Implementing Innovative Ideas in Structural Engineering and Project Management
Edited by Saha, S., Zhang, Y., Yazdani, S., and Singh, A.

ISBN: 978-0-9960437-1-7

FAST PROCEDURE TO ASSESS THE RISK OF LOSSES FROM EARTHQUAKE IN R/C BUILDINGS

MARCO MEZZI[1], FABRIZIO COMODINI[2], and ALESSANDRO FULCO[1]

[1]*Dept Civil and Environmental Engineering, University of Perugia, Perugia, Italy*
[2]*Faculty of Engineering, University eCampus, Como, Italy*

A simplified procedure for the risk assessment of the consequences of a seismic attack on an r/c building is presented in which the seismic hazard is taken from the probabilistic definition given by the national code and the vulnerability of the structure is evaluated according to a multi-scenario view. Three damage scenarios characterized by the extension of the structural collapses are considered for the risk evaluation. For each scenario the expected consequences on the building and occupants, injured and casualties, are computed. The calculation of consequences is based on the evaluation of a damage indicator that takes into account the extension of collapses of structural and non-structural elements. A risk indicator expressed in terms of annual probability of expected losses is finally determined.

Keywords: Seismic risk, Risk assessment, Existing buildings, R/C structures.

1 INTRODUCTION

The conventional seismic vulnerability assessments of existing r/c buildings can result in very small capacity indexes. High values of seismic vulnerability, calculated in accordance with the criteria provided by the codes, does not automatically imply a high magnitude of the consequences on the occupants under a seismic attack. Indeed the performance condition that identify the conventional limit state for the evaluation of the seismic vulnerability of the building provide the achievement of the capacity limit of a single structural element. This condition corresponds to a very localized damage not relevant in terms of consequences on the occupants. To know the actual condition of seismic risk related to the use of the building is necessary to carry out a proper risk analysis.

The risk assessment consists of the quantitative determination of the risk associated with a real situation of danger that is in the presence of a hazard for the safety of persons or the integrity of goods. The risk is expressed through two constitutive quantities and its numerical assessment requires the calculation of these two quantities: the value of the potential consequence (losses) connected to the occurrence of the hazard; the probability of occurrence of the event that produces the consequence.

A fast procedure for the assessment of the risk of consequences of a seismic attack on existing r/c buildings is illustrated in the following. It provides a sequence of steps that, through the analysis of hazard, vulnerability and exposure, lead to estimate the consequences.

2 DESCRIPTION OF THE PROCEDURE

The procedure for a fast assessment of the risk of losses from earthquakes in buildings having an r/c framed structural system is organized in nine successive operational steps that are briefly described one by one.

Step 1. The first step of the procedure consists of the definition of the seismic hazard at the site expressed by the peak bedrock acceleration (PBA) and the parameters of the elastic response spectrum, as a function of the return period, provided by the Italian code (NTC2008). The definition of the peak ground acceleration (PGA) accounts for the subsoil category according to the definition of NTC2008 and EC8 (EN1998-1 2004).

Step 2. The second phase of the procedure provides for the definition of structure data required in the subsequent calculation steps. Global data: building height, number of levels, total number of beams and columns, type of seismic analysis. Story data: elevation; interstory height; number of columns and of main and secondary beams; total floor area; number of deck fields (in the numerical model); equivalent area A_{TS} of the typical deck field (the ratio of the "total floor area" and "number of deck fields"); cantilevered surfaces; height and total length of claddings and partitions below the considered floor; walkable area below the deck with exposed people A_{EXP} (in general different from the floor area used to calculate A_{TS}); occupancy index; prevention factor.

Step 3. The structure capacity and the consequences are evaluated for three different damage scenarios defined on the basis of the number of collapsed structural elements (beams and columns). For each damage level other response parameters required for the evaluation of the consequences are also considered: interstory drift ratio D_R, floor acceleration a_f, types of element collapses. The considered damage levels are described in the following.

Limited Damage (LD) scenario: it corresponds to performance conditions that, according to the Italian code NTC2008, identify the life safety limit state and then the conventional vulnerability of r/c structures, which is the first collapse of a structural element. The LD scenario is characterized by a PBA $a_{g,LD}$ with return period $T_{r,LD}$. The scenario corresponds to very localized damage with limited consequences on the occupants.

