SAFEGUARD AND STABILISATION OF THE LEANING TOWER OF PISA 1990-2001

The International Committee for the Safeguard of the Tower of Pisa *

The Committee

The present section summarises the history and the activities of the International Committee for the Safeguard of the Leaning Tower of Pisa.

The Committee was appointed by the Italian Prime Minister in May 1990. It was conceived as an autonomous and multidisciplinary Authority, whose members were experts in arts, restoration and material, structural and geotechnical engineering. A complete listing of the experts who, from 1990 to 2001 have served the Committee, is given in the Appendix.

The circumstances triggering the appointment of the Committee can be linked to the following sequence of events:

a) In January 1989 the XI century's Civic Tower of Pavia experienced a sudden structural collapse killing four people.
b) In October of the same year a commission was established to make recommendation regarding the safety of the Tower of Pisa recalling the central and local authorities attention on the risk of:
- A toppling over because of the continuous increase of its inclination
- A fragile collapse of the South side masonry due to its relevant and continuos growing in inclination, which is aggravated during strong winds and moderate earthquakes whose occurrence in the area of Pisa has been effectively documented.

c) In January 1990 the Italian Government determined that the tower be closed to visitors for safety reasons.

The Committee for the Safeguard of the Leaning Tower of Pisa was established with the tasks of implementing stabilisation measures and any necessary intervention pertinent to the restoration of the Tower. The Committee was also requested to make recommendation for a most appropriate use of the Tower at the conclusion of the works.

By 1990, when the Tower was handed out to the Committee to be restored to health, its inclination was slightly above 5°1/2.

Based on the analysis of the history of the Tower its inclination started to appear during the second construction stage (Figs. 1 and 2).

It was, though, examining the results of the modern monitoring, begun in 1911, that it became clear that from late thirties to late eighties the rotation rate of the Tower had increased from 3-4 to 5-6 seconds per annum.

This alarming circumstance was a clear evidence of the precariousness of the Tower, which has always represented a serious concern and has guided the Committee in the formulation of the strategy which was based on some crucial circumstances:

(a) The belief that the complexity of the problems related to the safeguard of the monument would require a significant series of studies, analyses and experiments to acquire a comprehensive and extensive knowledge of the tower and of its environment. It was estimated that the Committee would need 3 to 4 years to carry out the investigation stage and to be able to single out the final interventions on the tower.

(b) After the first few meetings it soon became obvious that the Committee had to develop and deepen many important subject matters before reaching a unanimous agreement on the final intervention and because of its multidisciplinary nature this process would take years.

(c) On the other hand, the awareness of the reduced margin of safety with respect to toppling and to a structural collapse, not to mention its heavy responsibilities, made the Committee decide to implement some temporary and fully reversible stabilisation interventions, allowing to carry out the required research activities and to complete the decision-making process in condition of improved safety.

According to the above strategy the Committee, in the years 1991-1996, accomplished the research and studies essential to a comprehensible knowledge of all the relevant features of the monument and its environment. In the meantime, the temporary stabilisation measures were implemented.

The temporary structural strengthening consisted in a light circumferential prestressing of the most vulnerable section of the Tower's masonry located between the first and the second corniche by means of post-tensioned steel cables. The intervention was perfectly reversible and the cables were dismantled and replaced in 2001 by stainless steel wires wound round the drum as a very small band.

The temporary stabilisation of the foundation was achieved by applying 6 MN of lead ingots to the North side of the foundation. For the first time in the long history of the monument, a small (about 1 minute of arc) reduction of its inclination was exercised. During these five years, the Committee defined the strategy for the final stabilisation interventions, which had to be absolutely non-invasive and fully respectful of the internationally accepted principles for the preservation and restoration of a world-famous UNESCO-listed monument, such as the Tower of Pisa. The application of the lead ingots required a prestressed concrete ring around the base of the tower. Also this temporary measure proved to be perfectly reversible, and in 2001 the lead weights and the ring were removed without any damage to the marble facing.

The approach to the final geotechnical stabilisation consisted in a gradual and highly controlled extraction (called "underexcavation") of small volumes of soil from the depth ranging between 4 to 5 m beneath the catino and the North edge of the plinth, aimed at reducing the tower's inclination by half of degree. It was decided to implement preliminary ground extraction beneath the tower itself, with the objective of observing its response to a limited and localised intervention. To protect the tower from any unexpected adverse movement during this or any other intervention aimed at the final stabilisation of the monument, a safeguard structure was considered mandatory. The structure finally chosen consists of two sub-horizontal steel stays connected to the tower at the level of the third order.

After the very encouraging results of the preliminary underexcavation experiment, the Commission went on to the final underexcavation; 41 holes have been drilled. Between February 21, 2000 and June 6, 2001, when the underexcavation operations ceased, 1,568 extractions have been carried out, removing a total volume of 37.668 m^3 of soil. Around 60 % of this volume was removed below the catino, that is outside the perimeter of the foundation.

