# The safety verification plan in Genoa province (Italy): seismic assessment of public buildings in a low seismicity area

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**SUMMARY:**
The planning of seismic safety verifications of public-facilities by the Provincial Authority in a low-seismicity district (Genoa Province – north-western Italy) is described. The Seismic Office set down a plan aimed to assess the seismic risk, especially referring to Province-owned and available structures (about a hundred constructions, among which 110 structural entities may be identified). At now, comparing the outcomes, the applied multi-level procedure (Level 0: seismic observational screening; Level 1*: macroseismic vulnerability model) turns out to be feasible to define a priority chart and to quickly point out the critical situations among the complete stock. The ultimate result of the safety evaluation procedure, as required by rules, is the Risk Factor related to various performance limit states. The analysis of buildings resulting as more critical was deepened, e.g. by means of in situ survey of technological issues and constructive phases. This study is based on a previous research: available data were widened and reviewed; the complete building stock, both in terms of use (schools, Government offices, monumental heritage, etc.) and structural typology (pre-code r.c. frames, masonry, etc.), was analysed by means of Level 1* method.

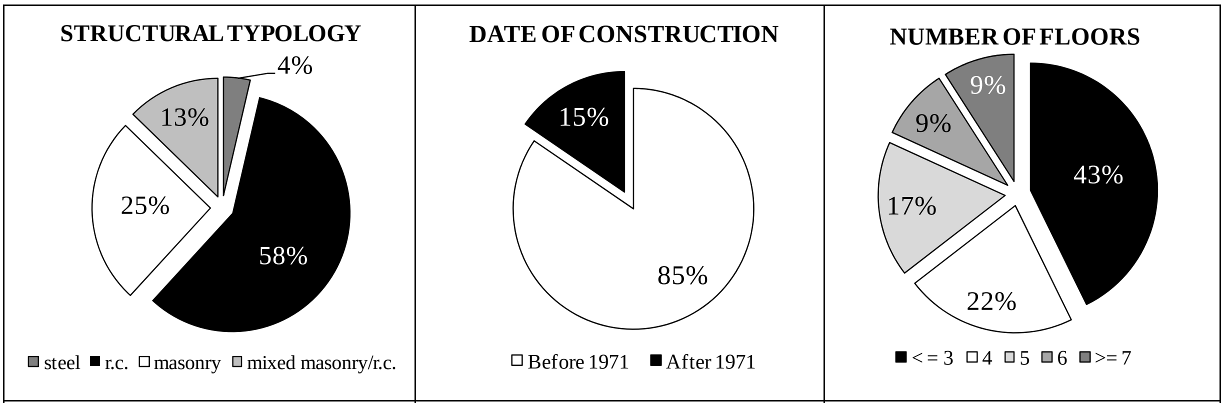
*Keywords: seismic vulnerability; strategic structures; school buildings*

## 1. INTRODUCTION

In order to accomplish the request of the Italian rules (O.P.C.M. 20$^{th}$ March 2003, no. 3274, D.P.C.M.-D.P.C. 21$^{st}$ October 2003 and further instructions), the Seismic Office of the Provincial Authority of Genoa set down a plan aimed to assess the seismic risk for public-facilities, especially referring to Province-owned and available structures.
This task started in 2007 and the verification level required by law in low-seismicity areas was achieved in 2011, relating to the complete building stock. The Provincial Authority of Genoa would like to go beyond the seismic safety verification required by law, keeping in mind that its territory (i.e. technicians, but also population) is not used to facing earthquake-induced issues. In fact, here the application of seismic design rules is compulsory from a few years.
This paper, based on a previous research (Raineri *et al*., 2010), is addressed to describe the study on widened and reviewed data and compare the results of vulnerability and risk analysis.

## 2. CASE STUDY: BUILDINGS OWNED BY THE PROVINCIAL AUTHORITY OF GENOA

The complete building stock owned and managed by the Provincial Authority of Genoa is diverse, both in terms of use (schools, Government offices, monumental heritage, etc.) and structural typology (pre-code r.c. frames, masonry, etc.).
In Figure 2.1, some data are shown about the complete building stock, analyzed in terms of 110 structural entities (for the sake of conciseness, named "buildings"); in many cases, in fact, more than one structure may be identified inside one construction.




(a) (b) (c)

**Figure 2.1.** (a) Structural typology; (b) Building age; (c) Number of floors of the buildings.

It can be noted that low and mid-rise structures are the main part of the stock: their vulnerability should be lower than for high buildings. On the other hand, considering that structural design became compulsory after 1971, 3/4 of the constructions are non-engineered structures (a small part of those could have been designed, but there is no possibility to get structural information).
About 20% of the stock is classified as monumental heritage (mainly masonry structures), and, because of that, not subjected to reach any pre-defined seismic safety level, but only to improve it in order not to compromise its intrinsic monumental value (Fig. 2.2).

| Building no.19 (massive masonry structure) | Building no.53 (r.c. structure) |
|---|---|

