Three-Dimensional Numerical Modelling of Longwall Mining from Final Highwall at Mae Moh Lignite Mine, Thailand

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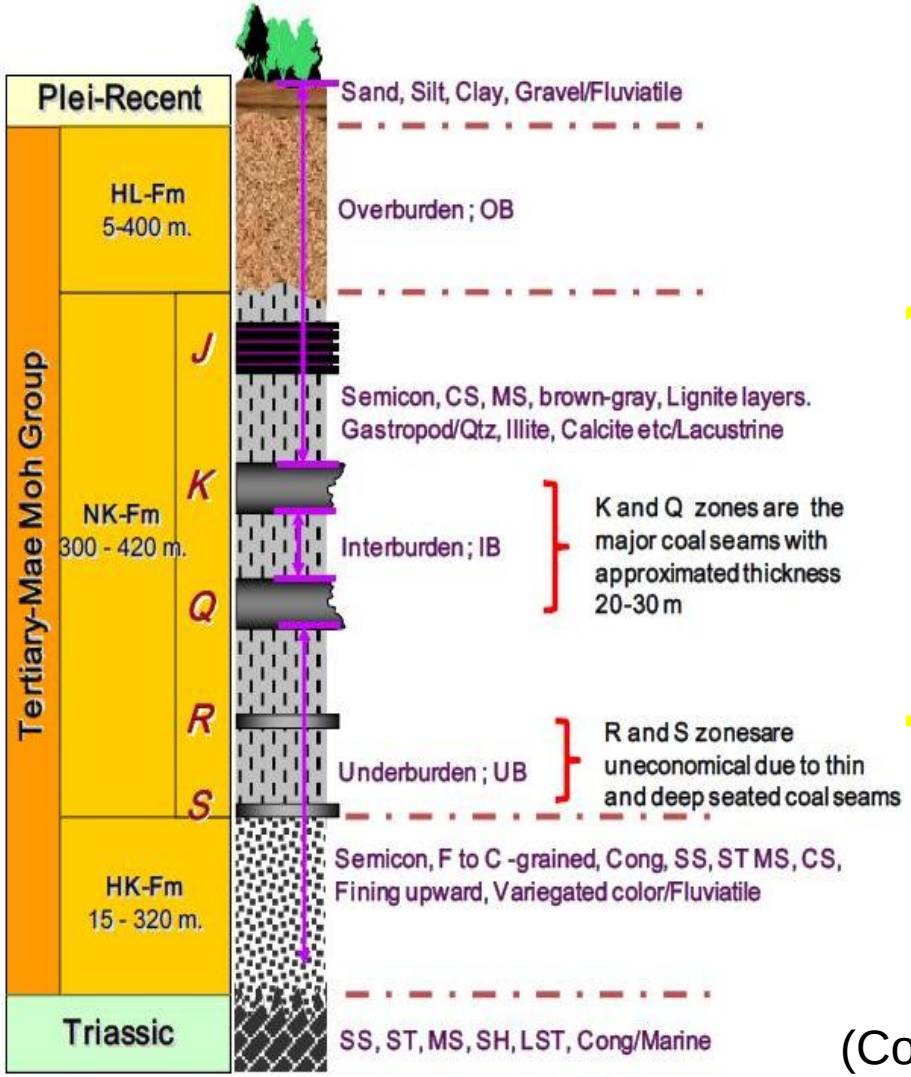
Outline

