DEFORMATION OF MINARETS PROCEDURE & APPLICATION

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ABSTRACT

After the earthquake of 12th October 1992 the archaeological building in Cairo have been badly hited. Then the Antiquities department decided to measure the inclination of minarets of mosques for the purpose of restoration. It was not possible in some cases to clime the minarets for fixing surveying marks. For periodical observations in traditional methods the same stations occupied in order to compare the results for deformation detection. These stations could be; in these areas; lost or damage easily. Therefore it was necessary to find a surveying techniques to measure the inclination as magnitude and direction and give the results independent from the observing stations without marking the minarets. These mathematical procedures and their analysis are introduced in this paper. Also applications of these methods are done on 115 minarets.

Keywords: Surveying minarets, Deformation, Origin Traverses, Solution.

1- INTRODUCTION

In Cairo as many Islamic cities hundreds or even more than thousands of minarets were built in different centuries.

The shape and height of each minaret is different than others, but generally for each period of centuries the shape and height are similar.

Figure (1) shows examples of different shape and height of minarets.

Those archaeological minarets are located in the old part of cairo where the streets are narrow and the buildings are old.

After the earthquake of 12th of October 1992 in Egypt the authorities decided to know the effect of that earthquake on the archaeological minarets. There was a clear inclination and damage of some minarets.

Since it is difficult to fix surveying point for regular periodical observation, a new surveying procedure was employed to determine the inclination as direction and magnitude of minarets independent of station of taking the observations.

Moreover in many cases it was impossible (or very difficult) to clime the minarets because of damage of them.

2- SURVEYING PROCEDURE

The surveying procedure is depending on occupying two stations such as A & B, Figure (2), where angle AMB is almost right angle.

The surveying procedure then is as follows Figure (3):

a) Set two theodolites at point A & B and prepare them for taking observations.

b) The zero direction of the theodolite at A is to B and at B to A.

c) At a vertical angle make the vertical hair tangent to the right and left sides of the minaret. From A & B, record the vertical and the two horizontal readings.

d) Repeat steps C at different vertical angles along the minaret at uniform parts of minaret.

e) Using EDM to measure the distance AB.

There are three cases for taking observations form A or B:

i) One of the vertical angles is zero.

ii) All the vertical angles are elevation or depression.

iii) Some vertical angles are elevation and others are depression.

