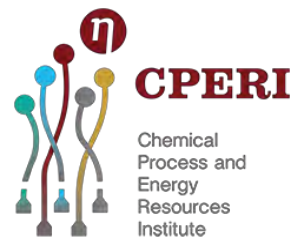




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# Slope stability of deep surface coal mines in the presence of a weak zone

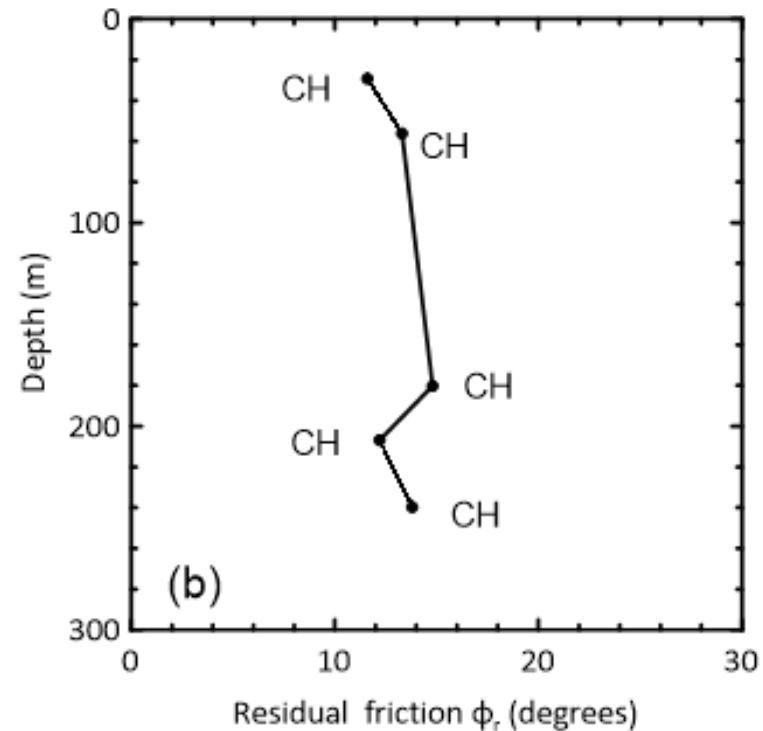
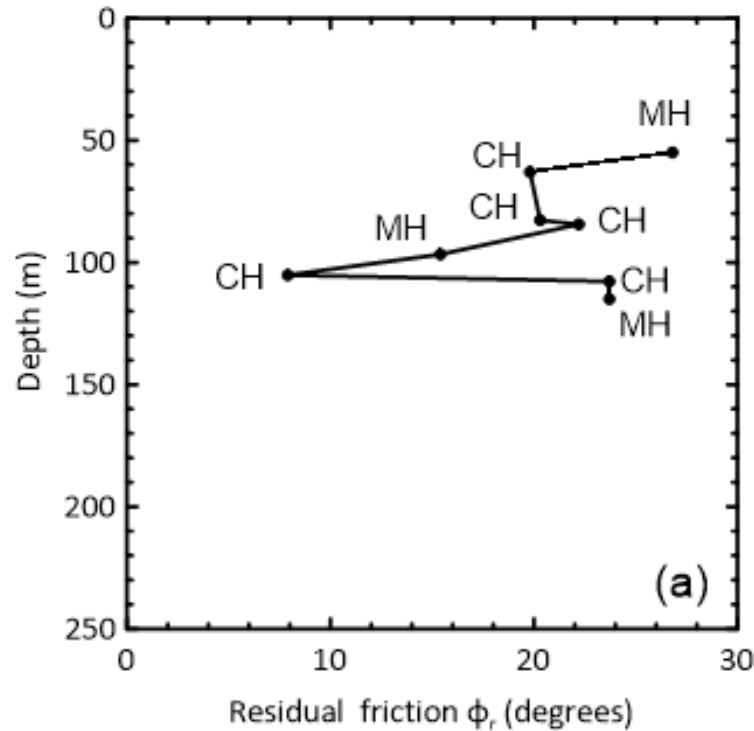
Alexandros Theocharis, Ioannis Zevgolis, Nikolaos Koukouzas

7-10-2022, Wroclow, Poland

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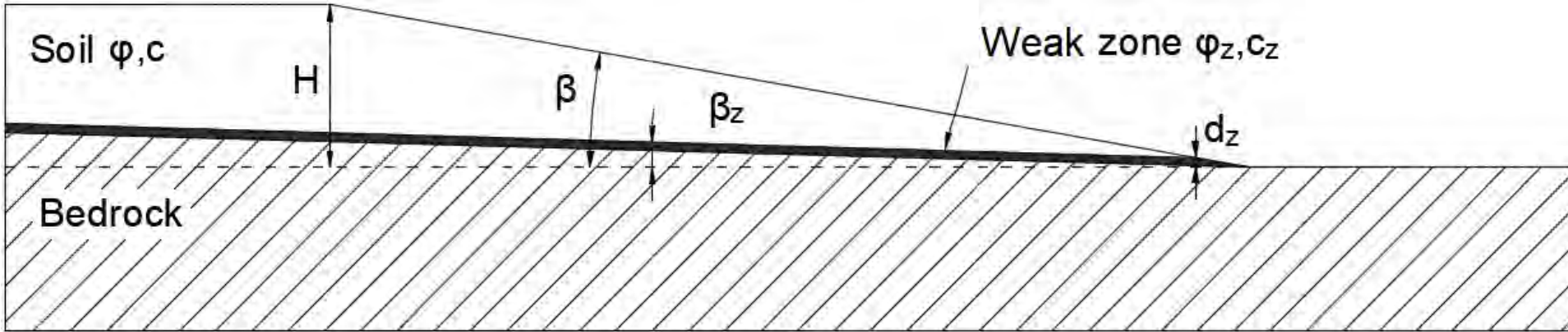
- The weak zone in lignite mines
- The weak zone stratigraphy – effects on stability
- Critical parameters (and not critical)
- Effect of water (simplified approach)

# Weak layer definition

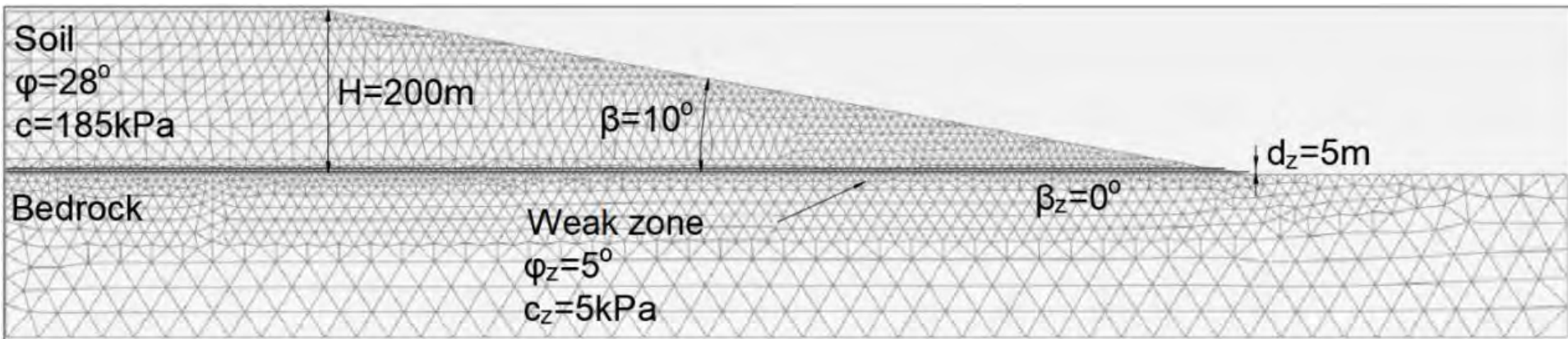


- In many cases, the failure mechanism is governed by a sub-horizontal sliding surface along a sensitive low strength clay or marl layer
- As the various geologic layers constituting the stratigraphy of Greek lignite mines can be identified having similar geotechnical properties, a homogeneous slope with some type of deep bedrock formation can be considered, for slope stability analyses

# (Simplified) Stratigraphy



Simplified stratigraphy of a surface coal mine slope with a weak zone at the bottom of the excavation



