Stability Design of Slopes in Carbonatite Complexes Characterised by Brecciation

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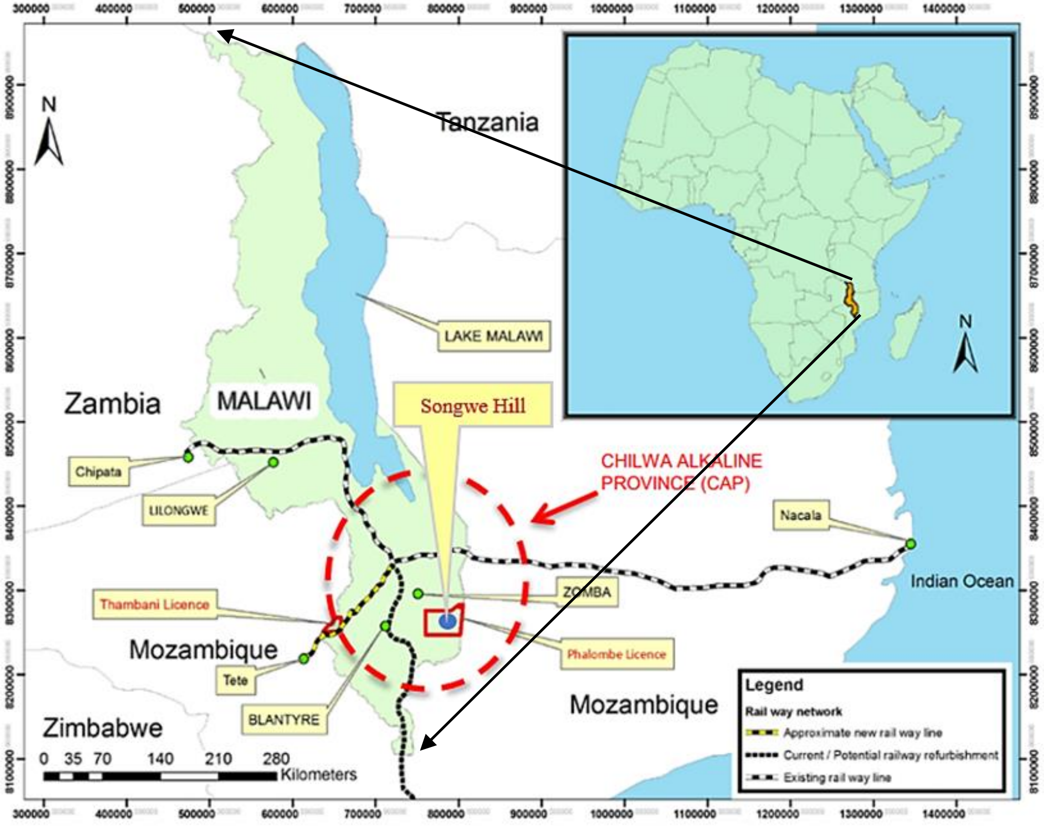
Location and Regional Geology



