13th World Conference on Earthquake Engineering
Vancouver, B.C., Canada
August 1-6, 2004
Paper No. 1180

INFLUENCE OF UNCERTAINTY OF HAZARD EVALUATION FOR INSURANCE RATING, A BOGOTA, COLOMBIA CASE

Jorge A. PRIETO-S.[1]

SUMMARY

Seismic risk evaluation is essential for insurance, reinsurance and brokerage rating. Estimating earthquake risk in many developing countries faces two major challenges. On one side, modeling seismic hazard is troublesome due to lack of regional specific attenuation relationships, not to mention inaccuracies in the source models obtainable. On the other side, local vulnerability functions are not available either. This paper examines the influence of using different attenuation relationships for annual earthquake loss estimation and the corresponding insurance rates of section B of the San Ignacio hospital building in Bogotá, Colombia. The variability in the hospital vulnerability is not considered to simplify the problem. The hazard model and the attenuation relations used are initially described. Then a brief structural description of the building is supplied. Afterwards, the method for vulnerability and risk estimation is shown. The results show significant difference between West North American and European equations. The conclusions highlight the need that the insurance sector has for abundant research in developing areas of the world.

1. INTRODUCTION

Accurate seismic risk evaluation is essential for insurance, reinsurance and brokerage rating. A proper determination of earthquake cover costs is fundamental in order to implement the financial strategy of an enterprise and for developing new products, for example. The cost of insuring or reinsuring a property or portfolio against earthquake depends not only of the technical risk estimation, but also of the current supply and demand conditions of the market. Notwithstanding, the minimum cover price must equalize the estimated average annual loss to safeguard the sustainability of a business.

Estimating earthquake risk in many developing countries faces two major challenges. On one side, modeling seismic hazard is troublesome due to lack of regional specific attenuation relationships, not to mention inaccuracies in the source models obtainable. On the other side, local vulnerability functions are not available either. This paper examines the influence of using different attenuation relationships for annual earthquake loss estimation and the corresponding insurance rates of section B of the San Ignacio hospital building in Bogotá, Colombia. The variability in the hospital vulnerability is not considered in detail to simplify the problem. However, it is worth to mention that uncertainty in vulnerability appears to play an essential role in loss estimation sensitivity. The hazard model and the attenuation relations used

[1] Director Geophysical Institute, Javeriana University, Colombia. Email: j.prieto@javeriana.edu.co

are initially described. Then a brief structural description of the building is supplied. Afterwards, the method for vulnerability and risk estimation is shown. The results, discussion and conclusions highlight the significant dependency on the attenuations relations employed and the need for abundant research in developing areas of the world.

2. EARTHQUAKE HAZARD

The method of generating uniform spectra, based on the ideas introduced by Johnson [1] and McGuire [2], was utilized to evaluate seismic hazard. Ten uniform spectra of acceleration, SA, for a damping ratio of 5% corresponding to periods of return, T_r = 50, 100, 250, 475, 775, 1000, 2500, 3500, 5000 and 10000 years were evaluated at the site of the hospital building. No soil effects were allowed for since the average shear wave velocity, V_s is about 1000 m/s, IGUJ [3].

2.1 Seismological model

An area of influence with a radius of 200 km centred at the hospital building site was analysed. The seismological model proposed by INGEOMINAS-UNIANDES [4] was used. This model divides the seismicity of the area of influence of the city of Bogotá into 16 sources. The geometry of the sources is shown in Table 1.

Table 1. Geometry of sources. Adapted from INGEOMINAS-UNIANDES [4].

