iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 4 **Issue:** IV **Month of publication:** April 2016

DOI:

Volume 4 Issue IV, April 2016
ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

Anti-Seismic reinforcement for highway network

Abhishek Yadav[1], Dr. A K Mishra[2]
[1]P.G. Student, Department of Civil Engineering, MMM University of Technology, Gorakhpur, Uttar pradesh, India
[2]Assistant Professor, Department of Civil Engineering, MMM University Of Technology, Gorakhpur, Uttar Pradesh, India

Abstract: This paper provides a novel practical method for analyzing an anti-seismic reinforcement (ASR) problem involving hundreds of transportation facilities on an urban road network subject to multiple earthquake risks. The relevant properties of the present method are: (i) it evaluates the performance of an ASR strategy, taking into account traffic congestion and travellers' trip-making or route-choice behaviour; (ii) it estimates the realistic damage patterns on the road network and their occurrence probabilities on the basis of recent advances in structural and earthquake engineering; (iii) it has clear, sensible logic and includes neither a black-box nor a ''lottery'' in the necessary procedures. We examine the computational efficiency and whether the present method is reasonable by applying it to a test scenario of the Kobe urban and suburban area.

I. INTRODUCTION

This paper addresses two important practical questions: How to evaluate the reliability of urban road networks against large earthquakes. How to mitigate the vulnerable road network from devastating earthquakes.Since the Great Hanshin-Awaji earthquake (1995), Japanese road networks have experienced severe damage from large earthquakes (e.g., Mid-Niigata, 2004; Fukuoka Western Offshore, 2005; Noto Peninsula, 2007; Shizuoka, 2009). The common and important aspects of these negative impacts of earthquakes are their extent and uncertainty: In each earthquake, multiple transportation facilities (e.g. bridges, tunnels, viaducts, embankments, and so on) were simultaneously disabled and their actual damage pattern could not be anticipated. Such simultaneity and uncertainty needs to be taken into account when evaluating the reliability of an urban road network against large earthquakes. The reliability of transport network has been intensively studied over the last two decades. Books by Bell and Cassir (1999), Bell and Iida (2003) showed earlier research activities in the field of transport network reliability analysis. When we discuss transport network reliability analysis, it seems necessary to identify the categories of the study topics such as routing and scheduling under uncertain conditions, flow models for degraded and congested networks, evaluation and measurement of reliability, and network design. Routing and scheduling under uncertain conditions include traveler's choice behavior in an uncertain network. Stochastic behavioral models and risk models can be applied in describing travel choice behavior. Khattak and de Palma (1997) studied driver's travel behavior in abnormal weather conditions. However, there were few studies on the individual user's route choice behavior in a damaged network. This is partly because the behavioral data for validating these are very limited. Flow models are essential for evaluating network reliability. These models aim at describing interactions between a traveler's choice behavior in a degraded network and the performance of the network. Asakura et al. (1999) formulated a Stochastic User Equilibrium model with elastic demand for describing a traveler's trip making and route choice behavior. Lee et al. (2000) applied interference theory and proposed a ''reliability assignment model'' which could be used for evaluating travel time reliability as well as describing network flows. Lam et al. (2008) formulated a reliability-based stochastic user equilibrium model considering uncertainties in both the demand and supply sides of a road network, and proposed a heuristic solution algorithm. They evaluated the impact of adverse weather conditions on the road capacity and the link travel time. Asakura (2007) discussed the requirements of network flow models that were used for transport network reliability analysis. He suggested that the flow models developed for an ordinary network state would be modified and applied to the recovery state of a network. The network flow model should have the characteristics of explicit link capacity constraints, decreasing demand due to traffic congestion and the uncertainty of a traveler's choice behavior.

