APPLICATION OF A PRIORITISATION SCHEME FOR SEISMIC INTERVENTION IN SCHOOLS BUILDINGS IN ITALY

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ABSTRACT :

A risk management framework has recently been developed to assign priorities for the rehabilitation of school buildings in Italy, and to give timescales within which retrofit or demolition must take place. Since it is not practical to carry out a detailed assessment of the 60,000 Italian state and public schools, the framework is a multiple-level procedure which aims to identify the highest-risk buildings based on filters of increasing detail, and reduces the size of the building inventory at each step. The first risk ranking is based on a strength deficit, which measures the difference between the current design forces defined for the building site and an estimation of the level of seismic resistance which was required at the time of design. The second ranking is based on lateral strength calculations that are already available for a large portion of the Italian masonry building stock, and that are obtained from a survey form that is familiar to Italian engineers. Finally, a simplified displacement-based methodology is used to give a more accurate assessment of seismic risk based on a limited amount of geometrical and material data. The final assessment leads to a capacity ratio and a risk rating, which are used within a transparent procedure to assign priorities for seismic intervention, and timescales within which detailed assessment leading to retrofit or demolition must take place. The first step of the methodology has been applied herein to the school building stock within two Regions in Italy and preliminary results are presented.

KEYWORDS: seismic risk, school buildings, prioritization, retrofitting

1. INTRODUCTION

The 2008 Sichuan earthquake has recently reminded us how important it is that school buildings perform better than other buildings due to the tragic and unacceptable consequences that occur when this is not the case (see Figure 1). The damage to 13,000 school buildings led to the death of around 10,000 children in this earthquake and this has resulted in calls for all school buildings in China to be surveyed and, where necessary, retrofitted. Similar action was stipulated following the 2002 Molise earthquake in Italy where the collapse of a school building killed 26 school children and their teacher.

Figure 1 Collapsed school buildings from the 2008 Sichuan earthquake
(http://www.miyamotointernational.com/Sichuan/index.php)

The main difficulties which are encountered when carrying out the seismic assessment and retrofit of buildings at a national level are related to the collection of data required to assess a significant number of buildings which are distributed over a large geographical area and subsequently, the choice of which buildings should be retrofitted first. This paper describes a proposal which has been made for prioritising the school buildings in Italy for seismic intervention and the initial applications which have been carried out.

2. DATA COLLECTION

There are over 60,000 state and public schools in Italy, and considering that each school has on average between 2 and 3 buildings, this means that the seismic performance of over 120,000 school buildings needs to be assessed. In the late 1990's in Italy, a significant effort was made as part of the *Lavori Socialmente Utili* (Works of Social Interest) decree to carry out surveys of the public buildings from 7 Regions in the most seismically active areas of the country (Abruzzo, Basilicata, Calabria, Campania, Molise, Puglia and Sicily). Another initiative to survey public buildings was carried out by the IRRS (Institute of Research of Seismic Risk) of the ex-CNR (National Council of Research) which involved the Regions of Abruzzo, Emilia-Romagna, Marche, Piemonte and Tuscany. These two studies included almost 25,000 school buildings (around 10,000 schools) and involved the compilation of 1st and 2nd Level GNDT forms; the 1st Level forms contain fields related to the location, use, geometry, age, quality of conservation, structural typology and, where present, earthquake damage, whilst the 2nd Level forms request more detailed information on the geometry and material properties of the buildings. The 2nd Level forms allow the *Conventional Resistance* to be calculated, which is the lateral strength of the weakest storey of the building divided by the building weight, and the *Vulnerability Index* (Benedetti and Petrini 1984, Angeletti *et al*. 1988) which is a weighted sum of parameters that take into account the type and configuration of the structural system and the quality and construction of the building materials.

In the past few years in Italy, the Ministry of Education has been carrying out a survey of all school buildings (*Anagrafe Edilizia Scolastica*) to identify various safety-related parameters. These survey forms are being collected at a Regional level and for the purposes of the present application the data related to the age, number of storeys and construction type for 2743 school buildings in the Regions of *Fruili-Venezia-Giulia* and *Marche*, which comprise about 90% of the school buildings in these two regions, have been obtained.

