# Guidelines for the safety and preservation of historical centres in seismic areas

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ABSTRACT: The explicit reference to the methodology framed and experimented by Antonino Giuffrè for the historical centres' analysis and subsequent intervention gives a univocal connotation to this contribute, which explains the procedure of the interventions' analysis and definition adapting the safety demands to those of the preservation. This procedure arises from a mechanical interpretation of the historical building industry with particular reference to its lacking points as far as the seismic action is concerned and leads to a conscious choice of intervention suitable criteria. Its mainly operative aim lends itself well to the establishment of guidelines that can generally direct the quality of the interventions on the historical centres' built-up heritage towards a homogeneous trend.

## 1 INTRODUCTION: "INTERVENING ON THE MASONRY STRUCTURES EMPLOYNG MASONRY TECHNIQUE"

It is fully acknowledged that the historical city's houses and their layout are an integrant part of the built-up heritage to be preserved. At the same time, it is clear that, in this context, the preservation concept takes on a particular meaning; in fact, the preservation action cannot have – if applied to the historical city – a static value, as the city has to go on living or, in certain cases, to continue being lived. Therefore, such preservation meaning has to fit in between modern life and that past which has always guided the city's development. Furthermore, now-a-day this dialectics has to include a brand new point of view, unknown in the past centuries, according to which all interventions have to be respectful of the work's historical nature. That's why a particular meaning of the preservation is now spreading: the *active preservation* (Giuffrè 1995a). It considers the possibility of modifying the building's present layout, if the necessary modifications to make it liveable are respectful of the history that has produced it. As you can understand, this concept includes the need of guaranteeing the safety in the event of a seismic action as primary demand for the preservation object's survival itself.

This approach, combining preservation demand with safety within the restoration of minor building, has spread in Italy thanks to the studies carried out for over ten years by Antonino Giuffrè. Since 1988, he has set up a methodology of analysis specifically aimed at the choice of the intervention through the comprehension of the historical masonry structure in all of its mechanical potentialities. This procedure, experimented in many Italian historical centres, has led to the realization of a tool, called "Practice Code" by Giuffrè, whose aim is the definition of a guide to the structural restoration intervention, duly identified with the building reality of each area object of study.

The building context, object of this analysis, is extensively examined in order to recognize, through the comparison of observations, the local building language, believing that each cultural area is strongly characterized by its own technical-building peculiarities, from which both the whole structural configuration of the building and the possibilities of decay and damage take ori-

gin, and for which the most appropriate techniques of intervention and, in particular, of seismic improvement have to be located.

The philosophy underpinning Giuffrè's approach can be synthesized quoting his own words: "to intervene on the work with masonry", which avoids using techniques in opposition with the ones considered as locally characterizing the built object.

After each seismic catastrophe – and we can mention as an example the last Italian earthquake of 1997 – we can observe that the historical masonry buildings that suffered heavy damage already had original construction defects or were in a state of structural decay due to neglect or inadequate transformations. On the contrary, the almost undamaged buildings proved to be work-manlikely built. This uniquely *experimental* observation allows us to affirm that a building which is *properly built* (or "*workmanlikely built*") and well maintained is able to resist to a middle-strong earthquake.

This is the procedure's fundamental point which makes us determine the building's construction quality generally deriving from both an overall correct organization of the structural elements composing it, and from the present structural efficiency of each one of them. Once we have recognized the construction and structural quality of the building or group of buildings of the analysis' context, and at the same time pointed out the lacking points and vulnerabilities, intrinsic or deriving from historical or recent transformations, we can define the appropriate intervention criteria for each particular local situation, considering the magnitude of the expected earthquake.

It is recognized that in most of the cases it's possible to realize the structural improvement just getting rid of the deterioration causes that have changed the original solidity and thus restoring such solidity. Sometimes, the local construction technique shows intrinsic lacking points which have to be eliminated by introducing protections unknown to the local construction vocabulary, but which can be easily planned within the wider masonry building language, and confirming those characteristics which have made it different from the modern techniques and guaranteed such a long life: first among all, the construction characteristic of "dismountability" which has always been present in all historical building industry, as a consequence of a building yard based on successive assemblings. In fact, an easy disassembling is the primary condition for the maintenance process that has allowed the city to live for so many centuries. Our modern interventions must not betray this connatural peculiarity and must not irreversibly add strongly individualized elements.

According to Giuffrè's point of view, the structural restoration project derives from the knowledge of the local construction techniques and from the recognition of their probable unacceptable inadequacy. The preliminary exact analysis for the intervention is the procedure's crucial moment as it provides information about "where", and even before about "whether", to intervene in order to restore the building's original stability. On the other hand, the knowledge of the "workmanlike construction", and of the way it has been detailed in the examined context, guides us in the choice of interventions closely related to the houses' material and historical reality, and able to guarantee safety and, at the same time, preservation of the historical cities' building cultural result.

