

# COMPLIANCE OF THE PRACTICE OF STRENGTHENING ANCIENT TIMBER STRUCTURE IN SEISMIC AREAS WITH THE OFFICIAL DOCUMENTS ON CONSERVATION

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## INTRODUCTION

Timber members are more affected by long period actions than by short time ones; besides, due to the fact that it is almost impossible to realize rigid connections between timber members, the connections are generally of the ductile type. For these and other reasons timber is the ideal building material in seism prone regions.

In seismic areas timber constructions behave perfectly as far as the connections are efficient but not rigid, designed to be suitable to resist also to dynamic forces, undergoing deformations but without breaking; one requisite is essential too, the presence of subsidiary members and units to realize a spatially efficient system, capable to withstand not only vertical but horizontal forces as well.

The constructions built in the seismic areas are generally made according to a few principles selected over the time by practise, these are appropriate geometry of the building, may be symmetry of the shape, a larger and heavier ground floor in comparison with the upper ones, presence of connecting members in every principal direction, efficient but ductile connections, bracings in the horizontal and, more, in all the vertical planes; good sizing and strength, of course, is a fundamental requisite.

These traditional principles, settled, selected and followed by experience and intuition, have been put a few decades ago at the base of the modern theory, legislations as well, on the seism-resistant construction. Therefore not only the strength of the members is the technical aim to be achieved and the efficiency of the connections in order to transmit the stresses but also the stability achieved with suitable design, connections adequate to transmit horizontal forces as well, impediment to displacement of the nodes of the structure, impediment to deformation of the meshes of the frame which constitutes the structure.

The experience of Italy where the ancient and the traditional constructions are generally made of masonry (stone or brick) and the upper floors are made of timber (the first floor being generally made of masonry vaults), the timber structures of the floors can play an important stabilization role of the whole building by means of connection to the walls thus obliging the construction to behave like an efficient box. In order to achieve this task the texture of the floors frame should be perpendicular to the weakest or un-buttressed walls; a condition which is not always respected, see for instance the low cost houses in a row, where the fiscal system suggested narrow fronts and higher depth of the apartments, therefore the beams being placed parallel to the front. The experience of the earthquakes in southern Italy at the beginning of the last century is very clear on this subject: all the masonry fronts collapsed because not anchored by the floors.

Strengthening a failed structure which has been hit by earthquake or retrofitting a structure to prevent failure by seism is a far more difficult task than repairing a common structure reacting only to static loads. In fact, in addition to the real technical difficulties in planning the repair of an ancient structure, the designed works must comply with the theoretical instances and the practice codes adopted in the place; these generally contain very strict prescriptions for the prevention of

seismic damage to the building, to persons and things. The worst aspect of this situation is that the prescriptions are generally the building rules for reinforced concrete or masonry.

For the ancient structures, however, there is the priority of the conservation ensuring their authenticity and integrity at the maximum possible extent.

Are the two needs compatible?

Aim of the paper is to start a discussion on the possibility of compliance of architectural and structural conservation principles with the official document on conservation and the practice codes.

## DAMAGE

It must be observed that, if a building has survived, this means that its structure is well designed and that it performed in a satisfactory way its duties till the present time. Nevertheless, due to aging, biotic factors, wind, earthquake, fire, misuse, war, accidents etc. the ancient structures are affected by decay of the material and mechanical failures.

The failures caused by seismic activity mainly concern the system level of the structural hierarchy.

The performance of a structure as a system is ensured by the subsidiary members (in a roof, for instance, the purlins together with the joists and the boarding), by the braces and by the units, working through the connections. The decay or the interruption of the relations between the different components of the mechanism, i.e. the partial or total loss of the condition of system, is the main effect of seism on timber structures. The connections between members, in fact, dissipate in deformation energy part of the tensions transmitted by the dynamic perturbations: till a certain extent, the members are preserved. To this effects there is to add the alteration of geometry of the structural components, of the units and of the same system, due to displacements and deformations, with the consequent loss of their bearing capacity. The related connections of course get loose or break.

