成功大學
資源工程

On estimating the geo-material properties of Choshuishi Alluvial Fan

Kuo-Chin Hsu[1], Chih-Chiu Tung[1], Chein-Lee Wang[1]

and

Youe-Ping Lee[2]

[1]Department of Resources Engineering

National Cheng-Kung University, Tainan, Taiwan, R.O.C.

[2]Water Resources Agency, Ministry of Economic Affairs, Taiwan, R.O.C.

Problem Statement and Methodology

- Poroelastic theory (Biot 1946, 1956, Roeloffs, 1996) is well constructed in solving a strain-pressure coupled system.
- The geo-material and hydrogeological properties must be known when applying the poroelastic theory to field.
- Both geo-material and hydrogeological properties may show heterogeneous due to the Choshuishi Alluvial Fan
- Estimate the geo-material property from coseismic data of 1999 Chi-Chi earthquake.

Poroelastic Theory

- Governing equations

$$\begin{cases} \nabla \cdot (G\nabla u_1) + \left[\frac{\partial}{\partial x_2}\left(G\frac{\partial u_2}{\partial x_1}\right) - \frac{\partial}{\partial x_1}\left(G\frac{\partial u_2}{\partial x_2}\right)\right] + \left[\frac{\partial}{\partial x_3}\left(G\frac{\partial u_3}{\partial x_1}\right) - \frac{\partial}{\partial x_1}\left(G\frac{\partial u_3}{\partial x_3}\right)\right] + \frac{\partial}{\partial x_1}\left(\frac{G}{1-2\nu}\Delta V\right) - \frac{\partial}{\partial x_1}(\alpha P) = 0 \\ \nabla \cdot (G\nabla u_2) + \left[\frac{\partial}{\partial x_1}\left(G\frac{\partial u_1}{\partial x_2}\right) - \frac{\partial}{\partial x_2}\left(G\frac{\partial u_1}{\partial x_1}\right)\right] + \left[\frac{\partial}{\partial x_3}\left(G\frac{\partial u_3}{\partial x_2}\right) - \frac{\partial}{\partial x_2}\left(G\frac{\partial u_3}{\partial x_3}\right)\right] + \frac{\partial}{\partial x_2}\left(\frac{G}{1-2\nu}\Delta V\right) - \frac{\partial}{\partial x_2}(\alpha P) = 0 \\ \nabla \cdot (G\nabla u_3) + \left[\frac{\partial}{\partial x_1}\left(G\frac{\partial u_1}{\partial x_3}\right) - \frac{\partial}{\partial x_3}\left(G\frac{\partial u_1}{\partial x_1}\right)\right] + \left[\frac{\partial}{\partial x_2}\left(G\frac{\partial u_2}{\partial x_3}\right) - \frac{\partial}{\partial x_3}\left(G\frac{\partial u_2}{\partial x_2}\right)\right] + \frac{\partial}{\partial x_3}\left(\frac{G}{1-2\nu}\Delta V\right) - \frac{\partial}{\partial x_3}(\alpha P) = 0 \\ \frac{\partial}{\partial t}\left(PQ^{-1}\right) + \frac{\partial}{\partial t}(\alpha \Delta V) = \nabla \cdot (\kappa \nabla P) \end{cases}$$

- Under undrained condition, static confined volumetric strain efficiency can be calculated as

$$\frac{\Delta h}{\Delta \varepsilon_{kk}} = -\frac{1}{\rho g}\frac{2GB}{3}\frac{(1+\nu_u)}{(1-2\nu_u)}$$

Poroelastic Theory (continue)

- Five methods to calculate the static volumetric strain efficiency

$$\frac{\Delta h}{\Delta \varepsilon_{kk}} = -\frac{1}{\rho g}\frac{2GB}{3}\frac{(1+\nu_u)}{(1-2\nu_u)}$$

I. Field measurements of volume strain

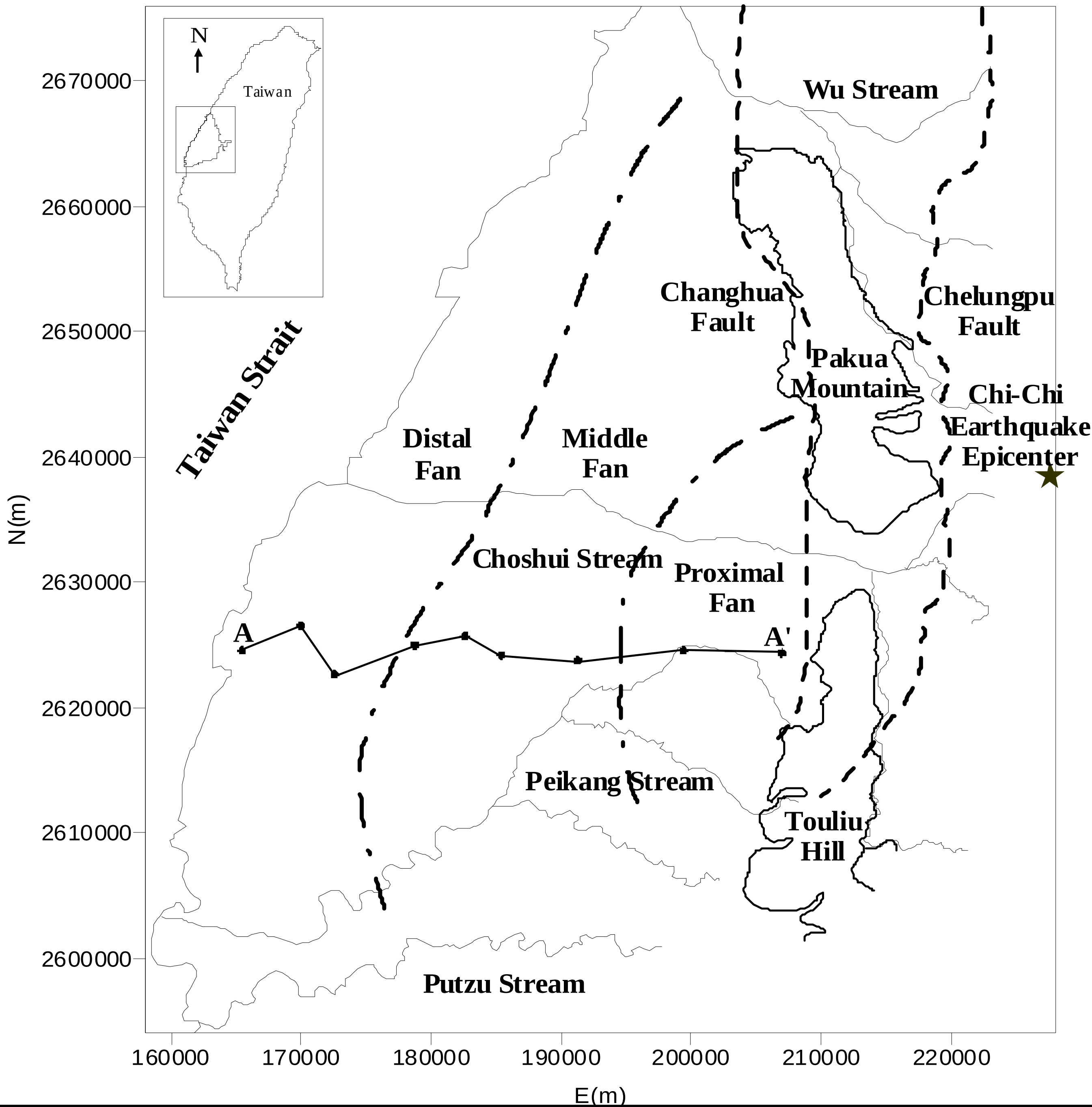
II. Fault-rupture model and dislocation model

