The effects of inherent distribution of discontinuities and stress-induced anisotropy on pore water pressure distribution of rock slope.

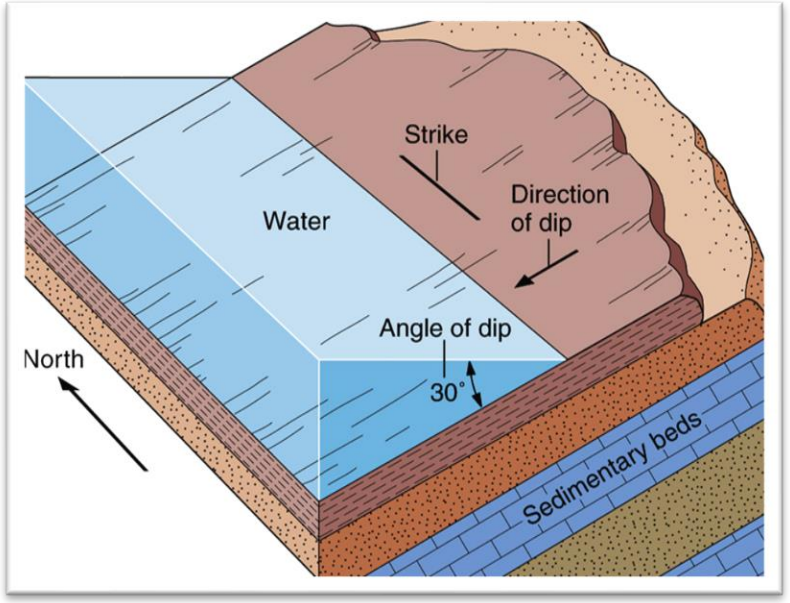
Presenter: Chia-Yi Liu
Advisor: Jia-Jyun Dong
Date: 2023/02/24

CONTENTS

Slope stability analysis

Source: https://www.nasc.gov.tw

Source:https://twgeoref.moeacgs.gov.tw/GipOpenWeb/wSite/ct?xItem=140858&mp=105&ctNode=1233



Source: https://www3.nd.edu/~cneal/planetearth/Lab-Structural/DipStrike.html

- A dip slope is described as a rock slope with layered structures stretching along its inclined direction.
- Dip slopes in the form of a sandstone and shale interlayer are a typical geological feature in northern Taiwan.

Slope stability analysis *(Duncun, 2004)*

Design data

Geological data

Rock strength

Ground water

Design methods

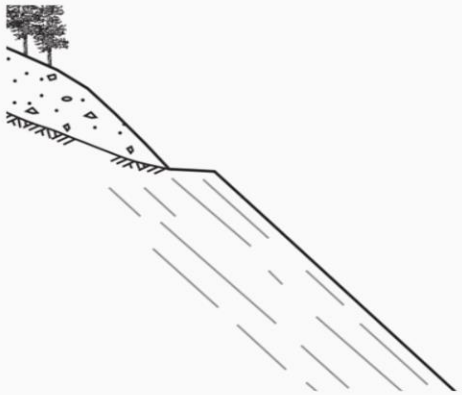
01 Limit equilibrium analysis

02 Numerical analysis

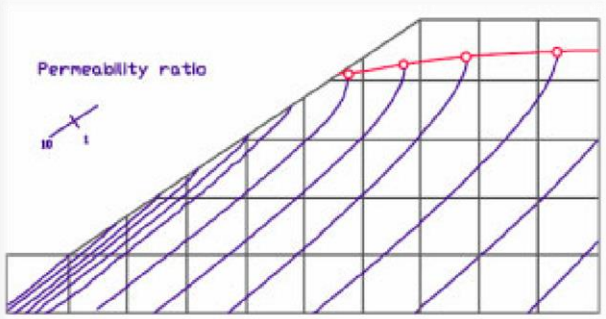
- Numerical analysis can examines the stresses and strains developed in the slope.

- The final target is calculating the factor of safety(fos) of the slope.
  - Fos > 1, safe
  - Fos ≤ 1, unsafe

Purpose



(Duncan et al., 2004)

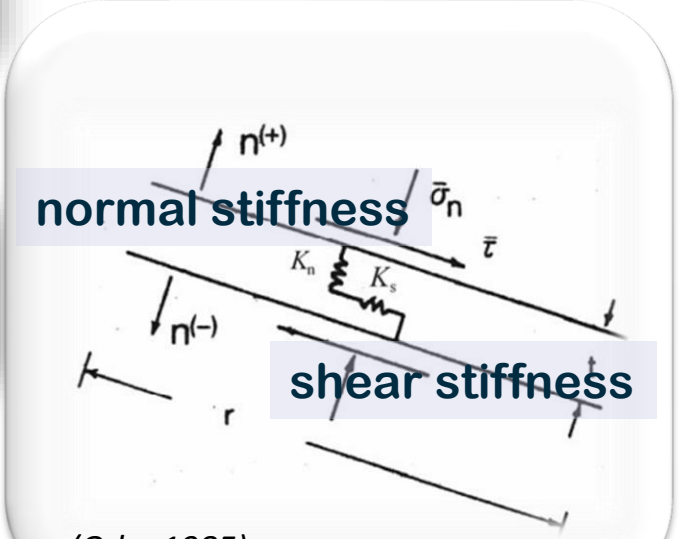


(Dong et al., 2006)

Geological data

Rock strength

Ground water

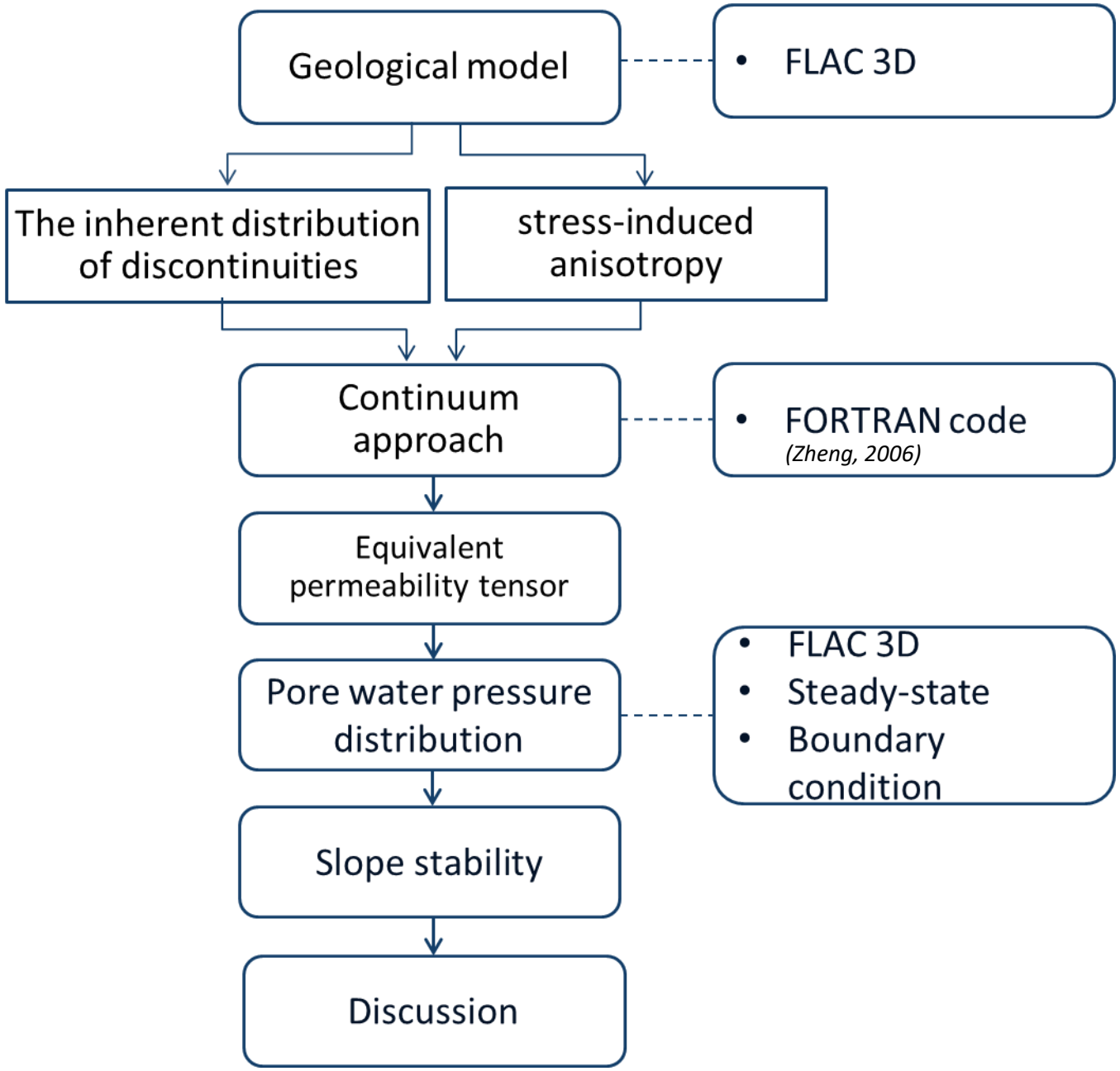


normal stiffness

shear stiffness

(Oda, 1985)

