THE SEISMIC VULNERABILITY OF SCHOOL BUILDINGS IN MOLISE (ITALY): THE “SAFE SCHOOL PROJECT”, FROM SEISMIC VULNERABILITY STUDIES TO AN INTERVENTION CLASSIFICATION

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ABSTRACT:

After the earthquake that hit Molise in 2002, the Region instigated a series of studies to assess the seismic safety of all public buildings and in particular school buildings. The Regional Authority invited the National Research Council - Construction Technologies Institute in L’Aquila (CNR-ITC) to coordinate and direct work The CNR-ITC launched specifically prepared “Guidelines for the evaluation of vulnerability of school buildings” and a database was set-up for the information collected using the forms provided with the guidelines. This report illustrates the criteria, methodology and instruments outlined in the guidelines which were drawn up to help orientate investigations already underway, ensuring coherence in line with the overall aims of the work. The most significant aspects of the entire project are illustrated: the problems that arose during the operative phase; the contents of the procedures and methodologies used; the results of the investigations and the summarizing of these results in a specifically designed document. The report concludes with a brief summary of some of the results of the database analyses and an illustration of the criteria for establishing programming priorities and the implementation of measures for reducing risk.

KEYWORDS: school buildings, vulnerability, seismic mitigation.

1. INTRODUCTION

After the October 2002 earthquake, the Molise Region passed a law (L.R. n.38/2002) to assess the safety of all public buildings, priority being given to schools, in order to gain an overall picture of actual conditions and potential seismic risks which were essential for drawing up prevention programmes (Dolce et al., 2007). The first activity financed was an investigation into the schools of the Province of Campobasso. In 2003, the Region approved guidelines (D.C.D. n. 71/2003) prepared by the Construction Technologies Institute of the Italian National Research Council (CNR-ITC), to assist investigations. The aim of these guidelines was to facilitate investigations and evaluations and ensure overall coherency, in line with the financial resources available and new national standards (OPCM 3274/2003). In the second phase the investigation was extended to include all of the schools in the Province of Isernia and the safety assessment of strategic public buildings also began. In light of the high costs involved, building assessments were structured on differing levels to allow the Administration to build up a picture of the situation in as short as time possible in order to be able to define planning priorities and the best use of resources. Notwithstanding the complexity and limited resources the extensive assessment programme of schools and public strategic buildings in Molise is in its final phase. This programme was one of the first of its kind on a national level and represents an important step not only because of the new hazard assessments and technical code but also because it highlighted problem areas. The data collected by the Molise Region and processed by the CNR-ITC are used to revise and update the database. Section 2 illustrates the school seismic vulnerability campaign, the suggestions and instruments contained in the guidelines and the data collection form; section 3 describes the database that was created and the results of calculations carried out concerning the latest updated version; section 4 describes the criteria adopted for the drawing up of the risk priority list and the definition of intervention programmes to reduce risk; section 5 describes the present state of investigations, the means of extending the evaluation to other public offices excluded from the initial assessment.