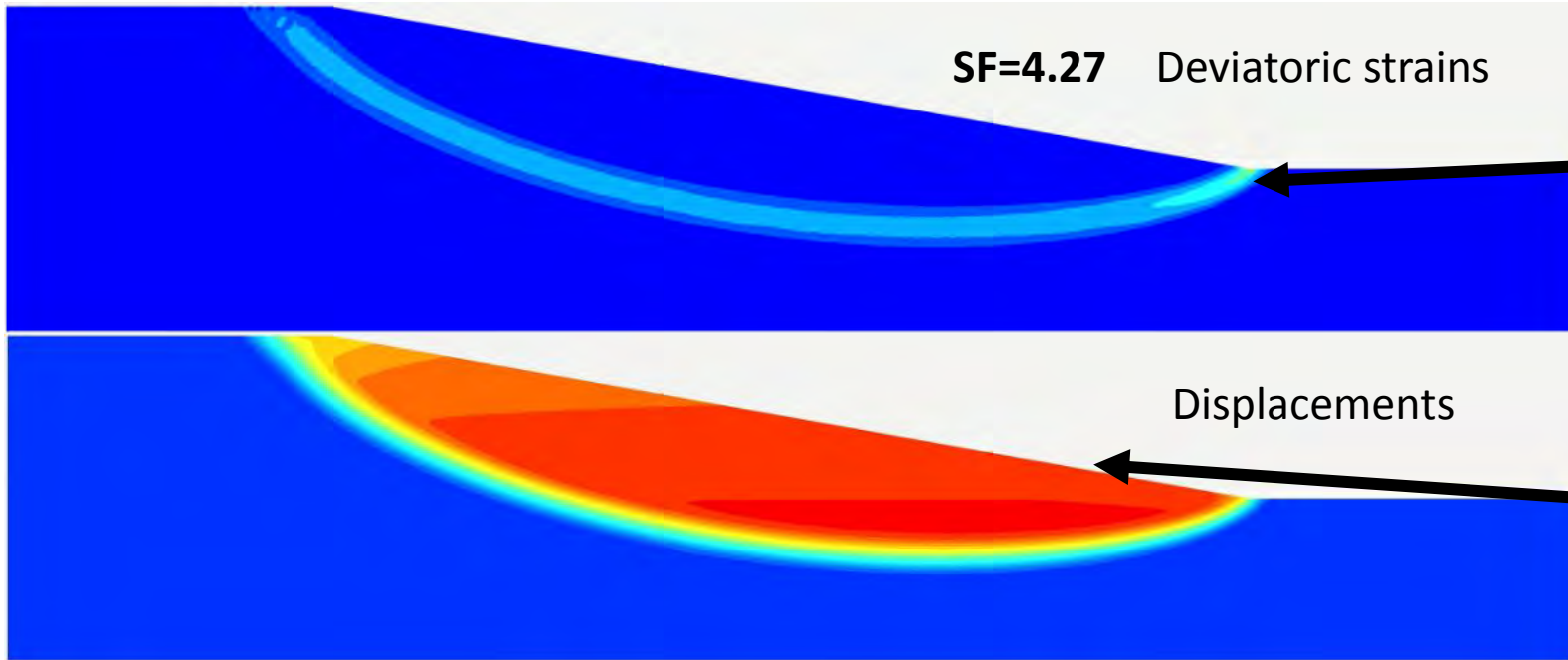
# Slope properties

Parameter	Symbol	Reference value	Examined range
Overburden's soil friction angle	$\varphi$ (°)	28	21 - 35
Overburden's soil cohesion	c (kPa)	185	40 - 185
Weak zone's (residual) friction angle	$\varphi_z$ (°)	10	5 - 15
Weak zone's (residual) cohesion	$c_z$ (kPa)	5	5
Slope height	H (m)	200	50 - 200
Slope inclination	$\beta$ (°)	10	8 - 14
Weak zone's inclination	$\beta_z$ (°)	0	(-6) - (+6)
Weak zone's thickness	$d_z$ (m)	5	0.5 - 5

\* Positive  $\beta_z$  indicates a dip (inclination) towards the excavation, i.e. against stability.

### Homogeneous slope

H= 200m  
 $\beta= 10^\circ$   
 $\phi= 28^\circ$   
c= 185 kPa  
 $\gamma= 17 \text{ kN/m}^3$   
dry conditions



SF=4.27

Deviatoric strains

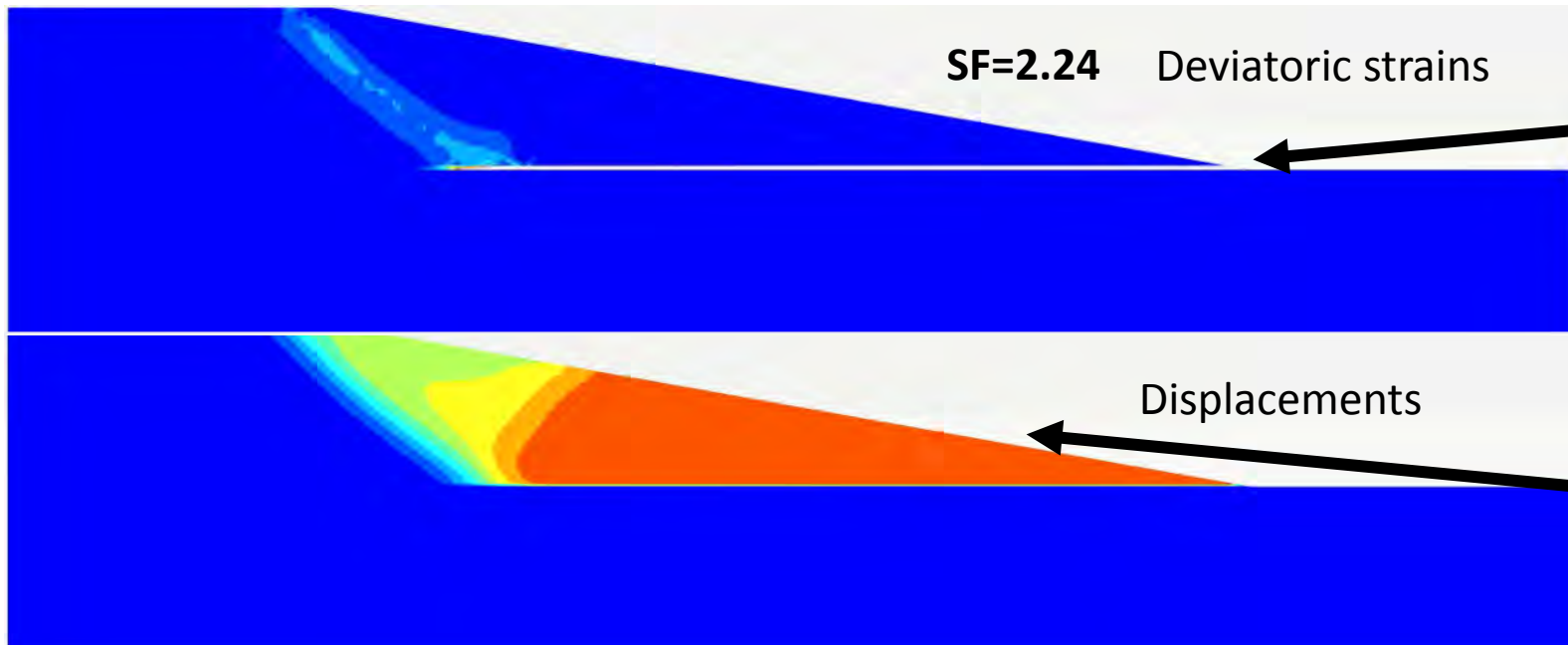
Displacements

Deviatoric strains show the failure surface

Displacements are large only inside the failure surface

### Sensitive zone in slope

H= 200m  
 $\beta= 10^\circ$   
 $\phi= 28^\circ$   
c= 185 kPa  
 $\gamma= 17 \text{ kN/m}^3$   
dry conditions  
 $\phi_z= 15^\circ$   
 $c_z= 5 \text{ kPa}$   
 $\beta_z= 0^\circ$



