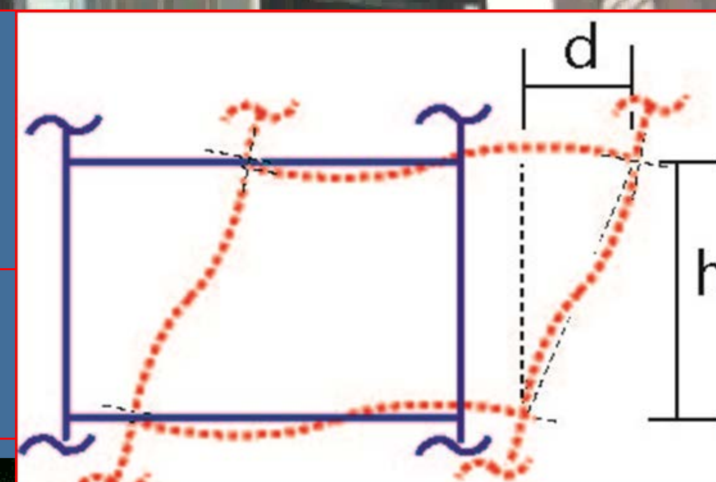
DRIFT ISSUES OF TALL BUILDINGS DURING THE MARCH 11, 2011 M9.0 EARTHQUAKE, JAPAN - IMPLICATIONS



Mehmet Çelebi, Earthquake Science Center, USGS, Menlo Park, CA.

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Outline

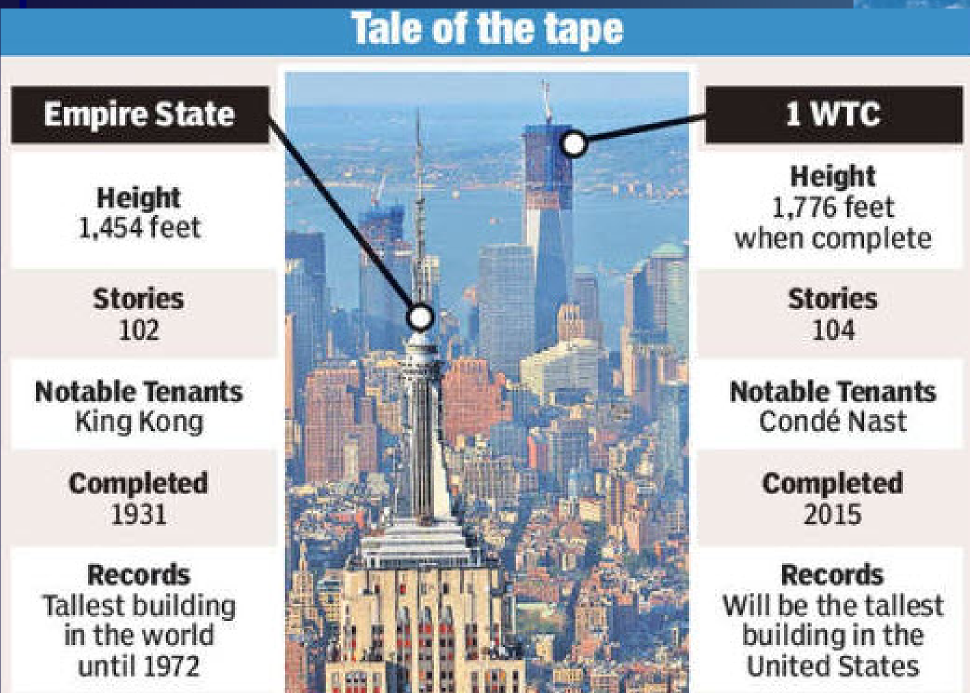
- 1. Why this subject?
  - Discussion of INTERRUPTED functionality of buildings at low ground level input motions caused by event at far distances.
  - Discussion of what may happen at larger input motions with similar frequency content.
  - Discussion of DRIFT RATIOS w.r.t. codes (Japan, USA, Chile)
- 2. Two cases:
  - Building A (770 km from epicenter)
  - Building B (350-375 km from epicenter)
- 3.CONCLUSIONS

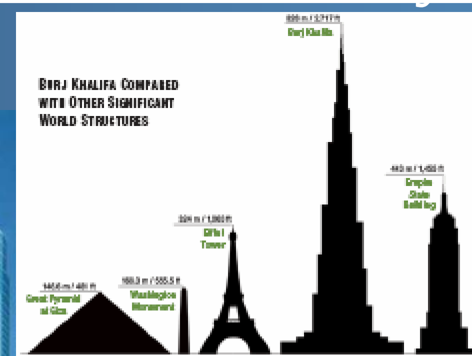
DRIFT RATIO (DR): CODES

- JAPAN: Max DR=1% for collapse protection level motions (level 2 used for buildings 60 m or taller [The Building Center of Japan, 2001a and 2001b]).
- UNITED STATES: MAX DR=2% for tall buildings for Risk Category 1 or 2. (Table 12.12, ASCE7-10, 2007).
- CHILE: MAX DR=0.2% [The Chilean Code for Earthquake Resistant Design of Buildings (NCh433.Of96, 1996) [effective since 1960's]

Tall Buildings

- More and more taller RC buildings are designed/constructed in the US as well as other parts of the world: Freedom Tower in NYC, 92 story Trump Tower (Chicago), 828 m tall Bhuj Tower in Dubai).Their performances are yet to be assessed and/or observed!





Selected Unique Buildings for Abu Dhabi Municipality

Courtesy: M. Ciudad-Real

Effect on tall buildings from events occurring from sources at large distances?? [Dubai: Bhuj Tower 828 meters, Planned: Kuwait: >1000m)

Tall Buildings in Chicago and Boston

According to Wikipedia:

In Chicago: 72 bldgs taller than 555ft (168 m) [37-108] stories

In Boston :27 buildings taller than 400 feet (120 m). "

- How will they perform during a strong event from distant sources??? [pictures from Wikipedia]

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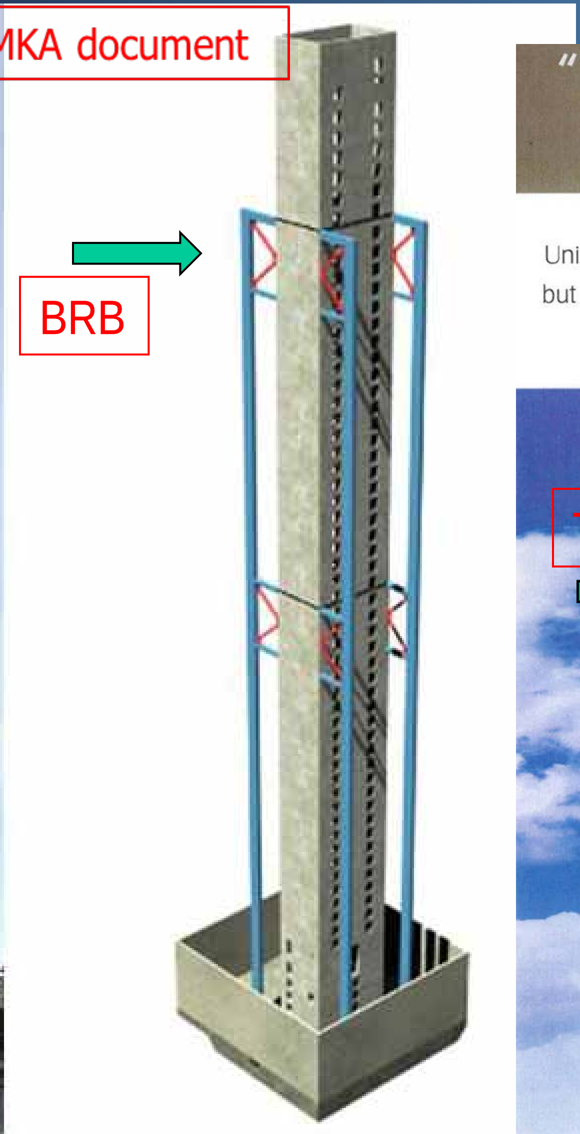
ONE RINCON TOWER (SF): RECENTLY COMPLETED COOPERATIVE PROJECT BETWEEN CGS (CSMIP) and USGS

(TSD) Tuned Sloshing Dampers and BRB(Buckling Restrained Dampers - also known as unbonded diagonal bracing)



"Tuned liquid damper" system

From MKA document

Unique water reservoirs at the top of the building not only aid in fire safety, but are also computer controlled to counterbalance building movement and provide an added degree of stability.

New Buildings in Los Angeles

From ASCE STRUCTURE Magazine, June 2012 (by R. Gerges, K. Benuska and C. Kumabe)

Fox Plaza Century City, Los Angeles, CA.

777 Tower, Los Angeles, CA.

One California Plaza, Los Angeles, CA.

Tall Buildings (from Tall Bldgs Council)

- 2011[88 buildings > 200 m in height]
- 2012[96 buildings>200m expected completion(most in China)
- (from left to right: “Marilyn Monroe”[Absolute Towers] in Toronto(August2012], Elliptical Bligh Street, Australia, Doha Towers, Qatar]

CHILE TALL BUILDINGS

- ~ 3,000 tall buildings (>10- stories) in Chile. ~ 80 damages and only 1 collapsed (Concepcion where 8 people were killed). [EERI:50 possibly to be demolished].

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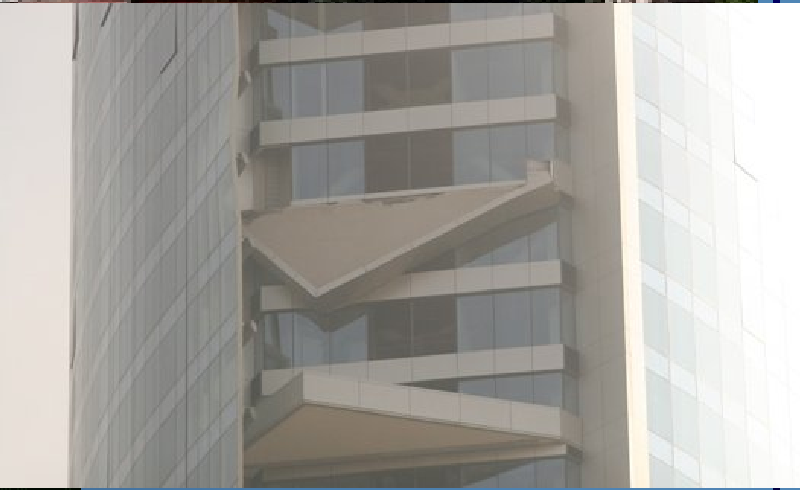
ENGINEERED STRUCTURES- SANTIAGO-TITANIUM BLDG (ACROSS FROM US EMBASSY)



ENGINEERED STRUCTURES- SANTIAGO

Two bldgs: Concepcion

- Confinement/thickness

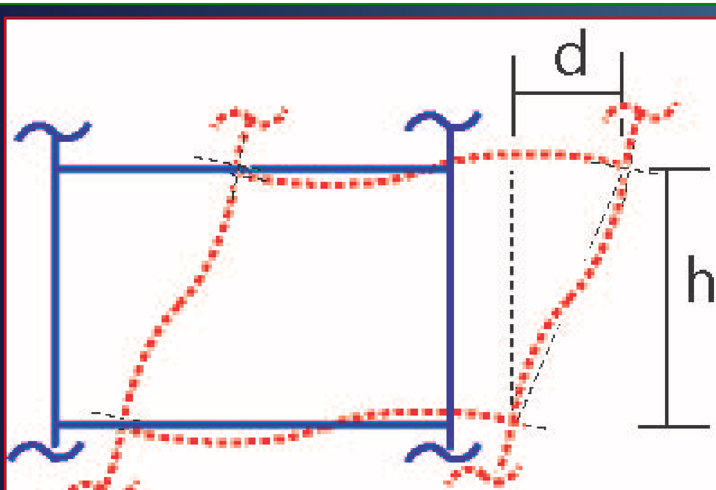
Santiago [core shear-wall]