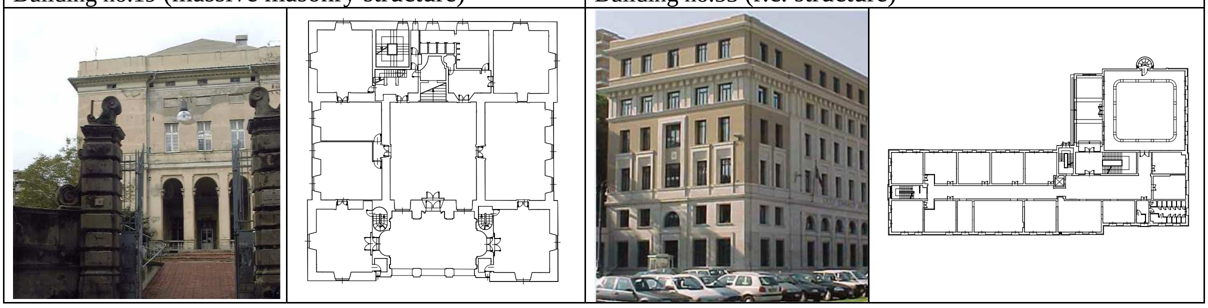
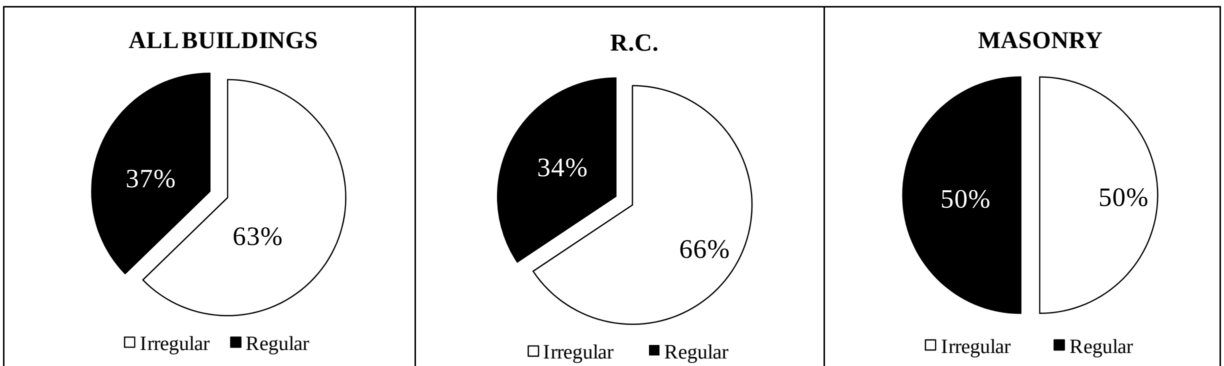


**Figure 2.2.** Overall view and plan configuration: monumental palaces (masonry and r.c. buildings) - (archive number is used).

Another significant feature affecting seismic vulnerability is regularity (in plan and in elevation). About 2/3 of the buildings are not regular in plan (Fig. 2.3). It is worth noting that, in case of masonry buildings, half of the plan configurations are regular: in fact, in case of ordinary and massive URM structures built using the so called "rules of thumb", if only minor modifications have been introduced, symmetrical and compact shapes are common.




(a) (b) (c)

**Figure 2.3.** Plan-configuration regularity: (a) all buildings; (b) r.c. structures (64 buildings); (c) masonry structures (28 buildings).

Once regularity in elevation is analyzed (Fig. 2.4), the complete sample and the two subsets show similar distribution.

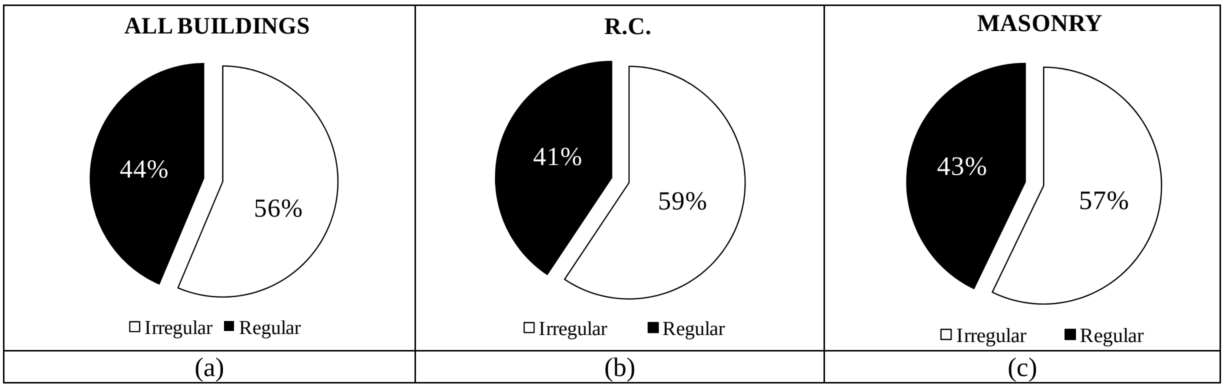



**Figure 2.4.** Regularity in elevation: (a) all buildings; (b) r.c. buildings; (c) masonry buildings.

The reasons of irregularity in elevation are different: in case of r.c. structures, it is mainly due to double-height rooms such as gymnasia or pilotis, while, in case of masonry buildings, structural modification on top (superimposed floor) or in plan is the most recurrent cause.

Several constructions, especially school-buildings, have the original use different from the current one. From this point of view, load and structural variations may often have modified the building vulnerability, sometimes imposing structural retrofitting in order to satisfy safety level compulsory for new-designed constructions.

In many cases, especially for masonry buildings, relevant structural interventions occurred to widen the usable space for school-rooms and offices (Fig. 2.5).