### 2 THE MECHANICAL BEHAVIOUR OF THE HISTORICAL MASONRY WORK IN THE EVENT OF THE EARTHQUAKE

For determining the masonry structure's constants and locating them in a general reference framework, it is useful to consider the historical construction culture as a whole of knowledge coded and directly handed down, and then systematically applied. In this sense, it is also useful to introduce the concept of "workmanlike construction", identifying all prescriptions relating to the building contained in the literature or orally handed down, or moreover deducible from the buildings, which has to be observed by the actors (architects and workers, each one in his own competence) in order to realize lasting structures, resistant to ordinary and exceptional events.

Therefore, we have to do with a set of practical rules which have increasingly become refined, achieving an exhaustive written definition in the nineteenth-century treatises, and in which masonry history's experience is summed up (Sacchi 1878, Donghi 1905).

It is interesting to notice how the prescriptions for building a good wall with raw stone - that is, the most common building type in the minor building - are re-proposed by different writers of treatises with the same wording, making it clear that they derive from the observation of the his-

torical city's walls and therefore crediting the long experimentation which has confirmed their validity (fig. 1).



Figure 1: different arrangements of masonry work following the "workmanlike construction"

In order to build a wall in "a workmanlike way", it is necessary to respect the following prescriptions:

- To make a prevalent use of big stones, being careful to place them in the wall structure in such a way as to correctly alternate the stones placed point outwards, which means that their greater length is placed crosswise with respect to the wall (diatones), and those placed or-thogonally to the previous ones (orthostats). This guarantees an efficient interlocking both in the plane and in the wall's thickness.

- Not to use an excessive quantity of mortar, filling with smaller elements the spaces between the big stones. In a good wall, the mortar plays a secondary role in comparison with the stones, while it is necessary to realize the highest stone compactness.

- To level up the surface at regular intervals, in order to prepare perfectly horizontal layers for the correct transmission of the vertical load between the rows.

It appears clear that these rules have a unequivocal static finalization. Their intent is to make the wall structure monolithic, while it is intrinsically discontinuous because of its nature, thus giving it an essential mechanical characteristic, as we will see, as far as its seismic behaviour is concerned. In this sense, the opinion on the construction quality, deriving from the comparison with the workmanlike construction, coincides with the opinion on the mechanical quality.

The walls constituting the load-bearing structure of the various historical centres' buildings generally show marked formal differences and, also within a similar built-up context, strong differences in the construction equipment can be noticed.

Actually, the problem of the diversity of walls - which can even be found inside the same wall, when the building has been built in chronological different phases - can be overcome just through the concept of "workmanlike construction". In fact, it describes the general characteristics of a good masonry, even though it is susceptible of very different applications in specific cultural contexts and has originated many local acceptations, consequent to the type of available stone material and the masons' technical knowledge.

Therefore, besides the external differences, the quality of a wall and, consequently, its mechanical effectiveness have to be considered by measuring the variance from the fundamental requisites defining the "workmanlike construction", that is, distinguishing the situations in which the "workmanlike construction" was carried out, or was not properly applied, or even omitted. This is an objective procedure that allows us to discover the walls' structural stability of a determined built-up context (fig. 2).



Figure 2: survey of a masonry work in the region of Grecanica (Calabria Region, Italy).

In the event of the earthquake the wall is supposed to resist, besides to the usual vertical loads, also to the horizontal action that can act in an orthogonal or parallel direction with respect to its plane.

In the first case, the most common collapse modality is the overturn towards the outside of the wall, mechanism already pointed out as an elementary motion at the end of 1700 (Rondelet 1834), and verified in all damage produced by earthquakes of a remarkable intensity (fig. 3).



Figure 3: Rondelet's collapse mechanisms of masonry walls under out-of-plane horizontal action.

If the wall is workmanlikely built, the past earthquakes' experience, with the observation of the damage produced, and the modern experimentations allow us to affirm that the wall, overturning, does not break up. The mechanism evolves through the formation of cracks which divide the wall into big monolithic blocks, the contact between which continues along fairly large surfaces, assimilable to cylindrical hinges, and whose internal cohesion is maintained, not infrequently, also after the collapse.

On the contrary, should the wall's structure be very far from being "workmanlikely built", "the cracks do not constitute clear-cut detachments, but are distributed on large parts of the wall. The kinematical motion cannot evolve because the changes of the loads' resultant with respect to the vertical, consequent to the wall's motion, reveal the defect of internal interlocking and breaks the masonry. The lower the wall's quality is, the more premature is the ruinous conclusion of the kinematical motion set off by the external actions" (Giuffrè 1993a). The earthquake's effects on such masonry, bearing intrinsic insufficiencies, are very heavy: the component stones come out of the wall structure and the masonry breaks into very small pieces rather than in big blocks.

Therefore, it is recognized that the wall structure's behaviour is rather governed by stability problems than by resistance ones and, subsequently, that the wall's analysis, aimed at the recognition of its construction quality, offers a mechanical result of a direct interest for the safety control.

In comparison with the horizontal actions, the behaviour of a good wall with raw stone does not differ from that of a monolith of the same dimensions, and this allows for the assessment of the stability of the first one referring to the second (fig. 4). Obviously, this operation, in which the wall's complex internal structure is completely ignored, is not permitted when the interest is concentrated on the detailed aspects of the structural behaviour, for which one has to necessarily refer to correspondingly more refined models.



