Towards better assessment for monitoring of deformation

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Monitoring of deformation is considered to be an important field of engineering surveying. Its prime function is the detection of spatial deformation to provide information on the stability of structures as well as extent of any movement or deformation of objects occurring over time. Searches for new monitoring techniques, and refining their methods of deformation measurements and analysis become a must. For large construction projects, it is necessary to compute and monitor their differential deformation using different techniques. This paper demonstrates the various techniques adopted for monitoring deformation and a comparative study on these techniques is performed. Moreover, an investigation for analyzing the precision concept for every technique is performed.

تعتبر دراسة تحركات القشرة الأرضية وما يصاحبها من تشوهات فى المنشأت من الدراسات الحديثة التي تعتمد علــى علــوم الجيوديسيا والجيولوجيا والجيوفيزياء .

وفى هذا البحث نتعرض للتشوهات في المباني والمنشآت وكيفية رصد وتحديد هذه التشوهات بالطرق المختلفة . حيــث تم إعداد دراسة نظرية تبين الطرق المختلفة التي يمكن استخدامها فى هذا المجال سواء طرق جيوديسية بأقســامها المختلفــة أفقية ورأسية وكذلك استخدام طرق التصوير الجوى وكيفية الاستفادة منه للحصول على تحركات وميول المنشآت وكذلك كيفيــة الاستفادة من النظام العالمي للتثبيت على الأرض في هذا المجال الحيوي والهام .

وقد تم عمل نموذج رياضي وذلك لاستخدامه في تحديد ورصد التشوهات في المباني وتم تطبيق هذا النمــوذج علــى الطــرق الجيوديسية المختلفة لحساب إحداثيات مجموعة من النقط وذلك برصد عملي لمناطق أثرية في الإسكندرية. وتــم الحصــول على النتائج ومقارنة وتحليل هذه النتائج بالنسبة للخيارات الثلاثة التي تم وضعها وهى باستخدام خط قاعدة أو باستخدام مضلــع ثابت أو أخذ النقط المختارة كأنها شبكة حرة. وفى نهاية البحث تم صياغة بعض النتائج التي تم التوصل إليها والتــي يمكــن منها اختيار أنسب وأفضل الأساليب لرصد التشوهات في المنشآت المختلفة .

Keywords: Differential Deformation, Close range, Free adjustment, minor Triangulation, Spatial movement, Precision.

1. Introduction

The actual accuracy of deformation surveys is quite necessary. In order to attain a higher accuracy deformation monitoring, all kinds of error occurring must be taken into consideration and the same of these errors must be comprehensively treated.

The integrated monitoring systems can be classified into two major methods, namely:

1. Geometrical method, which includes the following techniques:
   a. Geodetic measuring techniques (horizontal control networks-precise level nets-traversing –base line.)
   b. Photogrammetric measuring techniques (close – range photogrammetry)
   c. Space system-measuring techniques Global Positioning System (GPS).
2. Geotechnical methods, which include many different types of geotechnical instruments available for deformation measurements with reasonable accuracy. These methods are beyond the scope of this paper.

Referring to geometrical methods, which are the scope of this paper, the precision in positioning is the main factor that determines the applicability of any technique in deformation monitoring and detecting horizontal crustal movement.

The main objective of this paper is mainly to investigate and analyze the precision concept for the fixed and free geodetic networks.

Moreover this paper presents the analysis and the main results obtained from different techniques of geometrical methods adopted for deformation monitoring.

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The precision of a geodetic network may show the degree of propagation of random errors in the network. All information concerning the precision of the adjusted parameter is contained in the variance covariance matrix. Size of elements of the variance - covariance matrix expresses the precision of the network [1, 2].

2. Geodetic measuring techniques

According to the previous classification concerning the integrated monitoring system, the geodetic measuring techniques can be summarized in the following:
(A) Horizontal control networks
(B) Precise levels nets or lines.
(C) Traversing.

2.1. Horizontal control networks

These networks can be accomplished as micro–triangulation, micro–trilateration or hybrid micro–networks.

2.1.1. Adjustment of control networks

The adjustment for such networks is performed according to least squares. The precision measurements of the network are based on the variance – covariance matrix of the estimated coordinates.

Two alternative considerations of adjustment are performed namely:
i. Fixed Network,
ii. Free Network.

2.1.1.1. Fixed Network. In a stable region almost near to the structure to be monitored, the fixed network will be established and a so called zero-measurement will be applied separately. After that the fixed points with the monuments or targets fixed to the structure demonstrate a unique network.

Hence, the observations to be adjusted will be completed and the positional variations of the new net points as well as (targets) can be computed [3, 4]

It is obvious that the positional variation of the new net points (targets) can also be computed from both the estimated distance and the estimated direction between an arbitrary fixed point or points. The precision concept in this fixed network allows calculating both, variation and its standard error by applying the law of variance - covariance propagation.

