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Post-hazard Performance Prediction of Transportation Networks

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- System reliability analysis of lifeline network
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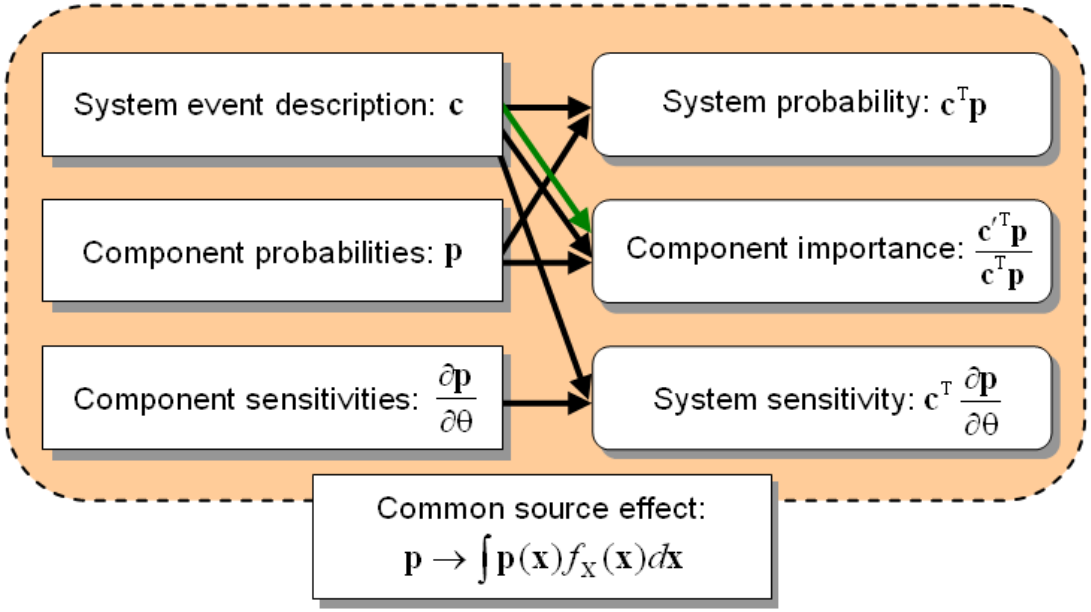
Background

- Bridge transportation network
  - Needs for optimal decision making on disaster management
  - Complexity
    - Multi-state of bridge damages
    - Network topology
  - Uncertainty
    - Uncertain seismic intensity and likelihood of bridge damage states
    - Corresponding traffic capacities of bridges
- Network reliability problem
  - Simulation-based methods
    - Easy to implement
    - Significant time/computational cost
  - Analytical methods
    - Provide many by-products efficiently
    - Few existing methods

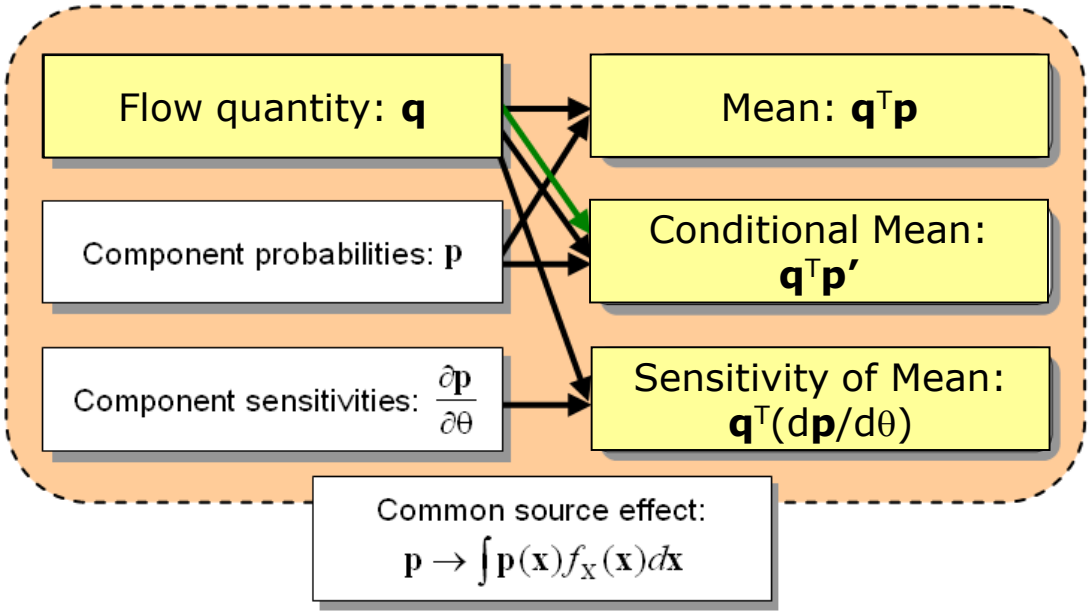
Matrix-based System Reliability (MSR) method