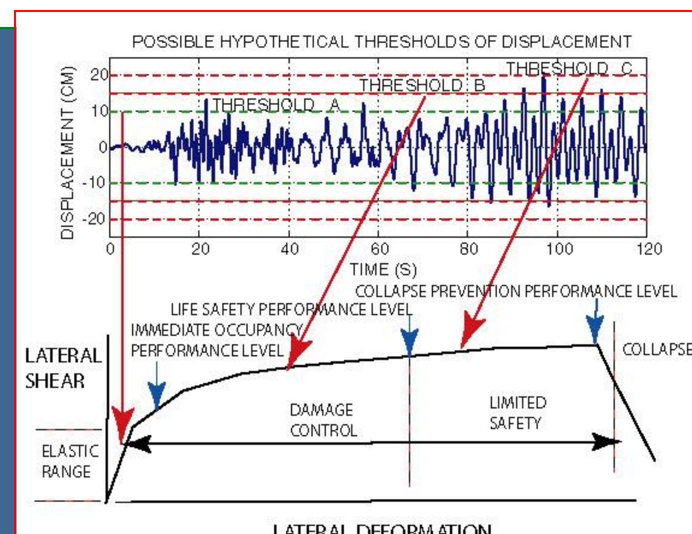
Parque Araucano building, Santiago. Building remained fully operational (from J.Maffei).

Tokyo: ~1500 high-rise bldgs,
~1000 base-isolated bldgs (from J. Moehle)

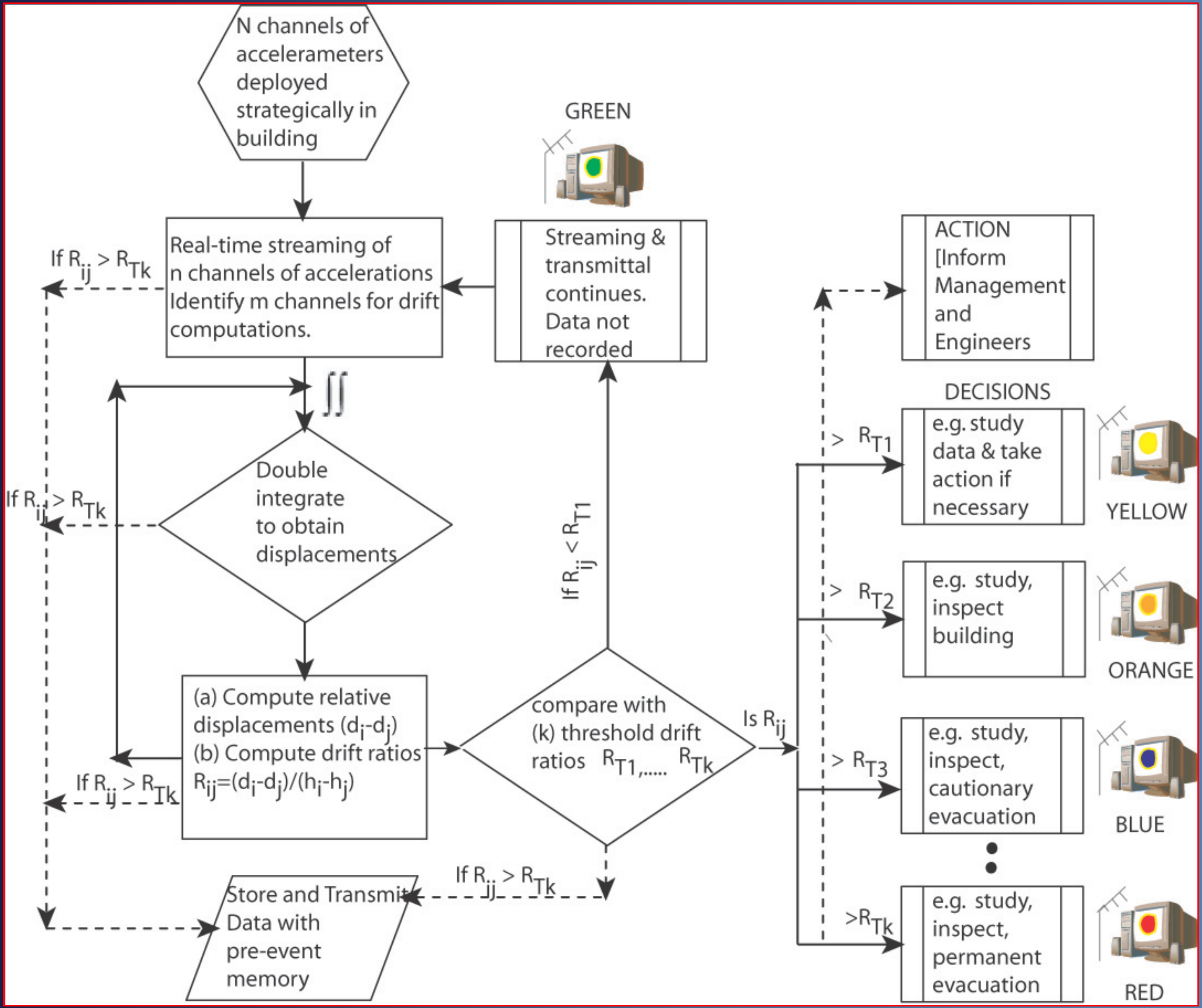
Drift vs. Performance

- 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 2: Displacement via Real-time Double Integration

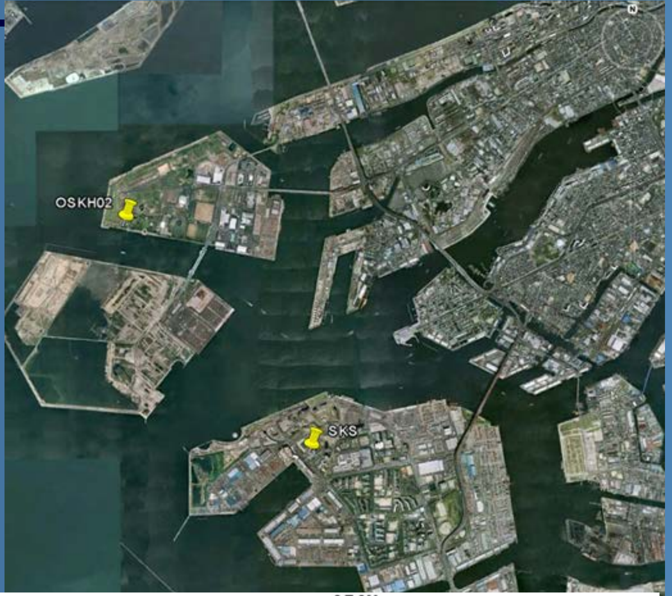


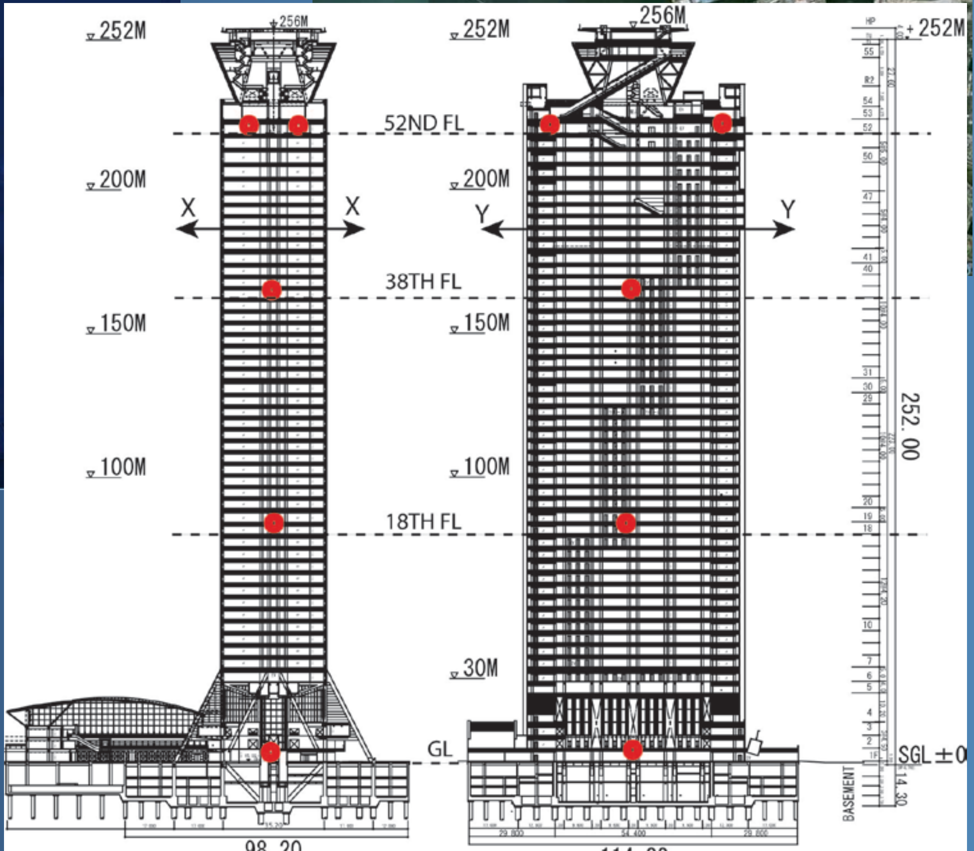
TWO CASES:

Building A: ~770 km from epicenter

Building B:~350-375 km from epicenter

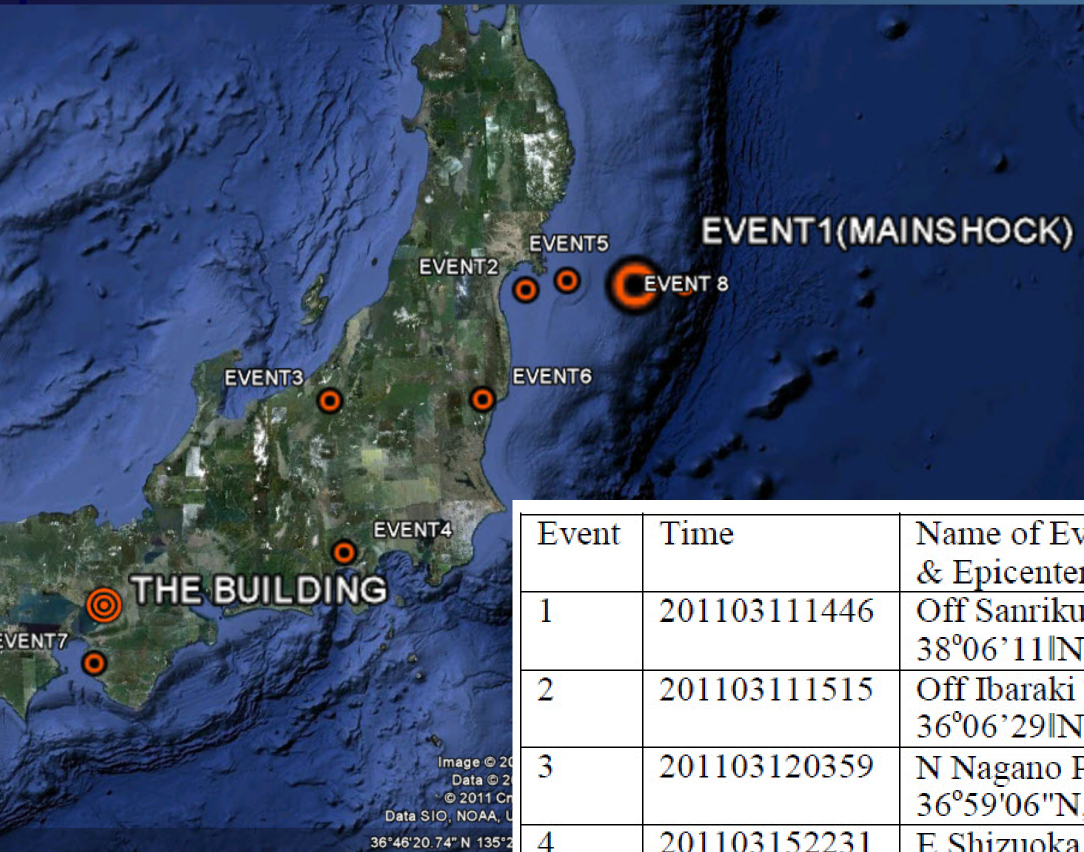
Building A; in Osaka Bay ~767 Km from epicenter of March 11, 2011 main-shock





