Optimized stability assessment of tunneling stress redistribution under geological lateral pressures

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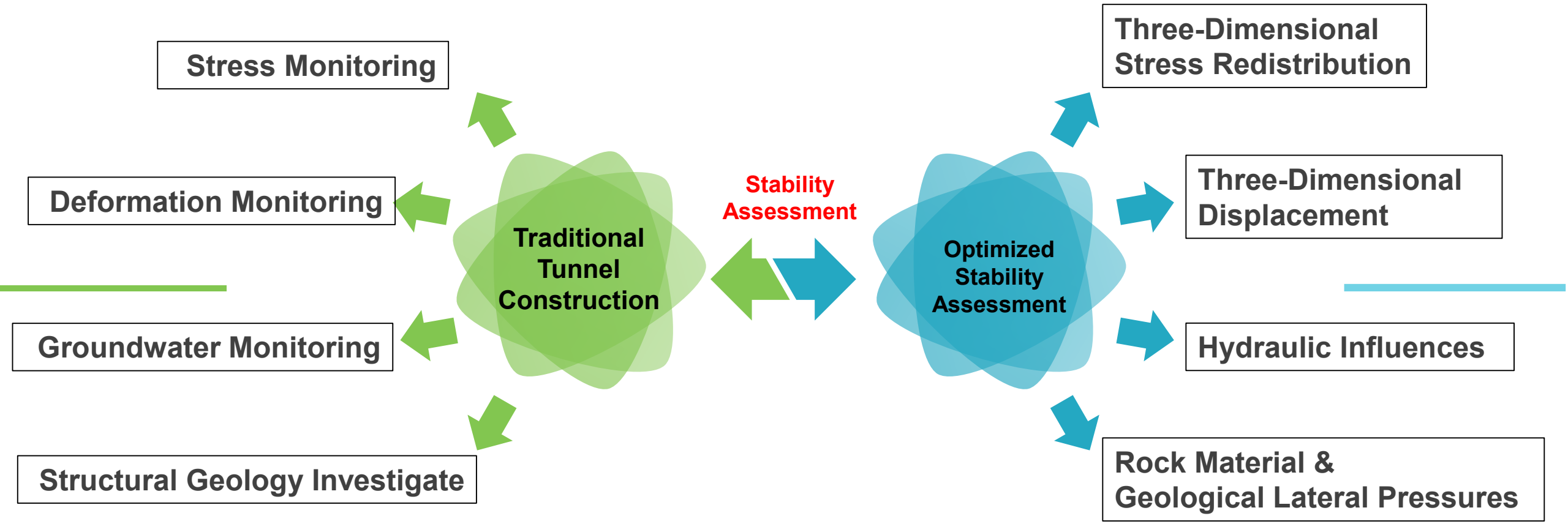
Catastrophic Tunnel Problem

