# PRE-STRESSED STEEL CABLES AND BARS IN CONSOLIDATION OF HERITAGES IN THE CAUCASUS AREA

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## ABSTRACT

Steel, and stainless steel in particular, is developing an important role in the conservation of historical buildings. This, thanks to a series of obvious advantages such as reduced bulk, limited cost, excellent strength and the possibility of immediate recognition. Furthermore, reversibility, durability and compatibility are three main criteria. Since many centuries, chains, cramps, and connecting iron elements have been used to absorb tension stress induced by the horizontal component of forces in arches and domes, or to improve faulty connections or replace missing ones. Nowadays, reinforcing “passive” steel elements and “active” pre-stressing ones, in form of cables or bars, are more and more adopted and accepted in consolidation interventions.

Some examples in which steel cables have efficiently solved difficult static problems involving damaged masonry structures are shown.

A pair of twin minarets in Azerbaijan have been studied and fully restored. Technological, structural and execution aspects will be illustrated in relation to these examples in which a *criterion of minimal intervention* was chosen.

**Keywords:** *stainless steel, active system, seismic advantages, compatibility, minimum intervention*

## INTRODUCTORY REMARKS

Today there is no unanimous reply to the question “how a restoration has to be carried out?”. It is therefore necessary to define what one means by the term “restoration” and the principles by which one operates in this field.

The international documents – the various “restoration charters” – offer a useful though not exhaustive point of reference. The principles they set out demand reasoned adoption rather than a scholastic act of faith. Above all, they demand that decisions should be taken in function of the ***specific situation*** of the monument to be restored.

There is one element that may be considered common to all restoration projects: in-depth analysis of the constituent materials and the structural condition of the monument in question. The crucial value of reference is that ***the safeguarding of the memory*** constitutes the best foundation for the future. The monumental complex indeed offers unrepeatable testimonies to the culture of the people who produced it and who have looked after them ever since; the loss or alteration of a part is always irreversible and would seriously impair the cultural growth of a civilization. It follows that the conservation of these monuments must be planned and executed on the basis of a deep analysis of the buildings, using materials and techniques that are mainly ***compatible*** with the existing ones.

The restoration must therefore strive to ensure the permanence of the monument with all the marks and layers of time and history that characterize its current state.

With regard to any consolidation work of an historical construction it must be stated that it is part of a wider-ranging process that can be called “the practice of conservation”.

The *first principle* asses that the historical building in its current state (the building is the primary source of knowledge) must accepted as a significant testimony in its full complexity, and that we must maximise our total knowledge of the building, assigning equal value and importance to all components of the building and to all the materials contained in it. The work to be performed will, therefore, be determined through careful and specific observation. In other words, it is important to study the individual object as a unique, unrepeatable instance.

The *second principle* asses that strengthening, considered as a single, exceptional intervention or as a part of a larger project for work on a building, must be organised with a cognitive, scientific approach to phenomena of degradation and ruin to assess **if and when** there is an effective need for intervention. An object is irreplaceable in that it is **unique**, because of elements of its material culture, because of its historic nature, because of the relationship that links it to other events, because it can be studied through many distinct types of reading. The type of work and the technology that best achieve the aims listed above are then selected on the basis of these assessments.

