Geometric Documentation of Structures After an Earthquake

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SUMMARY

This paper deals with a methodology for the precise geometric documentation of constructions after a dynamic phenomenon such as an earthquake.

An analysis of the documentation methodology is given, by using modern accurate total stations which can function without reflectors and allow for fast and accurate positioning of points where it is impossible to use geodetic targets or prisms due to inaccessibility and most often of hazardous nature. The achieved accuracy is calculated. Designs that can be produced are: ground plans at different heights, vertical sections and façades. In those plans the dimensions of all the structural elements of the construction, the damages such as cracks, turns or collapses that appear and the structural failure after the occurrence are all registered.

This is a very useful presentation in order to allow engineers or other scientists easy access in order to find the reasons to what caused the structures' destruction. Additionally, this documentation will be useful for the safe repairing of the construction, if possible and for the derivation of the total conclusions.

Finally, an application of the methodology is presented, for a specific construction, which had suffered a lot of damages during the 1999 earthquake in Athens. The ground plans and sections illustrate clearly all the deformations in the structural elements and also give detailed information about the way the building was constructed.

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1. INTRODUCTION

Structure deformations caused by violent natural phenomenon, such as displacement of the earth's crust, earthquakes or other interferences of initial failures are subject to investigation by many Geoscientists. The *geometric documentation* of a structure is the registration of the shape, size and place in the three-dimensional space at a given time.

The geometry of a structure change, over time, is caused by many reasons such as damages, earthquakes and ageing. Any registration is referred to the time of the measurements.

The geometric documentation of a structure is indispensable for the full registration of its deformation at any given moment and may be done so with credibility by geodetic methods using the modern digital total stations. The application of these methods depends on the following parameters:

- The final required accuracy of the documentation.
- The choice of the proper instrumentation.
- The design of the measurements.
- Measurement of detail points by the same accuracy.
- The calculation method
- The digital procedure of the measurements and the design of the structure's elements
- The procedure of the statistical control of the results.

Drawings that are usually produced for the geometric documentation of a structure are:

- *General plan*: The plan of the projection of the structure and the surrounding area on a horizontal plane.
- *Horizontal sections*: The plans of the projection of the structure on different horizontal planes, which cut the structure at different heights.
- *Vertical (cross or longitudinal) sections and fa ades*: The plans of the projection of the vertical elements of the structure on different vertical planes, which cut the structure at some specifically selected and previously defined positions.

The total number of the plans and the positions of the horizontal and vertical sections are defined accordingly to the complication of the structure and the particularities of the elements, which must be apparent in the documentation plans.

2. ACCURACY AND SCALES

The procedure of the geometric documentation begins by the definition of the required accuracy. The required accuracy of the detail points is determined by the user of the plans

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depending on demand of the study where the plans will be used. Given that, today, most plans are used in digital form, this is the basic criterion for the determination of the accuracy of the surveying and the technical procedure (methods and instruments). An accuracy of ± 5mm at the final determination of the X, Y and Z coordinates is today possible to be reached at. Also the choice of the plotting scale of the plans is very important. This can usually be done by taking into consideration the following:

- The size of the structure
- The required accuracy of the detail points
- The total cost of the work

The more common scales for the documentation of structures are 1:100, 1:50, 1:25 and 1:20. Table 1, illustrates the maximum permitted uncertainties in the determined coordinates X, Y and Z of each detail point, according to the used plotting scale.

Scale	Accuracy (σ_X, σ_Y, σ_H) (mm)
1:100	±25
1:50	±13
1:25	±6
1:20	±5

Table 1: Accuracy relative to the plotting scales

3. PROCEDURE

For a full geometric documentation of a structure an arbitrary local 3-d network was developed inside and outside the structure. The defined scale of the plans and the particularities that appeared determined the complexity of the network. All the indispensable distances, horizontal and vertical angles between the networks points were measured. The instruments and equipment that were used insured the reaching of the prescribed accuracy.
The 3-d network solution was done by the least square method. The following parameters were determined, which certified the accuracy and the credibility of the surveying:

- The coordinates X, Y and Z of the network points.
- The errors in the coordinates value for any desired confidential level.
- The absolute error ellipses for each point, for any desired confidential level.
- The relative error ellipses for all the pairs of points, for any desired confidential level.
- The final corrected values of the measured distances and azimuths of the network's sides and their corresponding accuracy for any desired confidential level.

