# A Need for Risk-Consistent Approach to Multi-Hazard Engineering

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# Hazards Considered

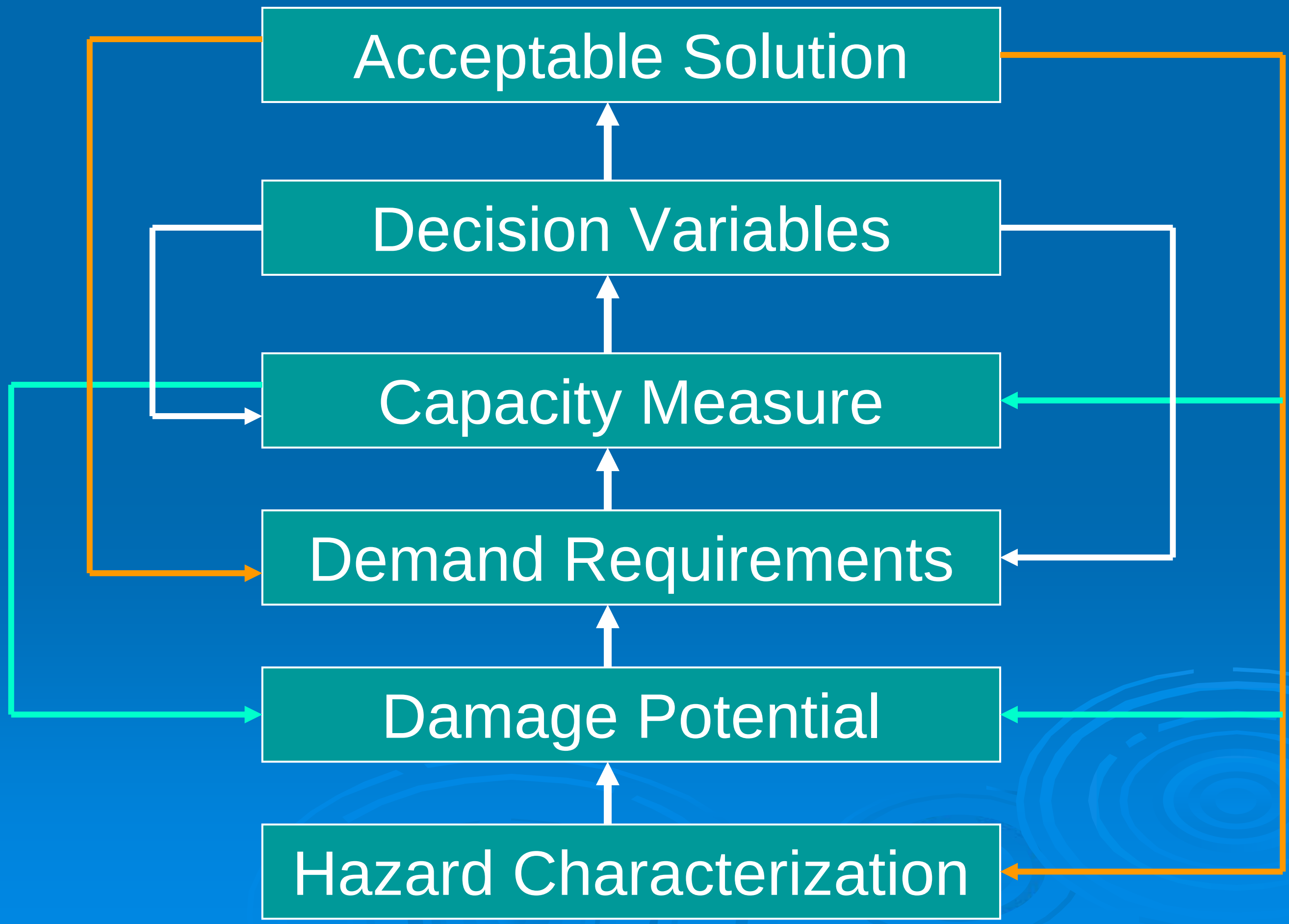
- Natural Hazards only
  - Earthquakes
  - Hurricanes
  - Floods
  - Fires
  - Other natural Hazards e.g. landslides should be considered on a local condition basis
- Occurrence determined Probabilistically
- Probability for each hazard event is different

# Interdependency of Hazards

- Some Primary causative Hazards lead to cascading effects resulting in other hazards:
- Fires following earthquakes
- Floods following hurricanes or tornados
- Tsunamis following earthquakes

Probabilities for *independent* events are different than for *interdependent* events

# Systems Approach to Hazard-based Hierarchy



# Interdependency of Response

Even at the Technical level – non-structural systems ignored, e.g.