1. Introduction
   - Abstract of Mae Moh lignite mine
   - Background and purpose of research

2. Numerical Analysis
   - Numerical modeling; $FLAC^{3D}$
   - Modeling procedure, results and discussion

3. Conclusion

Abstract of Mae Moh lignite mine



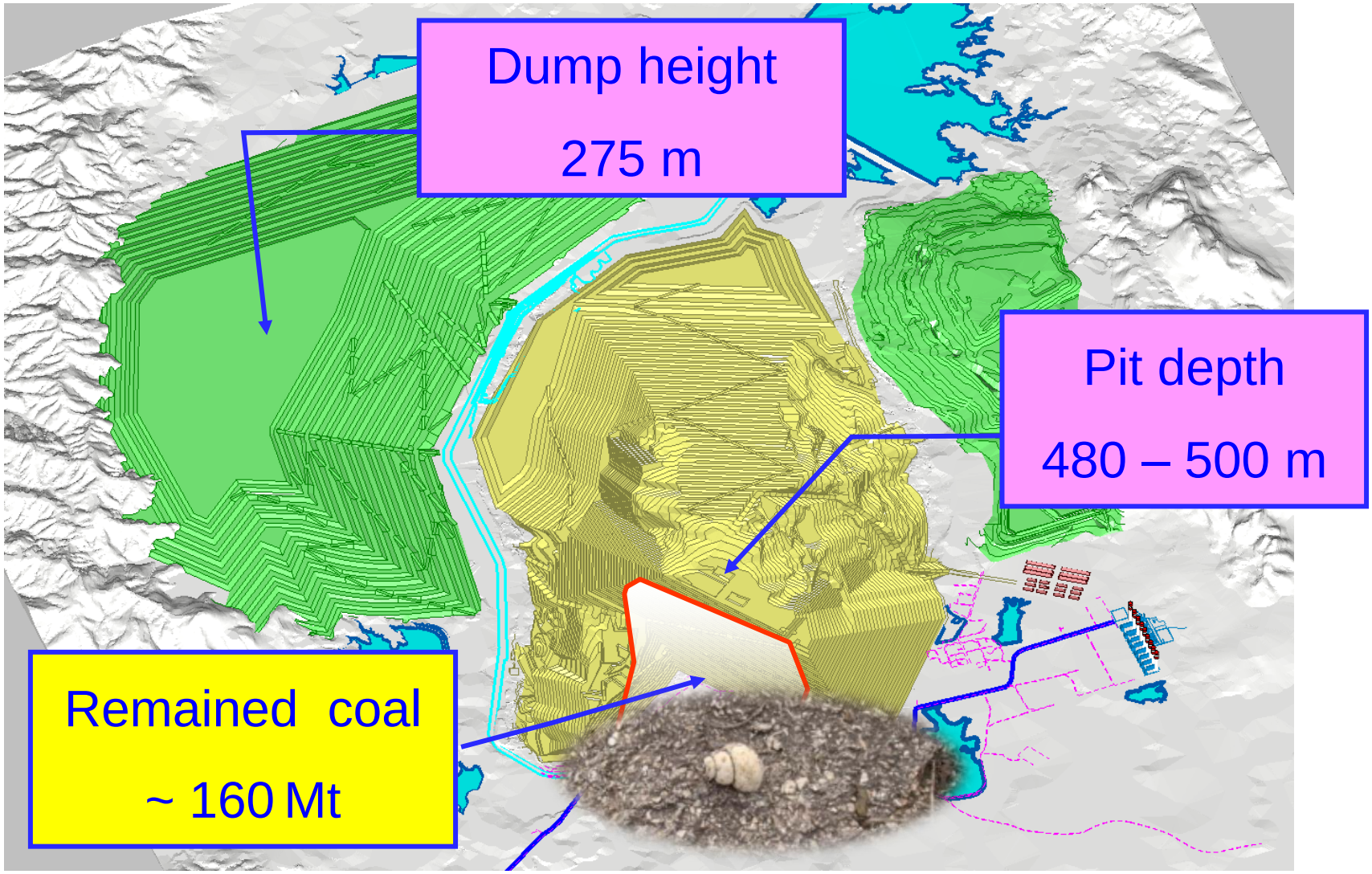
Mine	Mae Moh	Envirocoal	Newcastle Weak
Location	Thailand	Indonesia	QLD, Australia
Type	Lignite	Sub-bituminous	Bituminous
Heat value (kcal/kg)	2,810	5,200	6,420
Ash content (%)	20.1	1.2	14.0
Moisture content (%)	30.7	26.0	9.0
Volatile matter (%)	25.5	43.0	32.0
Fixed carbon (%)	21.5	40.5	51.5
Sulfur (%)	2.77	0.10	0.50

(Courtesy of EGAT)

