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SEISMIC RISK EVALUATION OF REINFORCED CONCRETE BUILDINGS

S. Tesfamariam[1] and M. Saatcioglu[2]

ABSTRACT

Seismic resiliency of new buildings has improved over the years due to better seismic codes and design practices. However, the vulnerability of seismically deficient older buildings, designed and built on the basis of older codes of practice, poses a significant threat to life safety and survivability of buildings. It is economically not feasible to retrofit the entire seismically deficient infrastructure. Therefore, there is need for a comprehensive plan to identify critical structures and prioritize their retrofit and upgrade requirements.

A risk-based evaluation technique is proposed in this paper to develop a ranking scheme for reinforced concrete buildings. The complex interaction between seismic hazard, building vulnerability and consequence of failure is handled in a hierarchical manner. Some of the risk parameters, expressed as linguistic quantifiers, are transformed into numerical values. An ordered weighted averaging (OWA) operator is used to aggregate through the hierarchy and obtain final risk index values for prioritization. The procedure is illustrated with a case study based on the reported data on seismic damage of reinforced concrete buildings during the 1994 Northridge Earthquake.

Introduction

The low frequency of earthquakes occurring in Canada and the little seismic damage observed in recent past has promoted complacency towards seismic risk among the general public, as well as the authorities responsible for seismic risk mitigation (Bruneau and Lamontagne 1994). However, the lessons learned from previous earthquakes and research on earthquake engineering over the last three decades clearly indicate that the Canadian infrastructure remain vulnerable to moderate to strong earthquakes. The vulnerability of existing buildings stems from the use of older design codes and/or poor construction practices at the time of design and construction. Most of these older buildings are currently operational and are required to be further assessed and upgraded to minimize seismic damage and to improve life safety.

Different techniques have been proposed to assess building vulnerability that encompasses different levels of complexity, ranging from a simple scoring method to more complex methods of nonlinear structural analyses. Ghobarah (2000) summarized and discussed advantages and limitations of these

[1]Institute for Research in Construction, National Research Council Canada, Ottawa, Ontario Canada K1A 0R6, Tel: (613)-993-2448; Fax: (613)-954-5984, E-mail: Solomon.Tesfamariam@nrc-cnrc.gc.ca
[2]Professor and University Research Chair, University of Ottawa, Ottawa, Ontario Canada K1N 6N5, Tel: (613)-562-5800 ext 6129; Fax: (613)-562-5173, E-mail: murat@uottawa.ca

methods. The level of sophistication required for such assessment depends on many factors, including the intended use of such information and the availability of funds for a possible retrofit strategy. The impending challenge of finding required resources for strengthening and upgrading necessitates ranking and prioritization for optimum use of available resources. A risk-based evaluation technique can be performed by integrating site seismic hazard, building vulnerability, and importance/exposure factor. Risk index I^R values are computed and used for ranking and prioritization of repair and upgrade strategies. Risk assessment of reinforced concrete (RC) buildings has been a research focus for over thirty years (FEMA-249 1994, Boissonnade and Shah 1985).

Seismic hazard, including local soil conditions can be obtained with relative ease from available seismic hazard maps and through site inspection. Similarly, the importance of a building can be established with relative ease based on its use and occupancy. On the other hand, the building vulnerability assessment involves the consideration of building characteristics and conditions, and hence poses challenges.

The objective of this paper is to develop and demonstrate a simple risk-based approach for seismic assessment of RC structures. An important step in the process involves the identification of building vulnerability parameters. Building vulnerability to ground shaking and associated damage can be grouped into two categories (Saatcioglu et al. 2001); i) factors contributing to an increase in seismic demand (e.g., soft story frame, weak column-strong beam, vertical irregularities); and ii) factors contributing to reductions in ductility and energy absorption capacities (e.g., construction quality, year of construction, structural degradation). In the proposed approach, the basic risk parameters considered in FEMA 154 (ATC 2002) for building vulnerability assessment have been adopted, consisting of building type, vertical irregularity, plan irregularity, year of construction and construction quality. This information can be readily obtained from a *walk down* survey and engineering drawings. Once the basic parameters of risk are established, then a suitable hierarchical structure can be devised for the three main components of seismic risk, which can be expanded into sub-components as illustrated in Fig. 1. This step is followed by the transformation of parameters into commensurable values and the use of an appropriate aggregation technique to compute relevant indices. These indices include building damageability index I^{BD}, building importance/exposure index I^{BI}, and seismic risk index I^R. A brief overview of the entire risk-based evaluation process is presented below with a descriptive case study.