2. "SAFE SCHOOL PROJECT": INVESTIGATIVE METHODS AND TOOLS

The phases outlined in the guidelines concerning the assessment of the seismic safety of school buildings were (Dolce et al., 2007): Phase 1: collection of administrative, technical and geological data and the preparation of a detailed summary report; Phase 2: measurements, tests and structural, geotechnical and geological investigations, as necessary; Phase 3: building vulnerability and seismic risk evaluations following the regional evaluation programme as follows: 1) analysis of the possible collapse mechanisms and the identification of the most probable ones; 2) analysis of the structures with simplified models able to quantify seismic resistance; 3) calculations to determine seismic resistance (vulnerability) according to the adopted model; 4) a summary of the results obtained and a risk evaluation; 5) analyses of further factors that may influence the vulnerability of individual buildings, that were not taken into consideration in the simplified model. The phases described above were all carried out by experts employed by the Molise Region with the technical and scientific coordination of the CNR-ITC and resulted in a series of technical plans and the preparation of a "Building Identity Card". The simplified structured calculation models provided with the guidelines were for masonry and reinforced concrete buildings and were developed following the 2002 earthquake and have been subsequently used in other investigative campaigns in Italy (Dolce and Moroni, 2005). The model for masonry buildings is based on the hypothesis of the formation of a floor collapse mechanism owing to wall plane action; the collapse mechanism for reinforced concrete buildings is based on the formation of a plastic hinges at least at one extremity of ech pilaster of a floor, considering the contribution made by the masonry infill panels. These models allow a quantitative evaluation of building vulnerability and an estimate of risk conditions using the Peak Ground Acceleration (PGA) at bedrock and the relative return period. The "Building Identity Card" described by the Guidelines is made up of a set of technical reports detailing the results of various types of investigations, graphs, photographs, calculations, structural and non-structural lack evaluations, the overall assessment and intervention options to satisfy general safety conditions in relation to local seismic hazard levels. Most of the information is summarized in the "Static Seisma Identity Card Summary form" (the CISS form) provided by the Guidelines. This form was prepared to ensure coherency in the information gathered by the investigations and represents the results of the investigative studies on seismic safety conditions in schools, making it easier to implement anti-seismic prevention measures. The CISS form is made up of one section that concerns the school complex and further sections for the individual buildings that make up the school complex. The unit of analysis used for the evaluation of the static seismic condition of a school is represented by a structurally identifiable building unit that is isolated or part of an aggregate. In the latter case, as occurs quite frequently in masonry buildings of historical centre, the structural unit is identified using the criteria usually used to assess vulnerability and also detailed in national standards. Varying types of information are entered onto the CISS form: data identifying the complex and buildings; technical and administrative data; geometric and dimensional data; chronological data, typological data; construction data concerning pre-existent damage or damage arising from the 2002 earthquake; results of the tests and investigations carried out on the structure itself and the ground; vulnerability characteristics, structural defects and the resulting intervention proposed. The form, which is in Excel, facilitates the compilation of data and is an easy to use instrument. The proposal for Guidelines to clarify and support activities to ensure a more rational and complete approach in line with OPCM 3274, was an important and necessary step taken by the Region. However it did not entirely compensate for the lack of initial orientation and the institution of an official office to coordinate and monitor the operation on a regional level. Observations made over the course of the project and examination of the plans produced by technicians highlighted: a certain degree of incoherency in the methodology applied; inappropriate investigations giving results of little use, the expense of which did not justify its objective value; badly documented tests performed on masonry and reinforced concrete buildings and dynamic testing providing frequency values which were not required. The decision to use simplified calculation models to assess vulnerability proved to be a success as it was adopted generally giving coherency to evaluations which could also be compared. However, in some cases the proposed models were used inappropriately with respect to the configuration and characteristics of the structural system. In other cases, the results contained errors owing to the incorrect use of the worksheets or a mistaken choice of parameters. These errors did not however affect the overall success of the operation.

3. DESCRIPTION OF THE DATABASE AND THE RESULTS OF THE INVESTIGATION.

All the information collected in the investigation into vulnerability in school buildings in Molise represents a database of considerable interest reflecting the scholastic patrimony of the Region. This data, after being computerized and checked has been processed in order to evaluate the typological and vulnerability characteristics of buildings in the region. Some of the results are illustrated below. Currently, 397 schools have been censored of which 233 have been investigated thoroughly (see Table 1, level 3). Schools that have received grants and have undergone or are undergoing work are approximately 200. The types of school are illustrated in figure 1 (left). Both figures 1 and 2 illustrate the distribution of vertical type structures identified with reference to the codes used in the CISS forms. The large number of buildings in reinforced concrete is apparent, approximately half of the sample, whilst masonry buildings made with natural elements constitute more than 30% of the total. The majority of horizontal structures are made from RC slab or RC and bricks.

