IMPROVING SEISMIC LOSS ESTIMATION FOR EUROPE THROUGH ENHANCED RELATIONSHIPS BETWEEN BUILDING DAMAGE AND REPAIR COSTS

M.P. Hill[1] and T. Rossetto[2]

[1] *PhD Candidate, Dept. of Civil, Environmental and Geomatic Engineering , University College London, London, UK*

[2] *Lecturer, Dept. of Civil, Environmental and Geomatic Engineering , University College London, London, UK*
Email: t.rossetto@ucl.ac.uk

ABSTRACT :

Within seismic loss estimation much research has been carried-out in regards to characterizing ground motions, but less in regards to building vulnerability (also known as fragility) and damage costs. There is especially little data in respect to earthquake damage costs. Reasons for this include the fact that major earthquakes are infrequent and do not always occur in the urban environment or affect the range of building types of interest. Furthermore, the usability of cost data in the latter case is often limited by the lack of detail in the associated cost data or by its unavailability. To circumvent this problem cost ratios (ratio of damage level to total construction replacement cost) are commonly used. However, the methodology for deriving cost ratios is often unsatisfactory given that supporting evidence of their applicability for diverse geographical areas and building types is not usually provided. New data and a new approach to cost ratio definition are presented in this paper. A survey of builders in seismically active Southern Europe was carried out to find representative prices of common repair types and new construction. The results are used to derive new 'repair cost ratios' and a proposal for a new damage scale and methodology to calculate cost ratios is presented. Consequent cost ratios are also given. This allows the user more flexibility in vulnerability analyses of ground motion on building performance as the cost will be derived not from generalized values of damage but from summation of the quantity of specified repair units. The manner in which this research can be used with vulnerability and seismic hazard studies is also outlined. This research will enable better-defined seismic loss estimation, especially where analytical vulnerability analyses are used, contributing to improved models that can be used by government planners or the insurance industry.

KEYWORDS: Damage, cost ratio, loss estimation, Europe

1. INTRODUCTION

Within seismic risk assessment, a cost ratio is defined as the ratio of cost of repair (recovery) to the cost of replacement of the building (see Equation 1.1 below and enhanced definition considerations in Section 2). Cost ratios allow a direct financial loss to be estimated for varying levels of building damage whilst requiring current data for the absolute value of complete building replacement. The losses for building damage calculated using these ratios are often further used to estimate non-structural construction losses, contents losses within a building, and business interruption losses, for example FEMA (1999).

[Cost Ratio (CR) for a given damage state (DS_i)] = [Cost of repair of damage state DS_i, (R_{DSi})] / [Cost of replacement (R_T)]

Abbreviating to: $$CR|DS_i| = R_{DS\,i} / R_T \tag{1.1}$$

It is the authors' judgment that the relationship between damage and losses has been underrepresented in the research effort within the seismic loss estimation field (Hill and Rossetto 2008a; 2008b). There is therefore a need to highlight some of the potential drawbacks of current approaches as well as to develop alternative complementary solutions for deriving cost ratios. The paper describes a piece of primary research undertaken to validate a proposed alternative direct analytical approach to cost ratio derivation. This research was conducted with a particular emphasis on loss estimation studies in Europe.

2. COST RATIO DEFINITIONS

It is generally indicated in existing studies or methodologies using cost ratios, for example FEMA (1999), whether replacement refers to construction cost (i.e. excluding land value costs) or to property market values. However, a general critique of such studies or methodologies would be that they do not usually indicated what 'replacement' actually refers to. A few studies do define replacement in more detail, for example in HAZUS (FEMA 1999) replacement is indicated to be in terms of structural repair and non-structural costs. Elsewhere, Blong (2003) adopts the definitions of a nationally authoritative source used for project estimation in the local construction industry. Bal et al (2008) also provides further detail by defining their '100% replacement value' to be the new building cost that would not include demolition costs of an existing building. On the other hand, Mouroux (2004) defines the 100% replacement value as half the "sell price" (i.e. property market value) where insufficient construction cost information is available.

Aside from the varying justifications (or lack thereof) that have been provided for cost ratio values within different studies (refer to review in Hill and Rossetto 2008a; 2008b), there is therefore also a need to define in more detail each term in Equation 1.1, in particular the 'cost of replacement of the building'. A number of considerations can be identified with regard to the definitions, and are indicated in Table 1. A method of cost ratio derivation should take into account such considerations where applicable.