Extended Damage (ED) scenario: it provides for performance conditions beyond the "collapse" of the first structural member, in fact it corresponds to the collapse of 10% of all the structural elements of the building or to the collapse of 20% of the structural elements of a single story. This scenario allows the possibility of local collapse of the construction involving relevant consequences for the occupants. The criterion used to define the scenario was recruited by analogy to the percentage of the collapsed portion of r/c buildings in the complete damage state estimated in the provisions of Hazus procedure (FEMA 2003) (Figure 1). The scenario is characterized by a seismic intensity $a_{g,ED}$ (value of PBA) having a return period $T_{r,ED}$.

Extreme Damage (XD) scenario: it provides for the collapse of 50% of all the elements of the structure. It represents an extreme performance condition of the construction to which an extensive collapse with very serious consequences on the occupants corresponds. The XD scenario is characterized by a PBA $a_{g,XD}$ with return period $T_{r,XD}$.

No.	Label	Description	Height			
			Range		Typical	
			Name	Stories	Stories	Feet
16	C1L	Concrete Moment Frame	Low-Rise	1 - 3	2	20
17	C1M		Mid-Rise	4 - 7	5	50
18	C1H		High-Rise	8+	12	120
19	C2L	Concrete Shear Walls	Low-Rise	1 - 3	2	20
20	C2M		Mid-Rise	4 - 7	5	50
21	C2H		High-Rise	8+	12	120
22	C3L	Concrete Frame with Unreinforced Masonry Infill Walls	Low-Rise	1 - 3	2	20
23	C3M		Mid-Rise	4 - 7	5	50
24	C3H		High-Rise	8+	12	120

	Model Building Type	Probability of Collapse Given a Complete Damage State*
16	C1L	13.0%
17	C1M	10.0%
18	C1H	5.0%
19	C2L	13.0%
20	C2M	10.0%
21	C2H	5.0%
22	C3L	15.0%
23	C3M	13.0%
24	C3H	10.0%

Figure 1. Estimates of the percentage of the collapsed floor area at complete damage state for r/c buildings from (FEMA 2003) and (FEMA 1999).

<u>Step 4</u>. The floor area A_{SD} associated to the damaged elements of the scenario quantifies the structural damage. A percentage of the field area A_{TS} is imputed to each collapsed element taking into account the direct and indirect retrofitting costs for the element type: main beam (50%); secondary beam (20%); column (40%). A coefficient accounting for the collapse type (1.0 for fragile failure, 0.5 for ductile failure, assumed as more resilient and less expensive to repair) then multiplies the floor area associated to the collapsed element. The collapse location along the building height has a significant influence on the consequences due to the possible collapse propagation along the vertical. As an example, Figure 2 reports the diagrams of the used propagation functions expressing the correlation between the story rate α (ratio of the number of the considered story to the total number of stories) and the amplification coefficient C_{ampl} of the deck area directly associated with the collapsed elements. The adopted method for attributing the floor areas can lead to impute an area that can be larger than the actual area associated to the single collapsed structural element.

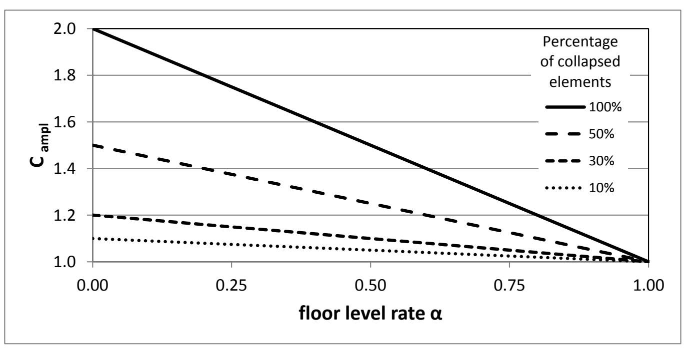

Figure 2. Diagrams of the amplification coefficient of the areas imputed to collapses as a function of the floor level and percentage of damaged elements at the level.

<u>Step 5</u>. The damage of the non-structural elements, claddings and partitions, is estimated in function of the interstory drift ratio D_i and its activation depends on the attainment of a limit value $D_i = D_{lim}$. Only a percentage (30%) of non-structural elements is assumed to be damaged at D_{lim} while all the elements are damaged at the achievement of an ultimate drift D_{ult} (1%). The area of claddings and partitions involved in damage scenario is expressed as an equivalent conventional floor area A_{NSD} through a conversion factor accounting for the differences in the unit repair cost, or in

the consequences for occupants, associated to the area of non-structural elements and floors. In the absence of adequate information, a factor equal 1.0 is assumed.