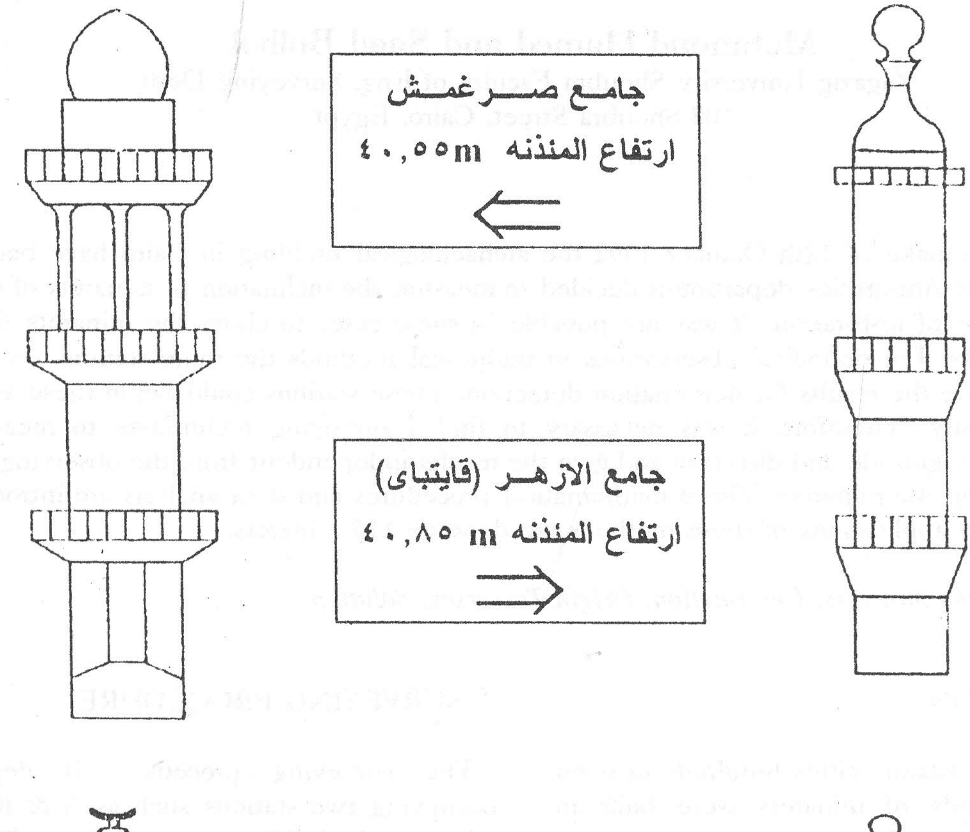

جامع صرغمش
ارتفاع المنذنه ٤٠,٥٥m
جامع الازهر (قايتباى)
ارتفاع المنذنه ٤٠,٨٥ m
جامع السنان باشا
ارتفاع المنذنه ٢٧,٠٥m
مئذنة عمرو بن العاص
ارتفاع المنذنه ٢٣,١٤ m

Figure (1)

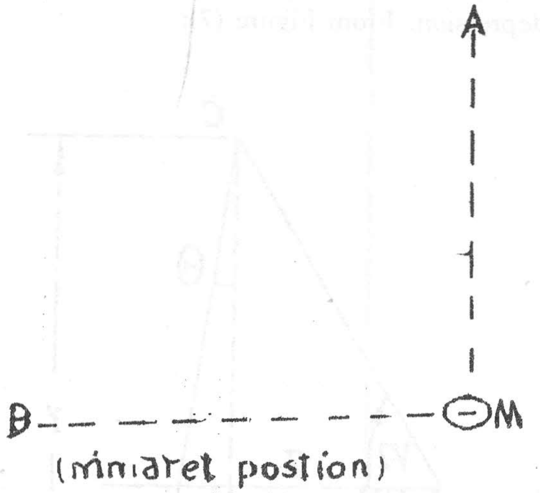


Figure 2.

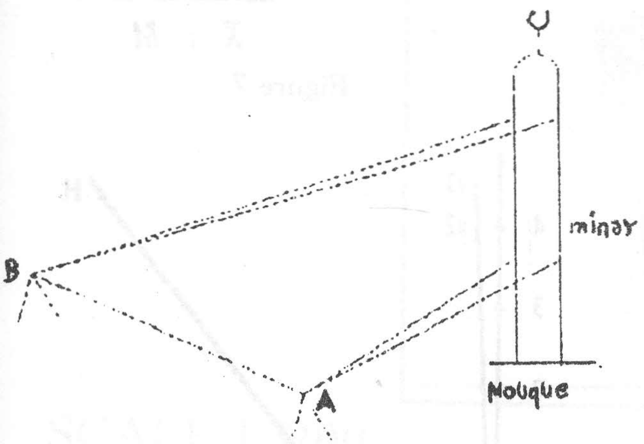


Figure 3.

3- MATHEMATICAL SOLUTION

case(1)where the vertical angle is zero:
In Figure (4) if the mean of the two horizontal readings at the horizontal plane(1) is denoted by D and the mean of the two horizontal reading at plane (2) is denoted by C at vertical angle V. If the horizontal reading at C is the same as at D then the minaret does not has inclination in the direction perpendicular to the line AM.

If the horizontal reading at C is different than D by horizontal angle H then distance X represents the horizontal inclination of the minaret of the measure part CD which vertical distance CD is Y. The inclination angle of the minaret is, θ and the distance AM is horizontal and denoted by Z. Then:

$$\tan\theta = X/Y \quad (1)$$

and

$$X = Z\tan H, \quad Y = Z\tan V \quad (2)$$

So,

$$\tan\theta = \tan H/\tan V \quad (3)$$

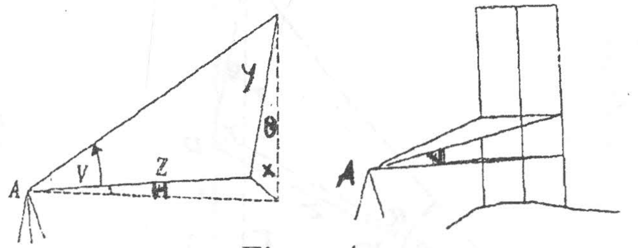
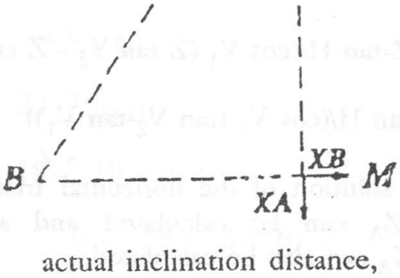


Figure 4.

