

# ***Theory of Multi-Hazards: A Quantification Procedure to the Process***

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# Outline

- ◆ History
- ◆ Benefits – Drawbacks
- ◆ Theory
- ◆ Analysis
- ◆ Design
- ◆ Life Cycle Cost (LCC)
- ◆ Relative Risk
- ◆ Structural Health Monitoring
- ◆ Case Studies
- ◆ Future Needs
- ◆ Closure



# History

- ◆ The recent devastating effects of hazards..
  - ◆ Earthquakes (Loma Prieta and North Ridge)
  - ◆ Hurricanes (Atlantic and Gulf Coasts)
  - ◆ Terrorism (Blast/PC mitigation needs)
- ◆ .. prompted the search for methods to limit
  - ◆ Social, and
  - ◆ Economic effects..
- ◆ This led to Multihazards consideration ideas.



# Multihazards: Advantages - 1

- ◆ Potential for an economic design and construction.
- ◆ A more accurate estimation of inherent resiliency of the system.
- ◆ A more accurate treatment/estimation of life cycle cost of the system.
- ◆ A more accurate analysis of the system
- ◆ Optimization of the Structural Health Monitoring (SHM) to increase experimental efficiency.



# Multihazards: Advantages - 2

- ◆ The multihazard design philosophy of a particular infrastructure project may affect the entire network on infrastructure systems.
  - ◆ For example, multihazard design of an important highway bridge may improve the reliability of the entire transportation network of the region that the highway bridge serves.



# Multihazards: Disadvantages

- ◆ Lack of a concise set of tools that can accommodate multihazards considerations.
- ◆ This results in spotty applications to an otherwise increasingly important subject.
- ◆ Thus, even though the infrastructures community realizes this value, there are no objective roadmaps to tap on the immense potential of the multihazards philosophy.
- ◆ This Presentation shows potential ways of quantifying multihazards



# Theory of Multihazards

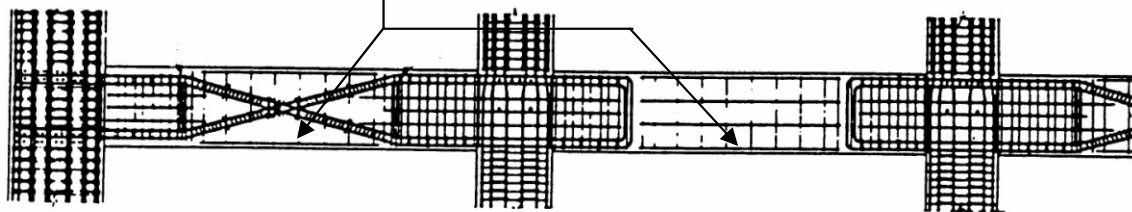
- ◆ *For a given system that is exposed to multihazards, there exists an inherent multihazards resiliency within the system. This multihazards resiliency implies an interrelationship between the manners that the system responds to different hazards.*



# Hazards Demands – Conflicting

- ◆ Different hazards can result in conflicting demands
  - ◆ Blast: inversely proportional to mass
  - ◆ Seismic: Directly proportional to mass
  - ◆ Wind: Independent of mass

Note lack of ductile detailing at center, where plastic hinges will form during blast events



# Hazards Demands – Consistent

- ◆ Hazards can have similar demands from systems.
  - ◆ Blast: Inelastic behavior
  - ◆ Seismic: Inelastic behavior
  - ◆ Wind: Elastic behavior



# Optimization is The Ultimate Goal

- ◆ To account for all those conflicting and consistent demands, an optimization of design is needed
  - ◆ Not necessarily formal optimization



# Multihazards Table (Bridges)

	Fatigue	Corrosion	Scour	Fire	Wind	Earthquakes	Impact	Overload	Wear & Tear	Gravity
Fatigue	NA	H	L	M	H	H	M	M	H	H
Corrosion		NA	M	L	L	L	M	H	H	H
Scour			NA	L	L	H	H	H	H	H
Fire				NA	H	H	M	L	L	L
Wind					NA	L	M	L	L	L
Earthquakes						NA	M	M	L	L
Impact							NA	H	M	M
Overload								NA	H	H
Wear & Tear									NA	H
Gravity										NA



# Multihazards Table (Buildings)

	Wind	Seismic	Fire	Corrosion	Blast	Flood	Other?
Wind	NA	H	M	L	H	M	
Seismic		NA	H	L	H	M	
Fire			NA	L	H	M	
Corrosion				NA	L	H	
Blast					NA	L	
Flood						NA	
Other?							NA

H – High inter -dependence  
M – Medium Inter -dependence  
L – Low Inter-dependence

