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Optimal Decision-Making for Improving Bridge Resilience

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Abstract

With the knowledge and technology accumulated over the past few decades, bridge engineers have a collection of design strategies, analysis tools, and detailings/devices/countermeasures that can be used to resist seismic and hydraulic hazards. Justification of the investment for protection may not always be straightforward because of the infrequent occurrence of major events and uncertainties in tolerable damages. Bridge owners need to tie such investment to the transportation system performance in order to determine proper spending and to optimize the effort. The level of resiliency is a good indicator to the performance of the transportation assets because it does not only focus on bridge safety but also considers the effect of disturbance to the road users and the communities in the network.

Resilience in the context of highway infrastructure includes the ability to reduce and resist disturbance or hazards, to quickly recover from degraded operation or damages, and to adapt to changes of the threats and the changes of the community, achieved with the optimal usage of limited resources. Managing the risks and consequences of seismic or hydraulic events are not completely different from managing those of construction, operation, and maintenance, and can potentially be put into a common risk management scheme. The effort of integrating the risk management of extreme events with that of transportation asset management is illustrated in this presentation. It can provide significant support to the State officials in making best decisions on the transportation planning.

Keywords: bridge, tunnel, extreme event, preparedness, risk management

1. Introduction

The disaster resilience of highway infrastructure is built on the ability of reducing and resisting disturbance, quick recovery, and adaptation. Monetary and natural resources are potentially consumed for accomplishing better resilience of the highway system. On the other hand, greater resilience would promote economic growth as well as the protection of human/natural environment. The level of possible achievement or improvement of resilience depends upon all factors involved. The decision on where and how much resource to use must be based upon good information on the potential outcomes compared among all alternative actions. While there may not yet be a universally accepted quantitative measure of resilience, many efforts have been made to provide decision-making factors concerning specific topics in highway performances. Maximizing cost saving and fiscal benefit is one of the common strategy to produce decision-making aids[1]. Reliability in travel time is another common factor that supports the operational goals[2]. Improvements of safety and security are of high importance to highway agencies[3][4]. It is also important that sustainability considerations are taken into account to make the system economically, socially and environmentally sustainable[5].

While the topic covers very broad engineering and scientific areas, a sound risk management approach can potentially summarize the complex engineering, social, economic, and environmental demands and offer feasible engineering solutions. Risk management usually include the evaluation of likelihood of occurrence and the severity of the consequences, then choose actions accordingly. This has been applied not only to the transportation asset management[6][7] but also to the corporate strategies of transportation agencies[8]. Managing the risks and consequences of extreme events, such as seismic or hydraulic events, are not conceptually different from managing those of construction, operation, and maintenance, and can be put into a common risk management scheme. The special challenges come from the extreme scale of likelihood and consequences, as well as the need for cross-disciplinary knowledge and techniques. The effort of integrating the risk management of extreme events with that of transportation asset management is illustrated in this presentation. The approach can provide significant support to the State officials in making best decisions on the transportation planning. Better supporting tools and procedures for the practice are being developed in various areas of research.

2. Risk Management

Regardless the type of application, a risk management includes a few general steps of establishing risk context, identifying risks, analyzing risks, evaluating risks, and then managing risks[8]. The analysis and evaluation of risks include the assessment of likelihood or frequency of threats, as well as the consequence from considered incidents. High likelihood/frequency combining with severe consequences imposes the greatest risk. Unlikely/infrequent threats with low or tolerable consequences are of low risks. Other combinations yield various levels of risk levels that need to be determined in these steps.

The consequences can be and effect to the asset, including the damage to structures, impediment of functions, or future maintenance issues. The associated cost to such risk is directly related to design, repair, rehabilitation, or replacement. The consequences can also be an impact to agency missions, quality of life, public/private properties, environment, and economy. The quantification of this class of consequences can be challenging in data availability and evaluation techniques. However, when a comprehensive evaluation is possible, it gives the State DOT or Metropolitan Planning Organization managers very useful basis for making important and difficult decisions, which enable a well-balanced planning and efficient operation.