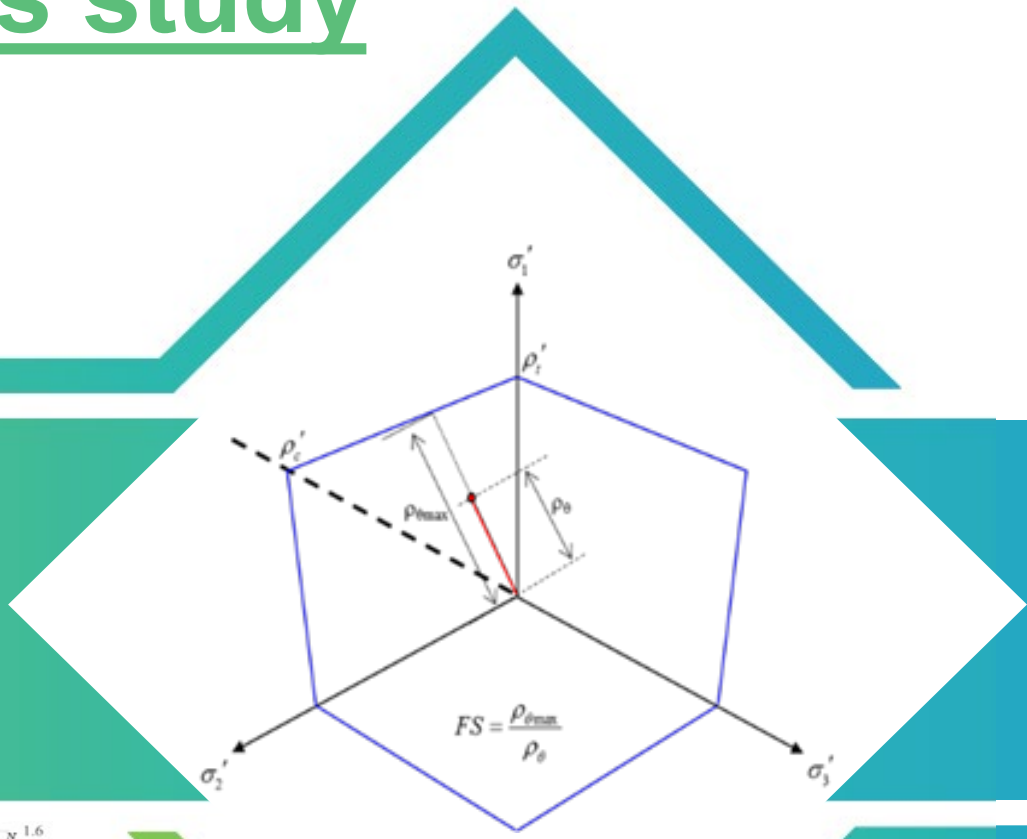
Key Issues for Tunnel Stability

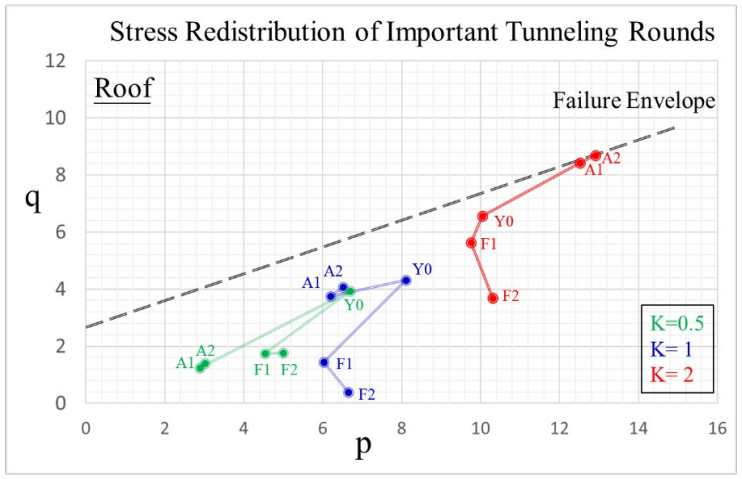


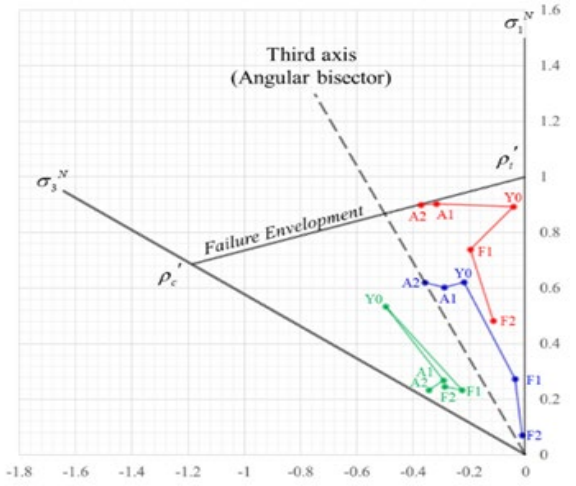
Purpose of this study

We Develop
New Optimized Stability Assessment