N.A.- Not Applicable



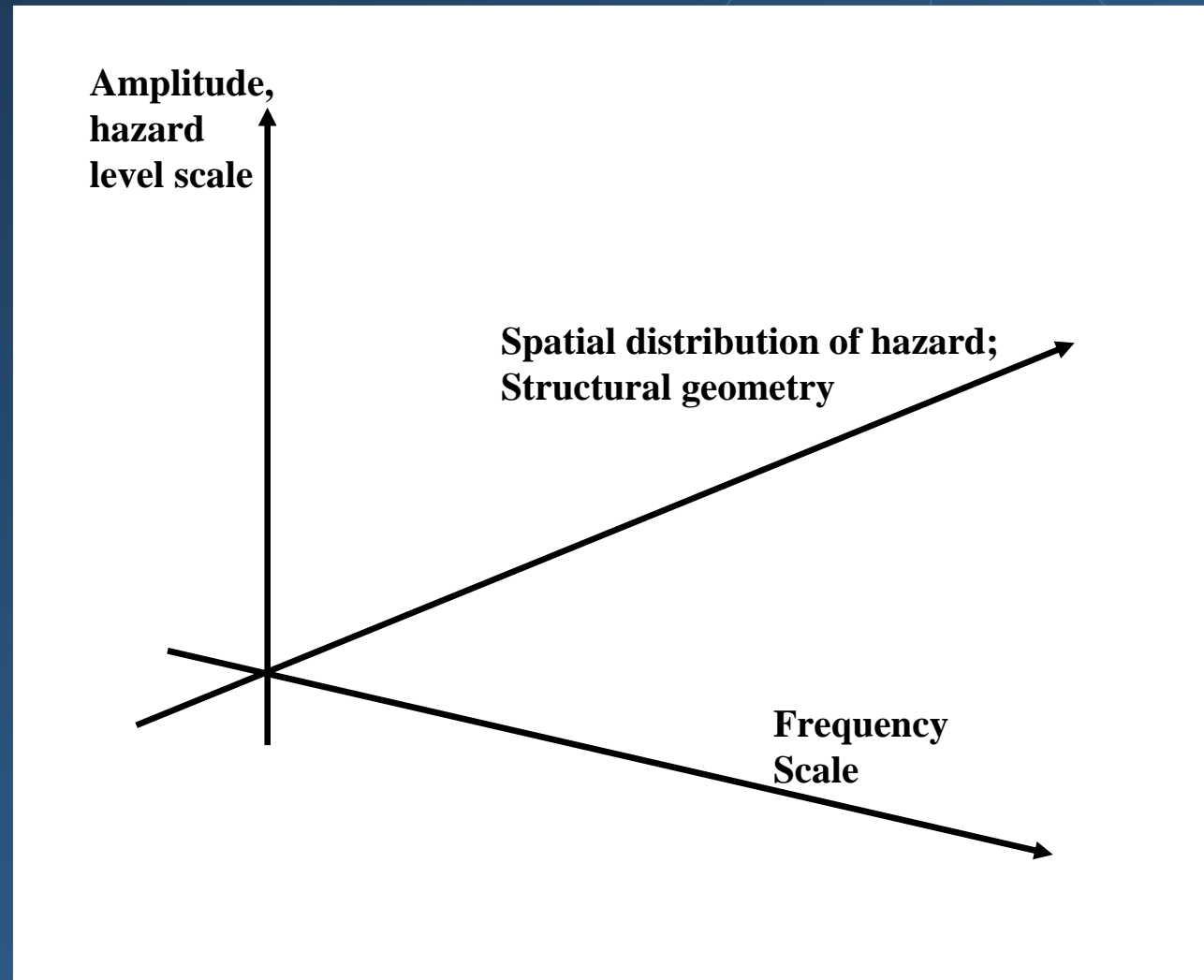
# Multihazards: Analysis

- ◆ Analysis needs vary immensely for different hazards.
- ◆ Degree of F.E. resolution depends on..
  - ◆ Geometry,
  - ◆ Time, and
  - ◆ Amplitude
- ◆ .. Characteristics of different hazards
- ◆ Failure to accommodate such needs would produce an inaccurate results