Source name	Longitude	Latitude	Average depth, km	Dip angle
Romeral	-75,82	4,29	22	90
	-75,58	4,76		
	-75,45	5,42		
Palestina	-75,58	4,54	32	90
	-75,14	5,14		
	-74,7	6,27		
Chapetón	-74,94	5,08	1	90
	-75,06	4,72		
	-75,39	4,33		
Mulatos	-74,96	4,58	45	90
	-74,82	5,93		90
Trigo-Bituima	-74,73	4,47	30	90
	-74,56	4,87		
	-74,44	5,62		
Viani	-74,36	5,05	8	90
	-74,51	4,88		
	-74,87	4,70		
Ibagué	-75,82	4,20	40	90
	-74,83	4,54		
	-74,76	4,62		
Cucuana-Rio Bogotá	-75,78	3,98	10	90
	-75,23	4,08		
	-74,8	4,28		
	-74,44	4,58		
Cambao-Cambra	-74,33	6,16	35	90
	-74,36	5,72		
	-74,6	5,46		

Source name	Longitude	Latitude	Average depth, km	Dip angle
	-74,73	4,8		
El Chocho	-74,92	4,47	15	90
	-75,46	3,77		
	-75,55	3,53		
Servita-Santa Maria	-74,59	3,18	30	-40
	-73,48	4,44		
	-73,18	4,96		
	-72,82	5,22		
Guaicaramo	-73,45	4,27	16	-45
	-72,51	5,4		
Yopal	-73,00	4,5	10	-40
	-72,55	5,15		
Boyacá	-73,31	5,69	10	90
	-73,16	6		
Soapaga	-73,29	5,3	16	90
	-73,03	5,88		
Circular source				

The ultimate magnitudes, M_u, at each source were obtained by using the relations given by Wells and Coppersmith [5]. A catalogue using 4516 events until 1995 was employed for assigning events to each source. Then, the Gutenberg and Richter parameters and the annual average rates of magnitude occurrence were estimated.

2.2 Evaluation of seismic hazard

The basic method for evaluating seismic hazard was introduced by Cornell [6]. Probability theory supplies the elements required to estimate hazard involving as many variables as wished. That is to say, very complex models can be dealt by using simple probability theory. Recent examples have been shown by Kiremidjian [7].

The annual rate of exceeding a given spectral acceleration, ν, i.e. the inverse of the period of return, T_r, was calculated thus:

$$\nu = \sum_{i=1}^{n} \nu_i = \sum_{i=1}^{n} \nu_{mo,i} \int_{mo}^{m\max} \int_{ro}^{r\max} P(SA \geq sa / r, m) f(r/m) f(m) dr dm \quad (1)$$

where n is the number of sources, 16 in this case,
$\nu_{mo,i}$ is the annual frequency of exceeding a magnitude mo in the source i,
$mmax$ is the ultimate magnitude, also named M_u at any source,
$rmax$ is the maximum distance between the site and the source,
$P(SA \geq sa/ r,m)$ is the conditional probability of exceeding SA given a distance r and a magnitude m,
$f(r/m)$ is the conditional probability density function of the distance given a magnitude,
$f(m)$ is the bounded probability density function of the magnitude

2.3 Attenuation relations

Despite of some recent attempts of providing spectral ordinates attenuation equations for Colombia, Alarcón [8], ground-motion data bases available are still limited either in magnitude, distance, soil conditions or parameter values. For example, the maximum magnitude available in the Alarcón dataset is **M**=6.2 corresponding to the 25 January 1999 Quindio earthquake, while the maximum ultimate magnitude of the seismological model is 7.2. Moreover, soil classification in terms of shear wave velocity at the stations is still not complete. In general, the magnitude-distance space of the Colombian database is unevenly distributed. Hence, relations developed for other parts of the world must be investigated and used.

A recent review of world-wide spectral attenuation relationships, Douglas [9], was consulted. Apart from the fact that the tectonic, geologic and topographic environment is different from one geographical area to another and therefore energy attenuation may differ considerably, the selection of relationships is difficult for other aspects. The definition of distance changes from one researcher to another. Some authors use the distance to the surface projection of the fault, also known as Joyner and Boore distance. Others use hypocentral distance or the closest distance to the seismogenic rupture, for example. The value of the spectral ordinates also changes. Several authors employ the average of the two horizontal spectral values, others use the randomly oriented component and another group utilizes the maximum of the two horizontal values. The functional form of the equations has also been evolved, from simple exponential expressions to intricate equations depending of many parameters. Furthermore, the equations developed for near-field sometimes do not provide a definition of what they understand by “near -field” in terms of a magnitude-distance expression, making bothersome the use of such relationships. All these factors do not facilitate the implementing of several equations in a general program for evaluating hazard and risk. In order to simplify the programming task and after checking the internal files of the author, seven equations with similar characteristic were chosen for the present work. The authors of the relations selected are included in Table 2.

