# A Proposal to Modify the DIN 4150-3 Vibrations Code Based on a Twenty-Years Blasting Experience .

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# A PROPOSAL TO MODIFY THE DIN4150-3 VIBRATIONS CODE BASED ON A TWENTY-YEARS BLASTING EXPERIENCE

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## 1. INTRODUCTION

A proposal to modify the DIN 4150-3 vibrations code will be presented in this paper. The idea to propose such a modification was matured to the author's mind during the last five years, after being involved in the blasting industry since 1981.

The DIN 4150-3 vibrations code is the third part of the DIN 4150 code and regards the vibrations effects on structures. The code is originally a German code, but it is widelly used in all European and other countries, an exception is made for North America.

The usefullness of this code is well recognized by engineers and specialists involved in structure dynamics, blasting industry, constuction works, tunneling excavation, mining activities etc. The author of this paper is a frequent user of this code and had through time the opportunity to test it, evaluate it and deeply appreciate it. There are allthough some points where the code lacks of detail and on these points could be ''fine-tuned''. Of course the necesity of well-generalized code remains out of discussion.

In any case these lacking points of the code will be discussed here, hoping to be taken under consideration during any future revision of the code in order to maintain it constantly up-dated.

## 2. GENERAL CONSIDERATIONS ON VIBRATIONS MEASUREMENT

Here are some general considerations on blasting generated ground vibrations and their measurement.

We can consider the transmission of a ground vibration disturbance as a series of particle impacts. The movement of a single particle impacts a number of other particles. These particles then impact other particles. This process advances the vibration as a waveform. The types of waves that are created vary depending on the type of the geological material transmitting the energy.

Immediately after the detonation of a certain amount of explosive material into a borehole, space waves (compression and shear waves), surface waves (Raleigh and Love waves) and a combination of them are generated and propagated in the earth. These waves are characterized by corresponding frequencies, propagation velocities and corresponding wave lengths as well.

While considering the effect of these waves on structures and buildings, the space waves (the compression waves in particular) are predominant when the distance between the blasting area and the measuring station is small, as in the case of rock blasting for inner city underground railways and roadways. The surface waves predominate when the distance is large, as it is in the case mines exploitation. In such cases the waves are of low frequencies, as compared to space waves.

In the close vicinity of a charged borehole the energy released by the explosive's detonation is inelastic. This means that the rock particles are deformed beyond their ability to return to their previous state. Thus fracturing and crushing of material occurs. Beyond a distance of approximately 30 to 35 hole diameters, the energy becomes elastic. That is, the particle deformations do not exceed the failure strength of the material. After the energy has passed, the particles return to their original state.

Seismic blast vibration is recorded as particle velocity. The three dimensional seismic energy is represented by three mutually perpendicular components intended as radial (longitudinal), transverse and vertical. The peak particle velocity is the largest velocity of the three components and can occur on any of them. The peak vector sum of the particle velocity is the square root of the sum of the quadratic velocities on every single component. The peak vector sum may or may not occur at the same instant as the peak particle velocity.

The DIN4150-3 code contains details for the investigation and evaluation of the effects of vibrations on structures, which are essentially designed for static loadings. The code specifies reference values by adhering to which, damages, which imply a lowering of the utility value for the structure, need not to be expected. A lowering of the utility value of the structure as a whole or of some structural elements through the effects of vibration, according to the code, is intended the impairment of the structure's safety factor, the lowering of the bearing capacity of the slabs, the appearing of cracks in the plastering, the already existing cracks widening and the partition walls separation from the load bearing walls or from the slabs.