In Figure (5); the horizontal triangle ABM can be solved as angles A, B and distance AB are observed, then distance AM is calculated. Therefore distances X and Y can be found from Equations (2) .

The same procedures is followed by the observations of station B. The actual inclination can be calculated from the inclination distances X_A & X_B from points A & B where X_B perpendicular to BM, X_A perpendicular to AM and angle M in the triangles AMB



actual inclination distance,
Figure 5.

case (2) where the two vertical angles are elevation or depression Figure (6).

If two elevation angles V_1, V_2 are for the two points C and D on the minaret, CD vertically is Y and its complement to the horizontal plane is Y'. Distance AD is denoted by Z' and its horizontal projection is Z. If the minaret has inclination by angle θ or distance X the horizontal readings at C and D are differed by horizontal angle H. Then:

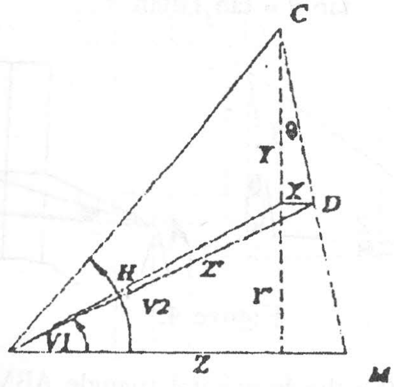


Figure 6.

$$X = Z' \tan H \quad (4)$$

$$Z' = Z/\cos V_1 \quad (5)$$

then

$$X = Z \tan H/\cos V_1 \quad (6)$$

$$Y + Y' = Z \tan V_2 \quad (7)$$

and

$$Y' = Z \tan V_1 \quad (8)$$

from (7) and (8)

$$Y = Z \tan V_2 - Z \tan V_1 \quad (9)$$

$$\text{where } \tan \theta = X/Y \quad (10)$$

Then, from Equations 6, 9 & 10:

$$\tan \theta = Z \tan H/(\cos V_1 (Z \tan V_2 - Z \tan V_1))$$

$$\tan \theta = \tan H/(\cos V_1 (\tan V_2 - \tan V_1)) \quad (11)$$

From the solution of the horizontal triangle ABM distance Z_A can be calculated and accordingly distance X_A can also be calculated.

If the two angles are depression, Formula (11) can be applied.

Case (3) where one angle is elevation and the other is depression. From Figure (7):

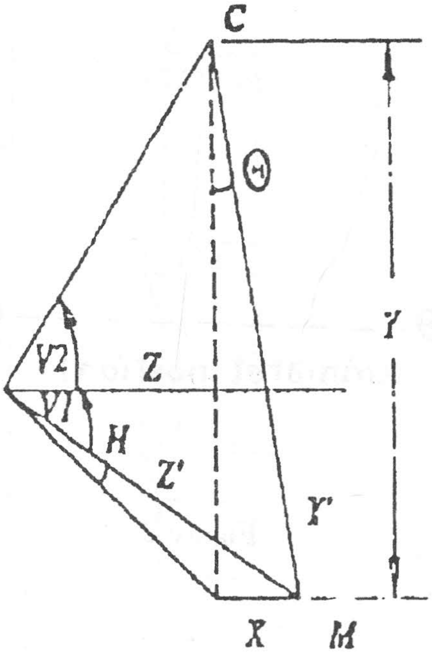


Figure 7.