III. Soil mechanics

IV. Porosity changes due to changes of groundwater level

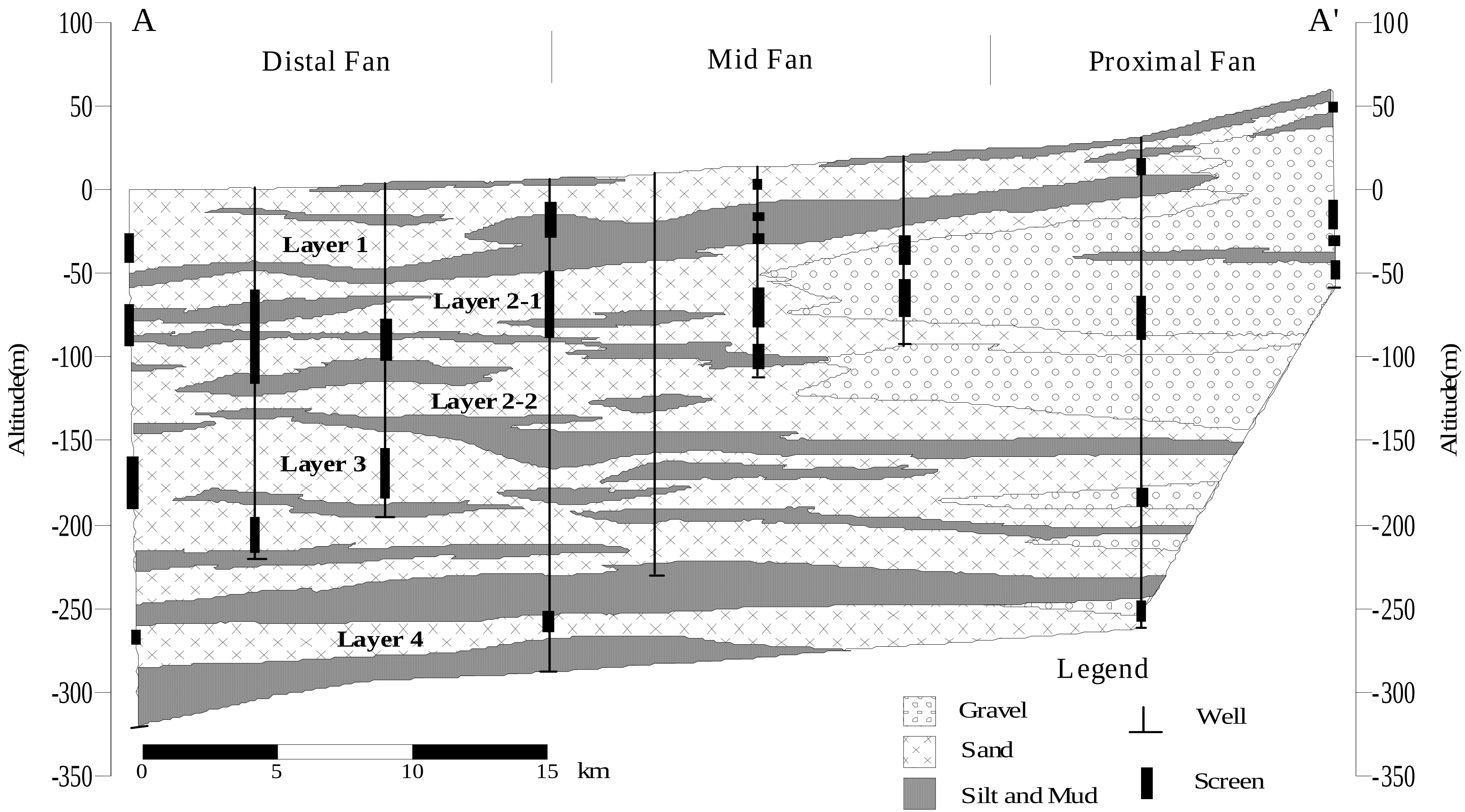
V. Porosity change due to vertical displacement of ground surface

Study Area

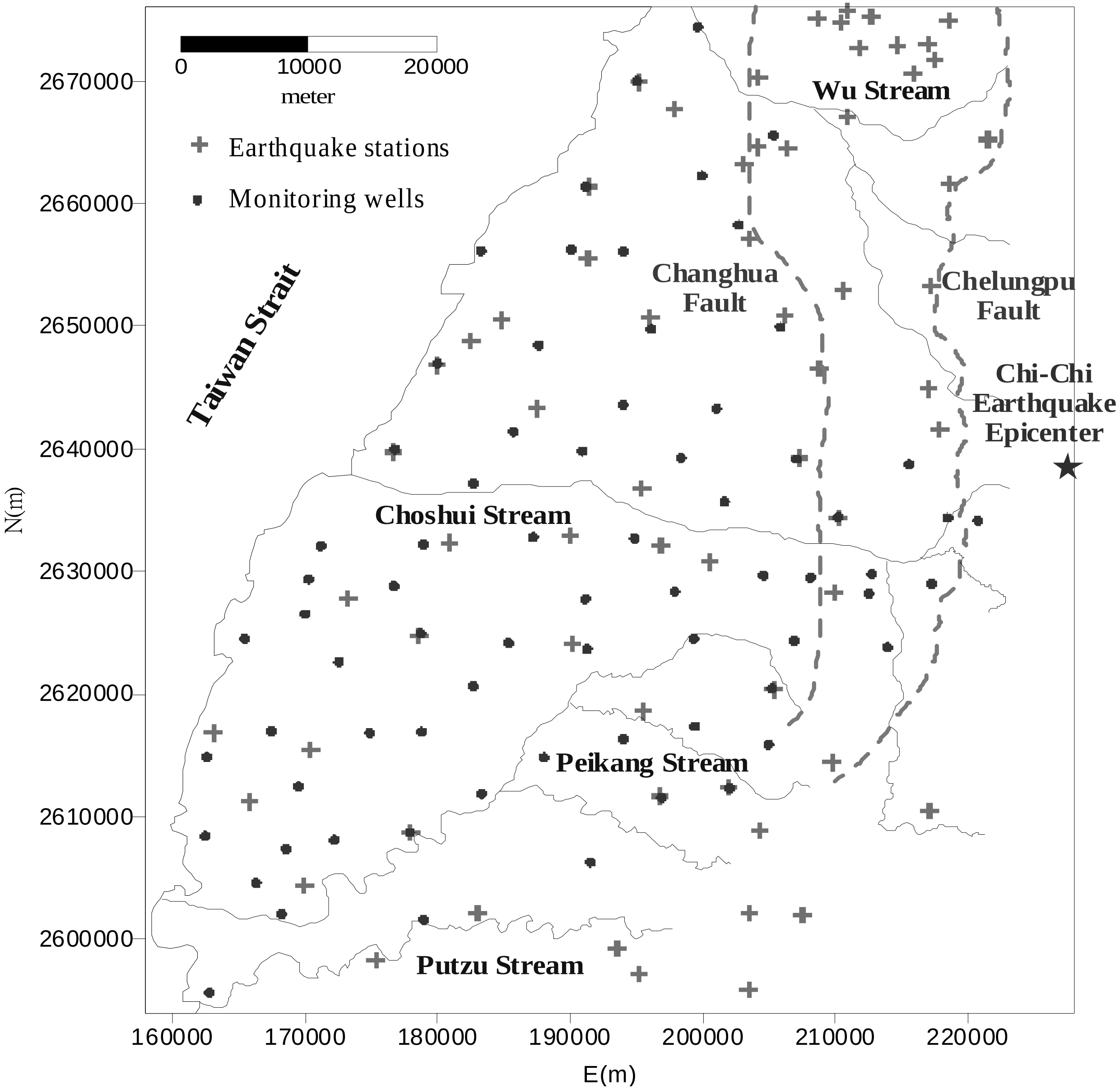


N
Taiwan
Taiwan Strait
Wu Stream
Changhua Fault
Chelungpu Fault
Pakua Mountain
Chi-Chi Earthquake Epicenter
Distal Fan
Middle Fan
Proximal Fan
Choshui Stream
Peikang Stream
Touliu Hill
Putzu Stream
A
A'
2670000
2660000
2650000
2640000
2630000
2620000
2610000
2600000
N(m)
160000
170000
180000
190000
200000
210000
220000
E(m)

