THE PIVOTAL ROLE OF INSTRUMENTATION IN ACHEIVING A SUSTAINABLE INFRASTRUCTURE

A Structural Engineer's Perspective

2022 UCI CEE Affiliates Meeting

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What is the problem?

- Achieving a sustainable infrastructure in USA is an important and noble objective.
- Most, if not all, of the efforts so far though are concentrated on analysis and design techniques and methodologies.
- But how would you ever know if you have achieved a sustainable building or not?
  - Not days, weeks or months after a disaster, but immediately?

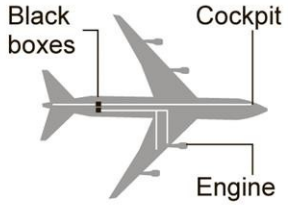
What is the solution?

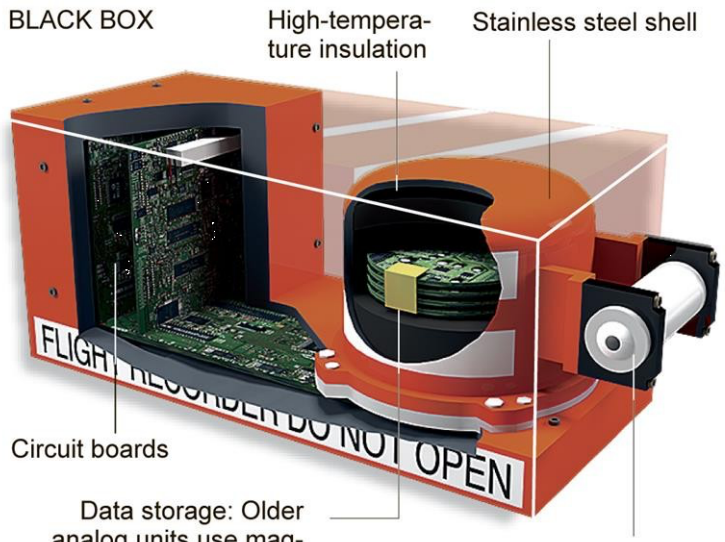
1. Use existing instrumentation
2. Instrument more structures
3. Move from instrumentation to health monitoring
4. Realize what Talhan Biro calls “Black Box for Structures

Talhan Biro's Concept of Building Black Boxes

Flight's memory stored in 'Black boxes'

Commercial aircraft are required to carry two data recorders. One records all radio transmissions and sounds in the cockpit and the other monitors parameters of the flight such as airspeed and altitude – all vital in reconstructing an accident.

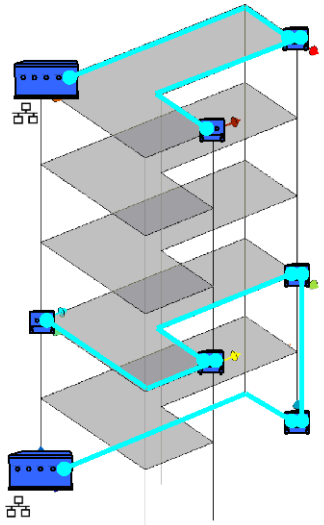




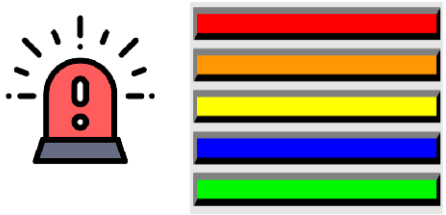
SOURCE: National Transportation Safety Board AP

Talhan Biro – GeoSIG Ltd – Blackbox concept can help promote widespread use of S2HM
Roadblocks and Incentives for Worldwide Adaptation and Implementation of Seismic Structural Health Monitoring (S2HM)

S2HM in a box: blackbox for structures



S2HM in a box



Factual data + Proven methods

After an event + Continuously

S2HM = Structural Seismic Health Monitoring

From: Biro, T. (2021), *Blackbox concept can help promote widespread use of S2HM*, Proceedings of 17WCEE, Sendai, Japan, October.

Cars + Accidents

Performance Target: **Life Safety**
Design: Nonlinear Analysis with performance target
Testing: Full scale Protype testing
Risk: **Unrepairable Car**
Solution/Timeline: **Replacement, days**
Funding source: **Insurance (+ Owner)**
Societal & Economic Impact: **a few people, $k**

Structures + Earthquakes

Performance Target: **Life Safety**
Design: Linear Analysis with performance aspirations
Testing: Generalized component testing
Risk: **Unusable Building and/or Infrastructure**
Solution/Timeline: **Costly Repair/Replacement , years**
Funding source: **Owner (+ some $s from insurance)**
Societal & Economic Impact: **thousands of people, $B**

Risk: Same performance target/aspiration, but vastly different Societal & Economic Impact

Cars + Accidents

Performance Target: Life Safety
Design: Nonlinear Analysis with performance target
Testing: Full scale Protype testing
Risk: Unrepairable Car
Solution/Timeline: Replacement, days
Funding source: Insurance (+ Owner)
Societal & Economic Impact: a few people, $k

Structures + Earthquakes

Performance Target: Life Safety
Design: Linear Analysis with performance aspirations
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Risk: Unusable Building and/or Infrastructure
Solution/Timeline: Costly Repair/Replacement , years
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Societal & Economic Impact: thousands of people, $B

Different Design Approach (MRI vs Xray) : Majority of Building Designs are based on linear-analyses, not driven by specific performance targets

Structural integrity and sustainability are not the same!

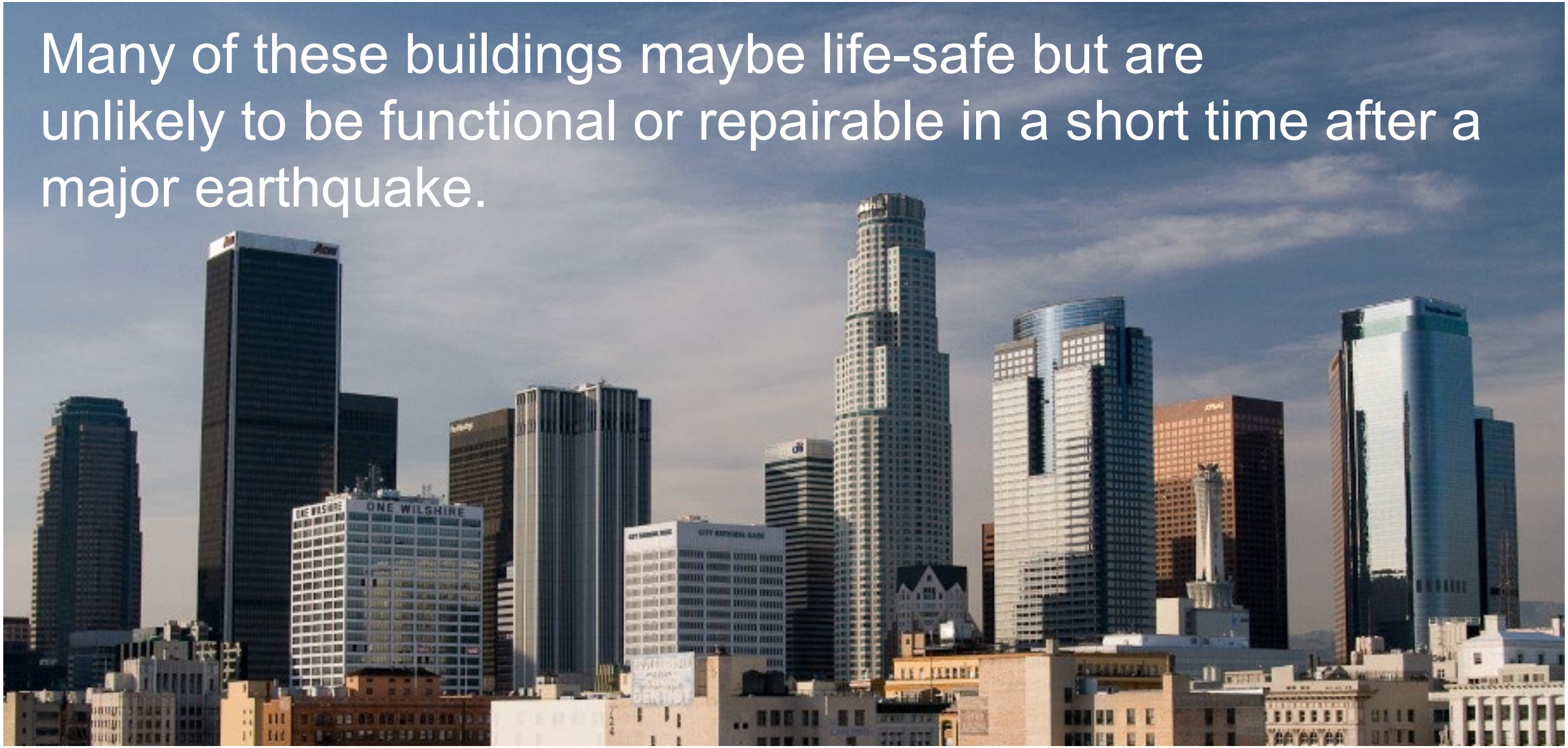

(Miranda, Kazantzi and Vamvatsikos, 2018)

Severe nonstructural damage at the International Airport in Santiago as a result of the 2010 Maule, Chile earthquake.

Structural integrity and sustainability are not the same!

