Frictional and kinematical characteristics of the Hungtsaiping landslide, Taiwan

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Outline

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  - Objective
- Methodology
  - Rotary shear tests
  - Newmark analysis
- Preliminary result
  - Friction characteristics
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Introduction

Study area

Geological condition:
JFES: Rock dip slope failure
HTP: Soil slope failure

Frictional characteristics:
JFES: Velocity weakening
HTP: not velocity-dependent

(Dong et al., 2009)
Introduction
Frictional characteristic

**Direct shear test**
Water content: natural water content
Slip rate: $10^{-5} \sim 1.5 \times 10^{-5}$ m/s
Shear displacement: ~ 10 mm
$\phi_r = 30.94^\circ$, $\mu = 0.60$

**Triaxial test (SCU)**
Water content: saturated
Slip rate: $10^{-6}$ m/s
Shear displacement: ~ 10 mm
$\phi_r = 21.12^\circ$, $\mu = 0.39$

(Ke, 2006)
Introduction
Newmark analysis

Rigid friction-block model

\[ L = \text{load} = mg \cdot \sin \theta \]
\[ R = \text{resistance} = \tau_c - A \]
\[ \tau_c = \text{shear strength} = c + mg \tan \phi \cos \theta \]
\[ c = \text{cohesion}, \phi = \text{angle of friction} \]
\[ A = \text{area of failure surface} \]

(Wilson and Keefer, 1983)

(Newmark, 1965)
Introduction

Newmark analysis

Planar failure

Backward analysis of friction coefficient

(Chen and Liu, 1990)

(Dong et al., 2009)
Introduction

Objective

- Soil slope stability analysis highly related with strength parameters, environment conditions and the selection of the profile to be analyzed.

- Discussing the reason on the absence of a catastrophic landslide at HTP landslide area during Chi-Chi earthquake.

Rotary shear tests

Newmark analysis (Circular failure)

Site investigation from previous studies (Dong et al., 2009)
Methodology
Physical property

Unified soil classification
Atterberg limit test

Mineral composition
X-ray Diffraction
- Whole rock analysis
- Oriented thin section

Grain Size Analyzer
Methodology

Rotary shear test

LHVR-Taiwan

Rotation drive system

Sample holder

Torque gauge

Axial LVDT

Axial load applicator

Rotary encoder

$\sigma_n$

Servo control system
**Experimental conditions**

Pre-consolidated: 1~5MPa
Normal stress: 1, 2, 3 MPa (shear tests)
    0.4 ~ 4 MPa (Teflon calibration)
Sample diameter (mm): 24.94
Water content: natural water content immersed in water
Shear rate: $2.1 \times 10^{-7} \sim 2.1 \times 10^{-2}$ m/s
Methodology

STABL

(Dong et al., 2009)
Methodology

STABL

Soil properties:
Total unit weight: 21.3 kN/m³ (Ke, 2006)
Saturated unit weight: 25.1 kN/m³ (Ke, 2006)
Friction coefficient, \( \mu \): from rotary shear test
Friction angle, \( \phi \): \( \mu = \tan \phi \)

Groundwater level:
Seep/W: finite element analysis software
(simulated by Sinotech engineering consultants, inc., 2008)

Analysis method:
Specify failure surface
Bishop method
Methodology

Newmark analysis

Use STABL to:
• Calculate the F.S for irregular sliding surface
• Find out the $A_c$ that when the F.S=1.0

Angular acceleration, $\ddot{\theta} = (k_h - k_y) g \frac{\cos \beta_{cg}}{R_{cg}}$

$$= \left( \frac{A_h}{g} - \frac{A_c}{g} \right) g \frac{\cos \beta_{cg}}{R_{cg}}$$

Displacement, $D = \theta R$

(Wen et al., 2003)

(Factor of Safety, $F.S = \frac{\text{Resistance force}}{\text{Driving force}}$)
Results
Physical properties

Atterberg limit test
(ASTM D4318-10)
LL = 31.81%
PL = 12.47%
PI = 19.34

Particle size distribution

Unified soil classification
↓
Low plasticity clay, CL
Results
Physical properties

X-ray Diffraction

Whole rock analysis

Oriented thin section

<table>
<thead>
<tr>
<th>Apparent content (%)</th>
<th>Smectite and mixed-layer clay mineral</th>
<th>Illite</th>
<th>Kaolinite</th>
<th>Chlorite</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>36.92</td>
<td>41.32</td>
<td>11.28</td>
<td>10.48</td>
</tr>
</tbody>
</table>
Two methods to correct the Teflon friction

No-load tests

- Every test use new Teflon sleeve
- No gouge between the host rocks

Normal stress cycle tests (NC tests)

- This test follow each shear test (use the same Teflon sleeve as the shear test)

Initial tightness:

(Tightness: Teflon sleeve’s inner diameter – host rock’s diameter)

Blue: Submerged in water
Orange: Room humidity
Results

Two methods to correct the Teflon friction:

- Black: uncorrected
- Blue: corrected by no-load test
- Red: corrected by NC test

Gouge had squeezed out from the Teflon sleeve.

Friction coefficient:
- Black: uncorrected
- Blue: corrected by no-load test
- Red: corrected by NC test
Varying velocity shear tests

▲ Over-consolidated
▲ Natural water content

• Normally-consolidated
• Immersed in water

Results
Rotary shear test
Results

Rotary shear test

Single velocity shear tests

- Normally-consolidated
- Immersed in water
No earthquake occurred
When F.S=1.00, $\phi=19.7^\circ \rightarrow \mu=0.36$
1. The landslide material is low-plasticity clay, which has about 37% apparent content of swelling clay minerals.

2. When the tests under over-consolidated and natural water content conditions, the friction coefficient is 0.3 - 0.4 and have velocity-strengthening characteristics.

3. Under normally-consolidated, immersed in water conditions, the frictional characteristics is velocity-neutral at low shear rate, but velocity-weakening at the shear rates exceed $2.07 \times 10^{-5}$ m/s.

4. The friction characteristics of single velocity shear tests more sensitive to the shear rate than the varying velocity shear tests.

5. If no earthquake occurred, the F.S of HTP area equal 1.0, the friction coefficient is 0.36.
1. Conducting single velocity shear tests under over-consolidated, natural water content condition.

2. Applying the velocity-dependent friction law (experiment results) to the Newmark analysis for circular failure to understand the kinematic characteristic of HTP area during Chi-Chi earthquake.

(Ferri et al., 2011)
Thanks for your attention.