Implications of Coseismic Groundwater Level Changes in Taiwan

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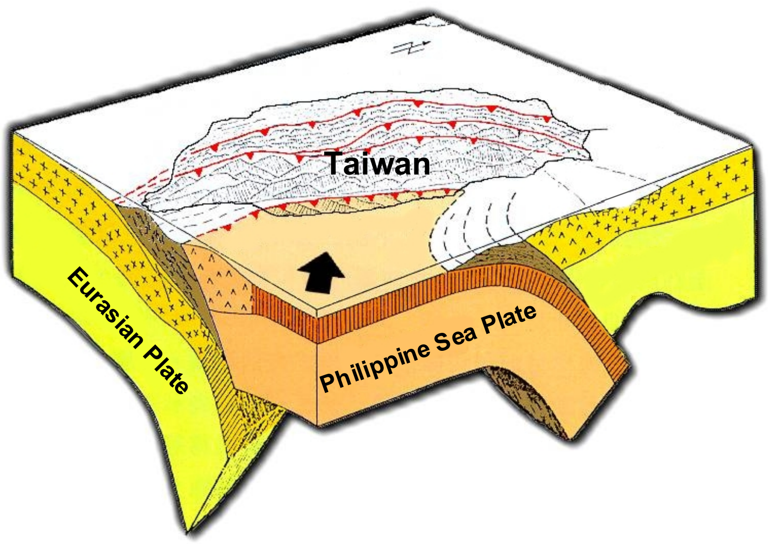
Tectonic Setting of Taiwan



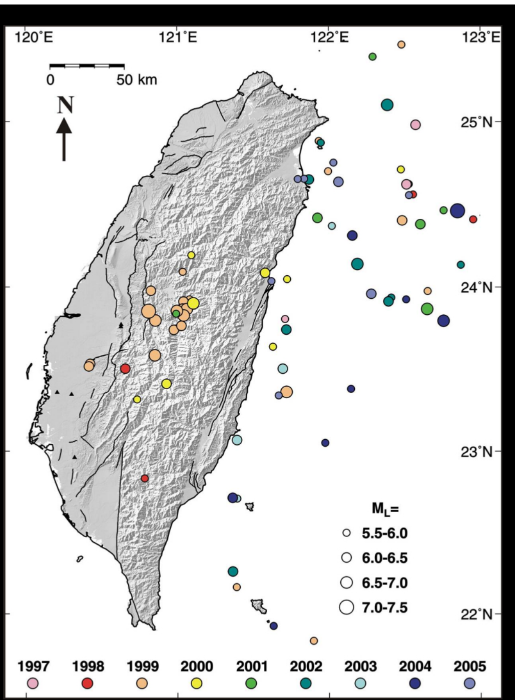
EQ Distribution in Taiwan

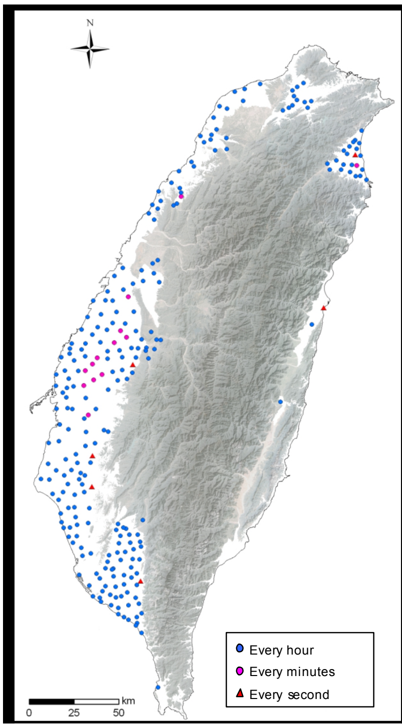
(1997-2005)

