Geodesic methods for modeling and protection of megalopolis objects

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Abstract. This article presents new techniques for the use of geodetic instruments when performing work on monitoring deformation processes and protecting monuments of cultural heritage. The prevention of dangerous deformations and destruction of building structures is an extremely important task, the solution of which ensures the preservation of all construction costs. For this reason, an increased attention was given to the development of early detection methods of possible structural damage to structural elements. There are many different methods for detecting displacement. Nevertheless, little work has been devoted to the development of real time observation methods. In addition to the existing methods, a permanently operating observation station is considered. The new method is based on: 1-The use of robotic motorized total station; 2- A preliminary calculation of the measurement accuracy. The actual results of the observations are given. Besides, the technique of preserving monuments of cultural heritage, including the creation of their models based on laser scanning and survey with unmanned aerial vehicles, is shown.

Introduction

Intensive construction and reconstruction of buildings, land and underground structures in large cities sometimes leads to the deformation of nearby objects. Construction work also includes excavation with the construction of various configurations of pits or trenches. The latter are strengthened with the creation of retaining walls, which, in addition to preserving production, serve as a screen protecting neighboring structures from the deformation process. But a deformation process could occur to the walls of open excavation during a subway construction; this deformation needs to be monitored.

Therefore, this article presents methodology of studying the deformation process. The accuracy of geodesic observation method (using Motorized Total Station MTS) is also substantiated.

Relevance

Many cases of the destruction of buildings and their structures are due to:

a) Inadequate design of the objects themselves and their grounds,

b) Lack of proper tracking of deformation process (during construction and operation).

Emergency cases are recorded in many countries. Some of them are shared.

One of the major disasters occurred in Shanghai (China) in June 2009, when a 13-storey building collapsed on Minshan District [1] on Lian Huanan Street (Figure 1).

Another collapse occurred on April 20, 2004 in Singapore. Highways Nicholl suddenly collapsed [2].
As reported, due to the destruction of the tunnel and earthworks under the highway at a depth of 30 m, an underground space was formed, which caused the collapse of the highway (Figure 2). As a result of the collapse, four people died and three were injured. In some cases, such accidents could be avoided by organizing observations of the deformation process.

**Research methodology**

During the construction of the metro in the city of Riyadh (the capital of Saudi Arabia), the station pit was dug out with fortified vertical outcrops of stone walls. The pressure exerted on these walls causes deformation and displacements that need to be assessed. This assessment should be more expediently conducted in a three-dimensional form (x,y,z). This will contribute to better interpretation of the type of deformations and comparison of critical tolerances. Figures 3, 4 show fragments of a metro station and the object of observation (retaining walls), as well as strong points, deformation marks.

Monitoring of deformation processes includes certain measurement intervals [3-6]. The proposed method of geodetic measurements includes the following operations:

- Searching for stable zones in which it is necessary to fix control (reference) points responsible for the orientation and binding of total station measurements.
- Installation of a fixed permanent station (TS) in such a way ensuring the visibility of control points and deformation marks.
- Planning and fixing on retaining walls deformation marks, which are reflective prisms (Figure 5).
Figure 4. a) Satellite image showing the subway station-box; b) a photograph of the site, showing the depth and three-dimensional form of produced station-box.

Figure 5. a) Deformation mark (mini-prism); b) The prism is installed and attached to a stone wall to be monitored.

Construction work is carried out close to buildings; therefore, high measurement accuracy (millimeters) is required to estimate deformations. The LeicaTM 50 total station is used with an accuracy of 0.6 mm + 1 ppm in distance measurement, 0.5" in horizontal angles (HA) and 1" in vertical angles (VA). Measurements are taken from a fixed station (Figure 6).

Figure 6. Motorized robotic total station (Leica TM 50)
Measurement using prisms are performed in the direct and reverse (clockwise and counterclockwise) directions. The data is stored on the server, and then the difference between the measurement cycles is calculated. As a result, the deformation values of the wall are determined.

The Total Station (fixed station - TS) is programmed for the observation mode of 6 reference prisms. In addition, to ensure that the total station is oriented and to observe deformation marks (prisms), the position of the TS itself is checked. The proposed measurement method has advantages over other known ones. The control of the deformation process is performed continuously in 3D (three-dimensional measurements) and 24 hours a day and 7 days a week. The use of satellite definitions in such projects is problematic. It is impossible to achieve the required accuracy, especially in height (Z-component). At the same time, the visibility of satellites having distributed geometry (uniform location in the visible sector) is necessary. However, in megacities, high buildings serve as obstacles which cause multipath propagation of the signal resulting in positional errors. Monitoring results should be in real time, but satellite measurements do not provide the necessary accuracy in RTK mode. When using static mode, post-processing is needed, but then the problem arises of ensuring the continuity of results in real time. Another important issue is the cost of geodetic works; ground measurements are clearly cheaper.