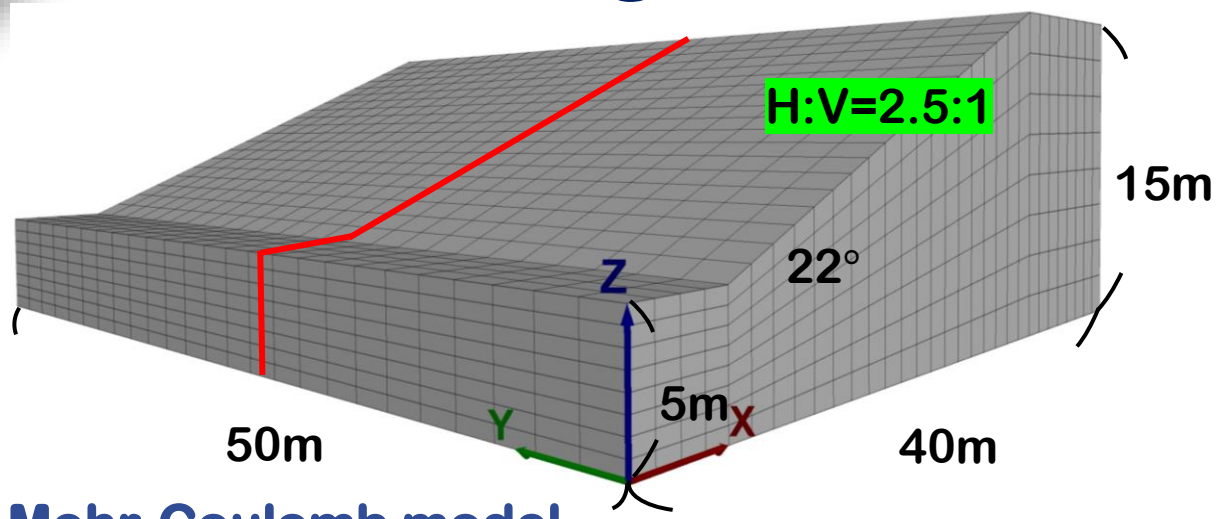
Flow chart

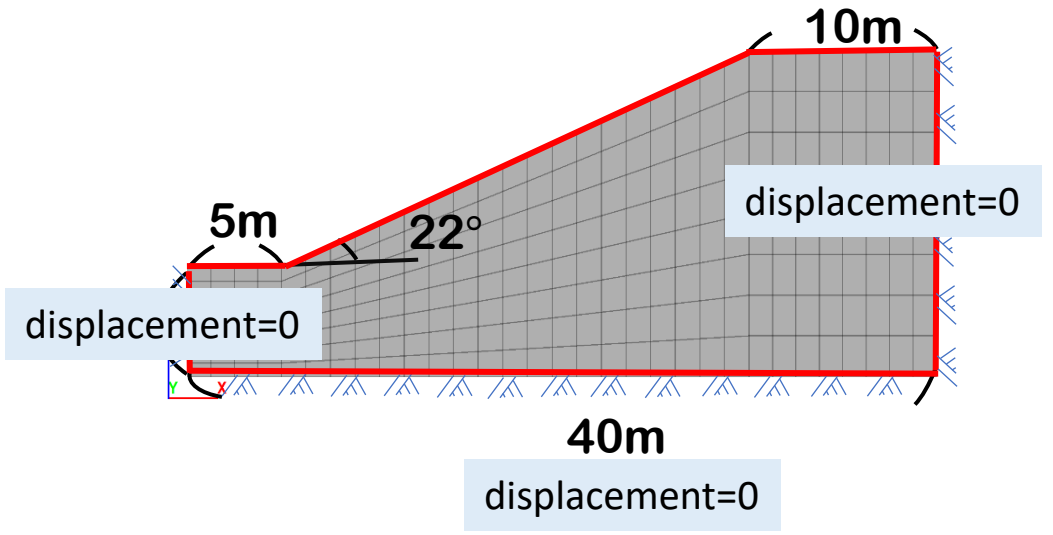

Geological model
• FLAC 3D
The inherent distribution of discontinuities
stress-induced anisotropy
Continuum approach
• FORTRAN code
(Zheng, 2006)
Equivalent permeability tensor
Pore water pressure distribution
• FLAC 3D
• Steady-state
• Boundary condition
Slope stability
Discussion

Methodology

- Model setting
- Continuum approach

Model setting



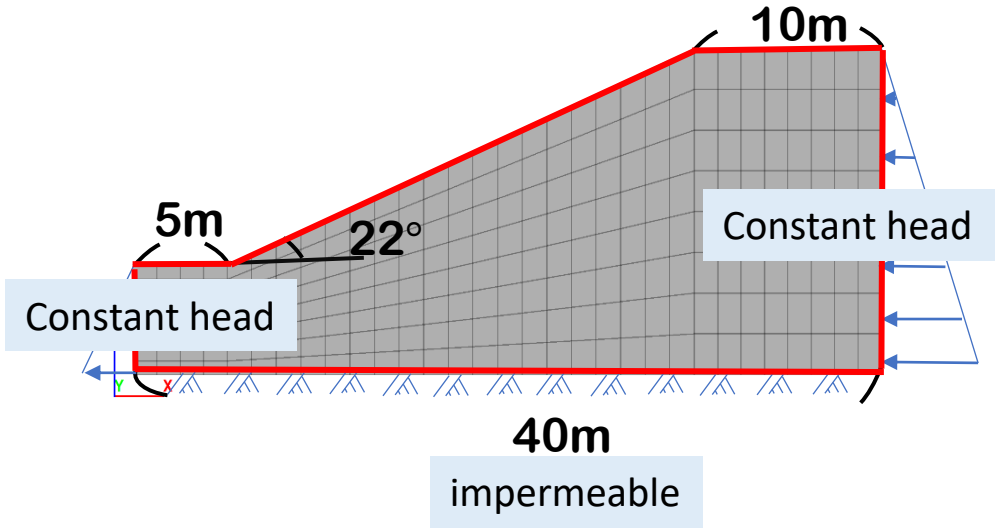


Mohr-Coulomb model

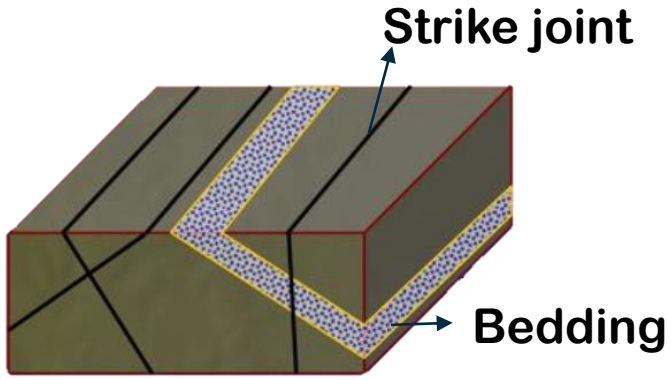
Material properties	Value
Dry density	18400 $(\frac{kg}{m^3})$
Young's modulus, E	200 (MPa)
Poison ratio, ν	0.3
Friction angle, ϕ	22.5°
cohesion, c	17.5 (kPa)
Stress ratio,$\overline{K}$	1.1

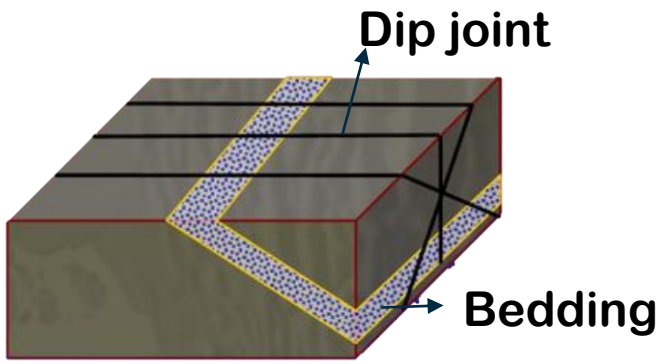
Material properties	Value
Fluid modulus,K_f	10 (kPa)
porosity, n	0.3
permeability, k (Mobility permeability)	$\frac{m^2}{Pa * sec}$
saturation,S	1

(CECI, 2021)
(Chen C. C.& Yu C. W., 1994)

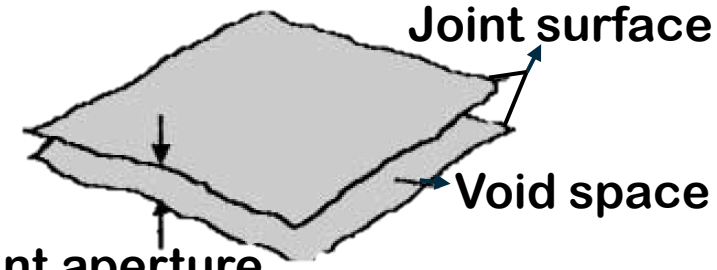


Continuum approach





(Veronika, 2019)

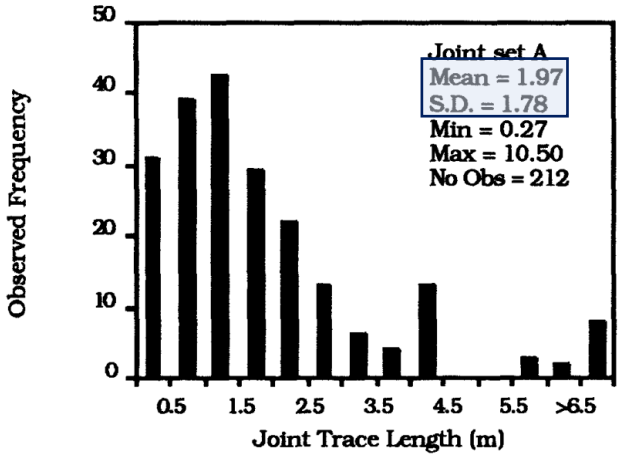


(Olsson, 2001)

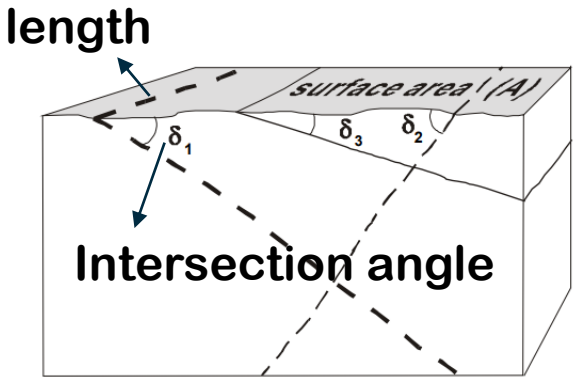
Discontinuities properties

- Orientation $\mathrm{E}(\hat{n})$
- Length $f(r)$
- Aperture $g(t)$
- volume density ρ

Equivalent permeability tensor

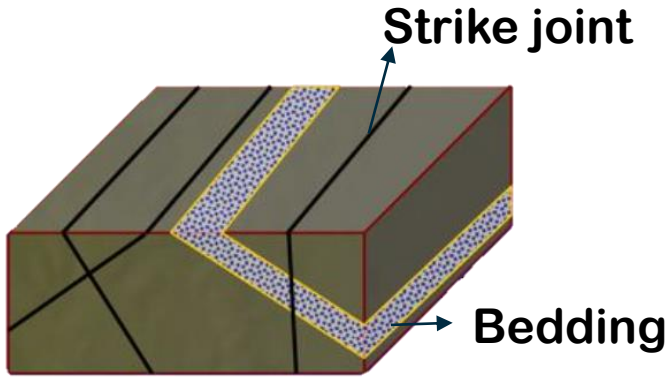


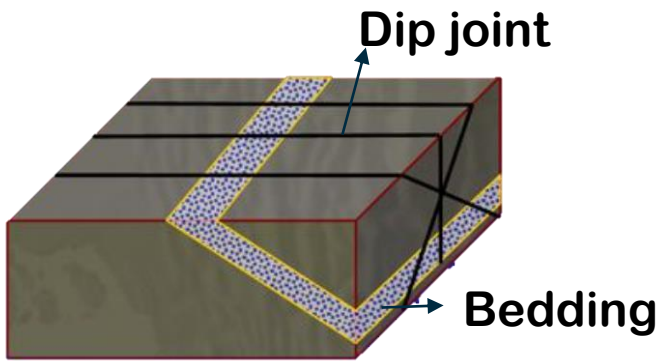
(Villaescusa, 1992)



(Palmström, 1996)

Continuum approach





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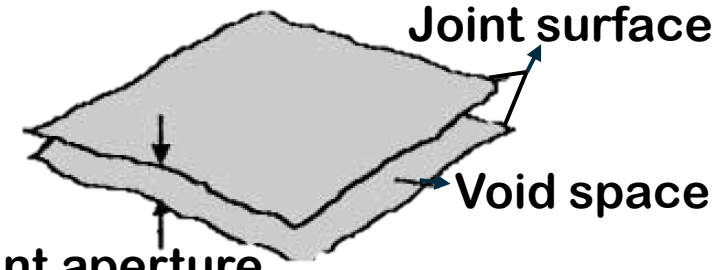

