RELIABILITY ANALYSIS OF URBAN TRANSPORTATION SYSTEM

Liu CHUNGUANG[1] And Gao HUIYING[2]

SUMMARY

Transportation system is regard as a part of lifeline earthquake engineering which is very important for earthquake resistant and reduction disaster. In this paper, three cases of transportation system are discussed, to analyze and study the reliability methods of components (road, street, bridge) in transportation system, network reliability way on the basis of units reliability regarded as control parameters, and the network optimum method. That will contribute a new theory base of reduction disaster plan to transportation system in pre-earthquake. After improvement of corresponding route according to the method presented in this paper, which will supply transportation system with elementary safety requirement for post-earthquake rescue under high seismic intensity disaster.

INTRODUCTION

Transportation system is a network system that is composed by three parts, which are road, railway, bridge. It is a key lifeline for land transport, and an access of evacuating people, sending disaster fighters and disaster engines, matter transport, and is also the destiny lifeline of earthquake resistant and disaster fighting.

When an earthquake occurred, the bridge and road will suffer different degree damage, which will be a bad influence on its service function and will be very unease for people's lives. In recent years, there are some very clear examples for destroying transportation in a strong earthquake. Such as the great Tang San Earthquake in China in 1976, the San Fernando Earthquake in American in 1971, the Hyogoken –Nanbu (Kobe) Earthquake in Japan in1995, which took great damages for transportation system, such as it stopped, bridge collapsed, road cracked and so on.

From seventies to now, the studies of lifeline earthquake engineering system were developed into the studies of network system damage, function destructiveness analysis, and reduction disaster policy analysis on the basis of the studies of structure earthquake engineering. Therefore, it is very important for reliability analysis of transportation system now.

According to the studies of pre-earthquake damage and whole thinking for earthquake disaster fields, we refine some parameters from affecting on the damages of road, bridge. So, we can analyze the network reliability of transportation system.

Since the early work of urban transportation system very little has been done in the area of system and component performance, it is perhaps some difficult to study without suitable method and computer. Eventually, it is very complex to simplify transportation system as mathematics model, it is very difficult to get accurate damage probability of components. All of above, which will take a difficulty to analyze network damage probability of transportation system.

How to work out plan before an earthquake comes? How to allocate existing the ambulance corps ? Where are its optimum places of the ambulance corpses? Which parts will be the most important and will be require to be

1 Associate Professor, Institute of Engineering Mechanics, China Seismological Bureau, Harbin, 150080, China.
2 Assistant Professor, Institute of Engineering Mechanics, China Seismological Bureau, Harbin, 150080, China

strengthened? For answering these problems, to ensure that transportation system has enough transportation capability while an earthquake comes. So, we will finish below studies.

Firstly, according to some study methods of components (road, bridge) reliability analysis before, we put

forward to new or more overall analysis methods. For studying the damage probability of transportation network system, we employ Monte Carlo simulation method, In addition, to employ vague synthesis judge method to study the optimum place of the ambulance corps so that it is higher efficiency and higher quality to finish disaster fighting job.

ACCESS RELIABILITY ANALYSIS OF TRANSPORTATION NETWORK SYSTEM

Transportation system is consisted probably of 3 components which are road, railway, bridge, and which have different analysis methods of earthquake vulnerability, on the behalf of earthquake resistant and reduction disaster of transportation system, we can only consider road, bridge as research objects in a urban transportation system.

Now, many studies indicate the function estimate of a network system can be simplified as the damage probability of any two points in a network system. Thus, the program for assessing damage probability of a network system is: Firstly, the urban transportation system can be regarded as a plan problem, analyze and estimate the damage probability of each road, then, employing Monte Carlo simulation method to resolve the damage probability of any two crossroads.

According to all kinds of types, the road can be divided into two kinds of roads, which are the road that does not included bridge, and the other one includes bridge.

Reliability Analysis of Road:

Road Reliability Analysis of not Include Bridge:

For this type, the road linked probability Pr is the whole road linked probability Ptr.

$$P_r = P_{tr} \qquad (1)$$

Road Reliability Analysis of Including Bridge:

For this type, the whole road is equal to the series connection of road component and bridge component. Either of road and bridge is destroyed, then the whole component is destroyed, thus, the whole road linked probability

$$P_{tr} = P_r \times P_b \qquad (2)$$

is equal to the road component linked probability times bridge component linked probability.

Earthquake Damage Degree Classification of Components of transportation system:

In road network system, according to necessary of network reliability analysis and studies of earthquake damage materials, we divide damage degree into 3 grades.

(1) Basic good. Road is basically good or slight crack, bridge is basically good, but some non-structures have slight damage. It can meet normal transportation capacity, and can be used.

(2) Slight destruction. Road has many cracks, but can be still gone through. Some parts of bridge have damages. It can be used by appropriately repairing and strengthening.

(3) Heavy destruction. The surfaces of road have many cracks. It is inevitable to repair in a period time, the important parts of bridge have damages. The load capacity will decrease.

