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What is needed for resiliance of tall buildings in San Francisco and elsewhere?

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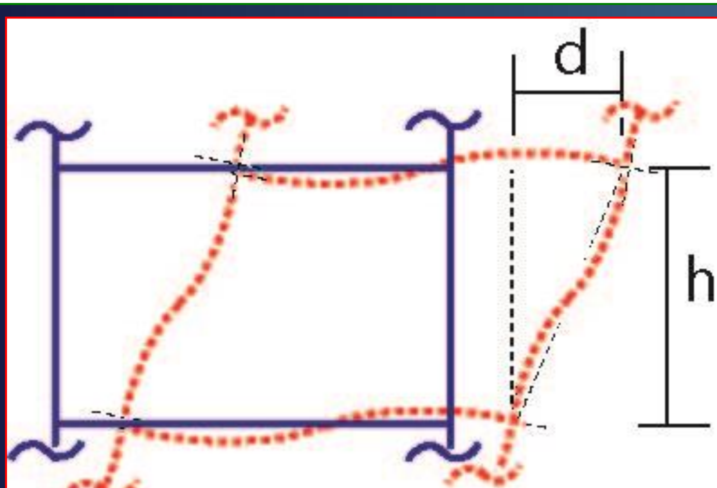
USGS
science for a changing world

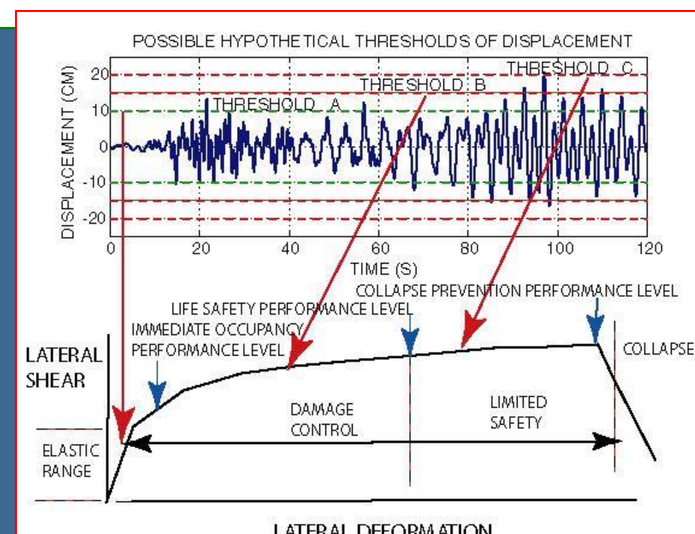
THE PROBLEM:Resiliency:

- The owner needs reliable and timely expert advice on whether or not to occupy the building following an event.
- Data gathered will enable the owner to assess the need for post-earthquake connection inspection, retrofit and repair of the building.

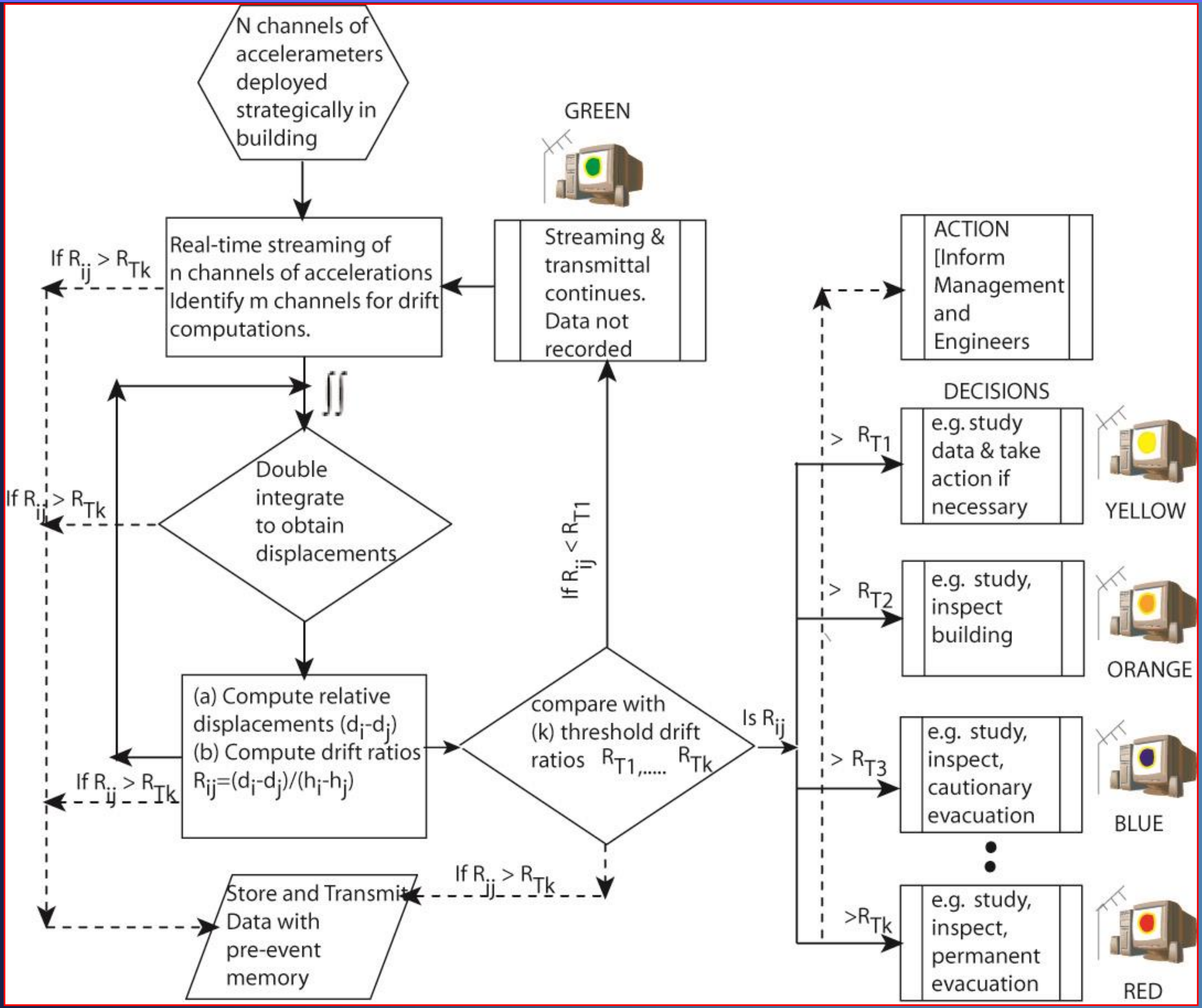
We compute drift ratios from recorded data:Why Drift Ratio? Connection to Performance

