Seismic safety assessment program of school building in Puglia (Italy): overview and case studies

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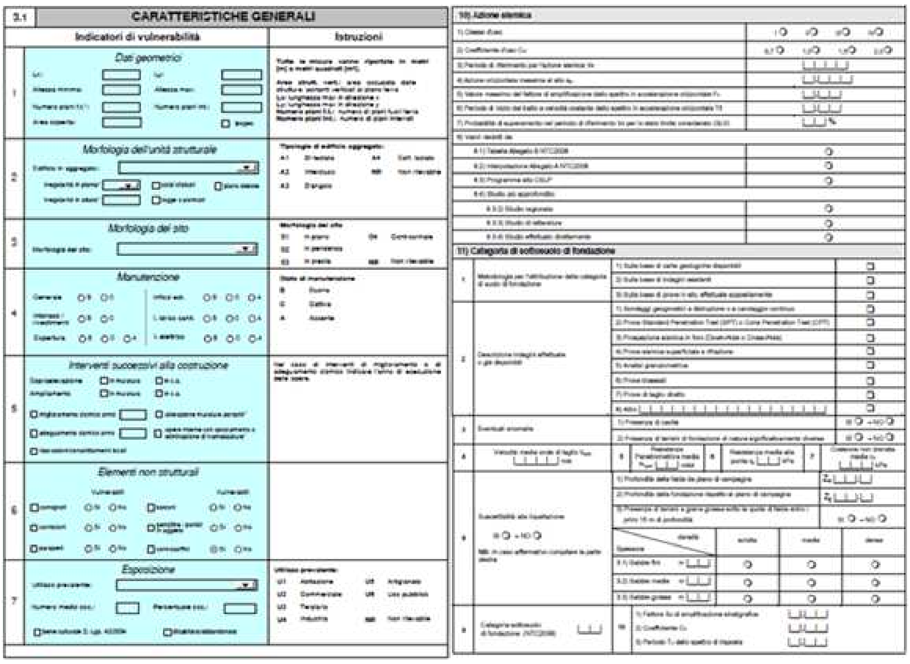
SUMMARY
Thanks to a specific fund provided by AdP-Puglia, a research study has been developed by the Department DIAC of Politecnico di Bari, drawing up a volume of "*Guidelines for the seismic assessment of strategic RC and masonry buildings*" addressed to the professionals in charge with the assessment procedures.
In the paper, the results provided by the seismic vulnerability assessment (according to the aforementioned Guidelines) for some school buildings located in the Province of Foggia are presented. The most significant data were statistically processed in order to classify the recurrent features and identify a paradigmatic typology which could represent, in the average, the characters and quality of the school buildings on the analyzed territory. Moreover, the seismic vulnerability has been quantified by means of a specific parameter: *CVS*, which is useful in order to establish a priority rating in the planning of the seismic retrofitting interventions and funding allotment.

Keywords: Seismic assessment, school building, case studies

1. INTRODUCTION

The observation of post-earthquake damages after recent seismic events has confirmed the need of systematically assessing the safety levels of existing buildings, which are mostly characterized by an unsatisfactory level of the technical design (mainly because the reference building codes are very obsolete) (Decanini et al., 2004; Ricci et al., 2011; Rossetto and Peiris, 2009). Recently, the Italian laws (OPCM, 2003, D.M. LL. PP., 2008) have stated that the public administrations have the obligation to perform the vulnerability assessment of the strategic buildings of their properties. This circumstance has determined, in the last years, a great attention of the technicians towards the procedures for the seismic safety assessment of existing structures, especially considering the necessity of updating their know-how with regard to the new developments of the scientific and regulatory framework. In this context, Politecnico di Bari and AdB Puglia have stipulated an agreement for the definition of *Guidelines for the safety assessment of RC and masonry public buildings* (Mezzina et al., 2010) and for the execution of the seismic vulnerability assessment of school buildings in the Province of Foggia. The guidelines are addressed to the professionals who are appointed for the assessment, with the objective of providing proper methodological and operational indications, with reference to the current Italian and European regulations (DM 14/01/2008; Circolare n.617, 2009; CEN, 2005[1]; CEN 2005[2]). The procedures outlined in the guidelines are designed in order to provide results consistent with current legal regulations, so that all the operations related to the preliminary knowledge and to the assessment can be used also in the subsequent phase of definition and execution of the retrofitting intervention.