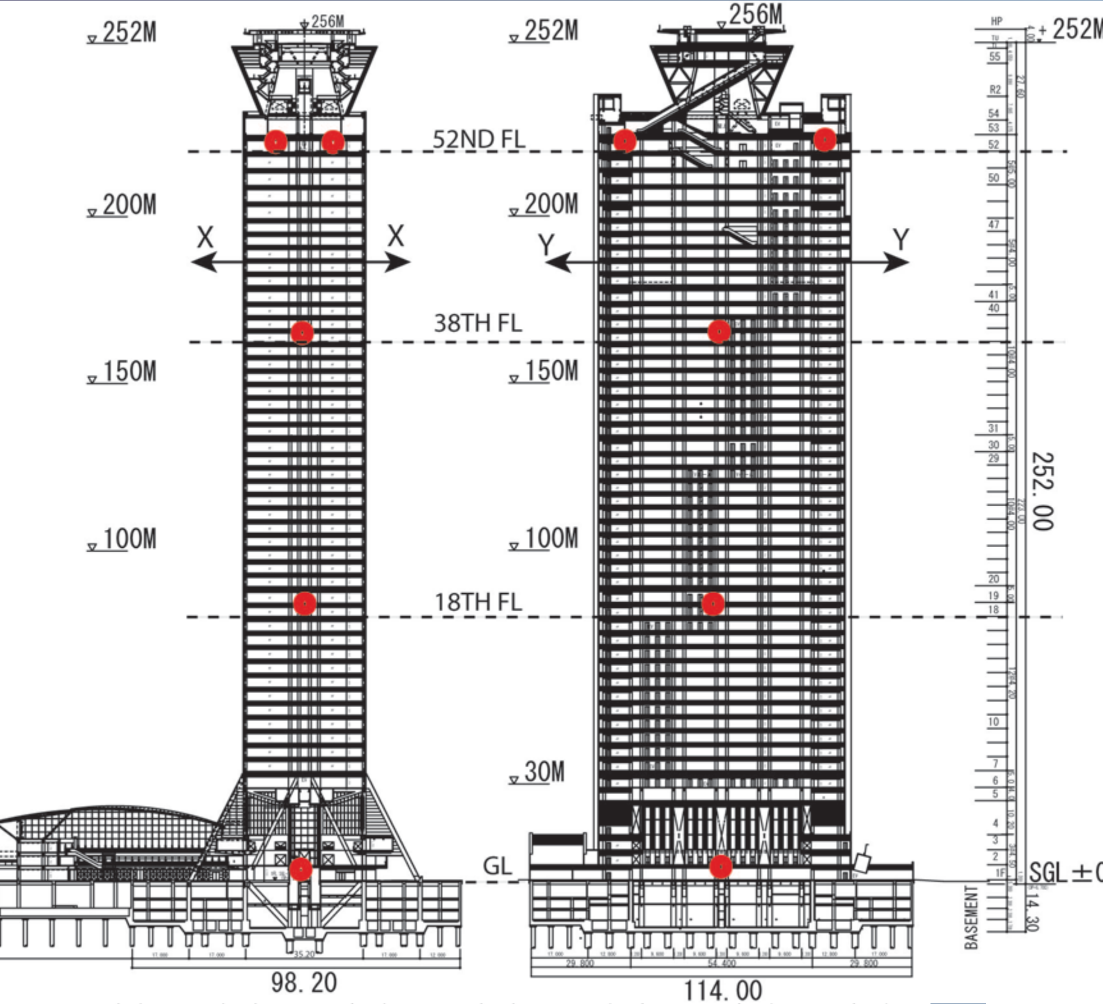
- 256 m tall (55 stories+3 story basement)
- Construction finished in 1995 (pre-1995 code, pre-(KIK-NET/K-NET). Vertically irregular, steel, moment-frame (rigid truss-beams/10 floor). No shear walls around elevator shafts
- 60-70 m long piles below foundation

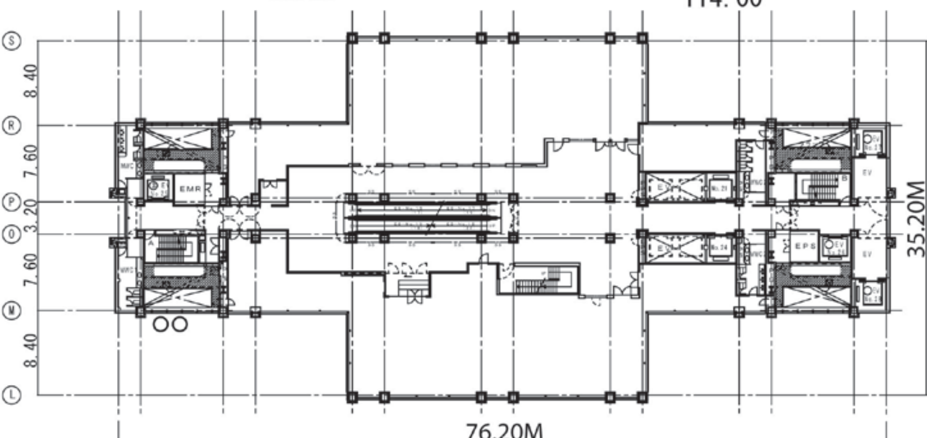
Building in Osaka Bay ~769 Km from epicenter of March 11, 2011 main-shock (numerous records but 8 events considered)

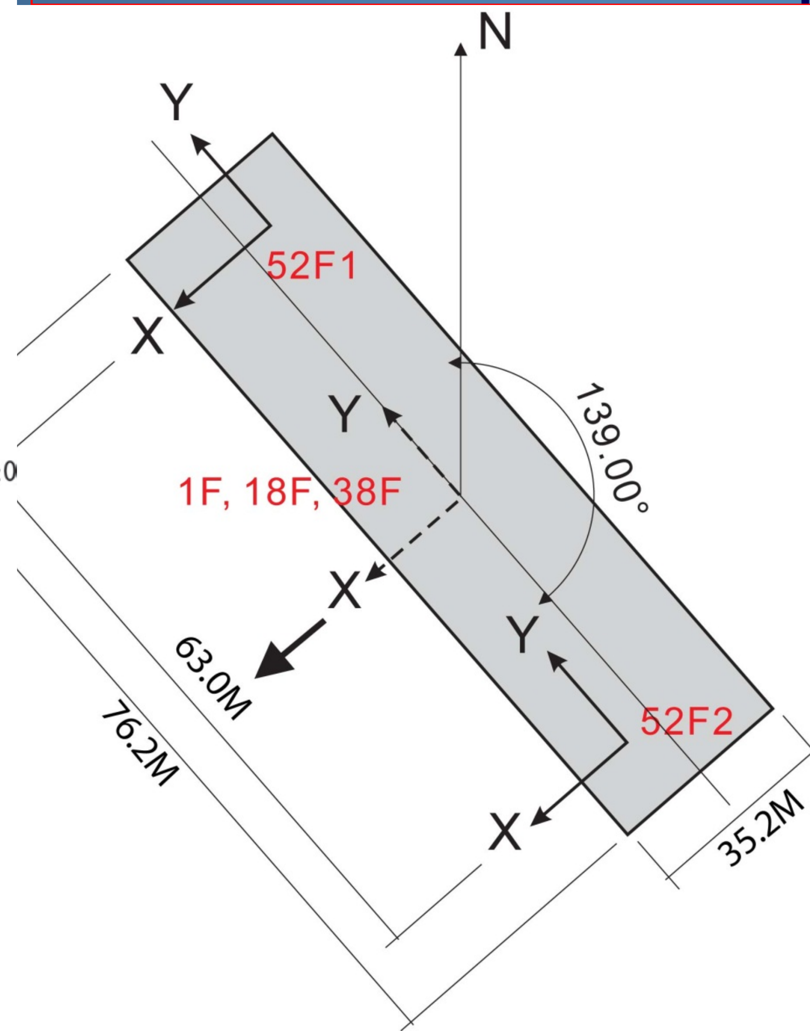


Event	Time	Name of Event & Epicenter Coordinates	M (JMA)	Dist (km)	Largest Peak Acc. (gals)1$_{st}$ Fl./52$_{nd}$ Fl
1	201103111446	Off Sanriku [Mainshock] 38°06’11∥N,142°51’36∥E	9.0	769	34.3/130
2	201103111515	Off Ibaraki Pref 36°06’29∥N,141°15’53∥E	7.7	555	9.2/120
3	201103120359	N Nagano Pref 36°59'06"N, 138°35'48"E	6.7	387	1/7
4	201103152231	E Shizuoka Pref 35°18'29"N, 138°42'47"E	6.4	309	1/6
5	201104072332	Off Miyagi Pref 38°12'11"N, 141°55'11"E	7.1	704	2/8
6	201104111716	Hama-dori, Fukushima Pref 36°56’42∥N,140°40’18∥E	7.0	539	1.5/8
7	201107051918	N Wakayama Pref. 33°59'24"N, 135°13'59"E	5.5	74	5/7
8	201107100957	Off Sanriku 38°01’54∥N,143°30’24∥E	7.3	816	1.5/13