- Window-wall systems & internal partitions may substantially impact the overall behavior of a structural system

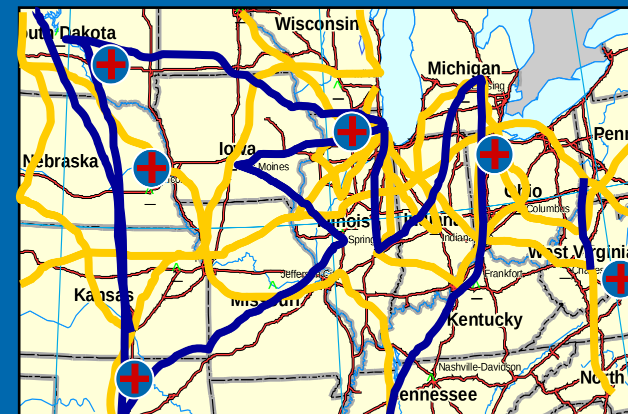
- Design-behavior of structural system does not always minimize damage to non-structural systems

*Interdependency is usually ignored*

# Interdependency of Response

- At the Economic and Societal level the issues are more complex
- Geographic Interdependency
- Physical Interdependency
- Societal Interdependency

# Global Interdependence




**Osaka Port- 1995**

25% of Japanese export through port .Disrupted world wide shipments

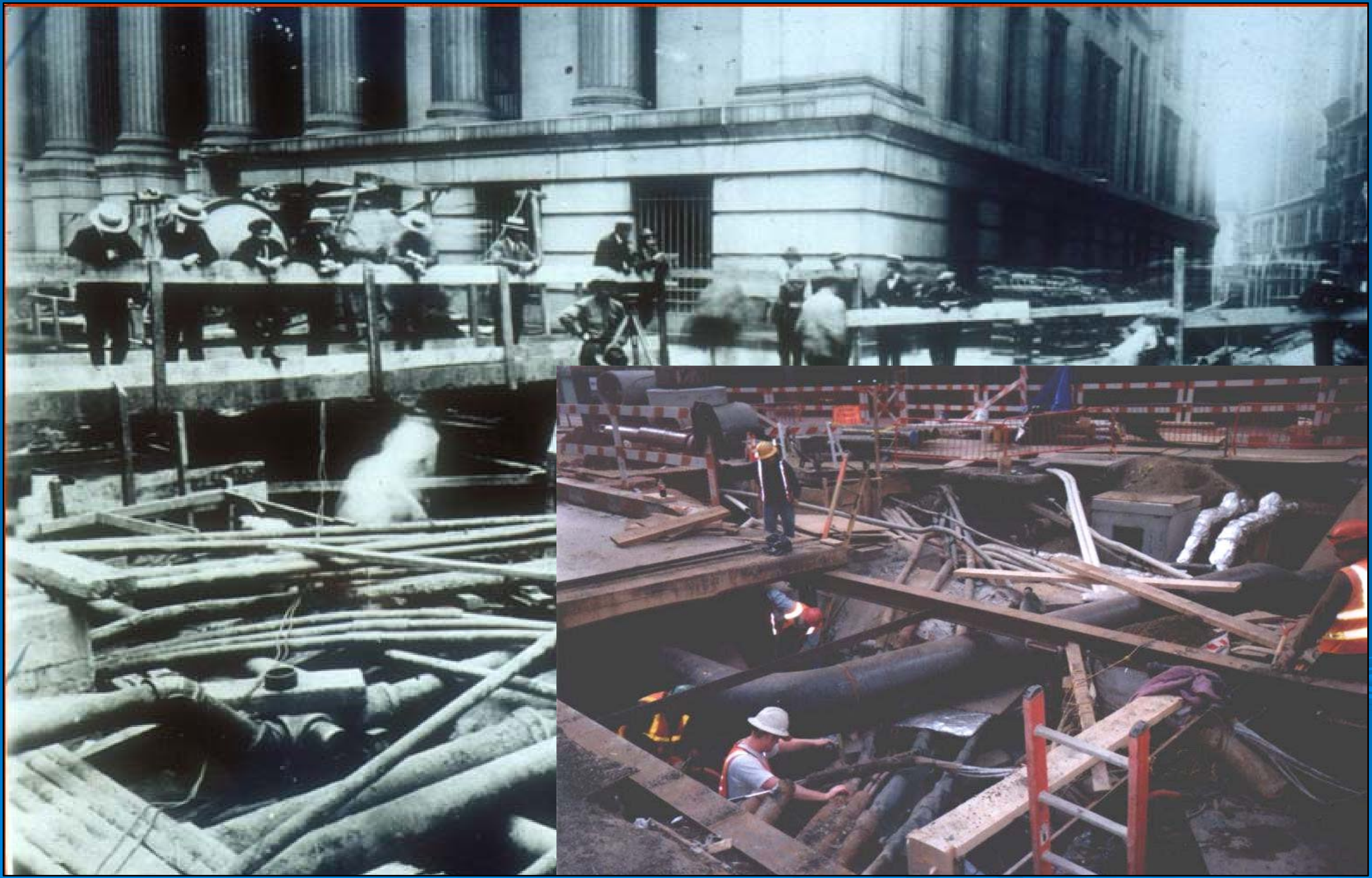
**Chi Chi EQ. –Taiwan '99**

Electronic Products shipments disrupted worldwide

**New Madrid Fault --?**

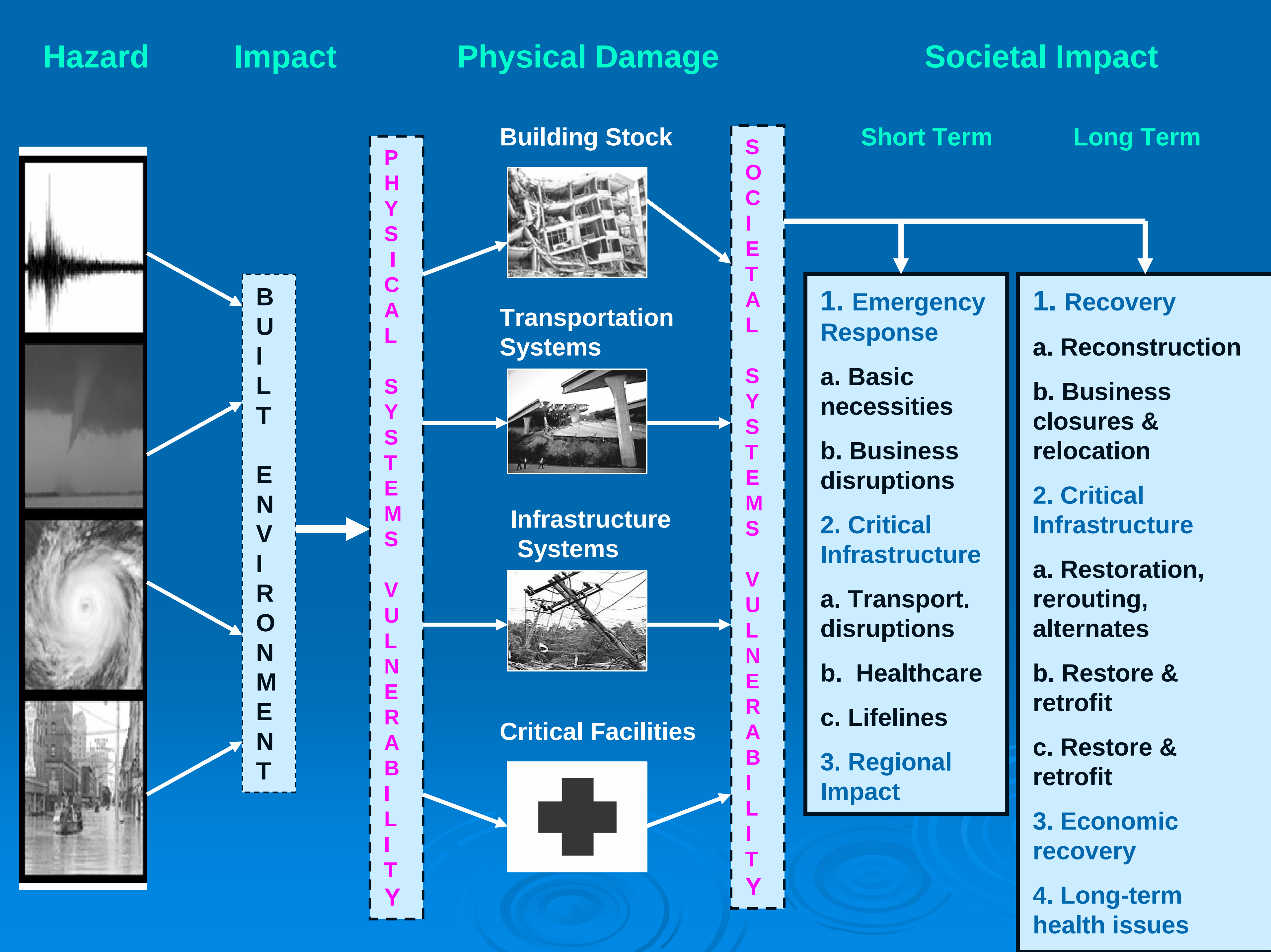
Major transportation hub for US – impact ?