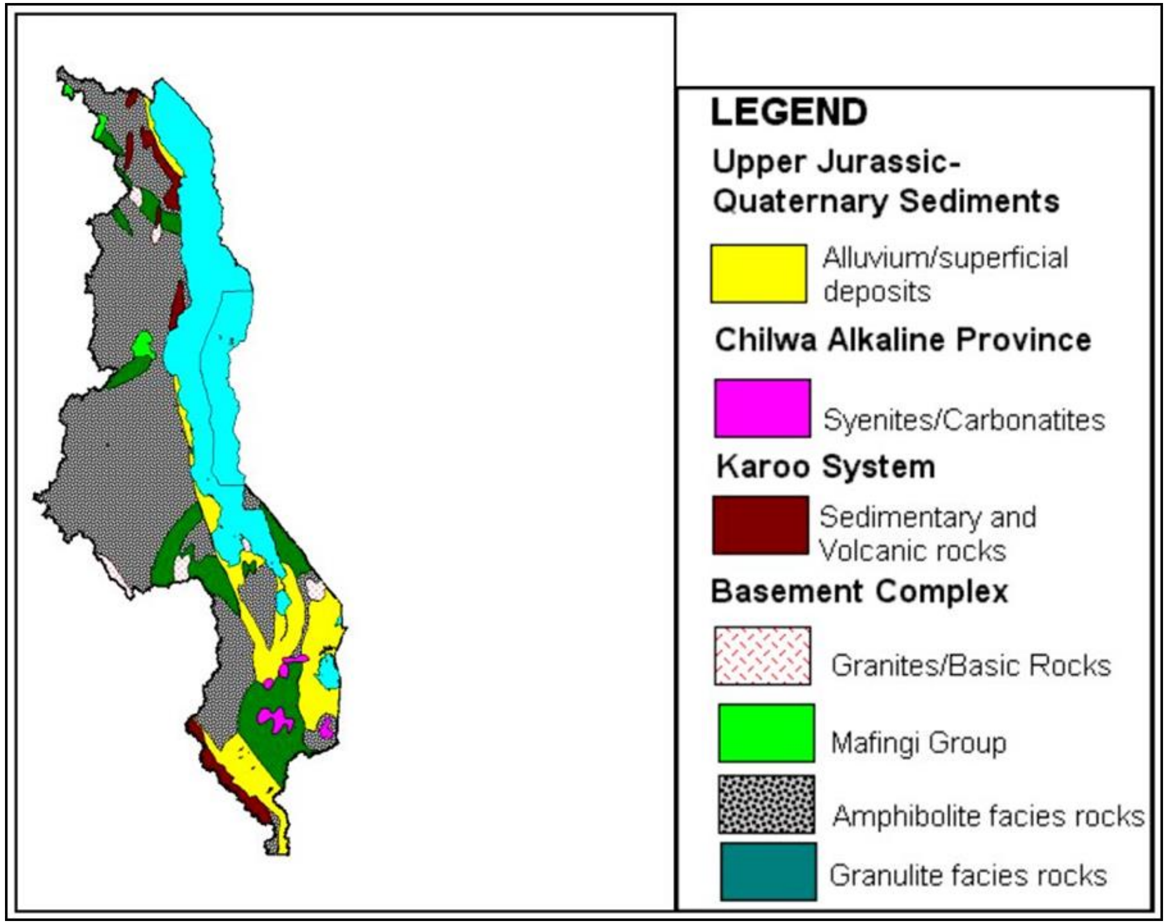


Figure 1 Map of Malawi showing project licensed area and regional geology

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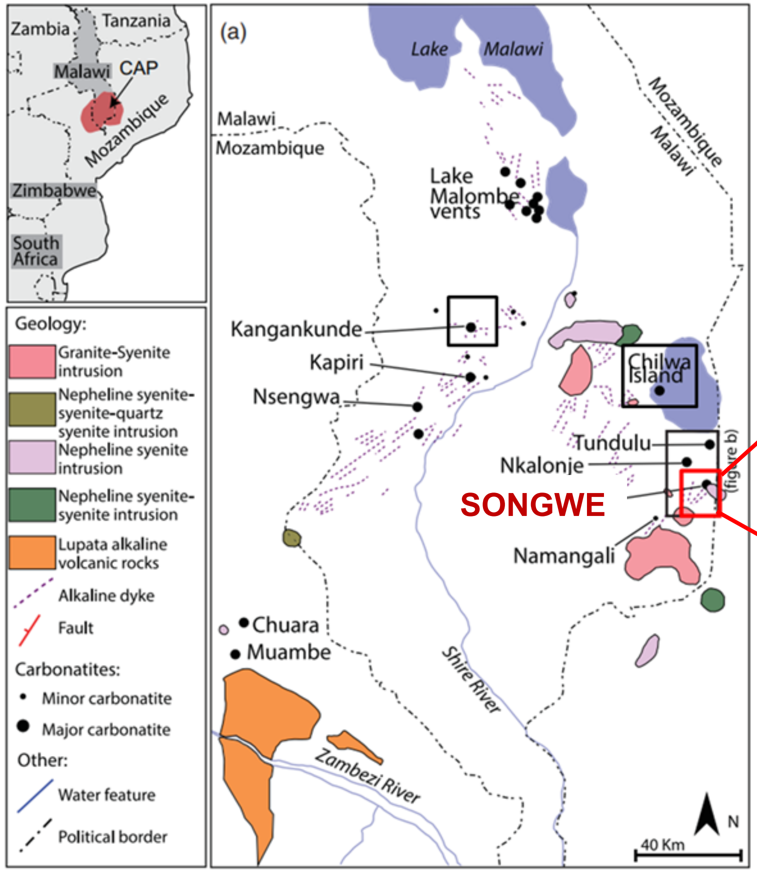
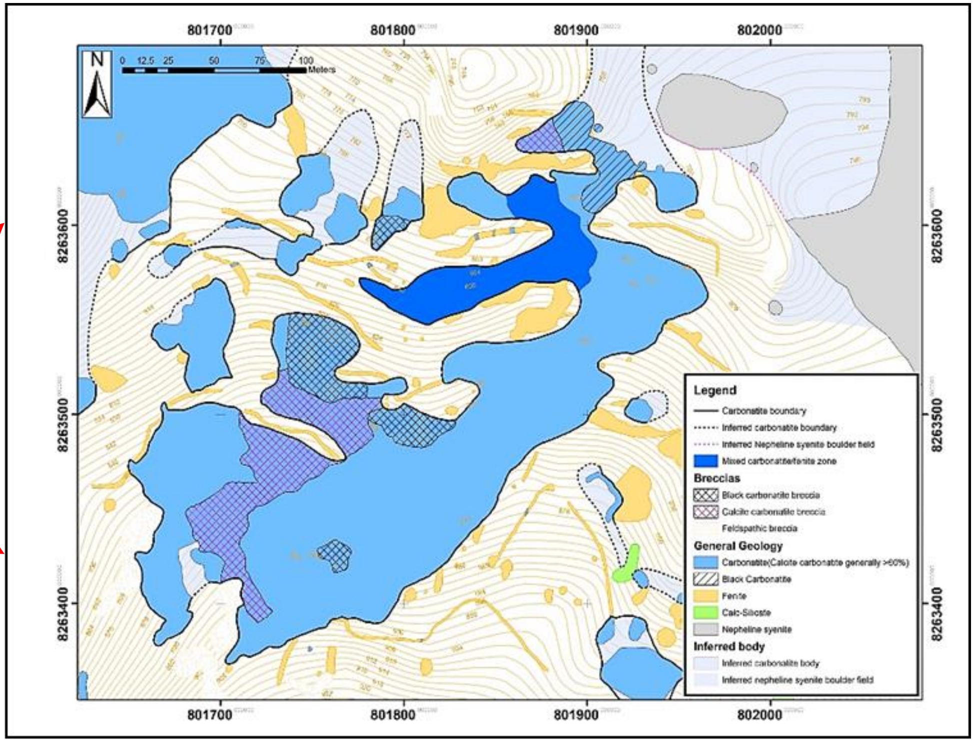
Study Area and Local Geology

The Songwe Hill carbonatite complex is mainly composed of carbonatite, fenite, breccias surrounded by syenites



Alkaline volcanic rock distribution (Broom-Fendley , et al., 2017)



Local geology of Songwe Mine site

Influence of In-situ Rock Damage

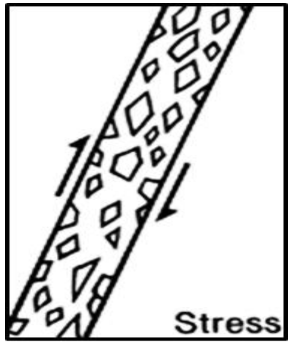
Complexity of failure mechanisms in rock slopes is when there is a combination of pre-existing geological weak planes and failure of intact rock

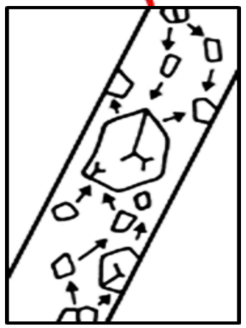
<u>Prior studies</u>: the control of folds and faults, shearing and clay-infill in joints, and disturbance caused by blasting

<u>This study</u>: considers the <u>in situ rock damage</u> in brittle form as a result of brecciation

Mechanisms in volcanic environments:

1. Fracture of rocks by tectonic or gravitational stresses along fault plane.
2. <u>Hydro-fracturing of rocks by highly pressured hydrothermal fluids in plane of weakness</u>





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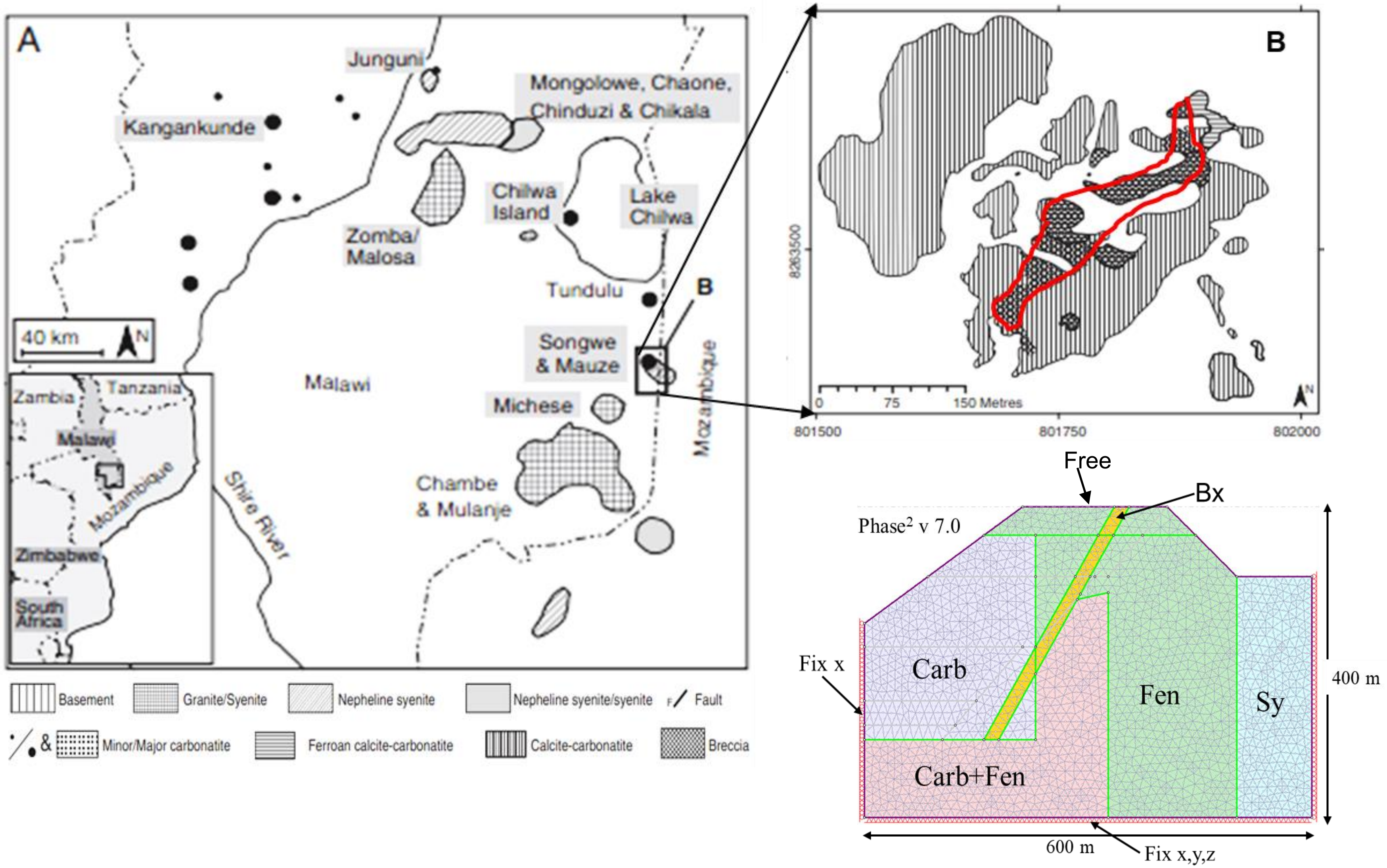
Model Development



