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VULNERABILTY AND MITIGATION IN HISTORICAL CENTRES IN SEISMIC AREAS
CRITERIA FOR THE FORMULATION OF A "PRACTICE CODE"

Antonino Giuffrè - Caterina Carocci

Terza Università di Roma - Dipartimento di Progettazione e Scienze dell'Architettura
Argiletum - via della Madonna dei Monti 40 - 00184 Roma (Italy) - FAX. **39.6.4818625

ABSTRACT

In this paper is presented a methodolgy for the seismic vulnerability analysis of the historical centres and the concerning mitigation criteria calibrated on a preservation point of view. Issue of the study is the compilation of a "Practice Code" made as a guide to the analysis and the design. The seismic vulnerability is pointed out with reference to the damage scenarios given by the macroseismic scales, correcting them in agreement with the effective conditions of the urban texture. Suitable intervention strategies, consistent with the original constructive techniques, are formulated. The damages are defined as rigid bodies mechanisms, and from such hypothesis both the design of the antiseismic intervention and the static and dynamic modeling derives.

KEYWORDS

Historical centres; Seismic vulnerability; Damage Mitigation; Preservation; Historical Techniques;

PREMISE

For more than ten years, aboveall in Italy, studies of seismic vulnerabulity of urban centres have been carried out. The classical methodology has been formulated with statistical criteria based on a rapid and extensive survey leaded by a given schematic form (CNR 1993). The items of the form are parameters characteristic of the building taken into consideration and the whole of the informations concerning all the buildings are statistically elaborated. The outcome of the research is the probability that a certain level of damage will be verified upon the expected seismic intensity. By means of this studies useful comparison were carried out among several urban centres verifying priorities and emergency of prevention intervention.

We have known for several years that antiseismic interventions in the masonry construction of old cities present a notable impact in the constructive reality of historical construction, and the instance of conservation - all the more pressing the more one observes the loss of identity of restructured houses and of the character of the cities - calls for such intervention being led by a precise awareness of the original structure and by structural choices which are knowingly consistent.

As a result it spreads a methodology of analysis of seismic vulnerability directed more precisely towards the choice of mitigation intervention through a reading of the historical structure in all its mechanical potentiality and its inadequacies concerning seismic action. In this type of investigation which we have put right and have already experimented on at various times, the construction of the urban fabric is still examined in extensive terms but concentrating firstly on the possibilities of damage which the constructive particularities typical of the site enable us to predict; then the most opportune techiques to rectify the structural insufficiencies are carefully considered. The outcome of the investigation is a "Practice Code" i.e. a manual offered to professionals as a guide to the comrehension of the historical structures of their city and suggestions on criteria and intervention techniques. The "Practice Code" is an operative instrument with which the local governments can check and render homogeneius the quality of intervention in their city.

THE TWO ASPECT OF THE "PRACTICE CODE"

Firstly we must introduce the two purpose which the Code establishes: in this approach the study of vulnerability is explicitly addressed to a design end and to a check of seismic safety.
Consequential ends: following a fact finding path which predicts seismic damage (vulnerability) intervention is projected (design purpose), and therefore, on the base of the same knowledge verifications are carried out which control the mechanical efficacy of the choices which have been made (purpose of seismic safety). The design process requires the comprehension of the constructive techniques and of their mechanical qualities, mechanical modellations necessary for verification come from the same data.

METHODOLOGY OF THE DESIGN PHASE

The first step of the investigation necessary for the formulation of the "Practice Code" concerns the general vision of the city. Its history, evolution, its periods of decadence and recovery allow us to determine the epochs in which the development of the city underwent homogeneous criteria. In this manner urban areas which contain similar contructions are identified and borders between zones built up with different systems are plotted out. This investigation allows us to drow the perimetrs of homogeneous areas and circumscribe those sectors in which the constructions present a common constructive typology. This is a criteria for generalizing observations which will come with time based on the survey.