Every year, there are

8.7 $M_L \geq 5.5$ earthquakes

4.2 $M_L \geq 6.0$ earthquakes





Monitoring Well Network

- 612 wells were installed at 255 monitoring stations .
- 1 to 5 wells at each station.
- Screened in sand or gravel.
- Water level records
  - Every hour
  - Every minutes
  - Every second

Pore Pressure Induced by Stress Change due to Fault Movement

Based on Biot's Consolidation theory

$$\frac{\partial P}{\partial t} = \frac{K}{\rho_W g(\beta_P + n\beta_W)}\nabla^2 P + \frac{\beta_P}{\beta_P + n\beta_W}\frac{\partial \sigma}{\partial t}$$

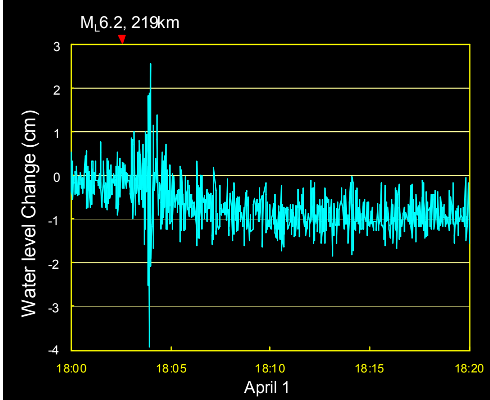
where β_P is pore compressiblity

β_W is water compressiblity

Coseismic: $\nabla^2 P \approx 0$ (no flow) → loading

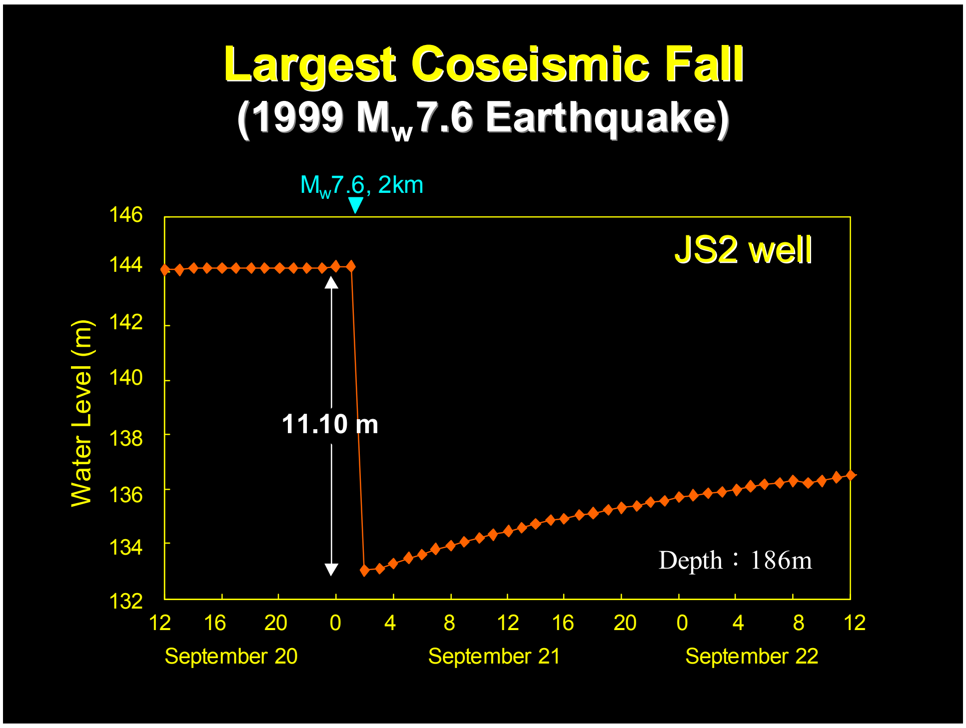
Postseismic: $\frac{\partial \sigma}{\partial t} = 0$ (no loading) → flow

