The 10th Taiwan-US-Japan Workshop
on Water System Seismic Practices

Design Strategies of Transmission Trunks across Normal Fault - A Case Study of Shanchiao Fault

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Outline

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- **Methodology**

  Simulation methods of a shear zone development

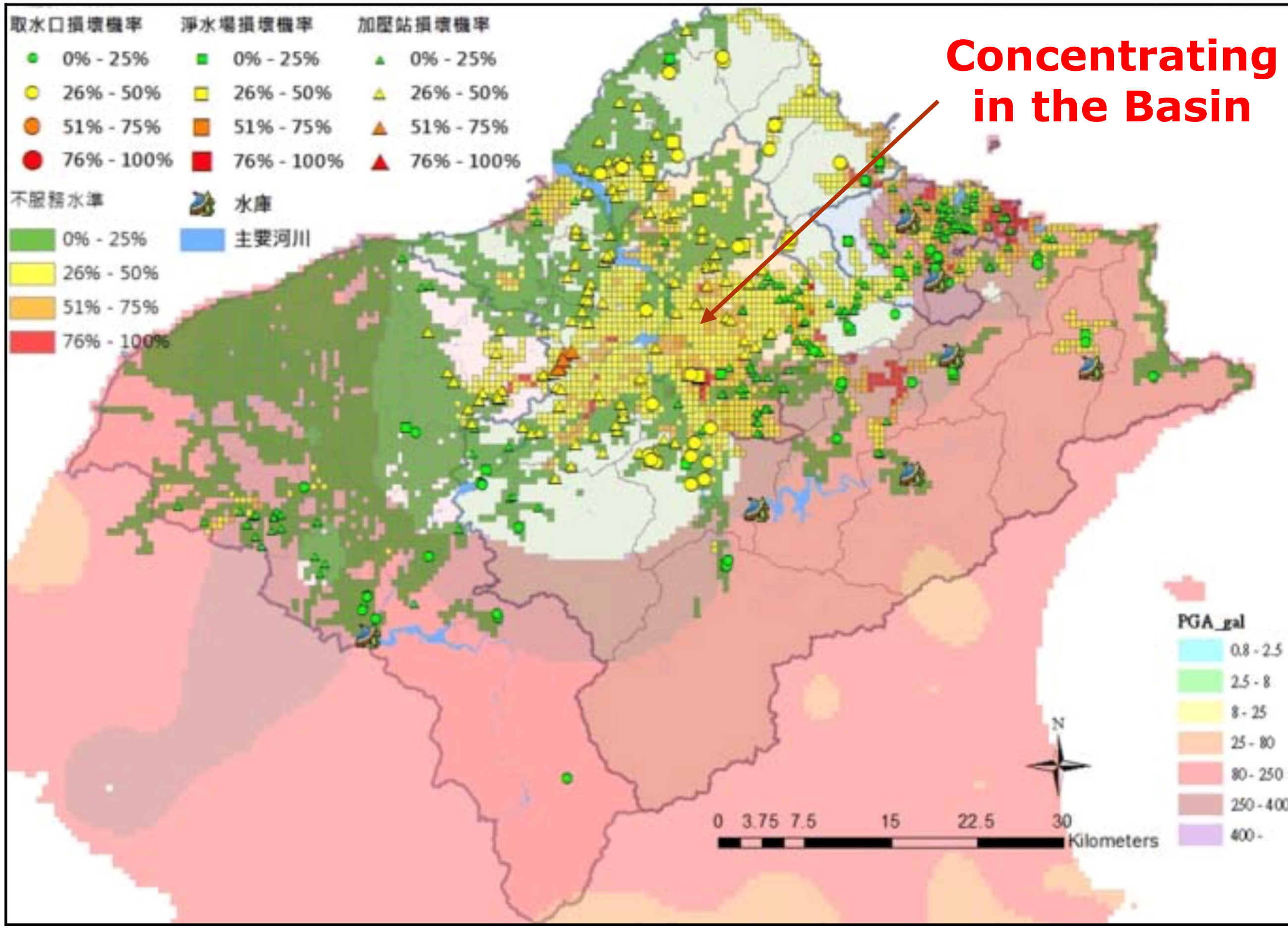
- **Results**

  The width on surface of the shear zone & suggestions for design

Introduction

The Shanchiao Fault : an Active, Normal, Growth fault

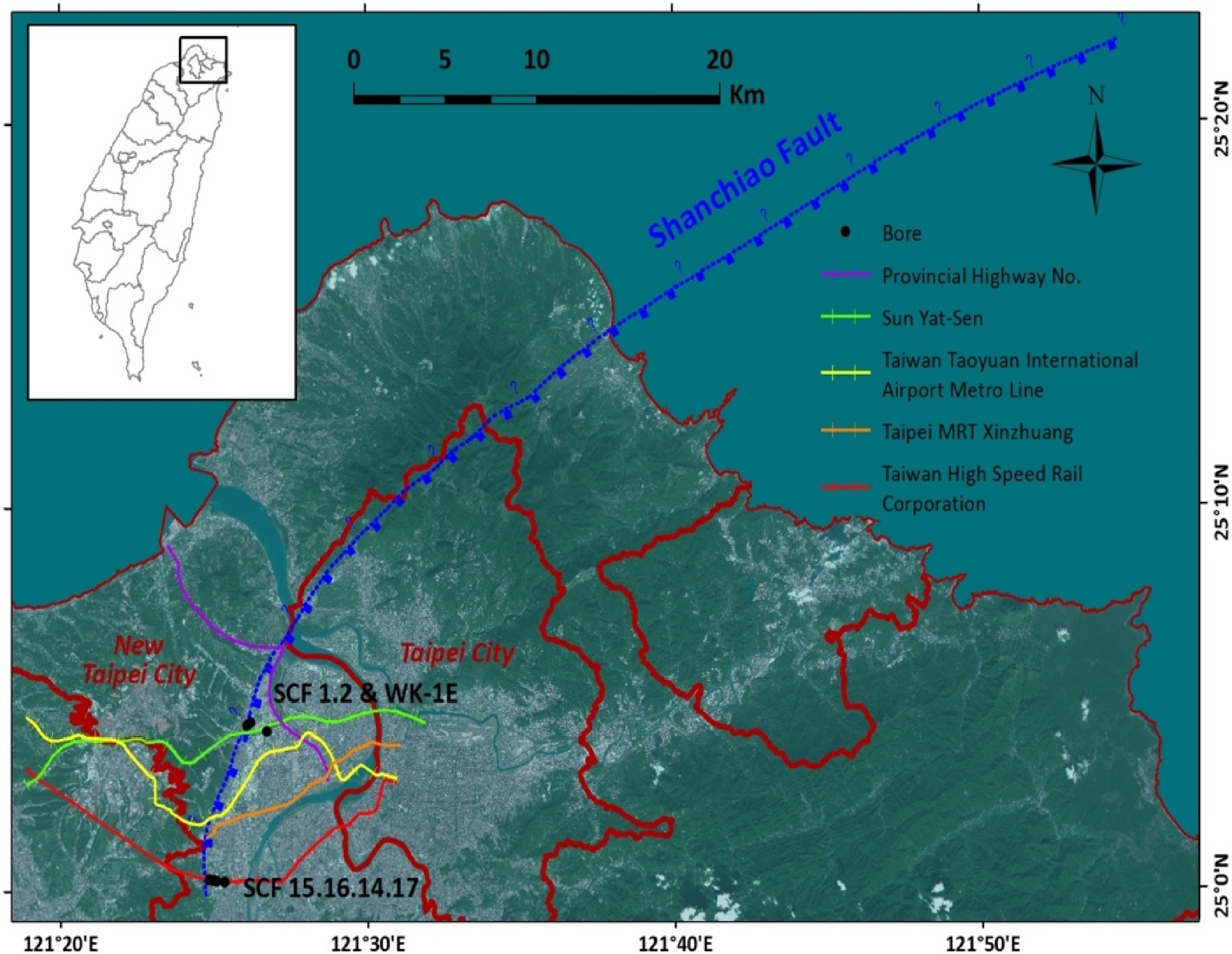
Earthquake Disaster Assessment in Taipei



The National Science and Technology Center for Disaster Reduction (NCDR) of Taiwan has analyzed for large-scale earthquake shocks in the Metropolitan Taipei area.

