Seismic risk of masonry buildings: methods compared for ICCM

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Abstract

The Italian Guidelines for Seismic Risk Classification of Buildings, issued by D.M. 28.02.2017, point to a vulnerability assessment to be understood primarily in terms of risk mitigation and in terms of optimization of the interventions. Considering the current serious condition of the Italian built heritage, which has been devastated by earthquakes because of its high vulnerability, the main goal is to provide a seismic classification methodology of existing buildings, before and after any interventions aimed to improving the vulnerability class. For masonry buildings, the Guidelines also provide a simplified approach based on a classification of buildings depending on their wall masonry type, their structural peculiarities and site hazard, identified through the zoning defined by the OPCM 3274/2003. The method allows to evaluate both the seismic vulnerability and the effectiveness of the interventions to be implemented to mitigate the risk. The purpose of the paper is a constructive critical analysis of the application of the above simplified method applied to buildings located in the province of Caserta, hypothesizing some interventions of improvement. The possible interventions of mitigation included in the procedures, are directed to strengthen in local way the building, to increase its safety index and to decrease the class of risk, they are the product of a study aimed to individualize its real necessity both in relationship to the type of intervention that to the part of the structure that is in the optics of the optimization of the same interested by it. The analyses were conducted with reference to two types of buildings particularly recurrent and representative of the built heritage of the province of Caserta and located into areas with different seismic hazards.

Keywords: **Classification, Seismic Risk, Masonry, Interventions, Province of Caserta.**

Introduction

The building patrimony of our Country is represented by constructions in masonry of which a wide part is situated in the historical centres. Such constructions deserve particular attention as bearers of inestimable values due to their existence in the time that makes her a rich historical, artistic and cultural palimpsest, and in how much the totality of them has not almost been realized with criterions seismic. Besides the existing buildings are characterized by problems concerning phenomena of degrade and longevity [1].
The actual strategy of seismic prevention is based on an unitary approach that foresees the seismic classification of the territory, the seismic planning of the new constructions and its projected toward the adjustment or the improvement [2], [3], [4]. The Directive the Ministers' President of the Council [5] (Directive 2011) furnishes indications for the evaluation and the reduction of the seismic risk for the protected cultural patrimony; compiled with the intent to specify a run of knowledge, evaluation of the safety level towards the seismic actions and project of the possible interventions conceptually analogous to that anticipated for the

constructions not protected, but opportunely suitable to the demands and peculiarity of the cultural patrimony [6].
Due to the recent code developments and of the growing attention given to the seismic safety of structures, especially after the last Italian earthquakes, the analysis and verification of existing building heritage have become a fundamental tool to assess the seismic vulnerability, to safeguard human lives and to plan structural interventions.
The Italian building heritage is characterized by high complexity and heterogeneity, both from architectural and structural points of view. For all these reasons, it is important to define a methodology to obtain comparable results to plan the future activities of risk analysis, assessment and management.
A significant number of older stone and masonry buildings are not in accordance with any of actual provisions code. The seismic risk assessment and seismic vulnerability assessment of existing building stock is essential for establishing priorities in a long-term prevention policy.
Vulnerability index method uses collected information of parameters of the building (plan, height, structural and non-structural elements, type and quality of materials). This method is used as one of several general methodologies for vulnerability assessment and seismic risk assessment.
Due to the scale and number of buildings involved, the methodologies currently available to assess the seismic vulnerability of urban areas usually require the treatment of a massive volume of data associated with the inspection and survey work, and for this reason the use of more simplified approaches is becoming more popular.
In [7] is to identify a methodology of verification easily manageable and adaptable to many different buildings, but at the same time able to determine the actual state of structure in terms of critical steps and structural deficiencies.
Actual condition obviously pushes toward an evaluation expeditious type, based on the logic to adjust how much patrimony possible but the choice of the typology of interventions adopted following the evaluations it doesn't result to always have been both decisive in comparison to a fragile and unstable starting condition that economic in comparison to a condition of urgency [8], many interventions adopted following the seismic phenomena are partially revealed ineffective to withstand the intense seismic actions [9].
In the present paper is effected a seismic analysis applying the method LV1 for the calculation simplified of the safety index before and after the interventions. Particularly it has been made an evaluation of the typology and the quantity of local interventions to adopt. The analyses were conducted with reference to two types of buildings particularly recurrent and representative of the built heritage of the province of Caserta and located into areas with different seismic hazards.
The aim of this paper is to provide the first steps in assessing seismic risk in Campania, which has been achieved through an investigation of the building typology by site investigation and existing plans and documentation.