- **Convenient**: matrix-based procedures for **c** and **p**; easy SRA calculation (inner product)
- **General**: uniform application to series, parallel, and any general systems
- **Flexible**: inequality-type information; incomplete information ("LP bounds" method)
- **Efficient**: no need to re-compute "**p**"; replace "**c**" for SRA of a new event
- **Common Source Effect**: can account for statistical dependence between components
- **Decision Support**: parameter sensitivities, component importance measure; inferences

* Song, J. and Kang, W.-H. (2009). System reliability and sensitivity under statistical dependence by matrix-based system reliability method, *Structural Safety*, 31(**2**), 148-156.

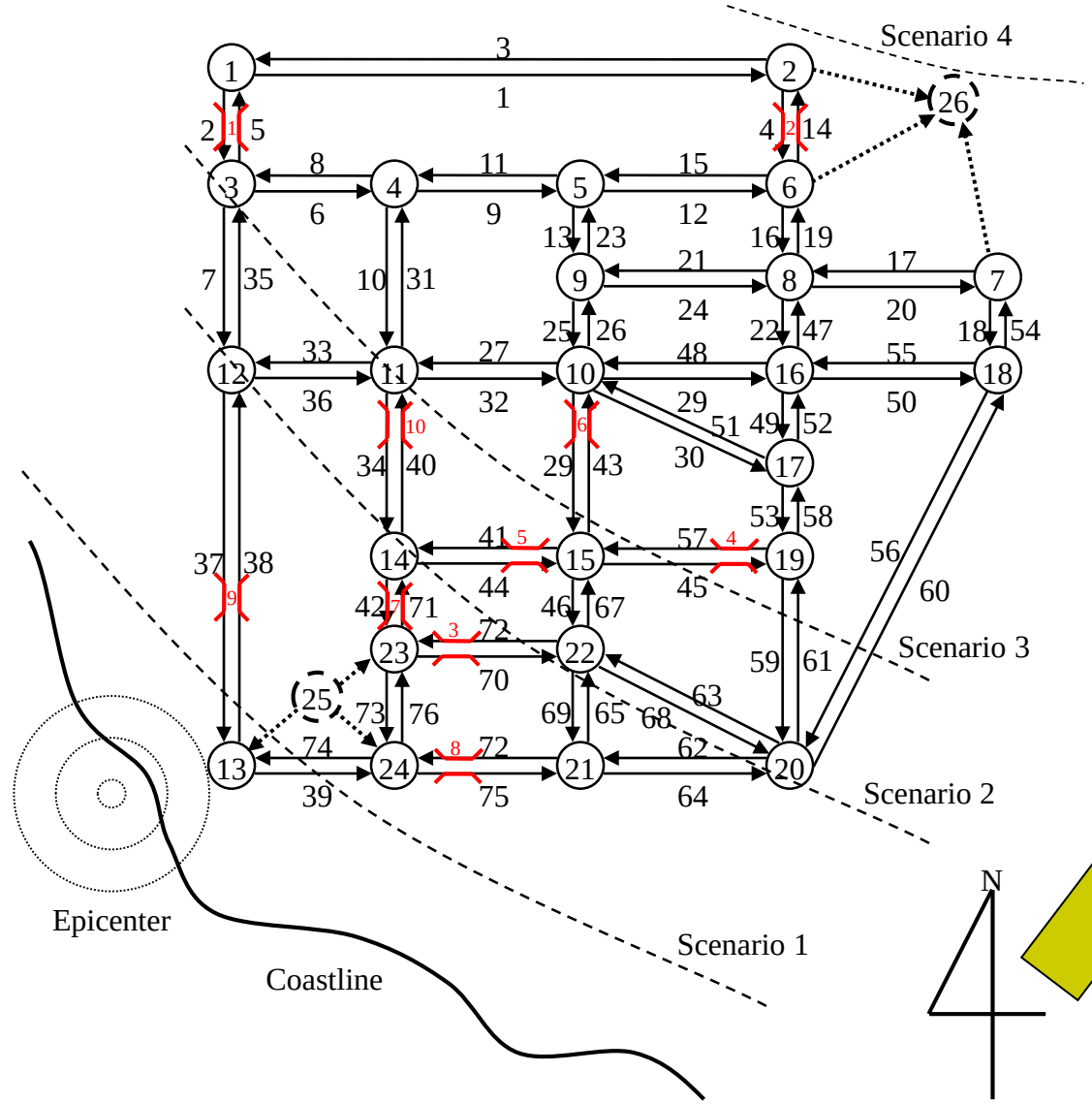
Extension of MSR method for network flow analysis



