Special Marking of 3D Networks' Points

for the Monitoring of Modern Constructions

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Abstract: In order to monitor the deformations of modern constructions a local 3D network was usually being established at the surrounding area. The centering error, of both the instrument and targets, causes significant uncertainties in the determination of the x, y, z coordinates of the network's points. In order to assure precise centering for both the instrument and targets, not only for the accessible but also for the inaccessible network's points, a prototype way of marking is being implied. A special semi-permanent portable metallic stand (photo 1) was manufactured for marking the accessible points. The stand provides forced instrument centering of the order of ±0.1mm. It is light enough to carry, it accelerates and facilitates the centering and leveling of the instrument as well as it eliminates the time needed for the measurements. The applied laboratory checks in order to certify the suitability of its use and the provided accuracy are being described. For the inaccessible points special targets were used. The targets were put in permanent attachments (photo 7), (photo 8), which were also manufactured. Useful conclusions were drawn when these special accessories were used in to a 3D network, which was established for the monitoring of a new football stadium. Two measurement phases were carried out. The first one with the stadium being empty and the second one when it was crowded (about 32000 people) during a significant football match.

Key words: Precise centering, point marking, geodetic control networks, monitoring modern constructions.

1. Introduction

The modern construction of huge structures as high buildings, bridges, tunnels, is very common nowadays. The monitoring of these structures assures their continuous and safe use. Local 3D geodetic networks are used for the monitoring of the deformation or the displacement of these structures as they compose an accurate and immediate solution. In

most cases, precision of the order of ±1mm is required [1],[2],[3].

Today the revolution of the technology provides the possibility of precise geodetic measurements. The modern total stations adjust automatically and electronically:

- the line of sight error
- the tilting axis error
- the compensator z and Hz error
- the V-index error
- the ATR collimation error (if is available).

These errors are calculated in real – time and the displayed measurements are free of them.

Thus, high precision is provided for angle and distance measurements in the field reaching the ±0.5″ and ±0.2mm correspondingly [4].

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The errors that still remain during the measurements are:

- the centering error of both the instrument and targets, which is very significant for the final result

- The error in the measurement of both heights of instrument and targets.

In order to exploitate the available precision and annihilate these errors, appropriate accessories such as centering bases, special targets, and digital levels must be used.

2. The Centering Error

The centering error c_3 (Fig. 1a) of the instrument causes an error σ_a (a′-a) to the measured angle as follows.

$$\sigma_a = \pm \frac{c_3}{D_1 \cdot D_1} \cdot (D_1^2 + D_2^2 - 2 \cdot D_1 \cdot D_2 \cdot \cos a) \cdot \rho^{cc} \ (1)$$

Where c_3 = the centering error of the instrument

D_1 = the distance from the target A

D_2 = the distance from the target B

a = the measured angle

A target B being at a distance D_2 from the instrument (Fig. 1b) which has a centering error c_2, causes an error σ_{b_B} in the measured direction (correspondingly for the target A) which can be expressed as follows:

$$\sigma_{b_B} = \pm \frac{c_2}{D_2} \cdot \rho^{cc} \ \text{and} \ \sigma_{b_A} = \pm \frac{c_1}{D_1} \cdot \rho^{cc} \quad (2)$$