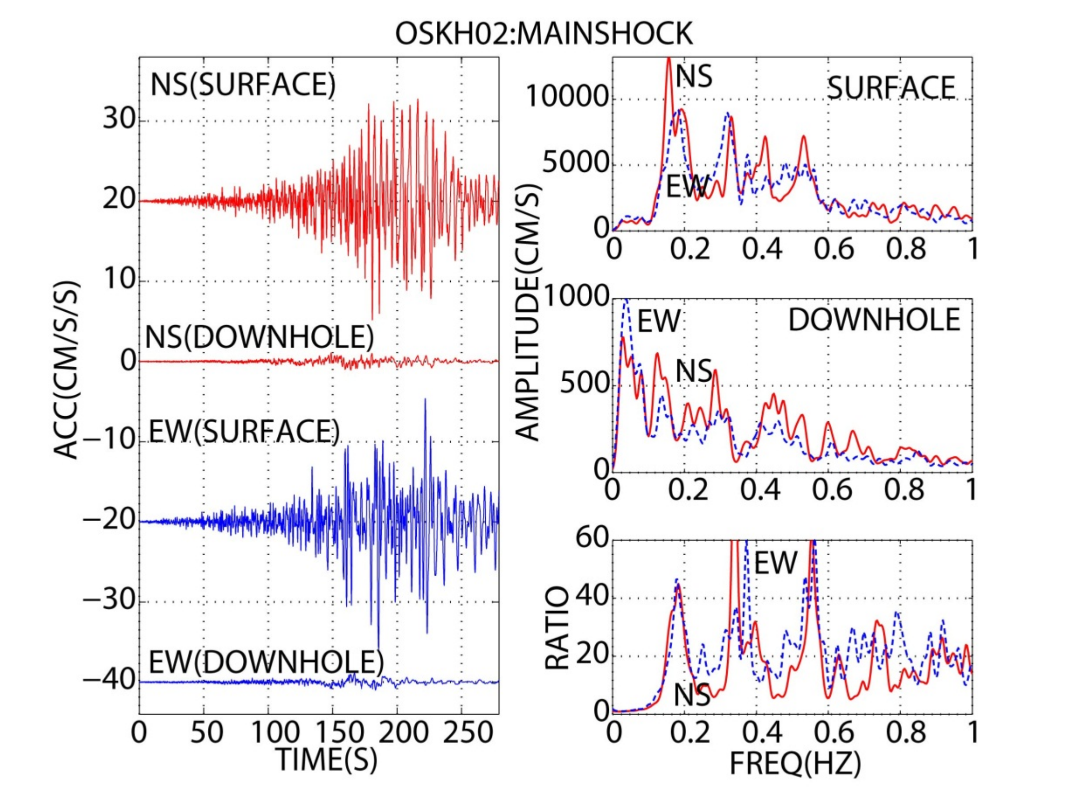
The building & instrumentation (sparse)

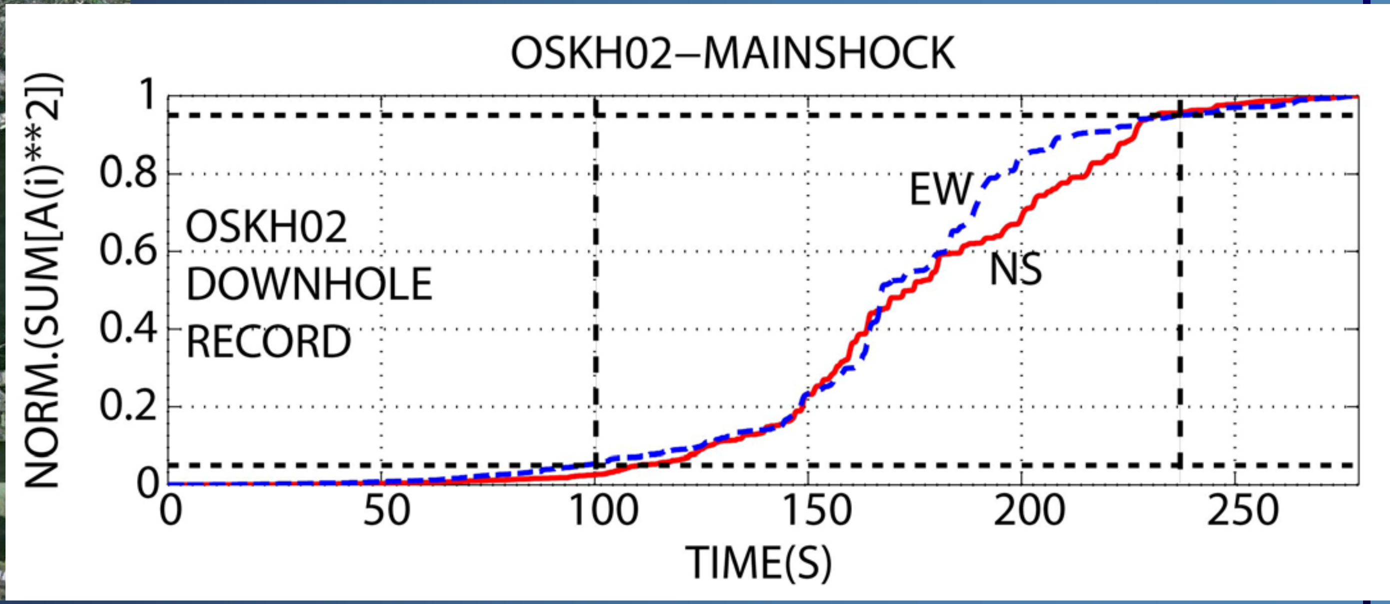




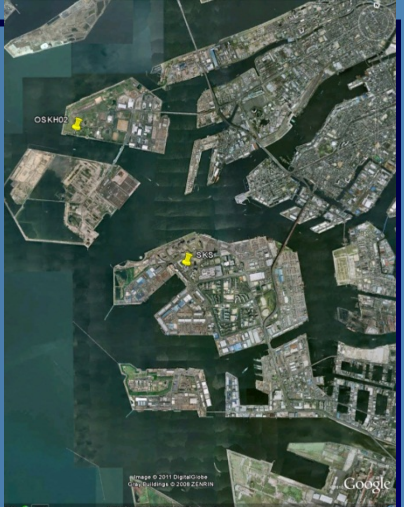


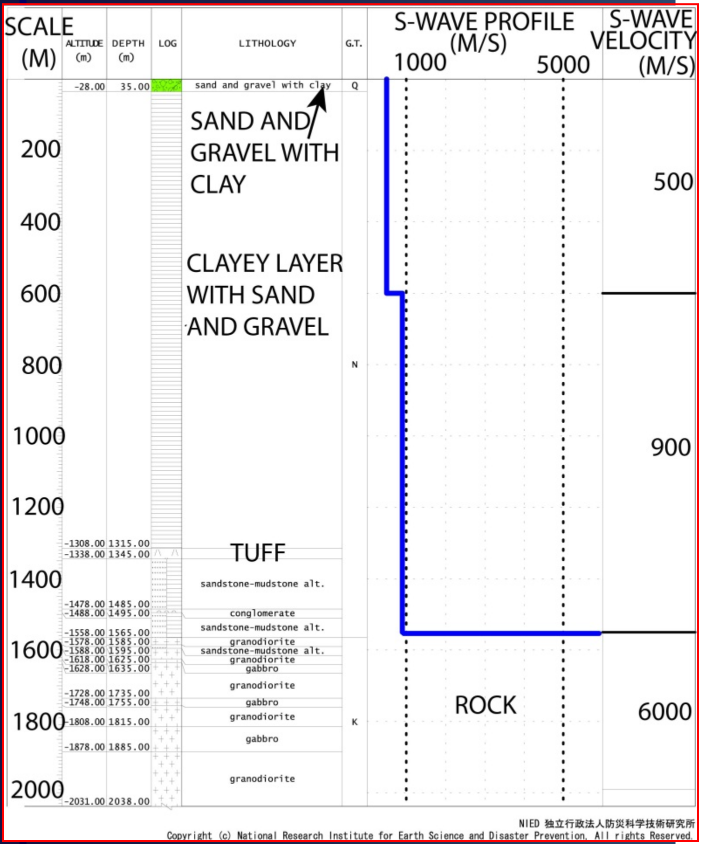
Closest Free-Field Station: OSKH02 (KIK_NET)
Record indicates
[(a) site frequency from actual data (~.14-.18 Hz) & (b) shaking duration]

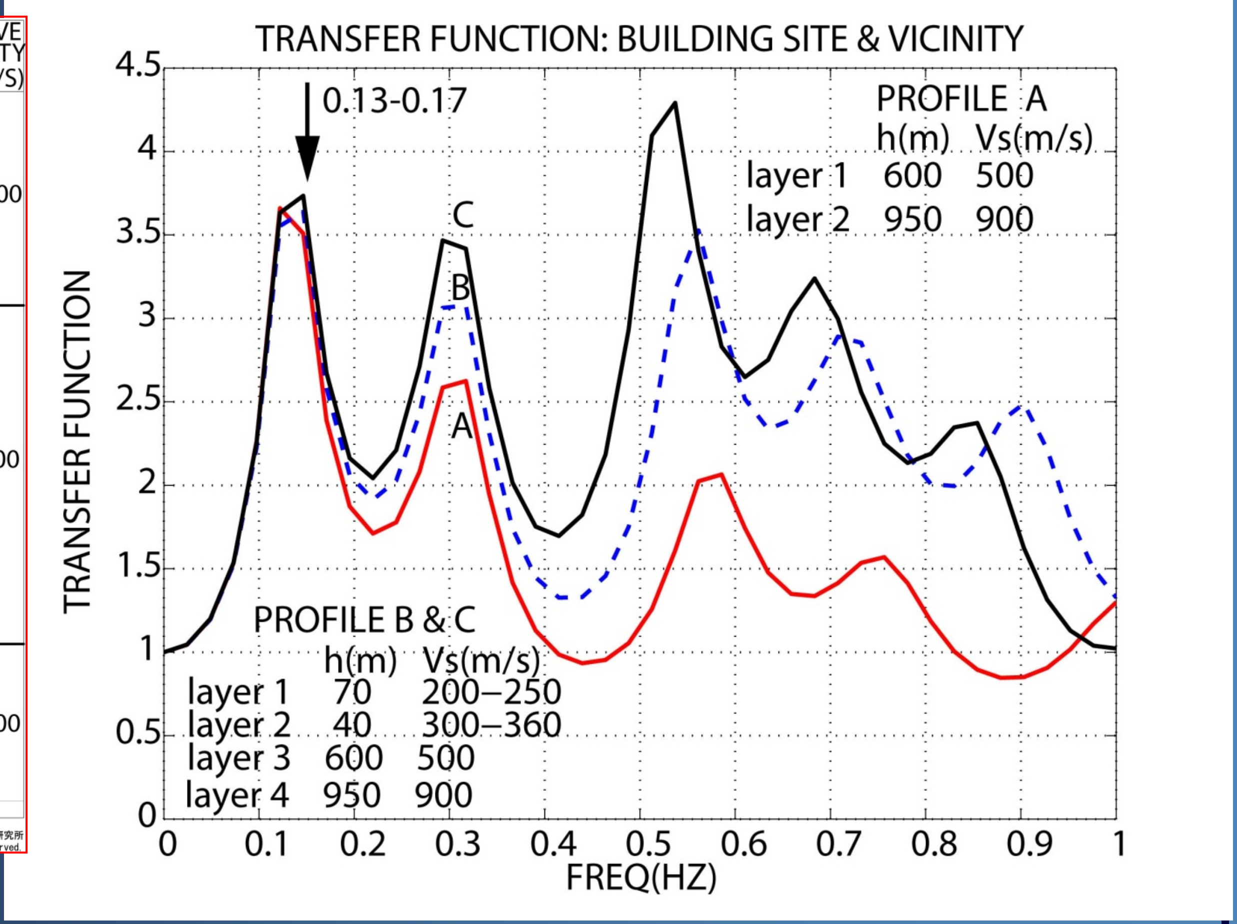


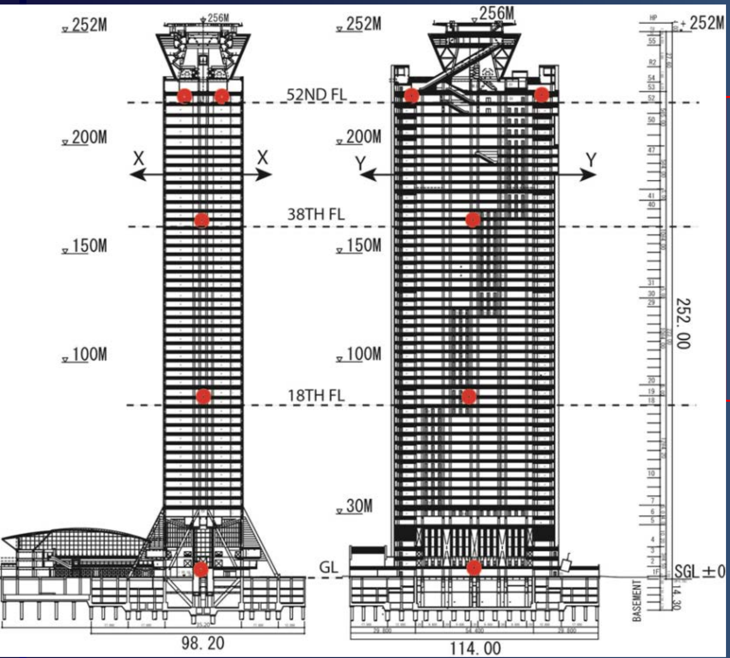


Site Info from OSKH02 and building site indicate similarities and hence result in similar site frequency as that of strong shaking data [f(site)~0.13-0.17 Hz]

