System Performance Under Multi-hazards

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Outline

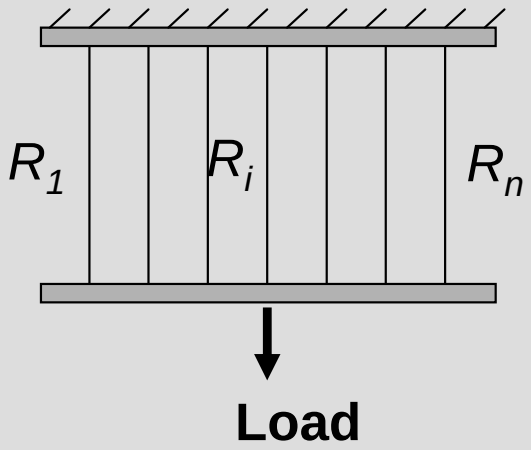
- Analysis and design considerations under multi-hazards
- Multi-hazard risk analysis of an offshore platform
- Life-cycle loss estimation (MCEER benchmark problem)

Analysis and Design Under Multi-hazards

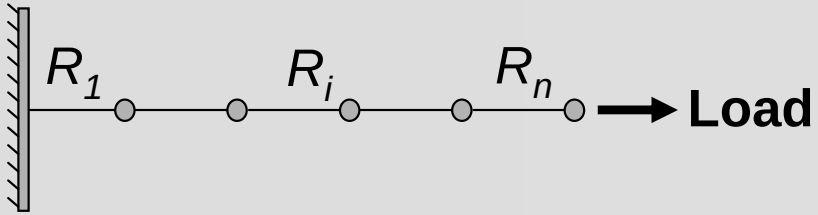
- Computational model:
  - Temporal/spatial discretization
  - Response level
- System fragility:
  - System topology
  - Hazard level
- Multi-hazards:
  - Consequences / safety levels
  - Hazards concurrence

- **System fragility** (topology / hazard level):
  - System with *n* components of capacity R_i