Cases Study

The present study analyses two residential buildings, representative of the large majority of the existing constructions in the historical center of the province of Caserta, in which it is possible to individualize two periods of construction, the XV century and the period between 1800 to the beginnings of 1900. The greatest part of the buildings is made by simple or massive stones and develops around a court or a central courtyard, generally raising for at least two or three floors. The constructions are whether isolated or inserted in united and they usually have gable roof not pushing and timber and metallic planking's.

Palazzo Petrucci-Novelli

The first building examined in Fig. 1 and Fig. 2, is a construction situated in Carinola as showed in Fig. 3, in the province of Caserta and it constitutes a typical example of the constructive typology of the area made by simple stone in regular blocks and it's located in a town which has an average-low seismic dangerousness. The thickness of the construction, realized around the XIV century, is 60 cm and it develops on two levels around a central courtyard where is an external staircase which colleague the ground floor to the loggia as showed in Fig. 4 and in Fig. 5. The decks have crossvaults, barrel vaults, plan floor and a roof made by wooden trusses. It has a compact form and an irregular morphology in both plant and elevated.

Figure 1. Building's exterior

Figure 2. Building's exterior

Figure 3. Layout of the historical center

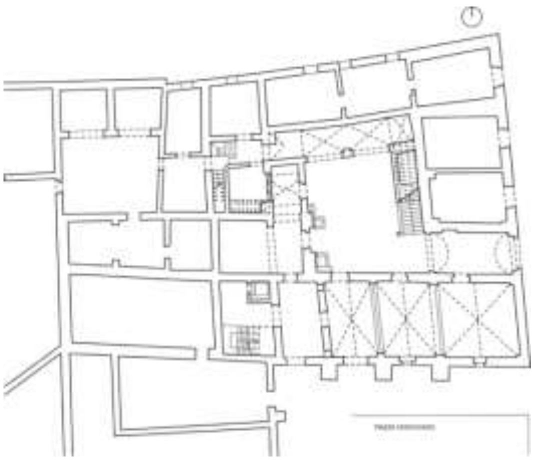


Figure 4. Floor Plan

Figure 5a. Elevations

Figure 5b. Elevations

Palazzo Ducale

This building showed in Fig. 6 and Fig. 7, situated in the commune of Piedimonte Matese Fig. 8, in the province of Caserta, it's a prototype of the constructive typology of the Middle Volturno's areas, next to the Appennino therefore a district to high seismic dangerousness. The palace, built in the XVI century, is made by a massive stone mixed to fieldstone and blocks of bricks with a thickness around 80 cms. The building has four levels with attics in wood articulated around a central court and it has a compact form and an irregular morphology in both plant and elevated as showed in Fig. 9 and Fig. 10.