3. PRIORITISATION METHODOLOGY FOR SEISMIC INTERVENTION

The methodology described herein for assigning priorities for the rehabilitation of school buildings, and to give timescales within which retrofit or demolition must take place, is based on an initial proposal by Grant *et al*. (2007), as briefly described in Section 3.1. Some modifications to the method proposed by Grant *et al*. (2007) have been made following initial applications using the data described in Section 2, which highlighted some inconsistencies with the first and second steps of the method; these modifications are described in Section 3.2.

3.1. Grant et al. (2007) Methodology

The proposed framework by Grant *et al*. (2007), outlined in Figure 2, comprises multiple levels of assessment of increasing levels of detail, each one substantially reducing the size of the building inventory for further consideration. Clearly, a detailed assessment of all the schools in Italy is neither practicable nor prudent, but without some crude level of risk assessment it is difficult to identify which schools should be given the most attention. A multiple-level procedure balances the need to implement urgent rehabilitation for those buildings that clearly represent the highest risk with the pragmatic problem of reducing the initial pool of around 120,000 school buildings to a more manageable number. The first step of the methodology is based on a desk study wherein the capacity of the buildings is assumed to be equal to the demand defined in the code which was in place when the building was designed. Converting to units of peak ground acceleration (PGA), this measure of expected building vulnerability may be compared with the 475-year return-period hazard maps from the most up-to-date seismic hazard studies (Gruppo di Lavoro 2004, Montaldo *et al*. 2005, OPCM 2006) carried out by

the Istituto Nazionale di Geofisica e Vulcanologia (INGV) and modern seismic design requirements (OPCM 2003), to obtain a relative measure of seismic risk based solely on building age and location. Site conditions are not considered at this assessment stage. The difference between current PGA and the effective design PGA from historical seismic codes gives the PGA deficit. For buildings designed before the introduction of seismic design requirements in a municipality, the Design PGA is assumed to be zero, whence the PGA deficit is equal to the PGA from the current seismic hazard maps. The Design PGA is used as a proxy for seismic capacity and therefore this assumption neglects the contribution to lateral resistance from wind and gravity design.
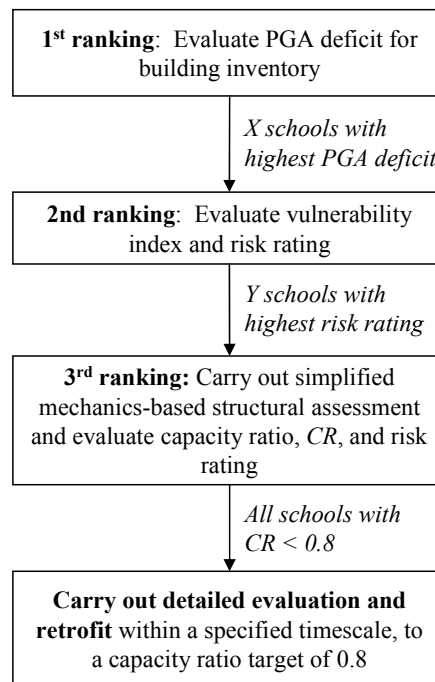

1st ranking: Evaluate PGA deficit for building inventory

X schools with highest PGA deficit

2nd ranking: Evaluate vulnerability index and risk rating

Y schools with highest risk rating

3rd ranking: Carry out simplified mechanics-based structural assessment and evaluate capacity ratio, *CR*, and risk rating

All schools with CR < 0.8

Carry out detailed evaluation and retrofit within a specified timescale, to a capacity ratio target of 0.8

Figure 2 Outline of steps in proposed risk reduction methodology (Grant *et al*., 2007)