The goal of decreasing the inclination of the tower by half a degree has been achieved. The settlement of the north side of the foundation was over 160 mm, while the south side experienced a heave of 11 mm. It is believed that this very positive behaviour is the effect of having limited to 2,5 m the penetration beneath the foundation.

The structural strengthening was prepared by means of extended nondestructive tests and limited to the minimum essential. It involved only the south side of the first and second order. The intervention consisted in low-pressure special grouting, which was carried out under highly controlled conditions, and in a small number of post-tensioned radial stainless steel bars, limited to the critical zone. The plinth of the tower was connected to the catino and circumferentially prestressed in order to counteract tensile stresses and increase the effective foundation area.

Application of conservation principles.

Raymond Lemaire and Roberto Di Stefano, both Past-Presidents of ICOMOS, provided the most authoritative guidance in terms of conservation principles.

R. Lemaire emphasised from the start how "exceptionally complex" saving the Tower of Pisa was, but he also stressed that the multidisciplinary approach itself proved the effectiveness of the method employed. Restoration could not be undertaken without reference to the most recent theories on the subject.

The "Venice Charter" had been the standard international document for thirty-five years. However, despite its great merits, it contains some ambiguities, which had recently emerged in discussions concerning the concept of authenticity. In the case of the Tower, there was no risk of such controversy, as it has survived practically intact. Past restoration has not added anything significant to the original aesthetic quality of the monument. So far, the replacement of marble affecting the small columns, the facing blocks and other sculpted details have kept the artistic message intact. It was therefore only a matter of proceeding no less delicately and rigorously and of maintaining the same quality of structure and appearance.

This rigorous respect of conservation principles informed the initial choice of the technical methods to be employed in the Tower's geotechnical stabilisation. For the methods considered were limited to those capable of preventing increase in inclination by "a rotation of the soil", thus avoiding the application of horizontal forces to the elevation of the Tower.

Once the efficacy of the technique was established, the question arose of how much importance was to be given to the straightening of the Tower. The Committee's answer was that it should be limited to a modest reduction of inclination, to the order of half a degree.

Contrary to the opinion expressed (rather superficially) by Eugène Viollet-le-Duc in 1836, according to which the Tower "would be infinitely better if it did not lean", the Tower's inclination forms an integral part of its history and must remain at the core of its memory.

Crowds of admiring spectators have always flocked to Pisa to see the Tower. This hardly surprises us today, as our familiarity with the principles of conservation allows us to see that what is important for the spectator is the psychological effect which the "antique" produces on him or her. And this is an effect which eludes rational analysis and which is grounded on a direct reaction to the sight of the monument, not so much as a source of aesthetic pleasure or as an item of scientific or historical interest, but rather in so far as it conveys something of the life of humanity.

Conservation has to taken into consideration not just aesthetic and historical, but also psychological factors. Assessment of an ancient monument is not based solely on the categories of "beauty" and "history", nor is it confined to those who, like Viollet-le-Duc, have aesthetic, scientific and historical interests. Those two categories do not exhaust the interest conveyed to man by works of the past, an interest that has its roots deep in the human psyche, and not just in an association of ideas belonging to our intellectual heritage. Even those who have little share in that heritage are able to express the awareness of the monument's value aroused in them by its mere perception.

This (as Alois Riegel stated) is the "value of antiquity", which includes the "historical value" perceived by the knowledgeable as the representation of"a particular and, so to speak, individual phase in the evolution of any of the various fields of human activity".

This allows us to understand the particular astonishment and wonder aroused psychologically by the Leaning Tower in crowds of tourists, who see in it both this value of antiquity and also the danger of its collapse, due to natural forces.

The human will, of which the Tower is the symbol, must remain for ever inscribed in the vision that humanity will retain of this fabulous enterprise: a magnificent undertaking which, right from the start, was compromised by an unexpected accident (the localised subsidence of the ground, which logically would have forced its progenitors to abandon its completion) and which, against and despite everything, underwent some improvements and was finally completed due to the outstanding pertinacity of Pisa's citizens. It is that superhuman energy, that unflagging determination which the Tower magnificently symbolises.

It is without doubt this that tourists unconsciously come to admire.

The memory of this human struggle to vanquish destiny and, despite everything, carry the work through to completion had to remain the fundamental object of our concerns throughout the conservation of the Tower. This was a duty bound up with the authenticity of the human message handed down to us by this prestigious monument.

Philosophy of the interventions.

For the purposes of conservation both kinds of value require human intervention in the life of the monument, not only so as to obtain material stability but also to preserve human values. In other words, the essential problem here is the conservation of part of the cultural heritage, a problem distinct from that of restoration. "To restore is one thing, to conserve another, indeed often its opposite," wrote Camillo Boito. Certainly, the best way to conserve ancient monuments would be "to leave them in peace, or, when necessary, rid them of the effects of previous restoration, more or less recent, and more or less unfortunate". Yet – as in the case of the Tower – it is not always possible to prevent the destruction and death of a work of art without having recourse to restoration, which is itself destructive (Ruskin). But the advice Ruskin himself gives concerning "an old building" is"bind it together with iron where it loosens; stay it with timber where it declines; do not care about the unsightliness of the aid: better a crutch than a lost limb".