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The detail points of the structure may be surveyed by using mainly the following two methods:

− *The polar coordinates method.* This method presupposes the direct measurement of the distances from the station point of the total station to any detail point. Today this method may be applied by the use of a modern digital total station, which measures distances, by a laser beam on any given surface without using a reflector. The evolution of the technology on such instruments has improved greatly with concern to the range and the measuring accuracy, which is about ± 3mm.

The advantages of the use of these instruments are:

− The accuracy that each detail point is marked by the laser beam
− The measurement of inaccessible points
− The prism holder man is not required for the measurements.
− The range of these instruments is today up to 600m and has significantly reached 5Km when a reflector is used to measure (Balodimos et al, 2004).

This improves the final succeeded accuracy of the surveying of the detail points, which may reach ± 4mm.
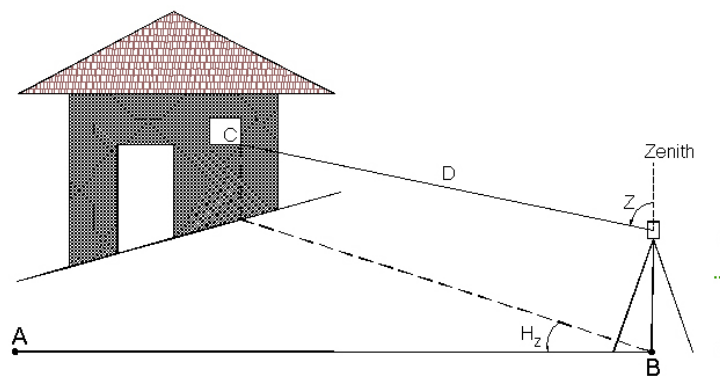

Figure 1: The polar method.

− *The intersection method.* By this method the coordinates X, Y and Z are determined by horizontal and vertical angle measurements to accessible or inaccessible points (fig. 2). The presupposition is that each point may be sighted simultaneously from two instrument stations.
  The points are marked by using a special laser pointer.
  Disadvantages of this method are:
  − The need of two instruments
  − The required visibility of each detail point at least from two stations, which ought to have intervisibility, as the two theodolites are mutually pointed for relative orientation.
  − The complexity of the demanded network.
  − The complicated calculations

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The choice of the appropriate method depends on the required accuracy, the particularities of the structure's detail points, the availability of equipment and furthermore the final cost and time invested.
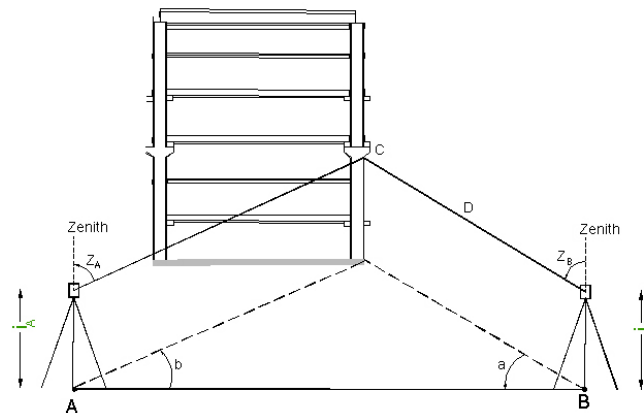
Figure 2: The intersection method.

4. CASE STUDY

The present case refers to the production of the appropriate plans of a preconstructed industrial building, which had suffered serious damages during the 1999 earthquake in Athens (fot.1) (Searching Project, NTUA, 1999 -2000). The aim of this project is the determination of the causes, which led, to the collapse of the building in question and to calculate the deformation of the building's structure accurately. The building has a double side roof. Its dimensions are 80m in length, about 20m in width and about 10m in height. It was made up of two separate floors, the main floor was actively used where as the second was used as a storage place.