2.1.1.2 Free network. In the free network there are no fixed points, consequently, all the net point coordinates are allowed to receive correction after performing the adjustment process.

The displacement of the new points can be calculated based on variance - covariance propagation and according to least - squares. Such a technique has always a minimum change in the external precision of the whole work.

3. Photogrammetric measuring techniques

Targets on the construction to be detected are fixed. An initial observation should be performed to represent a zero-measurement with available checkpoints in the object space. Group of observations using 3-D Measurements by digital close range photogrammetry is accomplished.
The photogrammetric results are compared with the zero-measurements results that are precisely obtained. For accuracy investigation the residual mean of systematic errors (RMSE) determined target point coordinates can be used as an accuracy measure. For more precise work and in order to obtain a high accuracy the following points may be recommended:
- Using a high-resolution panchromatic film.
- Using charge-coupled detectors (CCD) camera instead of ordinary camera.
- Performing self - calibration for the used camera.
- Determining the photo - coordinates of the targets precisely
- Avoiding the sources of systematic errors.

Finally, if the principles of any photogrammetric means were correctly used e.g. close-Range photogrammetry, a very high accuracy would be achieved.

4. Mathematical model of three dimensions

In this case applying the least squares (variation of coordinates) to the observation equation for three dimensions mathematical model is as follows [5,6]:

$$\delta A_{12} = \rho / L[\cos A_{12} \delta E_2 - \cos A_{12}\, \delta E_1 - \sin A_{12}\, \delta N_2 + \sin A_{12}\, \delta N_1], \quad (1)$$

$$\delta L'_{12} = \sin A_{12} \cos V_{12}\, \delta E_2 - \cos A_{12} \cos V_{12}\, \delta N_2 + \sin V_{12}\, \delta H_2 - \sin A_{12} \cos V_{12}\, \delta E_1 - \cos A_{12} \cos V_{12}\, \delta N_1 - \sin V_{12}\, \delta H_1, \quad (2)$$

$$\delta V_{12} = \rho / L' [\cos V_{12} \delta H_2 - \cos V_{12}\, \delta H_1 - \sin A_{12} \sin V_{12}\, \delta E_2 + \sin A_{12} \sin V_{12}\, \delta E_2 - \cos A_{12} \sin V_{12}\, \delta N_2 + \cos A_{12} \sin V_{12}\, \delta N_1], \quad (3)$$

where:

δA_{12} is the Observed – computed values for azimuth,

$\delta.L'$ is the Observed – computed values for inclined distance,

δV_{12} is the Observed – computed values for vertical angles,

$\delta N_1 \delta N_2$ is the Corrections for the northern coordinates for points 1& 2 respectively,

$\delta E_1 \delta E_2$ is the Corrections for the eastern coordinates of points 1&2 respectively,

$\delta H_1 \delta H_2$ is the Corrections for the orthometric heights points 1& 2 respectively,

V,L, A is the Observed quantities for vertical, inclined distances and azimuth,

ρ is the $(1/\sin 1'') = 206264.84$

Accordingly the least squares [V^T **W** V= minimum] solution will give the adjusted coordinates as follows:

$$\mathbf{AX} = \mathbf{b}, \quad (4)$$

$$(\mathbf{A}^T \mathbf{WA})\mathbf{X} = \mathbf{A}^T \mathbf{Wb}, \quad (5)$$

$$\mathbf{X} = (\mathbf{A}^T \mathbf{wA})^{-1} \mathbf{A}^T \mathbf{Wb}, \quad (6)$$

where:

X is The Vector of unknowns,

A is the matrix of coefficients,

W is the matrix of aporiori weight,

b is the vector absolute term δA, $\delta L'$, δV for all observations observed – computed,

$(\mathbf{A^TWA})^{-1}$ is the variance – covariance matrix where the diagonal are the variances and the off diagonal are the covariance, $(\mathbf{A^TWA})^{-1}$ can be called posteriori weights.

The estimated standard weight σ_o can le calculated from:

$$\sigma_o^2 = \frac{\mathbf{V\,W^TV}}{n-u}, \quad (7)$$

where:

n is the number of observations.

u is the number of unknowns.

By applying this model the results are shown in Table 1, and illustrated in Figs. 2,3, and 4.

5. Description of the practical network

5.1. Selection of the origin

Monitoring of deformation of a building is to measure the change in shape of parts or points on the building. Measurements should be taken using surveying instruments and special surveying techniques. Measurements are linear or angular. The measurements are to be converted to coordinates on a chosen reference coordinate system. The coordinate system should have an origin and three axes. Calculation of coordinates needs a mathematical model. Coordinate system can be local as the building is relatively small compared with the largeness of a country. The origin could be on the building itself or a traverse point of a traverse outside the building. The origin is normally taken outside the region of the building if all points on a building are subject to movement (i.e. in a stable area).

