BUILDING RESILIENCE AS A DESIGN OBJECTIVE

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Hot Topic: Building Resiliency
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Resilience

- Resilience is a measure of **persistence of systems** and of their ability to **absorb change** and disturbance and still maintain same relationships between populations (In Ecology; Holling, 1973).
- Three important characteristics are ability to
  1) absorb disturbances
  2) self organize
  3) learn and adapt

Community Resilience

- Resilience is the ability to **prepare** and **plan** for, **absorb** impacts of, and **recover** from, or **adapt** to adverse hazards and threats.

- A community's resilience reflects ability to absorb impact of a hazard and to **continue to operate**.

- In 2005 Hyogo Framework for Action (HFA) by 168 members of United Nations, it was used in: Building Resilience of Nations and Communities To Disasters.

Community Resilience

- Evaluating and enhancing resilience of a community to natural and man-made hazards should be conducted for a **system of systems**, which includes whole community composed of **various systems**, such as **transportation, water supply, communication**, etc., and the local, **socioeconomic context** within which they operate.

Community Resilience

- Community or system-of-systems resilience to adverse events should be evaluated and enhanced **before**, **during or shortly after (emergency response)**, and **longer term (recovery)**.

Risk

- Possibility that something unpleasant or unwelcome will happen (Oxford Dictionary).
- A probability or threat of **damage, injury, liability, loss,** or any other **negative occurrence** that is caused by external or internal **vulnerabilities**, and that may be avoided through preemptive action (Business Dictionary).

Risk

- Risk associated with a hazard is a function of **probability that hazard occurs**, and **consequences or damages**.
- Consequences are typically measured in terms of **property damages** and **lives lost**, **evacuation and recovery costs, lost profits** and **tax revenues** (UNDP, 1994).
- Effects that are more difficult to measure include disruptions of **people's everyday life** and **impacts on social capital**.

Risk

- There is a continuing effort to use **risk-based** (as opposed to **uniform hazard-based**) approaches in building codes (e.g. ASCE 7-10, 2010).
- For instance, in seismic design, a **uniform risk of collapse** is now used as basis of new **risk-targeted ground motion maps**, which is an effort to account for **uncertainty in structural capacity** (e.g. fragility) and **region dependent shapes of seismic hazard curves**.

Risk

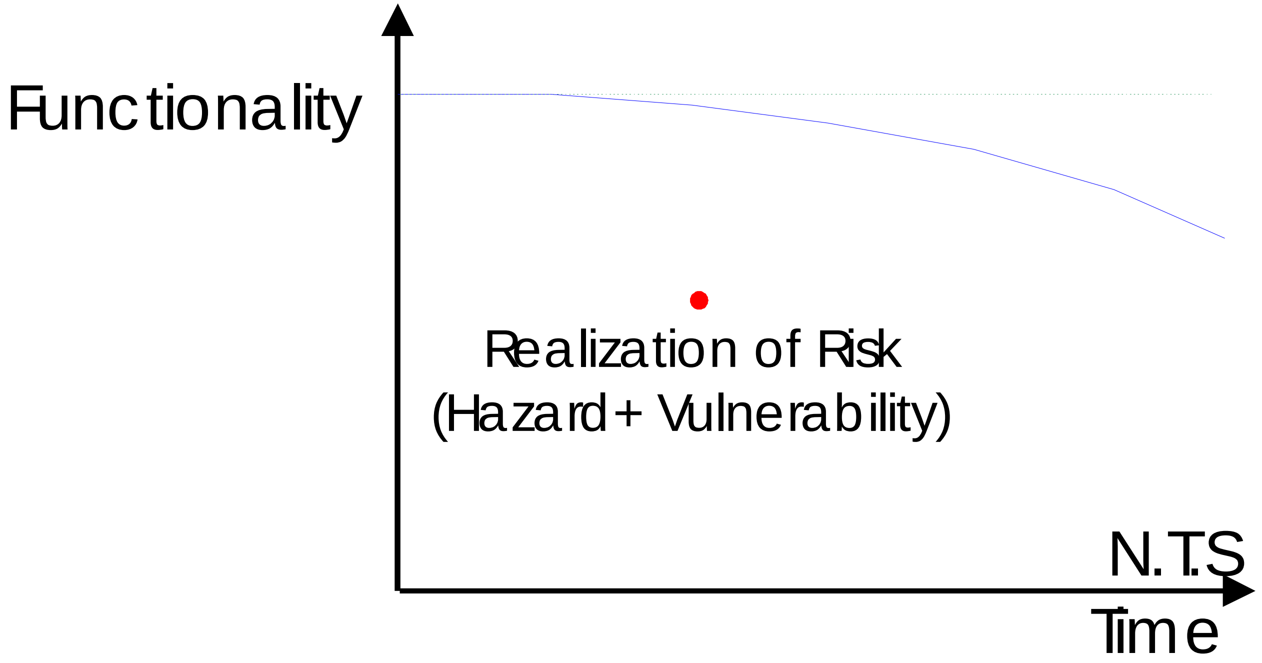
- While this is a step forward in achieving uniform risk (of collapse), it applies only to one hazard and one design level, i.e. design for extreme seismic ground motions.

- An extension of this effort is to account explicitly for resilience under multiple hazards.