Analyzed for the " Disaster Impact" and " Urban Function Failure"

A Threat – Shanchiao Fault



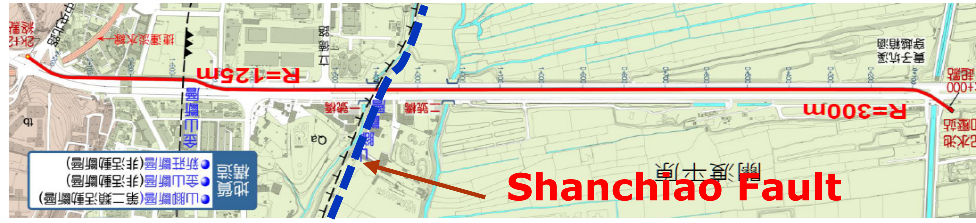
Shanchiao Fault may create a large-scale earthquake in the Metropolitan Taipei area.

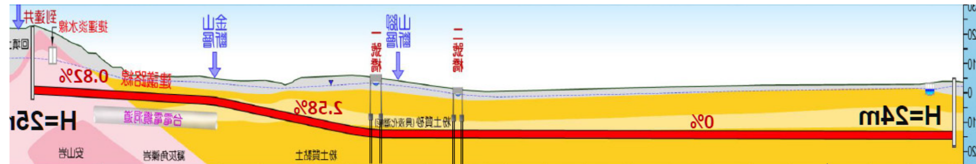
The maxium **magnitude** is about **7.1**, and the **depth** of the epicenter is about **10 km**.

So long in its length & surrounding west side of Taipei basin. Roads, railways & pipelines have to cross the fault

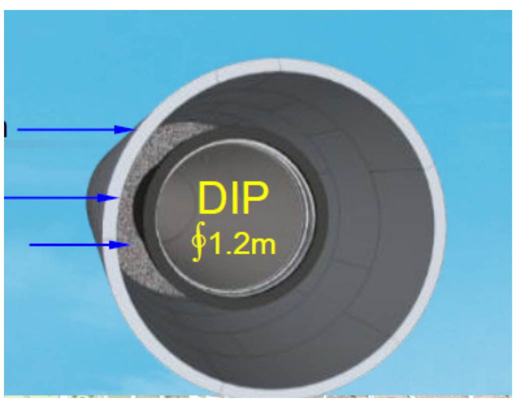
A water trunk designed across Shanchiao faults

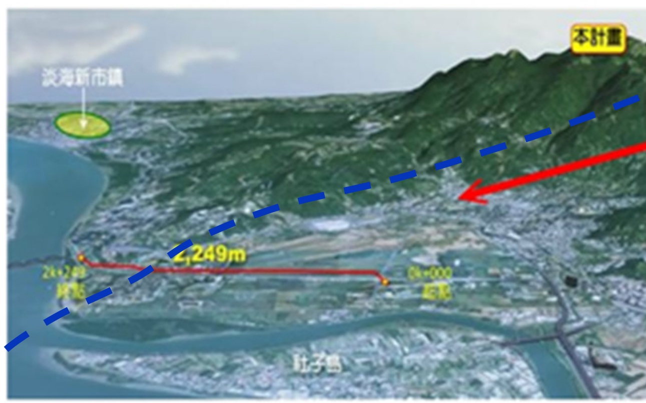
Dadu Line Project is for water supply to Tamsui area,
a 1200 mm water trunk within a 2000 mm shield tunnel, the length is 2249 m

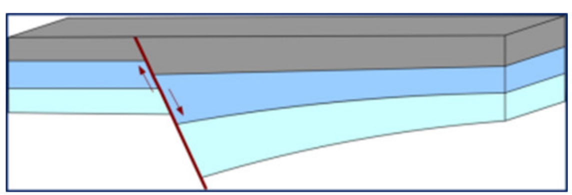




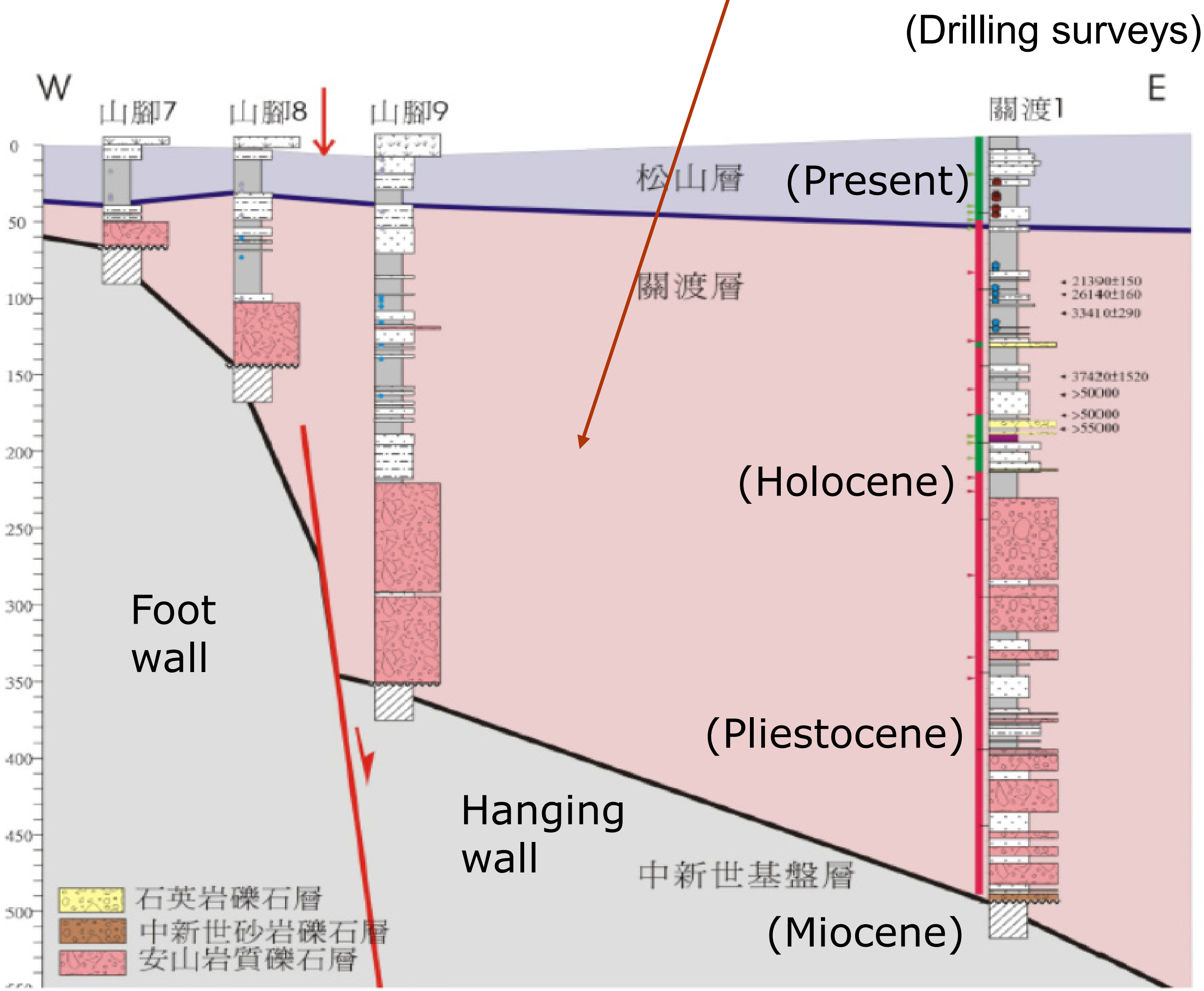
Dadu Line crosses Shanchiao Fault which still **remains active**