Hierarchical Earthquake Risk Assessment

The development of a complex mathematical formulation for a preliminary risk assessment and screening of deficient buildings is not feasible. Thus, the complex problem of aggregating building vulnerability parameters and their sub indices can be grouped into a simple and manageable hierarchical structure. The hierarchical structure follows a logical order where the causal relationship for each supporting idea is further subdivided into specific contributors. Miyasato et al. (1986) proposed a hierarchical structure for seismic vulnerability assessment of buildings, which has been adopted in this paper after some modifications, as illustrated in Fig. 1.

Fig. 1 shows a six-level hierarchical structure. Level 1 is for the overall goal of the analysis, i.e., *seismic risk*. The seismic risk is computed by integrating the parameters at Level 2, which reflects *building damageability* and *building importance/exposure*. The building importance/exposure parameter is computed by integrating *building use*, *building occupancy* and *economic importance at Level 3*. The building damageability is also computed by integrating the parameters at Level 3, which consist of *site seismic hazard* and *building vulnerability*. The site seismic hazard at Level 3 is computed by integrating *site seismicity*, *soil type and number of stories*, details of which are outlined elsewhere (Tesfamariam and Saatcioglu 2007). It is essentially based on the fundamental period of structure T_1 that can be related to the number of stories. T_1 is then used to estimate the spectral acceleration $S_a(T_1)$ either from site specific design response spectrum or existing representative earthquake record, reflecting site seismicity. The *soil type* is used to incorporate amplification or de-amplification of site seismicity based on the prevailing soil conditions.

