EVALUATING OPTIMAL STRATEGIES TO IMPROVE EARTHQUAKE PERFORMANCE FOR COMMUNITIES

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SUMMARY

This paper describes a new multi-benefit based strategy evaluation methodology to will help stakeholders (resident, business, government agency) within a community identify optimal disaster management strategies, based on their individual priorities and available resources. Different types of strategies (technical, financial, recovery) are compared over various attributes such as costs, benefits (economic, life safety, recovery), and ease of implementation. A strategy's effectiveness is evaluated in terms of how it improves the stakeholder's disaster performance. This performance is represented in terms of a new Performance Index (PI), that depends on both the level of impacts and the recovery efficiency in a disaster.

Case studies are presented to compare the effectiveness of earthquake risk management strategies for residents in Los Angeles County, California, U.S.A. Results show that retrofitting is not always the most effective solution but combining this with insurance is attractive for both the residents and the insurance company. More mitigation is not always better and strategies have an optimal level of implementation related to number of residents.

INTRODUCTION

Disasters result from the combination of a natural event, its impacts, and a community's socio-economic vulnerability. An event such as an earthquake or hurricane cannot be prevented from occurring, but disaster management can reduce the impacts and/or the vulnerability through mitigation, preparedness, and recovery. The question that needs to be addressed is what combination of these strategies would be optimal.

The first problem that arises is to define what optimal is. In a general sense, an optimal strategy would be one that provides the maximum benefits at the minimum cost. The problem is, that desired benefits change with the type of event (hurricane or earthquake) and stakeholder (resident or business). The second difficulty is that even for given set of impacts that are of concern and a budget, it is still not simple to identify the best strategy because each strategy affects the various impacts to a different level.

The rationale adopted in the current study was to develop a stakeholder focused approach instead of a strategy or benefit based approach as past studies have done. The advantage is that it is a stakeholder who decides whether or not to invest in risk management, and each group of stakeholders is likely to have similar priorities, which makes it feasible to evaluate strategies. To deal with the issue of multiple benefits, a new integrated measure of strategy effectiveness is created.

A discussion of the general approach adopted and the development of the effectiveness measure is presented in the following sections. Two case studies to demonstrate the practical application of the methodology.

APPROACH ADOPTED TO DEVELOP THE MULTI BENEFIT METHODOLOGY

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Probably the biggest challenge in developing the multi-benefit methodology lay in representing the different qualitative and quantitative benefits by a single integrated measure that allowed a feasible comparison of strategy effectiveness for any natural disaster, stakeholder, and impact. The measure had to provide an intuitive understanding of stakeholder benefits and be based on data that is available or that can be feasibly derived.

Past approaches typically transform benefits into an economic measure for purposes of comparison, but face the dilemma of assigning an economic value to issues such as life safety. Moving away from this path, the current study adopts a more global approach of evaluating benefits in terms of the change in a stakeholder's overall ability to sustain and recover from a disaster situation. This approach is similar to those adopted in corporate risk management, where strategies are evaluated in terms of a global performance measure for a company, such as efficiency or profit, that reflect how well a business is performing relative to others. These measures integrate both quantitative factors like product sales and qualitative factors such as customer service. Using a parallel approach, disaster management strategies are evaluated in terms of their effect on the 'disaster performance' of a stakeholder, where 'performance' is governed by the impacts and recovery efficiency in a natural disaster. Though a new concept, 'disaster performance' can be considered analogous to indicators such as quality of life and the human development index that are global indices used to compare the living standard and level of development for cities. This 'performance' is represented on a Disaster Performance Index (PI) Scale. The approach behind the methodology of the PI is organized into seven main steps illustrated in figure 1 below.

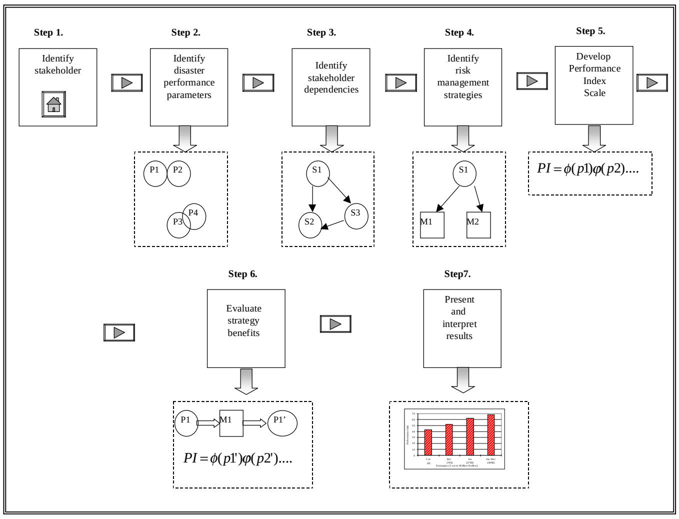

Figure 1.Approach for evaluating disaster performance to compare strategy effectiveness