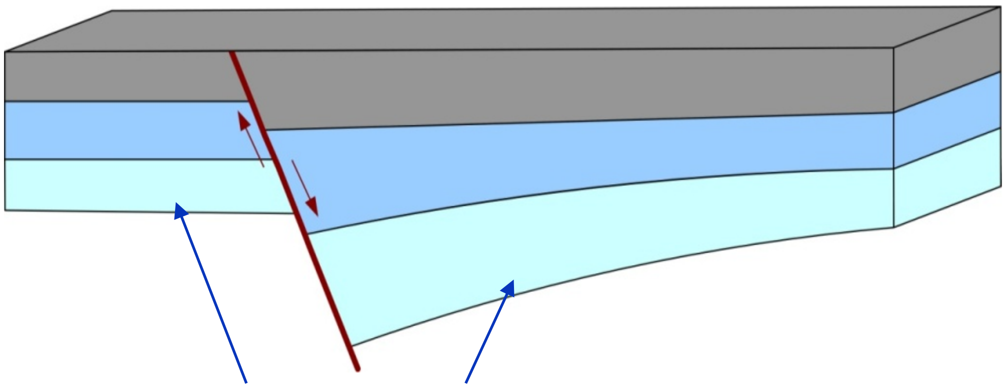
Shanchiao Fault has a thick sedimentation on hanging wall



陳文山(2011)

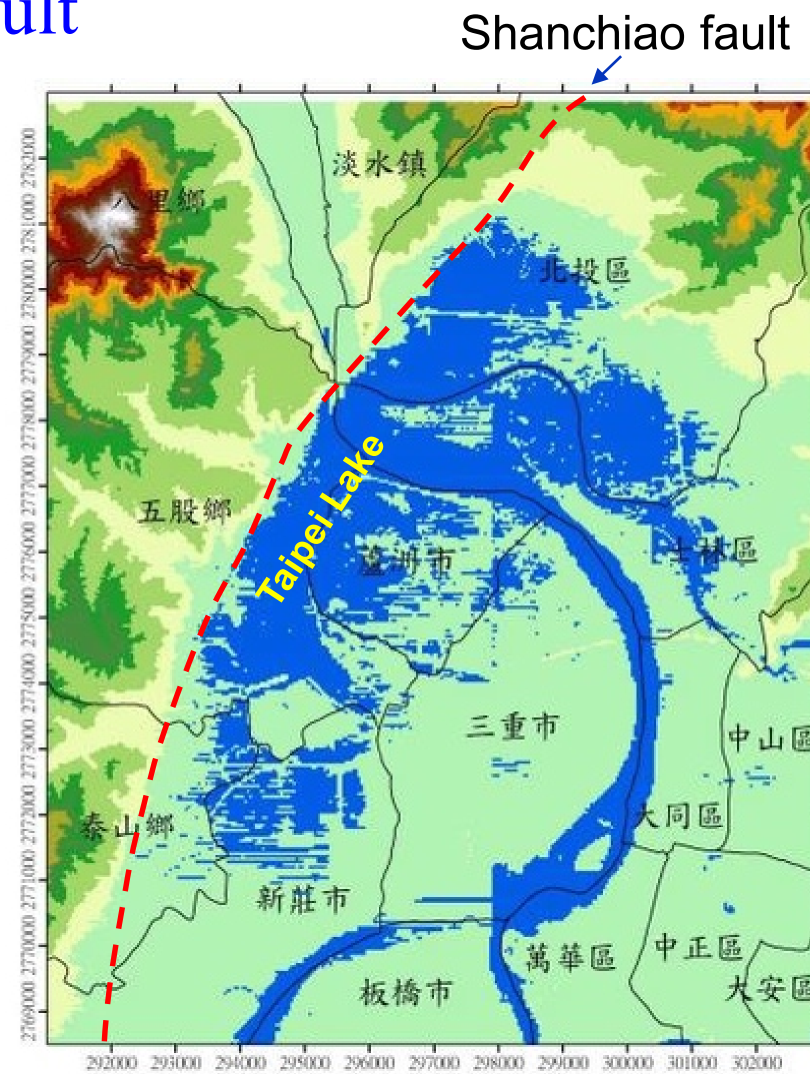
Shanchiao Fault is a Growth Fault

The structure of a growth fault



Identical sedimentation
but in different depths

The fault has several rupture
events & is still active !



(邱俊穎,2006)

West side of Taipei basin once has been a lake 300 yrs ago.
It might be an evidence for the fault movement (hanging wall sunk)

How to prevent the Dadu Line from damages ?

Methodology

Simulation methods of a shear zone development

Finite Element Method（FEM）

By using a continuum model to simulate the ground deformation, stress & strain on Dadu Line BEFORE fault rupture

