A RISK MANAGEMENT MODEL FOR INTER-CITY ROAD SYSTEMS

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ABSTRACT :

Seismic risk reduction for the intercity road systems, as the necessary tools for emergency response activities and reconstruction purposes in the aftermath of major earthquakes is of great importance, particularly for those countries which suffer form lack of widely spread reliable transportation networks. Regarding the possibility of complete blockage of the road because of extensive damage to either the road's body or to the road's key structural components on the one hand, and decision-making possibility of the people who use or are transferred in the road, as a lifeline (in the contrary to other lifelines which transfer a lifeless product) on the other, the risk evaluation and mitigation of the road systems are much more complicated than other lifelines. In this paper at first the effect of these features on the risk management process are thoroughly discussed, then a risk management model is introduced in which features on which the importance of a road in the transportation system of a county depends, as well as parameters affecting the road function in the aftermath of a major earthquake, are taken into consideration. The proposed risk management model is engaged with complete studies on 'road body' and 'its structural components'; definition of time- and user-dependent earthquake scenarios; and evaluation of earthquake economic losses. The proposed model is applied to Iran intercity road system and a prioritization scheme is suggested, which can be used by the authorities for budget assignment to various provinces of the country for seismic upgrading of the road system.

KEYWORDS: Risk Assessment, Road Service Area, Passenger and Cargo Transfer Capacity

1. INTRODUCTION

The intercity road systems are of essential use for rescue and relief, aid delivery, temporary settlement and reconstruction purposes in the aftermath of major earthquakes. The adverse effect of weak performance of roads on response and restoration activities has been proved in past earthquakes. The lack of efficiency of Kerman-Bam road because of Bam earthquake of 2003, which caused very long travel times of about 13 hours instead the 2.5-hour normal travel time, and the complete blockage of Chaloos road for several weeks because of Firoozabad Kojoor (Baladah or Kandovan) earthquake of Summer 2004, which resulted of very big economical impact to the people who used to use that road as their main transportation way(Iran Ministry of Road and Transportation, 2004), and finally, the blockage of Zarand-Dahooeiyeh road in Zarand, Kerman earthquake of Winter 2004, which hindered the response activities for several hours (IIEES Website, 2004), are just three samples which show the vital role of intercity road systems in increasing the casualty level and indirect losses of earthquakes. Similar situations had been observed in Chi-Chi, Taiwan earthquake of 1999 (NGDC, 2006). Therefore, seismic risk evaluation and reduction for these systems is of very great importance, especially for those countries, such as Iran, which do not have enough equipment and infrastructures and are suffering form lack of widely spread reliable transportation networks.

In spite of the high importance of intercity road system they have not taken into consideration by authorities as much as other transportation systems, and very few studies have been performed on the risk evaluation and reduction of these systems, and the available publications with regard to risk are mainly focused on the highway systems. For example, as one of the first works on the subject of risk assessment for highway transportation systems, Basoz and Kiremidjian (1996) have performed a study, in which a risk assessment methodology has been developed for lifeline systems. Their methodology is supposed to serve as a tool in the decision process for:

(i) retrofitting of critical structures in the system as a means of pre-disaster mitigation, (ii) pre-disaster emergency response planning, and (iii) emergency response operations immediately after a disaster. The objective of that study has been to assist in such decisions for minimizing life and dollar loss due to damage from natural or man-made hazards. Their methodology is based on vulnerability and importance assessment of the components in the system. They have employed hazard analysis, structural classification schemes, and fragility analysis to assess the vulnerability criterion for each component. The importance of a component has been assessed through network analysis and decision analysis methods. The network analysis methods have been used to assess the impact of damaged components on the system functionality. They have integrated the engineering, economic and social factors using decision models based on multi-attribute utility theory. While the concepts of their methodology are applicable to lifeline systems in general, the details have been developed for highway transportation systems subjected to earthquakes.

