Advance on Unloading Rock Mass Mechanics

Prof. Li Jianlin
Dr. Li Xinzhe

三峡大学
CHINA THREE GORGES UNIVERSITY

China Three Gorges University

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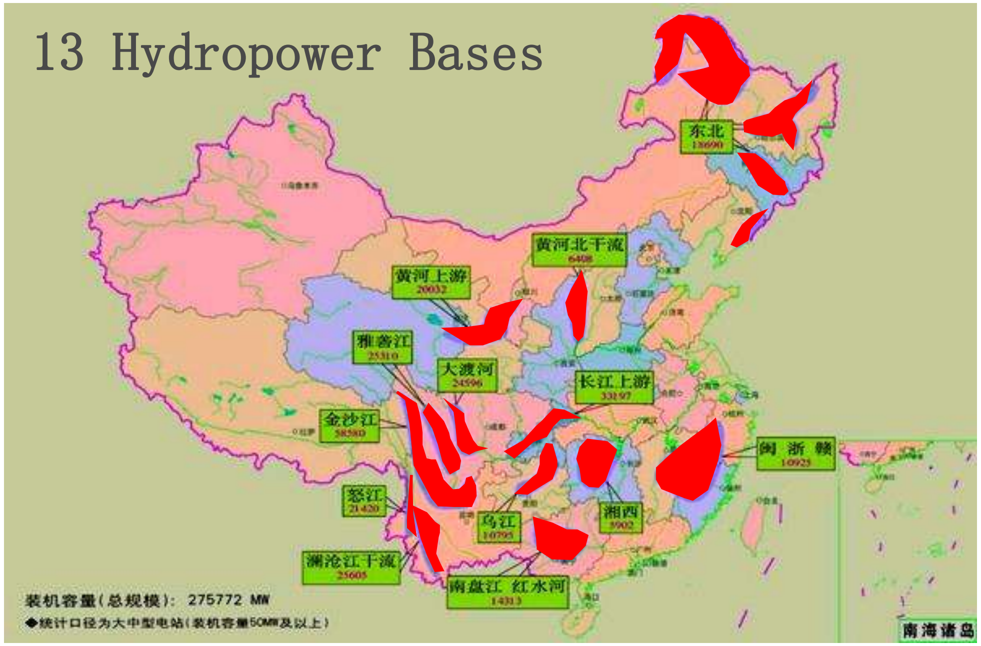
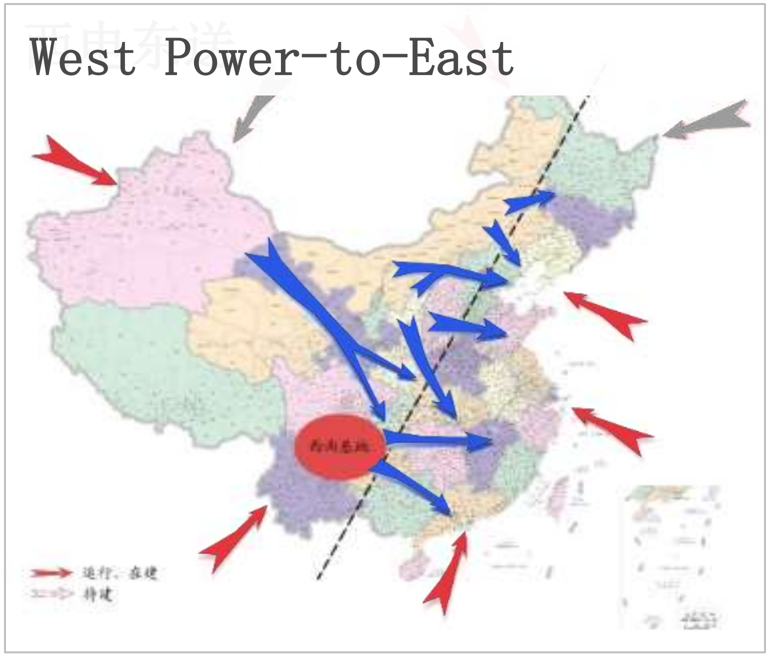
CONTENTS

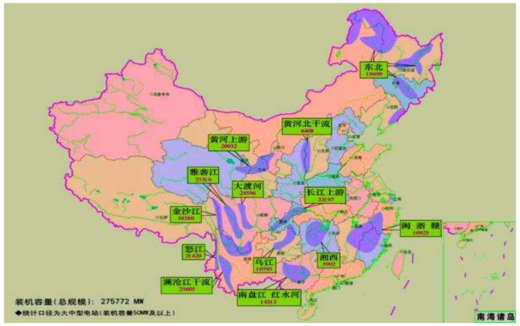
1.1 Industry Background

Over the past few decades, China has successfully built a number of hydropower stations. According to the National Energy Development Projects (2006-2015), plenty of hydropower based constructions have been built in China.





1. RESEARCH BACKGROUND

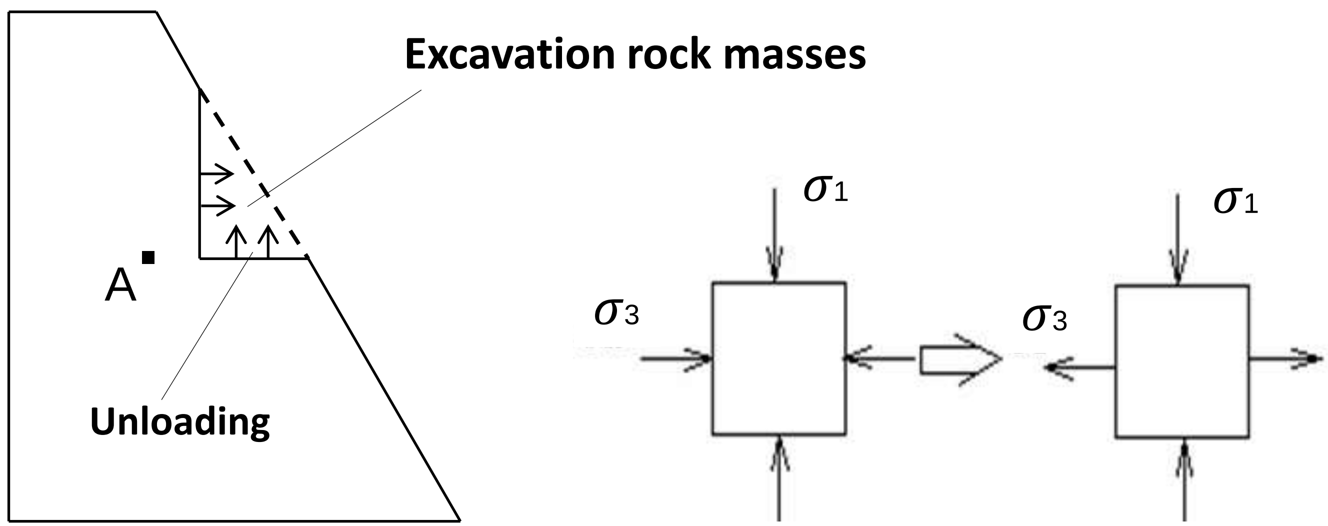


Hydropower Bases

1.2 Engineering Background

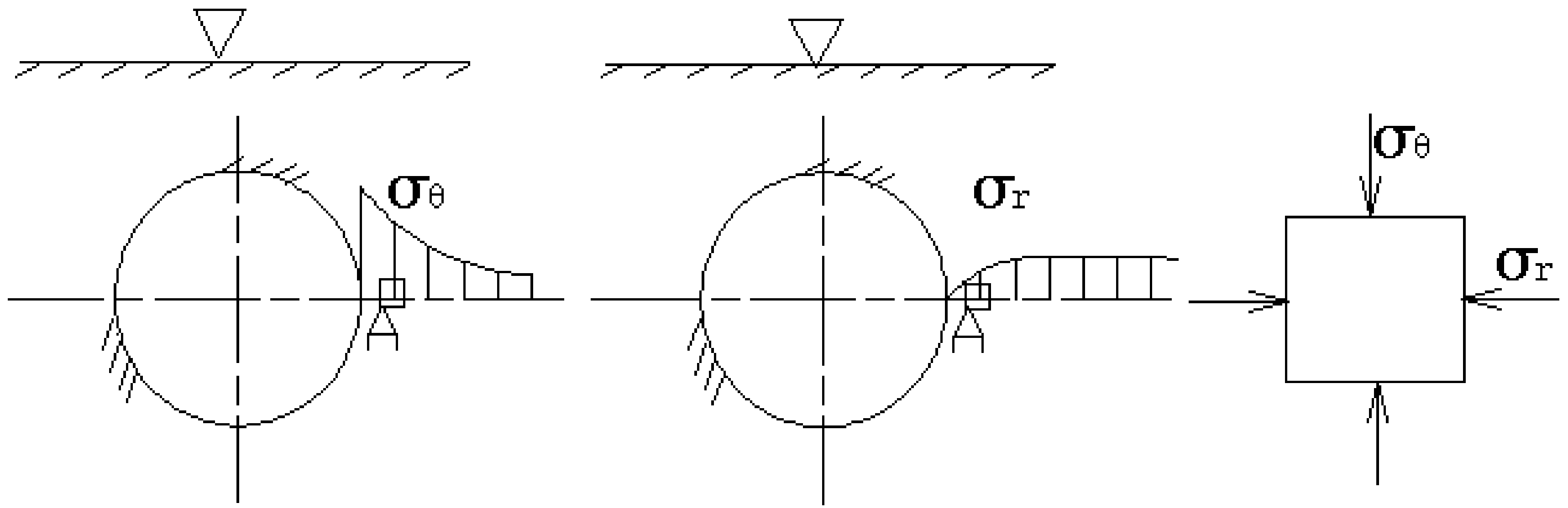
- **Three kinds of rock masses**

Example 1: Slope Engineering



- For point A
- Before excavating: σ_1, σ_3 → loading condition.
- After excavating: σ_1 →loading condition, σ_3 → unloading condition.

