MONITORING LEANING OF ALHADBA MINARET

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Abstract:
Alhadba minaret in mosul is one of the oldest islamic monuments with its surprising curvature, height and old age of over 800 years. During the past 50 years there was a considerable amount of leaning in the minaret due to various natural and human causes. The amount of leaning was generally increasing but there was no unified or fixed control that is referenced from various monitoring groups. This paper describes the effort to design and implement a monitoring system that can be referred in the future. Fixed control points and targets have been worked. Samples of monitoring results are presented. These measurements compose a complementary part of the data collection effort required for a major preservation project that is proposed to be conducted in the future.

Key words: Al-Hadba, leaning monitoring, heritage preservation.

مراقبة ميلان منارة الحدباء

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الخلاصة:

تعد منارة الحدباء من اقدم الآثار الأسلامية في العراق. واهم ما يوصف فيها هو عمرها الذي زاد على ثمانية قرون. اضافة الى ارتفاعها وانحنائها الملحوظ. وخلال الخمسين سنة الأخيرة كان هناك تزايد في الأنحناء لأسباب بعضها طبيعية واخرى بتأثير الأنسان. لقد لوحظ انه لم يتم اعتماد نظام موحد من نقاط مراقبة ثابتة لمراقبة الأنحناء من قبل فرق المراقبة المختلفة مما يخلق ارباكا في تفسير ومقارنة أية نتائج مراقبة. في هذا البحث نصف الجهود التي تمت لتصميم وتنفيذ برنامج مراقبة يمكن اعتماده حتى في المستقبل. يتضمن البرنامج تثبيت مجموعة من نقاط المراقبة ومجموعة اخرى من الأهداف كما يتضمن بعض النتائج الأولية للمراقبة. ان هذه البيانات تعد جزءا من التحضير لأعمال الصيانة المقترحة في المستقبل.
الكلمات المرشدة: الحدباء, مراقبة الأنحناء, حماية الآثار.

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Introduction

Al-hadba (the leaning) minaret is one of the oldest Islamic monuments in Iraq dated back to 1172 AD. Its location forms a focus in the older part of the Mosul city on the right side of river Tigris. The minaret is regarded as the Mosul city legend. Researchers study this monument for many interesting reasons some are listed below.

1- Particular leaning of the minaret.
2- Noticeable height (50 m) and age as compared to the nearby old city housings.See figure 1.
3- Resistance to centuries of deterioration due to weather, quakes, and human disturbance around the minaret.
4- Documentation of cultural heritage.
5- Preparation for restoration, maintenance, protection and safety.

The minaret has undergone maintenance operations at various stages of its life and probably the most obvious was that conducted by Fondedile S.p.A. company in the 1980s [1] which was performed to strengthen the body of the minaret as well as the foundation and the surrounding soil.
During the past decades, there were studies and tests to examine its construction materials, the carrying soil, foundations and record measurements in and around the minaret [2,3,4]. Of particular interest here is the direction and amount of leaning that have to be monitored accurately and systematically. Recorded surveying measurements of the amounts of leaning dated back to the sixties (1964). Reports at that period refer to leaning at various elevations on the surface of the minaret body. Unfortunately, the reference controls and the monitoring marks were not well documented. Later on, more monitoring operations were conducted for comparisons. Again their new references of measurements were not maintained. Leaning of the minaret was caused by many reasons. Ali [5] suggested that the wind pressure was the cause of that leaning. Other reasons are related to the underground foundation and soil [1].

Figure 1. Alhadba, a focus area within the old city of Mosul.

Presently, a committee of engineers from the governorate and municipality of Mosul is preparing to conduct a major conservation program to preserve and support the old minaret and develop the area in the nearby vicinity. A major requirement is to record the expected movements and any increase in leaning for the sake of documentations and stability monitoring. In this paper the author presents his effort to design a monitoring program and record the first results obtained during the past year monitoring period. The use of total station with reflectorless capability to measure the hard to reach and vulnerable locations around the trunk of the minaret. This work documents the techniques used for measurements and presents samples of results.