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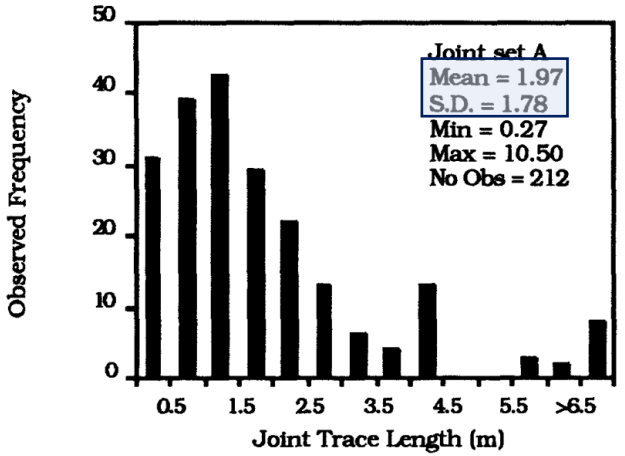
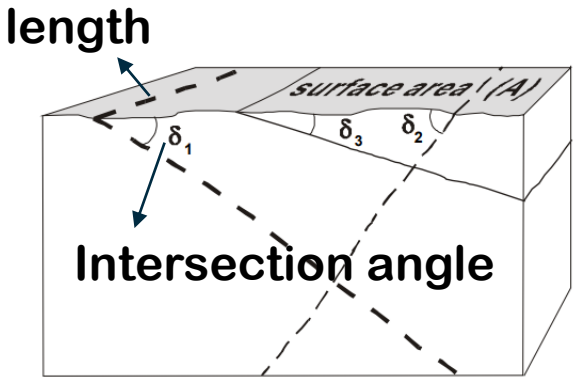


(Villaescusa, 1992)



(Palmström, 1996)

Results

① Uniform stress(0.25MPa) field

- The distribution of discontinuities

② Non-uniform stress field

- The distribution of discontinuities

Equivalent permeability tensor

Pore pressure distribution

Slope stability analysis (shear strength reduction)

- Factor of safety
- Strain increments

Results

① Uniform stress(0.25MPa) field

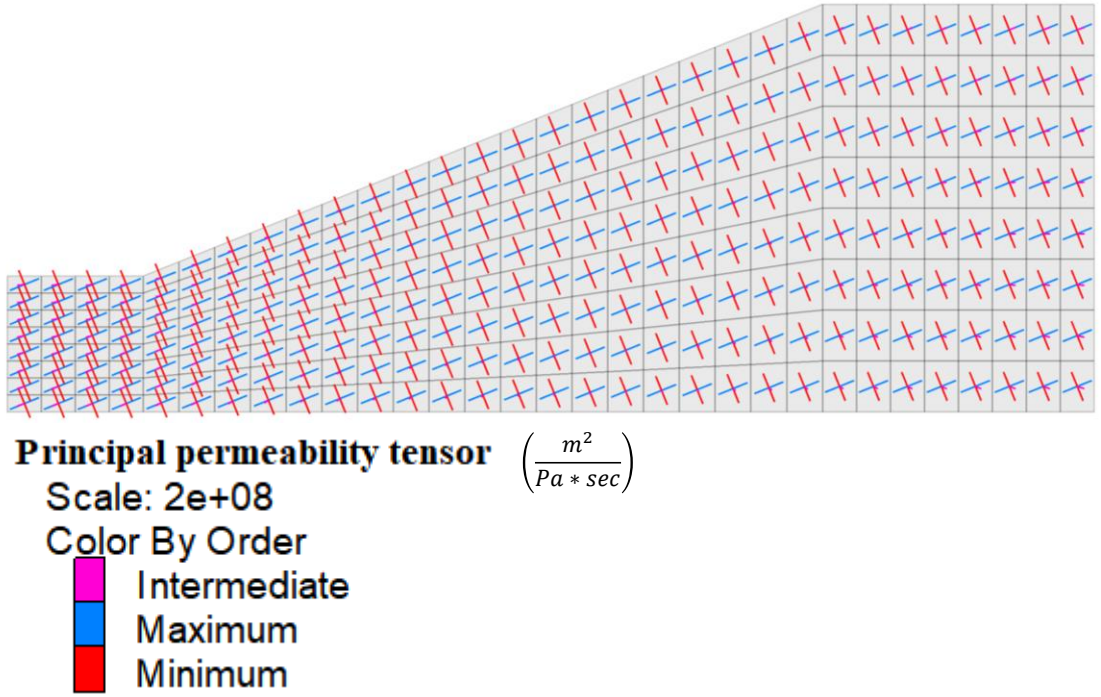
- The distribution of discontinuities

(Equivalent permeability tensor, pore water pressure variation and factor of safety)

The results of equivalent permeability tensor (under uniform stress field,0.25MPa)

- **Initial result**

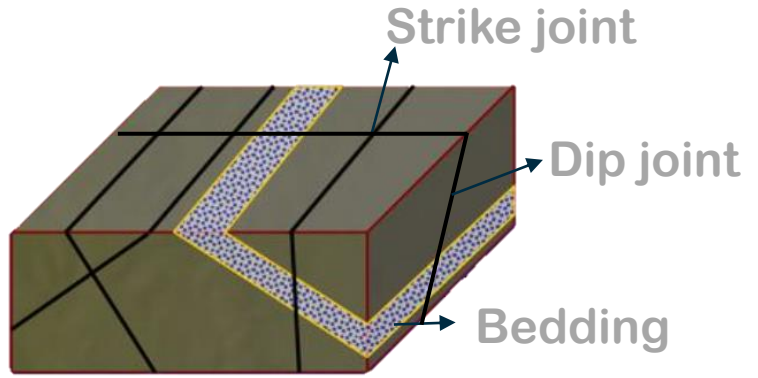
(no influence by the distribution of discontinuities)



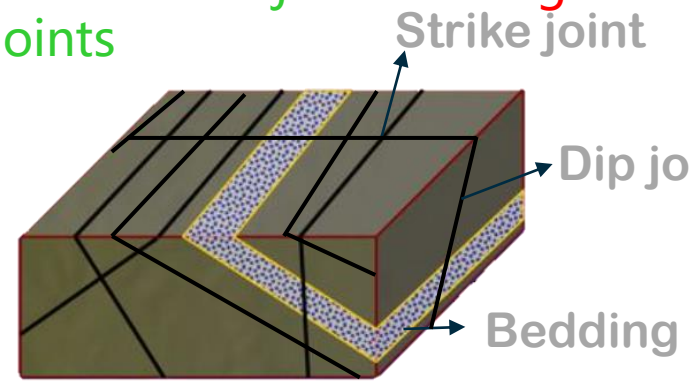
- Homogeneous & isotropic permeability tensor
- Maximum principal permeability is parallel to the slope surface

- **The distribution of discontinuities**

The number of strike joints are more then dip joints



The number of strike joints are significantly more then dip joints

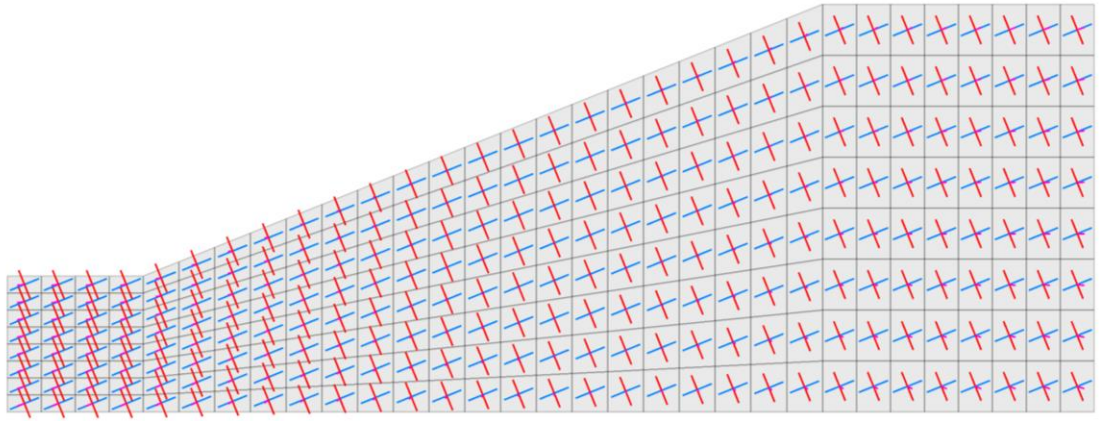


(The different level of anisotropic for discontinuities)

The results of equivalent permeability tensor (under uniform stress field,0.25MPa)

- **Initial result**

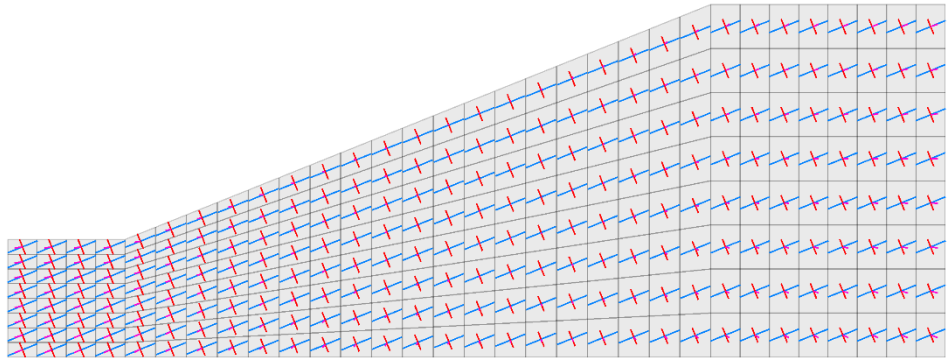
(no influence by the distribution of discontinuities)