Table 2. Attenuation relationships used.

Number	Author (s)	Reference
1	Ambraseys, *et. al..,* 1996	[10]
2	Ambraseys and Douglas, 2000	[11]
3	Boore, *et. al.* 1993	[12]
4	Campbell and Bozorgnia, 2003	[13]
5	Chapman, 1999	[14]
6	Joyner and Boore, 1982	[15]
7	Sabetta and Pugliese, 1996	[16]

Equations for subduction zones, e.g. Atkinson [17], were not utilized because the seismological model available is dominated by crustal events, without specific mention to subduction sources.

3. VULNERABILITY AND RISK EVALUATION

In order to estimate economic losses, the structural characteristics of the building must be modeled.

3.1 Description of the San Ignacio hospital building

The San Ignacio hospital construction started about 1950. A wing was updated and reinforced during the middle 80´s. The structure is formed by frames of reinforced concrete with unreinforced masonry infill walls. The floor slabs are reinforced in two directions. They were cast following the waffle construction type. Figure 1 and 2 shows the façade and a plant view of the hospital. Insurance rates were evaluated for section B only, which is exhibited in Figure 3.

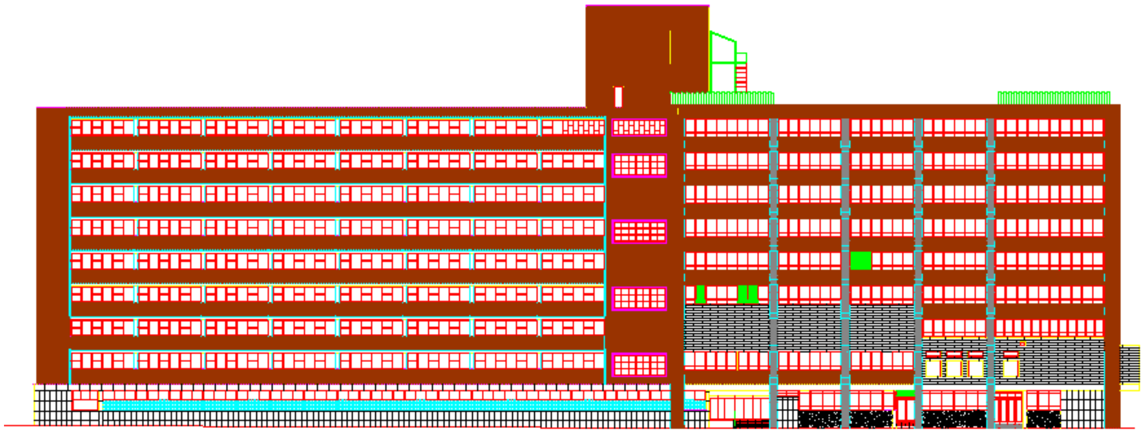

Figure 1. San Ignacio hospital, façade.