Example 2: Tunnel Engineering



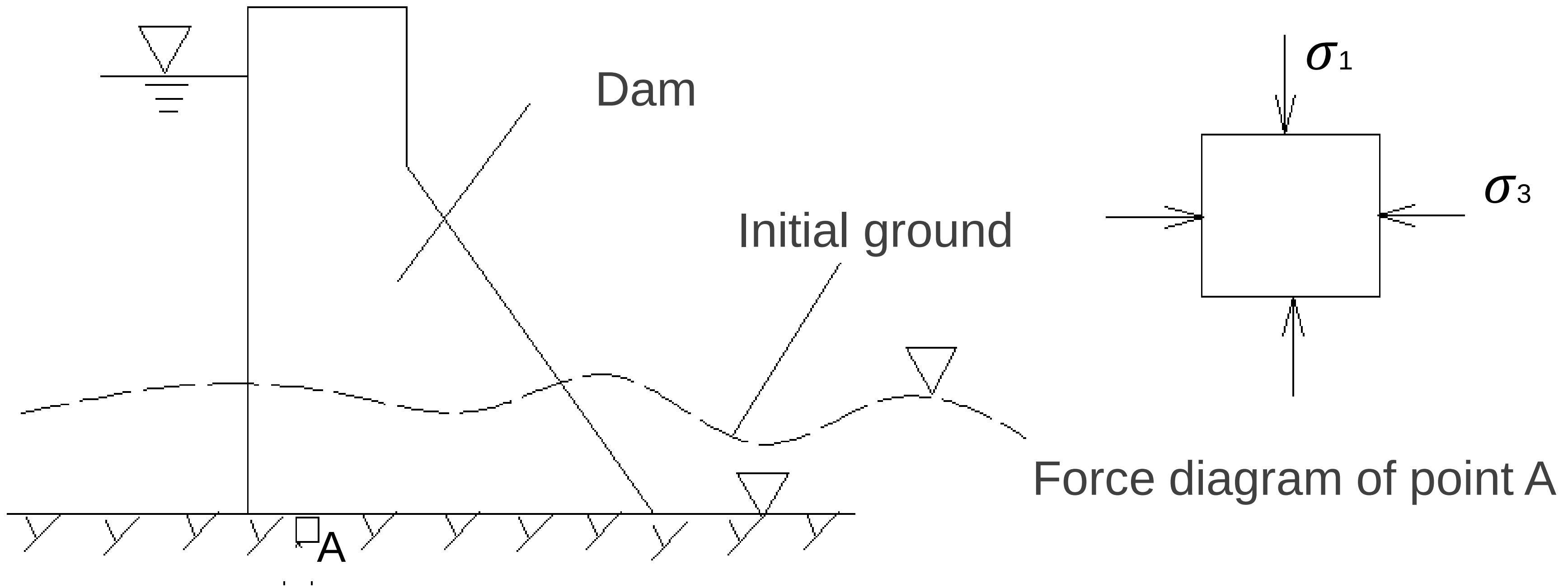
Distribution of σ_θ | Distribution of σ_r | Enlarged drawing of point A

- For point A

  Before excavating: σ_θ , σ_r →loading condition.

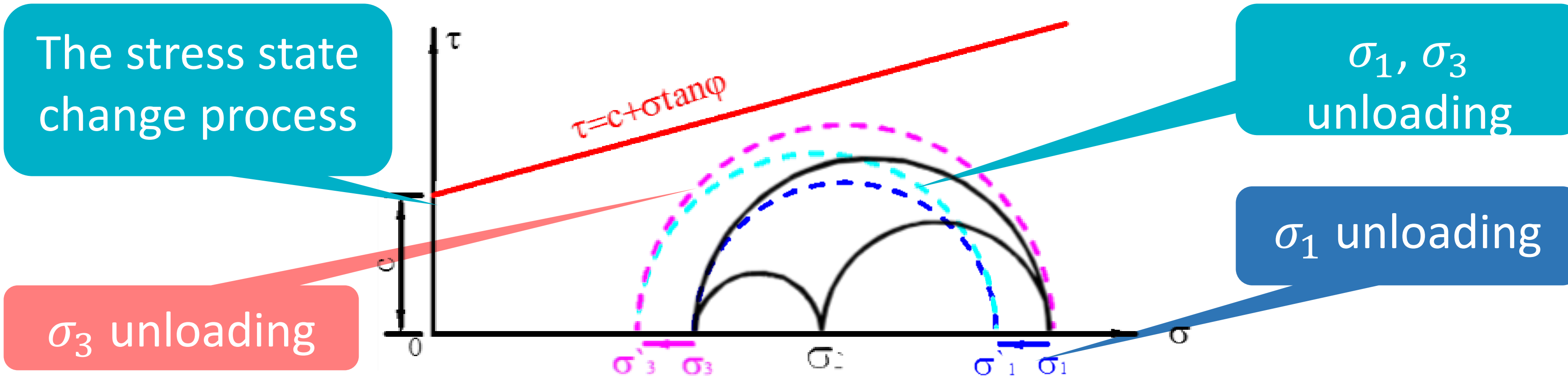
- After excavating: σ_θ →loading, σ_r → unloading.

Example 3: Foundation Engineering



- For point A
- Before excavating: σ_1, σ_3 → loading condition.
- After excavating: σ_3 →loading, σ_1 →unloading condition.
- Dam construction: σ_1, σ_3 → loading condition

Different unloading paths of the unloading rock masses



- In different forms of rock masses engineering, the mechanics action process of the rock masses is different.
- The mechanical properties of rock masses are varied during the process of bearing alterative forces.
- There are essential distinctions between the mechanical characteristics of rock masses under unloading and loading conditions.

1. RESEARCH BACKGROUND

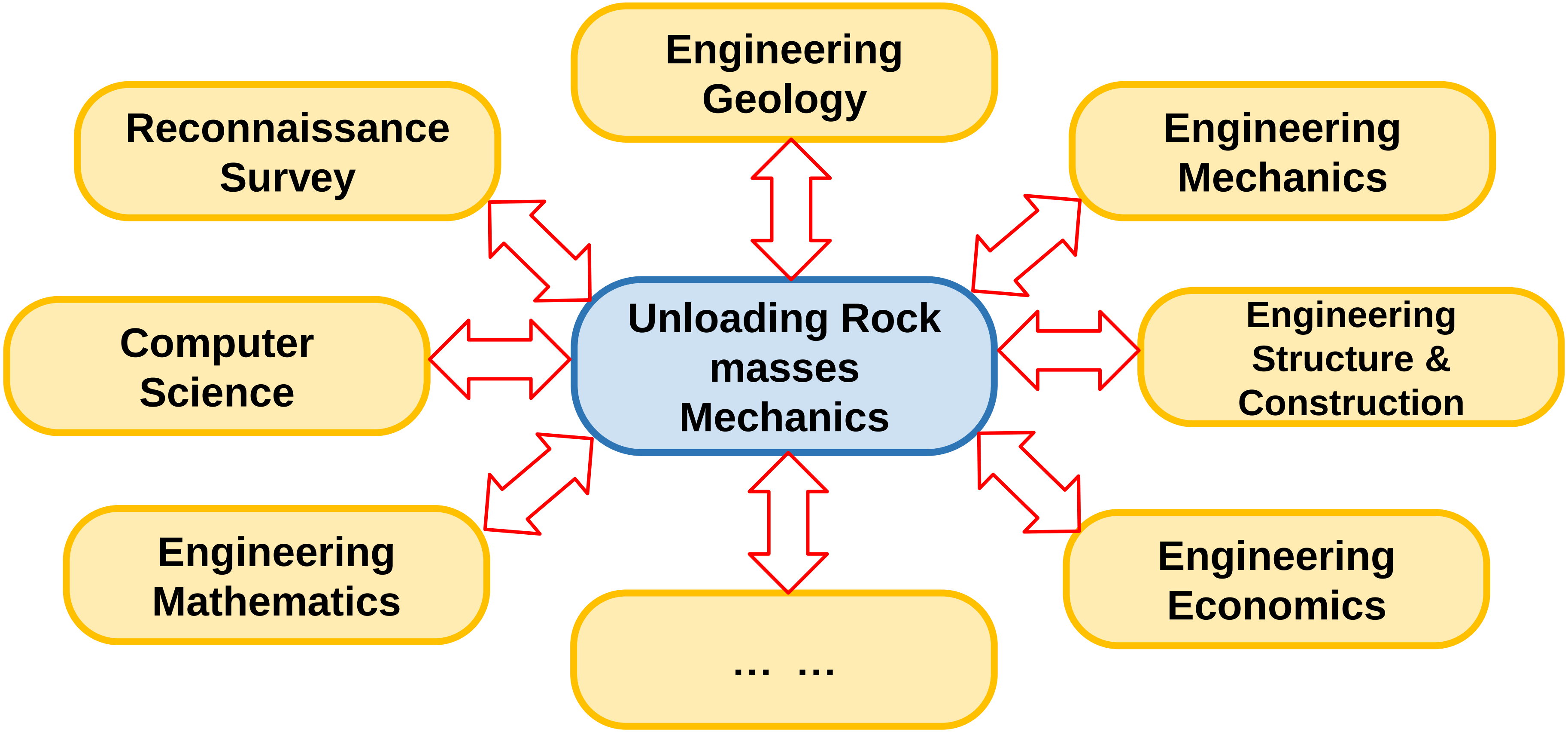
The discrepancy between the deformations computed by using traditional method (without considering unloading condition) and the actual deformations are shown in this table.