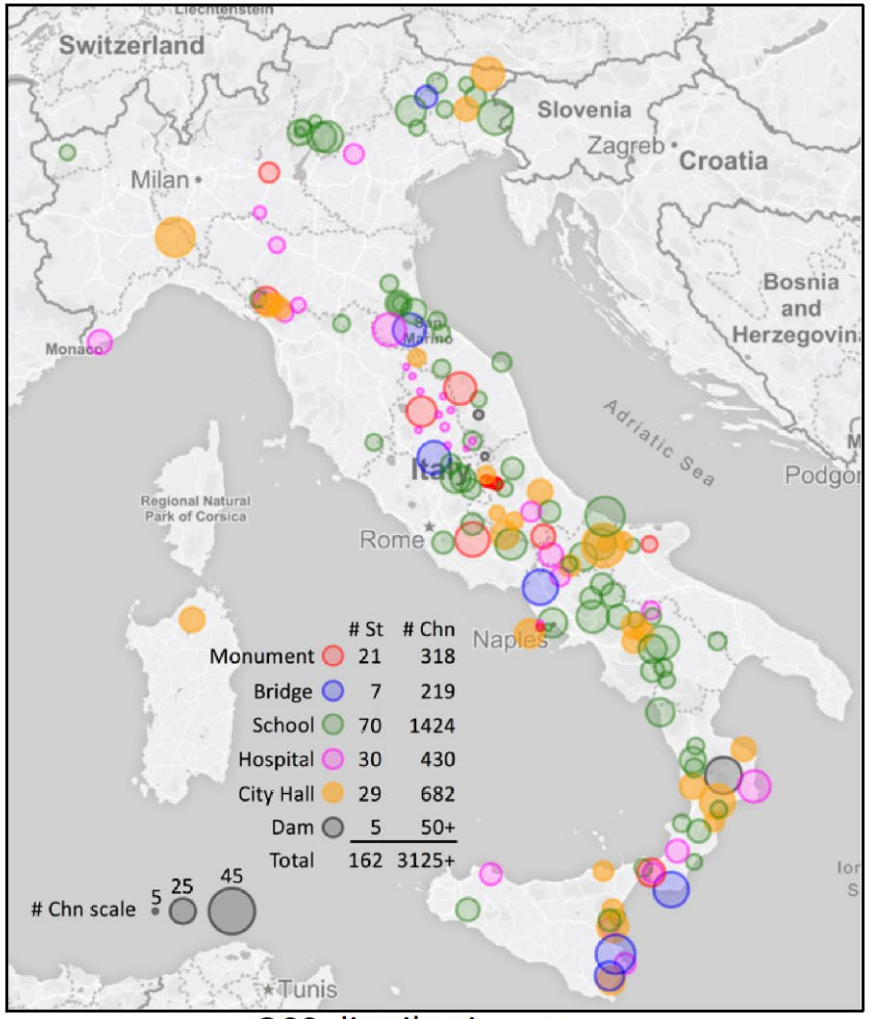
Severe nonstructural damage of the commercial building as a result of the 2011 Christchurch, New Zealand earthquake

Los Angeles Skyline



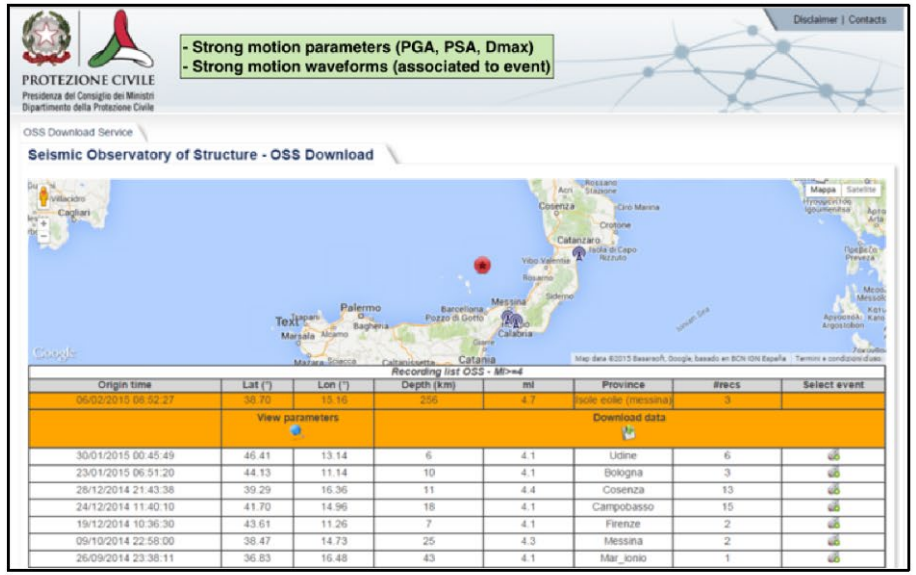
Many of these buildings maybe life-safe but are unlikely to be functional or repairable in a short time after a major earthquake.