The use of laser scanning is known [7]; it can give quality results, but it is difficult to ensure the accuracy of measurements at the level of total station measurement. In addition, the data is not obtained continuously, so the moment of occurrence of critical deformations can be missed. The comparison of laser scanning results with previous observations (point clouds) is very difficult.

There are also special measuring devices [8–10] that can be installed and attached to engineering structures, but this method is very difficult to use when tracking the deformation of the surface of an open mine wall (Rocks).

Optical instruments and sensors are also known (Marazio et al., 1989) [11,12], but they are also inferior in accuracy to modern electronic total stations.

Results and discussion

Table 1 and Figure 7 show the measurement results of displacements for one point (prism) on different dates. Table 1 shows the displacement of the same prism for the period from 12:00 to 23:00, but on different dates. Figure 7 shows the results of continuous monitoring for 40 hours. Small differences were detected, which clearly show the presence of deformations. This is very important, as it makes it possible to detect even small deformations within a millimeter, and to select the measurement interval.

| Time  | DX   | DY   | DZ   |
|-------|------|------|------|
| 12:00 | -0.30| -0.05| -0.60|
| 13:00 | -0.30| 0.00  | -0.70|
| 14:00 | -0.30| -0.10 | -0.50|
| 15:00 | -0.20| 0.00  | -0.50|
| 16:00 | -0.20| 0.10  | -0.30|
| 17:00 | -0.20| 0.10  | -0.30|
| 18:00 | -0.20| 0.10  | -0.50|
| 19:00 | -0.30| -0.10 | -0.60|
| 20:00 | -0.60| -0.20 | -0.50|
| 21:00 | -0.60| -0.30 | -0.60|
| 22:00 | -0.60| -0.30 | -0.50|
| 23:00 | -0.60| -0.30 | -0.50|

| Time  | DX1  | DY1  | DZ1  |
|-------|------|------|------|
| 12:00 | -0.50| -0.30| -0.40|
| 13:00 | -0.50| -0.30| -0.40|
| 14:00 | -0.50| -0.30| -0.40|
| 15:00 | -0.60| -0.30| -0.70|
| 16:00 | -0.60| -0.30| -0.70|
| 17:00 | -0.60| -0.30| -0.80|
| 18:00 | -0.60| -0.30| -0.80|
| 19:00 | -0.60| -0.30| -0.80|
| 20:00 | -0.70| -0.30| -0.60|
| 21:00 | -0.70| -0.30| -0.60|
| 22:00 | -0.80| -0.40| -0.70|
| 23:00 | -0.70| -0.50| -0.70|
The results of the proposed measurement technique show that even small displacements can be detected and illustrated using either tables or graphs. Continuous measurement and spot measurement on different dates draw a trajectory of displacements and allow engineering teams to predict the deformation and take measures in advance to prevent severe consequences.

**3D modeling in the protection of cultural monuments**

Three-dimensional modeling, in modern conditions, is the process of representing the physical surface of an object in a three-dimensional form by means of special measurements and methods implemented in computer programs [13].

Various impacts on cultural heritage sites cause their destruction. These include the temple of Baalbek: the Roman pearl.

Based on two technologies: 3D laser scanning and photogrammetry, a three-dimensional model of the temple of Jupiter in the city of Baalbek was built. The combination of these two technologies is an effective method for quickly and accurately recording the features of archaeological monuments for their preservation and future use.

3D data and HDR images were obtained as a result of a laser-scanning survey using a Leica P30 scanner [14]. The data was processed in Leica Cyclone software, which was carried out in several stages: data import, filtering, and cloud registration. As a result, a cloud of points and a polygonal 3D texture model (TRUVIEW) were obtained, according to which a dense and high-precision (millimeter) three-dimensional model consisting of more than 1,000,000 points was built.

For aerial photography a drone was used (unmanned aerial vehicle - UAV/Phantom 4 pro). Shooting of the temple was conducted with overlapping 80% (longitudinal and lateral) of the picked area. These photographs cover most of the temple, with the exception of closed areas.
Processing was carried out in several stages: automatic alignment of photographs, georeferencing of photos based on Ground Control Points (GCPs), correction of the internal and external orientation of the image, then creation of a three-dimensional super-dense cloud of points.