Table 1 Considerations for cost ratio definition

Consideration	Definition		
	Cost of repair (recovery)	Cost of replacement	Damage state
1	How is cost derived?	How is cost derived?	What is the cost of each damage state?
2	If cost is derived through direct consideration of repair: What repairs (recovery methods) are pertinent to building type?	Does it include demolition of the existing building?	If cost is derived through direct consideration of damage: How is damage related to cost of repair/replacement?
3		Is it an identical replacement of existing building?	How much damage causes each damage state?

4		Is the replacement building in accordance with modern standards and construction techniques?	How much of each pertinent repair (recovery) method is considered for each damage state?
5		Is replacement building a modern building type, reflecting historical changes in construction/architectural practice?	

Within this study replacement cost is taken to mean the construction cost of the primary 'shell' of a new building and excludes demolition or site clearing. However, for repair and damage, the considerations can only be more fully explored with new data (see section 6).

3. AN ALTERNATIVE TO POST-EARTHQUAKE DATA

Analysis of post-earthquake data is typically used as input for seismic loss estimation studies. Post-earthquake data concerning cost of repair or replacement of buildings damaged in earthquakes is limited by a number of factors: infrequent damaging earthquakes resulting in insufficient data, data at a macro-level or in differing formats, out-of-date data and propriety control. Furthermore, the level of refinement of data tends not to allow a component-based cost assessment to be carried out. Collection of new construction cost data lends itself to this component-level approach, providing current data in the format required for a study and not requiring any prior earthquake damage. This approach is therefore a complementary alternative to the empirical post-earthquake damage collection approach. Such collection of construction cost data should be performed within a survey, which enables enhanced statistical validity to be achieved. A methodology to derive explicitly-defined (see discussion in section 2) cost ratios has been developed, and is presented in section 6.

4. CONSTRUCTION COST SURVEY

A construction cost survey was undertaken in several countries in Southern Europe. Countries selected include Greece, Italy and Spain. These three countries, which border the Mediterranean sea, have differing levels of seismic hazard. Greece and Italy have a moderate to high seismic hazard, whilst Spain has a low to moderate hazard (GSHAP, 2008). However, these countries employ similar materials for their modern low to medium-rise residential building stock (namely reinforced concrete and masonry). Modern reinforced concrete repair methods, for example carbon fiber jacketing, are also available in these countries. It was therefore judged that a single questionnaire could be developed for a multi-country European survey. The purpose of the survey was two-fold, firstly to provide qualitative input and insight for the methodology of cost ratio derivation, see section 6, and secondly to investigate the research issues and limitations regarding such surveys. The latter will be expanded upon in this section.

4.1. Survey and questionnaire issues

In order to provide input for cost ratio definition it was judged that information regarding three areas would be required: 1) construction of new buildings (replacement), 2) demolition and site clearing (where new building, or part of, would be required), and 3) a variety of repair techniques for masonry and reinforced concrete. Initially, a pilot survey was carried-out using a multi-page questionnaire and wide variety of repair techniques. This pilot survey provided two key general findings: the questionnaire should be as brief as possible and that translation into native languages is necessary. Implementing the finding regarding length of questionnaire results in a compromise with quantity of questions (i.e. data). Based on the pilot study it was judged that a 1 page questionnaire would be an appropriate length. However, this resulted in a reduction in repair technique questions.

The survey would also employ modern technology, through use of email responses where possible. In light of the numerical responses required, the ability to present well-formatted tables, facilitate printing of the questionnaire if required, and crucially as widely-used and accepted software, it was decided that Microsoft's Excel could be used. Microsoft Word and custom interactive pdf forms were also considered but it was judged that they could not match either the formatting functionality or backwards compatibility of Excel at this time. A custom web-based survey was also discounted since it was decided that the ability to print the form if necessary and conserve the formatting was an essential requirement.

Most respondents were discovered through online searches, for example, via an online directory of builders or other construction professionals such as architects. A convenience sample is therefore used and an additional potential bias is therefore how much internet penetration exists within the local construction industries. It was generally considered to be satisfactory in the three countries described herein. The respondents were self-selecting. However, the response rate was low. One of the key recommendations to increase response rate would be that it is necessary to develop professional relationships through personal contact, often through telephone conversations, with respondents. However, it is recommended that a more efficient survey into construction costs could be facilitated by governmental organizations (such as municipal authorities responsible for building control) which have regular contact with construction companies during the construction regulatory process. Section 6 indicates why such survey data is of interest in seismic loss estimation.