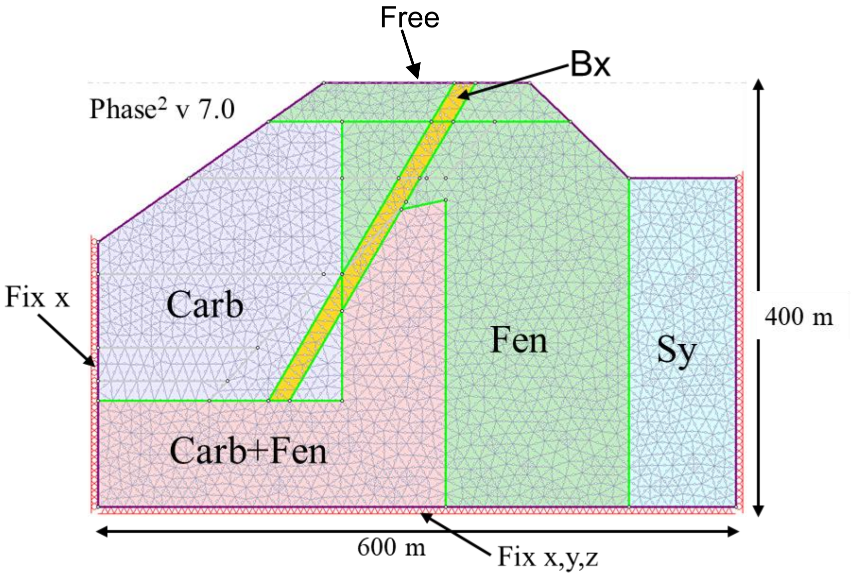
Model Development

※ The model built in Phase2

Scenarios:

a. Thickness of breccia varied between 10 m and 20 m

b. Different dip angles: 70° - 30°, the field dip considered ≥ 50°



Rock Type	*Uniaxial Compressive Strength (MPa)*	Density (g/cm^3)	*Young's Modulus (GPa)*	*Tensile Strength (MPa)*	*Friction Angle (°)*	*Cohesion (MPa)*	*Poisson Ratio*
Carbonatite	83.2	2.78	45.3	8.6	35	0.32	0.28
Fenite	118.6	2.70	44.4	10.4	36	0.30	0.29
Breccia	**37.5**	**2.35**	**17.6**	**3.37**	**30**	**0.10**	**0.22**
Syenite*	70.0	2.55	53.4	3.37	30	0.28	0.25

*Based on empirical values (Katz et al., 2000; Croll, et al., 2014)

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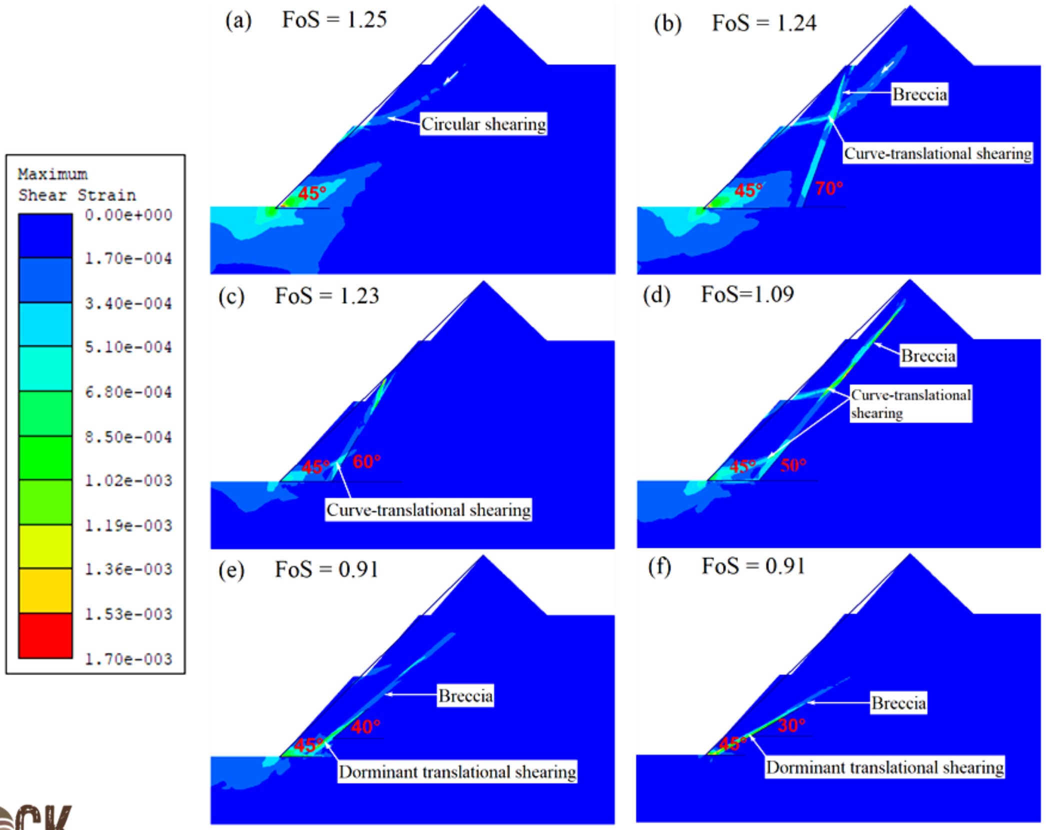
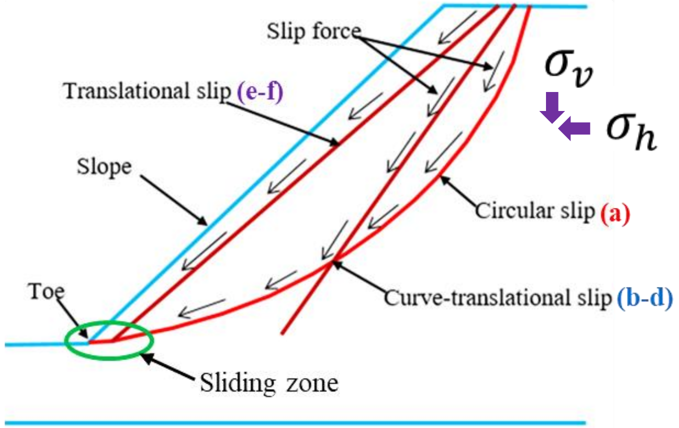
Influence of Breccia