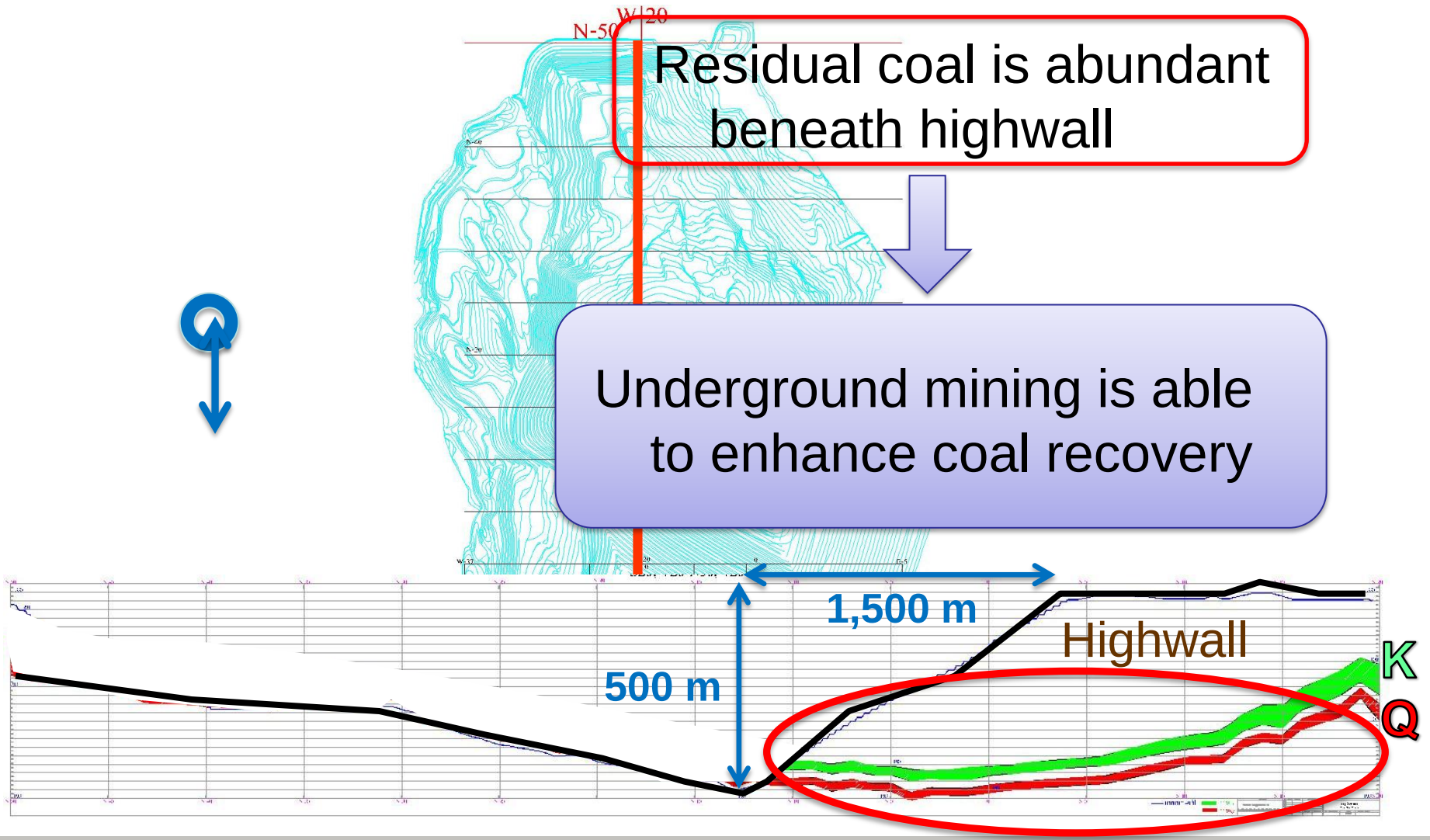
Desulphurization) Installed

0 Mil. unit of electricity/year