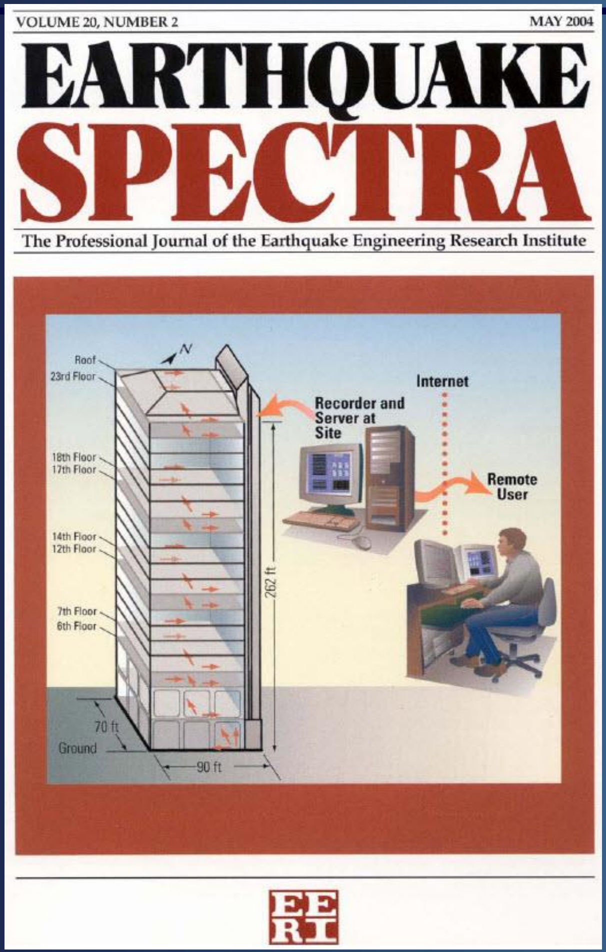
- The most relevant parameter to assess performance is the measurement or computation of actual or average story drift ratios. Specifically, the drift ratios can be related to the performance- based force-deformation curve hypothetically represented in Figure 1 [modified from Figure C2-3 of *FEMA-274* (ATC 1997)]. When drift ratios, as computed from relative displacements between consecutive floors, are determined from measured responses of the building, the performance and as such "damage state" of the building can be estimated as in the figure (below).





APPROACH : Displacement via Real-time Double Integration [softwares are marketed…many applications, Çelebi et al, 2004 Çelebi (2008)]





Real-Time Seismic Monitoring Needs of a Building Owner—and the Solution: A Cooperative Effort

M. Çelebi,[a] M.EERI, A. Sanli,[a] M. Sinclair,[b] S. Gallant,[b] and D. Radulescu[c]

A recently implemented advanced seismic monitoring system for a 24-story building facilitates recording of accelerations and computing displacements and drift ratios in near-real time to measure the earthquake performance of the building. The drift ratio is related to the damage condition of the specific building. This system meets the owner's needs for rapid quantitative input to assessments and decisions on post-earthquake occupancy. The system is now successfully working and, in absence of strong shaking to date, is producing low-amplitude data in real time for routine analyses and assessment. Studies of such data to date indicate that the configured monitoring system with its building specific software can be a useful tool in rapid assessment of buildings and other structures following an earthquake. Such systems can be used for health monitoring of a building, for assessing performance-based design and analyses procedures, for long-term assessment of structural characteristics, and for long-term damage detection. [DOI: 10.1193/1.1735987]

INTRODUCTION

In all seismic areas, local and state officials and prudent property owners establish procedures to assess the functionality of buildings and other important structures such as lifelines following a significant seismic event. Immediately following such an event, the decisions of functionality and occupancy of a building in most cases are based on visual inspections of possible damage to the structure. If the structure appears damaged, it is necessary to further examine and assess whether the damage condition of the structure presents an unsafe environment for the occupants or users of that structure. Therefore, to have instrumental measurements of shaking of a building or even a nearby ground site provides valuable information to decision makers.

In general, a system for seismic monitoring of structures must fulfill a stated need—that is, during and after a strong shaking event, the monitoring system should yield data that serve the specific purposes for which it has been planned. Each user of the structural response data may have a different objective. In general, from the viewpoint of an owner, the objective could be to use such data obtained by monitoring to increase the likelihood that the building will be permitted to remain functional following an event. In practical terms, this means whether, immediately after occurrence of an event, a building