- **Multi-state failures**: can handle more than two failure/damage states
- **Separation between network flow analysis and vulnerability analysis**:
  1) No need to repeat network flow analysis (**q**) for time-varying fragility (deterioration, etc.)
  2) No need to repeat probability calculations (**p**) for changes in network (new routes, etc.)
  3) Flow analysis for damage scenarios with high likelihood only (for approximation)

* Lee, Y.-J., Song, J., Gardoni, P., and Lim, H.-W. (2011). Post-hazard flow capacity of bridge transportation network considering structural deterioration of bridges. Structure and Infrastructure Engineering: Maintenance, Management, Life-cycle Design and Performance, 7(7), 509-521.

Bridge transportation network



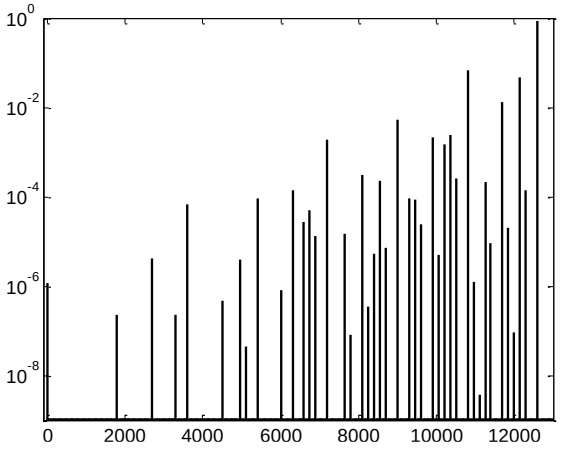
- Assumptions
  - Multi-state seismic fragility estimates w.r.t. drift capacity levels
  - Attenuation relationship (PSA & PGV)
  - Deterioration fragility estimates (Choe *et al*. 2007)
  - Multi-state flow capacity level proportional to number of open lanes
  - Deterioration scenarios
- Area-to-area flow capacity
- Further analysis for uncertain earthquake magnitude

Progress of Structural Deterioration (Corrosion) by Sea Air

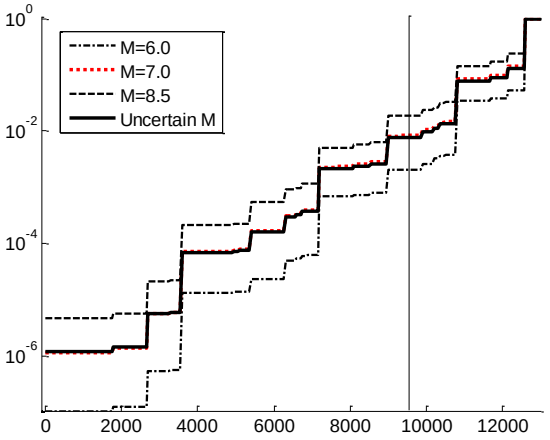
Uncertainty quantification of flow capacity

- Capacity distribution for a given seismic intensity

PMF (M=7.0)



