Saving minarets at risk in Afghanistan

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ABSTRACT: The minaret of Jam is now included in the World Heritage List. Such an outstanding tower built in the 12th century A.D., 65 m high and isolated in the mountains at the altitude of 1900 m, has exceptional value from the architectural and historical points of view. The author, on behalf of UNESCO, undertook investigations intended to assess the structural stability of the tower, including static and dynamic verifications. The study of the seismic hazard of Jam was the occasion to reconsider a catalogue of 1300 seismic events which reconfirm the high seismic risk of the city of Herat, where another set of important archaeological remains is also under the highest attention of UNESCO.

1 INTRODUCTION

The reasons of the dramatic loss of the architectural heritage in Afghanistan are not only earthquakes, but also destructions due to war.

The minarets to be saved are a fundamental testimony of the ancient roots of such unhappy people. Adding the minaret of Jam to the World Heritage List UNESCO is working for the preservation of such memories and for the civic and cultural reconstruction of the Country. The safeguard of the five minarets remained in Herat is part of the same project.

The knowledge of the Afghan civilization dates back to the end of the second millennium B.C. when the Aryan people had their capital in Herat, called Aria at that time. Zoroaster’s teachings and monotheistic doctrine started in northern Afghanistan around the year 600 B.C. and are known to us through the “Avesta” books, which influenced the religion in Iran for about twelve hundred years.

Alexander the Great founded new towns in the area and built the citadel of Herat, called at that time Alexandria Ariana, (330 B.C.).

The country professed then for centuries Hindu and Buddhist religion under various dynasties as Maurians, Bactrians, Kushans and Sassanids, until the Islamic conquest (Ghazni in the year 869 A.D.).

The Islamic dynasties of Samanides and Ghaznavides developed culture and art. The outstanding minaret of Jam was built by the Ghurid sultan Ghiyasuddin (1157–1202, buried in Herat) just before the entire destruction of the region due to Genghis Kahn in 1222.

During the 15th century Herat was again the capital of a splendid empire with the Timurid dynasty (Shah Rukh, Tamerlane’s sun, and the famous queen Gawhar-Shad). It was a golden era for literature, art and architecture. The nine minarets of Figure 1 are the vestiges of a large religious complex destroyed during the 19th century wars. Some of the most famous mystical Islamic poets of the Sufism as Jami were active there, following the ancient tradition dating back to Amr el Makki, Ansari, Sanai, Jalaluddin Rumi who left Balkh before the advancing hordes of Genghis Kahn (Schimmel 1973).

At the beginning of the 19th century a period of nearly continuous destructive wars began, during which Persians, British and Russians contended for Afghanistan involving local fights.
After 40 years of a monarchal parenthesis, in 1973 a new terrible period of war began and is still devastating the Country. Many Afghans left the Country several years ago; thousands of refugees of the 2002 war are coming back now and try to rebuild a destroyed society with productive activities and schools.

2 WHAT HAS TO BE SAVED?

Among the hundreds of archaeological sites, a number of important ancient buildings need urgent safeguard works, among them the minaret of Jam and the five minarets of Herat. Many minarets were lost in the past and the ones still existing are exposed to a serious risk of collapse for the seismic actions together with the effects of their dangerous inclination and the deficient state of the masonry.

The architect Andrea Bruno began in 1961 surveys and projects for the restoration of Afghan monuments together with the Italian Institute ISMEO, and then surveys and restorations in Jam and Herat from 1976 to 1979 for UNDP and UNESCO (Bruno 1981). The author, as Scientific Advisor of UNESCO, undertook recently (2002) investigations intended to assess the structural stability and seismic risk of the minarets in Jam and Herat and cooperate with A. Bruno for their restoration.

3 EMERGENCY SECURING OF THE MINARET FIVE IN HERAT

Minaret 5 is a brickwork tower 42 m high with a diameter of 5 m only at the base. It is built with hard bricks and was once at the corner of the demolished Musallah and stands now isolated in the garden of the Mausoleum of Gawhar-Shad.

The surface has an elegant kashi decoration with a geometrical pattern filled in with blue tiles (Fig. 7).
is cracked for one third of the diameter, and the edge of the masonry is subject to a very high compression, 1.2 MPa. Both data show that even a very moderate earthquake or a strong wind would cause the collapse of the minaret, as already happened to the four other minarets which were still standing in 1915 (Fig. 1).

The author undertook precise measurements in July 2003 with a Huggenberger removable deformeter and a high precision tiltmeter. In the space of four days of strong wind the strains measured across the horizontal crack showed a continuous periodic opening with a frequency of 0.5 Hz and a slight but continuous opening of the crack and an increase of the tower leaning (about 10 arcsec). The present tilt of the tower is probably due to several successive earthquakes; we are not sure of its evolution in time, but according to the available information the out-of-plumb was only 0.90 m in 1977. Other evident damages, as a wide opening in the shaft caused by a missile during the war, are less alarming than the overall lean, which may lead to a sudden collapse.