Hydrogeology of Choshuishi Alluvial Fan



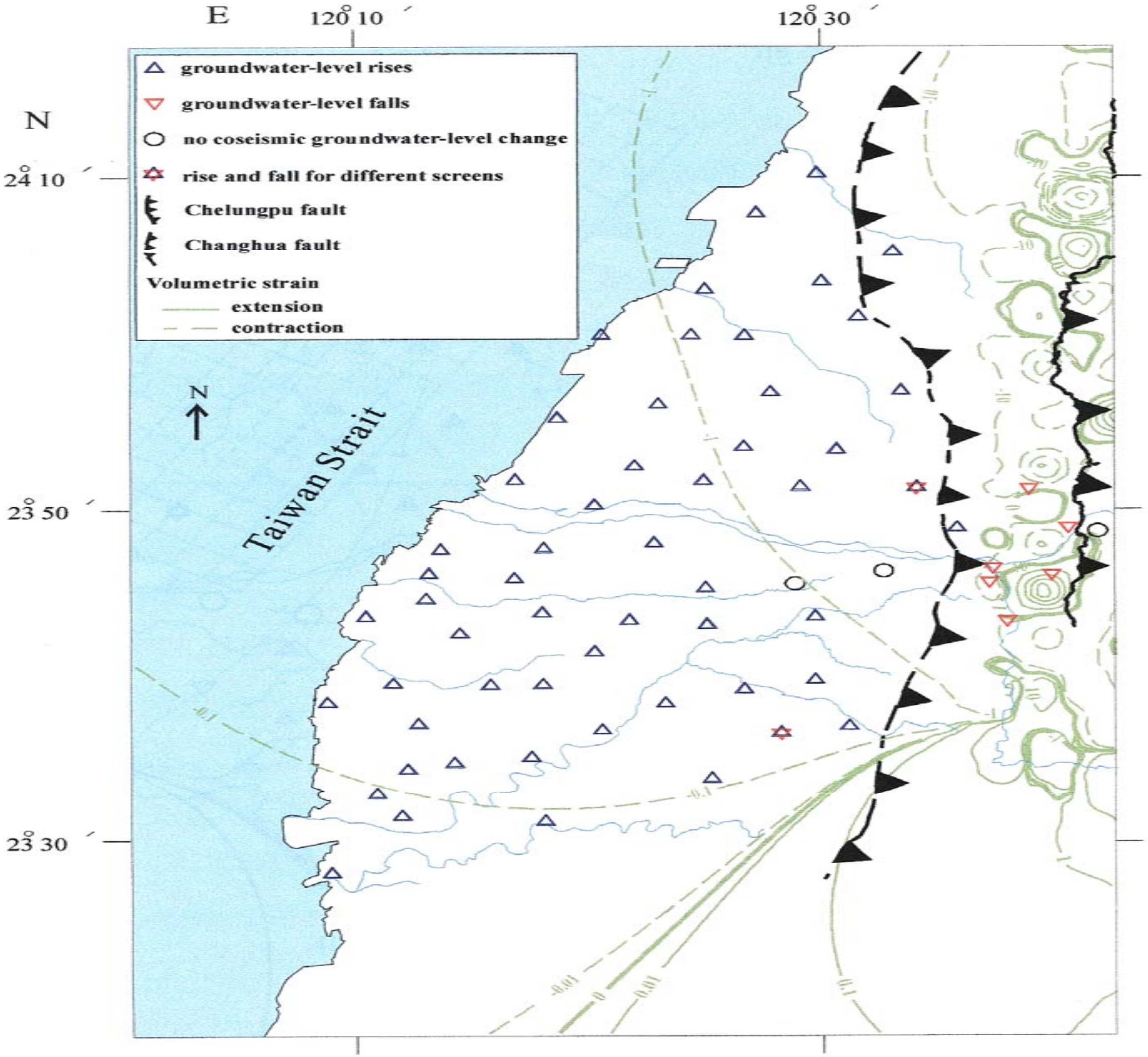
Locations of Monitoring Wells and Earthquake Stations



Volume strain from fault-rupture model and dislocation model (method II)

Unit: 10^{-5}

(Lee et al., 2002)



Estimating the static volumetric strain efficiency by soil mechanics (method III)

- Static volumetric strain efficiency

$$\frac{\Delta h}{\Delta \varepsilon_{kk}} = -\frac{B K_u}{\rho g}$$

- Skempton coefficient B

$$\frac{\Delta p}{\Delta \sigma} = B = \frac{1}{1 + n\left(C_p / 3C_s\right)}$$

- Undrained bulk modulus K_u

$$K_u = \frac{E_u}{3\left(1 - 2\nu_u\right)} \qquad E_u = \frac{1+\nu_u}{1+\nu} E$$

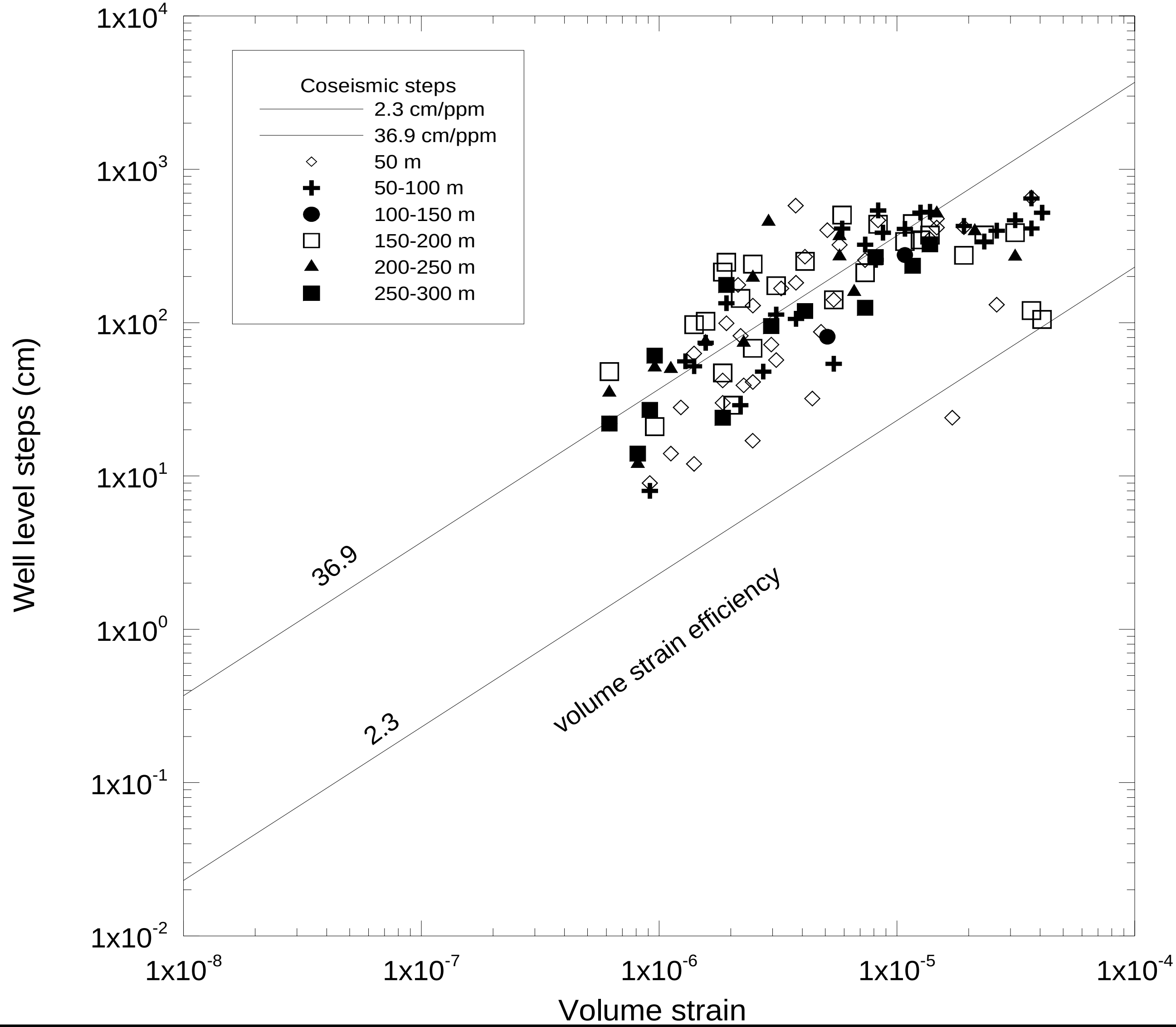
$$\nu_u = \frac{3\nu + B\left(1-2\nu\right)\alpha}{3 - B\left(1-2\nu\right)\alpha} \qquad \alpha = 1 - \frac{K}{K_s}$$