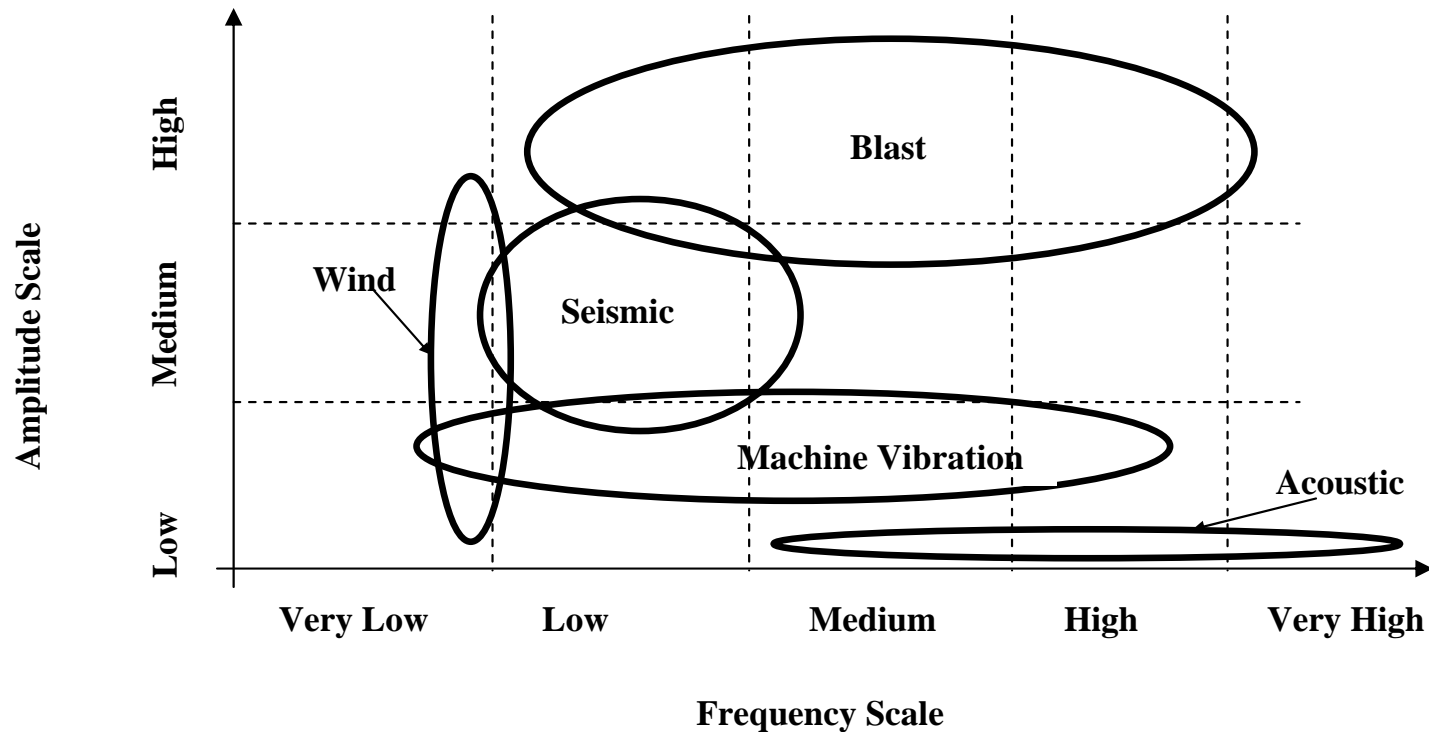


# Analysis of Hazards

- ◆ Definition of hazards include three parameters
  - ◆ Space
  - ◆ Time
  - ◆ Amplitude



