Masanobu Shinozuka Memorial Session

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From Probabilistic Fatigue to Load Combination Analysis and Urban Resilience – A 45-year journey

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Administrative Committee on Structural Safety and Reliability (1974)

M. Shinozuka, Allin Cornell, Alfredo Ang, James Yao, Emilio Rosenblueth

- Committee on Safety of Buildings
- Committee on Safety of Bridges
- Committee on Fatigue and Fracture Reliability
- Committee on Reliability of Offshore Structures

Probabilistic Fatigue and Fracture

Fatigue Reliability - A State of the Art Report by the Committee on Fatigue and Fracture Reliability

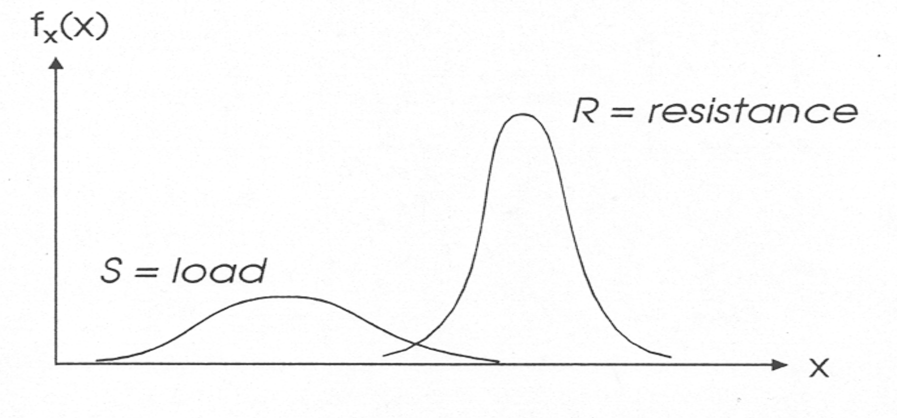
Technical Administrative Committee on Structural Safety and Reliability
(M. Shinozuka, Chair)

- Part I - Introduction (Ellingwood, B., Wirsching, P. and Yao, J.T.P.)
- Part II - Quality Assurance and Maintainability
- Part III - Variable Amplitude Loading (Wirsching, P.,Ellingwood, B.)
- Part IV - Development of Criteria for Design (Ellingwood, B., Wirsching, P., and Albrecht, P.)

Journal of the Structural Division, ASCE, Vol. 108, No. ST1, January 1982, pp. 1-88.

Measuring risk using reliability theory

R, S are random variables describing capacity and demand



P[LS] = P [R – S < 0] ≤ P_F ⇔ $\mu_{R\text{-}S} - \beta\sigma_{R\text{-}S} \geq 0$

μ, σ = mean, standard deviation

β = reliability index = $\Phi^{-1}(1 - P_F)$

Freudenthal, A.M., J. Garrelts, and **M. Shinozuka** (1966). "The analysis of structural safety." *J. Struct. Div. ASCE* 92(1):267-325.

Shinozuka, M. (1983). Basic analysis of structural safety. *J. Str. Engr., ASCE* 109(3):721-740.

First-generation probability-based limit states design (1979)

- Required strength (U_d) < Design strength (R_d)

$$U_d = \Sigma \gamma_i Q_{ni} \leq \phi R_n = R_d$$

- Required strength (ANSI A58.1-1982, now *ASCE Standard 7-16*)

$$U_d = 1.2 D + 1.6 L + 0.5 (L_r \text{ or } S \text{ or } R)$$

- Design strength (AISC, ACI, etc)

$$R_d = 0.9 R_n \text{ in flexure, etc.}$$

Load Combination Analysis for Reinforced Concrete Nuclear Plant Structures (Brookhaven National Laboratory: 1981-1987)

- Reinforced concrete containments
- Seismic Category I structures
  - Shear walls
  - Structural frames

Load Combination Analysis for Reinforced Concrete Nuclear Plant Structures (Brookhaven National Laboratory)

