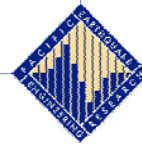


## Bridge Fragility Curves

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University of California, Berkeley*



## PEER Center Framework

- ◆ Divide and conquer!

$$P(DV > dv^{LS} | IM = im) = \iint G_{DV|DM}(dv^{LS} | dm) \cdot dG_{DM|EDP}(dm | edp) \cdot dG_{EDP|IM}(edp | im) \cdot dedp \cdot ddm$$

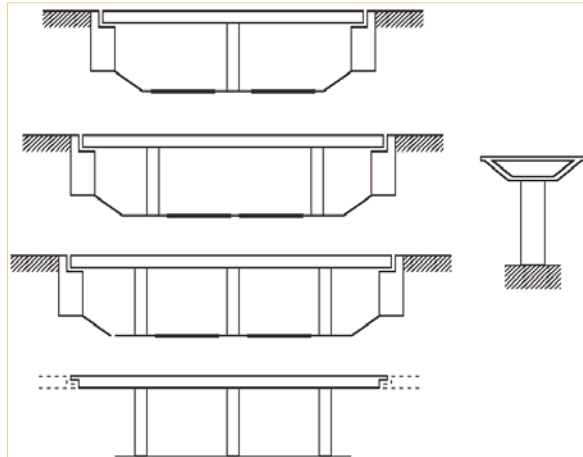
- ◆ Interim models:

- Hazard
- Demand
- Damage
- Decision

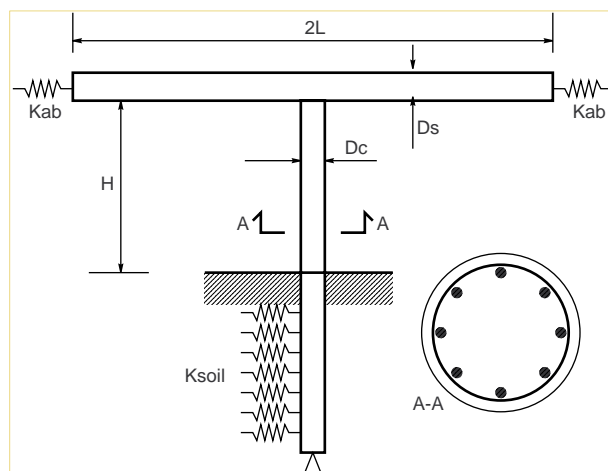
- ◆ Use a typical CA bridge example



## Generic CA Bridge Study



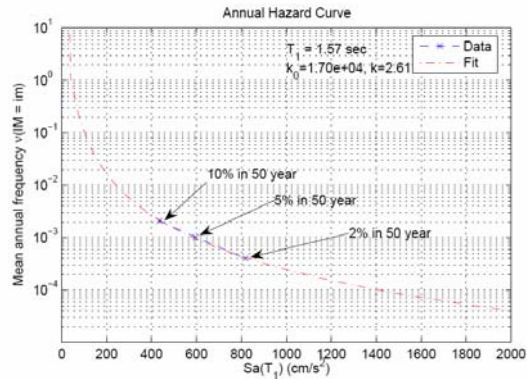
## Bridge Parameters



## Hazard Curve

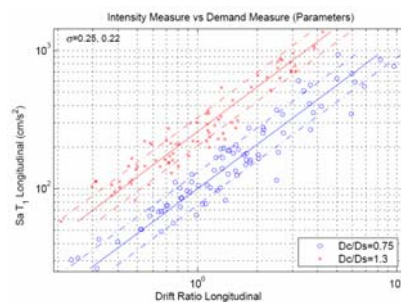
- ◆ How likely is a ground motion with this intensity at a given site?
- ◆ IM: A descriptor of ground motion intensity wrt. the seismic response of a structure
- ◆ Use USGS data:
  - Mean
  - Dispersion

$$S_a(T_1)$$



## Demand Model

- ◆ Given an IM was realized, how likely is it that a certain level of demand will be exceeded?
- ◆ EDPs:
  - Local: strain
  - Intermediate: curvature/rotation
  - Global: drift

