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Seismic safety and strengthening of historical buildings and urban fabrics

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ABSTRACT: In this paper the historical buildings are, first of all, accounted for "existent constructions" pointing out the necessity of a proper analysis related to the single components. Then the mechanical quality of the masonry work is analyzed, and the structure of the house is discussed with reference to its historical and geografical peculiarities. The vulnerability of the masonry houses is studied as depending from the actual fabric, involving both the house and its place in the urban texture. Finally some basic intervention criteria are presented with the aim to achieve the requested seismic safety preserving the historical nature of the original technique.

1 INTRODUCTION

1.1 *The historical buildings in the frame of existing property.*

The analysis of historical buildings belongs, first of all, to the wider topic concerning the studies of existent constructions.
Such basic attribute, the actual existence in opposition to the designed one, turns the analytical approach towards a different methodology.
The mechanical characteristics of materials and structures cannot be taken from the usual standard: they must be recognized in their actuality and consistently modeled.
The activity of surveying the existent structures at the purpose to find out their mechanical quality is a new task of the engineer, the first task and perhaps the most important.
Such task shows its extreme importance in old masonry buildings, in which structural elements and assemblages are completely different by the modern ones.
Even though same effort has been spent in the researches carried out in the last decade to experimentally evaluate local strength and mechanical properties, it must be observed that no much interest the technical literature shows on the survey and the interpretation of the actual, and often peculiar, feature of materials and structures.
The usual experimental tests, for instance those made by flat jacks, are arranged disregarding the strong discontinuity of the masonry, and dynamic tests are usually performed accounting for the whole building as a monolithic one. That is to say: they don't derive from a proper knowledge of those ancient buildings.
On the contrary the survey usually shows no-standard actuality of materials and structures, and the problem of modeling is the second task of the engineer, difficult to be practiced.
Once the task of direct observation has been accepted the first research concerns the time life of the buildings: for all that time it has been exposed to exterior events, and, for many historical buildings, such period is a good sample of the statistics concerning the actions.
The behaviour of the construction, demonstrated by damages suffered or not-suffered, is an extremely important experimental data, more realistic that a modern laboratory test because carried out on the prototype by actual external actions.
In this way a first, global, mechanical information can be achieved.

1.2 *The historical feature of the ancient buildings*

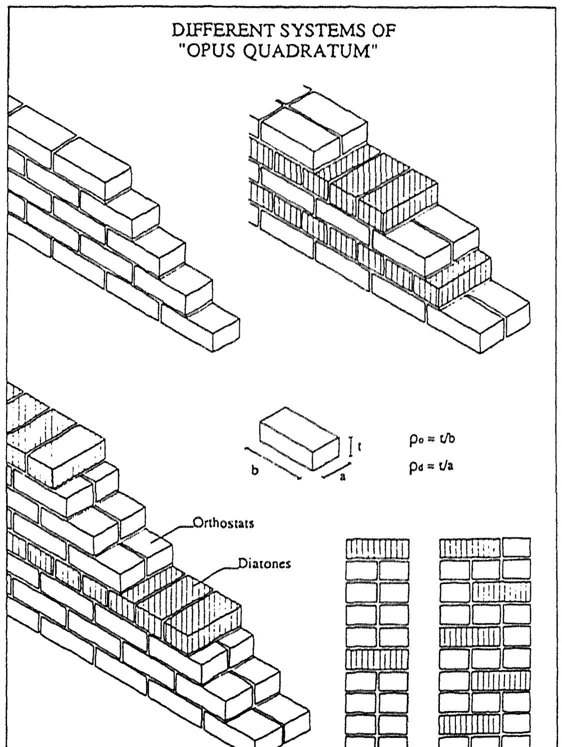
If from one side the time-life of the existent buildings, their history, offers mechanical experimental meanings, it must be regarded under an other point of view: just an historical point of view. The constructive techniques and the structural features are strictly dependent from the historical period of the construction.
In addition to the characteristic of existence the historical buildings present the characteristic of belonging to a

particular historical culture. A building from nineteenth century is structurally different from one of the eighteenth and from a building of Middle-Ages; a quick look to the history of architecture makes evident such differences through the centuries.
But not only the big cultural currents conditions the structural feature of the buildings, the local usage express it through a constructive slang often restricted to a limited area.
The historical building is affected by such peculiarities, which cannot be disregarded if the mechanical intervention want to be respectful of the cultural heritage represented by the structural features of its construction.
Respect which is task of the engineer, because he is concerned with constructions and just he can understand the structural and constructive reasons of the ancient buildings.
Nowadays such understanding is insistently required: persons assigned to the preservation of monuments ask the structural experts to examine deep down the old constructions in order to discover their proper statics and, if necessary, to intervene with a consistent structural language.

2 MECHANICAL NATURE OF THE HISTORICAL MASONRY BUILDINGS

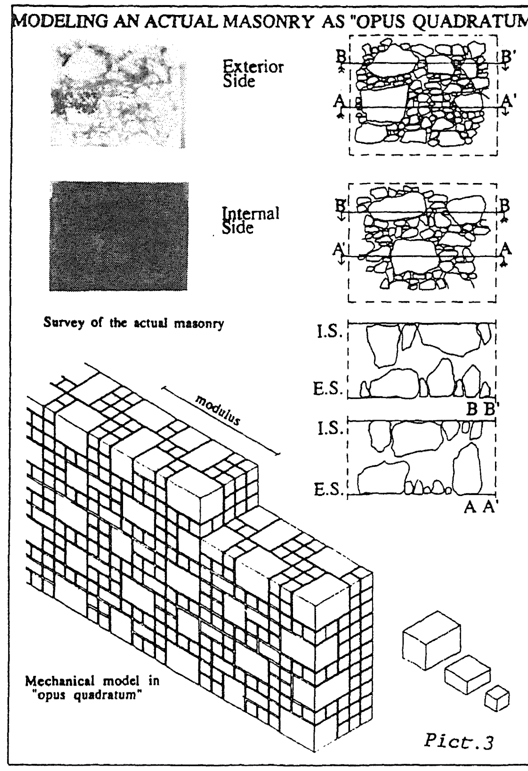
2.1 *Masonry work*

A superficial glance to an old masonry wall only makes out a mess of irregular stones and mortar. Such mess is usually modeled as an isotropic material lacking in tensile strength.
The literature offers many sophisticated and difficult mathematical developments, based on such an assumption, but quite few useful results.
Nevertheless a second glance to the masonry shows that the stones have been arranged respecting some rules; how mechanically remarkable those rules are, is the subject of other interesting researches.
We find useful a short account on this item.
First of all such researches take advantage by all the historical treatises concerning practical architecture[1]. All of them provide rules for the construction of walls with raw stone, and it is remarkable that those rules are common to all authors. That bears witness to their general objectivity.
The rules contain the following requirement:
a) set up the stones with interlocking throughout the thickness of the wall using "diatones": stones placed with their greater length crosswise with respect to the wall;
b) surround each stone with mortar, but without excess, using smaller stones and fragments of brick to fill the spaces between larger stones;
c) level up the wall at regular intervals, in order to provide horizontal layers for successive bands of stonework.
They are the rules of the art of building a masonry wall, translating an italian idiom they can be said "the rule of art".
Accounting for such rules it is possible to be an objective judge of the quality of the masonry wall. Work that has been carefully executed is clearly distinguishable from work that has not.
In these rules can also be seen the intention to recreate the principal features of the *opus quadratum*, as Vitruvius called the masonry made by squared stones. In fact the presence of "diatones" and the horizontal layers is the characteristic of such regular masonry.
Pict. 1 reproduces different systems of "opus quadratum" masonry; the presence of "diatones", transversal stones, more or less frequently placed through the wall, is pointed out.
It could be asserted that the "opus quadratum" is the ideal prototype, to which, more or less consciously every mason refers: he places the raw stones he uses alternating the lengthwise and the transversal layout,