Step 1: Identify Stakeholder Groups

The first step involves identifying the relevant stakeholder groups, defined as groups of people who are similar in terms of the types of impacts they suffer, their priorities for risk management, and the types of strategies to choose from. In the context of natural disasters, four primary groups are identified; Residents (homeowners and renters), Businesses (commercial and industrial), Lifelines (utilities and transportation), and Government agencies at all levels -federal, state, local).

Step 2: Identify Disaster Performance Parameters

In the second step, parameters affecting disaster performance for each stakeholder group are identified. The approach adopted was to select through an expert questionnaire survey, the critical factors for each of the four stakeholder groups. Experts surveyed included the following national and international groups

- Government Agencies – Federal Emergency Management Agency, Office of Emergency Services, United States Geological Survey, Association of Bay Area Governments
- Businesses – insurance and reinsurance companies, private corporations
- Lifelines – utilities

- Academia – engineers, economists, social scientists

Based on the survey results, disaster performance in general is found to depend on two primary components; the severity of impacts experienced in an event and the ability to recover. Impacts can occur in different forms such as injuries, physical damage, and economic loss. The recovery ability is driven factors like severity of impacts, pre-event preparedness, and socio-economic vulnerability. The survey also provided guidelines for likely mitigation priorities for the stakeholders. While multiple factors play a significant role in a stakeholder's disaster performance, not all can be incorporated into the current index. The omission results as a combination of difficulty in modeling a factor, lack of data, and the current aim to develop a simple though comprehensive index. Future improvements to the methodology will incorporate increasingly complex factors.

Step 3: Identify Stakeholder Dependencies

Within a community, each stakeholder group may be affected by the disaster performance of one or more of the other groups. For example a resident is affected by loss of power, which is linked to the performance of the Lifelines Group. Explicitly accounting for these interdependencies would make the strategy evaluation process unwieldy, thus in the current study this interdependency is accounted for in an indirect manner, in terms of the extent of impact reduction through mitigation by the indirectly affected group. For example, a dependant impact such as loss of power for a resident, will never be reduced completely by the resident since the loss is the responsibility of the utility company. But, a resident can partially reduce the extent of this impact through measures such as an emergency generator. However, because of the partial mitigation the resident's disaster performance will not be optimal. Dependencies currently accounted for are illustrated in the figure below.

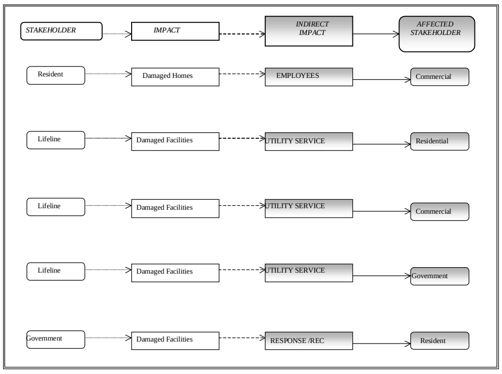

Figure 2: Stakeholder interdependencies

Step 4: Identify Stakeholder Risk Management Strategies

The choice of potential risk management strategies depends on the stakeholder and type of natural event. Strategies can be directed at one or more of the following targets; preparedness, mitigation, and recovery. Further, the type of strategy can be technical, financial, or informational/other. For illustration sample strategies for earthquake risk management are shown in the table below

Table 1: Examples of earthquake risk management strategies

Strategy / Stakeholder	Preparedness	Mitigation	Recovery
Residential	Earthquake Kit (IO)	Retrofit (T)	Insurance (F)
Commercial	Earthquake Kit (IO), Employee Training (I)	Retrofit (T)	Insurance (F)
Government	Employee Training (I)	Retrofit (T)	Insurance (F)

Step 5: Develop Performance Index (PI) Scale Values

Since the types of parameters contributing to disaster performance will vary in different situations, it becomes necessary to standardize the process of index development. Based on the results of the questionnaire survey described earlier, the PI is developed as a combination of two sub-indices, disruption and recovery efficiency. Disruption represents the severity of the impacts and is assumed to depend on three loss factors; economic, human, and lifeline. Recovery efficiency reflects the time to recover from the disruption to at least a pre-event level and is evaluated as a function of pre-event preparedness and socio-economic vulnerability.