Obviously, however, intervention is only admissible to guarantee the survival *in toto* both of the monument's material fabric and of the spiritual values, which it embodies. Otherwise we will not be prolonging the life of the monument but setting up a"dishonouring and false substitute" in its place.

Restoration is a technical undertaking that (as the Venice Charter states) requires the contribution of all sciences and technologies. These, however, do not intervene as auxiliary disciplines. Restoration is never the product of the isolated contributions of different disciplines, but by virtue of its own autonomy as a discipline provides the guidelines which each of the other disciplines involved must follow in order to reach the shared goal of Conservation.

In the case of the Leaning Tower – perhaps more so than in other cases – the principal problem posed the planning of its restoration was not so much the analysis of the monument and its subsidence, as the comparative evaluation of the various kinds of intervention considered, in which all individual areas of competence had to measure themselves against the principles of conservation. It was necessary to establish what risks would be run, both in the case of an absence of intervention and in that of each of the possible interventions considered – risks which might consist not simply in the Tower's collapse but also in the modification of its physical and material substratum. In the case of the Tower, the evaluation of risk was rendered even more difficult by the close relation between the terrain underlying the monument and the structures aboveground, so that even intervention limited to the terrain or to the water table would entail a high risk of provoking the Tower's collapse.

This difficulty of determining the risks involved (even more than that of finding suitable methods) was the major problem encountered in drawing up the plan for stabilising and restoring the Tower. And it may be for this reason that for several decades the various Committees appointed failed to reach the necessary final decisions.

Sixty years after Giovannoni pointed out that this was an opportunity for"the application of modern science and technology", the courage was found to act, even in the face of all those risks which t he vulnerability of all human activity renders inevitable.

*** The Committee**

Sixteen government commissions have studied, measured and worried over this Italian symbol for years, until the current international committee was put in place in 1990, with a mandate finally to take action. The present International Committee for the Safeguard and Architectural Restoration of the Leaning Tower of Pisa was appointed by the Italian Prime Minister on May 1990, based on a Law voted by the Parliament.

The Committee, a multidisciplinary body was composed of the following international scientists:

J. Barthélemy (Belgium) Architect, Expert on Preservation and Restoration of Monuments

J.B. Burland (UK) Geotechnical Engineering
M. D'Elia (Italy) Expert in Preservation and Restoration of Monuments
R. Di Stefano (Italy) Expert in Preservation and Restoration of Monuments
R. Calzona (Italy) Structural Engineer
G. Creazza (Italy) Structural Engineer
G. Croci (Italy)) Structural Engineer
M. Jamiolkowski (Italy) Geotechnical Engineer
G. Macchi (Italy) Structural Engineer
A.M. Mignosi (Italy) Expert in Preservation and Restoration of Monuments
L. Sanpaolesi (Italy) Structural Engineer
S. Settis (Italy) Expert in Medieval Art and Archaeology
F. Veniale (Italy) Mineralogist, Expert in Construction Stones
C. Viggiani (Italy) Geotechnical Engineer
Other distinguished Experts have served the Committee in the past:
M. Cordaro (Italy) Expert in Preservation and Restoration of Monuments
M. Desideri (Italy) Structural Engineer (until 1995)
F. Gurrieri (Italy) Architect (until 1992)
R. Lancellotta (Italy) Geotechnical Engineer (until 1996)
G.A. Leonards (USA) Geotechnical Engineer
R. Lemaire (Belgium) Expert in Preservation and Restoration of Monuments
F. Leonhardt (Germany) Structural Engineer
A. M. Romanini (Italy) Expert of Medieval Art

Overall, the Committee met every six weeks to take decisions as far as the execution of studies, the approval of design documents and the implementation of works were concerned. Reunions of a limited number of experts were held at regular intervals aimed at developing and preparing the documents to be approved during the plenary meetings.

For each important activity one or two member were appointed as scientific responsible. Some of the most relevant decision taken by the Committee were steered by the following members:

Cable Stay Safeguard Structure v J.B. Burland (UK)
Geotechnical Engineering
M. D'Elia (Italy) Expert in Preservation and Restoration of Monuments
R. Di Stefano (Italy) Expert in Preservation and Restoration of Monuments
R. Calzona (Italy) Structural Engineer
G. Creazza (Italy) Structural Engineer
G. Croci (Italy) Structural Engineer
M. Jamiolkowski (Italy) Geotechnical Engineer
G. Macchi (Italy) Structural Engineer
A.M. Mignosi (Italy) Expert in Preservation and Restoration of Monuments
L. Sanpaolesi (Italy) Structural Engineer
S. Settis (Italy) Expert in Medieval Art and Archaeology
F. Veniale (Italy)) Mineralogist, Expert in Construction Stones
C. Viggiani (Italy) Geotechnical Engineer
Other distinguished Experts have served the Committee in the past:
M. Cordaro (Italy) Expert in Preservation and Restoration of Monuments
M. Desideri (Italy) Structural Engineer (until 1995)
F. Gurrieri (Italy) Architect (until 1992)
R. Lancellotta (Italy) Geotechnical Engineer (until 1996)
G.A. Leonards (USA) Geotechnical Engineer
R. Lemaire (Belgium) Expert in Preservation and Restoration of Monuments
F. Leonhardt (Germany) Structural Engineer
A. M. Romanini (Italy) Expert of Medieval Art

Overall, the Committee met every six weeks to take decisions as far as the execution of studies, the approval of design documents and the implementation of works were concerned. Reunions of a limited number of experts were held at regular intervals aimed at developing and preparing the documents to be approved during the plenary meetings.