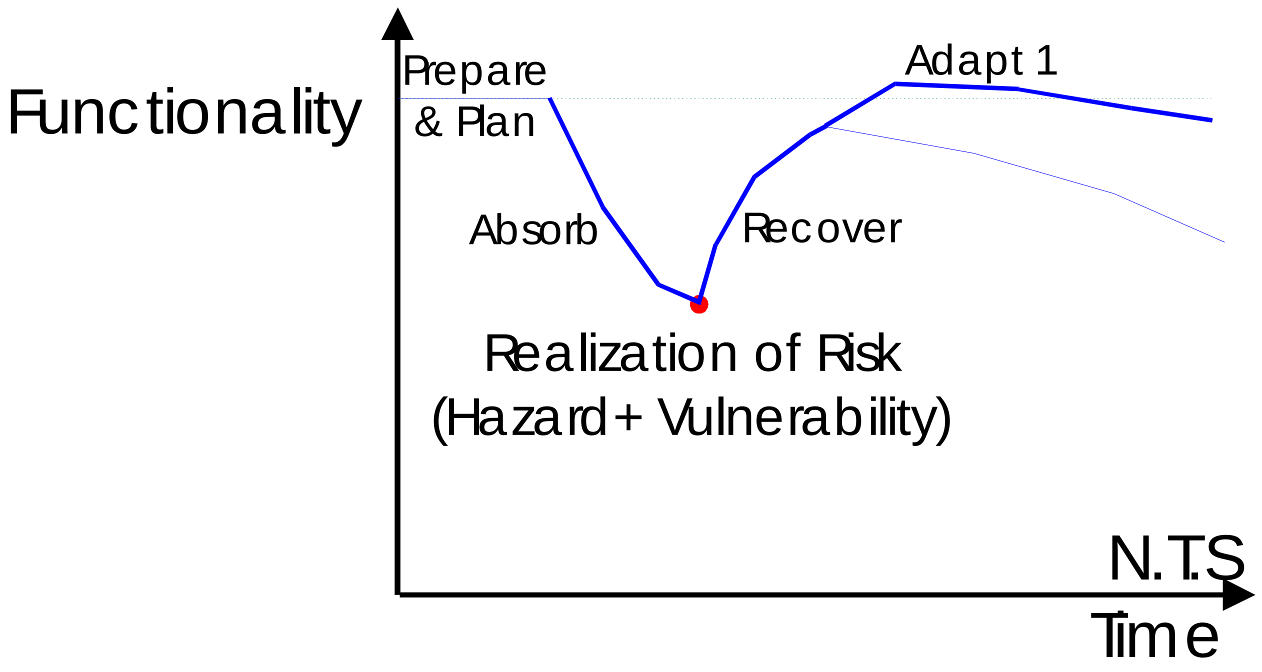
Risk vs Resilience

- Risk = Hazard + Vulnerability + Consequence
- Resilience has to do with restoring (Critical) Functionality in a reasonable period of time.