Origin could be an imaginary point anywhere near or inside the building, then by transformation form point of taking observations the coordinates can be transformed to the imaginary origin that helps to avoid fixing points which could be damaged or lost during the course of monitoring the deformation.

Axes of the coordinate system are preferable to be taken as the natural ones as possible. Natural axes are the vertical direction and magnetic or geographical north and east. These axes help to find the deformation component in a way suitable for the structural analysis.

As the measurements of deformation in Egypt are mainly for archaeological monuments, then registration of monuments is to be studied.

5.2. Three dimensions system

Normally three dimensions system of coordinates is used in many cases of monitoring deformation. The three axes are taken perpendicular to each other. The vertical axis is always the vertical direction of gravity.

The other two axes are horizontally by perpendicular to the vertical axis. One of the horizontal axis is to be taken as a natural direction such as the north direction, geographical or magnetic. The other horizontal direction is always the east direction.

Using new instruments such as total stations these measurements are taken.

Through software inside the total stations these mentioned observations are calculated to give X, Y, Z coordinates of the observed point related to the occupied one. The total station is considered as a measuring device with a computer.

5.3. Data acquisition

For the deformation study of a building, surveying of archaeological areas needs a modification of surveying techniques and special use of surveying instruments. The application was done for archaeological areas in Alexandria under the supervision of the author.

The tools used in cadastral survey of an archaeological area are normally total station and tapes. The total station is used for an area allowing the surveyor to move easily around the instrument. The experience shows that the total station cannot be used totally for all kinds of archaeological cadastral survey.

Tape measurement then is used to cover areas, which cannot be covered, using total station. Other cadastral survey instruments such as plane table does not cope with the accuracy required for archaeological cadastral survey.

Therefore, a combination between tape and total station measurements could be the ideal way for monument registration. The software of total station in this case transforms the measurements to digital coordinates. The tape measurements will be combined with the observation of total station.

For the clarity of this study, the local illustrated in Fig. 1 should be adjusted in three variances namely:

- variant (1): Base line,
- Variant (2): Fixed Traverse,
- Variant (3): Free Network.

6. Results and analysis

In this paper, the bases of three variant solutions for adjustment of station positioning are given. For such analysis, it is often required to plot the standard error as criteria for accuracy of station positioning. The comparative study includes the adjustment and treatment of the three variant different survey systems, namely: base line, fixed traverse as well as free network.

The results, in Table 1 and Figs. 2, 3 and 4, give the obtained accuracy of cadastral archaeological monument which lies between ± 2mm and ± 10mm. As the required accuracy that defined by archaeology one of the procedures mentioned for the three variants can be used.

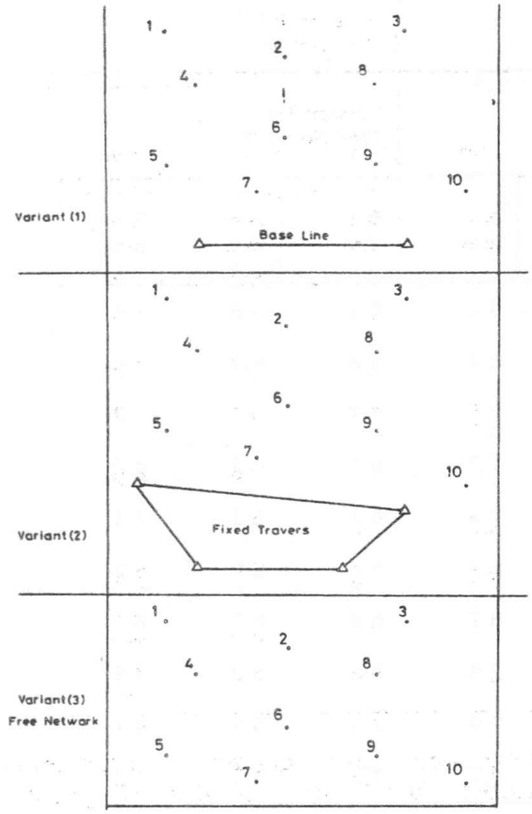

Fig. 1. Sketch illustrates the stations in three variants.

It should be noticed that in fixed traverse (variant (2)), the positional errors are always smaller than of the errors in base line (variant (2)).

Also, it should be noticed that the free network gave the smallest numerical values of all precision criteria (δ_x, δ_y and δ_z) at all points.