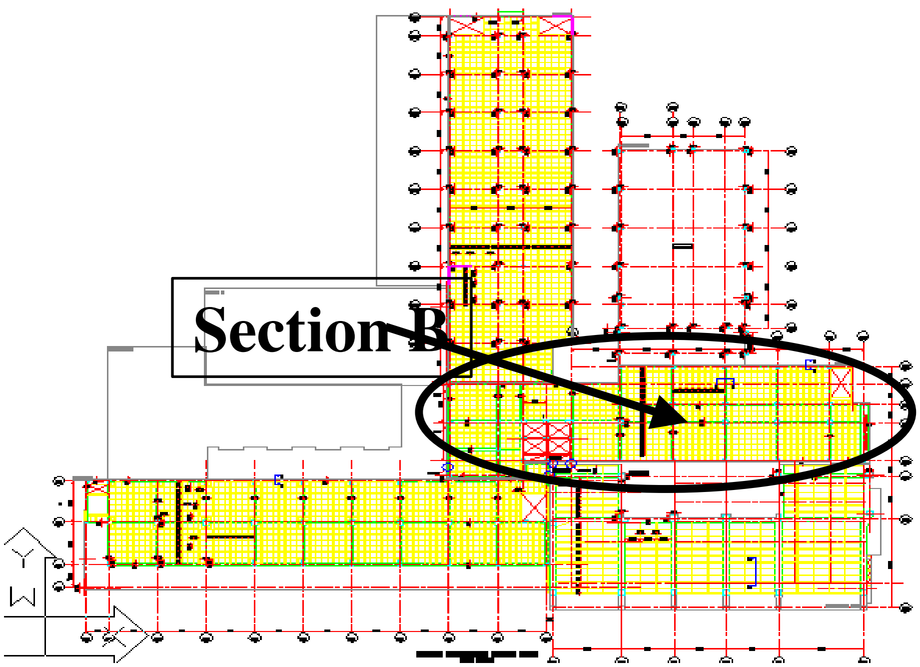

Figure 2. Plant view of the hospital showing section B.

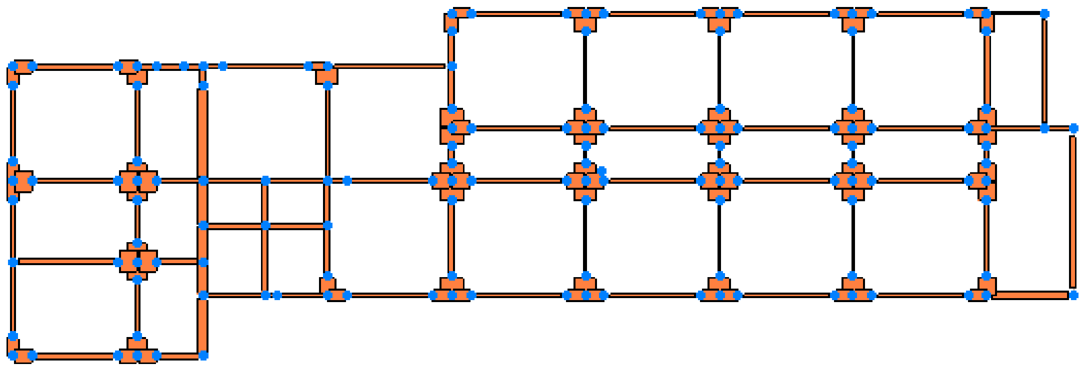

Figure 3. Section B of the hospital.

3.2 Vulnerability and loss estimation methodology

Vulnerability can be understood as the expected or average economic loss when occurs a level of ground motion, e.g. Intensity, spectral acceleration, SA, spectral displacement,, SD, etc, in a specific place. Risk reflects the probability of exceeding a given vulnerability in some time. The average annual risk is the annual mean vulnerability, i.e. to the expected vulnerability. The annual vulnerability, i.e. annual risk, is equivalent to the minimum annual insurance rate that can be charged to transfer such level of risk. In reliability theory, the annual risk represents the annual cost of failure.