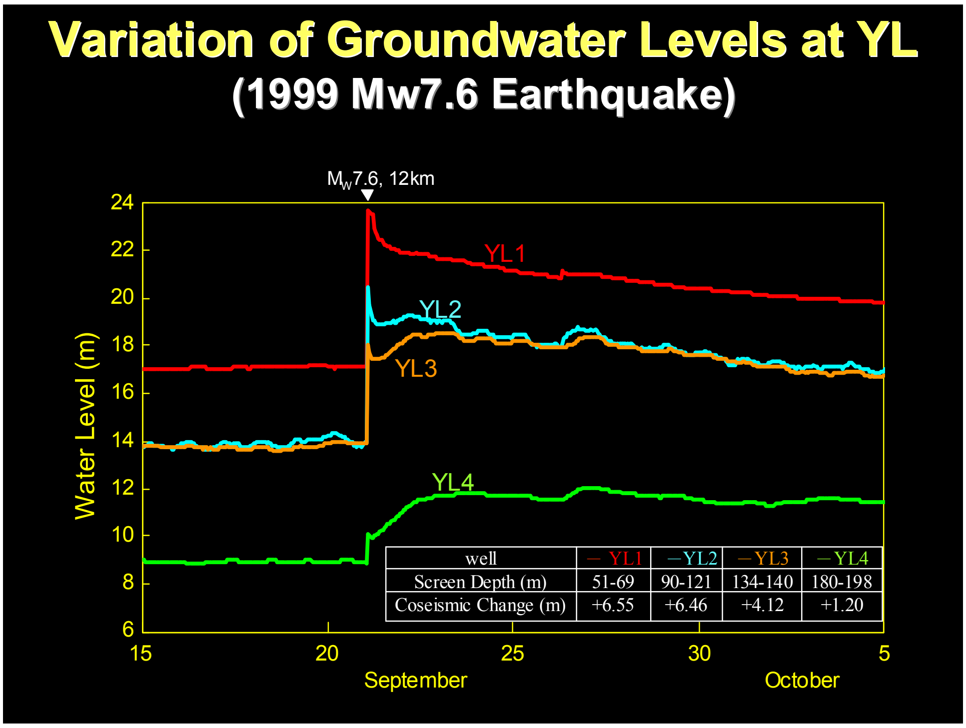
Persistent Change in the DW3 well (2006 M_L6.2 Earthquake)



1-sec data of water level

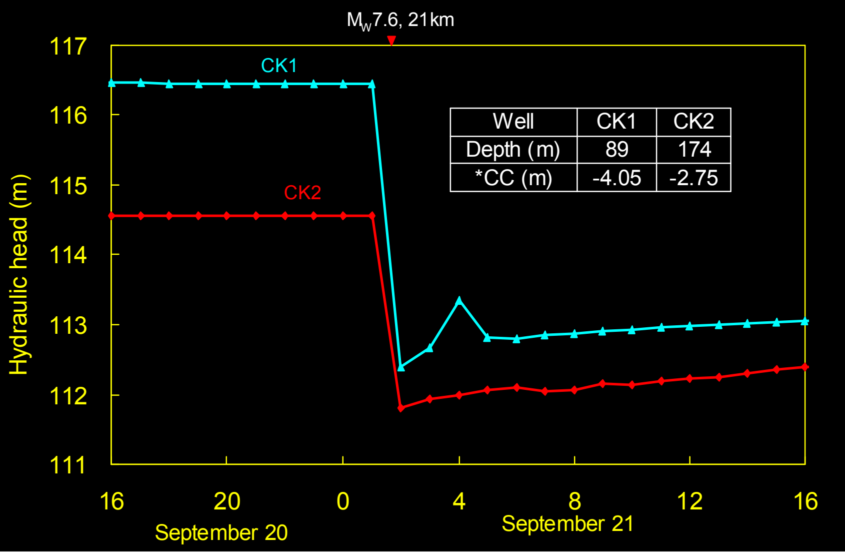
- On 1-sec data persistent change occurred gradually over a 4-minute period after the earthquake.
- Accompanied by oscillatory changes at the beginning due to passing seismic waves.