In the present paper, a statistical elaboration of the first set of results provided by the assessment program is presented, which concerned a limited number of school buildings located in the Province of Foggia. The data processing was made on the base of the summary data sheets compiled by the technicians in charge with the assessment, in which all the relevant design data and the results of the calculations were summarized (Fig. 1.1).


3.1 CARATTERISTICHE GENERALI

Indicatori di vulnerabilità | Istruzioni

Dati geometrici

Morfologia dell'unità strutturale

Morfologia del sito

Manutenzione

Interventi successivi alla costruzione

Elementi non strutturali

Esposizione

10) Azione sismica

11) Categoria di sottosuolo di fondazione

Figure 1.1. Extract from the summary data sheet form compiled by the technicians.

All data have been statistically processed in order to identify a paradigmatic typology which could represent, in the average, the characters and quality of the school buildings on the analyzed territory. In particular, the "average" features have been determined by using the percentage distribution of some significant parameters related to the geometrical, structural and seismic aspects. Moreover, a seismic vulnerability parameter *CVS* has been calculated for each school building. Such parameter is useful in order to establish a priority rating in the planning of the seismic retrofitting interventions and funding allotment.

2. CONTENTS OF THE GUIDELINES

The *Guidelines* include 4 Sections and 2 Annexes. In particular, in the 1st Section the general methodological aspects regarding all the structural systems are discussed, and the procedural protocol is outlined, specifying all the necessary steps, from the retrieving of existing data and information to the preparation of technical drawings and technical reports to be delivered. Sections 2-4 are specifically devoted to the safety assessment of existing buildings and in particular, Section 3 deals with existing RC buildings, whereas Section 4 deals with existing masonry buildings (which are not comprised in the present analyses), providing detailed indications about the determination of the confidence factor, the various methods of analysis and verification, as well as procedures for estimating the seismic vulnerability parameter *CVS* depending on the method of analysis used. The synopsis of the protocol provided by the Guidelines is shown in Fig. 2.1.

RETRIEVIAL OF EXISTING DATA AND DOCUMENTS

HISTORICAL-CRITICAL ANALYSIS

- Identification of the phases of design and construction
- Identification of the previous seismic history

SURVAY

- Complete survay of the geometry
- Identification of the structural system
- Survay of the constructive details
- Survay of the damage patterns and instabilities

MECHANICAL CHARACTERIZATION OF MATERIALS

- Analysis of data contained in the existing documents
- Definition of the plan of on-site testing
- Characterization of the soil

DEFINITION OF THE ACTIONS

- Vertical loads
- Seismic loads

DEFINITION OF THE STRUCTURAL MODEL AND CHOICE OF THE METHOD OF ANALYSIS

Structural analysis and verification for the different combinations of vertical loads

STRUCTURAL ANALYSIS AND VERIFICATION FOR THE COMBINATIONS OF THE SEISMIC LOADS

Identification of the structural elements that for which the safety verification is not satisfied

Figure 2.1. Synopsis of the protocol for the preliminary investigations and the safety assessment.

In the figure, the difference between the assessment performed in the presence of vertical loads and the assessment related to seismic loads is clearly highlighted. In fact, in the case of a negative result of the assessment, the choices that the technician has to do will be different depending on the type of load.

In the case of vertical loads, there are the following possibilities:

a) determining whether the use of the construction can continue without intervention;
b) indicate whether the use should be changed (downgrade, change of destination and/or imposition of restrictions and/or caution in using);
c) indicate whether it is necessary to increase or restore the carrying capacity.

In the presence of seismic loads, instead, it will be necessary:

a) to verify that the safety level is adequate to the present Italian Seismic Code;
b) to evaluate the seismic vulnerability coefficient (*CVS*), which will measure, on a homogeneous basis, the seismic safety level.

The vulnerability coefficient is aimed at providing an evaluation tool that is useful in order to establish the most appropriate intervention strategy and, at the same time, to identify, at the regional scale, a priority ranking for the mid and long-term mitigation programs and the related allocation of funding.

At the end of the different steps of the procedural protocol, the representative results obtained after the safety assessment for each school building have been summarized in a specific "*summary data sheet"*(Fig. 1.1). In the present paper, a preliminary analysis of the investigation is presented, on the basis of a statistical elaboration of the data sheet regarding a first set of buildings.