Figure 4: simplified mechanical models for analysing structural behaviours caused by the difference in masonry texture and in shape of unit blocks.



Figure 5: masonry types abacus in Ortigia (Siracuse, Italy).

The model proposed derives from the recognition of the existing analogy between the raw stone masonry, characteristic of our historical cities' urban contexts, and the *opus quadratum*, the isodomum and pseudoisodomum masonry attributed by Vitruvius to the Greek.

The main rule for the realization of a wall in opus quadratum is the same one already described for the walls with raw stone (alternation of diatones and orthostats, constituted in the case of the opus quadratum by perfectly squared blocks, staggering of the vertical joints, horizontal layers), and also the repercussions in terms of mechanical behaviour are the same (section's monolithic quality). Therefore, if, for one reason, the geometric regularity which characterizes the opus quadratum gives it a feature of construction archetype of the larger category of walls with raw stone, for the other it allows us to attribute to this very special masonry structure the function of mechanical model, which we're mainly interested in. Of the walls with raw stone, in fact, the opus quadratum maintains all and only the essential mechanical characteristics (internal discontinuity, absence of cohesion, monolithic quality guaranteed by the elements arrangement) and makes it possible to obtain an expression immediately and easily translatable into numerical terms. This way, the structural analysis of the historical masonry is traced back to a sequence of operations which looks like that proposed in any applied scientific discipline: observation of the phenomenon to be analysed (survey), mathematic formulation of the phenomenon (modelling), study of the phenomenon's progress on the base of the adopted mathematic formulation (analysis) (Giuffrè et al. 1994a).

The survey consists in a broad reading of the masonry of a determined context whose objective is to locate both the formal and dimensional characteristics of the wall stones and the rule used to assemble them. This reading leads to the construction of abacuses which include the various types of masonry in a decreasing quality order, that is, with respect to the "workmanlike construction" (fig. 5).

It is easy to associate the classified masonry types in the abacus with as many mechanical models whose structural behaviour is representative, concerning the above mentioned, of the real behaviour of the starting masonry types.

For this purpose, some results obtainable through the proposed mechanical model are of general importance and deserve to be underlined.



Figure 6: Physical and numerical tests on "opus quadratum" masonry walls; analyses of the masonry texture and load conditions on in-plane behaviour.

First of all, the limited distribution of the loads. The wall does not completely participate to the static effort of suffering the loads, only the parts directly concerned do. This is a consequence of the masonry internal discontinuity whose fundamental result is the modest, often marginal, material's resistance tensile strength, and, at the same time, it represents a mechanically motivated justification of the masonry structure's vision, in conditions of incipient collapse, as a whole of independent monolithic parts (Giuffrè, 1990).

The influence of the internal composition of the masonry structure on the overall stability is also interesting. An experimental and numerical analysis, carried out on opus quadratum models schematising the three masonry typologies surveyed in the historical centre of Siracuse (Giuffrè et al., 1994b), points out the decline of the resistance on the plane when the horizontal dimension of the blocks (orthostats) decreases, confirming the decreasing order of mechanical quality foreseen in the qualitative abacus realized by the direct analysis (fig. 6).

Analogous result is obtained for the wall resistance to the actions soliciting it outside the plane. Also in this case the decisive parameter is the horizontal dimension of the blocks (diatones) as resulting from both numerical analyses and physic experimentations on models in scale (Baggio 1993, Ceradini 1992): both types of analysis show how the resistance decreases in consequence of the defect of transversal interlocking (fig. 7).



Figure 7: Physical tests on "opus quadratum" masonry wall; analyses of the masonry texture on out-ofplane behaviour.

### 3 THE MECHANICAL BEHAVIOUR OF THE HISTORICAL BUILDING IN THE EVENT OF THE EARTHQUAKE

With exclusive reference to the historical centres' building of dwelling houses, we will try to point out the construction aspects which become important in the structural behaviour in the event of seismic action. Just like the construction type of the walls presents local acceptations conditioned by the local material and construction culture of the operators of a certain period, though respecting general rules coming from the common matrix of the opus quadratum, at the same way the organism-house develops on general rules even though it shows particular aspects closely relating to a geographic area and a historical period (Carocci 1996).

This means that an unwritten project existed and was known to the ancient builders: an implicit model, identifiable as outcome of the building experience and local culture, which they constantly referred to even following the local custom. That is, there existed a concept of house which included the intrinsic characteristics: distributive, formal and static.

With reference only to the structural theme, we can say that the historical house is composed of a masonry structure articulated in cells differently aggregated in the layout and superimposed in order to constitute multilevel units. The units' dimension varies little from 6x6 m; wall thickness is at times conditioned by the stones' dimensions but often close to 60 cm. Nevertheless, local conditions and materials can modify such trends.

The walls which form partitions support the horizontal elements: floors and roofs, and a connecting structure is placed between house's levels, the staircase.