- Hwang, H., Kagami, S., Reich, M., Ellingwood, B. and **Shinozuka, M.**, "Probability Based Load Combinations for the Design of Concrete Containments," **Nuclear Engineering and Design,** Vol. 86, No. 3, June 1985, pp. 327-339.
- Hwang, H., Ellingwood, B., **Shinozuka, M**. and Reich, M. (1987). "Probability based design criteria for nuclear plant structures." **J. Struct. Engr., ASCE** 113(5):925-942.
- Hwang, H., Kagami, S., Reich, M., Ellingwood, B. and **Shinozuka, M**. "Probability Based Load Factors for Design of Concrete Containment Structures," **Transactions, 8th Int. Conf. on Structural Mechanics in Reactor Technology,** Brussels, August 1985, Vol. M, Paper M1 2/6.

Load Combination Analysis for Reinforced Concrete Nuclear Plant Structures (Brookhaven National Laboratory)

- **Shinozuka**, M., Ellingwood, B., and Wang, P.C., "Probability Based Load Criteria for the Design of Nuclear Structures: A Critical Review of the State-of-the-Art," U.S. Nuclear Regulatory Commission Report NUREG/CR-1979, Washington, DC, April, 1981, 268 pp.
- Hwang, H., Kagami, S., Reich, M., Ellingwood, B., **Shinozuka, M**., and Kao, S., "Probability Based Load Combination Criteria for Design of Concrete Containments," U.S. Nuclear Regulatory Commission Report NUREG/CR-3876, Washington, DC, March 1985, 87 pp.
- Hwang, H., Nakai, K., Reich, M., Ellingwood, B. and **Shinozuka, M**., "Probability Based Load Combination Criteria for Design of Shear Wall Structures," U.S. Nuclear Regulatory Commission Report NUREG/CR-4328, Washington, DC, January 1986, 32 pp.
- Hwang, H., Reich. M., Ellingwood, B. and **Shinozuka, M**., "Reliability Assessment and Probability Based Design of Reinforced Concrete Containments and Shear Walls," U.S. Nuclear Regulatory Commission Report NUREG/CR-3957, Washington, DC, March 1986, 96 pp.

Load Combination Analysis for Reinforced Concrete Nuclear Plant Structures (Brookhaven National Laboratory)

Normal load combinations

- $1.2(D + F + R_o) + 1.6L + 0.5S + T_o$
- $1.2(D + F + R_o) + 1.6S + 0.8L + T_o$

Severe environmental load combinations

- $1.2(D + R_o) + 1.6W + 0.8L + 0.5S + T_o$
- $1.2(D + R_o) + 1.6E_{obe} + 0.8L + 0.2S + T_o$

- Extreme environmental and abnormal load combinations
  - $1.0(D + R_o) + 0.8L + E_{sse} + T_o$
  - $1.0(D + R_o) + 0.8L + W_t + T_o$
  - $1.0 D + 0.8L + 1.2P_a + R_a + T_a$

NB: If the dead load acts to stabilize the structure, the load factor on D shall be 0.9 and the load factors on L and S shall equal zero.

Community resilience

The ability of a community to prepare for and adapt to changing conditions and to withstand and recover from disruptions to its physical and non-physical infrastructure.

Why is community resilience important?

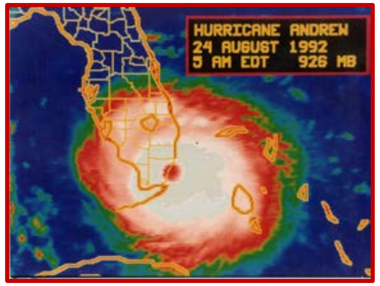
“To prevent a hazard from becoming a disaster”

- Recent disasters have revealed shortcomings in building practices that focus on performance of individual facilities.
- Populations and economic development are shifting to hazard-prone areas.
- Financial limits on public investments in infrastructure renewal
- Impact of global climate change on frequency/severity of environmental events
- Presidential Policy Directive 21 (PPD-21): Critical infrastructure security and resilience

Events in the US that shaped resilience

Natural hazard events

- 1992 Hurricane Andrew
- 1994 Northridge Earthquake
- 2001 World Trade Center (WTC) and Pentagon attacks
- 2005 Hurricane Katrina
- 2011 Joplin Tornado
- 2012 Superstorm Sandy
- …..
- 2018 Hurricane Michael
- ….