The survey of structural condition

The survey of the original constructive technique proceeds through a comparative analysis of the constructions of the area whose perimeters has been defined. In this phase the process follows the standard modes of analysis of vulnerability of the first level with the intention of identifying the constructive typologies which are at the base of the urban fabric. The number of floors, traits of masonry, the layout of floors and roofs, materials used and system of assemblages are all observed. At the same time the criteria of use of the house, from which some recurring structural conditions derive, are also noted. The architectonic parts as well as materials and techniques with which they were realized are not excluded. This analysis requires entering the house, researching the situations which can reveal construction details: plaster scraping, sinking roof, broken down walls...
In this way we recognize "the original construction mode", a "constructive technique" which determines the rules both of detail and criteria of assemblage of the construction. These rules are as complete and consistent as those which today supply the thechnical norms for new constructions even though they are more elementary.
The "reasons" for historical structures are thusly identified and useful mechanical considerations are obtained. Furthermore an average structural conformation is identified (and here the statistical viewpoint of the standard processes of evaluating vulnerability is pionted out again), which might reveal generalized inadequacies as far as seismic resistance is concerned.
The constructive characteristics observed in the various cases in question, firstly the construction of walls, show different levels of quality in the various buildings. In this phase of the study the case surveyed are placed in an abacus, oriented according to a progressive order of mechanical efficacy. The qualitative method with which in the charts of the second level of analysis of standard vulnerability each element is judged "good" - "average" - "bad" is used in this phase in order to arrange a systematic list. In order to arrive at more concretely quantitative evaluations only some elements of the list need to undergo experimentation (phisic or numerical) to quantify the traits of all the others.

The result of this phase of the project illustrates the constructive technique common in all buildings which are tipologically homogeneous. This has already been organised with a mechanical interpretation that leads the designer to his evaluation of the quality to attribute to each particular case. The identification of the constructive technique common to the internal structures in the area in question and of the criteria of structural assemblage, allow us to distinguish the "regular" condition from the case in which either because of inadequacy from the beginning or because of later tamperings, the rule has not been respected. This investigation, therefore, arrives at a comparative reading of the static conditions of the entire portion of a urban fabric.

Relationship between damage and seismic intensity: vulnerability and mitigation criteria

To carry on the investigation methodology we are presenting we must insert some consideration concerning the relationship between damage and macroseismic intensity, i.e. a first embryonic criteria for foreseeing damage.

Macroseismic intensity is defined by a description of damage scenarios. This is significant only in as much as the mechanical consistency of the construction is judged to be uniform throughout all the territory subject to earthquakes, to the degree that the same scenario of damage can be indicative of the same physic action.We have attempted a structural interpretation of such scenarios,especially for the eight and ninth degrees, with reference to the definition of the MCS scale: we believe we can affirm that the scenario of the eight degree affects the precarious portions of the constructions while that of the ninth degree, which exposes generalized damage affecting the greater part of the city,calls for an intrinsic and systematic characteristic of the masonry construction: the weakness of connections between facades and cross walls.

In judging the intensity of the eight degree as that which affects the precarious portions of the building we evaluate such precariousness with respect to a rule that has never been codified other than by the effective uniformity of the masonry structure,the number of floors,thickness of the walls.This constructive uniformity comes from the uniformity of the needs of the residents. During the last century the latter uniformity has gone astray or has been stabilized in forms completely different from the old ones.The constructions have been modified not according to former evolutionary criteria which however maintained the masonry structure within the general norm (except for precarious sporadic cases which earthquakes brought to light), but in the light of incompatible needs. For example, the number of floors has been multiplied; roofs have been turned into terraces by raising only a portion of the area without respecting supporting walls; walls have been knocked down to create larger rooms; spaces on ground floors through which trucks can pass have been opened.... With respect to the rules intrinsic to a historical city recent tamperings leave the buildings in a precarious state which an earthquake will ruthlessly not fail to demonstrate.

In addition to the tamperings decay must be taken into account as this is very wide spread through historical Italian cities which have been seriously neglected since the end of the Second World War. Partial collapses leaves tottering cornices, detached stone facings, and other unstable elements; seismic vulnerability of such situations is similar to that of chimneys whose collapse characterizes the seventh degree scenario.