Engineering	Actual deformation	Calculating deformation by traditional method
Lianzi cliff dangerous rock body in the Three Gorges	2.17m	10cm
Jinchuan mine slope	1.52m	20cm
Ertan hydropower station	17.57cm	3cm
The Three Gorges permanent lock slope	17.38cm	3.47cm

Considering the above all, one should study the unloading mechanics to solve those problems as a new approach.

2 Methodology

Multi-crossed Disciplines



2 Methodology

Research Procedure

Understanding of Rock Masses

↓

Utilization of Rock Masses

↓

Protection of Rock Masses

↓

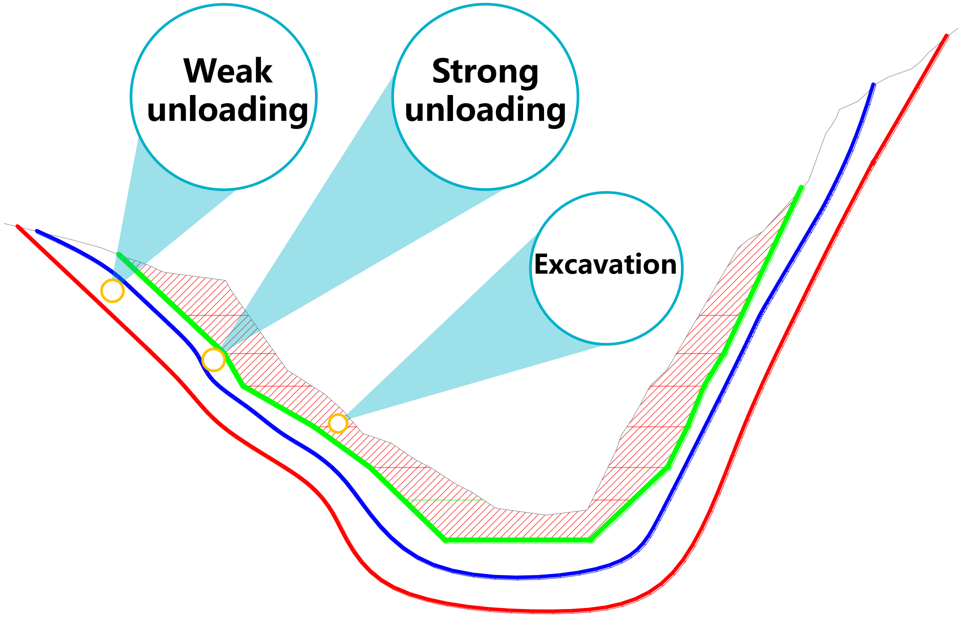
Monitoring of Rock Masses

3 Researech Contents

(1) Division of Excavation Damage Zone

The essential of unloading rock masses is that the adjustment of the internal stress state of the rock masses leads to the damage of rock masses quality during the excavation process.

Moreover, the stress adjustment in different rock masses region changes at different levels, corresponding to the different deterioration degree of rock masses quality. Therefore, how to divide the excavation damage zone becomes one of the key problems in the study of unloading rock masses.



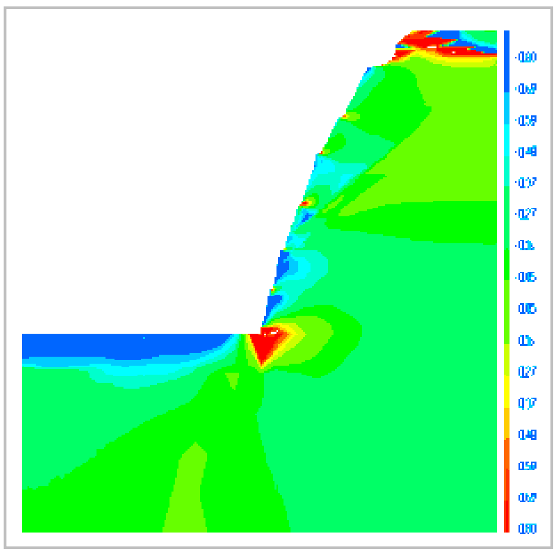
Excavation Damage Zone

3 Researech Contents

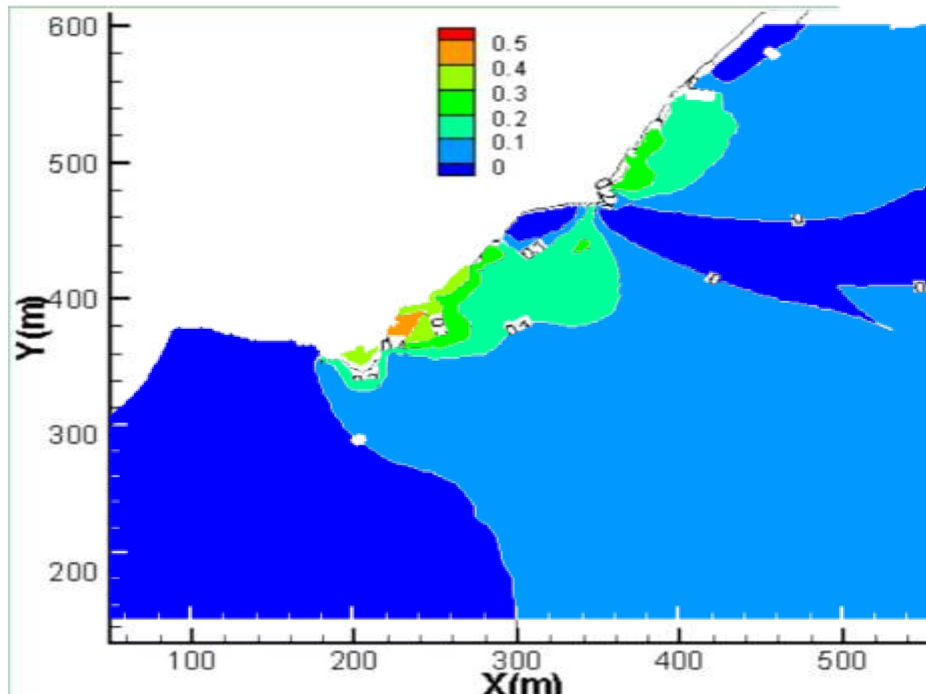
(1) Division of Excavation Damage Zone

Method of dividing Excavation Damage Zone

- In-situ stress measurement
- Acoustic wave test
- Numerical simulation



Distribution of horizontal stress

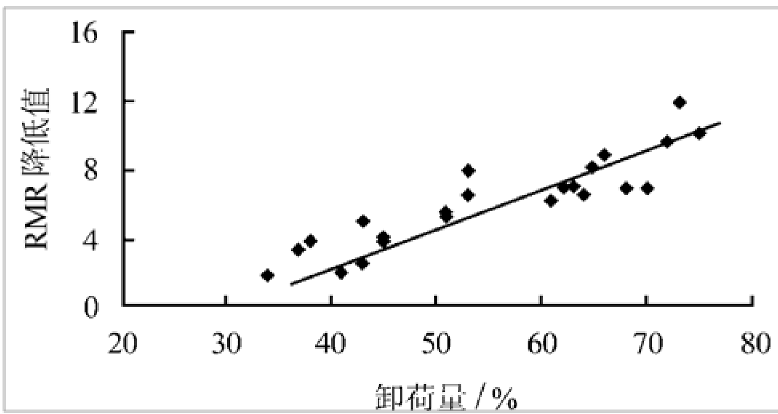


Distribution of point safety factor

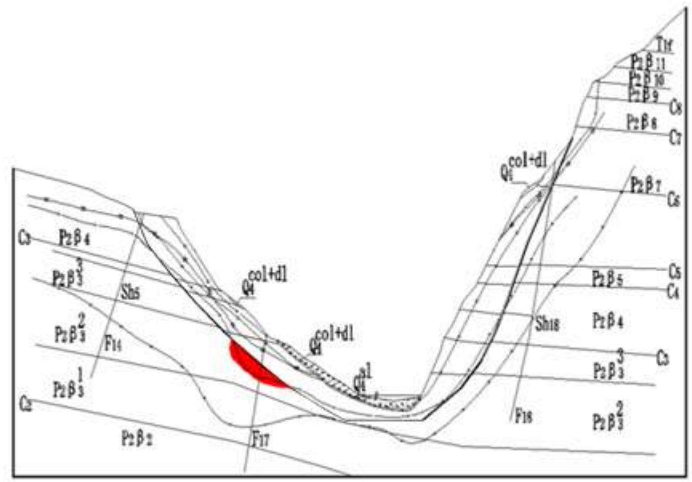
3 Researech Contents

(2) Quality Evaluation of Unloading Rock Masses

Excavation unloading effect of rock masses is introduced into RMR.