CDF

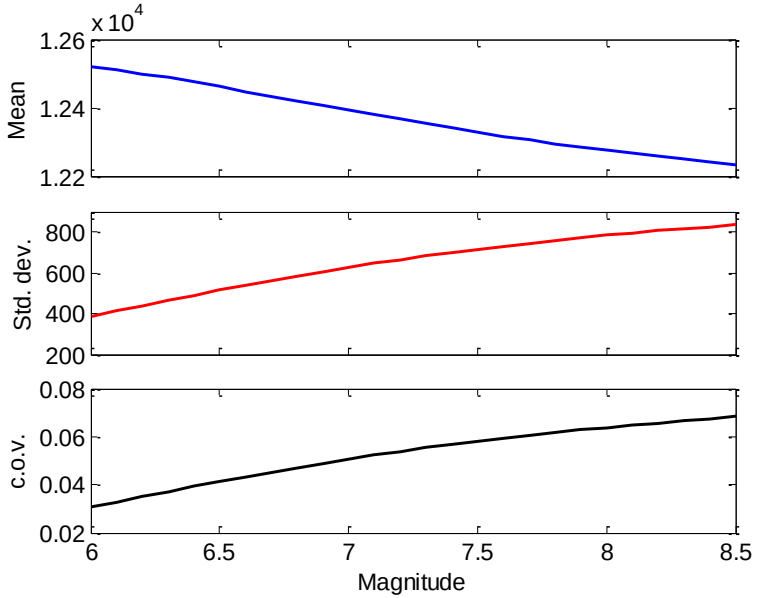


- Statistical parameters of flow capacity (M=6.0~8.5)

$$\mu_Q = \int_{\mathbf{s}} \mu_Q(\mathbf{s})\, f_{\mathbf{S}}(\mathbf{s}) d\mathbf{s} = \int_{\mathbf{s}} \mathbf{q}^{\mathrm{T}} \mathbf{p}(\mathbf{s})\, f_{\mathbf{S}}(\mathbf{s}) d\mathbf{s}$$

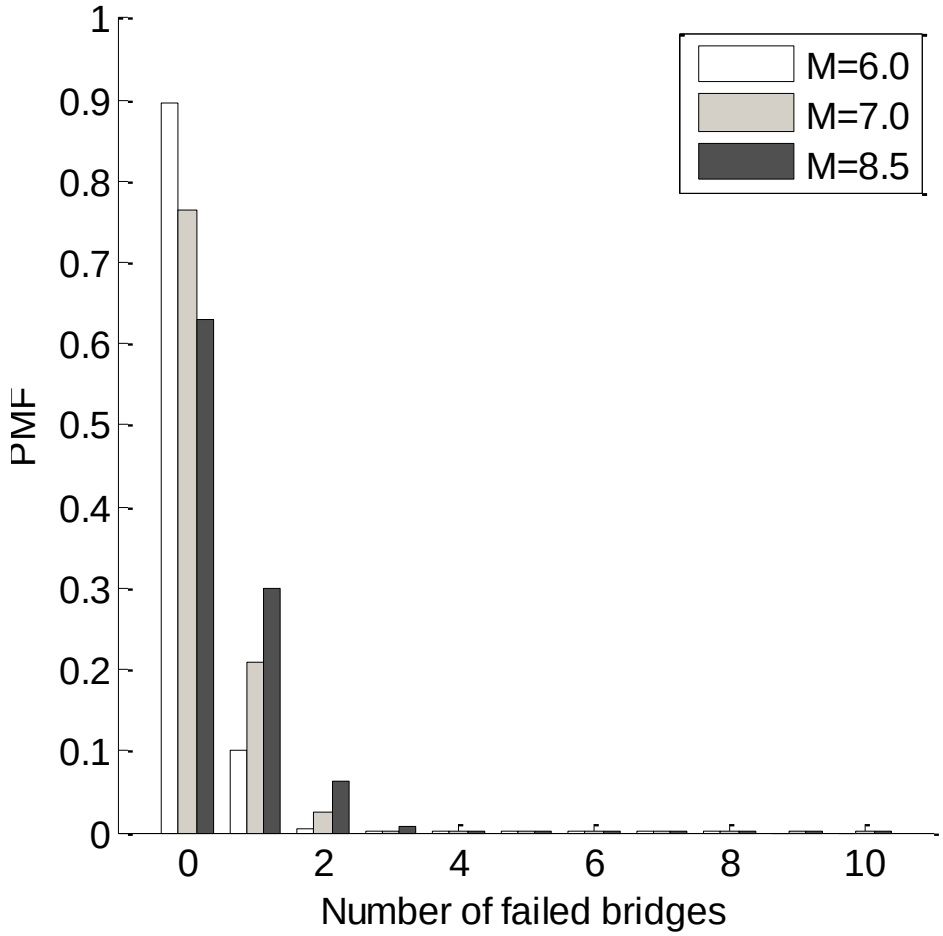
$$\sigma_Q^2 = \mathrm{E}[Q^2] - \mu_Q^2 = \int_{\mathbf{s}} \mathbf{p}(\mathbf{s})^{\mathrm{T}} (\mathbf{q}.*\mathbf{q})\, f_{\mathbf{S}}(\mathbf{s}) d\mathbf{s} - \mu_Q^2$$

