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A Macroseismic method for vulnerability assessment of Rationalist architectural heritage

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Abstract

The seismic vulnerability that characterizes the architectural heritage requires methods applicable at territorial scale, simplified but reliable for a proper risk assessment and subsequent planning of intervention strategies. For this purpose, in the present work a model for the seismic vulnerability evaluation at territorial scale was developed in order to analyze the buildings built in Italy between 1930 and 1940, belonging to the architectural movement of Italian Rationalism. Starting from the vulnerability model, based on the European Macroseismic Scale (Grunthal, 1998; Giovinazzi and Lagomarsino, 2004), the proposed methodology provides new parameters related to specific vulnerabilities of the Rationalist architectural heritage. The analysis of these buildings, represented by a sample geographically contextualized to Ligurian region (Italy), pointed out that the vulnerability is related to two main issues. The first is the formal characteristics, related to the research of lightness, transparency and boldness that characterized the new architectural language which, in those years, was developing in Italy, as in the rest of Europe. At the base of the formal choices is the use of reinforced concrete, a "new" construction technology: if the use of this material was a valuable tool for the formal renovation in architecture, it is true that it is, at the same time, the second cause of the vulnerability that characterizes the buildings belonging to the Italian Rationalism. In fact, it is necessary to take into account that the construction technique was in its "first step" at the beginning of the last century, and that, therefore, had not yet fully mastered, causing structural problems, in some cases, already from a static point of view. The scores of vulnerability, assigned to the parameters identified, have been calibrated through parametrical analysis on a building "prototype", from a real case study, selected as representative of certain recurring characteristics in the sample.

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Keywords: Macroseismic method; seismic vulnerability assessment, rationalism, reinforced concrete, parametrical analysis

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1. Introduction

The variety that characterized the architectural cultural heritage, from a typological, constructive and materical point of view, makes it necessary to differentiate the tools for the buildings structural behavior evaluation, and, in particular, for the seismic vulnerability assessment.

For the buildings built in Italy between 1930 and 1940, belonging to the architectural movement of Italian Rationalism, the analysis of a sample geographically contextualized to Ligurian region (Italy) shows that the vulnerability depends on two main reasons. The first issue is represented by the formal characteristics, related to the research of lightness, transparency and boldness that characterized the new architectural language which in those years was developing in Italy, as in the rest of Europe. At the base of the architectural choices is the use of a "new" construction technology, the reinforced concrete, which began to be used extensively in Italy because of its structural characteristics that made it preferable to the masonry construction. If the use of this material is a valuable tool for the formal renewal in architecture, it is true that it is, at the same time, the second and important cause of vulnerability that characterizes the Italian Rationalist buildings. In fact, you can not disregard the fact that the construction technique was in its "first step" at the beginning of the last century, and that, therefore, had not yet fully mastered (Iori, 2001). This situation determined, therefore, structural problems not to be underestimated, in some cases, from a static point of view. Material with poor mechanical properties, structural details not adequate and not able to guarantee the structural behaviors that underlie the verification methods proposed by current Technical Code, and design principles very far from those that are at the basis of new buildings, contribute to make it very difficult to ensure the structural safety for these buildings.

In order to preserve compatibility with existing methodologies for assessing the seismic vulnerability, from the method based on the European Macroseismic Scale, EMS-98 (Grunthal, 1998; Giovinazzi e Lagomarsino, 2004), new "behavior modifiers", associated with the specificity of Italian Rationalist buildings, were introduced and calibrated. The calibration of the scores to be assigned to behavior modifiers, introduced for the Italian Rationalist buildings, was done through parametrical analyses. The behavior modifiers, related to the constructive and structural characteristics, allow, by scores assigned to each of them, to increase or decrease the value of the Vulnerability Index that defines, according to the method, the propensity of a structure to be damaged by an earthquake.

Through the application of the proposed method to the sample of buildings in Liguria region (Italy) it is finally proved the "applicability" and the "validity" of the methodology. The results of the analysis of the sample show, in fact, that the proposed method is able to effectively estimate the higher vulnerability that characterizes the Italian Rationalist buildings when compared with existing reinforced concrete buildings with more modern design.