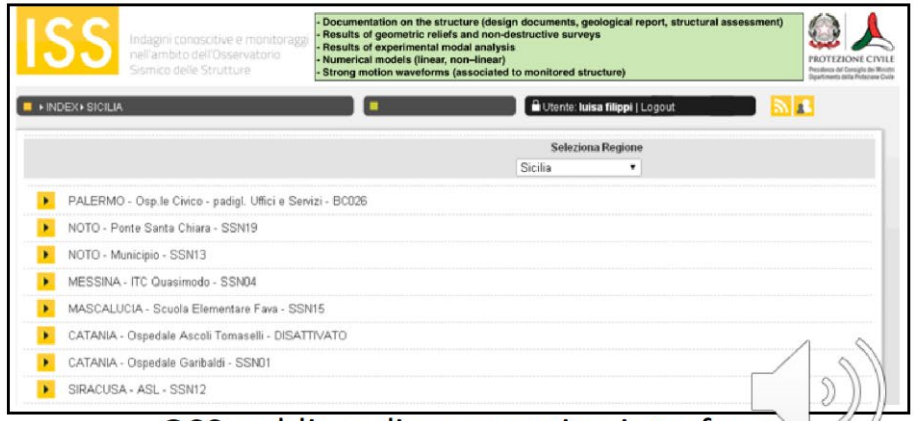
Europe Implementation of S2HM



OSS distribution map

European Experience - Italy

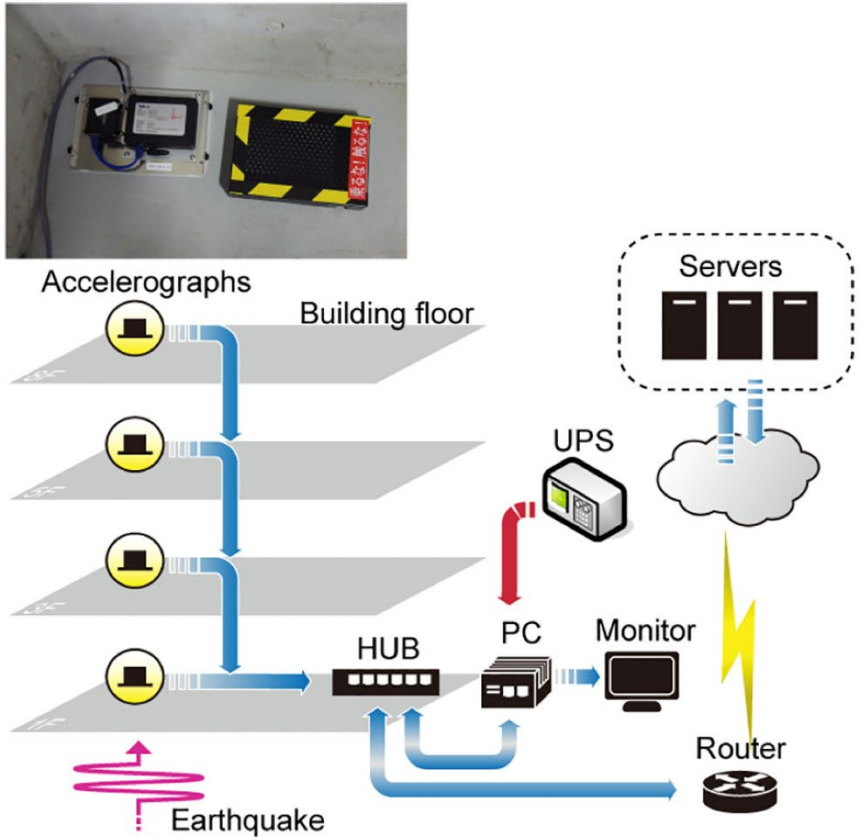


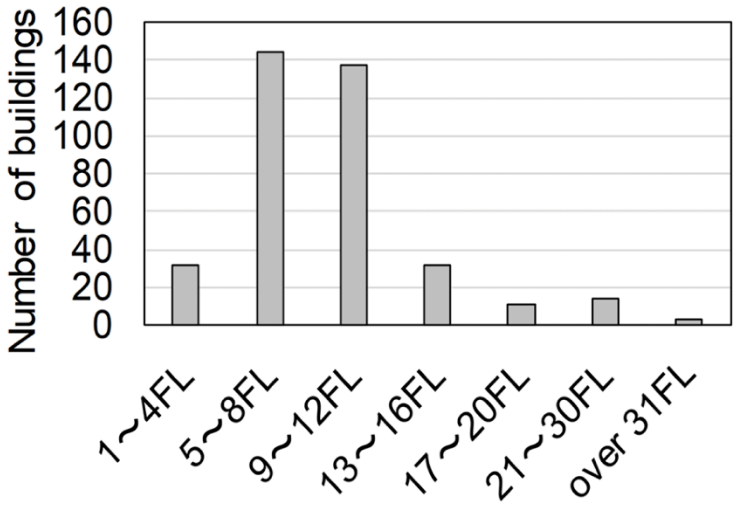


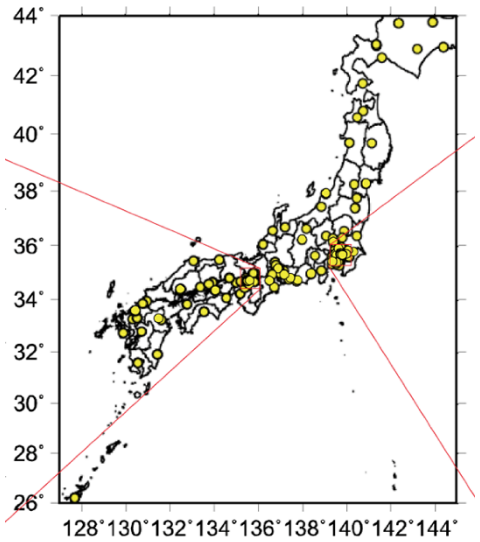
OSS public online reporting interfaces

From: Biro, T. (2021), *Blackbox concept can help promote widespread use of S2HM*, Proceedings of 17WCEE, Sendai, Japan, October.

Q-NAVI Installations in Japan







From: Kanda, K., Nakashima, M., Susuki, Y., and Ogasawara, S. (2021), *"q-NAVI": A case of market based implementation of structural health monitoring in Japan*, Earthquake Spectra, Vol. 37(1) 160–179, DOI: 10.1177/8755293020935884

California Seismic Network

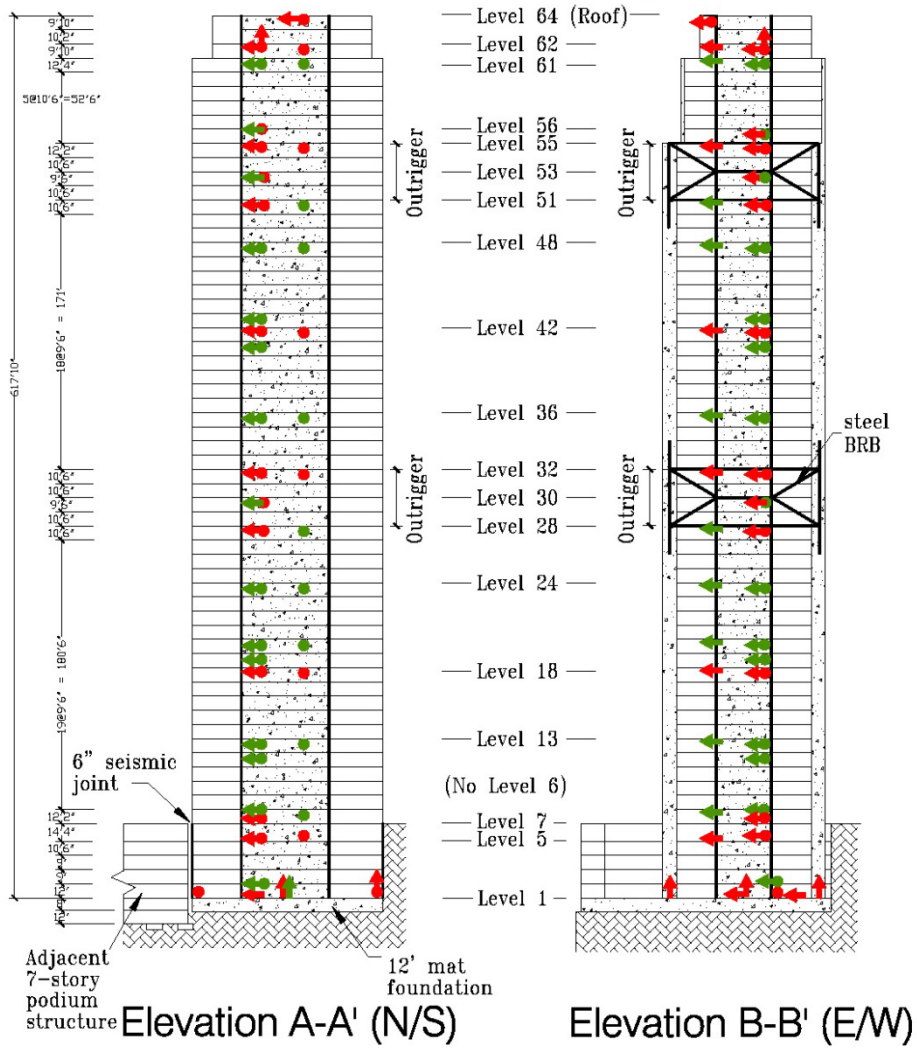
- California Strong Motion Instrumentation Program (CSMIP) contains data for 300+ extensively instrumented buildings
- All buildings are connected to a central server via Internet
- The data is automatically processed and sent to the server immediately following any triggering earthquake.
- This data is available at https://www.cesmd.org
- Individual owners can enter into an agreement with CSMIP to monitor their instrumented buildings and publish the data on the CSMIP server.
- USGS has a number of even more extensively instrumented buildings

San Francisco - 62-story Residential Bldg

(CSMIP Station No. 58389)
(NSMP Station No. 8389)

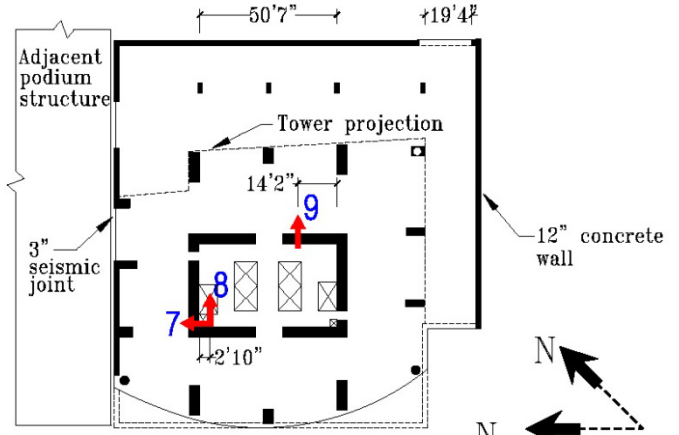
CSMIP Sensors (1–36)
NSMP Sensors (37–72)

SENSOR LOCATIONS



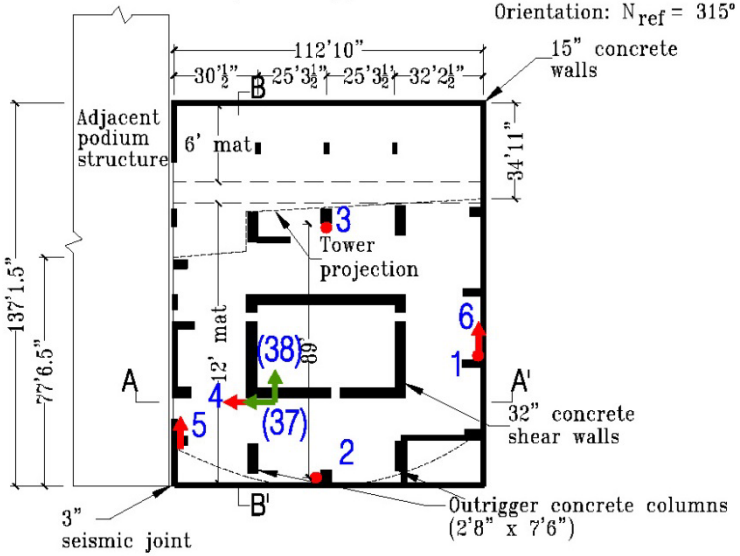
Elevation A-A' (N/S)

Elevation B-B' (E/W)