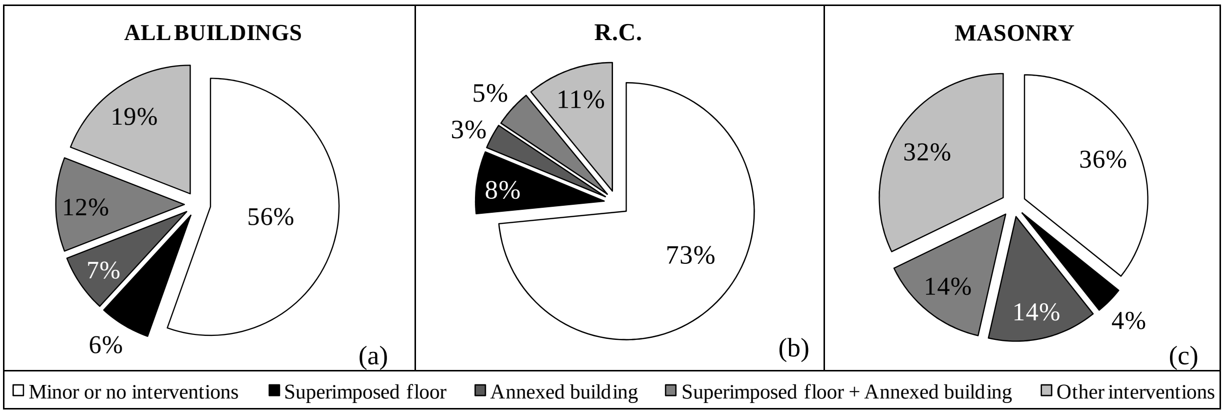



**Figure 2.5.** Structural modifications: (a) all buildings; (b) r.c. buildings; (c) masonry buildings.

Therefore, a floor may have been built on top of the school (superimposed floor), often using a diverse structural typology (e.g., r.c. frames). In other situations, annexed buildings (showing not-independent dynamic behaviour) were built (Fig. 2.6).

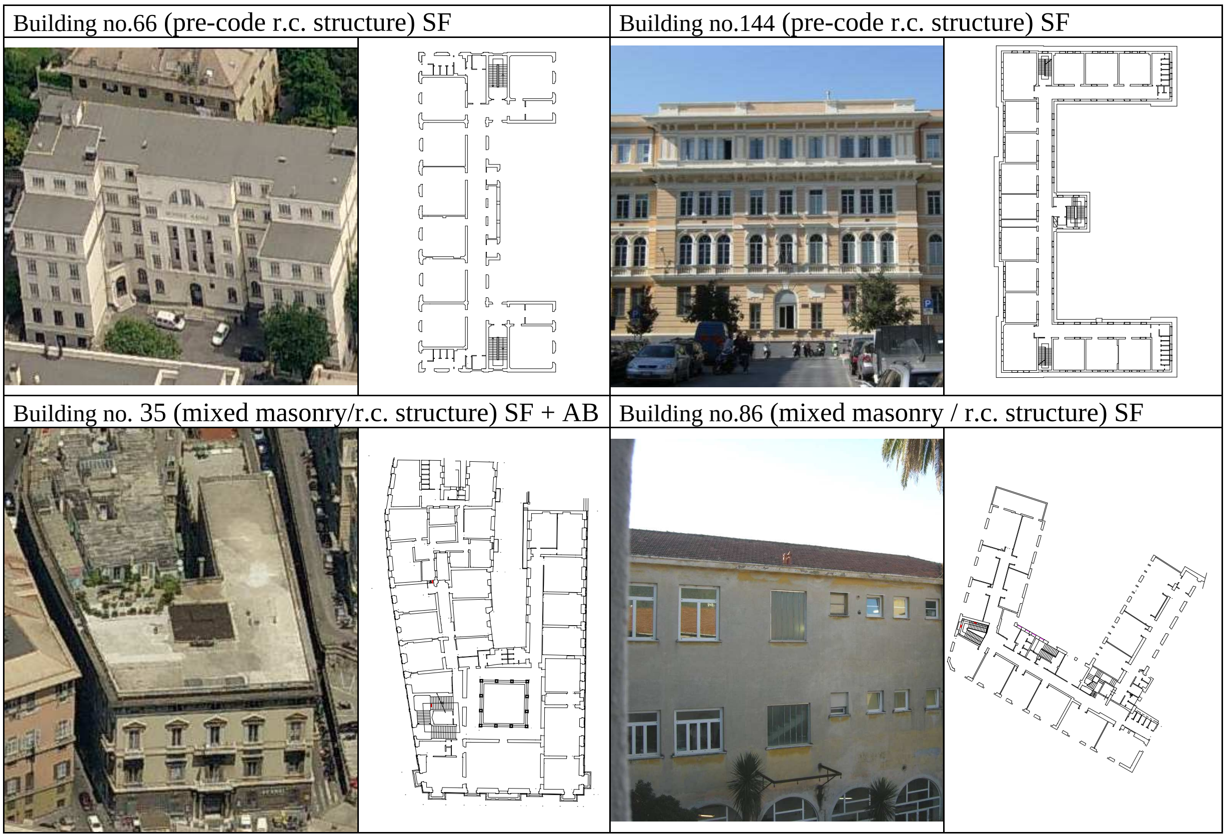



**Figure 2.6.** Overall view and plan configuration: SF = superimposed floor, AB = annexed building (archive number is used).

## 3. RISK ANALYSIS: THE APPLICATION OF MULTI-LEVEL APPROACH TO GENOA PROVINCE

In the following the brief scheme of the multi-level methodology is described. As previously discussed (Raineri *et al.*, 2010), in case of a wide stock of structures, the critical situations have to be quickly identified and a priority chart to point out the critical situations has to be defined, even if buildings having structural peculiarities need a detailed model.