2. The sample of buildings analyzed: recurrent typological-formal issues and technological-constructive problems

In order to develop a method for the seismic vulnerability assessment able to take into account the aspects that characterized the Italian Rationalist buildings from an architectural, constructive and technological point of view, it is contextualized the study to a sample of 79 buildings in Ligurian region (Italy).

The analysis of the sample, while reflecting the great variety of types that characterizes the architecture of those years (Barisione et al, 2004; Cevini, 1989), showed the presence of recurring formal and architectural elements. These formal choices that characterize the sample, representative of the Italian Rationalist buildings, related to the renewal of the architectural language which in those years was being implemented, denote the research for a structural boldness, that goes, sometimes, beyond the capabilities of a constructive technology, the reinforced concrete, of which have not yet had a full knowledge and control, even though it had quickly evolved into a few years.

It is clear, therefore, the need to take into account the vulnerability induced by these architectural solutions for the seismic risk assessment of the Italian Rationalist architectural heritage. For this reason, in the proposed method, we have introduced parameters related to the presence of the identified recurring architectural elements that determine structural problems in relation to seismic actions.

Fig. 1. (a) The seat of the local Fascist group Nicola Bonservizi (1938) L.C. Daneri; (b) Fish market (1933) M. Braccialini; (c) Fascist School (1937) C. Nardi Greco; (d) Colony "Gustavo Fara" (1935) C. Nardi Greco

Concerning to the materials, both the concrete that the steel have a continuous performance improvement thanks to the new production technology and thanks to the acceptance criteria that are developed with the update of Technical Code over the years (Mariniello, 2007). Refer only to the mechanical characteristics of the materials requires by the Technical Code for the construction of buildings, in the decade from 1930 to 1940, is not enough, however, to consider the issues that may characterized them. In fact, as known, the reinforced concrete has shown considerable problems of durability (Mezzina et al., 2008). Diagnostic tests carried out on some buildings built around the 30s and 40s have shown a degree of variability in the mechanical properties of the material: there are cases in which the material presents values of compressive strength such as not to allow classification as "structural concrete" according to the current Technical Code (Augusti et al., 2004). For this reason, in the vulnerability method, proposed for the Italian Rationalist buildings, it is taken into account the influence of concrete quality on the structural response, especially in relation to the possible presence of very low values of resistance.

With regards to the construction details, in addition to the descriptions given in the technical code, it was referred to the manuals (Santarella, 1927; Santarella 1932; Colombo, 1933), which represented an important reference for the designers in that period. In general, the most frequently constructive problems are:

- insufficient anchoring of reinforcing bars;
- presence of open stirrups;
- absence of stirrups in the nodes;
- steps of the stirrups not adequate to resist the shear stress and effectively confine the sections;
- reduced concrete cover.

The construction details affect significantly the seismic response of a building, especially with regard to the brittle type mechanisms. The brittle type mechanisms, to be avoided as prescribed by the current technical code, are mainly

related to shear failure and, at the same time, are those most frequently encountered in the structures of the present work. Taking account of all these aspects that characterized the Italian Rationalist buildings by technological and constructive point of view is essential in order to evaluate correctly their structural behavior, especially in the presence of seismic actions.

3. The calibration of the parameters introduced in the method: the case study

Once the critical issues that characterize the sample in this work, were identified it was necessary to understand how these affect the structural response, with particular reference to seismic actions. This additional step was done through sensitivity parameters analysis on a case study: the Fascist House in Genoa Bolzaneto. The sensitivity analysis, in fact, allows the identification of the impact of different parameters, in quantitative terms, in the seismic vulnerability evaluation, which is the final outcome of the application of the method.

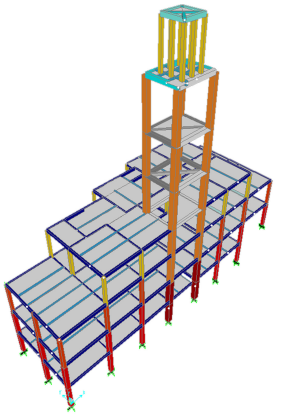
The case study was selected in the sample, as representative of a well defined typology: a building with Fascist tower and with recurrent technological and constructive characteristics.

