Climate effects, infiltration and triggering of landslides

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Overview of relevant research projects

- **HKUST Programs**
  - Emerging geohazards in Hong Kong and Pearl River Delta due to climate changes
    (PI: LM Zhang, Co-Is: CWW, YH Wang, YK Tung and DG Fredlund, CT Hsu, PA van Laak, and K Xu)
  - An explicit risk-based approach for large-dam safety decisions
    (PI: LM Zhang, Co-Is: Wilson Tang and YK Tung)

- **Research Grants Council of Hong Kong SAR**
  - Water infiltration through cracked soils for landslides study
    (PI: LM Zhang, Co-Is: Del Fredlund and Yuan Wang)
  - Investigation of failure of embankment dams and levees - from initiation to breach
    (PI: LM Zhang)
  - Large-scale geotechnical hazards caused by environmental actions: Impact of rainfall and reservoir filling
    (PIs: LM Zhang and YR Zheng)

- **Ministry of Water Resources, China**
  - Dam breach database and breaching parameters
Emerging geohazards in Hong Kong and Pearl River Delta due to climate changes

### Objectives
- To study short-term and long-term impacts of climate changes on landslides, floods formation and ground subsidence in Hong Kong and the Pearl River Delta
- To study hydro-geological conditions in ground at extreme drought climate
- To study the mechanisms of “surprising” floods and landslides following an extreme drought

### Pearl River Delta Natural Disasters Research Network
- HKUST
- Zhongshan University
- Pearl River Water Resources Commission
- Guangdong Water Resources Research Institute
- Coordinators: Dr Huang BS (Guangzhou)
  - Mr Geng Yang (Shenzhen)
  - Dr LM Zhang (Hong Kong)

Although only a gradual minor change in average annual rainfall and evaporation is observed, the yearly variations have become more extreme.

Abnormal climate phenomena such as extreme droughts, storms, typhoons and tides occur more frequently than ever in the last decade.

In the first half of 2004, Guangdong experienced five extreme climate events: one extreme drought, one 20-day cold front, one extreme heat wave, eight major storms, and seven major tidal events. This was unusual.

Focus on study of effect of extreme weather conditions on formation of geohazards and flooding

(After Leung et al. 2004)
- Example: effect of extreme weather on flood generation
- The climate conditions come into play through initial conditions

Example: effect of extreme weather on flood generation

The climate conditions come into play through initial conditions.

Effect of prior-rain climate conditions on surface runoff generation - A rainfall event after an extreme drought will generate a flood approximately twice as much as that in the normal condition, which explains “surprising” flood disasters that are not likely under normal prior climate conditions.
Water infiltration through cracked soils for landslides study

- Characterizing random crack networks in soil
- Crack dynamics: how do cracks develop and how do they interact with the climate?
- Water infiltration in cracked soils
  - Permeability tensor
  - Existence of representative element volume
- Role of cracks in landslide triggering

Water infiltration in cracked soil

- Cracks are common in clayey or expansive soil ground
- How are the geometrical characteristics of the random crack network described?
- How does water infiltrate in cracked ground?
Water infiltration in landslide scars/cracks

- Reactivation of landslide due to water infiltration through the cracks?
- Flow in partially filled cracks?
- Film flow, intermittent flow and fingering?
- Equivalent continuum?
Water infiltration in cracked dams

Dam safety and rehabilitation

Piping? Hydraulic fracturing? Self-healing?

How does matric suction cause the soil to pull away from embedded structures and cause contact seepage failures?

Flow along interfaces?

Crack dynamics

- Mechanisms of development of desiccation cracks
- Hierarchical crack structures
- Change of crack aperture with time, boundary, and environmental factors
- Crack occurrence repeatable or not?
- Statistical parameters of crack network: length, depth, aperture, orientation, density, location
- Random field description of cracks
- Precisely manufactured plates simulating fractures of spatially correlated aperture structure

**Does permeability tensor exist?**

Directional permeability satisfies an elliptical equation (Bear, 1972)
Permeability tensor for different sub-windows (Li & Zhang 2007)

\[
\begin{align*}
&k_{xx}^i, k_{xy}^i, k_{yx}^i, k_{yy}^i \\
&k_{xx}^{i+1}, k_{xy}^{i+1}, k_{yx}^{i+1}, k_{yy}^{i+1}
\end{align*}
\]