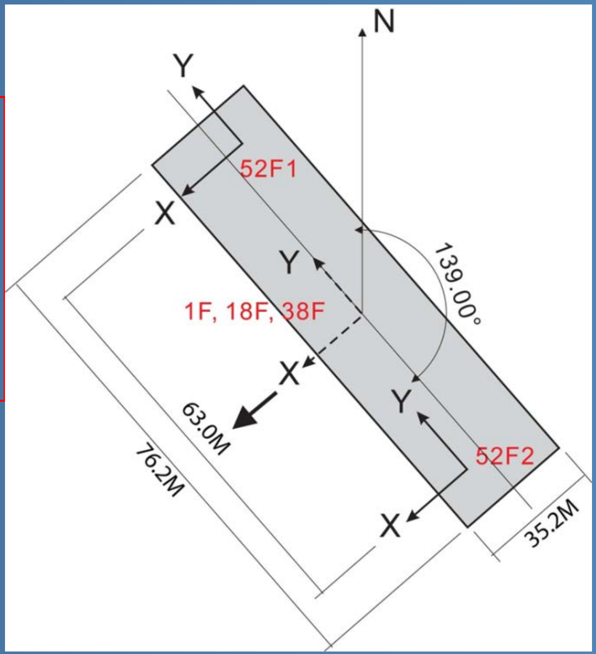


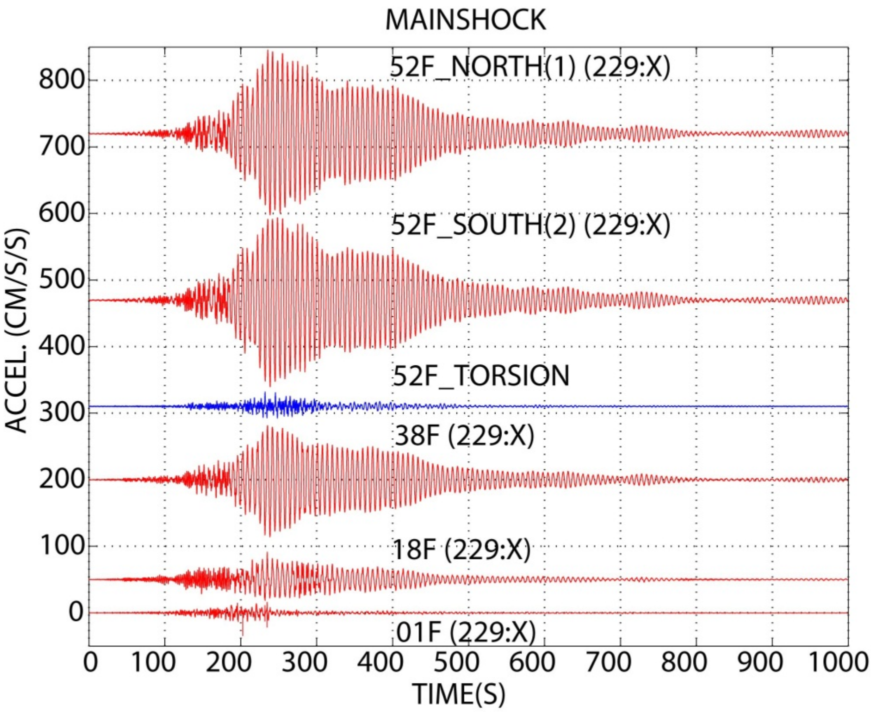


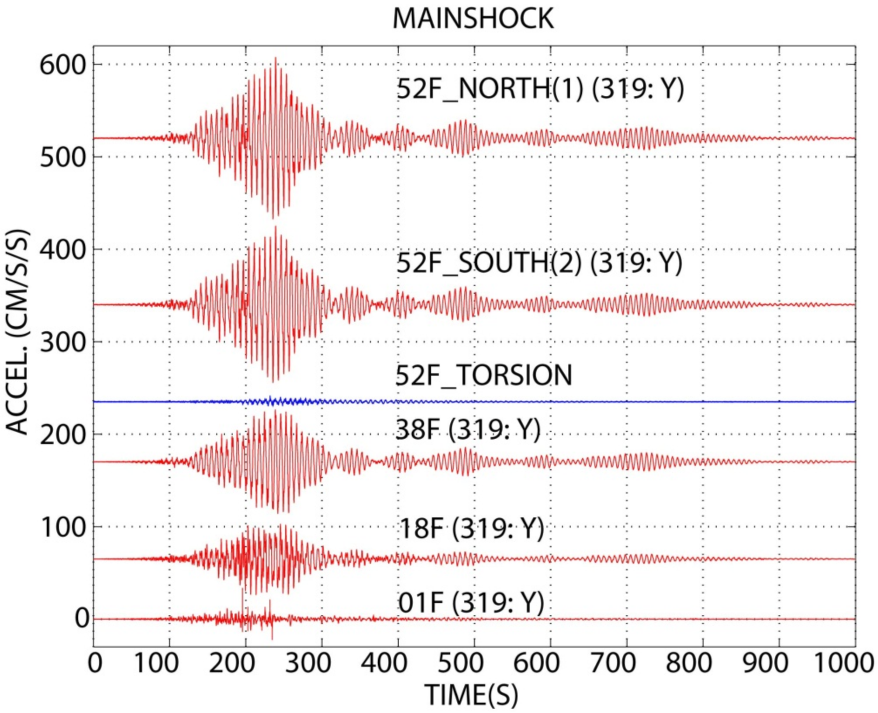


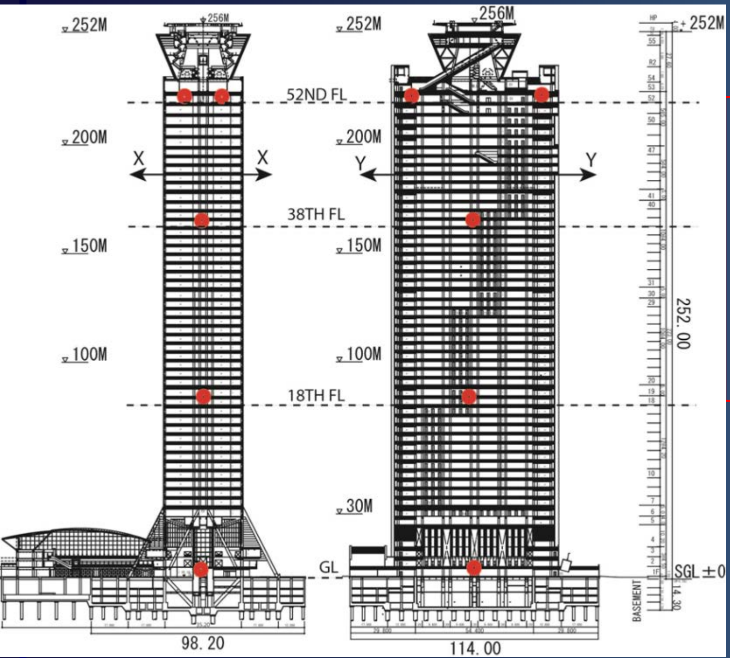


ACCELERATIONS RECORDED (MAIN-SHOCK)

