Building in seismic areas: towards a new prevention policy

G. Bongiovanni, G. Buffarini, P. Clemente & F. Saitta
ENEA, Casaccia Research Centre, Rome, Italy

SUMMARY:
"The regulations for design are to regulate those who cannot design" says a famous motto of the engineering school in Naples. It underlines that the art of well building is much more than just following the prescriptions of the codes. In fact, the respect of the rules given by the codes cannot guarantee the good performance of the building. This consideration leads to a different thinking about the usual seismic design rules. As a matter of fact, the last seismic events in the world questioned several assumption of the present design rules, prescribed by the seismic codes. Subjects of discussion are: the seismic hazard maps, which are often in disagreement with what happened in reality; the structural factor, which accounts for the capacity of the structure to dissipate energy and which is the same both in low and high seismicity areas; the seismic rehabilitation of buildings, damaged or not by earthquake, which should always retrofitted totally, especially when using new anti-seismic technologies. Finally we think that the limited safety should be noticed to people that go into the building. In general, we suggest that proper signals, clearly visible at the entrance of each building open to public, should advice people about the capacity of the building in supporting earthquakes.

Keywords: Structural safety, technical codes, seismic hazard, new anti-seismic technologies.

1. INTRODUCTION

Preventing is better than remediating. This is certainly true, but what we do in practice for a better prevention against earthquakes? A first observation is that most of the built environment is quite old and one should first distinguish between recent and old structures.

When a structure is old? In most of the new technical codes the design working life V_N is defined, as the period of time in which the structure should work according to its intended use, with ordinary maintenance interventions only. Usually, for normal structures, it is V_N = 50 years. So, for the scopes of this paper, it appears obvious assuming this as limit value between recent and old structures and to state that:

- for buildings younger than 50 years, any defects is to be associated to the design and/or to the construction phase;
- for buildings older than 50 years, the cause of any problem is to be a bad maintenance and the missing of controls.

It is worth noting that seismic codes of modern conception appeared not more than 50 years ago in most countries (in Italy in 1975). So one can state that structures built after that date should have been designed accounting for the seismic actions and with adequate structural details. As a result, structural defects are to be referred to design errors or to construction errors. For structures built before that date, speaking of design lack is not useful. It is worth noting that ancient structures, arrived up to our age, supported several seismic events without or with low damages. This consideration demonstrates their good structural conception and good quality of the materials. They were designed and realized very well and any lack in terms of reliability is due to a bad maintenance.

As stated by a famous motto of the engineering school in Naples, we are convinced that "the regulations for design are to regulate those who cannot design". This motto has several meanings, among these it underlines that the art of well designing is much more than just following the prescriptions of the codes. In fact, the respect of the rules given by the codes cannot guarantee the good performance of the structure. This consideration leads to a different thinking about the usual seismic design rules. In this paper some consideration about some important aspects of the design codes are discussed, with particular reference to the Italian technical code.

2. BASE SEISMIC HAZARD

The Tohoku earthquake that struck the East cost of Japan on March 11th, 2011, (05:46 UTC, Magnitude M=9.0), was the main shock of a seismic sequence that had started a few days before and lasted several days after, with lots of events of high magnitude. The main shock happened at about 130 *km* from the East coast of Honshu island, at a depth equal to 24.4 *km*. Sendai was the closest city (130 *km*), other cities interested by the quake were Yamagata (178 *km* E) and Fukushima (178 *km* ENE). Tokyo was at 373 *km* from the epicenter (Bongiovanni et al. 2010, Clemente 2011b).

In Fig. 2.1 the map relative to the occurrence probability of events of *JMA* (Japan Meteorological Agency) intensity not higher than *VI-low*, which corresponds to an acceleration peak value of about 0.4*g*, is compared with the epicenter locations of the damaging earthquakes occurred in the last 30 years. The map is clearly in disagreement with what actually happened. It is important to underline that seismic hazard classification is mainly based on the seismic history, on the return period concept and on the scarce knowledge of existing faults, capable or not. This approach doesn't account for high magnitude events, whose occurrence has been assessed in prehistoric age.