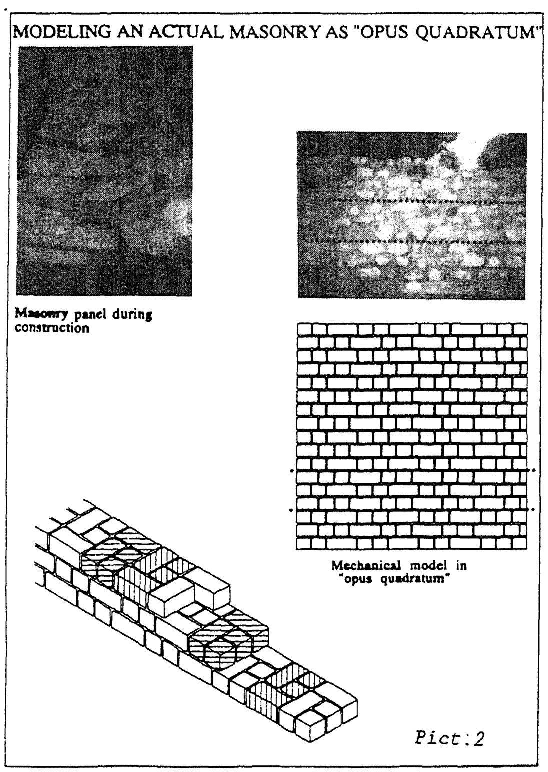


Pict.1

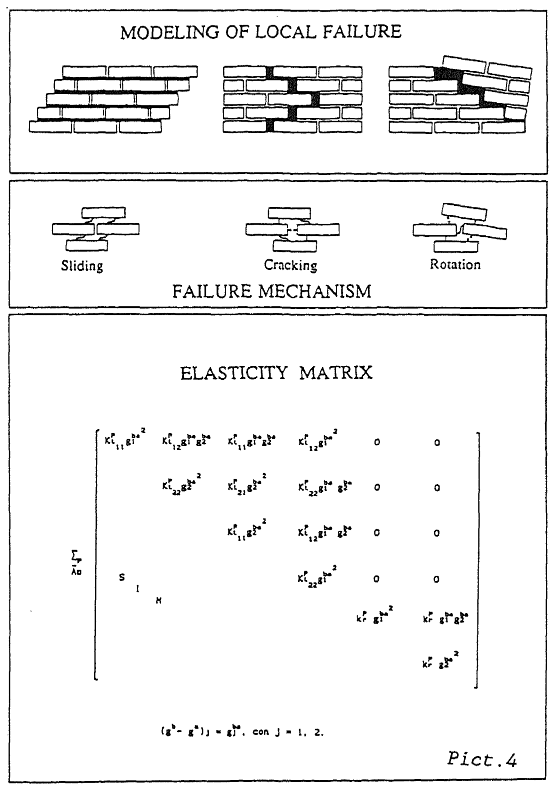
and he arranges, at regular spaces, an horizontal layers. For this reason the "opus quadratum" masonry can be taken as the mechanical model for all the derived forms of masonry.
Any raw stone wall in which it is possible to identify the size and the position of the stones can be analyzed in statistical terms, pointing out the average size of the blocks and the rule for positioning them implicitly applied by the mason. From such analysis the masonry can be modeled by squared units, of suitable sizes.
Modeling actual masonry by squared pieces is illustrated in *Pict.s 2* and *3*: the corresponding model of "opus quadratum" is thus defined, and the result of mechanical analysis carried out on the model can provide useful indications for the prototype.
Numerical analysis of such an assemblage has been already tried: *Pict. 4* shows the local failure mechanisms and the stiffness matrix worked out transforming the lattice material in a continuum with inner structure[2]. From such approach it is possible to carry out a non linear finite element which contains the geometrical peculiarities of the actual arrangement of the stones.
The possibility of modeling each masonry as a corresponding "opus quadratum" has a second advantage: until the mathematical model is elaborated enough it is possible to approach



Pict.3

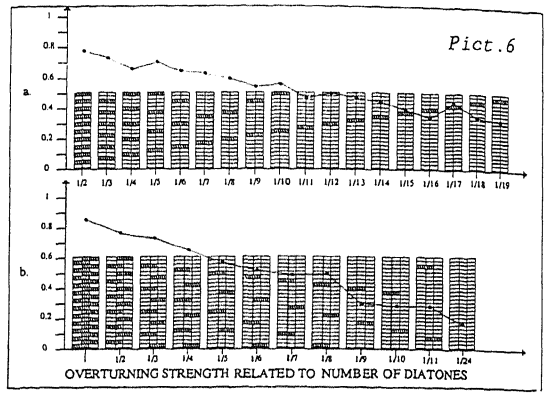


Pict:2



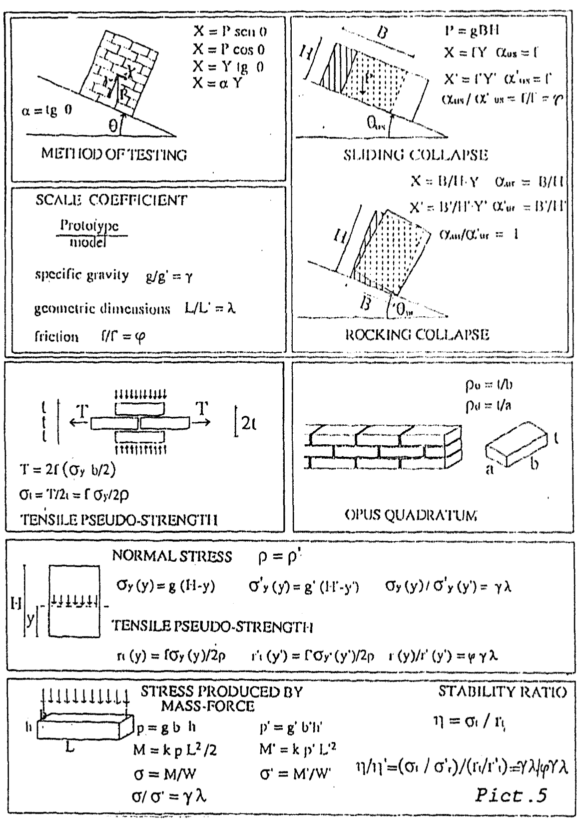
Pict.4

the problem in experimental terms, constructing scale models of "opus quadratum" masonry according to the rules pointed out by the statistical analysis of the prototype. Since the main problem is the behaviour of masonries under seismic actions the testing method illustrated in *Pict. 5* seems to be the most suitable: the model is placed on an inclinable frame whose inclination introduces a component of weight parallel to the layers of the masonry.[3]
The tangent of the angle of inclination plays the role of a "seismic coefficient".
An interesting result of such experimentations regards the behaviour of the wall stressed out of its plane, pointing out the presence of "diatones".
Pict. 6 shows that the overturning strength of the wall decreases with the increasing of the distance between the "diatones".
The "mechanical quality" of the masonry begins, so, to be measured with reference to its objective nature.
An other result regards the in-plane action. *Pict. 7* shows how the sliding or the overturning mechanism happen as function of the height of the wall and of the overlapping of the units.
Pict. 8 shows a crack produced by the 1908 earthquake on a masonry wall in Reggio Calabria, very similar to the cracks obtained