The main structural characteristic of such a building is to be realized through the juxtaposition of simple elements. As the walls are built placing stone over stone, according to precise assembling rules, the house can be seen as an assembling of structures duly superimposed: the walls forming the masonry cell, the horizontal elements forming the trampling area and the cover.

Another important peculiarity of the historical house derives from this fundamental characteristic: its aptitude to bear modifications. This aptitude is inborn in the component elements' nature: all of them can be dismantled and substituted by parts, including the walls, and this is fundamental in explaining the habit of the house maintenance, carried out through repair or substitution of pieces as they gradually deteriorate. In fact, houses are not objects defined at their first construction, but organisms ductile to evolution, available for the modifications required by the new needs of their users or by the changed situations in which they might be towards the surrounding build-ing layout. All our historical centres' houses are the result of an evolution implemented with the passing of centuries: the present aspect is the result of slow, but sometimes radical, transformations which can also deeply change the previously consolidated aspect.

It is worth noting here, returning to the theme of mechanics, that such modifications do not alter the structural consistency, if executed with competence. The historical centres are often palimpsests containing the rules for transforming a facade, closing a loggia, occupying a courtyard or inserting a new staircase (fig. 8).



Figure 8: historical transformations on the façade of a Città di Castello's house.

It is clear that the previously described house model finds in the historical cities' reality a very large range of details which modify both the overall aspect of the organism and the configuration of the component elements (fig. 9).

The ground morphologic conformation, for instance, definitely contributes to the definition of the local acceptations referred to the whole organism (Carocci et al. 2001a). Just think of middle and small dimension historical centres that - in the Italian case - are often located in steep areas where the house takes on a particular conformation having to adapt time after time to the existing differences in level: this natural link originates differentiated organizations, which can be typified, though, at a level both of fruition and mechanical characteristics.

And moreover, considering the differences that may be found at a level of component elements, we can observe differentiated modalities to solve the same structural problems, but again the case-histories can be reduced to recurrent schemes, which definite behaviours can easily be associated with.

The horizontal structures can be built with wood or masonry, realized with beams or vaulted. It's not useless to point out differences of behaviour between these two categories of construction: the wooden beams laid on the masonry can exercise a containing effect, even though weak, against the wall, while we know very well the push transmitted by the vaults to the pier walls also under ordinary efforts. But it is true, even though less known, that a higher thickness of the wall is constantly associated with the vaulted structures. We could just underline that the differences which might be found realizing the component elements and their connections can also induce remarkable alterations of the global seismic behaviour, and that, therefore, the specification of the local construction technique supplies useful elements to comprehend the appearance of the damage (fig. 10).



Figure 9: survey of masonry houses in Palermo's historical centre.



Figure 10: different constraints affecting collapse mechanisms.

The juxtaposition construction implies the lack of strong connections between the parts. The "consequence of this organic defect is the particular fragility of the historical house towards the seismic action. The horizontal component of the seismic acceleration pushes the surrounding walls towards the outside, orthogonally to the plane, and beyond a certain value it provokes their breaking" (Giuffrè 1995a).

The overturn of the buildings' external walls is what Giuffrè called the "first mode of damage". It represents the condition of the building's highest vulnerability and the consciousness of this possibility has often suggested, in the course of history, the use of chains to compensate for the lack of connection between the external walls and the ones orthogonal to them. The effectiveness of such chains consists in involving the walls orthogonal to the facade as containing elements. They resist to the seismic action transmitted by the facades as action "in the plane" and exert a higher resistance towards such strength. When the action overcomes the resistance, though, also the walls stressed in the plane can crack, according to the classic diagonal course which isolates a triangular part of the wind-brace wall and makes it participate to the cracking motion. This further damage modality - called "second mode of damage" - can be checked only when the "first mode" doesn't occur thanks to metallic connections (fig. 11).



Figure 11: "first mode" (A) and "second mode" (B) collapse mechanisms.

While the "first mode" is always ruinous, as it implies the complete collapse of the wall and consequent ruin of all supported elements, the "second mode" does not necessarily determine the collapse, though it still implies small, medium and even large cracks of the wind-brace walls.

Up to now, we have talked about the characteristics referring to the generalized structural configuration of the masonry buildings, and have given additional specifications about possible results of the local building procedure. But we also have to present those situations which have to be considered under the current standards of the masonry structure and thus represent conditions of particular precariousness.

Usually, these situations originate from inadequate modifications such as partial raising not respecting the wall's structure (fig. 12), openings in the external and internal walls without assessing the possible deterioration in the structure's behaviour, cuts produced in the urban texture by the demolition of buildings.



Figure 12: addition of upper storeys without internal transversal wall.

No historical centre has kept unaltered, modifications are not only numerous, but also repeated in the time, as they are endemic in the historical building's life. But, until the city got transformed with the same construction technique that had produced it, the innovations have rarely provoked a decrease in the structural stability. The static stability doesn't change if the transformations are carried out in the respect of the original construction rules; on the contrary, interventions are often consciously aimed at the stability's improvement.