For each important activity one or two member were appointed as scientific responsible. Some of the most relevant decision taken by the Committee were steered by the following members:

- Cable Stay Safeguard Structure: R. Calzona and L. Sanpaolesi
- Structural Strengthening : G. Croci and G. Macchi
- Under-excavation : J.B. Burland and. C, Viggiani
- Design and Technical Specifications of Architectural Restoration : M. D'Elia and R. Di Stefano
- Data Bank, Web Site, Special Volume summarising the works

of the Committee: S. Settis.

Moreover, M. Jamiolkowski chaired the Committee and R. Di Stefano acted as responsible for contractual obligation with respect to contractors operating on site.

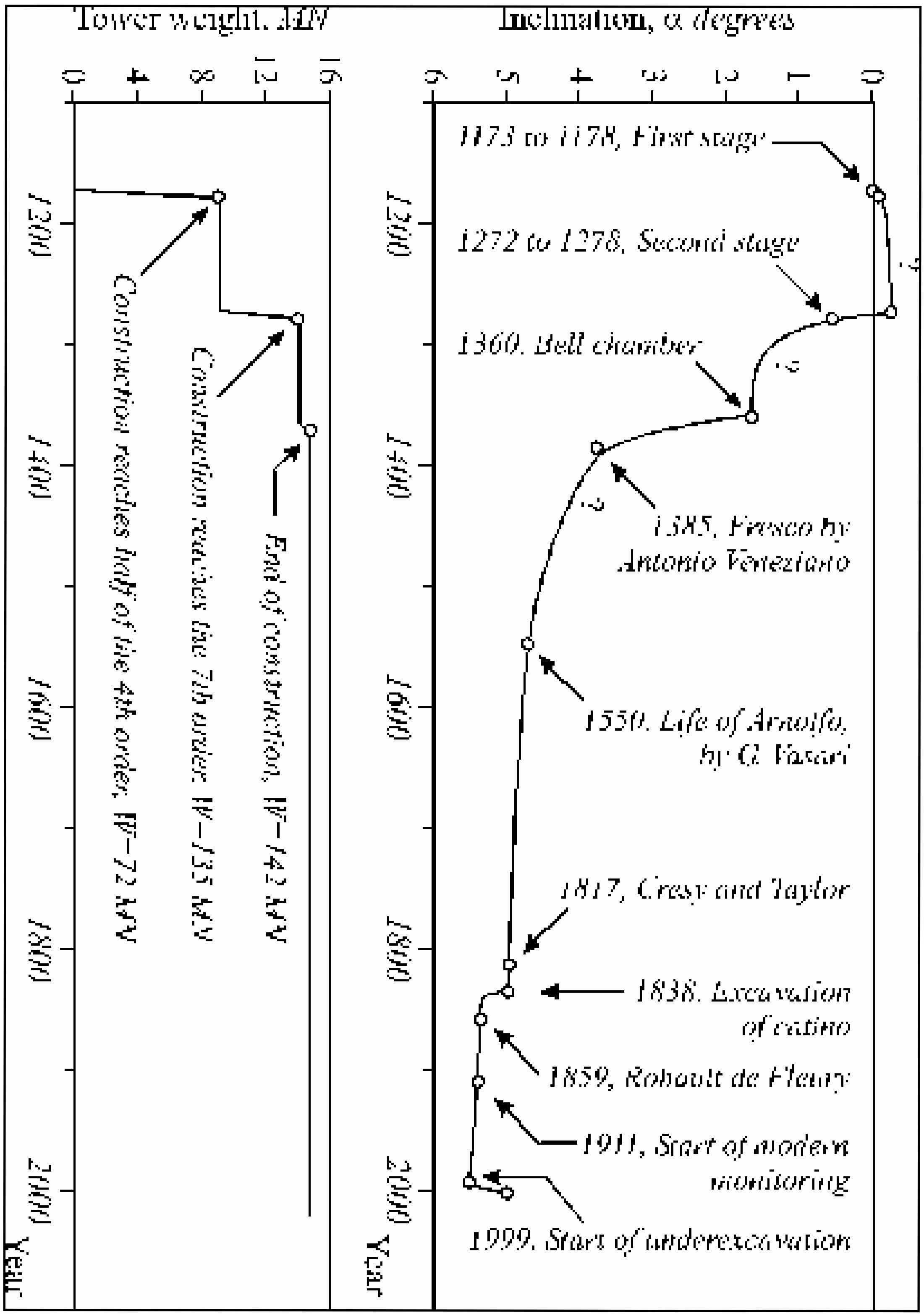

Fig. 1 - History of the Tower's inclination.