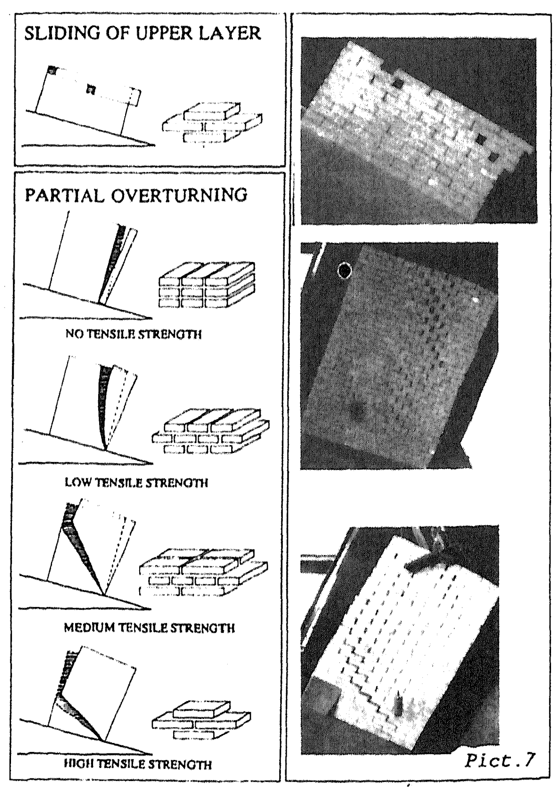


Pict.6

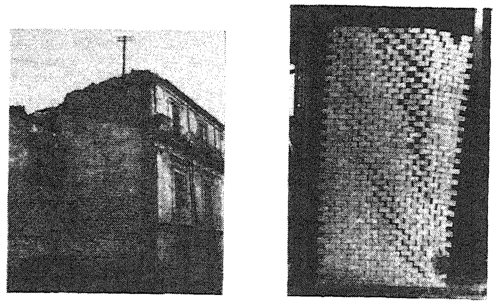
on the "opus quadratum" model: the partial overturning is the most usual failure mechanism; and *Pict. 9* shows the parabolic feature of the out of plane collapse. The damage of the Palazzata of Messina after 1908 earthquake is quite similar to the result of the laboratory test.
The agreement of these images proves the interest of the "opus quadratum" model, easy to be arranged and to be tested.
As final remark concerning the behaviour of masonry walls under horizontal actions it is useful to point out some limit inherent the usual testing on masonry panels.



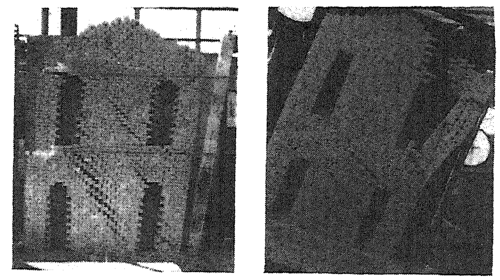
Pict.5



Pict.7

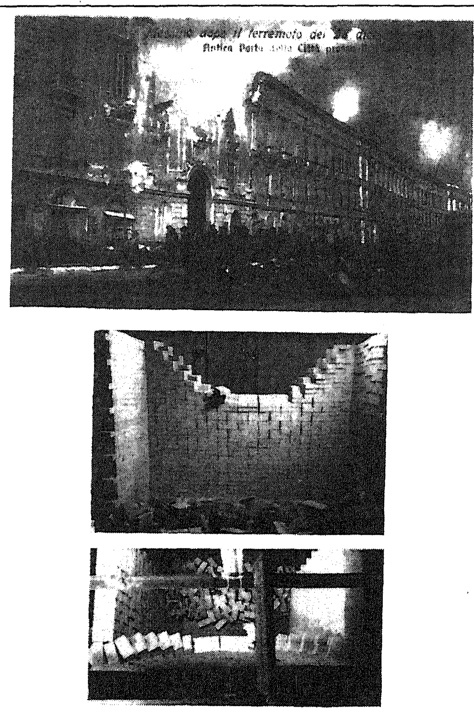


A. Vertical crack due to low tensile strength. Model and a house of Reggio Calabria hit by the 1908 earthquake *Pict.8*



B. Failure mechanisms for concentrated and distributed horizontal load *Pict.10*

On this subject the scientific debate is far from over: some insist on researching experimental methodologies which make it possible to measure by flat jacks the value of mechanical parameters such as resistance to compression or resistance to shear in terms of internal stress. Impossible experimentation, which in any case would produce no more than non-generalizable local information.
An other kind of test is usually carried out applying a concentrated horizontal force to the top of a masonry panel, together with a distributed compression: the relationship force-displacement is derived by it. Being this test widely generalized it produces comparable results, but it brings very poor information on the behaviour of the masonry under seismic action.



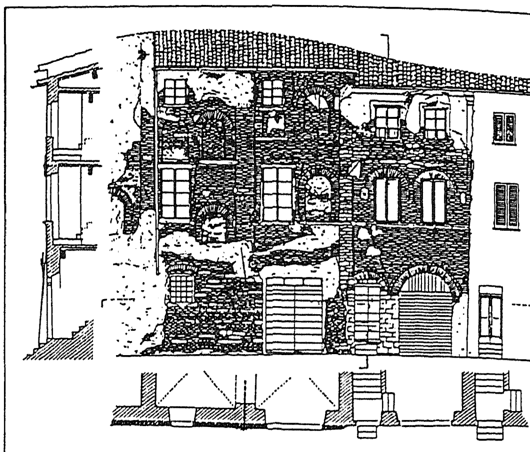
Partial collapse of the facade model and the "Palazzata" of Messina after the earthquake of 1908 *Pict.9*

The experimentation carried out on squared units masonry demonstrated a relevant difference between the failure mechanism produced by horizontal concentrated forces and the one produced by the distributed forces consequent to the inclination of the testing frame.
Pict. 10 shows the results of the experiment carried out in both the condition: the different distribution of internal stress produces a different crack pattern and a different value for the collapse load.
In historical buildings (this is an important difference from the new masonry buildings) the high thickness of the walls and the low weight of the floors make the load condition produced by the earthquake nearer to the distributed forces than to the concentrated ones: the usual testing method is not consistent with the actual stress condition.