The seismic actions defined by the codes are derived from the seismic hazard evaluation. The capability of the code to describe the actual seismic actions and the seismic behavior of the structures was deeply tested by the L'Aquila earthquake of 2009, M_W=6.3. The earthquake caused severe loss of lives (309 victims and more than 1500 injured) and damage (several collapsed structures and about 18000 unusable buildings) in L'Aquila. The earthquake was recorded by 6 accelerometric stations very close to the city, at zero Joyner-Boore distance from the fault. The recorded peak ground accelerations (0.3-0.65*g*) exceeded those expected by the Italian Code (*Norme Tecniche per le Costruzioni, NTC 2008*) for the return period T_R = 475 years, relative to the design of ordinary structures; they are comparable with those expected for T_R = 2475 years, *i.e.* the maximum allowable value used to design strategic structures, except for one site where, even for T_R = 2475 years, the expected value is lower than the recorded one (Masi, 2009). The response spectra of the recorded accelerograms show similar exceedance with reference to the elastic spectra of the code. From these occurrences the following question arise: why almost all the structures (most of which built with reference to old codes or without any code) did not collapse?

Something similar was observed during the New Zealand Christchurch earthquake occurred on February 22nd, 2011 (M_w = 6.3), when the actual motion exceeded the one of the code by 1-3 times for T_R = 2500 years. It appears obvious that the usual techniques for the evaluation of the seismic hazard and of all the related issues in seismic design codes should be revised.

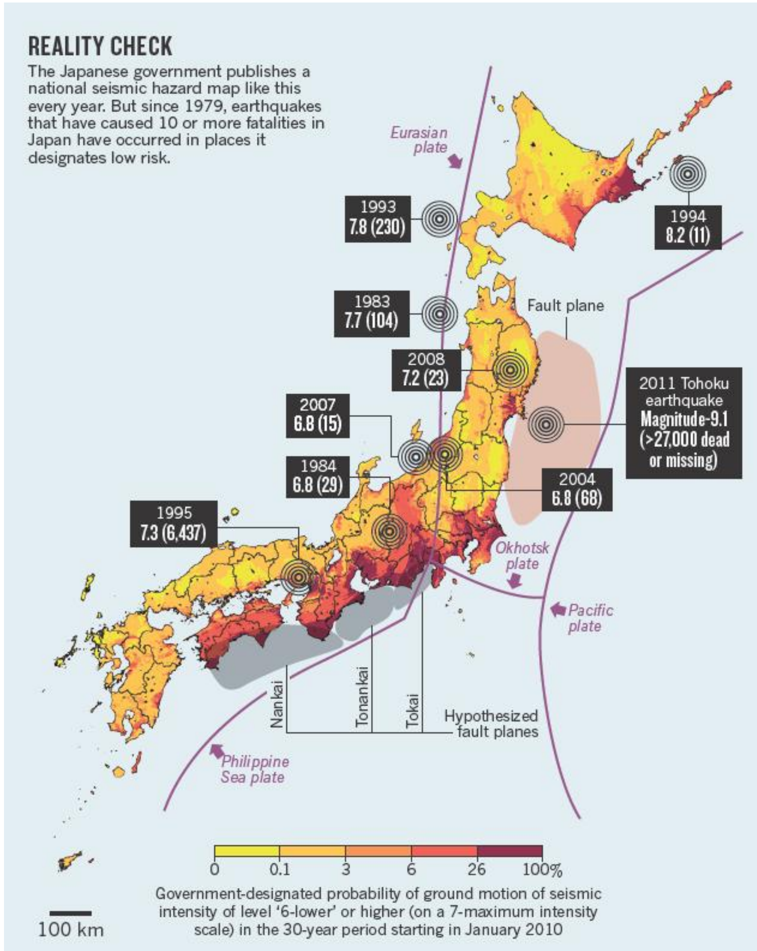


Figure 2.1. Probability of events with *JMA* intensity > *VI low* (Geller J.R., 2011)

3. DESIGN WORKING LIFE AND USE FACTOR

As already said, usually the new technical codes (as already said we refer to the Italian code) require the definition of the design working life V_N, which is the period of time in which the structure should work according to its intended use, without extraordinary maintenance intervention. Usually, for normal structures, V_N = 50 years. For structures in seismic areas, the use factor C_U is also to be defined, which assumes the values 1.0, 1.5 e 2.0, for normal, of high relevance and strategic structures, respectively. The product $V_R=V_N \cdot C_U$ gives the reference life from which the return period T_R can be deduced, which is related to the earthquake intensities to consider in the checks for each limit state. In practice, a certain value V_R can be obtained with different couples V_N - C_U. For example, consider the two cases:

Building A	$V_N = 50$	$C_U = 2$	$V_R = 100$
Building B	$V_N = 100$	$C_U = 1$	$V_R = 100$

Actually the two buildings will be equal in terms of seismic capacity, but they will have different use. It seems obvious to promote building *B* as strategic building for the first 50 years of its life and then to declass it to normal building for the remaining 50 years. Besides, building *A*, after a 50 years life as strategic building, could continue to be used for at least 50 years more, as normal building before its retirement. The paradox is very apparent. Safety is not just a joke with numbers. Safety should not depend on the design working life of the structure, which should be an architectural concept only, related to the suitability of the structure in satisfying its intended use. A structure with a design working life of 50 years should not be less reliable than a structure with a design working life of 100 years. This is not acceptable.

It seems good to fix a unique value for the design working life, and V_N = 50 years appears to be the most appropriate and also the maximum realistic one. As a result, the return period T_R and so the seismic design action will depend on the importance of the structure only, which is measured by means of the use factor C_U. Only in special cases, for structure of particular relevance and very expensive, a longer design working life could be considered and it should be fixed from time to time. But in these cases the value of the use factor should be consistent with the design working life (C_U = 2).

It is worth noting that, the maximum value of the return period for the collapse limit state, $T_{R,SLC}$ = *2475 years*, imposed by our knowledge about the seismic history, corresponds, for strategic structures in which C_U = 2, to a value of V_N just a little higher than 50 years; the corresponding return period for the life safeguard limit state is $T_{R,SLV}$ = *1215 years* (= $T_{R,SLC}$ */2.05*). If one assumes higher values of V_N, $T_{R,SLC}$ cannot increases and so $T_{R,SLV}$ tends to $T_{R,SLC}$. As a result, the required difference between the design earthquake intensity relative to the life safeguard limit state and to the collapse limit state is not observed. For example, with reference to a base isolated building, the isolation devices will not be designed with the safety level suitably higher than the safety level of the superstructure or, on the contrary, the last presents an unnecessary overstrength.

In conclusion, with reference to the limit states considered by the Italian code, the following two values of the return period should be assumed:

- 475 years, for normal buildings and with reference to the limit state of life safeguard (*SLV*); in this case a certain level of damage is accepted under strong earthquakes;
- 2475 years, for strategic structures and with reference to the collapse limit state (*SLC*), which guarantees a much higher level of safety to this type of structures, independently of the assumed nominal life.

The earthquake corresponding to the second higher return period could also substituted by the maximum credible earthquake, which is the event of highest intensity expected in the area. An intermediate value could be useful (975 or 1215 years) as $T_{R,SLC}$ associated to the first one or as $T_{R,SLV}$ associated to the second one.

4. BEHAVIOUR FACTOR

The seismic actions to consider in the structural design are defined by the design spectrum. This is deduced from the elastic spectrum, which represents the effective seismic acceleration in one direction, by means of the behaviour factor. In other words, the elastic spectral amplitudes are reduced in order to account for the capacity of the structure to dissipate energy during the earthquake. This capacity is very high if the structure will be damaged in a smart way during the quake, i.e., involving several sections and avoiding the collapse. The behaviour factor depends on the structural type and on the characteristics of the structural details.

Why we do not use the elastic spectrum as design spectrum? It is obvious that it is not suitable in practice realizing structures able to support the effective seismic actions in the elastic range, i.e., without damages, both for economic and architectural reasons. This is certainly true in high seismicity areas, so a reduction of the design seismic loads is usually allowed and the safety against collapse is entrusted to the ductility of the structure. Actually, technical codes allow using the same behaviour factors, for each structural type, also in low seismicity areas, where it is possible, also from an economical and architectural points of view, designing without any reduction of the elastic acceleration values.

Fig. 4.1 shows the elastic spectra relative to a high seismicity area (*HSA*) and a low seismicity area (*LSA*), respectively. The corresponding design spectra are also plotted for a typical value of the behaviour factor q. In the considered cases, the design spectrum relative to *HSA* presents amplitudes always higher than those of the elastic spectrum in *LSA*. As a result in *LSA* it would be possible designing structures without any reduction of the elastic seismic action and these structures will be able to support the effective earthquake without any damage. This concept is already applied in the Italian code for the superstructure of base isolated buildings, for which the minimum value $q = 1.5$ is allowed.