Basoz and Kiremidjian (1997) have also accomplished a study on risk assessment of bridges and highway systems from the Northridge earthquake, in which they have developed a risk assessment methodology for highway transportation systems based on vulnerability and importance criteria. As part of the vulnerability assessment they have proposed new bridge classes and new damage states for components of concrete bridges. Bridge damages observed in the Northridge earthquake have been analyzed to identify structural characteristics that correlate well with the observed damage. Then empirical fragility curves have been developed for bridges grouped by these structural characteristics. The observed damage data have been also compared to the available ground motion-damage relationships. They have discussed on the importance criterion for emergency response planning and management applications.

In the continuation of their studies Basoz and Kiremidjian (1998) have been modified and completed the aforementioned risk assessment methodology, developed for highway transportation systems, to serve as a tool in the decision process for emergency response management. In their modification they have developed some algorithms for connectivity analysis for emergency response (CAFER) and serviceability analysis, and have used them to determine accessibility of the disaster areas, available routes to the disaster areas, travel time delays and socioeconomic impacts.

With regard to risk management, studies have been performed mainly on hazard estimation as a prerequisite for risk management. For example, Brabhaharan (2000) has worked on earthquake ground damage hazard studies and their use in risk management in the Wellington region, New Zealand [5]. Mentioning hazard identification, awareness, vulnerability and risk assessment, mitigation and preparedness as important factors in reducing the risk from earthquakes, he has illustrated the assessment of ground damage hazards such as liquefaction and slope failure. He has used GIS mapping for a thorough study on the Wellington region of New Zealand to consider the effects of earthquakes on lifelines, commercial and residential complexes and infrastructures. He has stated that assessment of the risk to lifelines such as water supply, telecommunication and road networks helps manage the risk through prioritization and mitigation or planning for emergency preparedness. He has also claimed that risk-economic assessment is a valuable tool in this process.

Another example of the studies on risk management is the research performed by Savage (2000) on lifeline application of seismic zonation , which is again mainly with regard to hazard evaluation. Savage has notified that the integration of seismic hazard zonation maps with lifeline maps to improve earthquake risk management of lifelines (utility and transportation systems) takes logical advantage of their shared geographically distributed nature. Then he has identified several issues that are critically important in making such integration practical and effective, from the owner's perspective. His first claim is that individual earthquake scenarios, not multi-earthquake hazard maps, must be used in analyzing the possible damage and the impact on lifeline functionality caused by an earthquake. He has claimed that redundancy and other operational aspects of lifelines typically can accommodate some damage without reducing functionality, and this effect can only be evaluated in a scenario manner. Secondly he has stated that the current zonation assessment of ground failure hazards must be improved as a basis for analyzing earthquake damage and functionality of a ground-based or buried lifeline network. He has pointed out that maps of the distribution and amount of ground deformation for scenario earthquakes are needed. He has noted some progress in getting beyond the oversimplified "damage-per-mile" parameter to relate damage to degree of ground deformation as a function of soil type, water table, ground shaking parameters, and slope. Finally he has claimed that seismic zonation maps can provide only general indications of potential hazards and are not adequate for site-specific design. Based on his claim seismic shaking zonation maps can serve only as a basis for developing simplified design specifications for component manufacturing or standardized lifeline elements. In summary, he has stated that it is important for lifeline owners and operators to understand their needs for earthquake hazard information, and to use the current seismic zonation products wisely.

Shinozuka and his colleagues (2000) have studied damage assessment of the expressway network in Los Angeles County and Orange County in California during the 1994 Northridge earthquake under scenario earthquakes for emergency response decision support. They have suggested the use of Bridge Damage Index (BDI) and Link Damage Index (LDI) for damage assessment of expressway network. The values of BDI is between 0 and 1 depending on the level of damage, and the LDI value is calculated by SRSS rule as:

$$LDI = \sqrt{\sum_{j=1}^{JI} (BDIJ)^2} \tag{1}$$

They have suggested Table 1 for obtaining the link damage state based on the bridge damage indices.