Level 5 (Lobby) Plan

Structure Reference Orientation: N_{ref} = 315°



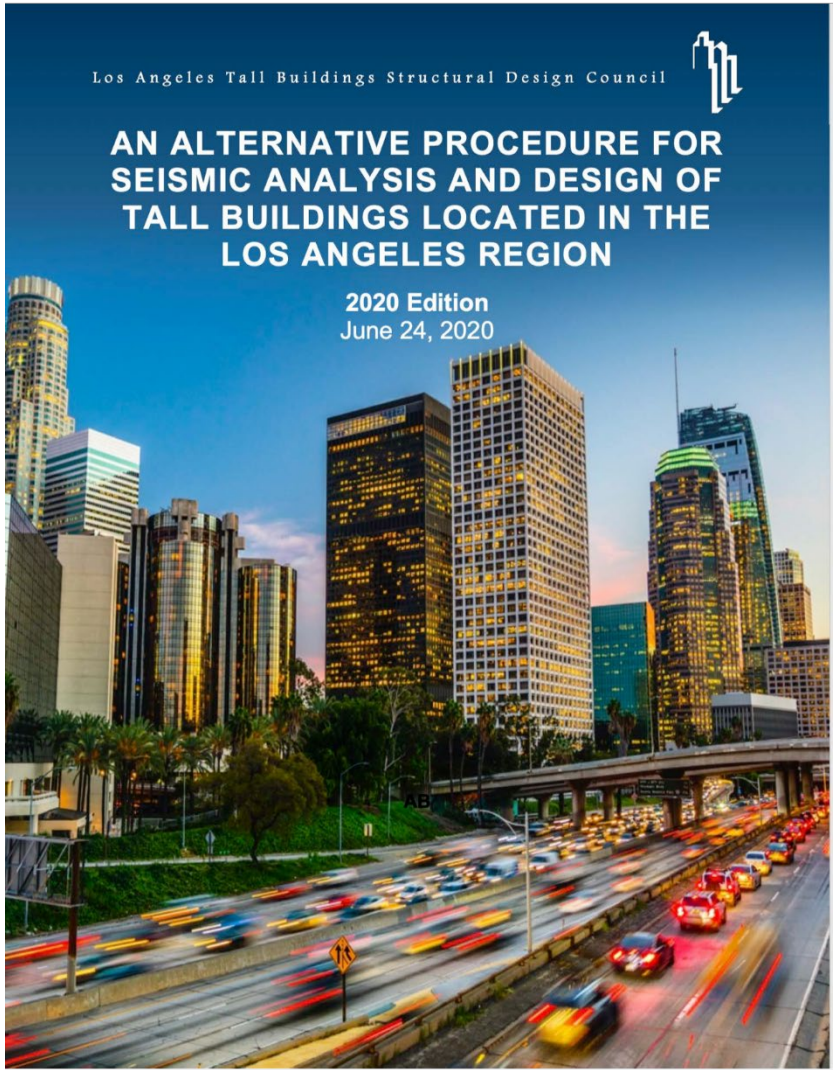
Level 1 (P4) Plan

(37) (38) = Level 2

Installed: 5/18/2012
Diagram: 7/11/2013 rev.

Courtesy of John Hooper

2020 LATBSDC Provisions



https://www.latallbuildings.org/documents

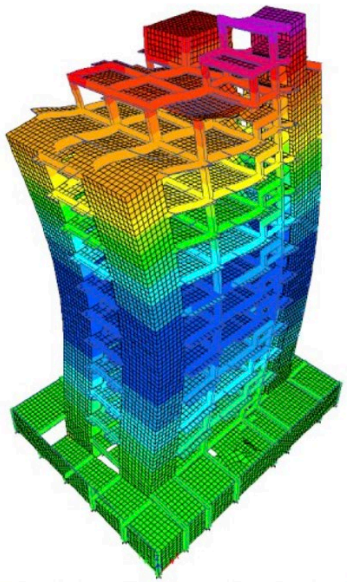
Table 8. Minimum Number of Channels of Instrumentation

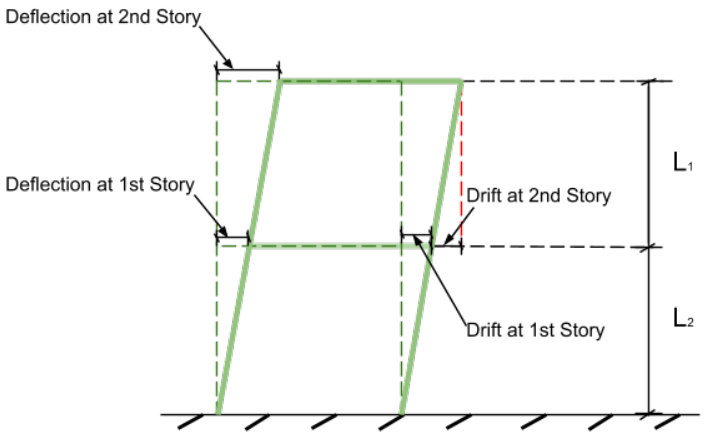
Number of Stories Above Ground	Minimum Number of Channels
6-10	12
11 – 20	15
21 – 30	21
31 – 50	24
> 50	30

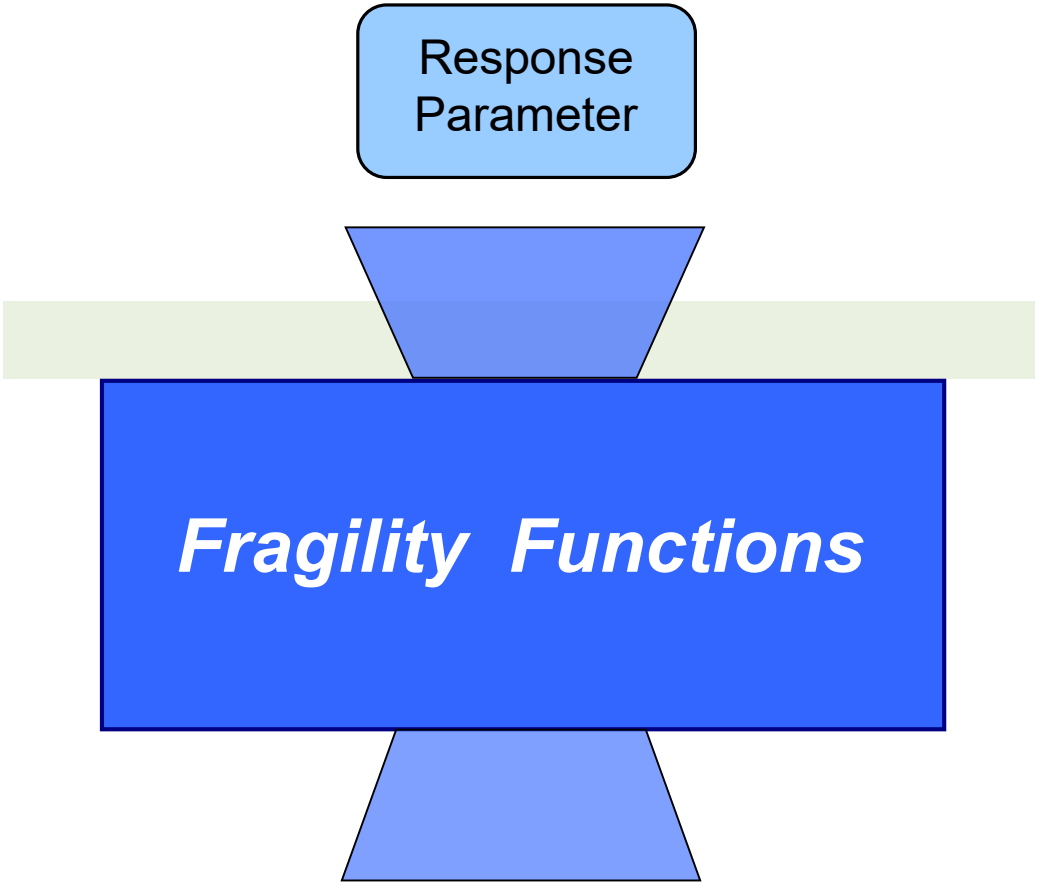
- Please note that for reliable real-time structural health monitoring and performance evaluations a substantially larger number of channels may be necessary (Naeim 2011).
- The sensors shall be connected by dedicated cabling to one or more central recorders, interconnected for common time and triggering.
- At least three uniaxial horizontal accelerometers on each chosen floor.