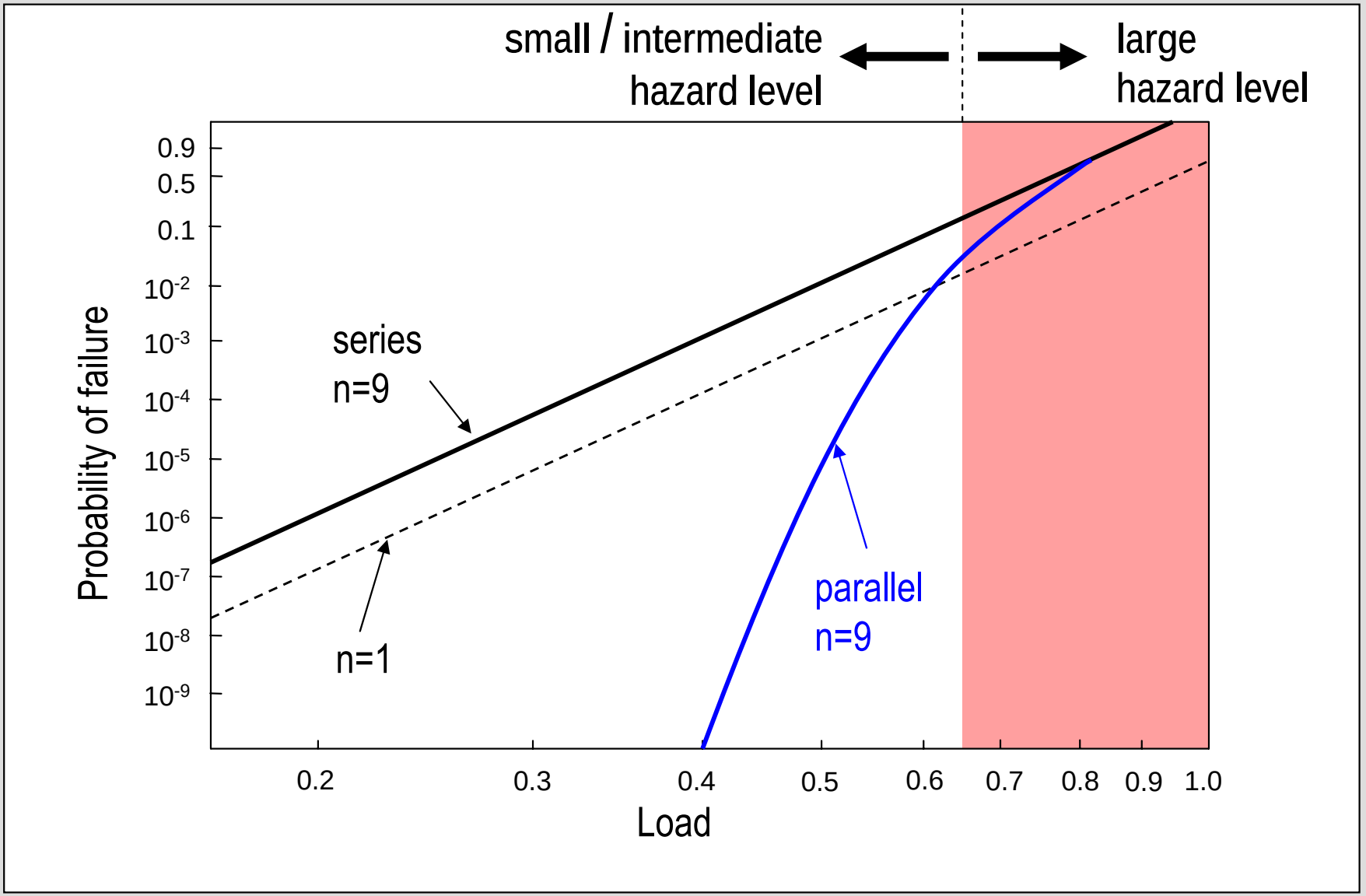
Brittle parallel system



Series system

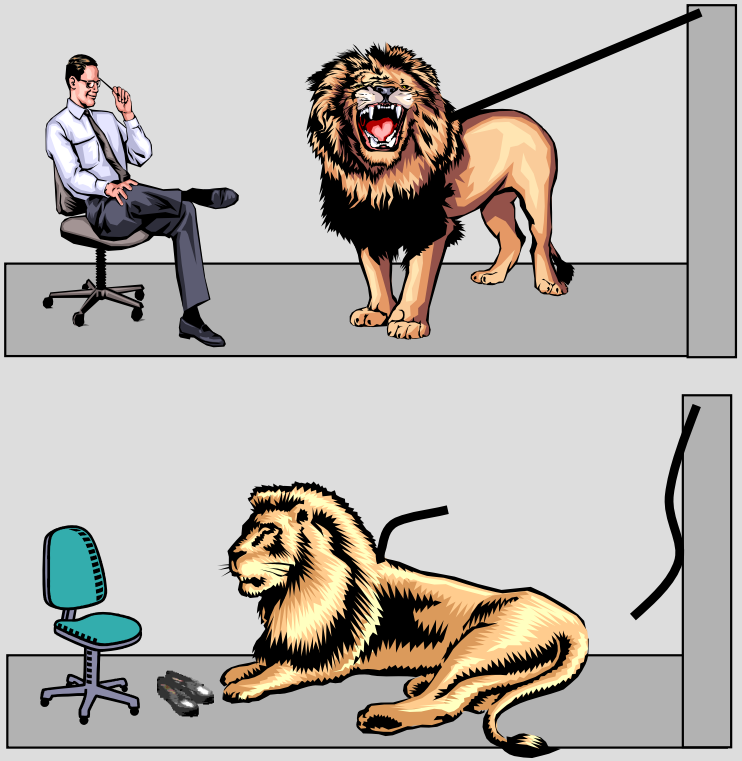


- System fragility (R_i ~ i.i.d. Weibull (ρ =10) random variables)



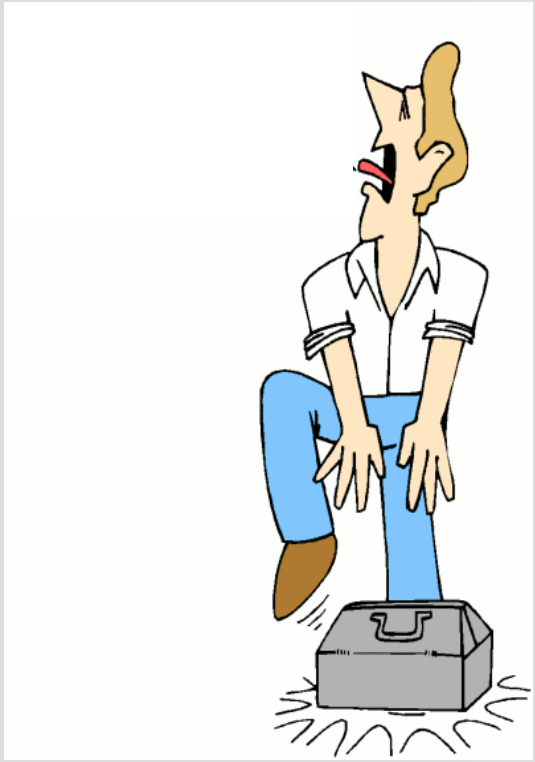
- Multi-hazards (consequences / safety levels):

Severe consequences



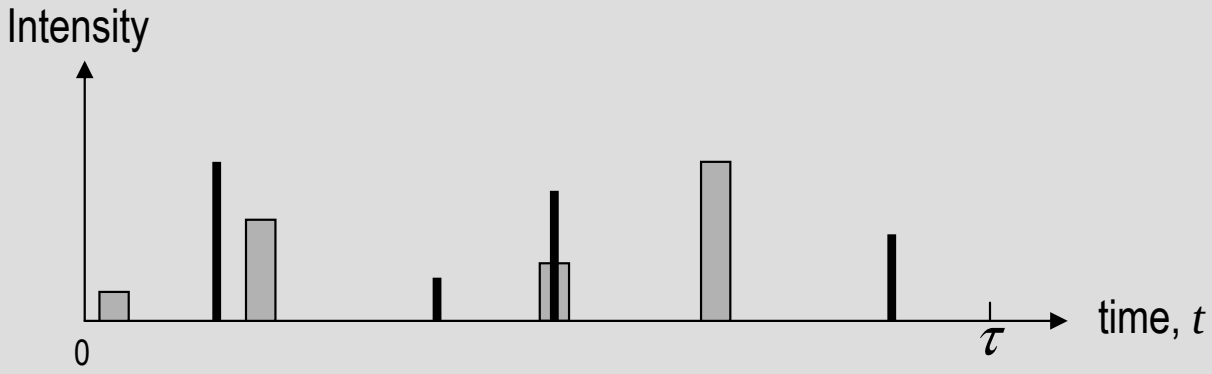
very large safety levels

Mild consequences



moderate safety levels

- **Multi-hazards** (hazards concurrence):
  - System under multi-hazards
    (*e.g.* earthquakes, hurricanes, extraordinary live loads, blasts)