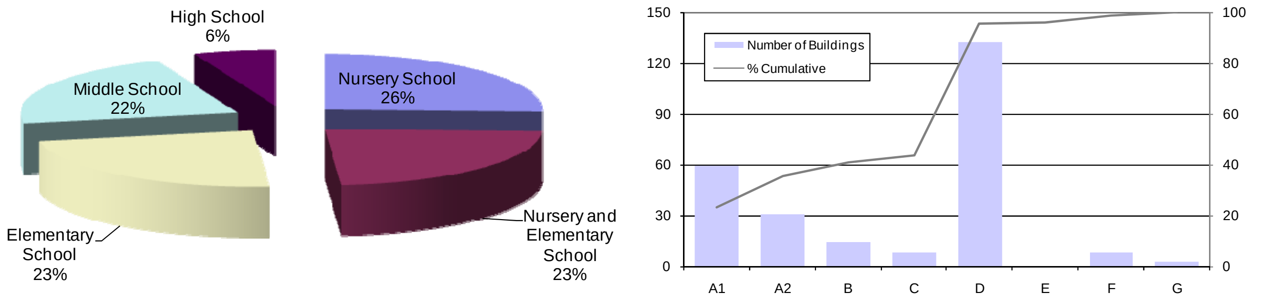

Figure 1 Distribution of buildings according to the level of instruction (top) and type of construction (right)

Construction types:	
A1 - masonry in natural irregular elements;	D - reinforced concrete;
A2 - masonry in natural regular elements;	E - steel;
B - masonry in manmade elements;	F - mixed masonry concrete steel;
C - masonry with mixed elements;	G - ready-made material;

Figure 2 (left) illustrates the situation with respect to the age of construction. The graph shows a gradual rise over time in numbers, starting after the first world war until the 1970s; an inversion then followed until a final drop in the 1990s. Considering the distribution per age of construction and the history of regional classification (most municipalities were classified as belonging to seismic zone after 1981) it becomes clear that the majority of buildings were designed and built in the absence of seismic code.
The graph in figure 2 (right) shows the distribution of buildings in percentage vs. number of floors above ground. This shows the majority of buildings are 1 or 2 storeys (which together make up 70% of the sample), 20% of buildings are three storey whilst limited number have 4 or 5 storeys. These are fairly typical values given the use of the buildings, the level of instruction and the size of the municipalities.

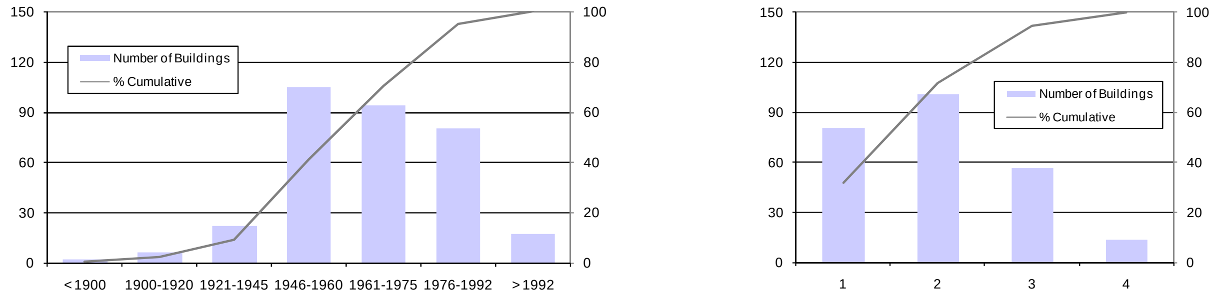

Figure 2 School building per era of construction (left) and per number of floors above round (right)

The simplified evaluations of vulnerability adopted (Dolce and Moroni, 2005) allowed an estimate of the PGA that would cause collapse to be calculated for the sample buildings indicated in the map in figure 3 (left) . The graph in figure 3 (right) shows the statistical distribution of the minimum values of collapse PGA (PGAc) with respect to the two orthogonal direction of earthquake. Note how the distribution values of the PGAc of masonry buidings is similar to that of buildings in reinforced concrete.