Table 1. Link damage state based on bridge damages

Link Damage State	**Link Damage Index**
No Damage	LDI < 0.5
Low Damage	0.5 ≤ LDI < 1.0
Moderate Damage	1.0 ≤ LDI < 1.5
Heavy Damage	LDI > 1.5

It should be noted that there are two shortcomings in the above method. First, using the SRSS combination rule can not take into account the states in which a complete collapse of a bridge has happened as a heavy damage state of the link, since if one bridge collapses in a link and other parts of the link remain almost intact, by considering a value of 1 for damage index of the collapsed bridge and values around 0 for other components, the LDI value, calculated by Eqn (4) will be around 1.0, which means moderate damage of the link. This is while the real damage state is heavy because of the collapsed bridge which has completely cut the link. Secondly, if several bridges in a link get just minor damage, having a damage index between 1.0 and 1.5 the LDI value may become more than 1.5 which means heavy damage to the link, while in fact the link is quite usable.

Hosseini and Yaghoobi (2002) have notified that there are two major differences between road systems and other lifelines: 1) the possibility of complete blockage of the road because of extensive damage to either the road body (the embankment), or landslide in trenches, or the road’s key structural components such as bridges, tunnels and culverts, while other lifeline systems are not usually totally interrupted, and can benefit from the existing redundancy, and 2) decision-making possibility of the people who are transferred by the road, as a lifeline, in the contrary to other lifelines which transfer a lifeless product such as oil, gas, or water, which makes the risk evaluation and mitigation of the road system much more complicated. They have then discussed that the risk management program can consist of four main parts: a) Identification and classification of natural and man-made hazards, and determining their occurrence probabilities for roads, b) Determining the prevention methods, including the hazard avoidance as well as vulnerability reduction ways, c) Creating the risk exposure plans based on the estimated risk value by using the hazard and vulnerability probabilities, and finally, and d) Developing the crisis management program to minimize the adverse consequences of hazards in damaged areas

In this paper a model is proposed for risk management of inter-city road systems which is engaged with: a) complete and overall studies on two main parts of each road, namely ‘road body’ and ‘its structural components’, b) definition of time- and user-dependent earthquake scenarios, and c) evaluation of earthquake economic direct and indirect losses. The proposed model have been applied to Iran intercity road system and a prioritization scheme has been suggest on this basis, which can be used by the authorities for budget assignment to various provinces of the country for upgrading the road system.

2. RISK, HAZARD, AND VULNERABILITY

Several definitions have been proposed by scholars for the concept of risk in relation with hazard and vulnerability since early 80s (Shah, 1984) to recent years (Hosseini and Yaghoobi, 2006). Davidson (1997) has proposed an urban earthquake disaster risk index (EDRI), based on the concepts of hazard (H), exposure (E), vulnerability (V), external context factors (C) and response situation (R), as the main variables, and giving a weight to each of these, as:

$$EDRI = w_H H + w_E E + w_V V + w_C C + w_R R \tag{2}$$

In Eqn (2) each of the main variables is calculated by combining its components and their weight factors. For example, H, which is the hazard, can be calculated by:

$$H = w_{H1}X_{H1} + w_{H2}X_{H2} + w_{H3}X_{H3} + w_{H4}X_{H4} + w_{H5}X_{H5} + w_{H6}X_{H6} + w_{H7}X_{H7} \tag{3}$$

Regarding the various nature of the incorporating data Davidson has suggested the following scaling.

$$x'_{ij} = \frac{x_{ij} - (\bar{x}_i - 2s_i)}{s_i} = \frac{x_{ij} - \bar{x}_i}{s_i} + 2 \tag{4}$$

In Eqn (4) x'_{ij} and x_{ij} are respectively scaled and un-scaled values of variable i in city j, a bar on x_i means the mean value of that variable and s_i is the standard deviation of that variable. Davidson has used the expert views for the values of weight factors.