Quantity of unloading	<30	30～50	50～80	>80
Value of RMR	-4	-8	-14	-16



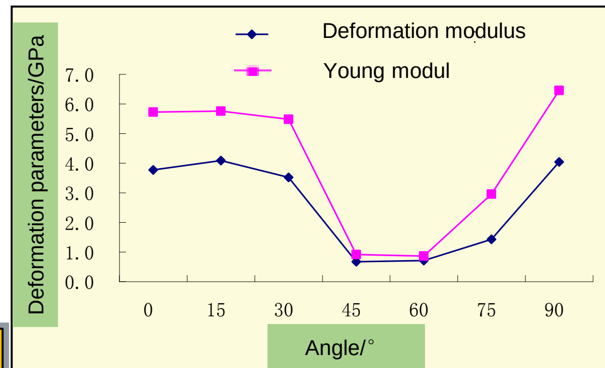
modified RMR

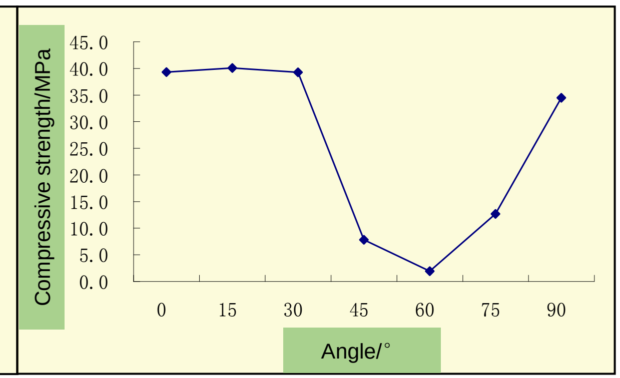
3 Researech Contents

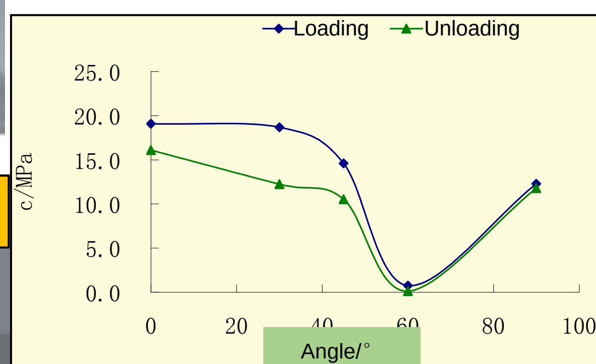
(3) Anisotropy of unloading rock masses

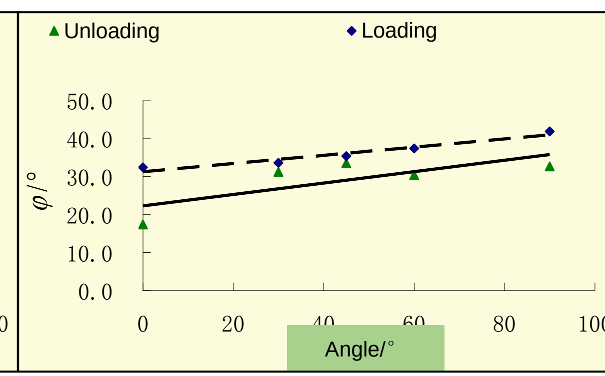
Anisotropic mechanical characteristics of jointed rock masses is revealed by experimental study.

0° 30° 45° 60° 90°







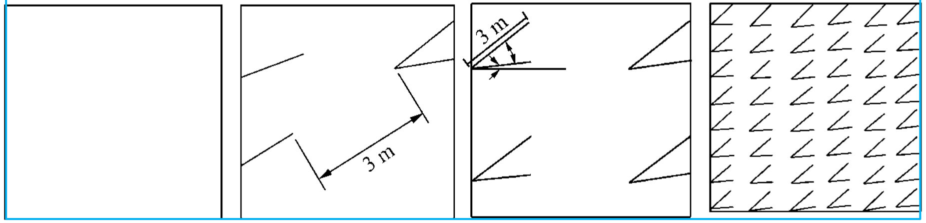


3 Researech Contents

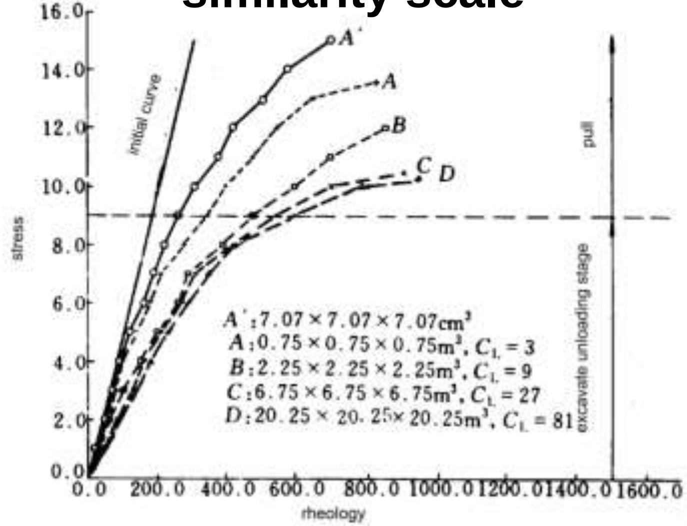
(4)Size Effect

Four sets of discontinuities in the Three Gorges Ship Lock

Model of jointed rock masses

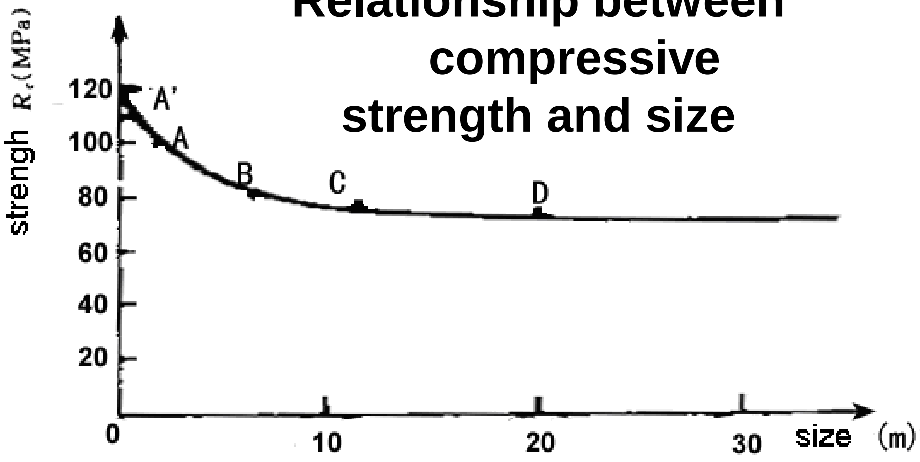


Unloading curves of different geometric similarity scale

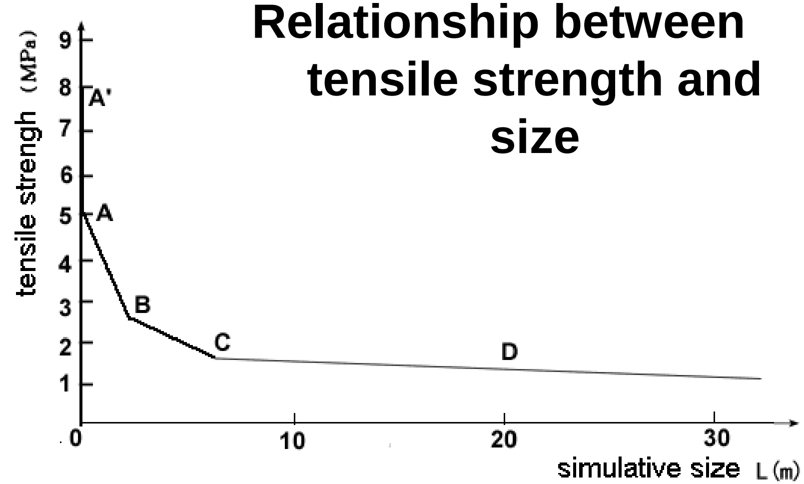


(4)Size Effect

Relationship between compressive strength and size



Relationship between tensile strength and size



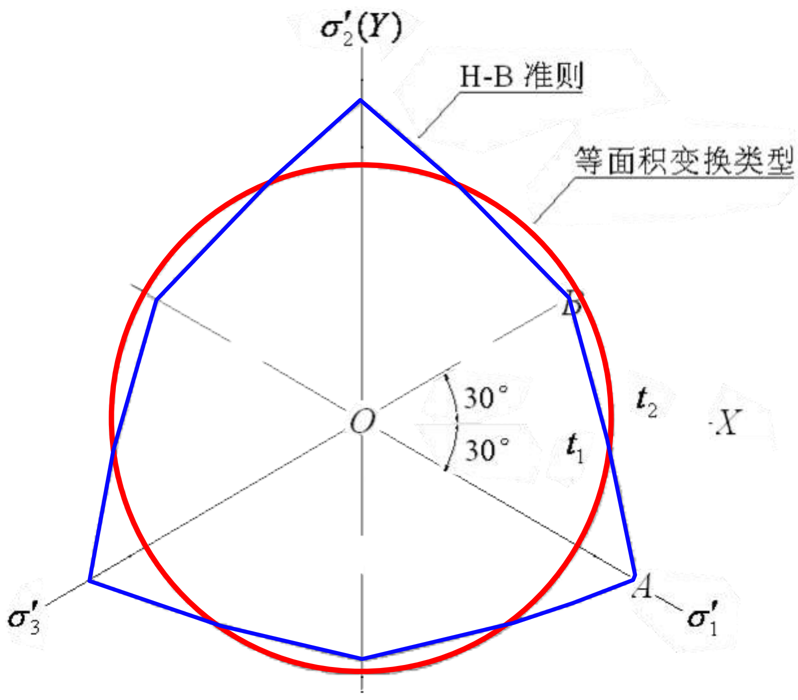
Deformation modulus varies with the size

Rock masses size(m)	0.75×0.75	2.25×2.25	6.75×6.75	20.25×20.25
Compressive deformation modulus (GPa)	50	45	38	35
Tensile deformation modulus (GPa)	6	4	2.0	1.5
Initial unloading modulus (GPa)	35	32	28	26

3 Researech Contents

(5) Yield criterion for unloading rock masses

Drucker-Prager criterion is established by considering the shear failure characteristics of unloading rock masses.