Permeability invariant

\[
k_{av} = \frac{k_{xx} + k_{yy}}{2}
\]

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<table>
<thead>
<tr>
<th>Crack set</th>
<th>Length (mm)</th>
<th>Aperture (mm)</th>
<th>Orientation (°)</th>
<th>Density (Lmp)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Standard deviation</td>
<td>Mean</td>
<td>Standard deviation</td>
</tr>
<tr>
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<td>40</td>
<td>13</td>
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<td>30</td>
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<tr>
<td></td>
<td>Lognormal</td>
<td>Lognormal</td>
<td>Normal</td>
<td>Density</td>
</tr>
</tbody>
</table>

* Suggested by Perret et al. (1999)
Non-orthogonal relative orientation will produce an anisotropic permeability tensor.

A small relative orientation leads to a larger permeability in the preferred direction.

Networks with larger mean crack apertures have larger permeability.

If a 20% relative error in permeability invariant is acceptable to find a REV, then the REV is 7.2 times the mean crack length.
Laboratory measurement of permeability tensor
- 200x200x200 three-dimensional permeability cell
- Pressure-controlled triaxial permeability cells for flow in empty or partially filled individual cracks

Field measurement of permeability tensor
- Large diameter double rings
- Two-stage borehole test
Large-scale geotechnical hazards caused by environmental actions: Impact of rainfall and reservoir filling

Task I: Synthesis of stabilization of TGRZ and Hong Kong slopes against environmental impacts (CLEU);
Task II: Laboratory testing and theoretical study of flows in unsaturated gap-graded soils (HKUST);
Task III: Analysis of transient flows and hydrodynamic pressures in natural terrain slopes under rainstorms and drawdown of reservoir water level (HKUST);
Task IV: Laboratory study of the shear strength of gap-graded soils and soil-rock interfaces at different water content and gravel content (CLEU);
Task V: Stability analysis of natural slopes considering reservoir water level changes and rainfall (CLEU);
Task VI: Centrifuge modelling of the effects of reservoir level change and rainfall on slope stability (HKUST);
Task VII: Evaluation and management of risk imposed by water-related environmental impacts (HKUST);
Task VIII: Enhancement of design codes against geo-hazards (CLEU).
Qianjiangping Landslide (13 July 2003)

The Qingan River was blocked by approximately 24 million m$^3$ landslide debris. A brick manufacturing factory slipped with the slide for approximately 500 m. (Photo from http://www.people.com.cn, Photographed by R. Cheng, 17 July 2003)

Rain-induced landslides: Yunyang, once the home of about 60000 people
Sifangjing landslide in Three-Gorge reservoir zone (bimodal)
Research plan

Characterization of pore geometry
Prediction

Laboratory testing of hydraulic properties for gap-graded soil
Measurement

Laboratory testing of hydraulic properties of unimodal soil
Prediction

Hydraulic properties for gap-graded soil
Simulation

Verification

Soil column tests

Centrifuge model tests

Water flow in natural soil slopes

Pore geometry (Effect of compaction effort)

![Graph showing pore geometry](image)
SWCCs for bimodal soils (Zhang et al 2004)

If the two characteristic grain components are far apart, two pore series may exist in the bimodal soil,

$$\theta = \eta \theta_f + (1-\eta) \theta_c$$

$\eta$ = fraction of the fine-grained characteristic component

$\theta_f$ = volumetric water content of the fine-grained characteristic component

$\theta_c$ = volumetric water content of the coarse-grained characteristic component

- Based on axis-translation technique
- Accurate pore-water pressure control (0.01 kPa)
- Large vessel (20 cm in depth and 29 cm in inner diameter), large soil specimen
- Available pore-air pressure control
- Accurate measurement of released water
- Drying curve & wetting curve
Large-scale 1D column for
- Infiltration test
- Measuring permeability function
- SWCCs

Infiltration process in three soils
Capillary rise process in three soils
Water content changes
Derived permeability functions
Thank you very much