SF=2.24

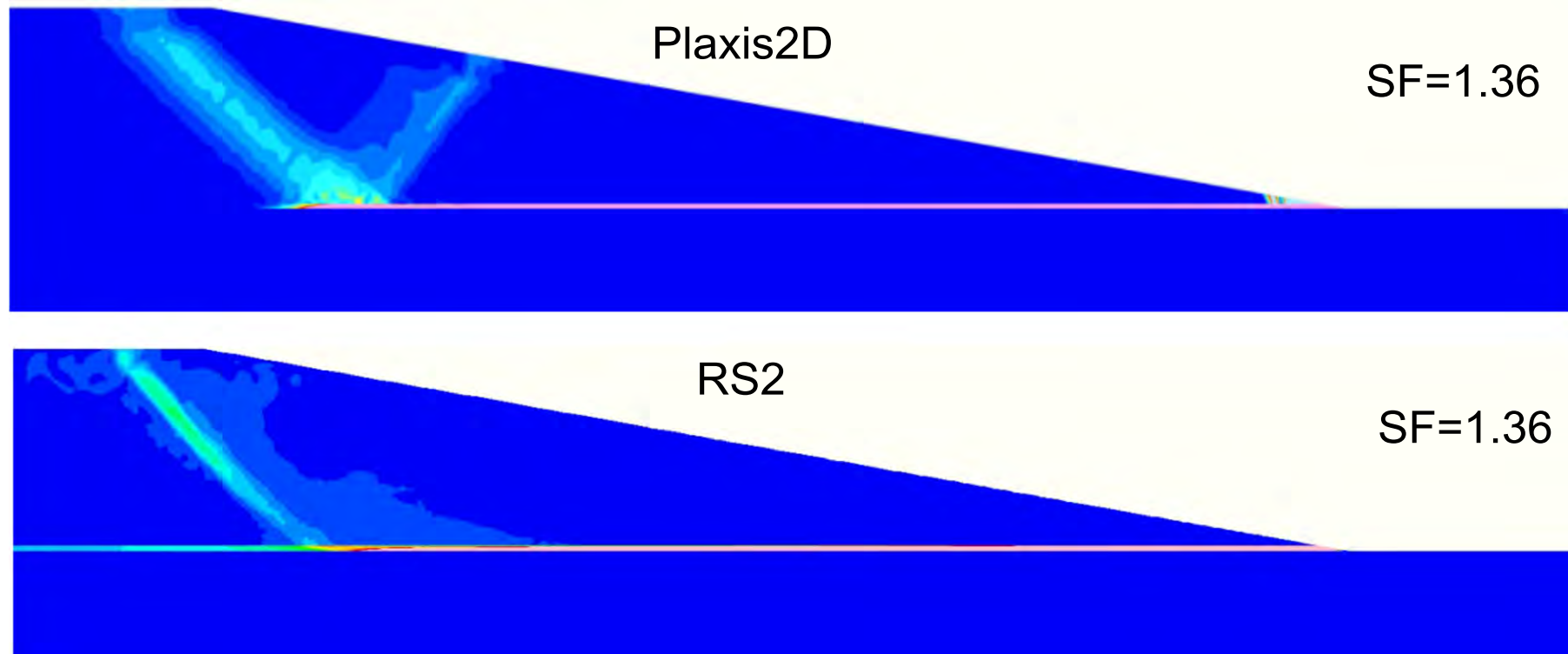
Deviatoric strains

Displacements

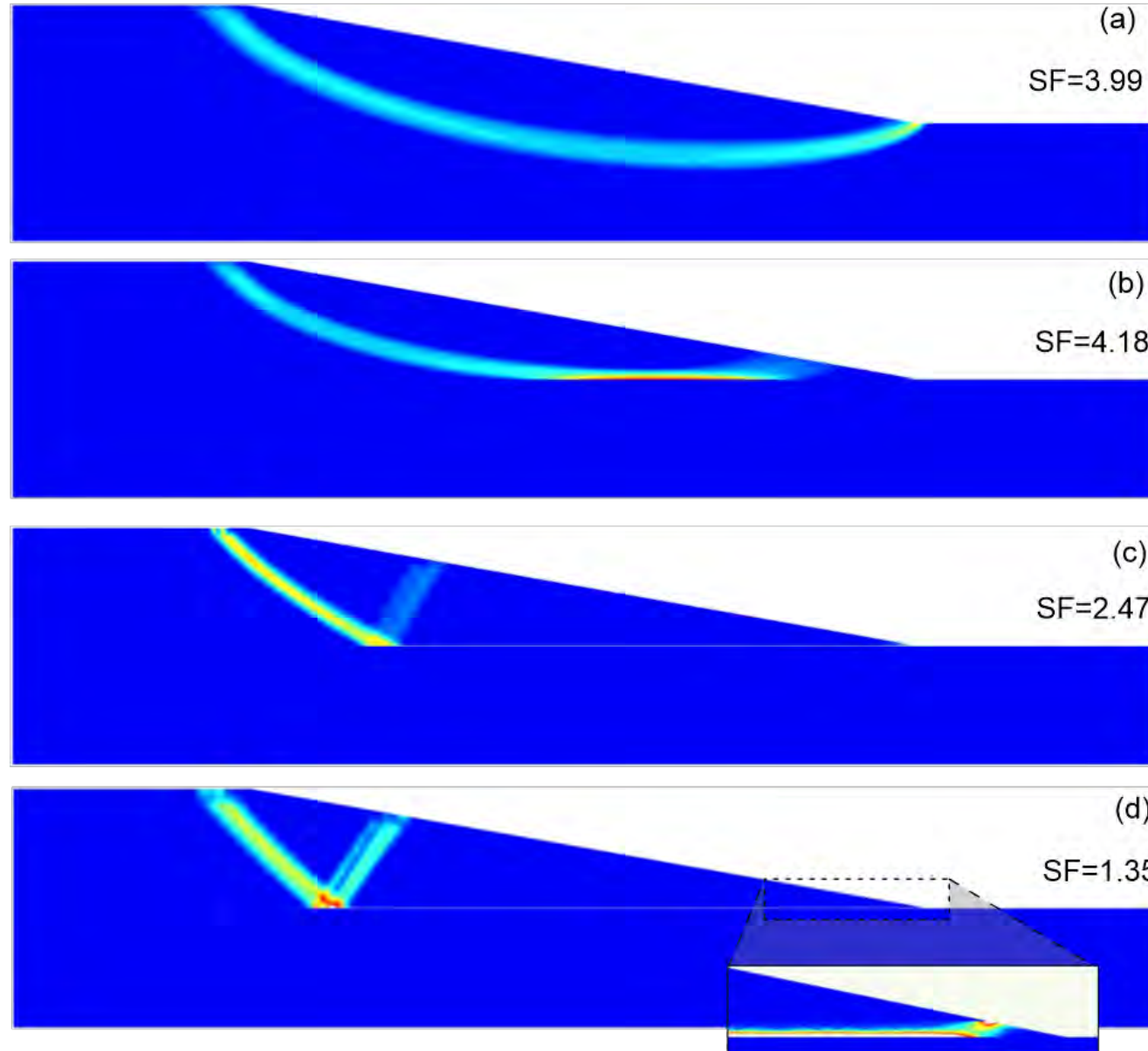
Deviatoric strains show the failure surface

Displacements are large only inside the failure surface

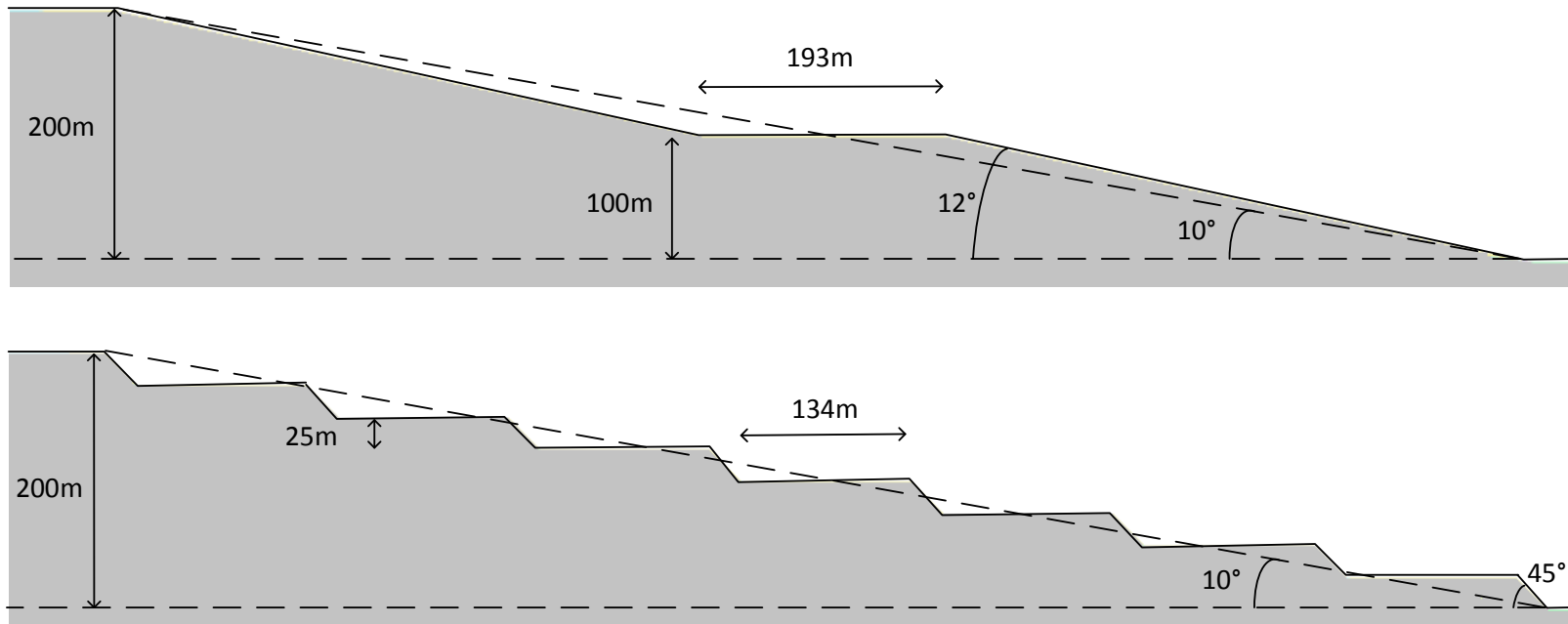
# Typical failure of the weak surface stratigraphy