Formulation of D-P criterion:

$$F = \alpha I_1 + J_2 + \beta\sqrt{J_2} - k = 0$$

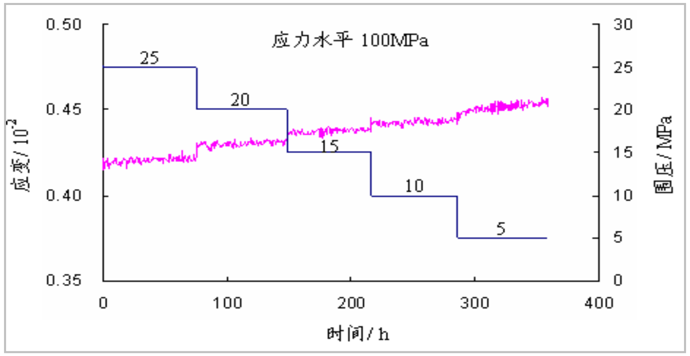
Material parameters:

$$\begin{cases} \alpha = -m\sigma_c / 12\cos^2\theta_\sigma \\ \beta = m\sigma_c\left(\sqrt{3}\sin\theta_\sigma + 3\cos\theta_\sigma\right) / 12\cos^2\theta_\sigma \\ k = s\sigma_c^2 / 4\cos^2\theta_\sigma \end{cases}$$

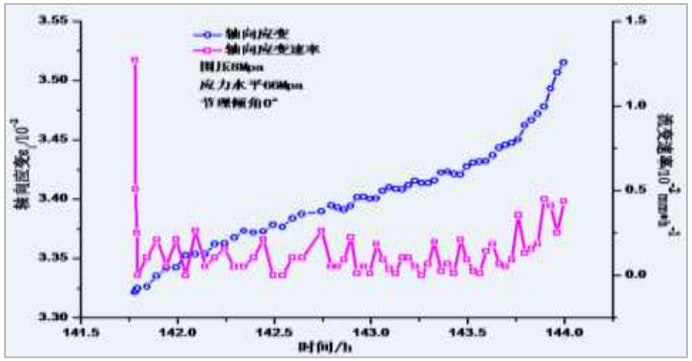
3 Researech Contents

(6) Creep behavior

The nonlinear constitutive model of unloading creep for jointed rock masses is established.

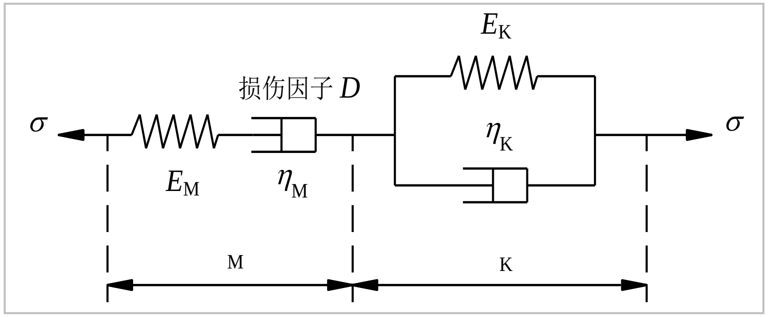


Creep behavior of intact rock



Creep behavior of jointed rock masses

Damage factor $D = 1 - (a\Delta\sigma)^{-b(t-t^*)}$



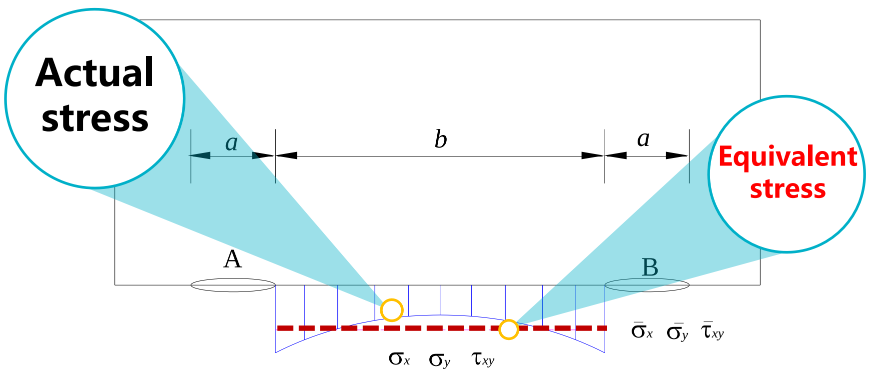
Nonlinear constitutive model

$$
\begin{cases}
\varepsilon = \dfrac{\sigma}{E_M} + \left(\dfrac{\sigma}{\eta_M}\right)t + \dfrac{\sigma}{E_K}\left(1 - e^{-\frac{E_K}{\eta_K}t}\right) & (t < t^*) \\
\varepsilon = \dfrac{\sigma}{E_M} + \left(\dfrac{\sigma}{\eta_M}\right)\left((a\Delta\sigma)^{b(t-t^*)}\right)t + \dfrac{\sigma}{E_K}\left(1 - e^{-\frac{E_K}{\eta_K}t}\right) & (t \geq t^*)
\end{cases}
$$

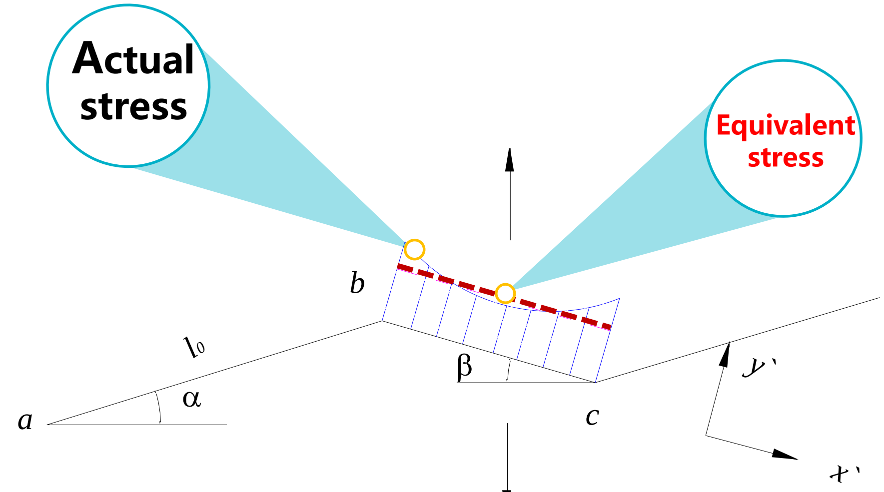
3 Researech Contents

(7) Fracture behavior

An equivalent analytical model of compression shear and tension shear for unloading rock masses is proposed.



Compression-shear fracture



Tension-shear fracture

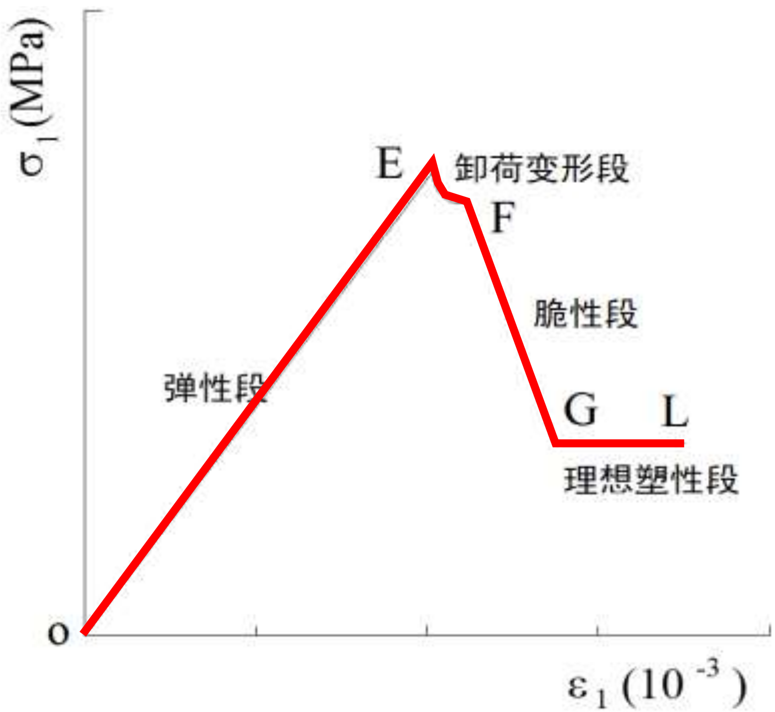
$$
\begin{cases}
m = -\dfrac{\sqrt{\pi a}(1/\varphi-1)\sigma_c}{\sqrt{2}K_{Ic}}s \\
16K_{IIC}^2 + \sigma_C\sqrt{2\pi a}(1/\varphi-1)K_{IIc}m = \dfrac{\pi a}{2}(1/\varphi-1)\sigma_c s
\end{cases}
$$

$$
\begin{cases}
m = 16K_{IIc}^2/\sqrt{2\pi l}K_{Ic}(1+K_{IIc}/K_{Ic}) \\
s = 32K_{IIc}^2/\pi l\sigma_c^2(1+K_{IIc}/K_{Ic})
\end{cases}
$$

3 Researech Contents

(8) Constitutive model of unloading rock masses

An incremental constitutive model of unloading rock masses and a hyperbolic nonlinear elastic constitutive model of unloading rock masses are established.