4.2. Questionnaire form

The English-language version of the finalized questionnaire form is provided in figure 1. The questionnaire was translated into the applicable native language (i.e. Greek, Italian and Spanish) prior to conducting the survey.

Initially, questions regarding demolition, site clearing, and new construction were included. The pilot survey indicated that construction units that are of immediate relevance to the construction or repair should be used. Additionally, actual quantities were preferred to provide the respondent with a more realistic context. The questions on new building construction differentiated between low-rise and medium-rise buildings and between the primary building construction and non-structural (installations and finishes) components. It was judged important to do this in order to better determine the replacement value (which is used to normalize other damage levels). Additionally, in order to enhance responses, ranges were asked for. The main compromise with regard to observing the 1-page length requirement for the questionnaire was with respect to the repair questions. It was decided that for the purposes of highlighting the use of the methodology, only questions on repairs and strengthening techniques for reinforced columns and basic brick masonry repairs would be retained. It was judged that such questions would still allow effects of frequent damage modes to be accounted for in the methodology. It was also decided that the survey could efficiently include construction duration questions which could provide important insight regarding recovery time.

Name	
Date	
Position	
Company	
TEL	
Email	
Country/Location	

Academic survey into Reconstruction & Repair After Earthquake
Contact me: Marc.Hill@ucl.ac.uk
Prices (not costs): but no tax included
Total Price = Total price of construction (not including land price)
Change "Euros" to local currency if required
See: Comments "? " below for more details

Stage	Description	Quantity &	Unit	Total Price (Euros)			Time (Months)		
				Minimum	Maximum	Probable	Minimum	Maximum	Probable
	Reconstruction								
-1	**Demolition of existing residential building:** reinforced concrete / brick	100	m3						
0	**Site cleaning**: remove debris from demolition	100	m3						
1a	**Construction of low-rise reinforced concrete/brick** (2-storey) residential villa **house** (75m2 per floor)	150	m2						
1b	**Installation house services** (water, wastewater, electrical, lighting, ventilation)	150	m2						
1c	**Installation house finishes** (windows, doors, bathroom, kitchen)	150	m2						
2a	**Construction of medium-rise reinforced concrete / brick** (5-storey) multi-family residential apartment **building** (250m2 per floor)	1250	m2						
2b	**Installation apartment services** (water, wastewater, electrical, lighting, ventilation, elevator)	1250	m2						
2c	**Installation apartment finishes** (windows, doors, bathroom, kitchen)	1250	m2						
	Repair								
	Brick Masonry Wall Repairs								
3	**Cement render of cracks (cosmetic surface repair)**	1	m2						
4	**Replacement of brick wall**	1	m2						
5	**Strengthen brick wall with steel wire mesh**	1	m2						
	Reinforced Concrete Column Repairs								
6	**Epoxy injection of cracks (1mm width)**	1	m.l						
7	**Replacement of Columns** (including steel reinforcement)	1	Column						
8	Strengthen **column** with **reinforced concrete 'jacket'**	1	Column						
9	Strengthen **column** with **carbon fibre 'jacket'**	1	Column						

Construction of building only. Includes: foundation, structure and brick cladding. Excludes: windows, external works, services, finishes, & land price.

Construction of building only. Includes: foundation, structure and brick cladding. Excludes: windows, external works, services, finishes, & land price.

Approximately 50mm layer of cement/sand mortar is reinforced with galvanised steel wire mesh (2mm diameter)

100mm layer shotcrete concrete around perimeter of column with 8 additional 16mm diameter steel bars for columns.

Thin carbon fibres woven into a fabric sheet applied/glued around perimeter surface of the column using an epoxy resin binder.

Figure 1 Questionnaire form (provided in MS Excel) for email-based survey (English version)

5. CONSTRUCTION COST RESULTS

The results presented herein refer to a survey conducted between December 2007 and July 2008. However, the survey is on-going and data is still being collected. The results presented here relate to a total of 18 companies (6 from Greece, 5 from Italy, 7 from Spain) that provided responses to the questionnaire. For the purposes of this paper, the results will be presented in combined format providing 'Euro-Mediterranean region' values. These should be used as an initial qualitative indicator for highlighting the method of section 6. Results presented here are in terms of the ratio of the unit 'probable' median for each stage to the unit 'probable' median for stages 1a and 2a [(1a+2a)/2]. The latter term is the median of the primary building construction of a reinforced concrete/brick masonry house and medium-rise building values, see figure 1. The purpose of presenting the information in this way is also indicated in section 6.