The PI is developed on a scale of zero to hundred, with a higher score representing better disaster performance. The low limit (0) corresponds to a worst case scenario event, while the high end (100) corresponds to a situation of no disruption (or loss). This choice for the high end was made to allow for the fact that over time, more effective strategies may be developed that will continue to improve stakeholder disaster performance as knowledge in this area and/or willingness to invest in risk management increases. Disruption and Recovery efficiency are also evaluated on a scale of zero to hundred. With rising losses, disruption increases, and with growing recovery time, efficiency decreases.

The extreme scale values need to be developed before any other analysis is carried out. A worst case scenario will again be different for each stakeholder and event type. A comprehensive approach would involve identifying a worst case scenario from all possible event and stakeholder combinations.

The index can be applied to deterministic scenarios and probabilistic analyses. The former approach allows strategies to be tested against specific worst case events, while a probabilistic analysis allows benefits to be compared on an annualized level and from a decision-making viewpoint this may be more appealing since this is the basis on which budget allocations are typically performed. The choice of which approach to use in developing the index depends on the risk management goals; preparing for a worst-case event, comparing annualized mitigation benefits, or evaluating benefits related to specific loss or recovery factors.

The mathematics behind the methodology for developing the index is described in a later section of the paper.

Step 6: Develop Post Strategy Implementation Index Values

Once the extreme index values are developed, the current disaster performance score for each stakeholder group can be evaluated and it represents the situation of doing nothing. A risk management strategy improves performance by reducing disruption, improving recovery efficiency, or both. Effectiveness of a strategy is evaluated based on the relative change in PI scores (pre and post strategy implementation), which is derived from the change in the component factor scores. The amount of these changes depends on the benefits derived from strategy implementation. Some quantitative work has been carried out in the past to estimate potential benefits from select mitigation strategies such as retrofitting and insurance. The current study integrates results from these studies. Additional information on this step is presented later.

Step 7: Present and Interpret Results

The final step in the approach is the presentation and interpretation of results. The PI has been developed as a relative rather than absolute scale. i.e., benefits from strategies are compared relative to each other. For example, one would be able to compare how strategy A affects overall performance or its component factors, relative to the change in those factor values because of Strategy B or to the do nothing (current) case. Similarly, the current case performance score could be compared to specific past event scores such as for the Northridge earthquake. This would provide an understanding of the relative change in performance compared to an event a community has experienced. The process of selecting a strategy is developed in a format similar to a decision tree analysis as shown in the figure below. Benefits from various strategies are integrated into the Index development process. The stakeholder then chooses where to allocate resources based on the cost and priorities; overall performance, disruption, recovery efficiency, or one of the factors. For ease of application, results are presented graphically in Strategy Effectiveness Charts (SEC), the format of which varies with the types of information to be included. Sample charts are presented in the case studies.

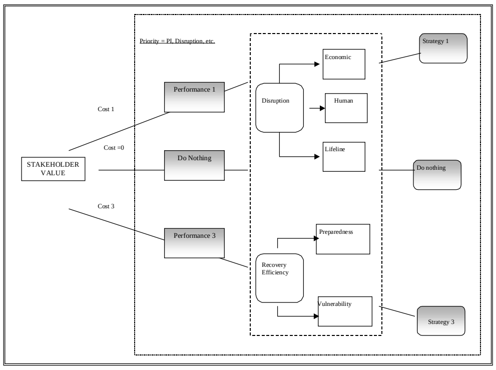

Figure 3. Decision tree for resource allocation

METHODOLOGY TO EVALUATE THE PI SCORES

The Index score is developed in three stages, each of which is described briefly below.