The building, realized between 1934 and 1936, is located in Genoa Bolzaneto; today belongs to the Society of Mutual Aid "La Fratellanza", which houses offices and associations.

The building has a approximately rectangular plan, a not regular elevation for the presence of a taper at the second floor and, especially, of the Fascist tower which rises 19 meters from the top of the building. In the Bolzaneto Fascist house are joined rationalist elements, such as large windows and the Fascist tower, with more traditional elements, such as moldings ornament of the facade. In addition to these, there are modern interpretations of traditional elements, such as cornices and window frames.

The calibration of the parameters to be introduced in the vulnerability method has been made by comparing the results of the static and dynamic analysis performed by a finite element modeling of the building.

a



b

Fig. 2. (a) external view of the principle facade (north side) of the Fascist house in Genoa Bolzaneto; (b) building modeling.

The checks in static conditions of the columns have shown a strong dependence of the result from the quality of the concrete, for very low values of resistance. In fact, the number of unverified columns increases exponentially if the concrete characteristics are poor, but for concrete classes greater or equal to C16/20 (according to the Italian Technical Coded classification) there is a little or no change in results. This observation is very important for the purposes of this work, because it can reasonably fix a threshold limit as regards the quality of the concrete, in order to determine the vulnerability of a structure, from a static point of view.

For the same concrete strength, the increase of the bars diameter brings down the percentage of unverified columns. The relevant fact is that the gap between a set of diameters and the other, is much larger that what you would have to pass from a concrete class to another. This difference increase dramatically with decreasing of

concrete class, therefore, if the concrete is characterized by a bad quality, the diameters of the bars becomes very important.

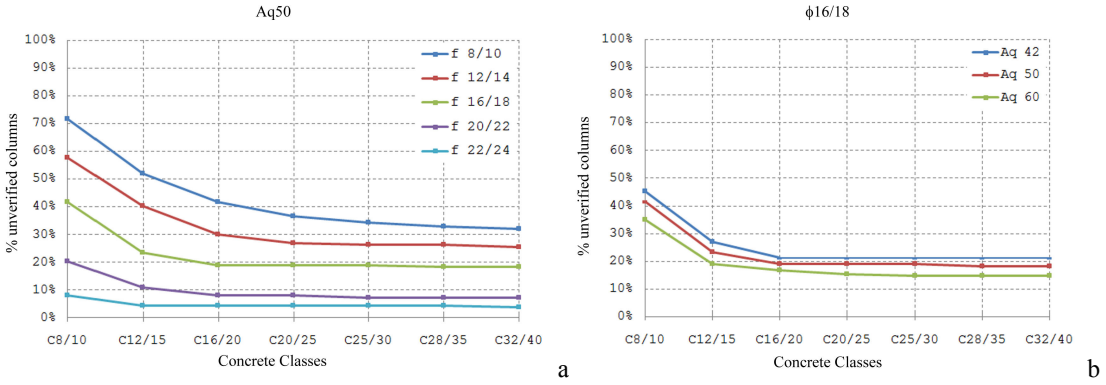


Fig. 3. (a) number of columns unverified in function of the concrete classes and the reinforcement bars diameters, for a steel type "Aq50"; (b) number of columns unverified in function of the concrete classes and the steel type for reinforcement bars diameters Φ16/18.

For the seismic response evaluation of the Fascist House in Genoa Bolzaneto, linear dynamic analyses with response spectrum were carried out. In particular, we have performed four sets of analyses, each aimed at identifying the importance of certain parameters in the seismic risk assessment, for the Italian Rationalist buildings. Therefore, in the analysis were kept fixed some parameters, while others were made change to understand their impact in the dynamic response of the structure. In summary, thought the dynamic analysis we wanted to highlight the influence of the following parameters:

- seismic hazard and type of soil (Group 1);
- stiffening due to the presence of the infill panels (Group 2);
- stiffening due to the presence of adjacent buildings (Group 2);
- presence of the Fascist tower (Group 3);
- presence of the staircase inside the Fascist tower (Group 4).