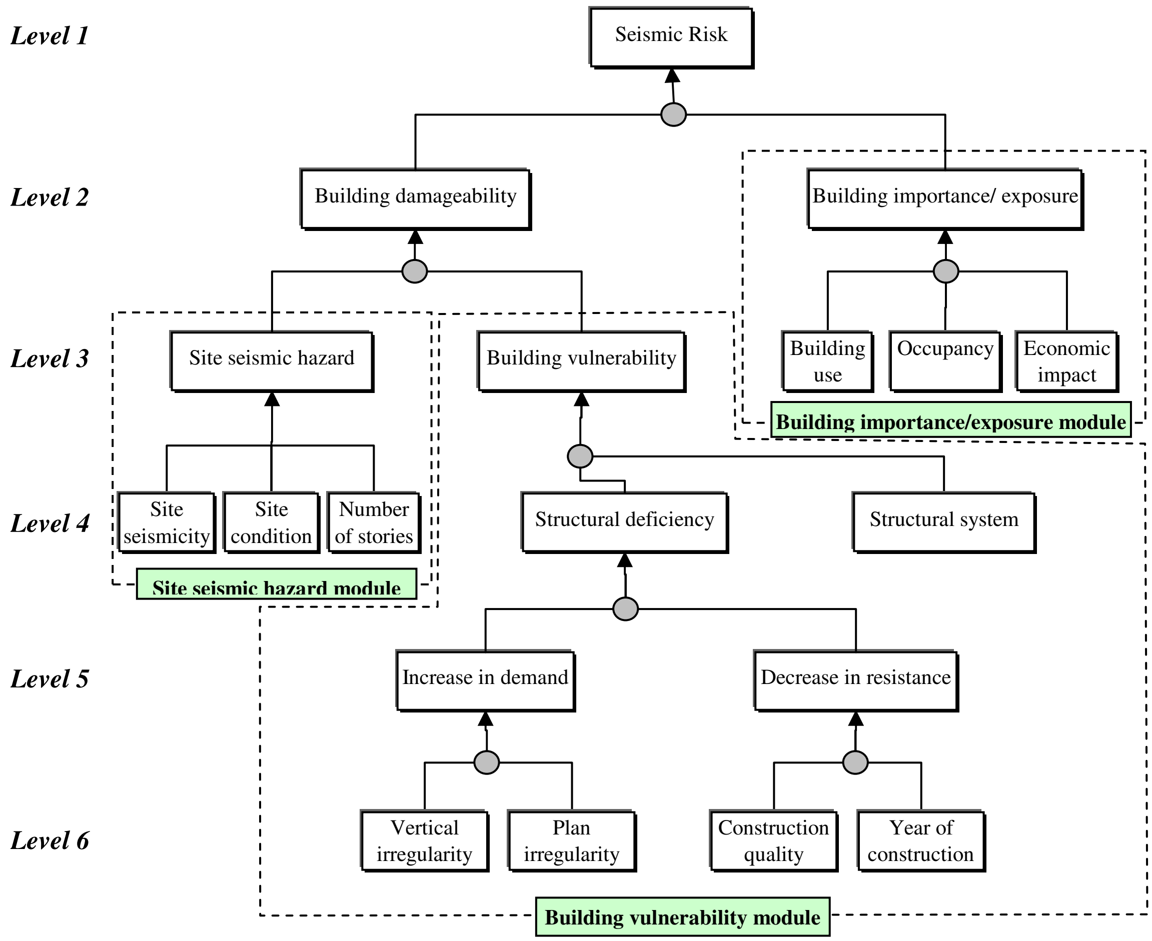

Figure 1. Hierarchical earthquake risk assessment.

Building vulnerability is computed by integrating inherent system performance, *structural system*, e.g., shear wall or moment resisting frame buildings, and *structural deficiency*. The structural deficiency is subdivided into input parameters that contribute to an *increase in demand* and *decrease in resistance*. The parameters that contribute to an increase in demand are *vertical irregularity* and *plan irregularity*. On the other hand, the parameters that contribute towards the decrease in resistance are *construction quality* and *year of construction*. As indicated before, the parameters of building vulnerability are limited to those also employed by FEMA 154 (ATC, 2002).

Transformation

Some of the basic risk parameters are provided through linguistic quantifiers, e.g., *poor*, *average*, *good*, as in the case of construction quality, or *numeric values*, as in the case of year of construction. These non-commensurate input units cannot be aggregated to compute the corresponding index values. Therefore, the basic risk parameters have to be transformed into a commensurable unit, e.g., an interval of [0, 1], where “0” and “1” are considered to represent worst and best values, respectively. Once the transformed values are obtained in a logical and commensurable framework, they can then be aggregated. The RC building types considered in this paper are C1 (Concrete Moment Frame), C2 (Concrete Shear Wall Buildings) and C3 (Concrete Frames with Infill Masonry Shear Walls). For the three building types, two sets of Models are developed, denoted as *Model(C1)* for RC building type C1, and *Model(C2, C3)* for RC building types C2 and C3. Some of the transformation values are obtained through an optimization process as discussed in the next section. As a result, two sets of transformation values are obtained, which corresponds to the two sets of models. A sample set of transformation values obtained through training the 1994 Northridge Earthquake building damage database is shown in Table 1.

Table 1. Transformation values for computing building vulnerability.

Basic risk items	**Inputs**	**Transformation**	
		Model(C1)	**Model(C2, C3)**
Vertical irregularity	Yes No	0.42 0.70	0.30 0.90
Plan irregularity	Yes No	0.35 0.87	0.49 0.53
Construction quality	Poor Average Good	0.10 0.50 0.90	0.51 0.75 0.75
Structural System	C1 C2 C3	0.40 - -	- 0.90 0.60

The site specific seismic hazard is also quantified through the transformation of spectral values into a commensurable unit within an interval of [0, 1]. This can be done by selecting a suitable function that can encapsulate the physical significance of spectral values that define seismic hazard. A decreasing exponential utility function was selected to transform $S_a(T_1)$ as shown below;

$$\begin{cases} 0.99 & S_a(T_1) \le min \\ \dfrac{exp(-(max - S_a(T_1)) * \beta) - 1}{exp(-(max - min) * \beta) - 1} & min < S_a(T_1) < max \\ 0.01 & S_a(T_1) \ge max \end{cases} \quad (1)$$