- The minimum principal permeability ↘
  the maximum principal permeability ↗

- **The distribution of discontinuities**

The number of strike joints are more then dip joints



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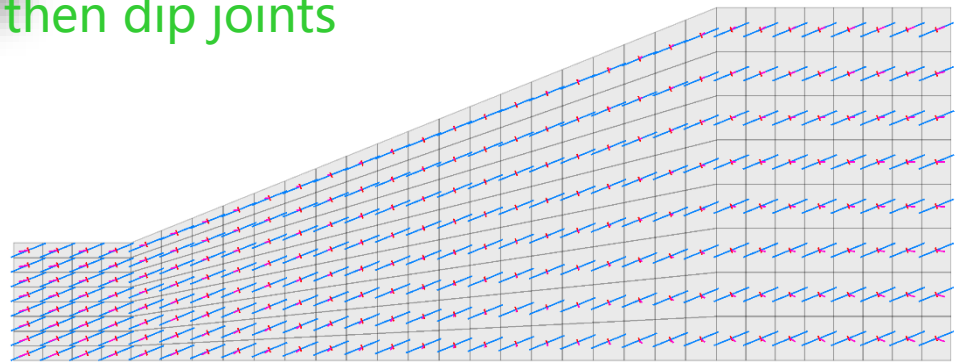
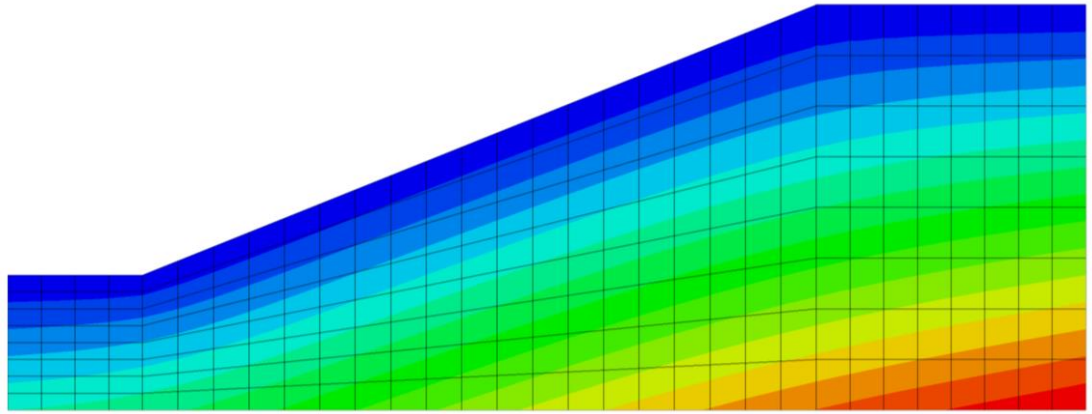


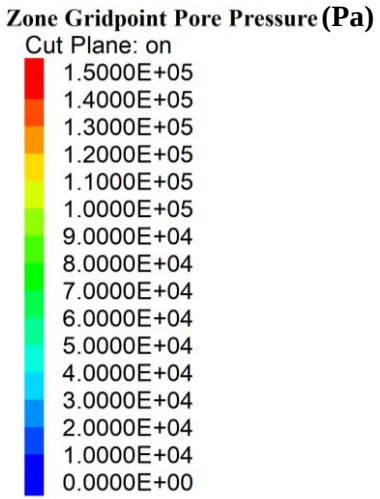
(The different level of anisotropic for discontinuities)

The results of pore water pressure distribution (under uniform stress field)

- **Initial result**

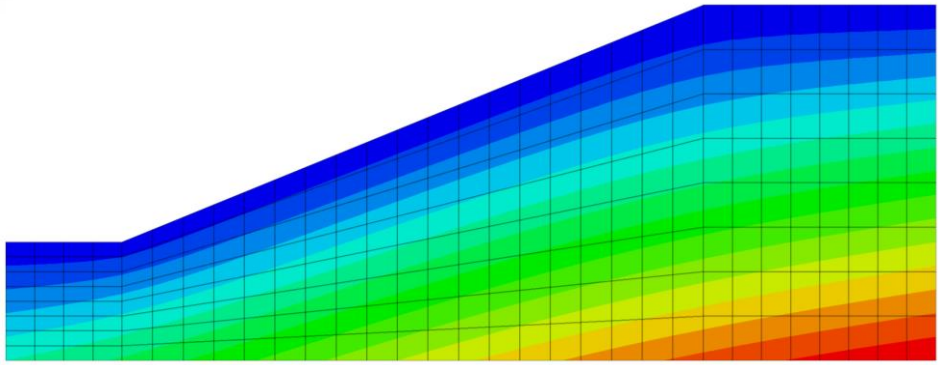
(no influence by the distribution of discontinuities)



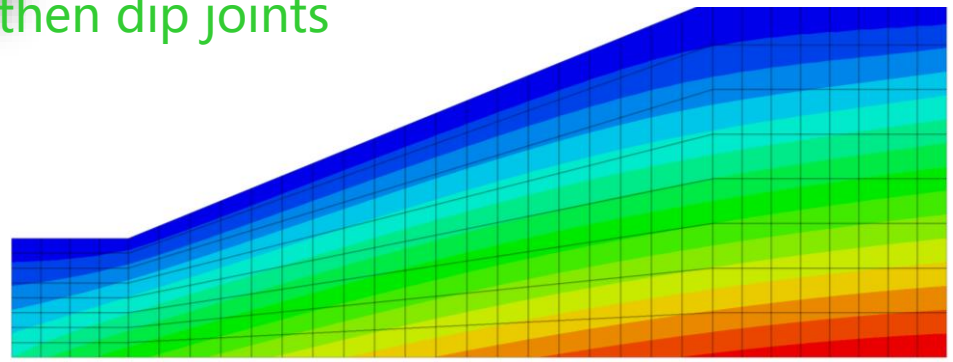


- **The distribution of discontinuities**

The number of strike joints are more then dip joints



The number of strike joints are significantly more then dip joints

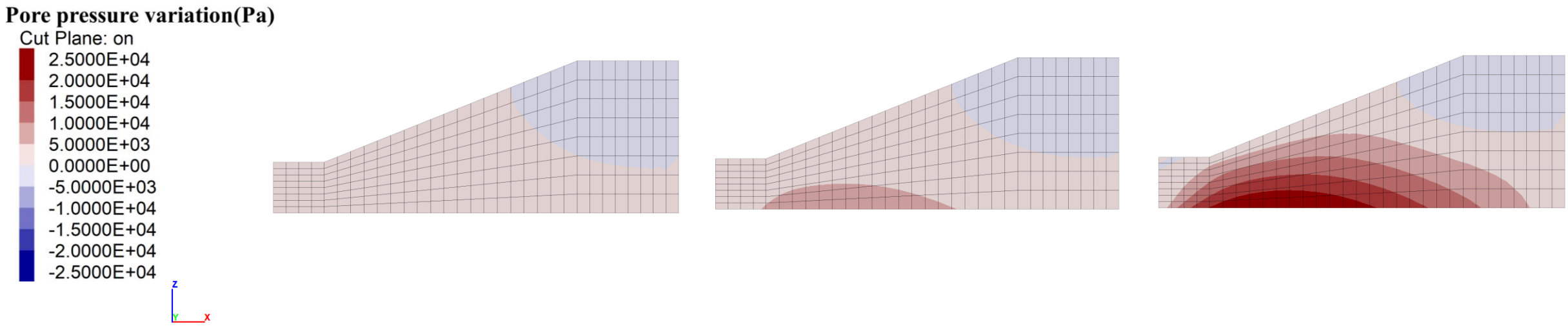


(The different level of anisotropic for discontinuities)

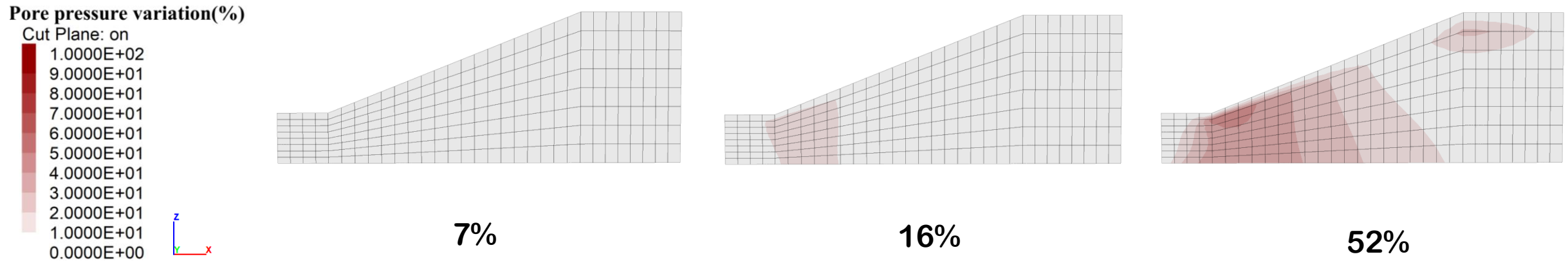
The variation of pore water pressure distribution

The level of anisotropic | **The number of strike joints more then dip joints** → **The number of strike joints significantly more then dip joints**

The absolutely variation



The relatively variation

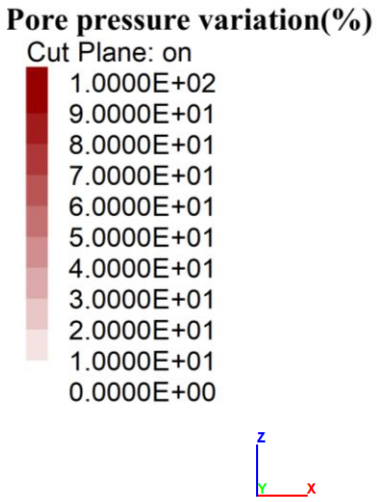


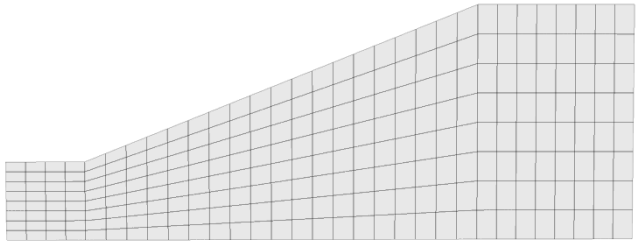
7% **16%** **52%**

The variation of slope stability analysis

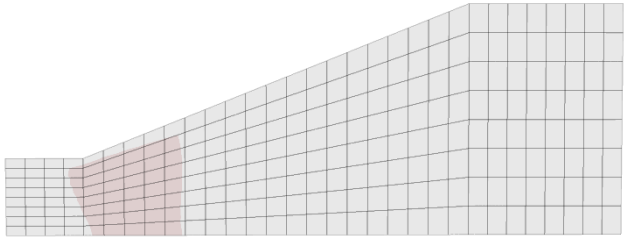
The level of anisotropic | **The number of strike joints more then dip joints** → **The number of strike joints significantly more then dip joints**