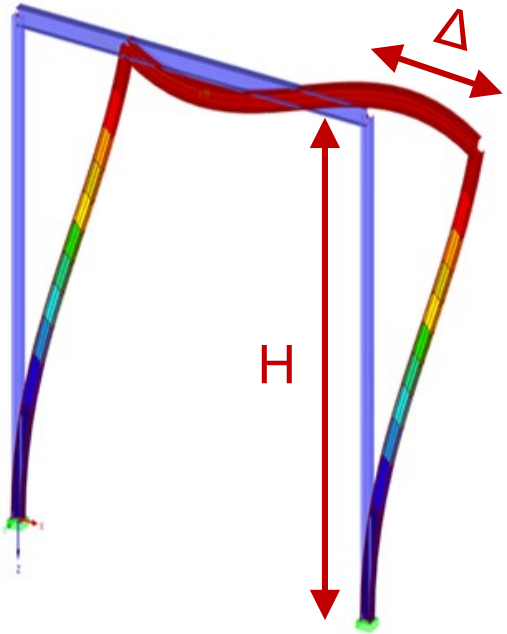
EXAMPLES OF UTILITY

Use of Fragility Functions









IDR = Δ / H

Animation courtesy of Prof. Eduardo Miranda

Example of a structural fragility function

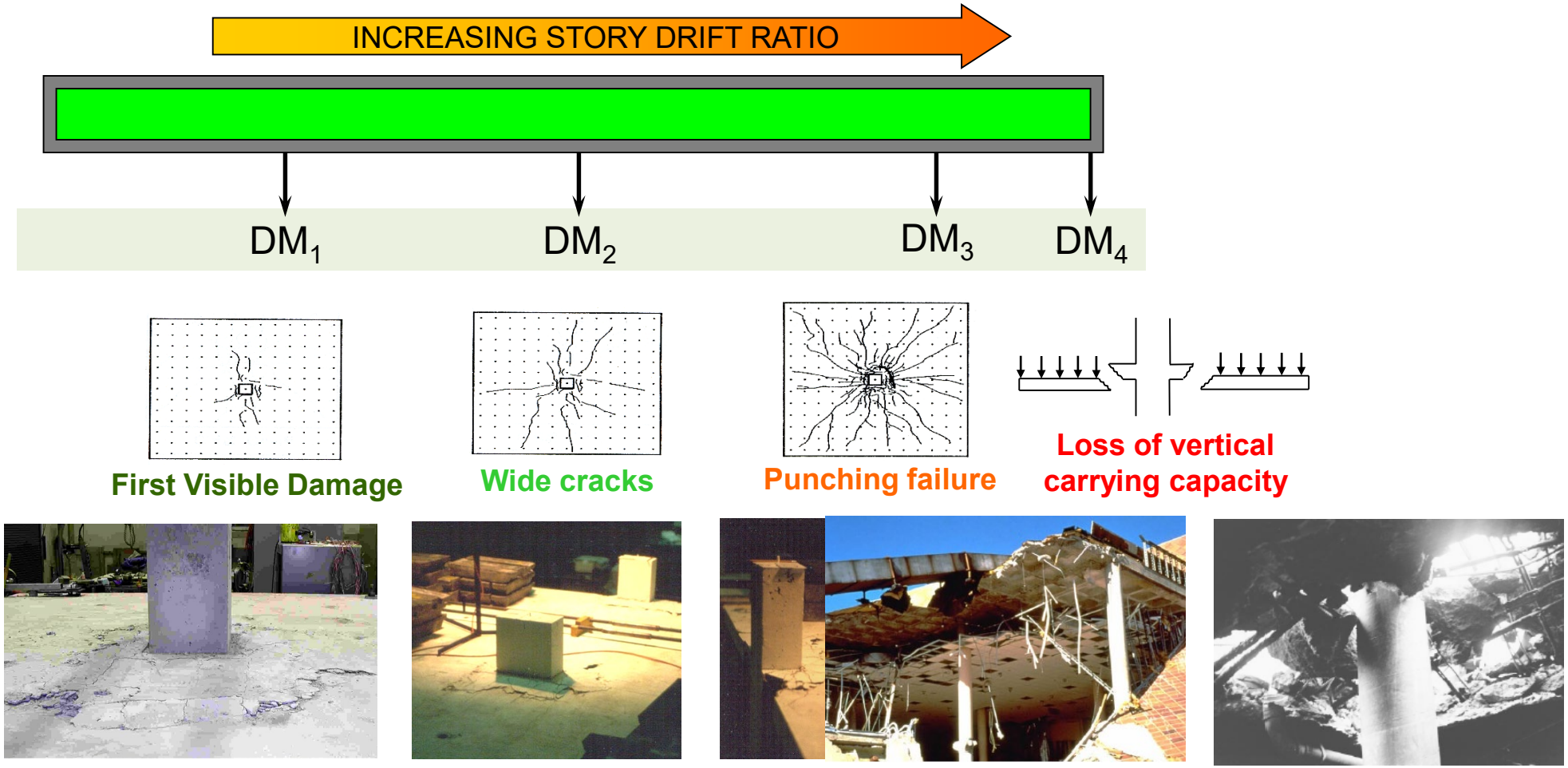
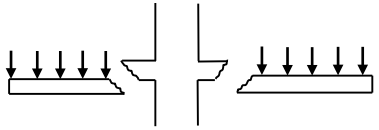


Illustration courtesy of Prof. Eduardo Miranda

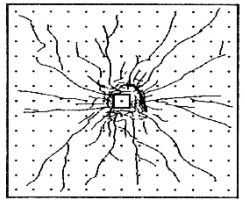
Example of a structural fragility function

(4)



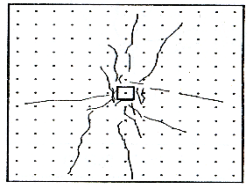
Loss of vertical carrying capacity

(3)



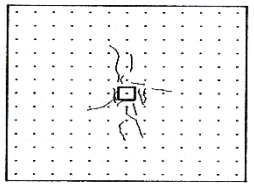
Punching failure

(2)

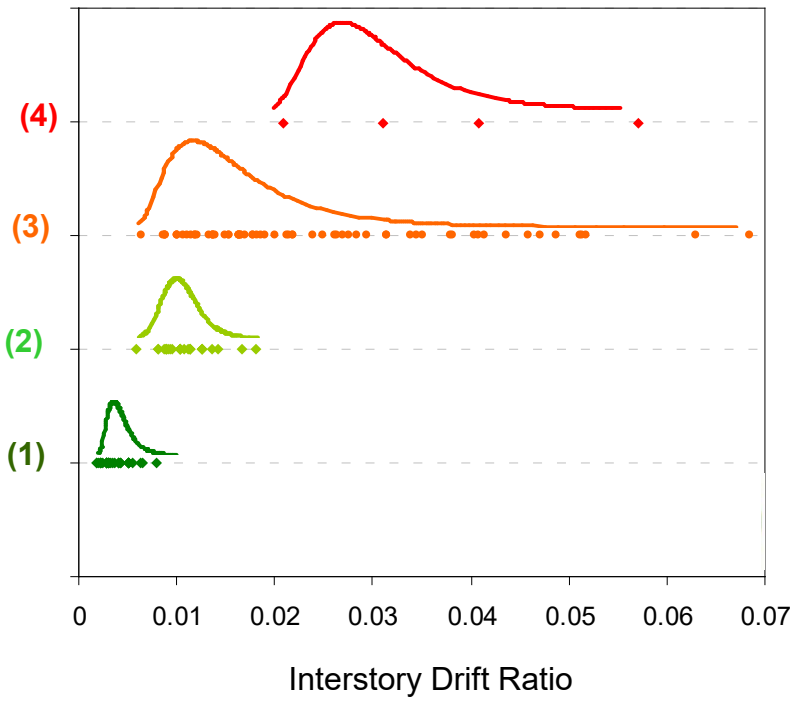


Wide cracks

(1)



First Visible Damage



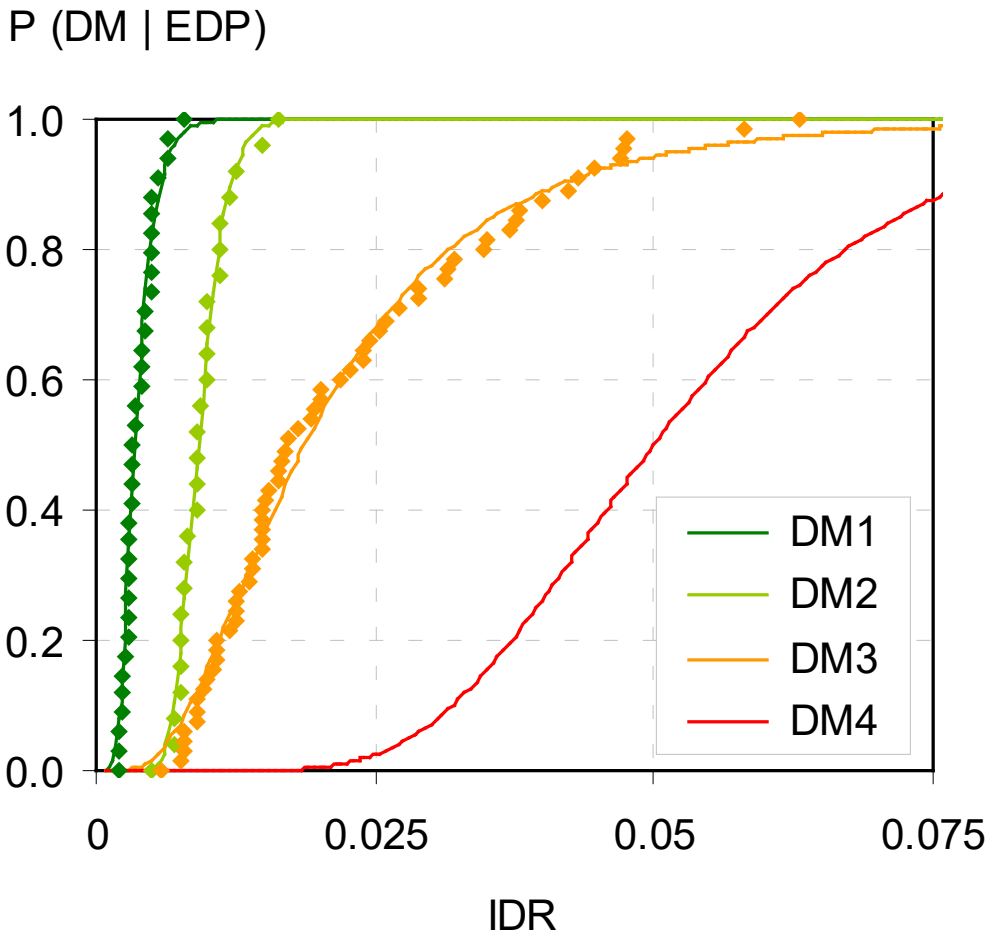
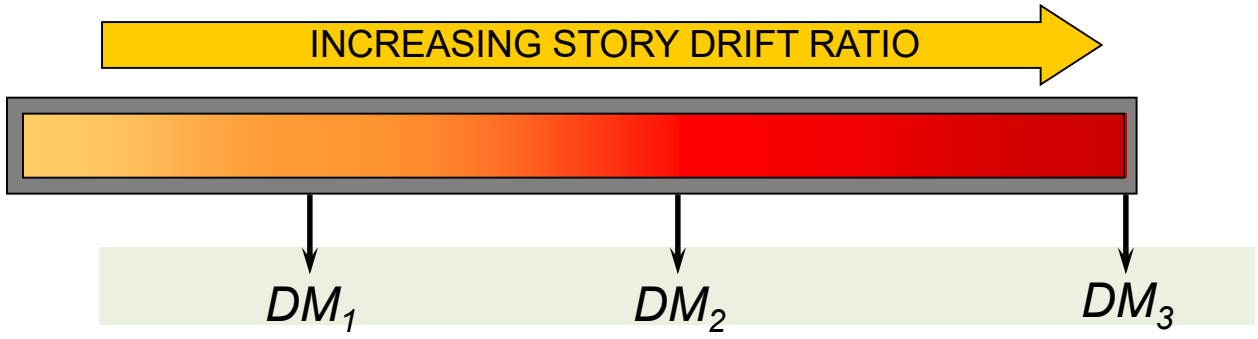
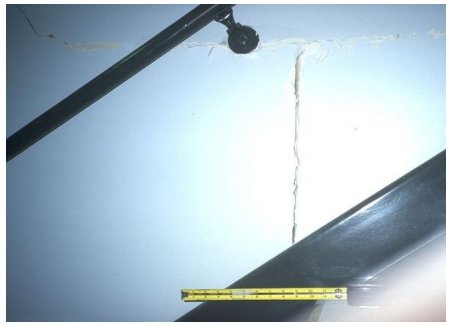