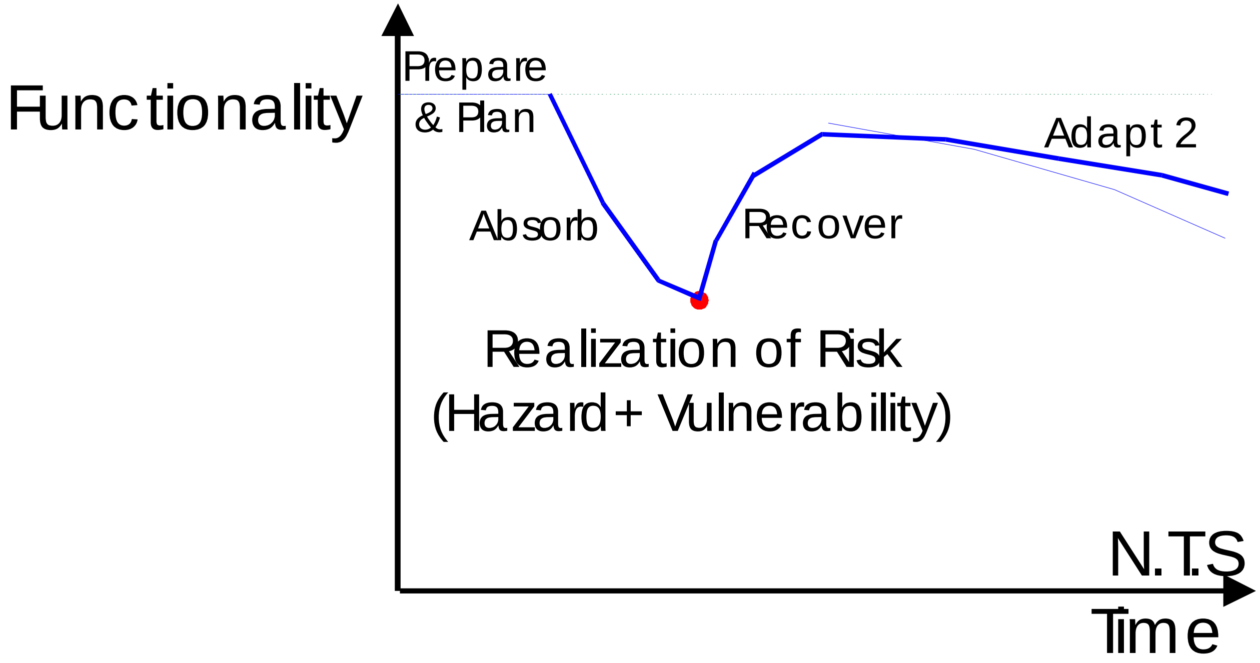
Risk vs Resilience



Risk vs Resilience



Risk vs Resilience



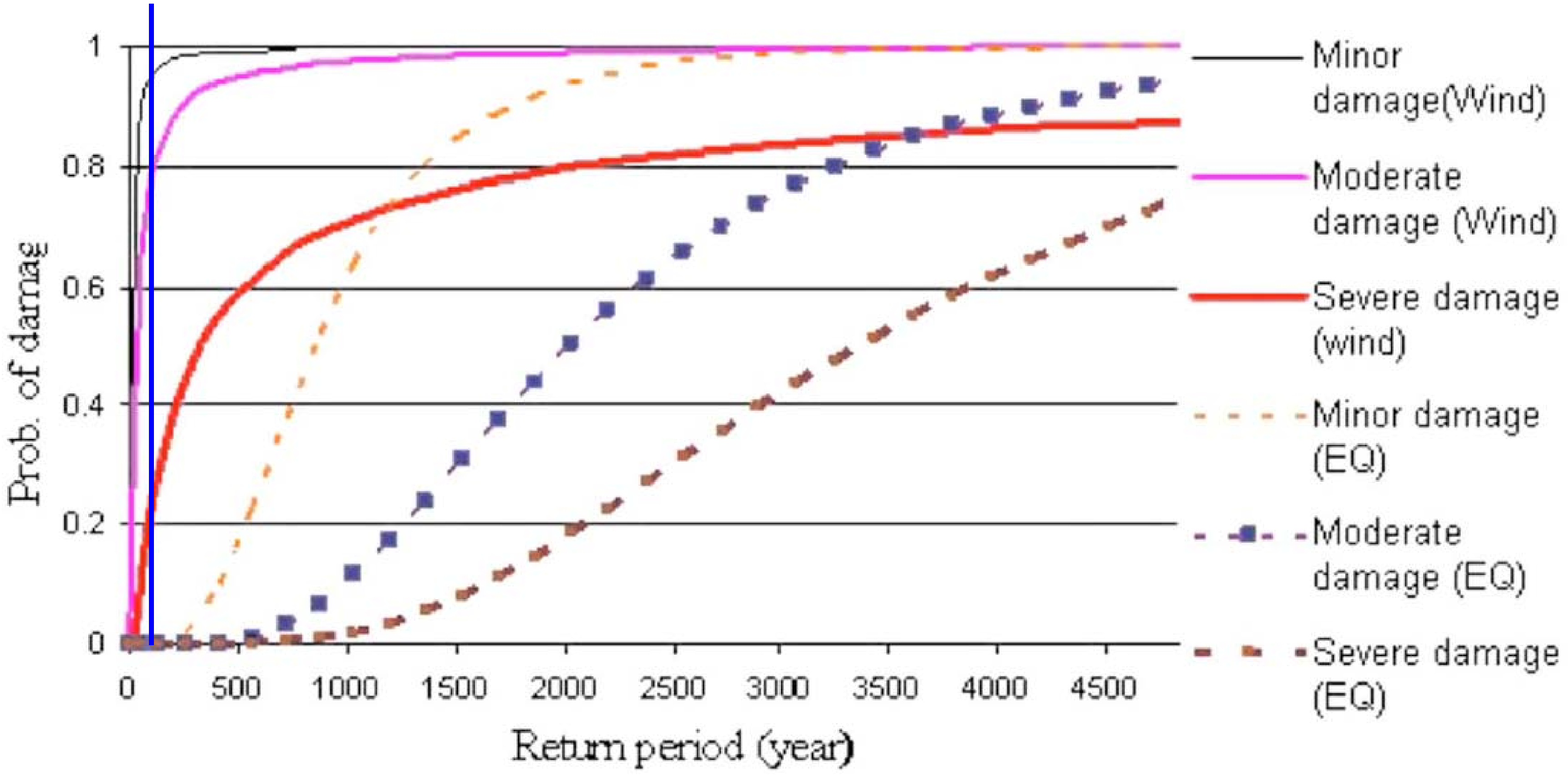
Building Resilience

- Resilience is better suited for systems, therefore, in building resilience we look at building as a **system**, which includes: **foundation, structure, envelope, and other non-structural components.**
- Resilience of a building for **multiple hazards** can be defined as its capacity to **absorb** impact of adverse