Lessons Learned from Disastrous Earthquakes

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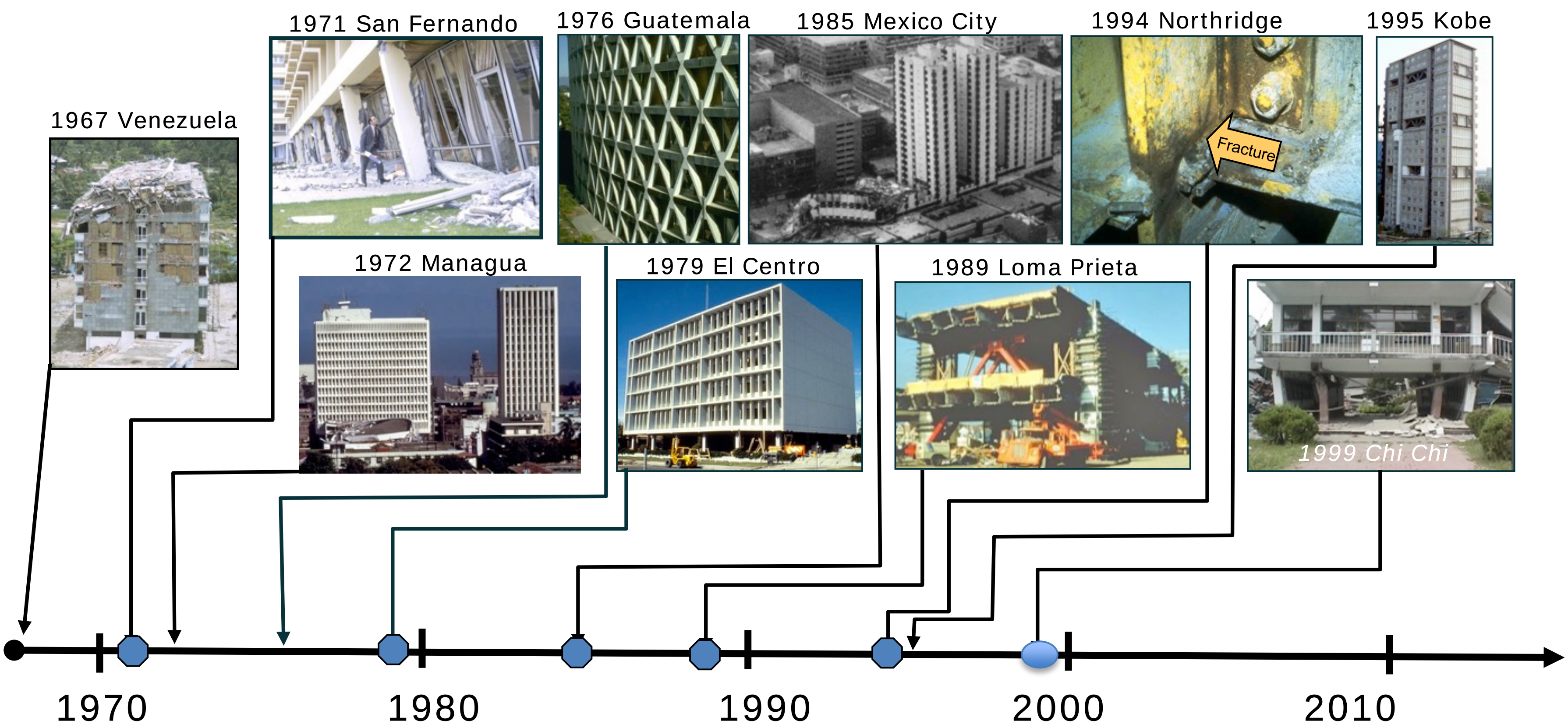
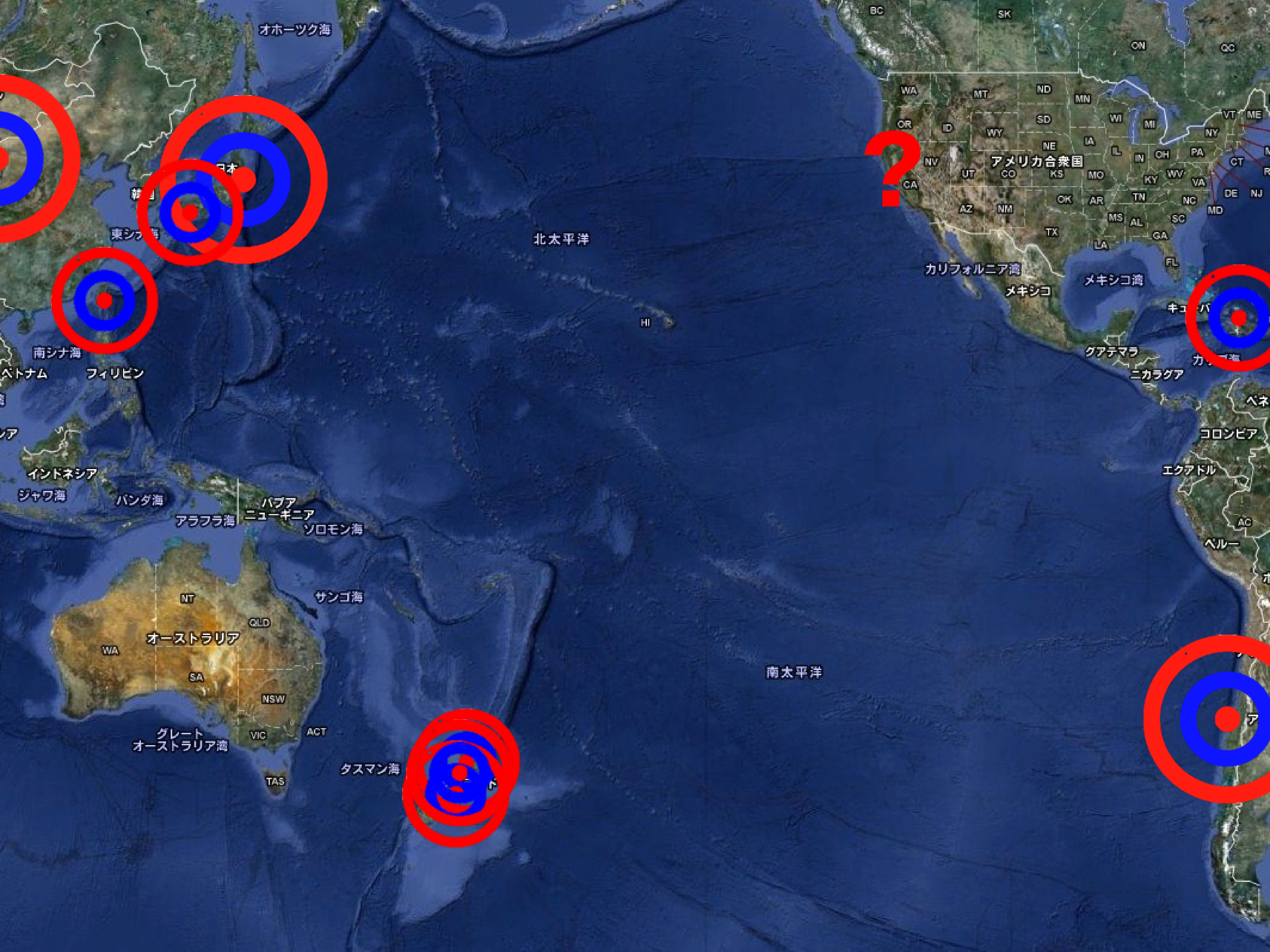
UC Berkeley

