Multi-hazards Design Criteria of Highway Bridge

by

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ABSTRACT

Following the philosophy approach of the AASHTO LRFD, a study of commeasurable criteria for multiple hazard comparison is carried out as a research task of a FHWA contract to MCEER. This paper describes the general approach undertaken by the MCEER researchers to establish a platform for proper comparison of various hazard events and their expected impact to highway bridges.

1.0 INTRODUCTION

Multiple hazards (e.g. earthquake, wind gust, flood, vessel collision, traffic overload and accidents, and terrorist attacks etc.) must be properly considered in highway bridge design in addition to the normal functionality requirements. Current AASHTO bridge design specifications have provided detailed hazard loadings for each identified hazard. To further examine the bridge resistance to multiple hazards; it is necessary to compare hazard events and their expected impact to bridges for which consistent measurement criteria need to be established. For example, a simple criterion can be used to consider the occurrence of various hazards such as the return period or probability of exceedence in a given time period. However, it is not fully justifiable to apply such a criterion to calibrate the design hazard loadings of bridges since many other influential factors and uncertainties such as hazard duration, vulnerability of critical components,
risk of hazard induced consequences, potential areas of impact and severities of hazard induced damage to a bridge may vary considerably from one hazard to another.

Indeed, in the current AASHTO specifications, the design hazard for earthquake is set at 475 year of return period, which has a 10% probability of exceedence in 50 years. Based on recent recommendation from NEHRP (NEHRP 2000), it is also intended to increase the return period to 2000~ 2500 years for significant bridges. And the proper return period of design earthquake is still under discussion in the research and professional community. Wind hazard is set at 50 year of return period according to ASCE 07-95. Scour is
set at 100 year return period following FHWA HEC 18. In comparison, live load is set at the maximum of 75 years, which is the design
life-span of the bridge (Ghosn, et al 2003). There is no uniform cross-the-board requirement for the hazard occurrence frequency set for design considerations.

2.0 FROM AASHTO LRFD TO IMPROVEMENT OF MULTIPLE HAZARD BRIDGE DESIGN

A main thrust of highway bridge design in the US is currently focused on the transition of AASHTO standard specifications to AASHTO LRFD specifications. Recognizing the advantage of LRFD design methodology, proper engineering comparison of multiple hazards for highway bridge design is important since the major uncertainty in design comes from the hazard loading demand.

From the point view of AASHTO LRFD design methodology, every bridge should be designed for the specified limit states. Both standard low intensity hazards a bridge experiences regularly and the extreme hazard events are represented by the design limit states. This means that the bridge

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structural system including its components and connections must be designed to reach the design failure mechanism first. Thus, unintended over-strength of a member or component is to be avoided, because it could result in damage (e.g. plastic hinge) at an undesirable location of the structure with adverse effects.

AASHTO LRFD differs from the AASHTO standard specifications in which the fundamental design methodology is founded on traditional allowable stress design, ASD, approach. A major weakness of ASD design is that all loads and load combinations are treated equally without considering the probability of both a higher-than-expected load and a lower-than-expected strength occurring at the same time and place. Therefore, it possesses little or no direct relationship between the assumed design standards and the actual resistance of many components in bridges, or the probability of events actually occurring (Kulicki 1999).

To overcome the weakness of the ASD approach, LRFD specifications are established on the basis of standard deviation or the coefficient of variation of a stochastic variable - failure index β, which is a measurement of a probability of failure for a given set of loads, or the nominal resistance of the components being designed.

The value of β directly corresponds to the probability of failure. The reliability indexes were evaluated for simulated and actual bridges designed according to the past specifications for both shear and moment. The range of reliability indexes cover a wide range from less than 2 to higher than 4. As the data prepared by (Nowak 1999) suggest that past practice is represented by $\beta = 3.5$, this value is selected as the target for the calibration of LRFD specifications. $\beta = 3.5$ corresponds a uniform probability of safety (1-probability of failure) which is equal to or greater than 99.98%.

The advantage of AASHTO LRFD is that it offers a uniform probability-based criterion to measure the safety level of a bridge design. Preferably, if a similar uniform standard could be established for comparison of the effects of multiple hazards on bridges, it would strengthen the AASHTO LRFD and provide a solid foundation for hazard load factor calibration. This, unfortunately, does not seem to be possible given the large uncertainties associated with hazard events and the reasons mentioned above. Following the fundamental methodology of LRFD and in view of lacking uniform criteria of hazard comparison in current multiple hazard bridge design, This FHWA research task is to explore and establish some possible and justifiable non-uniform commeasurable criteria.