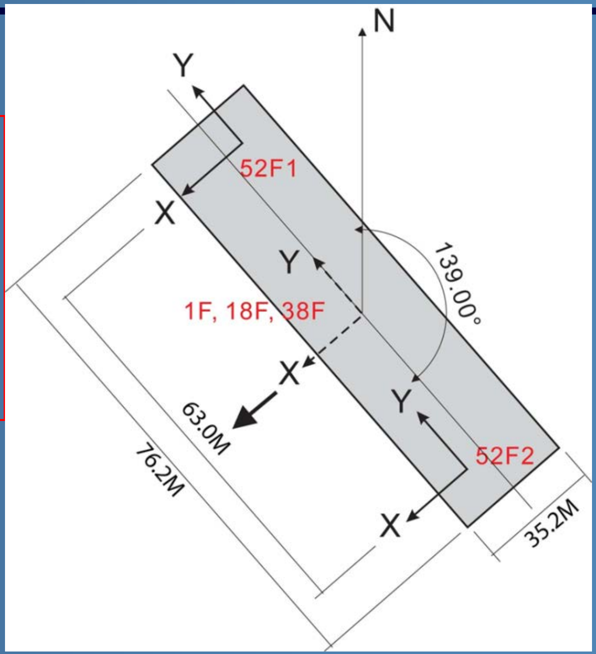


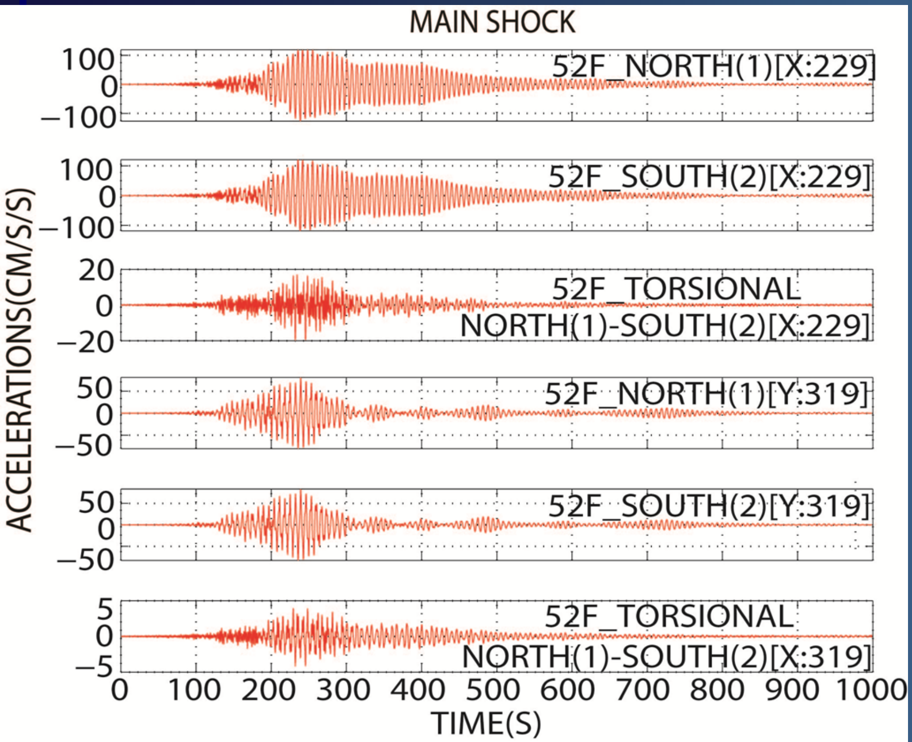


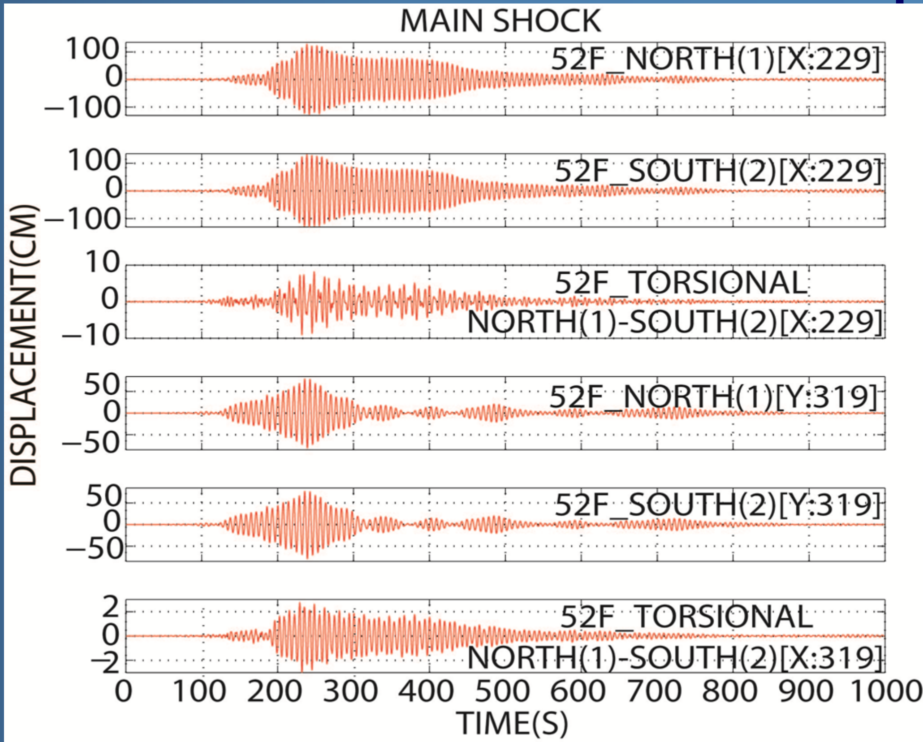




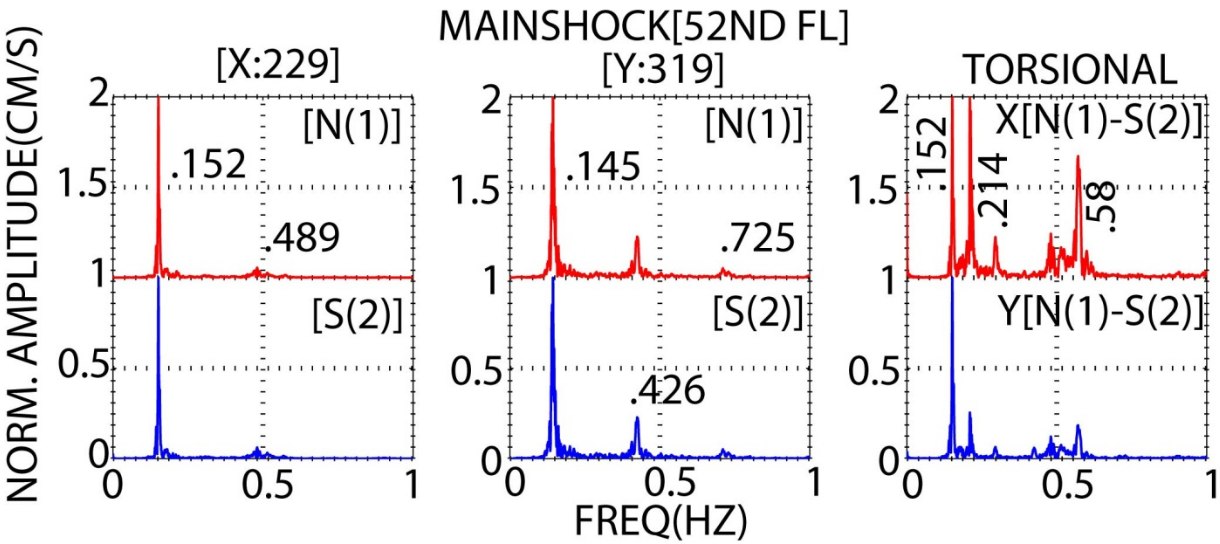
ACCELERATIONS & DISPLACEMENTS AT 52ND FLOOR

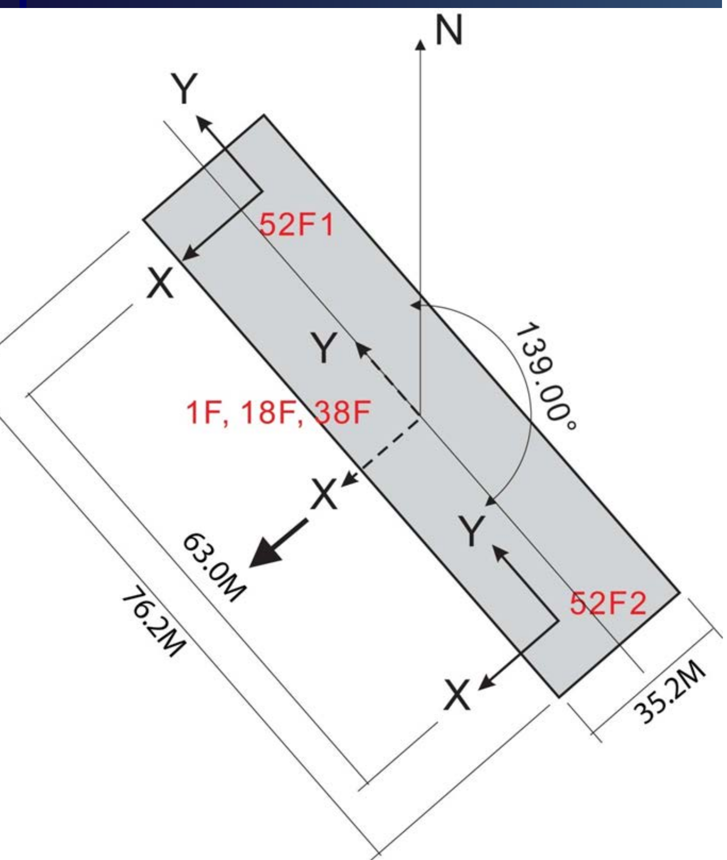


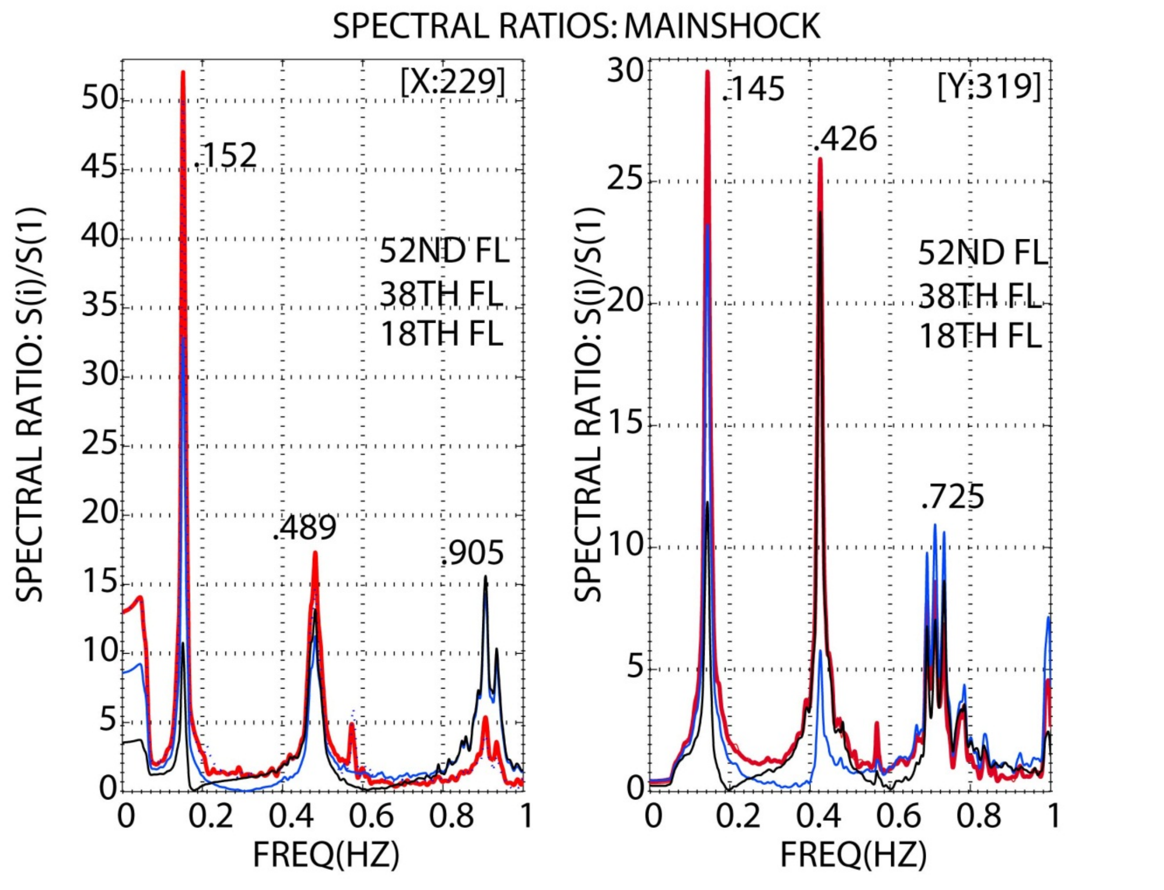




Amplitude Spectra and Spectral Ratio (w.r.t 1st Floor)