The absolutely variation

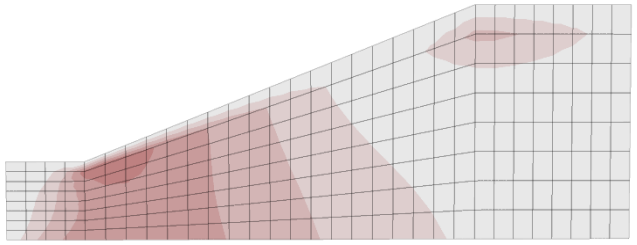




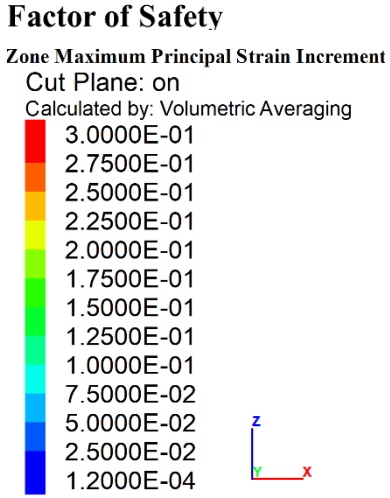
7%

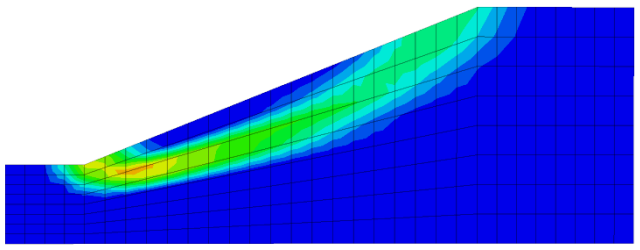


16%

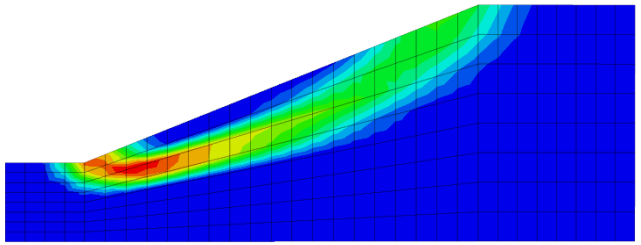


52%





1.406



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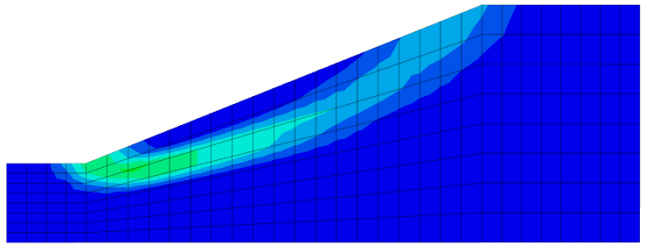


1.394

Results

② Non-uniform stress field

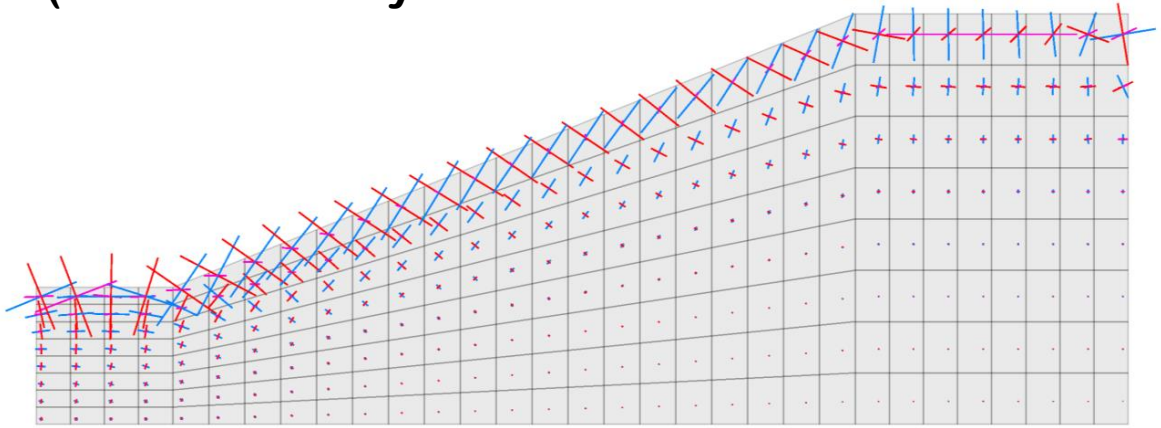
- The distribution of discontinuities

(Equivalent permeability tensor, pore water pressure variation and factor of safety)

The results of equivalent permeability tensor (under non-uniform stress field)

- **Initial result**

(no influence by the distribution of discontinuities)



Principal permeability tensor $\left(\frac{m^2}{Pa * sec}\right)$

Scale: 2e+08

Color By Order

Intermediate

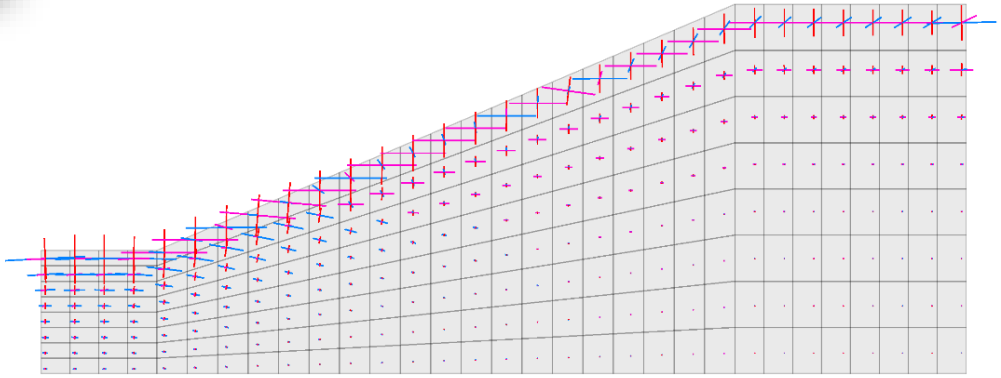
Maximum

Minimum

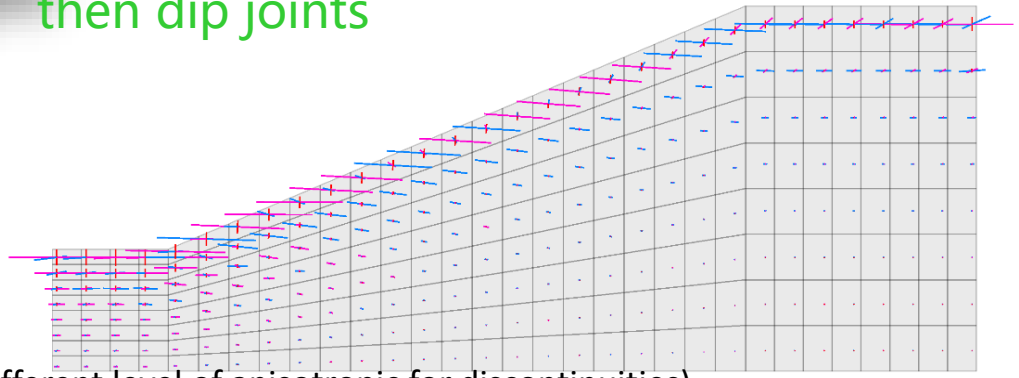
- ☐ Nonhomogeneous & anisotropic permeability
- ☐ Maximum principal permeability is parallel to the slope surface
- ☐ Depth ↗, the permeability tensor ↘

- **The distribution of discontinuities**

The number of strike joints are more then dip joints



The number of strike joints are significantly more then dip joints

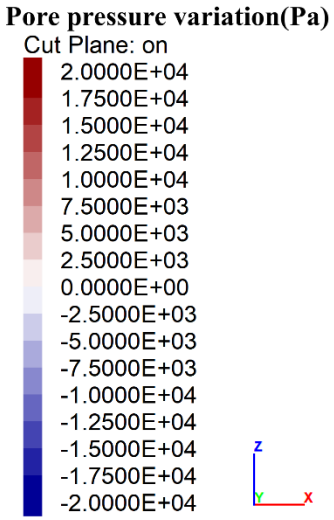


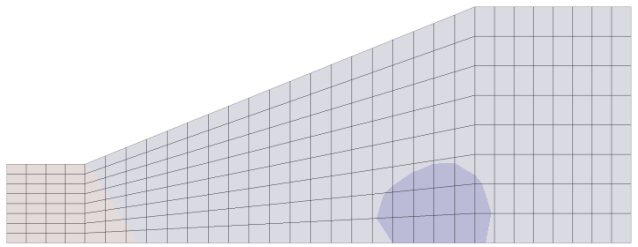
(The different level of anisotropic for discontinuities)

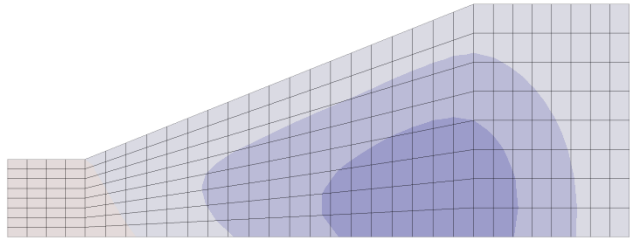
The variation of pore water pressure distribution

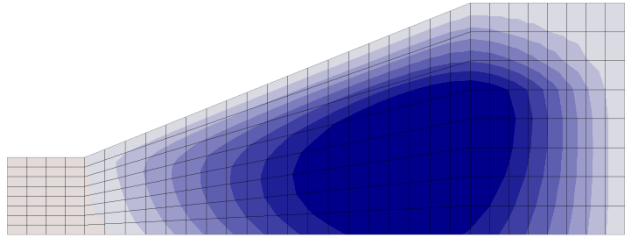
The level of anisotropic | **The number of strike joints more then dip joints** → **The number of strike joints significantly more then dip joints**

The absolutely variation

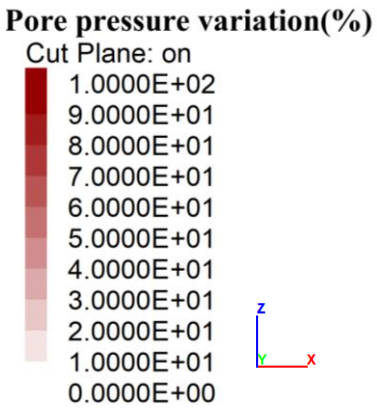


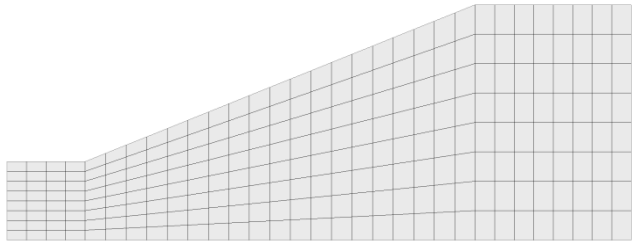


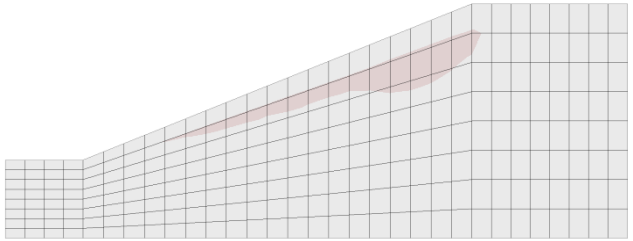


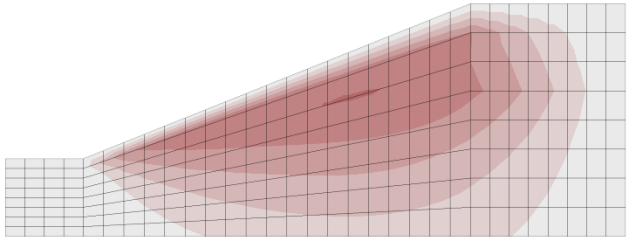


The relatively variation







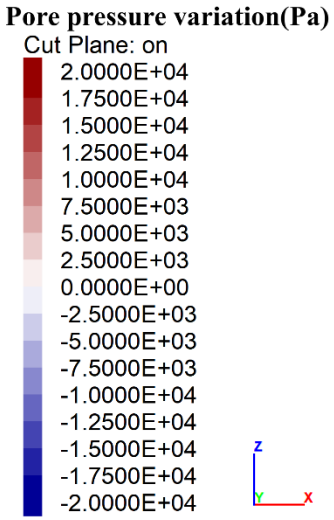


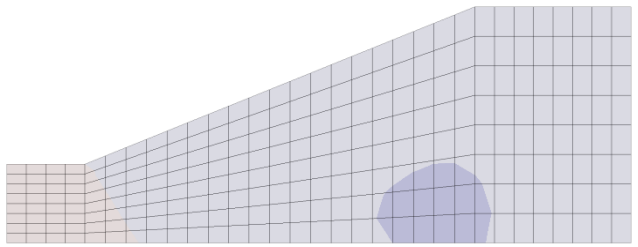
5% **12%** **51%**

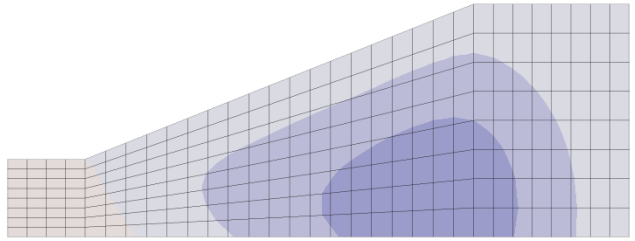
The variation of slope stability analysis