where, the shape adjustment parameter β = -3.0; the threshold values for $S_a(T_1)$ are $min =$ 0 and $max =$ 1, and the transformed values vary between 0.01 and 0.99. The year of construction (YC) is transformed through a suite of linear functions representing major milestones in the code development process, which reflects the knowledge acquired during the period (Tesfamariam and Saatcioglu 2007):

$$\begin{cases} 0.90 & YC \le Low\ code \\ -0.016YC + 32 & Low\ code < YC < High\ code \\ -0.0147YC + 29.444 & YC \ge High\ code \end{cases} \quad (2)$$

where the *low*, *moderate*, and *high code* corresponds to the major milestones in the improvement of seismic design codes; low code $(YC \le 1941)$, moderate code $(1941 < YC < 1975)$, and high code $(YC \ge 1975)$.

Aggregation

The basic transformed risk parameters are aggregated through a hierarchical structure to obtain the final risk index. Different aggregation procedures are available. Examples include; minimum, product (also known as fuzzy t-norms), maximum, summation (also known as s-norms), and OWA operators. Detailed discussions of the selection of appropriate aggregation operators are given by Klir and Yuan (1995).

In a typical decision making scenario, the aggregated values vary between minimum and maximum values. The minimum type operator can be used for high risk structures where the decision maker has a risk-averse attitude. At the other extreme, the maximum type operator is attractive for low-risk structures, where there is more tolerance for damage and the decision maker has risk-taker attitude. The OWA operator is a compromising type aggregator that has the capability of varying between the extremes, providing a vulnerability score that is neither risk-averse nor risk-taker. Therefore, this method is more suitable if the resultant vulnerability scores are to be used in such decisions as the establishment of insurance plans where insurance companies seek a trade-off between extreme cases (Rashed and Weeks 2003).

OWA operators have been applied for multi-criteria decision support systems that involve civil engineering applications. Examples include vulnerability to earthquake hazard (Rashed and Weeks 2003) and urban water management (Makropoulos et al. 2003). A brief synopsis on the basic principles of OWA operators and OWA weight generation is discussed in the following sections.

OWA operator

Yager (1988) first introduced the ordered weighted averaging (OWA) operator as a general mean type aggregator. An OWA operator of dimension n is a mapping $OWA : R^n \rightarrow R$ (where R = [0, 1]) that has an associated n weighting vector $W = (w_1, w_2, \cdots, w_n)^T$. The requirements to be satisfied are; $w_j \in [0, 1]$ and $\sum_{j=1}^{n} w_j = 1$. For a given n input vector ($a_1, a_2, ..., a_n$), the OWA aggregation is performed as follows,

$$OWA(a_1, a_2, ..., a_n) = \sum_{j=1}^{n} w_j b_j \tag{3}$$

where b_j is the j^{th} largest element in the vector ($a_1, a_2, ..., a_n$), i.e., $b_1 \geq b_2 \geq ... \geq b_n$. The weights w_j of OWA are not associated with any particular value, a_j, rather they are associated with the ordinal position of b_j. The linear form of OWA provides a nonlinear solution (Yager and Filev 1999; Filev and Yager 1998). Yager (1988) further introduced two characterizing measures associated with the weighting vector W of an OWA operator, the concept of $orness$ and a 'measure' called dispersion, $Disp$. The $orness$ and dispersion are computed as:

$$orness(W) = \frac{1}{n-1} \sum_{i=1}^{n} w_i (n-i), \text{ where } orness \in [0, 1] \tag{4a}$$

$$Disp(W) = -\sum_{i=1}^{n} w_i \ln(w_i) \tag{4b}$$

The $orness$ characterizes the degree to which the aggregation is like an *or* operation. When $orness$ = 0, the OWA is like a *minimum* operator, and conversely, when $orness$ = 1, the operator is like a *maximum* operator. The measure $Disp$ provides a degree to which the information in the arguments is used and is bounded by $0 \leq Disp \leq \ln(n)$. When $orness$ = 0 or 1, the dispersion is "zero" and when w_i = 1/n (a uniform distribution), the dispersion is maximum, i.e., $\ln(n)$.

