Structural Analysis of Historical Constructions, New Delhi 2006
P.B. Lourenço, P. Roca, C. Modena, S. Agrawal (Eds.)

Injuries, Past Repairs and Conservation Views for Stabilization of Sakyamuni Tower, China

Beatrice Messeri
IMT-Technology and Management of Cultural Heritage, Lucca, Italy

Gennaro Tampone
University of Florence, Department of "Restauro e Conservazione dei Beni Architettonici", Florence, Italy

Giacomo Tempesta
University of Florence, Department of "Costruzioni", Florence, Italy

ABSTRACT: The Tower is an extraordinary example of the oldest (XI century) and tallest (67 m average) timber building existing, designed with an innovative structural solution. The present paper deals with the assessment of structural behaviour, the efficacy of the cited repair works carried out and the real stability condition of the Tower; this is made the performing of static and dynamic analyses. One of the main aims is to individuate the vulnerability areas, predict the kind and severity of failure and to choose topic repairs without altering the original con-

1 HISTORICAL BACKGROUND

1.1 Conservation theories in Chin

The first activities of identification and appreciation of the monumental buildings in China were started in the Thirties of the XX century by a small group of illuminated people directed by Liang Sicheng and Liu Dunzhen; to this group and its followers we owe the first official list of monuments draft in 1961with a synthetic indication of the principal characteristics of the most important monuments. During the period from the 1950s to the 1990s the first bills on conservation of the relics were issued and the number of conservation projects increased considerably.

The *UNESCO Convention Concerning the Protection of the World Cultural and Natural Heritage* (1972) states that also China was involved in the concern for the ancient buildings and in up dating the theoretical thoughts; that the Country was therefore able to bring an important contribution in the international setting. Nevertheless, the principles on which the laws were relying on changed from case by case depending on the peculiarities of the monuments, this way proving the lack of criteria of general validity.

In 1982 the National People's Congress promulgated the *Law of the People's Republic of China on the Protection of Cultural Relics.*

Only in 2002 an official document: *Principles for the Conservation of Heritage in China*, issued by Chinese Committee of ICOMOS and approved by the State Administration of Cultural Heritage, clarified some aspects. The purpose of the document is to disseminate a series of professional guidelines for the heritage conservation, especially for the technical Officers of the far Communities of the immense territory. The document was also meant to change the trend followed in the provincial areas where in general the repair interventions on the monumental buildings, the consolidations and the adaptation works were accomplished by people and civil or religious communities with no definite plan, no reference to real conservation purposes but dictated from the necessity of their use or generic desire of renewal.

The last documents are *Principles for the Conservation of Heritage Sites* and the *Xi'an Charter* (ICOMOS 2005) which takes in consideration the main international documents as the *Venice Charter*. The *Nara Document on Authenticity* (1994) is extremely important because the theoretical statements of the Scholars who attended the Meeting try to conciliate the different positions of the Western Countries with those of the Eastern ones. Also important were the *Hoi*

An Declaration on the Conservation of Historic Districts in Asia (2003), the *Declaration on the Recovery of Bam's Cultural Heritage* (2004) and the *Seoul Declaration on Tourism in Asia's Historic Towns and Areas* (2005) and the *UNESCO Convention*.

The main purpose of the Xi'an Charter is: "*Stressing the need to address adequately the rapid or incremental transformation of cities, landscapes and heritage routes which result from changes in lifestyle, agriculture, development, tourism or large-scale disasters of natural or human origin, and to recognise, protect and sustain adequately the meaningful presence of heritage structures or sites in their settings as a way to reduce the threat these transformation processes constitute against the cultural heritage in the full richness of its authenticity, meaning, values, integrity and diversity". Another fundamental subject is "the establishment of buffer zones, and the ongoing opportunity this brings for international and interdisciplinary cooperation between ICOMOS, UNESCO and other partners".*

The document stresses that the setting of a structure, site or area characterizes the heritage and gives a specific significance and distinctive peculiarities; that to understand the setting "*requires a multidisciplinary approach*" and concerns the tangible and intangible values.

This document gives some general indications of the heritage's safeguarding and recalls some international principles to maintain it, as the constant monitoring and an accurate management.

