Using The Downhole Strong Ground Motion Array To Study The Nonlinearity Of Soft Soil Layers

Speaker: Yi-Wei Cheng

Reference

- Investigation Of Non-linear Site Amplification At Two Downhole Strong Ground Motion Arrays In Taiwan (K.L.Wen, 1995)
- Nonlinearity, Liquefaction, and Velocity Variation of Soft Soil Layers in Port Island, Kobe, during the Hyogo-ken Nanbu Earthquake (Aguirre, 1997)

Outline

- Introduction
- Data and Results
- Discussion
- Conclusions

Introduction

- **Nonlinearity**
- The nonlinear relation in the case of large strains may play an important role in ground motions at soil sites near the source during large earthquakes.
- It has been known that non-linear effects in near-surface deposits can be manifested in increased damping and reduced shear wave velocity.
- Since $V = 4Hf$, the decrease in shear wave velocity should be associated with the downward shift in the resonance frequency of the layer.
- A main obstacle to identifying non-linear site effect is that observed spectra are contaminated by source and path spectral contributions.

Introduction

- **Method**

$$R(t) = S_0(t) * P(t) * S_i(t)$$

↓ FT

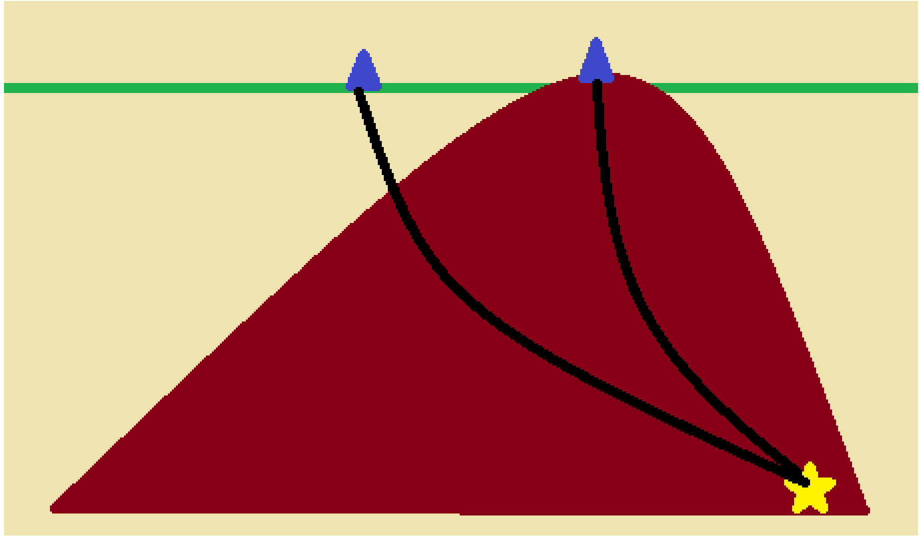
$$R(f) = S_0(f) \times P(f) \times S_i(f)$$

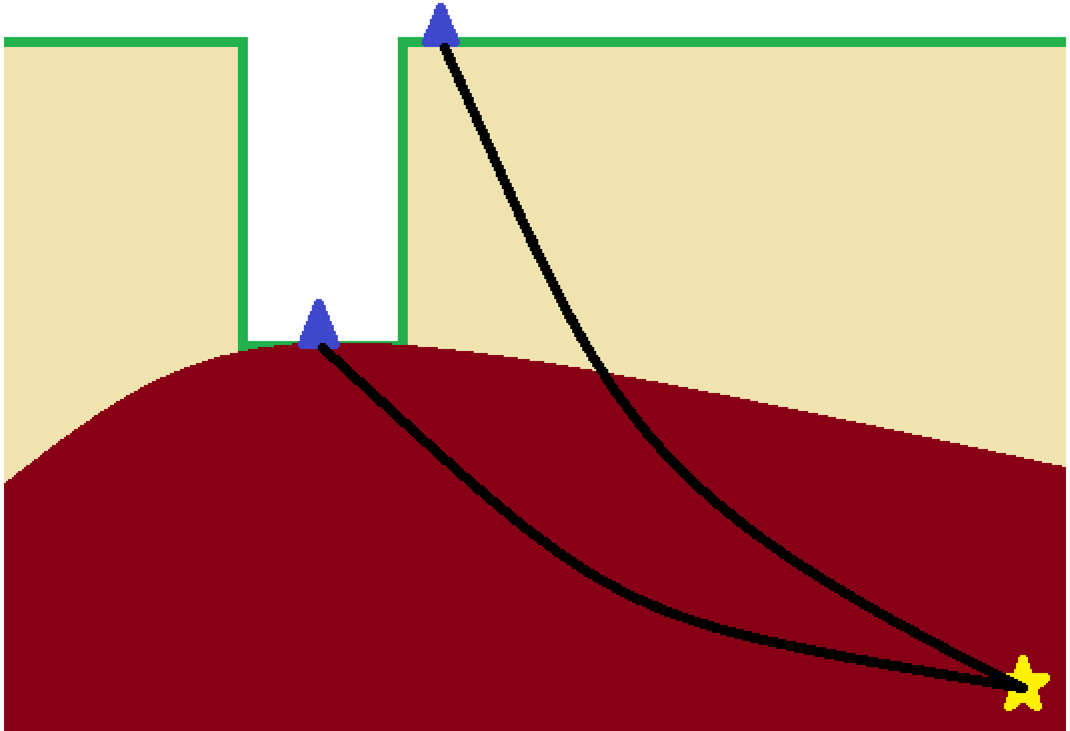
↓

$$\frac{R_s(f)}{R_r(f)} = \frac{\cancel{S_{os}(f)}\times \cancel{P_s(f)}\times S_{is}(f)}{\cancel{S_{or}(f)}\times \cancel{P_r(f)}\times S_{ir}(f)}$$