Disasters provide the impetus for change

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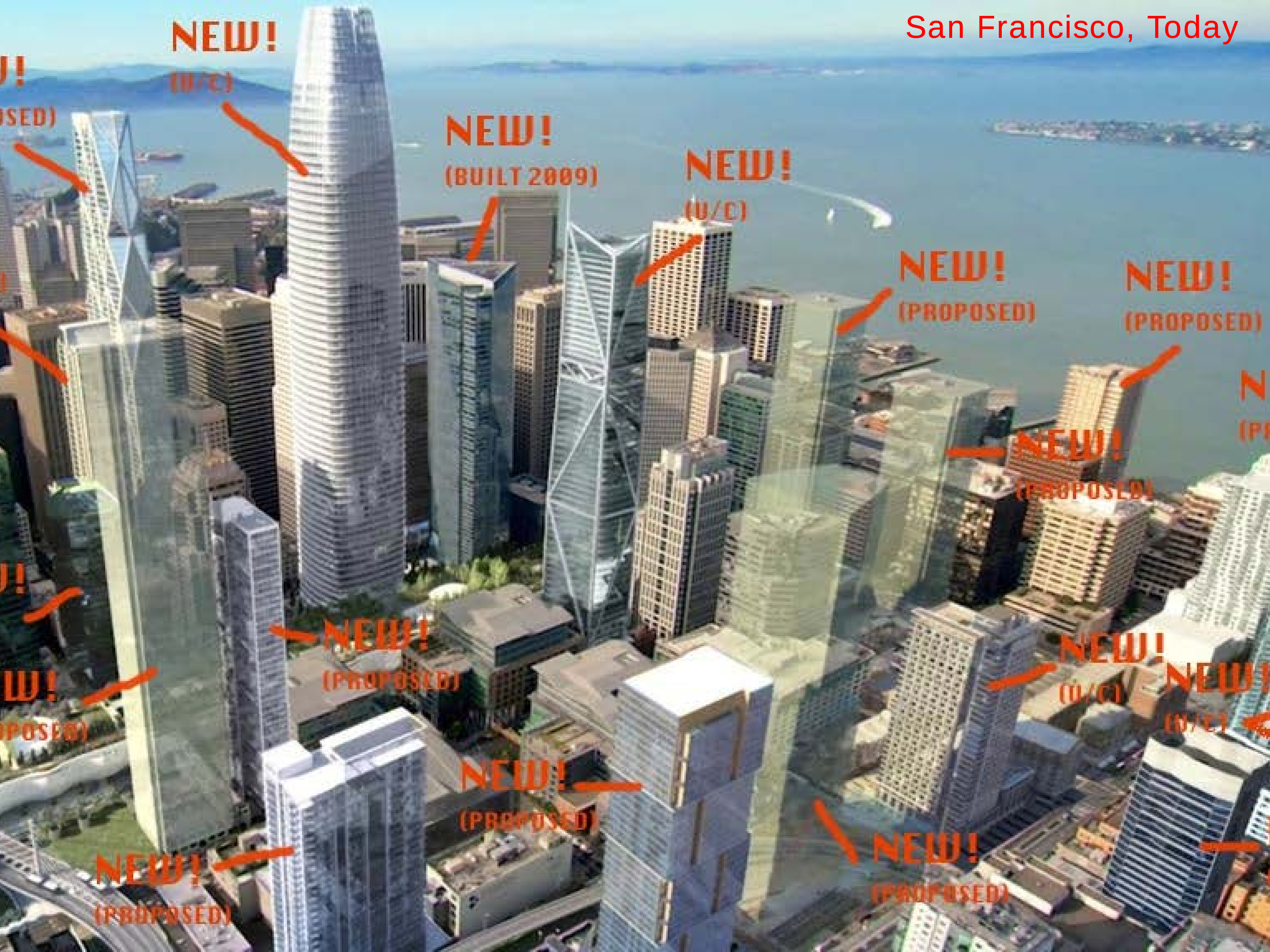
Progress in earthquake engineering

Driven by:

- Urbanization

San Francisco, 1960s


San Francisco, Today
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Progress in earthquake engineering

Driven by:

- Urbanization
- Architecture

Progress in earthquake engineering

Driven by:

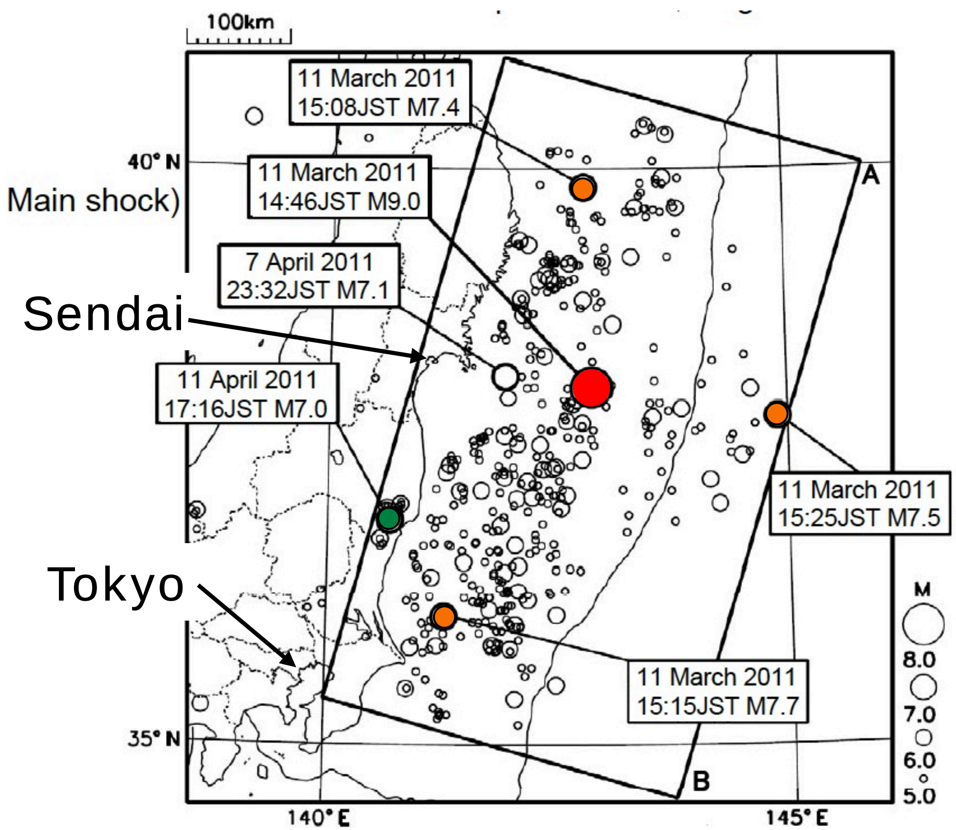
- Urbanization
- Architecture
- New Design Tools & Technology
- Economics
- Occupant, owner and public expectations
- Seismic events

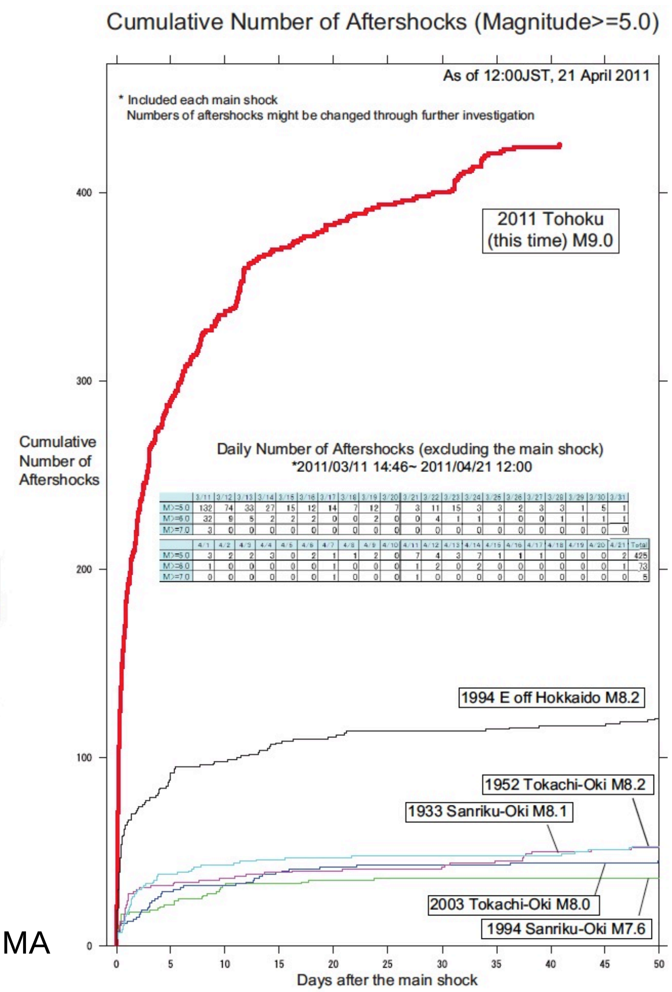
Seismic Events

Near fault ground motions provides an important and technically challenging focus