1. Data for each of loss and recovery factor is gathered for the stakeholder being considered. This data includes loss values for the disruption factors and data for parameters affecting recovery efficiency

2. The factors are combined into a disruption and recovery efficiency score

3. The two components are integrated into a global Performance Index Score

Stage 1: Collect Factor Data

Different sources are used for data collection such as the census and loss estimation models. Specific data incorporated from the models for disruption factors are listed below. Regional losses are attributed to specific stakeholders based on the occupancy types of the structures. For example, all losses related to residential structures are ascribed to residents.

- Economic loss – structural, non-structural, and content loss to different occupancy types

- Human loss – casualties in different occupancy types of buildings, displaced households

- Lifeline loss – time for which a utility may be out of service and projected repair time

The situation is slightly more complex for the recovery efficiency sub-index since data for recovery time is not available through generic software and is very event dependant. To deal with this, recovery time is assumed to be proportional to the level of preparedness and vulnerability. Data used to represent these are listed below

- Preparedness – this reflects the degree to which a stakeholder has made preparations in the pre-event period to recover from the disaster, for example through training, a recovery manual, an earthquake kit, insurance, government response efficiency.

- Vulnerability – this is defined by stakeholder characteristics, such as age of a homeowner and dependency on other sectors

Stage 2: Develop Disruption and Recovery Efficiency Scores

To incorporate the various parameters into the disruption and recovery scores, a normalization technique was developed to map the absolute values of the parameters onto scaled values from zero to hundred. The normalization is carried out to deal with three problems. First, the parameters have different units of measurement such as dollar loss and time without electricity. Second, the parameters have different scales of magnitude, for example, total economic loss and number of people injured. Third, a greater loss does not necessarily translate into a greater risk, since loss depends both on the vulnerability and value.

The aim of the disruption sub-index is to provide an understanding of the severity of the loss rather than simply represent absolute loss magnitude. This is an important distinction because it is the magnitude of the loss relative to the sustaining ability that is critical. For example, a $ 10,000 loss on a $1,000,000 home is much less severe than on a $100,000 home. The approach used to normalize each sub-index factor is discussed below.

Disruption sub-index

The disruption score (D) is developed as a linear combination of the three loss factors as shown in equation (1). The alphas are weights of relative importance and add up to hundred percent. These can be varied based on the priorities of a decision-maker. For example for a homeowner, the decision to invest in a mitigation strategy may depend only on life safety, i.e. α_2=1. The E, H, and L represent normalized loss values for economic, human, and lifeline loss. The normalization is carried out in two stages. First the factor is converted to a unitless scale independent of magnitude, and then modifying factors transform the scaled value into a severity loss factor.

$$D = \alpha_1 E + \alpha_2 H + \alpha_3 L \quad (1)$$

The unitless scaling is performed by simply dividing the loss parameter by exposure value. The second step is more involved and deals with scaling the unitless value to represent an impact severity. This is done through modification factors with a value relative to the average stakeholder group value (Equation 1.1). For example, a resident with a low income will be affected more than one with a higher income.

$$E, H, L = \left(\frac{E, H, L_{loss}}{E, H, L_{\exp osure}} \right) \varphi \left(\prod_{i=1}^{n} m_i \right) \quad (1.1)$$

$X_{exposure}$ = total property value, number of people, number of pipelines/transmission stations etc. depending on the loss parameter; m_i's = modification factors (annual revenue, savings etc.)

Recovery Efficiency sub-index

The recovery efficiency score (R) is a more qualitative component of performance than disruption. It is developed as a linear combination of the two factors as shown in equation (2). The betas are treated in the same way as for disruption. For example for a state policy-maker, the decision to invest in a mitigation strategy may be governed by improvement in response efficiency which depends on preparedness, i.e. β_1=1. The P and V represent normalized recovery values for preparedness and vulnerability and are developed as aggregated scaled values of their component parameters (Equation 2.1). The scale for each parameter is developed based on expert opinion and the actual parameter value such as amount of insurance is assigned a value on that scale. The aggregate values represent levels of the P and V, while the final R provides an indication of recovery time.

$$R = \beta_1 P + \beta_2 V \quad (2)$$

$$P, V = \sum_{i=1}^{n} e_i W_i \quad (2.1)$$

e_i = relative weight of the attribute representing preparedness or vulnerability, in terms of its effect on recovery; W_i = score of the attribute based on its relative value (i.e., amount of insurance relative to property value)