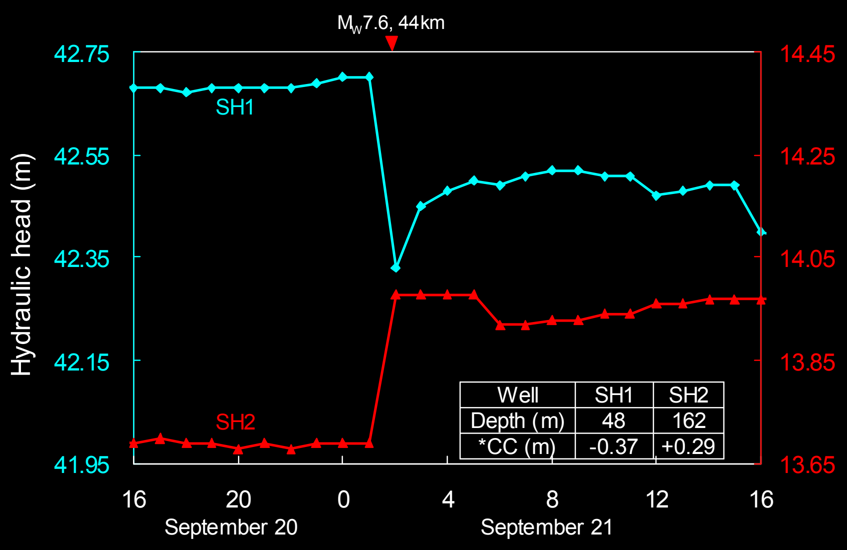
well	YL1	YL2	YL3	YL4
Screen Depth (m)	51-69	90-121	134-140	180-198
Coseismic Change (m)	+6.55	+6.46	+4.12	+1.20

Variation of Groundwater Levels
(1999 M_w7.6 Earthquake)



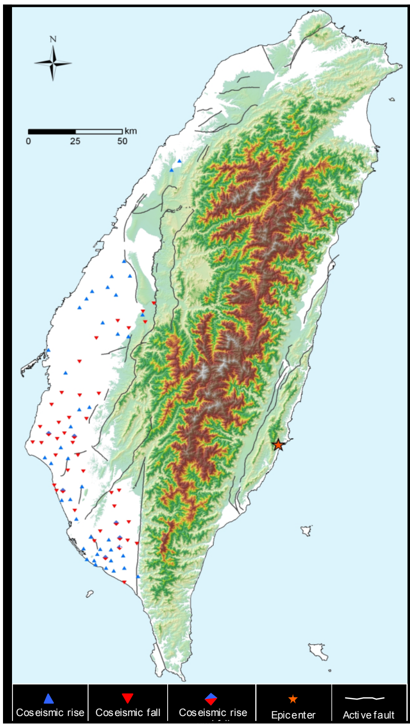
Well	CK1	CK2
Depth (m)	89	174
*CC (m)	-4.05	-2.75

Variation of Groundwater Levels at SH
(1999 Mw7.6 Earthquake)



Well	SH1	SH2
Depth (m)	48	162
*CC (m)	-0.37	+0.29

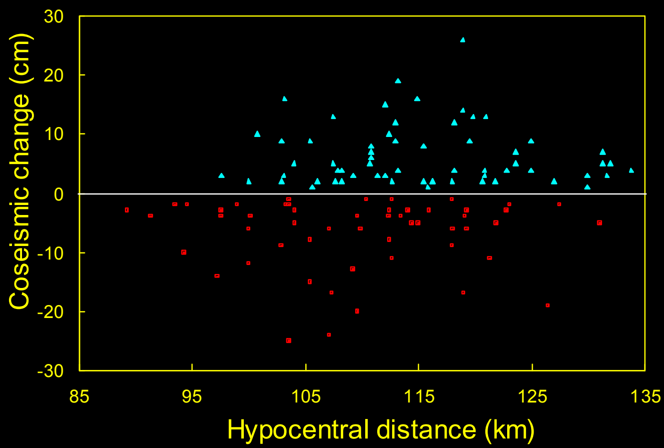
Spatial Distribution of Coseismic Changes (2003 M_L6.6 earthquake)