Background and Instrumentation

Monitoring the deformation and leaning of heritage and high rise structures is necessary during the life time of buildings to assess safety and maintenance works [6]. In literature there are many monitoring techniques that differ in many aspects such as cost, speed, precision and expert requirements. Well known methods are based on triangulation, GPS, Photogrammetry, Laser scanning and others [7,8]. Total station triangulation and trilateration methods use the high precision distance and angle measurements to produce 3D location of target points [9]. These methods need only limited experts and cost. In this research, The author uses Topcon Imaging Station IS-203 (a variant of robotic total station). This instrument have least readings of 0.2 mm in distance and 1″ in angle measurements see figure 2. In its reflectorless non-prism (NP) mode, this machine can measure up to 350 m distances. IS-203 is driven by the onboard TOPSURV surveying software that can use various functions to increase measuring productivity. In prism mode, the fine distance accuracy reaches ±(2mm + 2ppm X Distance) mse. While in non-prism mode the accuracy amounts to ±(5mm) mse. Angular accuracy is 3″.[10]

The instrument can be operated in the reflectorless automatic scanning mode to produce point cloud of targets in three dimensions.

Figure 2. Topcon Imaging Station at monitoring work.

Necessary corrections of measured distances are calculated internally by the instrument after feeding in the air pressure and temperature[10,11,12].

For precise elevation measurements, Topcon digital level with precision of 0.2 mm reading was used for fixing elevations of a set of control points.

Network of Control Points

In order to monitor deformation of an object, it is required first to locate a set of fixed control points. In this work, the ground control set of points have been selected considering the following limitations.

1- Control points must be far away from the minaret body to be out of any possible soil subsidence effects caused by the minaret. In the mean time, far locations may reduce accuracy of measurements.

2- Building materials of most nearby housings is not rigid enough to fix permanent control points on the roofs. Old houses are made of stone and gypsum.

3- Points must be far from nearby human disturbance knowing that the mosque is frequently crowded and situated near the center of the city.

4- Old city subsoil is generally composed of few meters of old ruins with cavities and loose compaction.

Taking all mentioned limitations into consideration we have only few suitable locations to fix (good) points. we have selected the set of control points shown in figure 3.

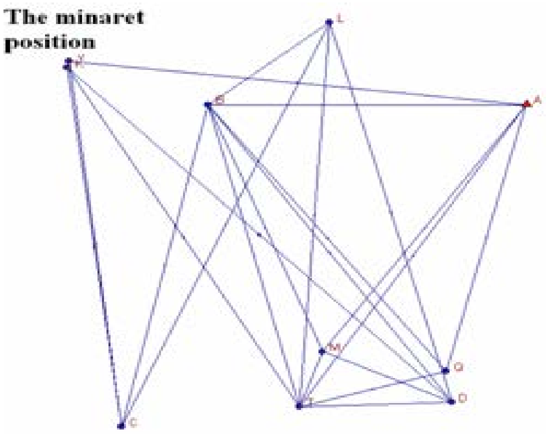

Figure 3. Network of control points.

Point (A), is the major control point fixed into the garden at about 70 m from the minaret base. It approximately faces the eastern convex side of the leaning body along the leaning line. Most of control points in fig.3 are not proposed for actual monitoring in the future. They are adopted only at this early stage in order to strengthen the network configuration and increase precision of coordinate measurements using least squares solutions. Some of these control points can not be used for setting up monitoring instruments. They are used for orientation of instruments during setting up.

Points D, Q are fixed on the (rigid) concrete ceiling of the mosque. They are stable and face clearly key target points on the trunk of the minaret. Using epoxy adhesive, at each point a steel bolt is fixed into a small hole drilled into the concrete roof. The bolt head have been treated against corrosion and a small point have been marked in the center of the head for precise setting of surveying instruments.