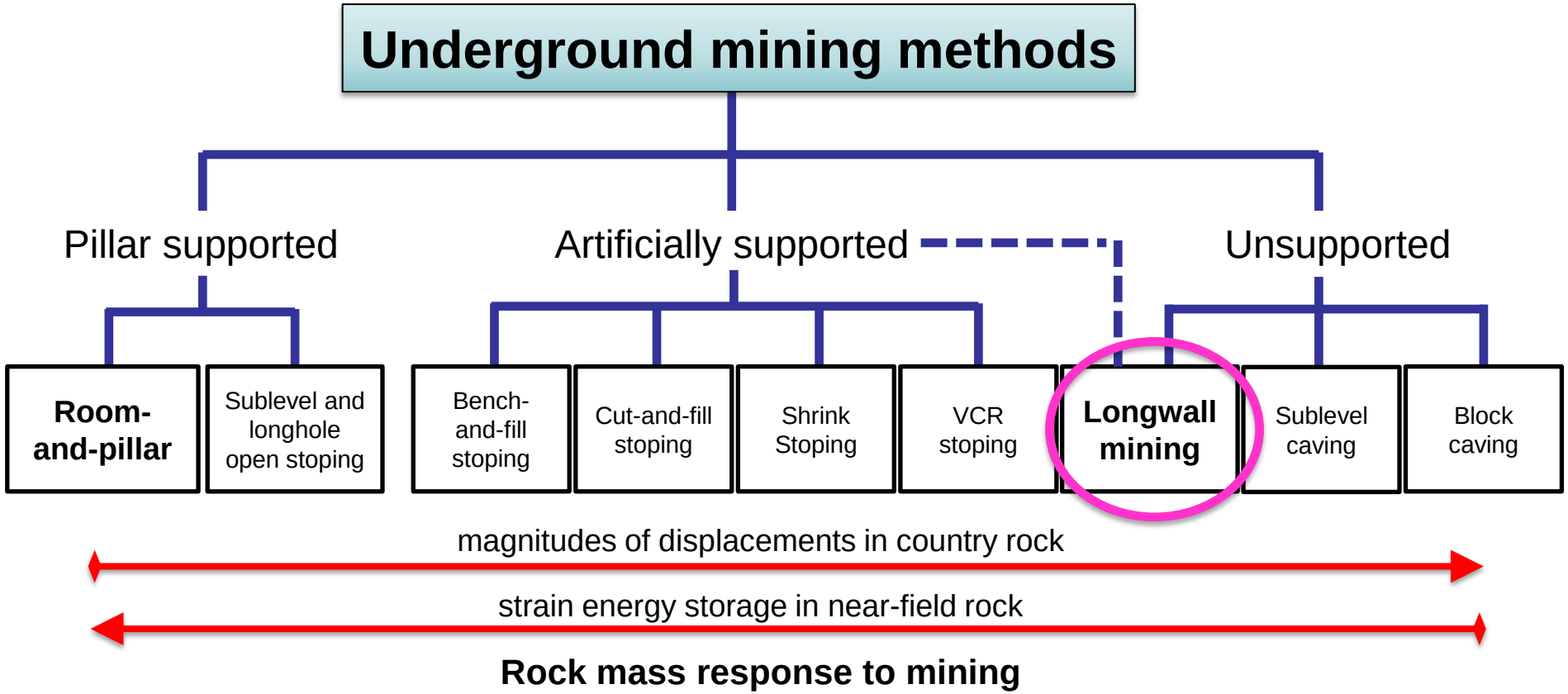
Mine map: plan view at the end of operation



