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THE PROBLEM OF LARGE SCALE EVALUATION OF MASONRY BUILDINGS SEISMIC RISK IN DEFINING INTERVENTION PRIORITIES

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ABSTRACT

The severe seismic events which struck Italy in the latest years have confirmed the notable vulnerability of masonry buildings to seismic actions, definitely showing the importance of a territorial control. The existing methods for large scale vulnerability assessment are here discussed and their limits in identifying the priorities in interventions are focused.

The recent Italian law [1] proposes a basic level of seismic risk evaluation also for cultural heritage (LV1). The purpose of this method is to find some simplified parameters to quantify the seismic risk for each building.

Starting from this method, a new procedure is proposed with the specific aim of defining a territorial priority list to program the interventions.

In this paper, the results of a simplified seismic analysis of 30 masonry buildings with artistic-historical value are presented. The SIVARS program, which applies the LV1 level, has been applied together with simple models based on equilibrium approach considering the out-of-plane collapse mechanisms.

The proposed method thus starts from a critical analysis of the real crack pattern of each building, which conversely is not taken into account by SIVARS method. In this way, the kinematic analysis is able to describe the local collapse mechanisms, which the results of the analysis has generally pointed out as the most dangerous for historical masonry buildings, while the SIVARS approach supplies a safety index connected only to the in-plane mechanisms.

The results obtained with this combined procedure are able to focus the most dangerous mechanisms in the analysed building population, giving an intervention priority list by mechanisms rather than by buildings. This allows to optimize the budget in order to raise the minimum safety factor of the whole buildings population, not focusing on the single buildings.

Keywords: *Seismic vulnerability assessment, Masonry buildings, Territorial level, Intervention priorities*

1. INTRODUCTION

1.1. The problem of control at a large scale

The assessment of a single building's seismic behavior is a very complex problem, particularly when dealing with old buildings, made in different phases, with disomogeneous materials and later modified and damaged. The structural analyses, linear or non-linear, static or dynamic, must therefore be always guided by a previous deep knowledge path, to inspect history, materials and technical details. On this basis, at present the research and the practicing have reached quite good results in predicting the local and global vulnerabilities of a building. Nevertheless, this approach is too much time (and consequently money) consuming to be applied at a large scale. Just to give an example, the Emilia Romagna Region (in northern Italy) has spent nearly 5 million € for the assessment of the seismic vulnerability of 675 buildings which were considered "strategic" in connection with a possible earthquake (hospitals, barracks, schools, etc.). Indeed, the OPCM 3274 [2], dating back 2003, imposed the assessment for all these buildings. Of course, these are many buildings and a great public economic effort is required, but

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they are only a small minority if compared to the complex of the existing structures. It comes clear that a detailed assessment of each of them would not be economically conceivable.

1.2. The existing methods for the vulnerability assessment of ancient masonry building

Several vulnerability models were proposed in the past to be applied on a large scale with the purpose of quantifying the damage in case of an earthquake (*risk analysis*) or to program the emergency management (*scenario analysis*) [3]. In Italy, the so called first level model introduce a relation between building typologies and vulnerability classes (probabilistic approach), while the second level method (semeiotic approach) also considers some information on the single buildings [4].

All these models have mainly the aim of obtaining a statistics on the damage distribution expected in the area, given the seismic level. These results are of little help when a program of works has to be defined to prevent or limit the damages expected.

The complete analyses carried out in the Emilia Romagna Region on the "strategic" buildings have indeed demonstrated that nearly all the existing masonry structures are not "adequate" to the modern codes. This result was easily predictable, as most of the analyzed building were built far before any seismic rule was introduced in the Region. The economic effort required to strengthen altogether these buildings and make them able to stand the seismic actions foreseen by the actual codes is unaffordable. It is thus necessary to define a priority list in order to budget the economic effort.

Therefore, the analysis cannot be limited to a typological approach, but should be extended to a deeper level of inspection, with a direct survey of the single building with its typological, material, technical and historical specificities.

A recent protocol was proposed for the seismic certification of buildings by Borri [5], in order to evaluate and compare the anti-seismic performance of a building. This proposal has the great advantage of being easy and quick, but at the same time includes on site inspections on the buildings and both local and global analyses. The aim of this protocol is to divide the built heritage in several classes, which could be used in the buildings conveyance or for insurance purposes, but can also be of help in creating a priority list for the interventions.