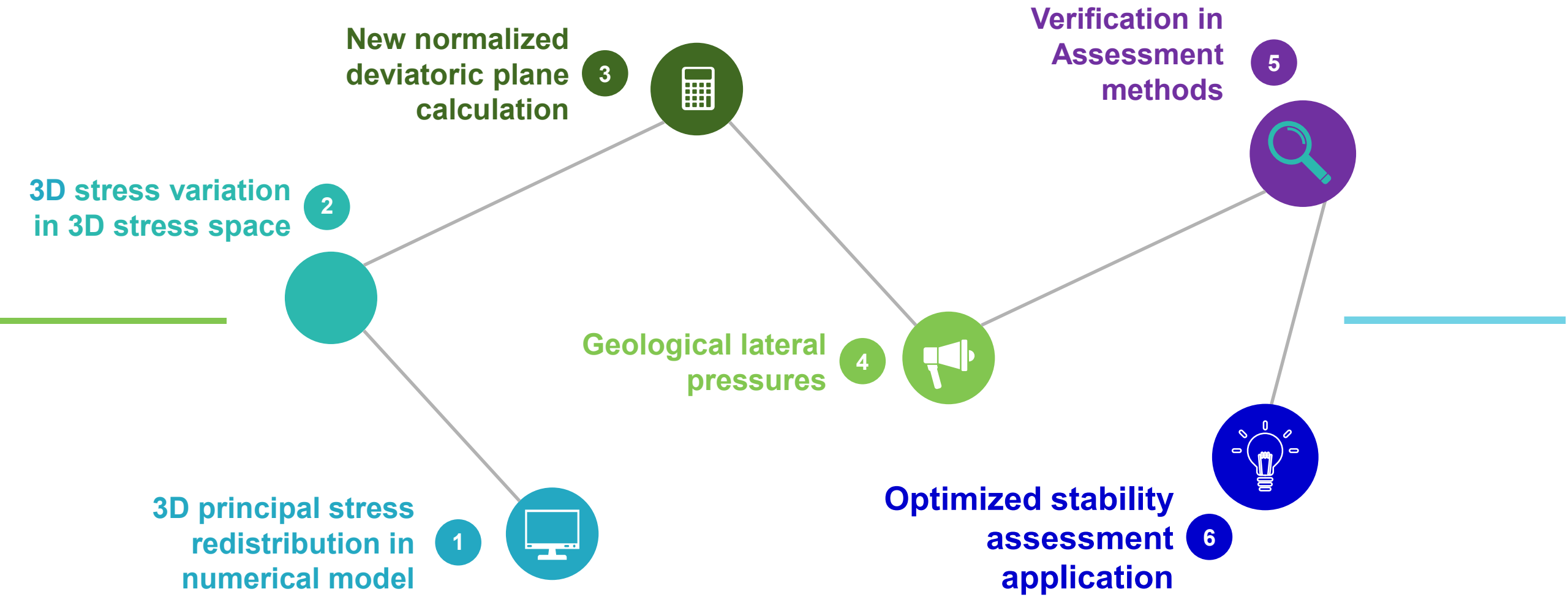
- ❖Normalized Deviatoric Plane of Mohr-Coulomb's envelope.
- ❖Three-dimensional Stress Path Redistribution
- ❖Difference in Geological Lateral Pressures