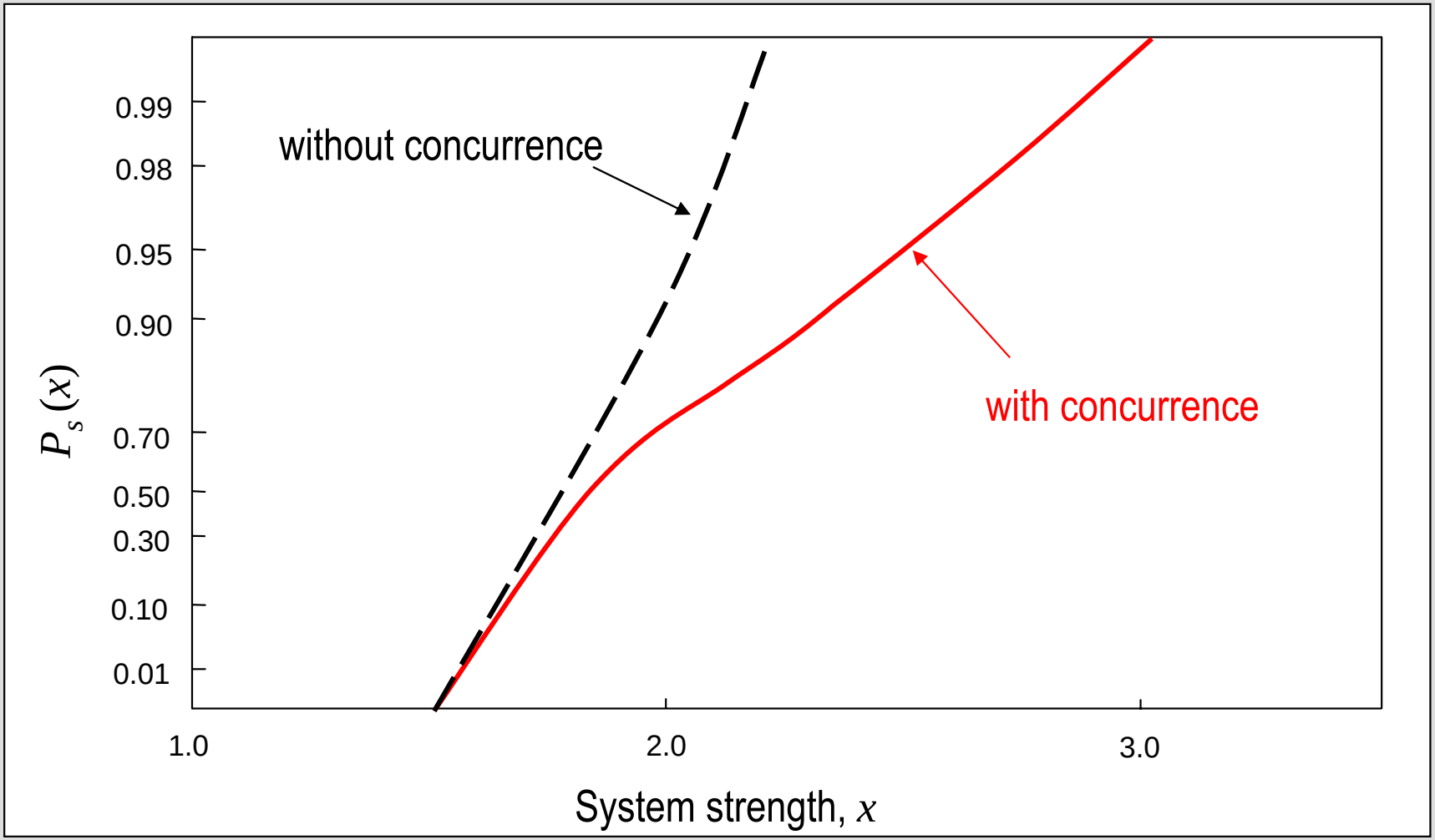
  - System reliability under 2 hazards in $(0, \tau)$

$$P_s(x) = \exp\left[-\upsilon_1\tau(1-F_1(x)) - \upsilon_2\tau(1-F_2(x)) - \upsilon_1\upsilon_2(\mu_1+\mu_2)\tau(1-F_{12}(x))\right]$$

υ_k = mean arrival rate of hazard k $\quad F_k$ = cdf of hazard k intensity

μ_k = average duration of hazard k $\quad F_{12}$ = cdf of combined hazard intensity