Estimating the static volumetric strain efficiency by soil mechanics (method III)

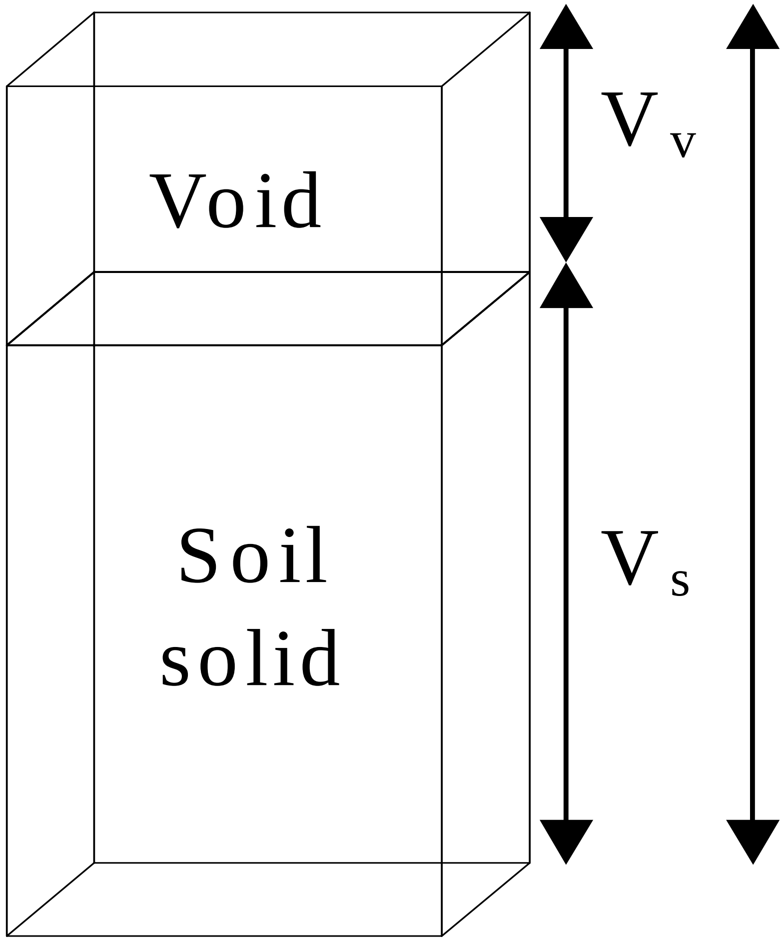
- For sand and gravel

Copmressibility of soil (Cs)	10^{-7}~10^{-10} Pa^{-1}
Copmressibility of water (Cp)	$4.4*10^{-10}$ Pa^{-1}
Porosity (n)	0.15~0.25
Skempton coefficient (B)	0.73~0.99
Poisson ratio (ν)	0.15~0.35
Young's modulus (E)	69~172 MPa
Undrained Poisson ratio (ν_u)	0.38~0.49
Undrained bulk modulus (Ku)	$3.1*10^8$-$3.73*10^9$ Pa
Strain efficiency	2.3~36.9 cm/ppm

Comparison of the static volumetric strain efficiencies by method II and III



Estimating the static volumetric strain based on changes in porosity (method IV)



$$V = V_v + V_s$$

$$d\varepsilon = \frac{n_1 - n_0}{1 - n_1}$$

Volume strain from groundwater level change (method IV)

- Under undrained condition and without thermal effect, porosities satisfy (Wang et al. 2001)