Mine map: plan view at the end of operation



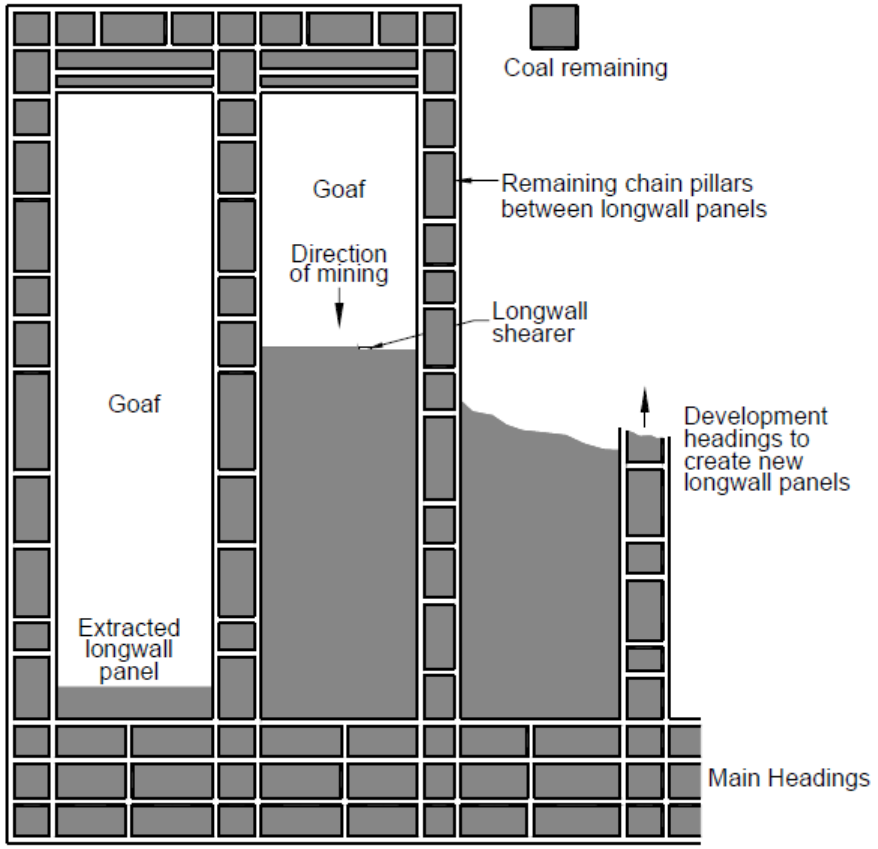
Underground mining methods

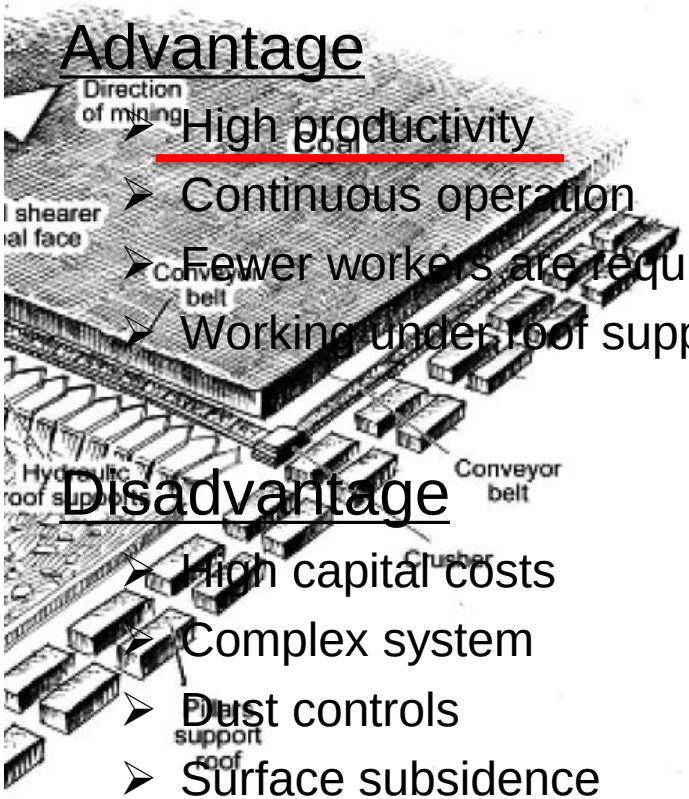


(Brady and Brown, 1993)

Longwall mining method

A coalbed is blocked out into a panel averaging nearly 100-200m in width by excavating gateways around its perimeter.