1.3. The new Italian code for the protection of architectural heritage from the seismic risk

In Italy, the main law reference on this subject is represented by the "Directive for the evaluation and reduction of the seismic risk of cultural heritage" [1], updated in 2011. Although this code is mandatory only for the enlisted cultural heritage, the approach it suggests is correct for all the masonry structures, built with traditional methods. This approach focuses first of all on the knowledge path which must be followed in order to make the required seismic risk evaluations on a sound basis. The Directive also gives indications on the different possible models to be considered for the analysis of the structural behavior and on the criteria to be followed in the choice of the strengthening interventions.

Three different levels for the seismic vulnerability assessment are introduced: LV1, LV2 and LV3.

LV3 represents the most detailed level, which considers the whole building with both its global and local damage mechanisms.

LV2 level consists in the seismic vulnerability assessment of single parts of the building (macro-elements), when the strengthening interventions are of limited extent.

LV1 is the level for large scale vulnerability assessment, and is based on qualitative analysis and simplified mechanical models. These models are applied and discussed in this paper.

2. THE LV1 LEVEL ANALYSIS

2.1. The different building typologies

The LV1 level simplified models try to find an equilibrium between the requirements of a large scale evaluation, which necessarily passes through the concept of "building typology", and the specificities that each historical building has. The Directive roughly divides the historical buildings in four main categories, depending on the recurrent characters that can be observed: palaces and villas, churches and theatres, towers, arched structures. For each building typology, a simplified mechanical model is proposed, in order to carry out homogeneously a large scale vulnerability assessment.

2.1.1. Palaces, villas and other structures with spine walls and intermediate floorings

The LV1 simplified model proposed for this kind of buildings is based on an algorithm which evaluates the shear strength of the walls in the two main directions. This strength is then connected to the corresponding peak ground acceleration, leading to the ultimate state, in the hypothesis that this ultimate state is reached for in plane mechanisms, in a global seismic behavior. Of course, this is not always the case: the Directive specifies that if the building is more sensitive to some local mechanism (due to lack of connections) the peak ground acceleration which triggers these elements should be calculated and compared with the simplified global model.

2.1.2. Churches, worship buildings and other structures with wide halls and without intermediate floorings

The simplified model proposed for this type of buildings (which includes also many theatres) is based on the concept that no global behavior can be assumed in this case, due to the lack of connections. Indeed, the seismic vulnerability is mainly ruled by the presence of macro-elements which can be affected by local collapse mechanisms. Therefore the Directive proposes a statistic model which calculates a vulnerability index based only on the number and efficiency of vulnerability elements and of anti-seismic elements.

2.1.3. Towers, belfries and other vertically developed structures

The seismic behavior of these buildings is mainly dependent on few specific factors: the slenderness, the connection between elements, the possible adjoining lower structures, the presence on top of vulnerable elements like belfries or decorative elements. Once these vulnerable elements have been specifically inspected, the clarity of the global structural scheme makes it easy to model it in a simple way, as a cantilever in the ground. The Directive then proposes some formulas for combined bending and axial load verification

2.1.4. Masonry bridges, triumphal arches and other arched structures

The specific damage pattern expected for the different types of arched structures (mainly bridges) is presented, but no simplified mechanical model is proposed for this kind of structures, due to the great difference in the seismic behavior among the several existing typologies. A specific analysis is therefore always required for this category.

2.2. LV1 for palaces and villas: the SIVARS application and the difficulties in identifying priorities

The Directive [1] introduces a program for the monitoring of the conservation state of the enlisted cultural heritage. In order to apply this program, the Ministry of Cultural Heritage introduced a specific informative system – named SIVARS – which can be accessed through web. It is both a database to collect all the structural information gathered on a building and a software to calculate its safety index with the simplified models. At present, the SIVARS is active only for the parts concerning towers and for palaces, villas and other structures with spine walls and intermediate floorings, which in facts are the most common typologies in historical widespread built heritage.
The database part – as tested during our research – is very efficient and precise although not all the real cases could be pigeonholed within the scheduled checkboxes. All the structural elements are inserted and the damages reported with their possible origin. Nevertheless, all these useful and precise data remain in the database part and are mostly not considered in the calculations.
The main problem encountered in applying this model was the fact that, as the Directive specifies, this model is based on the assumption that the building reacts as a whole and collapses for in plane actions. On the contrary, even when spine walls are present, the lack of connection between structural elements is always an issue in historic buildings. Therefore, most of the times also separate local analyses have to be carried out. It should also be noted that the Ministerial program (SIVARS) does not take into account analysis of the static type for operating loads, thus not evaluating possible structural shortcomings due to this type of stresses.
Moreover, also in the global analysis, the SIVARS system showed some problems, particularly when the analyzed building has parts with different heights, when the basement floor is present only in some zones or not all the floorings are at the same levels.
Another problem in order to identify the intervention priorities, as highlighted in [6], is the small range in which most of the safety factors are comprised. This, connected with the great uncertainty embedded in the simplified model, makes it very difficult to make a reliable list of priorities. To refine this list, the same authors [6] suggest to take into account other factors, like the possible damage to adjoining buildings, the interference with public roads and the possible land-slide triggering.