2.2 *The structure of the house* [4]

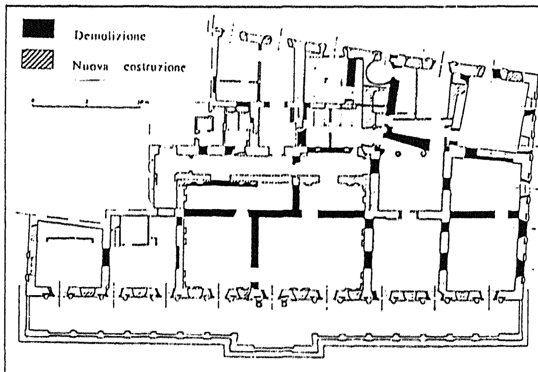
The study of masonry is but one step, albeit an important one, towards the study of the historical house. The house is a simple organism, made up of juxtaposed elements.
It has already been said that the construction of the wall respects general rules that come from that ideal common matrix which is "opus quadratum", but nevertheless there exist local implementations conditioned by the materials of the place and by the building culture of a certain period. In the same way the house-organism is articulated according to general rules, but offers particular aspects closely connected to a geographical area and an historical period. Observing the houses in different regions, it is easy to notice that there exists a common matrix translated into different realities. Such common matrix makes possible the

comparison between them. The houses are composed of elementary cells very similar to each other, in plan aggregated differently and superimposed in order to form units of more than one floor. The differences depend on the urban fabric in which the house is constructed: pre-existing elements, available spaces... Every new unit has been adapted to its neighbours maintaining constant the tendency to realize the configuration of the elementary cell with its dwelling surface. Certain tangled, picturesque urban fabrics, crisscrossed by small, tortuous dead-end streets, reveal themselves upon closer observation to be nothing more than a system of elementary cells, side by side and one atop the other like a bunch of grapes.
Only a few elements, elementarily assembled, make the house.
Stone over stone make the wall, the walls support floors and roofs, and between these is placed a structure connecting the various levels of the dwelling: the staircase.
In some geographical areas the first horizontal is realized with a vaulted masonry structure, reminder of a Roman practice.
The structural elementarity of the modest houses is the same in the most important palaces. A noteworthy feature of the historical house is its ability to sustain modifications, its being not an object defined by the moment of its first building, but an evolving organism. The little or big houses of our historical centres are all the fruit of an evolution carried out over the centuries: the aspect which they present to us today is the result of slow, but at times radical transformations.
Great transformations which profoundly changed an already consolidated aspect: walls are knocked down, built anew or built alongside others; windows have been closed, opened or transformed, roofs and floors are constructed with simplicity.
It is worth noting here, returning to the theme of mechanics, that such modifications, if executed competently, do not alter the structural consistency. It is not so much the lateral interlocking that the competent mason used to provided for, as the correctness of the path of the vertical loads. *Pict. 11* contains an extremely modified facade from Città di Castello: the old windows have been closed and new ones opened, offering to the internal forces paths different from those previously followed. Nevertheless the masonry shows no sign of suffering: it demonstrates to have acquired the consistence of a newly-built structure.
So the palace of the newspaper "IL TEMPO" in place Colonna in Rome shown in *Pict.s 12* and *13*. From 1871 to 1921 it supported so strong modifications at the interior and exterior walls that now it can be considered a different building, with respect to the original one.



Transformation of a facade (Città di Castello) *Pict.11*

Pict.12

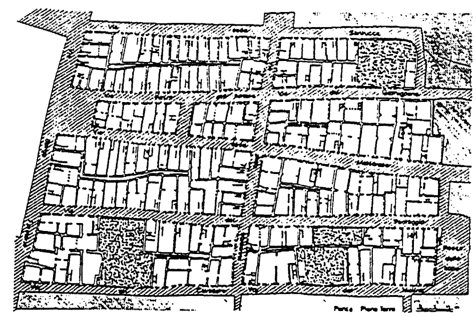


Confronto con la situazione al 1871 Pianta del piano nobile

Pict.13

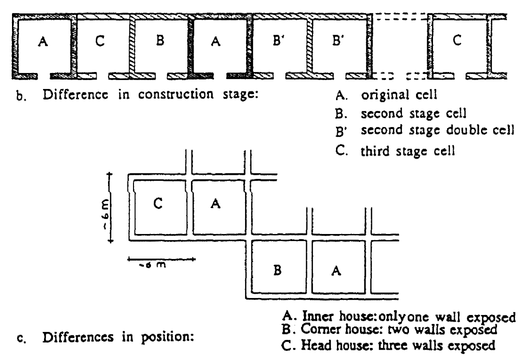
All this is possible thanks to that intrinsic characteristic of the masonry organism which we mentioned above: its being an assembled system of simple elements, easily replaceable and modifiable, and this is of prime importance in explaining the historical habit of maintenance of the houses through repair and substitution of the pieces as they gradually deteriorate.
And fundamentally it shows the effectiveness of such way to intervene when something in it requires to be repaired or substituted.
As the building is the result of an assembling process, all the houses put together in the city obey to a similar evolution.
Pict. 14 shows the urban texture of two quarters in historical Italian cities, very different from one another because one of them, La Mattonata in Città di Castello, is a quarter preventively planed for expansion outside the city walls in the 13th century, while the other, on the isle of Ortigia the historical centre of Syracuse, derives from spontaneous building.
The process of growth of the building texture in the historical city has an important structural aspect. The elementary cells lean against one another, often using the walls of preceding cells.
This process can be modeled, as it is illustrates in *Pict. 15*. The first model has been derived by the quarters of Città di Castello presented above; it shows the inserting of new cells between preceding ones. As a significant result of such process the non-connected angles have been pointed out, potential weak points in case of an earthquake.
The second model is referred to the feature of the urban fabric in Ortigia. It lists the positions in the texture which involve different exposure: one single exterior wall, two walls for corner-houses, three walls for end-houses.
An other element of vulnerability is so recognized.

Ortigia



Città di Castello

Pict.14



Pict.15

2.3 *The seismic problem in historical centres*

It is true that strong earthquakes have caused tragic destruction of masonry-built cities in the past, and recently many surviving buildings of the past have suffered other severe earthquake damage, but these events must be critically reexamined in order to avoid unfairly penalizing an entire construction category.
To declare masonry construction as earthquake-inefficient on account of the damage which some of it - much of it - has suffered during earthquakes would be comparable to condemning reinforced-concrete constructions because of the generalized collapses which have occurred on the Yugoslavian coast, as well as in the towns of Friuli and Irpinia in Italy. One measure of the seismic vulnerability of urban areas is contained in the definition of the macro seismic scale:

⇒ 8th degree: some partial collapses, and some buildings cracked;

⇒ 9th degree: some total collapses, and numerous buildings seriously damaged so as to be uninhabitable;