Illustration courtesy of Prof. Eduardo Miranda

Example of a nonstructural fragility function



Light cracking



Damage to panels

Damage to panels and frames

Illustration courtesy of Prof. Eduardo Miranda

Example of a nonstructural fragility function

Specimen Name	DS_1	DS_2	DS_3
S1	0.0013	0.0025	0.0056
S2	0.0013	0.0026	0.0068
S3	0.0013	0.0026	0.0070
S4	0.0013	0.0026	0.0075
S5	0.0013	0.0037	0.0079
S6	0.0014	0.0042	0.0081
S7	0.0017	0.0042	0.0094
S8	0.0017	0.0046	0.0102
S9	0.0019	0.0052	0.0113
S10	0.0020	0.0052	0.0115
S11	0.0021	0.0052	0.0115
S12	0.0021	0.0052	0.0188

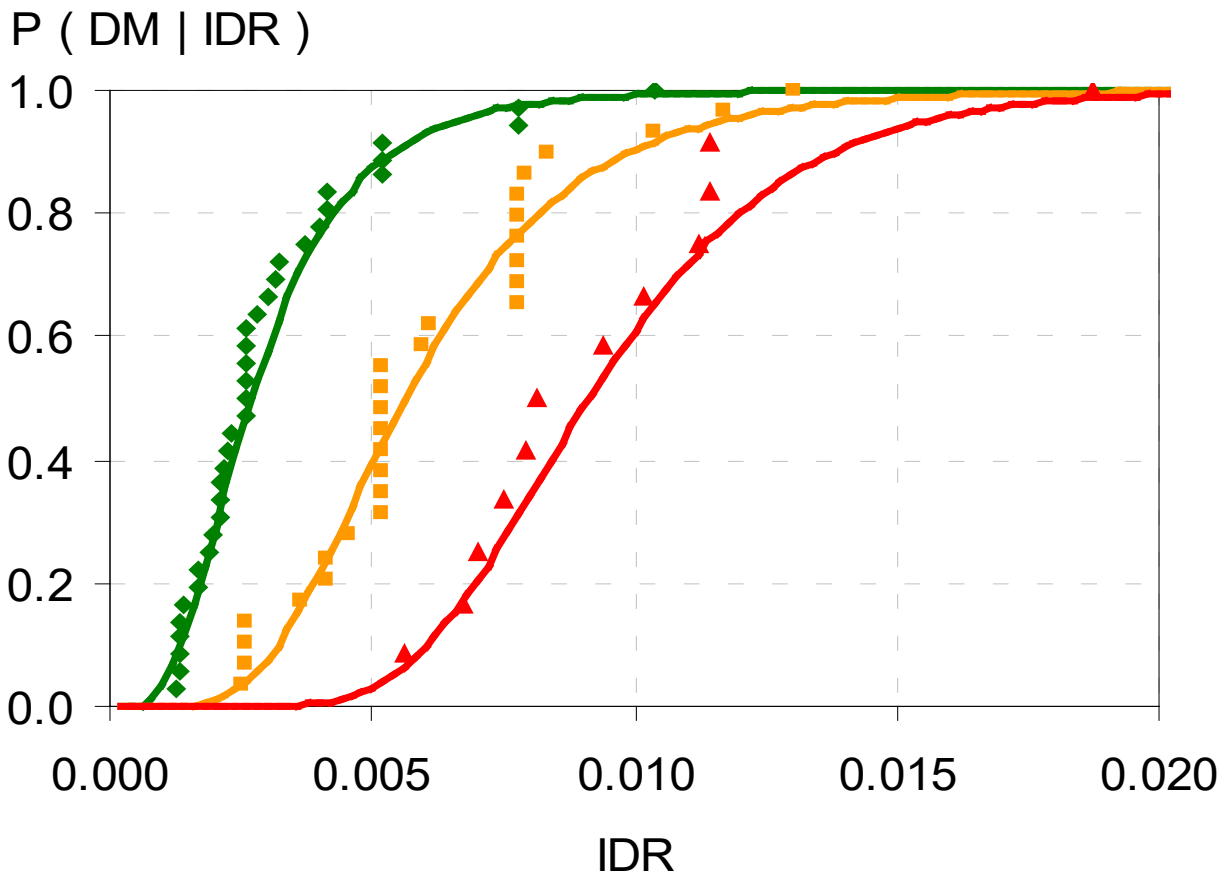


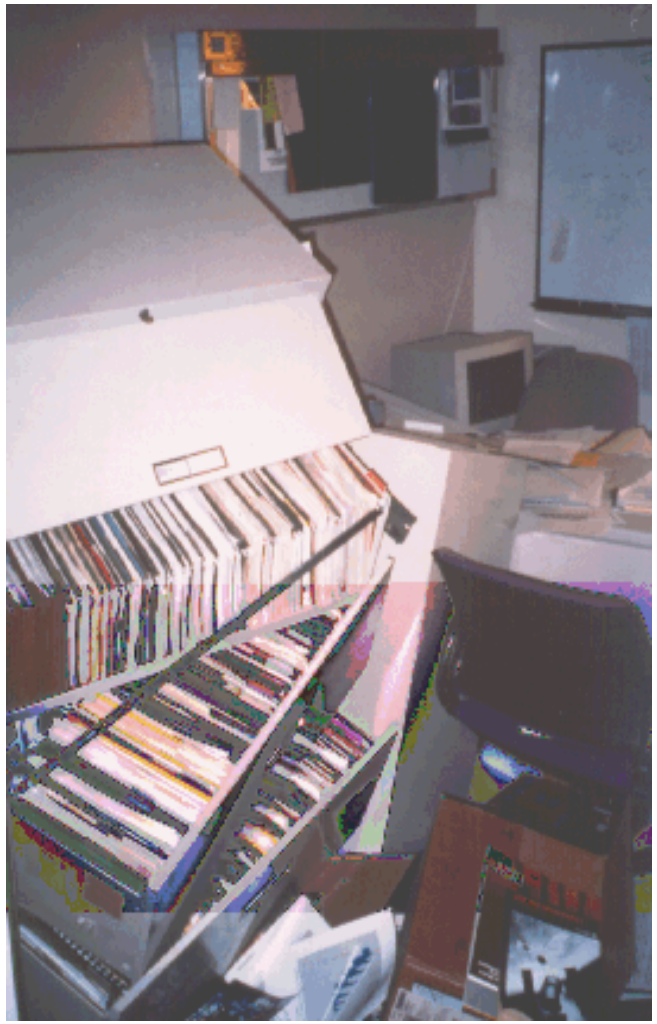
Illustration courtesy of Prof. Eduardo Miranda