For the conservation of the sites the most accurate document is *Principles of the Conservation of Heritage Sites* which contains a close analysis of the management of the sites and the kind of works allowed. It lists four types of interventions: regular maintenance, physical protection and strengthening, minor and major restoration; but a search in the document for critical assessments and ethical criteria of conservation would be vane. On the contrary it should be recognized that a few categories, abandoned since long by the western approach conservation philosophy, such as reconstruction of the sites condition and reconstruction of the buildings, are encouraged.

It must be stressed out, anyway, that most of the Chinese Operators of this sector do not share the opinion that the operation "to reinstate the historical conditions" is correct because it could be arbitrary and against the preservation of the historical witnesses.

The Chinese documents are similar only in the shape to those of the western culture of conservation but not in the spirit. Actually, the documents can be considered only as declaration of principles and a simplification of the possible interventions, besides they are permissive of many kind of modification, alteration, partial or total replacements.

Then, only the good quality of the materials, the sound building techniques and the lack of maintenance in the centuries allowed the monuments to survive safely, like the Sakyamuni Tower, with no substantial alterations.

Paradoxically, the increased attention to the monuments in China could be deleterious, as it happened in the past in the Western Countries; the crude necessities of political propaganda, the increase of financial funds and other circumstances, together with the technical progress, could produce severe damage to the heritage.

In some other Far East countries, distant by the awareness of the principles explicated in the Athens Charter (1931) and in the Venice Charter (1964), the conservation was mostly oriented to preserve the spiritual witnesses, according to the esthetical and formal conception; generally only a minor concern is attributed to the material consistency of the monuments, to the intrinsic values of the artistic and constructive techniques.

1.2 Conservation of the architectural heritage in Italy

It is interesting to start some comparisons. In Italy the modern approach to the architectonical conservation is due to Artists and Architects as Antonio Canova, Raffaello Stern, Giuseppe Valadier and others.

Important principles were expressed in the III Congresso degli Ingegneri e degli Architetti, 1883 when the so called *Prima Carta del Restauro Italiano* was issued.

The first "Instructions" (*Istruzioni per il restauro dei Monumenti, Ministero della Pubblica Istruzione*) with clear principles, were issued in 1938, just a few years after the Athens Charter, for the Officers of the Authority for Monuments who were having an official practice on the monuments and doing a control activity. The Gustavo Giovannoni's activity was fundamental in

this field. In the same period, 1939, were issued the two fundamental laws on the safeguard of artistic, historical and natural heritage and on the landscape.

Between the two world wars, there was a period of transition; several questionable interventions were made with the demolition of the most modern parts of the ancient buildings with transformation of their disposition and appearance; this mainly happened to plenty of religious and archaeological architectural complexes. The transformations made, justified or not in the planning phase, found their legitimacy, in the majority of the cases, in the necessity of reconstruct damaged parts of the monuments and in the discovery and the valorisation of artistic elements (pictures, decorative cycles, even sculptures, architectonical elements, earlier building phases) which were concealed under the added parts. Generally, the very large quantity of discoveries leads to the re-composition of the essential parts of the monuments, mainly relying on imagination more than on documented data.

This questionable practice, extended to all the national territory, contributed indirectly but decisively, to clarify the general intervention criteria. Nowadays there is an alignment to the international principles and an updating of the local laws.

The situation in the other countries was not so different: Victor Hugo in France, John Ruskin and William Morris in England and Alois Riegl in Austria, with many other scholars, from the XIX century contributed to the elaboration of the safeguard and conservation principles.

2 THE TOWER

2.1 General description of the Tower

The Sakyamuni Tower (Yingxian, Shanxi province) was built inside the Fogong temple during the Liao dynasty (1056; C14 confirms the period).

Since 1961, the Tower has been inscribed in the list of the most important historical relics under the protection of the State but until now it is not in the UNESCO's World Heritage list.

The Tower (with a pagoda shape) presents a stone podium, a body made of larch wood with an iron spire that reaches a remarkable height; it has an octagonal plan with the diameter of 30 metres at the ground-floor that decreases going up to the top. In the middle, in the main stories, there are a series of Buddha statues.