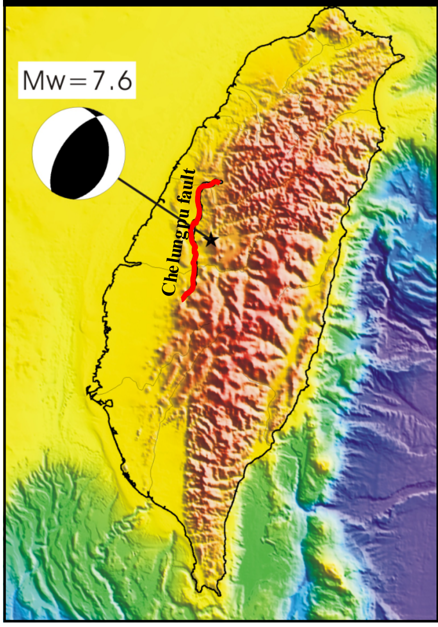
- Coseismic rises were observed in central and southern coastal plains.
- Coseismic falls appeared primarily in southwestern coastal plain and the area near the mountains.
- Distribution reflects the complexity of stress redistribution distant from the earthquake epicenter.

Coseismic Change vs Hypocentral Distance (1999 M_L6.6 Earthquake)

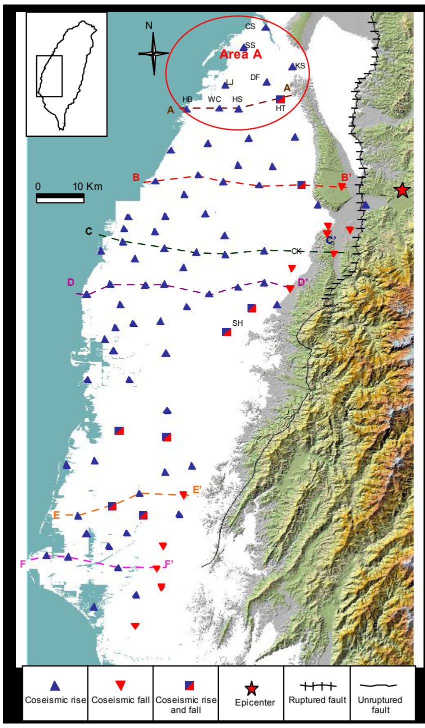
Poor correlation for coseismic changes distant from earthquake epicenter



1999 M_W 7.6 Chi-Chi Earthquake



- Local time: 1:47 a.m. September 21, 1999
- Epicenter: near Chi-Chi in central Taiwan
- Surface rupture due to thrust faulting extends 100 km
- Displacement is up to 10.1 m laterally & 8 m vertically



Spatial Distribution of Coseismic Changes (1999 M_w7.6 Earthquake)

- Coseismic rises prevailed away from ruptured segment.
- Coseismic falls appeared near the ruptured fault.
- Similar but less distinct distribution pattern near unruptured segment