# Frequency-Amplitude Hazards Spectrum

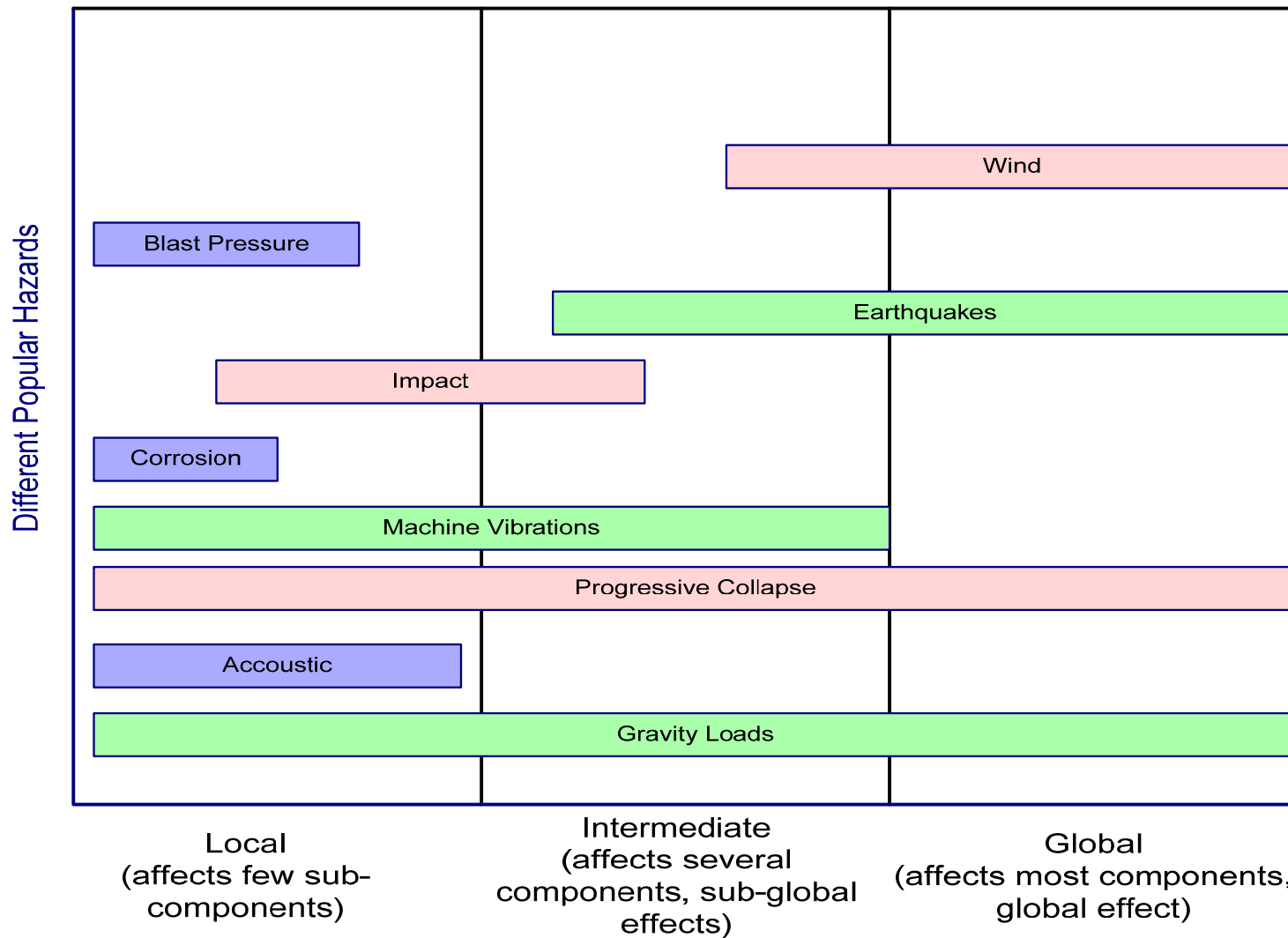


Qualitative Frequency-Amplitude distribution for different Hazards

A more comprehensive version  
Can be found in the new edition  
Of FEMA 452



# Spatial Extent of Hazards



# Design: Conventional

- ◆ Ensure safety by

$$CD_{ij} \geq AC_{ij}$$

- ◆ Ensure economy by

$$\textit{Minimize} \left( CD_{ij} - AC_{ij} \right)$$



# Design: Multihazards

- ◆ Ensure safety by

$$CD_{ij} \geq AC_{ij}$$

- ◆ Ensure economy by

$$\textit{Minimize} (CD_{ij} - AC_{ij})$$

- ◆ While satisfying the Multihazard capacity function

$$CP_{ij} = f(CP_{i1}, CP_{i2}, \dots, CP_{i(j-i)}, CP_{i(j+1)}, \dots, CP_{iNH})$$



# Example of Capacities Interrelationships – Tall Bldg.

- ◆ Wind drift requirements affect the lateral stiffness *capacity* of the building.
- ◆ The seismic design of the same building will also be affected by the same lateral stiffness *capacity* (in the form of vibration characteristics).
- ◆ Thus the interrelationship between seismic and wind designs is obvious:
  - ◆ A change in the wind capacity will have a direct effect on seismic capacity, and the reverse is true.



# Example of Capacities Interrelationships – Floor Vibrations

- ◆ The floor beams in an office building are designed for a given gravity weight *capacity*.
- ◆ The same beams would offer certain *capacity* (again, in the form of vibration characteristics) for perceived floor vibration.
- ◆ The two capacities are interrelated through the flexural properties of the floor beam:
  - ◆ Any change in the floor beam characteristics would affect both capacities.