Reliability Analysis of Components :

Reliability Analysis of Road:

For reliability analysis of road or street, it is considered not only the influence to linked probability of the damage of road or street cracks when an earthquake occurred, but also relation of brick obstruction capacity (B) and bounds of brick obstruction capacity (Bc). Then, to determine the linked probability, the linked probability of road component can be obtained from:

$$P_r = [1-(B/B_c)]\times \exp(-ul) \quad B \le B_c$$

Where, L is the length of road. u is damage probability by using how many damage places in one kilometer.

Reliability Analysis of Bridge Component:

According to statistics analysis method and 3 different earthquake damage degrees 1.5, 3.0, 4.5 respectively corresponding to basic good, slight destruction, heavy destruction, we employ the following formulas.

$$A_i = \prod_{j=1}^{9} \prod_{k=1}^{2\ or\ 3} W_{ij}^{X_{ijk}}$$

Where

Xijk=0, not have the Kth element of the Jth project in the Ith bridge.

Xijk=1, have the Kth element of the Jth project in the Ith bridge.

Ai is natural damage intensity of the Ith bridge, Wik is authority coefficient of the Kth element of the Ith project.

Reliability Analysis of Transportation Network System:

In order to assess the reliability performance of system during an earthquake, according to mathematics theory in network system, which are (1) Figure theory. (2) State probability method (3)Network theory. (4)Monte Carlo simulation method, employing Monte Carlo simulation method in this paper, which is suitable for complex connecting bars and points models, and it can meet engineering demands. The specific calculation program can be expressed as:

(1) To calculate damage probability of each component in transportation system Pij.

(2) To product any random number for each component Rij. (rij), to simulate damage state and compare each component random number with each component damage probability, to form vague relation matrix A, element of A matrix can be obtained by follow equation.

Aij=1, (pij rij); aij=0, (pij≥rij)

(3) Employing vague relation matrix method to resolve network linked characteristic. It is only necessary to gather K times square for A matrix. Thus, getting K squares of a matrix Ak, its elements indicate linked characteristic of any two points a, b.

(4) Repeat program (2),(3), to make enough sample number, then, the reliability of network system can meet the needs of accuracy in engineering.

From calculation above, we can obtain some demands linked probability of any two points, which may be crossroads or the ambulance corps , If there is only one ambulance corps in whole transportation system, this linked probability is reliability of the crossroads. If it is assumed there are m ambulance corpses in whole network system, then there are m different linked probabilities between this crossroads and m ambulance corpses. The reliability of this crossroads will be determined by the m linked probabilities. Assumption the linked probability of some crossroads and every ambulance corps is Pl(i). so, the reliability of this crossroads Pl

$$P_l = 1 - \prod_{i=1}^{m} (1 - P_l(i))$$

can be written as:

THE OPTIMUM MODEL STUDIES OF TRANSPORTATION SYSTEM

For a network model, to assume the important factor is same for every crossroads, and there is only one ambulance corps, by employing Monte Carlo method to analyze the linked probability of every crossroads under separately assuming every crossroads is the ambulance corps, we can refer the follow program to know which is the best place for the most efficiency service seismic disaster in whole system after earthquake.

(1) Respectively assuming every crossroads is the ambulance corps by employing Monte Carlo method.

(2) To obtain the average value of reliability of every crossroads when assuming every crossroads is the

$$\overline{X} = \frac{1}{n} \sum_{i=1}^{n} X(i) \quad i = 1,2,...n$$

ambulance corps.

(3) According to follow formulae, to get the best place of the ambulance corps.

$$\sigma = \left\{ \frac{1}{n} \sum_{i=1}^{n} \left[x(i) - \overline{X} \right] \right\} = \min \qquad \overline{X_m} = \left[\frac{1}{n} \sum_{i=1}^{n} X(i) \right] = \max(m)$$

PRE-EARTHQUAKE ASSESSMENT OF TRANSPORTATION SYSTEM

From network simulation results, we can see that important location will greatly affect network system function. For the whole transportation system, we need still to know which is the most important component in this system, or in one word, which component is the most influence action for service disaster in the system, so that are supplying theory base for strengthening and reduction disaster plan before earthquake comes, The specific program can be expressed as:

(1) Assumption the ambulance corps is defined, to calculate add matrix of reliability of every points to present combining matrix A

(2) Assigning the important coefficient b(i) of every crossroads, according to real network system, so, the synthesis judge result c can be written as:

C=A×B

in which, B is the important factor matrix of every crossroads.

(3) Separately in order to assume every crossroads is good in network system, repeat (1), (2), to obtain different C, the biggest C is the most important component.

EXMAPLE

In fig., 1, a urban transportation system is shown, of which there are 21 crossroads, 30 roads, in which include 3 bridges, according to methods above of road linked probability and bridge linked probability we can get the result of the probabilities of road and bridge that are listed in table 1 under earthquake intensity is 8.