As an example, one can think to a rotated truss (unit) of a roof timber work (system): when out of the vertical plane the truss will be incapable of bearing any load. The same or worst if the truss twists.

The shape of the building, i.e. the distribution of the masses, play a fundamental role in stability: particularly problematic are the buildings strongly asymmetric even if well braced.

In other words it is not merely a problem of strength of the members and units but mainly one of stability, i.e. a problem at the system level.

The failures are characterized by displacements, rotation, loss of verticality, loss of planarity, deformation (bending, twisting etc.), loosening of the connections.

Also important is the consideration of the action timbers can produce on other structural systems also present. The beams of a timber floor resting on masonry walls can produce an hammering effect on the supporting wall, if not properly tied, when this tries to return in place after the rotation caused by seismic event.

Collapse and falling down can occur as final event.

## AUTHENTICITY

On principle, it ought to be stated that the structures are important components of the architectures and that they deserve, for this reason, the same concern by the scholar or the conservator of the other part of the monumental buildings such as the historical vicissitudes, aesthetic qualifications, social involvements, lay out organization etc. They must be carefully conserved as the product of human intellect; survey, interpretation, diagnosis, prognosis, intervention of maintenance and repair are the phases of the protocol to be attended in order to

achieve integrated conservation. Preserving their authenticity is essential for correct understanding and estimation at any time.

An important point of discussion is what means authenticity for a load bearing structure. Authenticity is the original configuration thought by the Architect, the material specified in the contract and the assembly made by the carpenters according to the plans, the signs and witness of the failures, the past strengthening work; not excluding the object of accomplished historicizing such as the alterations and changes that were and still are consistent with the structure, therefore including also the changes of the configuration and behaviour when they were justified, for instance, as a successful strengthening measure.

The first important reference is to be found in the Venice Charter, art. 9, which states that “*the process of restoration is based on respect for original material and authentic documents*”.

The *Nara document on Authenticity* (1994) brings the attention to the respect for cultural diversity and the fundamental role of the authenticity of the cultural heritage in conservation and restoration planning, besides for “*the inscription procedures used for the World Heritage Convention and other cultural heritage inventories*” (N.D.A. 10). The inscription in the List of the *World Heritage Convention* can be a powerful deterrent to discourage alterations and preserve the authenticity.

The 13<sup>th</sup> point is emblematic: “*Depending on the nature of the cultural heritage, its cultural context, and its evolution through time, authenticity judgements may be linked to the worth of a great variety of sources of information. Aspects of the sources may include form and design, materials and substance, use and function, traditions and techniques, location and setting, and spirit and feeling, and other internal and external factors. The use of these sources permits elaboration of the specific artistic, historic, social, and scientific dimensions of the cultural heritage being examined*”.

No other official document is explicit on the authenticity of the structures, not even the specific principles on conservation of structures such as the Principles for the Preservation of Historic Timber Structures, (1999; see over) or the Principles for the Conservation, Analysis, Conservation and Structural Restoration of Architectural Heritage (2003; see over) and the successive Recommendations.

The cited statement of the Nara Document is mainly connected to the practice, sometimes followed, of wide demolition of the damaged parts and their reconstruction with new material or dismantling and re-assembling, may be in a different location.

The objection is that the material witness of the substance cannot be replaced. Once the original material is removed the authenticity is lost; the result may be an authentic copy but not the original. One of the consequences of removal is the impossibility of continuing research on the original system because the existing one is only a reproduction and, in the best cases, an interpretation of the original.