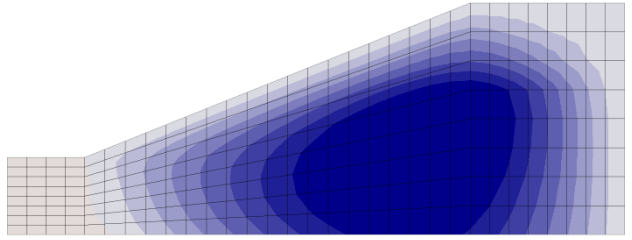
The level of anisotropic	The number of strike joints more then dip joints	→	The number of strike joints **significantly** more then dip joints

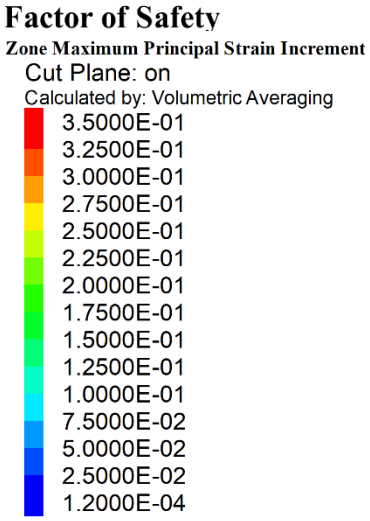
The absolutely variation

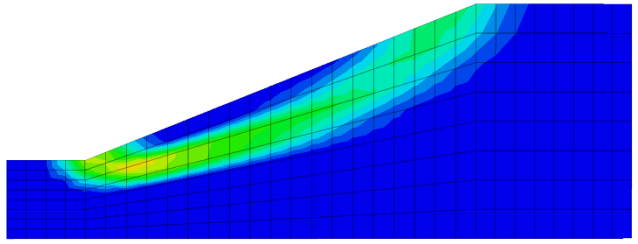




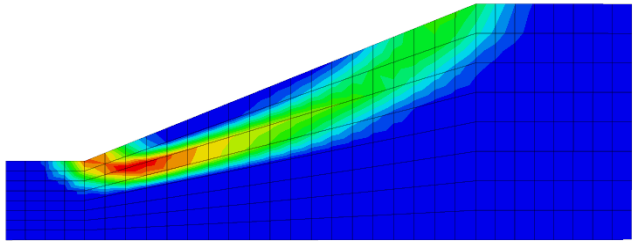








1.41



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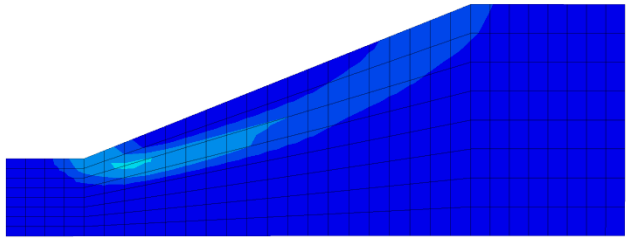
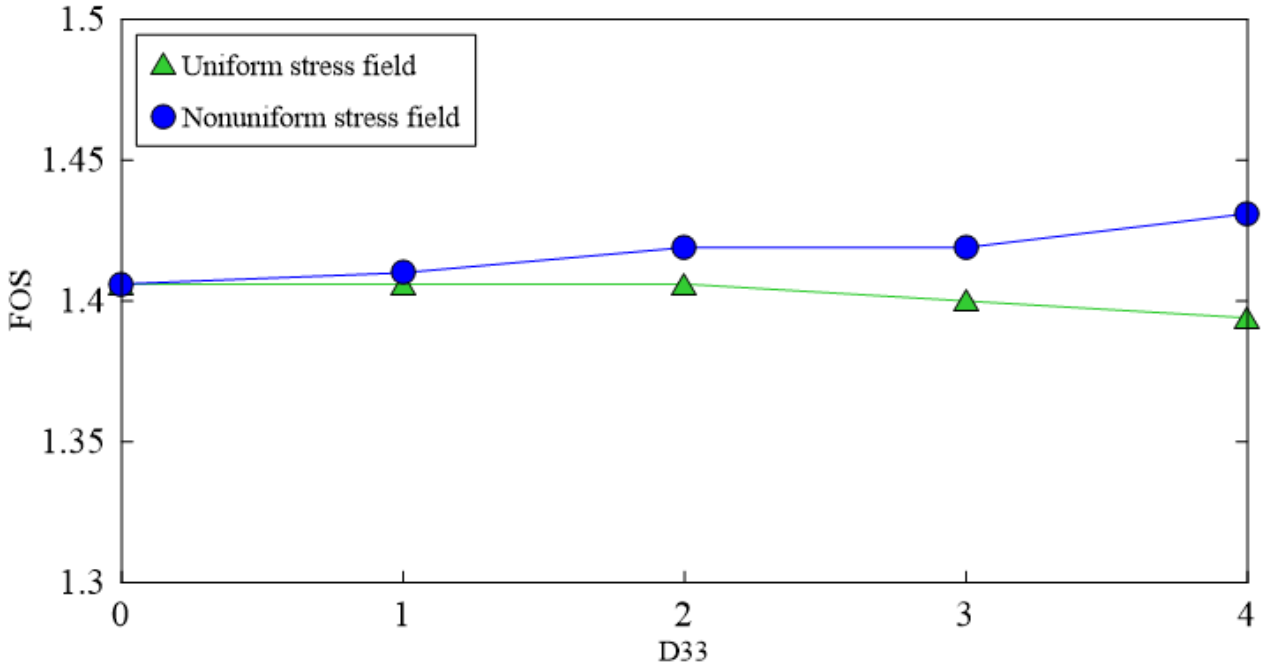


1.431

Conclusions

Conclusions



(The level of anisotropy for discontinuities)

① Considering the inherent distribution of discontinuities (under uniform stress field)

- Comparing the pore water pressure distribution on rock slope between different level of anisotropy for discontinuities under uniform stress field.
- The variation up to 52%.
- For factor of safety, the level of anisotropy for discontinuities increase, the factor of safety decrease.

➡ The influence due to the distribution of discontinuities.

② Considering the inherent distribution of discontinuities and stress-induced anisotropy (under non-uniform stress field)

- Comparing the pore water pressure distribution on rock slope between different level of anisotropy for discontinuities under nonuniform stress field.
- The variation up to 51%.
- For factor of safety, the level of anisotropy for discontinuities increase, the factor of safety increase.

➡ The influence due to the stress field.

Thank you for your attention!

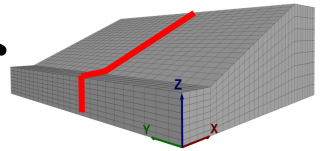
Results

① The stress-induced anisotropy

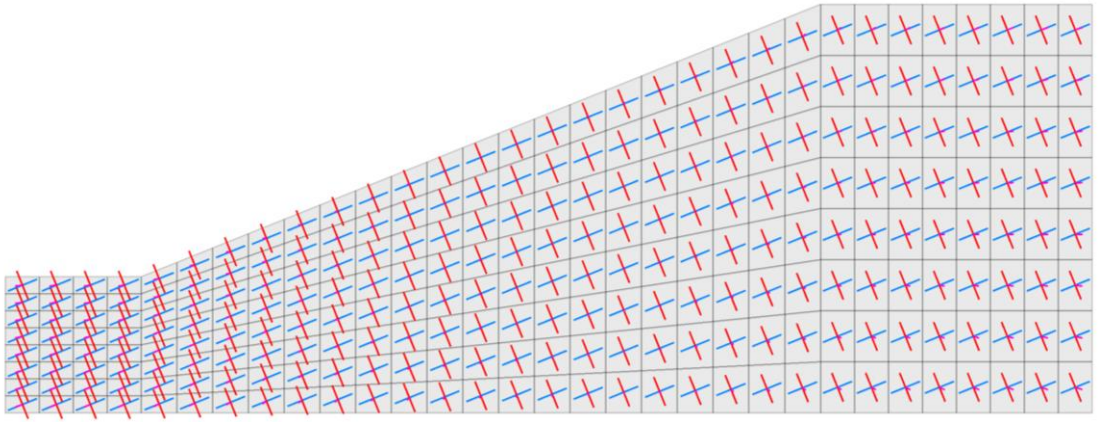
- Uniform stress field(0.25MPa)
- Non-uniform stress field

(Equivalent permeability tensor, pore water pressure variation and factor of safety)

The results of equivalent permeability tensor



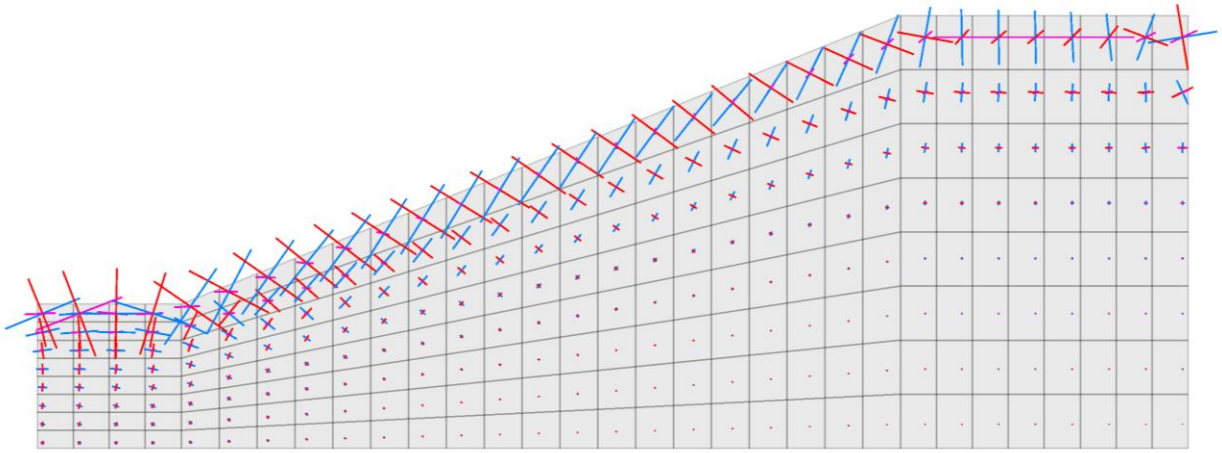
- **Uniform stress field(0.25MPa)**



Principal permeability tensor $\left(\frac{m^2}{Pa * sec}\right)$
Scale: 2e+08
Color By Order
Intermediate
Maximum
Minimum