Advantage

- High productivity
- Continuous operation
- Fewer workers are required
- Working under roof supports

Disadvantage

- High capital costs
- Complex system
- Dust controls
- Surface subsidence

Background and purpose of research

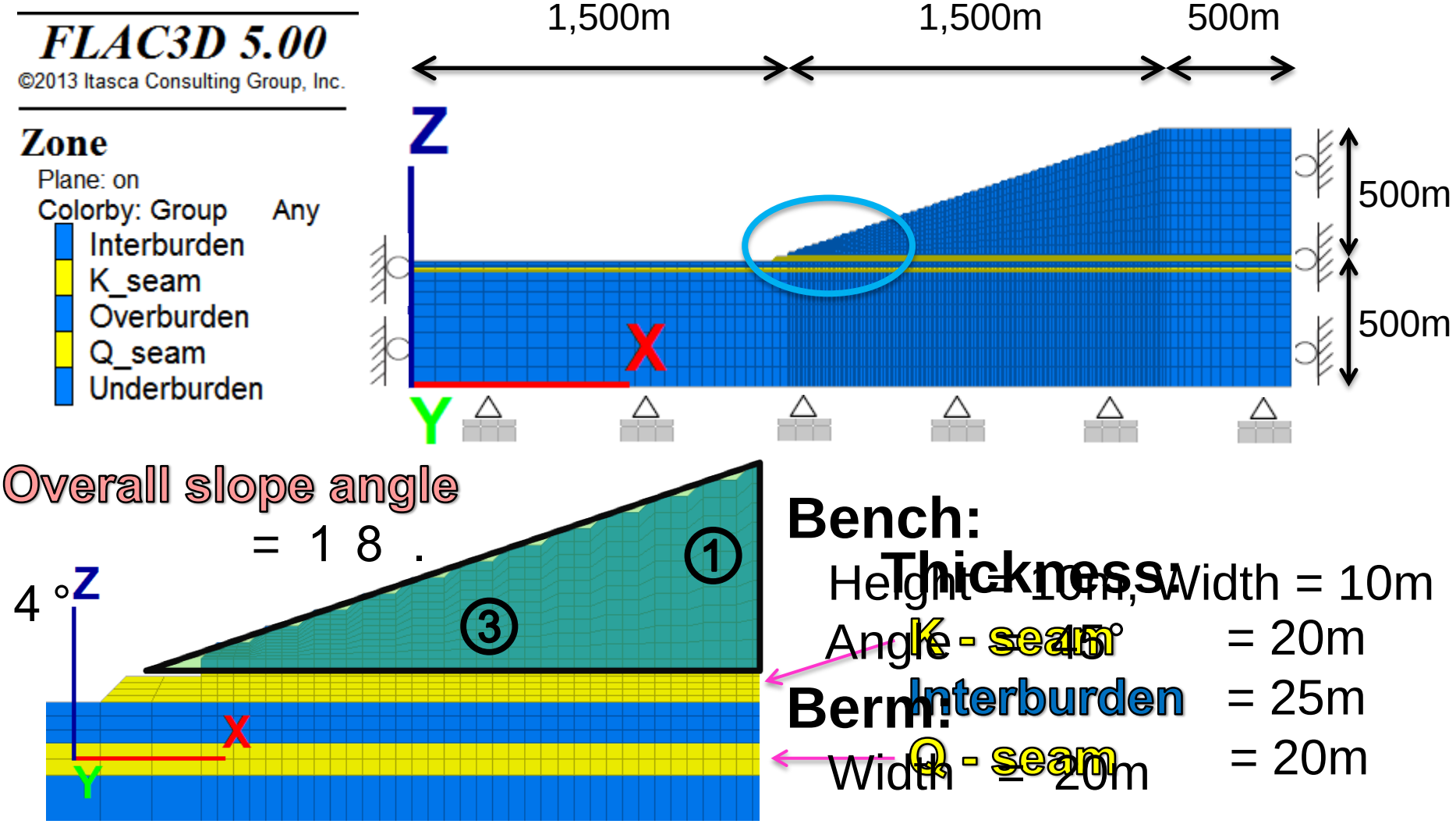
Development of underground mine is considered before the open-pit operation comes to the end.