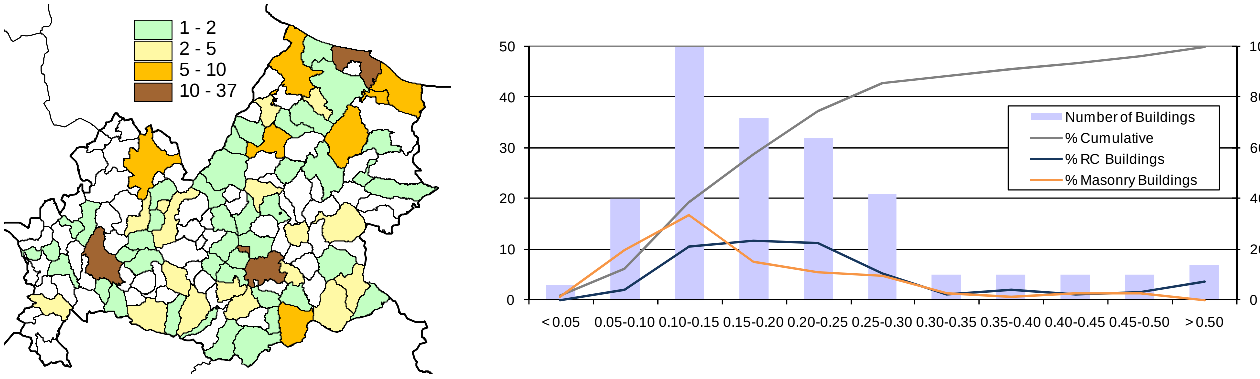

Figure 3 Number of school buildings with simplified vulnerability evaluations (left) and the distribution of the PGAc (right)

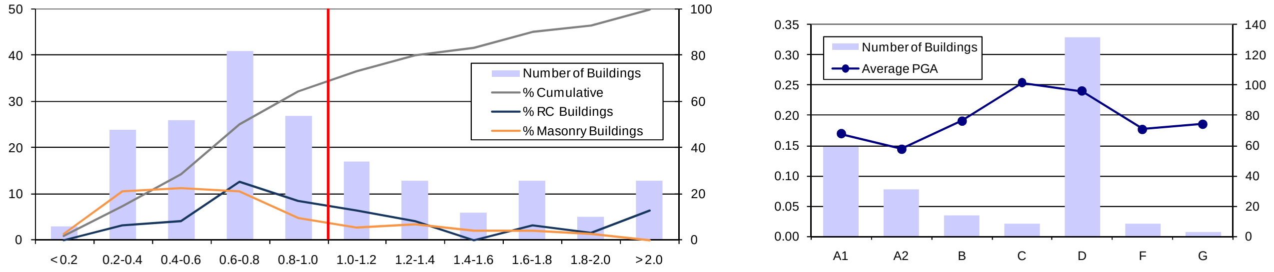

Figure 4 Distribution of buildings versus the ratio of PGAc / PGAr (left) and average PGAc of buildings versus construction type (right)

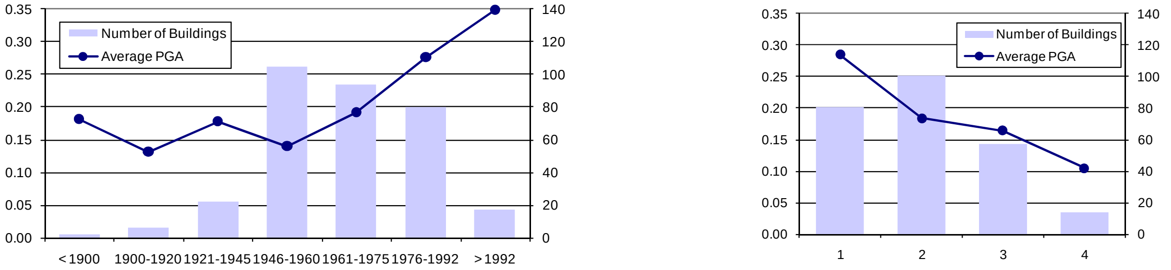

Figure 5 Average PGAc for buildings versus age of construction (left) and versus number of floors above ground (right)