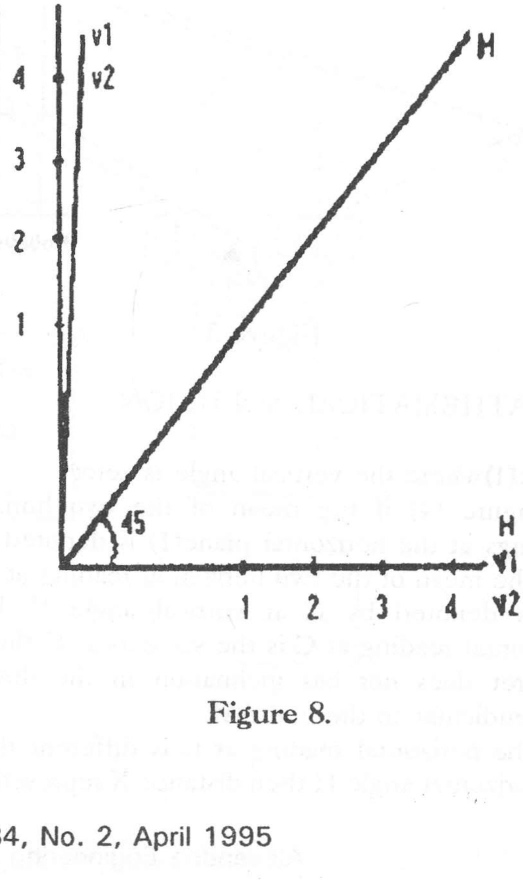
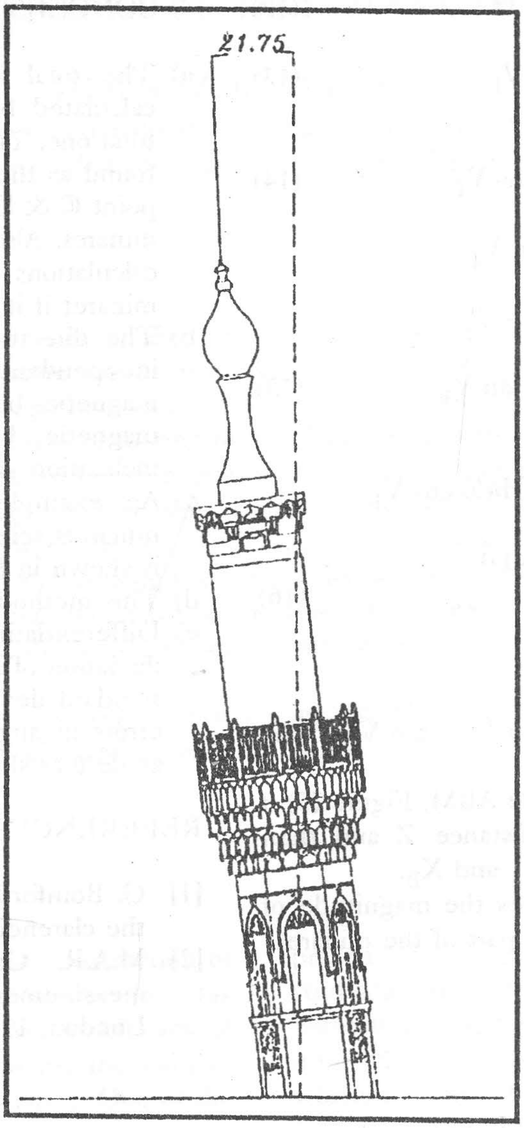


Figure 8.



SCALE 1 /200

SCALE OF INCLINATION 1 /20

The level of the street

The hight of minerat	40.85 M
The value of inclination	21.75 cm
The magnetic bearing of inclination	182° 59' 0.41''
The angle of inclination on the vertical	00° 18' 18.29''

Figure (8)

$$X = Z' \tan H \quad (12)$$

$$Z' = Z/\cos V_1 \quad (13)$$

Then,

$$X = Z \tan H/\cos V_1 \quad (14)$$

$$Y - Y' = Z \tan V_2$$

$$Y = Z \tan V_2 + Y'$$

$$= Z \tan V_2 + Z \tan V_1 \quad (15)$$

But

$$\tan \theta = X/Y = Z \tan H/(Z \cos V_1 (\tan V_2 + \tan V1)) \quad (16)$$

then :

$$\tan \theta = \tan H/(\cos V_1 (\tan V_2 + \tan V_1) \quad (17)$$

Also from the horizontal triangle ABM, Figure (5) it is possible to calculate the distance Z and then calculating the displacement X_A and X_B.
The resultant of X_A & X_B gives the magnitude of the inclination of the observed part of the minaret.

4- CONCLUSION

a) The total inclination of the minaret can be calculated by relating the observed part to the total one. The total height of the minaret can be found as the distance Y in Figure (7) if the two point C & D at bottom and height points of the minaret. Also these methods of observations and calculations can be applied to each part of minaret if it consists of different parts.

b) The direction of the inclination can be found independent of the points of observing if the magnetic bearing AM is measured and then magnetic bearing of the resultant of the inclination can be calculated.

c) An example of observing and calculating a minarets selected from 115 minarets observations is shown in Figure (9).

d) This method can be applied to any tower.

e) Differentiating Equations 11 and 17, the standard deviation of angle θ can be found as a function of standard deviations of H, V1 and V2. In practice errors in angles H, V1 and V2 give an error of angle θ as shown in Figure (8).

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