ESTABLISHING RELIABILITY-BASED DEMAND FOR BRIDGE DESIGN UNDER MULTI-HAZARD LOADS

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44th UJNR Joint Panel Meeting on Wind and Seismic Effects
NIST, Gaithersburg, MD

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Introduction

- **Current AASHTO LRFD specifications are formulated by using a reliability-based approach with the design limit states calibrated only for dead load and frequent live load.**

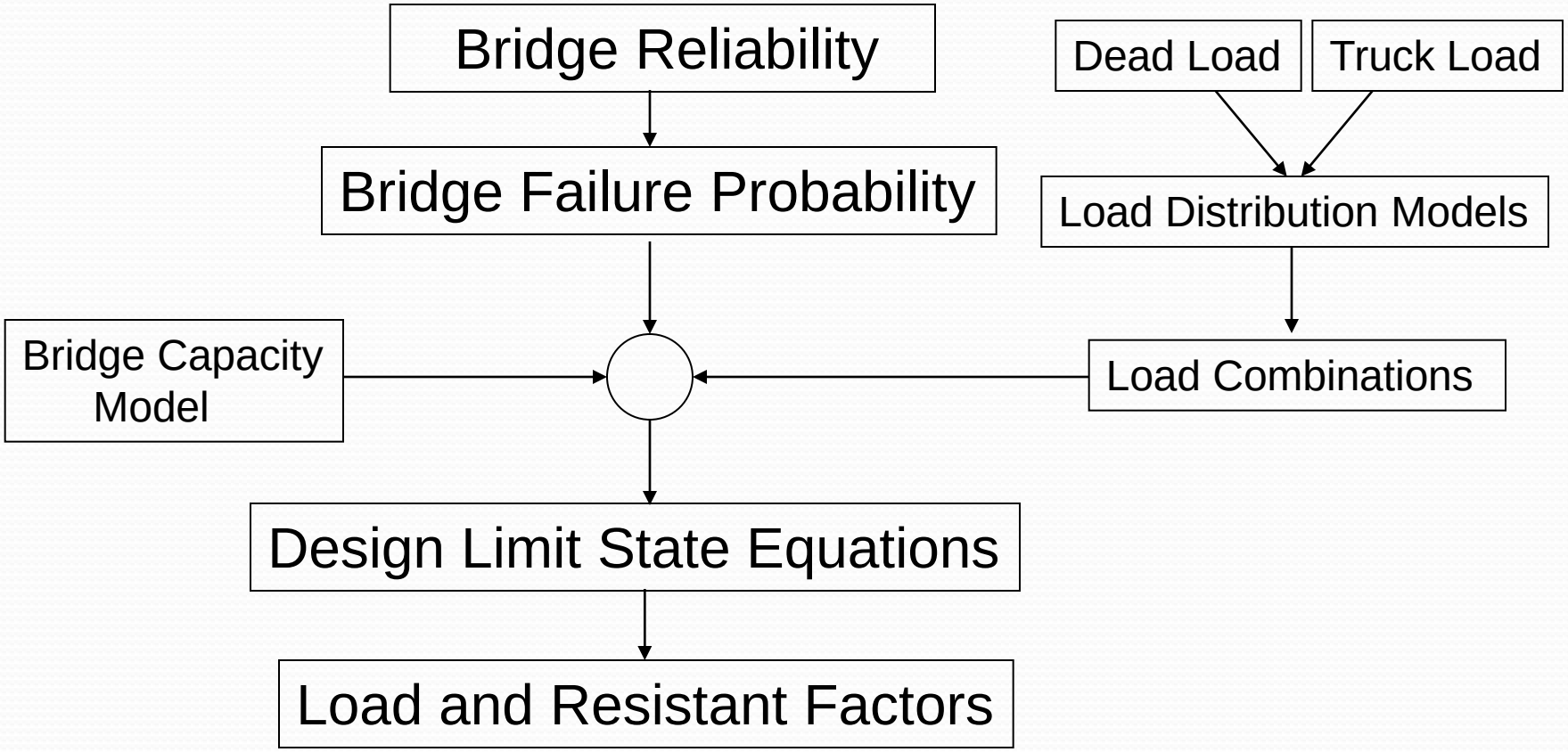
Introduction (cont' d)

- **Due to the lack of statistical data of extreme hazard loads (which are most likely time variables) and the corresponding bridge damage/failure information, MH-LRFD has not been successfully established.**

