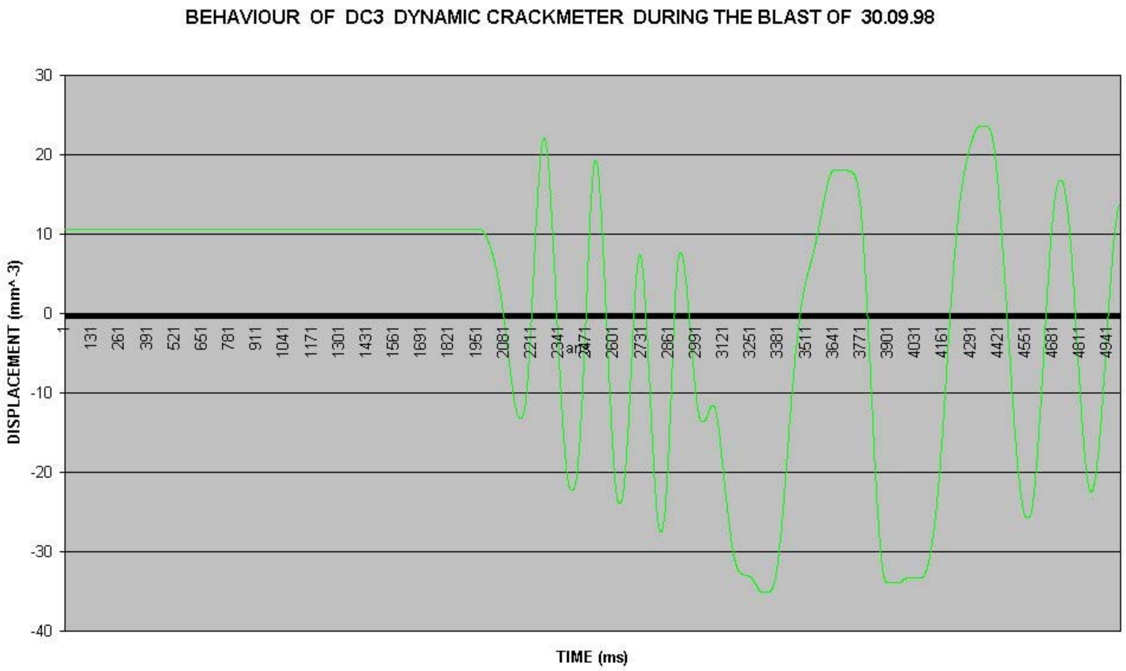


FIGURE 10: DYNAMIC CRACKMETER DC3 DURING THE 30.09.98 BLAST