events, **provide a minimum level of functionality after event**, and to **permit rapid rehabilitation** to a level of performance close to or even greater than its initial performance state.

Building Resilience

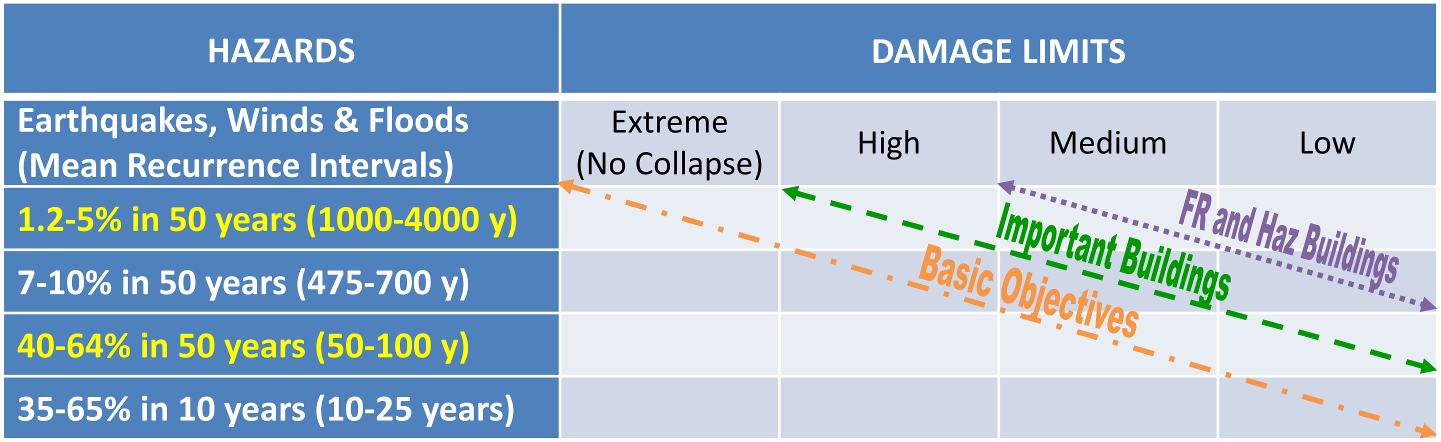
- **Resilience Metrics** may include **time to recovery**, **percent functional**, **casualties (collapse resistance)**, **cost**, and **social and environmental impacts**.
- There is a need to consider resilience in context of **multiple hazards**.