Research object for qualitative evaluation of the impact of brecciation on pit walls; OSA 45° and pit height 250 m



(g) Feasible failure pattern



Breccia orientation

※ The stability performance of the pit wall reduces with gentle dipping angle

☑ Brecciated section acts as a planar path for shearing

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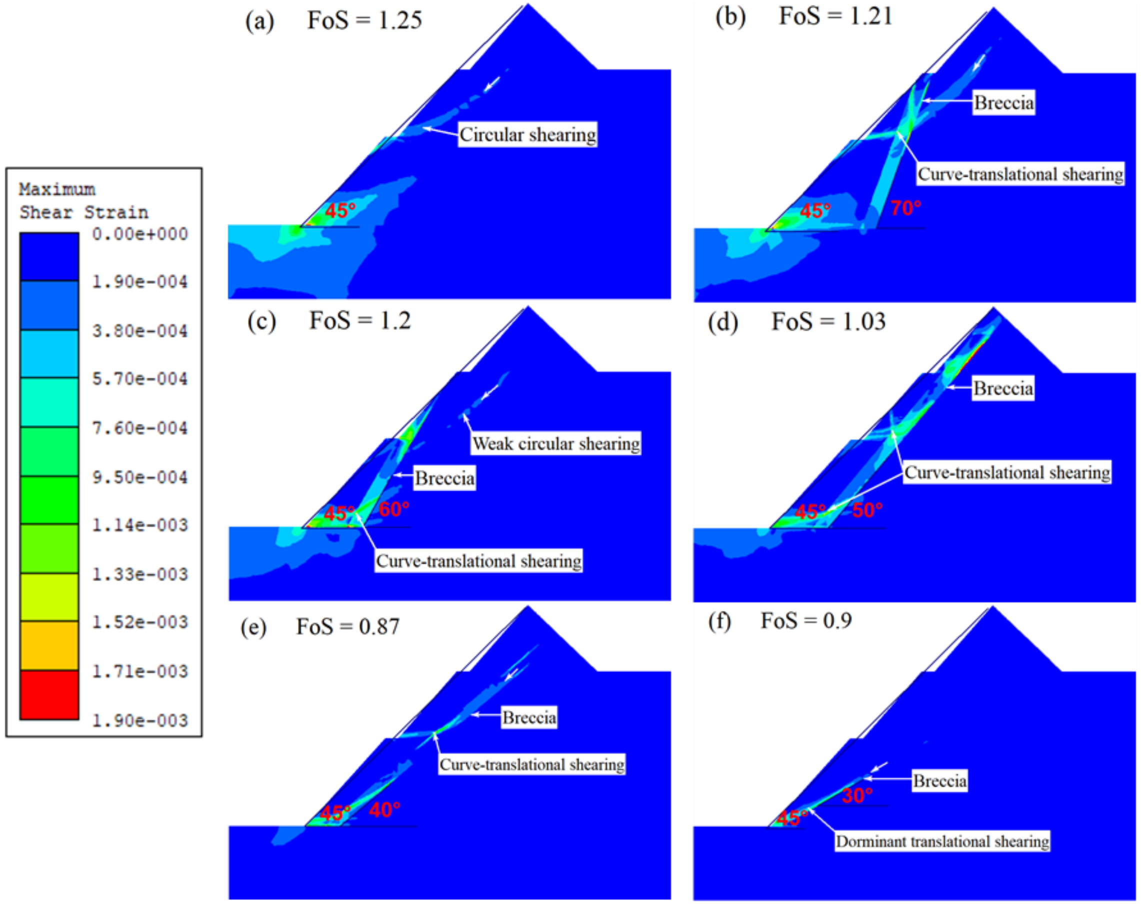
Influence of Breccia

Research object; OSA 45° and pit height 300 m



Pit wall stability conditions under 20m brecciated stretch

Breccia thickness

※No significant change in the stability performance of the pit wall with increase in the thickness of the brecciated rock

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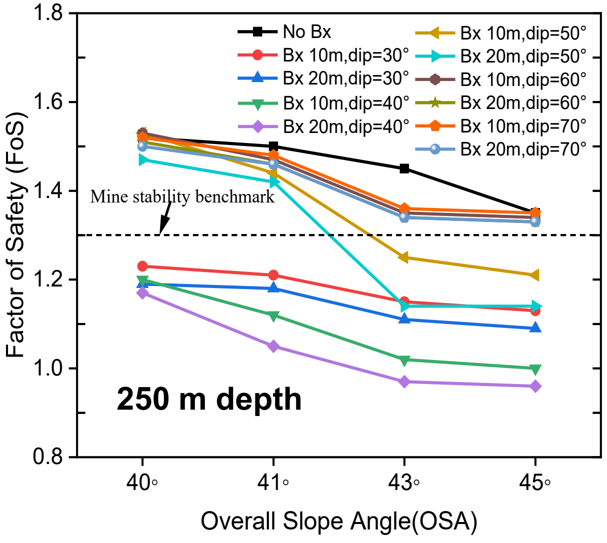
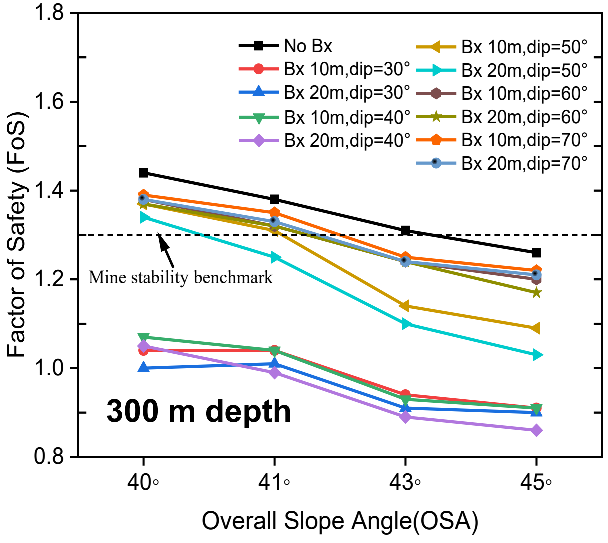
Recap of Rock Brecciation Impact