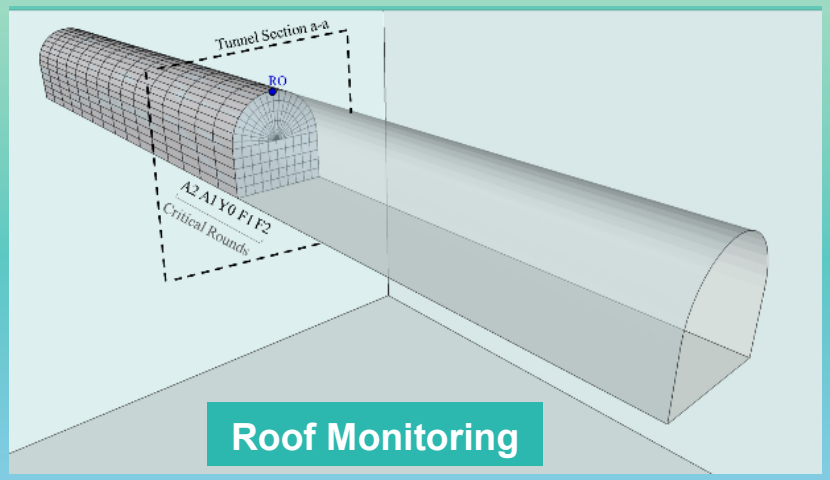




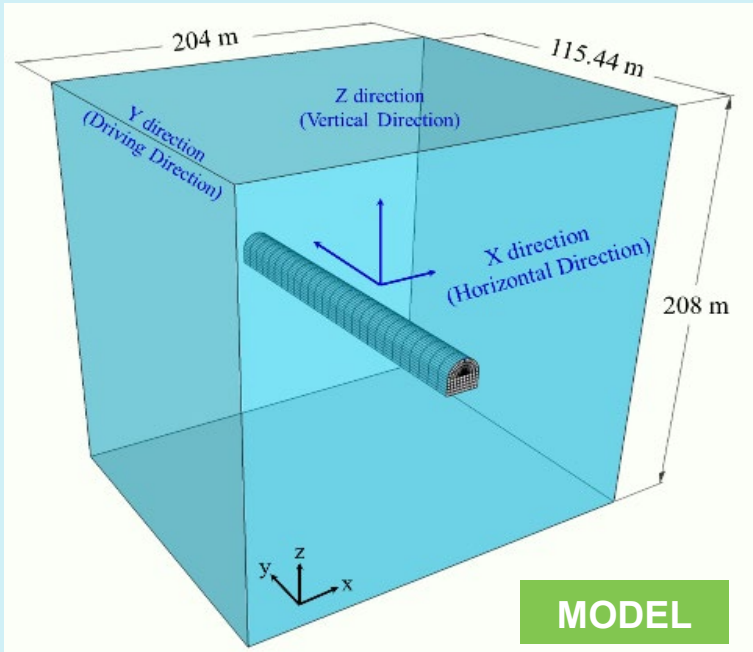
Analysis Process



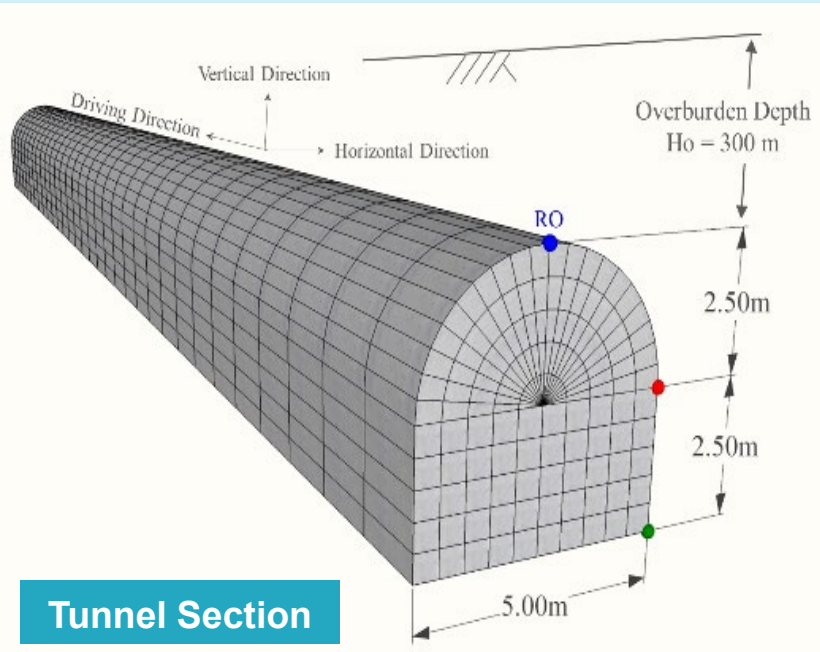
3D Tunneling Excavation Simulation in FLAC3D



Roof Monitoring

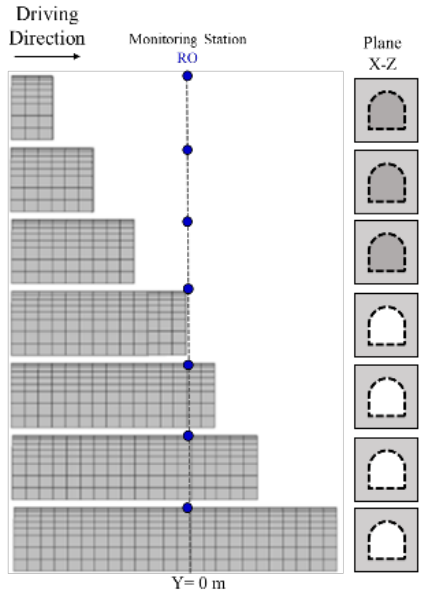


MODEL



Tunnel Section

- Generate the tunnel model for recording the 3D principal stress variations at tunnel roof during excavation.
- Establish the mechanism of overall 3D stress variations under different lateral pressure conditions (K=0.5,1,2) during excavation.