Multiple Hazards (Charleston, min. practice; Wood-frame residential)



Source: Li and Ellingwood, J. Struct. Eng. 2009.135:159-168.

Preliminary Hazard-Damage Matrix



HAZARDS	DAMAGE LIMITS			
Earthquakes, Winds & Floods (Mean Recurrence Intervals)	Extreme (No Collapse)	High	Medium	Low
1.2-5% in 50 years (1000-4000 y)				
7-10% in 50 years (475-700 y)				
40-64% in 50 years (50-100 y)				
35-65% in 10 years (10-25 years)				

Future variation (nonstationarity) of wind and flood hazards as a result of climate change and urbanization should be accounted for.

Relating Damage to Time to Recovery & Percent Functional

- Calculate damage levels using fragility functions.

- Identify damage to individual building components and systems and determine what percentage of building area is still useable for its intended function.

- Partial damage may result in partial occupancy, which is measured as a **percentage of functional area**, a primary resilience metric.

Relating Damage to Time to Recovery & Percent Functional

- Building Information Modeling (BIM) allows us to track these relationships. The total elapsed time—including lead-times—yields: **time to recovery**.

Collapse Resistance (Uncertainties)

- Develop new or use existing performance models in which the model error is accounted for

$$y_i = h_i(\boldsymbol{x}_i + \boldsymbol{\theta}_i) + \varepsilon_i$$

- Describe different types of damage functions, e.g. jth limit state

$$g_j(\boldsymbol{x}, \boldsymbol{\Theta}, \boldsymbol{\varepsilon}, IM) \leq 0$$

Collapse Resistance (Uncertainties)

- Fragility function for a hazard is calculated

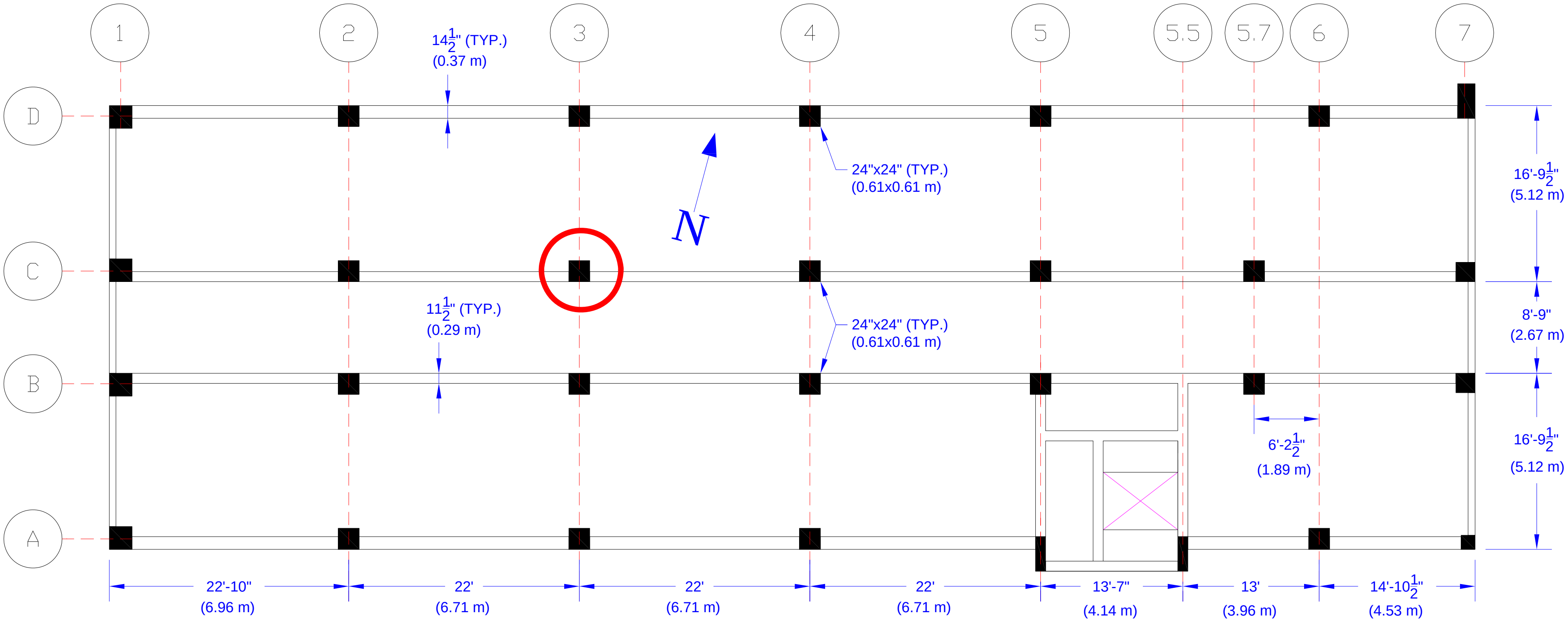
$$\begin{aligned} F(IM) &= P\left(\cup\, g_j \leq 0 \mid IM\right) \\ &= \int_{\cup g_j \leq 0} f(\boldsymbol{x})\, f(\boldsymbol{\Theta})\, \Phi(\boldsymbol{\varepsilon})\, d\boldsymbol{x}\, d\boldsymbol{\Theta}\, d\boldsymbol{\varepsilon} \end{aligned}$$

Collapse Resistance (Casualties)

- To minimize likelihood of mass casualties, **collapse resistance** is an important measure of resilience .
- For collapse analysis due to seismic ground motions, both **lateral instability** and **loss of gravity load carrying capacity** need to be considered.
- It is important to recognize that **element failure** does not necessarily constitute **partial or total building collapse**.