- What are characteristics of motions for design purposes?
- What are damaging (not dynamic) features of near-fault motions?
- What are effective and economical means for a structure to resist highly uncertain near-fault motions?
  - Large inelastic peak and residual drifts
  - Soft stories

Numerous Aftershocks: Cumulating/Repeated Damage





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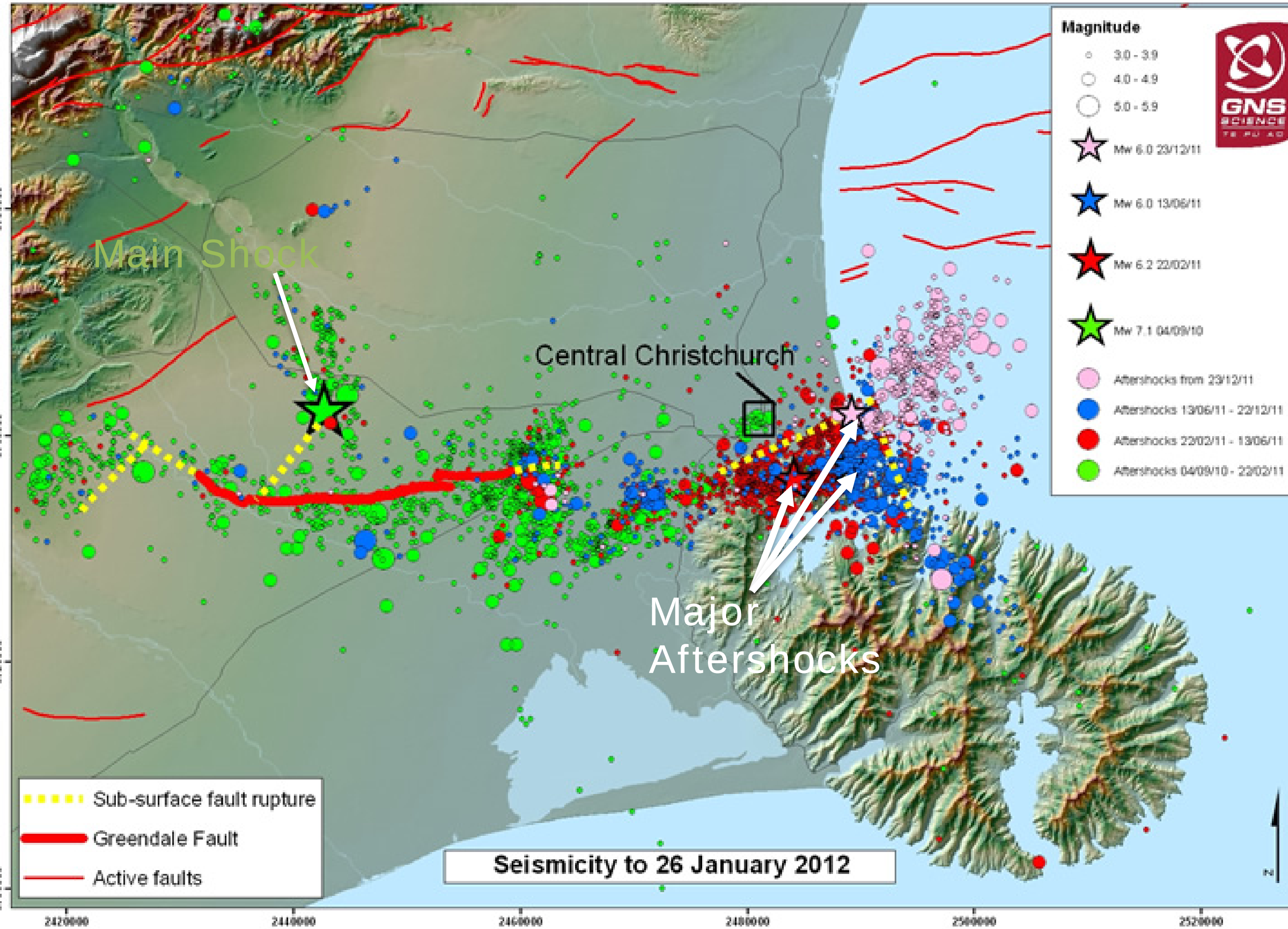
M>=5.0	132	74	33	27	15	12	14	7	12	7	3	11	15	3	3	2	3	3	1	5	1
M>=6.0	32	9	5	2	2	2	0	0	2	0	0	4	1	1	1	0	0	1	1	1	1
M>=7.0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

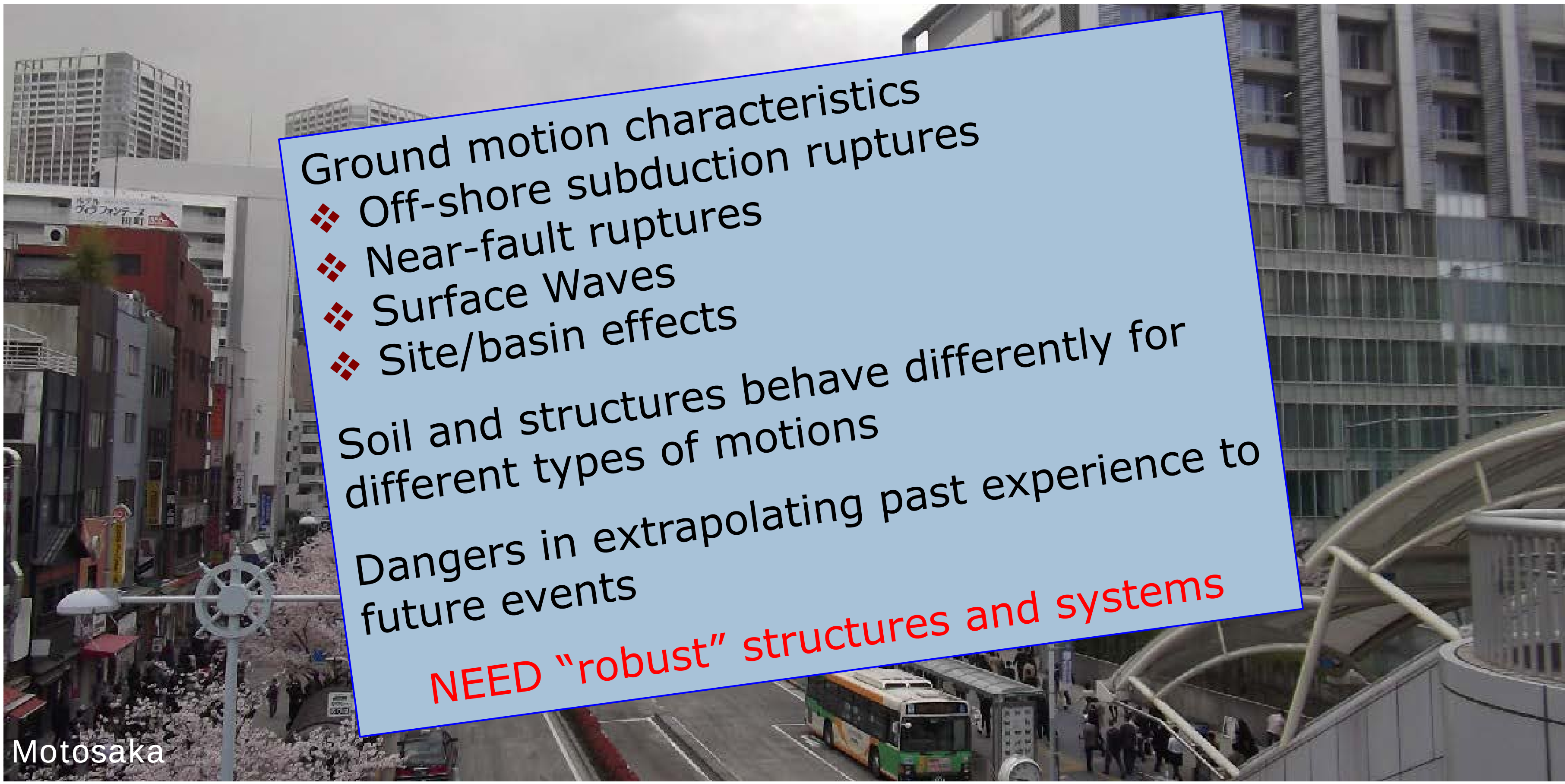
	4/1	4/2	4/3	4/4	4/5	4/6	4/7	4/8	4/9	4/10	4/11	4/12	4/13	4/14	4/15	4/16	4/17	4/18	4/19	4/20	4/21	Total
M>=5.0	3	2	2	3	0	2	1	1	2	0	7	4	3	7	1	1	1	0	0	0	2	425
M>=6.0	1	0	0	0	0	0	1	0	0	0	1	2	0	2	0	0	0	0	0	0	1	73
M>=7.0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	5