The total error in the measured angle caused by the instrument and targets centering error is given by the equation:
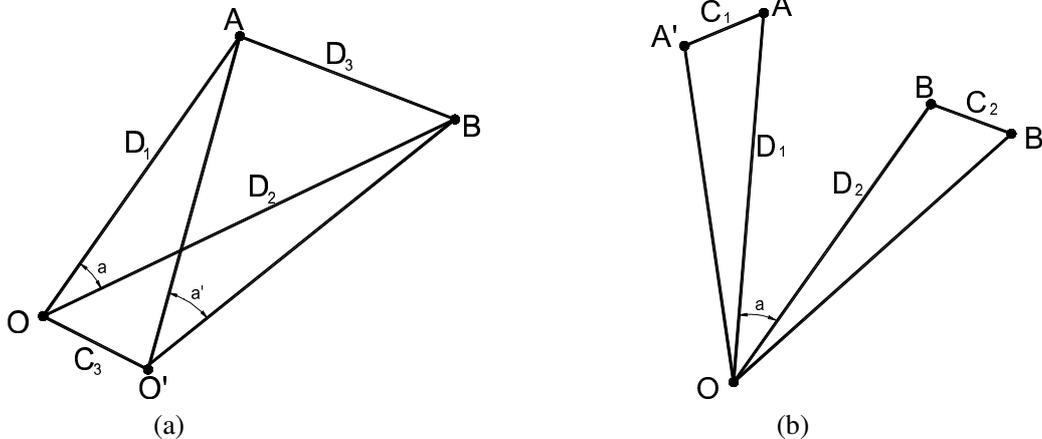
$$\sigma_c^2 = (\rho^{cc})^2 \cdot \left[\frac{c_1^2}{D_1^2} + \frac{c_2^2}{D_2^2} + \frac{c_3^2}{D_1^2 \cdot D_2^2} \cdot (D_1^2 + D_2^2 - 2 \cdot D_1 \cdot D_2 \cdot \cos a)^2 \right] (3)$$

Making the hypothesis that the distances between the instrument and the targets are equal ($D_1 = D_2 = D$), a $\to$ 100^g and the centering errors of both the instrument and targets are equal ($c_1 = c_2 = c_3 = c$) then the equation (3) gives [5]:

$$\sigma_c^2 \approx (\rho^{cc})^2 \cdot \frac{4 \cdot c^2}{D^2} \Rightarrow \sigma_c \approx \pm \rho^{cc} \cdot \frac{2 \cdot c}{D} \quad (4)$$

Fig. 2 presents the error in the angle measurement due to the centering error of both the instrument and targets. Especially as the monitoring networks of structures have short distances between their points, of the order of 20 to 100 m, the centering error may give additional significant uncertainties that fluctuate from 1 to 4 mm to the coordinate's determination.

3. The Marking Accessories

A special metallic stand was manufactured for marking accessible network points (photo 1), in order to eliminate the centering error of both the instrument and targets.

The special stand is composed by two separate parts:
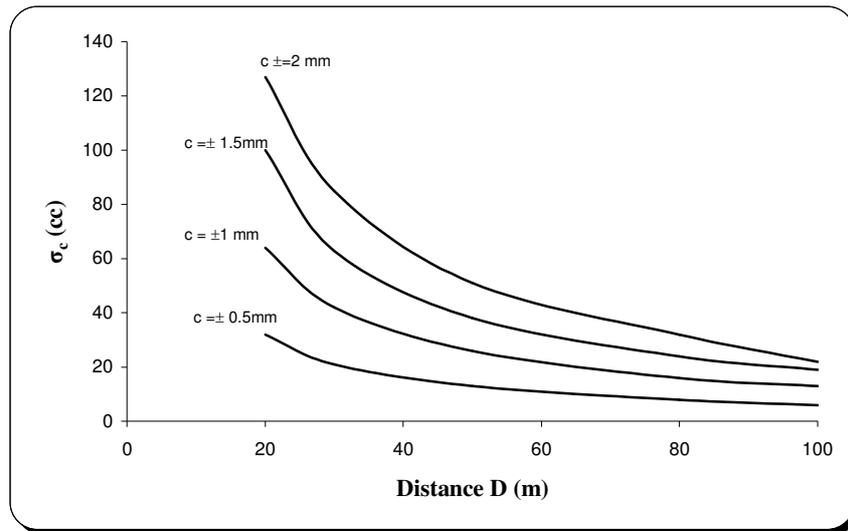
- The ground - base
- The pole

(a)   (b)

Fig. 1   (a): The centering error of the instrument, (b): The centering error of the targets.