It is clear that the scope and scale of the evaluation described above can easily go beyond hand calculation or simple computer work. Tools and associated data relevant to those threats and consequences are needed for the complex assessment to support well-informed judgment. Works have been done in many different areas

each deals with a specific type of threats or consequences. While not comprehensive, those works are already making transportation risk management more achievable.

3. Tools and Procedures

The risk assessment and evaluation concerning extreme events are sometimes more demanding because of the involvement of time scale. Extreme events can have a continuous variation from somewhat infrequent disturbance to very infrequent devastating disasters. A sound evaluation makes use of the hazard data, which include intensity, distribution, frequency, and other significant parameters. This needs to be then translated to the demand for the infrastructure, therefore to evaluate the possibility of damage and function degradation. Direct and indirect loss from the damage or function degradation can then be calculated to provide necessary parameters for making decisions[9]. FHWA has sponsored the development of the assessment tool for Risk from Earthquake Damage to Roadway Systems (REDARS)[10] that utilize earthquake scenario data to assess loss from highway operation beyond that comes directly from repair and retrofitting. This is an example of significant computation needed for extreme event risk management that links the threat to the decision-making parameters.

4. Current and Future Works

To support the risk-based management of transportation infrastructure, the Seismic and Multi-Hazard Resilience Program of FHWA promotes resilience against the disruption or damage from extreme natural events or accidental human actions so that bridges can fulfill the key role in the highway transportation network. The program also seeks best strategies to support transportation performance and asset management in addressing extreme events. A framework is being developed to identify the attributes of bridges and structures that support resilience in planning, design, recovery, and adapting. Special attention is given in the preparedness of highway agencies in conducting post-hazard works. Updating of fragility model and applications that support quick risk-based post-hazard inspection/investigation are also underway.

To provide risk-based decision-making support that boost highway system resilience, the program will venture more into characterization of direct and indirect loss from extreme events, risk evaluation procedures/tools considering extreme events, and probabilistic study on structural loads and resistance. Examples that demonstrate the risk-based management of transportation asset and performance management including the effect of extreme events will be provided to enable better life-cycle optimization of transportation infrastructure.

5. References

[1] Federal Highway Administration (2016): *Use of Benefit-Cost Analysis by State Departments of Transportation: Report to Congress*, https://www.fhwa.dot.gov/policy/otps/pubs/bca_report/senate_bca_report_05172016_revised.pdf.

[2] Sallman D, Flanigan E, Jeannotte K, Hedden C, and Morallos D (2012): *Operations Benefit/Cost Analysis Desk Reference*, FHWA-HOP-12-028, FHWA, Washington DC.

[3] Lawrence M, Hachey A, Bahar G, and Gross F (2018): *Highway Safety Benefit-Cost Analysis Guide*, FHWA-SA-18-001, Washington, DC.

[4] American Association of State Highway and Transportation Officials (2011) Bridge Security Guidelines, AASHTO Washington, DC.

[5] Federal Highway Administration (2018): INVEST User Guide, https://www.sustainablehighways.org/files/3429.pdf, FHWA, Washington, DC.

[6] Federal Highway Administration (2012): *Risk-Based Transportation Asset Management: Evaluating Threats, Capitalizing on Opportunities*, FHWA-hif-12-035, FHWA, Washington, DC.

[7] FHWA, AASHTO (2013): *AASHTO Transportation Asset Management Guide, A Focus on Implementation—Executive Summary*, FHWA-HIF-13-047, FHWA, Washington, DC

[8] American Association of State Highway and Transportation Officials (2012): *AASHTO Guide for Enterprise Risk Management*, AASHTO, Washington, DC.

[9] Moehle J and Deierlein GC (2004): "A Framework Methodology for Performance-Based Earthquake Engineering," *Proceedings, 13th World Conference on Earthquake Engineering*, Vancouver, BC, Canada, 2004.

[10] Werner SD, Taylor CE, Cho S, Lavoie JP, Huyck C, Eitzel, C, Chung H, and Eguchi R (2006): *REDARS 2 Methodology and Software for Seismic Risk Analysis of Highway Systems*, MCEER Special Report MCEER-06-SP08. University at Buffalo, Buffalo, NY.