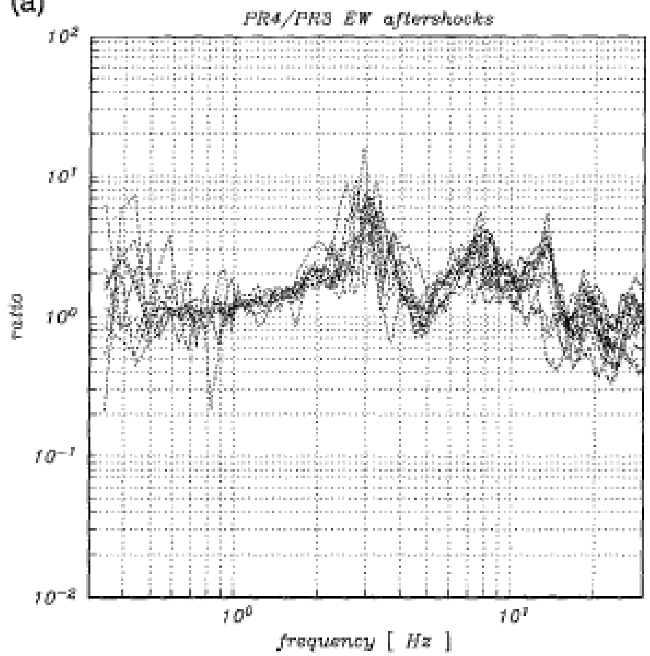
↓

$$\frac{R_s(f)}{R_r(f)} \approx \frac{S_{is}(f)}{S_{ir}(f)}$$

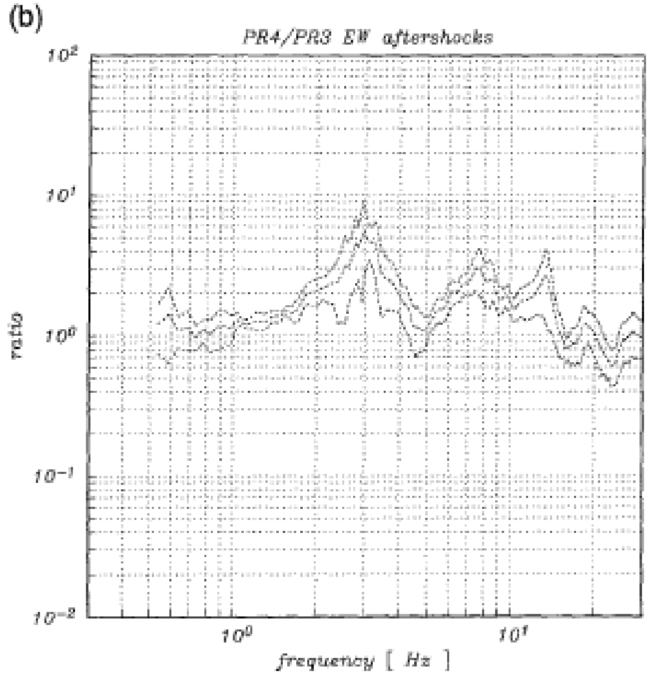




(a)

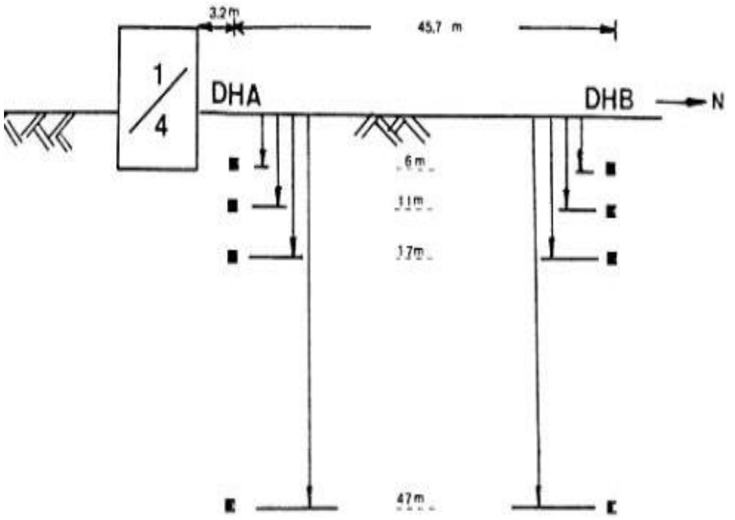

PR4/PR3 EW aftershocks
10^2
10^1
10^0
10^{-1}
10^{-2}
ratio
10^0
10^1
frequency [Hz]

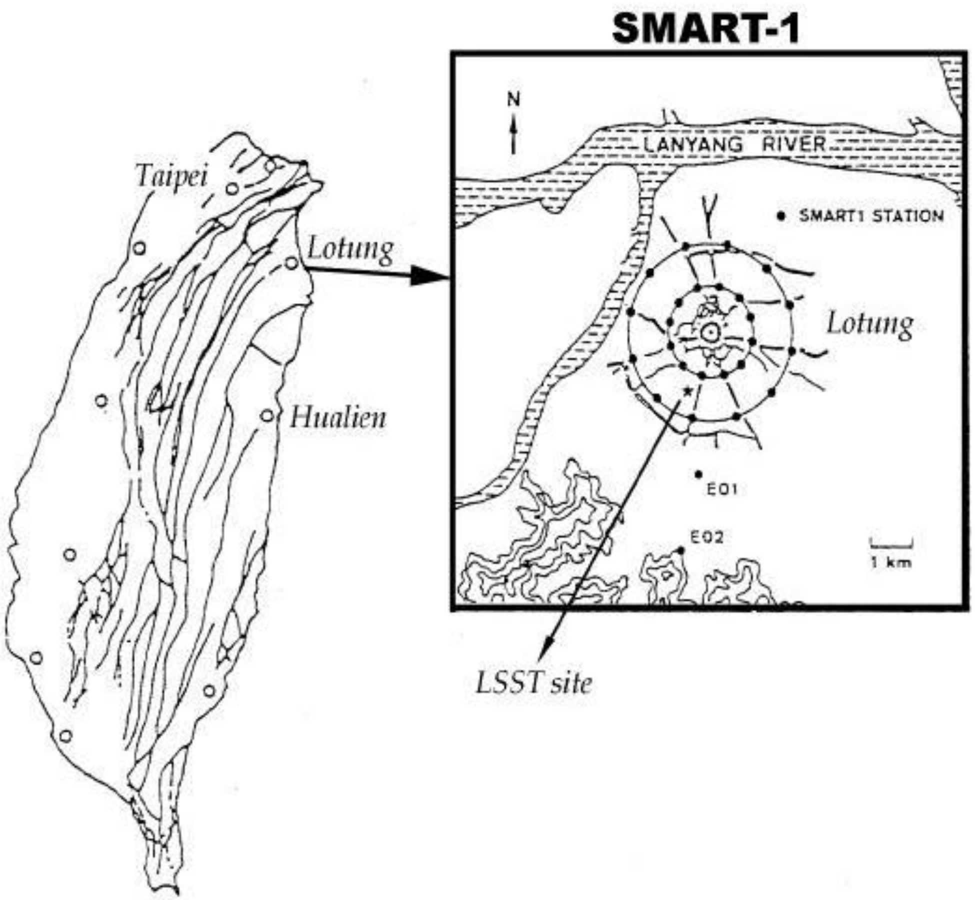
(b)


PR4/PR3 EW aftershocks
10^2
10^1
10^0
10^{-1}
10^{-2}
ratio
10^0
10^1
frequency [Hz]