From: JMA

*Numerous Aftershocks: Number, Size and **PROXIMITY***



Observation: Earthquake Engineering Effective in Reducing Loss of Life



Ground motion characteristics
- Off-shore subduction ruptures
- Near-fault ruptures
- Surface Waves
- Site/basin effects

Soil and structures behave differently for different types of motions

Dangers in extrapolating past experience to future events

NEED “robust” structures and systems

Sendai, Japan

Structural damage due to ground shaking was relatively light for new structures even in regions of very heavy shaking

Engineering tools available to prevent widespread loss of life

1999 Kocaeli, Turkey, Earthquake

2008 Wenchuan, China, Earthquake

Achieving "Life Safety" remains a major issue for developing countries and other regions susceptible to large but low probability events

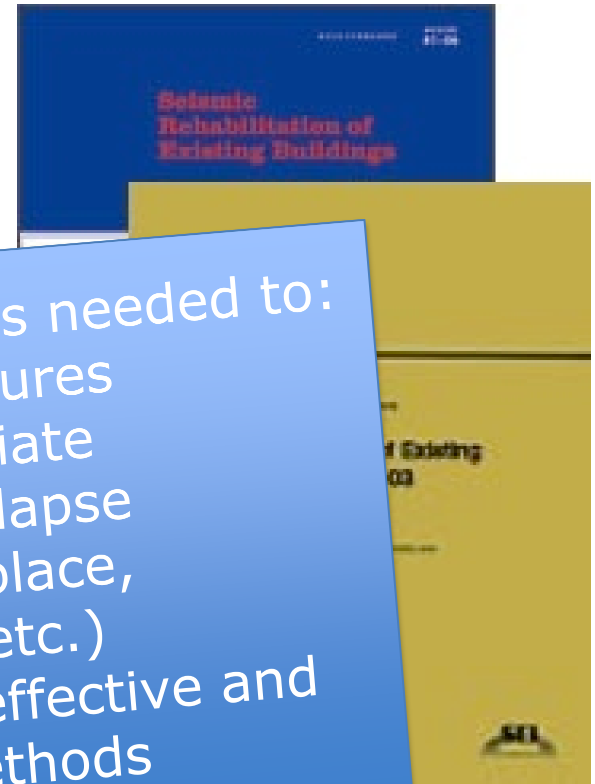
Policy - Enforcement - Low Cost Toughness - Education

Older buildings vulnerable (Sendai shown)

Older facilities remain vulnerable to earthquakes

Earthquake d
prompted nu
evaluation an

- Mandated fo
- At change i
  occupancy and major remodels
- Voluntary upgrades



Research-backed consensus standards exist and these are being continually improved by research

But much more research is needed to:

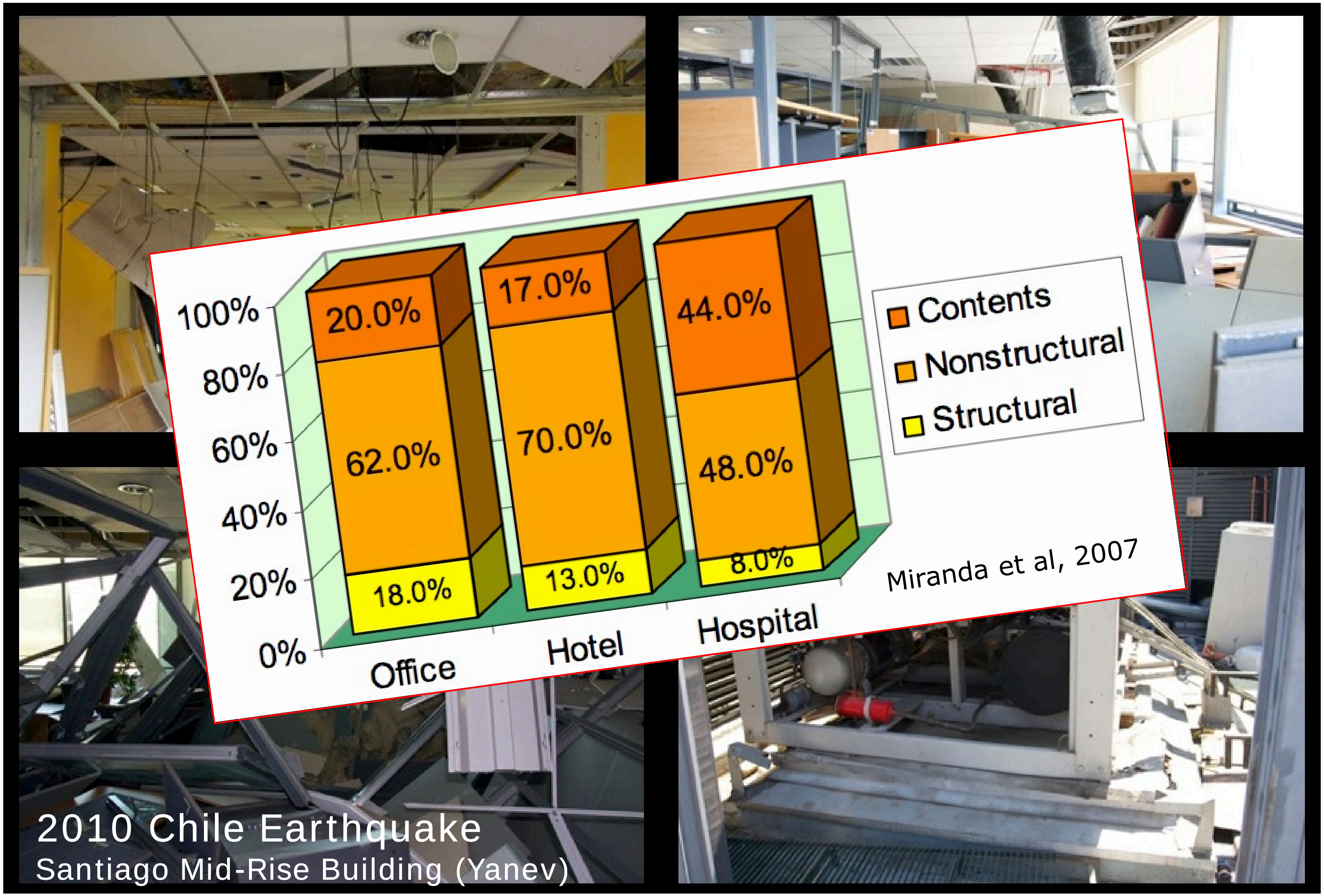
- Identify high risk structures
- Identify locally appropriate performance goals (collapse prevention, shelter in place, continued occupancy, etc.)
- Develop and validate effective and economical retrofit methods

How to repair a damaged structure?