Step 6. Also the damage of the contents is expressed in terms of an equivalent conventional floor area $A_{CD} = \beta / (1 - \beta) \cdot (A_{NSD} + A_{SD})$ defined as a function of the areas A_{SD} and A_{NSD} of the structural and non-structural elements, respectively, being β the ratio of the contents cost to the total construction cost. In accordance with FEMA 74 (1994) a value $\beta = 0.20$ can be assumed for residential or office buildings. The contents can be divided into classes (Table 1) and each class can be characterized by: the activation parameter, floor acceleration or interstory drift; the cost percentage β on the overall construction cost; the factors accounting for the actual presence of contents on each floor.

Table 1. Division of contents in classes (example).

Class	Activation Parameter	Value	β
Furnishings (cupboards)	Floor acceleration	0.25 g	6.67 %
Computer (equivalent)	Floor acceleration	0.20 g	6.67 %
Interior lights/false ceilings	Interstory drift ratio	0.5%	6.67 %

The activation acceleration values for the contents are obtained considering the limit equilibrium condition where the overturning action on the object equals the stabilizing one. In the absence of a direct dynamic analysis the floor acceleration is computed as ratio between the difference of shear forces above and below the level and the seismic mass of the floor.

Step 7. The total equivalent floor area computed in the considered scenario finally results $A_{TOTD} = A_{SD} + A_{NSD} + A_{CD}$. The direct economic loss is $C_{TOT} = C_U \cdot A_{TOTD}$, where C_U is the average market retrofitting cost per unit of floor area. By summing the cost of each scenario, multiplied by the annual probability of the event inducing that scenario, the expected annual cost is calculated. This value must be actualized and multiplied by the number of years of the residual building life to obtain the future cost.

Step 8. An index of global damage of the construction is defined as $ID = (\varphi \times A_{TOTD}) / A_{ESP}$ where A_{ESP} is the total walking floor area of the building that can be occupied by people and φ is a scale factor required to have a maximum value of ID equal 1.0. Indeed, the total area A_{TOTD} involved in damage scenario does not represent an actual walking floor area, but a quantity expressing the restoring costs of structural, non-structural and content loss in terms of floor area, calculated on the basis of equivalence criteria. On the basis of assessments made on sample buildings the adoption of a factor $\varphi = 0.5$ is adequate. The assumption cannot be, however, generalized and must be calibrated in function of the number of stories and areas of the floors of the examined construction.

The consequences on the occupants associated with the damage of the construction can be classified within four classes of severity according to what usually reported in the literature and to the criteria for the simple triage provided for mass events (Table 2). In the present procedure, however, it has been adopted a subdivision of the persons affected by the event in three groups: unharmed, including the light and very light injured, (classes of severity 0 and 1); injured, of medium or significant severity, (classes of severity 2 and 3); fatalities (class of severity 4).

Table 2. General classification of the consequences on the occupants.

Severity Class	Code	Description of the result
0	White	Unharmed or slight self-treatable wounds.
1	Green	Wounds requiring a minimum medical support that can be provided by paramedical staff.
2	Yellow	Wounds that require higher level of medical care and use of medical technologies but devoid of evolution with risk for life.
3	Red	Wounds that can determine a risk to the life if not appropriately and promptly treated.
4	Blue/Black	Immediate death or fatal injuries.

With the aim of calculating the percentage of occupants accordingly attributable to the three classes, reference is made to correlation curves (Figure 3) that, as a function of the index of global damage, express the percent of injured or fatalities on the occupants. The functions have been defined on the basis of statistical surveys on the impact of past seismic events reported in the literature, two examples of which are shown on the right side of the same Figure 3.

For values of the global damage index lower than 0.1 (limited damage) the percentage of victims is null, in fact, on real events, in these situations usually do not occur victims. A damage index equal 0.5 resulting from the procedure corresponds to a situation of very extensive damage, equivalent to the conventional collapse conditions of buildings reported in literature and to which a percentage of victims of 10% is usually attributed. The ultimate damage scenario corresponding to ID=1.0 can be associated to a total collapse of the construction for which a percentage of expected fatalities equal 20% of the occupants was assumed.