Data and Results

- LSST array

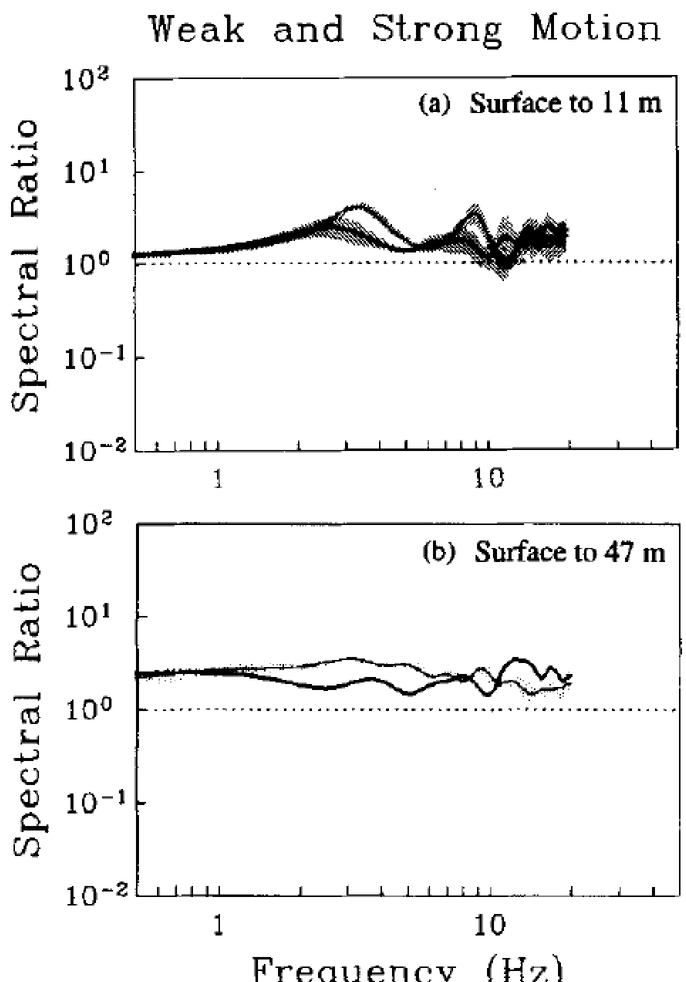




Event	Date	Depth (km)	M_L	△ (km)	$PGA_0/PGA_{11}/PGA_{47}$ (Gal)
Weak motion					
3	1985/11/07	74	5.5	17	27.3/12.0/9.3
5	1986/03/29	10	4.7	8	41.4/17.8/15.4
6	1986/04/08	11	5.4	31	35.4/15.2/13.0
8	1986/05/20	22	6.2	69	35.0/21.5/14.2
14	1986/07/30	2	4.9	5	57.5/31.2
20	1986/12/10	98	5.8	42	23.8/11.4
21	1987/01/06	28	6.2	77	31.8/16.8
22	1987/02/04	70	5.8	16	43.4/20.4
23	1987/06/24	31	5.7	52	31.7/11.5
24	1987/06/27	1	5.3	40	23.7/13.1
27	1988/09/18	63	5.6	68	22.3/11.1
Strong motion					
7	1986/05/20	16	6.5	66	223.6/113.7/96.9
12	1986/07/30	2	6.2	5	186.7/192.8
16	1986/11/14	7	7.0	78	167.2/94.6
Foreshocks to event 12					
9	1986/07/11	1	4.5	5	72.8/34.1/28.4
10	1986/07/16	1	4.5	6	70.0/26.3/19.2

Data and Results

- LSST array



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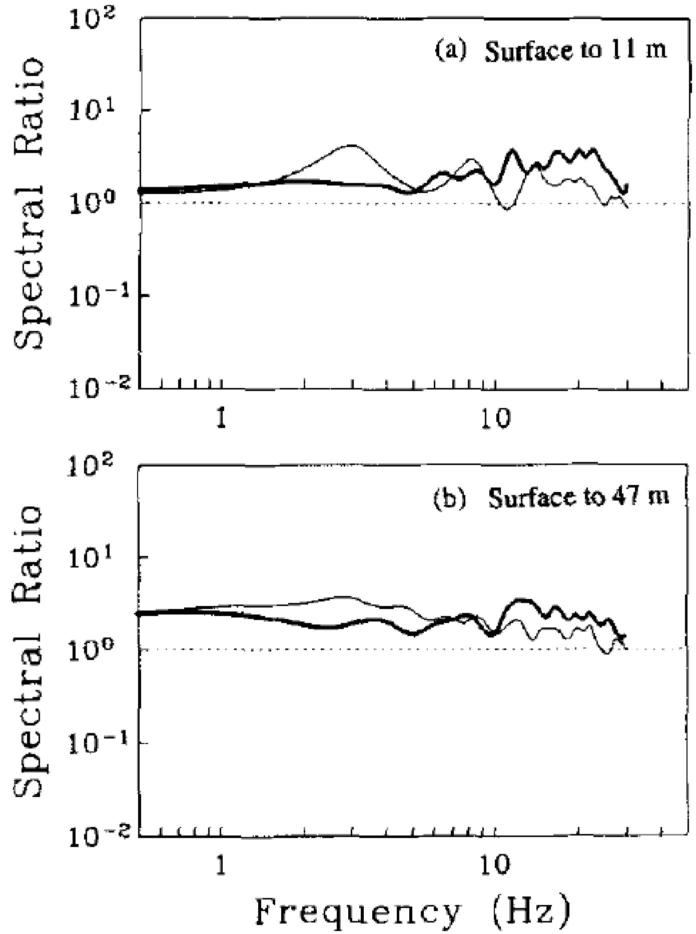
Data and Results

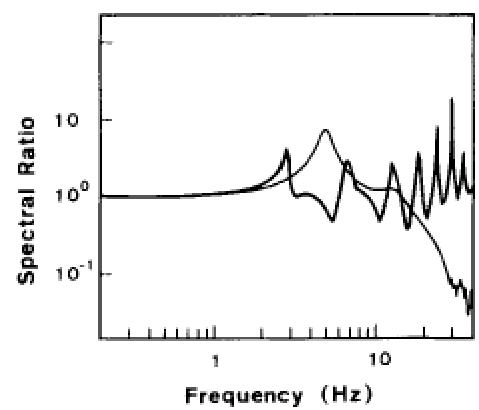
- LSST array

Aftershock 8 and main shock 7



G.Yu (1993)

Surface to center of 20 m-thick layer (theoretical)



					$PGA_0/PGA_{11}/PGA_{47}$ (Gal)
					27.3/12.0/9.3
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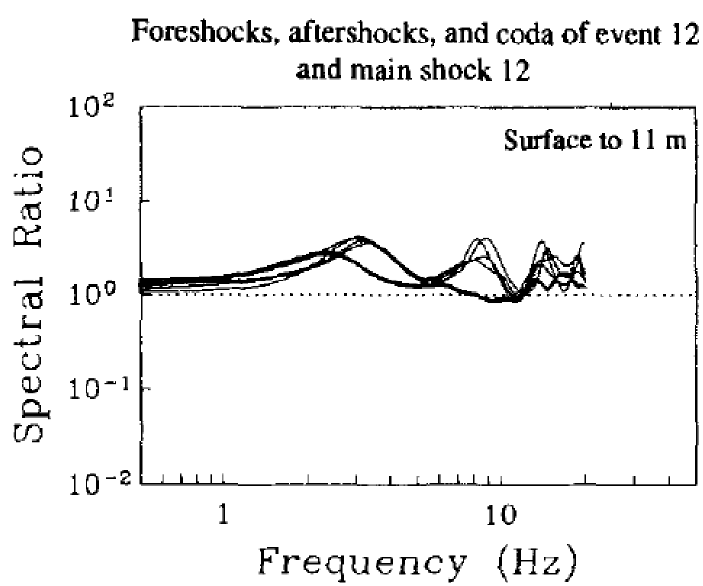
Data and Results