$$\delta_Q = \sigma_Q / \mu_Q$$



Analysis Results

- Probability with number of failed bridges

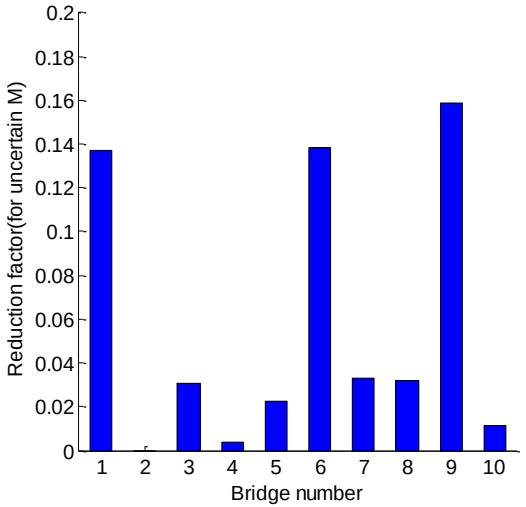


Analysis Results

- Conditional flow capacity (For 9th bridge, uncertain *M*)

Parameter		Value
Mean	$\mu_{Q\|9th}$	10,445 **(12,419)**
Standard deviation	$\sigma_{Q\|9th}$	930.47 **(582.41)**
C.O.V.	$\delta_{Q\|9th}$	0.0893 **(0.0470)**

- Importance measure for all bridges (uncertain *M*)