Both the numerical assessment and the site measurements showed such an extremely alarming situation and that emergency measures were evidently needed. There was not enough time for the implementation of the structural intervention prepared by the author and approved by UNESCO in April 2003, i.e. a stabilization of the foundation by means of single bar micropiles and strengthening of the elevation by means of a vertical prestress applied through high strength steel bars directly connected to the micropile bars. Therefore, emergency measures were applied to the minaret during July, August and September 2003.

The emergency securing was obtained by means of simple steel stays anchored to concrete blocks poured in the natural soil (out of any remains), avoiding in this way the necessity of driving piles as fixed points. The proposal was conceived in such a way to use only means available on site for the anchoring to the soil, and steel cables sent from Italy (together with their anchorages, hydraulic jacks etc.) in order to allow the implementation in few weeks, as suggested by the risky situation of the monument.

The concrete blocks, built by local workers, were embedded in the soil at a distance of 25 m from the basis of the tower. The centers of the blocks were placed on two axes 15° far from the maximum lean plane in order to secure the tower for an angle of 30°. In each block 4 steel pipes were embedded in the concrete in order to accommodate 4 stays and their anchorages.

Each stay was made with a single 0.6" strand of galvanized high tensile steel (area of 150 mm², strength 265 kN). Each stay was applied along a precisely defined path (see Fig. 4 and the model of Fig. 5): each strand starts from a concrete block and reaches the tower surface with the appropriate inclination, then is wounded to it along a variable angle spiral until a sub horizontal circle allows to begin a symmetrical
descending path towards the other concrete block and its anchor. This arrangement of the stays was essential in order to transfer to the tower the vertical component of the stabilizing action through the steel-to-masonry friction, therefore without slip and without heavy steel fastenings.

In that way the small force of 100 kN only, applied by jacks to each of the 4 strands, has been sufficient to close the base crack, to decrease the eccentricity of 0.65 m and therefore bring back the masonry to a state of total compression; the maximum stress was reduced to 0.6 MPa.

The strand application was performed in two weeks by a single technician sent there by ALGA and supported by local workmanship.

The continuous monitoring showed that the top of the tower moved back about 16 mm and therefore showed the favorable effect.

This quick, simple, efficient intervention shows how emergency works may avoid the total loss of some precious monuments in a cheap way and without invasive structures.

4 THE INCREDIBLE STORY OF THE MINARET OF JAM

The minaret of Jam is by far more important than the Herat minarets for its extraordinary size: 65 m of height, close to that of the Qutub Minar in New Delhi, that was built in the same period at the end of the 12th century, the tallest minaret in the world. Isolated in the mountains on the left bank of the Hari-Rud river 250 km east of Herat, at the altitude of 1900 m, the tower has great architectural and historical value and is now the symbol of Afghanistan in the World Heritage List. It is a monument very important for the history of the Ghurid dynasty and for the knowledge of the medieval Islamic architecture and civilization (Bruno 2003).

The architecture is highly sophisticated: the tower is built in fired bricks, and is formed by three cylindrical superposed shafts on an octagonal basis. The diameter of the base is 9 m only. Unusual feature is the presence of two helicoidal internal stairways leading up, one above the other, to a balcony at the top of the first tier, at the level of 40 m.

The bricks are used for a splendid decoration of the facing, with intricate geometrical and floral motifs and quotations of verses of Koran in Kufic script (the 19th Sura, Mary’s Sura, which is per se a surprising reference to a pre-Islamic religion). Below the first balcony, a monumental Kufic inscription in turquoise glazed tiles proclaims the name of the Ghurid Sultan Ghiyasuddin and even of the architect, Ali.

Nevertheless, such a monumental testimony of a famous empire was incredibly “lost” for 700 years, and

Figure 8. Jam minaret.

Figure 9. Jam minaret. View of the facing (Andrea Bruno 1963).

“rediscovered” only in 1944. Lost again and escaped new expeditions due to the immensity of the mountainous region, the tower was finally found in 1957 by André Mariq. In 1960 Andrea Bruno discovered the great risk of collapse due to the extraordinary lean (3.5°), the scouring by the river, the earthquakes.

Leaving aside the equally extraordinary problems posed by the tower, as e.g. its purpose in that inaccessible valley and the mystery of the famous Ghurid capital Firozkoh, still not found, the “minaret” of Jam is posing difficult structural engineering problems.

A first essential emergency intervention was implemented between 1975 and 1980 when A. Bruno installed metal gabions protecting the foundation from scouring. However, no further action was possible until 1999, when the protection was strengthened, and new missions took place in 2002.