- LSST array



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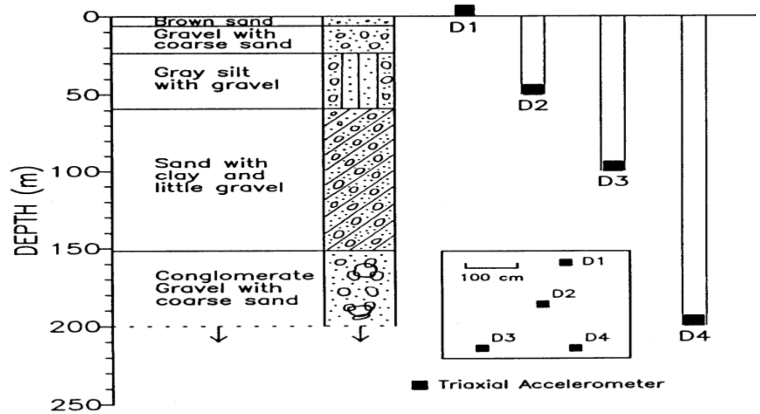
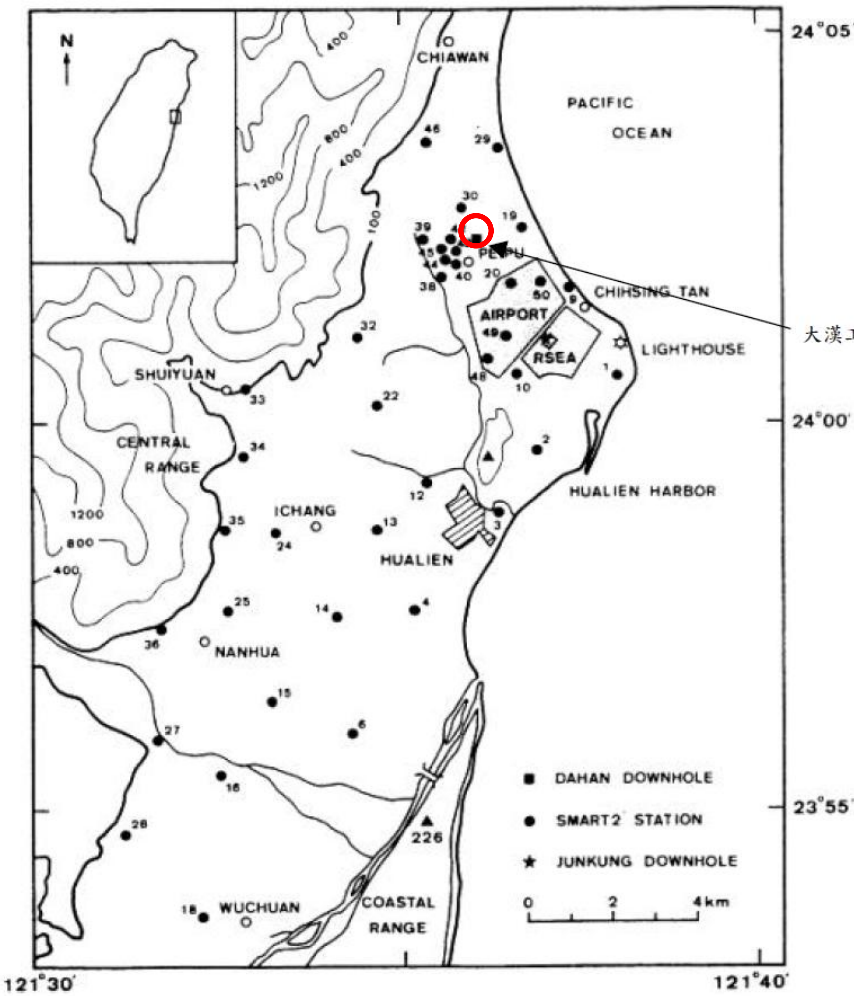
Data and Results

- SMART2 array

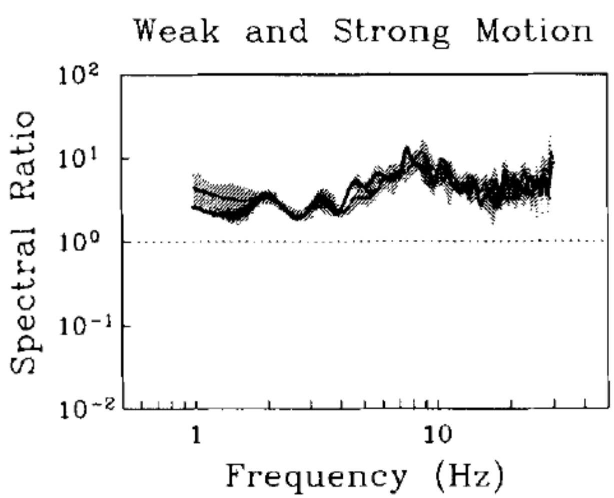




Event	Date	PGA$_0$/PGA$_{200}$ (Gal)		ML	Depth (km)	Hypocentral distance (km)
		EW	NS			
Weak motion						
176	1992/05/21	15.4/1.7	11.6/3.4	4.5	16.7	38.4
185	1992/06/30	17.5/4.9	16.5/4.2	4.5	28.6	33.9
189	1992/07/23	11.2/2.5	15.3/3.0	4.5	12.8	31.1
198	1992/10/09	16.5/2.3	5.1/2.9	4.1	15.9	24.1
222	1993/05/04	10.3/2.0	17.5/2.6	4.0	1.0	5.8
231	1993/06/24	11.5/1.9	12.0/2.6	5.2	65.0	87.4
234	1993/06/25	17.5/4.1	15.0/3.2	3.9	4.6	12.2
235	1993/06/26	17.0/4.1	12.8/3.1	3.6	6.7	11.6
Strong motion						
183	1992/06/25	160.2/34.8	93.7/28.3	4.5	22.7	24.2
192	1992/08/14	135.9/50.6	108.6/31.7	4.5	15.7	26.3
202	1992/12/28	117.6/24.8	154.4/23.4	4.9	16.2	32.4
Aftershock, coda						
184	1992/06/25	38.3/7.5	24.6/7.7	3.3	13.4	23.3
183coda		*	*			
192coda		*	*			
202coda		*	*			

Data and Results

- SMART2 array



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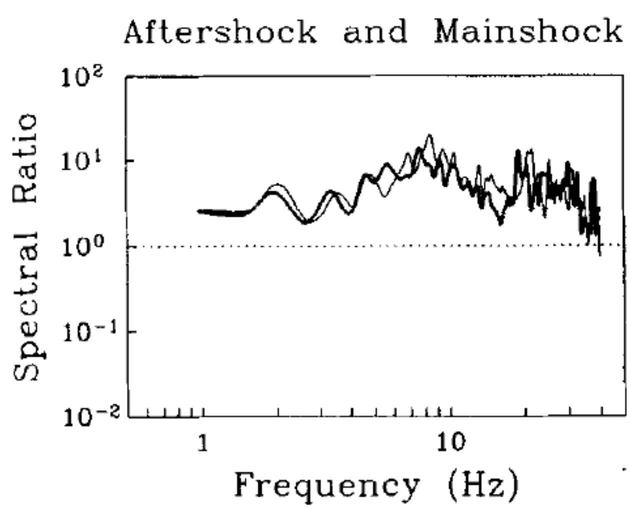
183coda		*	*			
192coda		*	*			
202coda		*	*			