The multi-level approach for the seismic safety evaluation suggested by O.P.C.M. 20th March 2003, no. 3274 and D.P.C.M.-D.P.C. 21st October 2003 is adopted. Special reference is made to two different procedures: Level 0) seismic observational screening; Level 1*) macroseismic vulnerability model (Giovinazzi and Lagomarsino, 2004), in order to have vulnerability models feasible for the analysis at the territorial scale.

It is worth noting that Level 1* analysis is not wholly matching Level 1 approach (FEM linear model or mechanical simplified model) suggested by O.P.C.M. no. 3274 Decree, but, accounting for the low seismic hazard of Genoa Province, it can be considered adequate for the case study. The analysis of buildings resulting as more critical referring to the site seismic hazard will be deepened.

In some cases, detailed information is available, allowing us to perform complete analysis by means of Level 1 approach (mechanical simplified model) and Level 2 procedure (FEM or macro-element model). At now, those studies have been put forward on 3 buildings, as results of a research programme developed by Department of Civil, Environmental and Architectural Engineering (DICAT - University of Genoa, Italy).

The safety evaluation procedure is applied using differently detailed data (Table 3.1), but the vulnerability and risk estimation has to be carried out through correlate parameters: the vulnerability index, the Peak Ground Acceleration (PGA) value related to the performance limit states, the expected performance level in terms of displacement and/or corresponding acceleration. In fact, the ultimate result requested by the O.P.C.M. no. 3274 Decree procedures is the Risk Factor related to various performance limit states (operational, damage, ultimate and collapse).

**Table 3.1.** Multi-level procedure for seismic analysis of strategic public buildings.

| PROCEDURE | Approach / Model | Input Data | Output and results |
|---|---|---|---|
| LEVEL 0 | Typological / expert judgement | Dimensions and shape.<br>Building age.<br>Structural typology.<br>Possible modifications.<br>Geomorphology. | Vulnerability and risk expert judgement.<br>Preliminary priority chart for more detailed studies. |
| LEVEL 1* | Typological / macroseismic model | Typological class EMS98.<br>Geometrical data (quick survey).<br>State of maintenance.<br>Building age.<br>Possible modifications/rising up.<br>Aseismic devices.<br>Position of the building in the aggregate.<br>Geomorphology.<br>Foundation. | Damage probability (predefined seismic input).<br>PGA value related to the performance limit states (indirect evaluation).<br>Risk Factor related to various performance limit states (indirect evaluation).<br>Ultimate priority chart for more detailed studies. |
| LEVEL 2 | Mechanical / Mechanical-numerical model (FEM or macro-element) | Exhaustive knowledge degree.<br>Detailed geometrical data.<br>Structural typology (elevation and foundation).<br>Material mechanical characteristics.<br>Loads.<br>Possible modifications/rising up.<br>Significant constructive details.<br>Geomorphology. | PGA value related to the performance limit states (direct evaluation).<br>Risk Factor related to various performance limit states (direct evaluation).<br>Dynamic properties.<br>Stress and displacement state.<br>Damage pattern (non linear analysis).<br>Retrofitting intervention choice. |

### 3.1 Macroseismic vulnerability model: Level 1* approach

The macroseismic vulnerability model (Giovinazzi and Lagomarsino, 2004) is a well-established method. Even if derived from the European Macroseismic Scale 1998 (Grünthal, 1998), it is based on and validated through the damage observation in many ordinary buildings, both using national (Giovinazzi and Lagomarsino, 2001) and European databases (Penelis *et al.*, 2002).
Briefly, the method is based on the attribution of the vulnerability index ($V_I$) for a single building. It is defined on the basis of its typology and refined through behaviour modifier scores, related to some clearly detectable parameters (maintenance state, material quality, structural regularity, etc.).
Once set the mean damage value $\mu_D^*$ (representing the 50% occurrence probability for a certain damage grade in a binomial probability distribution), in relation to certain performance limit state and EMS-98 damage grade definition, the macroseismic intensity $I^*$ is derived using the analytic expression of the vulnerability curves (Eqn. 3.1).

$$I^* = -6.25 \cdot V_I + 13.1 \cdot arctanh( 0.4 \cdot \mu_D^* - 1 ) \cdot 2.3 \qquad (3.1)$$

The obtained values for $I^*$ are associated to PGA values leading to the predefined performance limit state, through well-known relations. See Cattari *et al.* (2006) and Balbi *et al.* (2004) for the complete procedure.
In this study, Level 1* approach, by means of macroseismic method, is structured to be functional to the peculiar aims stated by O.P.C.M. no. 3274 Decree and to be efficiently applied to the buildings owned by the Provincial Authority of Genoa.
On the one hand, $I^*$ - PGA relationships calibrated using post-earthquake surveyed data in national areas are applied, because their choice could strongly influence the estimation. In Italy, relationships between the intensity data and PGA records have been proposed among others by Margottini *et al.*

(1992) and by Faccioli and Cauzzi (2006), which used data from earthquakes of the Mediterranean area (Italy, Turkey, Algeria, France and Slovenia). On the other hand, Risk Factors are evaluated in relation to various performance limit states, via associated mean damage value ($\mu_D$ equal to 1 for operational limit state OLS, $\mu_D$ equal to 2 for damage limit state DLS, $\mu_D$ equal to 3 for ultimate limit state ULS and $\mu_D$ equal to 4 for collapse limit state CLS). The Risk Factors (RF) are derived from the ratio between structural capacity (expressed by means of PGA value leading to each predefined performance limit state) and earthquake demand (expressed by means of PGA value on stiff soil, that is the hazard for each limit state, corresponding to various return periods $T_R$ of the earthquake).
Being Level 0 and 2 results described in Raineri *et al.* (2010), in the following, the only updating of Level 1* verification is discussed.