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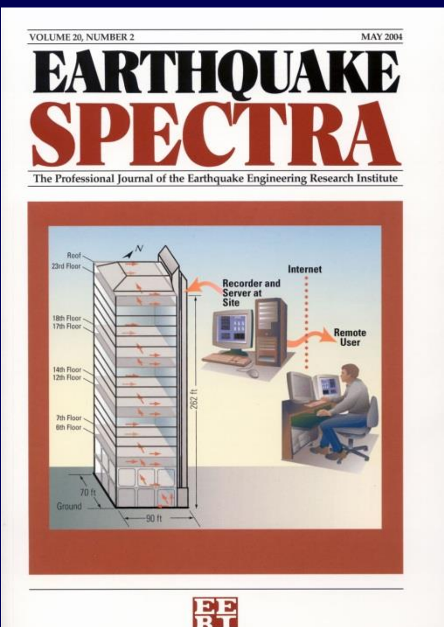
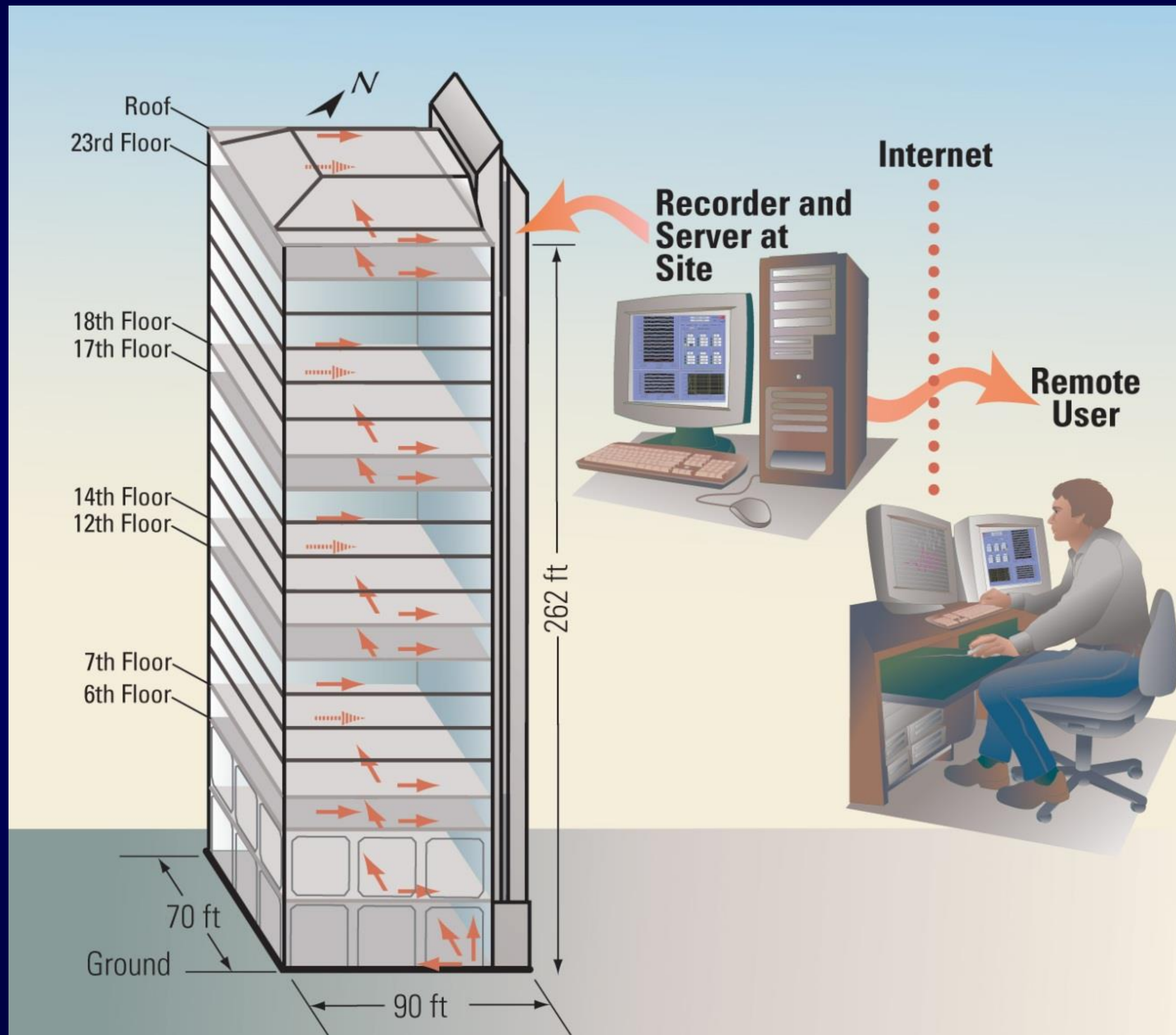
14 WCEE Beijing 2008

REAL-TIME MONITORING OF DRIFT FOR OCCUPANCY RESUMPTION

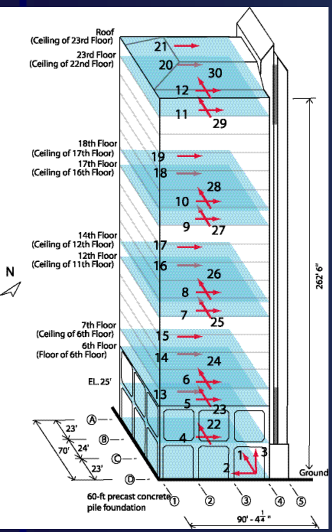
M. Çelebi[1]

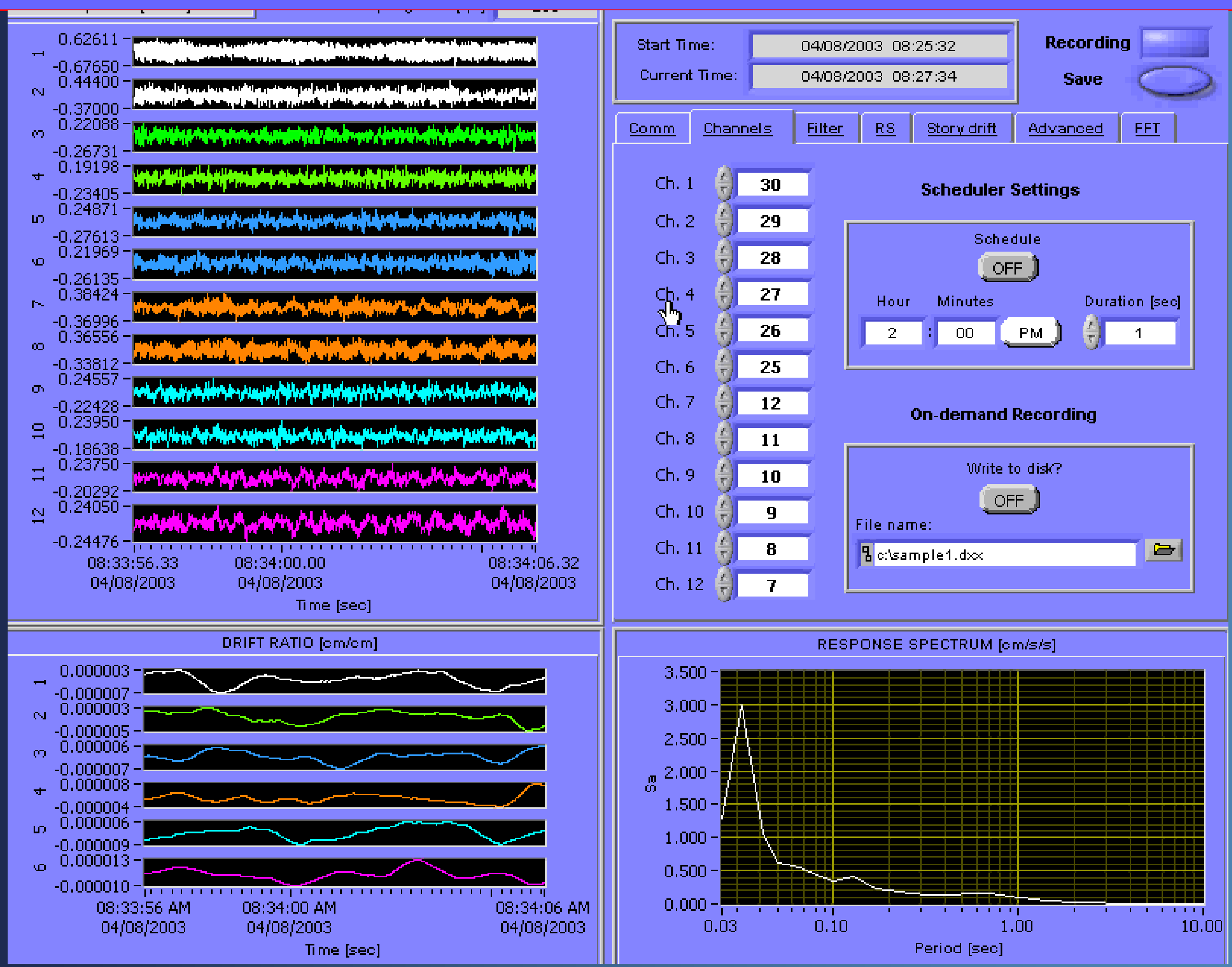
Development and Application (Celebi and others, 2004)