Generally speaking, a maximum design spectral limit value should be defined, based on economic and architectural considerations (in Fig. 4.2, the value $0.4g$ has been chosen). If the elastic spectral amplitude is lower than this limit value, then the elastic value is assumed also as design spectral value. If the elastic amplitude is higher than the fixed maximum design value, then this is assumed as design spectral value and a behaviour factor is considered to account for the capacity of the structure to dissipate energy. It will depend on the elastic spectral amplitude, i.e., on the seismic hazard at the site and on the fundamental period of vibration of the structure. This procedure is usual in the design of base isolated buildings (Clemente & Buffarini, 2010).

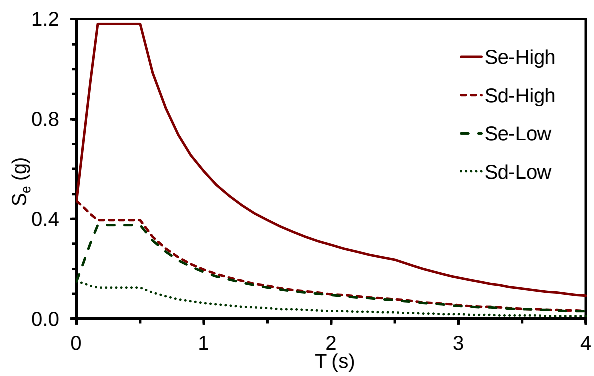


Figure 4.1. Elastic and design spectra in high and low seismicity areas

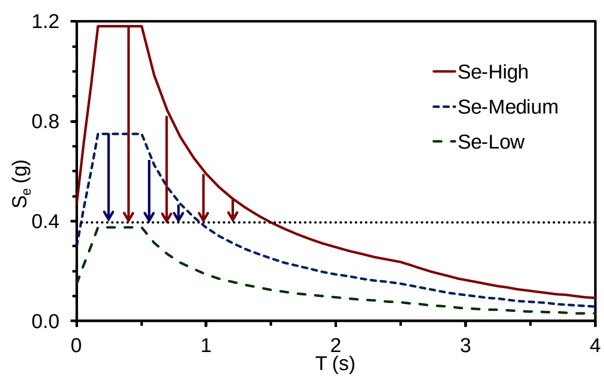


Figure 4.2. Ductility demand variable with the spectral amplitude

Obviously, the limit design value should vary as a function of the structural type. In order to analyze the importance of this consideration and its practice implications, consider the maximum pseudo-acceleration $a_g{\cdot}F_0{\cdot}S$ in the elastic spectra of the Italian territory (a_g = peak ground acceleration on hard soil *A*, S = soil amplification factor*;* F_0 = ratio between the maximum pseudo-accelerations and a_g). These are shown in Fig. 4.3 with reference to the rigid soil (soil *A*, $S = 1$) and for the return period T_R = 475 years.

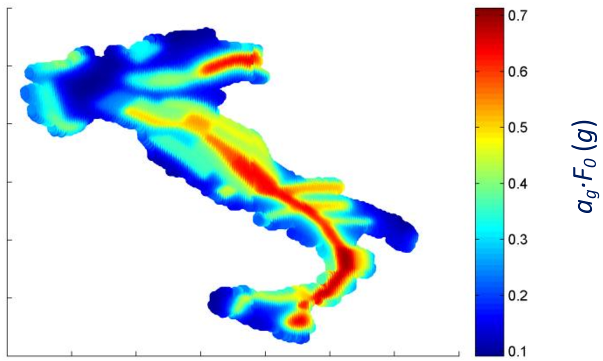


Figure 4.3. Maximum elastic pseudo-acceleration $a_g{\cdot}F_0$ (*g*) for rigid soil (T_R = 475 years)

The values of $a_g{\cdot}F_0$ give an idea of the distribution of the seismic hazard in Italy, but the actual spectrum values are also affected by the soil amplification factor *S* and vary with the return period.