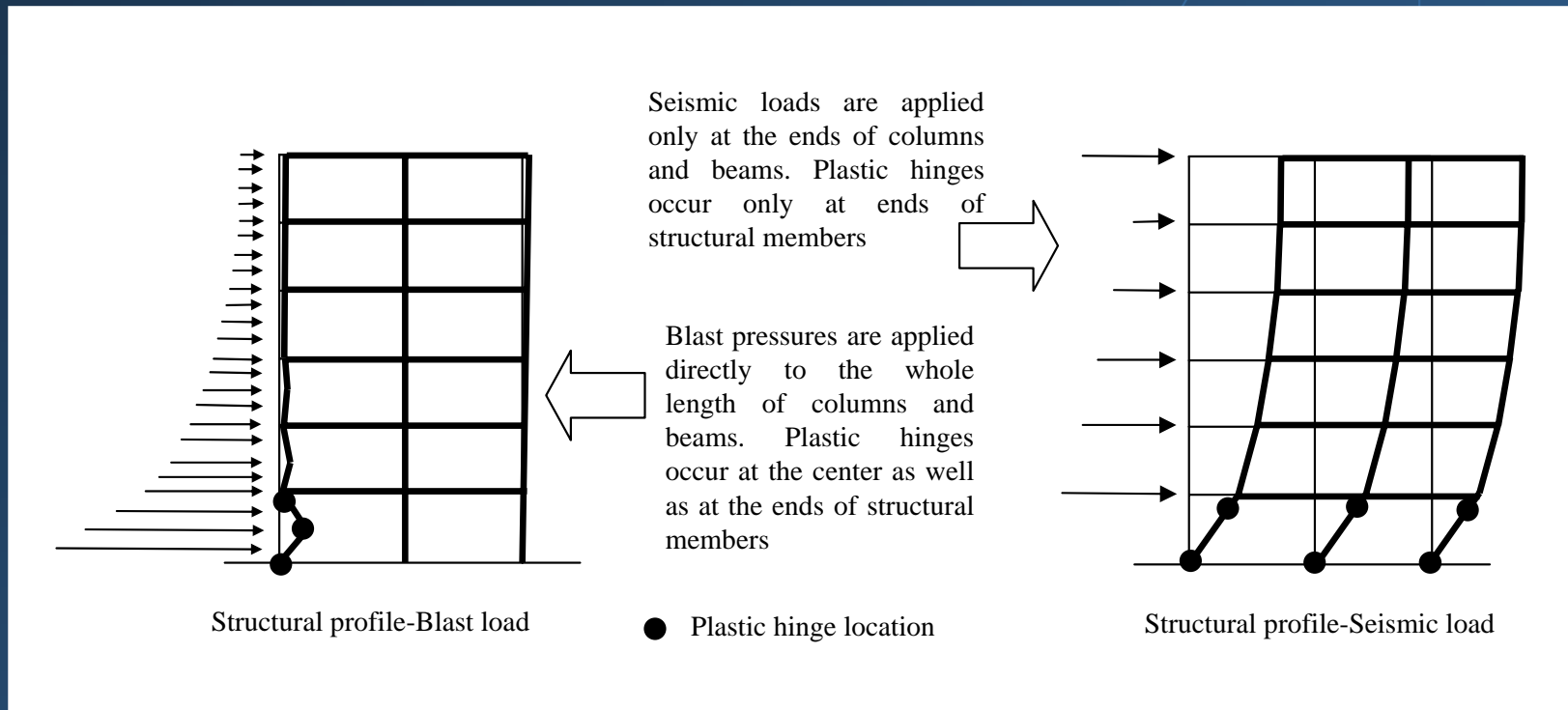


# Example of Capacities Interrelationships – Blast vs. Seismic Retrofits

- ◆ Blast and seismic designs of columns in framed buildings (or bridges):
- ◆ Good seismic design practice requires that there are no abrupt changes in properties of columns to avoid the phenomenon of soft stories.
- ◆ Blast design of columns might result in an abrupt change in column properties (due to fast attenuation of blast pressures).
- ◆ But, such an abrupt change would create the undesired seismic soft story behavior. Care must be taken to balance these opposing requirements of the two hazards.



# Seismic vs. Blast



- ◆ Spatial differences in loads will result in several differences in response, hence analysis and design steps



# Life Cycle Costs

- ◆ Perhaps the easiest manner to quantify Multihazard considerations
- ◆ This is due to the fact that it accounts for ALL parameters of the facility, and relate them in a single denominator: cost vs. longevity
- ◆ LCC is another emerging topic. Mostly in Bridges.
- ◆ Building owners/developers are resisting the concept, so far!!



# Life Cycle Cost (LCC): Conventional

- ◆ LCC is computed for single hazard as

$$C_j = \int h_j(x) c_{aj}(x) dx$$

- ◆ Total LCC is computed for multiple hazards as

$$C_T = \sum_{j=1}^{j=NH} C_j$$



# Life Cycle Cost (LCC): Multihazards

- ◆ LCC is computed for single hazard, accounting for other hazards as

$$C_j = \sum_{k=1}^{k=NH} \int h_k(x) c_{ajk}(x) dx$$

- ◆ Total LCC is computed for multiple hazards as

$$C_T = \sum_{j=1}^{j=NH} C_j$$



# Life Cycle Cost (LCC): Multihazards

- ◆ the sign of  $C_{aikj}$  controls how different hazards at different intensities can affect the total cost.
- ◆ If the sign is positive, then the  $i^{th}$  and  $j^{th}$  hazards have conflicting demands on the system, thus increasing the total cost.
- ◆ If the sign is negative, then mitigating the  $i^{th}$  and  $j^{th}$  hazards, which have consistent demands, can end up reducing the total cost.