Data and Results

- SMART2 array



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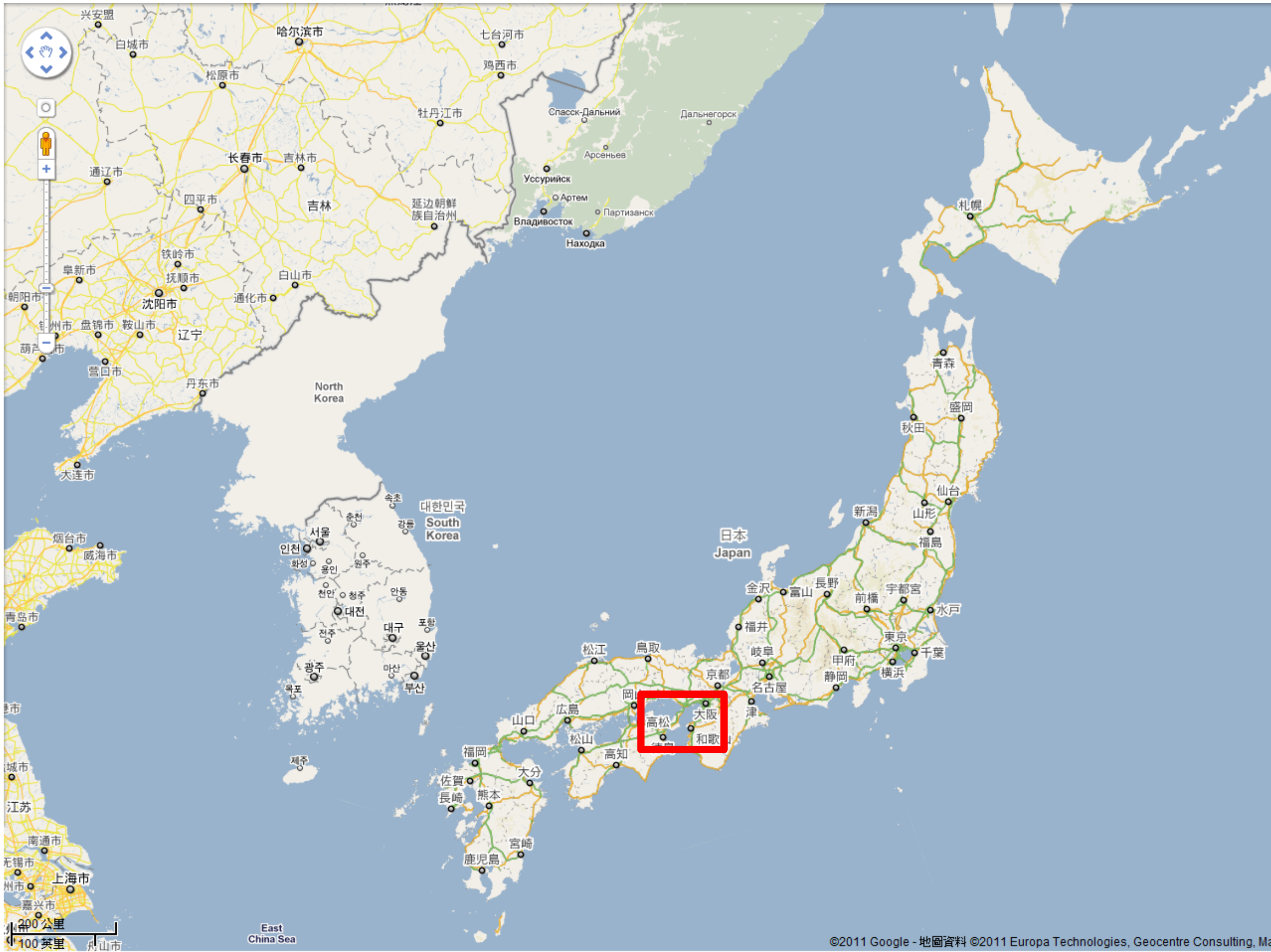
183coda		*	*			
192coda		*	*			
202coda		*	*			

Data and Results

- Japan array



Data and Results

- Japan array

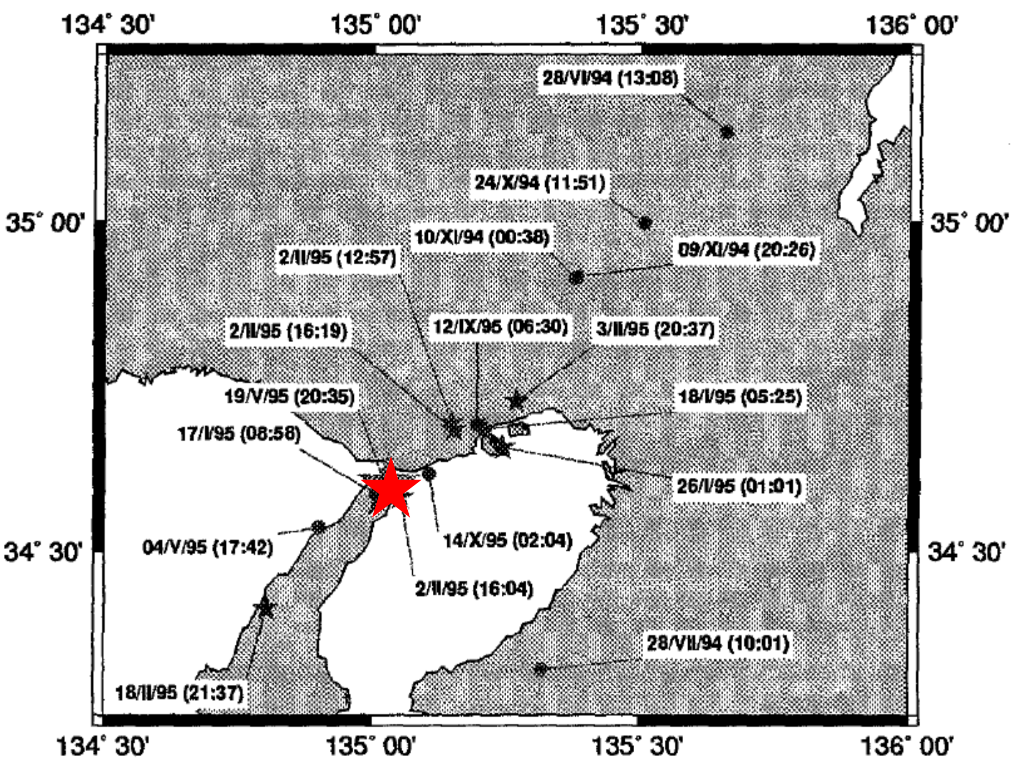


Table 2
Seismic Events Used in This Study

Date (year.month.day)	Time (hr:min:sec)	Depth (km)	Magnitude
94.06.28	13:08:53.02	16.0	4.6
94.07.28	10:01:52.04	11.5	4.1
94.10.24	11:51:10.72	15.1	4.3
94.11.09	20:26:56.41	10.4	4.1
94.11.10	00:38:17.72	11.1	3.9
95.01.17	05:46:46.74	16.0	6.9
95.01.17	08:58:16.14	18.8	4.7
95.01.18	05:25:40.39	9.56	3.0
95.01.26	01:01:18.38	11.01	3.3
95.02.02	12:57:22.13	5.94	2.4
95.02.02	16:04:19.55	12.80	3.4
95.02.02	16:19:27.71	17.24	3.4
95.02.03	20:36:55.32	5.22	3.0
95.02.18	21:37:33.66	20.42	3.8
95.05.04	17:42:02.18	16.2	4.3
95.05.19	20:35:38.97	20.8	4.1
95.09.12	06:30:26.41	15.7	3.9
95.10.14	02:03:59.15	16.8	4.8

Data and Results

- Japan array

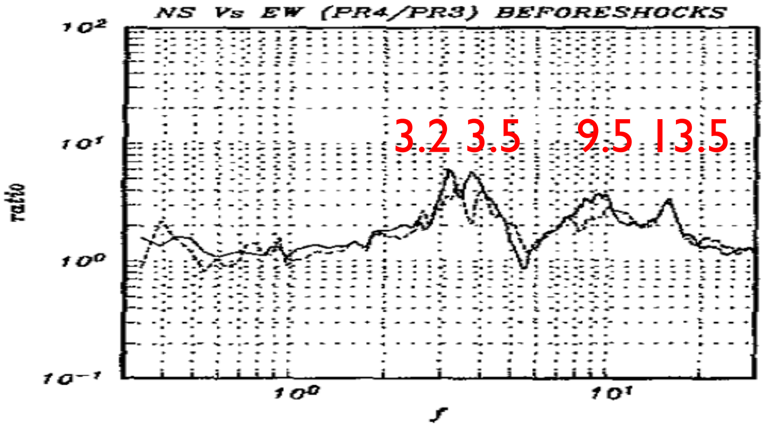
Table 1

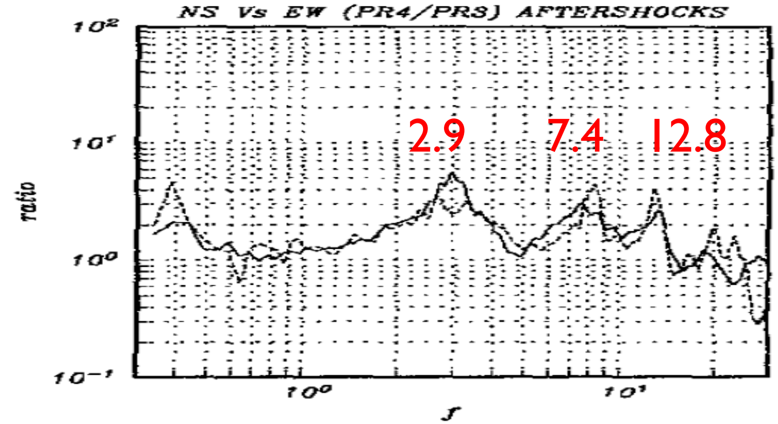
Original Soil Model in Port Island Vertical Array