20-story Baptist Hospital, Memphis, TN

Plan of a Wing



20-story Baptist Hospital, Memphis, TN

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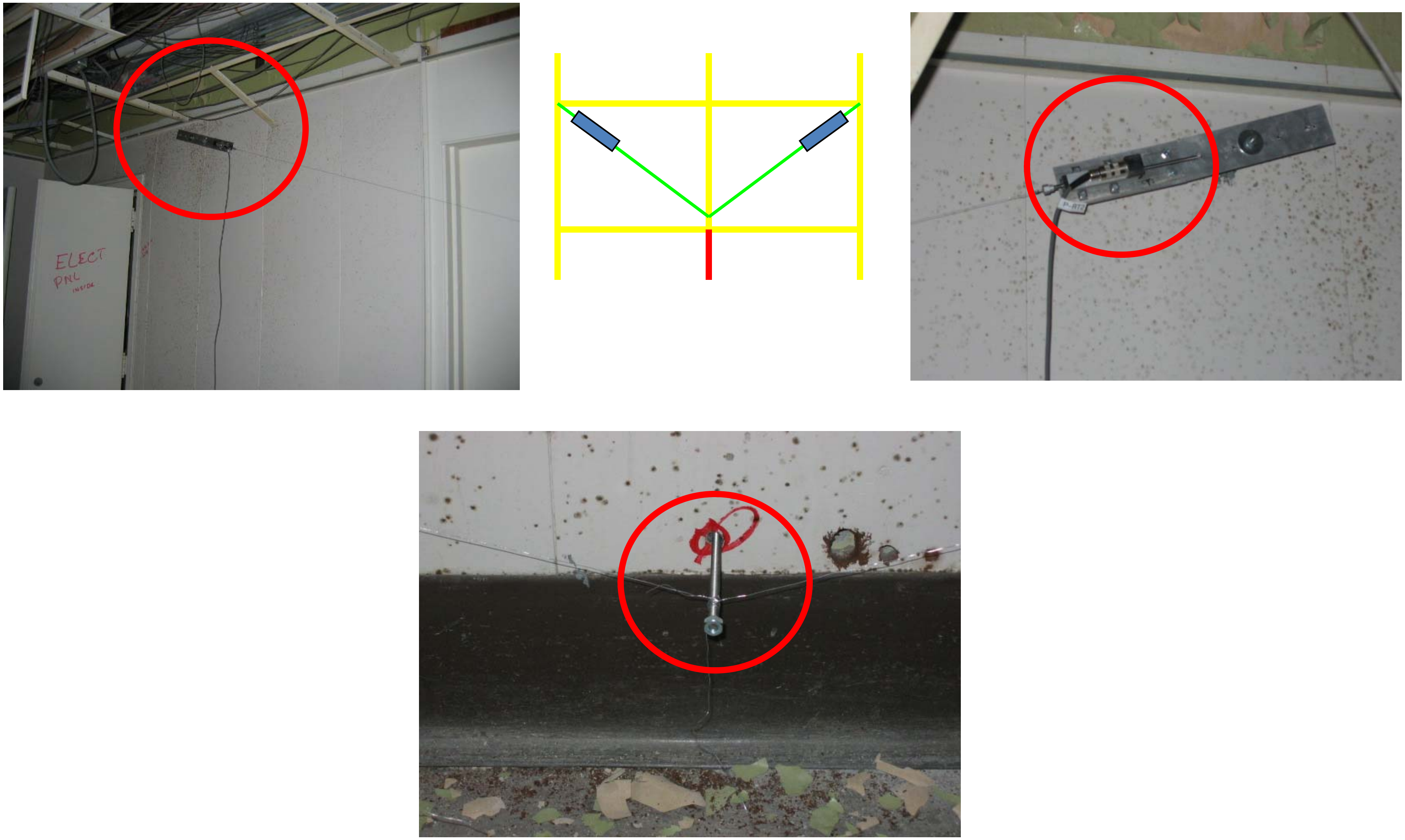
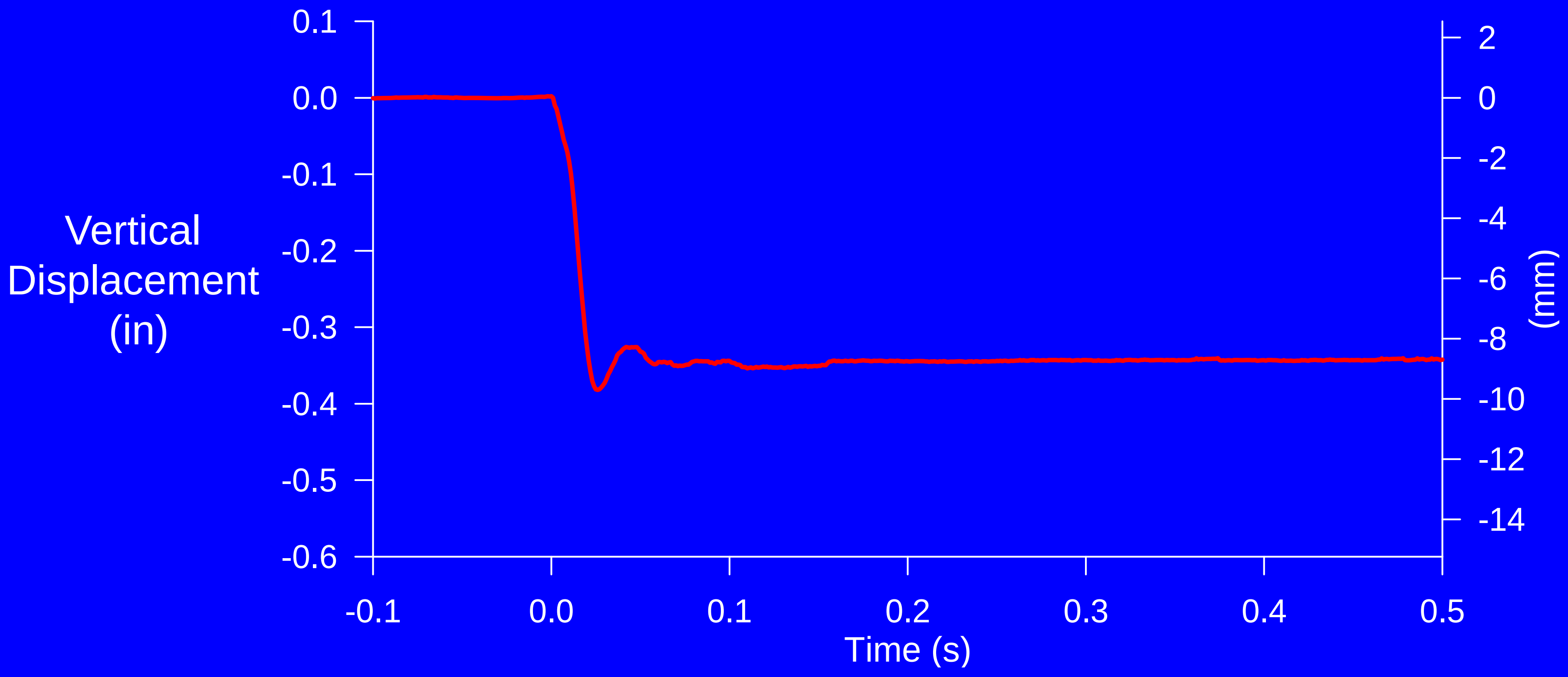
Linear Transformers (Displacement Measurement)