FEM can not simulate the behavior (slip line, shear zone) AFTER rupture

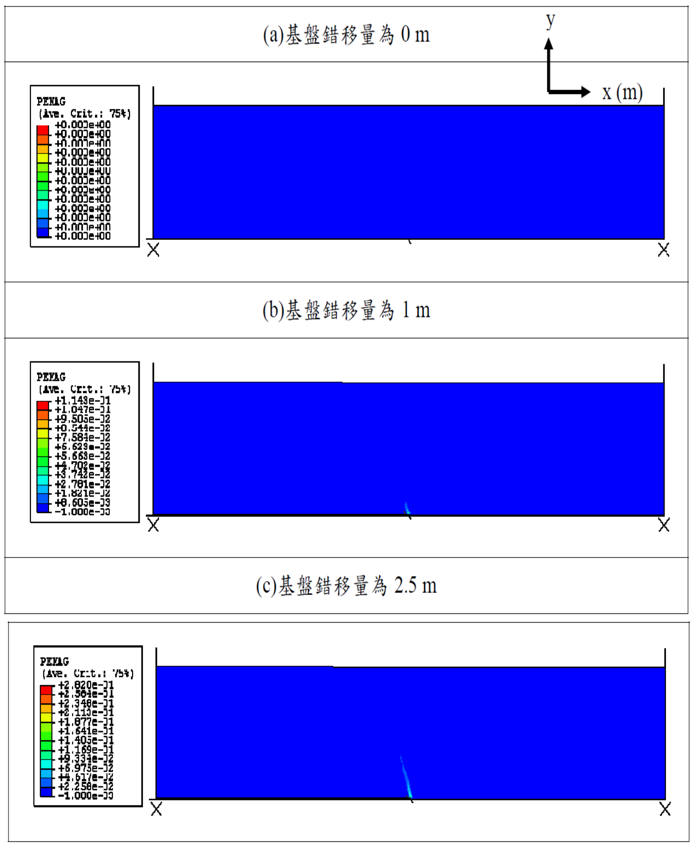
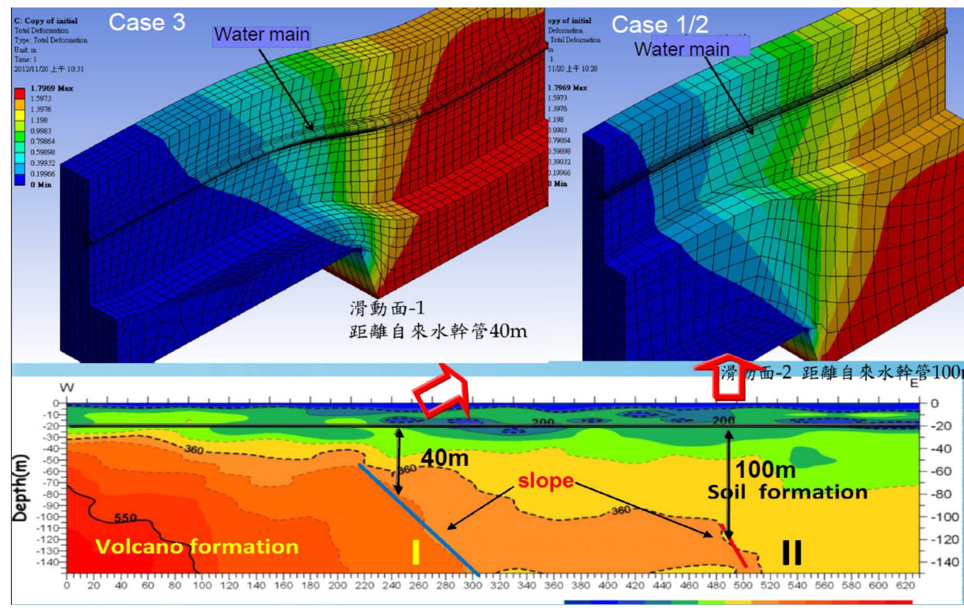


圖 4-7、覆土層厚度 700 m 塑性應變帶發展

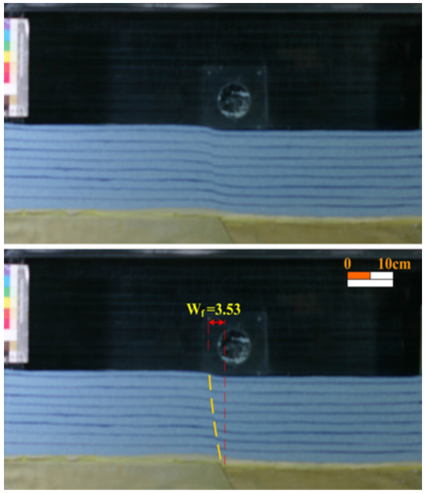
Chen (2007)

The simulation results may biased the safety side & lead to a misjudgment

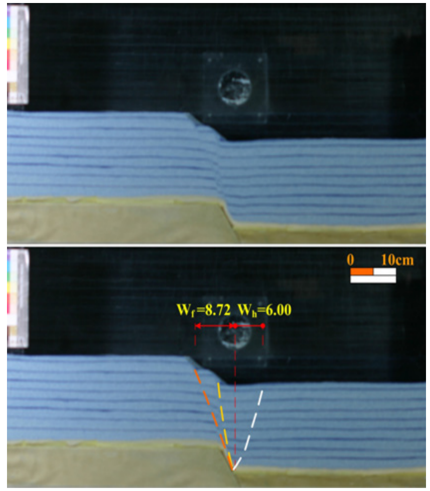


CECI (2014)

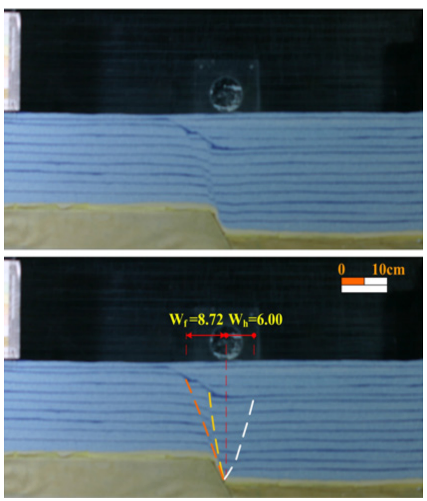
Sand Box Tests



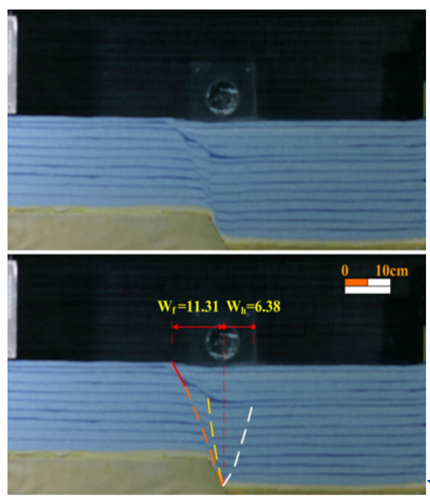
Small offset



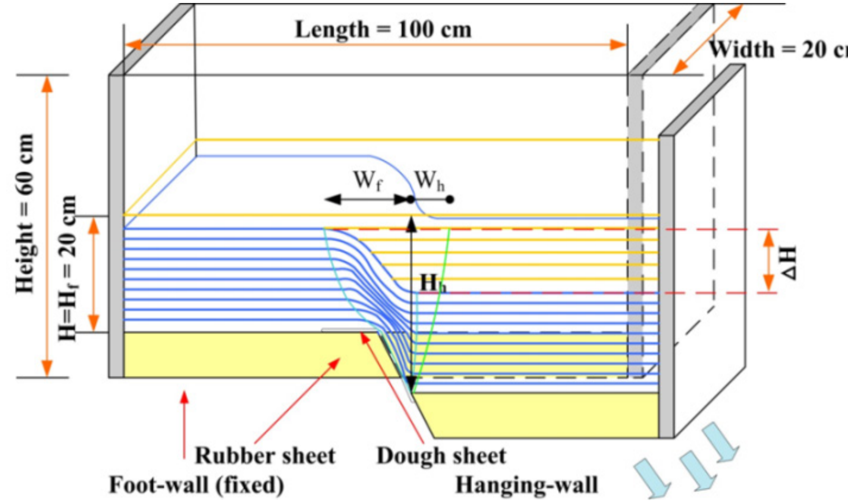
Large offset



upper sedimentation



Small offset with upper sedimentation



The authors conducted laboratory testing to explore the shear-band propagation in a growth normal fault(Chu, Lin et al. 2013) :