# Physical interdependence of various utilities





Courtesy O'Rourke


Hazard
Impact
Physical Damage
Societal Impact
BUILT ENVIRONMENT
PHYSICAL SYSTEMS VULNERABILITY
Building Stock
Transportation Systems
Infrastructure Systems
Critical Facilities
SOCIETAL SYSTEMS VULNERABILITY
Short Term
Long Term
1. Emergency Response
a. Basic necessities
b. Business disruptions
2. Critical Infrastructure
a. Transport. disruptions
b. Healthcare
c. Lifelines
3. Regional Impact
1. Recovery
a. Reconstruction
b. Business closures & relocation
2. Critical Infrastructure
a. Restoration, rerouting, alternates
b. Restore & retrofit
c. Restore & retrofit
3. Economic recovery
4. Long-term health issues

# Thresholds of Acceptable Hazards

- Earthquakes

  10% probability of exceedence in 50 years
- Hurricanes

  5% probability of exceedence in 50 years
- Floods

  100 year flood level
- Fires

  1, 2 ,3 , 4 hour fire protection of elements

# Thresholds of Acceptable Hazards

- The inconsistency in standards of "Hazard Risk Acceptance" is evident
- Based on:
  - Some historical data
  - Macro-scale mapping
  - Derived from economic viability
  - Social acceptability
  - Not in our control generally

***Not All hazards are low –probability-high consequence type***

# Current codes & Standards

- Define “code level” Hazards criteria
- No discussion of vulnerability
- Define specific performance requirements
- Define acceptable materials
- Define expected standards of quality
- Define structural systems
- Other criteria

*Codes generally address individual facilities not networks*

# Total Multi-Hazard Risk

- Total Risk = { Expected lives lost; Persons Injured; Property damage; Disruption of economic activity; Societal services disruption }

- Total Risk = f ( hazard, exposure, vulnerability)

- Total Multi-hazard Risk comprises of *ranking values of exposures* and their *contribution to vulnerability*

# Hazard Exposure

- For a specific location, exposure to a given hazard is same, however, the vulnerabilities are different

- Community exposure vs. Single facility exposure

- Some exposures can be reduced, e.g. floods, fires

# Vulnerability

- Vulnerability of a system to a hazard can be defined as a resulting aggregate outcome of degree of exposure, system sensitivity, and system resiliency

- Vulnerability of coupled Human-Environment System exposed to natural hazards depends on the dynamics of the system (Turner et al – May 2006, Sustainability Science)

# Vulnerability is contextual

- Given a degree of exposure, vulnerability depends on *system sensitivity*, and *system resiliency*.
- System sensitivity, and system resiliency depends on each subsystem and links between subsystems

# Contextual Nature of Vulnerability

- 1994 Northridge, CA Earthquake (6.9 mag.)