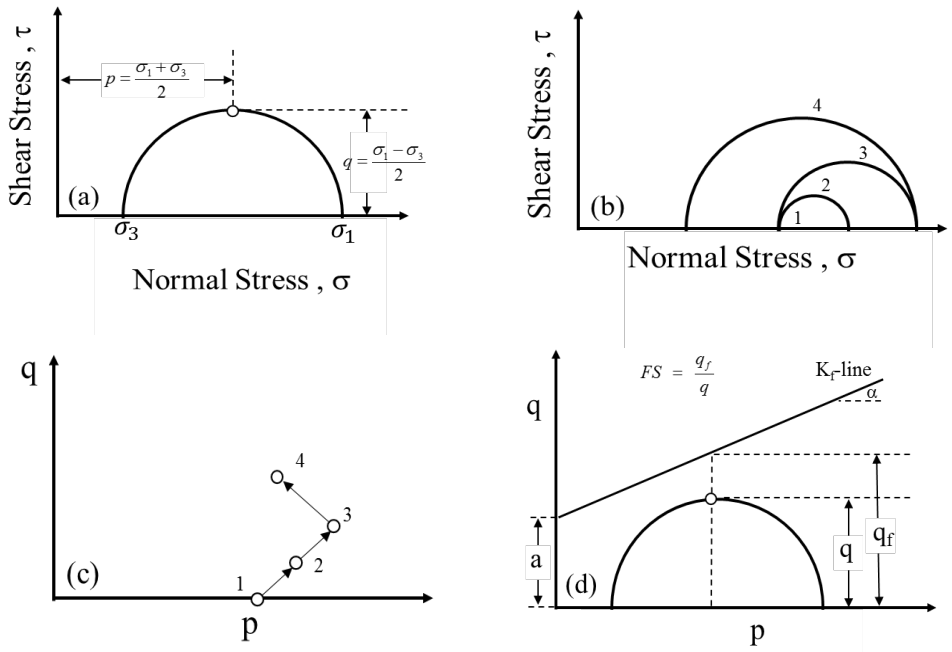


Critical Rounds

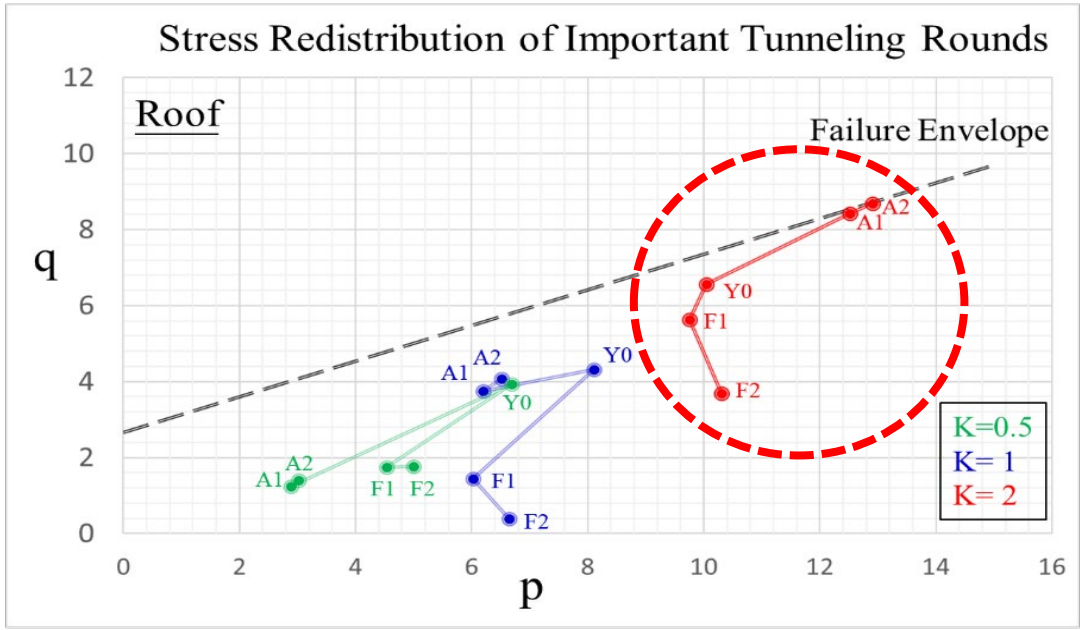
Tunnel Driving		approach to RO
F2	(Y = 4m)	2 Rounds before RO
F1	(Y = 2m)	1 Rounds before RO
Y0	(Y = 0m)	Arrival to RO
A1	(Y = -2m)	1 Rounds after RO
A2	(Y = -4m)	2 Rounds after RO
Tunnel Driving		away from RO

Traditional Mohr-Coulomb Failure Criterion

Traditional Stability Assessment (Lambe ,1979) :

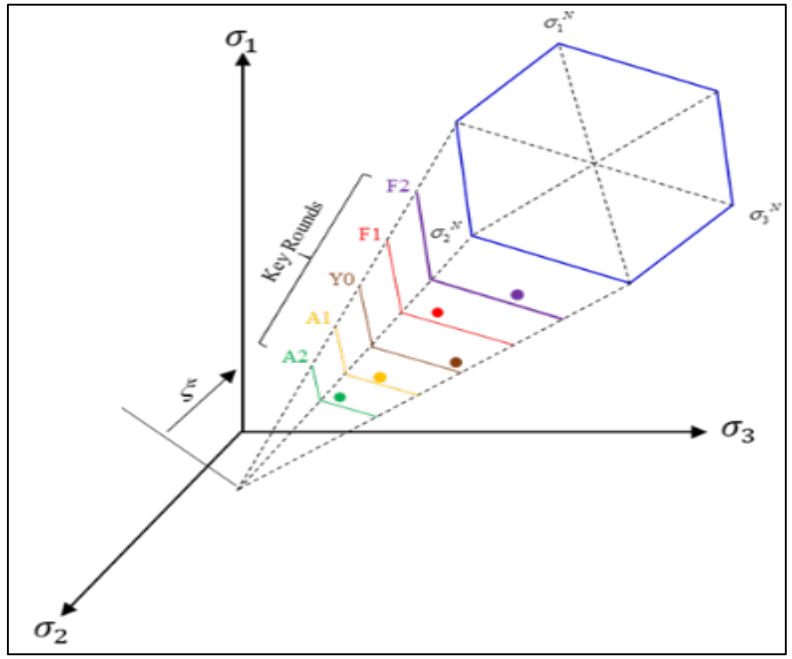


- This traditional method sometimes overestimates the stability by only considering the maximum and minimum principal stress (σ_1,σ_3) during tunneling.
- The ignored intermediate principal stress σ_2 may sometimes induce excavation risk, especially under contrasting lateral pressures.