OWA weight generation

Various techniques are proposed for generating the OWA weights (e.g., Sadiq and Tesfamariam 2006, Xu 2005; Filev and Yager 1998). When there is enough data, the OWA operator can be generated through training (Filev and Yager 1998). The training has to be performed under the previously defined OWA weight constraints. However, to avoid one of these constraints on w_j, i.e., $w_j > 0$, the OWA weights are transformed and normalized using an exponential function (Filev and Yager 1998):

$$w_i = \frac{e^{\lambda_i}}{\sum_{j=1}^{n} e^{\lambda_i}} \qquad i = 1,2,...,n \tag{5}$$

where λ_i is an optimization parameter of the exponential function. With the transformation of w_j using Eq. (5), w_j becomes positive for all values of λ_i. Let's assumed that d_k is observed RC building damage state. Hence, the constrained minimization problem is transformed to the following unconstrained nonlinear programming problem:

Minimize the instantaneous errors e_k *with respect to parameter* λ_i.

$$e_k = \frac{1}{2}\left(b_1 \frac{e^{\lambda_1}}{\sum_{j=1}^{n} e^{\lambda_j}} + b_2 \frac{e^{\lambda_2}}{\sum_{j=1}^{n} e^{\lambda_j}} + \cdots + b_n \frac{e^{\lambda_n}}{\sum_{j=1}^{n} e^{\lambda_i}} - d_k \right)^2 \tag{6}$$

The above problem can be solved by the gradient descent technique. Filev and Yager (1998) discussed a detailed derivation of the above minimization problem. For this paper, this problem constrained minimization problem is implemented through an Excel Solver program. For simplicity, the optimization of coefficient of determination is performed through varying OWA weights and transformation values. The coefficient of determination is computed form the estimated I^{BD} values and observed building damage states (Fig. 2).

The optimization results for the 1994 Northridge data are summarized in Table 2. Table 2 shows the OWA weights for Model(C1) and Model(C1, C3). Also shown in Table 2 are the $orness$ and corresponding $Disp$ values. Summary of the $orness$ values at each node of the hierarchy reveals interesting observations. For the Model(C1), at the lower level of the hierarchy, increase in demand and decrease in resistance, the $orness$ values are quite high, > 0.80. This indicates, the operators are acting more as a *maximum* type operator. Conversely, the $orness$ at the higher level, structural deficient is quite low, < 0.2, which indicates it is working as a *minimum* type operator. However, For the Model(C2, C3), the reverse is true. The $Disp$ values of both models show that the building vulnerability has the highest value.

Case Study

The Northridge Earthquake with a moment magnitude M_w=6.7 struck the San Fernando Valley on January 17, 1994. Because of its proximity to communities in the Los Angeles basin, there was tremendous damage (EERI 1994). The Northridge earthquake has highlighted the importance of economic consequences of failure (Elms 2004). This earthquake and the ATC-38 (ATC 2001) building performance and strong motion data have been adopted for the case study presented in this section to demonstrate the application of the proposed risk-based assessment procedure.

Table 2. OWA weights for the computing building damageability index I^{BD}

	Increase in demand	Decrease in resistance	Structural deficiency	Building vulnerability	Building damageability
	Model(C1)				
OWA weights	(0.844, 0.156)	(0.891, 0.109)	(0.150, 0.850)	(0.688, 0.312)	(0.945, 0.055)
orness	0.844	0.891	0.150	0.688	0.945
Disp	0.433	0.344	0.422	0.621	0.214
	Model(C2, C3)				
OWA weights	(0.401, 0.599)	(0.587, 0.413)	(0.243, 0.757)	(0.102, 0.898)	(0.945, 0.055)
orness	0.156	0.109	0.850	0.312	0.055
Disp	0.290	0.241	0.138	0.363	0.160

Data reduction

The data reported by ATC-38 (ATC 2001) have been evaluated and reduced to assemble the required information to populate the hierarchical structure shown in Fig. 1. As discussed earlier, the building types considered were limited to C1, C2 and C3. These types of buildings in the database are divided into two categories; as having flexible or rigid diaphragms. However, no distinction was made in the current assessment procedure between the two since the diaphragm type is not considered as a risk parameter. "Discontinuous columns" and "plan setbacks" were used as a surrogate measure of the vertical irregularity, i.e. the presence of either indicates vertical irregularity. Similarly, "open front plan," "other torsional imbalance," and "plan irregularities" were used as a surrogate measure of plan irregularity. For a given fundamental period of structure T_1, the spectral acceleration $S_a(T_1)$ was obtained from the response spectrum reported in ATC-38.