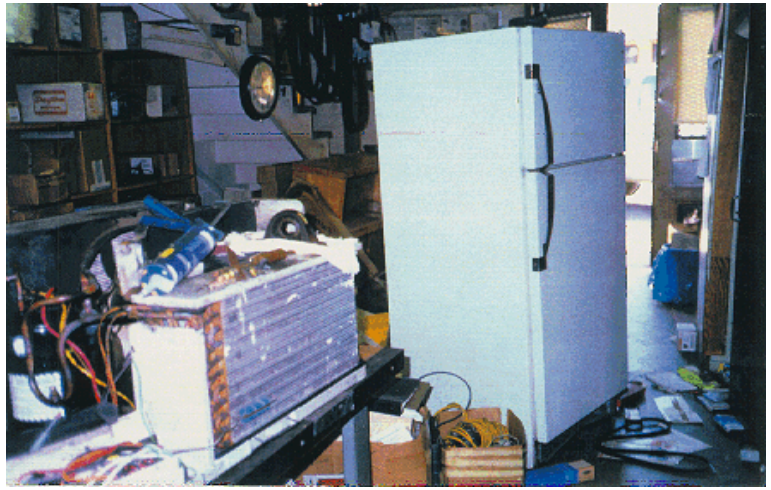
Example #1: Sylmar County Hospital

1994 Northridge Earthquake

Example #1: Sylmar County Hospital

- No significant structural damage but



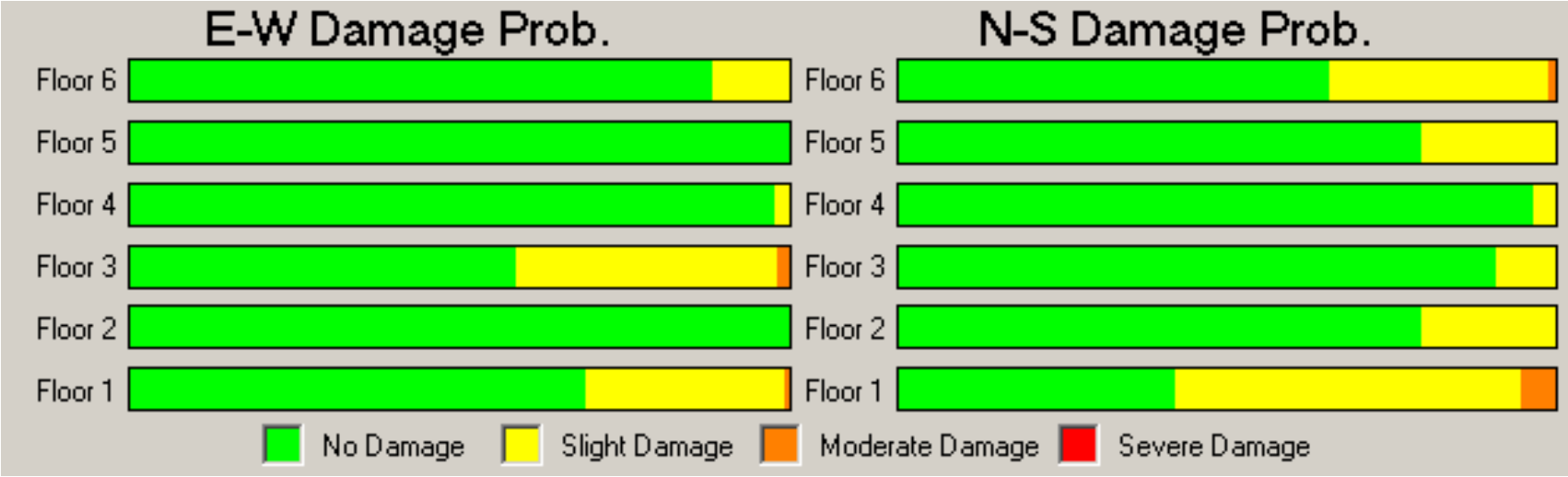


Photos from Naeim, F. (1997)

Example #1: Sylmar County Hospital

- Floor-by-floor structural system status:

Using HAZUS-MH Fragility Functions

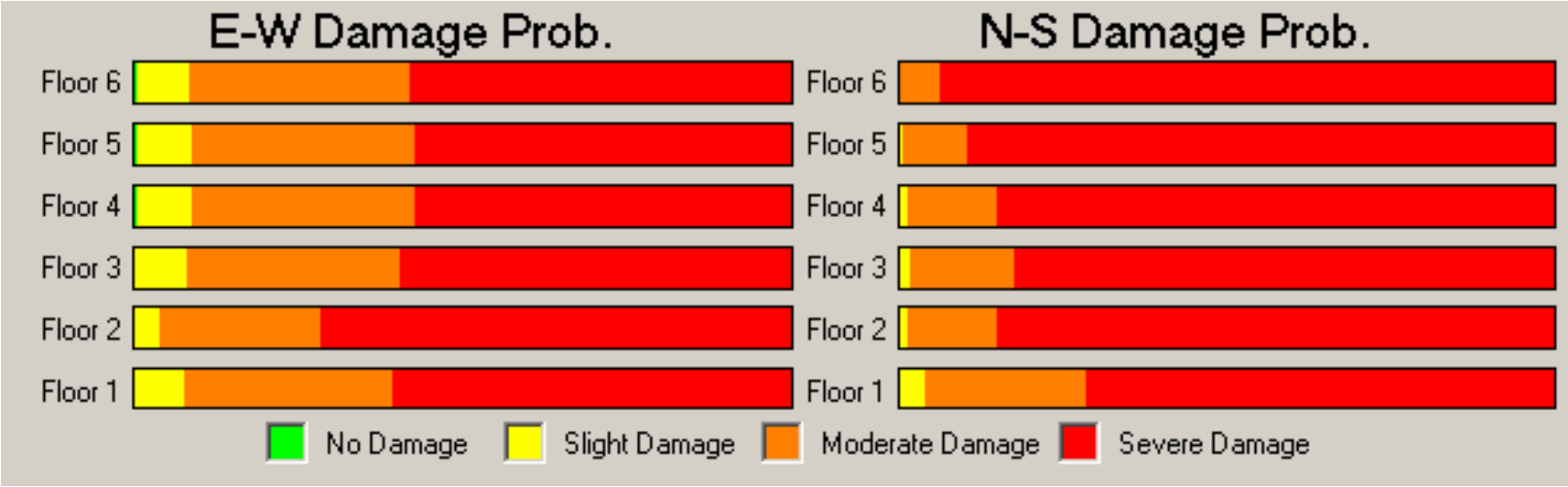


No Damage to Slight Damage

Example #1: Sylmar County Hospital

- Floor-by-floor nonstructural system status:

Using HAZUS-MH Fragility Functions



Moderate to Severe Damage

Example #1: Sylmar County Hospital

- Suspended ceilings on the first floor:

Using FEMA P-58 Fragility Functions

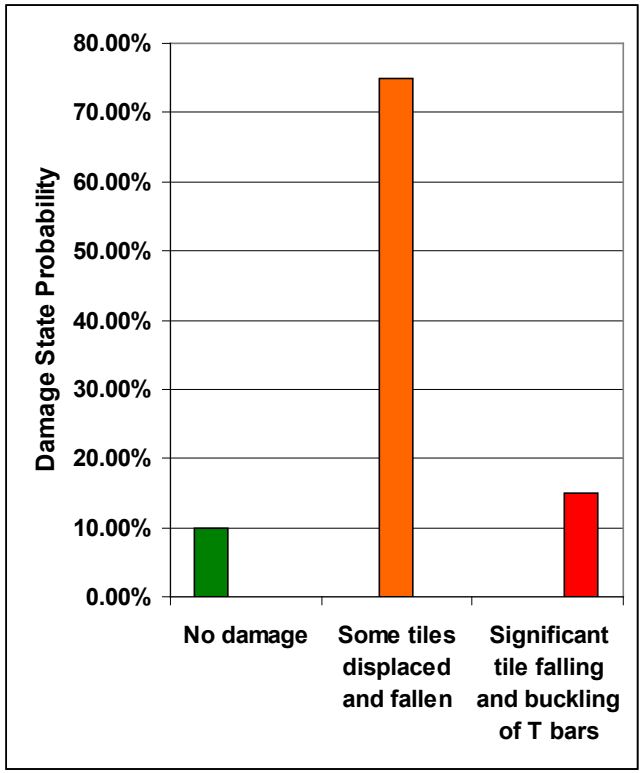


Photo from Naeim, F. (1997)

Example #1: Sylmar County Hospital

- Unanchored file cabinets on the 6th floor:

Using FEMA P-58 Fragility Functions

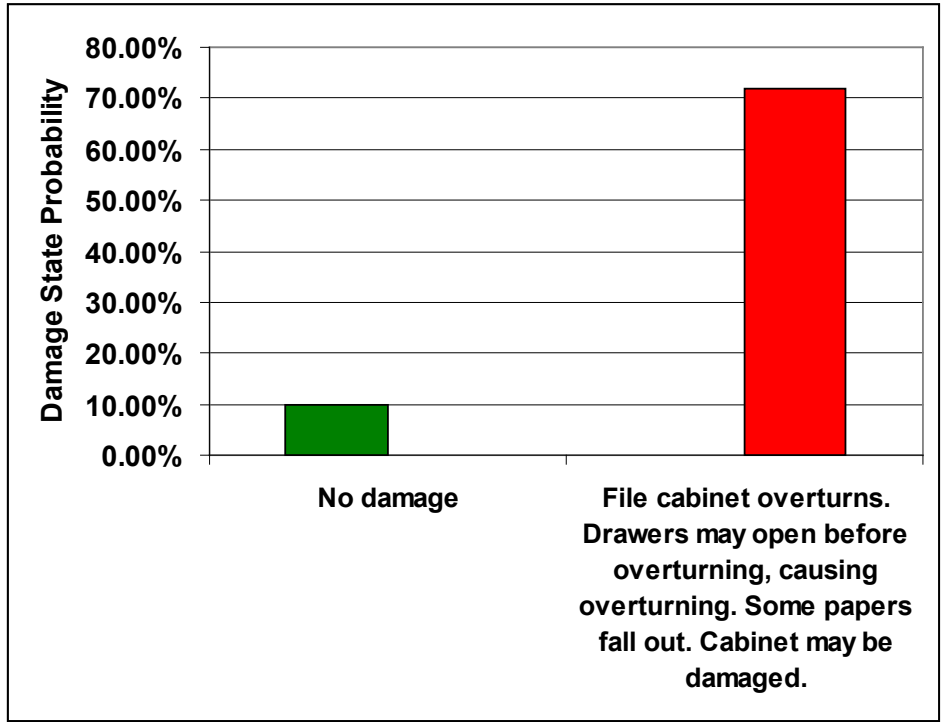
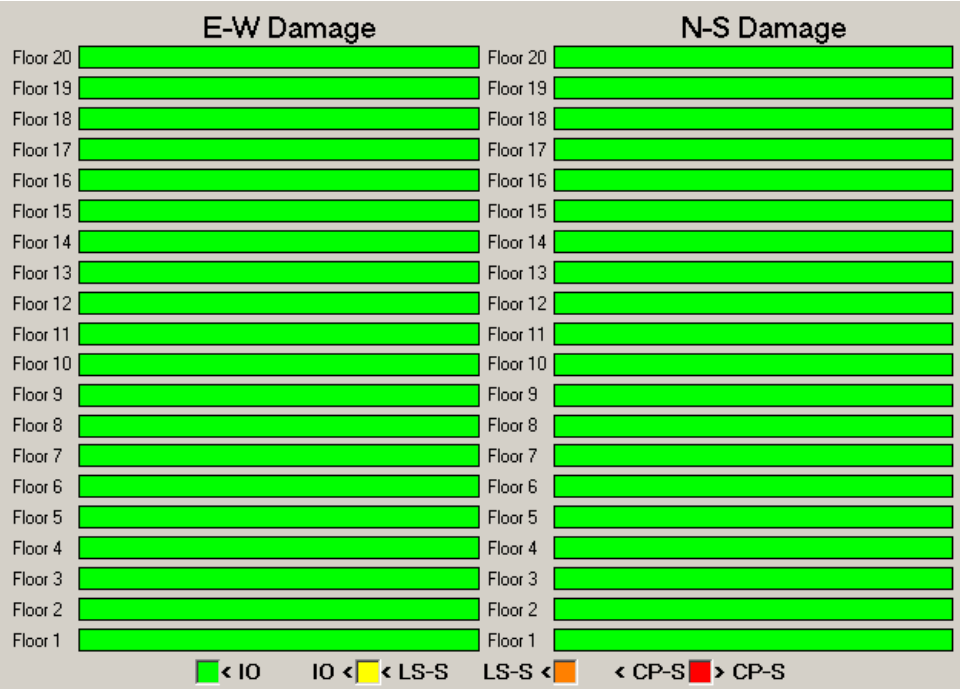


