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THE USE OF DETOURS AS A MITIGATING MEASURE FOR DISASTER RISK REDUCTION OF INTER-CITY ROAD SYSTEMS

Mahmood Hosseini[1] and Mehdi Behniafard[2]

ABSTRACT

In many provinces of developing countries there is just one single road connecting each city (or a sequence of cities) of the province to its central city. On the other hand, recent earthquakes have shown that roads are very sensitive either to direct effects of earthquakes or to their indirect effects resulting from the extensive use of the road for emergency response activities. Obviously, any blockage of a single road has very adverse short term and, and even long term effects on the response activities and restoration works after a major earthquake. On this basis, adding some redundancy to the road system by constructing detours in some particular sections of each road path can be a useful remedy. In this paper the possibility of using detours, and the benefits of using them for seismic risk reduction in the intercity road system has been studied, and a method has been proposed for this purpose. In the proposed method at first, the places in a road which have the potential of blockage due to earthquake are diagnosed. In the second step, among the location of high blockage potential those which have the possibility of detour construction are identified and classified based on the level of difficulty of detour construction work. A detour can substitute a single blockage location or several ones of them depending on how close together they are. In the third step, three following alternative mitigating measures are compared: a) retrofitting the vulnerable components or upgrading the seismic stability of vulnerable locations, b) preparing and storing the basic required tools and materials for construction of detours, where necessary, quickly after a major earthquake, and c) constructing the detours in advance. By comparison of these alternatives from economic and technical aspects, based on the experts' views using Analytical Hierarchy Procedure (AHP), the appropriate mitigating measure can be chosen.

Introduction

Several developing countries suffer from lack of full coverage of road transportation system. In fact, in many provinces of these countries there is just one single road connecting

[1]Associate Professor, Structural Eng. Research Center, the Int'l Institute of Earthquake Engineering and Seismology (IIEES), Tehran, Iran, Email: hosseini@iiees.ac.ir
2Graduate Student, Transportation Eng. Dept., School of Engineering, Science and Research Branch of the Islamic Azad University (IAU), Tehran, Iran, Email: mehdibehniafard@gmail.com

each city (or a sequence of cities) of the province to its central city. In other words, the road redundancy in most provinces is almost zero, and therefore, if the single existing path is interrupted by any means, the connection between the central city of the province and the other city (or city sequence) is cut. On the other hand, recent earthquakes, such as Bam (Iran) of December 2003 and Firoozabad-e Kojoor (Iran) of May 2004, have shown that roads are very sensitive either to direct effects of earthquakes or to their indirect effects resulting from the extensive use of the road for emergency response activities. Obviously, any blockage of a single road has very adverse short term and, and even long term effects on the response activities and restoration works after a major earthquake. On this basis, adding some redundancy to the road system by constructing detours in some particular sections of each road path, or at least, providing and storing the basic required tools in appropriate locations for construction of detours quickly after a major earthquake, can be a useful remedy.

So far, several studies have been performed on the seismic evaluation of transportation systems and some measures have been proposed for their seismic risk mitigation, which are mostly related to highways, and urban roads. Shigeki (1999) has presented the history of earthquake disaster countermeasures for road bridges in Japan by dividing the periods into before and after Hyogo-ken Nambu Earthquake. He has discussed three major factors in setting the priority in deciding the aseismicity and earthquake strengthening on the established road bridges, and has explained the important items for the aseismicity decision of the road bridges clarified from the experience of the Hyogo-ken Nambu earthquake disaster. Gordon and his colleagues (2001) have also worked on earthquake disaster mitigation for urban transportation systems, and have proposed an integrated methodology that builds on the Kobe and Northridge experiences. Hosseini and Yaghoobi (2002) have propose a methodology for the risk management of roads subjected to natural and man-made hazards in Iran, as a sample of developing countries, in which all natural hazards such as earthquake, landslide, and typhoon, as well as manmade hazards such as stealing, bombardment and sabotage are taken into consideration. It is believed Some smart auxiliary decision making techniques for post-earthquake emergency response of transportation systems has been also proposed (Guo 2003).

Post-Earthquake road unblocked reliability estimation based on an analysis of randomicity of traffic demands and road capacities has been also studied (Chen and Eguchi 2003). They have proposed a revised four-stage traffic plan method to estimate the post-earthquake traffic flow assigned to a road network. They have also suggest a post-earthquake road capacity estimation method that considers the seismic vulnerability of structures and the potential building collapse area that might occupy a road after a major earthquake. Through an analysis of the "randomicity" of traffic demands (traffic flow) and road capacities after an earthquake, and depending on reliability theory, they have tried to estimate the "unblocked" reliability of road segments and the reliability of the entire transportation network, and through the component importance analysis, they have suggested the improvement recovery plan for a transportation system that focuses on alleviating earthquake indirect losses. They have also given an example to illustrate the application of the unblocked reliability index in post-earthquake traffic condition estimation and in developing earthquake response strategies for urban transportation systems.

