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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Introduction

The Shanchiao Fault: an Active, Normal, Growth fault
The National Science and Technology Center for Disaster Reduction (NCDR) of Taiwan has analyzed for large-scale earthquake shocks in the Metropolitan Taipei area.

**Earthquake Disaster Assessment in Taipei**

**Concentrating in the Basin**

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.
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

(Drilling surveys)

(Present)

(Holocene)

(Pliestocene)

(Miocene)

Foot wall

Hanging wall
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!

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

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

\[ \Delta A = \frac{A_{\text{after}}}{A_{\text{before}}} \] ........volume strain

\[ \frac{a}{r} = R(1 + \Delta A) \] ........max elongation

\[ \tan 2\theta' = \frac{2}{\gamma} \] ........the axes of the finite strain ellipse

\[ \gamma = \tan \psi = \frac{\Delta x}{\gamma} \]

\[ a : \text{the long radius of the finite strain ellipse} \]
\[ b : \text{the short radius of the finite strain ellipse} \]
\[ A_{\text{after}} : \text{the area of the original square} \]
\[ A_{\text{before}} : \text{the area of the parallel square after shearing} \]
\[ r : \text{the radius of the original circle} \]
\[ \theta' : \text{the dip angle of the finite strain ellipse} \]
\[ \gamma : \text{the shear strain} \]
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.

<table>
<thead>
<tr>
<th>Finite strain ellipse</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>ellipticity</td>
<td>1.0</td>
<td>1.5</td>
<td>2.0</td>
<td>2.5</td>
<td>3.0</td>
<td>3.5</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>0%</td>
<td>41%(4%)</td>
<td>71%(7%)</td>
<td>95%(10%)</td>
<td>115%(13%)</td>
<td>133%(16%)</td>
</tr>
<tr>
<td>$\theta'$</td>
<td>None</td>
<td>-39.2'</td>
<td>-35.2'</td>
<td>-32.3'</td>
<td>-30.0'</td>
<td>-28.1'</td>
</tr>
<tr>
<td>Max elongation</td>
<td>1.0</td>
<td>1.5</td>
<td>2.0</td>
<td>2.5</td>
<td>3.0</td>
<td>3.5</td>
</tr>
<tr>
<td>color (砂箱)</td>
<td>1.0~1.5</td>
<td>1.5~2.0</td>
<td>2.0~2.5</td>
<td>2.5~3.0</td>
<td>3.0~3.5</td>
<td>3.5~4.0</td>
</tr>
<tr>
<td>color (銅面)</td>
<td>1.0~1.03</td>
<td>1.03~1.06</td>
<td>1.06~1.09</td>
<td>1.09~1.12</td>
<td>1.12~1.15</td>
<td>1.15~1.18</td>
</tr>
</tbody>
</table>
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)

Microscopic parameters of the Guandu numerical models

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ball radius/percentage of weight (m/%)</td>
<td>1.0m/(25%), 0.9 m/(25%), 0.8 m/(25%)</td>
</tr>
<tr>
<td>Normal stiffness of ball, $k_n$ (N/m)</td>
<td>$k_n = k_{no} \left(\frac{\sigma'}{\sigma_{vo}}\right)^{0.4}$; $k_{no} = 4.08 \times 10^6$ N/m</td>
</tr>
<tr>
<td>Shear stiffness of ball, $k_s$ (N/m)</td>
<td>$1/3k_n$</td>
</tr>
<tr>
<td>Normal stiffness of wall</td>
<td>$6.0 \times 10^{12}$ N/m</td>
</tr>
<tr>
<td>Shear stiffness of wall</td>
<td>$6.0 \times 10^{12}$ N/m</td>
</tr>
<tr>
<td>Friction coefficient of between ball</td>
<td>0.577 ($\varphi = 30^\circ$)</td>
</tr>
<tr>
<td>Friction coefficient of between ball and side wall</td>
<td>0.0</td>
</tr>
<tr>
<td>Friction coefficient of between ball and base wall</td>
<td>0.364</td>
</tr>
<tr>
<td>Density of ball (kg/m$^3$)</td>
<td>2600</td>
</tr>
</tbody>
</table>
Outcomes: the Shear Zones for fault slips

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

Foot wall
Fault line

Band Width
Distance

(a) slip vertically 0.21 m
(b) slip vertically 0.42 m
(c) slip vertically 0.64 m
(d) slip vertically 0.85 m
(e) slip vertically 1.06 m
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

- **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
THANKS FOR YOUR ATTENTION

A flexible oil pipe design in 1970s prevented a disaster brought by a 7.9M earthquake in 2002 (Denali Fault Earthquake Photos 07 Nov 2002)

Shift Happens!
(Denali Fault Earthquake Photos 07 Nov 2002)