Concerning the concept of precision for geodetic measuring technique, generally there are two factors affecting this accuracy:

i - Base line of geodetic network: in general, the accuracy decreases with increasing base line.

ii - Type of adjustment of the network: in general, free net adjustment gives a high accuracy than fixed points network terrestrial surveys with electronic distance measurement (EDM) equipment and theodolite; as well as recent total stations are the most commonly used for relative long distance up to 8 km

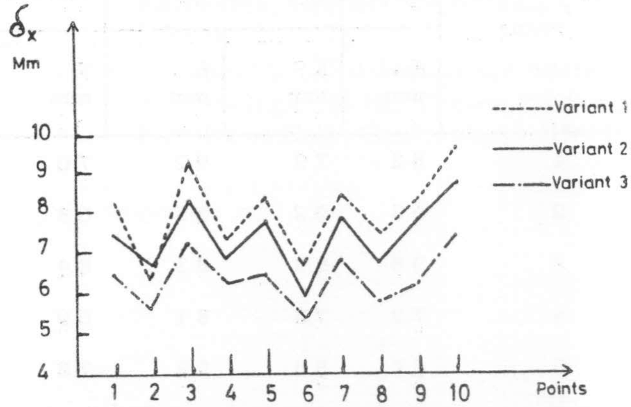

Fig. 2.Relations between the stations and δ_x

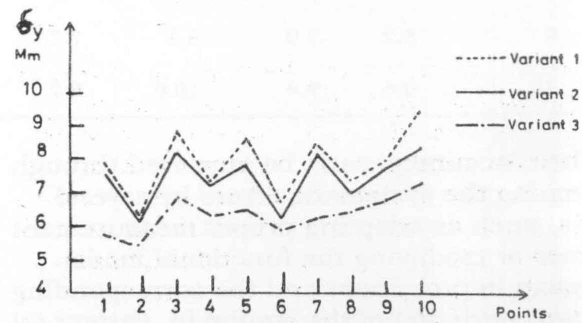

Fig. 3.Relations between the stations and

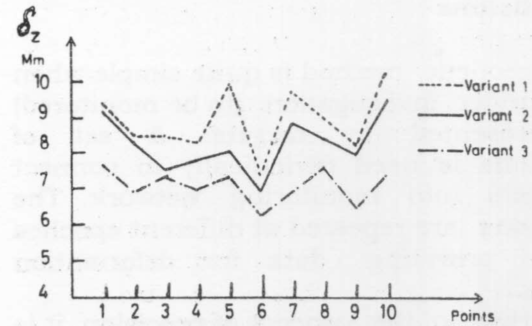

Fig. 4.Relations between the stations and δ_x

Table 1 The precision criteria

Points	Variant (1) Base Line			Variant (2) Fixed Traverse			Variant (3) Free Network		
	δ_x mm	δ_y mm	δ_z mm	δ_x mm	δ_y mm	δ_z mm	δ_x mm	δ_y mm	δ_z mm
1	8.2	7.9	9.2	7.6	7.6	9.1	6.5	5.6	7.6
2	6.3	6.2	8.3	6.8	6.1	8.2	5.6	6.3	6.8
3	9.8	8.9	8.3	8.4	8.2	7.5	7.1	6.7	7.2
4	7.2	7.3	8.1	6.9	7.2	7.7	6.1	6.2	6.9
5	8.4	8.6	9.8	7.8	7.6	7.9	6.2	6.3	7.1
6	6.6	6.7	7.2	5.9	6.1	6.9	5.4	5.9	6.2
7	8.3	8.5	9.6	7.9	8.3	8.7	6.8	6.1	6.7
8	7.5	7.3	8.8	6.8	6.8	8.4	5.8	6.2	7.5
9	8.2	7.9	8.1	7.7	7.8	7.9	7.1	6.6	6.3
10	9.6	9.4	10.0	8.7	8.2	9.7	7.3	7.1	7.2

Their accuracy can be improved through eliminating the systematic errors by several means, such as adopting proper measurement schemes or modifying the functional model. The mean improvement and the corresponding standard deviation of the station in variant (3) are displayed in Table 1 and illustrated in Figs. 2, 3 and 4.

7. Conclusions

The geodetic method is quite simple when objects under investigation (to be monitored) are represented by targets. A set of observations is used periodically to connect the targets into monitoring network. The observations are repeated at different epoches of time providing data for deformation detection.

Referring to the concept of precision, it is found that the free network is more practical and more precise than the fixed one, especially when relative deformation for the structure is required precise levels technique is more practical and quite enough for detecting the crustal movement.

Close-range photogrammetry represents a reasonable tool for monitoring most of moderate constructions.

Concerning the total station devices, the fundamentals of the equation for electromagnetic distance measurements have been developed from simplified easily understood concepts.

As a conclusion it can be said that, with proper elimination of systematic errors, and application of reductions to the required accuracy, such accuracy will meet the requirements of deformation work.

However a more integrated system for monitoring deformation, consists of:

1. Geotechnical equipment.
2. Geodetic measurement.
3. Close - range photogrammetry would provide a full representation and analysis for the deformed case.

A geodetic network with free points adjustment has emerged as a powerful tool for monitoring spatial deformation for structures.

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