- How safe is a damaged building?
- Does it need emergency repairs to make it safe for workers and adjacent property.
- What performance criteria should be used for permanent repairs?
  - Restore to pre-quake condition
  - Upgrade to current code?
  - Restore to other criterion?
- When to repair (immediately, later, etc.)?
- How effective are repair procedures?

WIDE SPREAD *damage due to soil liquefaction and permanent settlement*

Nonstructural Elements Pose Life Safety Concerns



Equipment protection

Will these topple if more realistic displacements imposed?

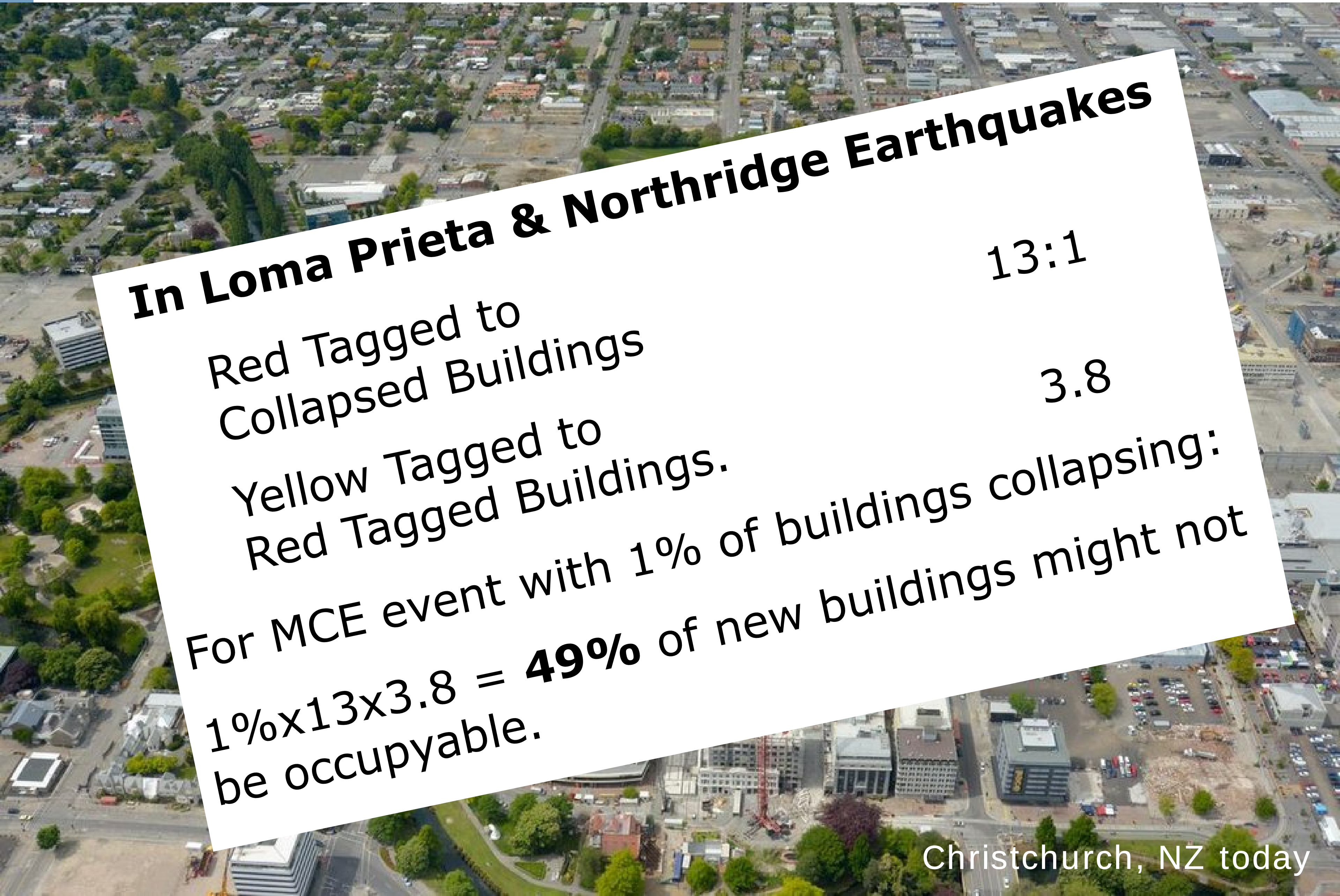
Disasters → Catastrophes

In Loma Prieta & Northridge Earthquakes

Red Tagged to Collapsed Buildings	13:1
Yellow Tagged to Red Tagged Buildings.	3.8

For MCE event with 1% of buildings collapsing:

1%x13x3.8 = **49%** of new buildings might not be occupyable.



Christchurch, NZ today

Disasters → Catastrophes

Resilient communities

Must provide citizens, organizations and businesses with facilities, infrastructure and services giving them the ability to "shelter in place" following a large earthquake and aftershocks

-- Without this, recovery will be slow --

Christchurch, NZ today

Next challenge for engineers: ***Earthquake-Resilient Structures***

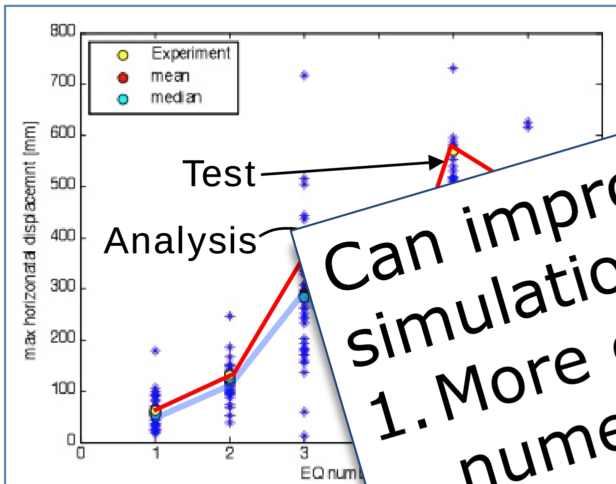
In *Earthquake Engineering*, our future challenge is to develop new or improved structures and infrastructure systems that:

- ✓ protect public safety, and are
- ✓ economical,

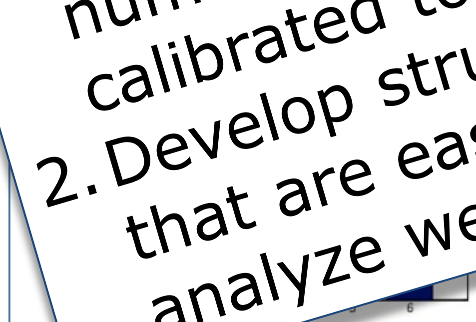
but that

- ✓ can be constructed quickly with minimal disruption to the public and to the environment, and
- ✓ **can withstand strong earthquake ground shaking (and other hazards) safely, with little disruption or cost associated with post-earthquake inspections and repairs.**

Can we trust simulation results?