There are peculiar cases of pre-fabrication like the Norwegian traditional timber rural dwelling the pieces of which were cut in winter time by the countryside carpenters and sold elsewhere in the Country after the accidental destruction of other villages, usually by fire, or disassembled and rebuilt elsewhere according to the moves of the family. Similar situations of pre-fabrication may be common to other Countries. The other well known and so often cited example is that of the timber Shinto shrines in Japan, for which a complete disassembling is planned, for maintenance, every twenty five years. On the purpose it must be recognised, amongst the other things which concern the spiritual and religious sphere, that for the oriental traditional constructions in timber the joints and the same way in which the members are connected are so complicate that it is almost impossible to get rid of a decayed member and replace it with a new one without disassembling the whole compound. The practice is certainly to be seen in connection with the ritual of building the house of the divinity and to keep alive the skill of the carpenters in the very complicate traditional design and technique of timber construction.

## REPAIR and IMPROVEMENT

In other words, the task is to upgrade an ensemble of structural units, working separately, into a system reacting in a multidirectional way.

The restoration activity must keep a character of exceptionality.

The authors agree with Gustavo Giovannoni, the Cammillo Boito's pupil, the protagonist of the Athens Conference on Monuments (1931), and the inspirer of the Italian Charter of Restoration (1932), who maintained that, amongst many restoration categories (liberation of a building from added parts, reconstruction, anastylosis, translation, ...), the strengthening work of the structure of a monumental building is probably, because indispensable, the only appropriate and justifiable intervention.

Universally accepted principles are that the load bearing structures must continue to play their planned function, intervention works must be reversible, as far as possible, at least in the intentions, and recognizable; the authors would like to add the concept that the interventions should be easily detectable on the spot (see over) even if the disturb of the visual fruition is not desirable.

When the prescriptions of the practice codes are literally followed by structural engineers in the design of the repair work, the operations turns generally to be devastating for the authenticity of the ancient structure because the original configuration, i.e. the same conception of it, is heavily altered, significant parts removed, new members replaced etc. In other words the slavish compliance with the practice codes may exclude the compliance with the contemporary theoretical aims and the official documents on architectural conservation.

When planning repair or prevention works, one of the possible ways to avoid this danger is to impose limits to the use of the building thus reducing the risks and the entity of any damage, therefore the entity of the works; a rational and continuous monitoring can help determinedly. But a limited use of the building is often judged not convenient by investors by an economic point of view which is always fundamental; neglect of the monumental buildings caused by shortage of budget can be, in these cases, a disappointing consequence.

Many codes admit exceptions for the monumental buildings and an improvement of the condition of the structure as aim of the intervention is accepted in place of the adequacy to a full concept of a seism-resistant structure.

In the practice, a careful reading of the structure will certainly indicate its weakest parts where the effects of past seismic perturbations are detectable.

Repair of the local failures (of members, units and connections) is the first step to be taken.

Second step is to ensure the stability of the structure by means of shoring, loosening the connections and reducing the displacements. The requisite of the stability can be achieved in several ways; a general criterion is to avoid detractions of parts and operate by means of recognizable structural additions. The integration of the bracings or the application of a systematic bracing is generally fundamental to prevent further displacements and deformations.

Criteria to be followed certainly are the realization, when possible, of steady permanent presidia to confer stability to the structure, the improvement, by means of subsidiary members or units, of the ensemble of structural elements and units transforming it into a system of parts efficiently interrelated, without elimination of the ductility of the single joints. In general making too stiff only a few parts of a structural system, operating on the members or the joints, is dangerous because they could cause serious damage to the building to which they belong; a balanced intervention is the best solution.

The technique largely diffused in Europe since a few decades, especially in seismic areas, to repair the timber floors applying and connecting a slab of reinforced concrete at the extrados of the structure of the floor, proves this assumption. The practise demonstrated that the excessive stiffness

of the floor reinforced in this way can be very harmful for the building during new seismic events: in the worst cases cut in the walls with motion of the entire floor will be the undesired consequence. It is a recurrent example of unbalanced measure.

About the joints, equipping them with “springs”, which are designed to work when the tensions induced by seism exceed certain limits (values), will prevent tearing of the structure in the parts which are not strengthened; in order to understand this approach it ought to be remembered that in any case the seism is an exceptional event.