**Fot.1:** Internal condition of the building after the 1999 earthquake

Initially a 3-d geodetic network consisting of eight stations was established inside and outside the building. The measurements of the elements of the network were carried out by a modified method of the ″three tripods″ (Balodimos, 1996), in order to eliminate all the leveling and centering errors of the instrument. Horizontal and vertical angles were measured

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as well as the distances between the points. The network was adjusted at an arbitrary reference system. The coordinates of the network stations were computed with an accuracy of ± 5 mm.

The EDM Leica DIOR 3002 mounted on the digital Theodolite Leica T1610 was used for all the measurements. Although this system is not homoaxial, requiring thus a geometrical reduction, it functions properly as the DIOR 3002 and has a strong laser beam with a narrow diameter, which marks clearly and accurately detail points which were measured. This total station measures distances up to 60m without reflector with an accuracy of ±3mm ±2ppm and also measures angles with an accuracy of ±10^{cc} (Leica Heerbrugg AG, 1993).

The survey contains measurements of the basic elements of the building, specifically the concrete body that carries the weight of the complete structure as (fig. 3):
– pillars
– support girders
– supporting bases of girders
– sitting foundations of pillars

Horizontal   *Vertical*
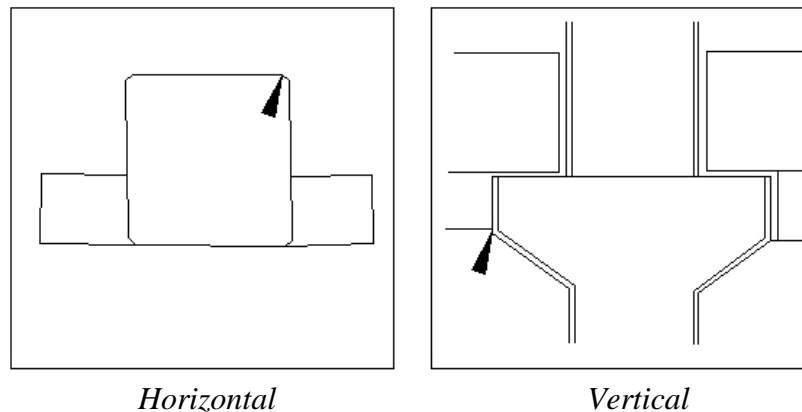
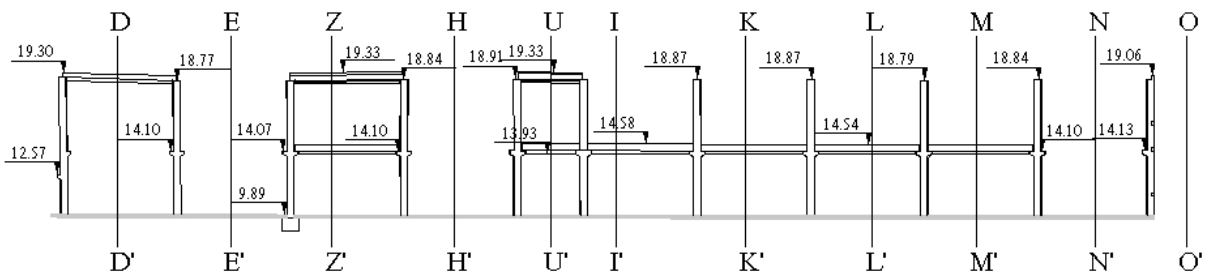**Figure 3**: Zoom of detail points in horizontal and vertical plan

In addition all the internal and external characteristics of the building are surveyed.

Appropriate software was used for all the calculations and drawings.
The plans produced were the following:

– Two 1:100 plans of horizontal sections of the building, at the level of 1.50m (fig. 5) and 6.50m from the ground.
- Three 1:100 vertical longitudinal sections - fa ades of the structure.
- Eleven vertical cross-sections - fa ades at specific positions (fig. 4) in scale 1:100.

The drawing of vertical longitudinal sections - fa ades of the structure and vertical cross-sections - fa ades were carried out on the appropriate vertical planes, after a coordinate rotating procedure. This permits the calculating of the points coordinates in a reference system of which two of the axes define to the plane of the section.