$$\frac{d(n\rho)}{dt} = 0 \qquad \frac{dn}{dt} = Ae^{-ct}$$

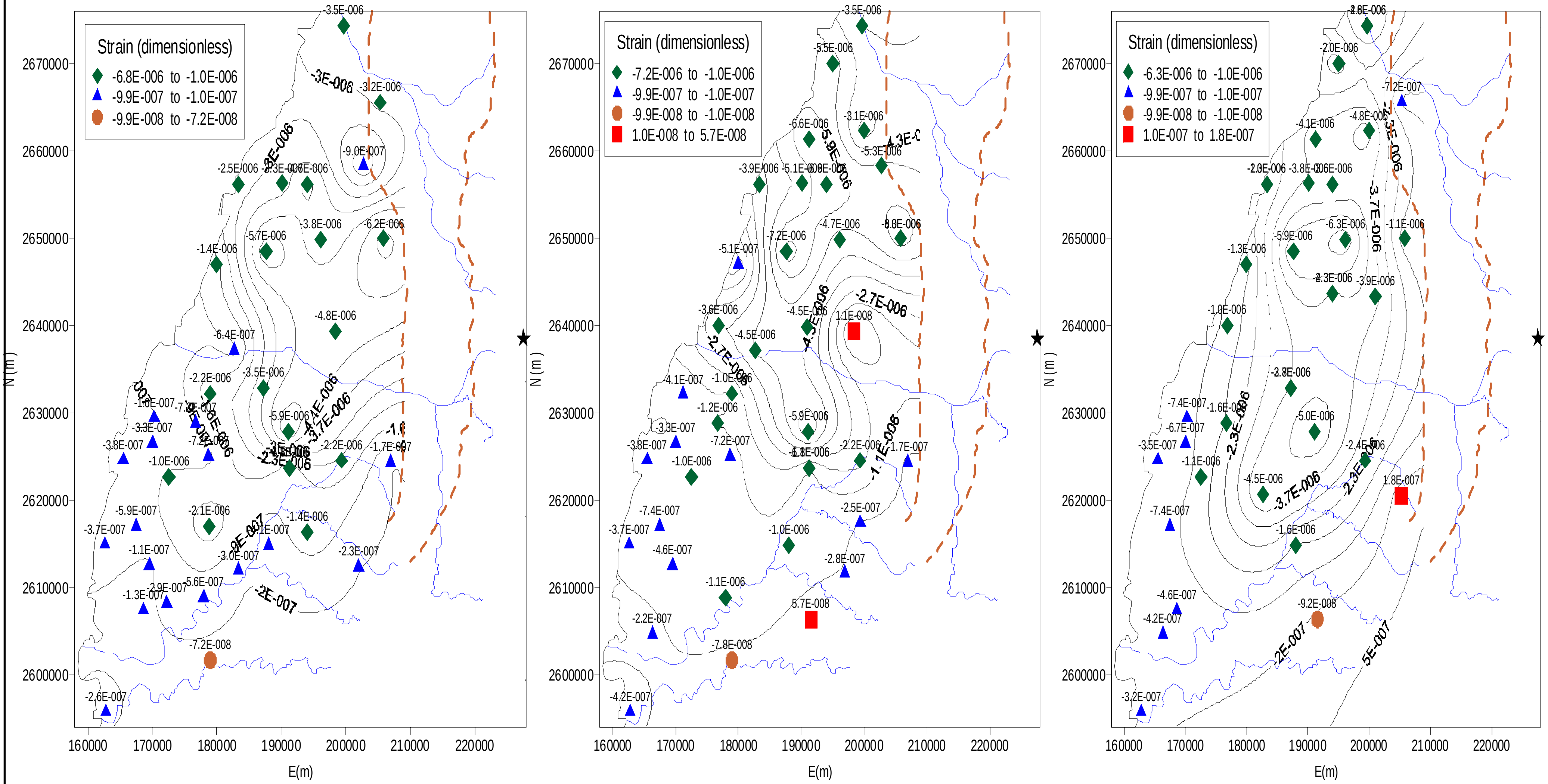
- Find coefficient A

$$\Delta h = \frac{A}{n\beta\rho g c}[e^{-ct} - 1]$$

- Calculate the change in porosity

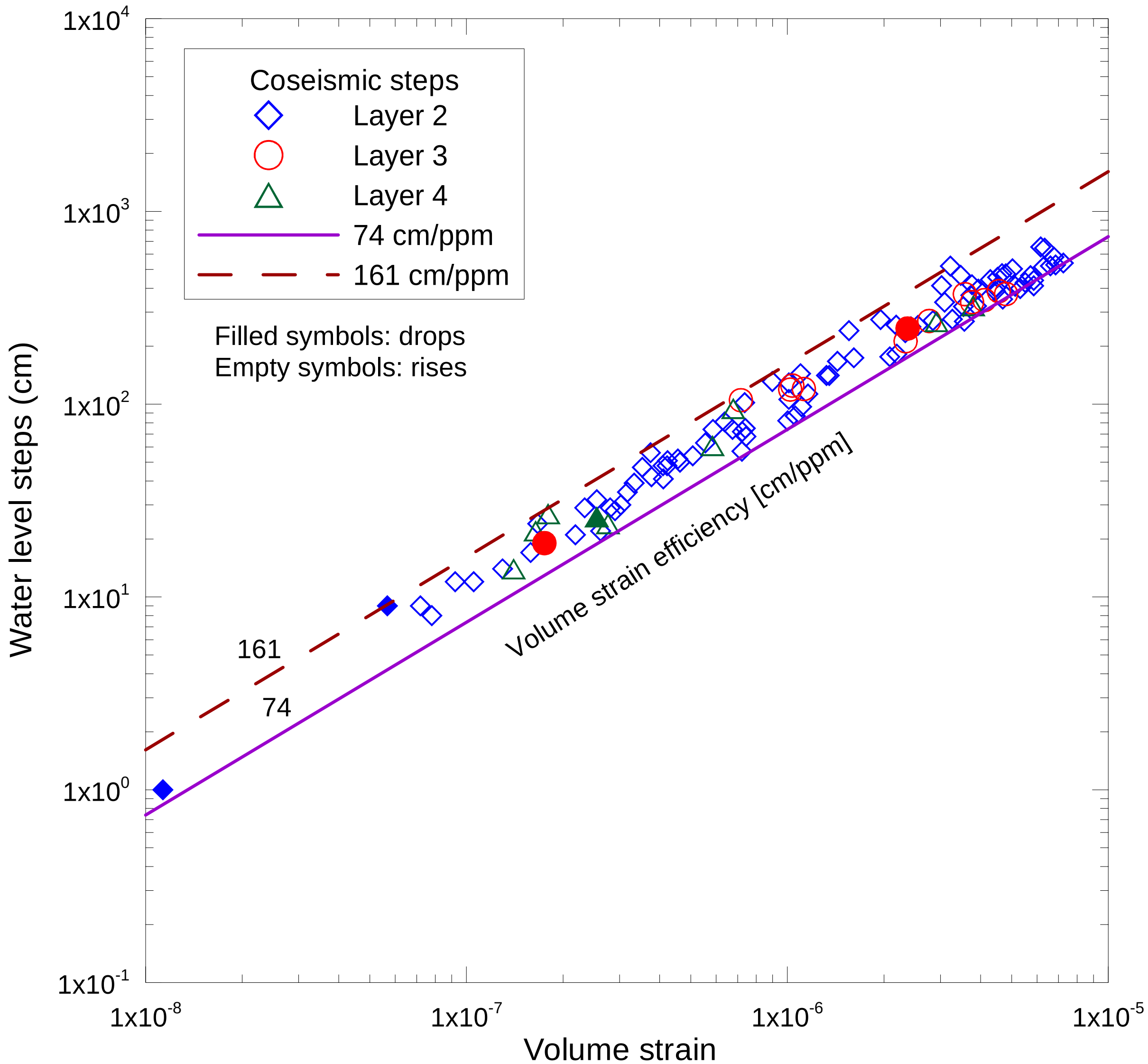
$$\Delta n = -\frac{A}{c}\left[e^{-ct} - 1\right]$$

Volume strain from groundwater level change (method IV)

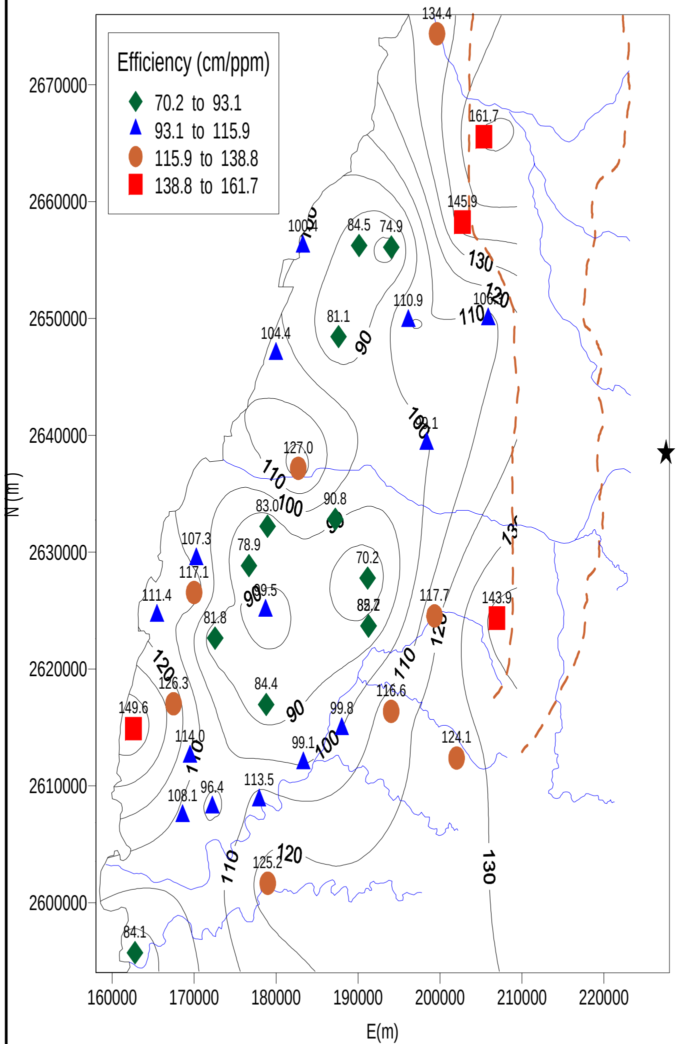


Layer 2-1　　Layer 2-2　　Layer 3

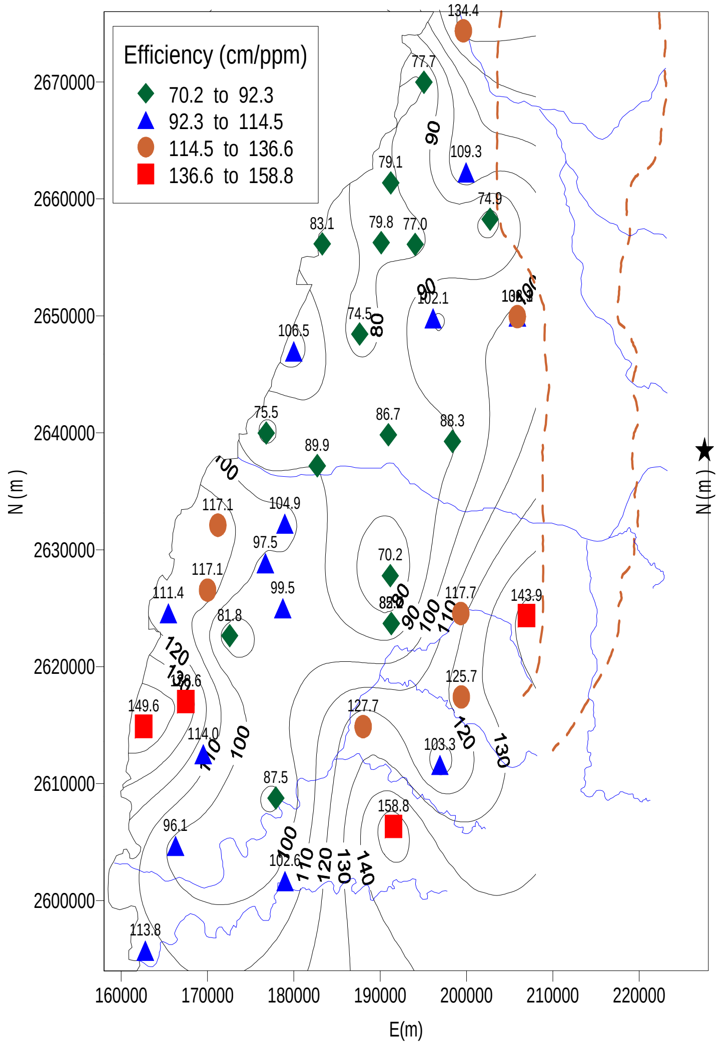
Static volume strain efficient from groundwater level change (method IV)