## POSSIBLE COMPLIANCE OF THEORY WITH PRACTICE

Possible reference points on this subject are: the Charters of Athens (1931), of Venice (1964), the Principles for the Preservation of Historic Timber Structures, Mexico City (1999) elaborated by the Wood International Committee ICOMOS (IICWC), the ISCARSAH document (Victoria Falls, 2003) Principles for the Analysis, Conservation and Structural Restoration of Architectural Heritage, and the following Recommendations (2004) issued by the same ISCARSAH, the Nara Document on Authenticity (1994) etc.

Two relevant parts of the Athens Charter are the point I and IV.

The first point is: *The historic and artistic work of the past should be respected, without excluding the style of any given period.* (a similar concept is also included in the Venice Charter).

The concern, which is a recent achievement, for the technological components of the monuments, is evidently missing; the sole components judged interesting are the artistic and historic ones. The principle of conserving all the witnesses accumulated on the monument, anyhow, can be projected to our times to include the strengthening works made in the past or to the changes of the structure, when these works are recognized being consistent with the structure, i.e. authentic in the extensive sense specified above.

The other point is IV: *“The judicious use of all the resources at the disposal of the modern technique and more especially of reinforced concrete.*

*They [the Participants to the Athens Conference on Monuments] specified that this work of consolidation should whenever possible be concealed in order that the aspect and character of the restored monument be preserved.*

*They recommend their adoption more particularly in cases where their use makes it possible to avoid the dangers of dismantling and reinstating the portions to be preserved”.*

The first part of this principle has been repeated in the Venice Charter (1964). The concept is universally accepted with the caution that the techniques adopted should be widely tested before application. Also for the consolidation of the timber structures a large technological progress is going on with the use of traditional or modern materials adequate for every necessity, especially structural adhesives, and updated operational tools.

About materials, the much higher strength of the new materials or products is very useful to reduce the dimensions of the strengthening devices, for their clean and neat design, their harmonious insertion on the monument.

The trend “timber to timber” to strengthen timber structures, started about twenty years ago, is very interesting; it can also be intended for the use of modern wooden products such as the glue laminated wood; but limitations come from the modest, in comparison with other materials like steel or FRP (see over), admissible tensions.

The Fibre Reinforced Polymers (FRP) are more and more widely used because of their interesting characteristics; the strips of FRP allow the putting in place of efficient, extremely thin, easily conformable ties resistant to tension. The bars are very useful in tension but, if the pieces are well confined, can also perform giving a contribution to compression.

Absolutely to avoid is anyhow, for several reasons, the current practice of wrapping timber parts with fabric of this material; in some cases nets can be used conveniently instead of fabrics.

The modern technology benefits of the surgical working accuracy of the operational machine; it is then possible to operate with suitable and almost harmless tools in very restricted areas of the wood, generally the affected ones, only for specific therapeutic or prevention purposes putting in place small size devices.

About the recommendation of “*concealing whenever possible the work of consolidation in order that the aspect and character of the restored monument be preserved*”, it ought to be said that the extensors of the Athens Charter, pushed by a visibilistic attitude towards the monuments, were concerned by a false problem.

In principle, the visual fruition of a monument cannot be spoiled by the sight of a consolidation device. According to the modern culture of architectural conservation the interventions should not be hid: the conservation work, the strengthening particularly, is an added value to the monument and the frank, discreet exposition of the strengthening devices contributes to the understanding of the configuration of the structure and of its performance.

Wisely this inconsistent concept has not been repeated in the Venice Charter.

A modern reading of the third paragraph of the Athens Charter, that reminds “*the dangers of dismantling and reinstating the portions to be preserved*”, can be made in the sense that dismantling and reassembling the buildings and the structures or simply the removal of parts and replacing with new ones is a dangerous operation (see also when discussing the Victoria Falls principles).