Elastic-brittle-plastic constitutive model

Plastic deformation

$$\{d\sigma\} = \left([D]_e - \frac{\left\{\frac{\partial F_{b-s}}{\partial \varepsilon}\right\}^T \left\{\frac{\partial F_{b-s}}{\partial \varepsilon}\right\}}{A + \left\{\frac{\partial F_{b-s}}{\partial \varepsilon}\right\}^T [C]_e \left\{\frac{\partial F_{b-s}}{\partial \varepsilon}\right\}} \right) \{d\varepsilon\}$$

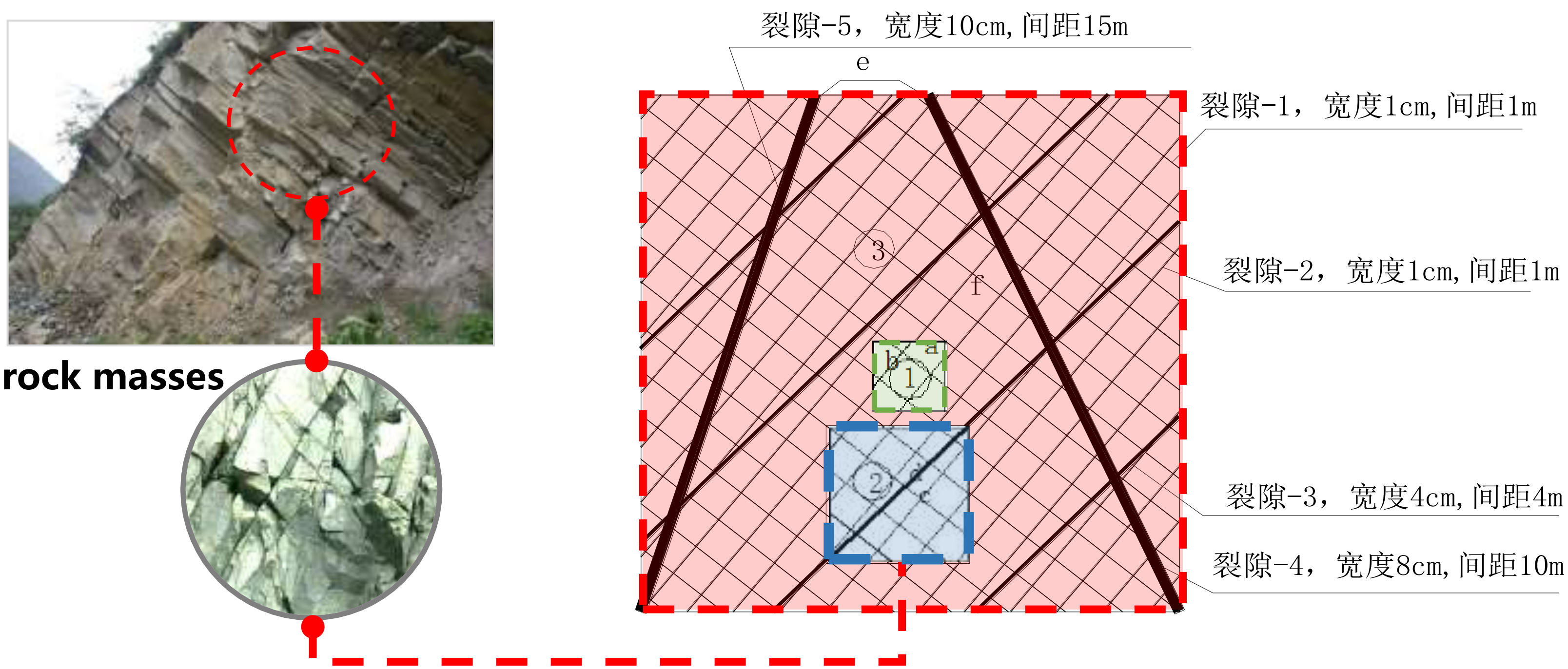
Yield function

$$F_{b-s} = \frac{E - E^b}{E^s - E^b} f_b + \frac{E^s - E}{E^s - E^b} f_s = 0$$

3 Researech Contents

(9) Determination of mechanical parameters for jointed rock masses

A method, which suggests starting from the small-size fracture to the large-size fracture to study the size effect of mechanical parameters, has been proposed to obtain mechanical parameters of jointed rock masses.



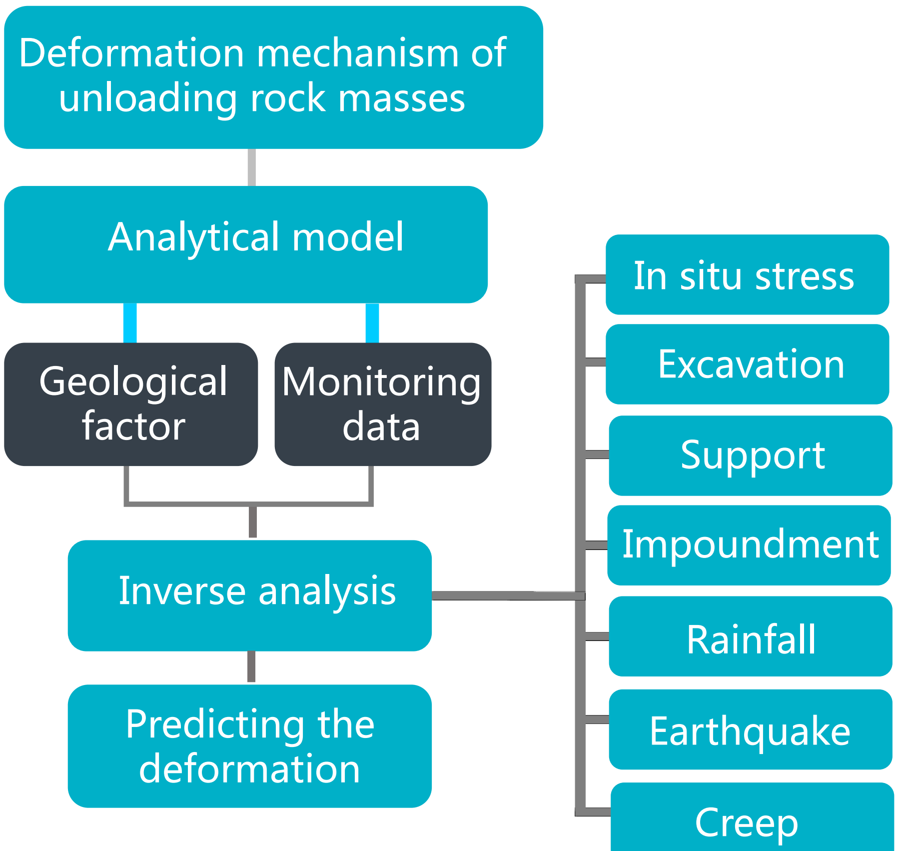
Jointed rock masses

Analytical model

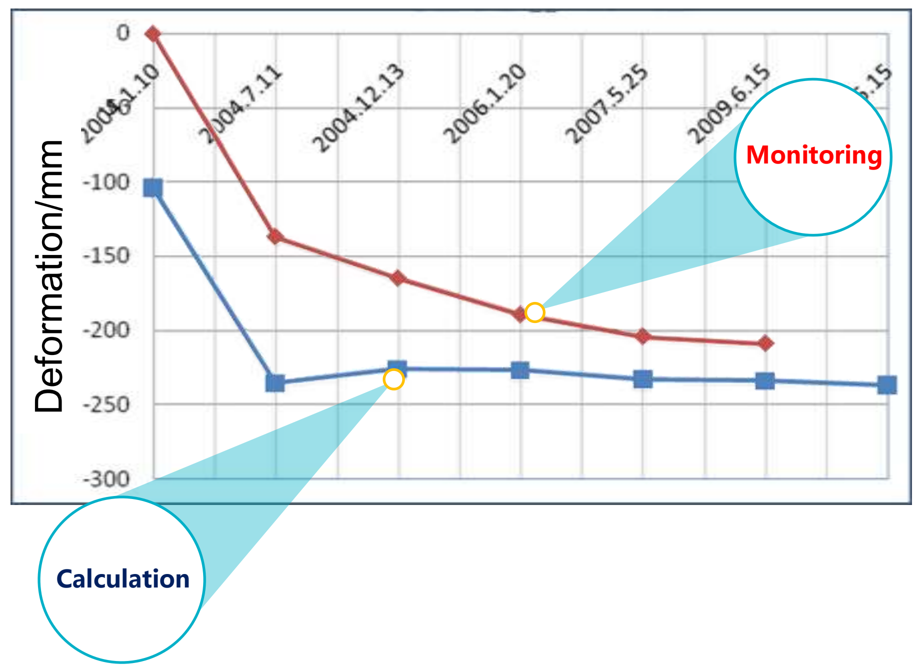
3 Researech Contents

(10) Inversion of mechanical parameters of unloading rock masses

Based on the artificial neural network, the excavation unloading effect has been considered in the inversion of rock mechanics parameters.