Coseismic changes in the study area A

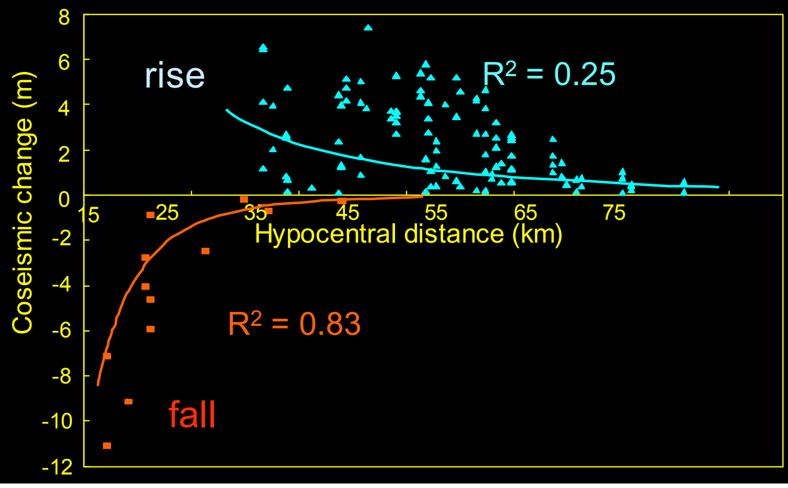
Well no.	Screen depth (m)	Coseismic change (m)	Well no.	Screen depth (m)	Coseismic change (m)
KS1	8-14, 24-30	0.38	WC1	5-17	0.13
KS2	***120-126***	**5.21**	WC2	18-60	2.76
KS3	185-197	1.05	WC3	***108-120***	**4.09**
DF1	***101-125***	**3.38**	WC4	186-204	3.38
DF2	162-174	3.73	HT1	8-20	1.25
LJ1	25-34	0.62	HT2	44-56, 59-65	1.31
LJ2	***108-120***	**5.22**	HT3	***112-130***	**3.98**
LJ3	180-198	3.47	HT4	264-276, 288-294	-0.26
SS1	10-16, 22-28	0.23	HS1	48-54, 60-66	3.51
SS2	***105-117***	**4.20**	HS2	***102-108, 114-120***	**5.28**
SS3	55-71	4.28	HS3	174-186, 192-204	3.72
SS4	158-170, 182-194	2.75	HS4	254-278	3.24
CS1	8-17	0.19	HB1	59-71	2.56
CS2	***102-120***	**4.66**	HB2	***103-115***	**3.23**
CS3	183-192	3.86	HB3	173-197	2.12
CS4	240-252	2.70	HB4	266-284	1.25

Largest Rises in the Study Area A

- Coseismic change in a gravel layer is greater than that in a sand layer.
- The largest rise was observed between 100 m and 130 m; correlating well with a gravel aquifer.
- Gravel is less compressible → Skempton coeff. B is smaller → stress change in gravel must be greater.

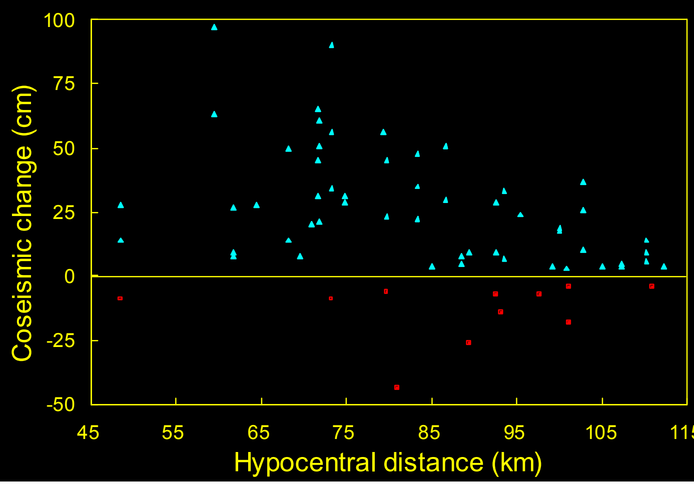
Coseismic Change vs. Hypocentral Distance
(1999 M_W7.6 Earthquake)

Good correlation for coseismic falls and fair for rises in the footwall of ruptured segment,



Coseismic Change vs. Hypocentral Distance
(1999 M_W7.6 Earthquake)

Poor correlation for coseismic changes in the footwall of unruptured segment



Conclusions

- Fault displacement has a strong impact on coseismic groundwater level changes.
- The magnitude of coseismic change is associated with characteristics, insteaqd of depth, of aquifers.
- Simple dislocation model not suitable for predicting the magnitude or direction of pore pressure change at a specific site.