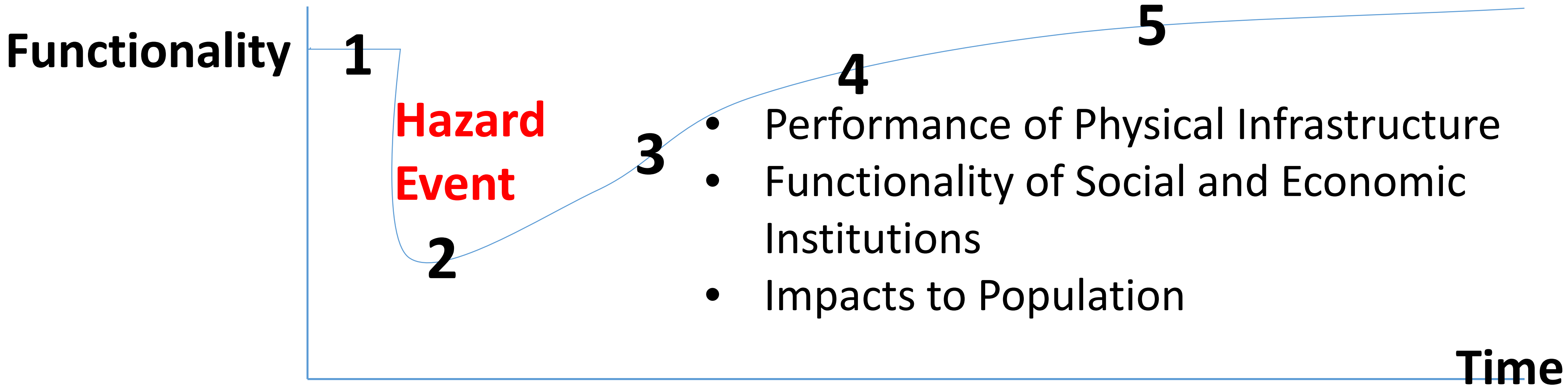


Source: GAO. | www.gao.gov

Federal disaster programs

- 1978 FEMA established
- 1992 FEMA reorganized *(emergency preparedness, mitigation and response)*
- 2002 DHS established (*security of critical infrastructure*)
- 2005 National Preparedness Goal
- 2006 National Infrastructure Resilience Plan
- 2011 Presidential Policy Directive-8 (PPD-8): National Preparedness
- 2013 PPD-21: Critical Infrastructure Security and Resilience