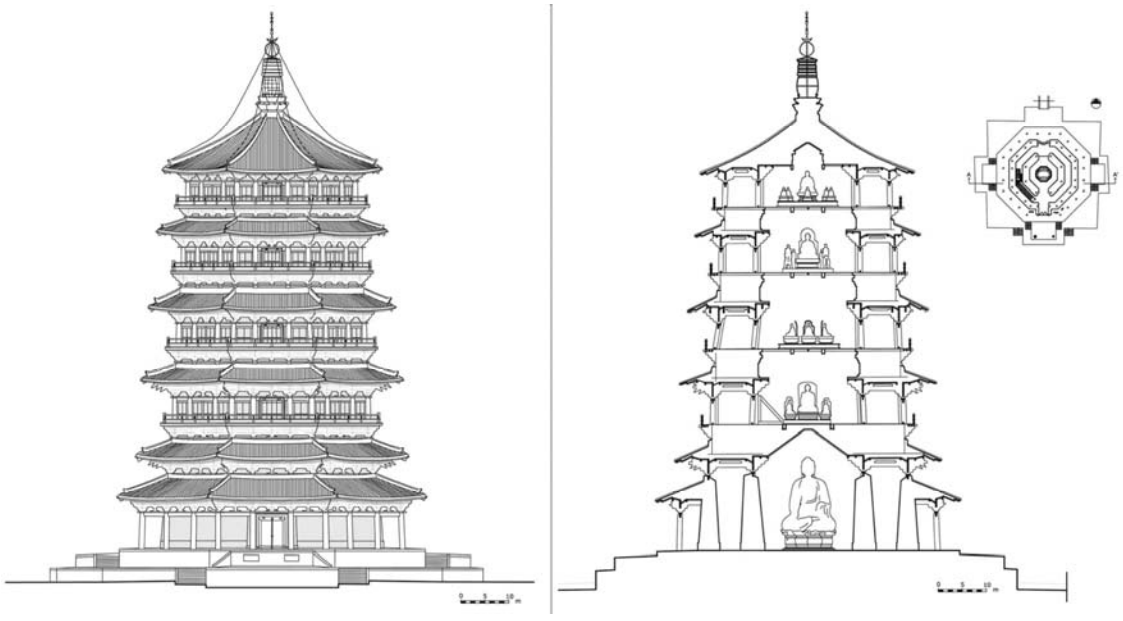

Figure 1 : South elevation and Transversal section A-A' Sakyamuni Tower (B. Messeri)

The Tower is composed by five main stories and four self-bearing mezzanine stories that give stability to the structure. It was designed with an innovative structural solution, because in the middle of the body there is no central mast like other similar ancient towers. This configuration is used only in two ancient wooden monuments, the Sakyamuni Tower and the Guanyin Hall situated in the town of Jixian.

One of its main peculiarities is the large number of *puzuo* (bracket systems or bracketing unit on the top of the columns); they are 416 totally and they are combined in 54 different ways to be adapted to different dimensions and structural positions (Messeri and Tampone 2005).

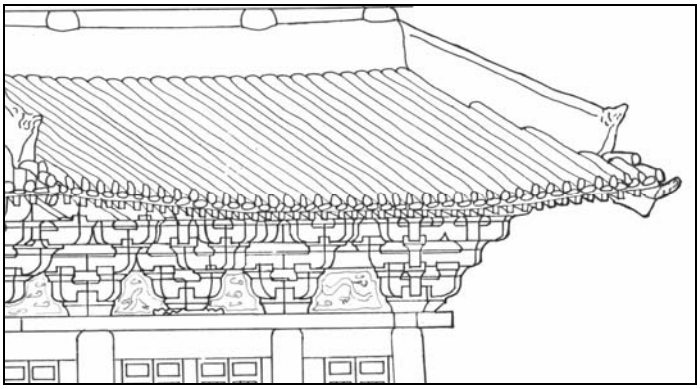

Figure 2 : *Puzuo* of the second story, located on south-west (B. Messeri)

2.2 Consolidation works

During the long life of the Pagoda a lot of calamities hit the building leaving tangible traces. The bomb attacks, the earthquakes, the natural decay, in addition to the bad restoration works, compromised the stability of the structure. For instance, the 1989's earthquake made severe damage to the structure.

It is believed that the general appearance of the Tower is not so different from the 1056 construction, and all the consolidation interventions carried out in the past were aimed to reinforce the structure and to give a more rational distribution of the loads. Reassuming, it can be said that the principal changes were carried out in the years 1191-1195, 1320, 1508, 1722, 1866 (Messeri 2005). The scientific and documental investigations and the interpretation of the plaques in the temple were fundamental in the reconstruction of the Pagoda story.