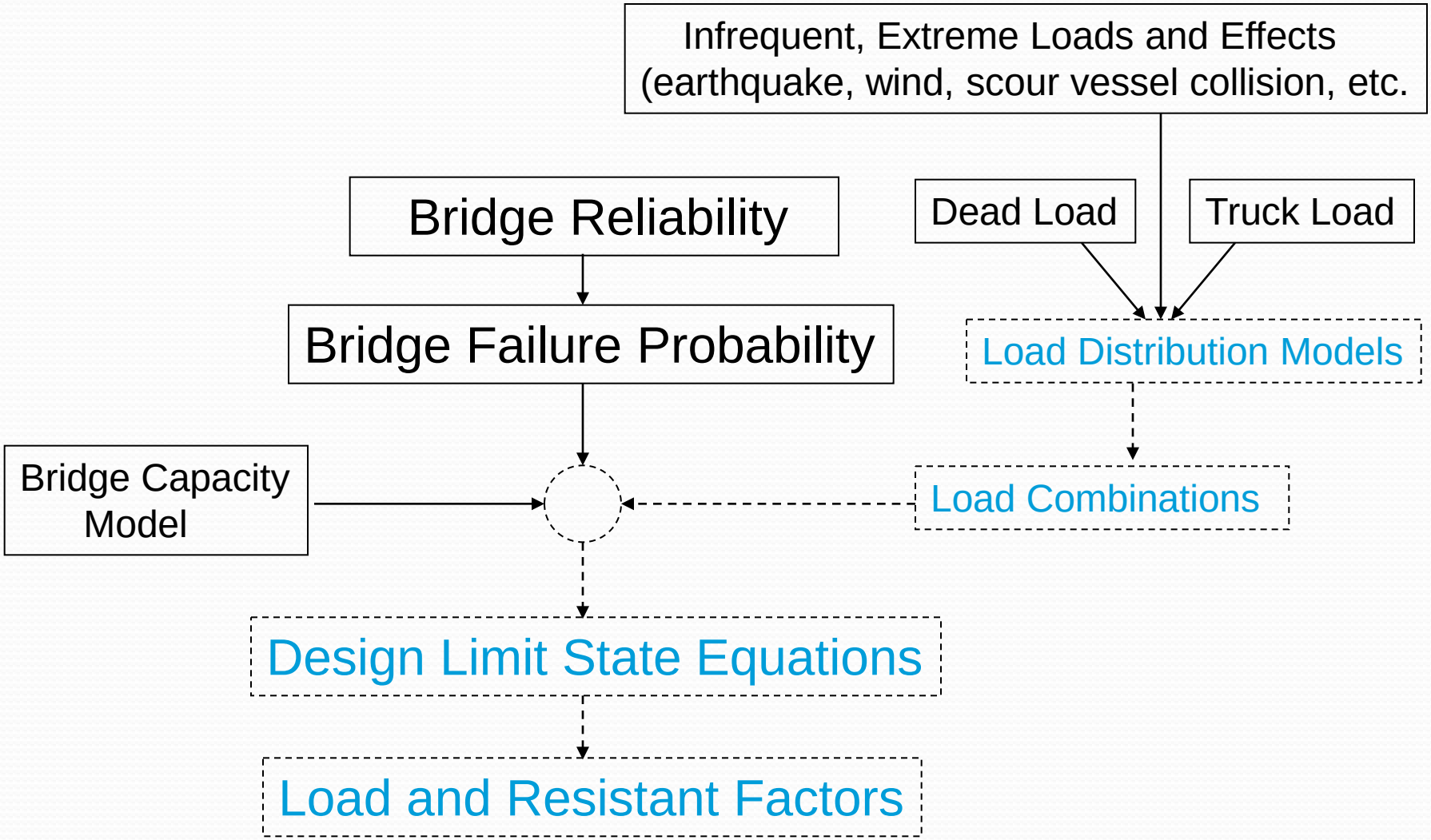
Introduction (cont'd)

- **This presentation briefly summarizes the objectives and challenges of a current MCEER research project, sponsored by FHWA, to explore and establish design principles and approaches for formulating multi-hazard LRFD.**

The Reliability -Based Approach for MH-LRFD



The Reliability -Based Approach for MH-LRFD (cont'd)



Bridge reliability under frequent loads

- **Relationship between bridge failure probability p_f and reliability p_r**
  - → $p_r = 1 - p_f$
  - → **Important concept of bridge failure probability**

- **The basic formula of bridge failure probability**
  - → $P(L \geq R) = p_f$
  - → **Defined as equation of failure probability**

Bridge reliability under frequent loads (cont' d)