# Relative Risk

- ◆ Conventional Relative Risk for Single Hazard

$$R_j = \sum_{i=1}^{i=NS} M_i V_i I_i$$

- ◆ Multihazard Relative Risk for Single Hazard

$$R_j = \sum_{k=1}^{k=NH} \sum_{i=1}^{i=NS} M_{ik} V_{ikj} I_{ik}$$

- ◆ Total relative Risk

$$R = \sum_{j=1}^{j=NH} R_j$$

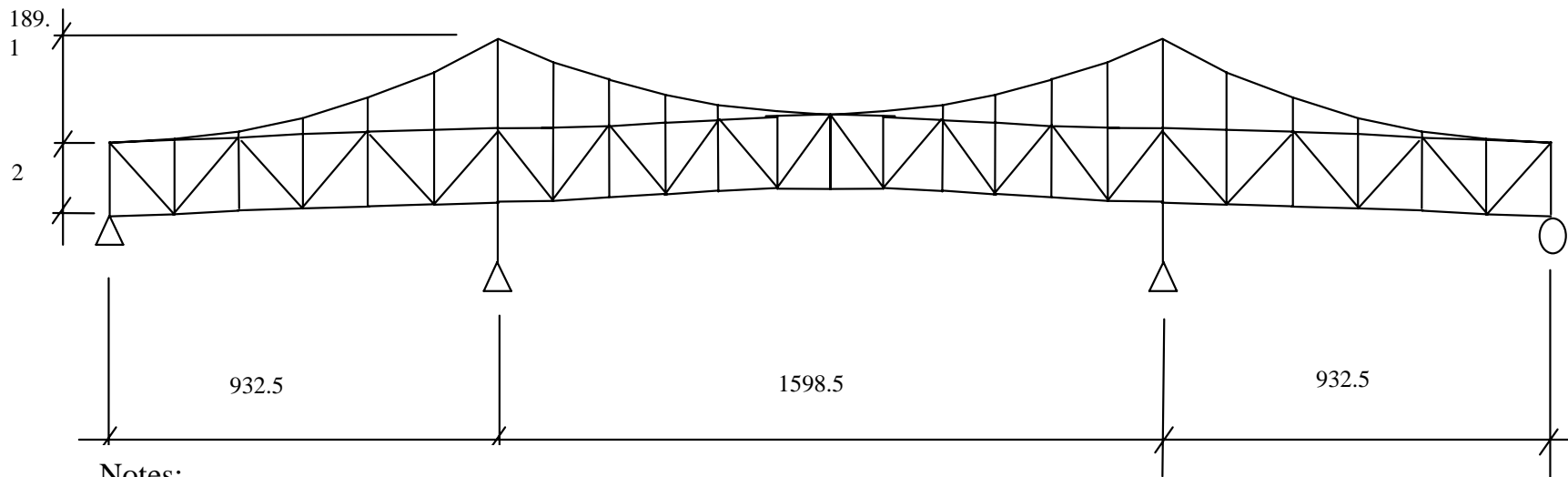


# Structural Health Monitoring (SHM)

- ◆ **Multihazards considerations manifest itself in many SHM applications**
  - ◆ **Optimal Sensor Locations**
  - ◆ **Value of Experimentation**
  - ◆ **“Serendipity” Principle**
- ◆ **In addition, it plays a major role in Decision-Making Techniques**
  - ◆ **Out of our current scope**



# Instrumentation of a Bridge



Notes:

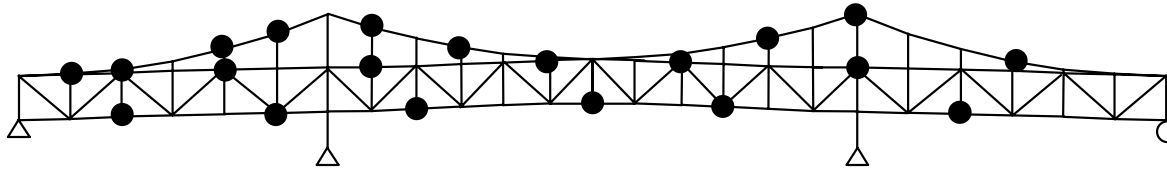
All dimensions are in Feet

First natural period = 2.57 Sec.

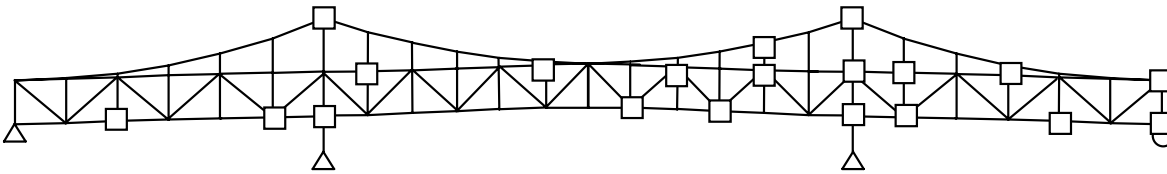
Figure 4. Bridge Structure for Optimum Sensor Locations



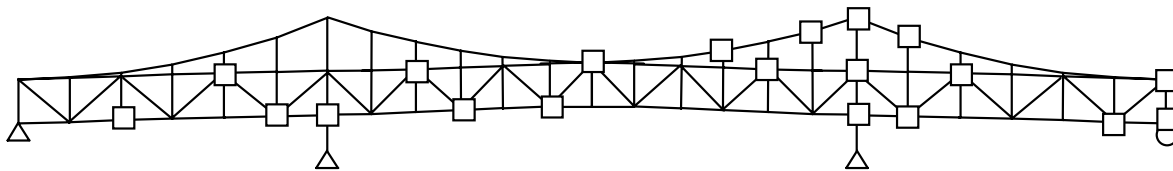
# DL / LL + Seismic Monitoring



a. OSL - DL based



b. OSL - SL based



c. OSL - Combined

Symbols:





-  -Fixed support
-  -Roller support
-  -Horizontal sensor
-  -Vertical sensor

Figure 5. OSL with a threshold of 0.5



# Value of Experimentation

- ◆ Can maximize value of any SHM experimentation if it is designed to accommodate more than single hazard
  - ◆ A seismic monitoring experiment (waiting for earthquake event) can have more value if combined with wind or live load monitoring
  - ◆ Can be accomplished with minimal extra cost!



# Serendipity Principle

## Serendipity Principle in SHM

Hazard # 1 (Target Hazard)

Hazard # 2

SHM Experiment designed only for hazard # 1

SHM Experiment designed mainly for hazard # 1, with additional considerations to other hazard possibilities

If targeting Hazard #1 for SHM experimenting was erroneous, the experiment would fail, since it was designed to monitor Hazard #1 only.

If targeting Hazard #1 for SHM experimenting was erroneous, the experiment would succeed, since it still can monitor Hazard #2