Various damage index classifications are reported in ATC-38. The document classifies the prevalent damage states into 7 distinct stages. Of these damage states, the damage states "none" and "slight" were combined as "none-slight" (N-S), and major and destroyed were combined as "major-destroyed" (M-D) in this current assessment procedure. Consequently, five discrete levels of damage were defined: *none-slight* (N-S), *light* (L), *moderate* (M), *heavy* (H) and *major-destroyed* (M-D). The building damageability index I^{BD} was categorized into these five damage states.

Model development, validation and calculation of damage indices

The OWA model proposed for use as part of the risk-assessment procedure was trained using Excel Solver program as discussed in the previous section. Of the 93 sets of data available for RC buildings, 73 and 20 randomly selected sets of data were used for training (model development) and testing (model validation), respectively. For the 73 training sets of data, the transformation values and corresponding OWA weights are summarized in Tables 1 and 2, respectively. The I^{BD} values computed for the training sets of data and corresponding damage state are shown in Fig. 2. Fig. 2 shows with increasing damage state level, as expected, the I^{BD} values shows a decreasing trend. A linear best fit regression line is fitted through the computed I^{BD} values and corresponding observed damage state. Further, the regression line and damage thresholds shown in Fig. 2 are used for damage classification. The process of obtaining discrete damage states is as follows; (i) compute the I^{BD} value, (ii) select the appropriate building model, Model (C1) or Model (C2, C3), (iii) trace I^{BD} value on the y-axis of Fig. 2 and obtain the corresponding intersection point, and (iv) read the damage state. Validation of the proposed method is performed through the remaining 20 datasets (Table 3). Tables 3 shows values for the basic risk input items and corresponding actual and estimated building damage states. In general, there is a good agreement between the estimated and actual damage states.

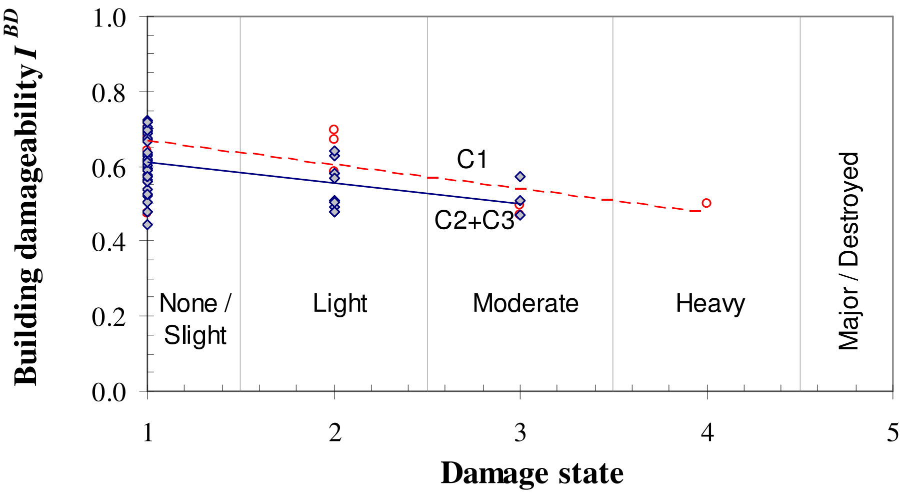

Figure 2. Northridge data building damageability index I^{BD} (model training).

Damage states and building importance/exposure information are used to determine the corresponding risk index I^{R}. The risk index values are computed using fuzzy rule base modeling as presented by Tesfamariam and Saatcioglu (2007). For ease of computation, results of the fuzzy rule based modeling can be presented as a risk contour index shown in Fig. 3 that entails use of building damage states and building importance index I^{BI}. These two indices can be computed through the same OWA aggregation technique.

For example, if Damage state = 3 (damage state "moderate") and I^{BI} = 0.6, from Fig. 3, it can be shown that the corresponding I^{R} = 0.52. The I^{R} values can be used for risk-based prioritization of buildings.