Displacement of 2nd Floor

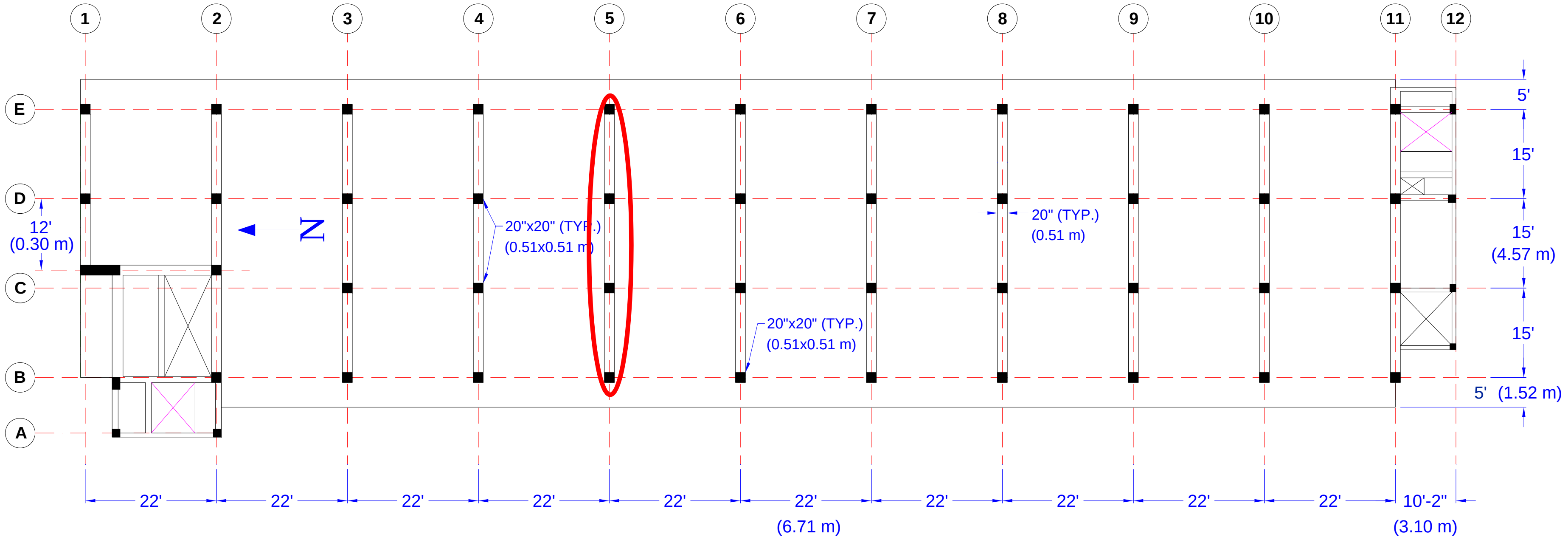


Vertical Displacement=0.34 in

20-story Baptist Hospital, Memphis, TN

10-story RC Structure in Little Rock, AR

Plan of Building



10-story RC Structure in Little Rock, AR

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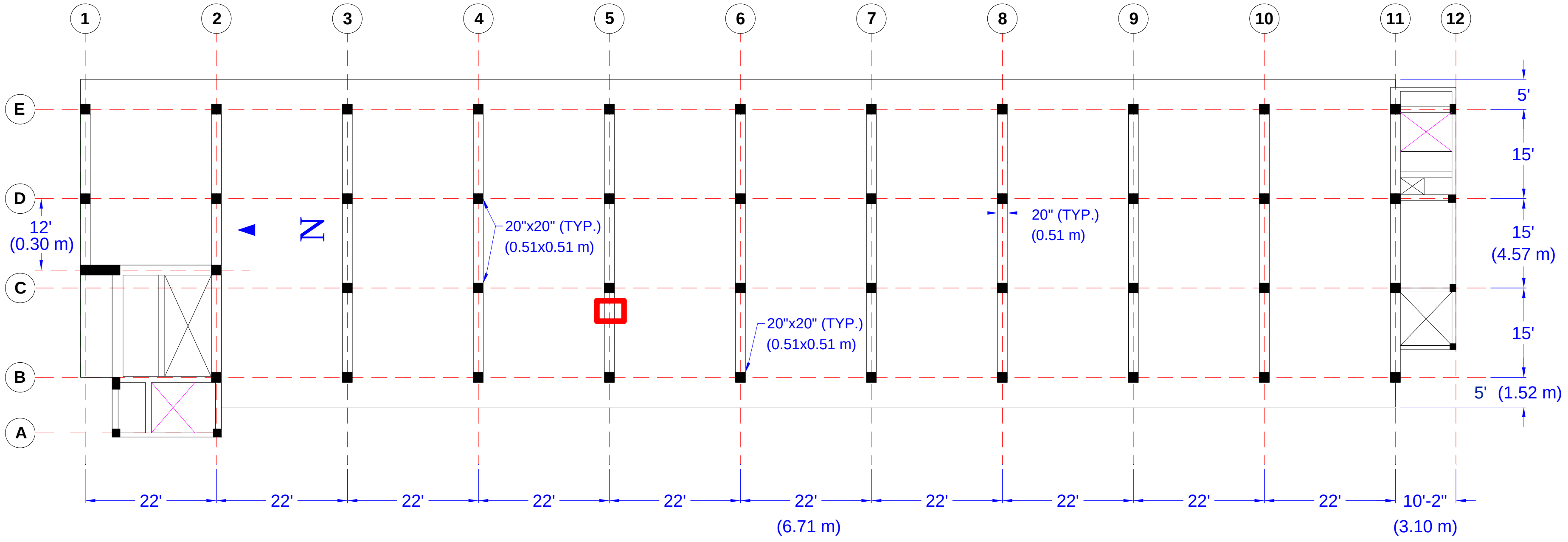
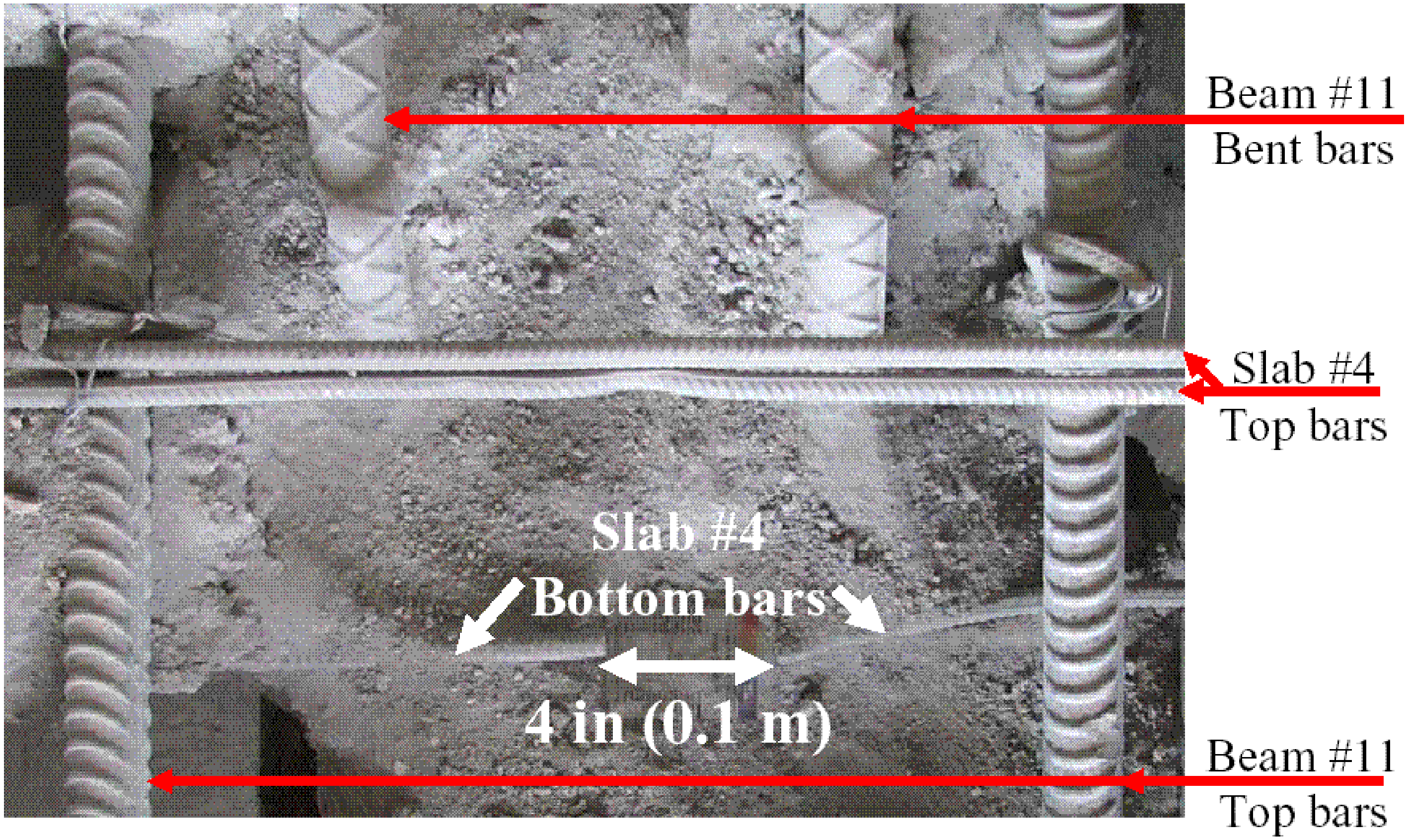
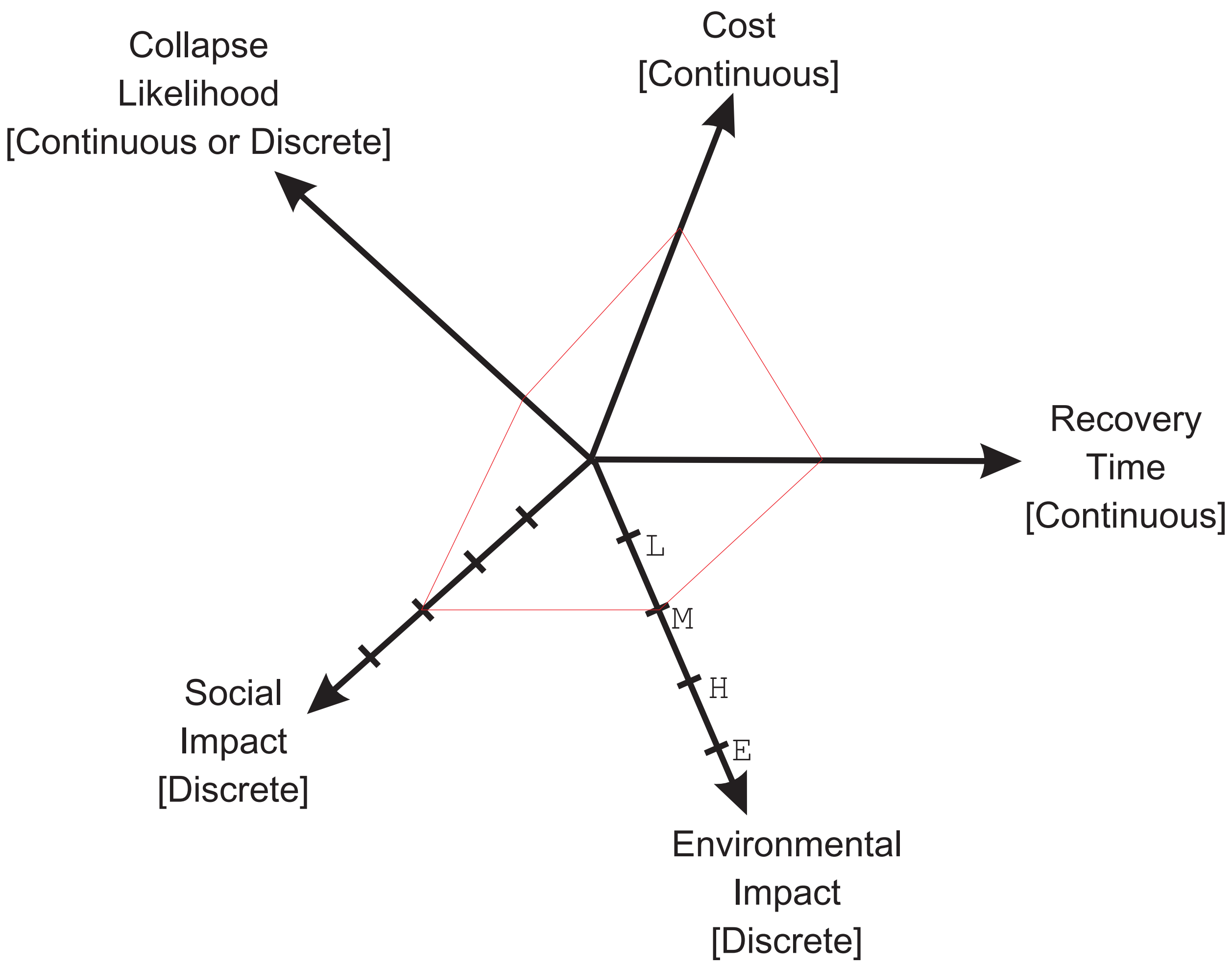
Plan of Building



Reinforcement Details



Decision Making



Building Resilience

- Buildings should be designed to limit maximum probability of exceeding each level of resilience criteria across multiple hazards.
- e.g. design criterion: Probability of requiring more than 15 days of time to recover 80% of normal functionality should be less than 50% over the lifespan of building for multiple hazards.

Building Resilience

- Develop a design framework that provides uniform resilience across different hazards, so buildings designed for **sites prone to different hazards** will have roughly **equivalent times to recovery** and roughly **equal loss of functionality** over a given **building lifespan**.

- **Goal:** Design buildings for **uniform resilience across multiple hazards** with different levels of severity.

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Acknowledgements

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Final Request

- Looking for **2 knowledgeable and motivated Structural Engineering PhD student to work on this topic.**
- Email: **sasani@neu.edu**

Thank you.