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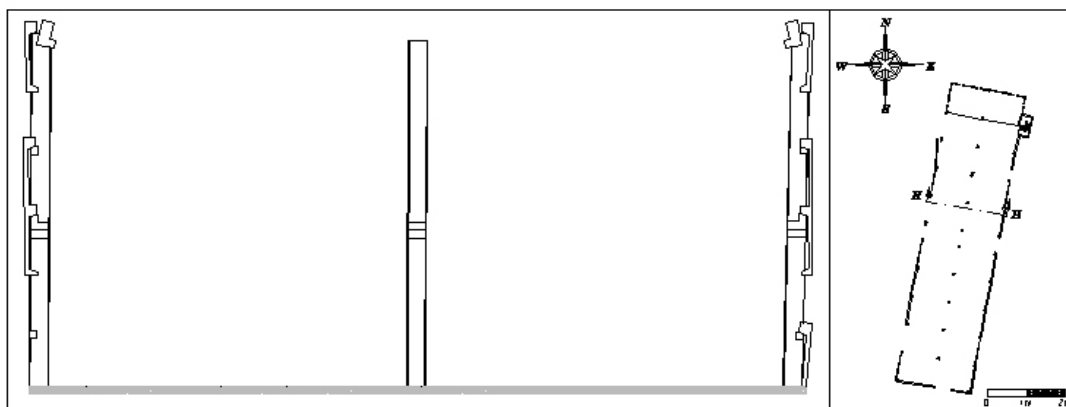Athens, Greece, May 22-27, 2004

Figure 4: A vertical longitudinal section of the structure.

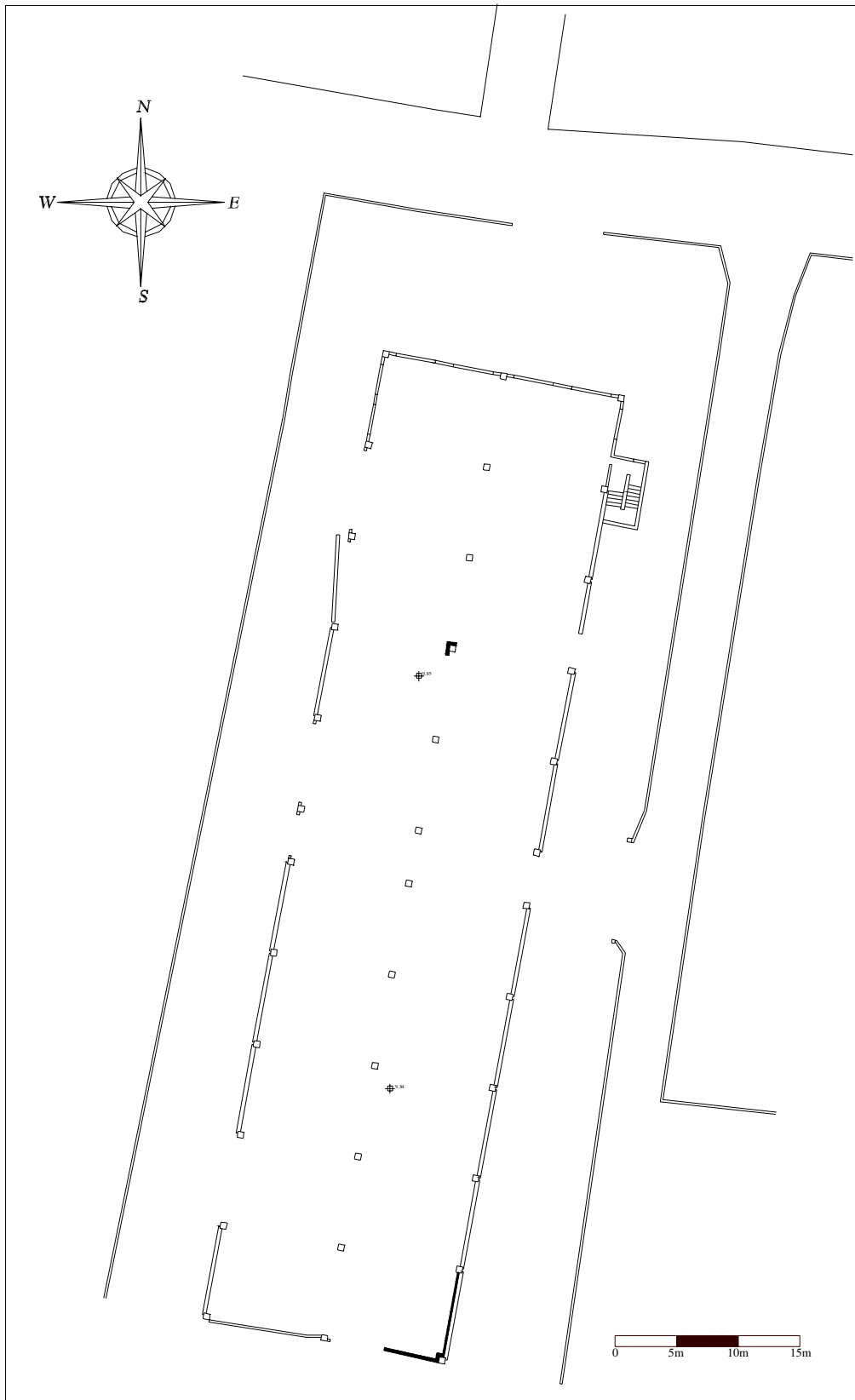**Fot. 2**: A part of a vertical longitudinal section of the structure.