3.0 COMMEASURABLE CRITERIA OF MULTIPLE HAZARDS FOR HIGHWAY BRIDGE DESIGN

The word “commeasurable” by definition means comparison on an “equal” basis. For comparisons of multiple hazard impacts or calibration of hazard loadings on bridges, the “equal” basis can be rather complicated to define. For example, a hazard classification based on a commeasurable return period is to set a reference for design loadings of individual hazards on the basis of hazard occurrences. In this regards, the commeasurable criterion has only considered the uncertainties of the hazard occurrence; but not the cause of hazards and the resistance of the structure. Vessel collision is a hazard which cannot be properly modeled by return period since the vessel size and weight in a particular river is physically restricted; therefore, the impact from collision will not significantly vary from one year to the next. It is measured as the rate of total collision incidents per year regardless of the location of the incidences.

The goal of a commeasurable criterion is not to judge the bridge design itself, but to offer an “equal” base to evaluate the possible impact of a potential hazard event on a bridge. As it is pointed out above, the “equal” base can be interpreted differently by “occurrence”, “safety”, “cost of repair”, “interruption of services” etc.

There are several available commeasurable criteria other than the simple return period criterion. Based on reliability index β, different hazards may be compared by their load effect demand on major safety related individual components as described in API-LRFD (API-1992), or classified component groups (e.g. all steel members in bending, compression, or shear). Improving the simple component failure/ safety criteria, a comparison criterion may include a full range of system and component failure consequences (Moses, 2001). Additional factors to be considered include non-hazard caused bridge down time such as repair, serviceability, operability and life cycle cost.

For multiple hazard bridge design, some non-uniform commeasurable criteria are inevitably needed to justify the targeted design hazard level. Although the selection of such a criterion may not be directly visible to the design engineers as it may have been implied in the code specified load combination factors, a clearly established relationship between the design hazard level, desired bridge performances, and balance of resources will help bridge engineers to understand the various options and solutions to meet the requirements of future bridge design against multiple hazards.

4.0 NON-UNIFORM COMMEASURABLE CRITERIA AND BRIDGE PERFORMANCE UNDER HAZARD CONDITIONS

As pointed out in the above section, commeasurable criteria of multiple hazards for bridge design are most likely non-uniform, and thus they are not suitable to be applied uniformly to all bridge design. It often is associated with the performance requirements, level of acceptable uncertainty and prioritized importance factors. For example, the following is suggested as some basic desired performance levels for highway bridges.

1. Minimum (Basic) performance level
   - Life safety
   - System integrity (superstructure, foundation, pier, bearing, tower, cable, deck, etc.)
2. Serviceability performance level
   - Full traffic service
   - Restricted traffic service (weight, speed, volume, direction)
   - Temporary down time
   - Alternative route
3. Beyond normal functionality level
   - Evacuation
   - Rescue
   - Special transportation tasks (disaster relief)
   - Repair
   - Collapse control

Corresponding to the above performance levels, there may be potential critical issues of bridge performances under hazard conditions, in particular, under the extreme hazard events. For example the following list summarizes a few issues in each of the relevant performance levels.

In basic performance level:

- Possible scenarios of mass casualty on bridge and tunnels under severe hazard conditions
- Possible scenarios of bridge failure modes that may lead to a loss of system integrity

In service performance level:

- Rapid assessment and inspection methods to determine the bridge health condition after a severe event
- Restricted bridge service with identified damage
- Temporary repair and the bridge capability limit after the repair
- Cost benefit balance of hazard plans (strengthening, restricted traffic, temporary downtime, routing, etc.) for critical bridges

In beyond normal functionality level:

- Assessment of available technologies for improved resilience to terrorist attack
- Collapse of bridge
- Cost structure of possible scope of desired level performance and corresponding expenses

Despite the over simplification of this short list, it serves to illustrate that in order to compare hazard and hazard impacts for highway bridge, a more comprehensive basis of comparison should be established. In particular, these factors and considerations may vary from bridge to bridge.

5.0 FHWA SPONSORED RESEARCH AT MCEER

MCEER has successfully conducted several research projects resulted in seismic design guidelines of bridges in recent years. In the present FHWA project, earthquake hazard is expanded to multiple hazard resistant bridge design.

The goal of this current research task is to pave the way for developing multi-hazard design guidelines for future highway bridges. Under this long range goal, there are two levels of efforts and currently been explored by MCEER researchers.

- Development of a comprehensive scope of the multi-hazard design for highway bridges
- Establishment of commeasurable criteria for bridge design against multiple hazards

For the comprehensive integrated approach

In general, multi-hazard design for future highway bridges may face many challenges ranging from considering more frequent low to moderate intensity hazard loadings to combined multi-hazard extreme events; establishing proper design criteria for hazard resistance to balancing resources for maximized utility benefit; ensuring the public transportation safety to minimizing life cycle costs of bridge maintenance and services, developing mandated requirements for minimum safety concerns to owner discretionary options of hazard resilient design. The comprehensive evaluation is to explore the challenges of the multi-hazard bridge design and identify the key areas for the next phase major effort. In this task, the comprehensive scope of multi-hazard design for highway bridges is to be explored by

1. Evaluating each individual hazard design requirements in AASHTO LRFD.
2. Screening issues of concern for multiple hazard events (from low to high intensity).
3. Holding advisory panel discussions to explore possible approach to address these issues.