Coordinates of control points have been calculated after collecting angular and distance measurements to all points using the total station in prism measuring mode. All angles and distances have been measured many times and averaged to obtain most probable values for calculations. Least squares 2D network adjustment have been carried out to find most probable values of coordinates. All coordinates are locally defined. The following table shows the achievable accuracy level. The solution passed the Chi squared test.

Table 1: Adjustment results of the control network.

Adjustment Statistical Summary

Convergence Iterations	= 3
Number of Stations	= 10
Number of Observations	= 28
Number of Unknowns	= 18
Number of Redundant Obs	= 10

Observation	Count	Sum Squares of StdRes	Error Factor
Angles	21	0.961	0.358
Distances	6	4.634	1.471
Az/Bearings	1	0.000	0.000
Total	28	5.596	0.748

The Chi-Square Test at 5.00% Level Passed
Lower/Upper Bounds (0.570/1.431)

Monitoring Targets

Targets are made of steel bolts of 2 cm head diameter worked using turning machine. The head was rounded and a small hole mark of 1 mm diameter was drilled in the head center representing the exact monitored mark. Bolts are white painted. See figure 4. A high crane was used to fix these targets and great care was taken in order not to hit the minaret surface or make any destruction as seen in figure 5. A bore hole of about 4 cm deep was drilled into the wall of the minaret, cleaned and filled with epoxy adhesive. Finally, the steel bolt pressed into place.

Bolts have been fixed in key locations along the total height of the minaret. Their positions are facing the set of control points and can be visible from more than one monitoring location.

Figure 4. Steel bolts prepared as targets.

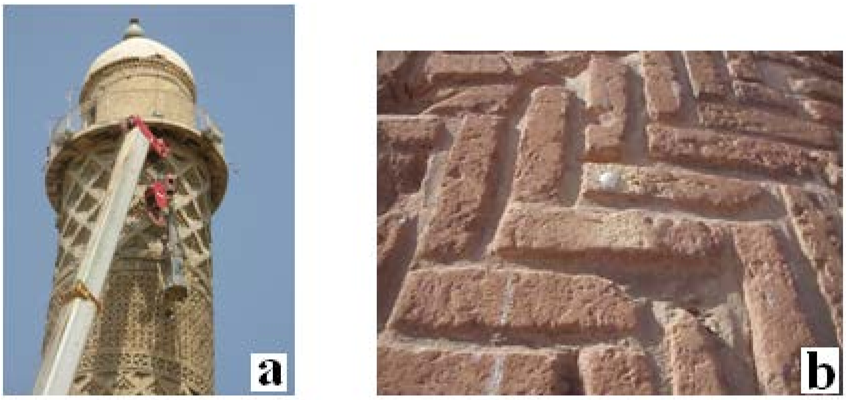

Figure 5. a) Fixing target points. b) Target point ready for monitoring.

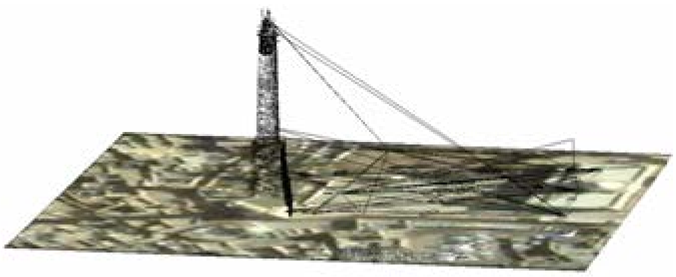

Figure 6. 3D view of monitoring lines of sight superimposed on Google Earth image of the nearby area.

Measurements and Results

All distance measurements have been made using prism and non prism modes of the total station. Moreover, scanning results in the form of point clouds have been analyzed.

During the past few months, results of deformation monitoring on selected points on the prism base of the minaret does not show significant side movement. However, it shows that the two western and eastern faces are not symmetrical as seen in figure 7. A possible differential tilt of the minaret base of about 2 degrees eastwards have occurred after construction.