Fig. 2   The error in the angle measurement σ$_c$ relative to the distance D and the centering error c.

The ground - base is circular with 20 cm diameter and 2 cm thickness; it has a hole with turns of screw in the center of 5cm diameter where the pole screws (photo 2). Also it has four holes at the circumference where special porps are put to firm it in the ground. The base was made by inox in order to protect it from rusting. It is solidify permanently in the ground by using cement and is levelled carefully, as it is very significant to be almost horizontal.

Photo 1   The stand on a network point.

Photo 2   The ground – base.

- The pole is a cylinder made by nickel-plated heavy duty steel, protected of the corrosion. It has length 118 cm, diameter 5cm and it weights about 8Kgr (photo 3).

The length of the pole must fulfil the following requirements:

▪   The pole should not oscillate during the measurements

▪   A medium height observer to be able to use it

▪   The line of sight of the instrument must overcome common obstacles as cars, motorcycles, etc.

The top of the pole is a flat circular disk of 12 cm diameter and 7 mm width. It has a projected screw at the center in order to put on the tribraches at a unique position (photo 4).

The bottom of the pole has also a flat circular disc and the projected part of its body is formed so as to be a screw (photo 5) in order to screw in the ground - base accurately at a unique position.

Each base is put permanently on the ground for marking the network point. On the contrary, each pole
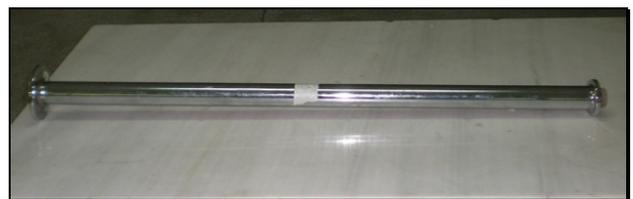

Photo 3   The pole of the stand.
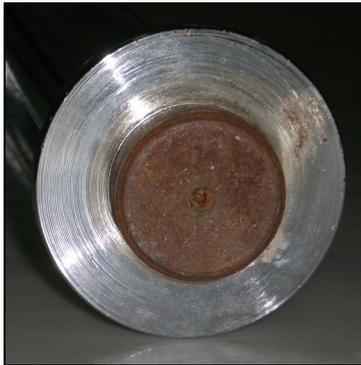
Photo 4   The top of the pole.

Photo 5   The base of the pole.

is put occasionally on any base during the measurement of a network [5]. The center of the screw of the pole's top defines the network's point. For any combination of pole and ground – base the same unique spatial point must be defined. For this reason all the poles were manufactured according to the following presuppositions:

•   All the poles must have the same length (The distance between the top and the bottom circular disks).

•   The center of the screw at the pole's top and the center of the screw at the pole's bottom must belong to the axis of the pole (cylinder). Also the axis of the pole must be perpendicular to both circular disks (bases of the cylinder).

•   Each pole must be screw exactly by the same way on every ground - base.

For marking inaccessible network's points, small circular bases are manufactured by steel (photo 7). They have 4cm diameter in order to put in them, by a unique way, a special magnetic target (photo 8). Each base has a hole in the middle where a screw is placed in

order to fix it permanently on the structure's body (photo 6).

Photo 6: The small base on the structure body.

Photo 7: The small base.

Photo 8: The magnetic target.

4. The Check of the Poles

The validation check of the stands' poles was carried out in a laboratory hall as follows:

Each pole was put at a convenient place in order to measure the adequate points on its body that allow the creation of its 3D plan.

The total stations Leica TDA 5005 and TDM 5000 which provide accuracy of $\pm 1.5^{cc}$ at the angular measurements were used simultaneously. The

instruments were put by turns on four selected positions (three pillars and a heavy duty tripod), as due to the shape of the pole all the desired points were not visible from two pillars only.