## 3. THE MODIFICATION PROPOSAL

The most important aspects, regarding structures' safety, to be taken in consideration by the modified code should be the following:

*a. Dominant frequency*

Between all the other physical quantities that fully describe any wave phenomena, i.e. particle velocity, displacement, acceleration and frequency, this last one is of critical importance, as concerns to structures' safety. Low intensity ground vibrations may induce major stress to a structure, if the dominant frequency is suitably similar to the structure's eigen frequency. On the other hand, stronger vibrations may result less harmful to structures' integrity, if the dominant frequency is far beyond the eigen frequency value. This is the well-known tuning phenomenon. When it occurs, the particles oscillation amplitude tends to infinite, this theoretically. In any case of dominant and eigen frequency coincidence, maximum dynamic loading is applying to the structure and structural failure is more likely to appear. That is why the particle velocity –only- is not sufficient to be a valid damage criterion. The particle velocity must be always evaluated together with the dominant frequency of the vibration. Although blasting generated ground vibrations are generally characterized by high dominant frequencies , the surrounding structures oscillate by induction with lower frequencies mainly because of construction features, because of the local geological and tectonic conditions and because of the dumping ratio between the blasting area and the structure.

*b. Structures' classification by vulnerability*

In the modern structured both civil and industrial environment, the constructions present a high grade of inhomogeneity. Therefore it is quite wrong to consider them equally when they undergo to dynamic loading conditions. The structural design, the construction materials, the foundations, the age and the time history of a construction are all important elements of differentiation of the structure's response to the imposed dynamic stress.

The ground vibrations generated by blasting and propagated into a structured environment have not the same impact to a recently constructed structure after modern seismic design codes and to an aged building.

The presence of the old and unique archaeological monuments in several countries and the undoubted need for their protection impose their defense against ground vibrations.

This is why the modified code has to classify the different structures by vulnerability for both financial and technical reasons. Furthermore has to consider separately the archaeological monuments by adopting safer limits in order to preserve them properly.

*c. Duration of the vibration*

The duration of the vibration is another important factor to the dynamic response of the structures. Structural fatigue does exist and is more evident in constructions that have been persistently under a certain regime of ground vibrations during a long period of time. In most of the international regulations the maximum allowable limit value for the particle velocity is referred to the case of casual or transient excitation and not to the case of continuous or steadily repeated excitation. In quarrying, mining and construction works blasting on site repeatedly occurs with a certain frequency, generally over long periods of time. So the maximum allowable limit value for the particle velocity to be used as damage criteria value must be properly defined.

*d. Vibrations' monitoring procedure*

The normalization of the vibrations' monitoring is extremely usefull and must be part of every code. Expressions such as ''… peak particle velocity must not exceed an x value, when measured on the ground in the proximity of public structures …'' cannot be used in vibrations codes because insufficient for procedure's normalization and even dangerous for the structures' safety, as far as, could be wrongly interpreted and misguide people in arguments like the one it follows: '' *since vibrations' monitoring is already performed on the ground in points that lay between the blasting area and the protected structures and the peak particle velocity is within the safe limit values, furthermore the peak particle velocity value on the structure is within the limit values as lower ''.* This is safety control by reduction and sould never be accepted by us, acting as consulting or supervising engineers. A code must clearly impose control measurements on both ground and structure points and must also prescribe the monitoring instrumentation and the data processing methods, as well.