Stages of Resilience



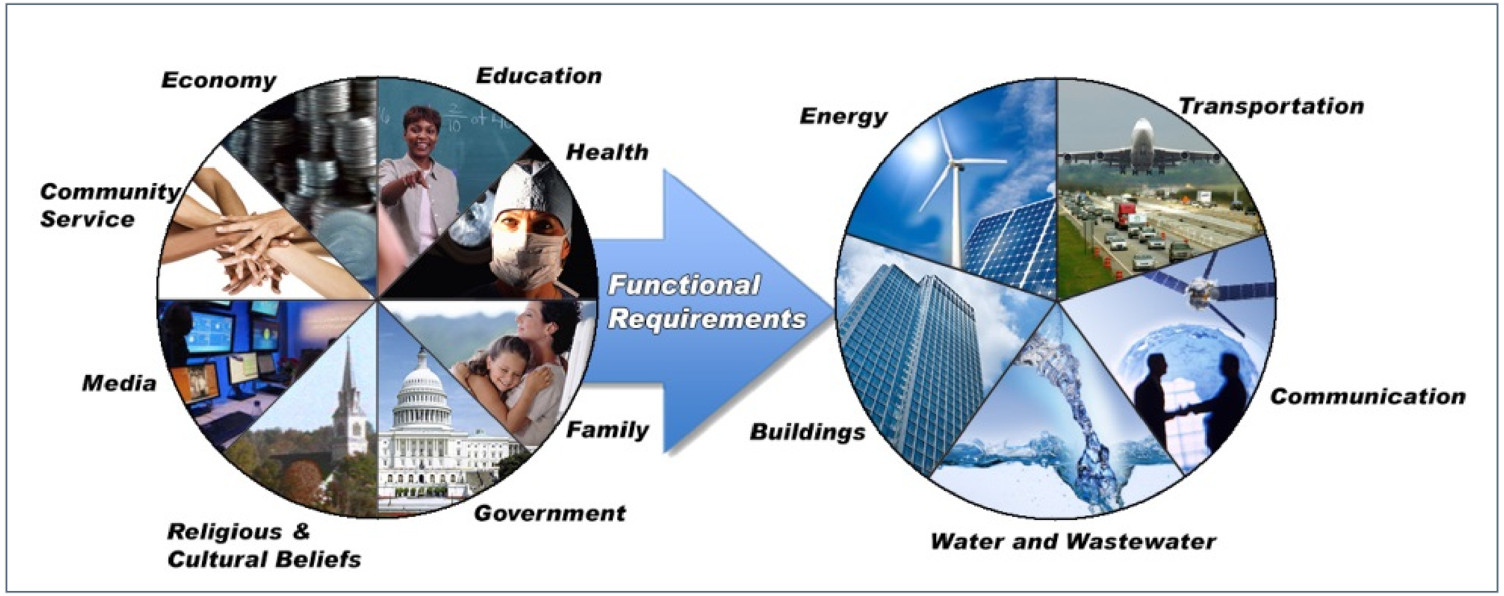
- Performance of Physical Infrastructure
- Functionality of Social and Economic Institutions
- Impacts to Population

1. Current state
- Existing vs. Desired Performance
- Dependencies

2. Immediate damage
- Loss of Life/Injury
- Physical Damage
- Loss of Function
- Decision Support

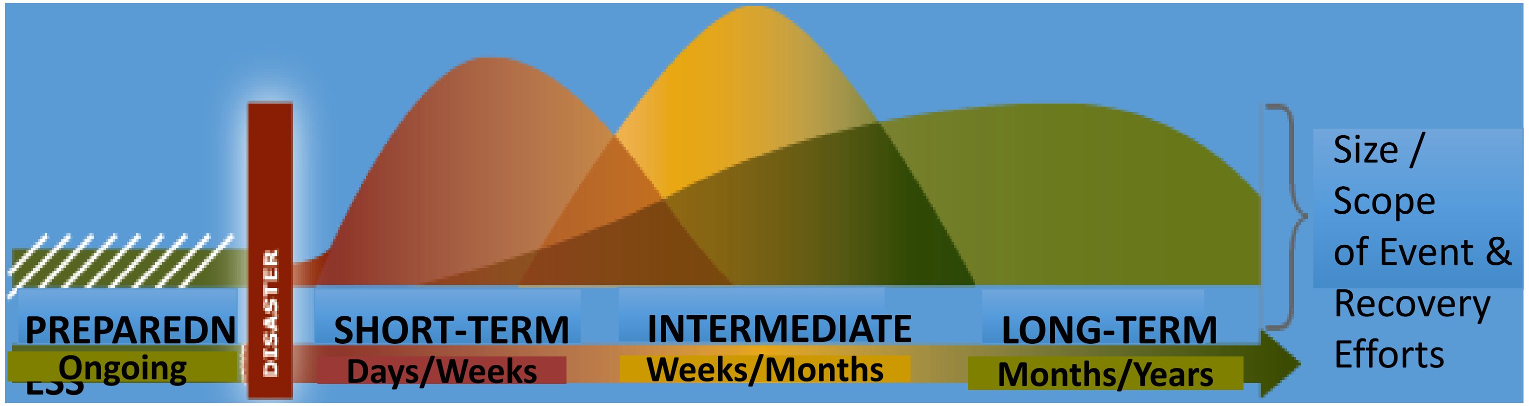
3-5. Recovery Stages
- Social and Economic
- Repaired Damage
- Recovered Functions
- Decision Support