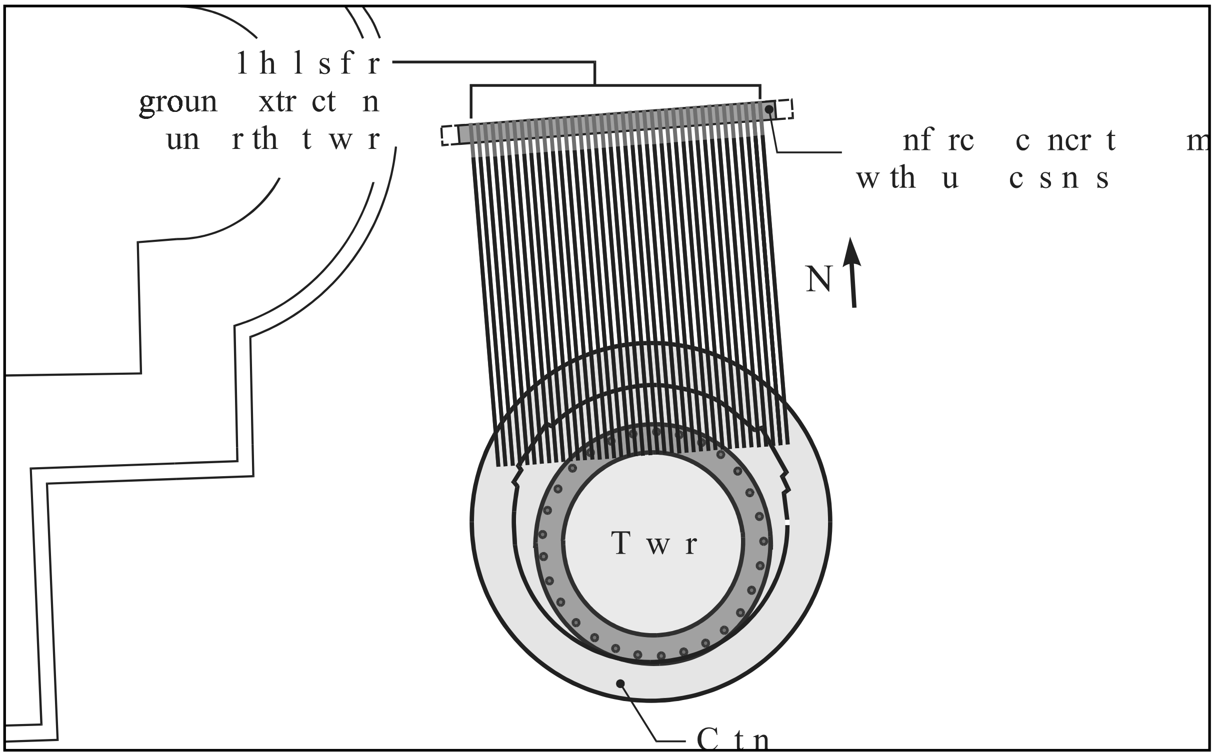

Fig 2 - Final underexcavation scheme.

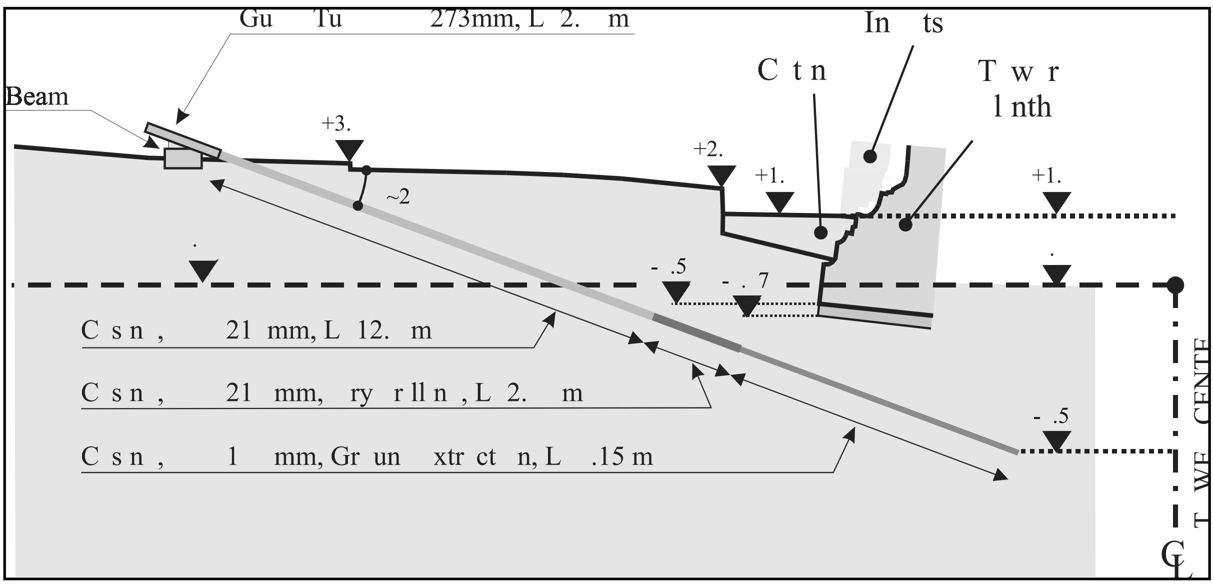

Fig 3 - Hole for soil extraction - Full underexcavation.