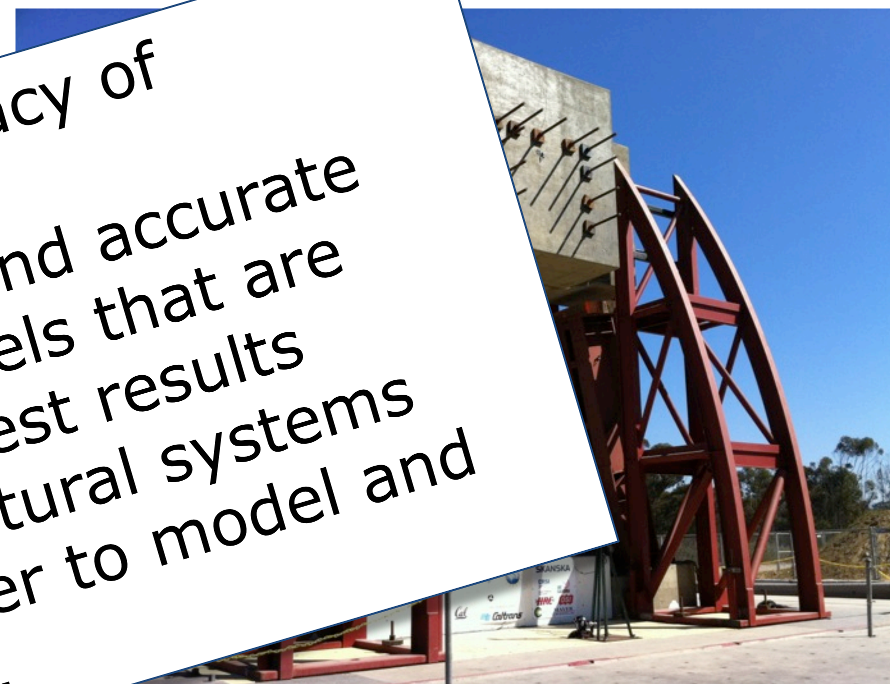


41 expert teams participated



Can improve accuracy of simulations:

1. More complex and accurate numerical models that are calibrated to test results
2. Develop structural systems that are easier to model and analyze well.



Full-scale 1D tests of circular column - Jose Restrepo, PI (PEER, Caltrans, UNR, FHWA, NEES@UCSD, NEEScomm & NSF)

PEER-NEES Blind Analysis Contest

(Terzic et al, PEER, 2015)

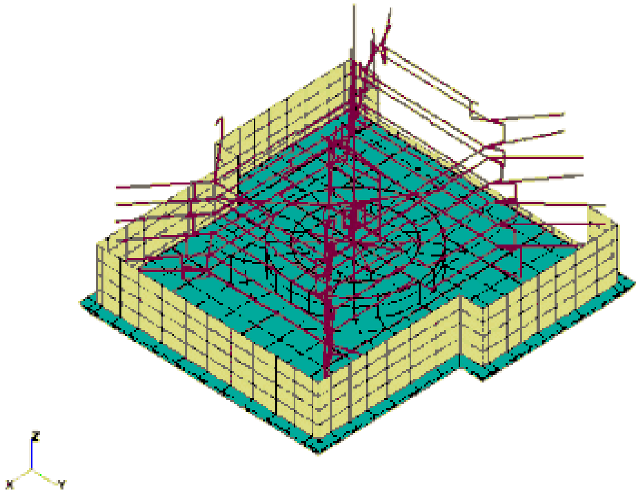
Common Characteristics of Disaster-Resilient Structures

- Earthquake resisting system that controls distribution of inelastic deformations
- Durable and/or easily replaceable energy dissipation regions/devices
- Easy and safe post-event inspection, including SHM
- Protect structural and nonstructural elements, and contents, by limiting
  - → Relative displacements
  - → Accelerations
- Self-centering mechanism to minimize permanent displacements.

Potential Opportunities at NCREE@Tainan

PEER/KEPCO/IAEA Hybrid Test of NPP

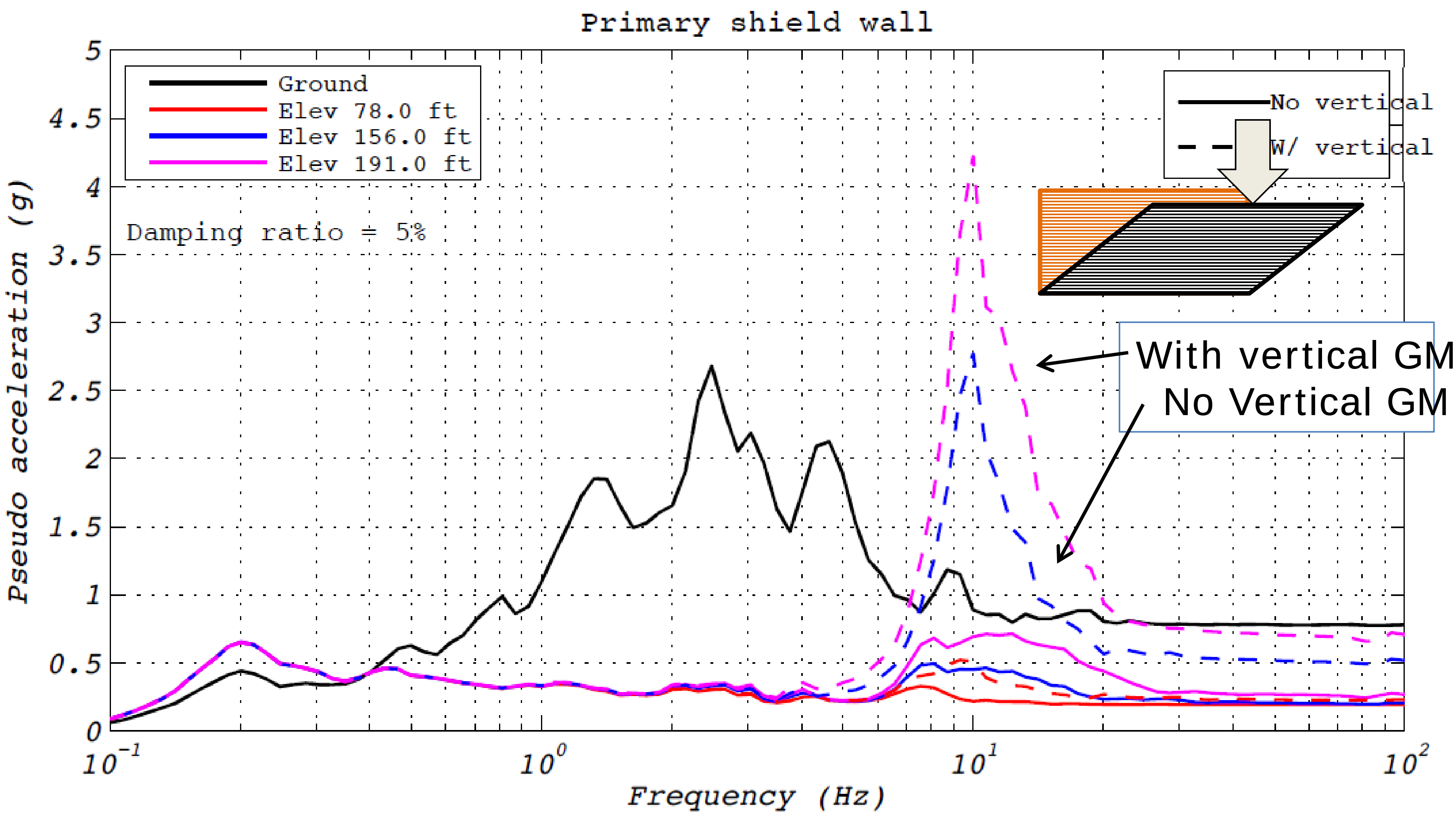
- Modified UCSD SRMD to carry out hybrid simulations of seismically isolated Nuclear Power Plant
- Relatively complex 3D model of superstructure
- Rock site (no soil modeled)
- Modelled isolators as various combinations of real and numerically simulated bearings