Ashby (2002) in his paper entitled ‘Development of a Risk Management Strategy for Part of State Highway 73 in the South Island of New Zealand’ gives the following formula for risk calculation.

$$R = P(H) \times P(S:H) \times P(T:S) \times V \times E \tag{5}$$

In Eqn (5) P(H) is the hazard probability, P(S:H) is the probability of occurrence of hazard in the considered area, P(T:S) is the probability of hazard occurrence when the considered system in the considered area, V is the vulnerability of the system, and E is the exposure factor.

In spite of various definitions and formulation proposed by scholar for risk, the UN/ISDR (2004) has suggested to use the following general simple formula for calculating the risk.

$$R = \text{Hazard} \times \text{Vulnerability} \tag{6}$$

Hosseini and Yaghoobi (2006) have introduced some key issues on seismic risk evaluation of intercity road systems for road authorities:

1. The design of the network as a redundant system so that access can be maintained even if one or more links are cut. This redundancy may be in the form of a combined transportation, like road and railway, and/or road and airport or helipad especially for hazardous routes.
2. The establishment of design and construction standards, which consider risk concepts to provide a “robust” system which is not easily damaged. Risk concepts must consist:
    a. Complete and overall studies on two main parts of each road; road body such as pavement, embankment, trenches, etc. and structural components such as bridges, tunnels, culverts, etc.

b. Definition of time- and user-dependent earthquake scenarios
c. Evaluation of earthquake economic losses with the most possible precision. These losses include direct and indirect damages like short- and long-term economic consequences, death and injury losses of people. In this evaluation, people must be classified by their education, age, professions, cultural values, importance in emergency response activities, etc.

3. Preparing the zonation maps based on the faults not the political and geographical boundaries
4. Establishing an international NGO for post-earthquake activities, whose members can do joint studies and communicate with each other without any limitations.

3. QUICK RISK ASSESSMENT METHOD

The proposed benefits form a somehow new concept for roads, the 'road service area', which is defined based on a major origin-destination pair and their surrounding industrial, cultural centers, or the centers of any type of economic activity as shown in Figure 1.

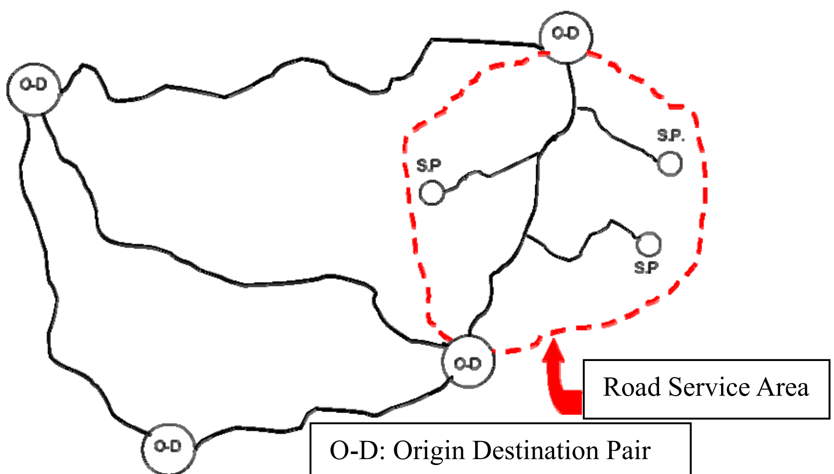

Figure 1. Road service area and its components

By using this concept, each country cab be divided into some "road service areas" and then these areas can be prioritized based on various parameters, including hazard, vulnerability, and the transportation service presented in each area. For this purpose the risk of service area Q can be calculated by giving a weight factor to each parameter as:

$$R_Q = \sum_{1}^{n} Factor \times Weight_{Factor} \tag{7}$$

in which Factor, $Weight_{Factor}$ and n are respectively the incorporating factors or parameters, their weights and the number of parameters. Then by combining all contributing parameters with their associated weights an importance ratio can be calculated for each "service area" based on which the prioritization can be performed. For scaling the incorporating parameters the following formulas can be used.