However,

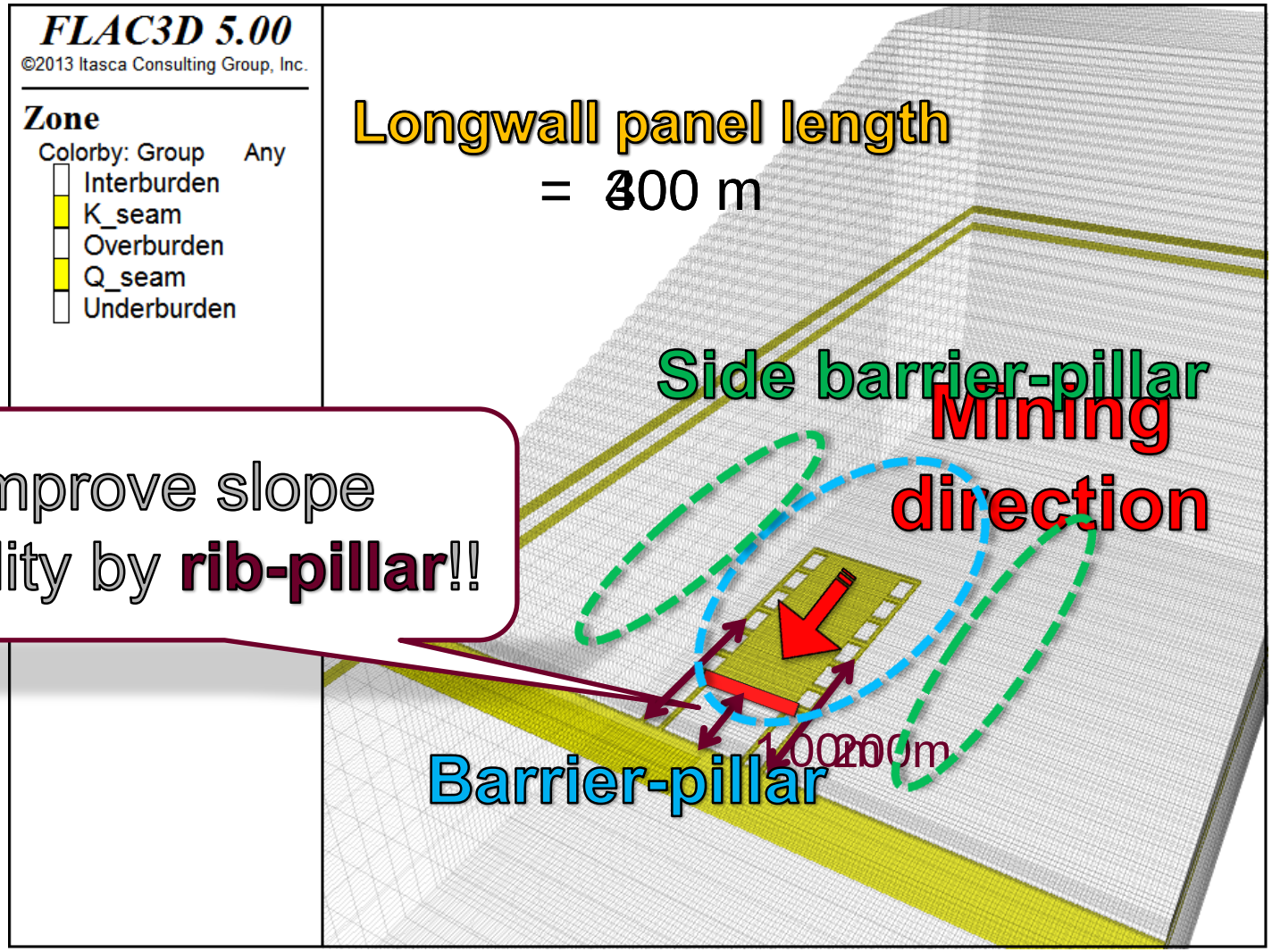
- ✓Adverse conditions (weak strength of coal, slope failures, etc)
- ✓No experience of longwall mining in Thailand

The purpose of this study is to examine applicability of longwall mining at Mae Moh mine by predicting the ground behavior using three-dimensional explicit finite difference program; $FLAC^{3D}$.