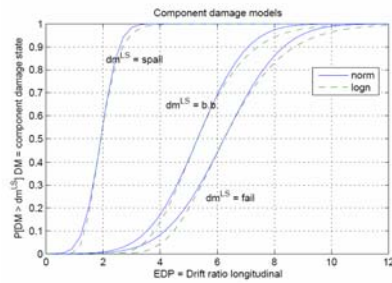


## Damage Model

◆ Given an EDP was realized, how likely is it that a certain level of damage will be exceeded?

◆ DMs:

- Spalling of concrete cover
- Reinforcing bar buckling
- Column failure (stirrups, bars, concrete)

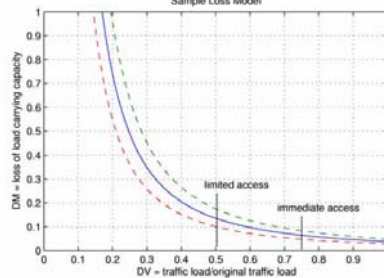
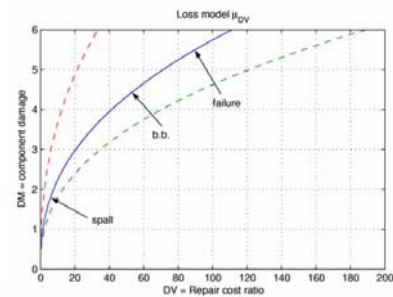


## Decision Model

◆ Given an DM was realized, how likely is it that a certain decision about the state of the structure will be made?

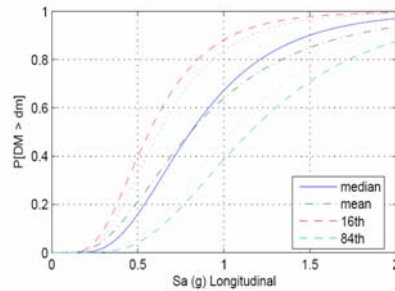
◆ Decision variables:

- Cost to repair or replace
- Time to repair or replace
- Available traffic flow
- Time to restore full traffic flow



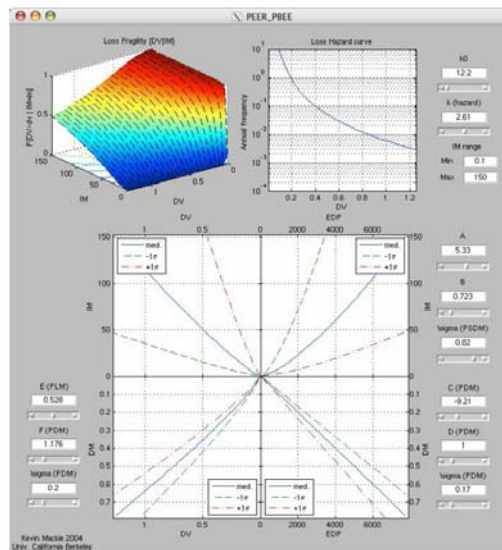
## Fragility Curves

- ◆ Fragility is a conditional probability of exceeding a limit state, given a level of seismic hazard
- ◆ Reflect uncertainties and non-linearity of the model
- ◆ Can be computed in three ways