3. VULNERABILITY AND SEISMIC RISK ASSESSMENT

3.1. General remarks about the seismic vulnerability of the existing building stock

A structural vulnerability analysis involves the assessment of the consistency of the existing building stock in a given area both from a qualitative and quantitative point of view, specifically appraising the propension of the constructions to be damaged by the earthquake. First of all, a methodology for the seismic assessment on territorial scale should thence specify how to carry out the inventory of the buildings, establish the level of detail and develop suitable models to correlate the ground motion's severity with the possible economic and physical damage. Finally, the buildings shall be classified according to a priority list.

In the past twenty years, two different approaches for the seismic vulnerability assessment have been developed, generally known as *Level I* and *Level II* approach. The *Level I* methods recognize a number of typological classes within the building stock, and for each of them define the vulnerability class (usually A, B and C). For a vulnerability class, the relationship between the seismic input and the damage suffered by the structure is provided by probability matrices - DPM (Damage Probability Matrix) (Braga et al., 1982). Clearly, this type of approach does not provide an assessment of the individual building, but can sort the analyzed building within a homogeneous typological set by its vulnerability index. The *Level I* methods are based on the data collected by the compilation of specific seismic vulnerability sheets, which contain typological and constructive records about the single building. The different records are scored on the basis of pre-defined scales and combined in order to define a *Vulnerability Index* $I_V=I_V(PGA)$, which is a function of the maximum peak ground acceleration on a rigid soil (Benedetti and Petrini, 1984). More recently, "multi-level" approaches are used, which provide different levels of deepening, with a progressive increase of the amount and detail of the information, and accuracy of the results obtained (HAZUS, 1999; Faccioli and Pessina, 1999). An example is given by HAZUS methodology, which represents very well the current standard adopted for seismic risk analyses. HAZUS methodology is based on the comparison between the "seismic demand", expressed in terms of the Adimensional Displacement Response Spectrum (ADRS), and the "structural capacity", expressed by an equivalent force-displacement curve obtained from an incremental non linear analysis. These approaches, which are usually called "semi-quantitative", are organized into multiple levels of analysis: they start from the regional scale up and finally arrive to the scale of the individual building, and are used to establish the seismic vulnerability of the constructions. Their application is conditioned by the great amount of basic data and by the relevant computational effort that is required for the assessment at the scale of the building. If the methodology is to be applied to a large urban area, it is then appropriate to single out a set of typological models that will represent a plurality of buildings, and it is appropriate, also to adopt some simplifications in the approach (Verderame et al., 2001).
The methodology outlined in the *Guidelines* belongs to the class of semi-quantitative approaches, and operates on two levels, providing the indications for the safety assessment of the building and quantifying the vulnerability level, according to the local seismic hazard and to the considered limit state.

3.2. The Seismic Vulnerability Coefficient (CVS)

As previously remarked, for the generic building the *Guidelines* provide the calculation of the coefficient *CVS*, defined as the ratio between the seismic action corresponding to the attainment of the *limit structural capacity* and the *seismic demand*, both evaluated in correspondence of the Limit State of Life Safety (LS) and expressed in terms of Peak Ground Acceleration (PGA):

$$CVS = \frac{PGA_C^{LS}}{PGA_D^{LS}} \tag{3.2}$$

Because of the variability of the spectrum with the period T_r, Eqn. 3.2 becomes quite complex. In a first approximation, it is possible to neglect this variability and to assume a constant acceleration spectrum corresponding to the return period used in the analysis (in the case of school buildings, and for the LS, it is: T_R= 712 years). Based on these assumptions:

- in a linear analysis, the coefficient CVS coincides with the ratio between the capacity of the first structural element which collapses under an increasing seismic action, and the effect produced, on the element itself, by the design seismic action (associated with T_R);
- in a non linear analysis, the coefficient CVS is the ratio between the displacement capacity and the seismic displacement demand, in correspondence of the LS ultimate state.

For RC buildings, the capacity expressed in the acceleration format (PGA_C^{LS}) is the PGA associated to the specific demand spectrum (i.e. with a non-unitary behaviour factor) which induces one of the following effects on a structural element:

1. attainment of shear collapse;
2. attainment of the failure in a beam-column node;
3. attainment of the ultimate chord rotation;
4. attainment of the limit capacity in the foundation.