After that, the destruction of some parts of the external *puzuo* and the finial made by the shots fired to the Pagoda in 1926 by the Japanese Army, were restored in 1928-1929 with the disassembling of the *puzuo* and the replacement of some parts. The majority of the works were not very invasive or destructive, except for those executed after 1933 that generated instability in the Tower; the main task of these works, which consisted in replacing the earthen walls with wooden lattice doors in the main stories, was to connect the outside of the Tower with the inside and reduce the load on the bottom of the structure.

The technical alterations, especially by a structural point of view, and the modification of the interior atmosphere of the many stories were remarkable: the structural system was deeply weakened for the loss of big inertial mass and the rigidity of the walls, the same atmosphere of twilight and mystical concentration that characterizes the inside of the Tower was partially destroyed with the breaking in of the light. Also the exterior appearance of the Pagoda changed remarkably.

Furthermore in the Fifties the triangular system of wooden braces on the first floor were connected to the columns by iron rings in the central part of the first story to contrast the inclination of the columns. Other minor interventions were executed to the vertical and horizontal members with the insertion of metallic joints, as well as the replacement of ruined parts with new ones.

But on the whole the structure can be considered authentic.

2.3 Present state: structural problems and perspective of conservation

The most important problems detected in the Tower are the *puzuo*'s deflection and the *pupai-fang* beam rupture, especially at the lowest stories, the local failures in many parts, some biological attacks and the rotation of the complete structure around its vertical axe.

The torsion occurs in the direction north-east and the columns of the first story are inclined 1/10 of the total height. According to the Chinese Conservation Centre for Monuments and Sites, the main reason of these damages were the bomb explosions but surely the earthquake shocks; the replacement of walls contributed in a significant measure. The triangular system of wooden braces used as reinforcement on the first floor solved the problem partially, because the original stiffness of the walls has not been actually re-established. In spite of the long survival influences the stability of the Tower, with the decay of the wood, the good quality of wood used, the larch, and the well advanced construction system allowed the survival of the structure.

The different use requirements at different times gave place to different dispositions of the buildings in the whole complex and lead to the demolition of parts and the reconstruction in some cases. The wars, the earthquakes, political choices and other events changed the configuration and the dimensions of the temple. Also during the XX century some demolitions of the external pray halls are recorded; perhaps they were made to recreate the ancient disposition with the Tower dominating the temple. As one can infer from the study of other cases, this phenomenon was diffused for a certain period of time in China, in fact only the main buildings escaped severe injuries or total ruin.

2.4 Analysis of the structural behaviour

To examine closely the structural system of the Tower, an analysis of the structure through FEM elements using the numerical codex Straus 7 has been performed. The structural model of the Tower has been defined with mono-dimensional elements (*beam* type) and bi-dimensional elements (*plate/shell* type) adequately positioned. The ground-floor earthen walls are defined with *plate/shell* elements, whereas the timber structure by *beam* elements. In the specific case the calculation of the building's self weight considers the density of the larch wood and those of an earthen nucleus for the ground-floor wall.

The Pagoda's base is supposed to be connected with the soil by spherical hinges; the internal connections between the members are schematised as fixed joints.

Some simplifications to the complex structural frame have been introduced even though the original assets are respected.

Table 1 : Mechanical Characteristics of the materials used for the calculation

Material	Modulus of elasticity N/cm^2	Density kg/cm^3	Thermal Expansion $°C^{-1}$
larch	1.40×10^6	6.50×10^{-4}	3.50×10^{-6}
raw earth	1.50×10^6	2.10×10^{-3}	1.00×10^{-5}

Table 2 : Structure self weight and overload

Timber buiding weight kN	Earthen walls weight kN	Overload kN
6678	47295	2795

The *puzuos* have been considered singularly as concentrated loads applied over the columns, the Buddha statue weight, the wood flooring weight, the pitches and the pinnacle weight have been put in as distributed load.

The model was used for both a general static analysis and a simplified dynamical analysis defined by an horizontal acceleration comparable to a medium-high intensity earthquake.

The application of such a dynamical load shows that the first story of the building is very strained and that some pillars undergo a rotation; as well the second story presents some remarkable stresses.