The ranking of schools based on PGA deficit is a rapid procedure for determining the relative seismic risk of municipalities and building stock in Italy based only on hazard and building age. The ranking does not consider features of individual buildings, and makes the broad assumption of uniform code compliance. Therefore, a relatively large number of schools, X, must be assessed in more detail on an individual basis for the second assessment stage. For this reason, the second stage is based on vulnerability assessment by visual inspection of the X school buildings identified in the first ranking using the GNDT 2nd Level forms described in Section 2 in order to calculate the *Vulnerability Index*. This index has been correlated with structural damage and collapse in past earthquakes, and an expression for the value of PGA likely to cause collapse as a function of the vulnerability index was obtained (Grimaz *et al*. 1996, Zonno *et al*. 1999). This updated estimate of the Design PGA is compared with the current PGA to estimate a risk rating based of the buildings, which also takes into account the variation of the hazard curve gradient throughout Italy:

$$\text{Risk\_Rating} = \left(\frac{\text{PGA}_D}{\text{PGA}_C} \right)^k \qquad (3.1)$$

where PGA_D is the PGA value from the 475-year hazard map, PGA_C is the Design PGA and k is the slope of the hazard curve. This risk rating gives an indication of how many more times at risk the buildings are compared to those designed to current regulations.

The first two rankings are based on simple risk-assessment methods that do not require inspection and specific studies of the various buildings under consideration; the first ranking requires knowledge of the construction

year and geographical location alone, while the second ranking makes use of previously collected building data, assembled in a national database. These methods are effective at reducing the large initial inventory down to a more manageable size, but do not provide the most rigorous estimate of seismic risk available. State-of-the-art assessment methods estimate the performance of structures in terms of displacement ductility levels reached under ground motion represented by a design spectrum. Hence the third and final step is based on a displacement-based methodology which compares the displacement capacity of the buildings (calculated from the geometrical and material properties of the buildings) with the displacement demand.

To aid in the distribution of funds and other resources, priorities and timescales for seismic intervention can be defined. In the proposed scheme, schools are first grouped by the risk rating, in discrete bands, and within each band of risk ratings, the schools are further grouped into bands based on the number of pupils, N. Finally, each occupancy band is ranked in decreasing order of a time-dependent hazard factor, which gives an indication of the locations where the hazard maps may underestimate the immediate hazard. Timescales for seismic intervention may also be defined based on the risk rating and building occupancy (see Grant *et al*. (2007) for further details).

3.2. Modified Methodology

The first step of the Grant *et al*. (2007) methodology has been applied to all of the school buildings in the database described in Section 2, whilst the second step has been applied to those school buildings for which the GNDT 2nd level survey form was available. In order to make the first two steps of the methodology comparable, rather than calculate a PGA deficit in the first step, the risk rating was calculated in the same way as step 2 (see Equation 3.1), using the Design PGA estimation based on the year of construction and location. A minimum Design PGA of 0.06g has been assumed for non seismically designed buildings; this assumption is necessary in order to allow Equation 3.1 to be used. The risk rating from the first and second steps for each school building (where both values have been calculated) are plotted in Figure 3. This figure shows that there is a poor correlation between the two values of Risk Rating, especially for the masonry buildings, and that the values of Risk Rating vary in the two steps by an order of magnitude. The reason for this difference in magnitude is due to the very high values of Design PGA which are obtained in the second step with the use of the equation relating vulnerability index to collapse PGA. The results also appear to suggest that there is a limited correlation for masonry buildings between the level of seismic design required at the time of construction and the actual strength of the building. As a result of these findings, it was decided that a more mechanics-based approach was required for the second step of the methodology and that the data available within the GNDT 2nd level forms should be used to calibrate the first ranking, which would still need to be based on a limited number of parameters.