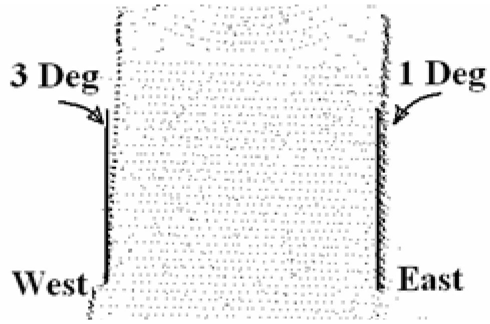

Figure 7. Inclination of opposite faces of the base prism compared to the vertical.

The centers of two circular sections at the ends of the trunk are out of alignment of more than 2.5 m as seen in figure 8a. The upper part of the cylindrical trunk have a maximum tilt angle of about 9 degrees out of vertical towards east as seen in figure 8b.

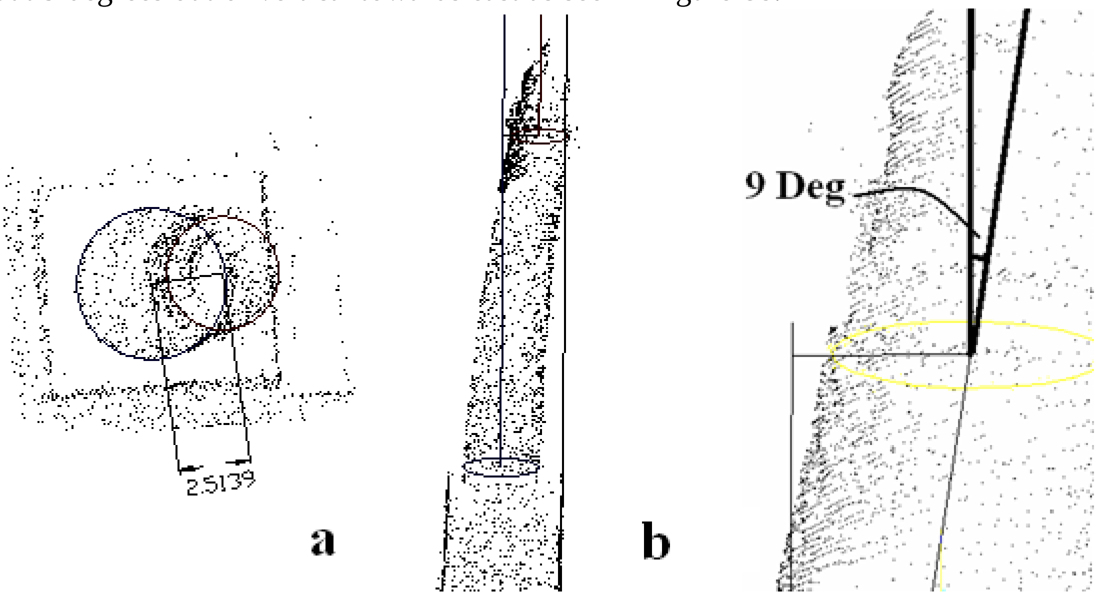

Figure 8. a) The relative eccentricity between the two circular sections at the ends of the trunk. b) Maximum leaning angle out of vertical at the top.

Distance measurements were performed using the reflectorless mode from control point A to the targets on the facing side. Horizontal components of movements in mm of selected targets during two periods (from Oct. 2011 to Jan 2012 and from Jan 2012 to to May 2012) are shown graphically in figure 9. The Jan reading is used as a comparison reference in this case. During the first period, the measured leaning direction is to the East (towards control point A) with increased amount of leaning of 20 mm at upper elevations. The direction reversed during the second period with amount of 15 mm. The cause of this movement is attributed to one or more of possible causes such as irregular temperature variation, differential settlement, properties of building materials wind effects etc. More sets of measurements are required to reveal the effect of each variable. The author concludes that the upper part of the minaret has obvious movement that changes in magnitude and direction according to seasons.