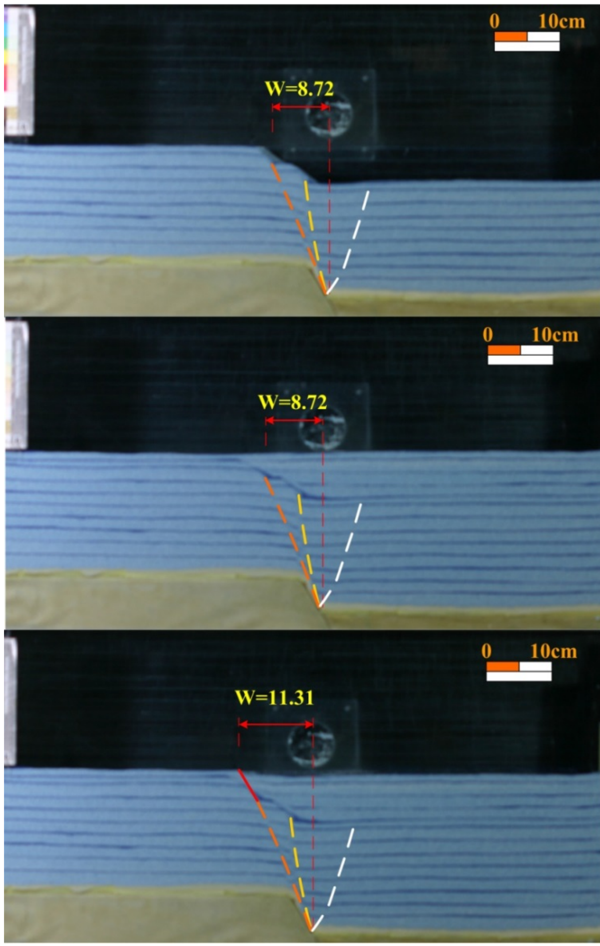
Although the upper sedimentation might be very thick, the shear band could still be propagated to the ground surface

Shear zone may damage the Dadu Line

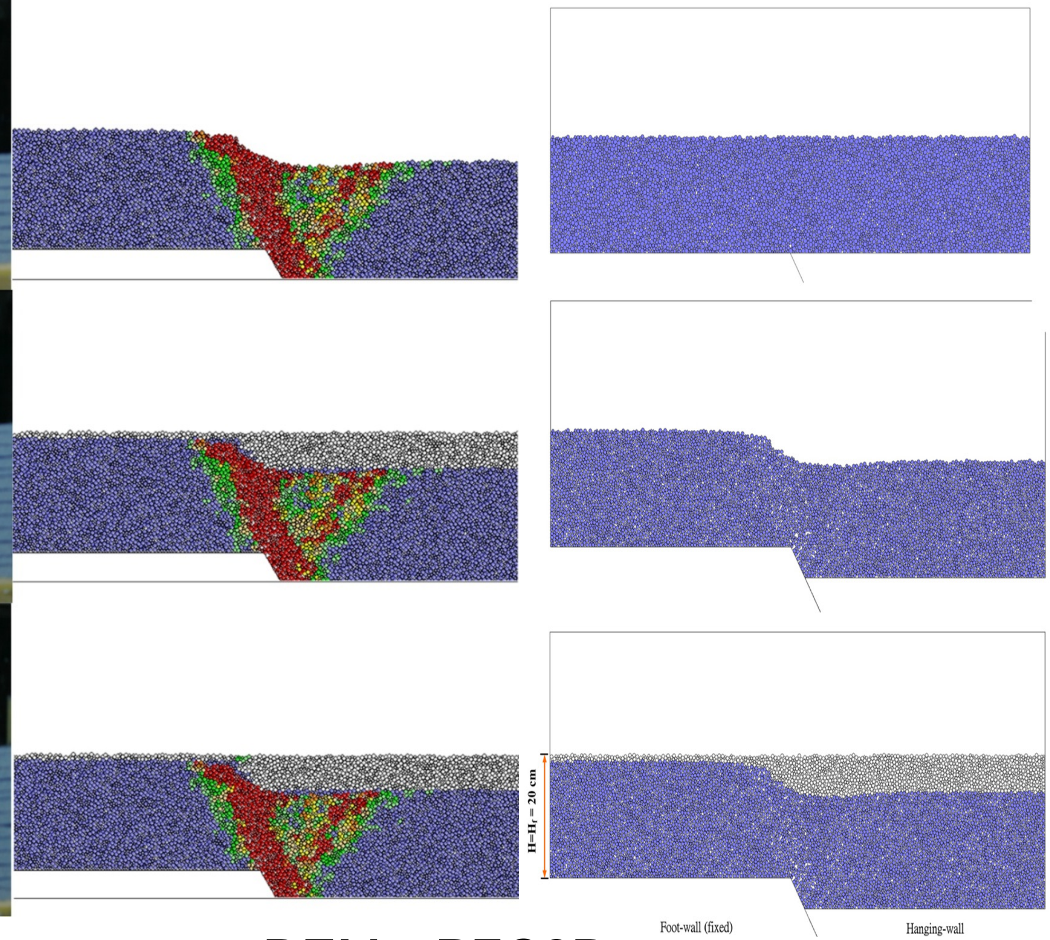
But sand box can not provides stress & strain analysis

Discrete Element Method（DEM）

The authors make use of DEM to simulate the discrete characteristics material. In recent years there have been many studies of fault modeling using DEM.(Seyferth and Henk 2006, Chang, Lee et al. 2013, Yang, Hu et al. 2014).



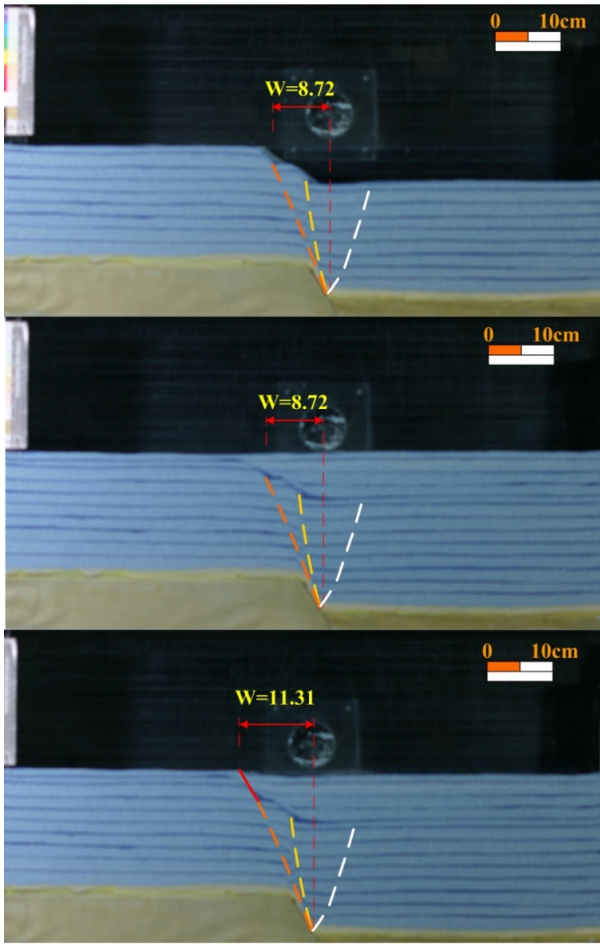
Sand box



DEM：PFC2D

DEM can not show shear strains

DEM can observe the particle movement and pore change. By using the observing circle or triangular mesh, stress changes can be calculated. However, the shear strain can not be shown in the PFC2D program. Need A NEW METHOD to do that.