Figure 6. Building's exterior

Figure 7. Building's courtyard

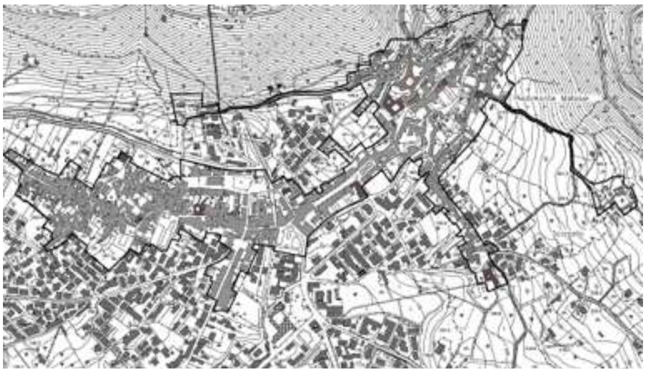


Figure 8. Layout of the historical center

Figure 9. Floor Plan

Figure 10a. Elevations

Figure 10b. Elevations

The Guidelines for the Reduction of Seismic Risk on Cultural Heritage

The Guidelines for the Reduction of Seismic Risk on Cultural Heritage (code DPCM 2011), linked to the NTCs 2008, has been compiled in order to specify a path of knowledge, evaluation and reduction of the seismic risk for masonry buildings. To evaluate the seismic safety, three different levels of increasing completeness have been identified of which the level LV1 concerns the evaluations of the seismic safety at a territorial scale. It is necessary to quantitatively evaluate the ground acceleration leading to the achievement of the structure ultimate limit state (SLV), with a pre-set probability of overcoming, and that attended in the site on a reference's period defined on the building's characteristics and its use. The seismic safety index is estimated by the relation between the return period of the seismic action provoking the generic limit state and the corresponding return period of reference related to the earthquake expected on the site. This is useful to underline the critical situations and to establish a priority for the future interventions. In the same way it's possible to define an acceleration factor defined by the relation between the acceleration which provokes the ultimate limit state and the acceleration expected on the site.

Palazzo Petrucci Novelli_The LV1 method

According to the procedure defined in the Directive 2011 for the method LV1-Palace and (X), the construction has nominal life equal to 50 year-old (buildings with ordinary performance levels), use class II, coefficient of equal use 1,00 (construction that foresees normal overcrowdings without dangerous elements for the environment), reference period for the seismic action equal to 50, category of soil class A specific for "very rigid appearing on the surface or terrestrial rocky heaps", coefficient of subsoil equal to 1,00 and topographical category T1 for "level surfaces, slant and isolated reliefs with middle inclination i<15°. Using a NTCs software, inserting the coordinates of the structure (Lat. 41.188625°, Long. 13.976842°) and the values mentioned, the ground peak acceleration results ag / g: 0,098g, the F0 factor equal to 2,675. The construction, made by simple stone has a proper weight equal to 16,0 KN/m3s, the permanent load Gk changes by the levels. For example, the first floor has both metal decking and desks with vaults, the desks of the second floor are in metallic profiles and timber, and the third floor introduces a timber's roof. Analyzing them, three values of Gk are gotten, respectively 12 KN/m2s, 6 KN/m2s and 1,7 KN/m2s. The confidence factor assumed is FC=1 ,35 (corresponding to complete survey of the building geometry and to limited knowledge of the mechanical properties of materials). Due to the characteristics and peculiarity of the structure, the shearing force is equal to 0,028 MPas for each level and the failure index is equal to 0,8 for the piers and the strength of the spandrel beams for all the levels in both the directions. The minor acceleration factor (0,45) isn't sufficient to make forehead to a seismic event.

Palazzo Ducale_ The LV1 method

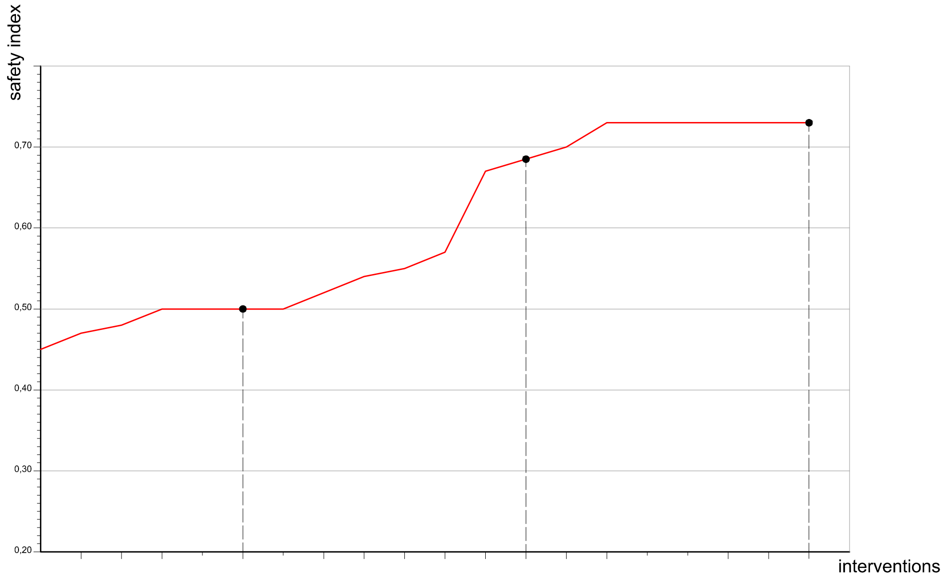
Using the same procedures above mentioned, the second construction has nominal life equal to 50 year-olds, use class II, coefficient of equal use 1,00, reference period for the seismic action equal to 50, category of soil class A, coefficient of subsoil equal to 1,00 and topographical category T1. Inserting the geographical coordinates in the software (Lat. 41. 41.365277°, Long. 14.383055°) and the other values above-mentioned, the design ground acceleration is ag / g: 0,249g, the F0 factor equal to 2,304. In contrast to the previously construction analyzed, this building has a mixed masonry composition in simple stone and fieldstone, so its proper weight is 19,0 KN/m3s, and has a permanent load Gk equal to 5,4 kN/m2s unchanged for all the floor excluding the roof for which it's 0,5 kN/m2s. The level of knowledge assumed for the construction is FC=1 ,35 and thanks to its characteristics and peculiarity the shearing force is equal to 0,028 MPas for each level and the failure index is equal to 0,8 for the piers and the strength of the spandrel beams for all the levels in both the directions. The smaller acceleration factor resulted by the analysis is equal to 0,25 indicate that the structures is unable to withstand the required seismic forces, provided by the seismic code.