We also find cases, though, in which the innovations make initial regular situations precarious, as it mainly occurred in the interventions of the second half of 19th century and those of 20th century (Carocci 1996). We can mention some of them:

- The construction good rules do not allow us to demolish complete load-bearing walls, as this would imply an alteration in the structural distance and, therefore, the introduction of a heavy precariousness. In fact, the corresponding facade has no contrasts anymore for a length much higher than the usual 6 m, because the wind-brace wall which resists to the seismic action is missing.

- It is not possible to create large spaces on the ground floors, just where the correct distribution of the loads should be guaranteed, or add an inappropriate raising of additional storeys, which might even be realized without considering the structural organism.

### 4 THE MECHANICAL BEHAVIOUR OF THE HISTORICAL TEXTURE IN THE EVENT OF THE EARTHQUAKE

The generalized characteristic of the historical centres' layout is the structural continuity of the single buildings. In fact, excluding exceptional cases, a masonry building is structurally connected with the adjacent one in order to form the block. The latter can be synthetically defined as a buildings system - also of remarkable dimensions - delimited by public and/or private un-built spaces.

This peculiarity of the historical layout is the reason why the analysis of the single building's behaviour doesn't result sufficiently exhaustive if not associated with a wider interpretation involving at least the buildings directly bordering the one which is object of the analysis.

As an example, it can be easily understood how some peculiarities of the structural response derive exactly from the particular location of the building within the individual building system in the block (fig. 13).



Figure 13: seismic damage mechanism depending both on the position of the house in the urban texture and the position of the openings in the external wall.

This consideration of fundamental importance is now explicitly expressed in the recent regulations issued following to the earthquake of Umbria and Marche in 1997. They state that it is not possible to prescind from considering the interactions between "conterminous buildings, which might result inexistent, of a stiffening or supporting kind, or aggravating the seismic risk".

To fully understand the implications of this statement, we can refer to an original vision of the historical building layout that defines it as a sequence of masonry boxes, which, even though individually built, do contain the aggregate notion since the beginning. In fact, according to the chronologically deferred building - characteristic of the spontaneous and unplanned construction of the historical building - each new house is built next to the existing one using part of the masonry structure (fig. 14).



Figure 14: damages resulting from historical evolution and transformation; constructive stages in a block.

This process implies that in a building aggregate only a few houses are constituted by close masonry cells (that is, where the perimeter walls carried out contemporarily foresee, for instance, a correct organization of the angular connections). The situation becomes more complex if we consider the fact that the same building aggregate, during its life, undergoes differentiated evolutive processes, consisting, in the most simple of the cases, in additional superimposed dwelling levels (Zampilli 1993). In the evolutive process, like in the previous phase of the very first construction, the raising of superimposed levels occurs in different moments and generally with a different chronological sequence (fig. 15).



Figure 15: constructive evolution of a block in Anavatos village (Chios - Greece).

Therefore, although the block has to be considered as a significant model of the urban texture, at the same time we have to observe that it can't be considered as a unitary element, because the present configuration is certainly the result of progressive transformations determined by juxtaposition of volumes and capillary modifications not always easily noticeable.

Within this framework, the analysis called "critical survey" (Cremonini 1994) seems to be of a fundamental importance. It is based on the systematic and, at the same time, synthetic registration of all relevant aspects for the formulation of possible damage mechanisms which can be started in the event of future earthquakes. This analysis aims at documenting at the same time the aggregate's real state and the process which has produced it.

Irregularities and weak points due to various reasons are assessed; namely, due to the site's morphologic characteristics (staggering of the foundations' level), to irregular elements both hori-

zontal and vertical (adjacent wall cells of very different dimensions, elements resulting from the progressive closing of open-spaces), to the integration of the buildings with pre-existing structures (castle or urban walls, ground supporting walls, terracing supporting structures).

Lacking connections are pointed out; lacking, namely, because of the building and transformation phases, of the existing discontinuity (flues, chased plants, openings in breach), of the openings' position (proximity to the corners, excessive width and length of the spaces, lack of alignment, reduced distance between openings), of the elimination of building load-bearing elements (lengthwise partition walls between two close cells), of the introduction of elements unconnected with the masonry box (leaning against it, overhanging, incongruous superfocations).

Contiguities are defined between different building systems which introduce unfavourable interactions due to previous structural interventions that have changed the rigidity characteristics of walls or floors, or the ratio between their weights, or due to integral substitutions carried out with load-bearing structure different from the masonry one.

Finally, the framework of the previous instabilities is interpreted in order to understand the overall mechanical behaviour in a synthetic vision which gathers all collected information, including the slenderness of the individual walls exposed and their connecting conditions (Fig. 16).



Figure 16: seismic damage scenario in the historical centre of Bagno di Romagna derived from the analysis of the "critical survey".

The aim of the "critical survey", therefore, is the formulation of a hypothetical damage scenario that could be set going by a future earthquake. This can be considered a concrete assessment of the expected damage both in terms of direct vulnerability - originating from the structural and transformation characteristics of each building of the block - and in terms of induced vulnerability - originating from the mutual interactions between buildings placed side by side, and from the repercussion that the damage effects can induce on the open spaces (fig. 17).