An accurate analysis of urban fabric as requested by the elaboration of a Practice Code supplies, as we have already stated, information concerning the original state and tamperings and decay the construction has encountered. This therefore allows us to make probabilistic forecasts of damage scenarios. The procedure is as follows: from the local seiemic history we can judge the probability of occurrence of diverse intensities, for example of the seventh, eigth and ninth degrees. The scenario of damage of each of such events is described by the macroseismic scale. Today, however, we have to add to this description the collapse of all situations created by decay or tamperings. With the probabilities with which it is correct to expect events of the seventh, eigth or ninth degrees, we can foresee partially different scenarios, certainly more serious than those which define such intensity, but correctly foreseeable by an examination of the current state of the buildings compared to that of the beginning of this century. Further element to foresee the additional damage scenario is the mechanical confrontation between the seismic resistance of the elements whose collapse characterizes the scenario corresponding to the macroseismic intensity, and new situations created by recent evolution.

With this procedure which, however, requires an accurate reading of the fundamental characteristics of the building and its current discordance with the norms a reliable analysis of vulnerability in terms of predicting seismic damage in the intensity function is carried out. We can conclude affirming that in order to judge the present situation of a structure we must know its history. In order to formulate probabilistic extrapolations

about expected earthquakes we have to correlate scenarios of damage from the past with the corresponding contructive scenarios, and those with those of today, and finally with the results of our interventions.
In addition to the probabilistic outcome of this investigation the mechanical interpretation of the damage scenarios enunciated by the macroseismic scale allows for a highly useful application of a projectional type. The expectations of particular damage scenarios suggests directly corresponding intervention strategies.
An awareness of the local seismic history must tell us if we need fear the event of an earthquake of the eighth or ninth degree, or our prevention policy must decide if we want to protect buildings from earthquakes of the eighth or ninth degrees.
On the base of that which we have stated about damage associated with such events for both cases precise intervention strategies can be formulated.

Eighth degree: we must eliminate precarious situations
Ninth degree: we must systematically contain all facades.

(If we expect an earthquake beyond the ninth degree, the intervention strategy is at the onset the same as that of the ninth degree, except for the results of safety verification which will be mentioned further on).
The enunciation of these strategies brings our approach closer to statistical methods, but the project's intention here is evident. Identifying the precariousness is the premise for rectifying it. In the following paragraph we shall see how such strategies are realized in precise operative criteria.

The mechanisms of damage

Having made this premise, the investigation on constructive types proceeds with the research of modes of damage.
The first step consists in identifying the "precariousness": outside walls too wide between tansversal walls, connections between right angled walls deteriorated, raisings not laid on supporting walls, roofs that have lost their roof ridges and which lean upon the tops of walls, walls whose transversal consistency has been destroyed by decay,.... The local constructive technique in the configuration we have defined as "average" supplies the threshold between "normality" and "precariousness" and this phase of the investigation does not require numerical checks.
Seismic action acting upon the masonry structure tends to highlight incongruities: the walls tend to detach themselves and set off as mechanisms of rigid bodies. The preferential lines of detachment are easily read on the base of the position of wall - external walls tend to tip over towards the outside - and the position of the openings which condition the fracture. According to the stucture of the building fabric several generalized damage mechanisms can be predicted. The Practice Code researches them and identifies their principle characteristics. If we wish to protect a building from the probable event of the eighth degree (probable in base of the seismic catalog) we have to design intervention capable of eliminating the abovementioned precariousness, by leading the tampered or worn and torn situations back to the norm. We will soon say more about the intervention techniques but we can already expect that the most natural formula to reconstitute the norm is truly the "norm" itself, i.e. the original technique and the original rules of assemblage. The most natural way to the prevent a detachment mechanism is to introduce connective elements capable of impeding its activation.
If we want to protect the building from the ninth degree, since the prediction gives a systematic detachment of the facades besides the precariousness we have to find a way to sistematically connect the external walls to the transversal ones.