Stage 3: Develop Performance Index (PI) Scores

The PI is inversely proportional to Disruption (D) and directly proportional to Recovery Efficiency (R) (Equation 3). These scores may be developed for single scenarios or multiple scenarios. In the latter case, PI values over different scenarios are aggregated linearly using the normalized probability of occurrence (probability for that event divided by the total probability of occurrence of all events considered) as the weight.

$$PI = \phi(D) + \varphi \left[R \left(\frac{1}{\theta(D)} \right) \right] \quad (3)$$

The low end of the PI scale corresponds to a worst case scenario event. Data from this event is used to develop the scaling parameters in the various relationships so that D=100, R=0, and PI=0. This scaling then provides the basis for carrying out other analyses. For more details on the methodology, refer to Gupta, (1997).

METHODOLOGY TO EVALUATE STRATEGY BENEFITS

Strategy benefits for a stakeholder are incorporated in terms of the changes in the performance index factors. The effect on performance is evaluated based on four parameters; the level of investment, number of parameters affected, the amount by which they are affected, and percentage implementation. For example, if a resident invests in non-structural retrofit techniques, they will affect economic loss and life safety, and thus indirectly improve recovery also. For each strategy a detailed 'effect table' is prepared to represent the parameters it affects and the amount by which it affects them. Data in these tables is derived from a combination of past studies and expert opinion. More detailed technical tables, such as changes in specific fragility curves for buildings can also be used. A sample table for a resident carrying out structural retrofitting is illustrated below. Once the factor values are modified, a revised PI score is evaluated as described in the previous section.

Table 2: Strategy effects

Type of structure/parameter	Cost ($ / sq. ft.)	Structural damage reduction	Content damage reduction	Life safety risk reduction
1940 wood frame – single family	12	20%	35%	1/30
1940–1960 concrete -multi family	9	25%	30%	1/20

RESULTS FROM THE CASE STUDIES

An analysis is carried out for residents in Los Angeles County, California by evaluating their performance over nine earthquake scenarios (Newport Inglewood 7.0; Santa Monica 7.0, 7.5; San Gabriel 7.5; Sierra Madre 7.0; Verdugo 6.8; and San Fernando 6.0, 7.0, 7.5). A time horizon of 20 years is used and scenario losses are generated using the program HAZUS (RMS 1997). Three strategies are compared; retrofitting, insurance, and earthquake kits. Three levels of retrofit are used; low, moderate and high. These vary in the amount of structural and non-structural retrofit. Three insurance policies are evaluated;10% deductible, California Earthquake Authority (CEA) policy with 15% deductible and limited content coverage, and 3% deductible with a 15% limit.

Study 1: Identifying Optimal Strategies For Residents

Concerns for residents include property damage, life safety, loss of utilities, displaced households, and recovery efficiency. Results are developed for the resident group as a whole. The average pre mitigation PI score over the events considered is about 47 (Northridge score = 66). To improve this performance, a strategy could be chosen using an SEC presented in figure 4a. The value of the marginal improvement in PI (ΔPI/cost) is illustrated along the vertical axis and the strategy cost on the horizontal axis. It should be noted that costs are modified by the likelihood of implementation (value shown in brackets). In general while retrofitting improves performance, the CEA policy is not effective because of its high cost (Note also that retrofitting affects life safety while insurance does not). High retrofit (HR) seems the most cost effective, but only if focused on the most vulnerable residents. Combined insurance and retrofit (NI+LR) however, is the next most cost effective at a high implementation level. Moderate retrofit (MR) and the 3% policy (NI) also have good scores. Benefits from low retrofit (LR) are significant compared to the level of investment involved. Earthquake kits (EQK) are a cheap alternative likely to be implemented by many residents, and may be used in conjunction with another strategy. The choice of a strategy may also be made based on one or more of its sub-index factor scores.

Study 2: Optimal Strategies Policy-Makers Should Encourage in Los Angeles County

The first case study illustrates that each strategy may be associated with an optimal level of implementation, not necessarily 100%. Results on strategy effectiveness for different implementation levels are shown in the SEC of

Figure 4b. The horizontal axis illustrates different strategies, while the vertical axis corresponds to marginal change in performance. Two sets of columns are shown for each strategy. The left column corresponds to expected implementation (shown in brackets), while the right column corresponds to 100% implementation.