The points which were measured on the pole's body were marked instantaneously by a pin-edge and they were aimed simultaneously by both the total stations. The points' coordinates x, y, z were calculated in a local arbitrary system via the intersection method using the horizontal and the vertical angles measurements.
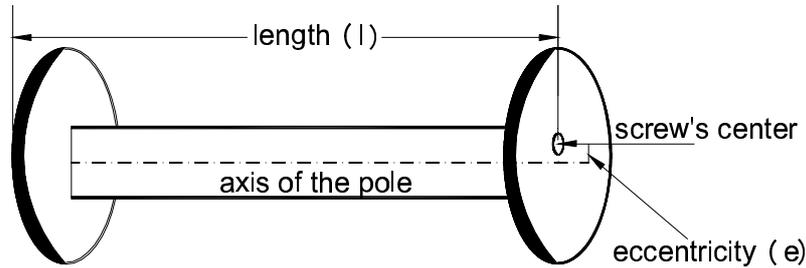
Fig. 3   The geometric characteristics of the pole.

The coefficients A, B, C of the top plane and A′, B′, C′ of the bottom plane as well as their uncertainties and the error of the unit weight σ_o of the adjustment were determined. At first the paralleling of the two planes is checked according to the calculated coefficients. Secondly the coordinates x_i, y_i, z_i of a point i which belongs to the top plane were determined. Afterwards the distance of this point i from the bottom plane of the pole, namely the length of the pole, was calculated by the equation

$$d = \left| \frac{A' \cdot x_i + B' \cdot y_i - z_i + C'}{A^2 + B^2 + 1} \right| \qquad (6)$$

The determination of <u>the eccentricity (e) of the top screw</u> (Fig. 3) relative to the axis of the pole was carried out as follows:

For both screws the best fitting circles were determined by the measured points on their circumferences using the least square method. The following equation was used

$$x^2 + y^2 + a \cdot x + b \cdot y + c = 0 \qquad (7)$$

There were measured points at the circumferences of both screws at the pole's top and bottom. Also the points which define both planes of the disks at the poles top and bottom were measured.

For the determination of <u>the length of each pole</u> (Fig. 3) the best fitting plane to the measured points was determined for both planes of the top and bottom of the pole, by the least square method, according the equation:

$$z = A \cdot x + B \cdot y + C \qquad (5)$$

The coefficients a, b, c were determined as well as their uncertainties σ_a, σ_b, σ_c. Then the center K and the radius R of each circle were calculated by the equations 8 and 9 correspondingly.

$$K \left(-\frac{a}{2}, -\frac{b}{2} \right) \qquad (8)$$

$$R = \frac{\sqrt{a^2 + b^2 - 4 \cdot c}}{2} \qquad (9)$$

The equation of the line which goes through the center of the bottom screw and is perpendicular to the pole's bottom base, namely the axis of the cylinder was determined as:

$$a_1 \cdot x + b_1 \cdot y + c_1 = 0 \qquad (10)$$

Finally the distance (e), namely the eccentricity, of the center (x_0, y_0) of the pole's top screw from this line was calculated by the equation

$$e = \left| \frac{a_1 \cdot x_0 + b_1 \cdot y_0 + c_1}{a_1^2 + b_1^2} \right| \qquad (11)$$

The table 1 presents the results for the four poles.

The results prove that all the poles were manufactured under the initial presuppositions and

they are appropriate for the unique and accurate marking of the network points.

Table 1 The geometric characteristics of the poles.

No	Length (l) (m)	σ_l (mm)	Eccentricity (e) (mm)	σ_e (mm)
1	1.1776	±0.4	0.09	±0.01
2	1.1780	±0.4	0.08	±0.01
3	1.1778	±0.4	0.05	±0.01
4	1.1776	±0.4	0.06	±0.01

5. Application

The "Karaiskaki" football stadium was built on 2004, in order to support the Athens Olympic Games. It's a modern construction of a capacity of 32000 people.