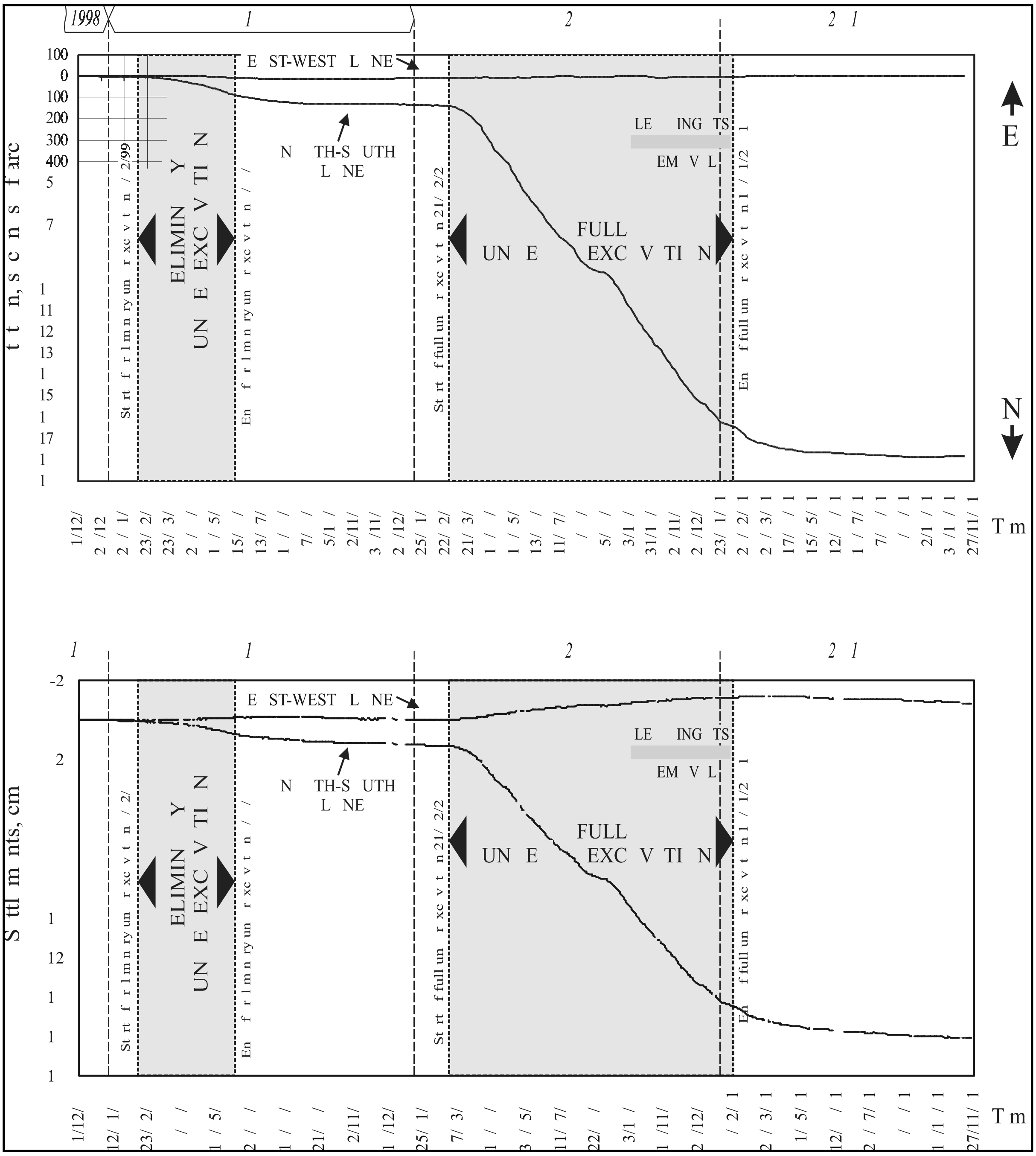

Fig. 4 - Results of full underexcavation.