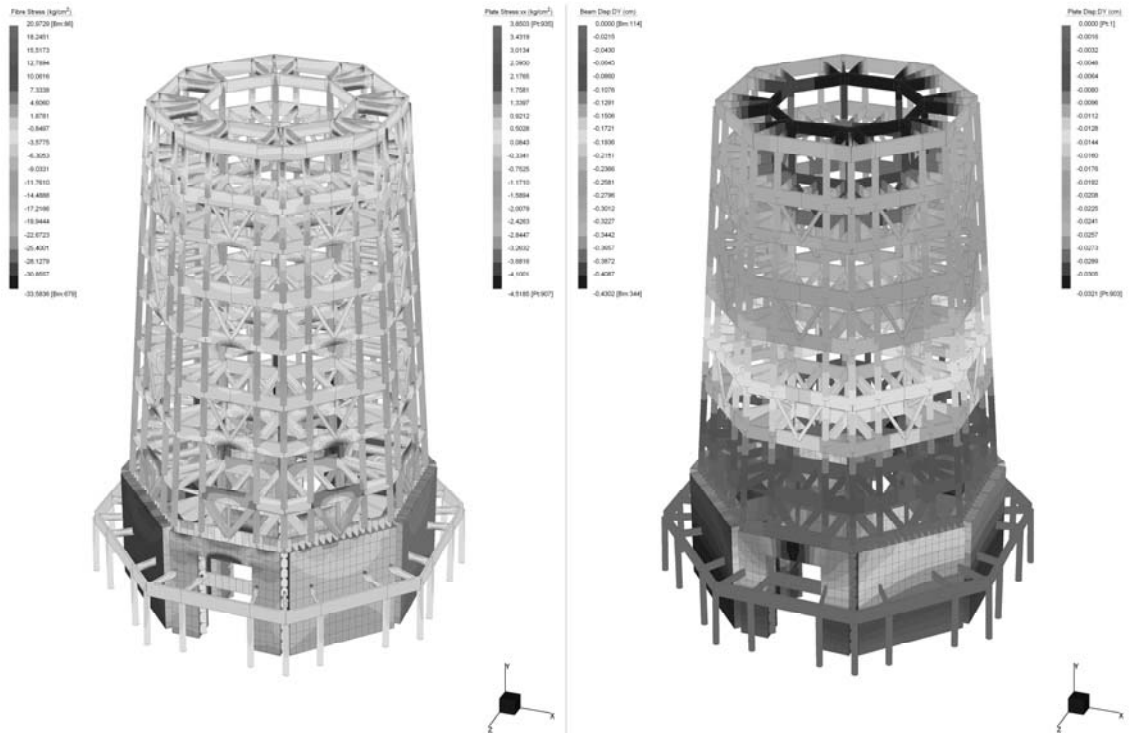

Figure 3 : Numerical model of the Sakyamuni Tower. Structure subjected to static loads. State of stress (left). Vertical displacements (right) (B. Messeri)

Table 3 : State of stress and displacements

Structure under the action of self weight and accidental loads		Structure under the action of self weight, accidental loads and medium-high earthquake		
Beam stress N/cm^2	Beam displacement max (y) cm	Beam stress N/cm^2	Beam displacement max (y) cm	Beam displacement max (zx) cm
205.67 -329.34 (internal pillars of the first story)	-0.43	434.77 -907.55 (external pillars of the first story)	-0.46	1.69

The initials intuitions about the real structure behaviour (Messeri and Tampone 2005, Messeri 2005) are confirmed by the numerical FEM analysis.

In fact the comparison between the behaviour of the model, in terms of general deformations (with dynamical loads applied) and the actual behaviour of the structure shows some analogies, which prove that the modelling is well fitting.

It should be noted that the structure has a peculiar anti-seismic conception, the fundamental period of vibration of the Pagoda is different from the predominant period of the soil, besides the suitable octagonal shape of the plan which makes symmetrical the configuration, the ductility of the system due to the use of wood with the damping effect, the comparatively light weight allowed the Pagoda to be preserved during the ages (Shiping Hu 1991). In fact, the documented conservation activity proves that the building was never seriously affected with structural failures.

We can deduce that the removal of the earthen walls of the main stories was a wrong and risky choice.