## 4. MACROSEISMIC VULNERABILITY MODEL AND RISK FACTOR EVALUATION

The complete building stock owned by the Provincial Authority was analyzed by means of Level 1* procedure; the structures have been studied by means of macroseismic method, evaluating the Risk Factor related to various performance limit states.
The protection level of strategic buildings and public facilities, set by rules, is higher than that of ordinary buildings. Thus, the expected seismic hazard corresponding to ULS, for example, is evaluated for return period $T_R$ = 949 years; in the studied sites of Genoa Province, the related PGA value on stiff soil (provided by a detailed seismic hazard map of the recent Italian Technical Rules D.M. $14^{th}$ January 2008) ranges from 0.073 g and 0.138 g.
By means of the procedure described in section 3.1, the structural capacity in terms of PGA associated to each limit state was carried out. $I^*$ - PGA relationships, used in these analyses, are chosen to be representative of Italian sites (Margottini *et al.*, 1992; Faccioli and Cauzzi, 2006). In case of PGA estimation, in regions of low seismic activity, the two chosen relationships are comparable. In Figures 4.1- 4.2, the obtained seismic capacity of the analyzed buildings is shown, in case of ULS, being the most significant structural condition. Generally, Risk Factors corresponding to the other limit states are higher than ULS.

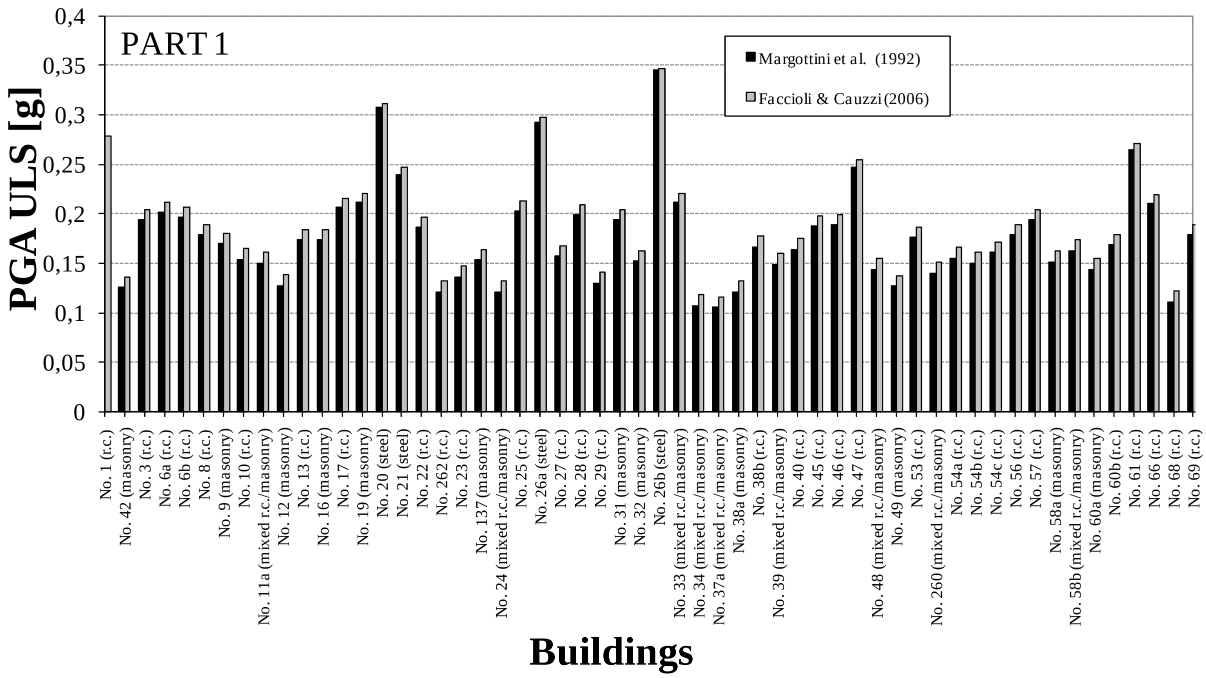



**Figure 4.1.** Level 1* procedure: structural capacity in terms of PGA associated to ultimate limit state (ULS) - Part 1.