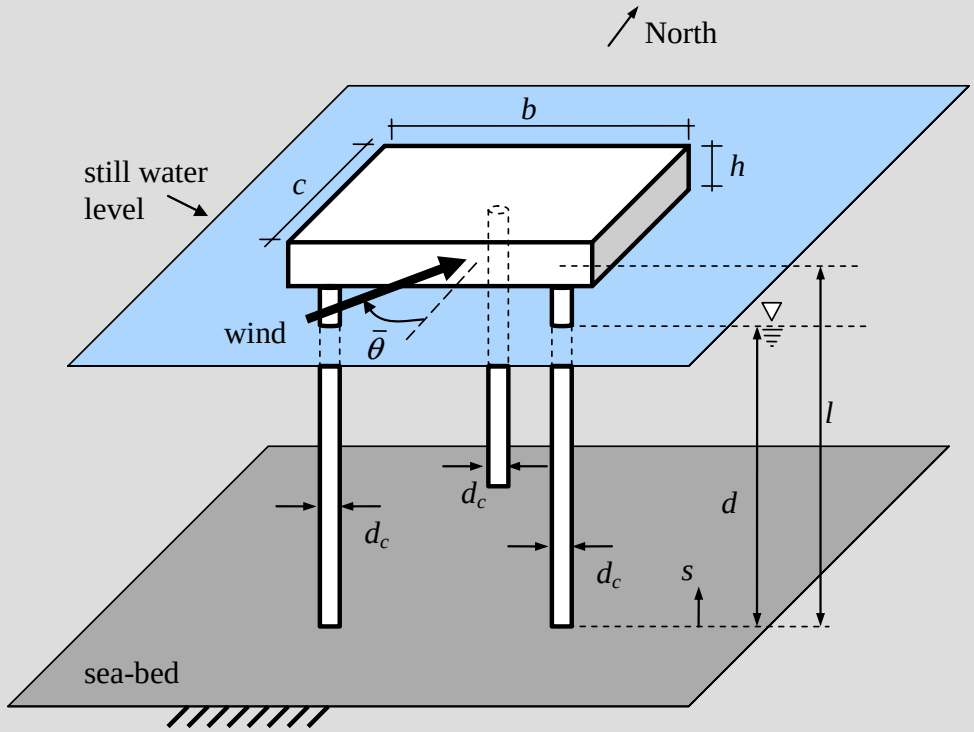
- System reliability $\left(\upsilon_1 = \upsilon_2 = 2/\text{yr},\ \mu_1 = \mu_2 = 10^{-3}\text{yr},\ \tau = 50\text{ yr},\ F_1 = F_2 = N(1, 0.09)\right)$



Note: $1\text{-}P_s(x)$ = system fragility under multi-hazards

Multi-hazard risk analysis

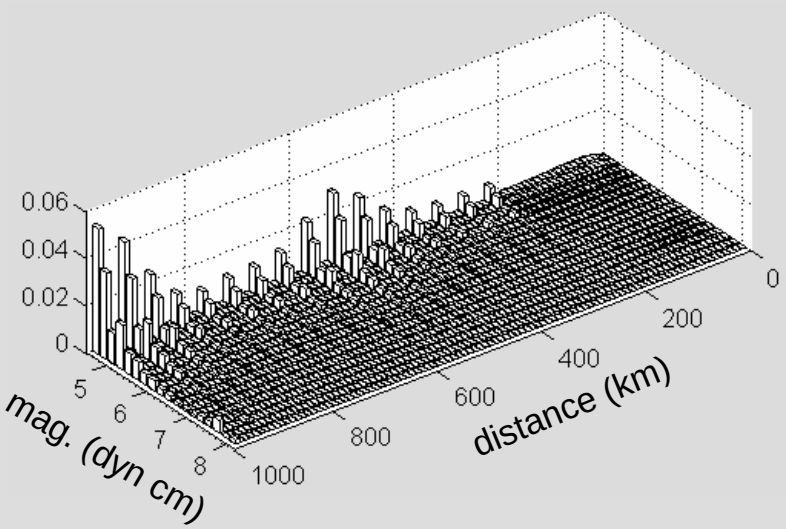
- System: Offshore platform



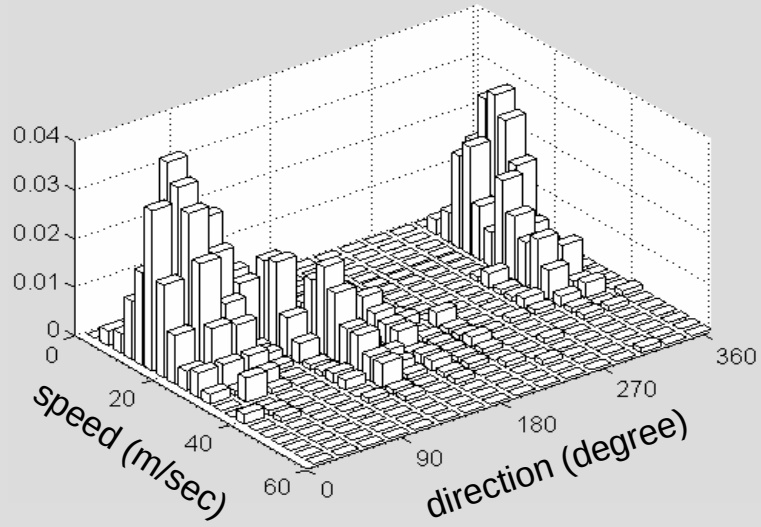
- Objective: Assess performance of the system during its design life, subjected to random earthquake, wind and wave loads

- Seismic and hurricane hazards at system site:

Seismic activity matrix



Hurricane activity matrix



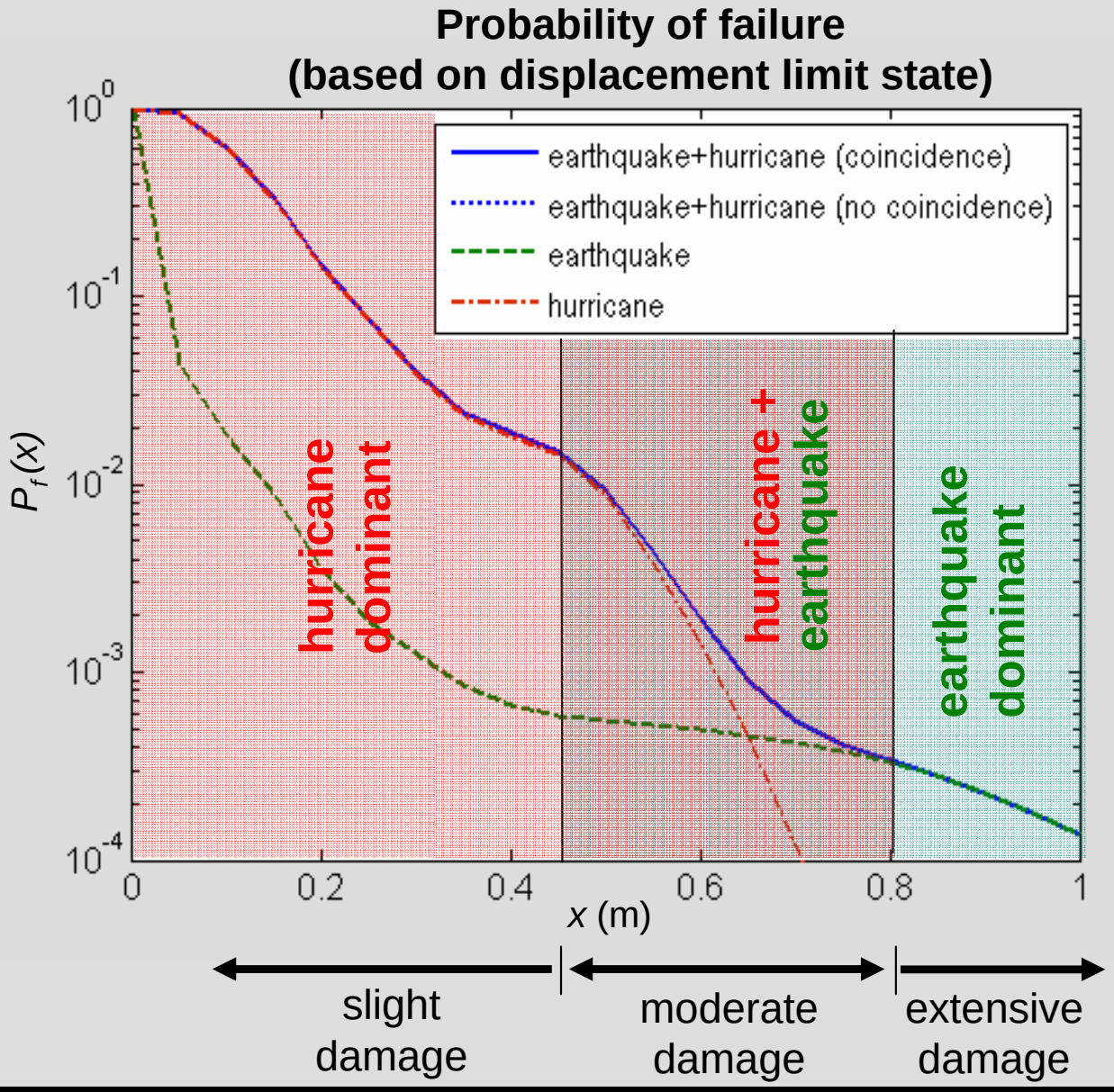
- System fragility in $(0,\tau)$:

$$P_f(x) = 1 - \exp\left[\left\{\upsilon_e P_{f,e}(x) + \upsilon_h P_{f,h}(x) + \upsilon_e \upsilon_h (\mu_e + \mu_h) P_{f,e+h}(x)\right\}\tau\right]$$

$$P_{f,e}(x) = \iint_{m,r} P_f(x \mid m,r)\, f_{M,R}(m,r)\, dm dr, \quad P_{f,h}(x) = \iint_{v,\theta} P_f(x \mid v,\theta)\, f_{V,\Theta}(v,\theta)\, dv d\theta$$

$$P_{f,e+h}(x) = \iint_{m,r} \iint_{v,\theta} P_f(x \mid m,r,v,\theta)\, f_{M,R}(m,r)\, f_{V,\Theta}(v,\theta)\, dm dr dv d\theta$$

- **Results:** τ=30 yrs, m=5.44*10^6 kg, *b*=*c*=50 m, *h*=5 m, *d*=50 m, *l*=55 m, d_c=3.7m, ω_0=5 rad/sec, ζ=4%, μ_e=20 sec, μ_h=20 min



Observations

- The effect of hazard concurrence is negligible
- System failure probability under multi-hazard can be accurately estimated by an envelop of the failure probabilities under single hazards
- Similar results have been obtained by Shinozuka et al., Reliability assessment of reinforced concrete containment structures, Nuc. Eng. Des. 80, 247-67, 1984.