In Fig. 4.4 the maximum elastic spectrum amplitude are plotted against the return period T_R for three different sites, of high (*H*), medium (*M*) and low (*L*) seismicity, respectively, and for the different soil types (*A, B, C, D, E*). From these the design values can easily be obtained by dividing them for the behaviour factor. The anomaly of the curve relative to soil *D*, in which the function $a_g{\cdot}F_0{\cdot}S$ does not increase always with T_R, is related to the variability law of the soil amplification factor for that soil type. It seems clear that these laws should be revised. It is also apparent that the spectral values are very high only in high seismicity areas. In medium and low seismicity areas, instead, the design can not to account for the ductility of the structures. The three sites of Fig. 4.4 were selected with reference to T_R = 475 years; the maximum elastic spectrum amplitude for T_R = 2475 years are relative to other sites.

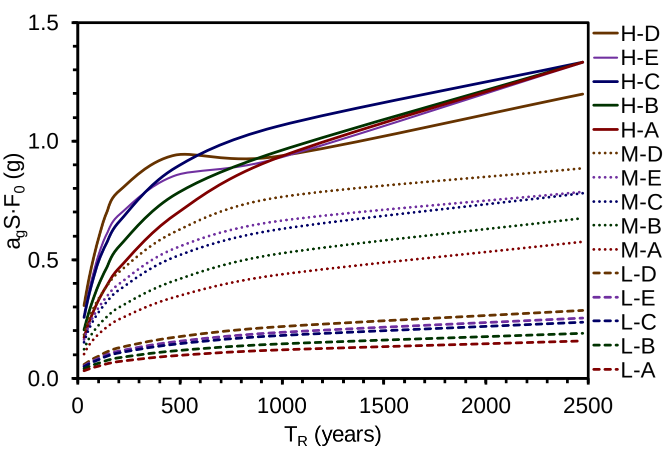
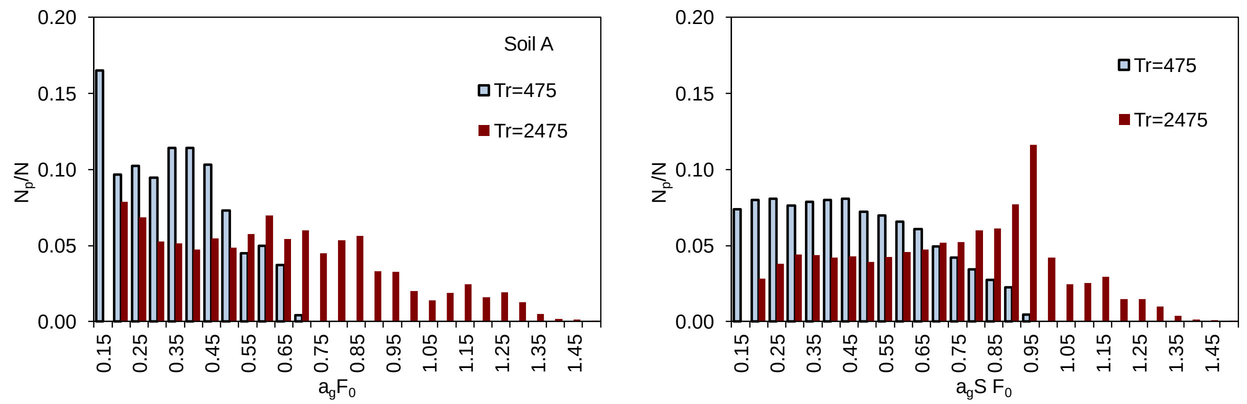


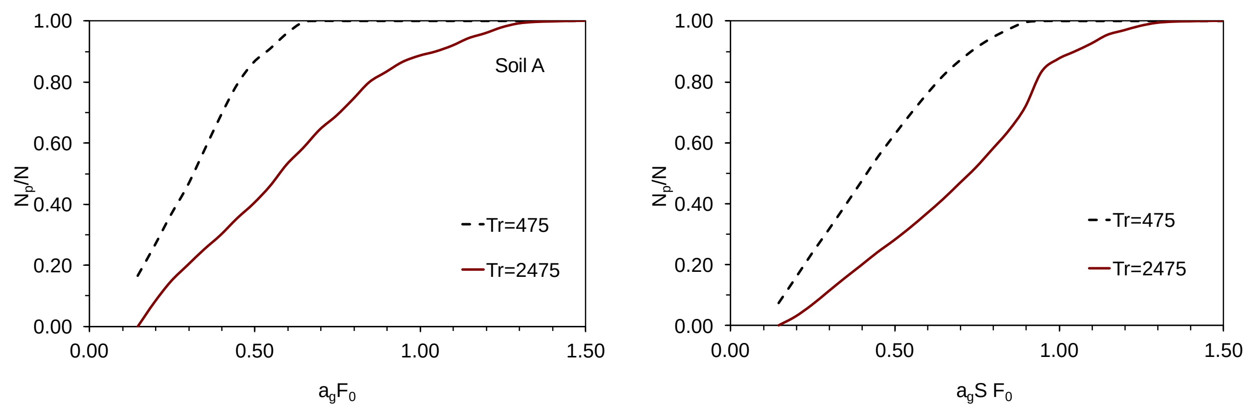
Figure 4.4. Maximum pseudo-acceleration in the elastic spectrum $a_gS{\cdot}F_0$ versus T_R for three sites of different seismicity (*H*=high, *M*=medium, *L*=low) and for the different soil types (*A, B, C, D, E*)