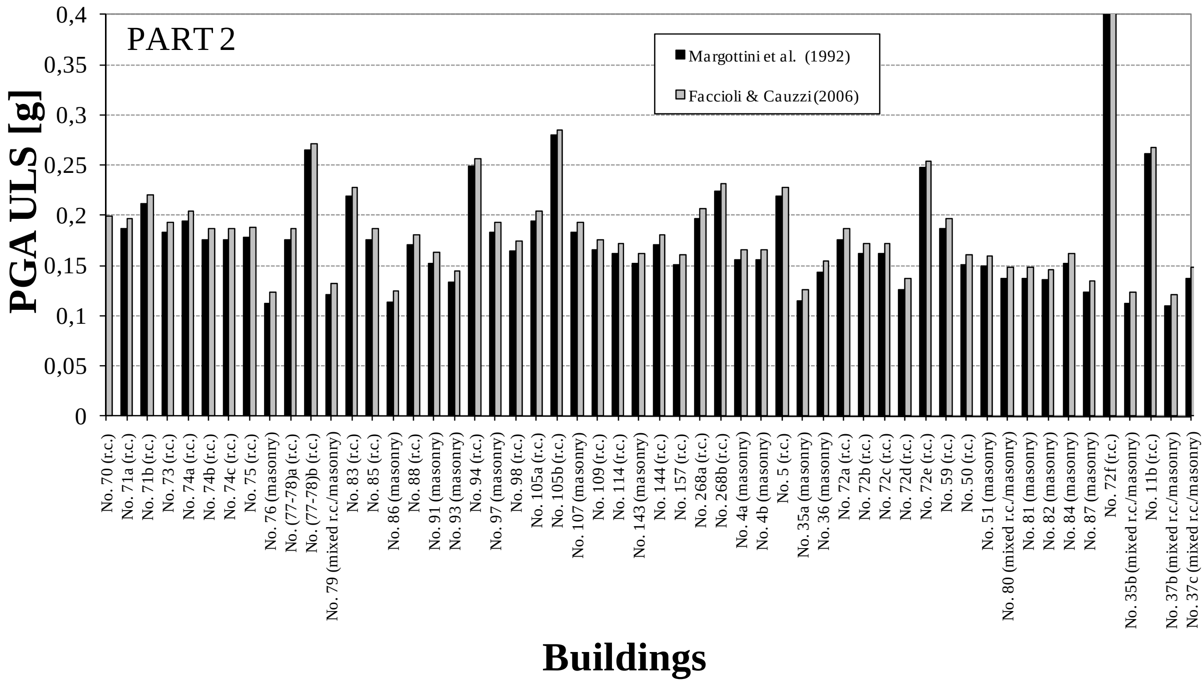



**Figure 4.2.** Level 1* procedure: structural capacity in terms of PGA associated to ultimate limit state (ULS) – Part 2.

For the sake of brevity, in Figures 4.3 and 4.4, only Risk Factors (ULS) are shown. The computed values are higher than 1 (safe state) in nearly all cases. Only one building, using Faccioli and Cauzzi $I^*$ - PGA relationship, and 3 buildings, using Margottini *et al.* relationship, turns out to have Risk Factor lower than 1. All the cited buildings (masonry and mixed r.c. and masonry structures), were modified in the past, by means of superimposed floor, annexed buildings or both. Moreover, it is worth noting that, even behaviour modifiers are considered in this simplified procedure, special characteristics, such as mixed r.c. and masonry structures, may need more detailed studies. Obviously, some of this buildings show capacity (PGA associated to ULS) similar to others, but the site hazard is much higher.