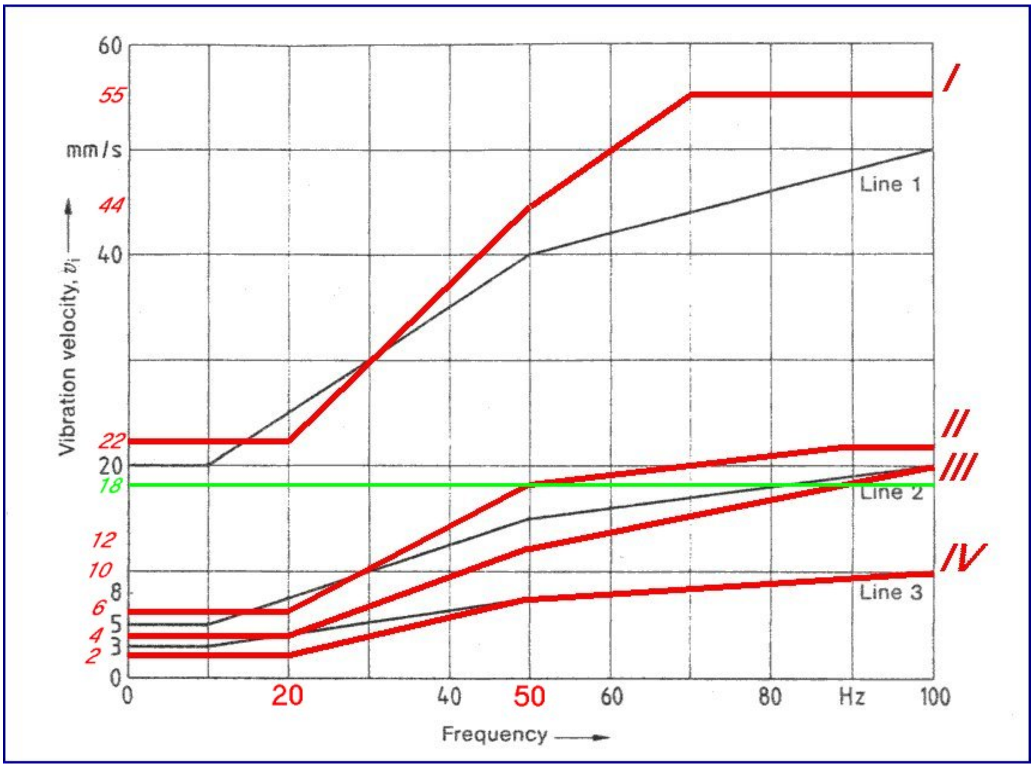
The modification proposal here presented is based on the blasting experience accumulated during the last twenty years worldwide. The basic principle of the proposal remains the effective humans' and structures' protection against ground vibrations. In the same time it supports and better documents the ''drill & blast'' excavation method, given that this method still remains the best one for rock fragmentation, worldwide.

The peak particle velocity in function of the frequency is still the best damage criteria to adopt. Particular attention must be paid in order to avoid confusing the peak particle velocity with the peak vector sum.

The structural damage has to be intended as cracks appearing and widening on the structural elements. Cracks in the plaster are considered to be ''minor damage of cosmetic character''.

The proposal is resumed in the following table and figure:

| CATEGORY | TYPE OF STRUCTURE | PARTICLE VELOCITY IN mm\s | | | MIDDLE OF THE UPPER FLOOR |
|---|---|---|---|---|---|
| | | FOUNDATION | | | |
| | | BELOW 20 Hz | FROM 20 TO 50 Hz | ABOVE 50 Hz | ALL FREQUENCIES |
| I | INDUSTRIAL BUILDINGS, HEAVY CONSTRUCTIONS | 22 | 22-44 | 44-55 | 44 |
| II | DWELLINGS & OFFICE BUILDINGS CONSTRUCTED AFTER RECENT SEISMIC DESIGN CODES | 6 | 6-18 | 18-22 | 18 |
| III | BUILDINGS OF CATEGORY II CONSTRUCTED AFTER OLDER SEISMIC DESIGN CODES AND ALREADY DAMAGED BUILDINGS | 4 | 4-12 | 12-20 | 12 |
| IV | ARCHAEOLOGICAL MONUMENTS AND STRUCTURES OF SPECIAL USE | 2 | 2-8 | 8-10 | 8 |



## 4. COMMENTS TO THE MODIFICATION PROPOSAL

a. One more category (category IV) is introduced including the archaeological monuments and the special use constructions as type of construction. The damage criteria for every category is represented by a critical broken line on the velocity-frequency diagramm. Every seismic event generated by a single blast is considered to be unable to provoke any structural damage, if the intersection of the velocity and the frequency values on the axis is found below the critical line corresponding to a particular structure. On the opposite, if this intersection point is found above that line, then there is a certain amount of probability for the structural damage to occur.

b. The low-frequency range is increased from 10 Hz to 20 Hz in order to include more structures' eigen frequencies into the lower allowable velocity limits for all categories of constructions.

c. The velocity limit values are better regulated in the area below 20 Hz.

d. The constructions are also distinguished in base of the modern or old seismic design codes they were constructed after.

e. Preventive evacuation of the buildings is proposed, when vibrations exceeding the limit value of 18 mm/s are expected, in order to avoid human disturbance.

f. All the proposed limit values should be reduced of 20%, if blasting should be prolonged over a long period of time.