![Figure 8. The point cloud model of the Jupiter temple](image1)

![Figure 9. Three-dimensional model of a dense point clouds with survey's shooting locations](image2)

The current technologies described above show that the accuracy required for the detailed archiving of cultural heritage sites can be achieved. The vertical facades of the temple were much more accurate and detailed according to ground laser scanning. In contrast, the planned areas were clearly recorded in the survey using UAVs.

**Summary**

The case studies and results obtained show the validity for the application of the proposed methodologies. These methodologies are based upon preliminary design and calculation allowing for the creation of a monitoring system to ensure the safety of the project environment and preservation of cultural monuments.

The demonstrated techniques reflect the trend of modern ideas and are research relevant. When using a robotic total station for real time measurement, many problematic issues are resolved. For example, one of the most important issues is the interval between observation cycles. The use of laser scanning technology and shooting with unmanned aerial vehicles (UAVs) is effective in optimizing the preservation of cultural monuments. This optimization is based upon the selection of areas (classification) and the accuracy of their shooting.

Obviously, it is advisable to remove the planned elements from the UAV, but it is more accurate to survey quasi vertical elements (windows, walls with architectural décor) using ground based scanning.

**References**

[1] Chai J, Shen S, Ding W, Zhu H, Carter J 2014 *Numerical Investigation of the Failure of a Building in Shanghai, China* (Computers and Geotechnics Journal) 55 482-493.

[2] Hight D W, Henderson T O, Pickles A R, Marchand S 2004 *The Nicoll Highway Collapse* (Yumpu Magazine). Information on http://www.yumpu.com.

[3] Mustafin M G, Kazantsev A I, Valkov V A 2017 *Monitoring of Deformation Processes in Buildings and Structures in Metropolises* (Procedia Engineering) 189 729 - 736.

[4] Kozhayev Zh T, Mukhamedgaliyev M A, Imansakipova B B, Mustafin M G 2017 *Geoinformation System of Geo-Mechanical Monitoring of Ore Deposits Using Space Radar Interferometry Methods* (Mountain Journal) 2 39-44.

[5] Nguyen H V, Mustafin M G 2017 *Analysis and Development of Methods for Assessing the Stability of the Reference Frames when Observing the Subsidence of the Earth's Surface* (Natural and technical sciences) 5 (107) 89-96.
[6] Mustafin M G, Naumov A S 2012 Methods of Monitoring Permissible Deformations During the Underground Utilities’ Construction (New materials and technologies in mechanical engineering) 15 198-201.

[7] Ran L, Yi T H, Ye X W., Dong X B 2012 Long-Term Deformation Monitoring of Metro-Tunnel Airshaft Excavation During Construction Stage (International Journal of Distributed Sensor Networks) Article ID 972893 pp. 1-11.

[8] Ye X W, Ni Y Q, Yin J H 2013 Safety Monitoring of Railway Tunnel Construction using FBG Sensing Technology (Advances in Structural Engineering) 16 (8) 1401–1409.

[9] Chen B, Xu Y L, Zhao X 2010 Integrated Vibration Control and Health Monitoring of Building Structures: a Time-Domain Approach (Smart Structures and Systems) 6 (7) 811–833.

[10] Roberts G, Cosser E, Meng X, Dodson A, Morris A, Me M 2003 A Remote, Bridge Health Monitoring System Using Computational Simulation and Single Frequency GPS Data (Proceedings of 11th FIG Symposium on Deformation Measurements, Santorini. 25-28 May).

[11] Stiros S, P simoulis P 2012 Response of a Historical Short-Span Railway Bridge to Passing Trains: 3-D Deflections and Dominant Frequencies Derived from Robotic Total Station (RTS) Measurements (Engineering Structures) 45 362-371. DOI: 10.1016/j.engstruct.2012.06.029

[11] Marazio A and other 1989 Monitoring of Dams and their Foundations, State of the Art (Bulletin 68 CIGBICOLD, Paris) 16.

[12] Novel C 2016 Comparing Aerial Photogrammetry and 3D Laser Scanning Methods for Creating 3D Models of Complex Objects (Bentley Systems).

[13] Information on http://leica-geosystems.com/products/laser-scanners/scanners/leica-scanstation-p40--p30