4. ANALYSIS OF THE SAMPLE

The analysis presented concerns a first sample of school buildings located in the Province of Foggia, where the assessment procedures and the related gathering of data is currently still in progress. At the end of the research work, the sample will consist of about 20 school buildings, while presently the statistical evaluation regards a sample consisting of 9 school buildings. The areas covered by the investigation, within the territory of the Province of Foggia (Italy), are shown in Fig. 4.1: the red dots indicate the location of the school buildings included at present in the analysis, whereas the blue dots indicate the buildings still under evaluation. The seismicity of the investigated area, expressed in terms of "maximum horizontal acceleration at the site - a_g", is comprised between *0.173g* and *0.253g*. Even if the coverage of the sample is still incomplete, the preliminary elaborations, which are summarized in the following sections, offer some interesting points for reflection.

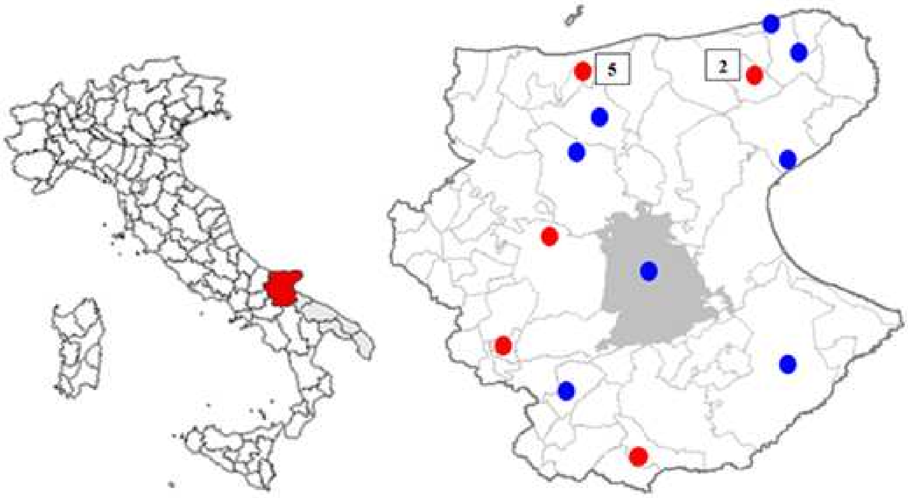


Figure 4.1. The area covered by the seismic risk analysis in the Province of Foggia (Italy)

4.1. The age of the sampled buildings

For an existing building, the age is important information, since it reflects the state of the knowledge at the time of the construction. Therefore, the classification of the buildings included in the sample is based, first of all, on the knowledge of the evolution of the Italian building codes in the twentieth century, taking into account also the progressive modification of the seismic zonation in the Italian territory. The Italian rules concerning RC buildings can be divided into two groups called respectively *first* and *second generation* (Sollazzo and Sgobbo, 2008). The regulations belonging to the *first generation* range from 1925 to 1939, and among them the main reference is represented by the Regio Decreto no. 2229 of 16/11/1939 (R.D., 1939), which has ruled the standard for the design and the execution of RC structures for about thirty years. The *first generation* ends with the issuing of the law 05/11/1971 n. 1086 that, for the first time, introduced the mandatory notification of any structural construction to the competent territorial offices. All the building codes issued until today belong to the *second generation*. In 1972, the law D.M. 30/05/1972 (D.M. LL. PP., 1972) introduced several innovations, including the concept of "*characteristic strength*", which paved the way for the probabilistic approach to the structural safety. The 1980 is a particularly significant year, since the semi-probabilistic limit state design method was introduced in Italy, and a vast operation of seismic zoning of the territory was completed. Furthermore, it is worth noting that only after 1980 the linear methods for the seismic analysis (equivalent static analysis and modal analysis), already introduced in the 70's, found a widespread application, also thanks to the new seismic classification of the territory. According to the evolution of the codes depicted in this short overview, two reference dates have been singled out for the classification of the buildings: 1972 and 1980. In Fig. 4.1.1, it is reported a pie chart showing the percentage distribution of the buildings with respect to the construction period. Actually, all the school buildings constructed after 1980 (green portion) are comprised within the range 1980-1983, and can then be reasonably considered very close to those of the class 1972-1980 with regard to the adopted construction practices. After this simplification, it can be assumed that more than 75% of the sample is referred to the regulatory and constructive practice of the '70s.