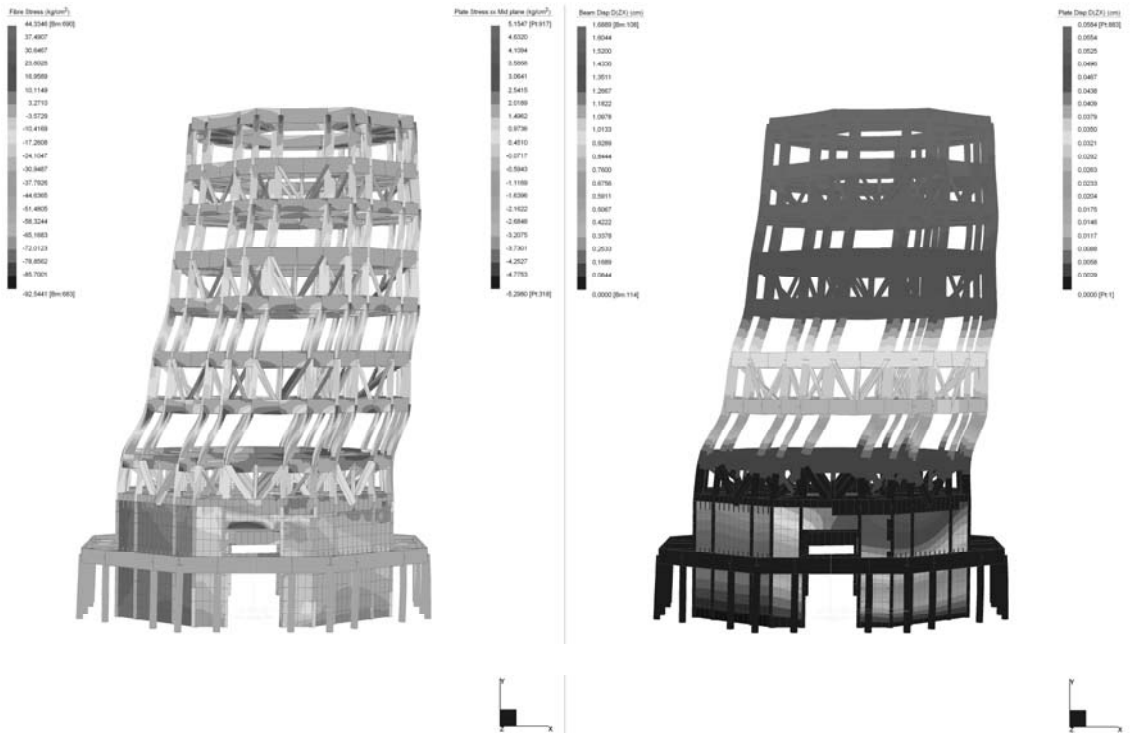

Figure 4: Numerical model of the Sakyamuni Tower. Structure subjected to static loads and to medium-high earthquake. State of stress (left). Displacements on zx direction (right) (B. Messeri)

2.5 Perspectives of conservation

The first task is to safeguard the whole area of the temple and the space around it creating a buffer zone where to include also the ancient wooden temple Jingtu with an example of interesting *zaojing* (type of coffer) dome; thus a general plan of the district is necessary to safeguard the monuments and the environment like the *Xi'an Charter* prescribes. The scholar Liang Sicheng described the relationship between the environment and a single or a group of historic monuments by saying "even the most beautiful flower needs green leaves to highlight its beauty". Some decisions of the local Authorities to organize the access to the temple with a commercial street are therefore wrong for the importance of the temple.

The other buildings inside the Fogong temple only need minor interventions.

The Tower kept, at least partially, its original look in the centuries. A meticulous survey of the building should be made in order to design well conceived and balanced solutions for its conservation.

Some scholars proposed in the past the complete dismantling of the structure but this kind of intervention is inconceivable because an enormous loss of timber, building knowledge and material elements would follow. Furthermore there are no real reasons to actuate such a radical measure. In the Chinese report on the Tower (by the Chinese Conservation Centre for Monuments and Sites, 2000) three types of methods for the conservation of this building are suggested: 1. Strengthening of the original components in order to recover or increase their resistance and endurance; 2. Replacement of the damaged components with new components; 3 Partial restoration, some new reinforcing components are added to increase strength of those that have lost their original strength so as to reduce their load".

Among them the third one seems to be the most suitable to the case. From the analysis of the structural model loaded only with the static actions it is possible to deduce that the structure is under a complex of stresses the values of which are minor of the admissible tensions for the larch wood; the repair of the damaged single members should be included in the first phase. The problem of the rotation of the Tower and the vulnerability to seismic events should be faced with adoption of measures such as the application of a series of wind-bracings at the first and second floor and possibly, as a prevention measure, at the upper stories. The openings need

stiffening too. The stiffening devices should be added with the interposition of shock absorbers, very useful in case of seismic events.