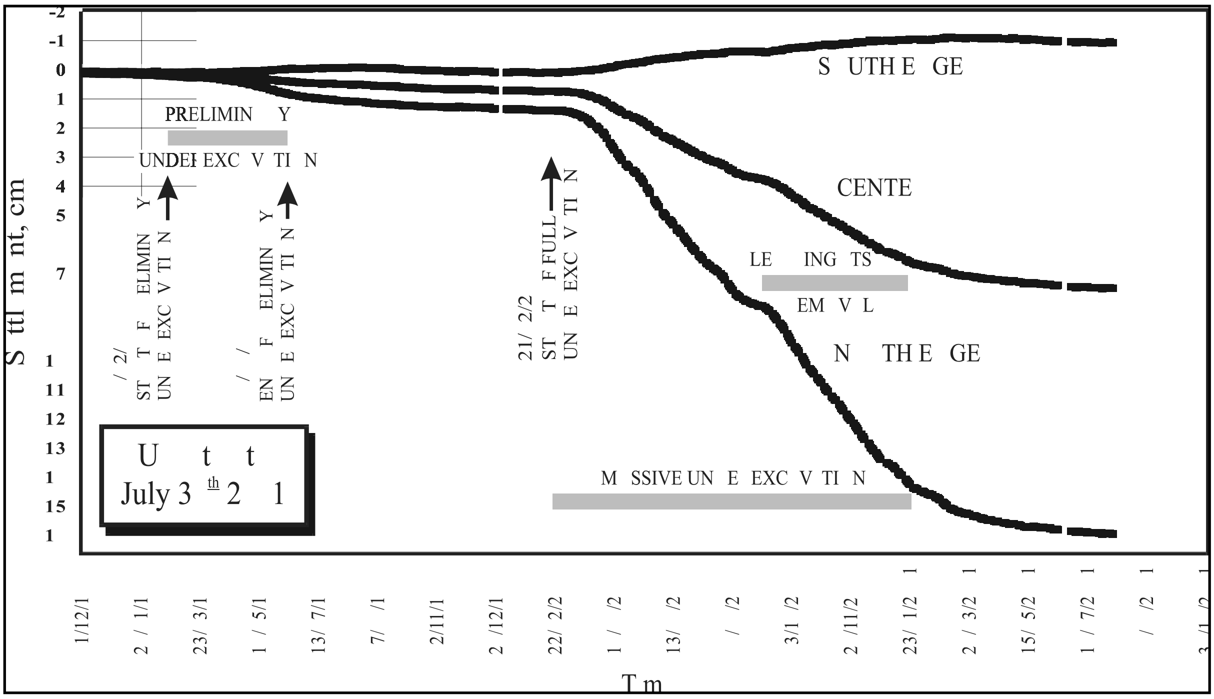

Fig. 5 - Results of full underexcavation

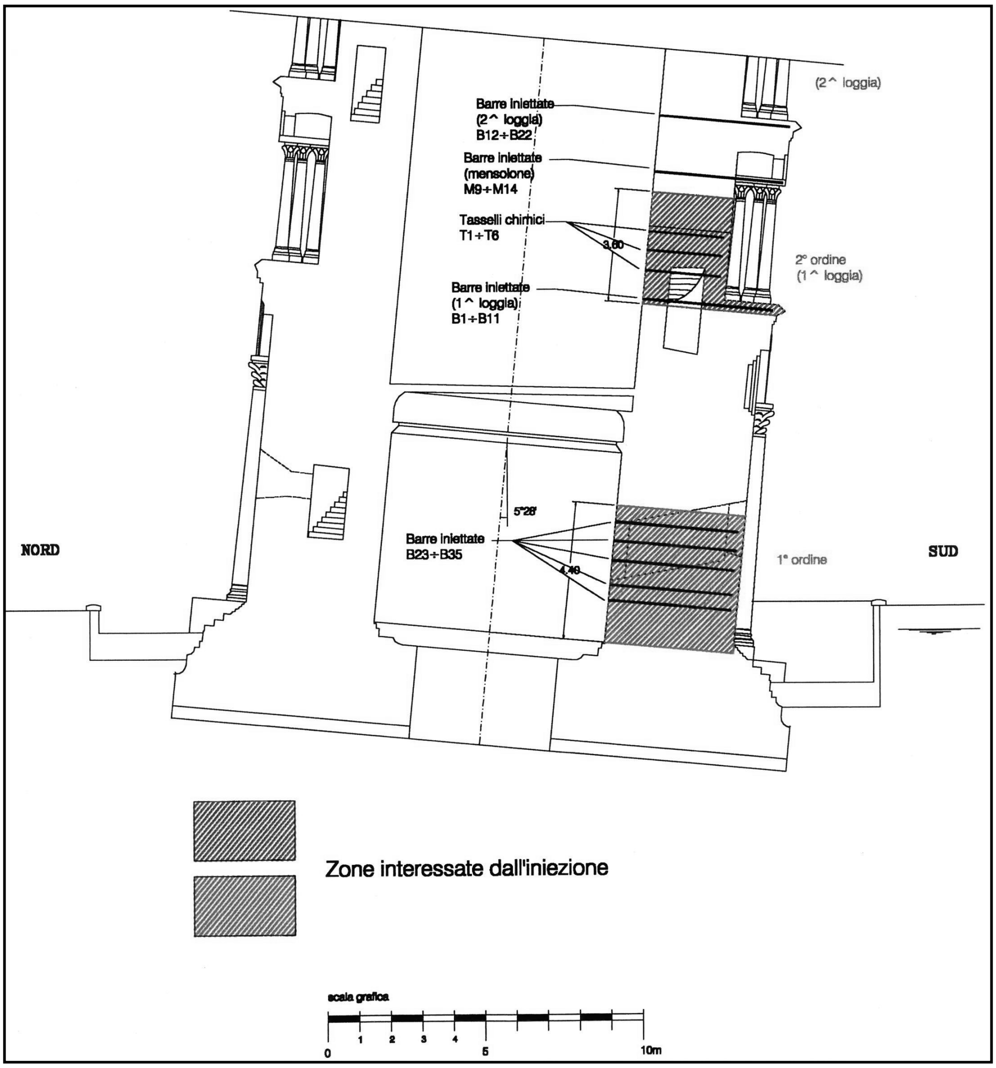

Fig. 6 – North-South section: view of the intervention by inox bars and grouting.

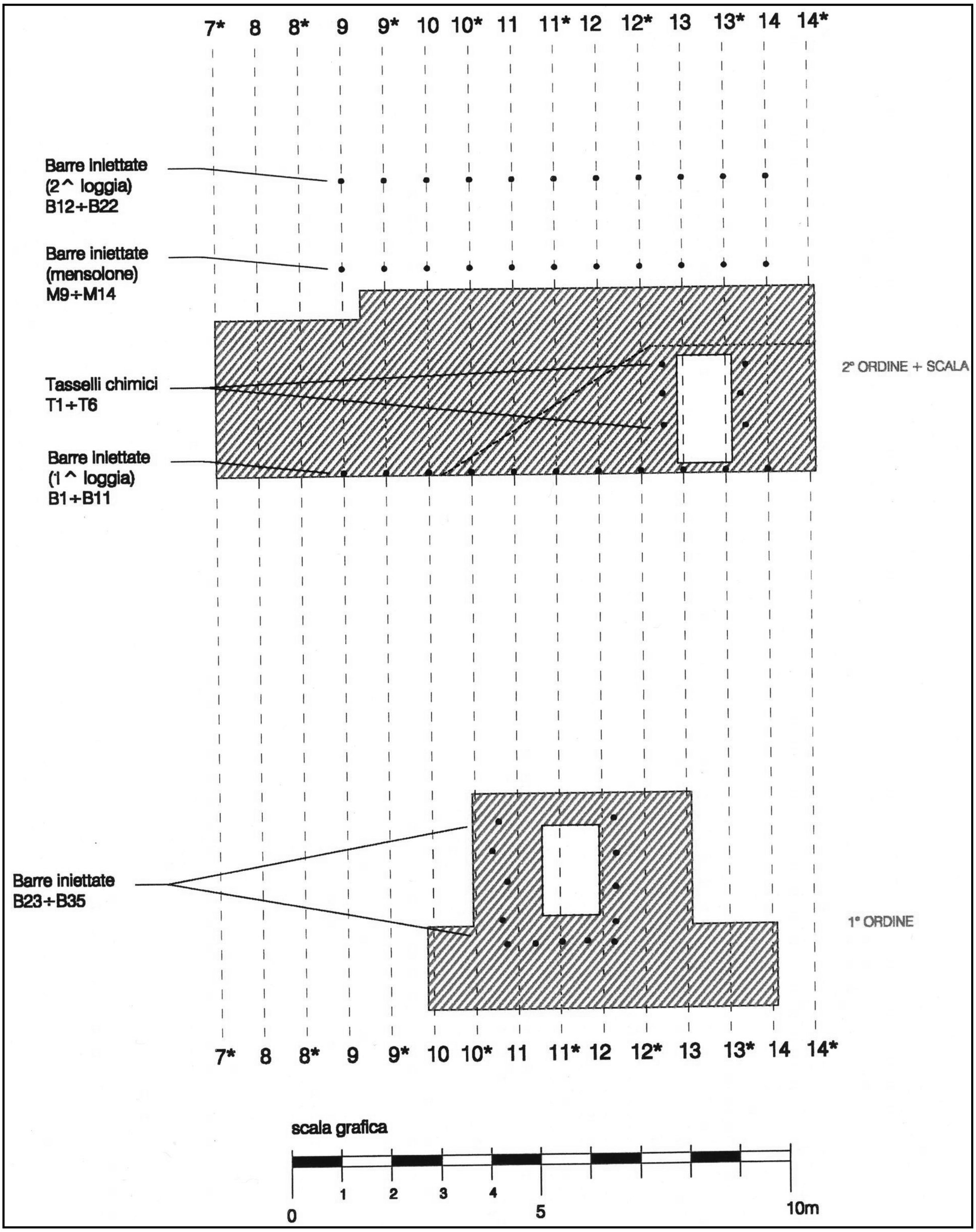

Fig. 7 – Global view of the intervention by inox bars and grouting