$$x'_{ij} = \frac{x_{ij}}{\max obs_i} \tag{8}$$

$$x'_{ij} = \frac{(x_{ij} - \min obs_i)}{(\max obs_i - \min obs_i)} \tag{9}$$

where x'_{ij}, x_{ij}, are respectively the scaled and un-scaled values of parameter i in service area j, and $minobs_i$ and $maxobs_i$ are minimum and maximum values of the parameter i. Since at present the service areas have not been defined for roads in Iran, and the statistical data have been prepared based on provincial division of the county, the provinces can be used instead of service area by using the following simple formula.

$$R_{Q(I)}(Link) = \sum_{k=1}^{2} R_{Q_k} \times QRAWF_k \tag{10}$$

in which $R_{Q(I)}$(Link) and QRAWF are respectively the initial value and the weight factor of parts 1 or 2 of a link between two central cities of the two adjacent provinces.

The parameters which are used in the risk calculation are of two kinds. One kind is related to seismic hazard and vulnerability, and the other is related to transportation service. The main parameters with regard to seismic hazard and vulnerability in each "service area" can be divided into following categories:

- The relative length of the road
- The relative number of key structures of the road
- The average number of key structures per kilometer
- The relative length in high seismic hazard zone
- The relative number of key structures of the road in high seismic hazard zone

Also, the main parameter with regard to transportation services in each "service area" can be divided into the following categories:

- The relative population
- The percentage of displaced passenger
- The percentage of displaced cargo
- The geographical conditions

4. APPLICATION OF THE PROPOSED METHOD TO IRAN

The proposed "Quick Risk Assessment Method" has been applied to Iran road system, however, as the "service areas" have not been defined yet for roads in Iran, the provincial divisions have been used instead. Table 2 shows the prioritization factors or risk indices obtained by the proposed method for the provinces which have had the highest risk indices, based on hazard parameter and lengths of the road segments in adjacent provinces.

Table 2. Prioritization factors obtained by the proposed method for provinces with highest risk indices

Name of Province	Risk or Prioritization Index
Tehran	0.71
Mazandaran	0.58
Khorasan Razavi	0.57
Kermanshah	0.54
Eastern Azerbaijan	0.54
Fars	0.53
Khuzestan	0.53
Qazvin	0.52
Gilan	0.52

More results of quick risk calculations by using other parameters can not be given here because of lack of space, and can be found in the main report of the study (Yaghoobi, 2006). If other parameters are included the results vary. To know how the risk indices change which various parameters a sensitivity analysis have been done, of which the results can not be presented here again because of space limitation, and can be found in the main report of the study (Yaghoobi, 2006). However, as it can be seen in Table 2, based on hazard parameter alone Tehran province has the highest index, this is while if the environmental parameter alone is considered Tehran will have a very lower rank.

The calculated risk indices can be used for making decision on the provinces which should be studied more in detail, and also for budget assignment for seismic upgrading of roads in various provinces. The main advantage of the proposed method is its simplicity. Furthermore, it is possible to add as many as desired parameters to the model without any difficulty, provided that appropriate weight factor of that parameter can be given on a reasonable basis.

5. CONCLUSIONS

Based on this study it can be concluded that:

- The risk management strategies, proposed for various lifeline systems are not usually inadequate for intercity road systems.
- The key issues proposed in this paper are believed to be very effective to reduce the risk of earthquake and its consequences in intercity road systems, particularly in developing countries like Iran.
- The proposed quick risk assessment model is a very simple and useful tool for prioritization of the country provinces for budget assignment with regard to national seismic risk reduction programs.
- The proposed model can be easily used in other countries by giving reasonable values to the model parameters.

It should be notified that the statistical data and the way they are classified in Iran and probably many other developing countries are not appropriate for disaster risk reduction purposes, including seismic risk reduction programs, and some modifications in this regard are necessary.

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