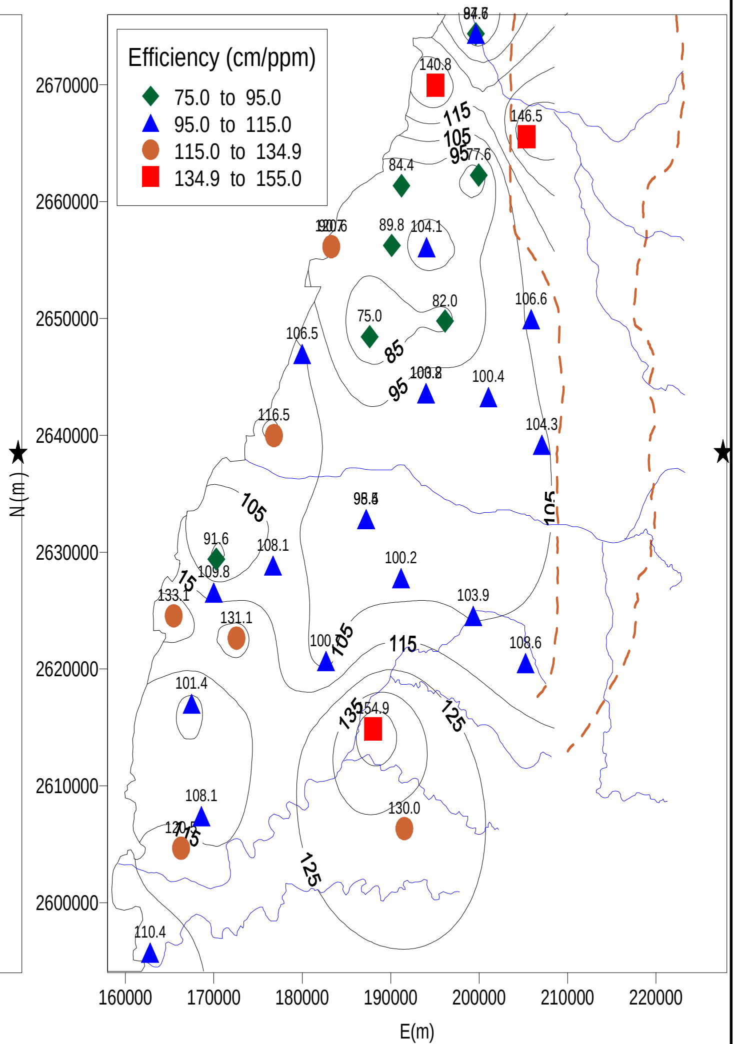
Static volume strain efficient from groundwater level change (method IV)



Layer 2-1



Layer 2-2



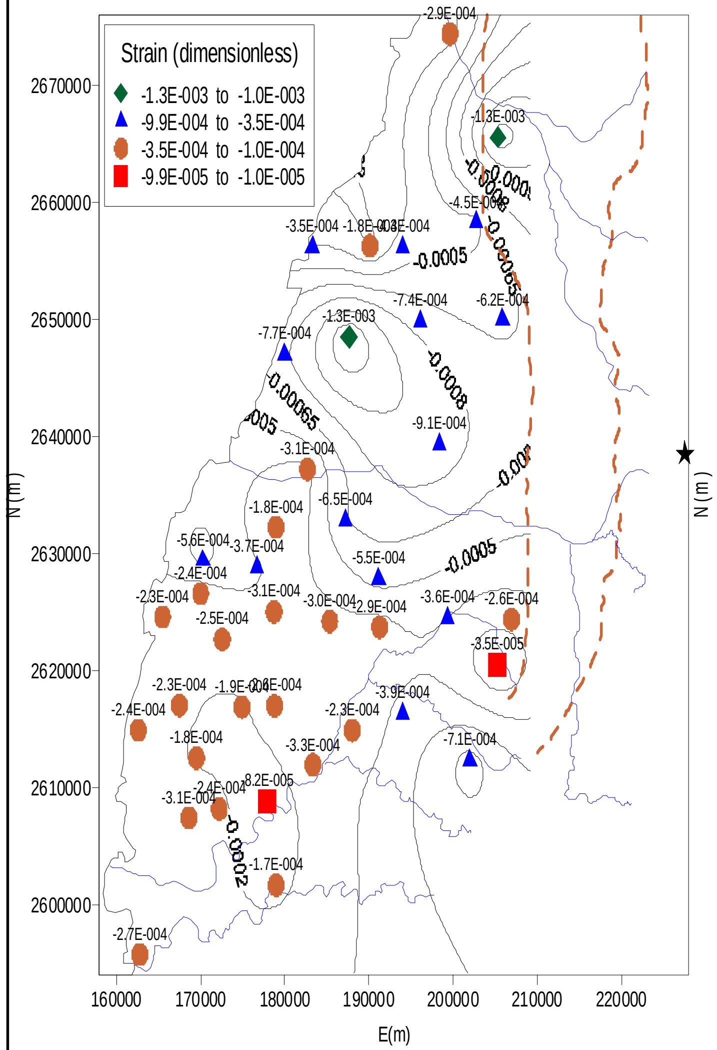
Layer 3

Volume strain from vertical displacement of ground surface (method V)

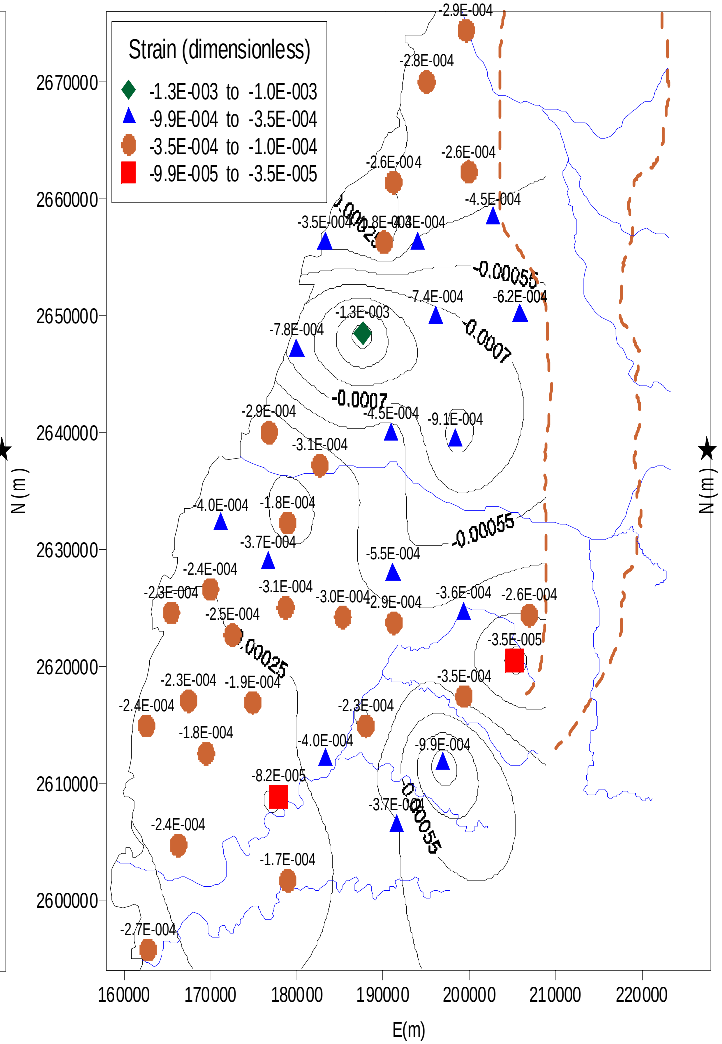
- The vertical displacements of the ground surface are assumed to be caused by the uniform compaction of aquifers.
- The change in porosity