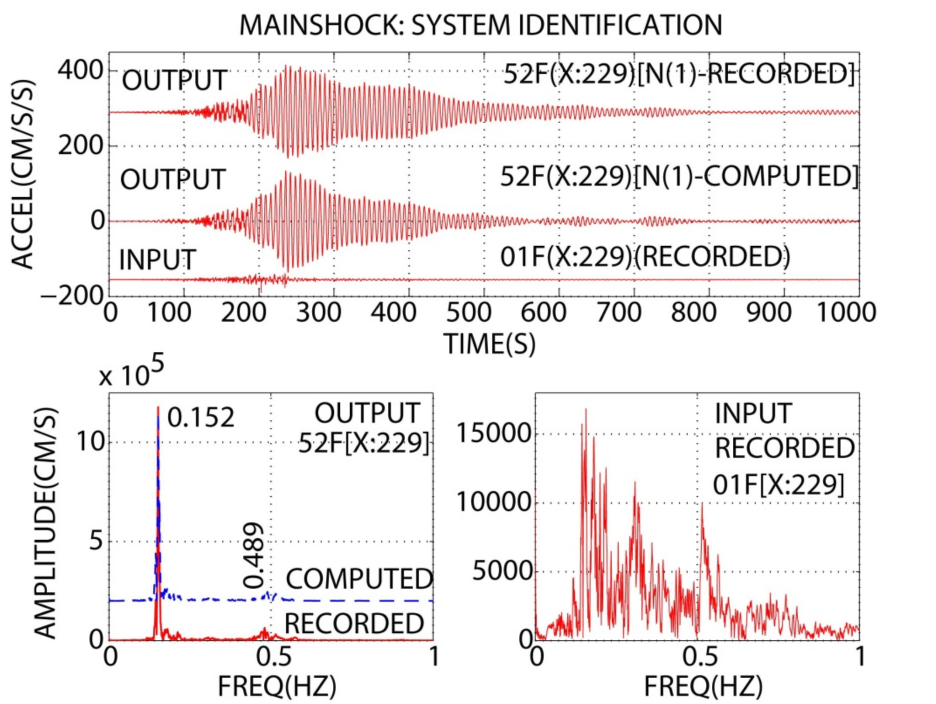


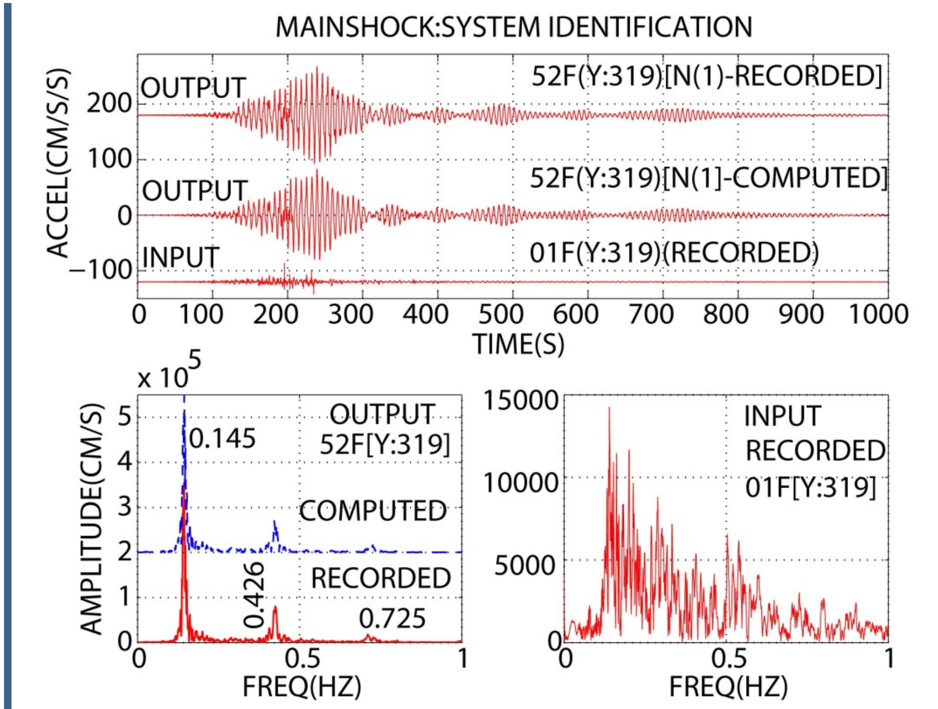




System Identification

ORIENTATION	X[229]			Y[319]			TORSION	
MODES	1	2	3	1	2	3	1	2
SYSTEM IDENTIFICATION								
MAINSHOCK [EVENT 1] (System Identification)								
Freq(Hz) [T(s)]	0.1524 [6.56]	0.4887 [2.05]	N/A	0.1447 [6.91]	0.4264 [2.35]	0.7250 [1.38]		
Damping (ξ)	0.012	0.020		0.016	0.001	0.020		





Design Analyses, Spectral Analyses & System Identification

ORIENTATION	X[229]			Y[319]			TORSION	
MODES	1	2	3	1	2	3	1	2
ANALYSES DURING DESIGN								
Freq(Hz) [T(s)]	.1887 [5.3]			.1724 [5.8]			.2703 [3.7]	
MAINSHOCK [EVENT 1] (Spectral Analyses)								
Freq(HZ) [T(s)]	0.152 [6.58]	0.489 [2.06]	0.905 [1.11]	0.145 [6.90]	0.426 [2.34]	0.725 [1.38]	.213 [4.69]	.58 [1.72]
SYSTEM IDENTIFICATION								
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Freq(Hz) [T(s)]	0.1524 [6.56]	0.4887 [2.05]	N/A	0.1447 [6.91]	0.4264 [2.35]	0.7250 [1.38]		
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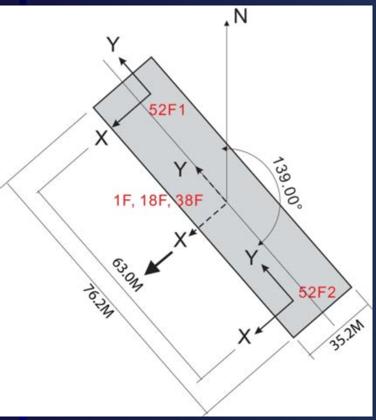
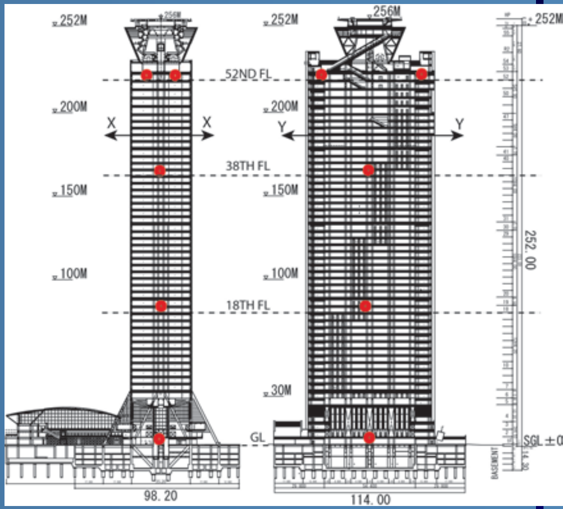
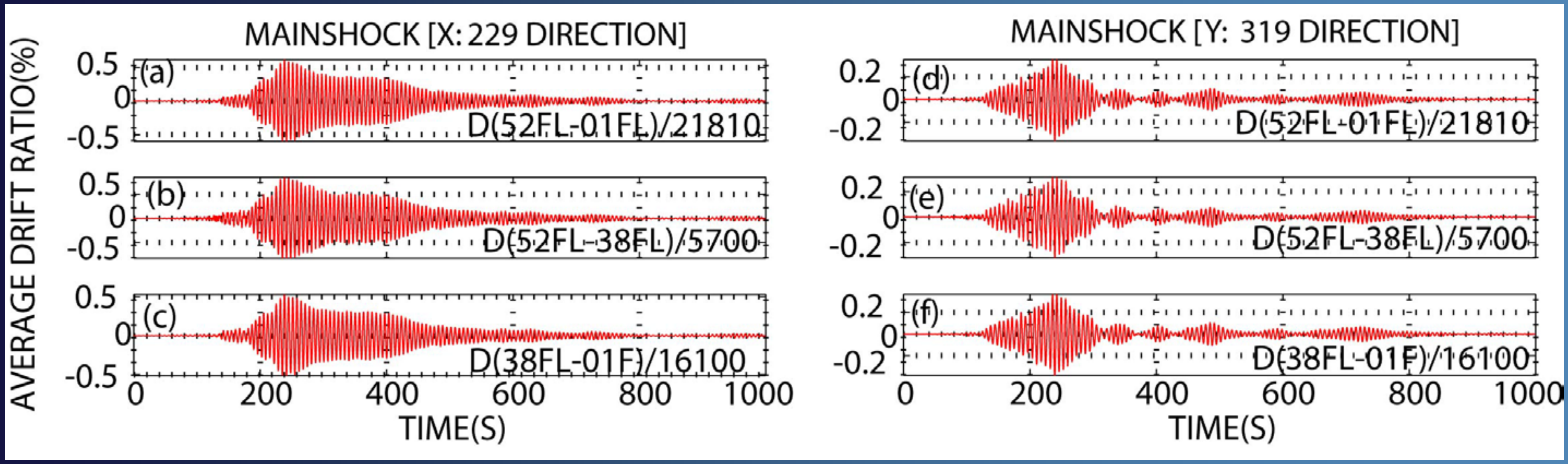
AVERAGE DRIFT RATIO

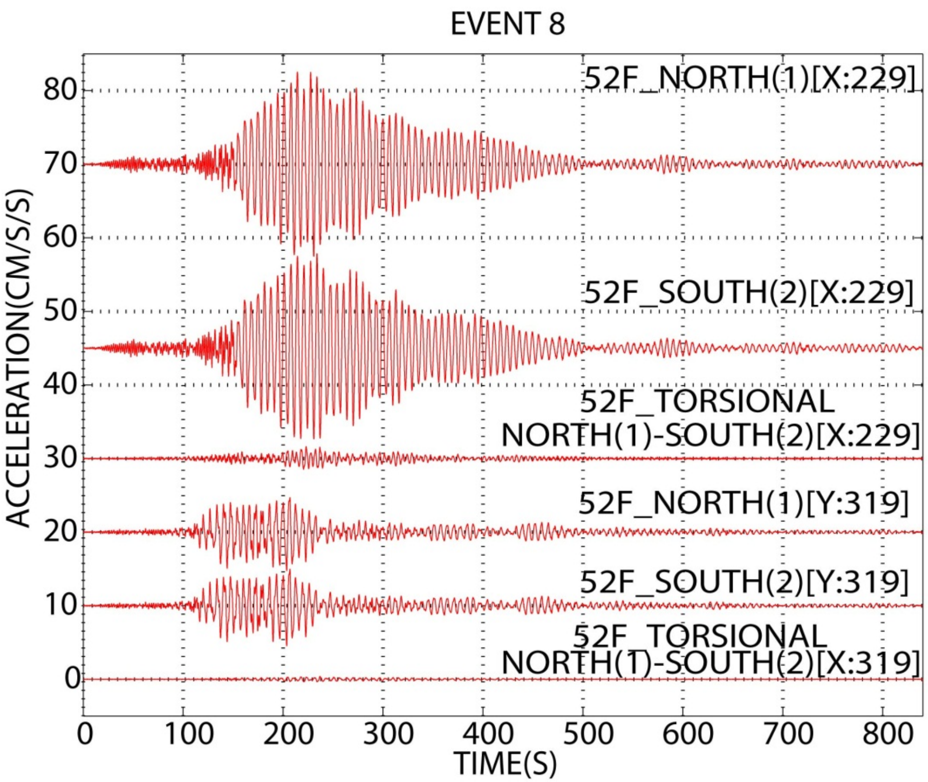


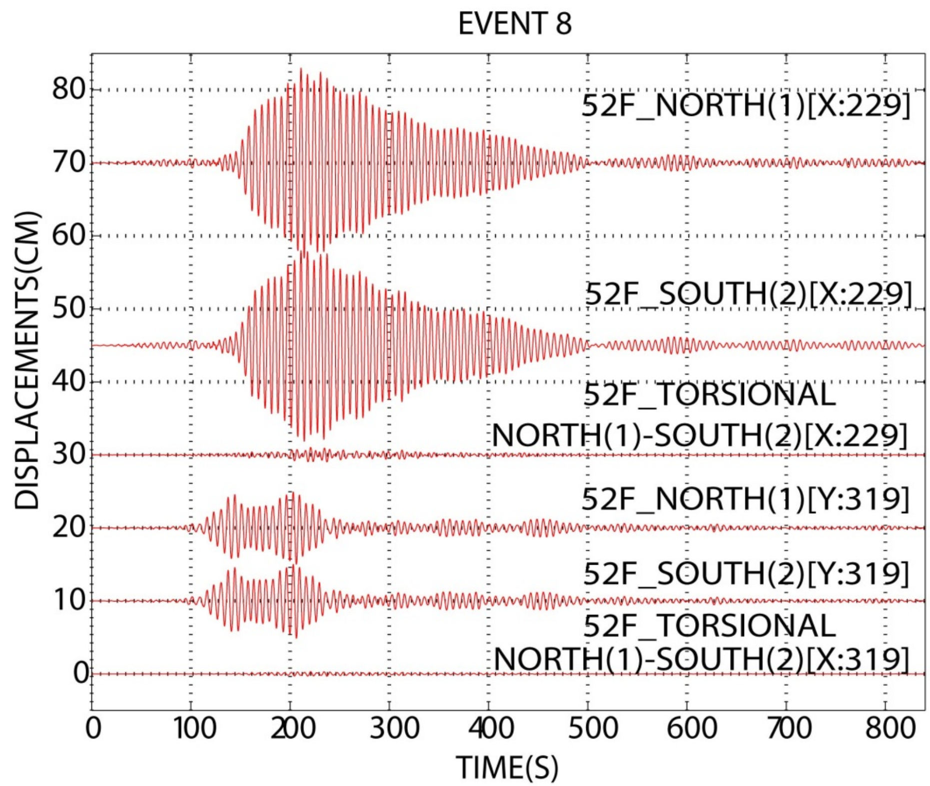
- Why average drift ratio?
- Sparse instruments
- ~.005 (or ~.5%) drift ratio (X-Dir)
- Implications(!!): 3%g input motion, ~.5% drift ratio: not-acceptable