As the stadium was constructed on a very sensitive area close to the sea, was decided to establish a permanent control network for monitoring the structure's behavior [6]. Twelve points compose the control network (Fig. 4).

The six accessible points of the network were placed at the area outside the stadium and they were marked with the above described stands (photo 1).
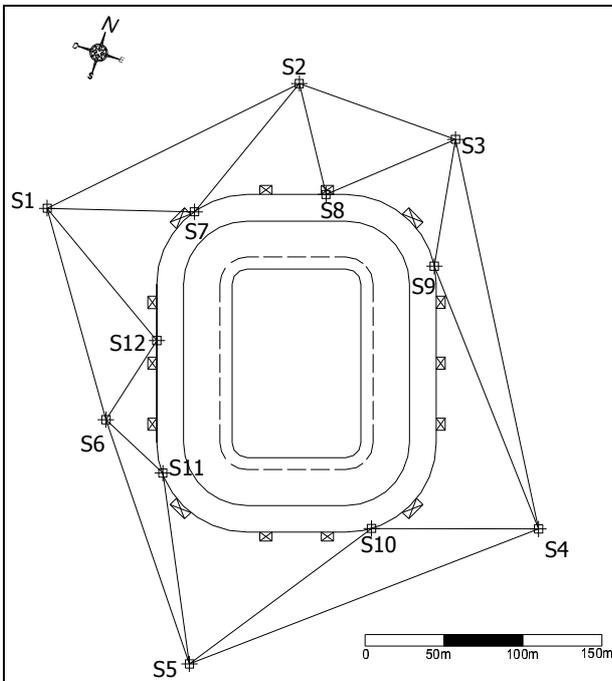
Fig. 4 The control network of the stadium.

The rest six inaccessible points were put on the supporting body of the stadium (photo 6). These points were also marked permanently by the small circular bases.

The network was measured twice. The first time with the stadium being empty and the second time when it was full of people during a very significant match. The measurement of the network was difficult especially in the second campaign, when the stadium and the surround area were crowded and the available time for the measurements was limited. This campaign would be not able to integrate without the use of the special stands.

The total station Topcon GTS 3003 was used for the measurements, which provide accuracy ±9^{cc} for the direction and ±2mm for the distance measurements.

The network adjustment was carried out in an arbitrary local reference system. The point S1 was considered stable as well as the bearing between the points S1 - S2. The time needed for each station measurements was maximum 20 minutes, namely 2 hours were needed for all the measurements. This was achieved by using the stand which facilitates the placing and the leveling of both the instrument and targets.

The total accuracy of the determined coordinates x, y, z is of the order of ±3mm. No statistical significant variations are observed for the networks points for confidence level 95%.

5. Remarks and Conclusions

The constant increase in the demand for high precision in field measurements for structure monitoring impose the use of special accessories.

The local geodetic micro-networks for structure monitoring must be measured using modern total stations which provide

• Adequate precision of the angle and distance measurements.

- Automatic and electronic adjustment of all the instrument errors.

The still remaining centering error of both the instrument and target in such networks causes remarkable errors in the angle measurement.

In order to eliminate or to efface the centering error special accessories must be used.

The described accessories which were used for marking the network's point had practical benefits and ensure:

- The unique precise centering (±0.1mm) for both the instrument and targets.
- Quick and easy placing on the desired point
- Easy leveling for the instrument within one minute.
- Easy transfer and storage.
- The permanence of the network's points.
- The stability of the instrument during the measurements.
- The minimization of the time needed for the measurements
- The deliberation of the height's measurement of both the instrument and target at each station as they are the same.

Using geodetic methods and first order total stations in the laboratory, the length and the eccentricity of the four stands were determined with an adequate accuracy.

It is remarkable that the ground – bases remain discreetly at the place permanently. On the contrary the poles can be used again to another geodetic network's measurement.

The measurement of the stadium's network was made possible by using these special stands, especially in the second campaign.

The achieved accuracy in the coordinates' determination is adequate for the monitoring of this construction.

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