Key Aspects of Community Resilience



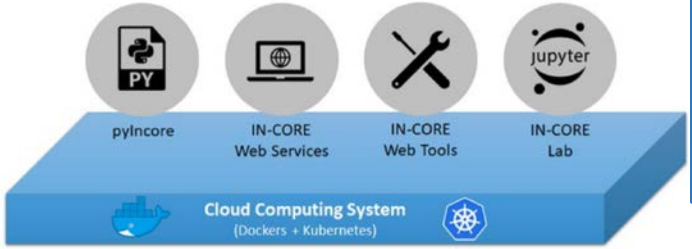
Social and Economic Reliance on Infrastructure

Recovery of Functionality and Built Environment



Resilience Modeling Environment

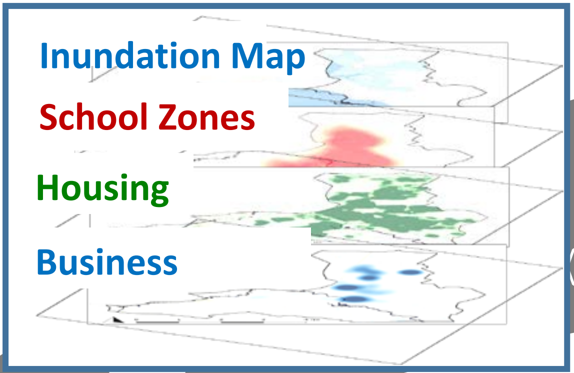
- Physical infrastructure
- Economic health
- Social services
- Information science



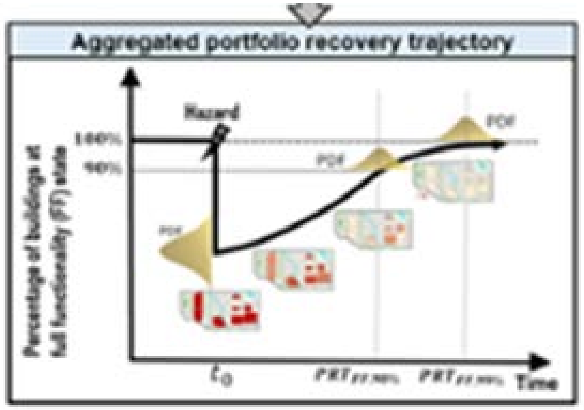
https://incore.ncsa.illinois.edu

https://github.com/IN-CORE/

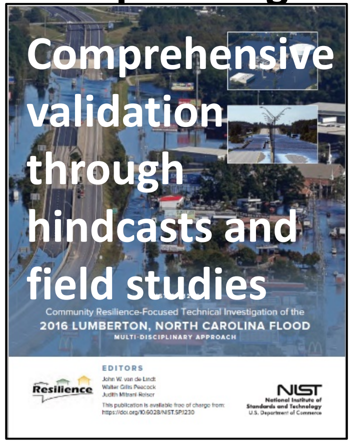
1. Damage and loss; impacts of natural hazards on communities



2. Multidisciplinary recovery with fully integrated supporting databases



3. Alternative actions to enhance community resilience & inform planning



The Science of Resilience

- **Shinozuka, M.**, Rose, A. and Eguchi, R.T. (1998). *Engineering and socioeconomic impacts of earthquakes*. MCEER Monograph Series, State Univ. New York at Buffalo.
- **Shinozuka, M.**, Feng, M.Q., Lee, J. and Naganuma, T. (2000). Statistical analysis of fragility curves." *J. Engrg. Mech. ASCE* 26(12):1224-1231,
- Bruneau, M., Chang, S. E., Eguchi, R. T., Lee, G. C., O'Rourke, T. D., Reinhorn, A. M., **Shinozuka, M.**, von Winterfeldt, D. (2003). A framework to quantitatively assess and enhance the seismic resilience of communities. *Earthquake Spectra*, 19(4): 733– 752.
- Chang, S. E., & **Shinozuka, M.** (2004). Measuring improvements in the disaster resilience of communities. *Earthquake Spectra*, 20(3): 739–755.

A heartfelt thanks to Prof. Masanobu Shinozuka for his intellectual leadership in addressing problems of relevance for the 20th and 21st centuries