- Homogeneous & isotropic permeability tensor
- Maximum principal permeability is parallel to the slope surface

- **Non-uniform stress field**

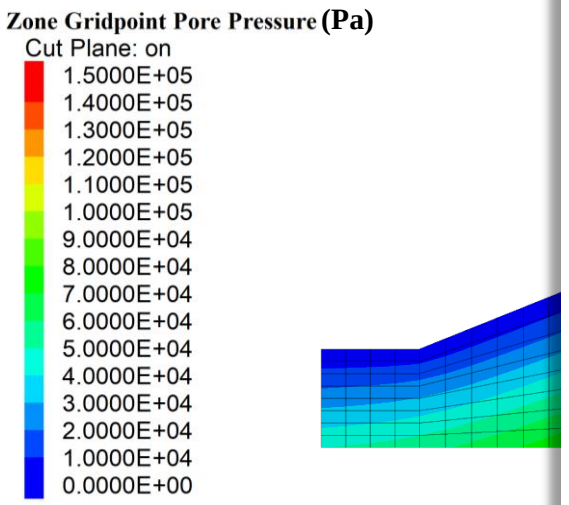


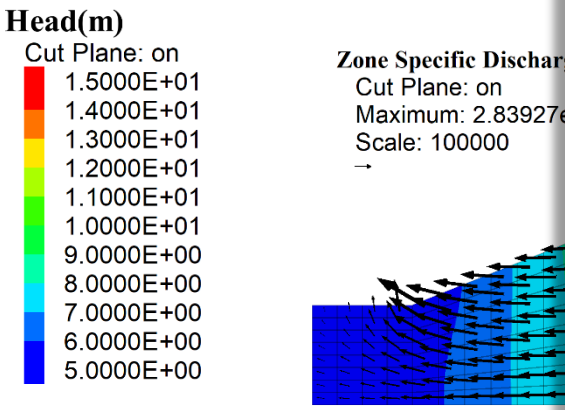
Principal permeability tensor $\left(\frac{m^2}{Pa * sec}\right)$
Scale: 2e+08
Color By Order
Intermediate
Maximum
Minimum

- Nonhomogeneous & anisotropic permeability tensor
- Maximum principal permeability is parallel to the slope surface
- Depth ↗, the permeability tensor ↘

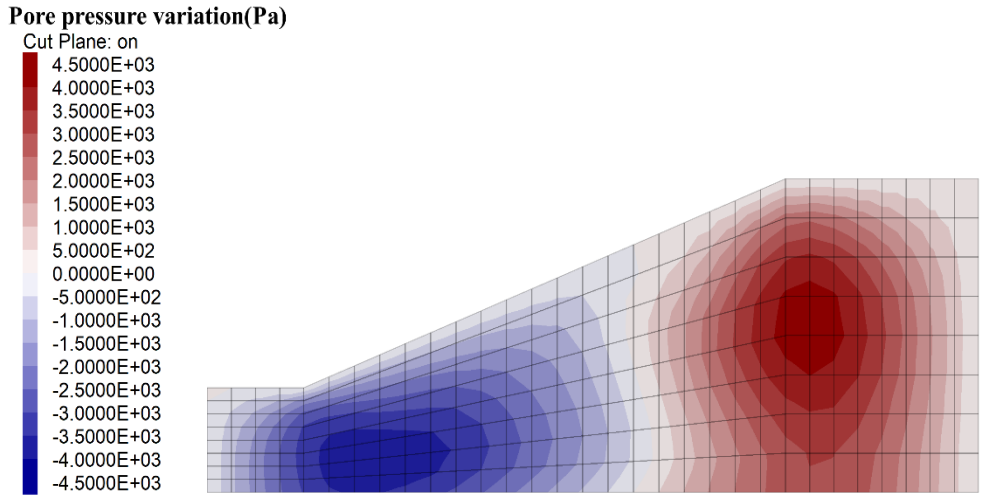
The results of pore water pressure distribution

- Uniform stress fi stress field

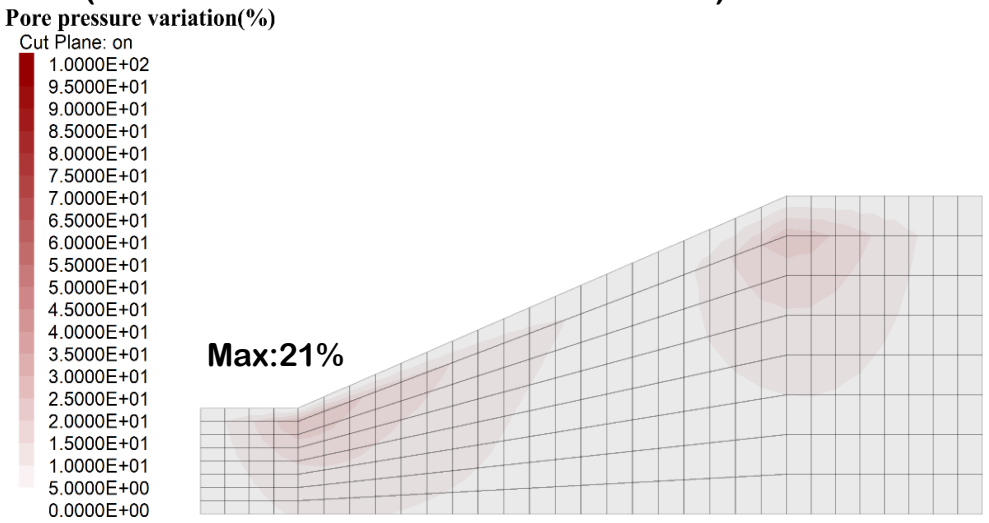


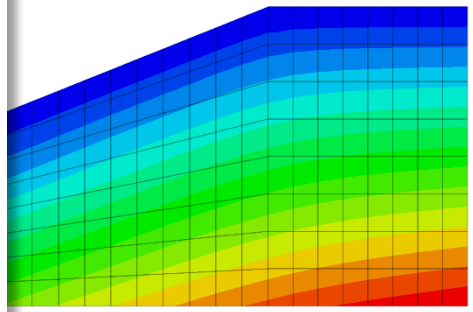


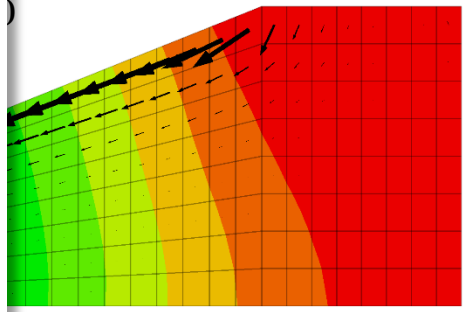
- The absolutely variation of pore water pressure (nonuniform stress field - uniform stress field)



- The relatively variation of pore water pressure (nonuniform stress - uniform stress)/uniform stress