(a) Stability condition at 250m pit height



(b) Stability condition at 300m pit height

※ In situ rock damage reduces the stability performance of pit slopes

☑ Significant at global slope angle of ≥43°

※ Breccia thickness has minimal impact on stability performance

※ The orientation of breccia emplacement has a significant influence

➢ Pronounced at gentle dipping angles viz. 30° & 40°

☑ Combined effect of circular and translational slip

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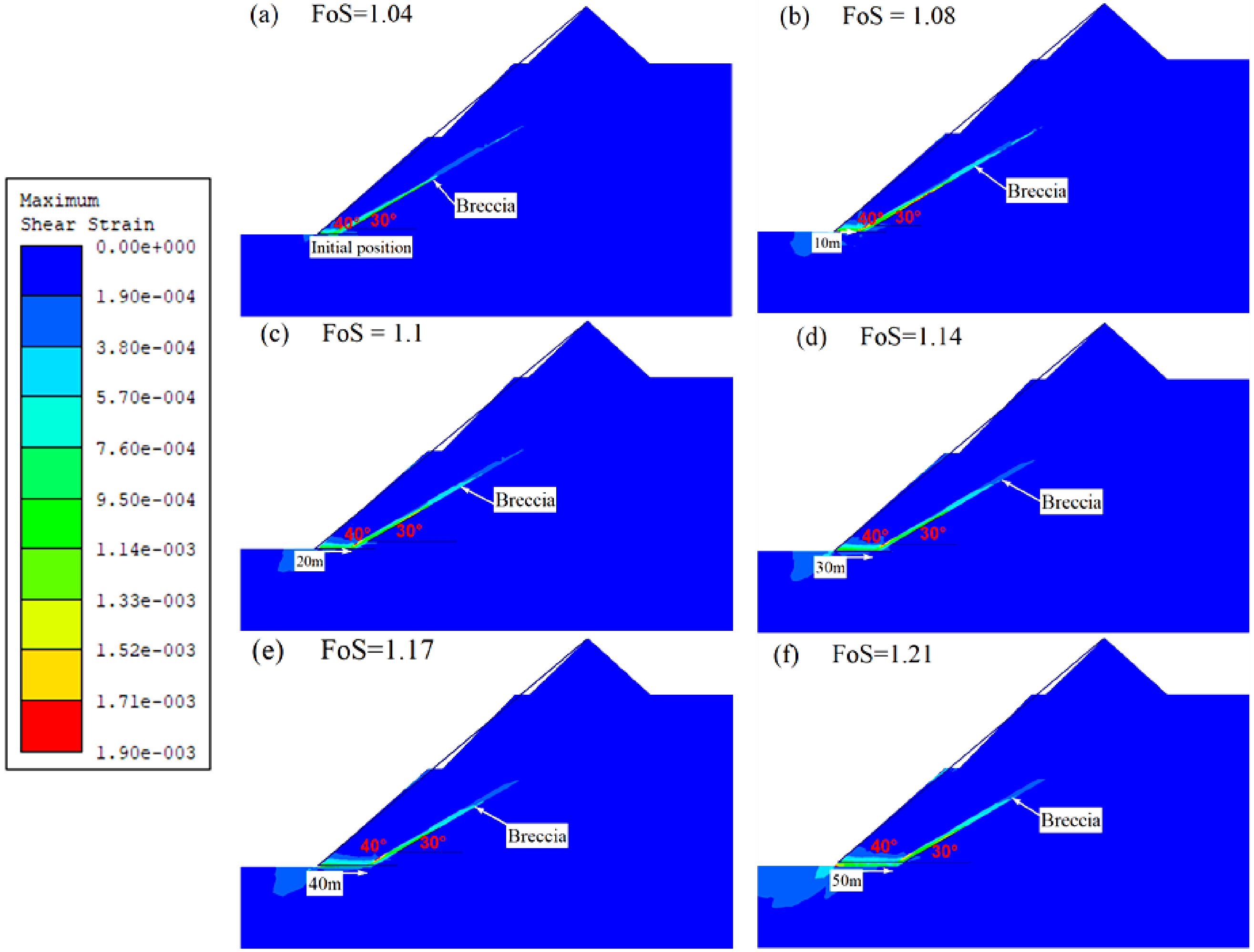
Position of Breccia vs Pit-wall Stability

Case 1: OSA = 40°, 30° dipping angle @ 300m



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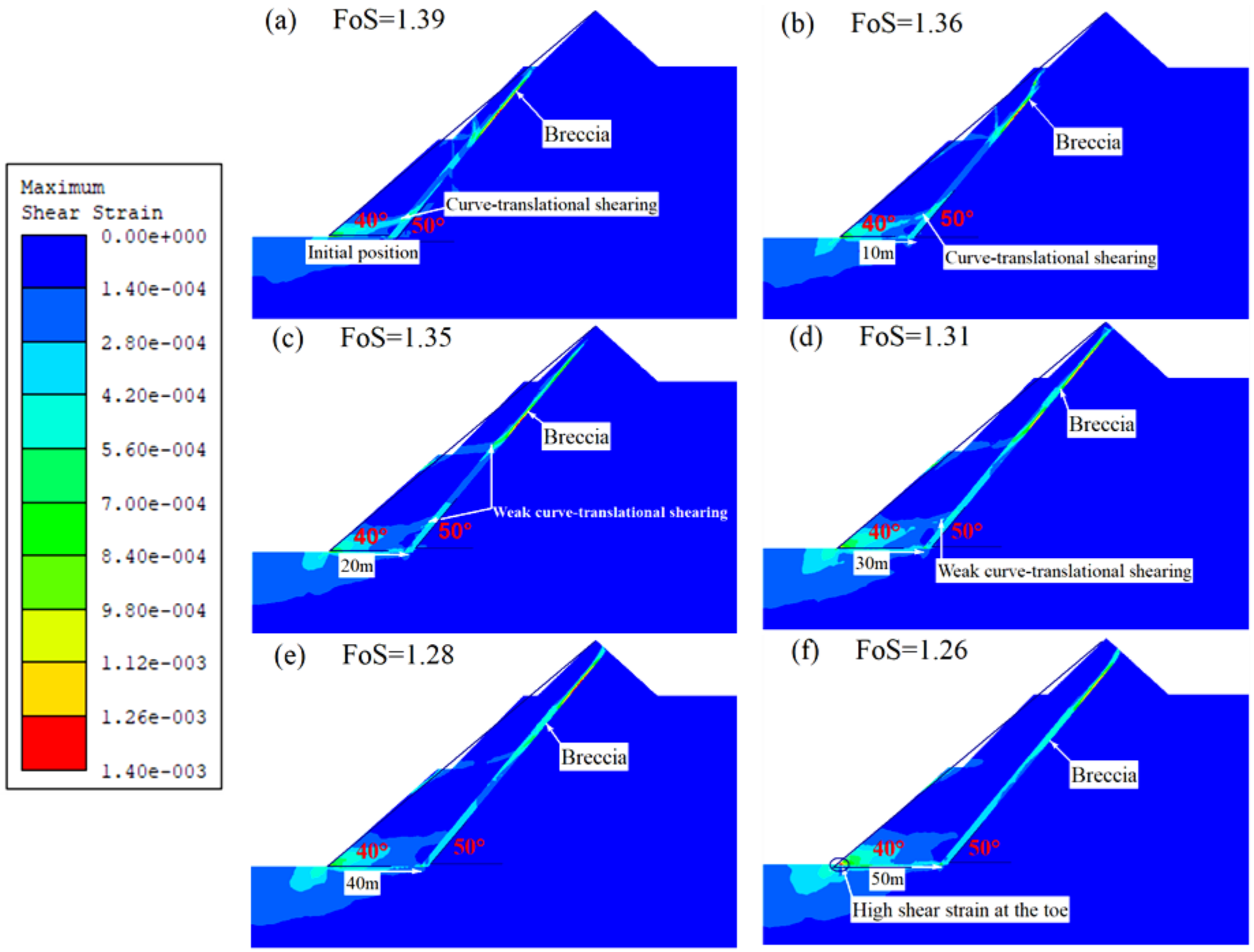
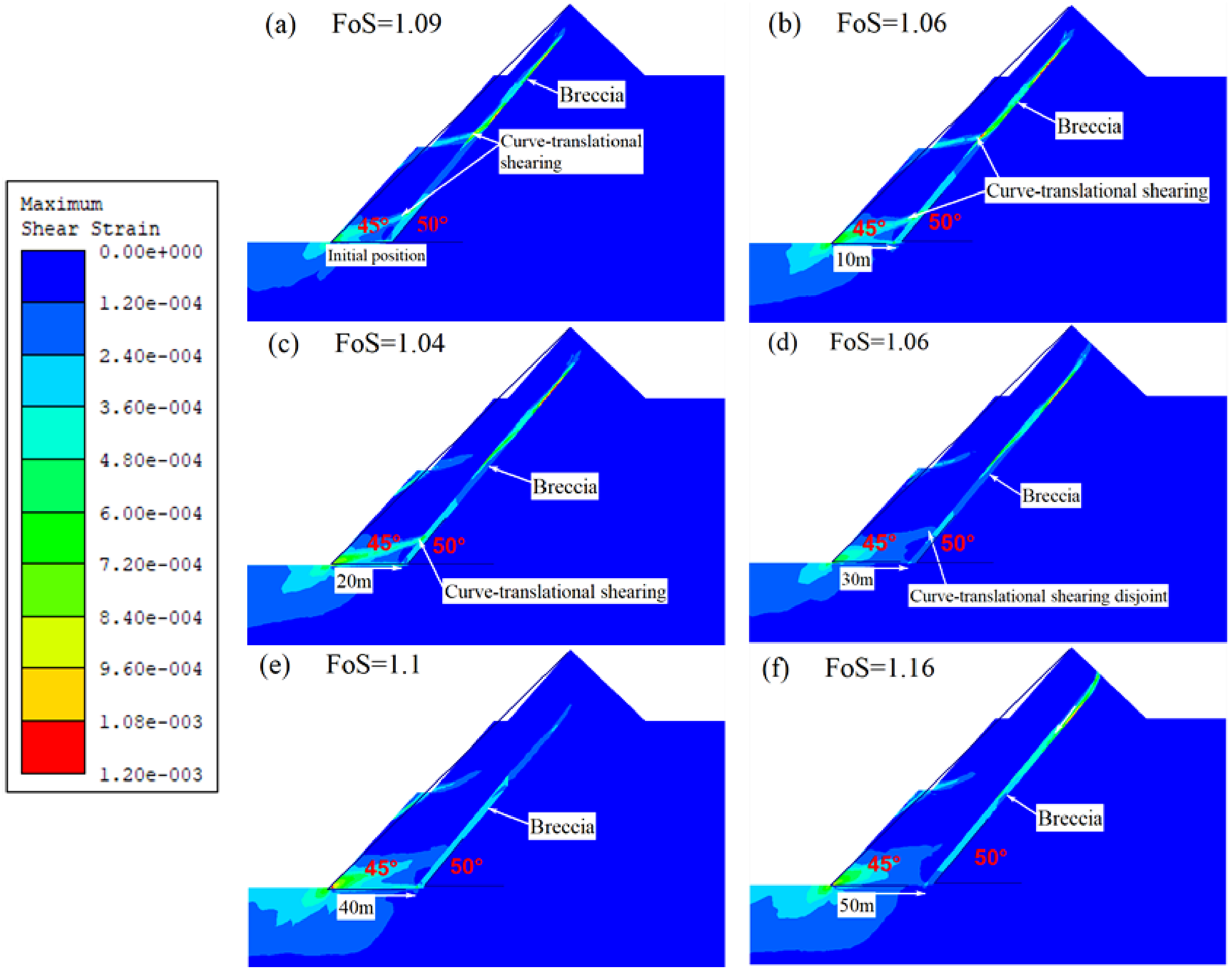
Position of Breccia vs Pit-wall Stability