The author was appointed by UNESCO in 2002 and was asked to undertake appropriate engineering investigations intended to supplement the structural survey, clarify the reasons of the lean, perform a seismic assessment and the structural analysis, prepare a plan of interventions.

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During the year 2002 a very important step was achieved in the knowledge of the Jam minaret: a very accurate geometrical survey (made by Santana and Stevens). It allowed an accurate determination of the permanent inclination, of the permanent weight and of the state of stress under permanent actions (Fig. 13).

The high value of the compression under gravity loading (1 MPa) is due to the exceptional tilt. It is higher than the values usually found in historical brickwork and may indicate a non-admissible risk of collapse under actions such as a strong wind or an earthquake, both expected actions in such a geographical situation. The opposite edge of the section is close to being in a state of tensile stress, so that the formation of horizontal cracks under variable and accidental actions is highly probable. Such a situation, similar to that previously existing on Minaret 5 in Herat, would be dangerous because of the overproportional effect of further actions.

A special concern arises for the evident deterioration of the brickwork at the minaret base.

Therefore, the seismic assessment of the tower is an essential step of the diagnosis. The work was carried out in the year 2003 at the ROSE School in Pavia by the author together with A. Menon and C. Lai (Menon 2004). It required sophisticated tools for determination of the seismic hazard of the site of Jam as well as for the dynamic analysis of the structure.
The problem of the seismic hazard of Jam was challenging, because the site is far away from populated areas where records of ancient earthquakes may be available. Another difficulty was the necessity of a rather refined estimation of a presumed low level of seismicity because even a moderate earthquake might be critical for the tower, already vulnerable because is highly stressed and damaged.

There is no direct evidence of large earthquakes occurred at the site in the literature. However, the tectonics and the historical seismicity of Afghanistan suggest a very careful study.

Figure 14. Horizontal hazard spectra.

Figure 11 shows the main fault systems in Afghanistan and that Jam is on the Herat fault, separating the northern plateau from the central massif. However, the Herat fault is believed to be an inactive fault in spite of evidence of considerable displacements of streams which might took place 10,000 years ago.

The historical and instrumental seismicity was studied on published catalogues including about 1300 events dating back to the first century AD.

Details of the catalogues and of the procedures used for their use are not within the scope of this paper. However, Figure 12 shows the epicenters taken into
account in the study: Herat and Jam can be identified, and the feeling that Jam may be prone to a moderate seismicity is roughly suggested by the map (but the poor information available in the mountainous zone should be kept in mind).

The seismic hazard of Jam was therefore assessed by means of different available procedures, namely the probabilistic and the deterministic one. Uniform hazard response spectra were then computed for different return periods and for horizontal and vertical acceleration (72-224-475-975 years).

The spectra were used for the dynamic assessment of the tower and the stress analysis was performed for the 475 year return period. As the first mode of vibration is placed between 1.1 and 1.3 sec according to the assumptions for the soil stiffness, the horizontal spectral acceleration is at the end rather small. Such a return period was chosen with the intention of demonstrating the effect of a low, yet realistic level of ground motion.

The modal analysis was performed with a stick model (concentrating the masses in 9 points). However, a soil structure interaction was considered in order to cover a spectrum of possible soil conditions of the tower foundations. In fact, the subsoil investigations envisaged since the year 2002 (as the only means being in measure to suggest the reasons of the tilt and provide data for a stabilization of the foundation) are still waited for the difficulties found in their implementation and equipment transportation. Therefore, the subsoil nature is still unknown.

The alternative assumptions of soft and stiff soil did not give very different results. However, the combination of the earthquake with the gravity loads, with stiff soil, would lead to rather high tensile stresses (0.27 MPa) and compression stresses (1.20 MPa). As such a tension could not be resisted by the masonry, the crack formation has to be considered, as well as a higher compression (1.62 MPa).

Such a state of stress, which corresponds to a realistic hypothesis in case of a rather probable earthquake, shows a not allowable collapse risk of the tower. An
improvement of the compression strength of the brickwork at the base of the tower seems therefore urgently needed. Given the great thickness of the shaft the only realistic way of improving the vertical strength seems the application of a circumferential prestress by means of high strength steel wires wound around the shaft at an high tension. Such a technique proved to be efficient and have little intrusivity on the Leaning Tower of Pisa. The use of 4 mm stainless steel wires would provide also a durability appropriate to a permanent intervention (Macchi 2001).

6 CONCLUSIONS

In two famous archaeological sites in Afghanistan, Herat and Jam, important ancient minarets are in danger of collapse for their deteriorated state, the accidental leaning and the earthquake risk. Urgent securing measures associated to deep scientific studies may help in preserving such masterpieces for the future.

REFERENCES