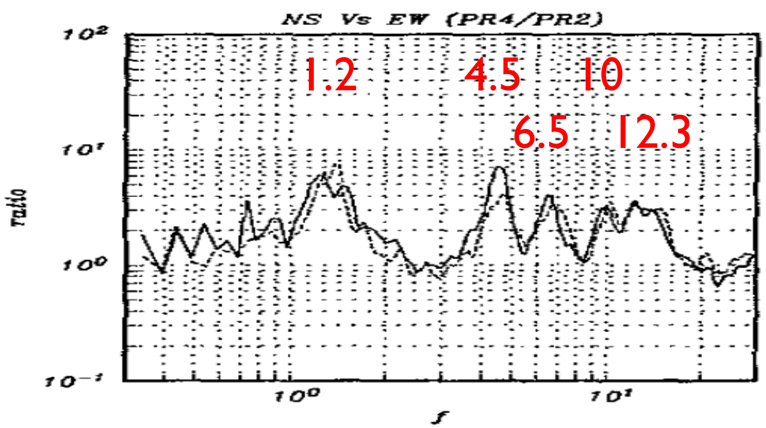
Depth (m)	Soil Type	Location of Accelerometers	V_p [km/sec]	V_s [km/sec]
0–2.0		*PR4-0 m	0.260	0.170
2.0–5.0	Gravel[R]		0.330	
5.0–12.6			0.780	0.210
12.6–19.0	Sandy gravel[R]	*PR3-16 m	1.480	
19.0–27.0	Clay		1.180	0.180
27.0–33.0	Sand	*PR2-32 m	1.330	0.245
33.0–50.0	Sandy gravel and sand		1.530	0.305
50.0–61.0	Sand		1.610	0.350
61.0–79.0	Clay			0.303
79.0–(85.0)	Sandy gravel	*PR1-83 m	2.000	0.320

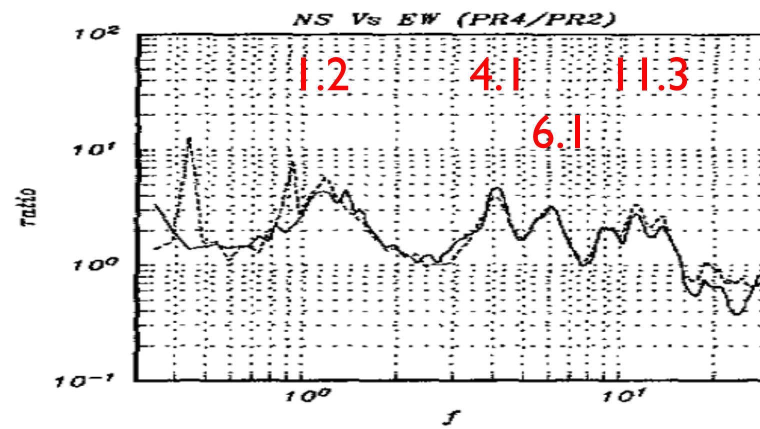
R = Reclaimed land.