It is worth underlining that the damage scenario, deriving from this type of interpretation made in the block's scale, does not generally result to be equivalent to the summation of the effects we can foresee by analysing the single component effects: in fact, if, on one hand, the vulnerability of the single house can derive from its configuration's weakness or from the precarious state of some of its elements, on the other hand, other vulnerabilities external and relating to the adjacent houses can contemporarily concern it producing a worsening of the damage.



Figure 17: seismic damage scenario on a block in Palermo's historical centre.

#### 5 THE VULNERABILITY AS A FORECAST OF THE SEISMIC DAMAGE SCENARIOS

The analysis of the historical built-up heritage in the above described scales allows us to define, in a very realistic way with respect to the local situation, both the expected damage and the values we can preserve. But, before starting the exposition of the appropriate intervention criteria for obtaining at the same time preservation and safety of the built-up heritage, we have to make some remarks on the extent of the intervention, which we have to refer to, in the prevention action.

Giuffrè's procedure indicates the definition of the *local seismic history* as a central element. First of all, it provides us with information about the list of macroseismic intensities historically registered and, if documented for a quite long temporal period, this allows us to interpret the *maximum historical event* as *maximum expected event* (Giuffrè 1995b).

It isn't useless underlining how much such procedure may vary at this point of the approach usually adopted for the analysis of the risk, where the expected seismic intensity is defined starting from the epicentral intensity and obtained through functions of attenuation. But both epicentres and functions of attenuation derive from the statistic processing of local historical data which in such a process loose their meaning of realistic forecast of what we can expect in the examined site.

Starting again from the examination of the local historical documentation – passing over the double mediation which leads from the site to the epicentre and from the latter to the site again -, we can concentrate on the local events, obtaining more realistic data from an objective point of view. The detailed analysis of the effects produced by past earthquakes on the examined historical centre, carried out by means of the historical documentation reading (Boschi et al. 1993, Guidoboni and Mariotti 1999, Boschi and Guidoboni 2001), provides us with important information about the response of the site's characteristic structural typology to the earthquake (fig. 18).

![](_page_14_Picture_1.jpeg)

Figure 18: damages on Palermo's historical centre caused by 1726/09/01 earthquake

At this points, we have to make a few remarks on the meaning of the macroseismic intensity with reference to the structural damaging of the historical built-up heritage. The macroseismic intensity, in fact, is determined through the description of damage scenarios. It can only be significant whether the constructions' mechanical consistency is considered uniform all over the territory concerned with the earthquakes, so that the same scenario can be indicative of the same physic action.

It can be significant only when the constructions' mechanical consistency can be considered uniformly present all over the territory affected by earthquakes, so much that the damage scenario too can be indicative of the same physic action.

A remark in structural terms of the scenarios characterizing the VIII and IX degree of the MCS's scale makes it possible to state that: while the effects described by the first one are located on the precarious parts of the masonry constructions, those produced by the second one create difficulties for the intrinsic characteristic of the masonry construction – weakness of the connections between parts – producing generalized detachments of the exposed masonry walls (Giuffrè 1993a, Carocci 1996).

Such remark contains an important application aspect, as in general terms it indicates two clearly different operation strategies whether the earthquake at issue has an intensity of the VIII or of the IX degree of the MCS's scale:

VIII degree: location and systematic elimination of the building precarious situations at the level of single building's elements, of the single building's configuration, and finally in the block's context;

IX degree: in addition to the previous prescriptions, it is necessary to foresee the systematic introduction of defences able to avert the mechanisms of "first mode"; that is, to introduce between the building's parts those strong connections that usually are not provided for by the masonry construction technique.

The extreme simplicity of the above mentioned general strategies is complicated in the reality by the fact that the damage scenarios described by the macroseismic scale refer to a building situation certainly more uniform than the present one: the present precarious aspects of the historical built-up heritage are certainly much more numerous and varied than those of the beginning of the  $20^{\text{th}}$  century – epoch in which the macroseismic scales have been defined – and these one, besides introducing new vulnerabilities, can also strongly modify the scenario's quality and extent.

Therefore, the suggestion of the intervention strategies provided by the macroseismic scales' scenarios being accepted, it is also necessary to preliminarily work at the elimination of the vulnerabilities substantially added in the course of the last century and assessed by means of the direct observation of the built-up heritage.

### 6 PRESERVATION AND SAFETY: CRITERIA OF STRUCTURAL INTERVENTION

The structural intervention is consequent to the above exposed analyses. We can distinguish two intervention levels for achieving the objective of a structural response increase: the first one concerns interventions aimed at improving the building's assembling, the second one at correcting the registered lacking points on the single component elements. Before coming to the heart of such divisions, it is necessary to make some preliminary remarks: we have seen how the masonry construction is able to bear modifications if respecting its intrinsic peculiarities, therefore the most convenient formula seems to be "the intervention on the masonry work with masonry technique", which guarantees the mechanical compatibility and, at the same time, the preservation meaning we want to attribute to our work. In particular, in every place examined by our analysis, we will work according to the masonry technique in the locally consolidated acceptation, eliminating the observed lacking points - both intrinsic and added by subsequent alterations - and re-proposing it in its best quality form, or rationalizing its constructive process.