In Fig. 4.5a the density function of the maximum spectral amplitude relative to soil *A* in the Italian territory is shown. The same diagrams is plotted in Fig. 4.5b in the hypothesis of homogeneous distribution of the soil types. From these the corresponding distribution functions were deduced and plotted in Fig. 4.6a and Fig. 4.6b. They represent, for each value of $a_gS{\cdot}F_0$, the percentage of the Italian territory in which this value is not exceeded. For example, if $a_gS{\cdot}F_0 = 0.4g$ is assumed as maximum design value, in almost half of the Italian territory the elastic design would be possible.



(a) (b)

Figure 4.5. Statistic frequency of maximum elastic spectral amplitude on the Italian territory, for two typical recurrence intervals (T_R = 475 and 2475 years) for (a) soil A and (b) in the hypothesis of uniform distribution of the soil types



(c) (d)

Figure 4.6. Distribution functions of maximum elastic spectral amplitude on the Italian territory, for two typical recurrence intervals (T_R = 475 and 2475 years) for (a) soil A and (b) in the hypothesis of uniform distribution of soil types

Seismic codes allow non to adopt the design details, usually required for anti-seismic structures, in very low seismicity areas. These were characterized, in the previous Italian code, as those in which the peak acceleration at the bedrock was $a_g \leq 0.05g$ for $T_R = 475$ years. For the future codes the new relation $a_gS \leq 0.07g$ is being considered that refers to the acceleration at the foundation base. We think that the parameter $a_gS{\cdot}F_0$ is more representative for the effects on the structure. The parameter F_0, which is a function of the site, assumes values up to about 2.9, mainly for low values of a_g (Fig. 4.7), so it appears suitable assuming $a_gS{\cdot}F_0 = 0.20g$ as limit value for the very low seismicity areas. It is worth pointing out that a suitable definition should refer to the actual spectral amplitude $S_e(T,\xi)$ at the vibration period of the structure and for its damping, in other words it would be more suitable defining "structures less sensitive to the earthquake at the site". This brings, in practice, to what already said about the use of the behaviour factor (see. Fig. 4.2).

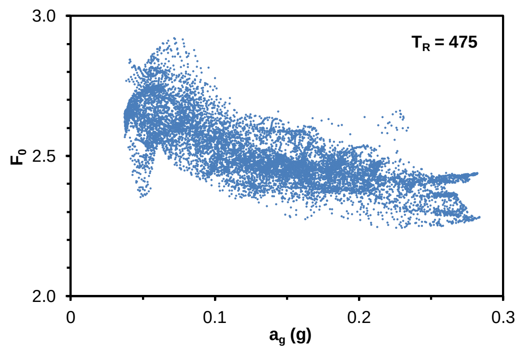


Figure 4.7. Couples a_g-F_0 in the Italian territory

5. SEISMIC RETROFIT OF EARTHQUAKE DAMAGED BUILDINGS

The seismic retrofit of an existing building should consist in giving it the same safety level of new constructions or, in other words, in giving it the capability to support the seismic actions prescribed by the present codes. It is clear that the complete seismic rehabilitation is quite hard, from both the economical and technical points of view. Therefore the technical codes usually allow a partial rehabilitation, i.e. a seismic improving, which is pursued by assuming a reduced seismic action (usually not lower than 60% of the demand of the present code). So the seismic improving consists in considering a design earthquake less severe than the actual one, and so a lower return period T_R.