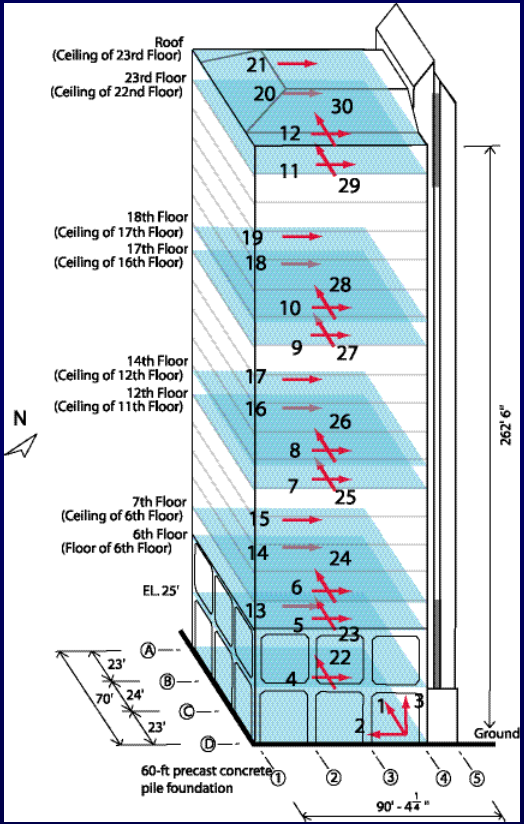


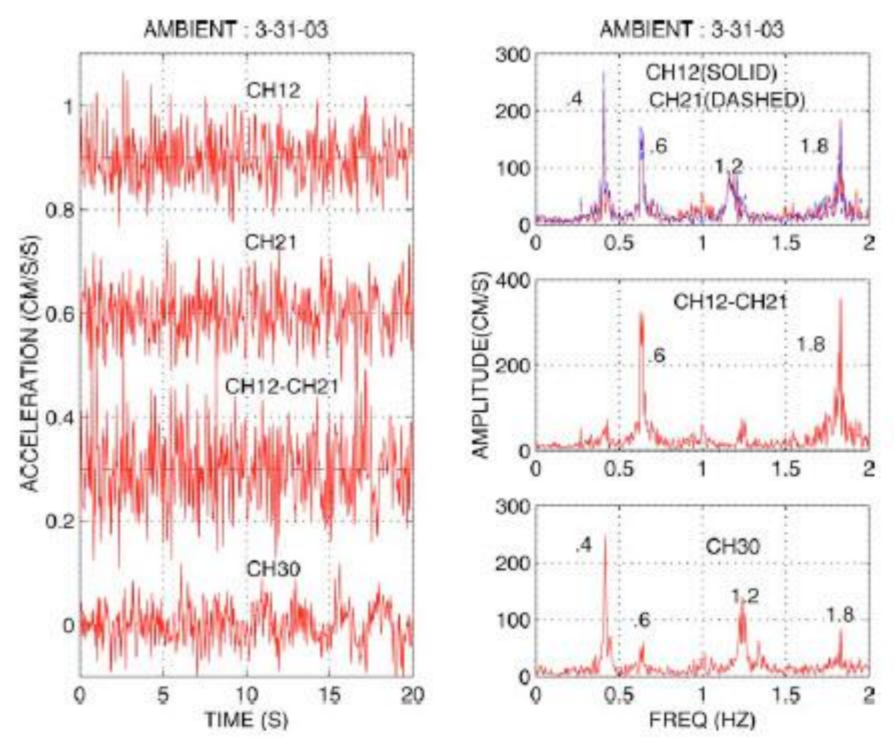
Such developments are useful – to assess & make informed decisions!