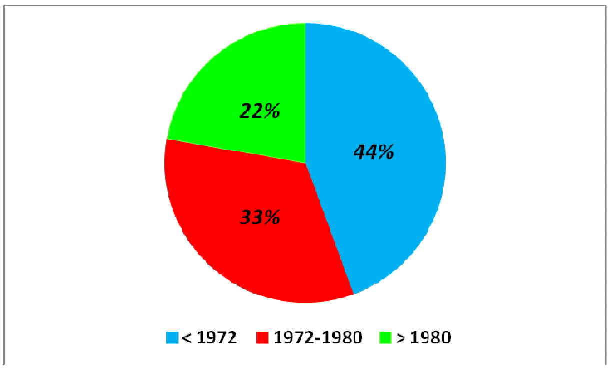


Figure 4.1.1. Period of construction

4.2. Number of storeys and structural regularity

For the Level II vulnerability assessment, i.e. the assessment at the scale of the building, it is necessary to preliminarily determine the parameters which characterize the geometric and structural configuration of the building. Two particularly significant parameters are the number of storeys and the regularity in plan and in elevation. The first one is related to the deformation capacity required to the structure, whereas the second one has important implications on the choice of the methods of analysis. The influence of the geometric configuration on the structural response of the building is worldwide recognized in all the national building codes. In particular, Eurocode 8 (CEN, 2005[1]) provides a detailed indication of the simplification that can be adopted in the numerical modelling and of the methods that can be adopted in the presence of the structural regularity, as shown in Tab. 4.2.1.

Table 4.2.1. Consequences of structural regularity on the seismic analysis

Regularity		Allowed Simplification		Behaviour factor
Plan	Elevation	Model	Linear-elastic Analysis	(for linear analysis)
Yes	Yes	Planar	Lateral force[a]	Reference value
Yes	No	Planar	Modal	Decreased value
No	Yes	Spatial[b]	Lateral force[a]	Reference value
No	No	Spatial	Modal	Decreased value

With regard to the non-linear static analysis (pushover), when the geometrical configuration is irregular (in plan and/or elevation), it is mandatory to adopt a spatial model, and to apply a lateral force distribution along one direction (*EC8 - §4.3.3.4.2.1(2) and (3)*)
The Italian Standards, instead, doesn't allow the use of the pushover analysis if less than *75%* of the total participant mass is activated by the principal modal shape. In the Fig. 4.2.1 and Fig. 4.2.2, the percentage distribution of the number of storeys and structural regularity are shown for the sample. It can be noticed that the generic building has been classified as irregular either if the plan or the elevation were irregular.

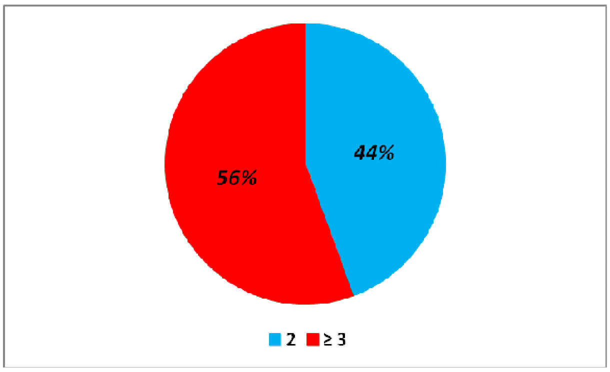


Figure 4.2.1. Percentage distribution of the number of storeys.

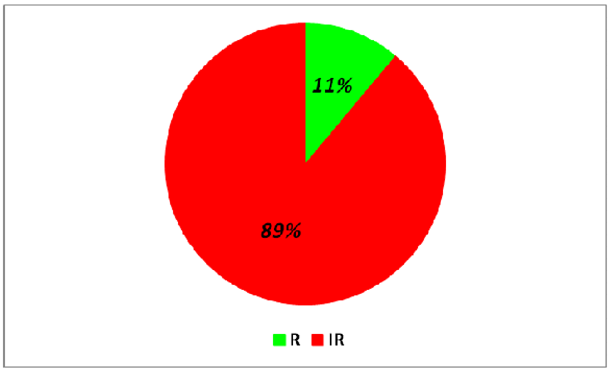


Figure 4.2.2. Percentage distribution of the structural regularity.