(a)   (b)
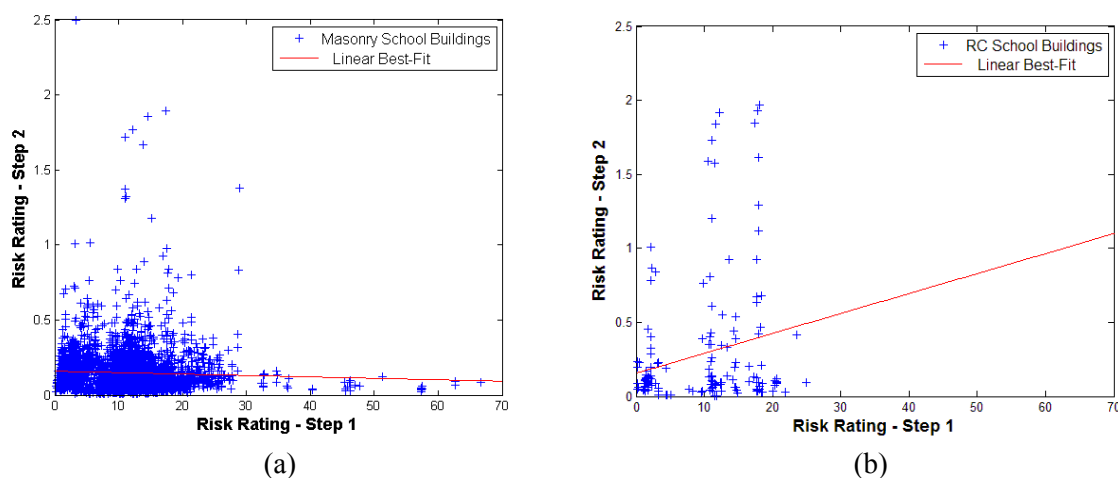
Figure 3 Risk Rating for Step 1 versus Risk Rating for Step 2 for the Italian database of school buildings for (a) masonry and (b) reinforced concrete buildings

Considering that the questionnaires (*Anagrafe Edilizia Scolastica*) which are currently being compiled for all school buildings in Italy contain the year of construction, the number of storeys and the construction type, it was decided that the modified methodology could make use of a prediction of the period of vibration of the buildings in order to estimate the demand in terms of spectral acceleration (SA). Hence, rather than calculate the Design PGA for all the school buildings in Italy, an Estimated SA value (which is directly related to the strength) would be calculated for the buildings, which could be compared with the Current SA obtained from the spectral acceleration maps produced by INGV at the period of vibration of the building. The Estimated SA value for masonry buildings can be obtained directly from the GNDT 2nd Level assessment forms (Dolce and Martinelli, 2007) – this is the *Conventional Resistance* factor described in Section 2 which is based on the area of the walls, the area of the floor, the specific weight of the masonry and the shear resistance of the masonry. Table 1 reports the mean values and the standard deviation of the Estimated SA which were obtained from these forms; it is clear from Table 1 that there is a strong correlation between the age of the buildings, the number of storeys and the strength: the strength is seen to decrease with an increase in height and age. The level of seismic design at the time of construction of the buildings was also considered as a third parameter, but a very poor correlation between the required seismic design and the strength was observed, thus confirming the findings described previously. It has thus been decided that this *Conventional Resistance* data should be used as a basis upon which the strength of masonry buildings should be estimated in the first step of the methodology. Considering the large variability in the Estimated SA, it has been decided that the 16th percentile (mean minus one standard deviation) strength would be used in the methodology to ensure that a conservative approach is applied and that the buildings at risk are carried forward to the second step of the method.

Table 1 Mean values and standard deviation (σ) of Estimated SA (g) obtained from the GNDT 2nd Level forms as a function of construction year and number of storeys.

No. of storeys	Before 1919		1919 - 1945		1946 - 1960		1961 - 1971		1972 - 1981		After 1981	
	Mean	σ	Mean	σ	Mean	σ	Mean	σ	Mean	σ	Mean	σ
1	0.36	0.17	0.39	0.19	0.48	0.21	0.46	0.21	0.49	0.22	0.55	0.30
2	0.25	0.13	0.30	0.14	0.36	0.18	0.36	0.17	0.39	0.17	0.45	0.25
3	0.20	0.10	0.24	0.09	0.27	0.11	0.29	0.14	0.30	0.12	0.29	0.12
4	0.18	0.08	0.18	0.08	0.22	0.09	0.24	0.08	0.21	0.05	0.22	0.06
5	0.15	0.05	0.19	0.11	0.20	0.08	0.2	0.09	0.24	0.06	0.21	-
6	0.13	0.04	0.13	0.03	0.11	0.02	-	-	-	-	-	-
7	0.11	0.03	-	-	-	-	-	-	-	-	-	-