Techniques of intervention

The cycle of the first phase of elaboration of the Practice Code (the design phase) concludes with the formulation of intervention techniques. The survey of the constructive techniques offers a series of systematic or particular cases of situations to be rectified and of possible collapse mechanisms to be prevented, The task of this sector is to design technical details extracted as far as possible from the same original lexicon with the addition of steel tie or masonry tie-beams. The surveyed masonry technique will be used as need be, to its greatest quality, or the constructive process will be rationalized by inserting (if the ninth degree is expected) generalized connections between the external walls and the right-angled ones. Some axioms of the masonry structure which have never been denied even thought particularized differently, will be respected. For example the construction's characteristic of "being disassembled" has always been present in all historical construction as a consequence of a builder's yard which proceeds for successive assemblages. The facility of disassemblage was the condition for the maintenance process and this has permitted the multi century duration of cities; this will not be interrupted by interventions which connect in an irreversible way elements with precise individuality. Moreover modern interventions should not eliminate the porosity characteristic of traditional materials which consents evaporation and impedes condensation of moisture.

The proposals of intervention which constitute the operative body of the Practice Code derive from qualitative considerations of regularization of abnormal situations and of controls of damage mechanisms and belong to the design phase. Seismic safety must be verified with mechanical procedures. This is the second purpose of the Practice Code and is explained in the following paragraph.

THE METODOLOGY OF THE SEISMIC VERIFICATION PHASE

The fundamental problem for the mechanical verification of masonry structures consists of correct modeling. The reality of the walls is not correctly interpreted by continuous and isotropic models, nor can resistent models defined by tensional characteristic be adopted. Its constitution with discreet assembled elements with mortar substantially lacking cohesion, makes that varying the strains path the behaviour of the wall evolves according to successive conditions of stability. And normally the collaps is caused by a loss of equilibrium: global instability, if the masonry work is well interlocked, local instability if it is lacking in transversal interlocking; as a rule, such last case drammatically anticipates the ruinous conclusion of the phenomenon. Then the quality of the wall should carefully accounted for.

The use of the abacos set up in the phase of survey, arranged according to the mechanical quality, has just the duty to graduate the prevision of the structural performance. This is a first foundamental link between the verification and the survey.

The seismic preservation design derives, as we saw, from the knowledge of the original techniques and from the identification of their inefficiencies. Different designs, as the aim of the prevention is the VIII degree or the IX degree (or the X too, for which the intervention is the same as for th IX except the more severe checks), but in any case designs leaded by the criterion of preventing the damage mechanism.

Afterwards the design presumes the hypothesis of a mechanism. It will be recognized through the survy of the building. As we said the masonry construction is an assembled work, and the continuity od the walls is marely an appearance as thy are made with stones put side by side. It is always possible that the wall is separated into portions, and every portion is kept undivided by the interlocking of the stones and by the compression stress which push them the one on the other. Often our analysis points out more than a mechnism: different hypotheses of subdivision are posible and all of them should be checked. Then we should evaluate the resistence of such mechanisms accounting for the restraints we place to control them. The basic methodology examines the equilibrium of the mechanisms of rigid bodies under the action of dead load and horizontal seismic forces proportional to it. The value of the proportionality factor related to the loss of equilibrium (when the mechanism starts moving) measures the static resistence of that damage mode.

The verification consists in comparing the static resistence of each foreseen mechanism with an assigned value of the seismic acceleration. Such value should represent the seismic design force, accounting for the design having been carried out with the aim to prevent a damage scenario related to the foreseen macroseismic intensity: the numerical verifications should be coherent to aspected event. Nevertheless the problem of relating the characteristics of the ground motion, for instance the pick ground acceleration, to the macroseimic intensity is yet under study. But an other problem arises: the dynamic response of stuctures whom damage mode has been modeled as a rigid bodies mechanism. The first results of the dynamic studies on structures oscillating with rocking motion concern a response spectrum valid for such structures (Giuffrè-Baggio-Masiani, 1989; Baggio 1993; Giuffrè-Carocci 1994). It is reproduced in the figure. It shows that under the seismic action the structure does'nt start moving until the draging acceleration reachs the value of its static resistance, and then it oscillates around the equilibrium position, moving from that as more as the seismic acceleration exceeds its resistance. It needs a peak ground acceleration much higher than the static resistance of the structure, to reach oscillations so strong to attain the loss of equilibrium, and the displacement must reach values close the half thikness of the wall.