$$(1-n_0)d_0=(1-n_1)(d_0-d)$$

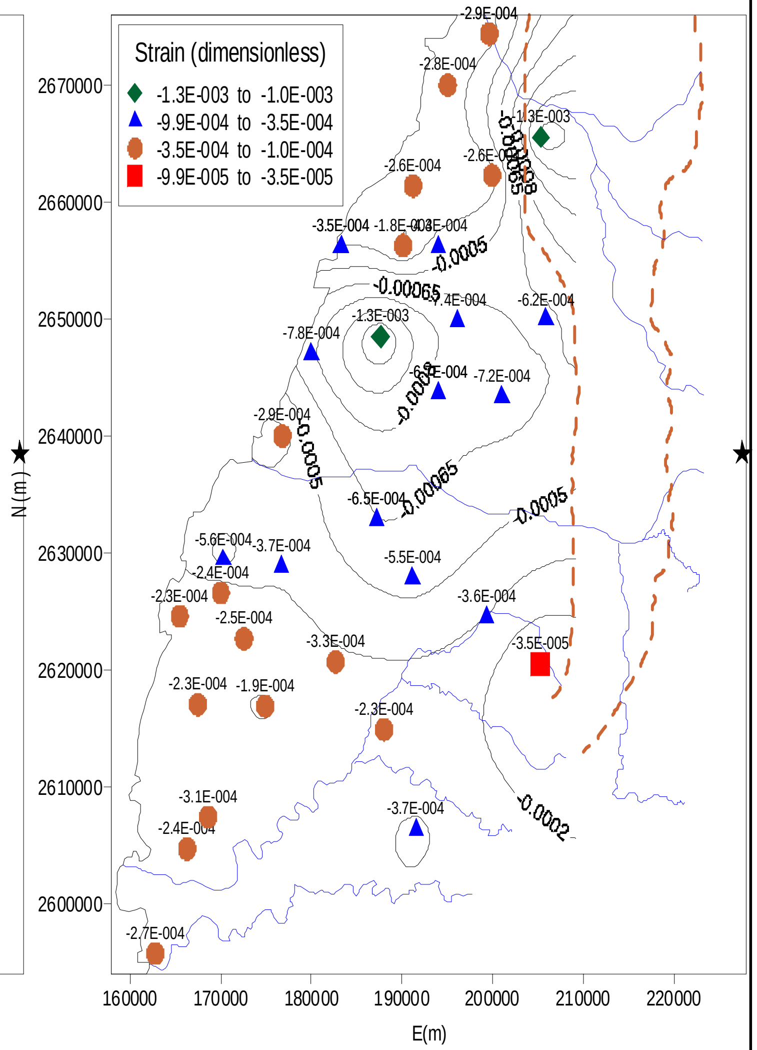
Volume strain from vertical displacement of ground surface (method V)