For the reinforced concrete buildings, there are only a limited number of GNDT 2nd Level forms and an initial study of the *Conventional Resistance* estimations of these buildings raised some doubts regarding the reliability of this parameter; in particular, there was a large variation in the shear resistance used (from 10 to 300t/m^2) and it was not clear if this was because the resistance of the concrete or the infill panel or both had been used, the specific weight of the material varied from 0.4-4.6 t/m^3 and even the permanent weight of the slab varied from 0.3-2.7t/m^2. Considering the improved correlation which was observed for reinforced concrete when the Design PGA values based on seismic classification were used (see Figure 2b), it was decided that the same procedure be used in the first step of the method for reinforced concrete, however now using predictions of Estimated SA.

The Estimated SA for RC buildings in the new proposal is predicted as a function of the seismic design in place at the time of construction, multiplied by a factor to consider overstrength. Up until 1975, the required elastic strength of a building was defined in Italy as a proportion of the weight, with base shear coefficients between 4 - 10% generally assumed depending on the seismic zone within which the building was located. In 1975 a spectral shape was introduced and thus the required elastic strength of the building became a function of the period of vibration. From 1984, importance factors were introduced for school buildings such that these buildings were designed to be stronger than other types of structures. For buildings built up until 2003, the aforementioned considerations were applied to define an elastic Design SA which was then multiplied by overstrength factors to obtain a more realistic estimation of the actual strength (Estimated SA). A mean

overstrength factor of 3.5 has been assumed based on the findings of Borzi *et al*. (2007); this high overstrength is mainly due to the conservative allowable stress approach used in design codes in Italy until very recently. For buildings built to OPCM (2003) (limit state design), the elastic strength should be more or less equal to the actual strength as the building is designed to have a lower inelastic strength (based on the use of behaviour factors), but due to overstrength it is likely that the actual strength would be on average similar to the elastic strength (Elnashai and Mwafy, 2002). Based on all of the aforementioned considerations a table of Estimated SA as a function of seismic zone (from 1 to 4) and year of construction has been compiled (see Table 2). It is noted that an Estimated SA of 0.21g has been assumed for non-seismically designed buildings (i.e. those in zones which have been not classified), based on the pushover calculations described in Borzi *et al*. (2008).

Table 2 Values of Estimated SA for reinforced concrete buildings as a function of seismic zone and year of construction

Date	Cat. I / Zone 1	Cat. II / Zone 2	Cat. III / Zone 3	Zone 4
Not classified	0.21g			
18/04/1909	0.28g			
5/11/1916	0.51g			
13/03/1927	0.51g	0.35g		
25/03/1935	0.35g	0.25g		
3/03/1975	0.35g $T_0 < 0.8s$ $\dfrac{0.30g}{T_0^{2/3}}$ $T_0 > 0.8s$	0.25g $T_0 < 0.8s$ $\dfrac{0.21g}{T_0^{2/3}}$ $T_0 > 0.8s$		
3/06/1981	0.35g $T_0 < 0.8s$ $\dfrac{0.30g}{T_0^{2/3}}$ $T_0 > 0.8s$	0.25g $T_0 < 0.8s$ $\dfrac{0.21g}{T_0^{2/3}}$ $T_0 > 0.8s$	0.14g $T_0 < 0.8s$ $\dfrac{0.12g}{T_0^{2/3}}$ $T_0 > 0.8s$	
19/06/1984	0.42g $T_0 < 0.8s$ $\dfrac{0.36g}{T_0^{2/3}}$ $T_0 > 0.8s$	0.294g $T_0 < 0.8s$ $\dfrac{0.25g}{T_0^{2/3}}$ $T_0 > 0.8s$	0.294g $T_0 < 0.8s$ $\dfrac{0.14g}{T_0^{2/3}}$ $T_0 > 0.8s$	
Ordinanza 3274/2003	1.05g $T_0 < 0.4/0.5s$[1] $\dfrac{0.42g}{T_0}$ $0.4/0.5s < T_0 > 2.0s$	0.75g $T_0 < 0.4/0.5s$ $\dfrac{0.3g}{T_0}$ $0.4/0.5s < T_0 > 2.0s$	0.45g $T_0 < 0.4/0.5s$ $\dfrac{0.18g}{T_0}$ $0.4/0.5s < T_0 > 2.0s$	0.15g $T_0 < 0.4/0.5s$ $\dfrac{0.06g}{T_0}$ $0.4/0.5s < T_0 > 2.0s$

[1] This corner period of the acceleration spectrum depends on the site condition – for sites A it is 0.4s and for sites B/C it is 0.5 seconds.