Interventions

The procedure for the evaluation of the seismic safety also includes the potential interventions of mitigations, aims to strengthen in local way the building and to increase its seismic safety index; the two analyzed constructions, have a seismic safety index inferior to 1, so they are both unable to make forehead to a seismic event. In preliminary analysis the structure is verified before the intervention with identification of the lacks and the level of seismic action for which the SLU is reached. The choice of the improvement intervention must be a motivated strategy aimed to interest a select portion for which improve the structural performance. Subsequently the technical choices and the materials are verified in order to apply them with the preliminary sizing of the reinforcements and the additional structural elements. Post intervention, a structural analysis will be effected. The evaluation of the safety and the design of intervention must be wide to all the parts of the structure potentially interested by changes of behavior, as well as to the structure in its whole. Starting from the condition of the single construction, with the purpose to increase the safety index of the structure, a first operation of analysis consists of combining interventions through which increases the shearing force from the first floor to the top in order to produce an increase safety index. Consequently, there are planned interventions which engrave on the collapse method through a further increase of the coefficients of collapse and strength gradually increasing until reaching a safety index greater than beginning.

Palazzo Petrucci Novelli_Interventions

The Figure 11 shows the increase's curve of the safety index, obtained through a combination of gradual increases of the shearing force (Ify) and the coefficients of collapse and strength of piers and the spandrel beams (Cc – Cr) from the initial safety index 0.45, thin to the ultimate 0.73. The points in black, represents the three values of the safety index reached increasing at the most the shearing force (Ify) and the coefficients of collapse and strength of piers and the spandrel beams (Cc – Cr) at the first to the top floor and then adding the maximum increases to the inferior floors. The gradual increase's curve of the seismic safety index and the points of maximum increase, differ between them for the different design choice, in the specific one the points of maximum increase hypothesize diffused interventions on the whole construction strengthening at the most the coefficients of collapse and resistance of the single piers and the spandrel beams (Cc – Cr) and the shearing force (Ify) to every floor without consider that, the result of the LV1 analysis and the consequent low safety index, could be due a specific lack located on the construction rather than to a general lack, contrarily the curve minimizes the interventions and the costs going to gradually increase the single coefficients and the single shearing force (Ify) (whereas is necessary) in the optics to reach a result of improvement but optimizing choices and costs. Following the hypothesis of the targeted and optimized interventions, the safety maximum index is obtained increasing the shearing force (Ify) by 50% to the third floor; 50% to the second floor and 20% to the first floor. The coefficients of collapse of piers and the strength of spandrel beams (Cc – Cr) (assumed equal in directions x and y) have been increased thin to 1 for the third and the second floor while they have been being unchanged at the first floor. In the second case globally maximizing the values, the curve quickly grows and steeply up to get a safety index equal to 0.73. In this case both the shearing force (Ify) (increased by 50% to each floor) and the coefficients of collapse of the piers and strength of spandrel beams (Cc – Cr) (passed by 0,8 to 1) have reached the maximum increase. The increase of the seismic safety index, is verified increasing by 20% the shearing force (Ify) to the first floor, considered the weakest floor, rather than increasing of 50% shearing force (Ify) to the other floors.