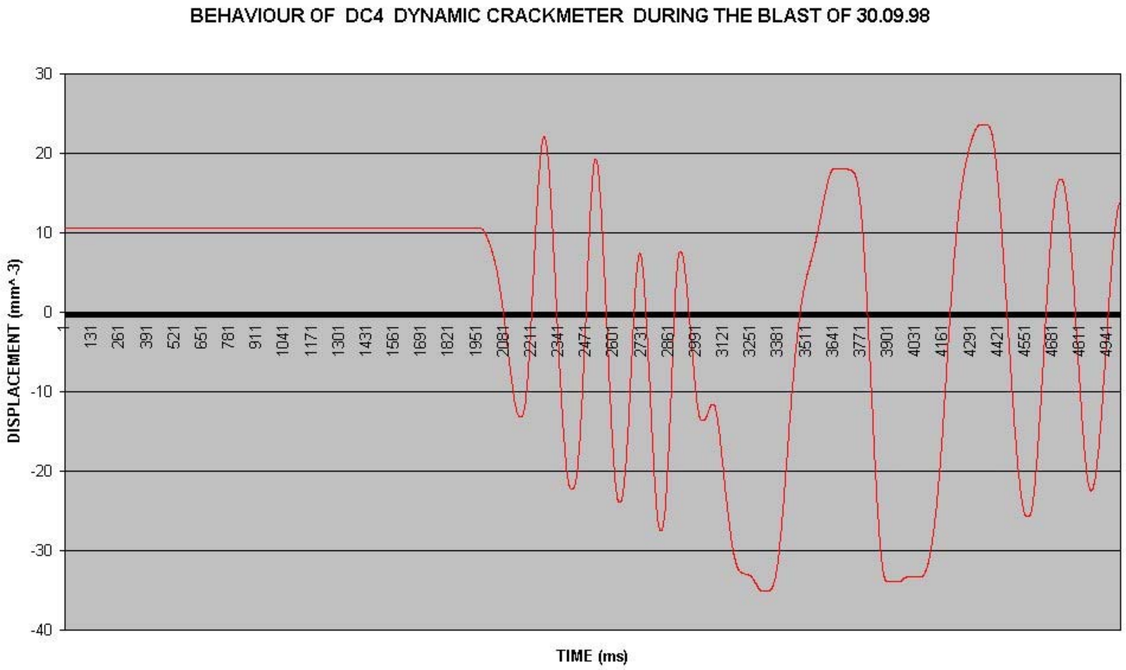
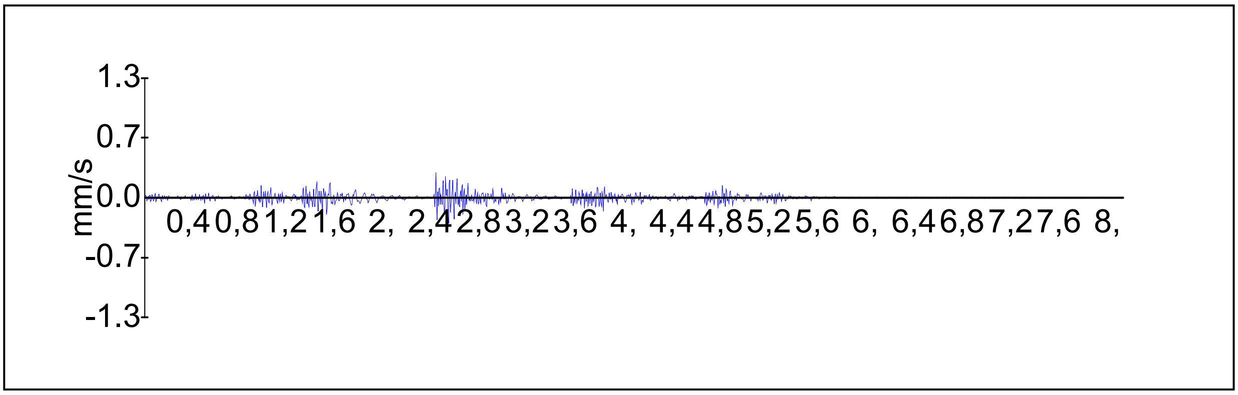
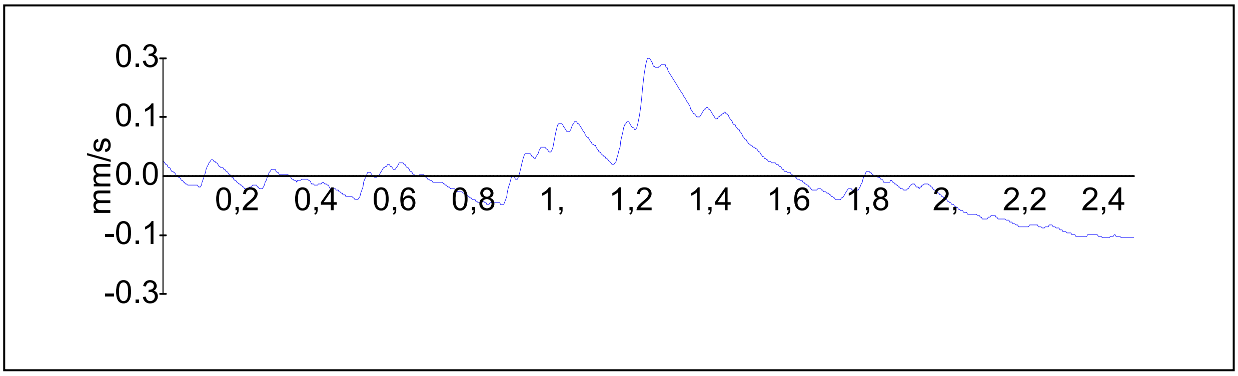