# Homogeneous to weak surface stratigraphy

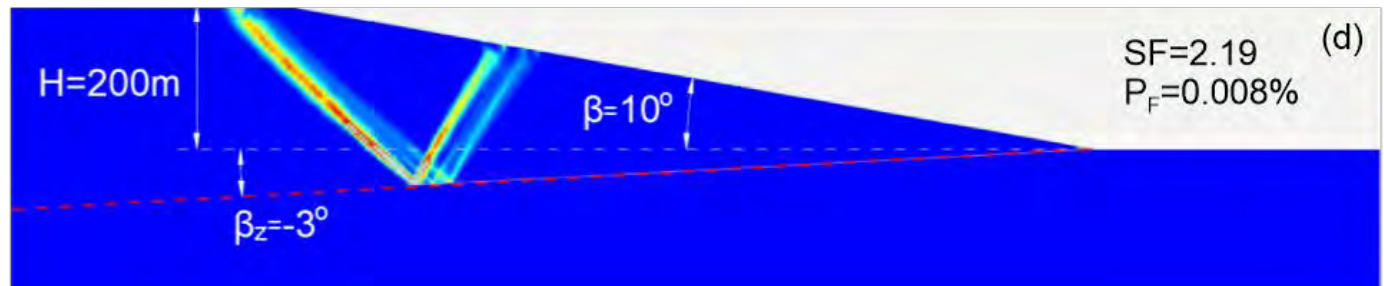
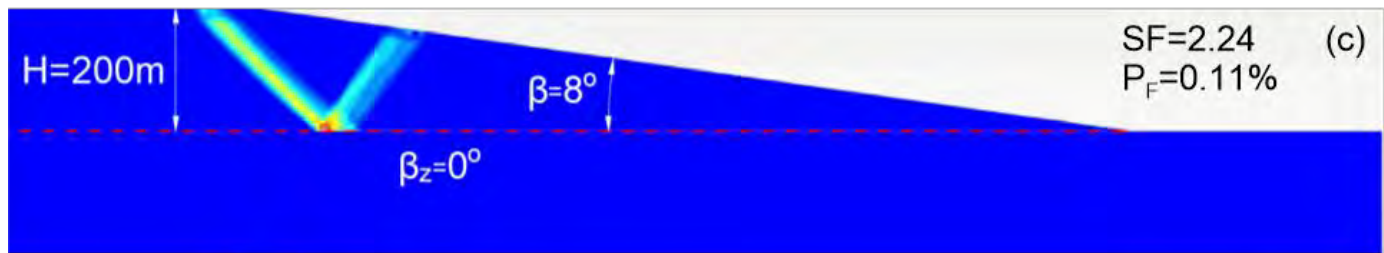
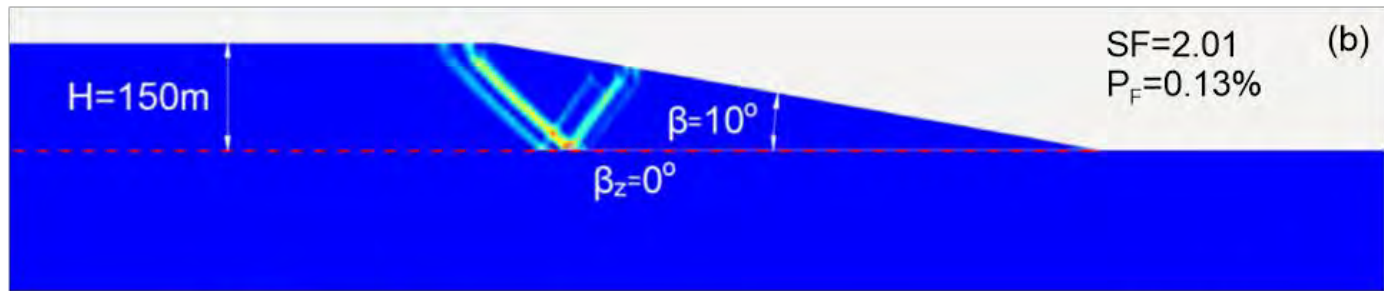
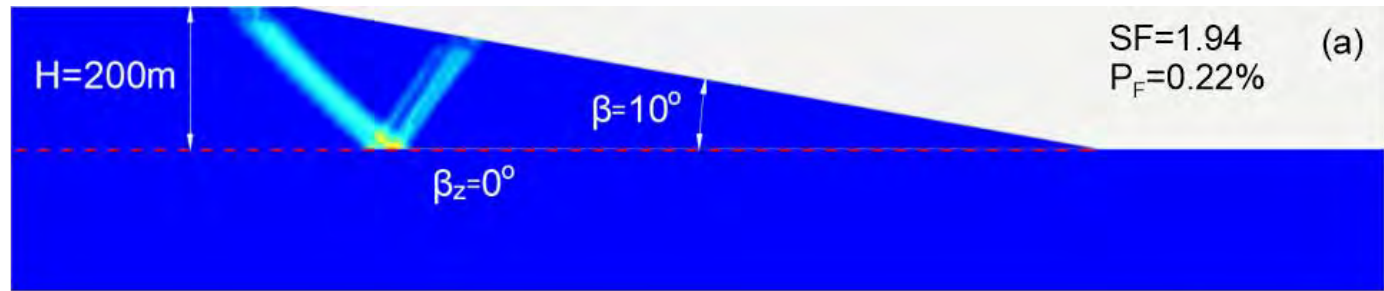


# Benches considerations

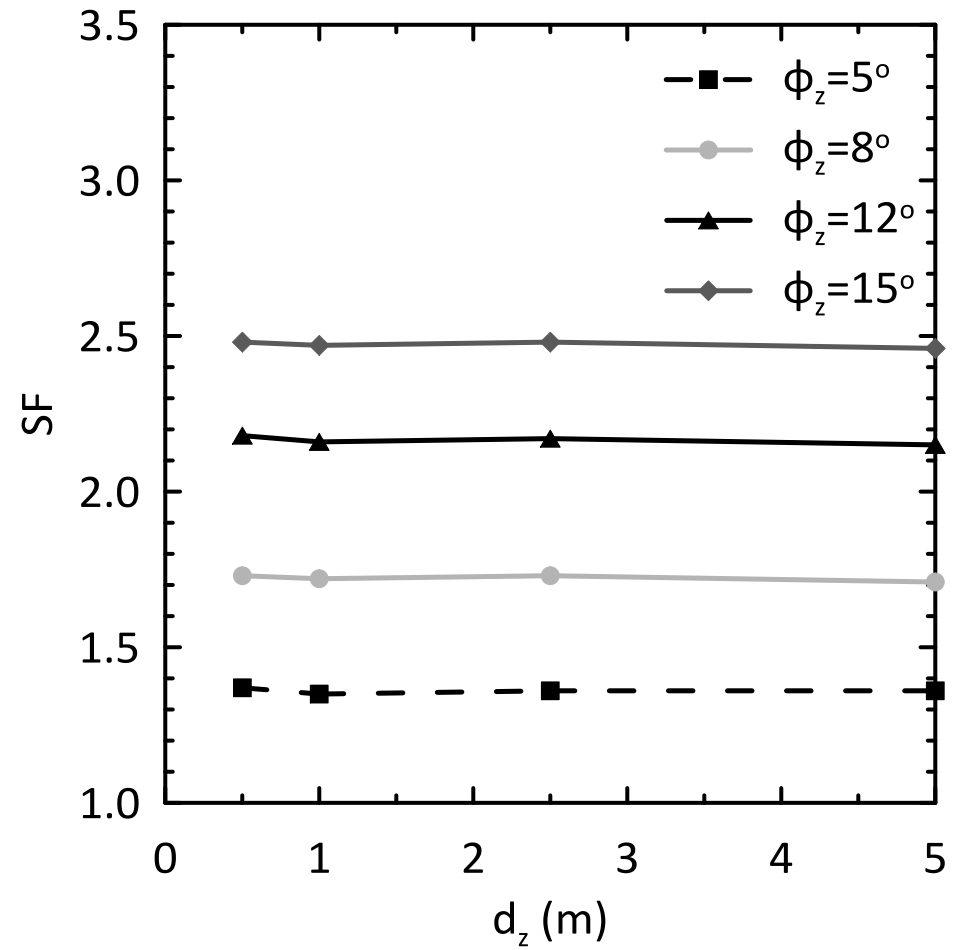
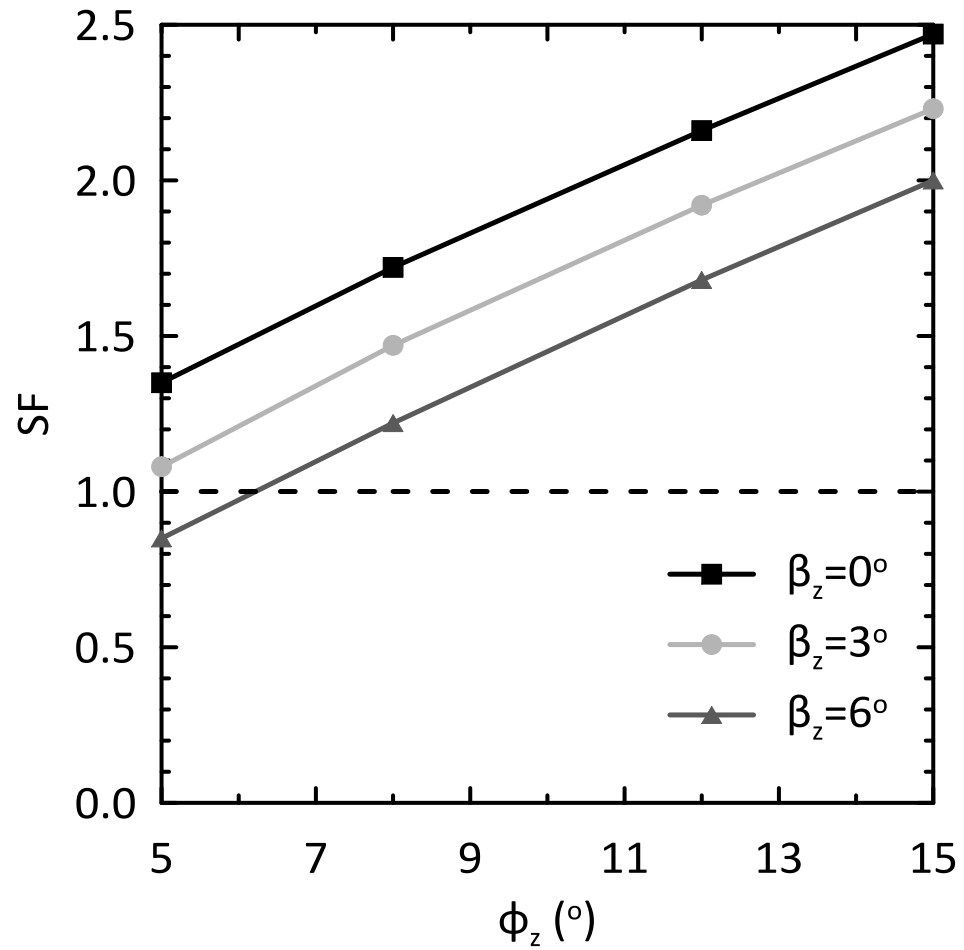