To evaluate the influence of seismic hazard on the variability of the dynamic analysis results, in the case study, we considered several seismic accelerations (a_g). There were carried out seismic analysis for 3 of the 5 ranges of PGA (Peak Ground Acceleration) in Ligurian region: in particular, we have chosen the range with minimum PGA (0,05g-0,075g), maximum PGA (0,150g-0,175g) and medium PGA (0,100g-0,125g). There are considered, therefore, three categories of subsoil (A, C and E, according to the Italian Technical Coded classification), in order to evaluate the influence of this parameter in the seismic risk assessment. There were obtained 9 different spectra, one for each of the 3 PGA ranges and for the 3 different categories of subsoil. In addition to the a_g value equal to 0.07g corresponding to the place where the building is located, we have considered two other Ligurian cities that would provide an elastic response spectrum for the medium and maximum PGA ranges.

For the parametric structural analysis, it was made reference to a Model A, which corresponds to the original configuration of the building. Starting from the Model A, we considered other models for assessing the impact of the contribution offered by infill panels or adjacent buildings stiffening and to assess the effects related to the presence of Fascist tower and a possible presence of staircase inside the tower. To assess the influence of external constraint with which it is simulated the presence of the adjacent historic building, we considered a Model A2, with no lateral constraints. Regarding the influence of the stiffening contribution of the infill panels, reference was made to the "equivalent strut" modeling proposed by Stafford Smith & Carter, 1969, Mainstone, 1971, Al-Chaar, 2002, Di Criscio, 2009. It was necessary to make 2 different models in addition to Model A: Model B, in which there is the stiffening contribution offered by the infill panels by means of the insertion of equivalent strut only if they have no opening; Model C in which there is the stiffening contribution of all infill panels by means of the insertion of

equivalent strut, properly reduced for the presence of possible openings. It was considered a further Model D, without Fascist tower, in order to evaluate the possible vulnerability induced by the presence of this element that characterized so strongly rationalist architecture. Since, in the original configuration of the Fascist House, the Fascist tower has an exclusively aesthetic and symbolic function, while in many buildings of the same typology, it contains the staircase, it seemed appropriate to understand what influence they may have in dynamic structural response. Therefore, we considered a Model E with a hypothetical staircase inside the Fascist tower.

With the Group 1 analysis it has highlighted the importance of the subsoil category in the seismic risk assessment. Although the soil characteristics influence directly the seismic hazard, they may be taken into account as an additional vulnerability element of the building, because, in presence of a bad soils, may arise problems already from a static point of view, regardless of the amplification phenomena which occur in the event of an earthquake. Furthermore, the soil on which stands a building can be considered as its intrinsic peculiarity and as any other factor that may characterize the structure. This approach is made possible by the use of tabs proposed in scientific literature (Di Capua et al., 2009) which allow to obtain information about the soil without a geological survey campaign, and it is valid for a seismic risk assessment at territorial scale, given the difficulty of achieving a depth knowledge.

The analysis of Group 2, in particular the comparison between the results of the checks carried out on the Model A and the Model A2, have shown how adjacent buildings with shared structure lead to a better dynamic structural response of the building, due to the stiffness offered by the presence of the external constraint and by the increase in mass. The stiffening determines less tension in the columns in case of dynamic actions, which leads us to consider the presence of adjacent buildings with a shared structure a factor that improves the seismic structural response.

The comparison of the results of the checks carried out on the Model B and the Model C, in relation with the Model A, showed that the stiffening contribution given by the presence of the infill panels must be diffused and regular. If the distribution of the panels is irregular, the stiffening contribution plays a negative role in the dynamic response of the structure. The contribution provided by the presence of very rigid infill panels inside the reinforced concrete structural frames, furthermore, can be negative for the shear stress transmitted on the node. It determines, in fact, the condition of weak column-strong panel because, as always happens in the Italian Rationalist buildings, the external walls are very thick and made of solid bricks and, therefore, are characterized by a considerable stiffness in their plan. At the same time, the columns are not clamped in the nodes. So, the great stiffness of the panels is associated with a certain weakness of the node that determines shear-type collapse mechanisms. You can, however distinguish two levels of dangerousness based on the failure modes of the panel: 'crushing' mode and 'sliding' or 'diagonal tension' mode. In first case, the equivalent strut generates a concentrated stress on the node of the column much greater than the one occurs in presence of a 'sliding' mechanism.