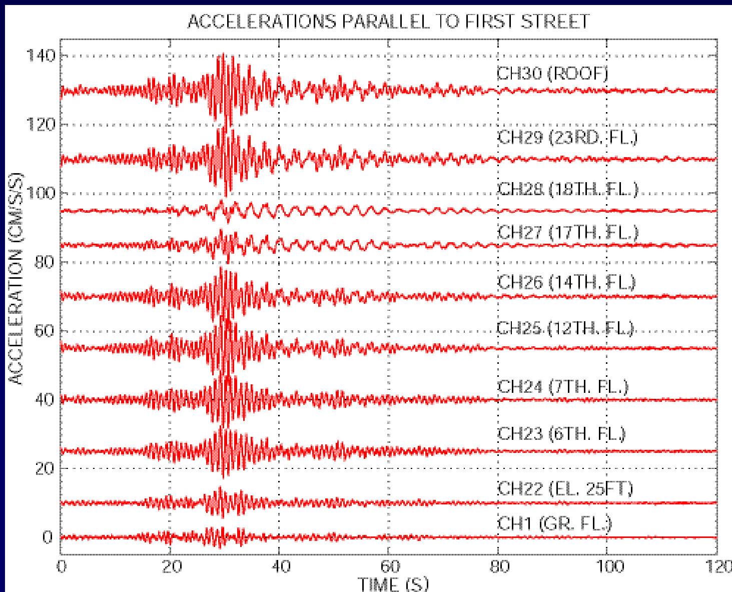


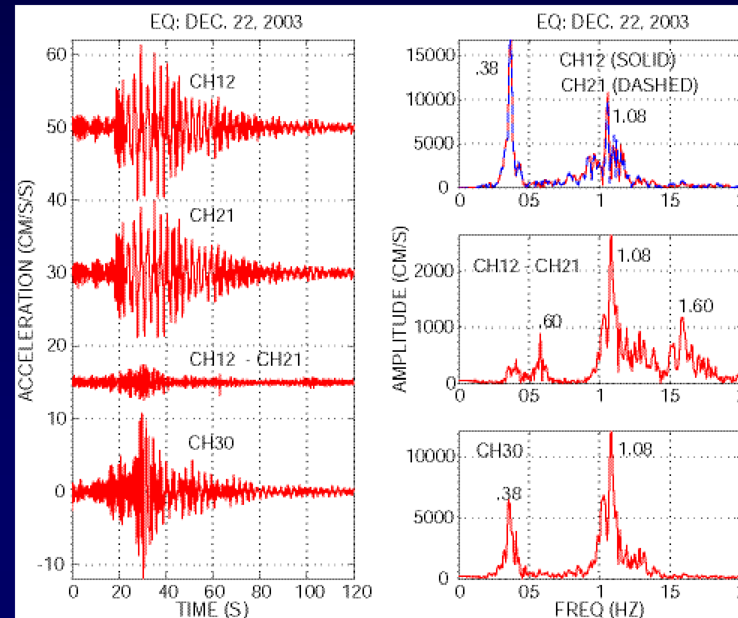
Ambient Data of 3_31_2003

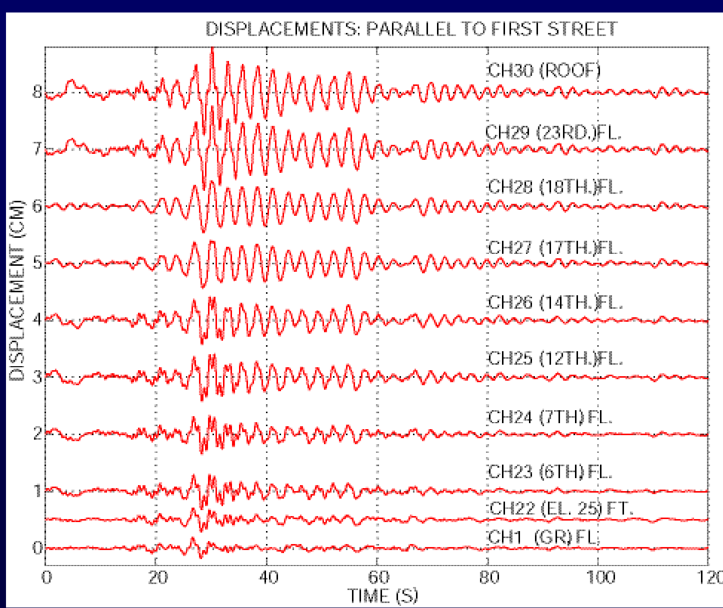


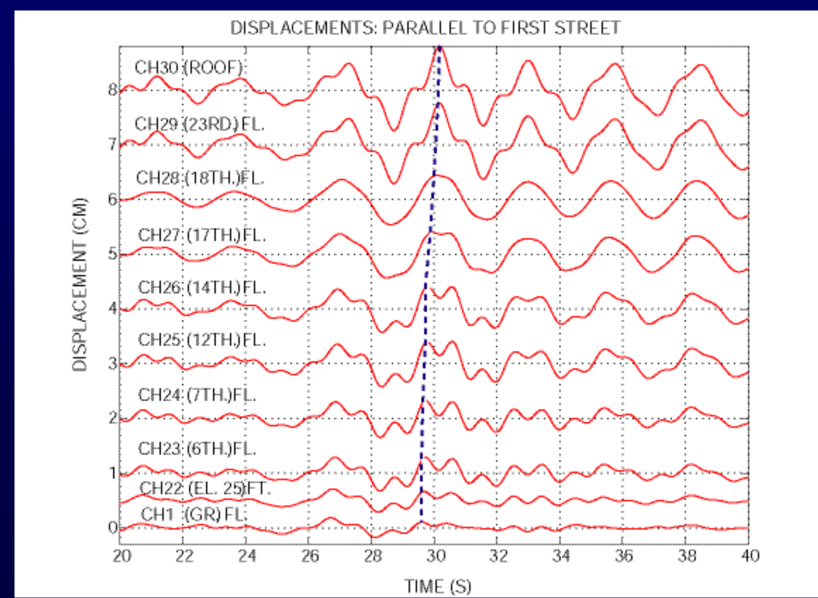


Sample "Small" Earthquake Response Data: San Simeon Earthquake of 12/3/03







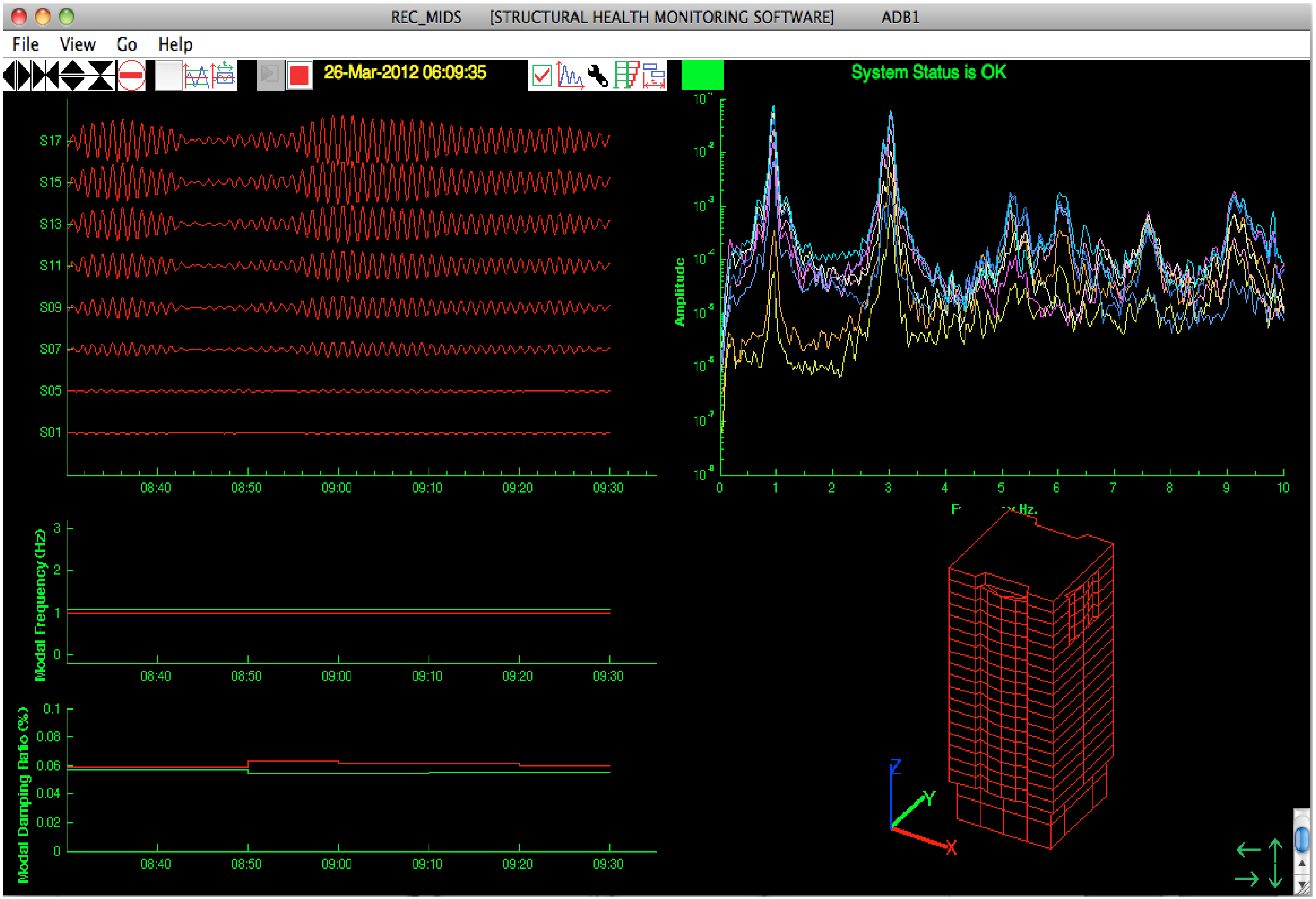


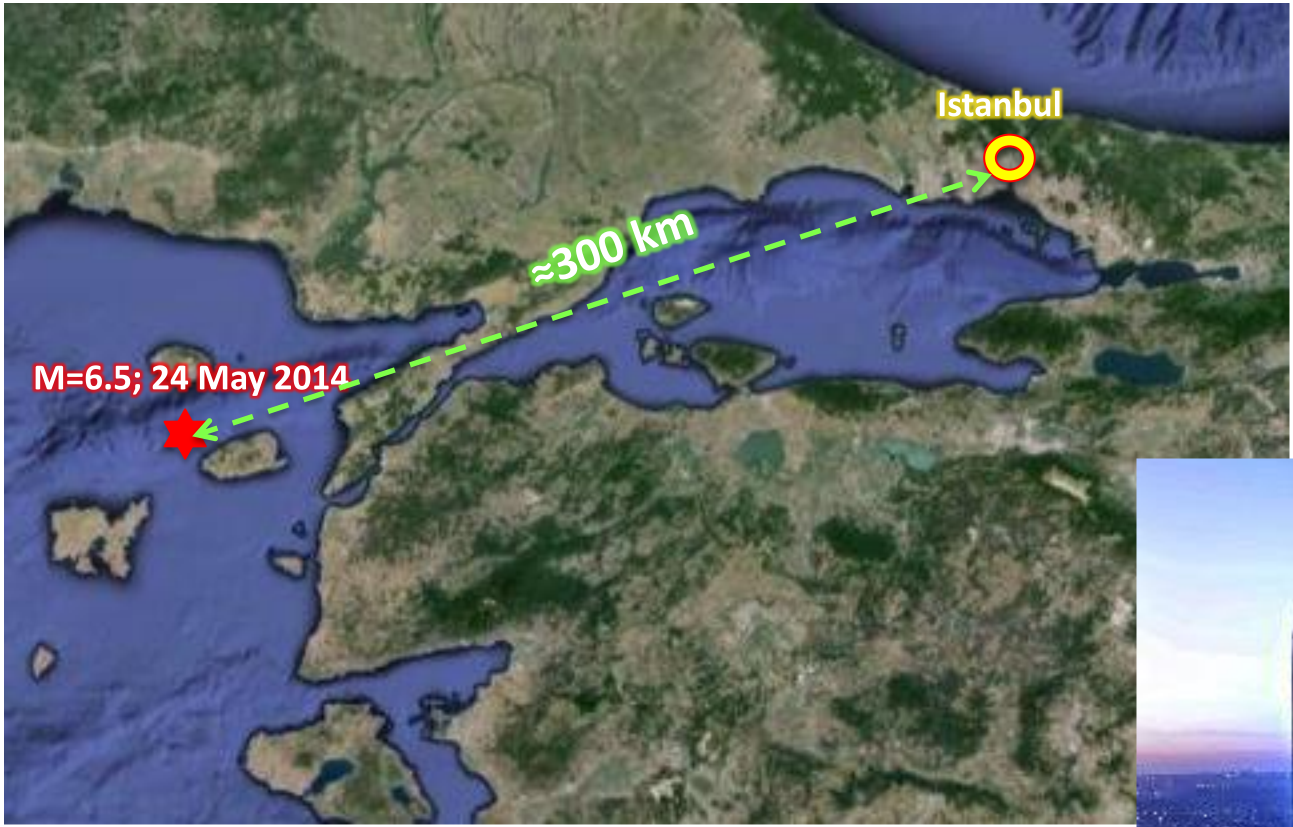
Commercial Versions (using same specs and flowchart) installed at some banks
[3 components: (1) sensors, (2) DAQ’s & Processors, (3) Display&Alarm system for informed decisions]
(*Figure* from D. Sokolnik)

Selected Unique Buildings for Abu Dhabi Municipality

Courtesy: M. Ciudad-Real

REAL-TIME ANALYSIS OF STRUCTURAL HEALTH MONITORING DATA
Figure: Courtesy E. Safak