  65 fatalities, $40b economic loss, limited interruption

- 1995 Kobe Earthquake (6.9 mag.)

  5500 fatalities, $150b economic loss, major interruption

- 1999 Turkey  Earthquake, magnitude (7.6 mag.)

  17,000 fatalities, $13b economic loss, major interruption

  *Economic losses must be viewed as a % of total GDP of a nation*

Vulnerability here is considered only in physical infrastructure, in two contexts:

1. Individual facility level

2. Network level

Vulnerability Redefined:

Vulnerability is defined as likelihood in future, at a given point in time, a *level of performance lower* than an established benchmark

# Vulnerability

1. Single Facility Vulnerability

2. Network Vulnerability

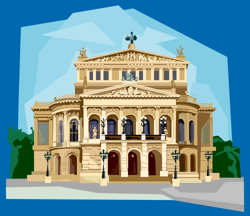
- Measures and dimensions for each are different

# Vulnerability Assessment

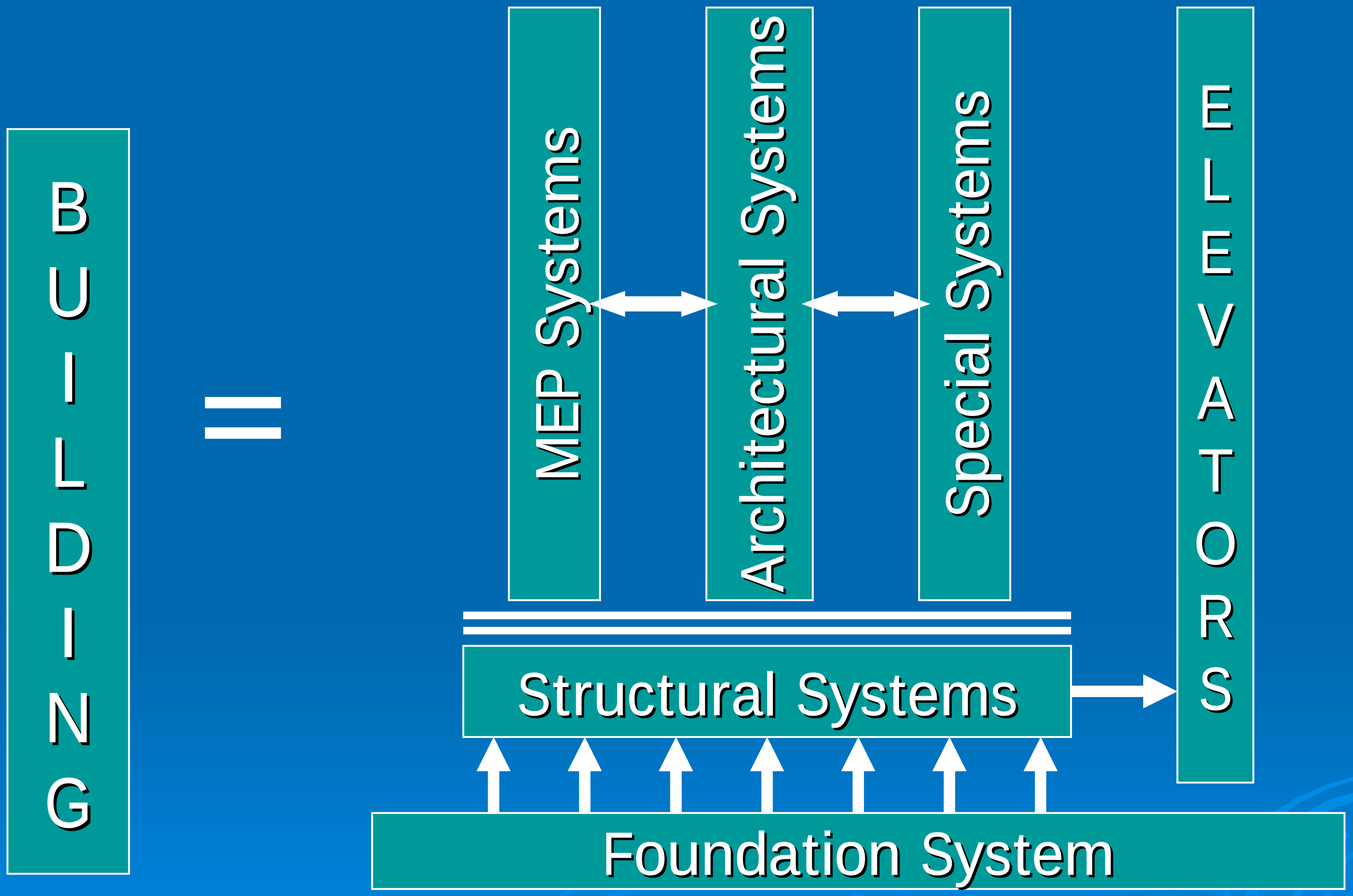
1. Single Facility Vulnerability