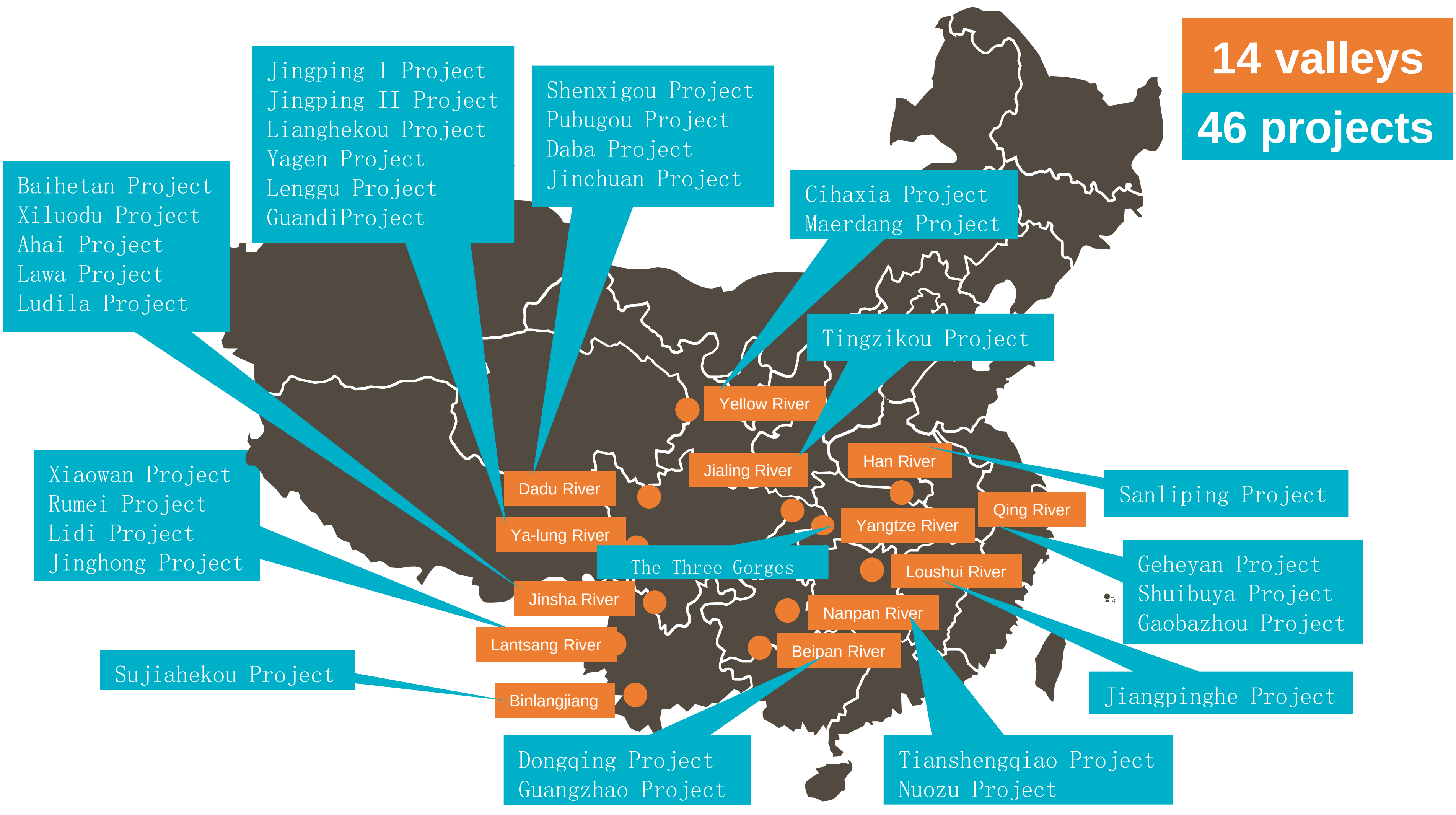


Comparison of calculation and monitoring in slope



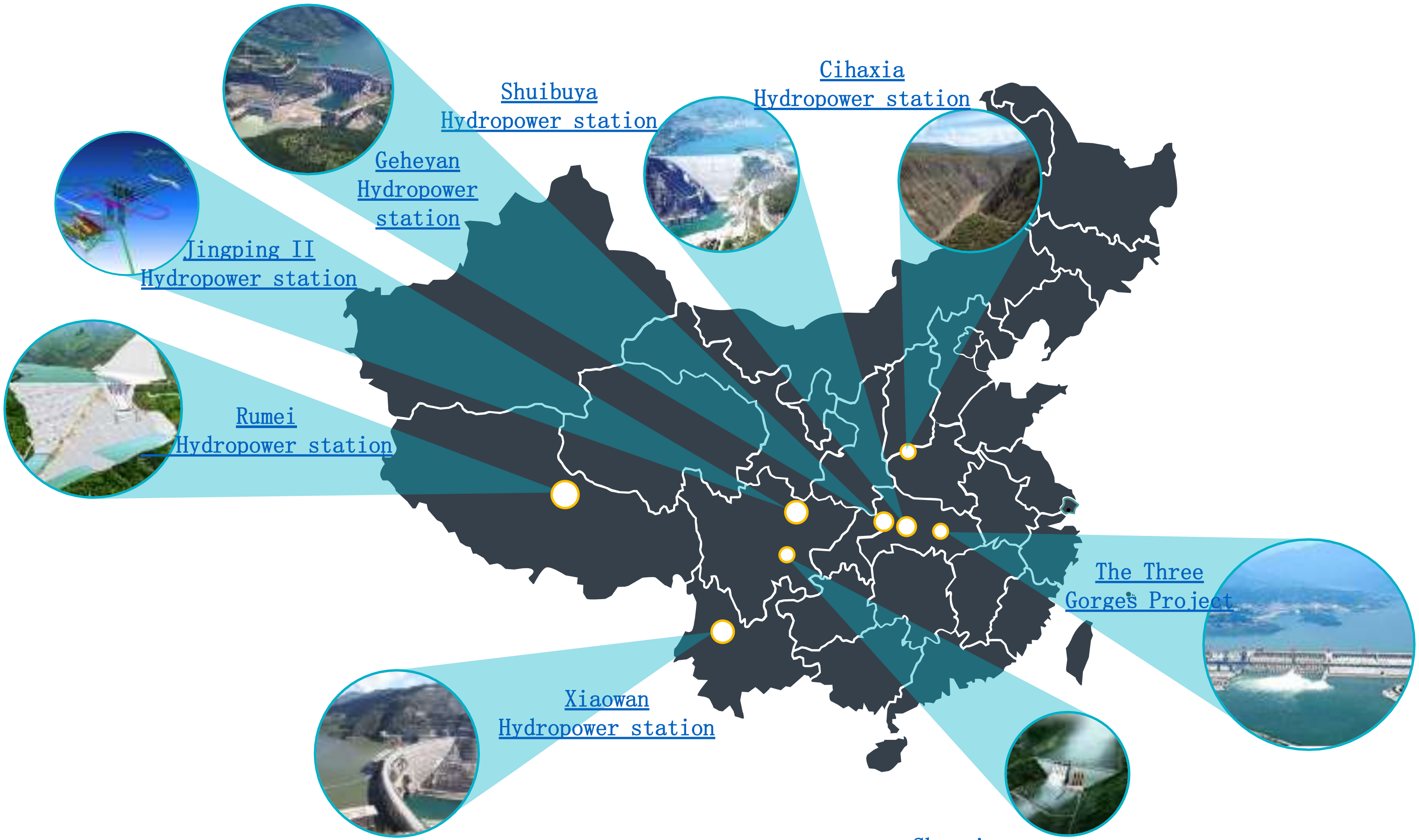
4. ENGINEERING APPLICATION

4.1 Applied valley



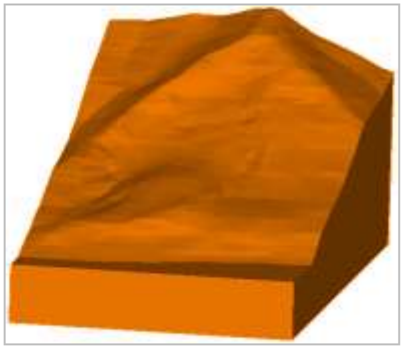
4. ENGINEERING APPLICATION

4.2 Applied Engineering

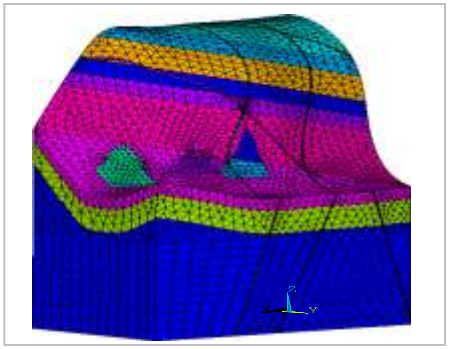


4. ENGINEERING APPLICATION

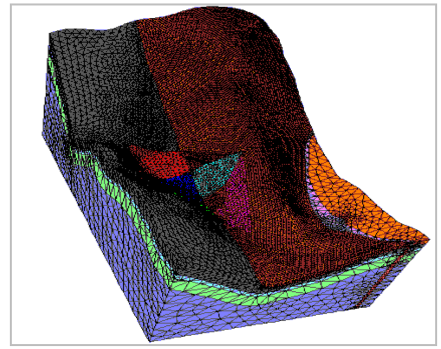
4.2 Applied Engineering



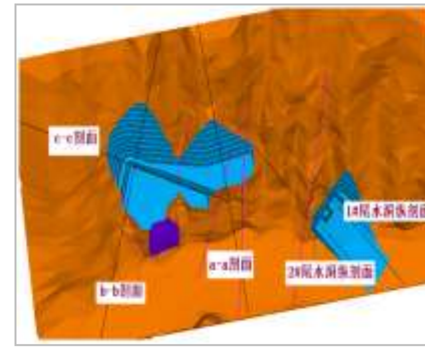
Landslide-Geheyan



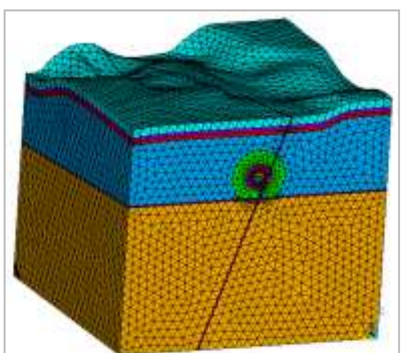
Slope-Jiangpinghe



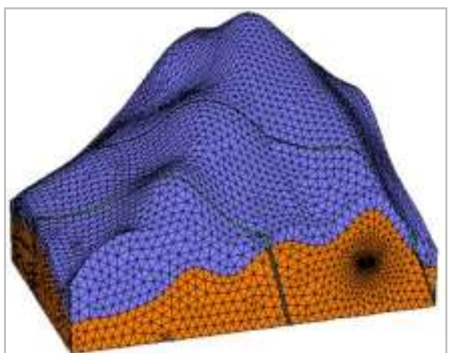
High slope-Rumei



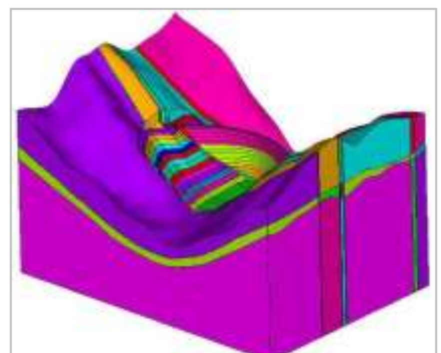
High slope-Jinchuan



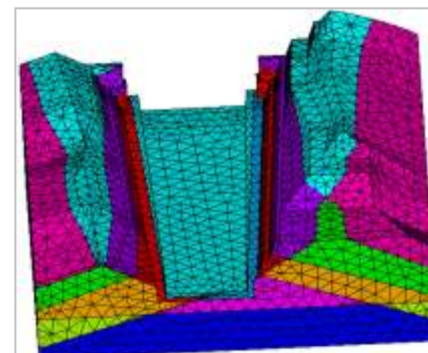
Tunnel-Dashankou



Tunnel-Danba



Slope-Xiaowan



Slope-Dongqing

5. RESEARCH PLATFORM

5.1 Introduction of CTGU

5.2 Research team

Team members

5.3 Research platform

- National Field Observation and Research Station of Landslides in Three Gorges Reservoir Area of Yangtze River

湖北长江三峡滑坡国家野外科学观测研究站地理位置图

5.3 Research platform

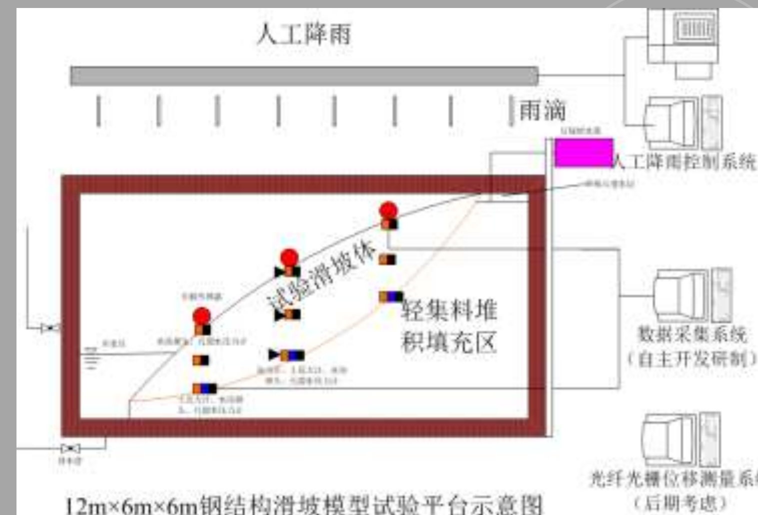