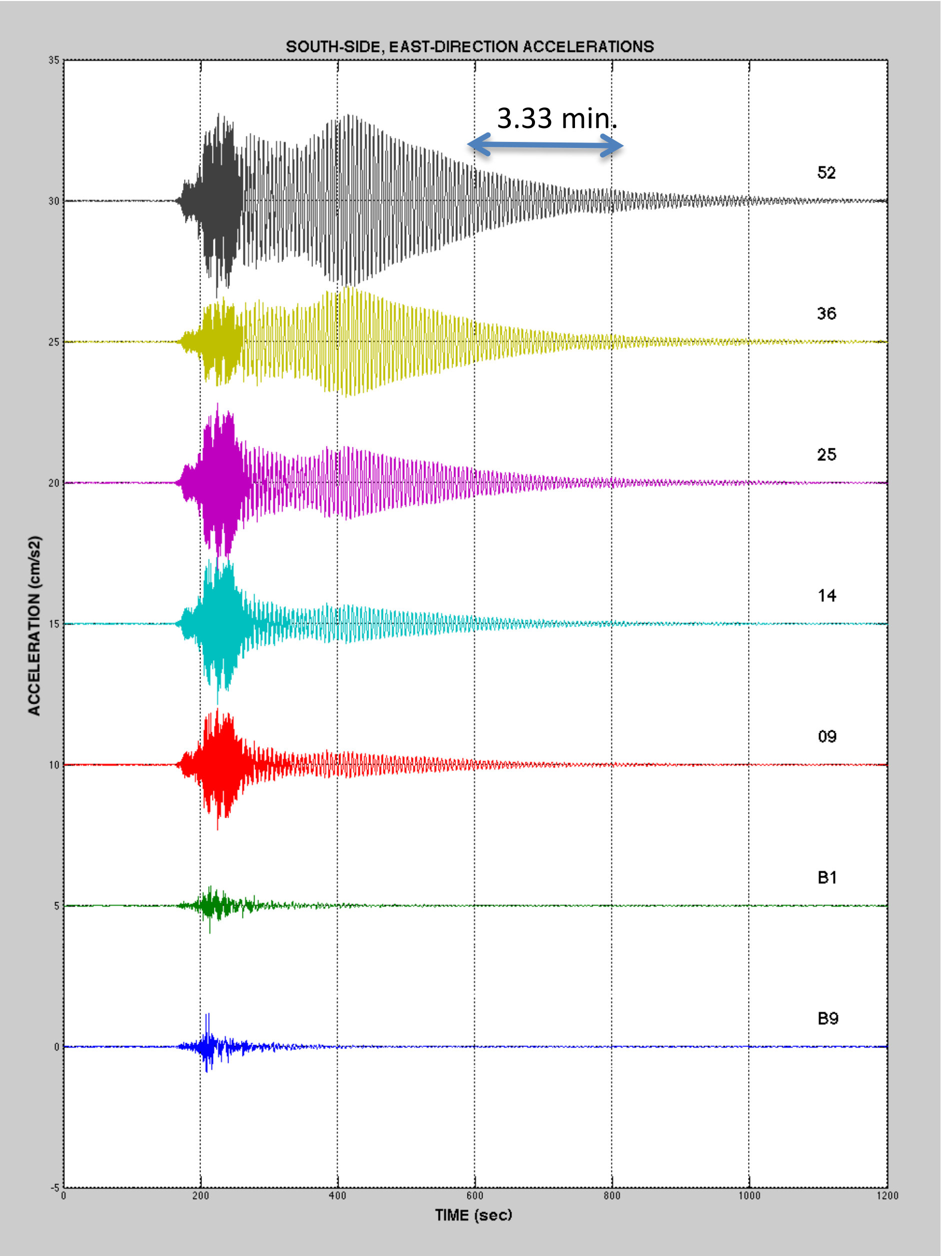


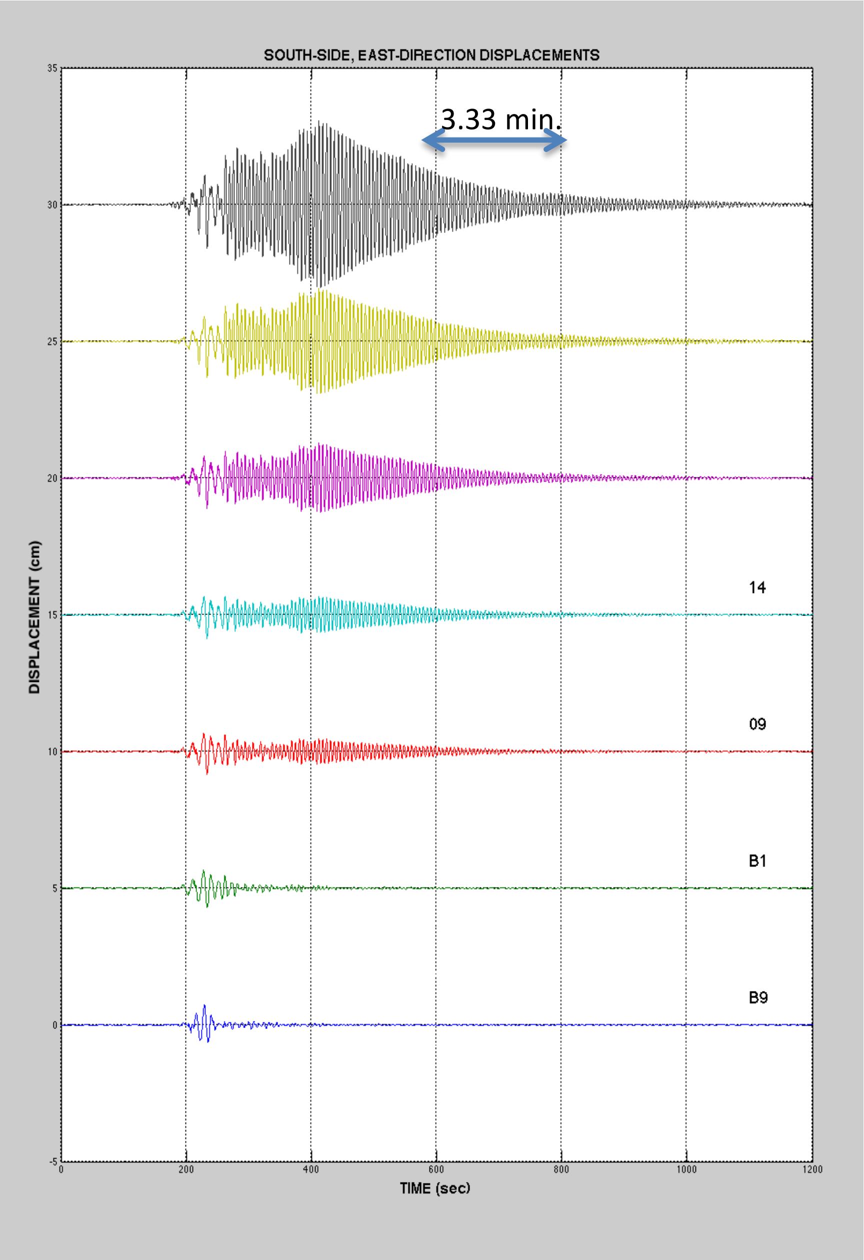


62-story Sapphire Tower
(the tallest building in Istanbul)
Figure - courtesy E. Safak

Matlab based formulation of SHM software by Safak & Kaya (*Figure* from E. Safak)

Figure (courtesy E. Safak)





CONCLUSIONS [what we learned?]:

- Measured data from carefully crafted monitoring <u>based on observed data </u>are being successfully used (in US, Japan and other countries) to make informed decisions in near-real time about behavior, performance and occupancy of buildings.
- <u>Not covered here: Some bridges in Korea</u>.