Case 2: OSA, 40°, 50° dipping angle @ 300 m



Position of Breccia vs Pit-wall Stability

Case 3: OSA = 45°, 50° dipping angle @ 300 m



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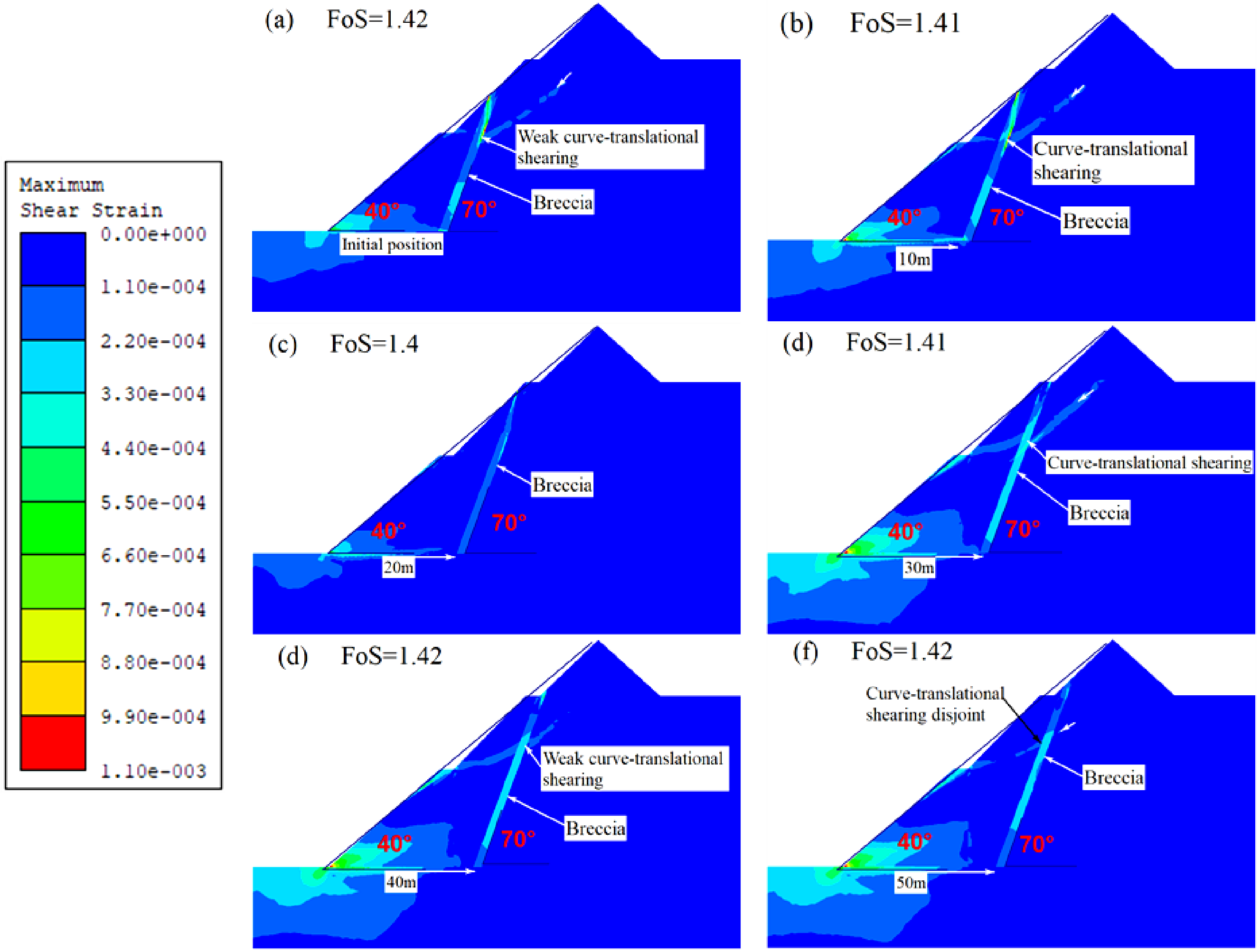
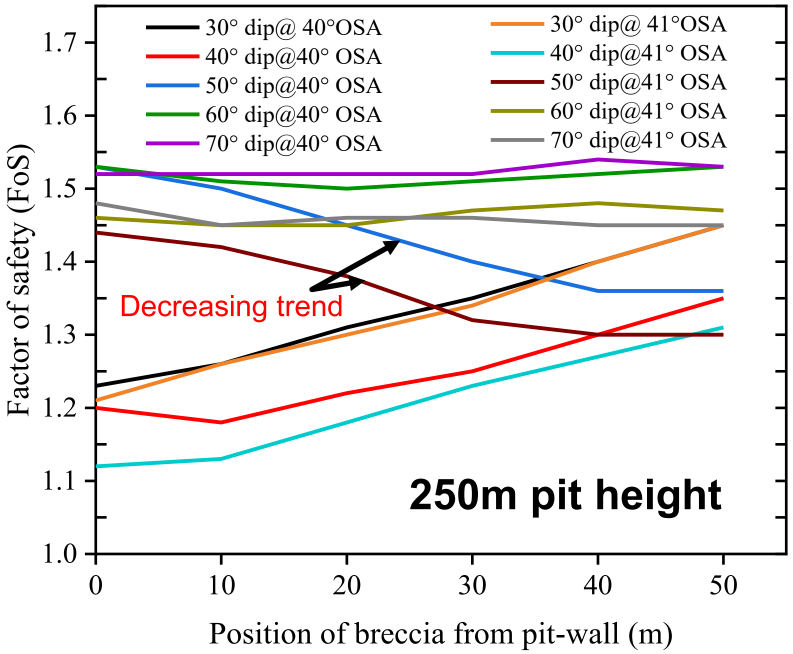
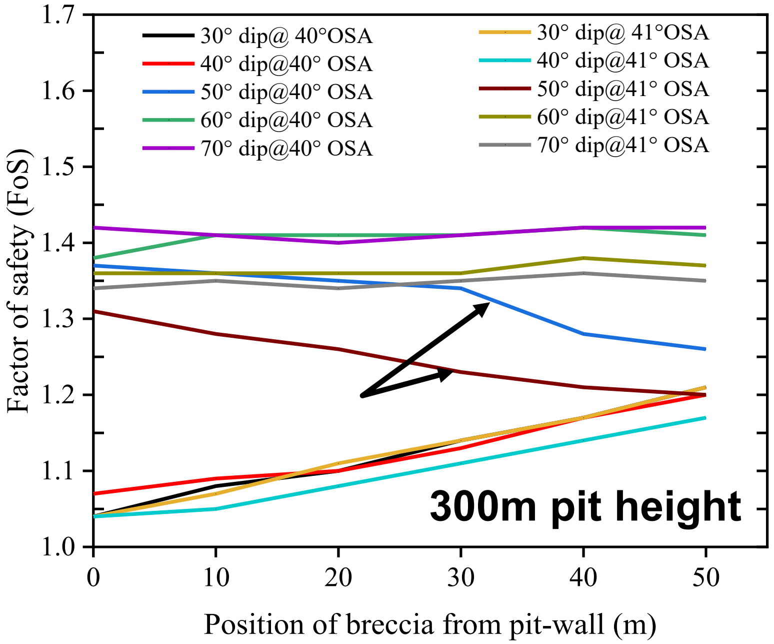
Position of Breccia vs Pit-wall Stability