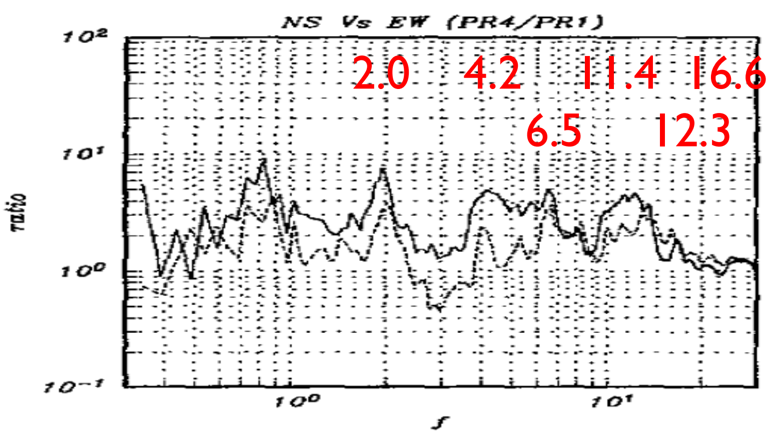
CL-EW
DL-NS

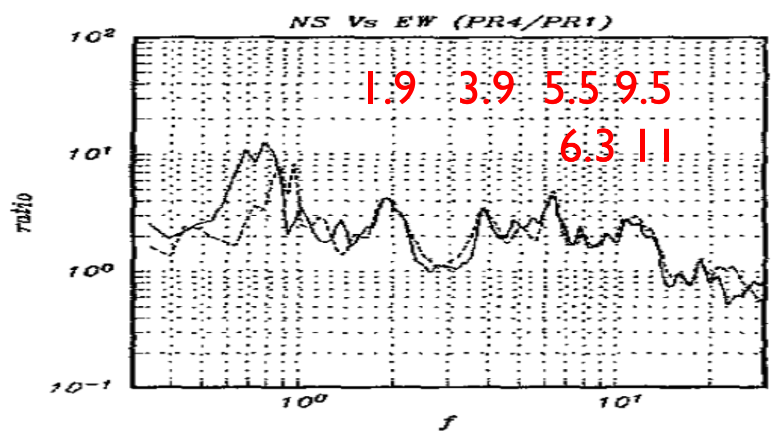

NS Vs EW (PR4/PR3) BEFORESHOCKS
3.2 3.5 9.5 13.5
ratio
f


NS Vs EW (PR4/PR3) AFTERSHOCKS
2.9 7.4 12.8
ratio
f


NS Vs EW (PR4/PR2)
1.2 4.5 10
6.5 12.3
ratio
f

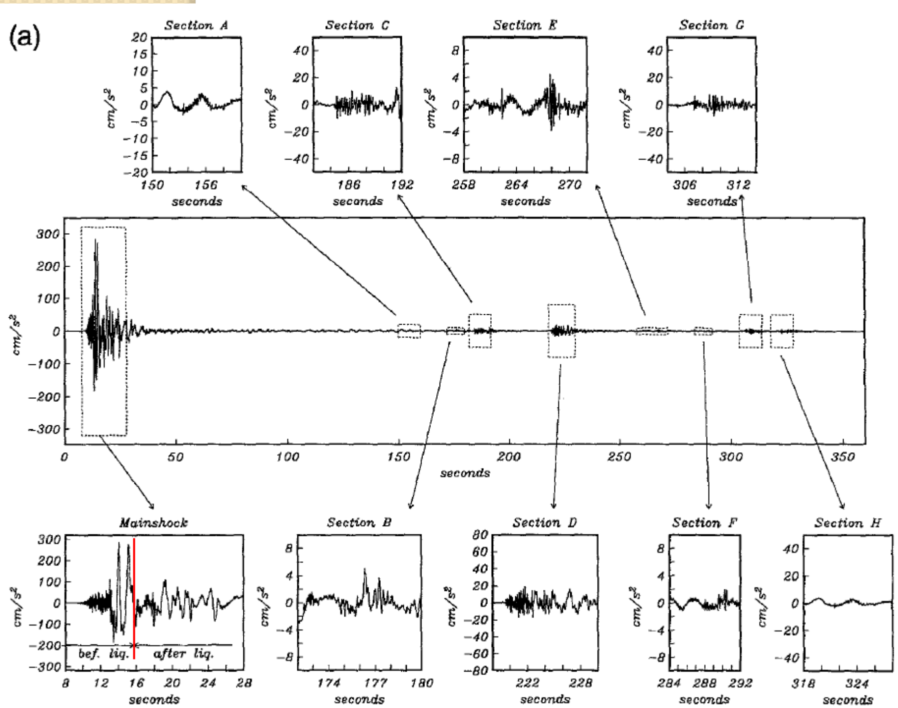

NS Vs EW (PR4/PR2)
1.2 4.1 11.3
6.1
ratio
f

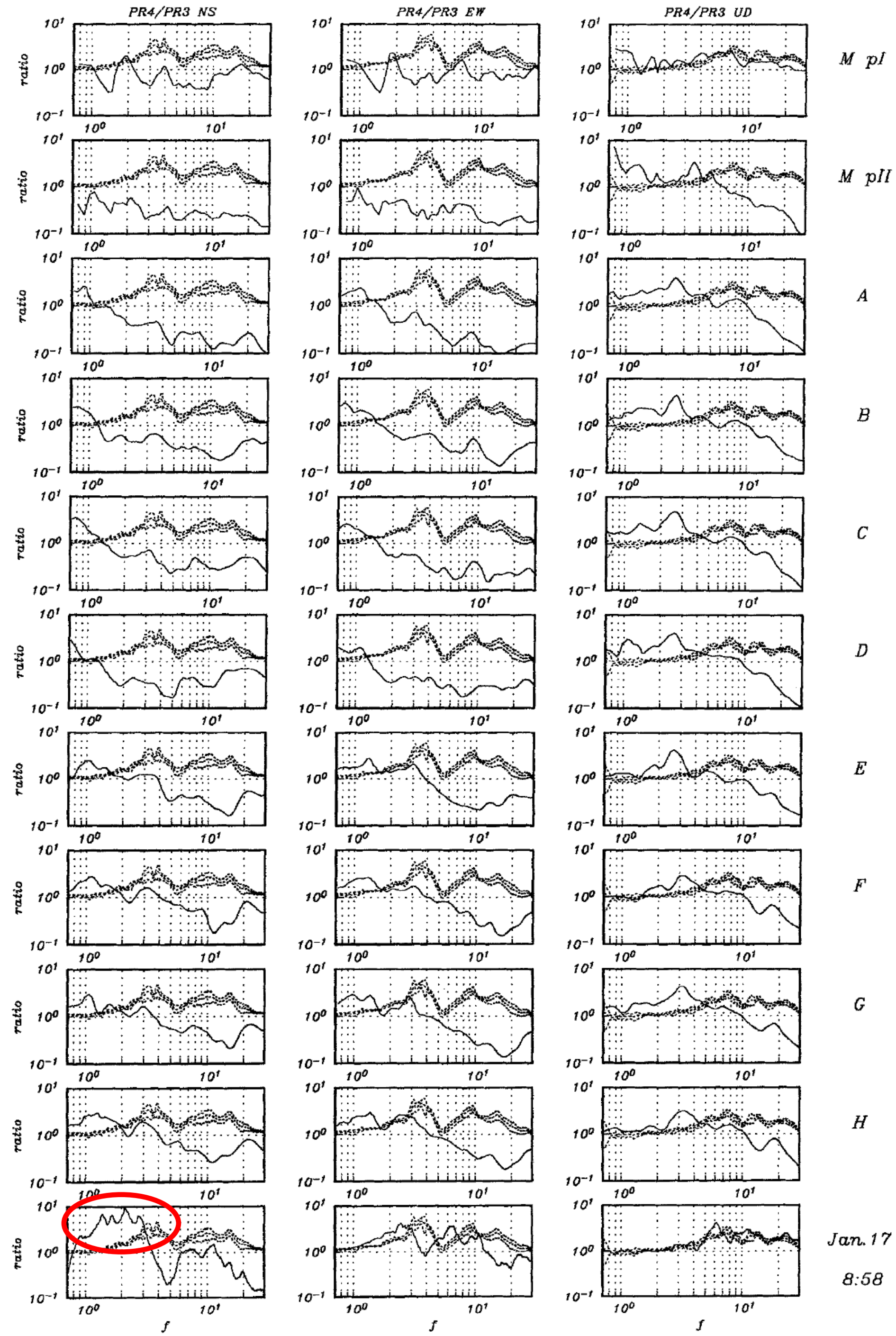

NS Vs EW (PR4/PR1)
2.0 4.2 11.4 16.6
6.5 12.3
ratio
f


NS Vs EW (PR4/PR1)
1.9 3.9 5.5 9.5
6.3 11
ratio
f

Results

- Japan array

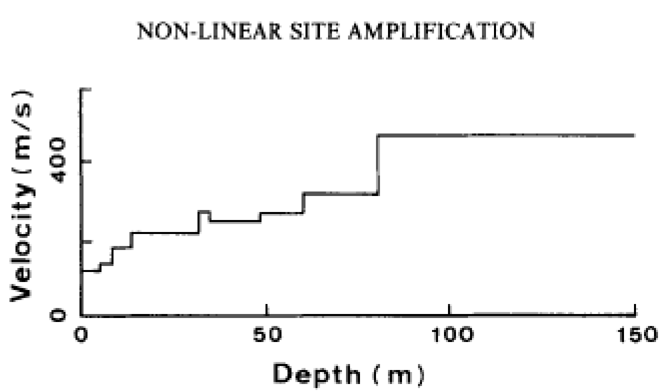




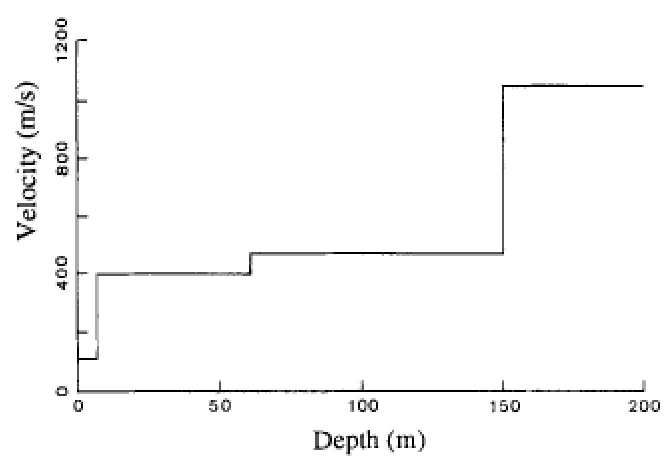
Discussion

- No statistically significant non-linear response is detected on the SMART2 array, that is tentatively accounted for by the stiffer soil conditions and weaker accelerations achieved at the SMART2 site.