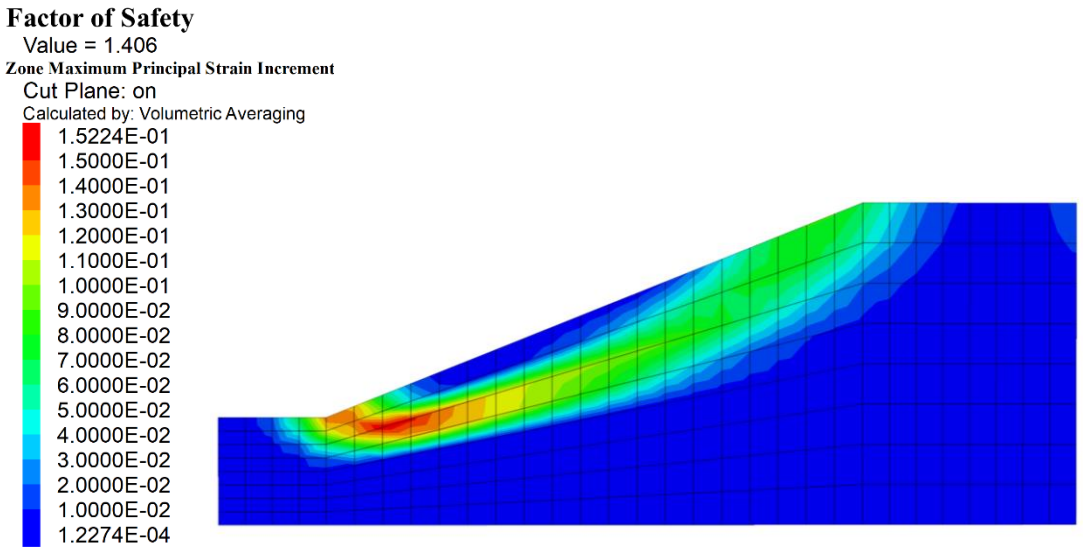




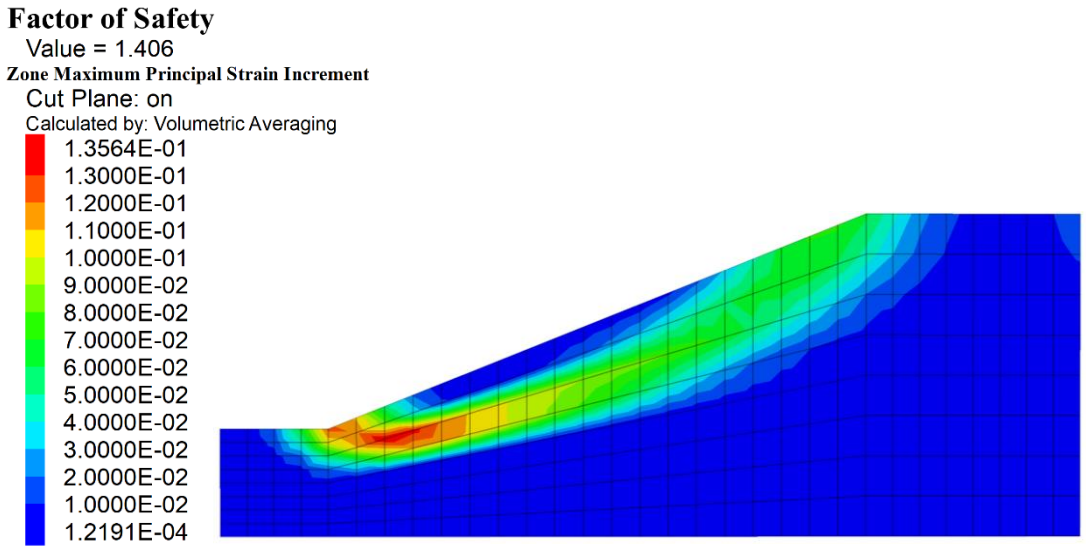


The results of slope stability analysis

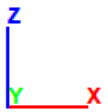
- **Uniform stress field(0.25MPa)**



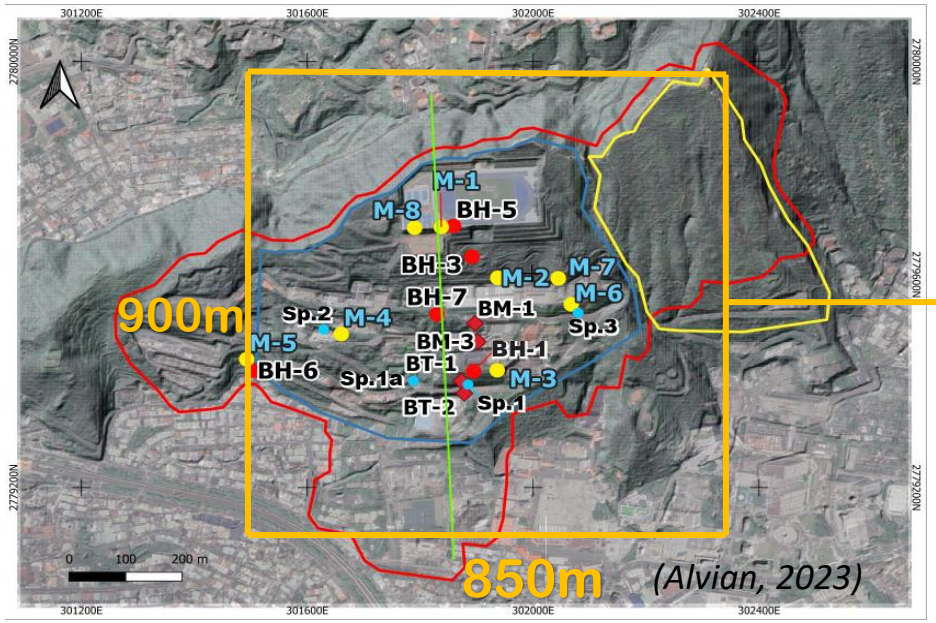
- **Non-uniform stress field**

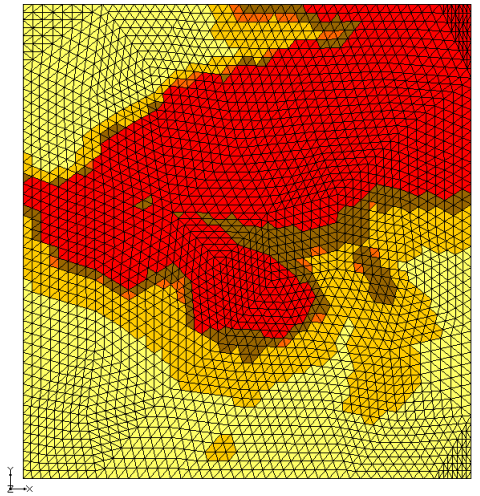


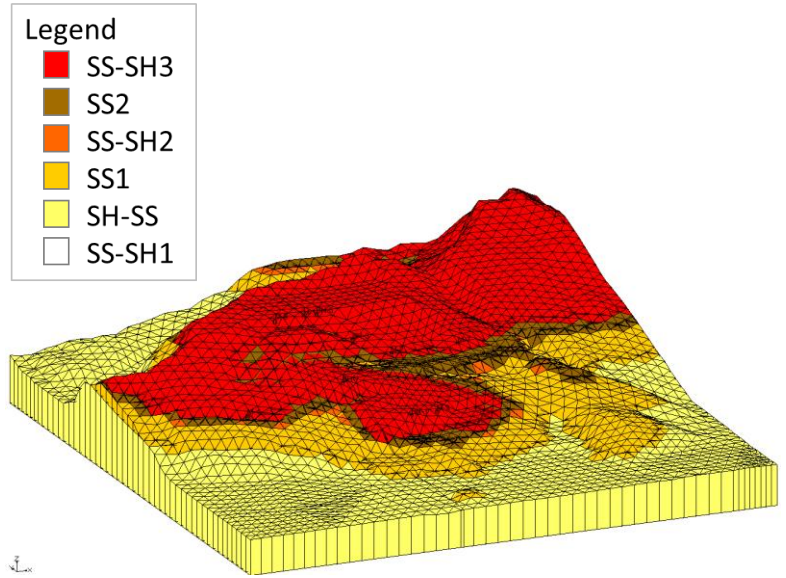
- ☐ Same value of factor of safety
- ☐ Same distribution of maximum principal strain increment
- ☐ It’s no significant influence under this situation.

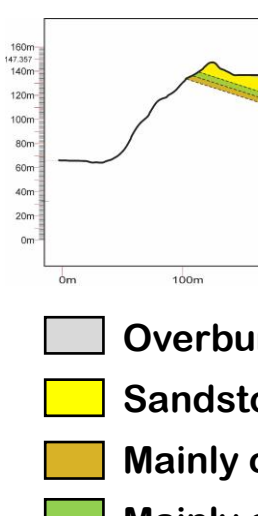


Future work







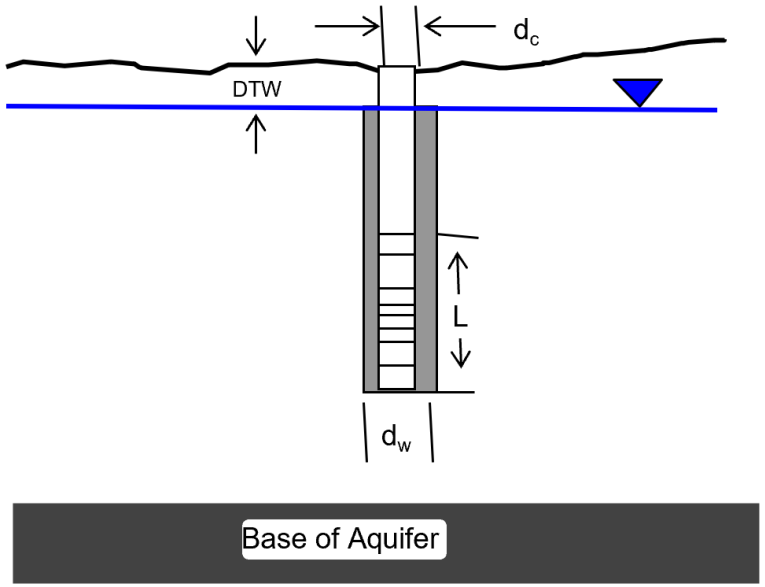


(Made by Alvian)

- Overburden & Colluvium
- Sandstone
- Mainly composed of ss with sh occasionally
- Mainly composed of sh with ss occasionally

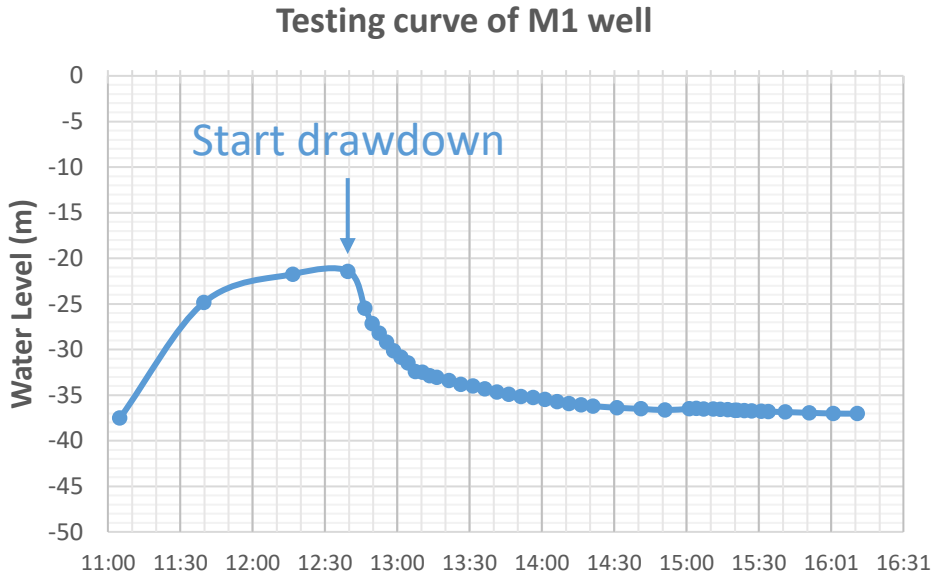
Main target → **Mushan Formation's sandstone**

Bouwer and Rice Method (Bouwer and Rice, 1976)



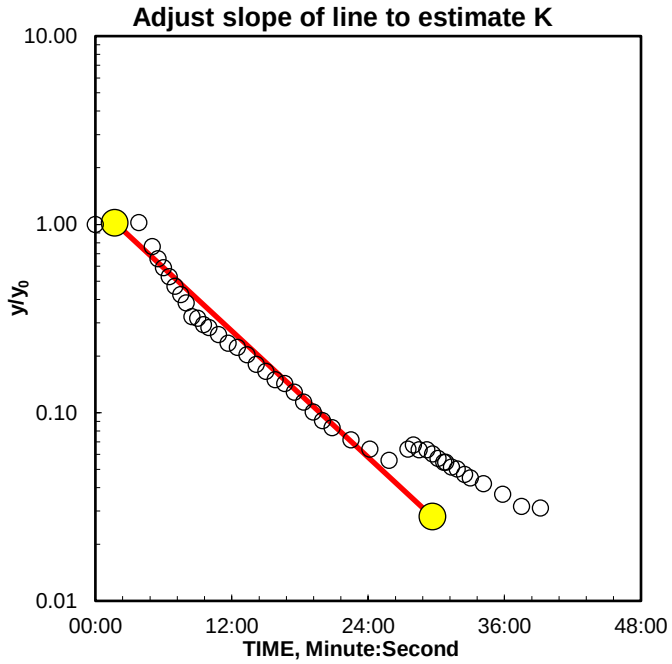
INPUT

Construction:	
Casing dia. (d_c)	70mm
Annulus dia. (d_w)	120mm
Screen Length (L)	48m
Depths to:	
water level (DTW)	37.5m
Top of Aquifer	1m
Base of Aquifer	49m
Annular Fill:	
across screen	Coarse Sand
above screen	Open Hole
Aquifer Material	Fine-Grained Sandstone
FLOW RATE	0.05183liters/s



ASSUMPTION

- Originally designed for the analysis of data from wells in unconfined aquifers.
- This test provides a very local estimate of hydraulic conductivity or transmissivity in the near vicinity of a well.
- Well is of finite diameter and may partially penetrate the aquifer.



COMPUTD

K = 7.8E-08 m/s

Common Rock Properties (m/s)		
Aquifer Material	Likely Kmin	Likely Kmax
Clay soils (surface)	3.53E-08	3.53E-06
Fine-Grained Sandstone	3.53E-09	3.53E-06
Medium-Grained Sandstone	3.53E-06	3.53E-05
Shale	3.53E-13	3.53E-10

(USGS, 2004)