DRIFT RATIO APPLICATIONS in CODES

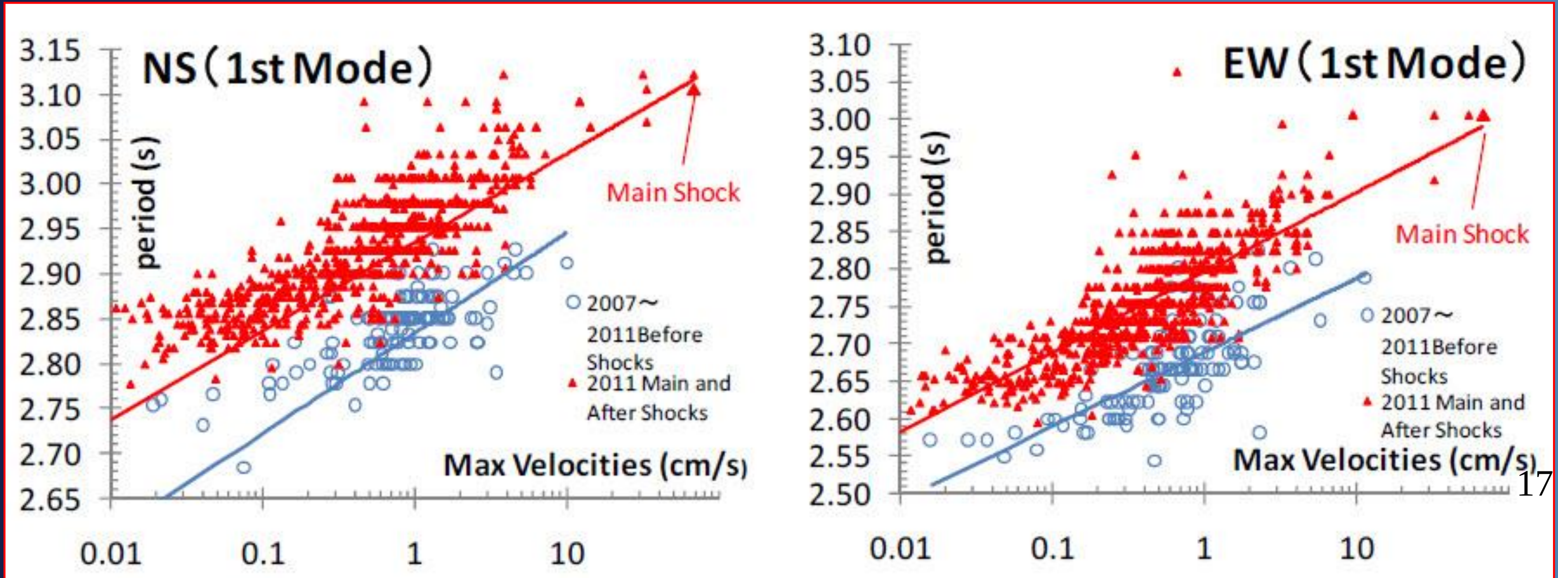
Table 1. Upper Limits of Drift Ratios (Japan, Chile, USA, Turkey, New Zealand and Eurocode 8).

Code	Upper Limit Drift Ratio (%)	Comment	Reference:
Chile	0.2	Results in elastic design	Nch433.Of96 (1996)
Japan	1.0	Max for buildings taller than 60 m. For collapse prevention (level 2) motions	Building Center of Japan 2001a, b.
USA	2.0	No collapse state	ASCE7-10 (2007):
Turkey	2.0	Can be increased by 50 % in case of some steel frames	DBYYHY (2007): Section 2.10.1.3, Eqn: 2.19 in Turkish Code (2007)
New Zealand	2.5		NZS1170.5(2004)
Eurocode 8	1.0 (max)	for buildings having non-structural elements fixed in a way so as not to interfere with structural deformations, or without non-structural elements	Section 4.4.3.2, Eqn: 4.33 Eurocode 8 (2008)

Note for JAPAN:Based on such thresholds set by the *Building Standards Law of Japan* (BCJ, 2001a,b), Kubo et al. (2011) state that, <u>if story drift ratio is over 1%, then moderate to severe damage can occur</u>; if it is within the range <u>of 0.5% to 1%, then minor damage can occur</u>. Therefore, the average ratios computed here can be taken as conservative indicators of what may have occurred in the buildings.

Long Term Observation Results: Permanent Shift in Fundamental Period: Kogakuin Building [Bldg C] (from Hisada and others, 2012)

Question is: What to do about resiliency of these buildings during future large earthquakes (suggestions: add dampers, retrofit by other methods)



SUMMARY: Other Studies Using Observed data the system records during small & large earthquakes (not real-time)

Table. Epicentral distances, peak accelerations and displacement and computed average drift ratios of the buildings supplemented by peak accelerations of ground motions recorded at stations in proximity to the buildings.[H=height of building used to computed average drift ratios, DR=drift ratio].

Bldg	Epicentral Distance (km)	Peak Accel. at ground level (gals)	Peak Accel. at top floor (gals)	No of floors	Rel. Displ (cm)	H Height (m)	(Ave) DR (%)
A	767	30	130	54	~130	218	~.5
B*	~375	142	236	54	54.2	216	~.2
C**	~375	92	340	31	33.4	119	~.5
D**	~375	92	302	29	34.9	90	~.4
E (RC)	~384	98	198	37	~20	118	~.15
*from Sinozaki (pers.comm, 2012), **from Hisada et al (2012a and 2012b)							
Peak accelerations (gals) at Free-Field Stations in vicinity of the buildings							
Free-Field station		NS	EW				
KIKNET:OSKH02\surface		13	15				
OSKH02\downhole		1	1				
KNET: TKY007		198	165				

CONCLUSIONS

- 1. A pragmatic and implementable structural monitoring array can be deployed in tall buildings to facilitate their speedy recovery and resiliency.
- 2. An algorithm based on recorded accelerations, displacements and drift ratios computed from observed data provides timely and informed decision making process.
- 3. Several buildings in San Francisco area and elsewhere have been instrumented primarily for this purpose.

THANK YOU!

Q?