- 1 to 9 benches with heights between 20m to 100m
- The failure surface was similar among all models regardless of the benches' number and geometry.

# Critical parameters - Variations

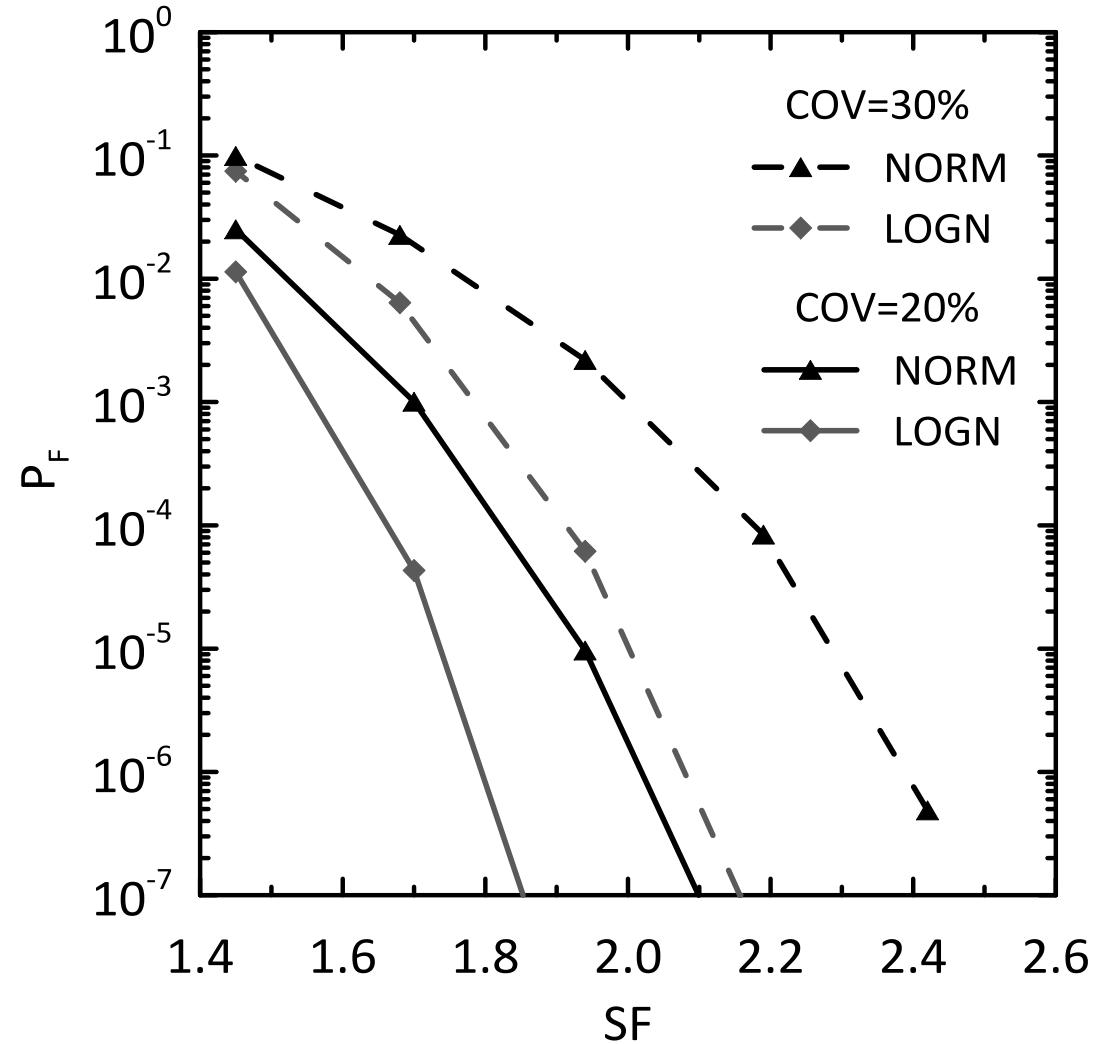


# Critical parameters (and not)

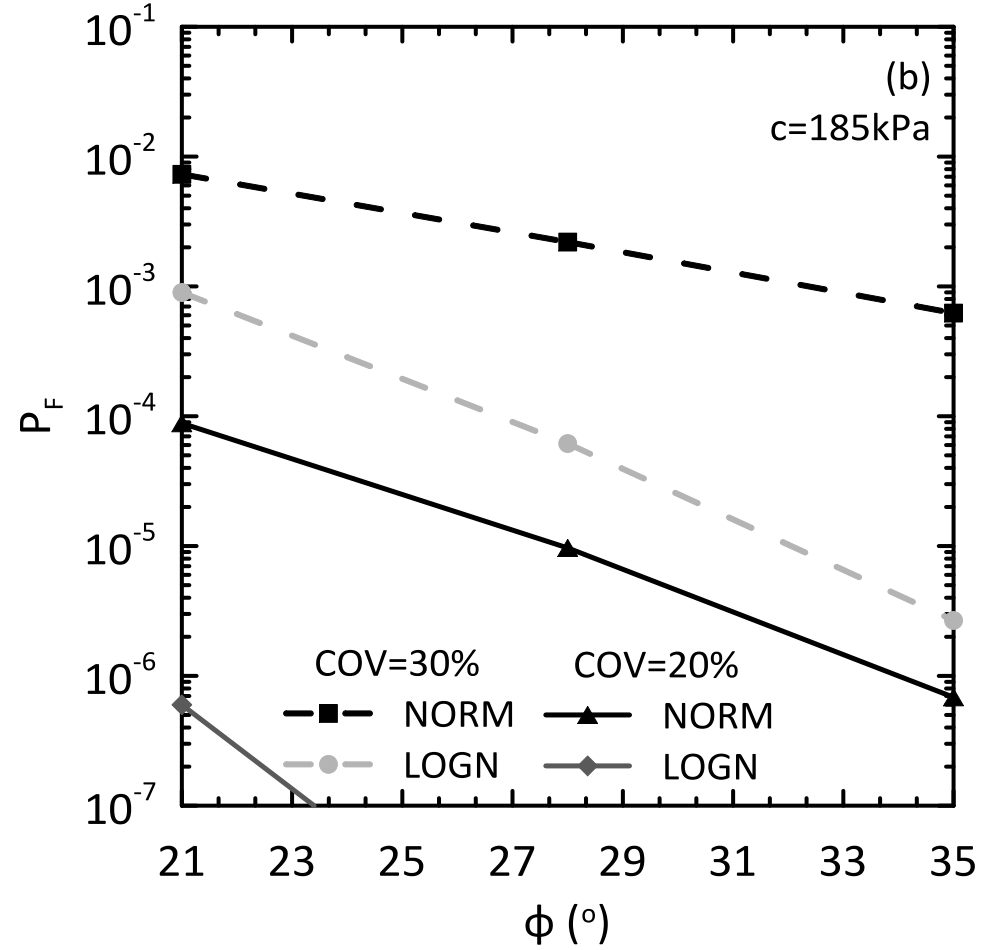
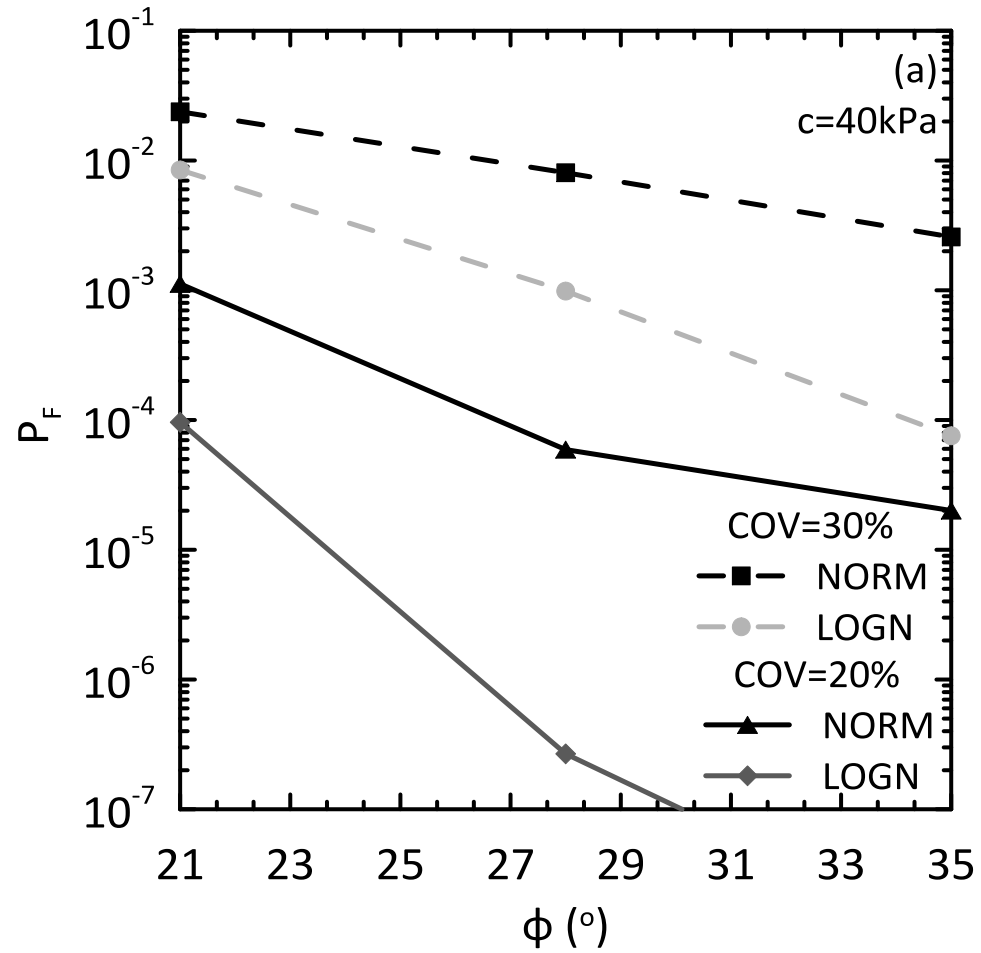