## 5. THE SPECIFIC CASE OF VIBRATIONS MONITORING ON ARCHAEOLOGICAL MONUMENTS

The specific case of vibrations monitoring on archaeological monuments presents some particular aspects and therefore special attention must be paid when it comes to perform measurements on them.

People become more and more interested in the protection and restoration of ancient monuments and structures over the years, appreciating the value of historic sites, as they represent the relevant links between present time and our course in history. Most of the monuments stand on for some thousands of years resisting to natural phenomena such as earthquakes, volcanic eruptions, floods and human activities such as war destruction and improper use.

Construction vibrations represent the largest and in many cases the most dangerous category of man generated ground vibrations. Activities such as rock blasting, soils dynamic compaction, pile driving, mines blasting, mechanical trenching, blast densification of sands, structures demolition with explosives are some of the usual sources of ground vibrations. Other vibration sources are railway traffic, special machinery's functioning, heavy road traffic conditions, etc.

One point of great difference between a monument and a modern construction is their age. A state of natural equilibrium is established between the monument's structure and the surrounding host material.

The monument structures are mostly characterized by an enormous complexity because of the many different constructional styles, the many different construction materials and the many different men-interventions on them during the lifetime of the monuments. Because of this complexity, it is very difficult (or quite impossible) for the specialists to produce any behavioral models based on SDF or MDF analysis techniques. Major concern for the structures integrity comes from the differential displacements (even between short sectors of the structure), which are the norm rather than the exception in the case of the archaeological monuments under shocks and impacts.

The nature of the shock is most important for the archaeological monuments. A single-cycle excitation has to be regulated by a damage criteria, which has to be different from the damage criteria that regulates a continuous or periodically repeated excitation. When multi-cycle excitation occurs, fatigue effects are quite unavoidable. In this case damage criteria must be flexible, adaptable and by time diminished, in any case.

When it comes to protect an archaeological monument against hazardous vibrations the international standards should be just a guideline and a reference during the pre-blast site survey and trial-blasts program. During the execution of the works the monument must be continuously (24 hours per day) monitored by a multi-parameters monitoring network, in order to provide the specialists with all the valuable information about its own behavior under dynamic load.

Here are some guidelines to the continuous vibrations monitoring works:

- Location choice for the vibrometrical stations installation on the monument and on the ground.
- Proper sensors choice (accelerometer, velocitymeters or both).
- Topological study of the seismographic network which permanently controls the vibrometrical stations. Telemetric capabilities and call-back options are preferred.
- Installation and initial setup of the seismographic network.
- Vibrations parameters in dual-mode measurements (single events and continuous), data post-processing and reports production including zero-point-crossing frequency analysis and 3-D representation of particles displacement.
- Continuous adjustment of the scaled-distance model.
- Continuous control of maximum vibrometrical parameters and cease of vibrations generating activities, if necessary, in case of maximum allowable limits override.
- Modification of the works method statement (if necessary) in order to fit again into the maximum allowable limits. There are many suitable techniques to mitigate vibrations hazard on monuments. In case of blasting works some of these techniques are the sequential blasting technique, the proper use of the firing system, the various controlled blasting techniques (presplitting in particular), the favorable blast's direction, the immediate muck removal and the proper use of damping materials.