Recently Hosseini and Yaghoobi (2008) have proposes a risk management model for inter-city road systems. Also Liu and his colleagues (2008) have introduced the seismic reliability of transportation system components, and the damage grade and its definition of the transportation system network in earthquake. According to the property of transportation system network, combined with graph theory and network analysis theories and methods, they have constructed a model for transportation system network connectivity analysis. They have used Warshall algorithm in the fuzzy mathematical manipulation, and by transforming the adjacency matrix have obtained the reachability matrix, based on which the connectivity of transportation system network can be decided on.

More recently a study has been also performed on optimum path analysis of post-earthquake transportation considering multi-objective based on GIS (Cao et al. 2009). Through the investigation and analysis of the status and influence factors of post-earthquake disaster on urban transport system, they have tried to introduce the study of route choice for post-earthquake transporting exigency based on the principles of timely, security and economy of the transport route choice under exigency situation. They have discussed that to describes the above three decision-making parameters, it is necessary to establish their objective functions through processing the dimensionless technique and weight aggregation so as to set up a mathematical model for evaluating the utility of prepared route, and model merges collected information according to the expectation utility attributes as well as to make the multi-attribute decision-making problems into the single one. They have also claimed that in order to find a scientific post-earthquake transportation route and define a scheduling decision-making method in an emergency rescue transporting center and enhance the response effect of the emergency rescue, it is necessary to choose and establish the highest expectation utility plan. They have used the network-analysis model of ArcGIS Engine to develop decision information system having the ability of transportation system management, optimum path analysis and searching.

It is seen that in spite of several measures which have been proposed for encountering the post-earthquake situation of transportation systems, base on the existing and available publications the use of detours have not been addressed so far. In this paper the possibility of using detours and the benefits of using them for seismic risk reduction in the intercity road system has been studied, and a method has been proposed in this regard and has been applied in some sample cases to show its efficiency.

The Method for Making Decision on the Use of Detours

Disaster risk mitigation in general has three main parts, which should be taken into consideration simultaneously to be quite effective. These parts are: 1) developing the future systems based on disaster avoidance criteria, 2) upgrading the existing systems to be less vulnerable subjected to disastrous events, and 3) getting prepared (and maintaining the preparedness) for future emergency conditions. Making decision on using detours basically relates to the third part. To find out whether using a detour is an appropriate countermeasure for reducing the seismic risk of an inter-city road or a part of it, and to make the final decision on using it, a three-step procedure can be used as follow:

- At first, the places in a road which have the potential of blockage due to earthquake are diagnosed. These places include the locations of the vulnerable key structures such as bridges, tunnels or retaining walls, and the locations of high embankments or deep trenches, which have the low safety factor of slope stability, and the places which have high potential of rock-fall, large settlement or liquefaction.
- In the second step, among the location of high blockage potential those which have the possibility of detour construction are identified and classified based on the level of difficulty of detour construction work. A detour can substitute a single blockage location or several

ones of them depending on how close together they are. The difficulty of the detour construction depends on the conditions of the area in which the detour is supposed to be constructed.

- In the third step, three following alternative mitigating measures are compared: a) retrofitting the vulnerable components or upgrading the seismic stability of vulnerable locations, b) having prepared the basic required tools for construction of detours, where necessary, quickly after a major earthquake, and c) constructing the detours in advance. By comparison of these alternatives from economic and technical aspects the proper mitigating measure is chosen.

To make the comparison of the three aforementioned alternatives, regarding the existence of several qualitative factors incorporating to each of economic and technical aspects, the experts' views approach using Analytical Hierarchy Procedure (AHP) and an appropriate computer program can be used. Furthermore, regarding the limitation of the resources for risk mitigation, before making decision on using detours in roads it is reasonable to make a prioritization of various roads in a country with respect to their need to detours. The AHP can be used for this purpose as well. The detail of using this procedure is explained hereinafter.

Using AHP for Making Decision on Using Detours

To use the AHP for prioritization of roads or their parts for using detours there are some main sets of factors, each containing some factors as given in Table 1.