Thus, the proposal we are putting forward here is to critically use the local construction technique, like modern culture allows us for, giving back to the buildings their lost resistance or improving a sufficient resistance. This way, we will modify and restore the buildings, but their historical consistency will still be the matrix of the change.

The aim of the interventions on the structural assembling is to introduce actions able to eliminate, when necessary, the intrinsic and generalized lack of connections of the historical masonry structure. The continuity of the masonry wall is purely apparent, its division into pieces is always possible, as single pieces are held together by the interlocking between the stones and the compression pushing them one against the other. Such eventuality, connoting anyway the nature itself of the historical construction, occurs more frequently in correspondence of the buildings' corners: even though all masonry walls were built together, and all crossings have the natural continuity, a destructive earthquake detaches them and makes them inevitably collapse (Giuffrè and Carocci 1999).

There exists a way just to eliminate such intrinsic weakness of the historical building. Leon Battista Alberti, in his treatise, explicitly refers to the *bindings*, made with big stones, "*which go around the walls along the whole length in order to keep the corners tight and chain the work structure*" (Alberti 1996) and, three centuries later, Rondelet improves Alberti's suggestion by proposing to introduce inside the wall iron chains with the purpose of tying up "together the walls so that they cannot act one against the other, but rather help each other" (Rondelet 1834).

In these suggestions, we can easily recognize the same finality of realizing roof-masonry-tiebeams on top of the walls, which is provided for by the present seismic norms.

And it's Alberti again who attributes the instabilities observed in the Constantinian ancient basilica of St. Peter to the excessive length of the walls, "*not reinforced by curved parts nor supported anywhere*". In this case too the seismic norms seem to re-interpret the ancient rules of the good construction technique by fixing a limit for the largest distance between the parting walls for the newly built buildings.

![](_page_16_Figure_1.jpeg)

Figure 19: masonry tie rod in a Palermo's historical building.

Therefore, the need of roof-masonry-tie-beams and intermediate tie-beams. The most appropriate technique for realizing the first ones is that of the *armed roof-masonry-tie-beams*: this is actuated through the re-construction of the top portion of the masonry cell's wall – using the same stone material of the existing wall, but improving its texture – and inserting inside its thickness a metal bar to which the cover's wooden elements can be anchored. This way, we obtain the connection of the walls that constitute the building's structure skeleton and also a significant connection between roof and walls, assigning to the cover's elements the task of holding the walls (fig. 19).

The reinforced concrete roof-tie-beams, unfortunately still very common, have demonstrated in too many circumstances not to be able to effectively work as *bindings*: because of the difference in rigidity, with respect to the masonry which they are built on, with the consequence of differential motions which favour the disconnection, and also because of their usual thickness exiguity, which doesn't guarantee an adequate transmission of the containing effect essentially linked to the friction on the contact surface.

![](_page_16_Figure_5.jpeg)

Figure 20: inter-storey tie rods in Palermo's historical centre.

Inter-floor anchorages, connecting the external walls with the internal walls orthogonal to them, usually imply a lighter work burden as they can easily be placed at the level of the existing floors, over the wooden structure; at times, the same beams can be organized so as to have the function of tie-beams through the apposition of metal anchorage to the heads. In both cases the floor will remain, as it was in the past, a wooden structure resting on the walls to support the flooring, but it also assumes the function of containing, well inserted between them, the four walls delimiting it, guaranteeing their mutual distance without wanting, though, to realize the "rigid diaphragm" hypothesized in the simplified models of analysis supplied by the procedures used for other structural typologies (Giuffrè and Carocci 1997a, Carocci et al. 2001b).

The tie-beams' external anchorages represent, for the tied-up walls, exact supporting links and, the transmission of their containing action to the whole wall involves the texture's quality of the latter. If the masonry is well done, also chainings placed at a distance corresponding to the masonry dimension (5.6 m) are acceptable, while, for masonry of lower quality, are necessary also intermediate anchorages to impede the breaking of the walls due to bending strength (Fig. 20).

The last type of interventions, which is included in the category we are here describing, is that of the construction of new masonry walls: it is aimed at reducing the panels of the exposed walls, when the masonry cell is characterized by an original unacceptable distance between the windbrace walls. From the technical point of view, the realization of the new walls does not present particular problems as it can make use of the knowledge, acquired during the analysis, of the "workmanlike construction" according to the local context, eventually corrected in the case it was originally insufficient.

![](_page_17_Figure_4.jpeg)

Figure 21: intervention proposals on masonry walls types in Anavatos village (Chios - Greece).