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## INTERNET RESOURCES

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

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

ERGOSE s.a. (HELLENIC RAILWAYS ORGANIZATION PROJECTS): www.ergose.gr

GREEK CULTURE MINISTRY: www.culture.gr

INTERNATIONAL SOCIETY OF EXPLOSIVES ENGINEERS: www.isee.org

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

O.S.M.RE (OFFICE OF SURFACE MINING & RECLAMATION): www.osmre.gov/osm.htm

SEISMOTER - GEOPHYSICS & BLASTING: www.seismoter.com

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

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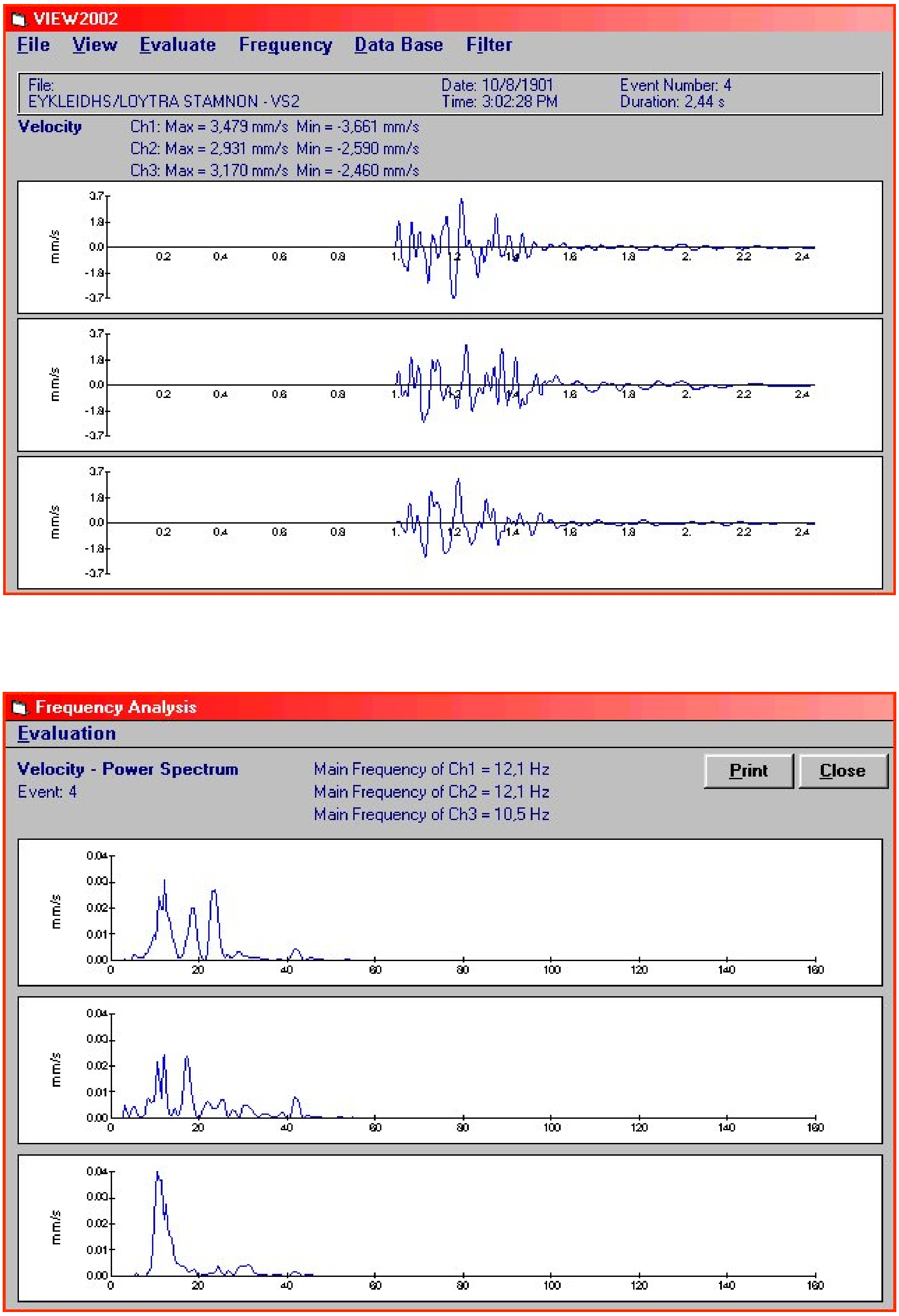


Figure 1: Typical recording of particles velocities and power spectrums from construction blasting near the walls of the ancient town of Stamna – Ionian Sea, Western Greece.