II. SOLUTION METHOD

A. Scope of the proposed method: readability rather than efficiency

It is difficult to obtain a rigorous solution of the ASR problem [P] for a large scale network with hundreds of facilities for the following three reasons. Firstly, [P] involves 0-1 integer programming (IP) that is NP-hard, which implies that there is no polynomial time algorithm for solving [P]. Secondly, [P] involves mathematical programming with equilibrium constraints (MPEC), and thus it might be a non-convex optimization problem. In other words, [P] could have multiple local optima and any solution method might find a different solution for each different initial condition. Finally and perhaps most critically rigorous evaluation of

Volume 4 Issue IV, April 2016
ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

the objective function of [P] could be impracticable. The accurate evaluation of the objective function demands complete enumeration of possible damage patterns, whose total number, 2kAk, could be unfeasibly large for even small networks: for the case with only 40 links, the total number of possible damage patterns is $2^{\|k\|} \approx 1.1 \times 10^{12}$.

This implies that it would take one year to evaluate the social losses for all possible damage patterns, even if one can solve the UE/ED assignment problems for 34,865 patterns within one second.

For these reasons, it seems natural to use meta-heuristics to find the ‘‘optimal’’ (or at least ‘‘better’’) ASR strategies of the problem [P]. Well known such meta-heuristics are simulated annealing (Metropolis et al., 1953); the tabu search (Glover, 1989a,b); the genetic algorithms (Goldberg, 1989); the ant colony optimization (Dorigo et al., 1996; Dorigo and Blum, 2005), the cross-entropy method (Rubinstein, 1999; Rubinstein and Kroese, 2004), and so on.

However, the aim of this article is to find a ‘‘reasonable’’ ASR strategy that might not be ‘‘efficient’’ but would be useful for actual decision making involving many nonprofessional stakeholders, – some ofwhommight prefer a more ‘‘readable’’ method rather than an ‘‘advanced’’ one. Therefore, we propose a simple and readable method with the following characteristics:

1) *It can be implemented for realistic problems with reasonable computational burdens.*
2) *It requires neither advanced mathematics nor proficient simulation techniques.*
3) *It includes no ‘‘black-boxes’’ and anyone can obtain the same solution from the same set of input data.*

The subsequent subsections show the key concepts of the proposed method. Section 3.2 proposes an approximation of the objective function using the ‘‘most likely’’ damage pattern, which enables one to reduce the computational effort for evaluating the objective function as well as dramatically reducing the size of alternative strategies as shown in the subsequent two sections: Section 3.3 provides the notion of the ‘‘target scenario’’ and ‘‘the target facilities’’, which is used for reducing the ASR strategy set.

III. REDUCTION OF THE STRATEGY SET BY AN ALL-OR-NOTHING REINFORCEMENT POLICY

The ASR problem [P] is quite difficult to solve since it is a non-convex 0-1 IP with control variables, whose total number of possible combinations equals to $2^{\|A\|}$, which is also astronomically large for dozens of facilities. The number of alternative strategies, however, can be reduced by combining the most-likely approximation and the all-or-nothing policy for seismic capacity assignment.

Since the most-likely approximated objective function remains identical for the strategies that do not affect the mostlikely damage for each earthquake scenario, we can exclude such strategies from consideration. In other words, we need to be concerned only with s-target transportation facilities for each target earthquake scenario $s \in S^*$. We then adopt an all-or-nothing reinforcement policy for each scenario-wise target facility set. That is, for each target scenario $s \in S^*$ we uniformly assign the high seismic capacity (H) for every s-target facility. According to such an all-or-nothing policy, we choose a subset of the target scenarios rather than a subset of the transportation facilities. Let $B^* \leq S^*\_$ be a reduced ASR strategy, that is, the set of target scenarios, whose target facilities are uniformly assigned the higher seismic capacity (H). Each reduced ASR strategy ^b is associated with a set of transportation facilities, i.e., $Bb^* := U_{SCB}B^*(s)$, which is the set of transportation facilities that are assigned the higher seismic capacity under the reduced ASR strategy b*. Exploiting the most-likely approximation and the strategy reduction, the ASR problem [P] can be reduced to

$$[\mathrm{R-P}] \quad \min_{\hat{\mathbf{b}} \in 2^{S^*}} \hat{Z}(\hat{\mathbf{b}}) := \frac{1+\rho}{\rho} \hat{f}(\hat{\mathbf{b}}) + K(\hat{\mathbf{b}}),$$