# Examples of Multihazards Designs

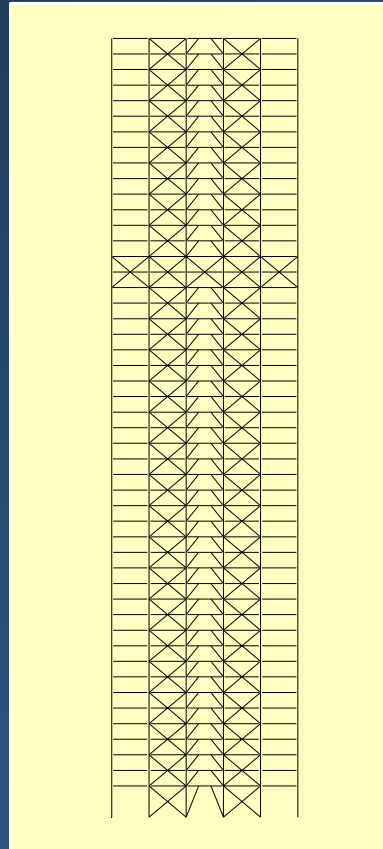
- ◆ The theory stipulates that there are
  - ◆ an inherent resiliency in buildings / bridge that can be accommodated to maintain safety levels while reducing costs (Case 1, design)
  - ◆ Interaction between hazards through structural systems (Case 2, design)
  - ◆ Life-Cycle Cost Considerations (Case 3)



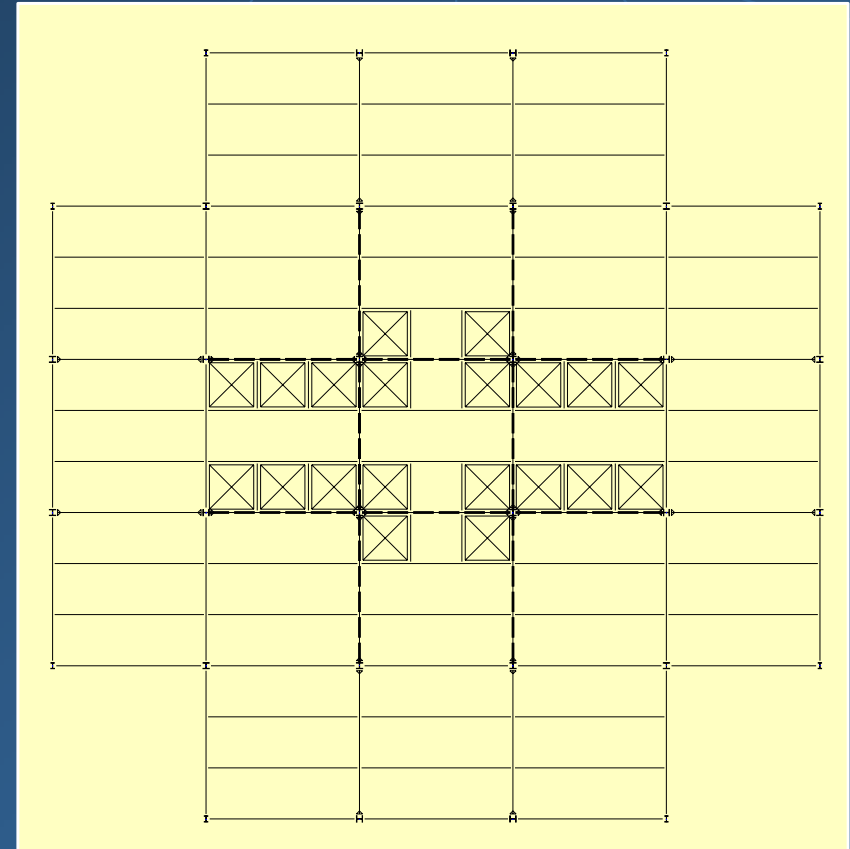
# Case 1: Progressive Collapse + Wind: Inherent resiliency between hazards

49 stories building  
Steel braced frame  
One outrigger at 35 floor

Need to design for:  
1-Wind (IBC, NYC location)  
2-Progressive Collapse (Remove single column approach)



Elevation



Plan

Three designs were produced for the building:

- A1 – Wind only
- A2 – Wind + Progressive Collapse (independently)
- A3 – Wind + Progressive Collapse (Multihazards)



# Case 1: Results

Design Case	One Hazard at a time (independent designs)		Multihazards
	Case A1 (Wind only)	Case A2 (Wind + PC)	Case A3 (Wind + PC)
Steel Weight (Tons)	8351	9564	9412
Cost (\$3150/Ton)	\$26.310M	\$30.13M	\$29.65M

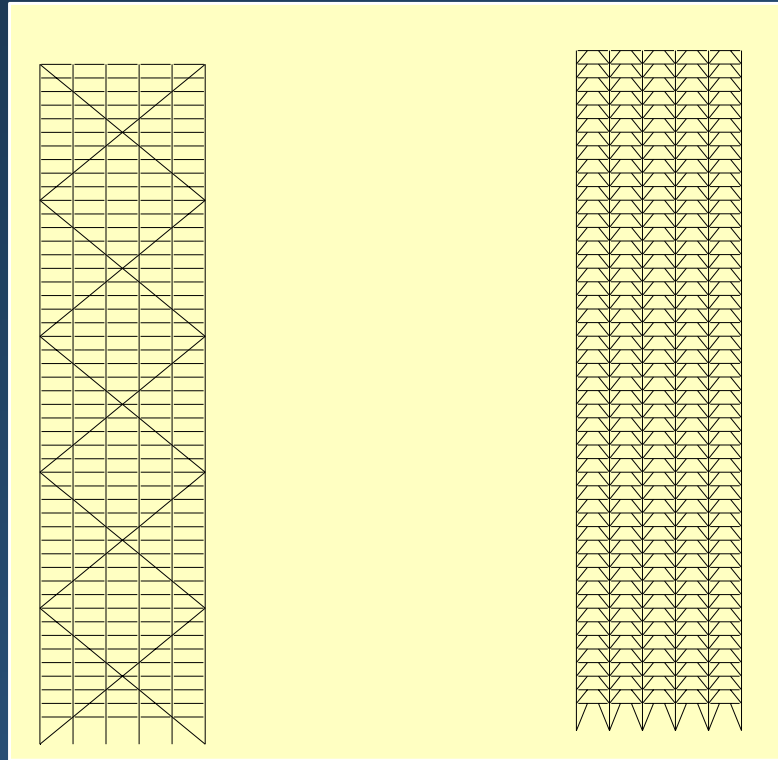
Multihazards design structural saving = \$480,000  
(1.5% savings)