**THE TWIN MINARETS IN KARABAGLAR VILLAGE (AZERBAIJAN)**

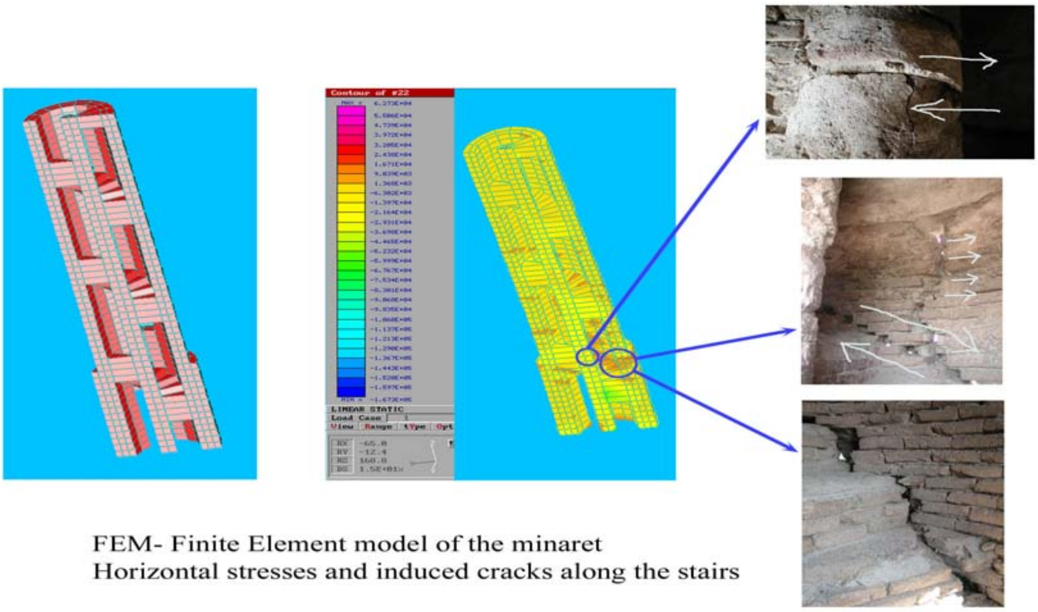
The Nakhichevan –city famous monumental complex in south Azerbaijan almost certainly inspired that of the near village of Karabaglar, which comprises a monumental gateway flanked by twin minarets (both now truncated) and a mausoleum. The existence of constructions between the monumental gateway and the mausoleum of Ghudi Khatun suggests that they are one of the oldest examples of the genre in the entire area of ancient Iranian culture. The brick structure of the twin minarets at Karabaglar appears to be of the simplest and most widely used types in ancient Iran, with an ***internal spiral staircase*** revolving around a central spindle. A parallelepiped structure in brick rises from stone foundations, and the entire exterior is sheathed in brick. The minarets are currently of different heights and bear many signs of cracks. There appears little doubt that the structural damage has been caused by one or more seismic events; first the minarets were probably "decapitated" as a result of the whiplash effect of an earthquake shock; later shocks probably caused the motion of translation and rotation of the minaret at its base.

Correct interpretation of the phenomenon will require research to identify the type and characteristics

of earthquakes that have struck the area in the past. An initial interpretation however has been done, using a discrete element numerical model of the structure in a non-fissured state. It will  follow another analysis in its current state with cracks.

As for **the taller minaret,** the first task was to investigate the kinematical action underway in an attempt to provide a quantitative description of the phenomenon of expulsion of part of the masonry in the lower half of the minaret. It is clear that earthquake stress was severe in the circular-section lower part. The additional presence of two factors – a big window that interrupts the continuity of the walls and a spiral staircase that gave raise to a substantial structural eccentricity – caused a sideways slippage of the minaret, which at the same time rotated in a clockwise direction. The photographs clearly show the spiral dislocation of the bricks, visible both inside and outside, immediately above and below the section held in place by the bricks of the staircase. In other words, ***the spiral staircase very probably acted simultaneously as a local reinforcement agent and as an element of global asymmetry***; the combined effect was cracking due to rotation-translation motion. The zones of masonry immediately above and below the spiral staircase show signs of severe concentrations of tension that could have caused the masonry to break.

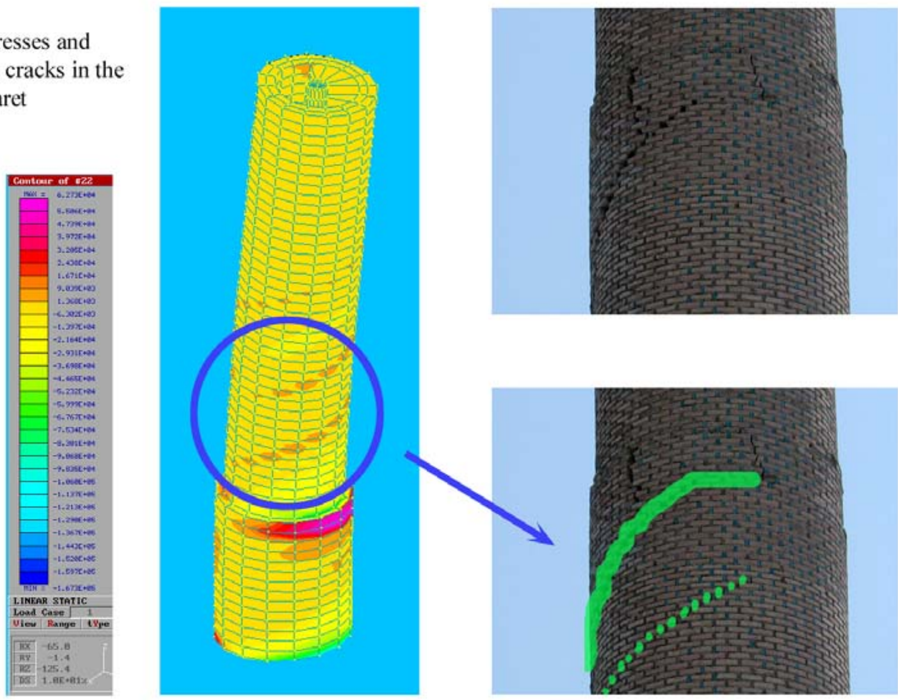
As for **the lower minaret,** it was also, probably, "decapitated" by a seismic event; in this case, however, the absence of discontinuity in the walls (by contrast with the window and the door in its twin) avoided the dramatic consequences visible in the