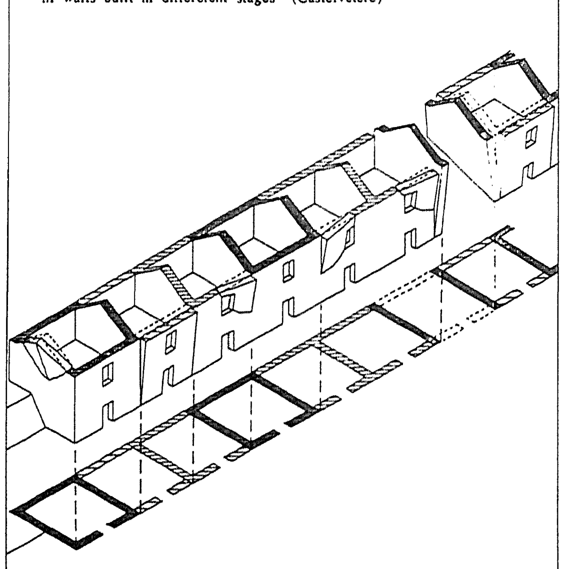
⇒ 10^{th} degree: total destruction.
Obviously these definitions have a statistical meaning, valid for the average of the constructions, which cannot be applied to the individual building. But in effect the only differences from one building to another are the physical condition of their parts, or particular features of urban aggregation: differences clearly recognizable. This makes it possible to move from the statistical level to the individual one. The forecasting of the seismic behaviour of the buildings in historical centres can be carried out by identifying the average norm of construction and comparing to it the individual feature. Any difference which decreases the mechanical qualities will be evident. The 8^{th}degree earthquake will produce localized damage in those cases - and only in those cases - in which the general rules have not been respected, or in which deterioration has made them useless.
Intensity above the 8th degree involves the fundamental concept of masonry construction: its nature as a system easy to be assembled and disassembled.
Preventive action is essential, but it calls for understanding of the actual mechanics.
This will be discussed a bit later.

2.4 *Resistant mechanisms and dynamic response*

Since houses built according to the traditional norms resist the 8th degree of the macro seismic scale, but are in large part damaged by the 9th degree, the 9th degree can be taken as their resistance threshold.
It should be noted that the basic urban fabric of historical cities is characterized by not very connected walls.
The collapse of such houses due to the forces of inertia of an earthquake normally occurs with the fall of the perimeter walls, directed outwards. In *Pict. 16* it can be seen a street in Messina after the 1908 earthquake. The fall of the facade walls for overturning is evident.
The studies carried out to date on historical centres have produced a series of concordant features of collapse: accounting for the overall structure of the building, considering the particularities of the construction phases and the position within the urban fabric, a range of possible forms of collapse has been identified.
Pict. 17 shows the first model illustrated above. The aggregation pattern of the cells which subsequently have occupied any free room is schematically pointed out. With reference to the cell originally built the aggregation can present perimeter walls with one edge connected and the other juxtaposed, or with both the sides simply put near preexisting walls.

Pict. 16

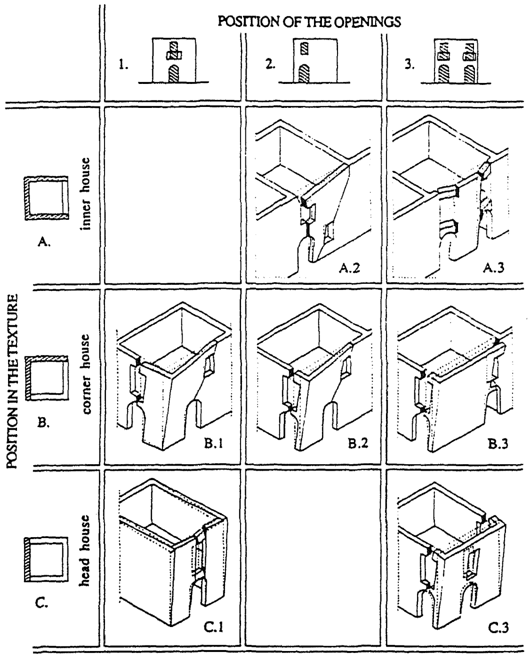
Failure mechanism resulting from lack of continuity in walls built in differerent stages (Castelvetere)



Pict.17

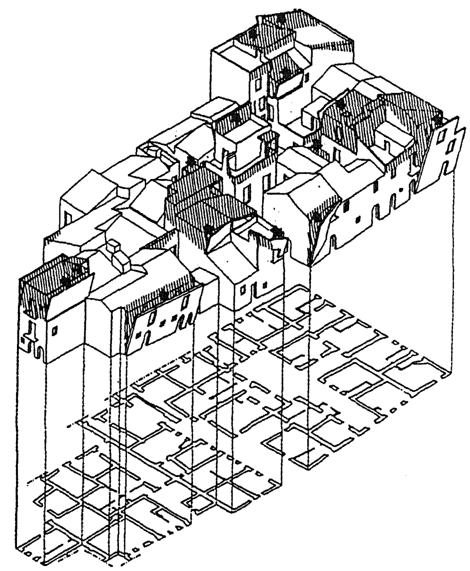
The possible collapse mechanisms are evident; various cases are shown in the figure. Without a probabilistic measure it can be predicted that non-connected corners or walls constructed between two pre-existing

Failure mechanism depending on the position of the house (Ortigia)



Pict.18

PREDICTION OF DAMAGE IN A PORTION OF URBAN FABRIC (ORTIGIA)



Pict.19

buildings can suffer damage at the 8^{th}degree but for sure they will be damaged over the 8^{th}.

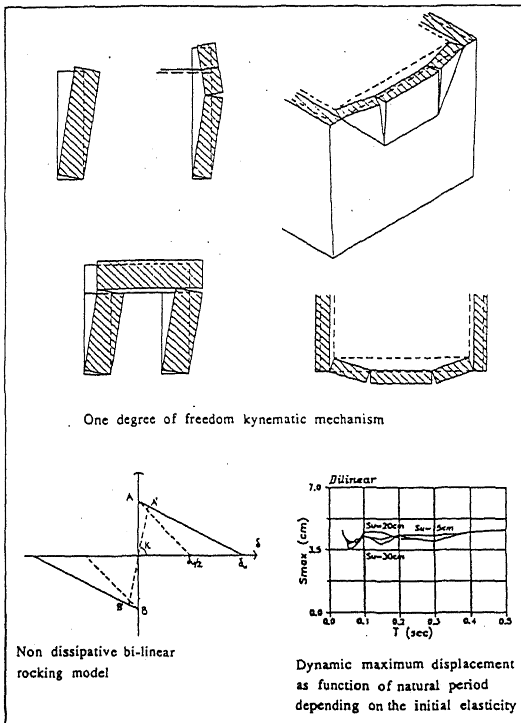
The second model regards the highly connected urban texture. In this case the fundamental parameter of earthquake vulnerability is the position of the house. *Pict. 18* shows a grid with the most characteristic failure mechanisms as function of the positions in the urban texture and regarding the openings in the walls.

The formulation of the grid is an operative instrument: the examination of each individual building can be carried out on the basis of such specifications, and a prediction can be made as to which mechanism it is subject to.

Pict. 19 reports the sketch of a group of houses in the city of Ortigia and the damage derived by the application of the grid.