# Safety and/or reliability analysis

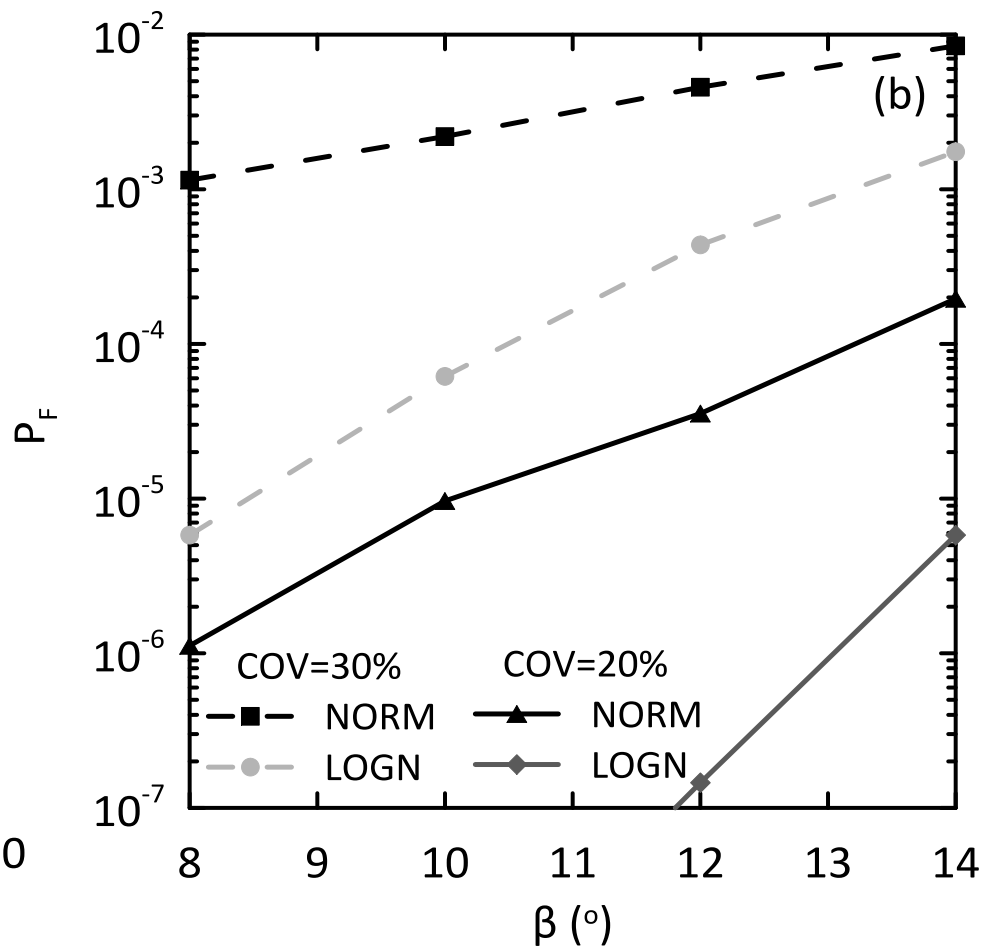
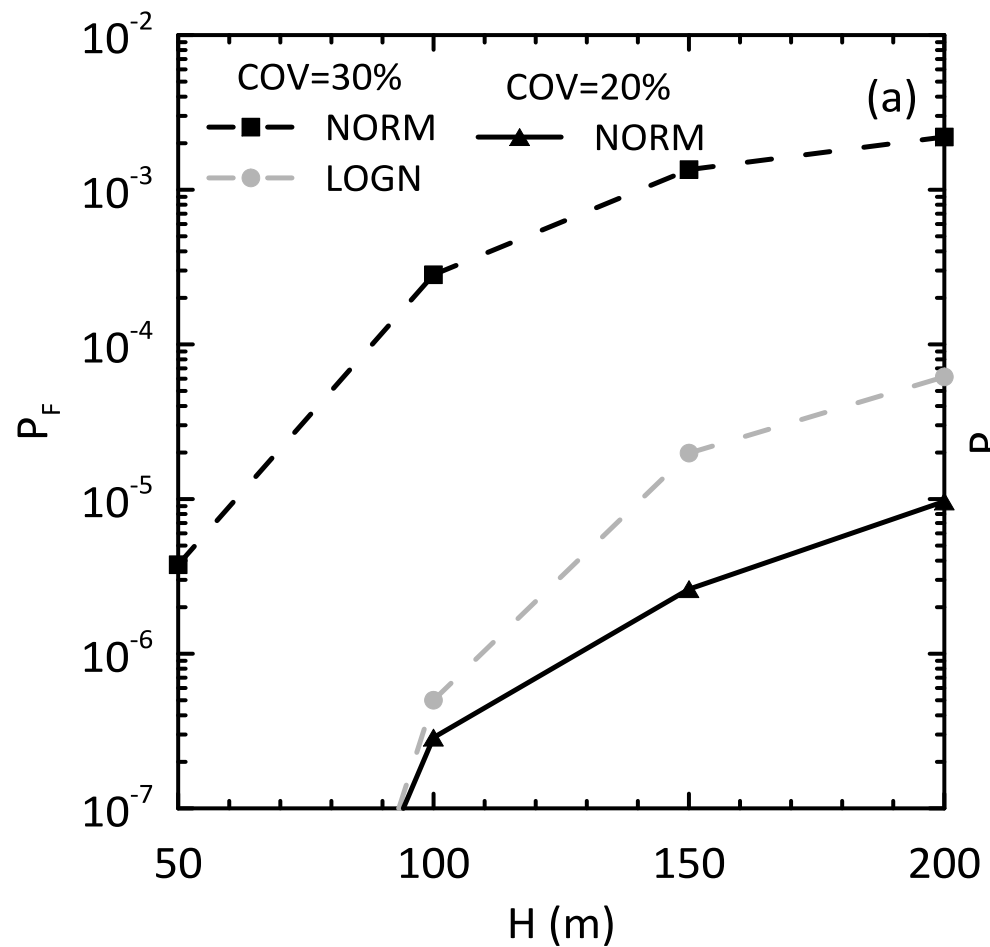
Random variable:  
 $\varphi_z$  weak zone's residual  
shear strength