LSST 193gal >SMART2 150gal



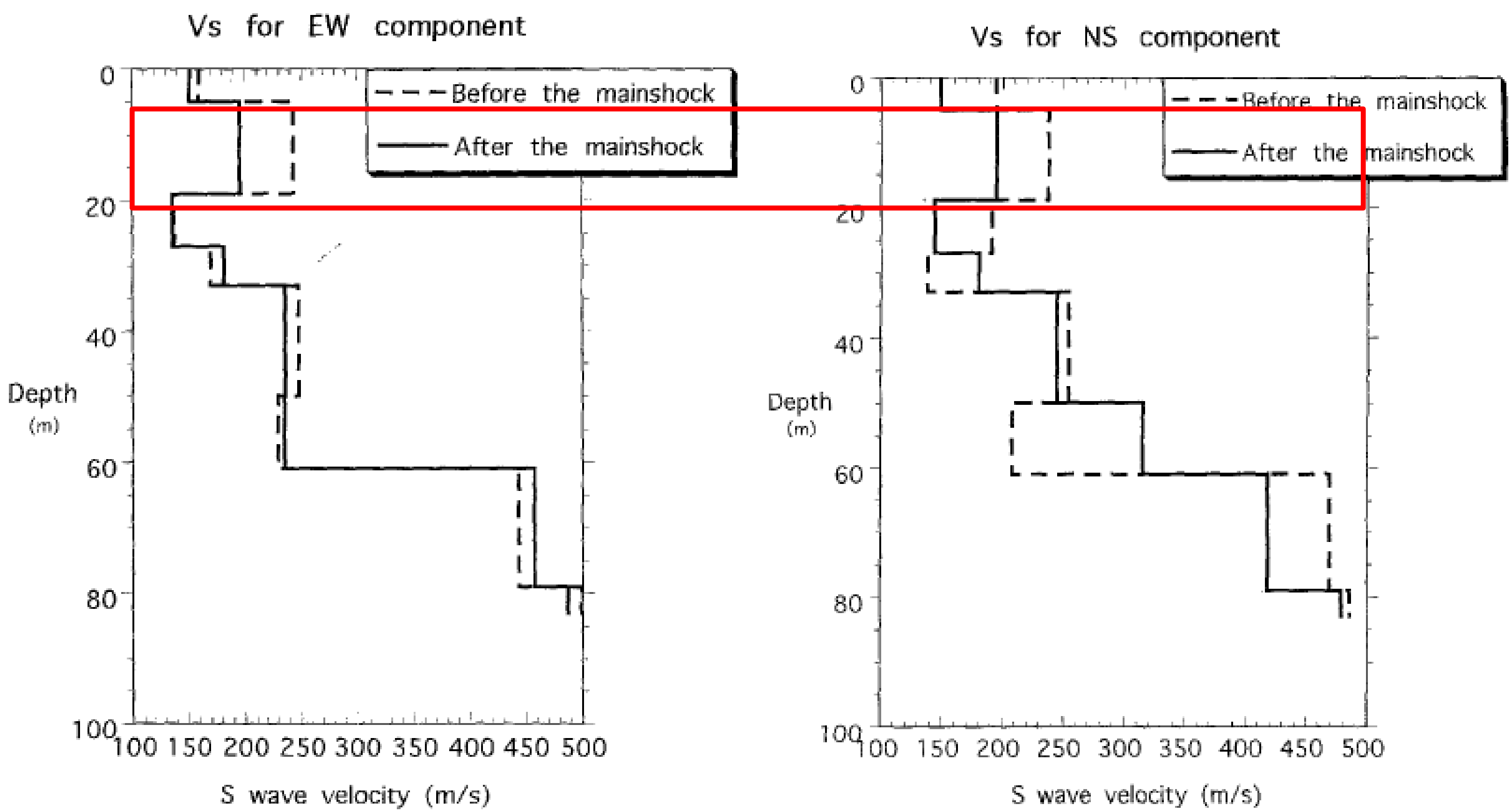
LSST



SMART2

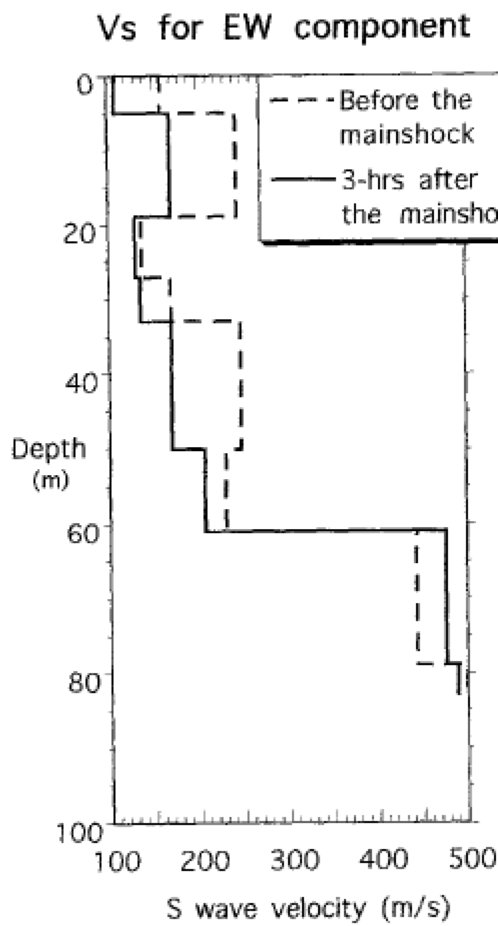
Discussion

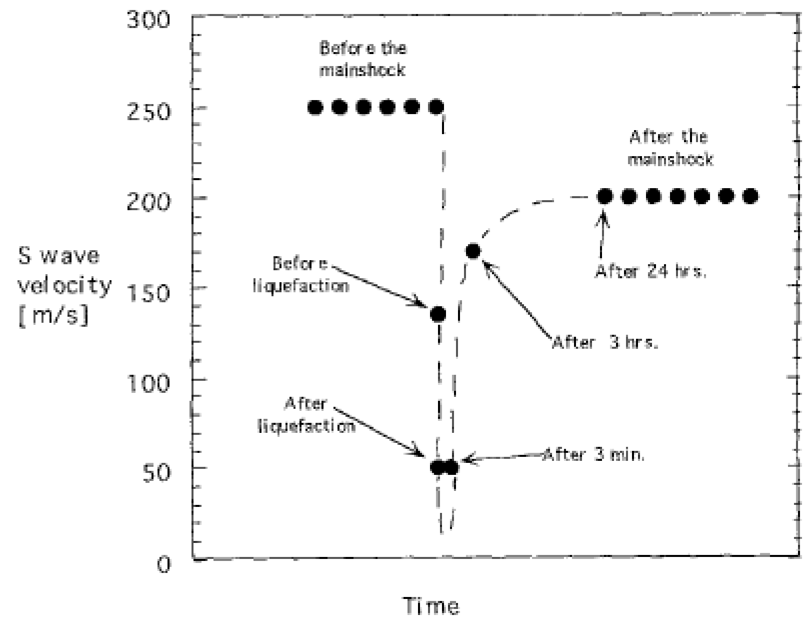
- The change of the S-wave velocities in the surficial layers affects the peak frequencies of the ratios.



Discussion

- The liquefaction causes a permanent variation of the elastic properties of the liquefied layers.





Discussion

- Change in velocity only can be explained with a simultaneously increase of density and reduction of G.

$$V = \sqrt{G/\rho}$$

Conclusions

- The peak frequencies in the spectral ratios of the strong motion are shifted to lower frequencies comparison to the spectral ratios of the weak motion.
- The non-linear amplification can be detectable at certain soil conditions above a threshold acceleration level.
- The clear differences between the velocity structures obtained before and after the mainshock.
- Deamplification is one of the characteristic symptoms of non-linear ground response of strong motion compared with the weak motion.