The graphs show that the typological characters of the buildings in the analyzed territory have a high degree of homogeneity, that is the necessary basis for the application of "semi-quantitative" methods aimed at identifying the representative typological class of a local context (see § 3.1). Indeed, for almost 90% of the sample, the geometric configuration is irregular ("IR"), mainly in plan, with a number of storeys that is generally equal to 2-3 (i.e. 1-2 levels in which seismic masses are concentrated).

4.3. The quality of the materials

Some remarks about the quality of in place concrete will be now presented, by analysing the data obtained by the experimental on site investigations performed over the buildings. In fact, it was found that the concrete was typically affected by the greatest dispersions, and thence it plays the major role in the vulnerability assessment. With regard to the steel, in the buildings dated back to the 70's reinforcement bars are of non-corrugated type, with values of the admissible tensile strength comprised between *140* and *200 MPa*. It is worth mentioning that in those years the possibility of using high adherence bars had just been introduced, but their widespread use only began in the 80's. The resistances obtained from tensile and bending tests performed on specimens extracted from the structural elements were in line with the original design specifications.

4.3.1. Assessment of the strength of in-place concrete

The considerations about the quality of in-place concrete in the sampled school buildings are based on the average strength indicated by the technicians in charge in the technical reports, and therefore are taken "as they are", without discussing the specific problems about the procedures adopted for the numerical elaboration of the experimental results and for the correlation with non destructive tests, as well as for the identification of the homogeneous classes of concrete. The percentage distribution of the compressive strength of concrete for the sampled buildings has been calculated by referring to the minimum characteristic value (R_{ck}) provided by the reference code of the time (D.M. 30/05/1972), which is R_{ck} = *15 MPa.* In the analyses, it was accounted for the deviation that is typically found between the strength of in-place concrete and that measured on cast specimens during the concrete placement, that is related to the different curing conditions (Masi and Vona, 2009). In particular, the Italian Building Code *NTC* - § 11.2.6, reports verbatim: "*the average value of the in-place strength (which is defined as the structural resistance) is generally lower than the average values provided by strength test results from standard-cured cast specimens (which is defined as the potential resistance)*", and that "*an acceptable average value of the structural strength should be not lower than 85% of the design value.*". The diagram presented in Fig. 4.3.1.1 illustrates the comparison between the average strength (f_m) provided by the tests, both with the design value f_{cm} = medium cylindrical compressive strength (red line), both with the expected medium cylindrical in-place strength $f_{insitu,m}$ (blue line), evaluated according to the following relationship:

$$f_{cm} = 0.83R_{ck} + 8 \implies f_{insitu,m} = 0.85(0.83R_{ck} + 8) \tag{5.1}$$

The values reported in the figure have been normalized by f_{cm}.
In the study, the evaluation of the medium values of the compressive strength has been made by assuming as a reference the minimum acceptable value provided by the building code "D.M. 30/05/1972" (according to the preliminary analysis presented in § 4.1, this is the reference law for more than *75%* of the buildings of the sample), which is equal to R_{ck}=*15MPa*. By this assumption, derive the following reference values: f_{cm}=*20.5 MPa;* $f_{insitu,m}$=*17.4 MPa*. The approach is similar to that proposed some years before by the American Standards ACI 228 (American Concrete Institute, 1998), which provide the acceptance criteria for the compressive strength of concrete based on core testing. By denoting with f_{core} the strength obtained from cores, and with $f_{c,st}$ the standard strength deriving from normalized cast specimens, the concrete can be accepted if: $f_{c,mean} > 0{,}85 f_{c,st}$ and $f_{c,min} > 0{,}75 f_{c,st}$.