Where, $\hat{f}(\hat{\mathbf{b}}) := \sum_{s \in S^*} \lambda(s) \left\{ \hat{T}(s, B(\hat{\mathbf{b}})) + r(s, B(\hat{\mathbf{b}})) \right\}$ is the most-likely approximated annual social loss for the reduced ASR strategy b*. The optimal solution for the reduced ASR problem [R–P] can easily be found by straightforward direct comparison: The number of all possible strategies, $2^{\|S^*\|}$, is small enough to enumerate, and the objective function for each strategy can be evaluated with moderate computational effort.

Here we should note that the most-likely approximation and scenario-wise all-or-nothing reduction above cause potential bias: approximated objective values can be either overestimated or underestimated, and the optimal ASR strategy in the reduced set could result in a considerably worse solution. We should recognize the potential bias of the proposed method and apply carefully the method to the actual problems.

IV. THE TEST CASE: KOBE URBAN NETWORK

It shows the target area, which consists of seven subareas: Kobe, Akashi, Inami, Miki, Nishinomiya, Ashiya and Takarazuka.

The road network, the link travel time function and the O–D demand function

We use a road network with 1001 nodes and 2671 links as shown in Fig. 7. This network is built by adding the Kita-Kobe Line

Volume 4 Issue IV, April 2016
ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

(Route 7) and the Kobe-Yamanote Line (Route 31) of the Hanshin Expressway to the network used in the Road Traffic Census (RTC) in l999.

We adopt the BPR-type link travel time functions:

$$t_a(x_a) := t_a^0\left\{1 + \alpha\left(\frac{x_a}{\mu_a}\right)^\beta\right\},$$

where t_a^0 and la are the free-flow travel time and the link capacity of link a, respectively, both of which are embedded in the road network data. For the global parameters, we use the values a = 1, b = 3, estimated by Asakura and Nishitani (1991). For the monetary value of travel time, we use (Yen per minute) c = 50 (Yen per minute).

We constructed 17,287 O–D pairs from the RTC 1999, for which the total demand was 2,960,160 vehicles per day in the normal condition. Damages on the transportation network affects transportation demand in the short term (e.g. from the first 72 h to one week after an earthquake), as well as in the long term (e.g. from the several years to decades). In the short term, increases in transportation demand for search and rescue, emergency relief and restoration activities cause severe congestion. Note that these activities are affected by a wide range of uncertain factors, for example, the distribution of survivors and injuries, the location of damaged transportation facilities, depots for emergency supplies, and disaster medical centers, etc. In the long term, the transportation demand may shift according to changes in the economic structure (e.g. households' and firms' location patterns, inter-industry and inter-regional input/output structures, and so on). Such short- and long-term effects are extremely difficult to estimate as, to the best of authors' knowledge, there is no practical framework for describing such post-disaster traffic conditions as well as comprehensive quantitative surveys that can be used as input into such a framework.

For these reasons, we focus our attention on the middle-term transportation demand changes for damaged networks with several assumptions, some of which may seem inadequate but inevitable for our analyses. We first assume that each O–D pair w 2W has Qw potential users who have a common reservation price for the trip, H. According to this assumption, the demand function of the O–D pair w 2W is specified as

$$D_w(C_w) = \begin{cases} Q_w & \text{if } 0 \geqslant C_w \geqslant \Theta \\ 0 & \text{if } \Theta \geqslant C_w \end{cases}$$

We further assume that the total number of potential users for each O–D pair is equivalent to the actual traffic volume for the O–D pair in the normal network, which is estimated from the RTC 1999. We use an ad hoc value for the opportunity loss cost that is in hours. This can be considered the maximum one-way travel time that can be spent by a daily traveller, who spends 8 hours of inactive time each day.