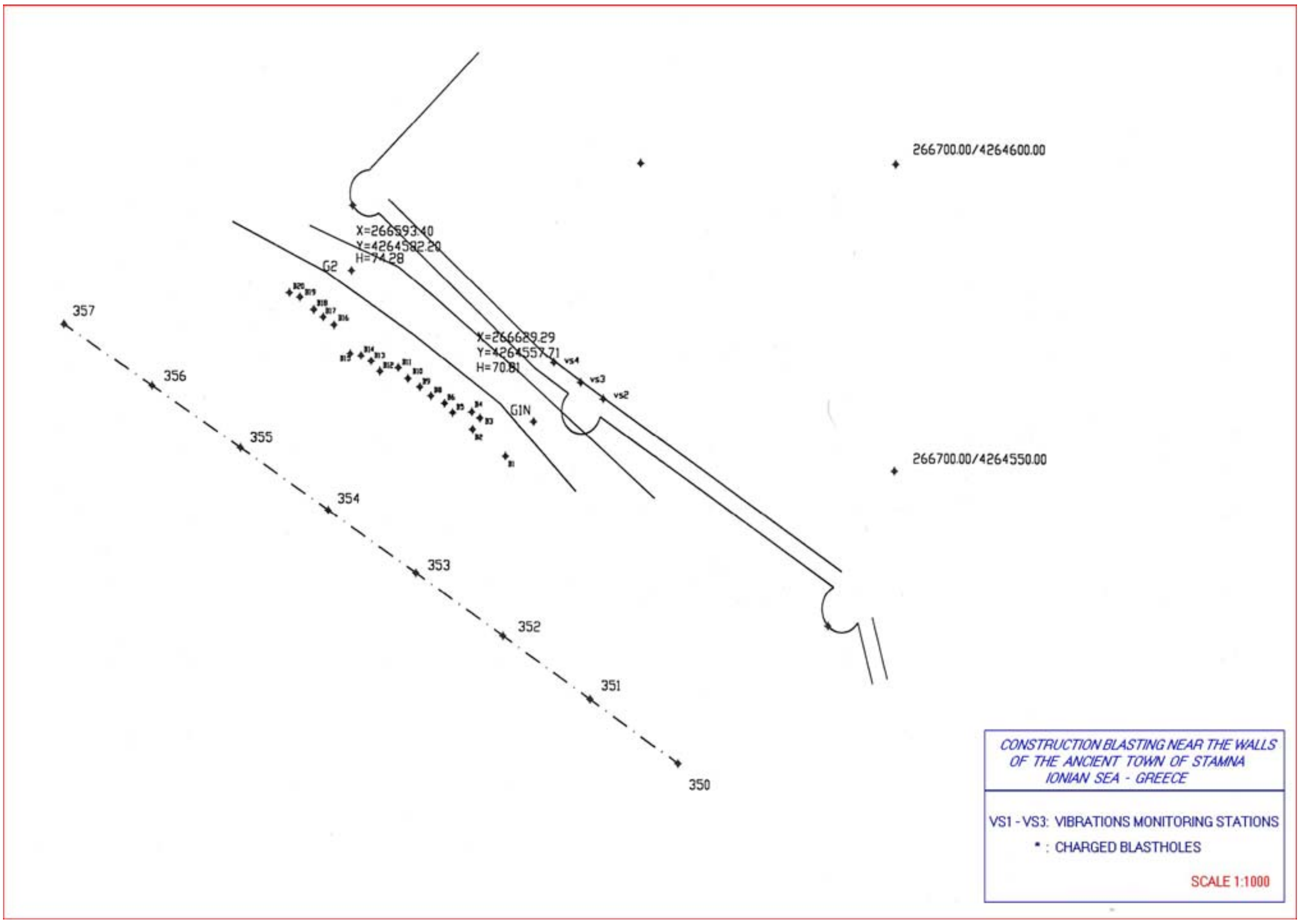


Figure 2: Construction blasting near the walls of the ancient town of Stamna – Ionian Sea, Western Greece.

Photo 1: Installing a vibrations monitoring station MR2002 on the ancient wall in the archaeological site of Stamna - Ionian Sea, Greece.

Photo 2: Cabling an MS2003 sensor, under the supervision of the archaeologists.

Photo 3: Blasting at 10 m. away from the ancient wall.
Close and safe blasting may be possible!

Photo 4: The medieval castle of Platamon and the railway tunnel under construction in Mount Olympus - Northern Greece.