This work considers only direct economic losses due to physical structural damage caused by ground motion. Nonstructural damage, ground failure effects, loss of function losses and indirect losses are not allowed for. Procedures and equations used to estimate expected losses can be found in Benjamin [18], EERI [19], FEMA [20], Prieto-S. [21] and Kiremidjian [7]. The HAZUS99 methodology, FEMA [20], was used for the present work to estimate expected losses. It can be shown that the average annual risk or vulnerability expressed as a fraction of the total value of a structure is given by

$$r_a = V = \int_{\nu \min}^{1} \sum_{i=1}^{nda} E(V/DA)\left(P(DA_j > da_j / Sd) - P(DA_{j+1} > da_{j+1} / Sd)\right)\nu(Sd)\,d\nu \qquad (2)$$

where $\nu(Sd)$ is the annual rate, i.e. frequency, of exceeding a given spectral displacement, *Sd*, or acceleration, *SA*, already obtained by equation (1). It is worth mentioning that the building spectral displacement, *Sd* is evaluated at the point at which the seismic demand, i.e. the spectrum, balance the structural supply, i.e. the pushover curve. *Sd* values are obtained by using the capacity spectrum method. The computer program SAP2000 was utilized in this work to obtain *Sd* values for the hospital building.
$P(DA_j > da/Sd)$ is the conditional probability of exceeding a damage state, *da*, given *Sd*. This conditional probability is also called fragility. Examples of fragility relations are given by HAZUS99.
E(V / DA) is the expected loss, i.e. vulnerability, for a damage state *DA*,
nda is the number of damage states considered,
νmin is the minimum annual rate of exceedence considered. The loss that corresponds to this value or to its inverse, the period of return, is also known as probable maximum loss, PML.

The internal part of equation (2), the one controlled by the sigma, Σ, symbol, yields the loss corresponding to a given annual frequency or period of return. On the other hand, the external integral of the equation supplies the average annual loss or insurance rate. Losses were evaluated by changing only the attenuation relations according to Table 2. Fragility curves were kept constant.

4. RESULTS

The spectral displacements of section B of the hospital, evaluated for different periods of return and using the attenuation relations mentioned in Table 2, are shown in Figure 4.

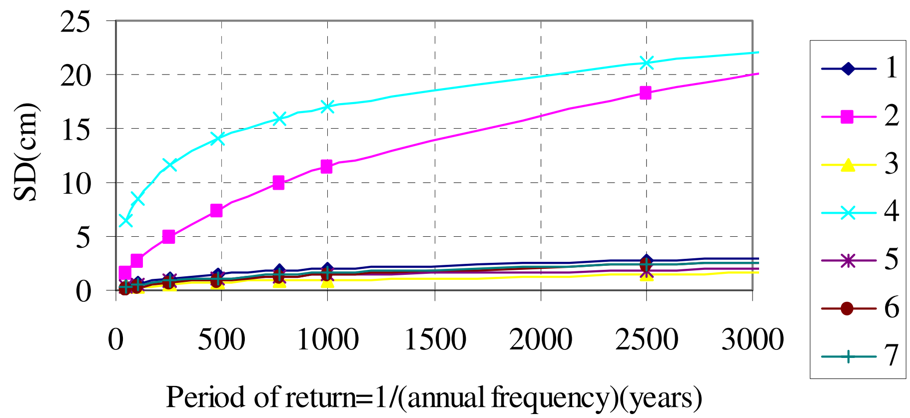

Figure 4. Spectral displacements of section B. Numbers corresponds to attenuation relations given in Table 2.

Note from Figure 4 that there are two relations, i.e. numbers 2 and 4, yielding extremely high values of spectral displacement. Those curves belong to the near-field equations given by Ambraseys [11] and Campbell [14]. The other equations, i.e. 1, 3, 5, 6 and 7 are grouped in a more consistent range of displacements, lower than 5 cm for periods of return below 3000 years. Hence, losses for different displacements or annual frequencies were evaluated for the latter restricted set of equations, which exhibits consistent variability. Results are shown in Figure 5.