V. THE EARTHQUAKE SCENARIOS, THE SEISMIC INTENSITY DISTRIBUTIONS

.From the viewpoint of earthquake engineering, we first generate 23 earthquake scenarios for possible earthquakes in the target area shown in Table 1, in which columns two to four are the locations of the epicenters, the seismic intensities at the epicenters and the annual occurrence probabilities for each earthquake scenario. Although there are several ground motion intensity measures e.g., the peak ground acceleration (PGA), the peak ground velocity (PGV), the spectrum intensity (SI) and so on, we adopt the modified spectrum intensity (SI') proposed by Kagayama et al. (1999). The SI' for each earthquake scenario on each geographical mesh in the target area is calculated using the Annaka-Yamazaki-Katahira formula (Annaka et al., 1997).

VI. THE TRANSPORTATION FACILITIES AND FRAGILITY CURVES

In this analysis, we focus our concern on the road bridge as the transportation facility, for which a number of studies have examined the fragilities against the seismic intensity based on realistic data and physical experiments as discussed later. We specified 859 road bridges in the target area by exploiting the feature codes in the DRM (Digital Road Map) data in the target area.

It is noteworthy that the link-closures could be caused by damage to other road facilities (e.g. tunnels, viaducts, embankments and pavements) as well as the collapse of buildings. Although these effects could be taken into account in the present framework, we focus our attention on the damage to road bridges due to availability of data.

Each road bridge is assumed to have the same seismic performance as a reinforced concrete (RC) bridge pier designed using the seismic intensity method. We also assume that an ASR universally upgrades the seismic capacity to that of an RC bridge pier designed using the horizontal load bearing capacity method. For details on the seismic performance, readers are referred to

International Journal for Research in Applied Science & Engineering Technology (IJRASET)

Kagayama et al. (1999). The fragility curve of a road bridge with a seismic capacity level m 2 {H,L} is represented as a lognormal function:

$$\psi_b^m(F_b) = \Phi\left(\frac{\ln F_b - \theta^m}{\xi^m}\right),$$

where $\theta = \ln \mu^m - \frac{1}{2}(\varepsilon^m)^2$ and $\varepsilon^m = \ln(1 + (\sigma^m/\mu^m)^2)$; μ^m and σ^m are the mean and the standard deviation of the damage probabilities that depend on the seismic capacity of the road bridge. We use the following parameters that are estimated by Kagayama et al. (1999): $(\mu^l, \sigma^l) = (50,20)$ and $(\mu^h, \sigma^h) = (64.5, 21.5)$.

VII. LINKAGE OF DATA USING THE GEOGRAPHICAL INFORMATION SYSTEM (GIS)

Since the previously mentioned data (on the road network, the earthquakes and the transportation facilities) have their own format, we use the GIS (Geographical Information System) to handle them systematically. It enables us to obtain the following data:

A. The set of transportation facilities on each link, $\{B_a|a \in A\}$.

B. The seismic intensity on each transportation facility for each earthquake scenario, $\{F_b(s)|b \in B, s \in S\}$.

VIII. OTHER DATA FOR EVALUATING THE SOCIAL LIFE CYCLE COST

We evaluate the anti-seismic reinforcement cost of a bridge as 60 million yen. This is the difference between the construction cost of a new bridge with either higher seismic capacity or lower seismic capacity, which is estimated at 400 million yen or 340 million yen (Yoneda et al., 1998). The restoration cost of a bridge is estimated as 1,600 million yen based on

Table 1

The earthquake scenarios.

Adachi and Shoji (2003). The length of the recovery period is calibrated as 310 days based on experience of the Great Hanshin-Awaji earthquake in 1995 (Hanshin Expressway Company, 2003). Finally, we set the social discount factor as σ = 0.04according to the cost-benefit analysis manual (Ministry of Land, 2003).