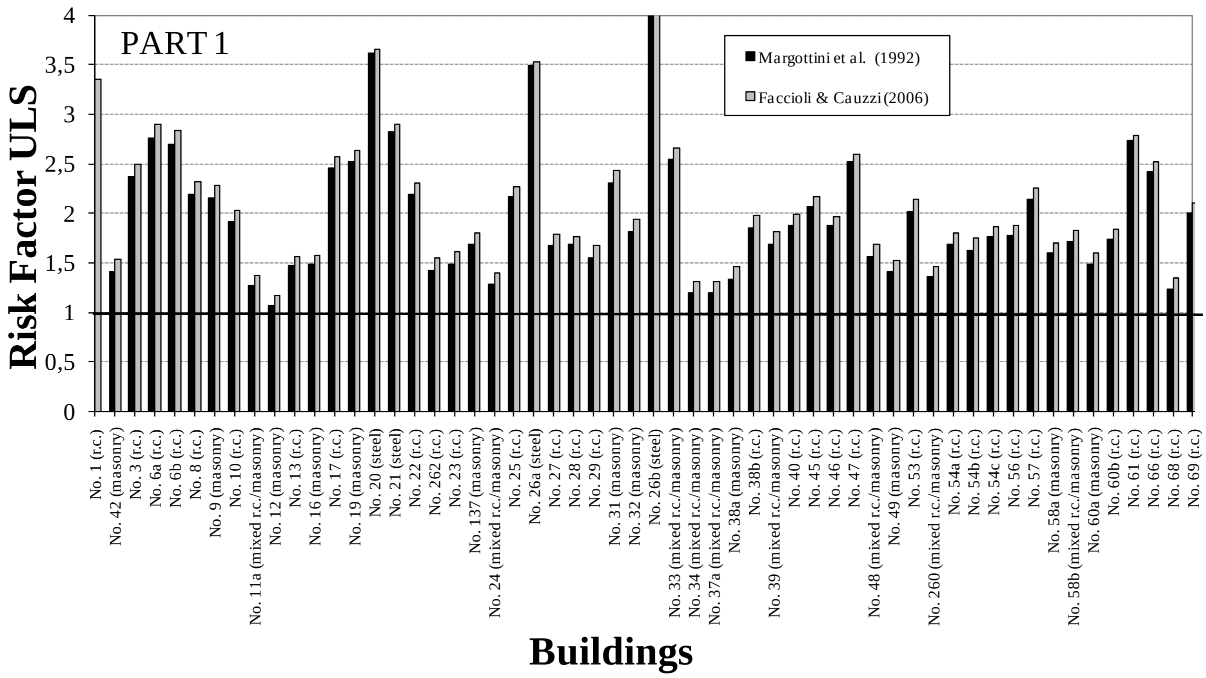



**Figure 4.3.** Level 1* procedure: Risk Factor associated to ultimate limit state (ULS) – Part 1.

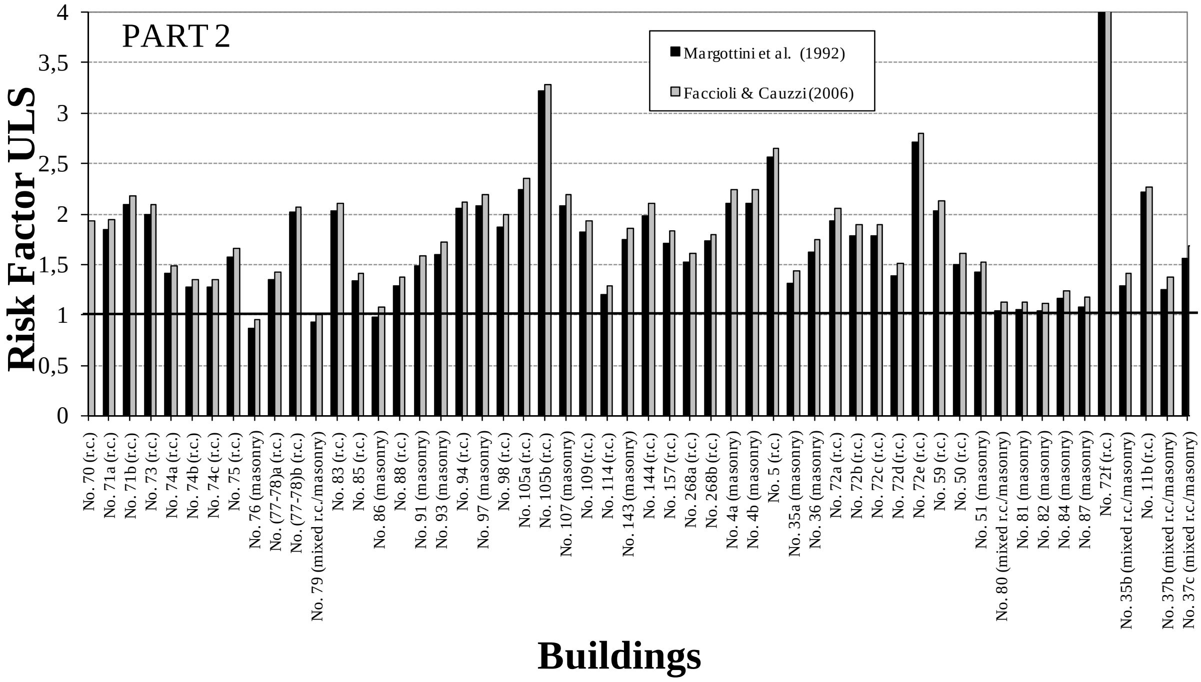



**Figure 4.4.** Level 1* procedure: Risk Factor associated to ultimate limit state (ULS) – Part 2.

As previously discussed (Raineri *et al.*, 2010), the typological vulnerability index $V_I$ assigned to steel structures, on the base of EMS-98 vulnerability classes, seems to be tuned referring to ductile frames with bracing; possibly this feature does not match with the constructive techniques and design criteria applied to the case study (Buildings no. 20, 21, 26a and 26b).

In case of building no. 72f, the Risk Factor (ULS) is higher than 4, because this low-rise r.c. structure (built in 2006 by the Provincial Authority of Genoa) was designed using aseismic guidelines and rules (O.P.C.M. 20th March 2003, no. 3274 and further instructions).

## 5. OUTPUTS OF THE SAFETY VERIFICATION PLAN IN GENOA PROVINCE

Two are the main outputs of this study: on the one hand, the available data were widened and reviewed, leading to analyze the complete building stock; on the other hand, a priority chart pointing out the critical situations in terms of Risk Factor (ULS) was defined.

A preliminary priority chart among the complete stock was determined, on the basis of which a review process has been carried out. This procedure implies the in-depth documental research (investigating in all the available archives, both owned by the Provincial Authority and external ones) and detailed in situ survey. In many cases, this survey cannot have been exhaustive, because buildings are daily used.

The review process was applied to about 25% of the buildings: in the most cases, in situ findings or additional documental investigations turn out to increase or keep unchanged the vulnerability index ($V_I$) of the building. In fact, the reviewed behaviour modifier scores, mainly related to the presence of significant structural interventions (not classified as refurbishment) or poor quality constructive details, lead to refine the vulnerability index value, lowering the Risk Factor (for which the safe-state values are higher than 1).

Some special features were added to the review list: in particular, those constructions being contemporary strategic and monumental buildings. As an example, Level 1 verification (simplified mechanical model) was developed by Department of Civil, Environmental and Architectural Engineering (DICAT - University of Genoa, Italy) in case of building no. 97 (Fig. 5.1).