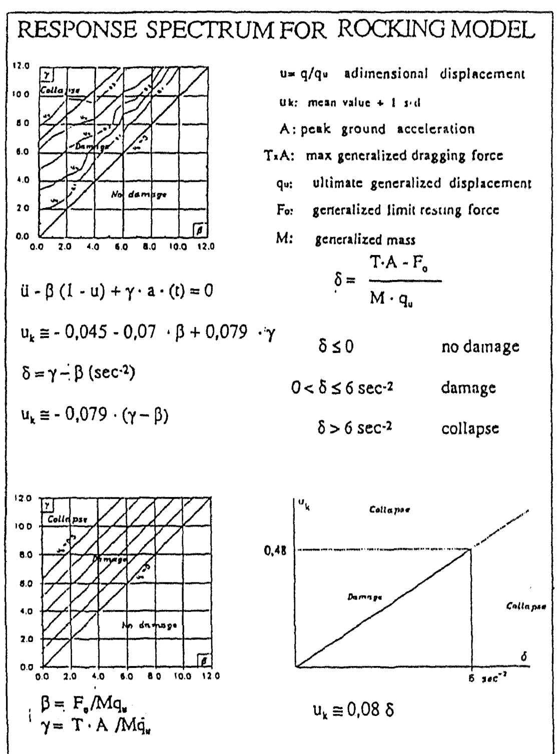
A scenario like the 9^{th} degree derives, as it is evident, since all the detachments primed over the 8^{th} degree have been put into effect.

Once pointed up the collapse mechanisms the numerical analysis can be performed for each of them, evaluating the horizontal forces which produces the loss of the equilibrium. Such static check is justified by the results of dynamic analyses which are shortly presented in the following. [5]



Pict.20

Pict. 20 shows a number of models of oscillators. They have in common the possibility of being represented by a single generalized displacement parameter, which is to say that they are single degree of freedom systems.
The force-displacement relationship can always be brought back to the non-dissipative bilinear model reproduced in the figure, the "rocking model", in which the initial stage, theoretically rigid, can also assume the slope corresponding to a characteristic of elasticity, while the second, declining segment reveals the reduction of the stabilizing effect of the vertical load during displacement which brings the kinematic chain to the limit of stability.
It is important to notice that the second brunch increases his slope if the masonry quality decreases.
This model has two important features.
First: it has been clearly demonstrated[6] that the value of initial elasticity has absolutely no influence on the dynamic response when the latter enters the decreasing segment. The initial elasticity, certainly present in masonry structures, is difficult to quantify; but since it does not condition the result it is not essential to measure it.
The dynamic response of this type of oscillator is conditioned by the second brunch, but in a way similar to that of the phenomena of elastic instability: the response doesn't change if the slope increases a bit, but if the quality decreases so much that the ability of rotation of the wall is halved, collapse is inevitable. It is important to notice that so poor quality can be easily and objectively recognized by the comparison with the rules of the masonry art. This consideration makes strongly meaningful the judgment on the quality of masonry: it is not the resistance in terms of stress which conditions the dynamic response, but the mechanical "quality". If the quality is acceptable, if it does not differ greatly from the rules, the dynamic behaviour is well represented by the rocking model, and it is possible to rely on the results of numerical calculations.
It is opportune to point out that the model examined, the kinematic chain of rigid bodies, represents a highly idealized masonry situation, but no more idealized than it is the case when the theory of elasticity is applied to the study of the response beyond the elastic range of buildings in reinforced concrete, with all of their superstructures.
For the "rocking model" a response spectrum has been evaluated: it is reproduced in *Pict. 21* and it allows to evaluate the maximum displacement expected as function of parameters concerning the peak ground acceleration and the static strength of the model to horizontal forces.
Accounting to the response spectrum a static check equivalent to the dynamic analysis can be performed.
If the first collapse mechanism will be controlled by suitable devices the right angle walls, acting as buttresses, are called to resist all the horizontal seismic forces. When their resistance is exceeded a "second-mode of damage" arises, but this behaviour is ductile enough: the crack pattern of walls loaded in their plane, as has been observed after earthquakes, demonstrates the high ductility of the structure. After cracking the wall does not leave the plane, does not move towards an unstable configuration, but remains in any case upright, still available to support the weights it is loaded with.
Only if the texture of its stones is severely out of norm the local disconnection which follows the cracking can cause a detrimental disgregation, but this possibility can be verified in a preliminary moment, looking at the quality of the wall. The forecasting of the seismic behaviour of the buildings in historical centres can be carried out by identifying the average norm of construction and comparing to it the individual feature. Any difference which decreases the mechanical qualities will be evident and will foresee damage.



Pict.21

3. INTERVENTIONS CRITERIA AND CONSTRUCTIVE DETAILING

It could be asserted that the historical constructive technique, put right after centuries of direct experimentation, contains in itself the details which makes it safe against earthquakes, and they suffer damage only when such rules have not been applied. That is true, in some way, but only in part, only with reference to the light seismic intensities, more frequent, that persist in memory of people.

Accounting for more destructive intensities it should be first stated that the original, historical, masonry technique is not enough to safely withstand strong earthquakes. The common characteristic of those constructions, the lack of connections that makes them so easy to by assembled but as much easy to be disassembled, offers a weak side to the seismic action. If the intensity exceeds the 8^{th}degree the historical houses, however well built, will be more or less damaged.

Looking once again at the past constructive history we discover that the ancient builders used to strengthen the damaged buildings with works that showed, during next earthquakes, their effectiveness.

The criteria were derived by static remarks: the overturning of the exterior walls suggested to put buttresses from the outside or chains from the inside.

One part of the research carried out in the last years, with the purpose to define philological methods of intervention on historical buildings, was directed to find out such original details and to document their behaviour.[7]

The collected data have an historical side, but from an other side they contain a topical message: they suggest the correct approach to the problem of assured seismic safety to the buildings of the urban fabric. In fact "mechanical correctness" in the interventions can be obtained by operating on the historical masonry structure with masonry techniques.

Before illustrating such statement it is useful to spend a few words on the usual way to strengthen masonry.

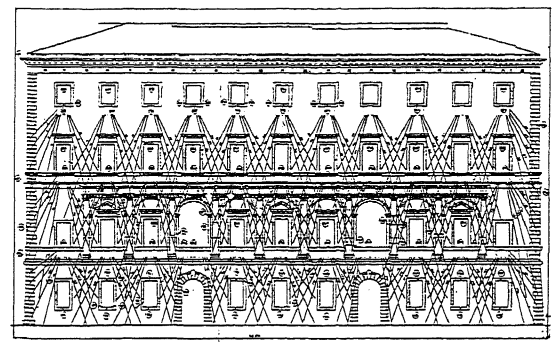
Starting from the intervention on the temple of Cerere in Paestum, where the original structure of superimposed stones, after two thousand and fifty hundred years of standing, was transformed in a reinforced frame, the practice of drilling the walls, inserting in the masonry metal bars, and injecting the hole with cement, became so consolidated that nobody asks how to demonstrate the effectiveness of such a peculiar mixed structure.