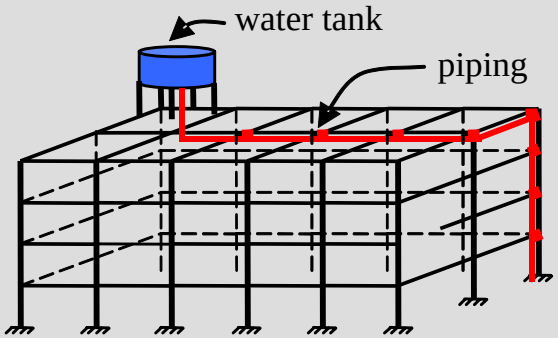
Benchmark Problem (seismic hazard)

- Structural/nonstructural systems:
  - MCEER West Coast Demonstration Hospital
  - Nonstructural systems
    - heating, ventilating, air-conditioning
    - partition walls
    - piping

- Objective: Develop a method for estimating life-cycle capacity/cost for the MCEER Demonstration Hospital

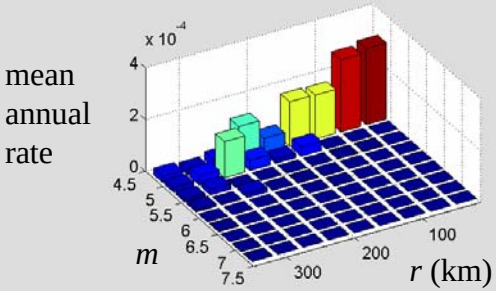
Methodology:

Structural/nonstructural system definition

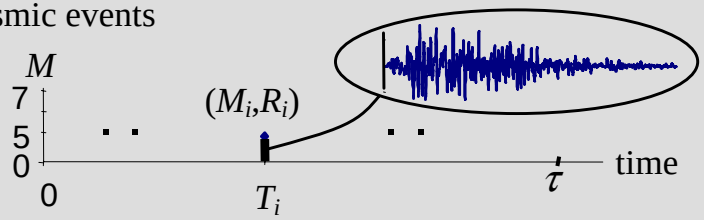


Seismic hazard

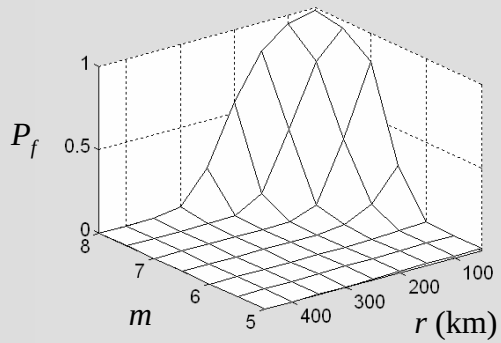
- USGS → seismic activity matrix



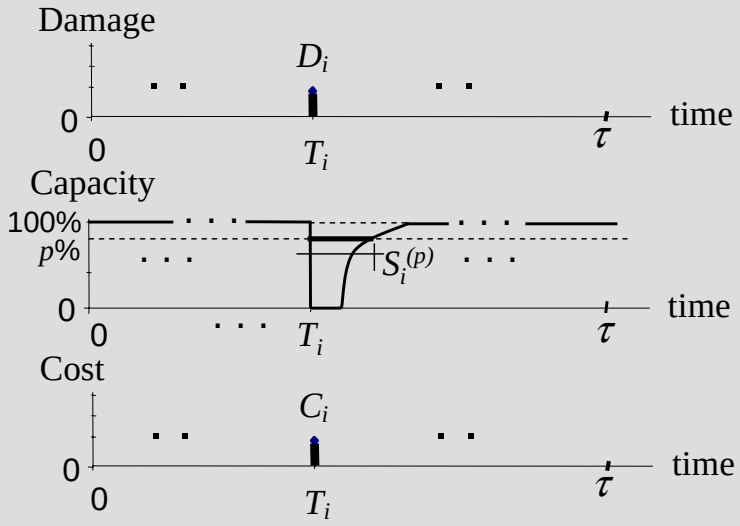
- Seismic events



Fragility surfaces
(for specified limit states)



Life cycle capacity/cost estimates



Life cycle capacity/cost estimates:

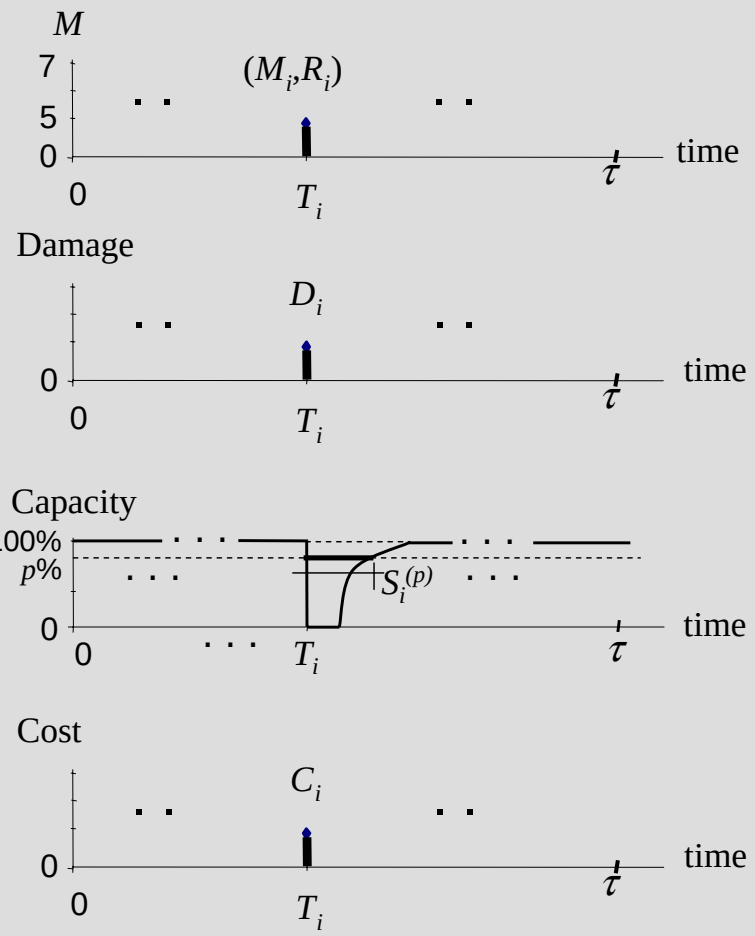
- Capacity estimate during time τ

$$S_p(\tau) = \sum_{i=1}^{N(\tau)} S_i^{(p)}$$

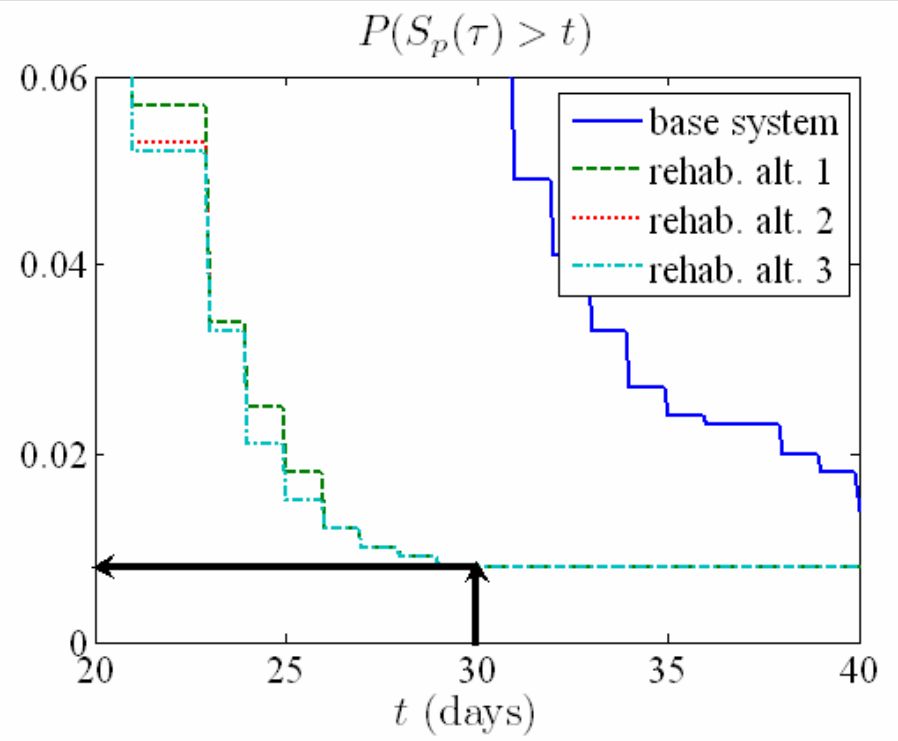
- Cost estimate at time τ

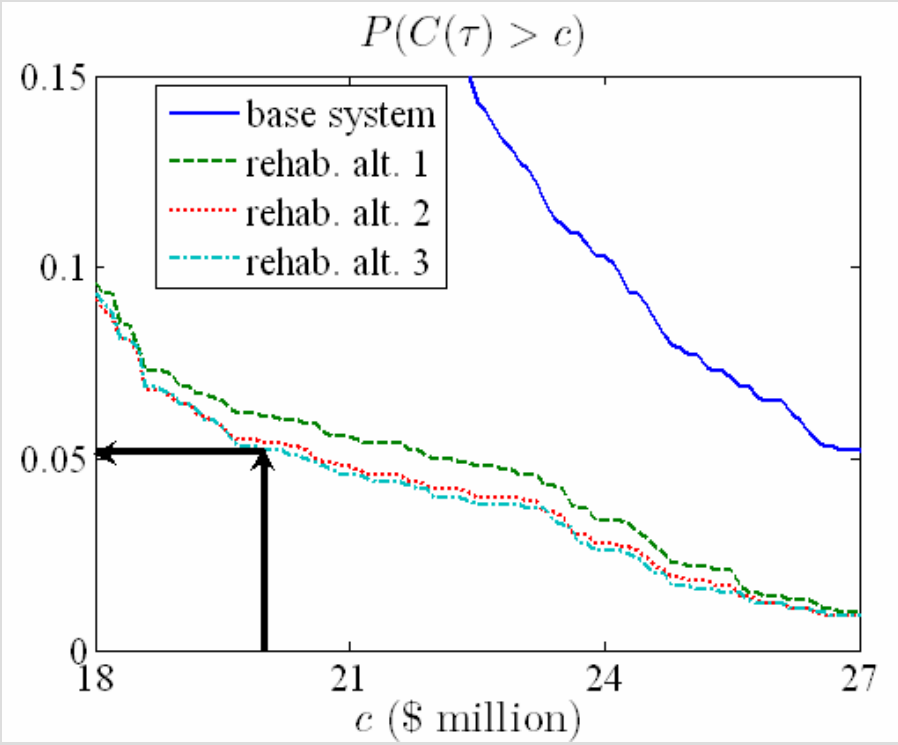
$$C(\tau) = \underset{(\nearrow)}{\text{rehabilitation cost}} + \sum_{i=1}^{N(\tau)} \underset{(\searrow)}{C_i/(1+dr)^{T_i}}$$