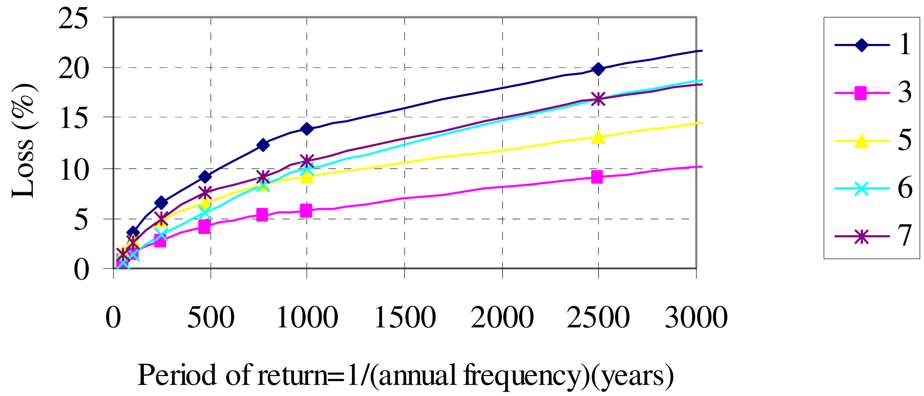

Figure 5. Loss variability. Numbers corresponds to attenuation relations given in Table 2.

The PML values obtained for a period of return of 1000 years varies from 6% to 14% of the building value, which means more than 100% difference, as can be seen from figure 5. In order to observe ranges of variability of insurance rates, equation (2) bounded at 0.001 annual frequency, i.e. Tr=1000 years, was evaluated. The results are summarized in Table 3.

Table 3. Insurance rates for Tr=1000years

Number	Author (s)	Reference	Rate ($\%_0$)
1	Ambraseys, *et. al..,* 1996	[10]	0.885
3	Boore, *et. al.* 1993	[12]	0.462
5	Chapman, 1999	[14]	0.805
6	Joyner and Boore, 1982	[15]	0.453
7	Sabetta and Pugliese, 1996	[16]	0.772

5. DISCUSSION

The high spectral displacements obtained by using near-field equations must be carefully assessed. High values may be the result of using attenuation equations without properly limiting magnitude and distance ranges of applicability at each source. It is believed that the inclusion of near source attenuation relations into a seismological model is possible only if proper definitions of near-field in terms of magnitude-distance equations are provided.

The significant differences in PML values observed in Figure 5 are preserved in the evaluation of insurance rates. Table 3 shows variations of almost 100% in the rates calculated by using European, with values around 0.8‰, and West North American, with values about 0.4‰, attenuation equations. This variation does not seem to be related with individual authors but with groups of researchers of Europe and North America respectively. Hence, it is believed that insurance rate dissimilarities may be related to different tectonic, geologic or even topographic features. If this is the case, there is no reason for using simple logic trees, or weighted averages, when using the European or West North American attenuation equations in other areas of the world. The high uncertainty evident in the insurance rate determination due to variability in hazard should be tackle with local research in the geographical areas of interest.

6. CONCLUSIONS

Variability in insurance rates estimation due to uncertainty in hazard evaluation, difference in attenuation equations, was examined. This is of paramount significance for insurers, reinsurers and brokers working in developing regions of the world. The use of different attenuation relationships in the case of a section of a hospital in Bogotá, Colombia highlights the following aspects:

The inclusion of near source attenuation relations into a seismological model is possible only if proper definitions of near-field in terms of magnitude-distance equations are provided.

Ratings obtained by using equations developed in West North America differ significantly, i.e. 100%, from those evaluated by utilizing European relationships. These dissimilarities may be due to differences in the tectonic, geologic and even local topographic characteristics.

The use of logic trees to assess differences in hazard environment does not appear to have a physical rationale. High uncertainty in hazard evaluation in developing areas should be dealt fostering local research. It is in the own interest of the international insurance and reinsurance sector to contribute alleviating the hazard gaps present in developing areas.

ACKNOWLEDGMENTS

The author wants to acknowledge Alfonso Amézquita and Edgar Muñoz for kindly supplying the structural model of the hospital building.