The SEC illustrates that benefits in general increase with higher levels of implementation, though not in proportion to the rise in costs. Thus, decisions based on 100% implementation levels may not always be the best. HR is effective when focused on the most vulnerable groups (about 10% of residents). But as implementation rises, the increase in performance is much lower than the corresponding increase in costs. Comparatively, MR and LR are better to encourage since the increase in benefits is somewhat proportional to the change in costs. An interesting feature is that the results inherently account for indirect mitigation benefits. For example, if more residents implement LR, there will be lesser demand for response, and thus government efforts will be better. A higher implementation level for NI is more effective than for OI. The effectiveness of the CEA policy actually decreases as more people implement it, simply because it is effective only for the high risk groups. For EQK however, benefits increase almost proportionately with implementation, and this is a strategy that should be encouraged. This SEC could be used by a policy maker to choose what strategies should be encouraged, which ones should financial incentives be provided for, and which ones should be focused only on vulnerable groups.

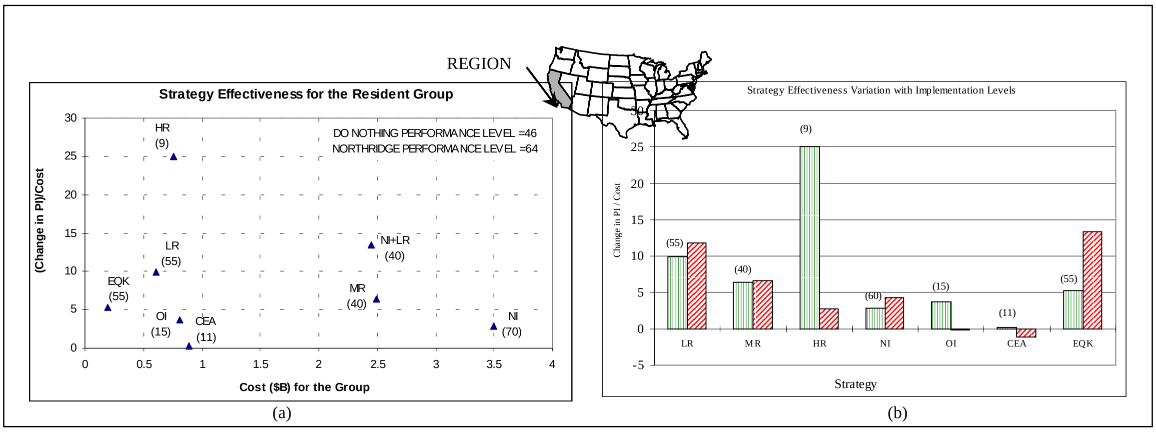

Figure 4: Case Study Results

CONCLUSIONS

A major problem hindering disaster management efforts is the difficulty in identifying optimal strategies to improve community resilience. This paper presents a new multi-benefit methodology that compares strategies using the approach of improving stakeholder '*disaster performance*'. A Performance Index (PI) is developed to compare strategy effectiveness and it incorporates different impacts, recovery problems, and socio-economic vulnerability. Results are presented in Strategy Effectiveness Charts (SEC) that compare the effectiveness of strategies (preparedness, mitigation, recovery) based on the stakeholder's priorities and resources. As a case study, the methodology is used to compare earthquake risk management strategies for residents. The results present interesting conclusions. First, contrary to popular belief, retrofitting all buildings is not the best solution in all cases. Second, since performance does not always increase proportionately with the level of investment, more investment in mitigation does not necessarily mean more benefits. Third, combining retrofit and insurance can prove to be attractive to both residents and insurers. Finally, mitigation activities focused on low performance groups provide the maximum benefits in terms of improving a community's performance. This paper aims to encourage readers to think about natural disasters with a new perspective (community performance) and suggests one solution to the problem of identifying optimal risk management strategies. The methodology is intended to be a first step towards multi-hazard risk management approaches.

REFERENCES

Gupta, A.(1997), "Performance Based Strategy Evaluation Methodology for Earthquake Risk Management", *The John A. Blume Earthquake Engineering Center, Report No. 122. Stanford University, Stanford, California.*

Risk Management Solutions Inc. (1997), "HAZUS 1997: Earthquake Loss Estimation Methodology", Technical Manual, *Volume I, II, & III, Prepared for the National Institute of Building Sciences*