Table1. The sets of factors, incorporating the need of a road to detours, and the related factors

The main set of factors	The factors
Geographical conditions and natural features	- Locating in a plain, a hilly area, or a mountainous area - Temperature and humidity conditions - Amount and type of precipitation - Existence of natural features like river, jungle, etc.
Importance of the road in the country	- Road classification - Amount of passenger and cargo transported by the road - The importance of the road 'service area' in the country (Hosseini and Yaghoobi Veyeghan 2008) - The existence of parallel roads - Road-side economic activities
The seismic hazards threatening the road	- The PGA level - Potential of each of the geotechnical hazards such as landslide, liquefaction, faulting, large settlement, and rock-fall
Number and type and/or length of key structures	- Number and type of bridges, and culverts - Number, type and length of retaining walls, tunnels, and galleries
Age of the road and quality of construction	- Aging of road facilities, and fatigue of the key structures - The road body material, and quality of construction
Existence of safe locations and their conditions and accessibility	- Number of safe locations - Total area of safe locations - Average distance of road from safe locations - Accessibility to safe locations

Each of the sets of factors, given in Table 1, are assigned a weight factor between 2 (very low) and 9 (very high) in AHP. These weight factors are obtained by experts' views using some specific questionnaires. The results of the survey for assessing the experts' views for the main sets of factors are as given in Table 2, and for the factors in each set as given in Tables 3 to 8.

Table 2. The weight factors assigned to each set of the main sets of factors by experts' views

The main set of factors	The weight factors
Geographical conditions and natural features	7.7
Importance of the road in the country	7.1
The seismic hazards threatening the road	7.8
Number and type and/or length of key structures	7.4
Age of the road and quality of construction	3.9
Existence of safe locations and their conditions and accessibility	6.2

Table 3. Factors related to geographical conditions and natural features, and their weights factors obtained by experts' views

Factors	The weight factors
Locating in a plain area	3.3
Locating in a hilly area	4.8
Locating in a mountainous area	8.4
Temperature and humidity conditions	5.2
Amount and type of precipitation	5.6
Existence of natural features like river, jungle, etc.	7.0

Table 4. Factors related to importance of the road in the country, and their weights factors obtained by experts' views

Factors	The weight factors
Road classification	7.8
Amount of passenger and cargo transported by the road	7.2
The importance of the road 'service area' in the country	8.4
The existence of parallel roads	7.6
Road-side economic activities	4.2

Table 5. Factors related to the seismic hazards threatening the road, and their weights factors obtained by experts' views

Factors	The weight factors
The PGA level	9.0
Potential of landslide occurrence	9.9
Potential of liquefaction occurrence	7.1
Potential of faulting occurrence	5.0
Potential of large settlement occurrence	6.1
Potential of rock-fall occurrence	7.8

Table 6. Factors related to key structures of the road, and their weights factors obtained by experts' views

Factors	The weight factors
Number and type of bridges	7.8
Number and type and/or length of retaining walls	6.5
Number and type and/or length of galleries	6.1
Number and type and/or length of tunnels	7.0

Table 7. Factors related to age of the road and quality of construction, and their weights factors obtained by experts' views

Factors	The weight factors
Aging of road facilities	4.6
Fatigue of the key structures	4.6
Types of the road body material	4.7
Quality of construction	3.0

Table 8. Factors related to existence of safe locations and their conditions and accessibility, and their weights factors obtained by experts' views

Factors	The weight factors
Number of safe locations	4.1
Total area of safe locations	4.9
Average distance of road from safe locations	3.7
Accessibility to safe locations	5.0

Estimating the Costs

One of the main requirements for making decision on using detours is the costs of each of the three mitigating measures for risk reduction, which are: a) retrofitting the vulnerable components or upgrading the seismic stability of vulnerable locations, b) preparing and storing the basic required tools for construction of detours quickly after a major earthquake, and c) constructing the detours in advance. It is obvious that the costs are time dependent, and particularly are affected by economic instability in non-developed and even developing countries. Therefore, the time factor should be considered carefully in cost estimations. For this purpose the basic costs of the three mitigation measures are estimated based on the present conditions, and then are modified for the time they are considered to be applied.

Application of the Proposed Method to Real Cases

To show the efficiency of the proposed method it has been applied to some sample cases, including a road in a hilly, hot and arid area and another road in a mountainous and cold and rainy area, and so on. The results related to the road in mountainous and cold area (Tehran-Chaloos road in northern Iran) are presented here briefly. More results cannot be presented due to lack of space, and can be found in the main report of the study (Behniafard 2009).

To apply the proposed method, the considered road was divided into ten segments of almost the same length, and the prioritization factors, explained in the previous section, were compared in these ten segments, using the Expert Choice computer program. Tables 9 to 11 show the comparisons of some of the prioritization factors as samples, including the geographical conditions, importance, and key structures.