Conclusions

Central to the risk assessment and risk management is the decision maker's attitude. As such, any method developed in the quantification of earthquake risk has to reflect this phenomenon. In this paper, the decision maker's attitude is incorporated in the aggregation process using the OWA aggregator. A simple, yet intuitive hierarchical earthquake risk evaluation method is proposed and validated using observed states of damage. This method is flexible enough to incorporate new damage mechanisms.

Results of the proposed method show good correlation with observed damage, albeit extracted from limited data sets. However, in order to develop a generalized formulation, further investigation and calibrations with different databases are warranted.

References

ATC, 2001. *Database on the Performance of Structures Near Strong-Motion Recordings: 1994 Northridge, California, Earthquake*. Applied Technology Council, ATC-38 Report, Redwood City, California.

ATC, 2002. *Rapid Visual Screening of Buildings for Potential Seismic Hazard: A Handbook*. (Second edition), prepared by the Applied Technology Council, published by the Federal Emergency Management Agency, (FEMA 154 report), Washington, D.C.

Boissonnade, A.C. and Shah, H.C., 1985. *Use of Patter Recognition and Fuzzy Sets in Seismic Risk Analysis*. Report 67, Stanford, California: John A. Blume Earthquake Engineering Center.

Bruneau, M. and Lamontagne, M., 1994. Damage from 20th century earthquakes in eastern Canada and seismic vulnerability of unreinforced masonry buildings. Canadian Journal of Civil Engineering, 21: 643-662.

EERI, 1994. *Northridge Earthquake, January 17, 1994; Preliminary Reconnaissance Report*. Earthquake Engineering Research Institute, Oakland, California.

Elms, D.G., 2004. Structural safety-issues and progress, *Progress in Structural Engineering and Materials* 6: 116-126.

FEMA-249, 1994*. Assessment of the State-of-the-Art Earthquake Loss Estimation Methodologies*.

Filev, D.P., Yager, R.R., 1998. On the issue of obtaining OWA operator weights, *Fuzzy Set and Systems* 94: 157–169.

Ghobarah, A., 2000. Seismic assessment of existing RC structures, *Progress in Structural Engineering and Material* 2: 60-71.

Saatcioglu, M., Mitchell, D., Tinawi, R., Gardner, N.J., Gillies, A.G., Ghobarah, A., Anderson, D.L., and Lau, D., 2001. The August 17, 1999, Kocaeli (Turkey) earthquake—damage to structures, *Canadian Journal of Civil Engineering* 30: 715-737.

Sadiq, R., and Tesfamariam, S., 2006. Probability Density Functions based Weights for Ordered Weighted Averaging (OWA) Operators: An Example of Water Quality Indices, *European Journal of Operational Research*, doi:10.1016/j.ejor.2006.09.041.

Tesfamariam, S. and Saatcioglu, M. 2007, Risk-based seismic evaluation of RC buildings, to be submitted to *Earthquake Spectra*.

Makropoulos, C. K., Butler, D., and Maksimovic, C., 2003. Fuzzy logic spatial decision support system for urban water management, *Journal of Water Resource Planning and Management* 129: 69-77.

Miyasato, G.H., Dong, W., Levitt, R.E. and Boissonnade, A.C., 1986. Implementation of a knowledge based seismic risk evaluation system on microcomputers, *Int. J. of Artificial Intell.* 1(1):29-35.

Klir, G. J. and Yuan, B., 1995. *Fuzzy Sets and Fuzzy Logic: Theory and Applications*, Upper Saddle River, NJ: Prentice Hall International.

Rashed, T., and Weeks, J., 2003. Assessing vulnerability to earthquake hazards through spatial multicriteria analysis of urban areas, *International Journal of Geographical Information Science* 17(6): 549-576.

Xu, Z., 2005. An Overview of Methods for Determining OWA Weights, *International Journal of Intelligent Systems* 20: 843-865.

Yager, R.R., 1988. On ordered weighted averaging aggregation in multicriteria decision making, *IEEE Transactions on Systems, Man and Cybernetics* 18: 183-190.

Yager, R.R, and Filev, D.P. 1999. Induced ordered weighted averaging operators, *IEEE Transactions System Man and Cybernetics*, 29: 141–150.

Table 3. Northridge earthquake model validation data.