For the probable cost values between stages -1 and 2c the medians are a product of a sample size of 16 to 18 with a minimum of 5 results per country. For the probable cost values between stages 3 and 9 the medians are a product of a sample size of 11 to 14 with a minimum of 4 results per country (3 results per country for questions 5 and 6).

Figure 2 can be interpreted as follows. The monetary value of stage -1 (demolition) is 0.046 times the monetary value the median of 1a and 2a (normalized value; i.e. 1.0, or €430 in this case) and is the value per unit (cubic meter). The monetary value stage 1b (installation of house services) is 0.620 the monetary value of the normalized value, whilst stage 4 (masonry wall replacement) has a monetary value of 0.074 the normalized value. The values for these stages are for each square meter of floor area and each square meter of wall area respectively.

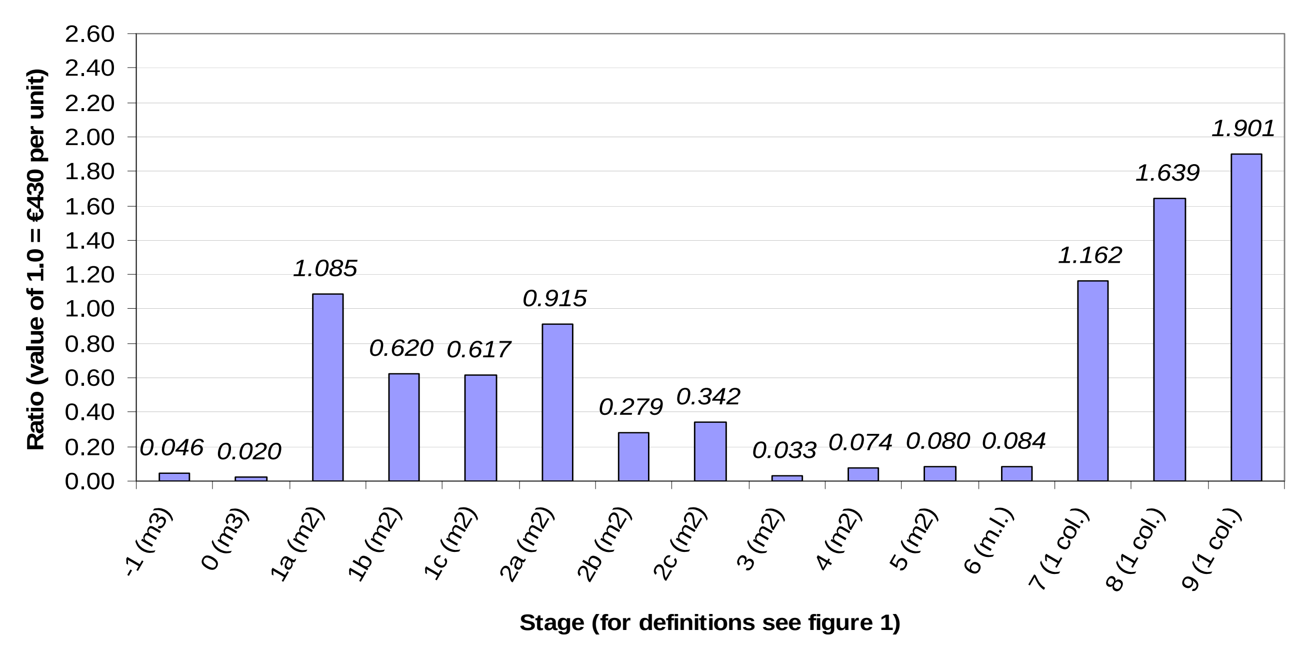

Figure 2 Euro-Mediterranean Region: Ratio of unit stage cost medians (normalized to median of 1a+2a; December 2007 to July 2008)

6. ALTERNATIVE METHOD FOR DERIVING COST RATIOS

The results of the construction cost survey are used here to outline an alternative method for deriving cost ratios. This method would be particularly suited to advanced analytical vulnerability methods, such as 3D finite element analysis, that can capture information at the structural component level. In essence, the methodology consists of determining the quantity of component damage to columns and brick walls and deciding which and how much of a repair should be used or whether the building requires demolition and replacement. The assumption is that prior to a decision of building replacement being taken, damage to reinforced concrete columns and brick walls will be of predominant structural importance. The cost ratio is determined through summing the required quantities of repairs to the building at the damage level of interest unless replacement is deemed necessary, in which case the required demolition and site clearing is taken into account. The methodology can therefore be expressed mathematically, see Table 2.