Figures 4,5 and 6 consist samples of the produced plans.

Figure 6: The vertical cross section H - H′.

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Figure 5: The plot of the horizontal section of the structure at a level of 1.50m from the ground.

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Produced plans of horizontal and vertical sections give the opportunity of calculate the deviation of each structural element from its proper position. The deviation of all the pillars were calculated from their true vertical positions.

Results shown in table 2. This table can help the Geotechnical and Structural engineers to extract safe and useful conclusions about the structure's deformations and construction.

The first level for the determination of the deviation from the vertical, for each pillar was at a height of 9.00 m while the second level was at a height of 4.20 m from ground level.

SECTION	Left pillar		Central pillar		Right pillar	
	1st level	2nd level	1st level	2nd level	1st level	2nd level
D – D	11	5	0	0	5	2.5
E – E	17	8	5	2	19	9.5
Z – Z	11	5	0	0	52	25
H – H	5	3	4	2	19	9
U – U	0	0	0	0	14	6.5
I – I	7.5	3.5	2	1	14	7
K – K	18.5	9	2	1	14.5	5
L – L	10	5	2	1	18	8
M – M	10	5	2	1	0	0
N – N	0	0	16	7	0	0
O – O	0	0	5	2.5	2.5	1.2

Table 2: Deviation from the vertical position (cm)

5. CONCLUSIONS

The geodetic method by using the digital total stations without reflectors proved to be efficient for the reliable documentation of a structure. The general plan and the plans of the vertical and horizontal sections and fa ades produced, provided full and accurate geometric information for all the elements that composed every detail of the structure

The main characteristics of the geodetic method as applied in this project are:
- The convenience and speed of the measurements.
- The accuracy within a few millimeters was achieved in the positioning for even the inaccessible points of the structure.

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This accurately and trust – worthy documentation produced by Surveying engineers offers an enormous assistance to other Geoscientists and Structural engineers in order for the right decision to be reached concerning the failure of any given structure.

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Leica Heerbrugg AG, 1992, Users manual for T1610 and Dior 3002

BIOGRAPHICAL NOTES

Evangelia Lambrou, born on November 16, 1965 in Pireaus
1983 Graduated from the 2nd high school of Piraeus.
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Research interests:
−   GPS
−   Measure and monitoring deformations and displacements of structures and large earth areas
−   Surveying and documenting monuments
−   Investigating the orientation of monuments
−   Determining the astronomical azimuth and coordinates Φ, Λ using digital geodetic instruments.
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- Determining the astronomical azimuth and coordinates Φ, Λ using digital geodetic instruments.

Publications and presentations: 10

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