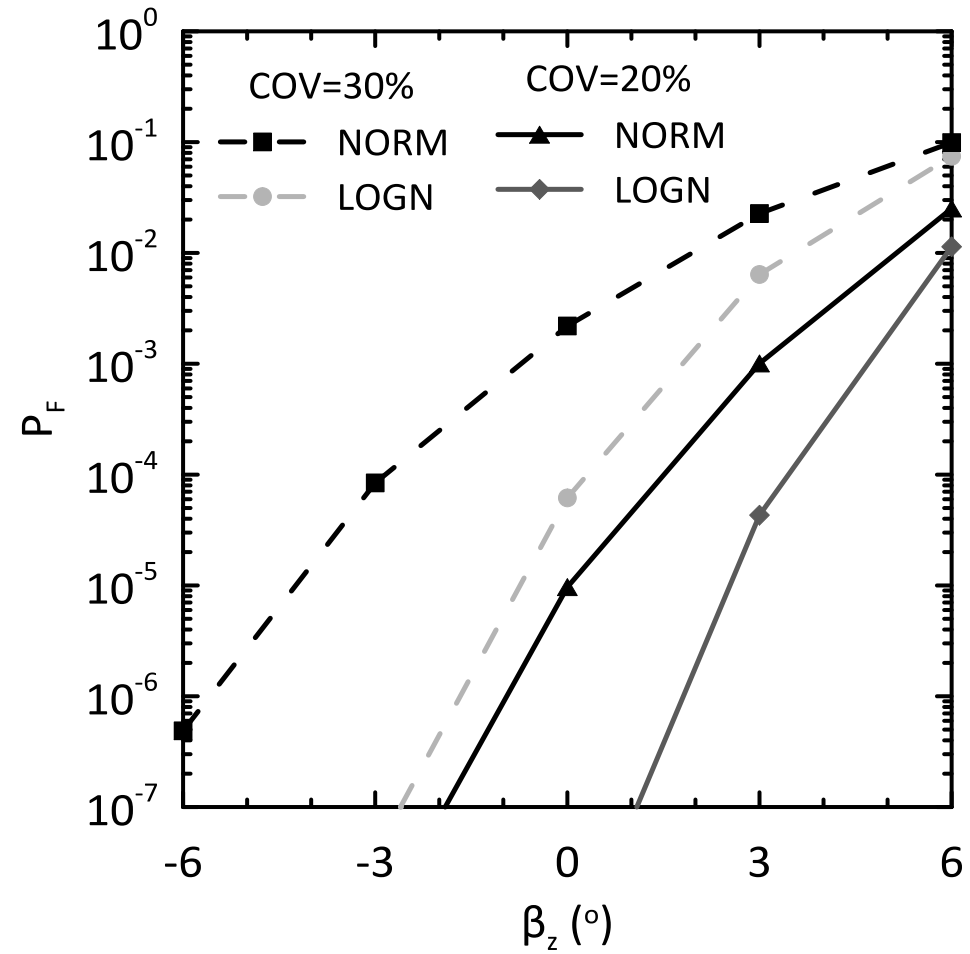
# Overburden soil's strength



# Slope's height and inclination



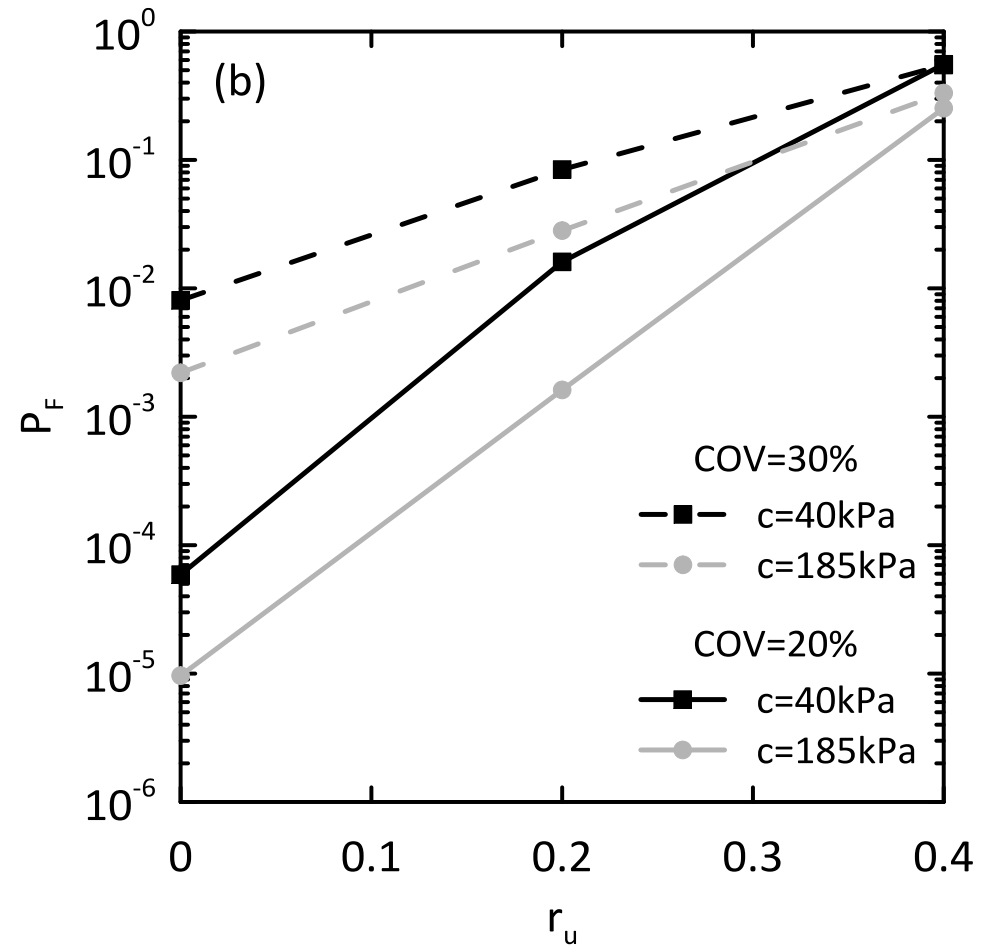
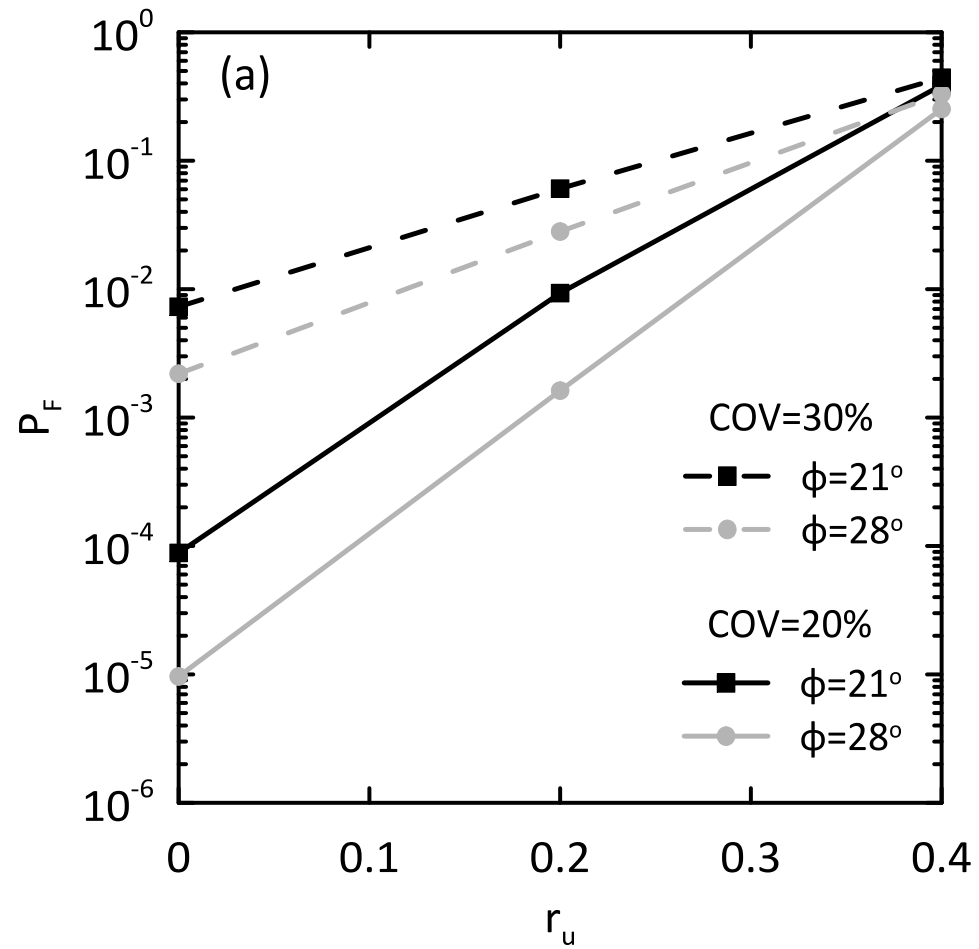
# Weak zone's inclination