In short, if the peak ground acceleration reachs the static resistance of the mechanism the first cracks of detachment appear. More high values of the peak acceleration give rise to more high displacements and the cracks become more manifest. Over a given value the collapse occurs. The distance between the value of the peak ground acceleration which provokes the first detachment and the value which provokes the collapse measures the pseudo-ductility of the masonry construction; and such pseudo-ductility is usually very high to judge by the sets of cracks which can be observed in masonry buildings damaged but not collapsed. They show capillary cracks and cracks tens of centimetres wide.

Thees considerations lead to define as multiplier for the verification of the stability of the mechanisms, that is to say as collapse verification, a lower value than the expected peack ground acceleration. As much lower as more stability to the oscillations the masonry wall can offer. Infact if the masonry work of the walls subject to oscillation is not of good quality the wall breaks up sooner it reachs the limit displacement. In this case the collapse follows closely the first detachment.

It can be asserted that in order to verify masonry walls of good quality, made with stones of considerable dimensions as regards to the thickness of the wall and well interlocked cross-wise the wall, the horizontal force can be evaluated by dividing the peack ground acceleration by a ductility factor equal to 1.6; but this value must be reduced to 1 with the decreasing of the quality of the masonry work until the last case contained in the abacus.

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CAPTIONS

Fig. 1 The different features of the masonry work found in the survey in Ortigia has been arranged in an abacus. They has been ordered from the best to the worse mechanical quality. The last type requires a ductility factor equal to 1 (de Felice 1993).

Fig. 2 The collapse mechanisms delineated for the masonry buidings in Ortigia: they depends on the position of the house in the urban fabric and on the position of the openings in the facade (Ceradini 1993).

Fig. 3 The response spectrum for rocking model. In this proposal, on safety purpose, the maximum generalized displacement produced by the earthquake has been limited to the 48% of its ultimate value (Giuffrè-Carocci 1994; Giuffrè-Baggio-Masiani 1989).

Fig. 4 Costructive details designed for di Practice Code of Ortigia (Giuffrè 1993)

Fig. 5 Partial damage mechanisms esamined by a bi-linear model (rocking model) accounting for an initial elasticity (Giuffrè-Carocci 1994)

Fig.6 Mechanisms of collapse of masonry walls loaded in plane: different collapse modes derived by the pseudo-tensil strength concerning the quality of the interlocking among the stones (Giuffrè-Carocci 1994)

Fig. 7 Collapse mechanisms pointed out in a little house in Ortigia (design phase) (de Felice 1993)

Fig. 8 Antiseismic intervention in the little house reproduced in Fig.7 (De Benedictis-de Felice-Giuffrè 1993)