Table 2 Cost ratio equations

$$CR|DS_i| = R_{DS\,i} / R_T \quad \text{(from Equation 1.1)}$$

$$\text{with} \quad R_T = {(R_{1a} + R_{2a})}\big/{2}$$

$$\text{and} \quad R_{DS\,i}(m^2) = \alpha R_{-1} + \beta R_0 + \chi R_{1b} + \delta R_{1c} + \varepsilon R_{2b} + \varphi R_{2c} + \gamma R_3 + \eta R_4 + \kappa R_5 + \lambda R_6 + \mu R_7 + \nu R_8 + \omega R_9$$

where $\alpha, \beta, \chi, \delta, \varepsilon, \varphi, \gamma, \eta, \kappa, \lambda, \mu, \nu, and\omega$ are constants determined from the damage quantities found during the vulnerability study and are the ratio of the damage to the relevant stage normalized to 1m^2 of floor area. These parameters should assigned values for each damage state.
R values can be taken from data such as that in Figure 2

Through use of the ratios in Figures 2 to 7, the only absolute cost required is for stages 1a and 2a (primary building construction costs), thus adhering to the cost ratio concept. It is also possible to consider only stage 1a or 2a independently, but using the combined data for both (35 responses in total for the cost values) increases validity of the median; of crucial importance since it used to normalize the other values. It is seen that the cost ratios are explicitly defined with regard to both damage quantities used (vulnerability study output) and cost definitions (see Figure 1); replacement in this case will be the primary building construction cost. This is in keeping with the recommendations of Table 1.

6.1. Example

In order to use this method, it will be necessary to firstly determine from the inventory assessment the floor area, building volume, wall density, building height and quantity of columns. These values should then be normalized to a square meter of floor area. In the subsequent vulnerability assessment, each damage level should be numerically described in terms of level and quantity of walls and columns damaged, and which (if any) repair would be appropriate for that level. This consideration would provide the numerical values of the parameters α to ν in Table 2. It is noted that the following examples, given in Table 3, include damage values which do not refer to a rigorously defined damage state, since they are used solely as theoretical examples. The examples are therefore for the purpose of highlighting the versatility and straight-forward application of the method which offers those conducting analytical vulnerability assessments the ability to provide loss-estimates based on structural component damage according to their own criteria.

Table 3 Examples outlining method

Building inventory characterization: The following theoretical example building is used [inspired by typical building plan presented by Leggeri et al (2002; figure 3A)]: a reinforced concrete frame building with masonry infill with approximate floor area dimensions of 20m by 13m giving an area of 260m^2 per floor. It has 18 columns and 99m length of masonry infill wall. Assuming the walls are 0.25m thick, floor is 0.25m thick and columns are on average 0.4m by 0.4m, then the volume per floor can be approximated at 148m^3 for a 3m interstorey height.
Normalization of building inventory: For 1 m^2 floor the building has 0.07 columns, 0.38m length of wall, and 0.57m^3 volume
Vulnerability assessment at damage level i, Example 1: For a theoretical damage state where it was found only the equivalent of 10% of walls (one-face only) required re-rendering after a minor earthquake and no other damage occurred (note: R_3 has already been normalized to R_T; see Figure 2 for values), Cost Ratio (CR) is determined as follows: $CR = R_{DS_i}(m^2) = \gamma R_3 = 0.038 \times 0.033 = 0.0013$ $assume\ \gamma = 10\% \times 0.38 m/m^2 = 0.038 m/m^2$ $R_3 = 0.033\ \ from\ \ figure\ \ 2$ $with \alpha = 0, \beta = 0, \chi = 0, \delta = 0, \varepsilon = 0, \varphi = 0, \eta = 0, \kappa = 0, \lambda = 0, \mu = 0, \nu = 0, and \omega = 0$
Vulnerability assessment at damage level i, Example 2: For a theoretical damage state where it was found 10% of columns required carbon fiber jacketing, 10% of masonry walls replacement, and the equivalent of 25% of walls required re-rendering Cost Ratio (CR) is determined as follows: $CR = R_{DS_i}(m^2) = \gamma R_3 + \eta R_4 + \omega R_9$ $\therefore CR = (0.095 \times 0.033) + (0.038 \times 0.074) + (0.007 \times 1.901) = 0.02$ $assume\ \ \gamma = 25\% \times 0.38 = 0.095\, m/m^2; \eta = 10\% \times 0.38 = 0.038 m/m^2; \omega = 10\% \times 0.07 = 0.007\, col./m^2$ $R_3 = 0.033; R_4 = 0.074; R_9 = 1.901\ \ from\ \ figure\ \ 2$ $with\ \alpha = 0, \beta = 0, \chi = 0, \delta = 0, \varepsilon = 0, \varphi = 0, \kappa = 0, \lambda = 0, \mu = 0, and\ \nu = 0$
Vulnerability assessment at damage level i, Example 3: For a theoretical damage state where it was found sufficient damage has occurred to oblige demolition and building replacement. 100% of primary building shell needed replacing, as did installations and finishes (note R_{-1}, R_0, R_{2b}, R_{2c}, have already been normalized to R_T; see Figure 2 for values) gives Cost Ratio (CR) as:

$$CR = R_{DSi}(m^2) = \alpha R_{-1} + \beta R_0 + R_T + \varepsilon R_{2b} + \varphi R_{2c}$$
$$\therefore CR = (0.57 \times 0.046) + (0.57 \times 0.020) + 1 + (1 \times 0.279) + (1 \times 0.342) = 1.66$$
$$assume \quad \alpha = 0.57\ m^3/m^2\, ; \beta = 0.57\ m^3/m^2\, ; \varepsilon = 1; \varphi = 1$$
$$R_{-1} = 0.046\, ; R_0 = 0.020\, ; R_T = 1; R_{2b} = 0.279\, ; R_{2c} = 0.342 \quad from \quad figure \quad 2$$
$$with\ \chi = 0, \delta = 0, \gamma = 0, \eta = 0, \kappa = 0, \lambda = 0, \mu = 0, \nu = 0 \ \ and\ \omega = 0$$

7. CONCLUSION

The construction cost survey provided initial data that has been used to outline an analytical method for deriving cost ratios. This method provides an alternative but complementary approach to existing empirical methods. The derivation of cost ratios in this manner also allows damage state definitions that are more in keeping with the damage scale characteristics recommended in Hill and Rossetto (2008a; 2008b). It is recommended that more data collection research is conducted to provide quantitative statistical validity.

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REFERENCES

Bal, I.E., Crowley, H., Pinho,R., and Gulay, F.G. (2008). Detailed assessment of structural characteristics of Turkish RC building stock for loss assessment models. *Soil Dynamics and Earthquake Eng*, **28:10/11**, 914-932.

Blong, R. (2003). A new damage index. *Natural Hazards* **30:1**, 1–23.

Federal Emergency Management Agency (FEMA) (1999). Earthquake Loss Estimation Methodology HAZUS99 Service Release 2 (SR2) Technical Manual, Washington D.C., U.S.A.

Global Seismic Hazard Assessment Program (GSHAP). Global Map. Available at: http://www.seismo.ethz.ch/GSHAP/global/, Accessed: 15/07/08.

Grünthal, G. (ed) (1998). European Macroseismic Scale 1998, European Seismological Commission, Luxembourg.

Hill, M., and Rossetto T. (2008a). Comparison of building damage scales and damage descriptions for use in earthquake loss modelling in Europe. *Bulletin of Earthquake Engineering* **6:2**, 335–365.

Hill and Rossetto (2008b). Do existing damage scales meet the needs of seismic loss estimation? *The proceedings from the 14th World Conference on Earthquake Engineering*, *12-17th October 2008*, Beijing, China.

Leggeri, M., Viola, E., Lacava, G. (2002). Housing Report Reinforced concrete frame building, Report 30. World Housing Encyclopedia. Available at: http://www.world-housing.net/wh100063.pdf, Accessed: 15/07/08.

Mouroux, P. (2003). RISK-UE An advanced approach to earthquake risk scenarios with applications to different European towns, Final Report. European Commission, Brussels. Available at: ftp://ftp.brgm.fr/pub/RISK-UE/, Accessed: 24/08/07.