3. THE PROPOSED METHODOLOGY

The existing methodologies for large scale seismic vulnerability assessment are too un-specific to be used as a base to enlist the priorities in interventions: some, like Lagomarsino and Riuscetti, start from the census data, but it's evident that this approach is too generic and without a contact with the real buildings for our purpose.
A list of priorities should focus first on the most dangerous elements and these cannot be identified without a specific analysis of the single building. Back in 1993, Franco Braga wrote "*the first step to do assess the safety level of the monument .... is to study its history and to find, through it, the characteristic behaviour*". Moreover, the Directive itself underlines the important role that the knowledge has when dealing with existing structures. The first step to understand and evaluate the stability conditions of a building is to know it, to touch it, to spend time in it.
The SIVARS model do requires a survey of the building, its materials and it decay phenomena, but as we have experimented during our research, it does not consider most of these information in the calculations and also does not consider the possible local mechanisms. Giuffré [7] defined the out of plane local mechanisms as "first mode" mechanisms, because they are the first to develop and the most dangerous. Also Binda et al. [8] showed the better adaptability of the kinematic models instead of the global models to the real constructive conditions and their reliability to describe the real damage situation.
For this reason we believe that before considering a complex building as a whole, it is important to understand the parts which compose the whole and to calculate the single local mechanisms with the connected risk levels.
Other approaches [5] consider also the local mechanisms, but they were made for different purposes and are useful to classify the risk level of each building. Nevertheless, an approach able to spot the single problems, rather than giving a number or a rate for the whole building, appears more suitable for the aim of a better budget organization.
In order to follow the Ministerial approach, the proposal is to make the global analysis with the simplified methods proposed by the Directive, then to make the local analysis, with simple linear kinematic models based on the on site inspections and empiricism reappraisal. This also allows to classify the mechanisms, instead of the buildings, thus calibrating at best the use of the always limited resources.
As Borri recalls [5] in the large scale classifications the personal experience and judgment of the technician plays an important role, but at the same time it is important to have unbiased criteria, as from these calculations and considerations will derive also the economic assignments.
The main difference with the Borri's approach, besides the global model which is slightly different, is in the final product, related to the different objectives: instead of a classification of the buildings, based on the highest vulnerability element, made to compare a building with the other, the proposed methodology produces a classification of the vulnerabilities (which are usually more than one for each building), in order to focus the interventions on the most dangerous elements of the whole buildings stock, even if they are in different buildings.

4. THE SEISMIC RISK ASSESSMENT AT TERRITORIAL LEVEL

In this work, the seismic assessment analysis of 30 masonry buildings with artistic-historical value, all belonging to the "palace" category, has been carried out, with the final aim of finding out a priority list for interventions, strongly related to the identified risks, at territorial level (LV1).
Moreover, some indications on the works to be done in order to reach a more suitable seismic risk index have been proposed after the analysis, considering the enhancement of this parameter with the aim of setting up a managing plan for cultural heritage safety.
The seismic assessment passes through the estimation of a "seismic safety index", defined as the ratio between the capacity of the structure and the seismic demand. Generally, if this ratio is more than 1 the seismic safety test is reliably satisfied. If not, some indications have to be given in order to convey to the building this "safety".
It's necessary here to underline that for historical buildings this parameter has not to be considered "compulsory" but, as reported in the Directive, "*an important quantitative parameter in a global qualitative evaluation*". Therefore the aim, in enlisted buildings, is to improve the seismic behavior, not necessarily reaching a safety index of 1.