Building no.97 (masonry structure) SF + AB

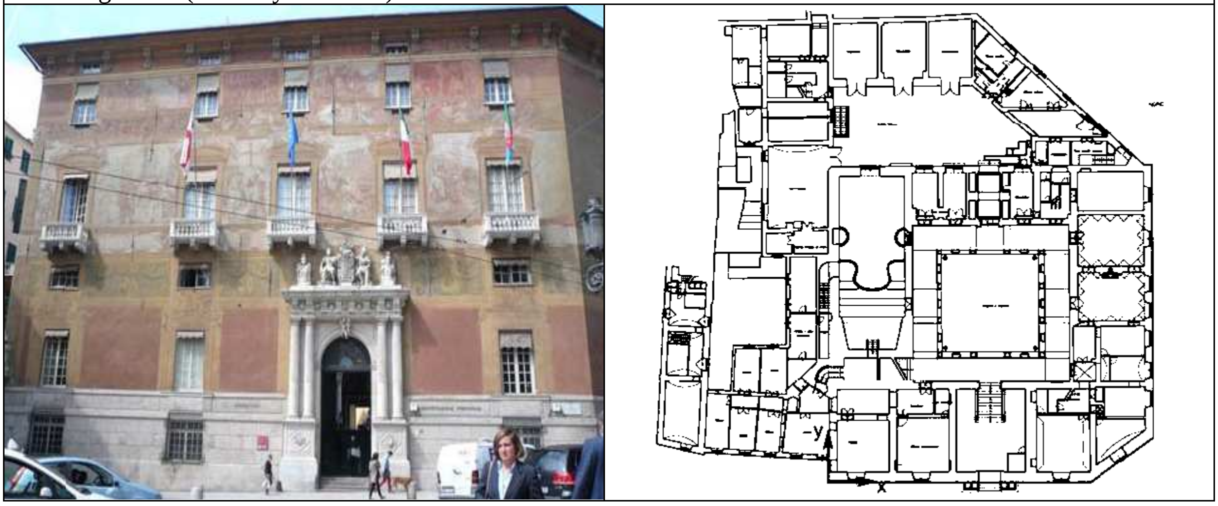


**Figure 5.1.** Overall view and plan configuration: SF = superimposed floor, AB = annexed building (archive number is used).

This further evaluation point out Risk Factor equal to half the value of Level 1* method, confirming that buildings having structural peculiarities (e.g. strong irregularity or mixed structures) need a detailed model.
In Table 5.1, Level 1* priority charts (obtained by means of Faccioli and Cauzzi $I^*$ - PGA relationship) are shown. In this case, the lists are computed both for the complete sample and for r.c. frame buildings.

**Table 5.1.** Level 1* priority chart referring to: (a) complete sample; (b) r.c. frame buildings.

(a)

| Building | Risk Factor (ULS) |
|---|---|
| No. 76 (masonry) | 0.947 |
| No. 79 (mixed r.c./masonry) | 1.008 |
| No. 86 (masonry) | 1.078 |
| No. 82 (masonry) | 1.115 |
| No. 80 (mixed r.c./masonry) | 1.121 |
| No. 81 (masonry) | 1.130 |
| No. 12 (masonry) | 1.169 |
| No. 87 (masonry) | 1.174 |
| No. 84 (masonry) | 1.237 |
| No. 114 (r.c.) | 1.281 |

(b)

| Building | Risk Factor (ULS) |
|---|---|
| No. 114 (r.c.) | 1.281 |
| No. 74b (r.c.) | 1.355 |
| No. 74c (r.c.) | 1.355 |
| No. 68 (r.c.) | 1.356 |
| No. 88 (r.c.) | 1.371 |
| No. 85 (r.c.) | 1.417 |
| No. (77-78)a (r.c.) | 1.427 |
| No. 74a (r.c.) | 1.486 |
| No. 72d (r.c.) | 1.505 |
| No. 262 (r.c.) | 1.553 |

If the masonry and mixed r.c. / masonry buildings are accounted for, only no. 114 is replaced by no. 34 (masonry - Risk Factor equal to 1.311).
The chart referring to the complete sample points out higher vulnerability of masonry and mixed r.c. / masonry buildings. Nevertheless, it is worth noting that 7 structures (among 10 buildings in the list) were modified in the past, by means of superimposed floor, annexed buildings or both.
About 16-24% of the structures (difference due to the $I^*$ - PGA relationship) have Risk Factor (ULS) lower than 1.4.
In paper no. 3551 (Cattari & Ottonelli, in press) an in-depth study by means of mechanical simplified models (Level 1) is carried out among the r.c. building sample. It also describes the priority chart obtained through diverse criteria, implying the outputs of both mechanical and macroseismic procedures. See the cited paper for a thorough dissertation about the obtained priority list, referring to r.c. frame buildings.

## 6. FINAL REMARKS

The Provincial Authority of Genoa – Seismic Office, in 2007 set down a plan aimed to assess the seismic risk for the public-facilities, especially referring to Province-owned and available structures.
In 2011, the complete building stock, both in terms of use and structural typology, was investigated, achieving the verification level, required by law at now in low-seismicity areas.
Based on a previous research, nowadays this study goes beyond rule requirements in case of low hazard. Trying to accomplish a more accurate verification level, the analysis of buildings resulting as more critical was deepened, e.g. by means of in situ survey of technological issues and constructive phases. Moreover, part of the building stock (56 r.c.-frame structures) was also studied through mechanical simplified models by Department of Civil, Environmental and Architectural Engineering (DICAT) of the University of Genoa (Cattari & Ottonelli, in press).
Thanks to the definition of a priority chart, a time table of further verifications (Level 1 and 2, implying FEM or macro-element models) is scheduled, as required by law in the years to come. The administrative process and the annexed technical documents (defining the requirements of Level 1 and 2 verifications, including experimental test campaign) have been also set up, in order to regulate the tender procedure.
It is worth noting that besides this technical plan, the Seismic Office of the Provincial Authority of Genoa is deeply involved with earthquake protection topics, also relating to the design check carried out for newly-built or refurbished strategic constructions.

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