1. Suppose L and R are normal distributions, a standardized variable β (reliability index) is specified directly relating to p_f.
2. Known β, as well as the variation of load L and resistance R, mean values of L and R, μ_L and μ_R, where

$$\mu_L = \eta\, \mu_R$$

3. Bias B and nominal value and mean value are related by

$$B(.)\, N(.) = \mu(.)$$

4. Load and resistant factors can then be determined

$$\gamma_D\, D_L + \gamma_L\, LL = \Phi\, NR$$

Bridge reliability under frequent and extreme loads

Failure Probability (P_f) = $P_{occurrance}$ x $P_{chance\ to\ cause\ failure}$

Example:

- **Earthquake 1000yr return period , small $P_{occurrance}$ but large $P_{chance\ to\ cause\ failure}$,**
  → P_f not small
- **Truck load, return period in minutes, high $P_{occurrance}$ but small $P_{chance\ to\ cause\ failure}$,**
  → P_f not large

Bridge reliability under frequent and extreme loads (cont' d)

- **Frequent Loads:**

Dead load, Truck load

* High occurrence probability

**Combinations can be treated as random variables.

- **Infrequent Loads and Effects:**

Earthquake, wind, scour, vessel collision

* Low occurrence probability but with extreme high magnitude

**Combinations must be treated as random process.

Extreme Loads

- **Time variables, difficult to get distribution model of load combinations**
- **Method to deal with these loads, separate variables**

  → using partial failure probabilities first, then combine them together

Method of Partial Failure Probability

$p_f = p_{f1} + p_{f2} + p_{f3} + \ldots$

$\mu_{L1} = \eta_1 \mu_R$

$\mu_{L2} = \eta_2 \mu_R$

$\mu_{L3} = \eta_3 \mu_R$

……

→

example

$\gamma_D D_L + \gamma_L LL + \gamma_E E_Q = \Phi NR$

Selection of Loads

- **Second challenge to establish MH-LRFD : to determine the loads that should be considered for bridge failure and those that may be neglected.**

- **Feasible criteria for load rejection is the value of partial reliability.**

$$p_{fi} \leq \kappa\, p_f \quad \text{example } \kappa = 0.1$$

Equivalent Load Effect

- **Third challenge, non-force based hazards: foundation movements, fire damage, bridge scour, etc.**
- **To include scour in formulating the bridge failure probability: reduction of capacity effect ΔR to equivalent load effect.**

$$P(L \geq R - \Delta R) = p_f \rightarrow P(L + \Delta R \geq R) = p_f$$

$$\mu_{\Delta R} = f(\mu_C)$$

$$\gamma_{\Delta R} = f(\gamma_C) \rightarrow \gamma_C = f^{-1}(\gamma_{\Delta R})$$

Range of Acceptable Reliability

The load and resistance factors are established through certain bridge component reliability.

-Should not change for different bridge designs.

-Variations in design will always exist.

Range of Acceptable Reliability (cont'd)

-Design sensitivity analysis conducted by varying size, material type, span, height, and other bridge parameters, denoted by B_P, → how load and resistance factors change.

$$\delta(B_P) \rightarrow \delta(\gamma_i \Phi)$$

If load and resistance factors ($\gamma_i \Phi$) fixed, reliability will vary

$$\delta(B_P) \rightarrow \delta(\beta) = \Delta\beta$$

Range of Acceptable Reliability (cont' d)

- **Challenge: the need for a criterion to quantify the result of sensitivity study.**

With a variation of the bridge design parameters and with fixed value of load and resistance factors, the reliability index will change. Assuming the variations, β_U, β_L, are upper and lower limit of the indices within allowable range $[\Delta\beta]$,

$$\Delta\beta = \beta_U - \beta_L \leq [\Delta\beta]$$

Load Importance Factor

- **Different weighting functions or importance factors have used to deal with relative importance of specific situations and/or consequences in establishing the demand for bridge design.**
- **For example, importance factors are used for different types and/or locations of bridges. Another example is the weighting function of different type of seismic regions for earthquake resistant design of structures.**

Load Importance Factor (cont'd)

- **Emphasize the importance of load specification**
  → concept of load importance factors
- **Example, denoting the load importance factors for dead, truck and earthquake load effect by II_D, I_T and I_E,**
- **load importance factor $I_{(.)}$ will not change the relationship between the nominal and mean values of a load, namely**

$$I_{(.)} B_{(.)} N_{(.)} = I_{(.)} \mu_{(.)}$$

Summary

- **There is a need to handle MH-loads on the same platform with the regular loads. That is, all hazard loads applying on a bridge, as long as they can affect the bridge safety, should be equally considered. All the loads factors should be calculated based on the entire bridge failure probability. To do this, several significant challenges are facing the researchers. This short paper briefly summarizes these difficulties and the approaches that are being pursued to address these challenges.**

Thank you!

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