To conclude, the modifications applied to the original Grant *et al*. (2007) methodology relate mainly to the first and second ranking. The first step is now based on an estimation of the Estimated SA (strength) of the building as a function of the year of construction, number of storeys and, in the case of reinforced concrete buildings, the location. The Current SA value, which is to be compared with this Estimated SA value, using the form of Equation 3.1 in order to calculate the Risk Rating, is obtained from the 475 year spectral acceleration maps produced by INGV at the period of vibration of the structure. The periods of vibration of the buildings have been estimated based on the recent mechanics-based vulnerability assessment methods discussed in Borzi *et al*. (2008) and Crowley *et al*. (2008) where for masonry buildings the period of vibration is a function of the height, whilst for reinforced concrete buildings it is a function of both the height and seismic design. The second step of the method is now the same as the first step, but a more reliable estimation of the strength of the building and the period of vibration should be obtained using the GNDT 2nd Level forms.

4. PRELIMINARY APPLICATION AND VISUALISATION OF RESULTS

The first step of the modified methodology, to define the buildings which should pass onto the second step, has been applied to all of the school buildings in the two Regions of *Friuli-Venezia-Giulia* and *Marche* using the type of construction, number of storeys and year of construction from the *Anagrafe Edilizia Scolastica*

questionnaires in order to calculate the Estimated SA. All of the school buildings have been automatically geocoded based on the street address in the database; where there were difficulties finding the coordinates automatically, the coordinates of the municipality were assigned. These coordinates have allowed the 475 year return period spectral acceleration to be obtained from the INGV seismic hazard maps based on the period of vibration of the building. These spectral acceleration estimates have then been amplified using a site classification scheme for Italy, based on 1:500,000 geological maps (Amato and Selvaggi, 2002), and the amplification factors in OPCM (2003). Where the coordinates of the school building were known, the site classification below the coordinate was obtained, whilst when the municipality coordinates were used, a weighted average of the site conditions within the municipality was applied. The slopes of the spectral acceleration seismic hazard curves for various periods of vibration have also been calculated for use in the Risk Rating calculation. The histograms of Risk Rating for the two regions are shown in Figure 4 whilst a colour-coded representation of the risk ratings plotted in Google Earth for each of the school buildings is presented in Figure 5. Such geovisualisation of the results allows the characteristics of each school building to be automatically retrieved and allows the buildings with Risk Ratings higher than a given value to be directly visualized.
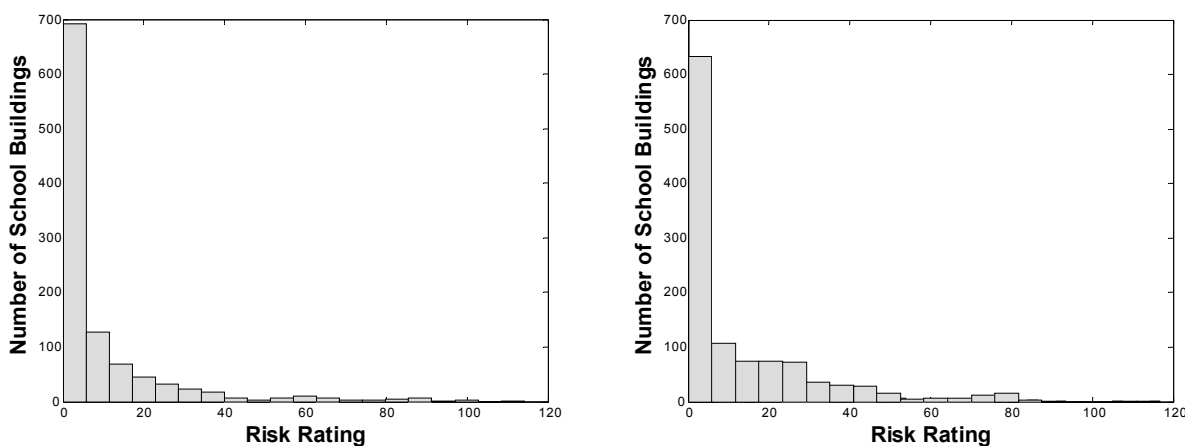