- Key Laboratory of Geological Hazards on Three Gorges Reservoir Area（China Three Gorges University）， Ministry of Education

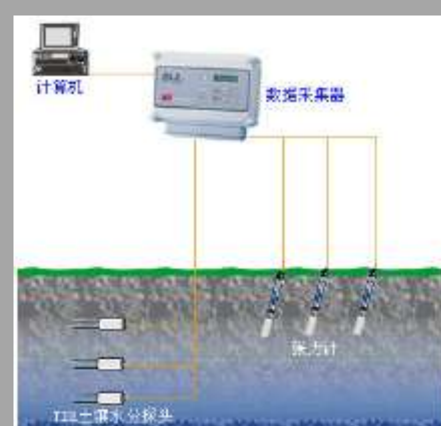
Monitoring System

5.3 Research platform

➢Equipment（1）

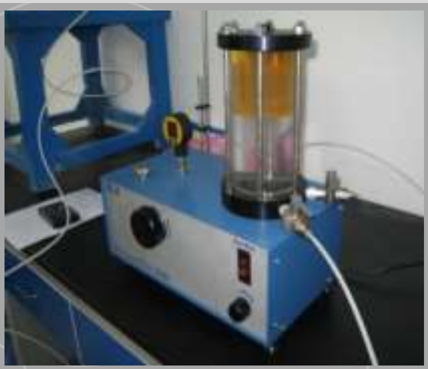
Three dimensional landslide physical model test system (12mx6mx6m)



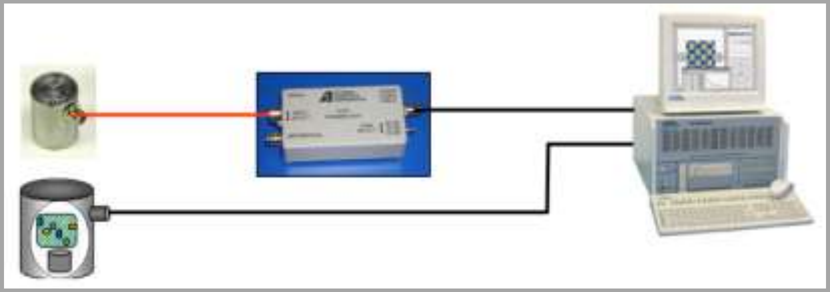


5.3 Research platform

➢Equipment（2）



ELE rock seepage system



PCI-2 acoustic emission detection system

ST500 three-dimensional non-contact surface profilometer

RMT-150C rock mechanics test system

Adaptive automatic triaxial testing machine

RLW-2000 triaxial creep test system

5. RESEARCH PLATFORM

5.3 Research platform

➢Equipment（3）：

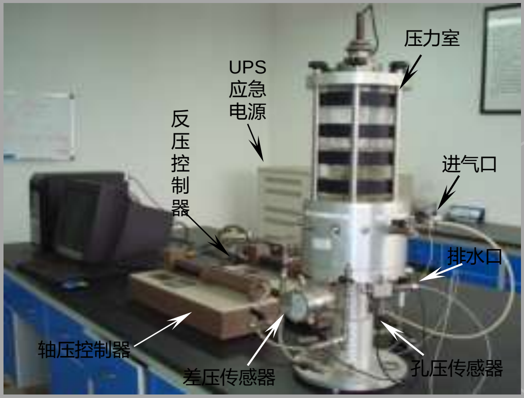
quadruple direct shear apparatus for unsaturated soil

JSM-7500F scanning electron microscope

Computer controlled electro-hydraulic servo soil dynamic triaxial testing machine

DHJ-50 large single shear、direct shear apparatus

The soil-water characteristic curve tester



HKUST-GDS unsaturated soil triaxial apparatus

Unloading Rock masses Mechanics

THANKS

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