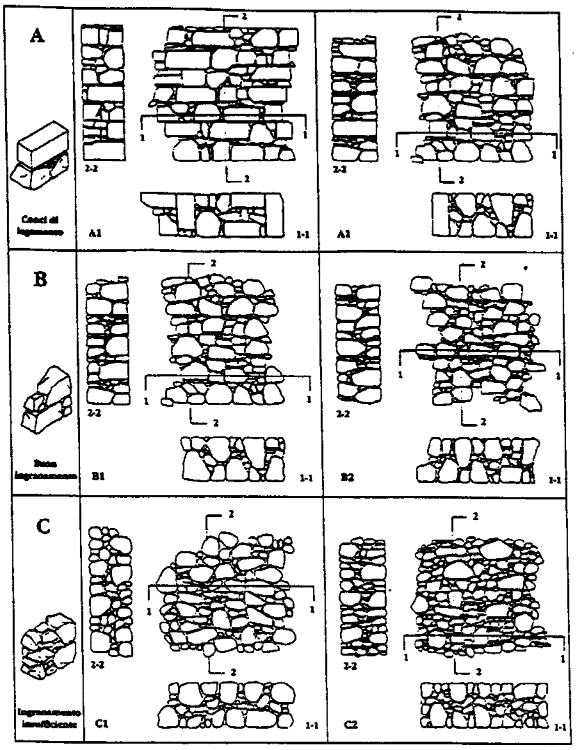
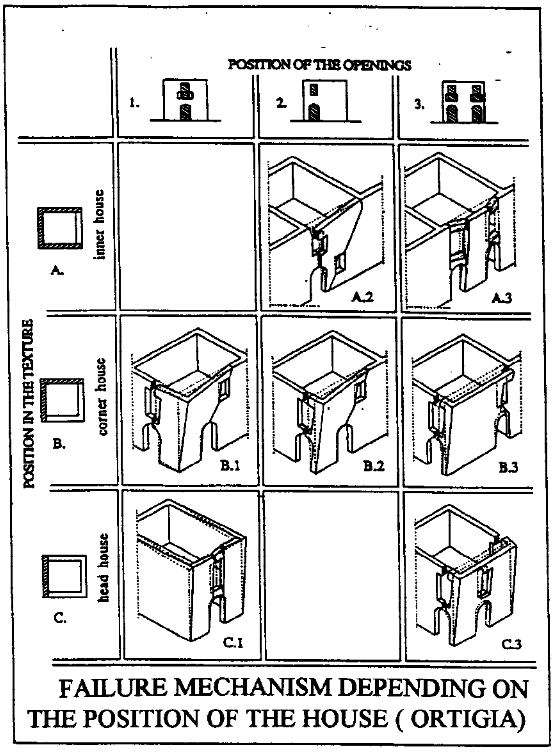
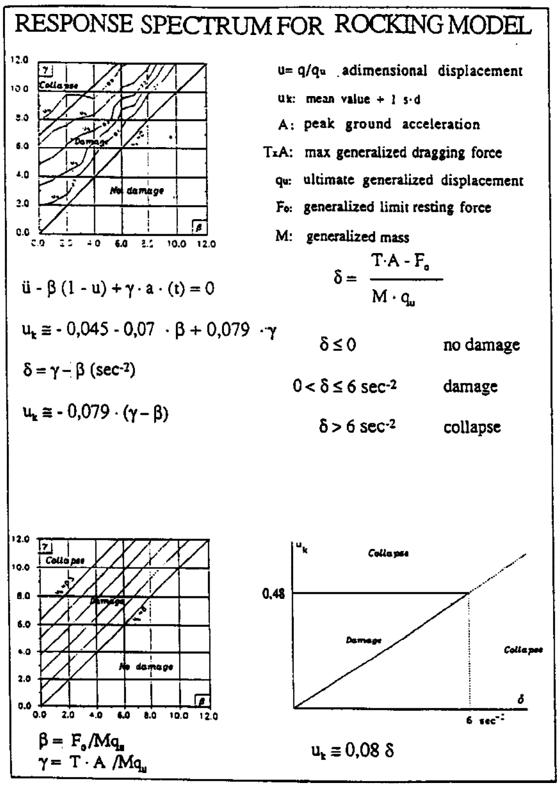


FIGURE 1



FAILURE MECHANISM DEPENDING ON THE POSITION OF THE HOUSE (ORTIGIA)