Repeatability





Repeatability

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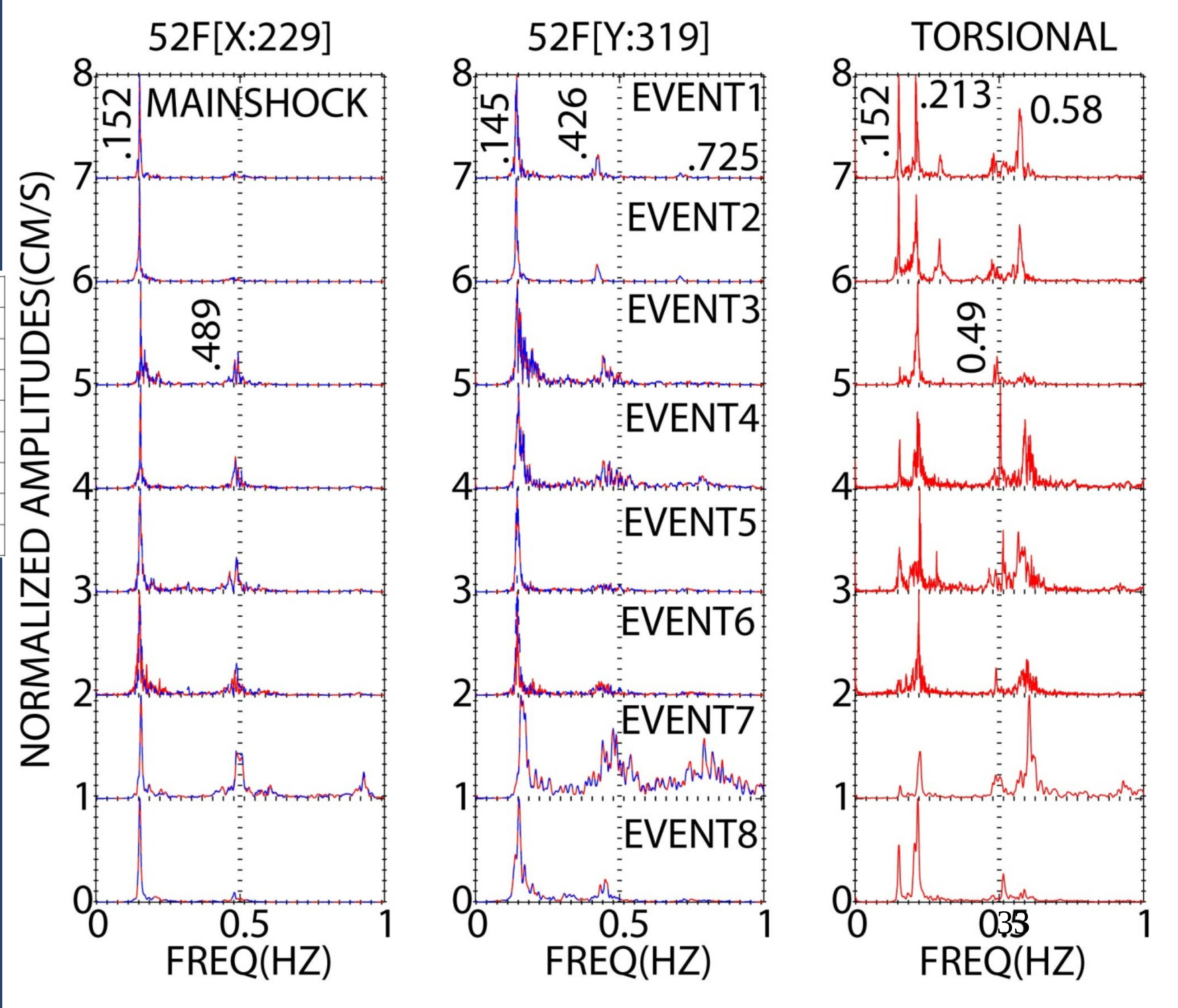
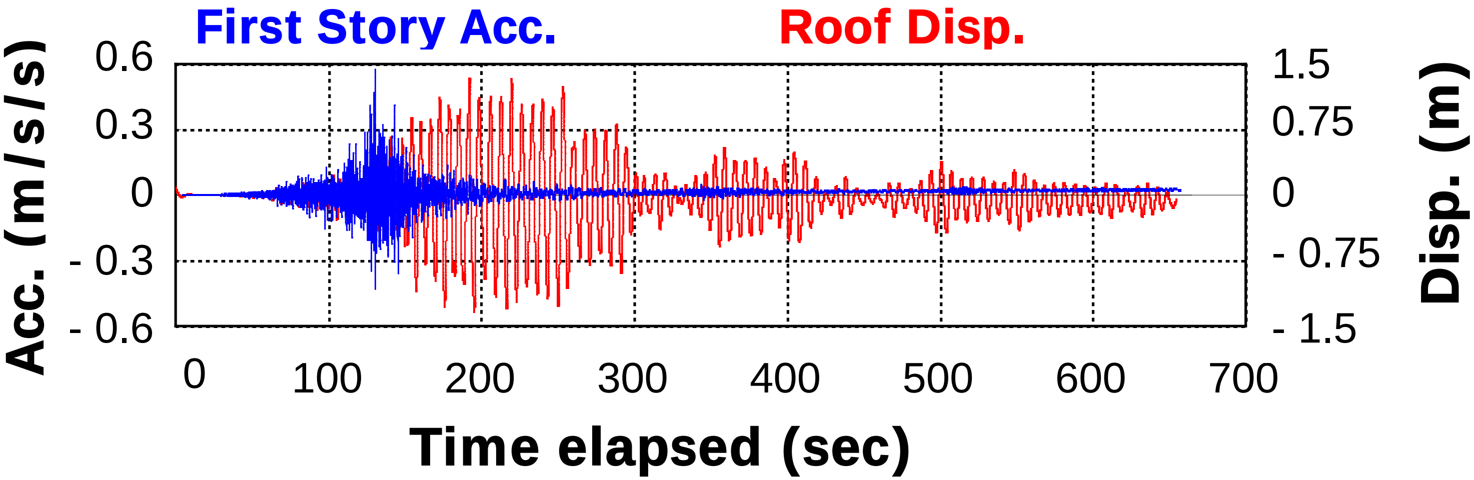


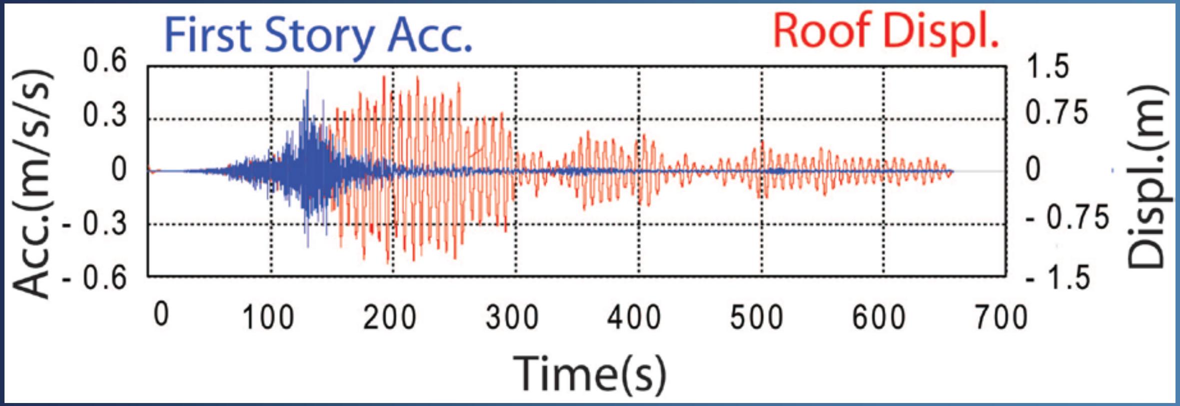
Building B: 55-Story Shinjuku Center Building in Shinjuku, Tokyo (~350-375 km from Epicenter)

According to EERI Special Earthquake Report (EERI Newsletter, 2012), the 54-story Shinjuku Center Building was constructed in 1979. The report states: “The structure’s height is 223m, and the first natural period of the structure is 5.2 and 6.2 seconds in two perpendicular directions. The dampers were calculated to have reduced the maximum accelerations by 30% and roof displacement by 22%

High-rise buildings: (Example: 55-Story Shinjuku Center Building in Shinjuku, Tokyo) (courtesy: J. Moehle)



Built 1975, retrofitted 2009 viscous dampers): First story acceleration (BLUE~max ~0.35g) This is not large. Roof displacement time history (RED ~1.5m) Most notable is the long time motion over 10 minutes. Courtesy: J. Moehle).



- AVERAGE DRIFT RATIO: 150/22300 = ~0.7% < 1% according to Japanese practice.
- However: the actual drift ratios computed from relative displacements divided by story heights between some of the pairs of two consecutive floors are certainly to be larger than the average drift ratio computed using the maximum roof displacement divided by the height of the building

CONCLUSIONS (1/2)

- 1. For small ground level input ground motions as in the two cases presented herein, these two tall buildings deformed significantly to experience sizeable drift ratios.
- 2. Collection of such data is essential (a) to assess the effect of long period ground motions on long period structures caused by sources at large distances, and (b) to consider these effects and discuss whether the design processes should consider reducing drift limits to more realistic percentages (c) finally, further applications of unique response modification features are feasible to reduce the drift ratios.

CONCLUSIONS (2/2)

- 3. Behavior and performances of these particular tall buildings far away from the strong shaking source of the M9.0 Tohoku earthquake of 2011 and large magnitude aftershocks should serve as a reminder that, in the United States as well as in many other countries, risk to such built environments from distant sources must always be considered.
- 4. The risk from closer large-magnitude earthquakes that could subject the buildings to larger peak input motions (with similar frequency content) should be assessed in light of the substantial drift ratios under the low peak input motions experienced during and following the Tohoku earthquake of 2011.

THANK YOU!

Q?