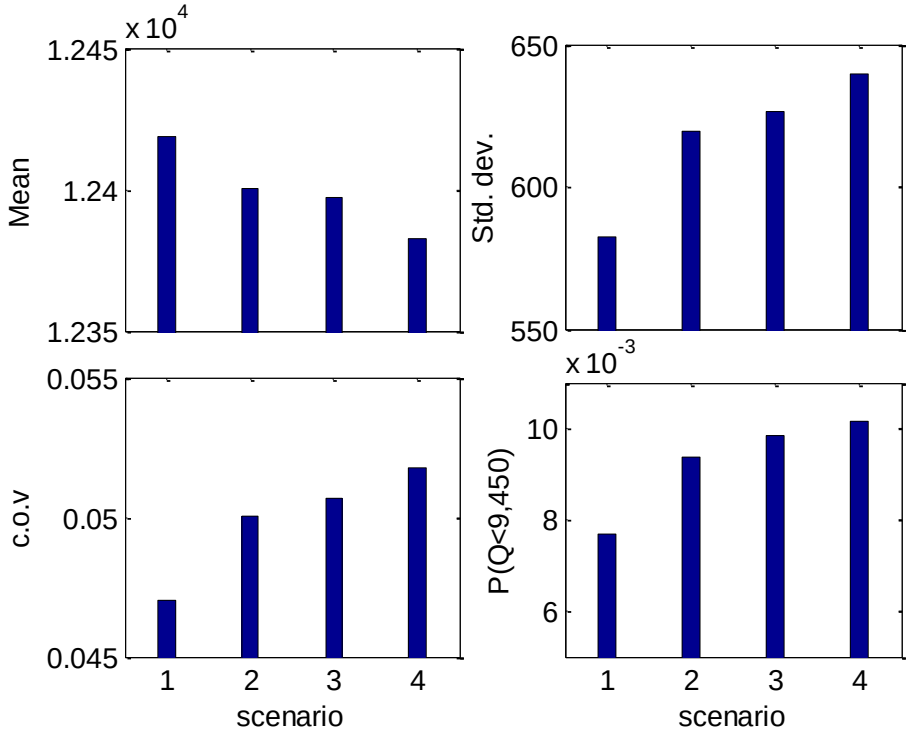


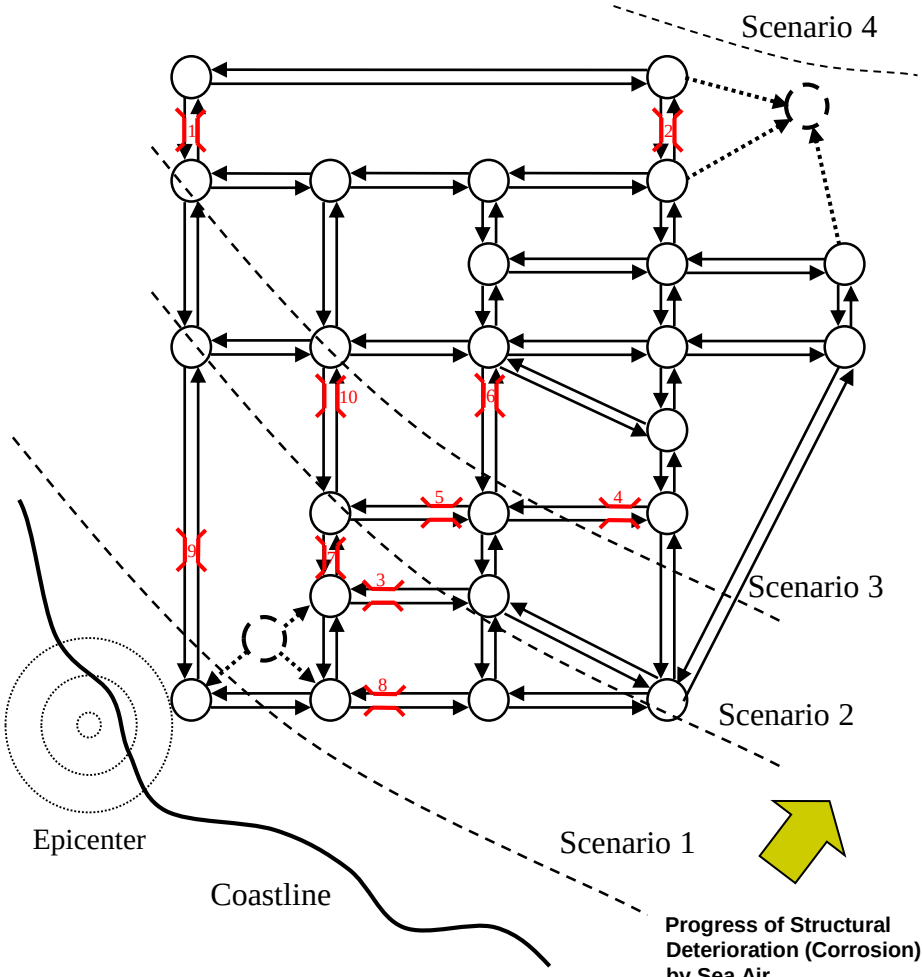
$$RF = 1 - \frac{\mu_{Q|\text{bridge failure}}}{\mu_Q}$$

1st, 6th, and 9th bridges are most important

Analysis Results

- Flow capacity with deterioration
- Assumptions





Progress of Structural Deterioration (Corrosion) by Sea Air

Future Research

- More realistic traffic analysis

- Maximum flow capacity → Total system travel time
- User equilibrium traffic assignment
- Larger size & more complex topology

- Network interdependency

- Interdependency among several lifeline networks
  ; Damage on a lifeline hampers other lifelines.
- Very critical to the post-hazard prediction of lifeline networks

- Further application to risk-based disaster management

- Optimization for effective decision-making on bridge repair
- Cost-benefit analysis

Conclusions

- A network reliability analysis framework employing the MSR method is proposed to analyze the post-hazard flow capacity of bridge transportation network
- It is shown that the proposed framework is applicable to multiple damage states of bridges caused by earthquakes or deteriorations through a numerical example
- Various statistical moments and probability functions of the network flow quantity can be obtained through simple matrix-based calculations of flow capacity vector and probability vector conveniently and efficiently
- The proposed framework will be further developed and used for various future research topics.

Thank you!

Any questions?

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