FIGURE 11: DYNAMIC CRACKMETER DC4 DURING THE 30.09.98 BLAST



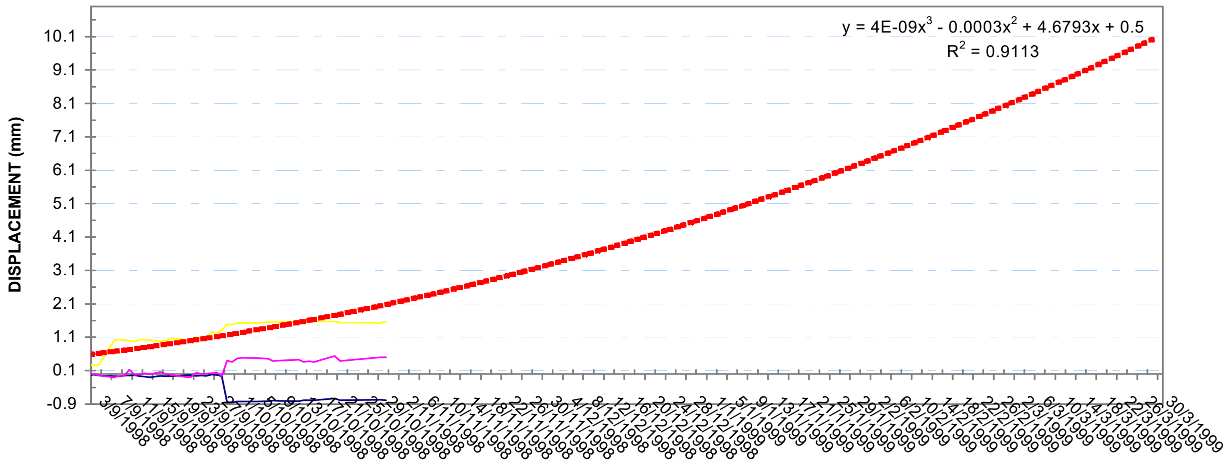
07.07.1998 BLAST RECORDING



12.02.1998 BLAST RECORDING

<u>FIGURE 12: VIBRATIONS</u>
RECORDINGS

BEHAVIOR TREND OF SC9 3D-JOINTMETER



	11-Ιουν	15-Ιουν	18-Ιουν	24-Ιουν	2-Ιουλ	7-Ιουλ	13-Ιουλ	17-Ιουλ	21-Ιουλ	30-Ιουλ	7-Αυγ	26-Αυγ	29-Αυγ	2-Σεπ	8-Σεπ	11-Σεπ	16-Σεπ	21-Σεπ	25-Σεπ	28-Σεπ	1-Οκτ	8-Οκτ	14-Οκτ	21-Οκτ
X	0	0	0	0	0	0	0	0	0	-0.01	0.03	-0.05	-0.04	-0.05	-0.07	-0.04	-0.06	-0.04	-0.06	-0.07	-0.82	-0.79	-0.78	-0.78
Ψ	0	0	0	0	0	0	0	0	0	-0.02	-0.06	-0.05	-0.03	-0.01	-0.06	-0.03	0.06	-0.09	0.01	-0.06	0.47	0.39	0.36	0.39
Z	0	0	0	0	0	0	0	0	0	0.05	0.14	0.16	0.19	0.27	1.04	0.97	0.98	1.03	1.11	1.31	1.52	1.57	1.56	1.54