REFERENCES

Agnew N., Demas M., 2002, *Principles for the Conservation of Heritage Sites in China*, Los Angeles-Getty Conservation Institute ICOMOS-China, Los Angeles: The Getty Conservation Institute

Chinese Charter on the Restoration, *Conference on the Conservation and the Development of the small and Medium Monumental Towns*, 1983, Yangzhou

Ceschi C., 1970, *Teoria e storia del restauro*, Roma: Bulzoni

Chen Mingda, 1980, *Wooden Pagoda in Ying County*, Beijing: Wenwu Chubanshe

Chinese Conservation Centre for Monuments and Sites, 2000, *A Brief Introduction to the Wooden Pagoda in Yin County, Shanxi Province*

Clought R. W., Felippa C. A., 1968, *A Refined Quadrilateral Elements for Analysis of Plate Bending. Proceeding of the Second Conference on Matrix Methods in Structural Mechanics*, Ohio: Wright-Patterson Air Force Base

Gridley M. L., *Images from Shanxi of Tejaprabha's Paradise*, sta in: *Archives of Asian Art* produced by the Asia Society, LI, anno 1998-1999, p. 7-15 (British Library, London)

Guo Qinghua, 1999, *The Structure of Chinese Timber Architecture. Twelfth Century Design Standards and Construction Principles*, London: Minerva Press

Gurrieri F., 1992, *Restauro e conservazione. Carte del Restauro, Norme, Convenzioni e Mozioni sul patrimonio architettonico ed artistico*, Firenze: Polistampa

International Charters for Conservation and Restoration Introduction by Michael Petzet, 2004, Paris: ICOMOS

Jokiletho J., 1999, *History of Architectural Conservation*, Oxford: Butterwoth Heinemann

Larsen K. E., Marstein N., 2000, *Conservation of Historic Timber Structures. An Ecological Approach*, Bath: Butterworth-Heinemann

Leddderose L., 1997, *Ten Thousand Things. Module and Mass Production in Chinese Art*, Princeton: Princeton University Press

Messeri B., Tampone G., 2005, *La straordinaria Torre del Budda Illuminato (Sakyamuni) di Yingxian nella provincia dello Shanxi* in: *International Conference on the Conservation of the Ancient Wooden Structures. Proceedings (edited by Gennaro Tampone*), Florence: Collegio degli Ingegneri della Toscana, I vol., pp.176-192

Messeri B., 2006, *La naissance du concept de patrimoine en Chine, XIX-XX siècles di Zhang Liang. Recensione*, ANANKE n. 47, January 2006

Messeri B., January 2006, *La conservazione in Cina oggi. Considerazioni sui documenti ufficiali e su alcuni cantieri* , ANANKE n. 47

Messeri B., 2005, *L'antica Torre del Budda Illuminato a Yingxian, Cina. Riparazioni compiute in passato e prospettive di stabilizzazione*, Bollettino degli Ingegneri della Toscana, November-December 2005 n° 12, pp.11-20

Principles for the Conservation of Heritage Sites in China, ICOMOS 2004, XV ICOMOS General Assembly- Scientific Symposium ICOMOS, Xian, 17-21 October 2005

Proceedings of ICOMOS 15th General Assembly and Scientific Symposium, 17th-21st October 2005, Xi'an (China) vol.1-vol.2, 2005, Xi'an: World Publishing Corporation

Rowe G. P., Kuan Seng, 2005, *Architectural Encounters with Essence and Form in Modern China*, Cambridge-London: Mit Press

Steinhard Shatzman N., 1997, *Liao Architecture*, Honolulu: University of Hawaii Press

Shiping Hu, *The Earthquake-Resistant Properties of Chinese Traditional Architecture*, in: "Earthquake Spectra" n°3, anno 1991 (VII), pp. 355-389

Xi'an Declaration on the Conservation of the Setting of Heritage Structures, Sites and Areas, XV ICOMOS General Assembly-Scientific Symposium, Xi'an, 17-21 October 2005

Tampone G., 1996, *Il restauro delle strutture di legno*, Milano: Hoepli

Zienkiewicz O. C., 1971, *The Finite Element Method in Engineering Science*, London: Mc-Graw Hill

Zienkiewicz O. C., Morgan K., 1983, *Finite Elements and Approximation*, New York: John Wiley

Zhang Liang, 2003, *La naissance du concept de patrimoine en Chine XIX-XX siècles*, Paris: Éditions Recherches-IPRAUS-Collection: Archithèses