As stated before, the index has been calculated by applying both the methodologies previously described: global analysis (SIVARS) and local mechanisms (kinematic approach) and the results were then combined together.

4.1. The SIVARS results

The global analysis has been carried out by SIVARS program application, after the survey and the geometrical identification of all the buildings.
In order to define the global behavior of a building it is necessary to estimate the masonry strength in its plane. As stated before, the resistant mechanisms of a structure are developed in response to combined compression and bending actions or shear stresses in the walls parallel to seismic force direction. In step with this, a global behaviour of the building can be assumed only once the effective reciprocal toothing of horizontal and vertical structures is verified, but this is not foregone in historical buildings.
Starting from this assumption, very difficult to be verified at LV1 level, the buildings have been then calculated by SIVARS code considering their "box-behavior". Through the analysis of structural elements, the evaluation of the acceleration corresponding to the ultimate state is calculated for each floor, by comparing the shear strength of the building in each direction with the average shear stress in the vertical wall panels.
While this program is very efficient in order to describe the buildings with their real consistence (structural and geometrical organization, damages report) contributing in setting up an important data base of existing cultural heritage, as a calculation instrument it was found to be not completely reliable.
If, in facts, the program needs to apply some rough approximation, admissible in relation to the level of verification (such as some medium coefficients for stiffness, homogeneity and eccentricity estimation), this approximation can hardly describe in a reliable way, such different structures, which in their own peculiarities manifest their cultural value, giving a reason for their conservation.
On the 30 buildings surveyed, only few could be considered consistent to the proposed "palace" typology, with adequate toothing between walls and without prevalent thrust elements. It became clear from the damage survey of the most of these buildings that, especially in the case of complex typological organization (different levels) and thrusting elements, the global behavior could not be described in a proper way. Moreover, some "irregularities" (as in modeling the basements, often present only in some areas of the buildings, or the different heights of a single building) has often led to identify, inside the same structure, different units which could be considered dynamically independent.
This fact, added to the not complete reliability of the final result of global analysis by SIVARS, has influenced our analysis methodology, pointing out that, even applying the global analysis, it is not so automatic, nor realistic, to get a final seismic safety index which can be considered representative of the single building.
Stated all these uncertainties in results, the analysis carried out on the 30 buildings has pointed out quite homogeneous results, finding seismic safety index average values around 0,4 and 0,8.
Moreover, we have to stress that, in almost 30% of cases, the same SIVARS automatic final report has pointed out the scarce reliability of the calculated value, admitting its incapacity to properly consider the surveyed cracks and deformation and the damage information inserted during the analysis. In these cases, the same SIVARS suggests to verify the buildings by local mechanisms, which often represent the most risky and probable events during an earthquake.
The scarce reliability of these results, joined to the very narrow gap between the values obtained for such numerous buildings clearly show the lack of validity of a list of intervention priorities for the 30 surveyed buildings based on a pure global simplified analysis (which actually is the only one foreseen by the law).

4.2. The local analysis results

As stated before, in most cases historic buildings do not show a clear global behavior but tend to react to the earthquake as a set of independent parts (macro-elements). Having observed the damage patterns, it has been possible to define the most probable local mechanisms, and the kinematic approach has been applied to the 30 analyzed buildings.
Simplified methods for the calculation of activation mechanism acceleration are foreseen by the current law by means of kinematic analysis linear or nonlinear, which concern out-of-plane collapse mechanisms.

In this work the local mechanisms have been calculated by linear analysis, finding different values for each building in relation to the different collapse mechanisms. Some further investigation have been made by non-linear analysis method, where limit displacements are considered, finding, as predictable, even notable differences in reached values for the same mechanism, generally more reliable. However, considering the territorial level of the seismic risk evaluation (LV1) and the rough approximation assumed by the global model here used (SIVARS), the final indexes here considered for the definition of the subsequent priority list are the linear analysis ones.
The first survey phase and the real consistence of loads and geometry of the structure is the base, together with the crack pattern survey, for this type of calculation, reliably considering all the peculiarity of the examined building.
Considering the surveyed crack patterns, and geometrical and structural considerations, the most common local mechanism analyzed – on 30 buildings – has been the possible overturning of walls, especially when subject to horizontal static forces due to the presence of vaults or thrusting roofs.
Moreover, always starting from the geometrical and crack survey, some further mechanisms of vertical bending of the walls have been considered, probable in presence of tie rods at discontinuous levels, which are not taken into account by the SIVARS method.
As predictable by the significant crack pattern and the state of damage showed by most of the analysed buildings, the seismic safety indexes calculated by linear analysis have generally shown lower values than the global analysis ones, confirming the local mechanisms as the most probable (and dangerous) for historical masonry buildings.
Furthermore, this analysis has given multiple values for a single building, taking into account the different behaviour of different parts of the same historic complex and thus indicating where a possible lack of safety actually resides.
The analysis carried out on the 30 buildings has pointed out quite homogeneous results, finding seismic safety index average values – for local mechanisms – around 0,1 and 0,3.