Ify	3th floor	1,1	1,2	1,3	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5
	2th floor	1	1	1	1	1,2	1,3	1,4	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5
	1th floor	1	1	1	1	1	1	1	1	1	1	1,1	1,2	1,5	1,5	1,5
Cc - Cr	3th floor	0,8	0,8	0,8	1	1	1	1	1	1	1	1	1	1	1	1
	2th floor	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,9	1	1	1	1	1	1
	1th floor	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,9	1

Figure 11. Safety Index curve of Palazzo Petrucci Novelli

Such analysis underlines as despite both design choices are succeed in optimizing the strength of the building increasing its safety index from 0.45 to 0.73, in the first case the interventions would be inferior, less expensive and really located on the parts interesting from structural lacks while in the second case it would intervene over the minimum, globally on the whole building and in very more elevated economic terms.

Palazzo Ducale_Interventions

In this case as underlines in Fig. 12, the LV1 method, returns an initial safety index equal to 0.25 that being smaller than 1 expresses a meaningful insufficiency to make forehead to a seismic event, condition mostly criticism in comparison to the first case study. Also for this second building has been effected a double analysis on two different design choices, the first one with a gradual increase of the factors while the second through the pursuit of the maximum result gotten contemporarily maximizing the increases. Otherwise from the previously case analyzed, for this typology of construction, the real raising of the index safety and relative structural improvement, is gotten for both the design choices, increasing at the most the shearing force (Ify) to every floor in both the directions that the coefficients of collapse of the piers and the strength of the spandrel beams (Cc – Cr). In the specific case, the curve, that represents the gradual increase that conducts to a passage of the safety index from 0.25 (initial scenery) to 0.52 are obtained increasing by 50% the shearing force (Ify) to the fourth floor; by the 50% to the third floor; by the 50% to the second floor and finally by the 50% to the first floor. The coefficients of collapse of piers and the strength of spandrel beams

(Cc – Cr) (assumed equal in directions x and y) have been increased thin to 1 for all the levels.