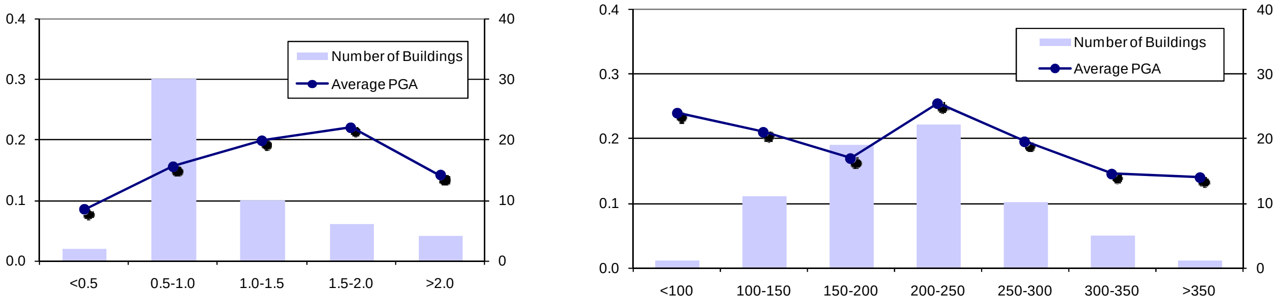

Figure 6 Average PGAc of masonry buildings versus shear strength τ_k (left) and average PGAc of rc buildings versus compressive strength σ_k (right)

From the ratio of collapse PGA (PGAc) to reference PGA (PGAr) relative to the seismic zone in which each building is situated deriving from the seismic classification adopted by the Molise Region GR del 02-08-2006, the level of risk for each school building in the sample can be determined. Figure 4 (left) shows the statistical distribution of buildings versus the ratio of PGAc / PGAr, distinguishing between masonry and reinforced concrete buildings; the vertical line distinguishes between cases with ratios less than 1 and over 1. A high percentage of the Region's buildings (more then 50%) do not satisfy the safety conditions for earthquakes. Masonry and rc buildings shows a similar situation, slightly worse for the former group. The PGAc values were also correlated to other building characteristics. Figure 4 (right) shows the average PGAc values for each category considered. In some cases the data is without a doubt influenced by the low number of buildings belonging to each class and therefore not significant. Figure 5 (left) the PGAc is correlated to the age of construction and therefore indirectly to the standards and building styles of that period. In this case with the exception of buildings constructed before 1919 the average PGAc gradually increases reaching a peak in recent years. Figure 5 (right) shows the correlation between collapse PGAc and the number of floors above ground level; earthquake resistance falls with the increasing number of floors with the exception of five storey buildings in all probability buildings that have been constructed recently in accordance with seismic code. The PGAc values for school buildings were also correlated to the resistance class of the materials used in construction: compressive strength σ_k and characteristic shear strength τ_k. Figure 6 (left) shows the correlation with reference to the τ_k of the masonry and, as expected, the seismic resistance of a building increases with increasing values of τ_k. The correlation between the PGA and the compressive strength of concrete (Figure 6, right) does not reveal a link between the two parameters. Indeed many test certificates observed during the collection of material lacked important information and in some cases the technical committee experienced great difficulty in interpreting their results. This led to the Molise Region and the CNR-ITC drawing up more severe guidelines to censure more reliable results with the aim of improving future evaluations.

4. CRITERIA FOR THE PROGRAMMING OF INTERVENTIONS

Two criteria were proposed for earthquake safety interventions: one based on the seismic risk which was used to establish priority and the level of improvement to be satisfied, whilst the other criteria referred to economical aspects that allowed an estimate of the costs involved and the economical benefit of the same. Priority was established using the following seismic risk index:

$$Ir = PGAc/ PGA_{10\%} \tag{4.1}$$

where PGAc refers more specifically to the acceleration to the bedrock that determines severe damage and therefore a loss of structural resistance; $PGA_{10\%}$ is the acceleration value with the probability of exceeding 10% in 50 years (return period 475 years).
The cost of intervention in the second criteria is based on the size of the building, its vulnerability and any damage suffered. The cost so calculated was compared with a reference cost, bearing in mind the surface area of the building actually used and the number of occupants. The surface area of school buildings was determined in function of the actual number of students, the number of classes, the level of instruction of the school in line with the parameter set down by Department of Education, University and Research.

5. THE STATE OF PROGRESS OF THE INVESTIGATION PROGRAMME

As mentioned earlier, the Region has extended investigations into seismic safety to all strategically important public buildings for civil protection. However it was immediately clear that the economical costs of studies similar to those carried out for schools would not have been feasible and would not have been completed in the times set down by the Administration. A new methodology was therefore devised allowing for differing methods for establishing vulnerability with different levels of detail to be used. This approach has enabled the Region to deal with a continually evolving situation. The strategy adopted was divided into 3 phases:

1) Completion of the census of schools and strategic public buildings;
2) Financing and execution of vulnerability investigations by the team of experts for the majority of the

buildings in the census;

3) The calculation of a simplified vulnerability estimate for the remaining buildings in the census.