Sand box

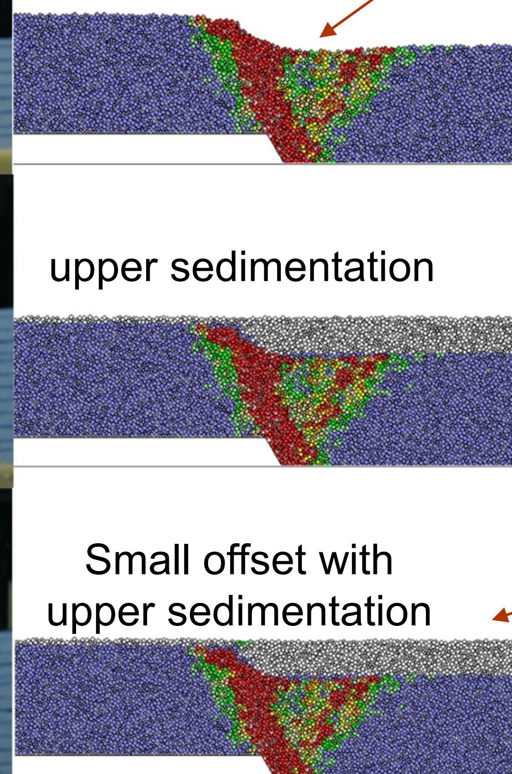
Large offset

Stress changes

upper sedimentation

Small offset with upper sedimentation

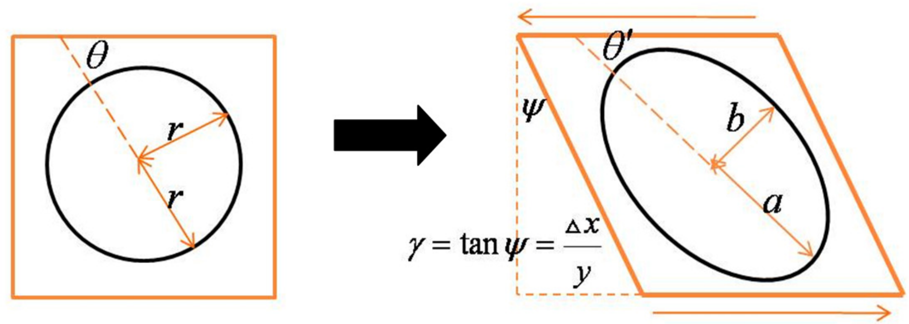
Can not show shear strain at this stage



DEM：PFC2D

Introducing a Strain Ellipse algorithm

Strain Ellipse according to the analytical method of structural geology suggested by Ramsay (Ramsay and Huber 1983)



$R = \frac{a}{b}$ ....*ellipticity*

$\Delta_A = \frac{A_{after}}{A_{before}}$ ....*volume strain*

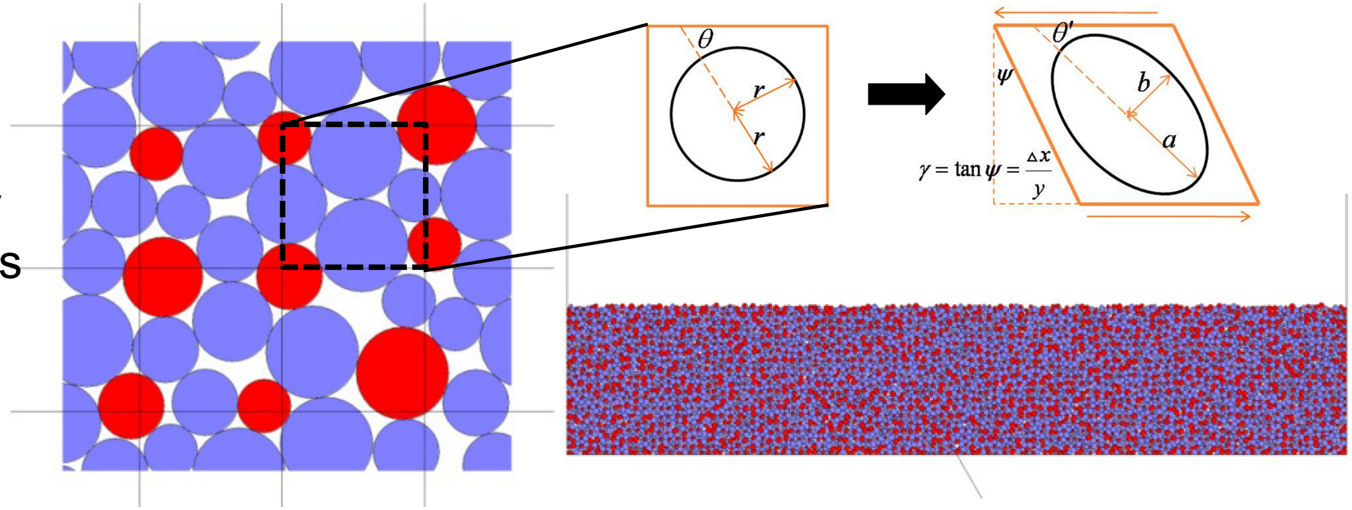
$\frac{a}{r} = R(1+\Delta_A)$ ....*max elongation*

$\tan 2\theta' = -\frac{2}{\gamma}$ ....*the axes of the finite strain ellipse*

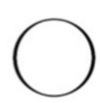
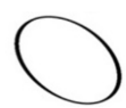
a : the long radius of the finite strain ellipse
b : the short radius of the finite strain ellipse
A_{after} : the area of the original square
A_{before} : the area of the parallel square after shearing
r : the radius of the original circle
θ' : the dip angle of the finite strain ellipse
γ : the shear strain

Involves MATLAB for strain calculation

Using MATLAB as a post processor to translate a grid-history text-data file which was produced through PFC2D simulation



By tracing the particles' positions to calculate strain then giving colors

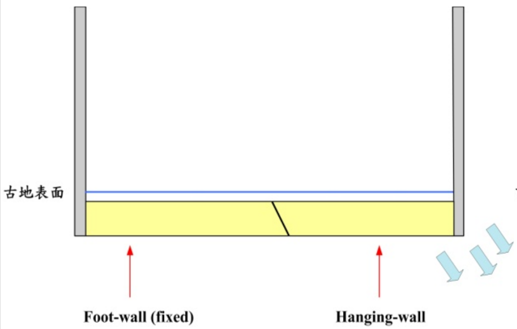
Finite strain ellipse							
ellipticity	1.0	1.5	2.0	2.5	3.0	3.5	4.0
γ	0%	41%(4%)	71%(7%)	95%(10%)	115%(13%)	133%(16%)	150%(>18%)
θ'	None	-39.2°	-35.2°	-32.3°	-30.0°	-28.1°	-26.6°
Max elongation	1.0	1.5	2.0	2.5	3.0	3.5	4.0
color(砂箱)	1.0~1.5	1.5~2.0	2.0~2.5	2.5~3.0	3.0~3.5	3.5~4.0	4.0~
color(剖面)	1.0~1.03	1.03~1.06	1.06~1.09	1.09~1.12	1.12~1.15	1.15~1.18	1.18~