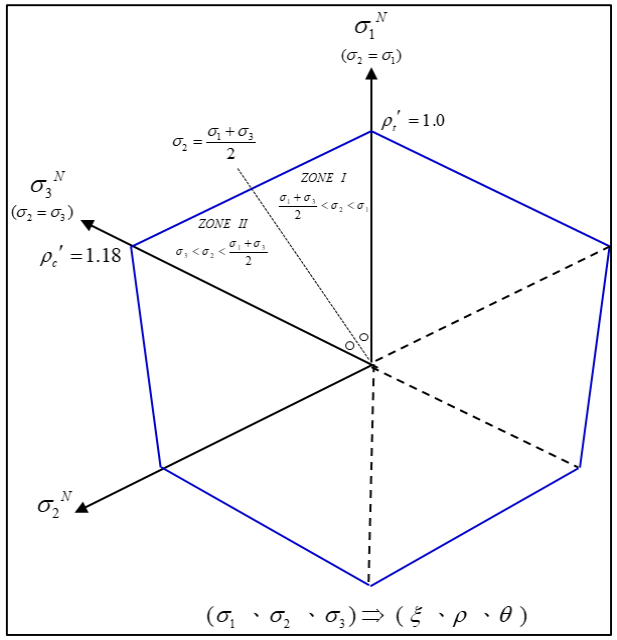
Lateral Pressures	K=0.5	K=1.0	K=2.0
Critical Rounds \ Factor of Safety	FS	FS	FS
F2	4.41	26.9	2.94
F1	4.27	6.30	1.53
Y0	1.89	1.93	1.23
A1	5.23	1.91	1.02
A2	4.59	1.75	1.00

Optimized Stability Algorithm with Normalized Deviatoric Plane.



Every deviatoric planes represents every tunneling rounds in 3D stress space.

- Normalized deviatoric plane such as an $(\sigma_1{}^N, \sigma_3{}^N)$.
- The third axis (angular bisector) are calculated within the stress σ_2 bellow