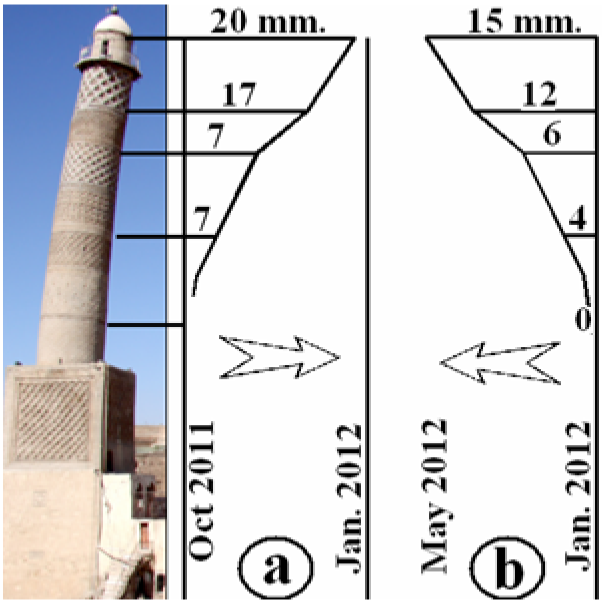

Figure 9. Horizontal movements (mm) of targets in two periods, (not to scale) Oct. 2011-Jan. 2012- May. 2012. a) Increased leaning. b) Reduced leaning.

Photogrammetric Measurement

Two sets of data have been compared to predict the history of amount of leaning using photogrammetry. First, an old photograph of the minaret probably dated back to year 1925 have been analyzed. The second set resembles a 3D representation of the minaret prepared using the scanning capability of the IS-203 instrument. In order to make realistic comparison, care was taken to estimate the location of the shooting camera in order to orient the two data sets into same alignment as much as possible. Figure 10 shows the overlay of the two sets and amount of leaning. From this overlay, the author expects that during the last 90 years, there was a considerable leaning movement of the upper points of the minaret that amounts to more than 2.5 m eastwards. The prismatic base overlay doesn't coincide well due to base tilt as shown earlier un figure 7. The author argues that the major part of leaning of the minaret have been occurred during the last century.

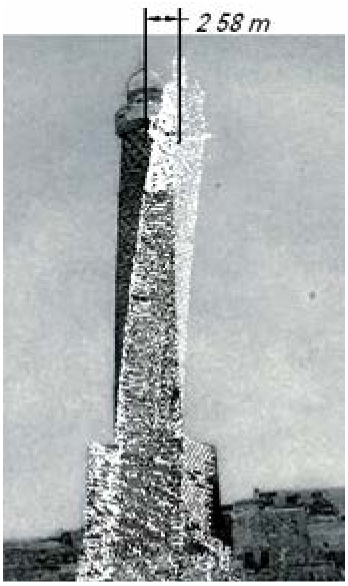

Figure 10. Estimated leaning during the last 90 years.

Conclusions

In this work, we have fixed permanent control points as well as permanent target points. Researchers in the future can refer to this system for continuous monitoring of leaning and comparison.

During the period of monitoring, we notice the movement of upper half of the minaret. Maximum horizontal movement was observed at points in the upper part (kubba). The movement is less at lower elevations. The amount of eastward horizontal leaning in upper points increases in cold winter as compared to hot weather measurements. The probable effect of differential temperature on leaning is arguable and needs more research. Other probable causes of leaning are due to differential settlement of the base, wind effects, earthquakes and physical properties of the building material. We need more data collection and research to separate effects of these variables. Comparing with old photographs, the author concludes that the most amount of leaning in the minaret has occurred during the last century. We expect that, on earlier dates, the minaret had less amount of curvature from what we see recently.

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