FIGURE 2



RESPONSE SPECTRUM FOR ROCKING MODEL

$u = q/q_u$ adimensional displacement

u_k: mean value + 1 s·d

A: peak ground acceleration

T×A: max generalized dragging force

q_u: ultimate generalized displacement

F_0: generalized limit resting force

M: generalized mass

$$\ddot{u} - \beta\,(1 - u) + \gamma \cdot a \cdot (t) = 0$$

$$\delta = \frac{T \cdot A - F_0}{M \cdot q_u}$$

$$u_k \cong -0{,}045 - 0{,}07 \cdot \beta + 0{,}079 \cdot \gamma$$

$$\delta = \gamma - \beta \; (\mathrm{sec}^{-2})$$

$$u_k \cong -0{,}079 \cdot (\gamma - \beta)$$

$\delta \leq 0$ no damage

$0 < \delta \leq 6\ \mathrm{sec}^{-2}$ damage

$\delta > 6\ \mathrm{sec}^{-2}$ collapse

$\beta = F_0/Mq_u$
$\gamma = T \cdot A\,/Mq_u$

$u_k \cong 0{,}08\ \delta$

FIGURE 3

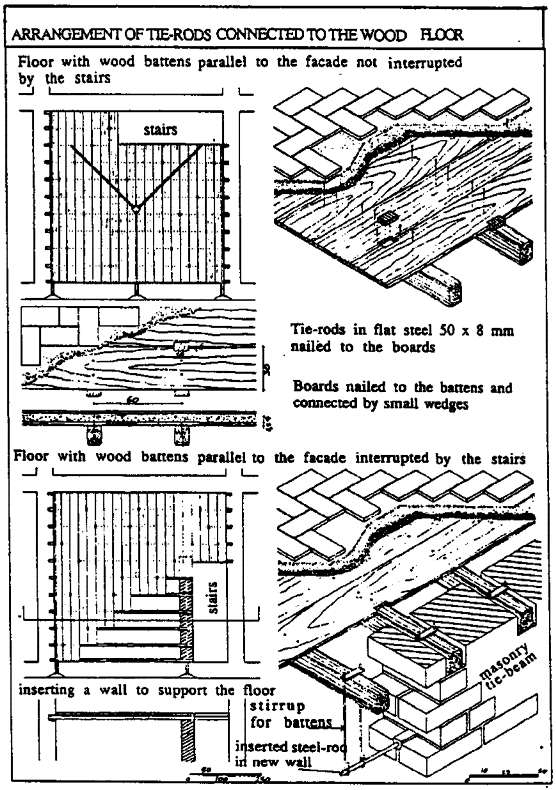
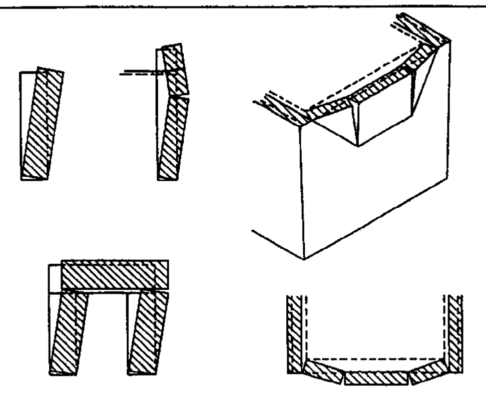
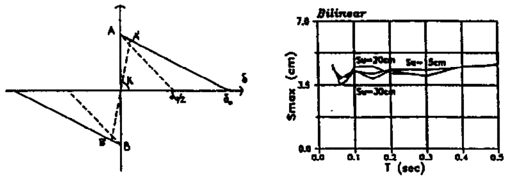


FIGURE 4



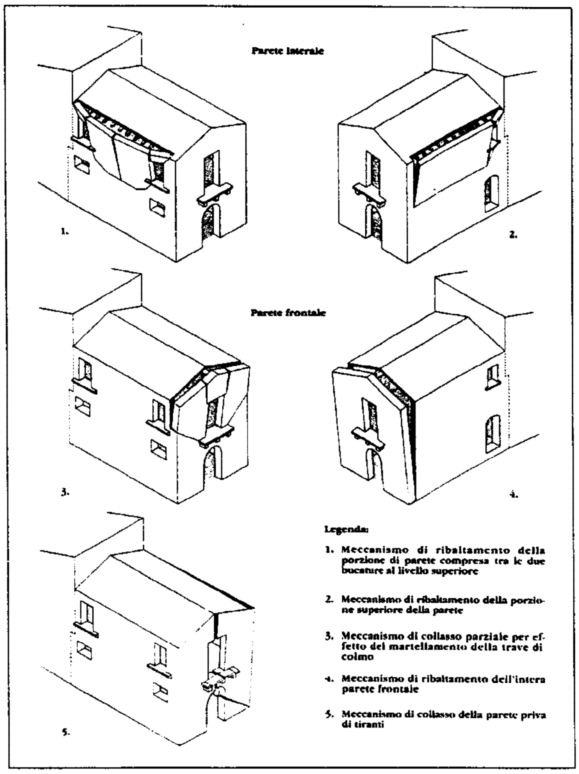
One degree of freedom kynematic mechanism