Taking into account that the return period depends on the reference life V_R, given by the product of the design working life V_N and the use factor C_U, one can conclude that the partial rehabilitation translates in a reduced design working life or a limited use of the building. This could lead to a safety level lower than the minimum one, which is relative to the return period T_R = 475 years. This is not acceptable, and so is a value of V_R lower than 50 years.

If the seismic retrofit is done by means of base isolation, the total rehabilitation should be pursued. In fact, when the structural safety is entrusted to a limited number of devices, these should be designed with reference to a higher seismic action, i.e., to a longer return period (Martelli et al., 2011).

Usually, the buildings that have suffered few damages during seismic events are not considered, because they must not be retrofitted nor improved but just repaired, if necessary. This is wrong. The absence of apparent damages does not guarantee against future earthquakes and also those buildings should be totally retrofitted. It is worth pointing out that for these cases seismic isolation is the best solution because it allows making the superstructure, which is not damaged and certainly useful from an architectural point of view but able to support only a very low seismic action, reliable to future earthquakes (Bazzurro et al. 2009a and 2009b, Celebi et al. 2010).

Finally, a special consideration is for cultural heritage buildings, for which the traditional techniques, based on the increasing of strength and ductility, are not suitable. In fact, they are often not reversible, make use of materials different and incompatible with the original ones and determine changes in the original structural conception. The last aspect is very important, because cultural heritage buildings were obviously design without accounting for the seismic actions, and so are vulnerable even to moderate events. Usually, a suitable equilibrium between the two requirements should be pursued, i.e., a partial seismic improvement can be obtained, preserving the original monumental characteristics, identity and historical value. Base isolation could be a suitable solution for the rehabilitation of historical structures. It aims at the reduction of seismic actions, thus avoiding significant damages to the structure and its contents even under strong earthquakes, and presents very low interference with the structure itself. Innovative solutions for the application of seismic isolation to cultural heritage structures have already been proposed (Clemente and De Stefano 2011a, Clemente and De Stefano 2011b). Besides a good knowledge of the dynamic behaviour of the structure is very important (Clemente and Buffarini 2009, De Stefano and Clemente 2009).

6. INSURANCE, INFORMATION AND BUILDING BOOK

It appears obvious that the structural reliability should influence the economic value of the structures. For example the market value should be lowered in the case of building not seismically efficient and it should be prohibited selling buildings with a safety level lower than a minimum one. A compulsory insurance against damages caused by natural events would be advisable. First of all this would allow to relieve the government from the reconstruction costs after natural disasters. Besides, the insurance companies will be motivate to control the effective health status of the buildings in order to fix the insurance premium and to avoid heavy expenses after earthquakes (Clemente, 2011a).

The recent events pointed out the issue of the information about natural disaster as prevention technique. It appears obvious that citizens should be informed about the actual hazards in order to give them the freedom to decide what to do to preserve their own life. Alarming could be wrong, but not informing is worst. It should be advisable to inform people that are getting into a building about the seismic capacity of this, for example by writing "non anti-seismic building" on a signal in front of it. In general, we suggest that proper signals, clearly visible at the entrance of each building open to public, should advice people about the expected static and seismic response with respect to the present technical codes.

The knowledge of the health status of each structure should be pursued, in order to individualize the critical aspects and to formulate new proposals. The institution of the so called "building book", which contains all the information about the life of the building, could be useful. It should aim at two purposes:

- the first one is related to the single case and is to point out the necessity of more detailed analyses, such as experimental investigations; any defect due to the design or to the maintenance must be pointed out, also with reference to the site characteristics;
- the second one is related to the planning of the territory and should allow the individualization of the objectives and the priorities, also in terms of civil protection.

Finally, the institution of a special list of structural designer could improve the quality of the constructions. Only technicians that have passed specific examinations in seismic engineering should be included in this list.

7. CONCLUSIONS

The way of prevention is still very long and the reconstruction costs, after seismic events, are too high. In any case the efforts in the prevention direction are still very few. The words of Kofi Annan were very pessimist: "Building a culture of prevention is not easy. While the costs of prevention have to be paid in the present, its benefits lie in the distant future. Moreover the benefits are not tangible; they are the disaster that did not happen" and may also truncating the carrier to some candidate *superman*. The conclusion of a recent study by Ambraseys and Bilham (2011) is not less alarming: they calculated "that 83% of all deaths from building collapse in earthquakes over the past 30 years occurred in countries that are anomalously corrupt".