Table 9. Comparison of the prioritization factor of geographical conditions for the ten segments of Tehran-Chaloos road, obtained by Expert Choice computer program

Road Segments	62614 NW	62614 SW	62621 NW	62621 SW	62622 NW	62622 SW	62623 SE	62632 NE	62632 SE	62632 SW
62614NW		1.75	2.8	2.33	*1.14**	*1.25*	*1.02*	4.66	3.5	3.33
62614SW			1.6	1.33	*2.0*	*2.2*	*1.7*	2.66	2.0	1.9
62621NW				*1.2*	*3.2*	*3.6*	*2.8*	1.6	1.25	1.2
62621SW					*2.62*	*3.0*	*2.33*	2.0	1.5	1.42
62622NW						*1.12*	1.14	5.33	4.0	3.8
62622SW							1.22	6.0	4.5	4.28
62623SE								4.66	3.5	3.3
62632NE									*1.3*	1.4
62632SE										*1.05*
62632SW										

*Normal fonts mean the dominancy of rows, and underlined italic fonts mean the dominancy of columns

Table 10. Comparison of the prioritization factor of importance for the ten segments of Tehran-Chaloos road, obtained by Expert Choice computer program

The factors	Type of road (highway, freeway, major road, minor road)	Good and passenger transportation scale	Effect of roads on territories	Existence of parallel roads	Economic activities around roads (agriculture, industry) rearing, stores, restaurant)
Type of road		1.071	*1.077*	1.02	1.861
Good and passenger transportation scale			*1.154*	*1.05*	1.73
Effect of roads on territories				1.099	2.0
Existence of parallel roads					1.824
Economic activities around roads					

*Normal fonts mean the dominancy of rows, and underlined italic fonts mean the dominancy of columns

Table 11. Comparison of the prioritization factor of key structures for the ten segments of Tehran-Chaloos road, obtained by Expert Choice computer program

The factors	Number, size and material of bridges	Number, size and material of retaining walls	Number, size and material of galleries	Number, size and material of tunnels	Situation of Trenches	Material of the road body	Standards of design and performance of road and its structures
Number, size and material of bridges		1.201	1.275	1.113	1.168	1.66	1.53
Number, size and material of retaining walls			1.062	1.079	*1.028*	*1.382*	1.273
Number, size and material of galleries				1.146	*1.092*	*1.3*	1.2
Number, size and material of tunnels					1.05	1.491	1.374
Trenches situation						1.421	1.309
Material of the road body							*1.085*
Standards of design and performance of road and its structures							

*Normal fonts mean the dominancy of rows, and underlined italic fonts mean the dominancy of columns

Based on the prioritization factors obtained by the computer program for all six sets of factors and combining them the final prioritization factors for all segments were calculated as shown in Table 12.

Table 12. Final relative prioritization factors for all 10 segments of Tehran-Chaloos road

Segment No.	1	2	3	4	5	6	7	8	9	10
Prioritization factor	0.117	0.092	0.093	0.102	0.117	0.101	0.902	0.900	0.890	0.106

As expected, the summation of relative prioritization factors for all segments, given in Table 12, is equal to 1.000. It can be seen in Table 12 that there is not big differences between the priorities of the 10 segments of the considered road, which is because of the similar conditions along the whole road, however, the 1st segment which is in the vicinity of Amir Kabir Dam, and the 5th segments, which include the very long Kandovan tunnel, have more priority. To choose the best mitigation measure among the three possible ones, cost analyses were done. It should be noted that in cost analysis corresponding to the second mitigation measure, i. e. preparing and storing the basic required tools and materials for construction of detours, where necessary, quickly after the earthquake, the equivalent values of lives of the injured people, who would die due to delay in emergency response should be taken into account. For this purpose the equivalent blood money (almost $45,000 for each person) was considered in this study. Obviously to have a reasonable estimation of the number of injured people a scenario-based risk evaluation approach should be used. Therefore, the considering the most probable scenario is quite logical. On this basis, for the indentified segments (1 and 5) of Tehran-Chaloos road cost analysis showed that construction of detours in advance is more beneficial than retrofitting the vulnerable components of the road segments and also much more beneficial than preparing and storing the basic required tools and materials for construction of detours, where necessary, quickly after the scenario earthquake, mainly because of the blood money of the injured people who would die due to delay in rescue activities, as the detours are constructed. In addition to economic aspect, construction of detours is technically easier than retrofitting all vulnerable components of the indentified segments (Behniafard 2009).

Conclusions

In this paper the possibility of using detours and the benefits of using them for seismic risk reduction in the intercity road system has been studied, and a method has been propose for this purpose. In the proposed method decision making on the use of detours is done based on economic and technical comparison of the following three mitigating measures: a) retrofitting the vulnerable components or upgrading the seismic stability of vulnerable locations, b) preparing and storing the basic required tools and materials for construction of detours, where necessary, quickly after a major earthquake, and c) constructing the detours in advance. To show the efficiency of the proposed method was applied to some sample cases, including a road in a hilly, hot and arid area and another road in a mountainous and cold and rainy area, and so on. Comparison was done based on the experts' views using AHP, and employing the Expert Choice computer program. Results showed that proposed method has satisfactory efficiency for decision making, and in most cases construction of detours in advance is both technically and economically more acceptable.

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