Case 4: OSA = 40°, 70° dipping angle @ 300 m



Pit-wall Stability vs Position of Breccia Recap





※ The further away the breccia from the pit wall ⇨ high stability performance esp. at gentle dipping angles 30° and 40°.

※ However, at dipping angle of 50° the performance of the rock slope reduces

☑ Combined effect of circular and translational slip

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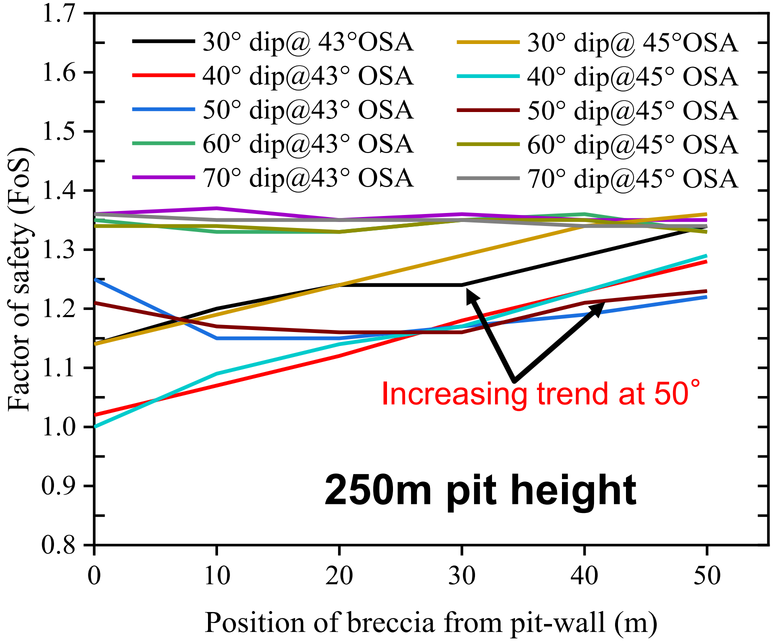
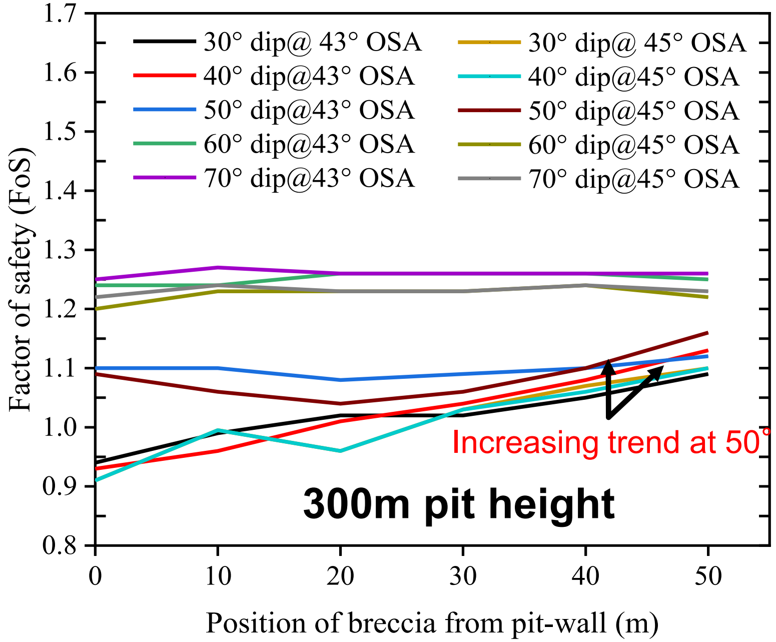
Pit-wall Stability vs Position of Breccia Recap





※ Exceptional trend at 50˚

- The circular shearing failure path and the translational shearing failure path become **disjointed especially at ≥ 40 m**

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Interactions of In-situ Stress & Breccia