No scientific way exists to give a mechanical reason to this practice, but without criticism the engineers, all over the world, go on designing something like those reproduced in *Pict. 22*.

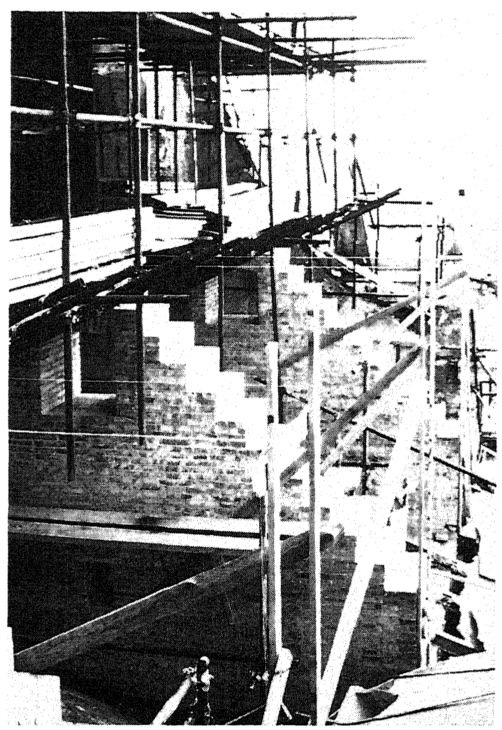
The silliness of such a technique is evident: it is quite indifferent to the nature of the original structure and its mechanics, impossible to be modeled and analyzed, are probably quite ineffective.

On the contrary, recent views in the static restoration of historical buildings, requires to derive the technique of the intervention from the original ones, avoiding to introduce detailing *extraneous to the actual* constructive lexicon.

Such basic philosophy requires to replace the insufficient details with more efficient ones, looking (until that is possible) at the



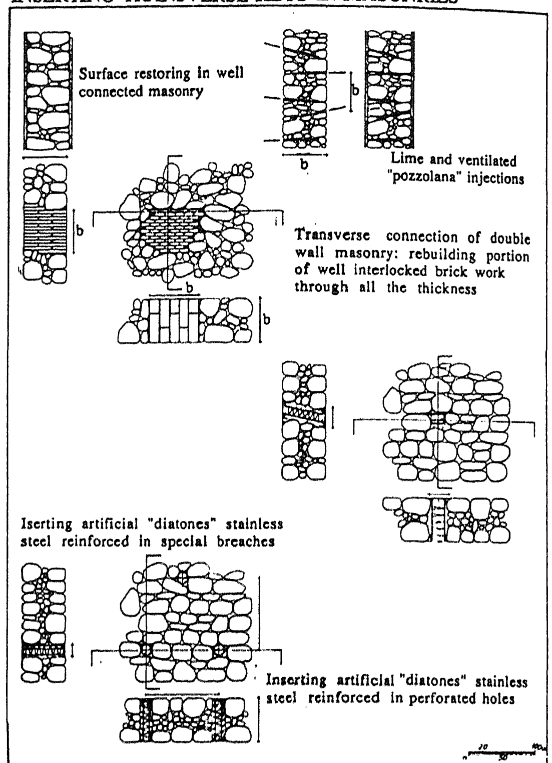
Pict.22



Pict.23

consolidate masonry practice. From an operative point of view it would not be difficult to list the possible defects which constructions present and to suggest remedies for them. Some weaknesses, which concern the logic common to all types of construction, its intrinsic disconnection, are so generalized that they admit the formulation of general criteria of intervention, valid anywhere; others are proper to a local construction feature, and must be solved in their own way.
For this reasons in addition to general codes containing the fundamental criteria, local codes are necessary which specify the local peculiarities of the constructions, and suggest proper remedies for damages or inadequacies.
Such "practice codes" should contain, first of all, the detailed description of the local constructive technique, to make known to the designers the peculiar nature of the present urban fabrics, and then they should illustrate the most common weaknesses and suggest the details of the interventions.
The most common necessities, as we have said, are first of all those which regard the masonry, that is, the mechanical qualities of the wall. How to intervene when the walls are seriously insufficient is up to now an unresolved problem. Our predecessors knew that a poor wall had to be rebuilt, and they performed reconstructions. Today we can - perhaps we "must" - make this choice in some cases.
Pict. 23 shows a restoration yards, where masonry walls has been rebuilt.[9] *Pict. 24* shows some possible ways of intervening on walls of inadequate quality. Proposals range from the reconstruction of portions of wall which cross the entire thickness of the existing one, to the insertion of artificial diatones realized in reinforced concrete.[10]

INSERTING TRANSVERSE KEYS IN MASONRIES

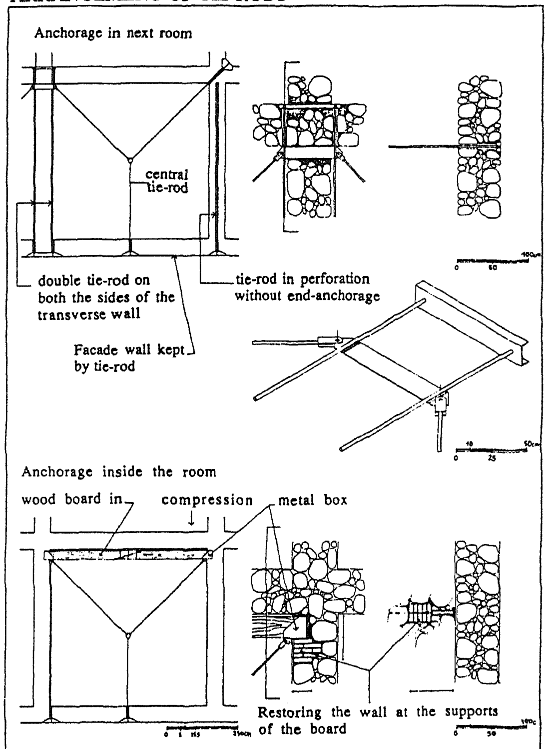


Pict.24

The second problem, of "structural" importance, involves the very nature of historical construction techniques and concerns, as has been mentioned, out-of-plane overturning of the exterior walls.
This danger concerns the eventuality of a more then 8^{th} degree earthquake, and it is general; there is not a single building in the history of construction that does not present this problem, even if all of the masonry walls have been built together.
The exterior walls must be connected to the transversal ones.
The way to obtain such connection, through the wooden floors, is suggested by the *Pict.s 25-26*, referred to the buildings of Ortigia, the centre city of Syracuse.