4.3. The list of priority: interventions instead of buildings

At the end of the analysis, the results obtained by the two methods have been compared and the average values obtained on the 30 buildings are reported in the following table (Tab. 1).

Table 1 The different average values for seismic safety index (Is) reached by the two methods

METHOD	FAILURE/BEHAVIOUR HYPOTHESIS	I_S (AVERAGE VALUE)
SIVARS	GLOBAL BEHAVIOR – in plane mechanisms lack of shear resistance	**0.4 – 0.8**
LOCAL ANALYSIS	LOCAL MECHANISMS – out of plane overturning – equilibrium loss	**0.1 – 0.3**

It results immediately clear what is already well known from empiricism: for masonry buildings, mainly for historic ones, the greatest risk, and the most probable one, lies in possible local mechanisms activation during the seismic events.
Hence, this overview clearly shows the limit of a classification of seismic risk (at territorial level) exclusively based – as foreseen by the law – on the SIVARS method: it doesn't take into account the most dangerous aspects of individual buildings, thus overestimating the seismic capacity.
The evidence of this is easy to get by examining in detail the results obtained during the research, applying the two methods to one of the 30 examined buildings. In Tab. 2 the values obtained by the two methods for seismic safety index (Is) on Building 3 are shown. Moreover, for each hypothesized collapse mechanism, an intervention is proposed, in order to reach a suitable increase in safety for the analyzed structure.
Observing the Is values, the index obtained by the SIVARS method was found to be sensibly higher (Is = 0.52) than those obtained from the local mechanisms analysis method (Is = 0.28), thus attributing to the same building an un-realistic overestimated capacity.
Moreover, the two first indices, related to specific local mechanisms and more reliable, allow to locate the damage and therefore to plan a specific intervention on the building. Indeed, despite also the Is values for local analysis have been calculated by means of simplified methods, they can constitute a reliable basis to organize a list of necessary interventions for building safety improvement.

Therefore, the intervention priority list obtained by the SIVARS method – following the procedure actually foreseen by the current law – is substantially different from what we can obtain considering the effective buildings seismic behaviour.

Table 2 Priority list for a single examined building (B.3) for seismic assessment and related interventions

Building 3 – Is evaluation				
Ranking	**Is**	**Method of analysis**	**Mechanism**	**Proposed intervention**
1	**0.28**	Local Analysis	External walls tipping vault thrust	tie rods insertions at floors level
2	**0.45**	Local Analysis	Edge wall tipping Thrusting roof	nailing elements – coverage wooden beams connection
3	**0.52**	Global Analysis (SIVARS)	lack of shear resistance	global reinforcement for shear behavior improvement

As an example, in Tab. 3 the Is ranking obtained by SIVARS method and referred to 3 of the 30 examined buildings is shown.

Table 3 Classification of 3 representative examined buildings, following the SIVARS method

SIVARS – based list		
Building	**Is (SIVARS)**	**Ranking**
Building 1	*0.43*	*1*
Building 2	0.52	2
Building 3	0.52	2

The small range in which the index values are comprised (from 0.43 to 0.52) joined to the rough approximation made for index calculation, confirms what stated before [6] on the lack of validity of this method in making a reliable list of priorities at territorial level.
What we can reach from this "list" is not really a ranking, being almost the whole buildings at the same risk level (as building 2 and 3).
Conversely, in Tab.4 the list based on Is index is shown, considering not just the values obtained by SIVARS method but also those referred to local mechanisms analysis.