Building ID	Structural system	Building use	Number of stories	Spectral acceleration	Vertical irregularity	plan irregularity	Construction quality	Year of construction	Actual damage state	Estimated damage state
CDMG231-GZ-16	C1	S	6	0.37	N	N	Good	1966	2	1
CDMG579-SI-01	C1	O	9	0.40	Y	Y	Average	1924	1	4
CDMG231-ER-01	C3	S	3	0.54	N	Y	Good	1931	3	2
USGS233-GZ-16	C1	H	16	0.23	N	N	Good	1960	1	1
CDMG231-GZ-19	C3	S	3	0.37	N	Y	Good	1931	1	1
CDMG688-RE-04	C3	S	5	0.42	N	N	Good	1950	1	1
CDMG231-GZ-06	C2	S	4	0.54	N	N	Good	1950	2	1
CDMG231-GZ-11	C2	S	4	0.54	N	N	Good	1961	1	1
CDMG370-ER-10	C2	G	3	0.96	N	N	Good	1980	1	1
CDMG370-ER-12	C2	O	3	0.96	N	N	Average	1950	1	3
USGS233-GZ-15	C2	G	7	0.23	N	N	Average	1960	2	1
USC058-MB-11	C2	S	2	0.41	N	U	Good	1994	1	1
CDMG463-AC-07	C2	W	1	0.29	N	Y	Good	1940	1	1
CDMG303-JH-07	C2	RS	1	0.60	N	N	Good	1960	1	1
USC021-GTZ-02	C2	S	2	0.41	N	Y	Average	1930	2	4
CDMG231-GZ-14	C2	S	4	0.54	N	N	Good	1965	1	1
CDMG231-GZ-15	C2	S	5	0.37	N	Y	Good	1961	3	1
USC060-GTZ-01	C3	GV	1	0.41	N	N	Good	1970	1	1
USGS233-GZ-02	C3	O	3	0.94	N	N	Good	1950	1	2
CDMG231-GZ-02	C2	S	4	0.29	Y	Y	Good	1957	2	1

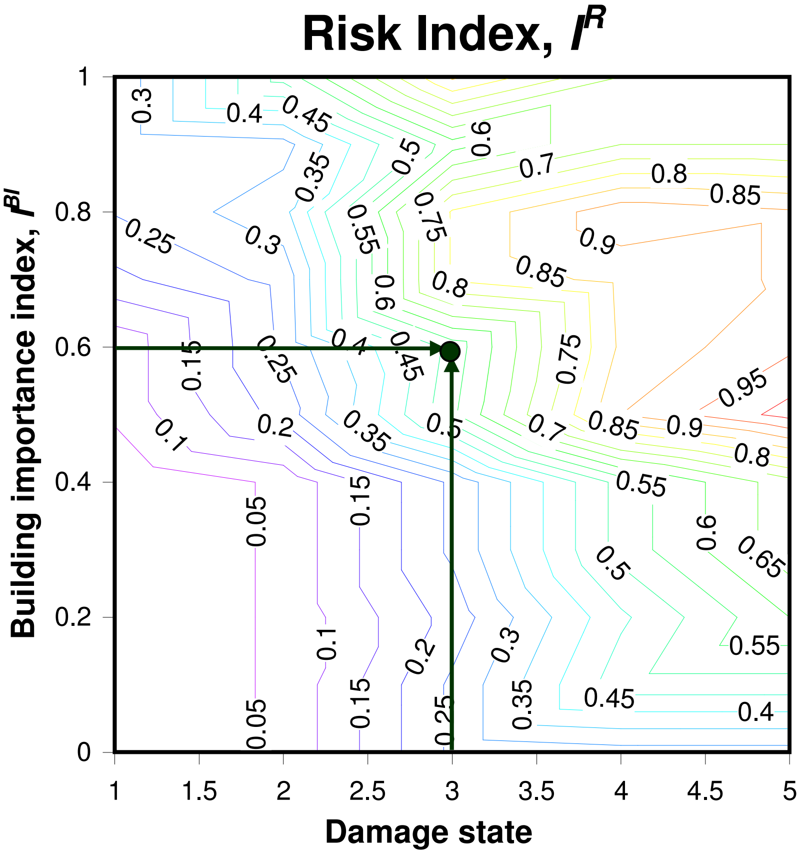

Figure 3. Risk contour index I^R.