For Commeasurable Criteria Evaluation:

Within the short time duration of the project (two years), a focused effort is to be pursued to address the issue of developing consistent criteria to compare the effects of various hazards on bridges based on current AASHTO LRFD. This effort is to be limited to a few hazards at the beginning, which includes earthquake, wind, and flood. It will be extended to other hazards such as vessel collision, fire, traffic overload and potential man-made hazards in the future. Upon establishing some commeasurable criteria, a Monte Carlo simulations shall be carried out to check the various probability distributions between different loadings (load types and intensity) and the relevant critical failure modes. In particular, a safety based criterion will be compared to consequence-based criteria. The study is to be carried out following the path described in Figure 1.

6.0 SUMMARY

The above described research is the first step of a longer term R&D effort to improve bridge design guidelines against multiple hazards. The current research is to demonstrate in quantitative terms the benefits and limitations of some commeasurable criteria to be possibly employed for multiple hazards comparisons in bridge design. The effort is to extend the LRFD methodology and to explore a quantitative model for evaluation of multiple hazard load factor assumptions adopted in design code specifications.

7.0 ACKNOWLEDGEMENT

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8.0 REFERENCES

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In Figures 12 and 13 the soil stiffness and soil damping coefficients are plotted for two different amplitudes (ρ_{T1} = 0.002 m and (ρ_{T2} = 0.0015) vs. forcing frequencies. Both charts indicate a nearly linear decay in soil stiffness and soil damping with increasing forcing frequencies. This indicates that the soil softens with increasing the exiting frequency.

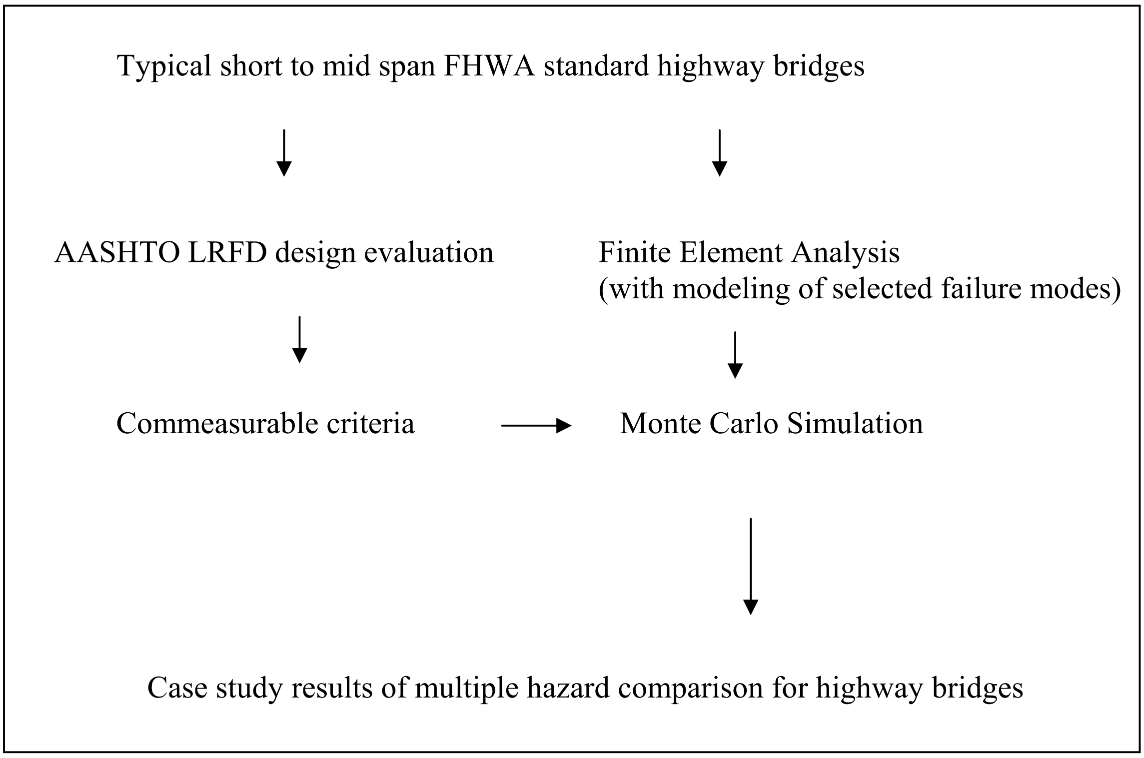

Figure 1. Project Study Path