Firstly, Assumption the important factor of every crossroads is same, and there is only one ambulance corps. Secondly, respectively assuming 1 and 9 is ambulance corps to calculate every component reliability in whole network system by employing Monte Carlo method. The result are listed in table 3 and table 4. In addition, assuming there are two ambulance corpses, their places are 1 and 9. The result is listed in table 5. From these tables above, we can see the more ambulance corpses in transportation system, the higher reliability of transportation system.

According to the method above, we can find the most efficiency place of the ambulance corps in saving disaster, which is the 14th crossroads . The most important component is unit 16, in which the different important factors are listed in table 2.

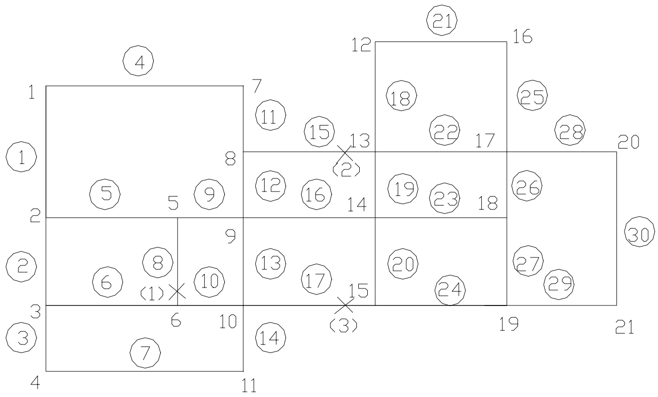

Fig. 1 Model Figure

Figure Scale: ----Bridge; i ----The ith Crossroads; i----The ith road; (i) ---The ith Bridge

CONCLUSIONS

The general guideline for performing transportation system risk and decision analyses is provided in this paper. In the introductory part of this paper, the new methods of urban transportation components road, street, bridge reliability analyses are presented with serious discussions for disaster prediction method previously of urban transportation system, which consider not only the influence to linked probability of the damage of road or street cracks when an earthquake occurred, but also relation of brick obstruction capacity and bounds of brick obstruction capacity. We get the connection between earthquake damage degree and linked probability so as to analyze easy network system reliability,that is 3 kinds damage grades and damage probabilities. Finally, a model of transportation system is analyzed, and some meaning conclusions have been brown, so, reliability analysis of urban transportation system in this paper is a theory basis for plans of anti-earthquake analysis and damage mitigation.

REFERENCES

1 Wu Wanfeng, Wu Wandou "Vague mathematics and computer application",electrical press.

2 Ronald T, Eguch (1984)"Seismic Risk and Decision analysis of lifeline System" lifeline Earthquake Engineering Performance, Design and construction.

3□ Zao Chenggang, Feng Qimin (1994)“Lifeline Earthquake Engineering” Seismology Press.

Table 1 Damage Probabilities of Units

Units	Damage	Units	Damage	Units	Damage
1	0.12	11	0.26	21	0.22
2	0.18	12	0.31	22	0.57
3	0.21	13	0.27	23	0.18
4	0.07	14	0.19	24	0.61
5	0.22	15	0.76	25	0.51
6	0.32	16	0.45	26	0.20
7	0.11	17	0.59	27	0.38
8	0.79	18	0.37	28	0.27
9	0.44	19	0.31	29	0.30
10	0.37	20	0.25	30	0.18

Table 2 Points Important Factors of Model

Points	Factors	Points	Factors	Points	Factors
1	0.8	8	1.0	15	0.8
2	0.7	9	0.6	16	1.0
3	0.9	10	0.8	17	0.4
4	0.6	11	0.6	18	0.6
5	0.4	12	0.6	19	0.3
6	0.6	13	0.8	20	0.8
7	0.8	14	0.6	21	0.5

Table 3 Points Reliabilities of Model (1 Crossroads is Ambulance Corps)

Points	Reliability	Points	Reliability	Points	Reliability
1	1.0	8	0.838	15	0.587
2	0.928	9	0.825	16	0.269
3	0.4846	10	0.808	17	0.539
4	0.781	11	0.778	18	0.588
5	0.833	12	0.541	19	0.500
6	0.770	13	0.588	20	0.455
7	0.951	14	0.625	21	0.449

Table 4 Points Reliabilities of Model (9 Crossroads is Ambulance Corps)

Points	Reliability	Points	Reliability	Points	Reliability
1	0.823	8	0.839	15	0.669
2	0.845	9	1.0	16	0.307
3	0.833	10	0.889	17	0.619
4	0.807	11	0.823	18	0.673
5	0.820	12	0.618	19	0.575
6	0.797	13	0.667	20	0.524
7	0.811	14	0.720	21	0.517

Table 5 Points Reliabilities of Model (1 and 9 Crossroads are Ambulance Corpses)

Points	Reliability	Points	Reliability	Points	Reliability
1	1.0	8	0.974	15	0.864
2	0.989	9	1.0	16	0.495
3	0.974	10	0.979	17	0.824
4	0.958	11	0.961	18	0.865
5	0.9698	12	0.825	19	0.787
6	0.953	13	0.863	20	0.741
7	0.991	14	0.895	21	0.734