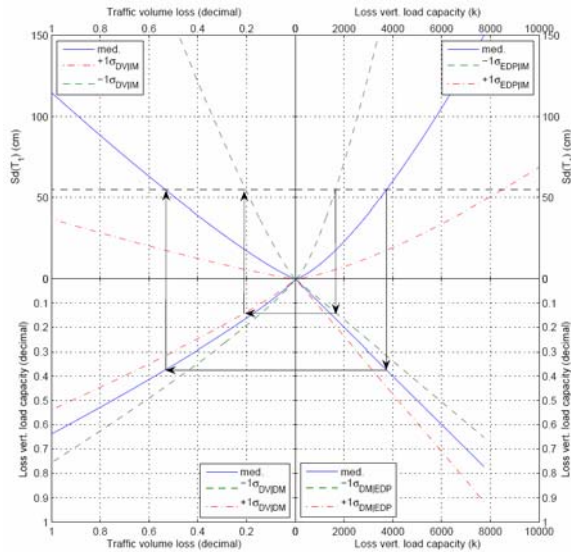
## Computing Failure Probability

- ◆ Given the interim models, Matlab tool computes the conditional probability of failure (mean and dissipation)



## Computing Failure Probability

- ◆ Use a graphical method, Fourway, to obtain the conditional probability of failure (mean and dispersion)



## Computing Failure Probability

- ◆ Assume all interim models are log-normal
- ◆ This makes a closed-form solution possible:

$$E\hat{D}P = a(IM)^b$$

$$P(DV > dv^{LS} | IM = im) = 1 - \Phi \left[ \frac{\ln(dv^{LS}) - (E + FC + FDA + FDB \ln(im))}{\sqrt{d^2 f^2 \sigma_{EDP|IM}^2 + f^2 \sigma_{DM|EDP}^2 + \sigma_{DV|DM}^2}} \right]$$

- ◆ Allows consistent derivation of LRFD-like design equations

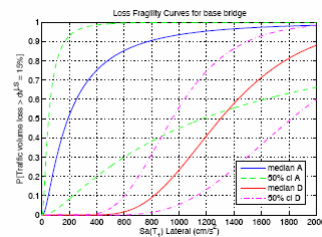
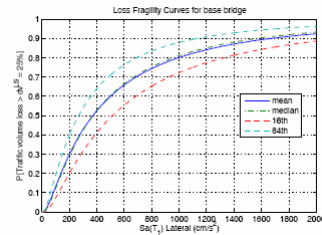
$$\lambda D < \phi C$$



## Fragility Curves and Decisionmaking

### ◆ Dispersion is key:

- Small dispersion allows making decisions with high levels of confidence
- Large dispersion results in low confidence and necessitates large safety factors in conventional design



## ... Do Not Kill the Messenger!

### ◆ Deficiencies of the model in:

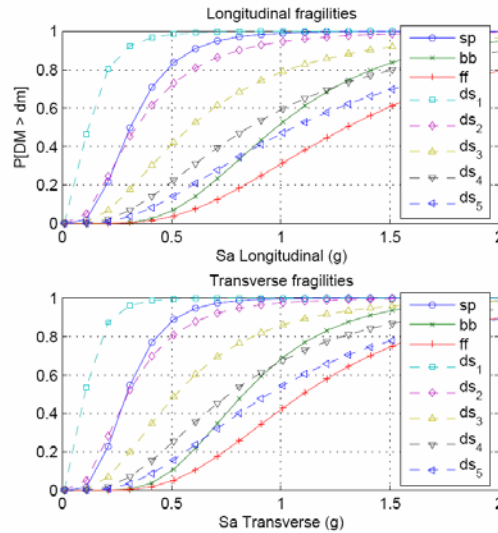
- Limit state selection
- Interim model selection and formulation
- Fragility curve dispersion
- Seismic response mechanism of the structure

are only reflected in the fragility curve, not the other way around



## Parameterized Bridge Fragility Curves

- ◆ Parameterized wrt. bridge R-factor
- ◆ Compare well to HAZUS fragility curves for damage states (ds1 through ds5)



## Conclusions

- ◆ Fragility curves are a way of expressing the conditional probability of exceeding a limit state for a structure during an earthquake
  - They are a tool for performance-based design
  - They capture the uncertainty and non-linearity present in the evaluation and/or design process.



**Thank you!**