Figure 4 Histograms of risk rating for all of the school buildings in the Regions of *Friuli-Venezia-Giulia* (left) and *Marche* (right)
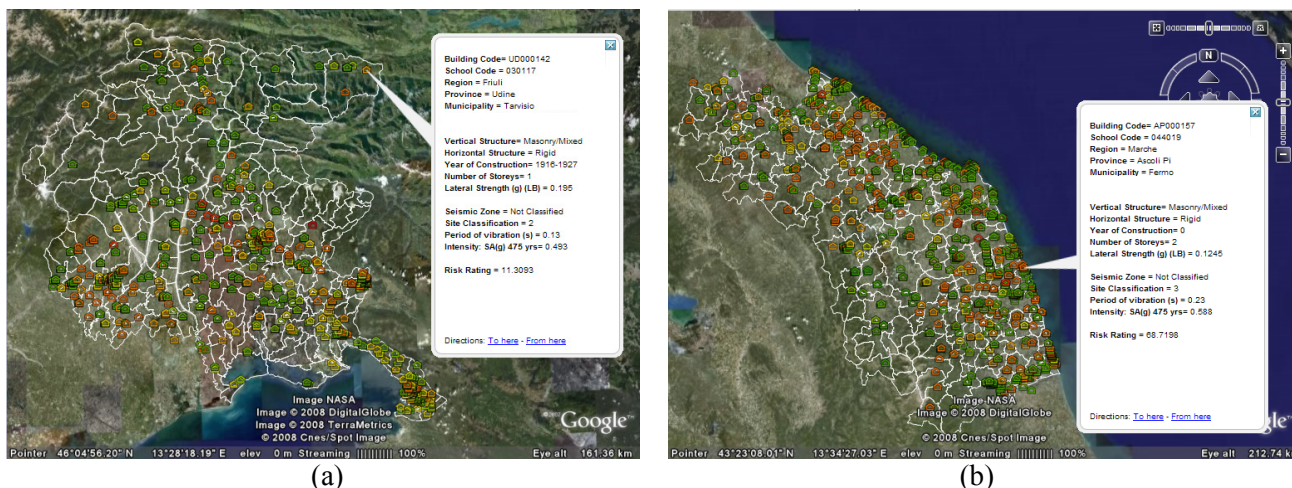

Figure 5 School buildings geocoded in Google Earth and colour-coded by risk rating (a) *Friuli-Venezia-Giulia* Region, (b) *Marche* Region

5. CLOSURE

Following the calculation of the Risk Rating for the school buildings based on the first approximation of the

strength, the buildings must be ranked in order of decreasing risk rating. From this approximate assessment of seismic risk, a number of schools, X, must be selected from the top of the list for further assessment. The value of X must be selected by authorities based on a number of factors, particularly the time, money and engineering personnel available to carry out the next, more involved, levels of seismic assessment. If very little further assessment is required to evaluate the second ranking, due to the availability of existing assessment data, a larger value of X could be considered. Overall, selecting a small value for X ensures that further assessment and eventual retrofit can take place much sooner for the most high-risk schools while selecting a large value ensures that individual high-risk schools that are not identified using the simple Risk Rating are not ignored. If very little further assessment is required to evaluate the second ranking, due to the availability of existing assessment data, a larger value of X could be considered.

Future developments of this work will involve the collection of questionnaires for all of the Regions in Italy so that the first step of the methodology can be applied at a national scale. Where the 2nd Level GNDT survey forms are already available, the lateral strength and period of vibration used in the first step will be taken directly from the forms. On the other hand, where these forms aren't available, the first level screening, as carried out in the application presented herein, will allow the school buildings to be identified for which more detailed inspection using the GNDT forms is required.

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