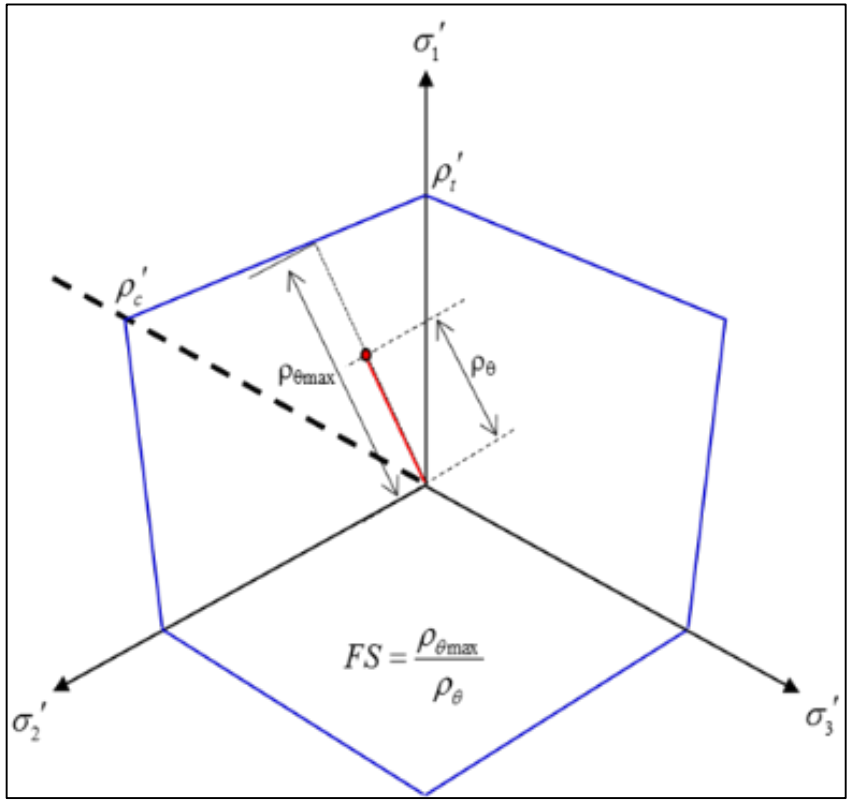


ZONE II

$$\sigma_3 < \sigma_2 < \frac{\sigma_1 + \sigma_3}{2}$$

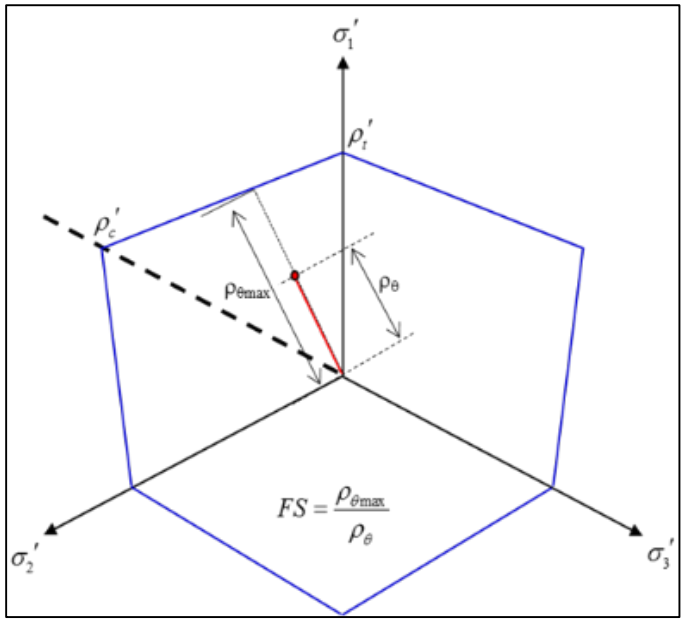
ZONE I

$$\frac{\sigma_1 + \sigma_3}{2} < \sigma_2 < \sigma_1$$



$$FS' = \frac{\rho_{max}}{\rho_\theta} = \frac{\sqrt{2} * cos\phi - \frac{\sigma_1 + \sigma_3}{\sqrt{2}} * sin\phi}{\left| \frac{\sigma_1 - \sigma_3}{\sqrt{2}} \right|}$$

Optimized Stability Algorithm with Normalized Deviatoric Plane

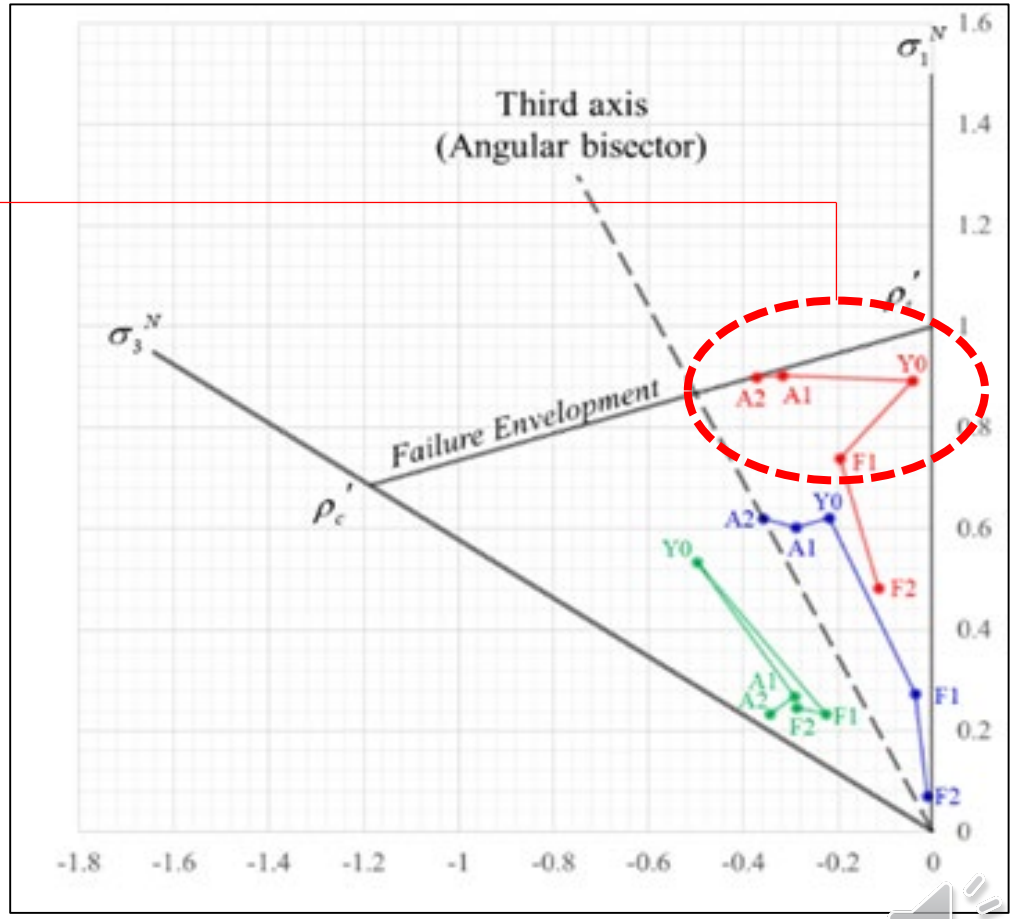


$$FS' = \frac{\rho_{max}}{\rho_\theta} = \frac{\sqrt{2}*cos\phi - \frac{\sigma_1+\sigma_3}{\sqrt{2}}*sin\phi}{\left|\frac{\sigma_1-\sigma_3}{\sqrt{2}}\right|}$$

The case K=2.0 shows a more conservative stress path condition at the end of excavation

Lateral Pressures	K=0.5		K=1		K=2	
Critical Rounds \ Factor of Safety	FS	FS′	FS	FS′	FS	FS′
F2	4.41	3.08	26.9	13.6	2.94	1.95
F1	4.27	2.90	6.30	3.54	1.53	1.26
Y0	1.89	1.50	1.93	1.47	1.23	1.10
A1	5.23	3.41	1.91	1.47	1.02	1.01
A2	4.59	3.11	1.75	1.40	1.00	1.00