ID	Epicenter	SI' at the epicenter	Annual occurrence probability
1	The inland crust	1.26	0.108 E−00
2	The inland crust	2	0.639 E−01
3	The Nankai Trough	2.82	0.208 E−01
4	The inland crust	3.55	0.158 E−01
5	The inland crust	4.47	0.119 E−01
6	The Nankai Trough	5.62	0.903 E−02
7	The inland crust	7.08	0.670 E−02
8	Yamasaki	8.91	0.488 E−02
9	The Nankai Trough	11.2	0.342 E−02
10	The inland crust	14.1	0.228 E−02
11	Uemachi	17.8	0.156 E−02
12	West of Awaji Island	22.4	0.957 E−03
13	Arima-Takatsuki	28.2	0.614 E−03
14	The median tectonic line	35.4	0.396 E−03
15	The inland crust	44.7	0.272 E−03
16	Arima-Takatsuki	56.2	0.205 E−03
17	Osaka Bay	70.8	0.163 E−03
18	Rokko	89.1	0.128 E−03
19	Rokko	112	0.930 E−04
20	Osaka Bay	141	0.598 E−04
21	Rokko	178	0.361 E−04
22	Rokko	251	0.262 E−04
23	Rokko	398	0.465 E−05

IX. CONCLUDING REMARKS

The present article proposes a novel framework for finding a reasonable solution for the anti-seismic reinforcement (ASR) problem of transportation facilities of an urban road network under multiple earthquake risks. The present method has the following notable

aspects. First, it evaluates the transportation disutility as a sum of the total travel time and the opportunity loss cost, the latter of which becomes vital if the travelers give up their trip due to an extremely high travel cost or the loss of all possible routes caused by earthquakes. Second, it estimates the realistic damage patterns on the road network and their occurrence probabilities on the basis of the recent advances in structural and earthquake engineering. Third, it dramatically reduces the size of alternative strategies to an enumerable level, by introducing the most-likely approximation and the allor-
nothing policy corresponding to the target scenarios.

We applied the present method to a test network in the Kobe urban area and demonstrated that (i) the most likely approximation enables us to evaluate the social life cycle cost for each ASR strategy with reasonable and practical computational effort for a practical large-size urban road network; (ii) the all-or-nothing policy effectively reduces the set of ASR strategies – both the ‘‘too weak’’ earthquakes with very short recurrence intervals and the ‘‘too strong’’ earthquakes with extremely long recurrence intervals can be excluded; (iii) it shows a rough breakdown of the social life cycle cost for each ASR strategy (e.g. the ratio of the ASR cost to the social life cycle cost). Our framework can be applied not only to other areas facing potential earthquake risk but could also be extended to other types of disaster, such as floods, hurricanes, and so on. The following data are necessary to apply the present method: (1) the disaster scenarios (e.g. floods caused by different rivers); (2) the distribution of the disaster intensity for each scenario (e.g. inundation height); (3) the location of vulnerable transportation facilities (e.g. tunnels, embankments, viaducts, pavements, etc.), which should be consistent with the disaster intensity distribution; (4) the fragility function for each type of transportation
facility with and without disaster prevention. A few further remarks are in order: Firstly, the present method uses the (static) UE/ED traffic assignment model to calculate the transportation disutility. However, we have not examined whether or not such a static/equilibrium-based assignment is suitable for representing the actual traffic flows on a malfunctioning network after the earthquake. This emphasizes
the importance and necessity of further analyses and modeling of post-disaster traffic flows. Secondly, it should be noted that the present method merely finds the optimal ASR strategy among the reduced alternatives obtained by the most likely approximation and the all-or-nothing policy. This means that the accuracy and efficiency of the present method depend on those of these reduction techniques, for which rigorous analyses would be interesting future work. Finally and perhaps most importantly, how reasonable the present method is inevitably depends on the accuracy of all the inputs, i.e. the fragility and location of each bridge, the seismic intensity distribution of each earthquake scenario and the transportation demand function for each O–D pair, all of which could vary. In other words, there might be no merit in discussing the details of some specific elements, without considering the balance of accuracy among all the parameters.