Non dissipative bi-linear rocking model

Dynamic maximum displacement as function of natural period depending on the initial elasticity

FIGURE 5

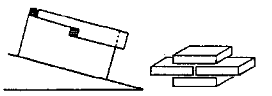


Legenda:

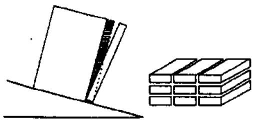
1. Meccanismo di ribaltamento della porzione di parete compresa tra le due bucature al livello superiore
2. Meccanismo di ribaltamento della porzione superiore della parete
3. Meccanismo di collasso parziale per effetto del martellamento della trave di colmo
4. Meccanismo di ribaltamento dell'intera parete frontale
5. Meccanismo di collasso della parete priva di tiranti

FIGURE 7

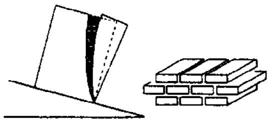
SLIDING OF UPPER LAYER



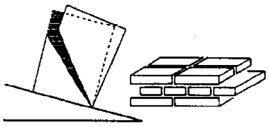
PARTIAL OVERTURNING



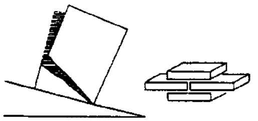
NO TENSILE STRENGTH



LOW TENSILE STRENGTH



MEDIUM TENSILE STRENGTH



HIGH TENSILE STRENGTH

FIGURE 6

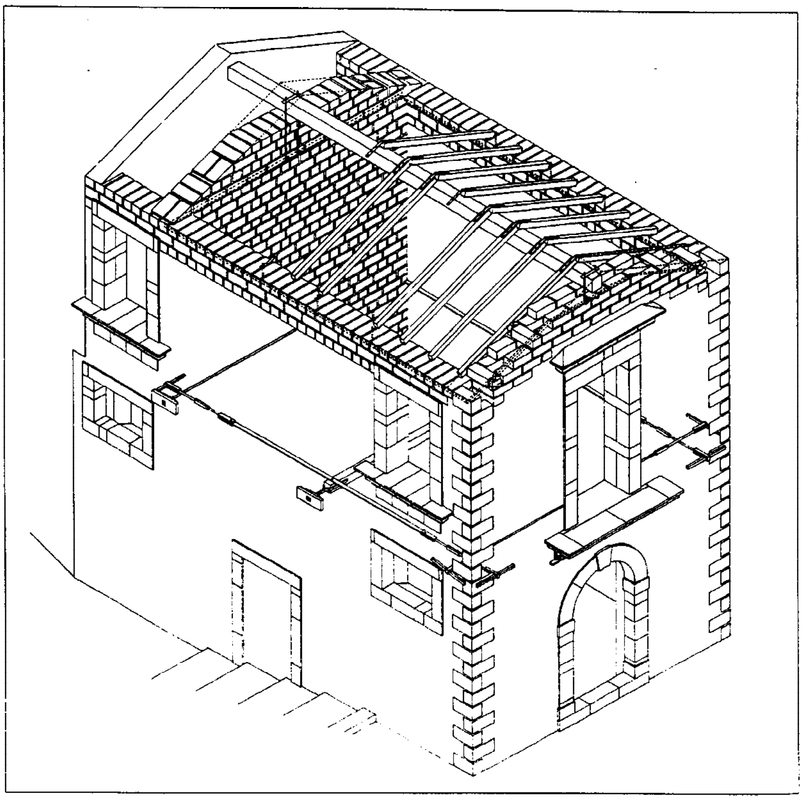


FIGURE 8