Near Real Time Hybrid Simulation Test

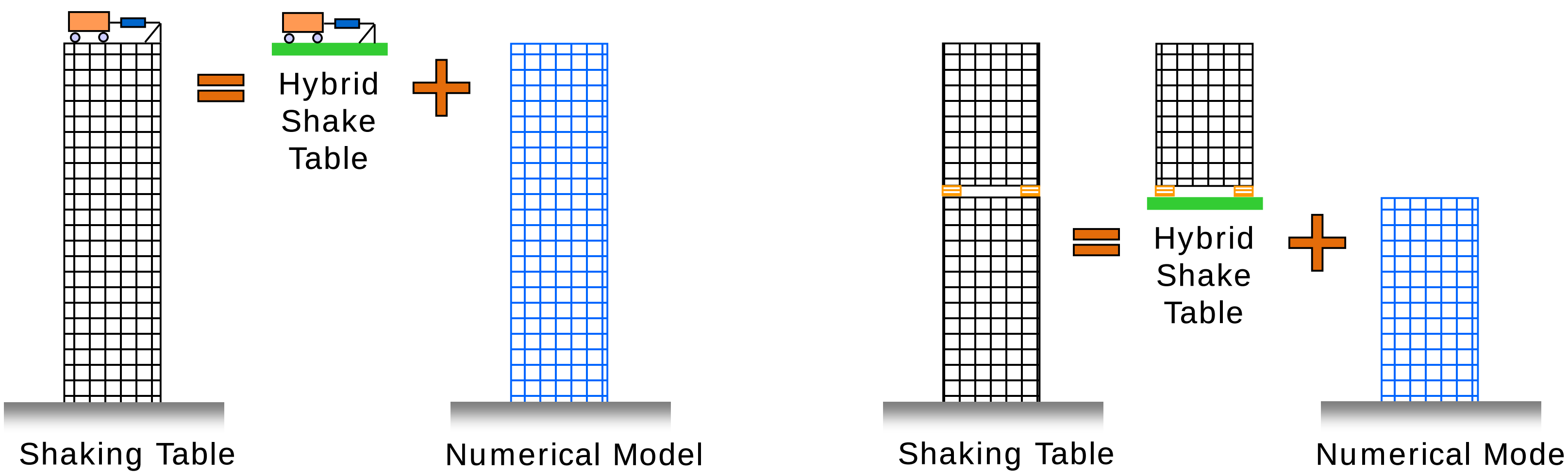
APR1400 model in OpenSees **SRMD at UC San Diego**

Floor spectra w/o & w/ vertical input



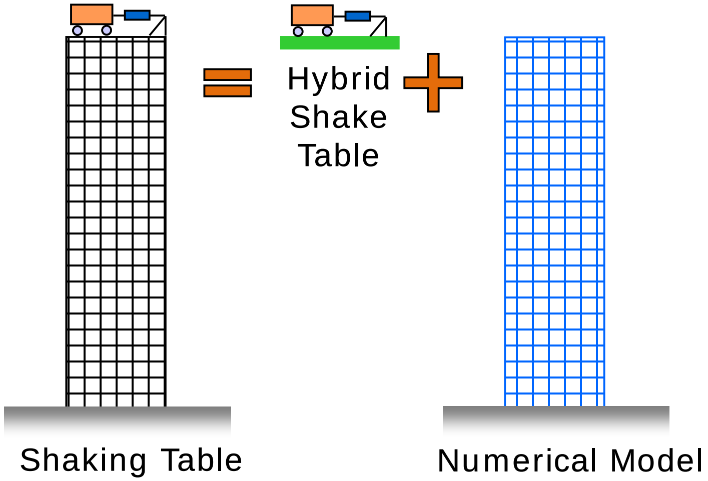
Another idea: Hybrid ("Smart") Shaking Tables

- Large systems such as tall buildings, bridges with variable column height & large Soil-Foundation-Structure Systems are difficult to test on shake tables