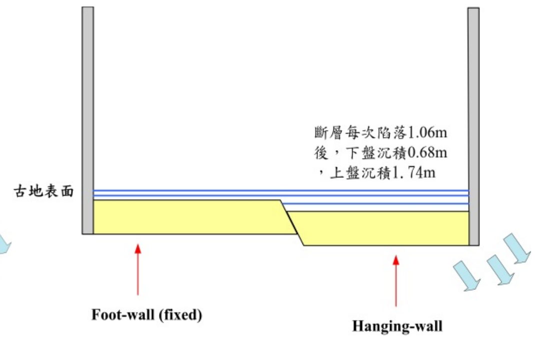
Results

The width on surface of the shear zone & suggestions for design

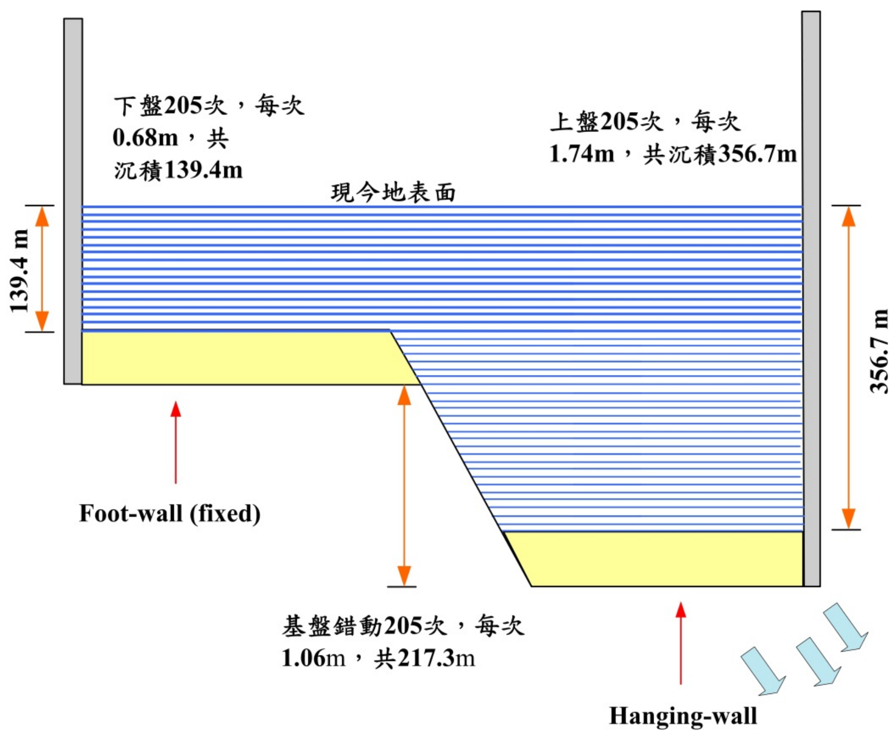
Preprocess : creating a Growth Fault profiles

(Making a real Shanchiao Fault model in DEM software PFC2D)





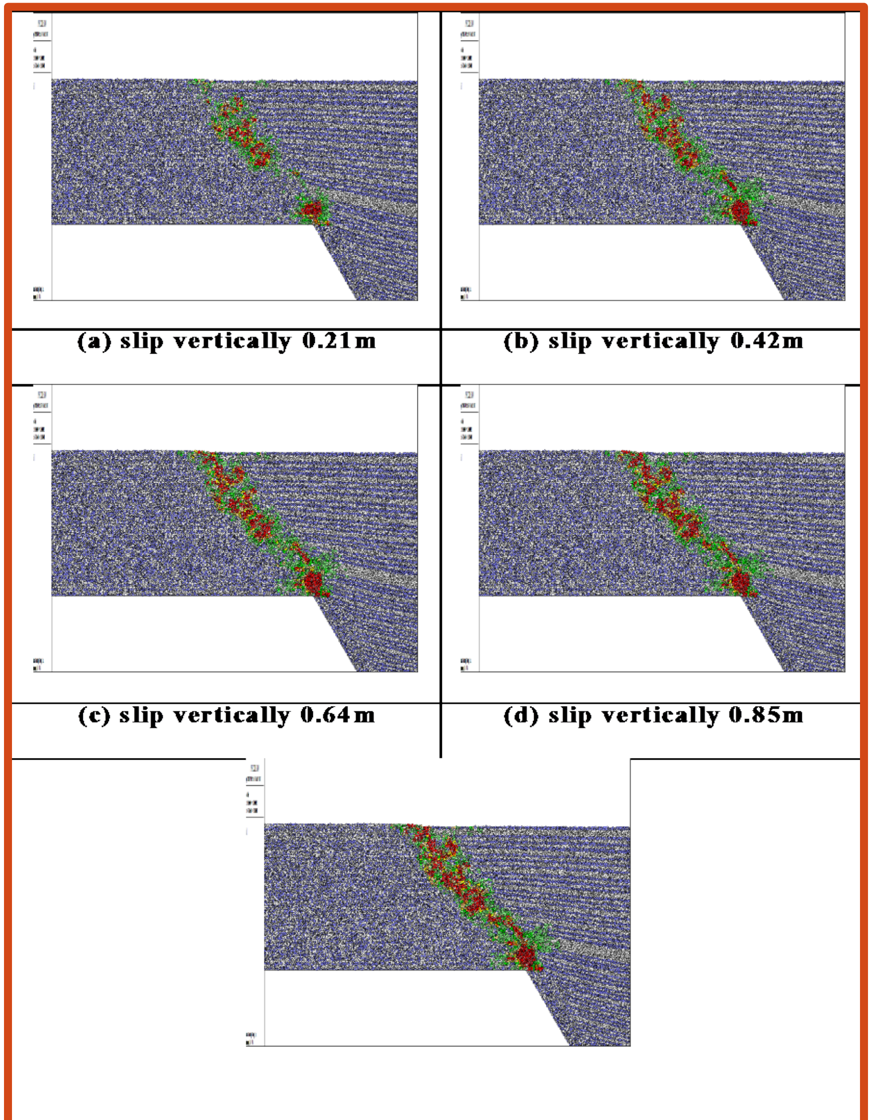
Wells and Coppersmith (1994) normal fault M =6.78+0.65* log(AD) or log(AD) =-4.45+0.63* M When AD= 1.06m. M=6.8



Microscopic parameters of the Guandu numerical models

Parameters	Values
Ball radius/percentage of weight (m/%)	1.0m/(25%)、0.9 m/(25%)、0.8 m/(25%)、0.7 m/(25%)
Normal stiffness of ball, k_n (N/m)	$k_n = k_{no}(\frac{\sigma'_v}{\sigma'_{vo}})^{0.4}$; k_{no}= $4.08 \times 10^6\ N/m$
Shear stiffness of ball, k_s (N/m)	$1/3k_n$
Normal stiffness of wall	$6.0 \times 10^{12}\ N/m$
Shear stiffness of wall	$6.0 \times 10^{12}\ N/m$
Friction coefficient of between ball	0.577 ($\varphi = 30^o$)
Friction coefficient of between ball and side wall	0.0
Friction coefficient of between ball and base wall	0.364
Density of ball (kg/m^3)	2600