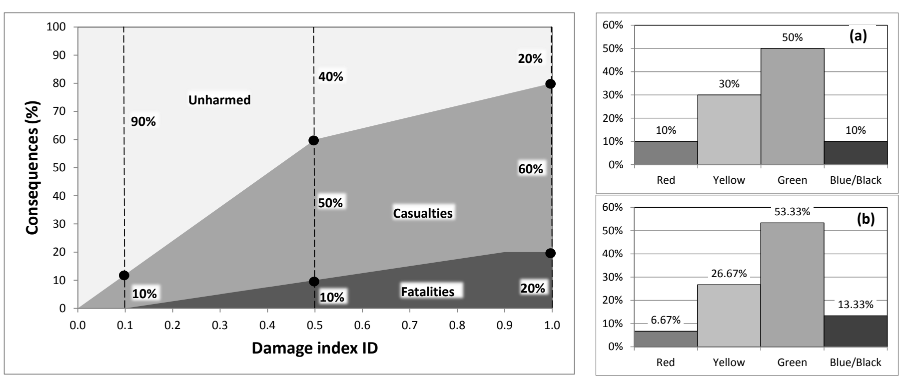

Figure 3. Correlations between global damage index and casualties or fatalities. Distribution of patients in post-earthquake conditions: (a) Lupoi et al. (2008), (b) Hazus (1997).

A factor I_{DD}, function of the interstory drift ratios, modifies the calculated values of the consequences. I_{DD} allows taking into account situations of existing buildings in which the parameters of the global response are not related to the damage state of the structural elements. The modification factor I_{DD} is defined as a function of the average value of the interstory drift ratios of the building $D_M = \sum_i^N D_i \cdot A_{f,i} / \sum_i^N A_{f,i}$ where D_i and $A_{f,i}$ are the interstory drift ratio and the floor area of the *i*-th level, respectively. I_{SD} is equal to 1.0 for $DM\ 1 \leq$ % and varies linearly from 1 to 3 for D_M varying from 1% to 3%.

The absolute values of the consequences on the occupants depends on the actual exposure, that is on the occupation index I_O, expressed as average number of people daily present per unit of floor area, and on the prevention factor F_P, variable between 0 and 1, which takes into account the prevention conditions, both physical and cultural, in the areas subjected to assessment. The total number of exposed people is $N_{EXP} = F_P \times I_O \times A_{EXP}$ that, multiplied by the percentages of casualties, fatalities and unharmed people, gives the expected number of persons in each of the classes of consequences.

Step 9. The probability of the consequences calculated through the described procedure for each damage scenario is given by the annual probability of the event that induces the considered damage scenario $P_1 = 1/T_R$. By summing the number of victims, or casualties, expected for each scenario, each multiplied by the annual probability associated with that scenario, the number of victims, or casualties, generally expected in a year is calculated. The estimate of expected losses in a number of years can be finally calculated by multiplying the expected consequences in a year by the number of years of the considered time interval.

3 CONCLUSIONS

A procedure has been outlined allowing for a fast calculation of the risk of consequences from a seismic attack on the occupants of an r/c framed building. It is based on seismic assessments performed for some damage scenarios differentiated for the extension of the structural collapses. The quantitative assessment of the risk of consequences - economic losses or consequences on the occupants - provides realistic values of the risk related to the use of the building. In many cases of existing buildings characterized by high values of vulnerability it has been observed that, in a limited number of years (5-10), the risk of consequences on the occupants is small. The risk assessment allows to schedule suitable actions for the building enhancement based on programming the financial resources and the use of the building.

References

EN1998-1, *Eurocode 8: Design of structures for earthquake resistance - Part 1: General rules, seismic actions and rules for buildings*. CEN, Brussels, 2004.

FEMA 74, *Reducing the risk of nonstructural earthquake damage - a practical guide*, Washington DC, 1994.

FEMA, *HAZUS®99 User's Manual - Earthquake loss estimation methodology*, Washington DC, 1999.

FEMA, *HAZUS®-MH MR4 Technical Manual - Multi-hazard Loss Estimation Methodology Earthquake Model*", Washington DC, 2003.

Lupoi G., Franchin P., Lupoi A., Pinto P.E., Calvi G.M., *Probabilistic Seismic Assessment for Hospitals and Complex-Social Systems*, IUSS Press, 2008.

NTC2008, *Norme Tecniche per le Costruzioni D.M. 14 gennaio 2008*, Consiglio Superiore dei Lavori Pubblici, GU Repubblica Italiana, 2008.