REFERENCES

1. Johnson, R. A. “An earthquake spectrum prediction technique”, *Bulletin of the Seismological Society of America,* 1973, Vol. 63, 1255-1274.
2. McGuire, R K. “Seismic design spectra and mapping procedures using hazard analysis based directly on oscillator response”, *Earthquake engineering and structural dynamics*, 1977, Vol. 5, 211-234.
3. IGUJ. “ Microzonificación sísmica del campus de la Pontificia Universidad Javeriana”, Informe de estudio geosísmico (In Spanish), Instituto Geofísico Universidad Javeriana, 2002, Bogotá.
4. INGEOMINAS-UNIANDES. *Amenaza Sísmica, subproyecto no. 14, informe definitivo*, (In Spanish), 1997, Enero, Bogotá.
5. Wells, D and Coppersmith, K. “New empirical relationships among magnitude, rupture width, rupture area and surface displacement” *Bulletin of the Seismological Society of America,* 1994, Vol. 84, 974-1003.

6. Cornell, S K “Engineering risk analysis”. *Bulletin of the Seismological Society of America,* 1968, Vol. 58, 1583-1606.
7. Kiremidjian, A S. “Earthquake hazard and risk evaluation”, *Lecture given during the international course on innovations in insurability and earthquake risk*, 2003, Javeriana University, April, Bogotá.
8. Alarcón, J. E. “Relaciones de atenuación a partir de espectros de respuesta para Colombia”, *Proceedings of the II Colombian Conference on Earthquake Engineering,* 2003 (In Spanish), Medellín, October.
9. Douglas, J. “Ground motion estimation equations (1964-2003)”, *Research report 04-001-SM*, 2004, Department of Civil and Environmental Engineering, Soil Mechanics section, Imperial College, January, London.
10. Ambraseys, N. N., Simpson, K A and Bommer, J J. “Prediction of horizontal response spectra in Europe”, *Earthquake engineering and Structural Dynamics*, 1996, Vol. 25, 371-446.
11. Ambraseys, N. N. and Douglas, J. “Reappraisal of the effect of vertical ground motion on response”, *ESEE report 00-4*, 2000, Department of Civil and Environmental Engineering, Imperial College, August, London.
12. Boore, D. M., Joyner, W. B., & Fumal, T. E. “Estimation of response spectra and peak accelerations from western North American earthquakes” An interim report. Open-File Report 93-509, 1993. U.S. Geological Survey. 70 pages.
13. Campbell, K. W. and Bozorgnia, Y. “Updated near-source ground-motion (attenuation) relations for the horizontal and vertical components of peak ground acceleration and acceleration response spectra”, *Bulletin of the Seismological Society of America,* 2003, Vol. 93 (1), 314-331.
14. Chapman, M. C. “On the use of elastic input energy for seismic hazard analysis”, *Earthquake Spectra,*1999, Vol. 15 (4), 607-633.
15. Joyner, W. B., & Boore, D. M. Prediction of earthquake response spectra. Open-File Report 82-977. 1982, U.S. Geological Survey.
16. Sabetta, F. and Pugliese, A. “Estimation of response spectra and simulation of nonstationary earthquake ground motions”, *Bulletin of the Seismological Society of America,* 1996, Vol. 86 (2), 337-352.
17. Atkinson, G. M. And Boore, D. “Empirical ground-motion relations for subduction-zone earthquakes and their application to Cascadia and other regions”, *Bulletin of the Seismological Society of America,* 2003, Vol. 93 (4), 1703-1729.
18. Benjamín, J. R. y Cornell, C. A. “Probability, statistics and decisions for civil engineers*”,*1970. McGraw-Hill, Inc.
19. EERI. “The basics of seismic risk analysis” EERI committee on Seismic Risk. *Earthquake Spectra*, 1989, Vol. 5, No. 4, 675-702.
20. FEMA-NIBS. “*HAZUS99”*, Earthquake loss estimation methodology, Technical manual. Federal Emergency Management Agency and National Institute of Building Science.1999, Washington, D. C.
21. Prieto-S, J. A. “Development of a ground-motion for earthquake loss assessment”, *PhD thesis,* Imperial College, 2002, London.