The evaluation of the Fascist tower influence in the dynamic response of the structure was carried out through the analysis of the Group 3 and the Group 4. The Model D, without the Fascist tower, has almost exclusively translational vibration modes; the addition of the tower causes an increase of the period and of the rotational components. The increase is even more relevant in the presence of the staircase inside the tower (Model E). In summary, the tower determines a strong irregularity in elevation of the building which leads to an increase of mass and eccentricity that must inevitably be taken into account in the vulnerability method proposed in this work. The increased flexibility found in Model E, with the staircase inside the Fascist tower, leads us to believe that this architectural choice increases the seismic vulnerability of the structure. Since the presence of the tower in the Fascist Houses is very frequent, as well as the presence, inside, of vertical connections for accessing to the different floors, the result has been generalized and considered as a parameter in the vulnerability method proposed in this work.

4. The proposed vulnerability method

The analysis of the sample of Rationalist buildings in Liguria region and the detailed evaluation of the case study allow to identified the vulnerabilities that characterized a certain typology of buildings. With reference to the Macroseismic method (Grunthal, 1998; Giovinazzi e Lagomarsino 2004), it is defined a vulnerability index V, given by two main contributions: one associated with the typological class, V_0, which is a function of the structural material, and one associated with the presence of behavior modifiers related to the constructive and structural characteristics.

$$V = V_0 + \Delta V_{mk} \quad (1)$$

In this study, from the typological class RC1 (reinforced concrete buildings without Earthquake Resistant Design), we have defined new behavior modifiers proposed for the sample of Italian Rationalist buildings, calibrated on the results of the sensitivity parameters analysis.

Table 1. New behavior modifiers i the vulnerability method for Italian Rationalist buildings.

Behavior modifiers		Reinforced Concrete
		ERD level:Without
Use	Not used	+0,04
	Used, with strategic functions	+0,02
	Used	0
Number of floors	Low (1-3)	-0,02
	Medium (4-6)	0
	High (≥7)	+0,04
Adjacent buildings	Independent structure and insufficient aseismic joints	+0,02
	Independent structure and aseismic joints	0
	Shared structure	-0,02
Concrete classes	≤C12/15	+0,04
	> C12/15	0
Longitudinal reiforcing bars (Φ)	Φ8/10	+0,04
	Φ12/18 and concrete ≤C12/15	+0,04
	Φ12/18 and concrete >C12/15	+0,02
	≥Φ20	0
Plan irregularity	Geometry	+0,04
	Mass distribution	+0,02
Vertical irregularity	Geometry	+0,02
Frames or walls disposition	In two directions	-0,02
	Absent or insufficient in one direction	+0,02
Infill panels	Confined with weak column and crushing mode	+0,08
	Confined with weak column and sliding mode	+0,04
	Not confined - straight (ribbon window)	+0,02
	Not confined - concave or convex	0
Presence of Fascist tower	With staircase	+0,04
	Without staircase	+0,02
Presence of protruding element		+0,02
Soft storey	Pilotis	+0,08
	Large openings and heavy/stiff floors	+0,08
Foundation	Beams	-0,04
	Connected	0
	Isolated	+0,04
Soil type	(A)	-0,04
	(B and C)	0

	(D)	+0,04
Enlargement	Shared structure	-0,02
	Independent structure and aseismic joints	0
	Independent structure and insufficient aseismic joints	+0,02
	Staggered floors	+0,02
Superelevation	Number of superelevated floors/Total number of floors	
	Structural irregularity	
	Full	
	Partial	

Sup.Tot.	1-2	3-5	6
1	+0,04	+0,02	0
2	-	+0,04	+0,02

The seismic vulnerability method proposed, for evaluation at territorial scale, takes into account the architectural and constructive peculiarities of the Italian Rationalist buildings and, therefore, allows you to properly assess the seismic risk that characterized this architectural heritage in Italy, so important not only numerically, but also qualitatively. The method allows to determine risk rankings to be used, with other administrative, economic and financial parameters, as priority lists to program the seismic improvement interventions. The method is configured, therefore, as a valid tool for the seismic risk assessment of the Rationalist architectural heritage in Italy and, consequently, to identify and ensure effective management criteria for the protection of this architectural heritage.

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