Outcomes : the Shear Zones for fault slips



(a) slip vertically 0.21m

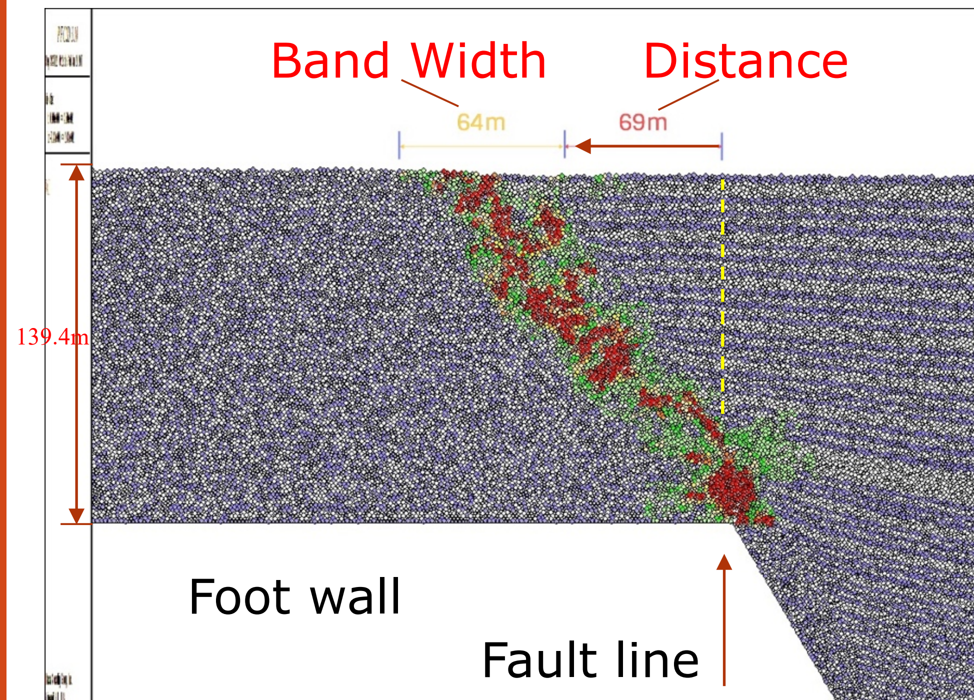
(b) slip vertically 0.42m

(c) slip vertically 0.64m

(d) slip vertically 0.85m

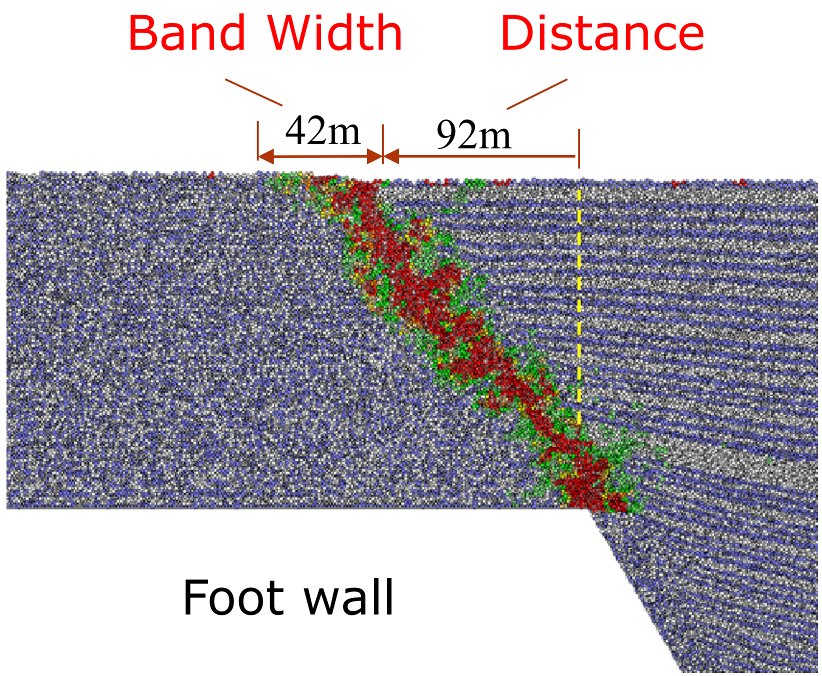
(e) slip vertically 1.06m

Simulating a fault slip : 1 m
Magnitude will be about 6.8



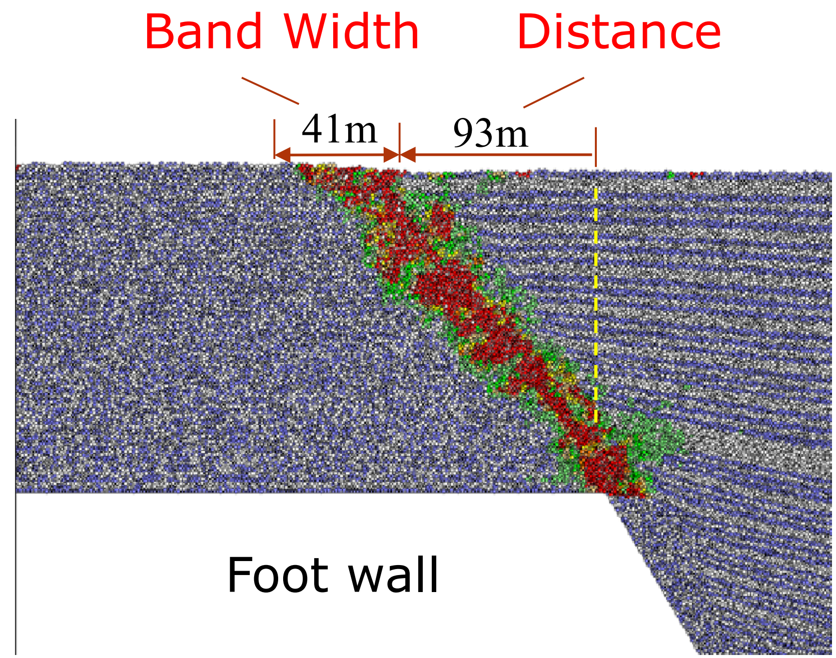
Shear-zone on surface has a Distance from projection of fault line, also has a Band Width

Simulations for larger slips



Fault Slip = 2.0m

Magnitude 7.0



Fault Slip = 2.5m

Magnitude 7.1

Wells and Coppersmith (1994),

Normal fault: log(MD) = -5.90+0.89*M (M = Magnitude, MD = Max Displacement)

Conclusions & Suggestions

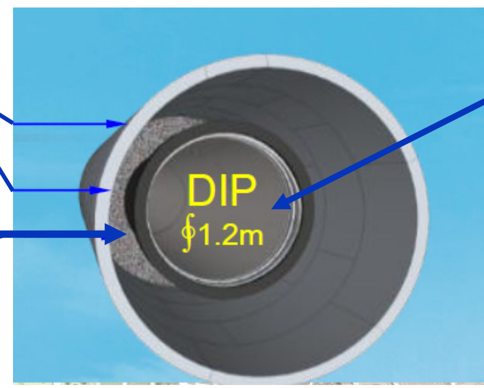
The shear zone generated by fault slips depends on location and dip angle of the fault.

There are 2 ways to deal with the shear zone :

- Flexible Joints & flexible filling materials:

Shield Tunnel

Filling materials
(Using loose sands)



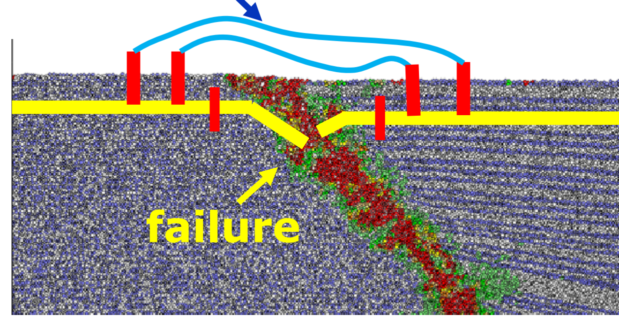
Pipeline: Using Flexible Joints

Internal pipeline may survive the small fault slips

- A bypass system:

branch pipes can be arranged outside the shear zone to maintain the water supply when large-scale fault slips destroy the trunk pipe

Temporary hoses



trunk

THANKS FOR YOUR ATTENTION

A flexible oil pipe design in 1970s prevented a disaster brought by a 7.9M earthquake in 2002

Denali fault

(a) before (b) after

Shift Happens!

(Denali Fault Earthquake Photos 07 Nov 2002)

Contact Information of the Author