# Case 2: Seismic + Wind: Interaction between hazard through the system

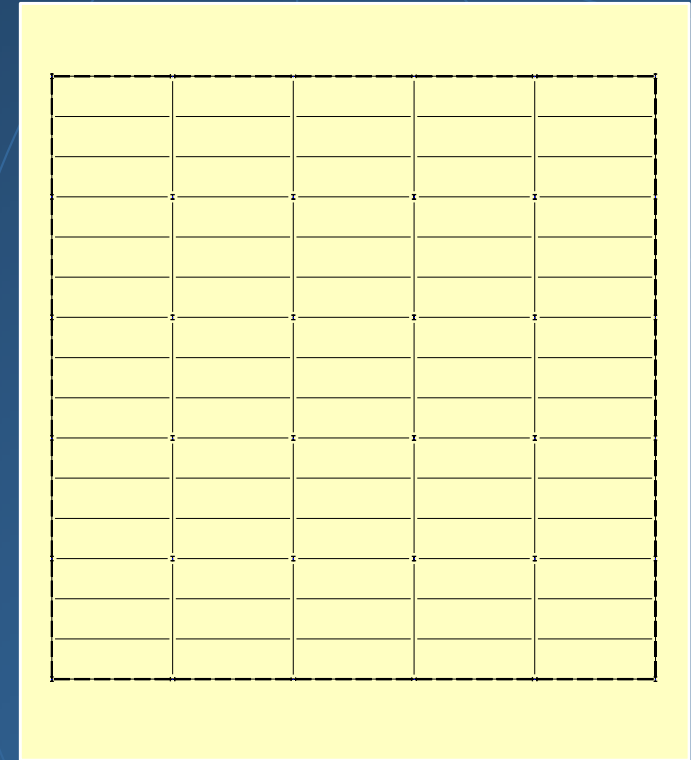
49 stories building  
Steel braced frame

Need to design for:  
1-Wind (IBC, NC location)  
2-Seismic: User Group II.



CBF

EBF



Plan

Four designs were produced for the building: B1 – Wind only (CBF), B2 – Wind + Seismic (CBF), B3 – Seismic Only (EBF), and B4 – Wind + Seismic (EBF)



# Case 2 Results

Case	Frame Type	Hazard	Max. Base Shear (K)	Steel Wt. (Tons)	Cost (\$3150/Ton)
B1	CBF	Wind only	4137	7430	\$23.40M
B2	CBF	Wind + Seismic	5398	7607	\$23.96M
B3	EBF	Seismic only	3317	7219	\$22.74M
B4	EBF	Wind + Seismic	4818	7867	\$24.78M

Optimum multihazards design can be different from optimum designs when accommodating hazards separately! ( about 820K, 3.5%, savings)



## Case 3: Seismic + Blast Retrofits: Life Cycle Cost (LCC) Considerations

- ◆ A building similar to building B, in a seismically exposed region, needed a blast retrofit
- ◆ The owner decided to employ an LCC to investigate least expensive retrofit Blast system



# Case 3 Results

<b>Retrofit Strategy</b>	<b>Blast retrofit independently from Seismic future demands</b>	<b>Blast + Seismic demands considered in a multihazards strategy</b>
Life Cycle Cost	\$8.6 M	\$7.3 M

Multihazards Life Cycle Cost savings are about \$1.3M, (18%).



## Comments on Cases

- ◆ In all cases: there were obvious cost savings, without any drawbacks, for a Multihazards logic.
- ◆ All of the cases depended on an 'engineering judgment,' qualitative treatment
  - ◆ There are no clearly defined, step-by-step multihazards methodologies



## Current Efforts

- ◆ **FEMA 452 is a major effort underway that provides for a multihazards-multidisciplinary considerations of**
  - ◆ **Flood, wind, seismic, CBR, and Blast**



# Future Needs

- ◆ Code-based language that recognize multihazards demands and pitfalls (both consistent and conflicting)
- ◆ More emphasis on LCC for infrastructures, especially socially significant infrastructures
- ◆ Emerging importance of Risk vs. Reliability issues



# Future Needs

- ◆ **Better recognition and understanding of the all important Analytical needs of different hazards**
- ◆ **Encouraging NDTs and SHM multihazards solutions**



# Closure

- ◆ Why Multihazards now?
  - ◆ Maintain, or increase, safety and security of public and infrastructures
- ◆ Reduce costs
  - ◆ Construction / retrofit
  - ◆ Life Cycle



# Questions?