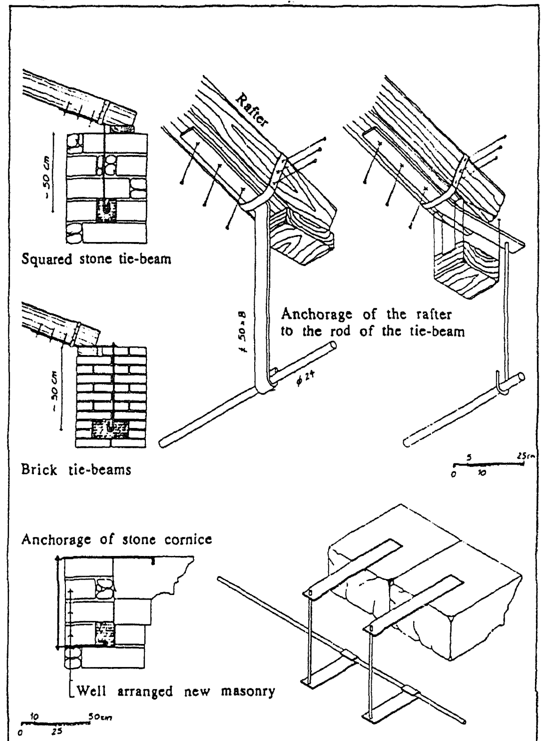
An other important intervention concerns the tie-beams. Recall the insistence with which Leon Battista Alberti[11], in 15^{th} century recommended the continuity of the cornices which form a "belt" half-way up and at the top of the building; but it is Rondelet who, at the end of the 18^{th} century, suggests placing metal ties along the walls.
The use of chains - metal ties placed within or along the wall to confer them continuity - is a recent complement to the art of masonry, but one whose aim is to satisfy a long-felt need. It can be adopted in modern interventions.
The recent proposals suggest to avoid the reinforced concrete tie-beams, but to implement the continuity of the masonry putting metal bars inside the walls. At the top of the wall it is possible to reconstruct a portion of masonry using an accurate interlocking between the stones, and insert an iron bar within the thickness of the wall. This creates a "masonry tie-beam" which combines the recommendations of Leon Battista Alberti with the counsels of Rondelet; and at the same time it follows, even though not to the letter, the indications which today's technical norms provide us with.
The roof beams should be anchored to this metal bar by means of clamps, assigning to the wooden structure the task of holding the wall.
Pict.s 27-28 illustrate these interventions. Half way up the wall the chain should be inserted in perforation.

ARRANGEMENT OF TIE-RODS



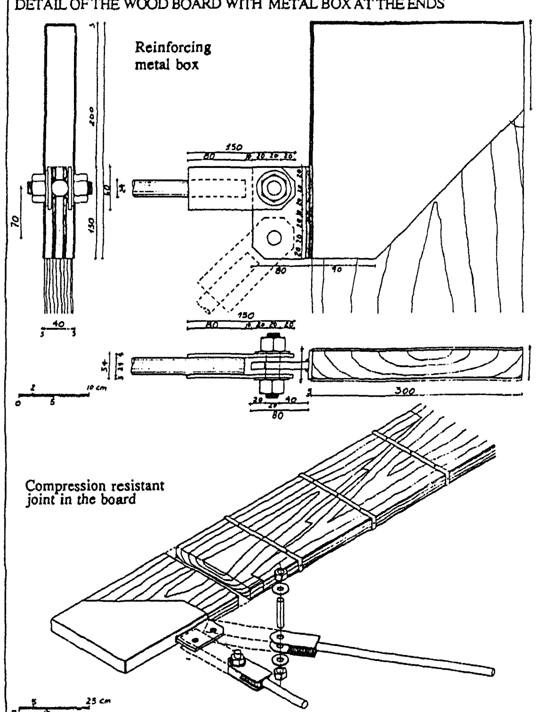
Pict.25

THE MASONRY TIE-BEAMS ON THE TOP OF THE WALL

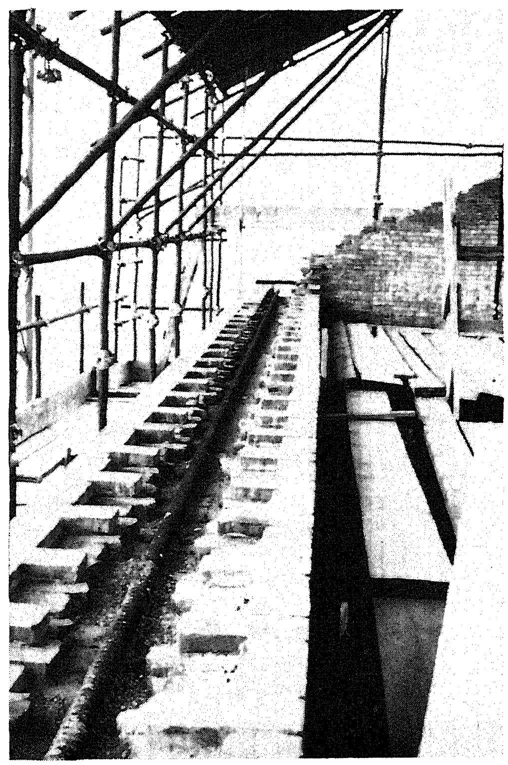


Pict.27

DETAIL OF THE WOOD BOARD WITH METAL BOX AT THE ENDS



Pict.26



Pict.28

4. CONCLUSIONS

We can conclude this report by stating that the technical examples illustrated here are no more than generic proposals, whose only purpose is to stimulate the research of useful details with reference to the actual nature of the construction in which we are working.
The historical architecture should be deeply studied in its actual mechanical resources; it would appear evident that often the original structure was, originally, statically sound, as it is demonstrated by its age, and slow degradation, or consecutive little damage, or sudden tampering, make it needy of strengthening. In the most cases with the addition of a consistent improvement it is able to resist earthquake as much as a reinforced concrete frame building.

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[1] At the beginning of the XIX century Rondelet gave the fundamental rules reproduced by the most of the next treatisers: J.Rondelet, Traité theorique et pratique de l'art de batir, Paris 1802.

[2] Such approach has been carried out by P.Trovalusci in her doct. thesis, Rome 1992.

[3] This kind of experimentation has been carried out by V.Ceradini in his doct. thesis, Rome,1992

[4] This paragraph, as the most of the present report, has been derived from: A.Giuffrè - C.Carocci, "Statics and dynamics of historical Masonry buildings", presented at the "International Workshop on Structural Restoration of Historical Buildings in Old City Centres", Heraclion, Crete, May 1992.

[5] Details of the following dynamic analysis have been reported in A.Giuffre', C.Baggio, R.Masiani in XV EAEE Regional Seminar, Ravello Sept.1989.

[6] C.Baggio, R.Masiani, "Dynamic Behaviour of historical masonry", IX IBMAC, Berlin 1991, vol.I, pag.473.

[7] F.Ferrigni, "S.Lorenzello: alla ricerca delle anomalie che proteggono". Consiglio d'Europa, Centro universitario per i beni culturali, Ravello, Dic.1989.

[8] See, on this purpose, the studies carried out by the EAEE working-group 7 "Seismic Aspects of Preservation of Historical Monuments", convenor C.A.Syrmakezis.

[9] Sant'Angelo dei Lombardi Cathedral, damaged by the Irpinia earthquake in 1980.

[10] Such detailing derive by a "practice code" implemented for the historical town of Syracuse, in Sicily (to be printed); see V.Ceradini - A.Giuffrè, "Vulnerabilità e conservazione nel quartiere della Graziella in Ortigia", 5° INAEE, Palermo, 1991, vol.1,pag.139.

[11] Alberti, De Re Aedificatoria, Roma XV century.