Layer 2-1

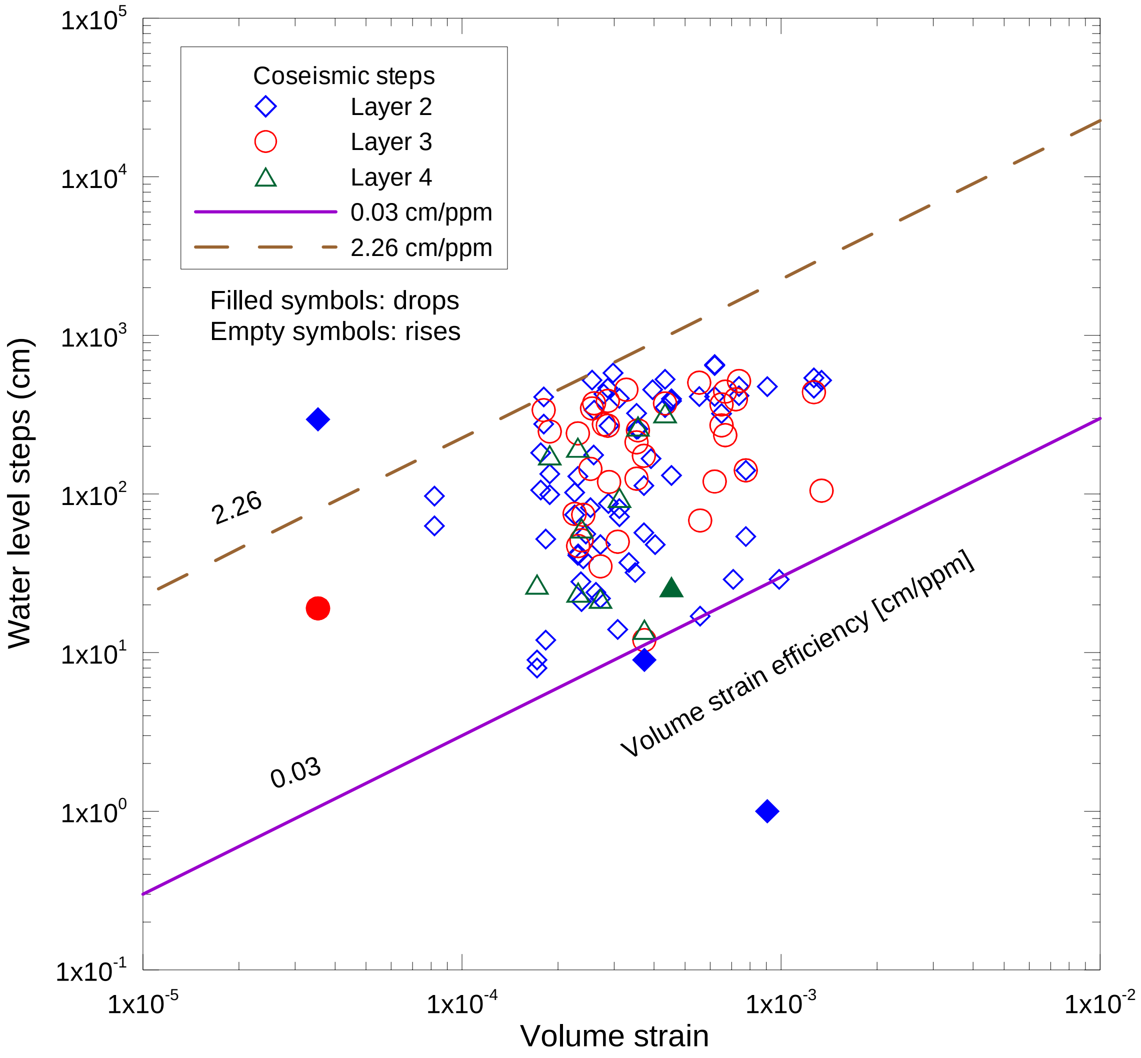


Layer 2-2

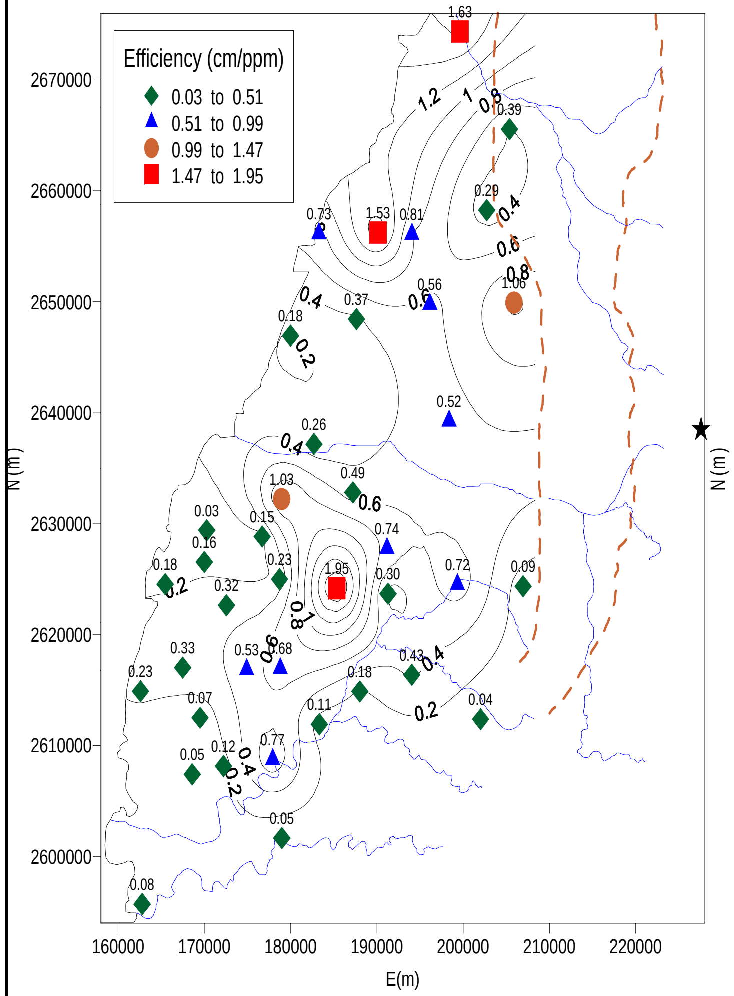


Layer 3

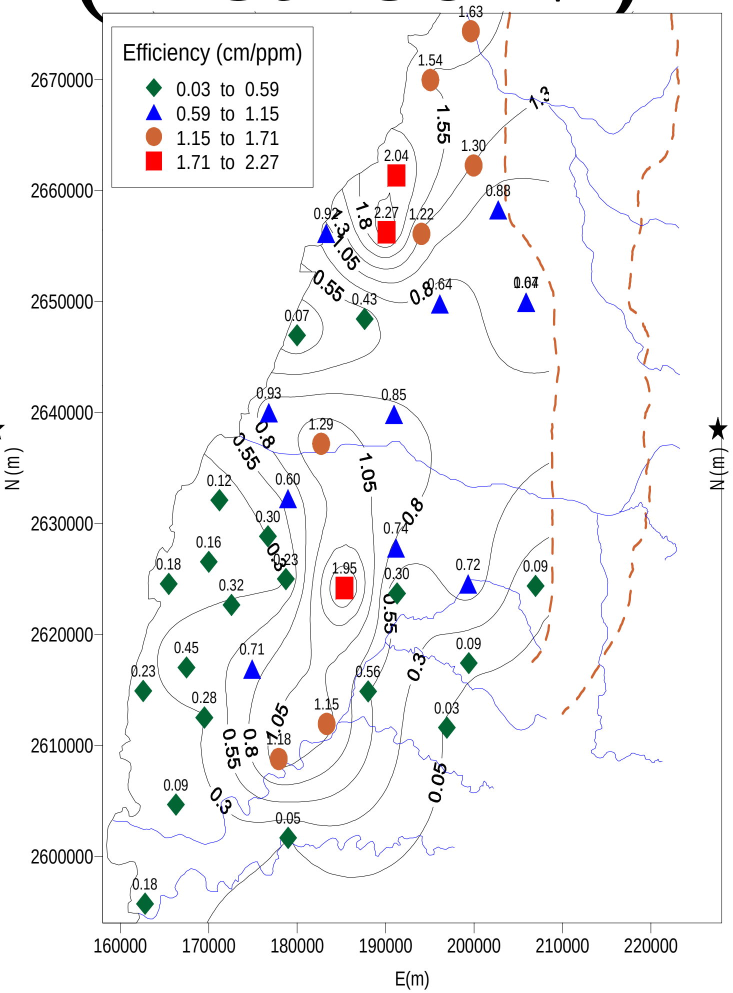
Static volume strain efficient from vertical displacement of ground surface (method V)



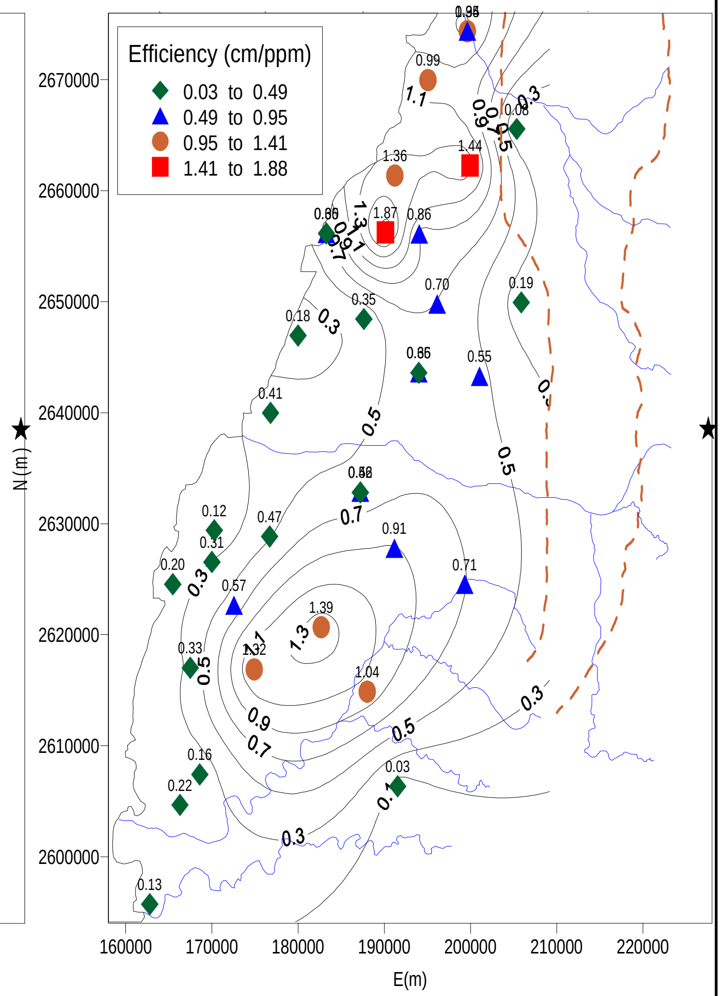
Static volume strain efficient from vertical displacement of ground surface (method V)



Layer 2-1



Layer 2-2



Layer 3

Comparisons of volume strain

- Method II: Fault-rupture model and dislocation model : $10^{-4} \sim 10^{-7}$
- Method IV: Porosity change based on groundwater level change : $10^{-6} \sim 10^{-8}$
- Method V: Porosity change based on vertical displacement : $10^{-3} \sim 10^{-5}$

Comparisons of static volume strain efficiency for the aquifer

- Method II: Fault-rupture model and dislocation model : 2.01-157.68 cm/ppm
- Method III: Soil mechanics : 2.3-36.9 cm/ppm
- Method IV: Porosity change based on groundwater level change : 74-161 cm/ppm
- Method V: Porosity change based on vertical displacement : 0.03 – 2.26 cm/ppm
- Roeloffs and Quilty (1997) :

  interbeding of sand and clay：36~39cm/ppm,
  interbeding of sand and gravel：47~51cm/ppm

Conclusions

- Properties of geo-material are required in using the poroelastic theory. The lumped parameter, static volume strain efficiency, can be calculated from the different methods.
- The volume strain efficiency shows spatially heterogeneous. This may be used to interpret the spatial pattern of water level change in the 1999 Chi-Chi earthquake..

成功大學
資源工程

Conclusions (continue)

- Method III is easy to use for obtaining the static volume strain efficiencies for different soils. It requires the information of lithology in depth and the upscaling procedure.
- The results of method IV are close to those of method II. It only requires the information of water level change.

Conclusions (continue)

- Method V may overestimate the strain. It requires both data of ground-water change and vertical displacement of ground surface.
- The results from different methods need to be explored to identify their appropriateness.