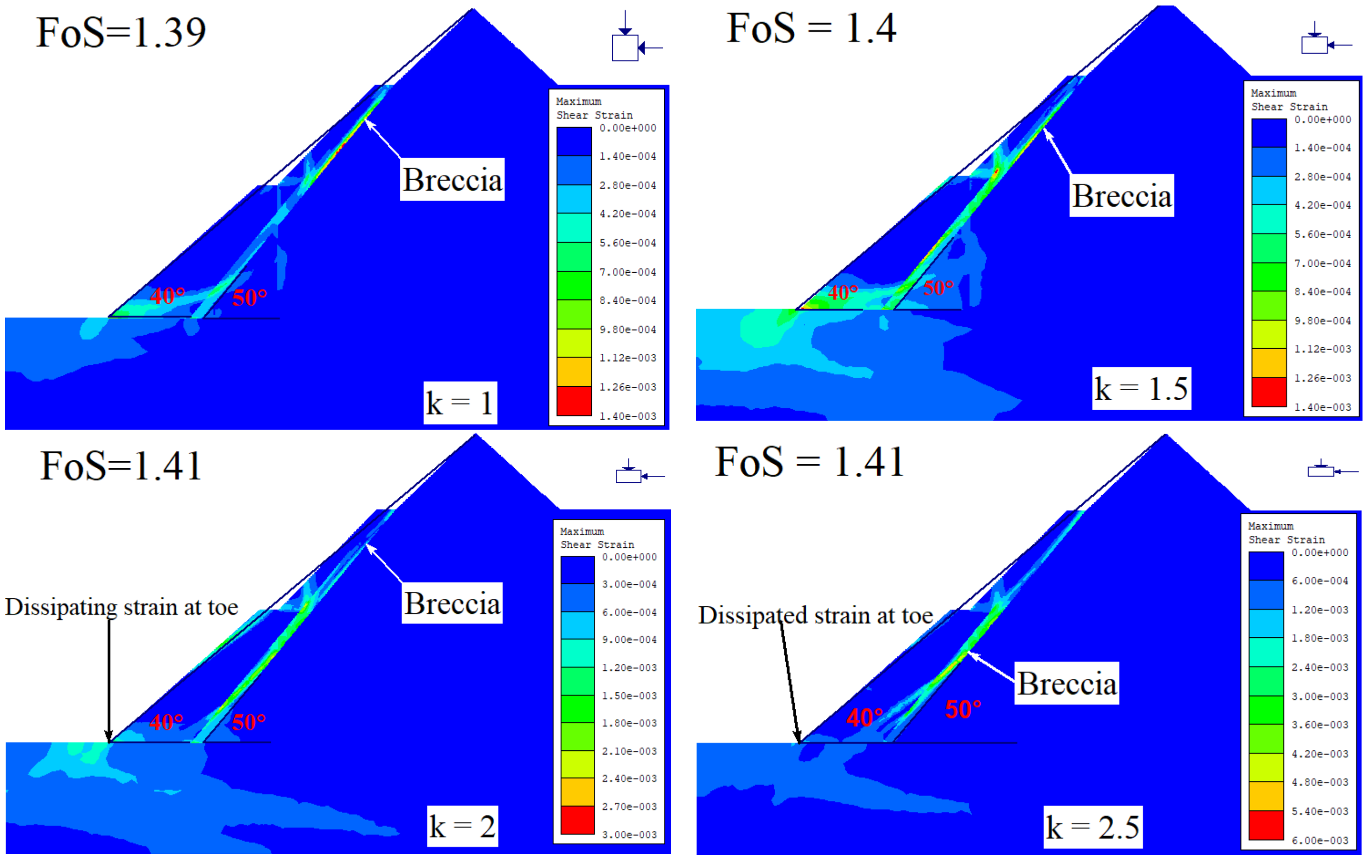
※Carbonatite rock masses are inherently inhomogeneous and geological features such as **breccias** can change the stress field, which can have a bearing on the stability of the pit walls

※Simulation undertaken at different stress ratios

- To comprehend the impact of the interactions between the stress regimes and breccia on slope performance

In-situ Stress Ratio vs Brecciation

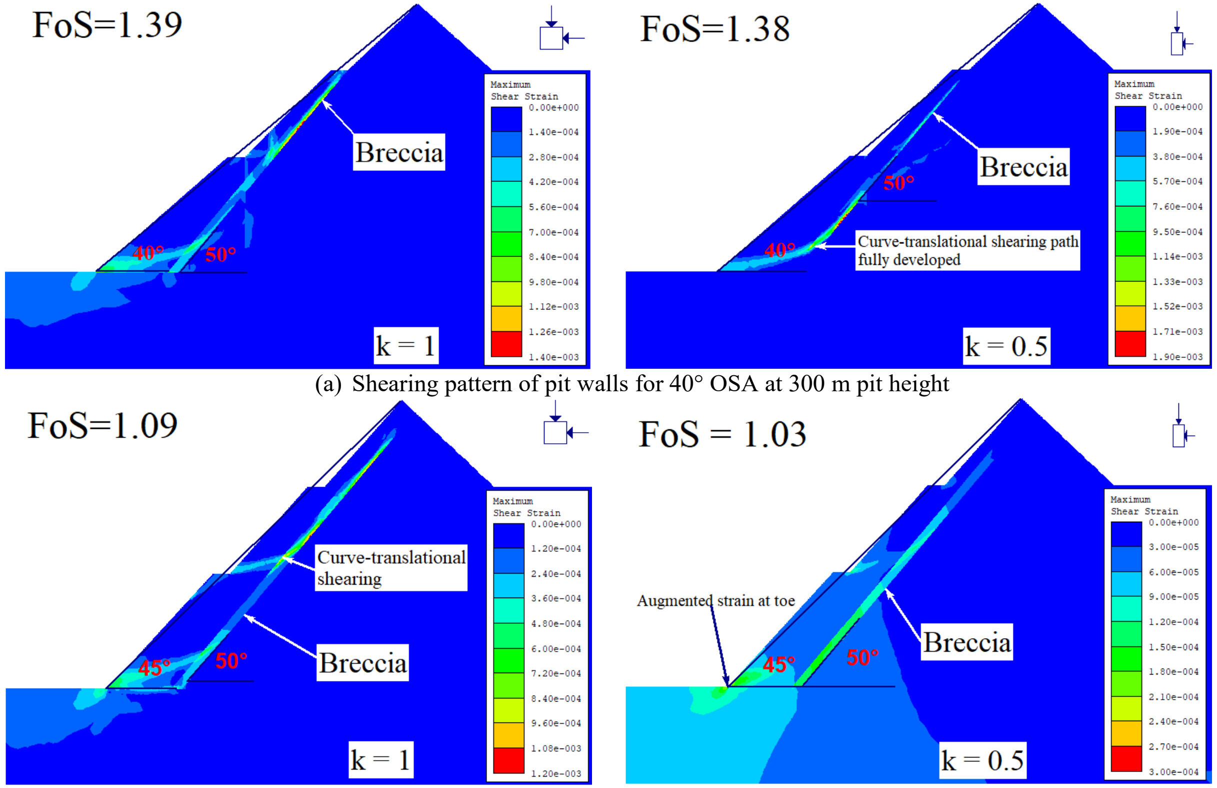
Research object: OSA = 40° , Bx dip = 50° @ 300 m



※Redistribution of stress and shearing strain along the breccia influences the slope performance

In-situ Stress Ratio vs Brecciation

Research object: OSA = 40°, 45° and Bx dip = 50° @ 300 m



(a) Shearing pattern of pit walls for 40° OSA at 300 m pit height

(b) Shearing pattern of pit walls for 45° OSA at 300 m pit height

※ High vertical stress increases the loading effect;

- Circular and translational shearing path adjoining in (a)
- Distinct translational failure path and the intensification of shear strain at the toe of the pit slope (b)

Conclusion

※ Brecciation in competent rock mass has the capability to reduce the pit wall stability performance

- ➢ Important to consider at preliminary stage when identified
  - ☑ The **ratio of 1:5** between the breccia distance from slope toe and pit depth is proposed for adoption to counter its impact.
  - ☑ If breccia is close to the final slope, a deliberate effort should be made **to mine out or truncate it**.

※ In general, the African average regional stress is determined to be at k = 1.5 (Stacey & Wesseloo, 1998)

- ➢ Nonetheless, the regional tectonic stresses variation depending on structural setting are a critical consideration when undertaking the design.

Thank you