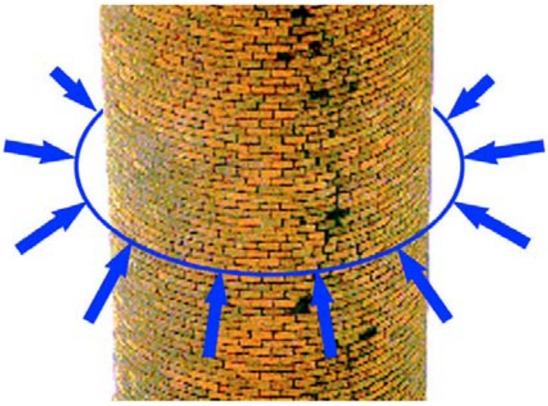
FEM- Finite Element model of the minaret
Horizontal stresses and induced cracks along the stairs

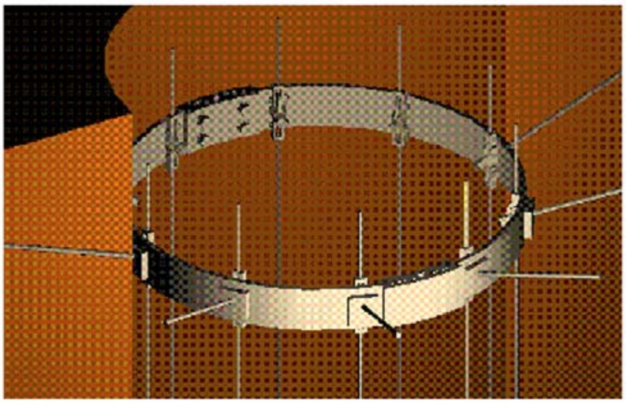
taller minaret. In fact it seems to feature just one horizontal lesion, due to shearing stress.
Numerical analyses have highlighted, also here, a marked torsion affecting this minaret.
On the basis of the data currently available, we have noted a fairly good correspondence between the pattern of cracks visible on the monument and the areas subject to the greatest stress according to the numerical analyses.
To reach objective and demonstrable results, however, the model will have to be *"cross-checked"* against free oscillation tests conducted on site and using artificial noise or natural events such as wind, with measurements being taken by accelerometers distributed over the surface of the structure in question. Similar experimental and numerical investigations, aimed to parameter identification, have been conducted by the author on various masonry towers in Northern Italy.

Traction stresses and consequent cracks in the tallest minaret



The chosen system of consolidation must support the existing structure, must be located inside the minarets and must involve only modest intrusion into the existing masonry. It has to offer immediate and substantial improvement to the resistance and ductility of the structure; it should not, however, substantially alter its rigidity in order not to comprise its interaction with the adjacent structures. The consolidation system has to be of the "active" type, i.e. capable of acting immediately, even before the





seismic event, by adopting a system of pre-compression.
It is under investigation the feasibility, for example, of laying rings of thin (6 mm diameter) stainless steel cable along the mortar joins in the external wall in the areas of major lesion.
A complementary method that is under consideration is the use of *radial binding elements*. The method is suggested by the current presence in the minaret of strips of wood placed along the edge of every step but now often missing or rotted by rainwater. These wooden elements were certainly intended to prevent damage to the edge of the steps but it is also possible that they had a structural function by using a traction-resistant material to bind the external wall to the central spindle. It might be beneficial to conceive of consolidation as a revival of this system of radial retaining, introducing new edging strips of wood, below which would be inserted a length of small-diameter stainless steel cable, injection-anchored to the masonry and capable of performing a retaining function. Vertical cables, parallel to the inner surface of the cylindrical wall, will be added too, to contrast the structural eccentricity induced by the global out of verticality of the minaret.
More details can be found on **www.jurina.it.**

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