A. Structural Vulnerability

i. Age of facility
ii. Construction material
iii. Foundation system
iv. Height of facility
v. Type of structural system
vi. Capacity of lateral load system
vii. Plan and vertical irregularity



# Building System



# Vulnerability Assessment

B. Operational Vulnerability

i. Non–Structural systems

ii. Exit ways

iii. Essential equipment and other tools necessary for operation

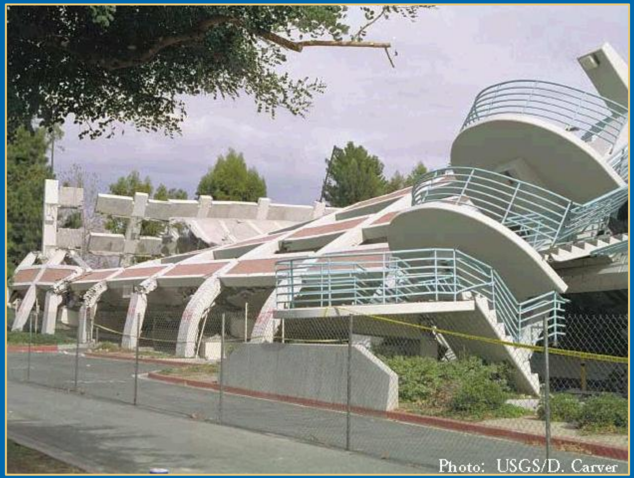
# Capacity Measure

- Capacity determination of a structure or a system (pre damage or post damage) is not easy. Techniques involve: analytical models, computer simulation, physical model simulation in the laboratory, non destructive on-site tests etc.
- Advances in hybrid simulation, visualization, large computer systems with fast speed help in accuracy of capacity determination

❖ Retrofitting built environment is extremely important:

1. In North America, only 1% gets replaced each year

2. Will take 100 years to completely replace existing built environment




Parking garage – Northridge 1994

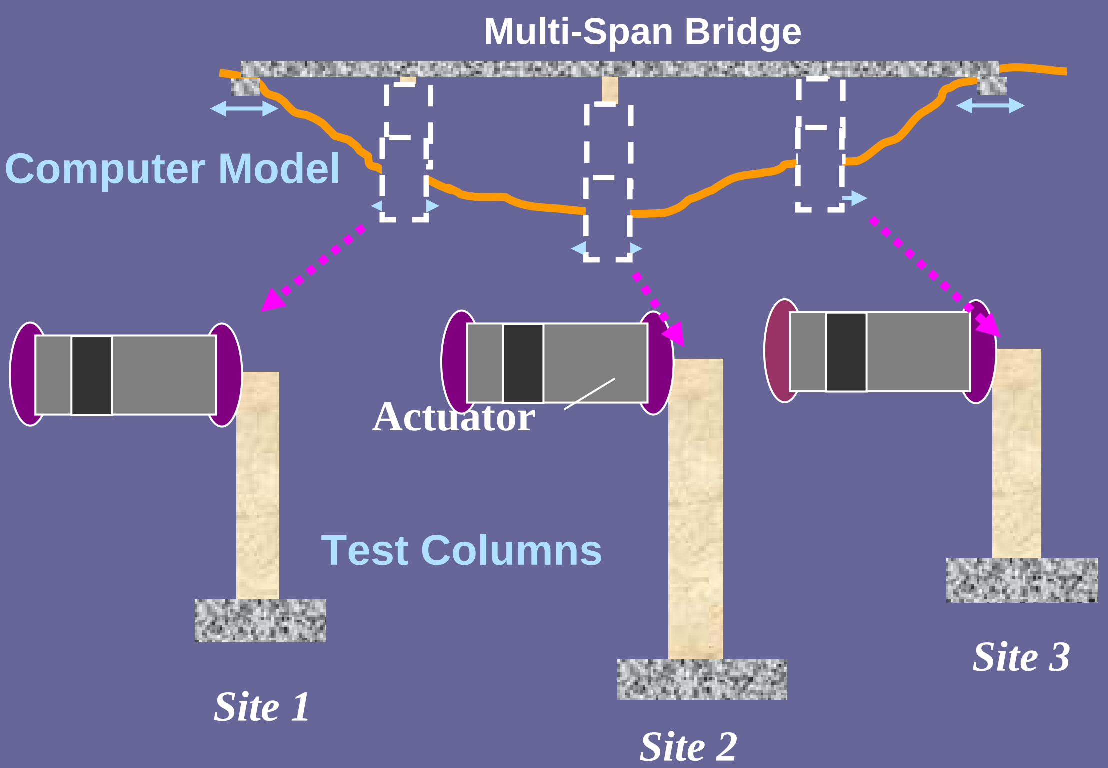
**Soft story**

Apt. Bldg.- Loma Prieta - 1989

**Inadequate capacity of non participating elements**

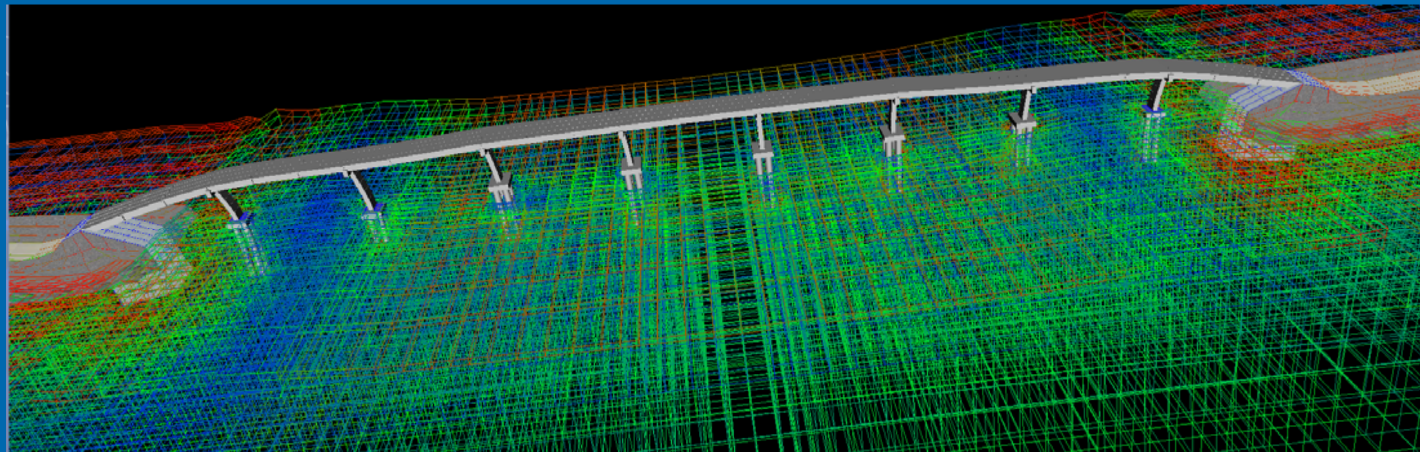
**Excessive Drift**

Kobe Earthquake - 1995

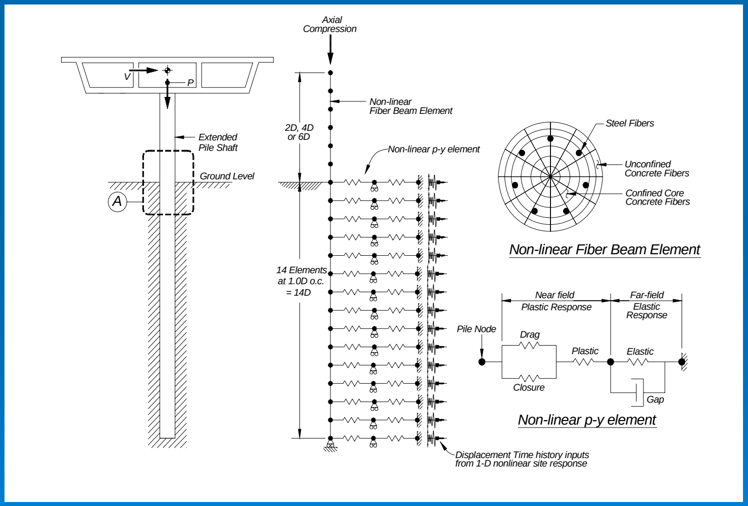



*Geographically Distributed Tests*

Real –time testing on simulated basis



Model of the Entire bridge including abutments




Soil-Foundation- Structure Interaction



Courtesy PEER

# Vulnerability Assessment

## 2. Network vulnerability

i. Most vulnerable component determines vulnerability of a series type network

ii. Vulnerability of weakest link determines network vulnerability

iii. Hard linkages vs. flexible linkages

iv. Alternate network routes

# Highway Network System

Network Solution

- Links connected -

Isolated structure Solution

**Parallel Type**



Courtesy MAE

# Vulnerability Assessment

## Networks

- Is the network *series* type or *parallel* type?
- Determine the *weakest link* in series type
- Determine its contribution in the overall performance of the network
- Determine the capacity of the weakest link based on demand imposed