Table 4 Classification of 3 representative examined buildings, following our proposed methodology, for interventions instead for buildings

Priority list – territorial level – PROPOSED METHODOLOGY – based					
Building	**Method of analysis**	**Mechanism**	**Is**	**Proposed intervention**	**Is**
Building 1	Local Analysis	Wall vertical flection vault thrust – tie rod	**0.1**	tie rods insertions at floor level	**0.43**
Building 2	Local Analysis	Wall vertical flection vault thrust – tie rod	**0.18**	tie rods insertions at floor level	**0.45**
Building 3	Local Analysis	External wall tipping Vault thrust	**0.28**	tie rods insertions at floors level	**0.45**
Building 1	Global Analysis (SIVARS)	Lack of shear resistance	**0.43**	global reinforcement for shear behavior improvement	**1**
Building 2	Local Analysis	External wall tipping	**0.45**	tie rods insertions at floors level	**0.52**
Building 3	Local Analysis	Edge wall tipping Thrusting roof	**0.45**	nailing elements – coverage wooden beams connection	**0.52**
Building 2	Global Analysis (SIVARS)	Lack of shear resistance	**0.52**	global reinforcement for shear behavior improvement	**1**
Building 3	Global Analysis (SIVARS)	lack of shear resistance	**0.52**	global reinforcement for shear behavior improvement	**1**

As we can see, the range of the Is values is larger, leading to a more significant ranking of the same buildings. Moreover, for each building the most probable local mechanism is immediately clear, allowing to assess the most efficient strategy of intervention. In column 5 a brief description of the proposed intervention to contrast the relative mechanism (local or global) is reported, while in column 6 the new Is index of the building, reachable after the intervention, is listed.

5. CONCLUSIONS

In this paper a new method for a simplified seismic risk analysis at territorial level (LV1), is presented. The proposed methodology recovers the empiricism and the critical analysis of the real crack patterns of the single building, which conversely is not considered by the SIVARS-based method foreseen by the current Italian law. The SIVARS is here adopted for global analysis, while the proposed method includes, in the assessment of a reliable seismic risk list, also the kinematic analysis, to describe local collapses – most dangerous and probable for masonry buildings.
The method has been applied to 30 masonry buildings with artistic-historical value.
The results obtained with this combined procedure are able to focus the most dangerous mechanisms in the analyzed buildings population, allowing to set up a list ranked on intervention priorities instead of a building-based one. This allows, first of all, to enlarge the range of the synthetic index of seismic safety (Is) in which the building population can be enlisted. Moreover, at a time of scarce economic resources, where it is not possible to intervene to make all the "un-safe" buildings completely "safe", the method focuses on the need to address at best all the possible resources, raising homogeneously the safety level of a building population, operating selectively on the most dangerous mechanisms.

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REFERENCES

[1] *Direttiva del Presidente del Consiglio dei Ministri* (2011) Valutazione e riduzione del rischio sismico del patrimonio culturale con riferimento alle Norme Tecniche per le Costruzioni di cui al D.M. 14/01/2008.

[2] *Ordinanza del Presidente del Consiglio dei Ministri n. 3274* (2003), Primi elementi in materia di criteri generali per la classificazione sismica del territorio nazionale e di normative tecniche per le costruzioni in zona sismica.

[3] Giovinazzi S., Lagomarsino S. (2001) Una metodologia per l'analisi di vulnerabilità sismica del costruito. In: *Proc. X Congresso Nazionale "L'ingegneria sismica in Italia* Potenza-Matera, 9-13 September 2001.

[4] Corsanego A., Petrini V. (1994) Criteri di valutazione della vulnerabilità sismica del patrimonio edilizio esistente sul territorio nazionale. *Ingegneria Sismica.* (1):16-24.

[5] Borri A., De Maria A. (2011) Un Protocollo Metodologico per la Certificazione Sismica degli edifici In: *Proc. ANIDIS* Bari.

[6] Carvelli S., Podestà S., Spadaro I. (2011) Tutela del Patrimonio Monumentale dal Rischio Sismico: Individuazione delle Priorità di Intervento. In: Proc. ANIDIS Bari.

[7] Giuffrè, A. (1991) Vulnerabilità e conservazione nel quartiere della Graziella in Ortigia, In *Atti del 5° Convegno Nazionale L'Ingegneria Sismica in Italia*, Palermo.

[8] Binda L., Cardani G., Saisi A., Valluzzi M.R., Munari M., Modena C. (2007) Multilevel approach to the vulnerability analysis of historic buildings in seismic areas. *Restoration of Buildings and Monuments.* 313(6):413-442.