REFERENCES

[1] Annaka, T., Yamazaki, F., Katahira, F., 1997. Proposal of peak ground velocity and response spectra based on JMA 87 type accelerometer records. In: Proceeding of 24th JSCE Earthquake Engineering Symposium, vol. 1, pp. 161–164.
[2] Asakura, Y., 2007. Requirements for transport network flow models used in reliability analysis. IJCIS 3 (3/4), 287–300.
[3] Asakura, Y., Hato, E., Kashiwadani, M., 2003. Stochastic network design problem: an optimal link improvement model for reliable network. In: Bell, M.G.H., Iida, Y. (Eds.), The Network Reliability of Transport. Pergamon, pp. 245–259.
[4] Asakura, Y., Kashiwadani, M., 1991. Road network reliability caused by daily fluctuation of traffic flow, pp. 73–84.
[5] Asakura, Y., Kashiwadani, M., Hato, E., 1999. Flow model and performability of a road network under degraded conditions. In: Ceder, A. (Ed.), Transportation and Traffic Theory, Proceedings of the 14th International Symposium on Transport and Traffic Theory. Pergamon, pp. 257–281.
[6] Asakura, Y., Nishitani, H., 1991. Empirical studies on parameter estimation of travel time function in traffic assignment. Memoirs of the Faculty of Engineering, Ehime University 12 (2), 107–118.
[7] Bell, M.G.H., Cassir, C., 1999. Reliability of Transport Networks. Research Studies Press, UK. Bell, M.G.H., Iida, Y., 2003. The Network Reliability of Transport. Pergamon, Oxford, UK. Chen, A.H., Yang, H., Lo, H., Tang, W.H., 2002. Capacity reliability of a road network: an assessment methodology and numerical results. Transportation Research Part B 36 (3), 225–252.
[8] D'Este, G.M., Taylor, M.A.P., 2003. Network vulnerability: an approach to reliability analysis at the level of national strategic transport networks. In: Bell, M.G.H., Iida, Y. (Eds.), The Network Reliability of Transport. Pergamon, UK, pp. 23–44.
[9] Dorigo, M., Blum, C., 2005. Ant colony optimization theory: a survey. Theoretical Computer Science 244, 243–278.
[10] Dorigo, M., Maniezzo, V., Colorni, A., 1996. Ant system optimization by a colony of cooperating agents. IEEE Transactions on Systems, Man, and Cybernetics, Part B 26 (1), 29–41.
[11] Du, Z.-P., Nicholson, A., 1997. Degradable transportation systems: sensitivity and reliability analysis. Transportation Research Part B: Methodological 31 (3), 225–237
[12] Glover, F., 1989a. Tabu search I. ORSA Journal on Computing 1, 190–206.
[13] Glover, F., 1989b. Tabu search II. ORSA Journal on Computing 2, 4–32.
[14] Goldberg, D.E., 1989. Genetic Algorithms in Search, Optimization, and Machine Learning. Addison-Wesley Pub. Co..
[15] Hanshin Expressway Company, 2003. Development of a simulation model for recovery process of road network systems after earthquake. In: Technical Report

by Association for Disaster Prevention Research.

[16] Huang, H.-J., Bell, M.G.H., 1998. Continuous equilibrium network design problem with elastic demand: derivative-free solution methods. In: Bell, M.G.H. (Ed.), Transportation Networks: Recent Methodological Advances. Pergamon, pp. 175–193.

[17] Iida, Y., Wakabayashi, H., 1989. An approximation method of terminal reliability of a road network using partial minimum path and cut set. In: Proceedings of the 5th WCTR, Yokohama, pp. 367–380.

[18] Jenelius, E., Petersen, T., Mattsson, L.G., 2006. Importance and exposure in road network vulnerability analysis. Transportation Research Part A 40, 537–560.

[19] Kagayama, T., Okunishi, F., Suzuki, N., Sawada, Y., 1999. A disaster prevention system for the Nicholson, A., Du, Z.-P., 1997. Degradable transportation systems: an integrated equilibrium model. Transportation Research Part B: Methodological 31 (3), 209–223.