As far as the mentioned second category of interventions is concerned, that is, the one aimed at correcting the lacking points observed on the single construction elements, it is necessary to anticipate that it is not possible to supply an exhaustive range of solutions. In fact, this should take into account all the different local situations which are, actually, potentially limitless and for which it is necessary to prepare a case-history of adequate technical solutions each time we study a historical context. For such reason, here we only present some general indications of interventions, able to improve the most common construction instabilities that might affect the seismic behaviour.

With reference to the interventions on the masonry, we have to remember the consideration already expounded, which points out as most severe seismic effect for the masonry walls that of the collapse due to loss of balance: global instability, if the wall is well connected, local instability if the wall is lacking in transversal interlocking.

The abacuses of the masonry types, built during the survey and arranged according to a decreasing mechanical quality, have the function of grading the masonry's performance and suggesting the interventions suitable to each masonry type located.

As an example, in the cases where the survey discovers the habit to build double walls with a poor filling and without any transversal connection, the intervention can only foresee the reconstruction of the insufficient walls with the help of the "workmanlike construction", being aware of the fact that in such cases also a very light earthquake can provoke tragic consequences.

On the contrary, when a generally well organized masonry texture is locally lacking in transversal interlocking, it can be sufficient to introduce the missing connections, that is, the diatones: these can be realized with different techniques to be selected according to the knowledge of the particular context (fig. 21).

And again, another case frequently noticed is that of the damaged or cracked walls. Here too, the knowledge of the requisites, that a good masonry should have, addresses us to the most opportune type of intervention, in a mechanically consequent way (Giuffrè and Carocci 1997b).

For the masonry damaged and subject to continuous alterations, it is necessary to give back to the walls their original consistency, by eliminating the repairs unduly carried out and arranging corrections accurately interlocked to the adjacent walls.

For the cracked walls, the simple sealing up by means of injections and plastering with compatible material can be sufficient if the cracks are superficial; on the contrary, it might be necessary to make a correction with the so-called technique "stitch and unstitch" for those cracks which, developing deeper, introduce relevant interruptions in the original continuity of the wall (fig. 22).

![](_page_18_Figure_5.jpeg)

Figure 22: intervention proposal on a vault in a Matera's house.

With the purpose of allowing the floors to connect the different walls types, it is necessary to make the various wooden frames resistant to the solicitations acting in their level without suffering relevant disconnections. The adoptable construction strategies depend, as always, on the particularities of the context.

For the floors with simple frame and superimposed wooden planking, for instance, we can simply superimpose a new planking orthogonal to the existing one, making it fit well with the existing one by means of nails. This way, the floor reacts indifferently along the two directions of the masonry cell showing a higher general rigidity in the plane.

For the floor with double frame and brick flat tiles superimposed to the wooden elements, we can adopt a more elaborated solution, consisting in nailing over the joists, in correspondence with the main beams, some boards placed in the space occupied by the flat tiles. Furthermore, the joists' heads will be inserted in iron basins nailed on the main beams. This strategy allows us not only to prevent the joists from coming out of their support, but also to make the floor structure continuous and to consequently improve the rigidity in the plane.

A final notation can concern the problem usually created by the covers; it is well known that their behaviour, in a seismic perspective, is connected to the possible presence of pushing structures. The integral disassembling of the cover, necessary for realizing the roof-masonry-tie-beam, makes it possible to completely reorganize the structure so as to rationalize the placement and allows us to solve the push problem through the anchorage of the roof's main frames to the roof-masonry-tie-beam itself (fig. 23). As we have already seen for the floors, also for the covers it appears convenient to have the possibility of counting on a higher rigidity in the plane and this can be achieved with modalities similar to the previously described ones.

![](_page_19_Figure_1.jpeg)

Figure 23: intervention proposal on wooden roof structure in an Ascoli Piceno's historical building.

In synthesis, as it can perhaps be observed in the above mentioned occasional case-histories, we want to point out that the proposed interventions respect the language coherence of the masonry structure, using techniques which are similar to the original ones but also containing 19<sup>th</sup> century's and modern science's suggestions for improving its mechanical characteristics.

### 7 CONCLUSIONS

The control of the masonry constructions' earthquake-proof safety can be carried out by assuming as unifying criterion the concept of "workmanlike construction". If correctly interpreted, it confers to the historical masonry typologies an intrinsic resistance to the earthquake. In this sense, it can be affirmed that the "workmanlike construction has the same generalizing function of the structural calculation" (Giuffrè 1993b, Giuffrè and Carocci 1994) and, like the latter, tough with conceptually different tools, it allows us to recognize those constructions which can be listed in the "mechanically controlled category". Within such category – that is, of the constructions whose peculiarity of being earthquake-proof is susceptible of demonstration – are included as many different constructions as the numerous local acceptations consolidated in different epochs and places. For such a reason, it is not possible to formulate generally valid operative prescriptions: the awareness of the differences in the construction tradition is followed by the need of preventive intervention techniques which can only be determined locally.

A guidelines hypothesis for the seismic prevention of the historical centres' built-up heritage has been formulated on founded concepts of masonry mechanics, but it only has to offer performance indications, remitting to local technical directives the task of specifying, starting from the knowledge of the technique and history of each place, the technical details able to satisfy the safety requisites.

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