- Other weaker links with strategic locations may have larger impact on the overall network performance

- **Determine vulnerability score for the network**

# Vulnerability Scores
## Single Facility

| Facility | Earthquakes | Hurricanes | Floods | Fires | Total |
|---|---|---|---|---|---|
| A BC Co.- Office HQ | | | | | |
| Hazard | 100 | 50 | 25 | 20 | |
| Exposure | 50 | 100 | 25 | 5 | |
| Structural Vulnerability | 3 | 2 | 1 | 1 | 7 |
| Operational Vulnerability | 8 | 4 | 1 | 2 | 15 |
| Total Risk | 161 | 156 | 52 | 28 | 397 |

# Hazard Scores

Earthquakes:

- Very High exposure = 100
- High Exposure = 75
- Medium Exposure = 50
- Low exposure = 25

Similar scores can be assigned to other hazards

# Total Risk Scores

**Typical Risk Score = Hazard x Exposure x Vulnerability**

- Earthquake Structural Risk = 100 x 50 x 3 =1500
- Earthquake Operational Risk = 100 x 50 x 8 = 4000
- Hurricane Structural Risk = 50 x 100 x 2 =1000
- Fire Structural Risk = 20 x 5 x 1 = 100
- Flood Operational Risk = 25 x 25 x 1 = 625

Various risks can be compared and facilities can be appropriately designed for performance

Combined quantitative and Bayesian Decision Framework is required

to

**Develop a risk-consistent approach to multi-hazard engineering**

# T H A N K   Y O U