Photo from Naeim, F. (1997)

Example #2: Universal City Hotel

- 1994 Northridge Earthquake
  - Deterministic floor-by-floor structural system status

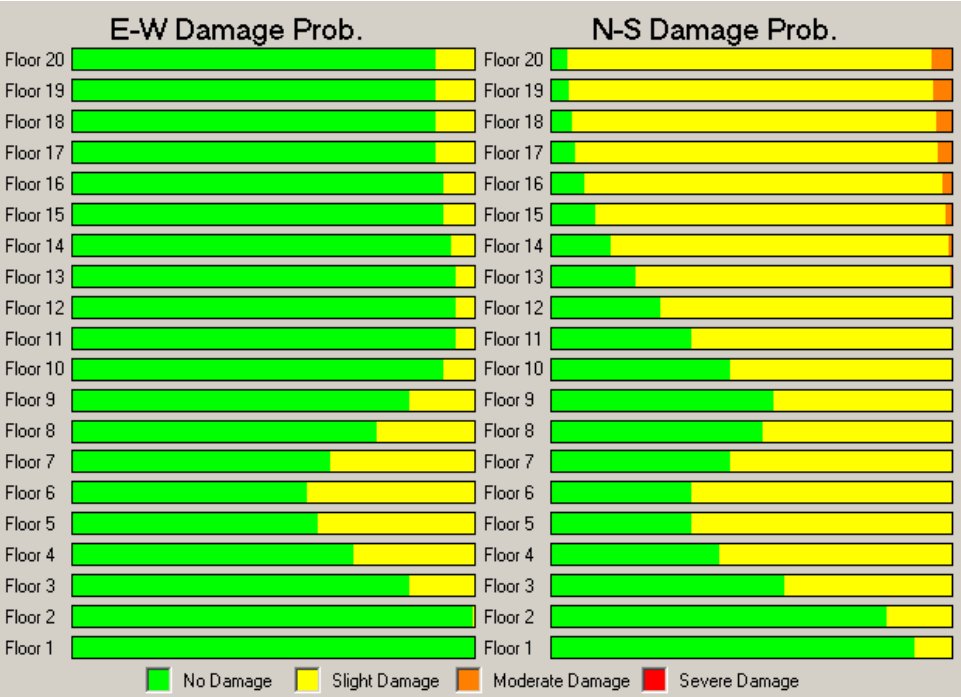


Status: **Immediate Occupancy**

Example #2: Universal City Hotel

- Probabilistic floor-by-floor structural system status

  Using HAZUS-MH Fragility Functions

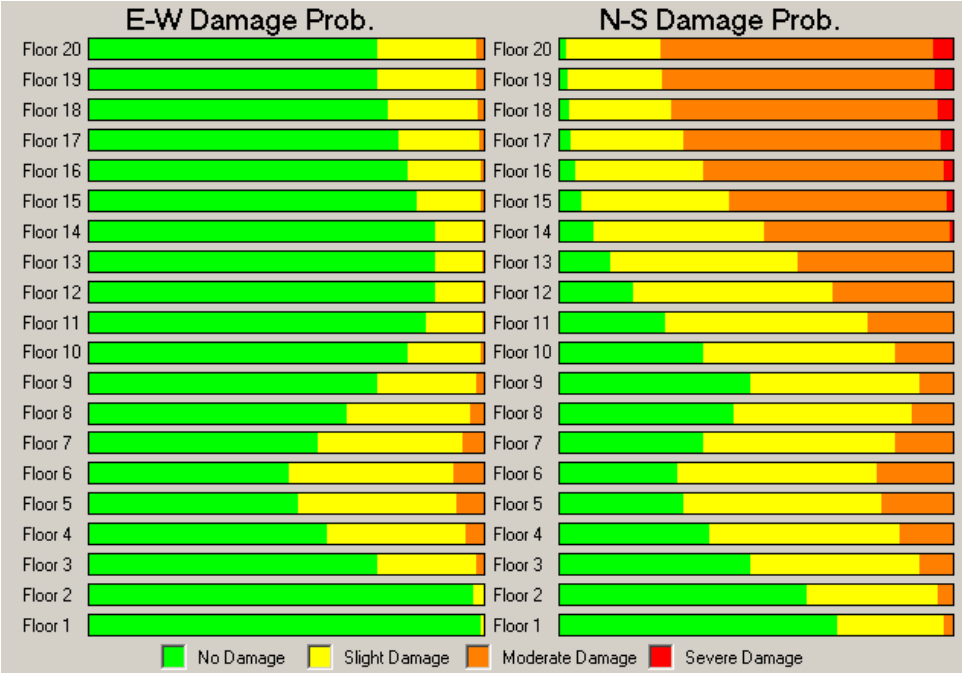


Status: **No Damage** to **Slight Damage**; **damage more likely in the N-S direction.**

Example #2: Universal City Hotel

- Probabilistic floor-by-floor nonstructural system status

  Using HAZUS-MH Fragility Functions

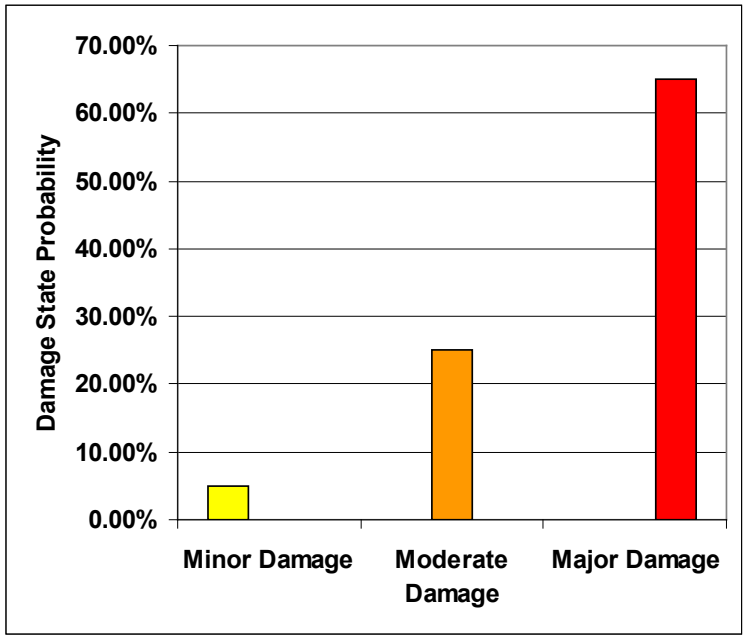


Status: **No Damage** **to** **Severe** **damage; damage more severe in the N-S direction and in upper floors**

Example #2: Universal City Hotel

- Suspended Ceiling at Penthouse

Using FEMA P-58 Fragility Functions



Status: **Major damage**

Photo from Naeim, F. (1997)

EXAMPLES OF S2HM IMPLEMENTATION IN CALIFORNIA?

None!

Despite some incentives provided by cities like San Francisco

Conclusions

- We need an attitude and a cultural change
- The relatively low cost of instrumentation and S2HM and the huge post-earthquake advantages it provides must be made clear to the public.
- Attractive incentives should be thought of and provided to those who implement S2HM.
- Changing the culture may not be easy but it is absolutely necessary if we want to achieve a sustainable infrastructure.

Thank you!