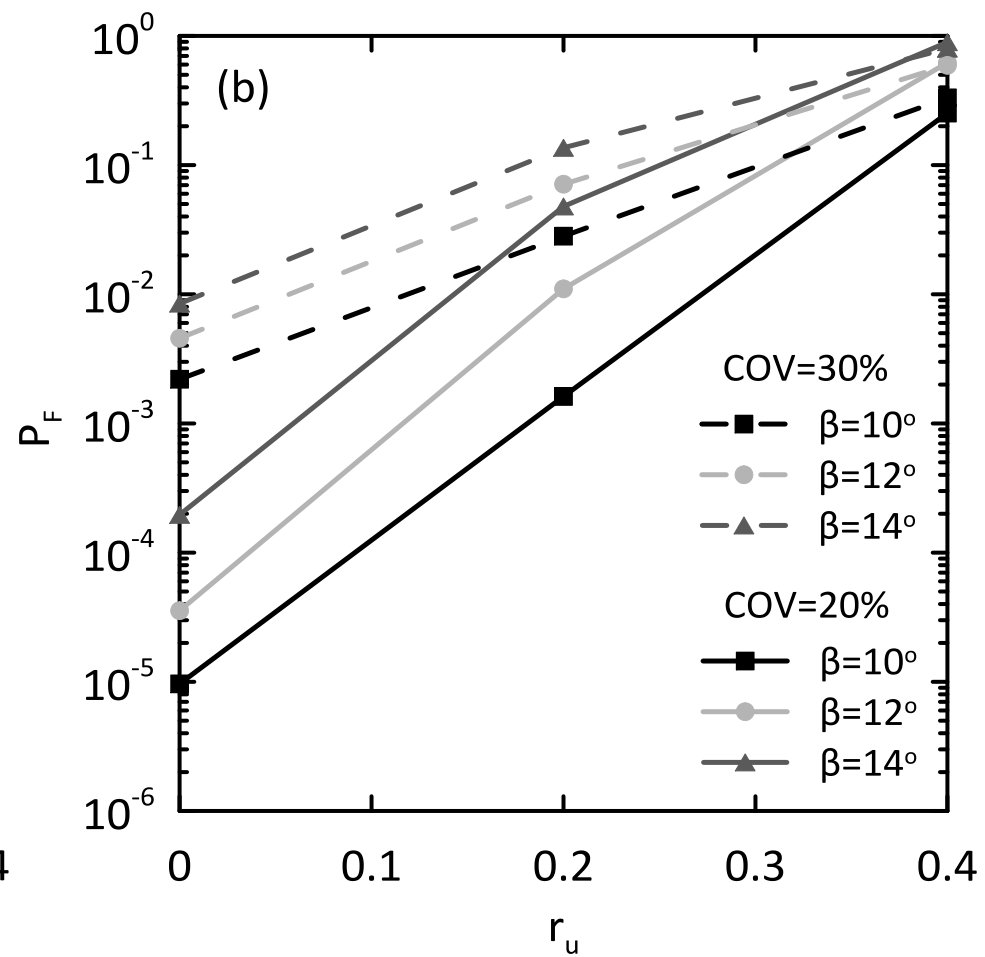
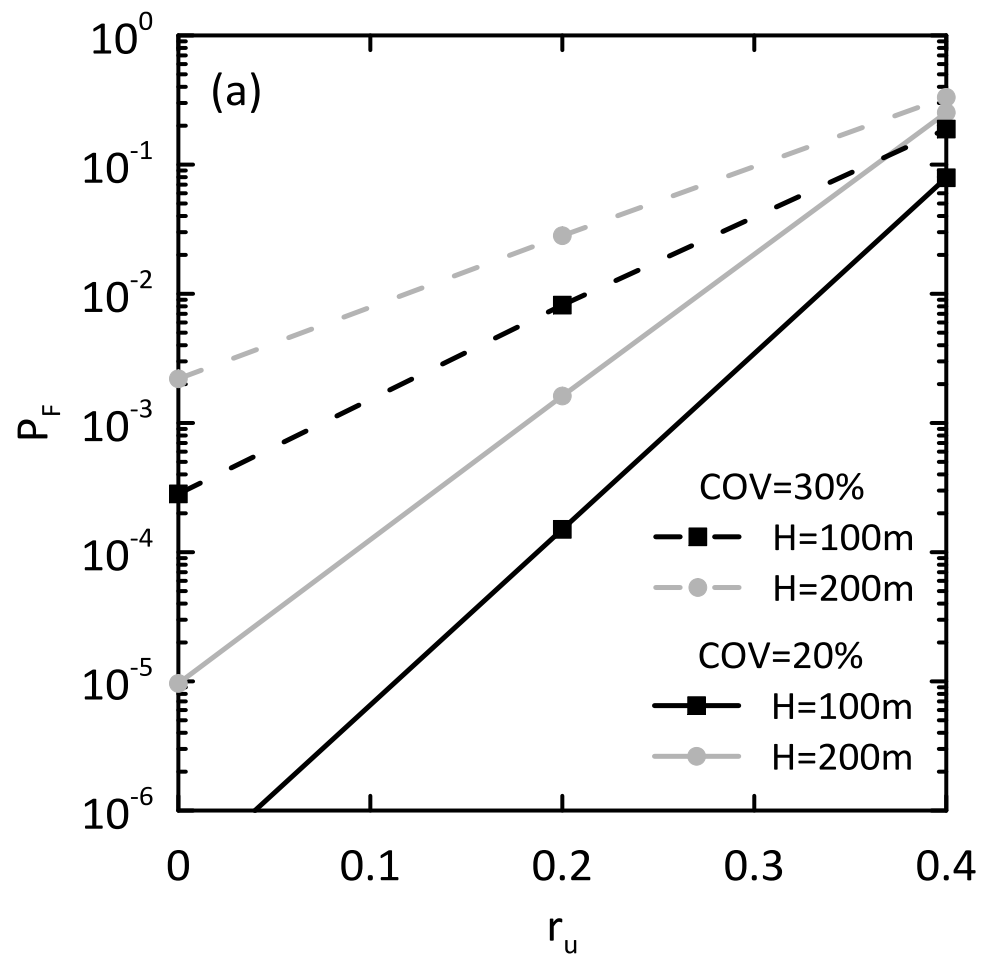
The effect of water on slope stability

Simplified  $r_u$  approach

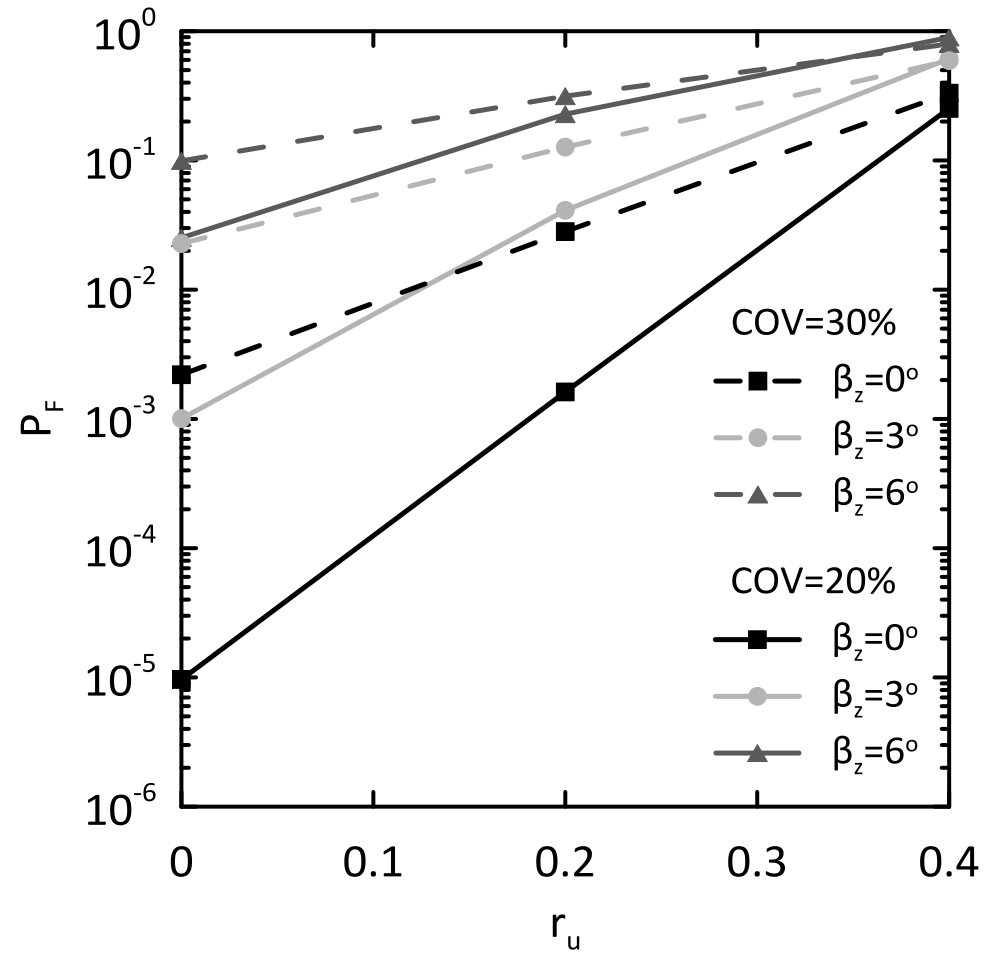
# Overburden soil's strength



# Slope's height and inclination



# Weak zone's inclination



# Conclusions

- The weak zone stratigraphy leads to a type of failure common in such mines of several countries, such as Greece, Turkey, Poland, and Australia, while failure incidents related to a weak zone have been reported worldwide on various occasions.
- The effect of benches on the SF does not exceed 11%.
- All analyses present similar failure surfaces with a part in the weak zone that reach the ground surface with a transition of approximately 45°.
- The most critical parameter is the weak zone's strength.
- The uncertainty of the weak **zone's** strength, investigated through two different COVs, affects the PF dramatically.
- Water is another crucial parameter.

Thank you !