By the didactic point of view, which is of major importance, it ought to be said that every witness concerning the history of the building, as the consolidation devices, should be immediately readable on it so as to allow a comprehensive interpretation, starting a complete process of appraisal of the structural system in its full context.

In any case the modern devices are discreet, not visually invasive.

The quoted Principles elaborated by the International ICOMOS Wood Committee, adopted by ICOMOS in the General Assembly of Mexico City, 1999, represent a fundamental achievement in the culture of the conservation, not without a few defects. Still questionable, for instance, the criterion of replacement with the same material, of the same botanic species, with the same technique, the same nails, the same tools etc. ....: it seems to be a pedantic attitude, mainly adopted in order to excuse unnecessary replacements of authentic parts, and category of intervention generally justified, especially in the Eastern European Countries, with the necessity of keeping alive the old crafts, those of the carpenter in a specific way. To the author’s opinion, it is the skill in using the most advanced techniques for conservation work, where advanced, in this case, means that they are based on the knowledge of the ancient technique and reach the planned results with minimum of damage to the authenticity of the monument, made in compliance with the conception of the structure, the real task of the present times. It is a skill of this kind that must be improved and disseminated amongst workers, not the obtuse repetition of techniques of the past; what does not exclude the possibility of simple, traditional interventions when possible, appropriate and efficient.

About the Principles of IICW, in the aim of recording the damage, it is interesting the point: “*recognize the vulnerability of structures wholly or partially in timber due to material decay and degradation in varying environmental and climatic conditions, caused by humidity fluctuations, light, fungal and insect attacks, wear and tear, fire and other disasters*”: here it is evident the lack of concern for, it ought to be said the same notion of, mechanical failure.

It is interesting the introduction of the concept that, at the side of authenticity, it is necessary “*to maintain the physical integrity of the historic structure or site*”.

In the Principles for the Analysis, Conservation and Structural Restoration of Architectural Heritage (ISCARSAH, 2003), very modern and appropriate are the following concepts.

*“Value and authenticity of architectural heritage cannot be based on fixed criteria because the respect due to all cultures also requires that its physical heritage be considered within the cultural context to which it belongs.*

*It is wrong removing the structures but keeping the facades.*

*Deteriorated structures whenever possible should be repaired rather than replaced*

*Dismantling and reassembly should be undertaken only when conservation by other means impossible or harmful”.*

But the following point 1.5: *“Restoration of the structure in architectural heritage is not an end in itself but a means to an end, which is the building as a whole”* is confused, restrictive, anyhow a matter of discussion because sometimes the only purpose of conservation is conservation, especially when the object of concern has extraordinary qualities.

The Recommendations issued by the same ISCARSAH, approved in 2004, have very little indications about the wooden structures.

The Burra Charter in the various editions, the other Charters, the Xi’an Charter (2005) and other local Charters issued to apply the general concepts to geographic or cultural peculiarities, have, in general, no ethic motivation or a too unpretentious approach to the spiritual and intellectual reasons of conservation. They seem mainly dictated for the use of operators; according to them, any kind of intervention is allowed on the monuments as far as one – administrator, professional, contractor - is able to find the right justification amongst those listed in the same Charter.

The Xi’an Charter and, some years before, the Convention Concerning the Protection of the World Cultural and Natural Heritage (1972) are in the same style.

## CONCLUSIONS

It is possible to plan, also in the seism prone areas, the strengthening of the timber structures in compliance with the official documents and the codes of practice, as far as the application of the prescription is not made in a pedantic and slavish way but putting structural concepts at the base of the design.

The technology of the conservation preceded, due to the progress in other fields, the theoretical instances and it is so advanced, today, that it can satisfy almost any need. Interventions made not in compliance with the conservation culture are generally the product of lack of technical knowledge.

The industry should make some further steps in order to invent and offer products which are specifically designed for the various needs of the architectural conservation and not only inspired by the marketing strategy. It will then be possible to suggest more advanced policies for the active conservation, in particular the strengthening of the bearing structural systems.

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