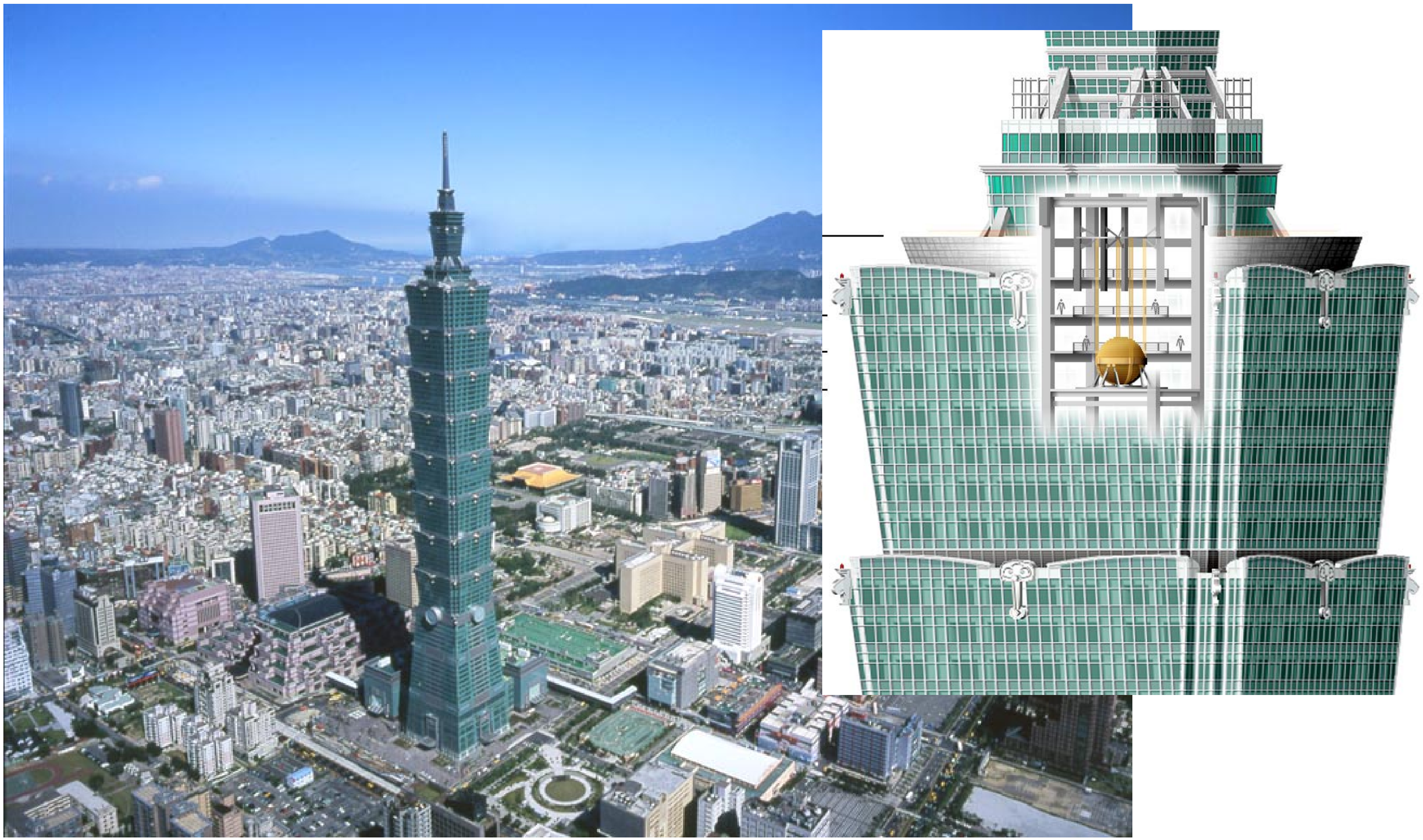


Shaking Table Implementations

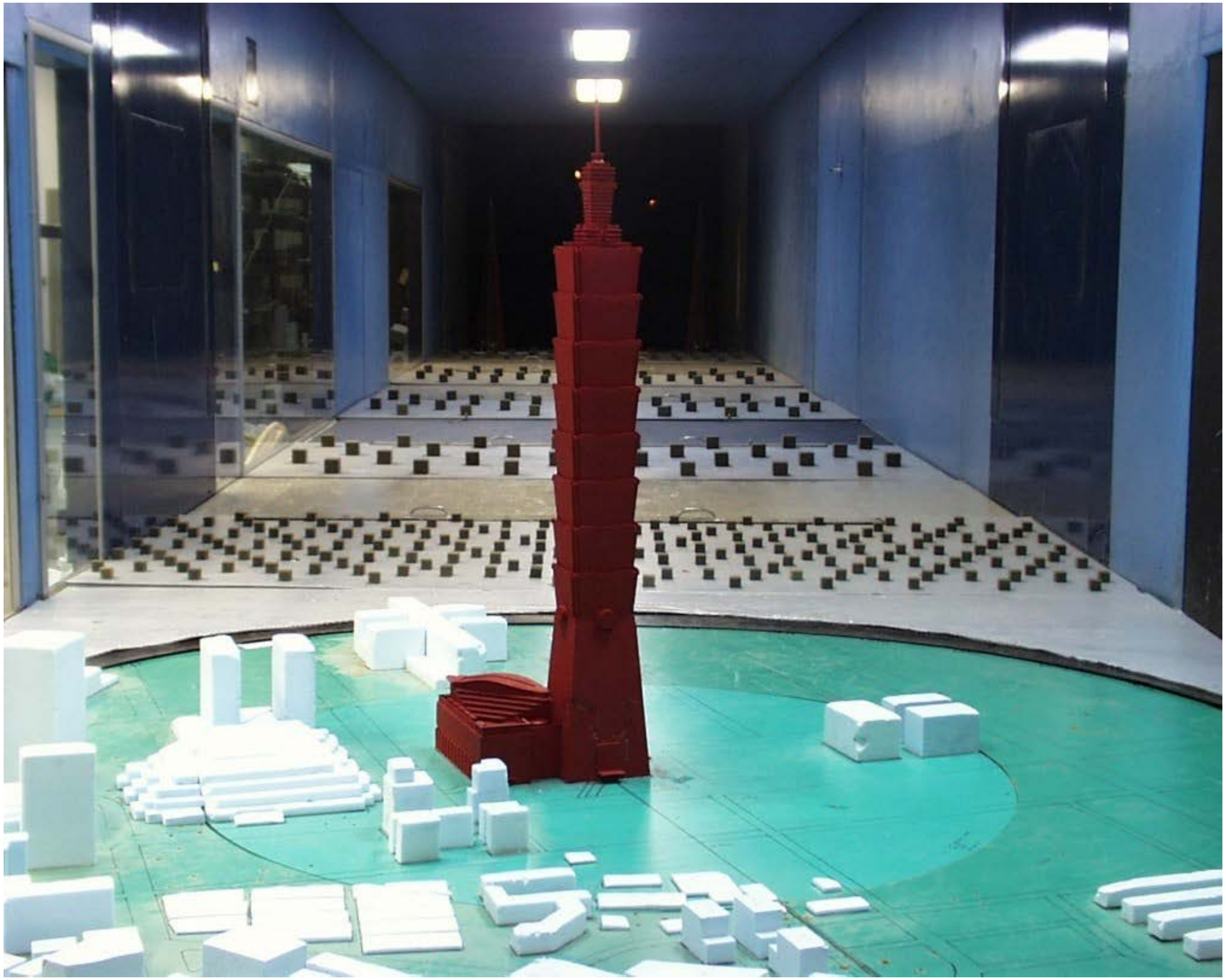
- UC Berkeley
  - Long stroke 1D table
  - 6 DOF table
- Tongji University
  - Four table array
- Implementation for:
  - Seismic excitations
  - Wind excitation (in progress)



Aerodynamic Loads + Structural HS

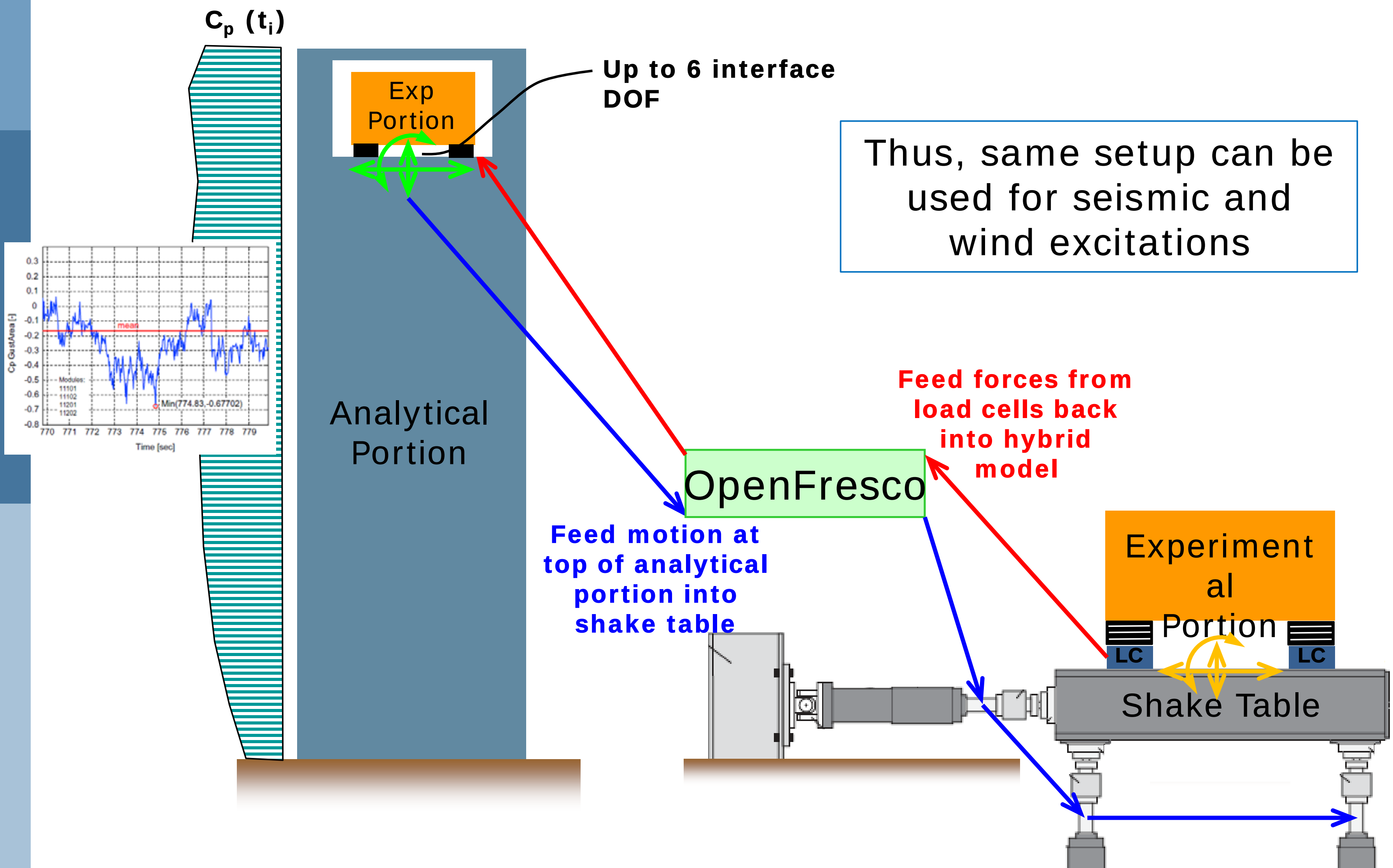


Aerodynamic Loads + Structural HS



Aerodynamic Loads + Structural HS

Thus, same setup can be used for seismic and wind excitations



Resilience: the next challenge in earthquake engineering

Earthquake engineering relates to managing seismic risk to "locally" acceptable levels.

Need:

- Reliable and cost effective methods for assessing and reducing vulnerability of the existing inventory of structures and lifeline systems
- Robust structures that are insensitive to structural and ground motion characteristics.
- Refined performance-based engineering methods:
  - To achieve with high confidence continuing functionality following significant earthquakes
  - Identify reliable and low cost methods to prevent collapse under exceptionally rare seismic events.
- Resilient lifelines and service networks.
- Accurate simulation methods and models