The vulnerability estimates, studied to take into consideration the varying levels of investigation, were then used to draw up a risk classification list for the financing of improvement of resistance to earthquake or to change the use of the buildings. The levels of investigation established are detailed in Table 1. In 2003, the Department of Civil Protection (DPC) issued a decree establishing three levels for earthquake testing of strategic public buildings, accompanied by a summary form for the results (DM 21-10-2003). These three levels correspond to the levels of study of the data obtained in columns 2 and 3 of table 1.

Table 1 Levels of study in the vulnerability investigations

Level of study	**Corresponding level of monitoring DM 2003**	**Level of monitoring DM2003**	**Instruments**	**Criteria – method**
1	0	0	Level 0 form	PGA Deficit related to the Norm's values
2	0,5	0	Level 2 GNDT form and/or equivalent methods	Vulnerability measurement with typological indicators and estimate of the PGA
3	1	1	VC and VM (or equivalent) with additional local collapse mechanism if necessary	Simplified, global mechanical verification
4	1,5 - 2	1 - 2	Global verification with linear analyses	Mechanical verification in terms of resistance and deformation
5	2	2	Global and local verification with non-linear analyses	Definition of capacity curves with reference to individual local mechanisms.

The first level of study corresponds to the census phase in which data is collected concerning the age of planning and construction and the building typology. An initial risk estimate is made assuming that the buildings have to comply with the seismic rules in force at the time of their construction, defining the PGA deficit with respect to current values. (Calvi et al, 2007). For the first level, it is therefore enough to determine the value of the earthquake action of the project corresponding to the period of construction of the building (design PGA). The design PGA is considered 0 for very old buildings built before the introduction of seismic code or situated in zones that were not considered at seismic risk. The data concerning this first level of study are the same for the level 0 form of the DPC, especially the age of construction and the construction typology. The second level of study entails vulnerability evaluations with methods based on construction typology and the identification of vulnerability indicators. The method adopted is an adaptation of the GNDT second level form which is based on the determination of a vulnerability index obtained by summing the points relative to the characteristic parameters of the earthquake behaviour of the building. The PGA corresponding to the level of vulnerability evaluated with this method is estimated through correlation (Dolce and Martinelli, 2007 – Zonno, 1999). The third level of study entails the global mechanical verification with simplified models such as the VC and VM method (Dolce e Moroni, 2005). This method can be considered comprehensive for buildings up to 4 storeys and when it is possible to demonstrate that local mechanisms not taken into consideration would not affect the evaluation. Analyses of local collapse mechanisms can be added if this is considered necessary. The fourth level of study corresponds to level 1 of the DM 21-10-2003, whilst level 5 corresponds to level 2. In parallel to vulnerability evaluations the Region has run an investigation to define local site effects.

With reference to Table 1, the following data is available:

1) A census of all public buildings within the Region (level 1 study);
2) level 2 studies on the majority of public and strategic buildings and all religious buildings;
3) level 3 studies on school buildings following the investigations carried out with LR 38/2003.

6. CONCLUSIONS

The aim of this study was to present the work carried out in the field of earthquake safety for public buildings in Molise Region. This programme instigated by the Molise Region is one of the first of its kind after new legislation was introduced in 2003 resulting in the seismic classification of the territory and a complete revision of the technical norms for construction. The study of school buildings has led to the construction of a considerable database which more than amply meets the aims set up in the Molise Region's campaign, in particular the setting up of action programmes to reduce seismic risk. Some of the problems that have arisen during this programme have been highlighted as have the results which provide information concerning building characteristics, vulnerability and risk. Data shows that over 50% of buildings do not meet current earthquake safety requirements. Varying levels of investigation were established to incorporate strategic public buildings into the study providing the Region with the information and criteria necessary to implement earthquake safety measures while the information campaign was still under way. Lastly, the use of financial resources was optimized allowing more in-depth studies and interventions on those buildings that revealed defects in lower level investigations.

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