TIME

FIGURE 13: BEHAVIOR TREND OF THE SC9 3-D JOINTMETER

PHOTO 1: THE PLATAMON CASTLE

PHOTO 2: THE TRIAL BLASTS PROGRAM

PHOTO 3: THE SOUTH ACCESS AREA OF THE TUNNEL, THE PLATAMON CASTLE ON THE TOP OF THE HILL AND Mt. OLYMPUS IN BACKGROUND

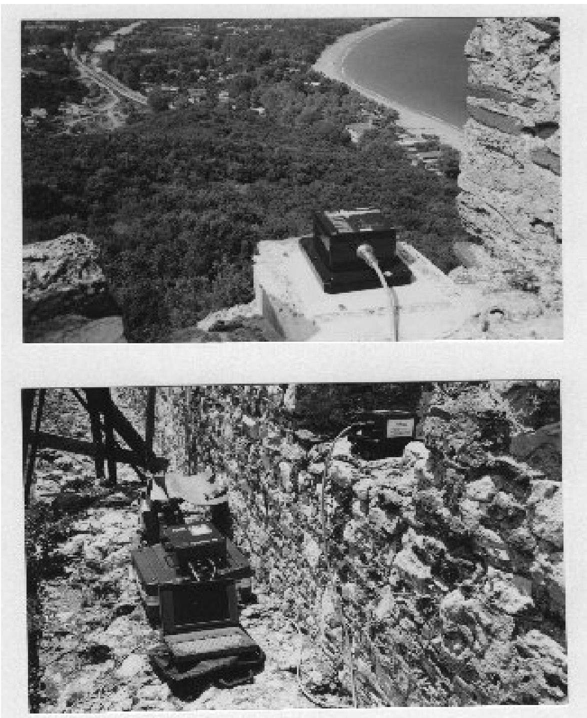


PHOTO 4: THE MR2002 VIBRATION RECORDING SYSTEM IN LOCATION V1

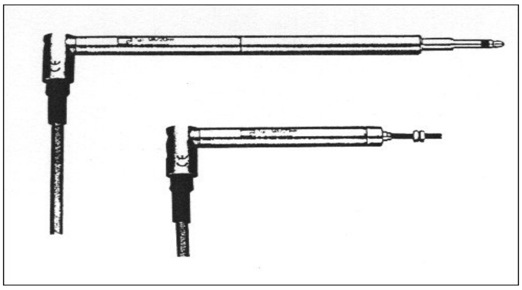
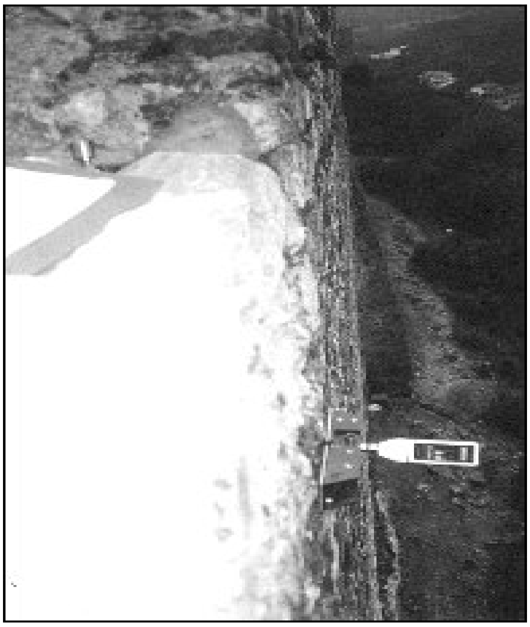


PHOTO 5: DYNAMIC CRACKMETER



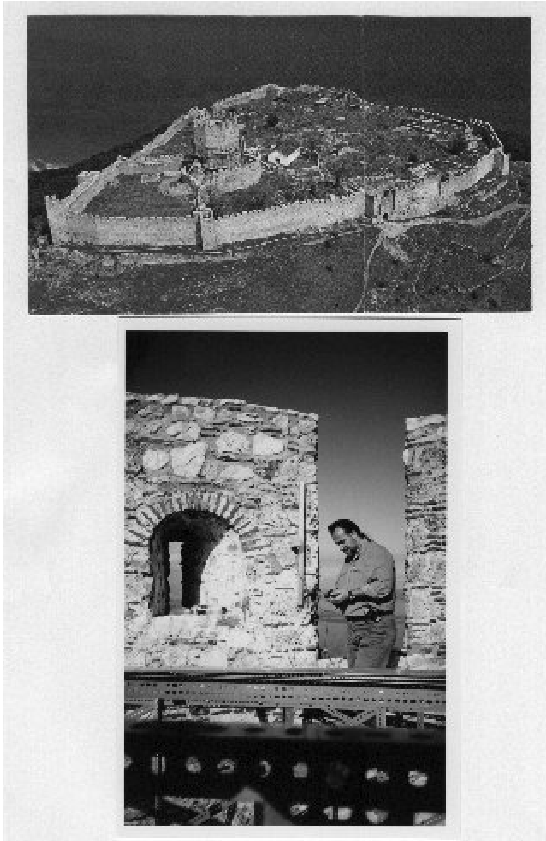
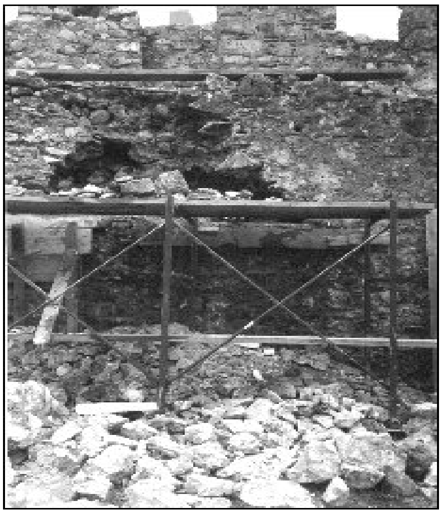


PHOTO 7: TL4 TILTMETER

PHOTO 6: 3-D JOINTMETER



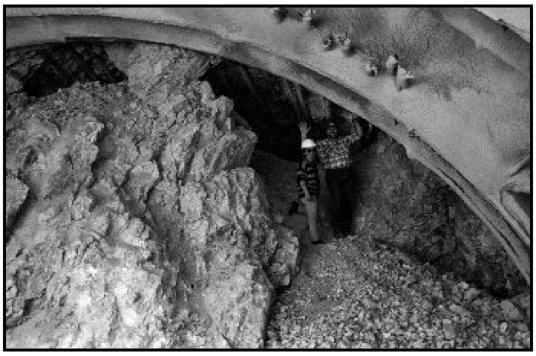


PHOTO 9: TUNNEL BREAKTHROUGH

PHOTO 8: MONUMENT'S STRUCTURE REINFORCING WORKS