REFERENCES

Ambraseys N., Bilham R. (2011). Corruption Kills, *Nature* 469, 143-145.

Bazzurro P., Alexander D., Clemente P., Comerio M., De Sortis A., Filippou F., Goretti A., Jorjani M., Mollaioli F., Mosalam K., Price H.J., Court C.P., Schotanus M., Stewart J. (2009a). *Learning from Earthquakes. The Mw 6.3 Abruzzo, Italy, Earthquake of April 6, 2009*. EERI Special Earthquake Report — June 2009.

Bazzurro P., Benedettini F., Clemente P., Martinelli A., Salvatori A. (2009b). "Lezioni dal terremoto dell'Abruzzo: il comportamento degli edifici visto dall'angolo prospettico della regola d'arte nel costruire". *Energia, Ambiente e Innovazione*, ENEA, Roma, No. 3, 28-45.

Bongiovanni G, Clemente P., Verrubbi V. (2011). "Il terremoto di Tohoku dell"11 marzo 2011". *Energia, Ambiente e Innovazione*, No. 1-2, 16-20, ENEA, Roma (in Italian).

Çelebi M., Bazzurro P., Chiaraluce L., Clemente P., Decanini L., De Sortis A., Ellsworth W., Gorini A., Kalkan E., Marcucci S., Milana G., Mollaioli F., Olivieri M., Paolucci R., Rinaldis D., Rovelli A., Sabetta F. and Stephens C., (2010). "Recorded Motions of the Mw6.3 April 6, 2009 L'Aquila (Italy) Earthquake and Implications for Building Structural Damage: A Review". *Earthquake Spectra*, Volume 26, No. 3, pages 651–684, August 2010; © 2010, Earthquake Engineering Research Institute.

Clemente P. (2011a). "Edifici in zona sismica: verso una nuova politica di prevenzione". *Proc. Convegno CASA: Sicurezza e Energia* (Rome, 25th Nov. 2011), http://www.uriaroma.it/images/stories/convegni/ (in Italian)

Clemente P. (2011b). "Tohoku Earthquake of March 11th, 2011". Contribution to *Italy in Japan 2011. Science, Technology and Innovation*. http://www.enea.it/it/internazionali/enea-in-japan-2011/

Clemente P., Buffarini G. (2009). "Dynamic Response of Buildings of the Cultural Heritage". In Boller C., Chang F.K., Fujino Y. (eds), *Enciclopedia of Structural Health Monitoring*, John Wiley & Sons Ltd, Chichester, UK, 2243-2252. ISBN 978-0-470-05822-0.

Clemente P., Buffarini G. (2010). "Base isolation: design and optimization criteria". *SIAPS 1-1(2010) 17--40. DOI 10.2140/siaps.2010.1.17*, Mathematical Science Publisher.

Clemente P., De Stefano A. (2011). "Application of seismic isolation in the retrofit of historical buildings". *In Brebbia C.A.& Maugeri M. (eds) Earthquake Resistant Engineering Structures* (Proc., ERES 2011, Sept. 7-9, Chianciano, Italy), 41-52, WIT Transactions on The Built Environment, Vol. 120, ISSN 1743-3509 (on line).

Clemente P., De Stefano A., Renna S. (2011). "Isolation system for existing buildings". *Proc., 12th World Conf. on Seismic Isolation, Energy Dissipation and Active Control of Structures - 12WCSI* (Sept. 20-23, Sochi, Russia), ASSISi.

De Stefano A., Clemente P. (2009). "Structural health monitoring of historic buildings". In Karbhari V.M. and Ansari F. (Eds) *Structural Health Monitoring of Civil Infrastructure Systems*, Woodhead Publishing Ltd, ISBN 978 1 84569 392 3.

Geller J.R. (2011). "*Shake-up time for japanes seismology"*. NATURE| doi:10.1038/nature10105 - 2011

Martelli A., Clemente P., Forni M., Panza G., Salvatori A. (2011). "Recent development and application of seismic isolation and energy dissipation systems, in particular in Italy, condition for their correct use and recommendation for code improvements". *Proc., 12WCSI* (Sept. 20-23, Sochi, Russia) , ASSISi.

Masi A. (2009) Prime riflessioni sull'esperienza del terremoto in Abruzzo. *Assemblea Nazionale dei Presidenti degli Ordini degli Ingegneri Roma 9 maggio 2009*, http://www.tuttoingegnere.it/