$\Rightarrow$ Optimal rehabilitation strategy



- Performance measures (compare 3 rehabilitation alternatives)

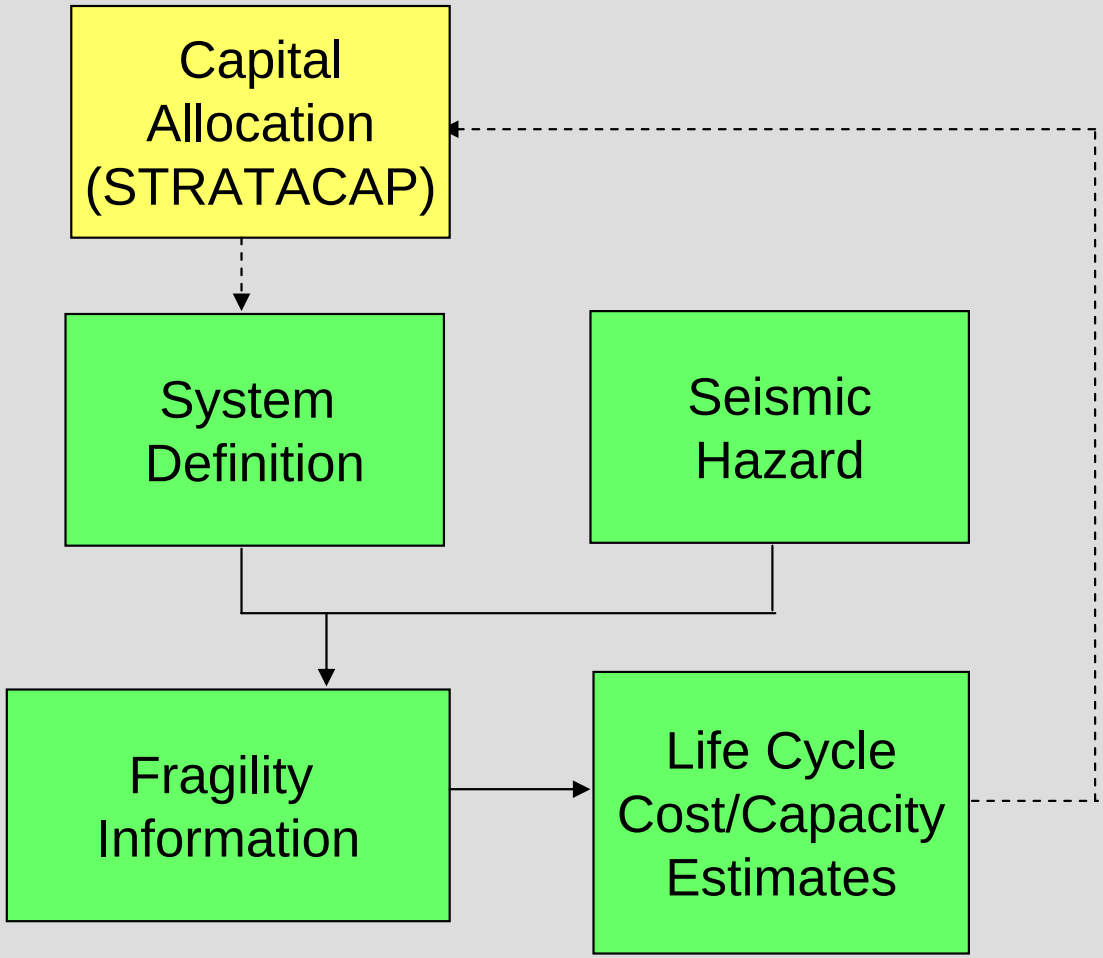




- Example of optimal rehabilitation strategy: minimize $P(C(\tau)>20)$

  $\Rightarrow$ rehabilitation strategy 3

- Capital allocation decisions:



Why Multi-Hazard Engineering?

- Different actions can be dominant at different reliability levels. In our offshore example:
  - If $P_f \geq 10^{-2}$, then H is dominant (serviceability limit state)
  - If $P_f \leq 0.5*10^{-3}$, then E is dominant (ultimate limit state)
  - If $10^{-2} \leq P_f \leq 0.5*10^{-3}$, then load combination is relevant

- Design provisions for one action can have a positive or a negative impact on a system response to another action, for example:
  - Since earthquakes, wind, and wave loads have different frequency content, optimal stiffness for earthquake and wind may differ
  - Optimal design (cost + reliability) requires to consider all relevant actions on a system simultaneously

Road to Multi-Hazard Engineering

Step 1: Develop probabilistic models characterizing both the temporal and spatial variation of all loads acting on a structure.

Step 2: Develop efficient algorithm for life cycle calculation of structural alternatives.

Step 3: Use life cycle findings to select an optimal design alternative in multi-hazard environment.