Tunneling stresses variations in deviatoric plane

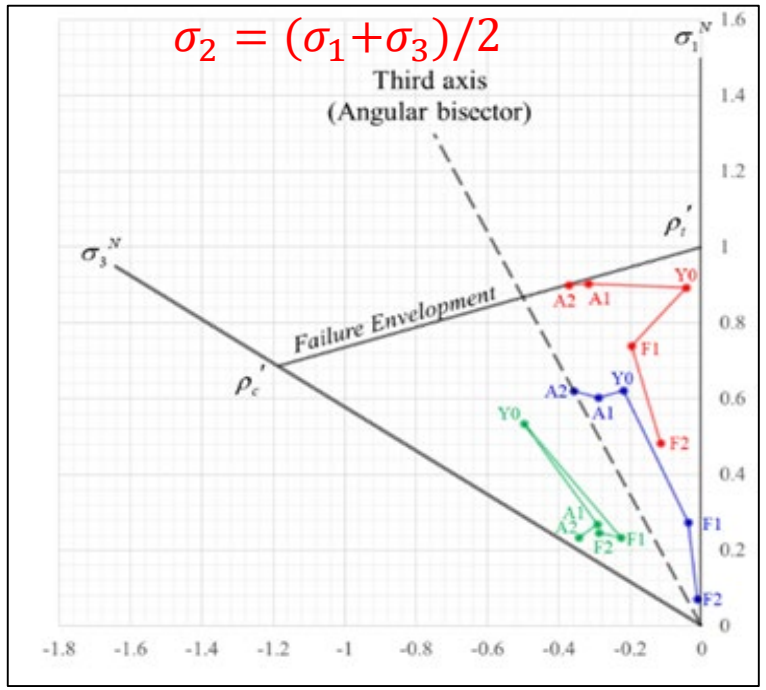


K=0.5 、 K=1.0 、 K=2.0

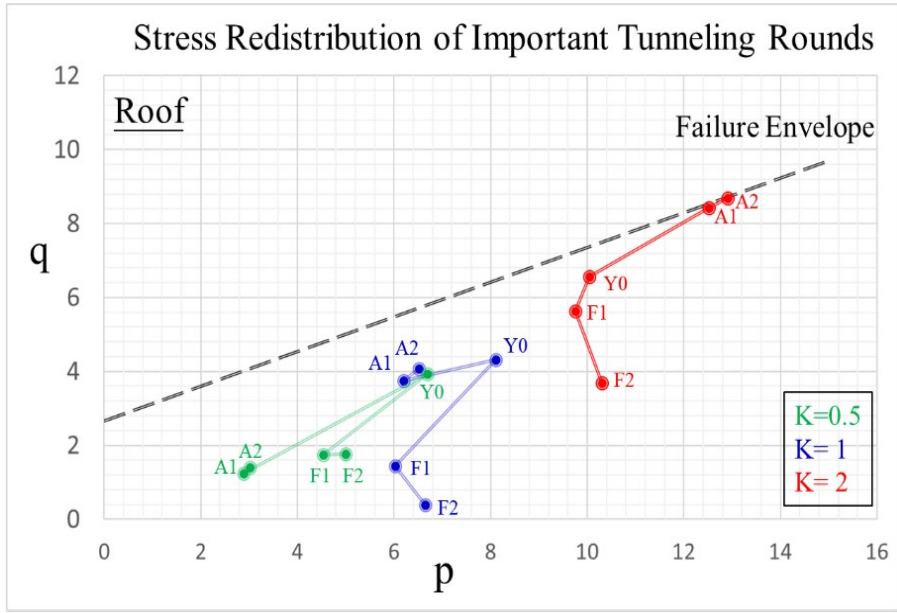
Compare the Assessment Methods

Optimized Stability Assessment

Traditional Stability Assessment



If Stress state is located right on the third axis (angular bisector), two approaches give the same FS.



$$FS' = \frac{\rho_{max}}{\rho_\theta} = \frac{\sqrt{2}*cos\phi - \frac{\sigma_1+\sigma_3}{\sqrt{2}}*sin\phi}{\left|\frac{\sigma_1-\sigma_3}{\sqrt{2}}\right|} = \frac{2c_f*cos\phi-(\sigma_1+\sigma_3)*sin\phi}{|\ (\sigma_1-\sigma_3)\ |} = FS$$

CONCLUSIONS

1. The conventional safety assessment (FS) will not always yield the most robust and reliable tunnel engineering design.

3. The normalized stability algorithm of 3D safety evaluation (FS′) is an enhancement over and above the shortcomings.

2. Traditional Mohr's circle application omits the influence of intermediate principal stress, which is more suitable for preliminary and rapid estimation.

4. Optimized evaluation algorithm including the comprehensive consideration of 3D principal stress variations , which is more robust in assessing stability.

Thank You