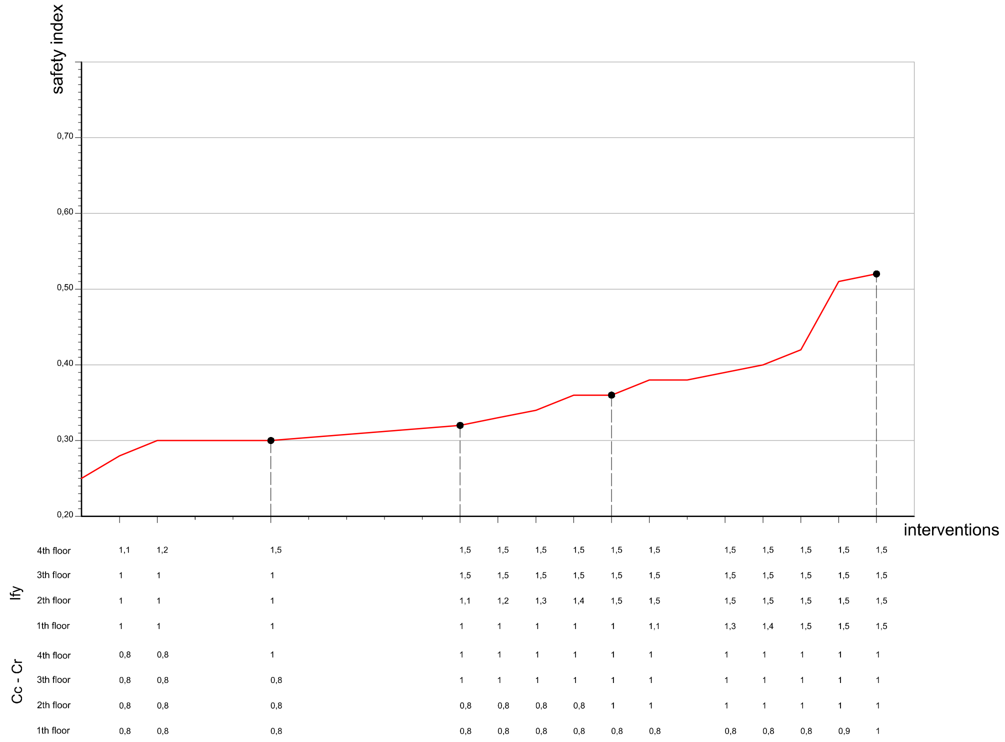


Figure 12. Safety Index of Palazzo Ducale

The points in black instead, representative of the second typology of design choices, show as increasing all the values from the fourth floor up to the first one, it's obtained a seismic safety index equal to that gotten from the first scenery of intervention, passing from 0,25 to 0,52. For the analysis of this construction, otherwise from the first one, the attainment of the increase of the safety index is contextually achieved for both the sceneries maximizing the increases of the resistances, delineating therefore as the real improvement of the strength ability of the building object of analysis is bound to a design choice of intervention globally put in work on the whole construction.

Conclusions

This paper deepens some aspects linked both to the estimation of the vulnerability of the masonry buildings and both to the choice of the interventions to adopt, with specific reference to those reverting in the area of Caserta.
Particular attention has been set on the simplified methods of evaluation which requesting a less deepened knowledge on the structure, they conduct to results that can be more reliable, but being of faster application, they are particularly suitable for the analyses of consistent champions, as in the case of the historical centers. The simplified method LV1 has been applied, on two representative buildings of an ample quantity of residential buildings of Caserta: a building of the historical center of Carinola, area with a low-average seismic dangerousness, representative of the regular buildings realized in simple stone and a second construction built in the historical center of Piedimonte Matese, area with an elevated seismic dangerousness, strongly irregular in its configuration and realized with mixed material of various typology. Analogous results have been caught by numerous constructions similar to

the examine ones, confirming the extendibility of the conclusions that are derived to an ample portion of the built patrimony of the northern area of Caserta.
Seismic vulnerability has been valued using a quantitative type of procedure: the method LV1 for the simplified calculation of the safety index introduced by the Directive of the 2011. For the first building (*Palazzo Petrucci-Novelli*), representative of the area of Carinola, the result caught through the LV1 method, based on the shearing force of the building walls, conduct to a middle vulnerability. The results achieved from the second Building (*Palazzo Ducale*) underlining a high vulnerability.
The LV1 method, operate in order to appraise the SLV seismic action of a building, choosing subsequently to effect interventions of reparation and developing a LV2 analysis which is necessary to confirm the real necessity of the interventions, considering the maximum acceleration to the floor of reference in the site; in the elements in which the SLV acceleration is already superior to this last, wouldn't be necessary to proceed would to the seismic improvement of that part.
It is clear that a simplified type of approach, needs reduced time but able, at the same time, to optimize the interventions. LV1 allows us to get a series of coherent information for the attainment of the objective and addresses toward the calculations that will allow to increase the safety index, studying the global/geometric state of the construction to be able to found a project of intervention. Individualized the formality of collapse, through LV1 that allows us to individualize the weak portions, on which it is necessary to intervene of it, it's simple to use the LV2 method, to extend to these parts of the construction to be able to develop the project of intervention and to choose its typology. The analyzed cases are representative of many others sceneries verified in the time in which, as in the case of *Palazzo Ducale*, in the optics to improve much possible patrimony, has been select to realize a series of interventions on the whole construction at the expense of costs and times but as they had showed, that determined benefits would be produced in every cases opting for a number of interventions done on the whole construction, otherwise in the case of *Palazzo Petrucci-Novelli*, the strength increase of the safety index and the strength ability of the structure would be achieved choosing to adopt interventions focused to located and weak parts of the structure that would have produced the same effects and the same benefits of interventions realized on the whole structure. Proceeding, for simplified models, could be neglected different peculiar characters but surely a whole series of fundamental parameters wouldn't be neglected neither in phase of analysis nor choosing interventions.

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