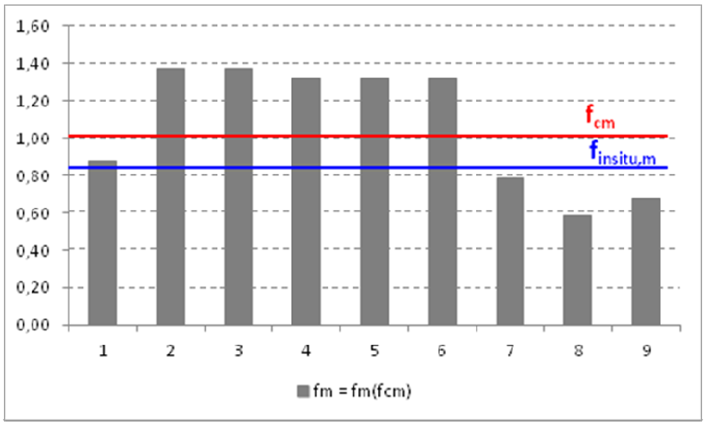


Figure 4.3.1.1. Comparison of the strength of in-place concrete for the sample compared with the medium value of the design strength f_{cm} = *20.5MPa* and the minimum value of the in-place strength $f_{insitu,m}$ = 17.4MPa (in the normalized scale of the graph, they are respectively equal to 1 and 0.85).

It can be noticed that for more than 30% of the school buildings the average resistance obtained from the investigations on materials (f_m) is below the minimum acceptable value f_{cm} (buildings No. 8 and No. 9). In the elaboration of this first sample the heterogeneity of the results is evident, and mainly a basic division into two main groups can be made: a group for which the concrete strength is well above the required minimum, and a group for which the values are instead significantly below the minimum.

5. SEISMIC VULNERABILITY ASSESSMENT OF THE SAMPLES

5.1. Determination of CVS

From the seismic assessment of the individual buildings, the values of the coefficient CVS defined in § 3.2 have been extrapolated. In Fig. 5.1.1 it is shown the graphical representation of the percentage distribution of the school buildings that have, respectively a CVS coefficient comprised in the intervals $CVS < 0.5$; $0.5 < CVS < 1$; $CVS > 1$. This diagram allows having an immediate idea of the seismic "efficiency" of the analyzed buildings. The definition of the aforementioned reference intervals for CVS is a simplified method aimed at providing a qualitative but effective representation of the seismic vulnerability, which actually corresponds to three coarse vulnerability levels: "*severe*", "*light*", "*absent*"

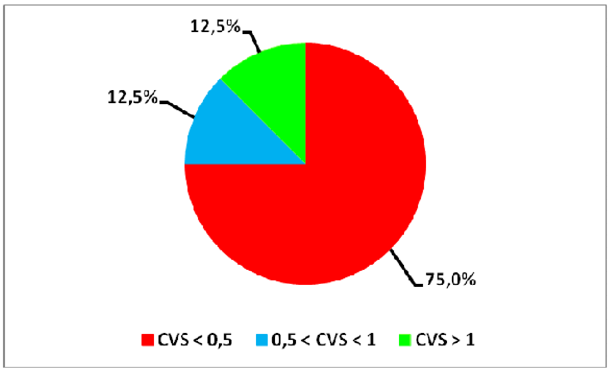


Figure 5.1.1. Percentage distribution of the seismic vulnerability of the school buildings expressed as a function of the coefficient *CVS*.

By the analysis of the results, it is quite evident that the presence of a severe seismic vulnerability for the samples is mainly related to the inadequacy of the technical standards used as reference in the period of construction, above all with regard to the prescriptions about the seismic design. In fact, the only group of buildings for which the seismic vulnerability is absent are those dated back after 1980 (which only represent 12.5% of the sample).

6. FINAL REMARKS

In the present paper, a statistical elaboration of the first set of results provided by the seismic assessment of a number of school buildings located in the Province of Foggia (Italy) is presented. Even if the sample is still quite small (9 case studies have been presently completed on a total number of 20 school buildings included in the research program) the elaboration of the preliminary data, with regard to some significant parameters (period of construction, number of storeys, structural regularity), in the form of percentage distribution charts, provided some interesting elements of analysis. In particular, it was possible to identify a paradigmatic typology representing, in the average, the characters and quality of the school buildings on the analyzed territory. The features of this model building are: irregular geometric configuration; low rise; adequate safety level only under vertical loads. The comparative analysis between the average strength of in-place concrete (provided by destructive and non-destructive tests) and the reference values (medium cylindrical design strength f_{cm}; medium cylindrical in-place strength $f_{insitu,\ m}$), points out that the differentials are particularly relevant, with samples characterized by very low values and others showing very good values. In particular, for some buildings the strength of in-place concrete is even 40% lower than the required standard. With regard to the seismic vulnerability, it was appraised by means of a specific coefficient *CVS*, which highlighted that as many as 75% of the buildings have a very low CVS (<50% than the minimum threshold).

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