Numerical modeling - *FLAC*^{3D}

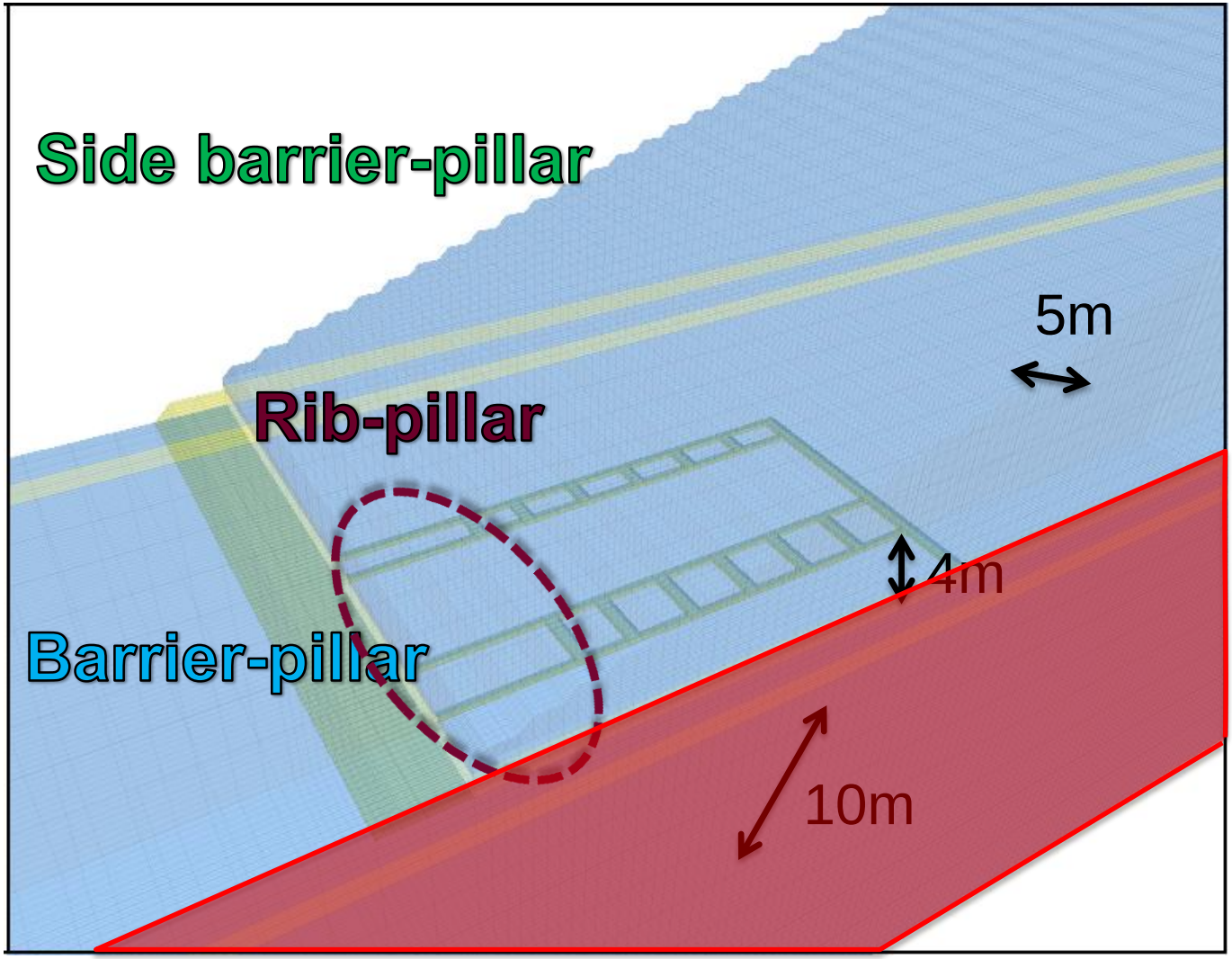


FLAC^{3D} – Mining scenario



Improve slope stability by **rib-pillar**!!

$FLAC^{3D}$ – Pillars for safer operation



$FLAC^{3D}$ – Material properties

Material properties used in simulations

(Courtesy of EGAT)

Materials	Clay stone	Coal
Density (kg/m^3)	1,950	1,430
Young's modulus (MPa)	10,000	100
Poisson's ratio	0.25	0.4
Internal frictional angle (deg)	25	22.3
Cohesion (MPa)	1.75	0.16
Tensile strength (MPa)	0.1	0.1

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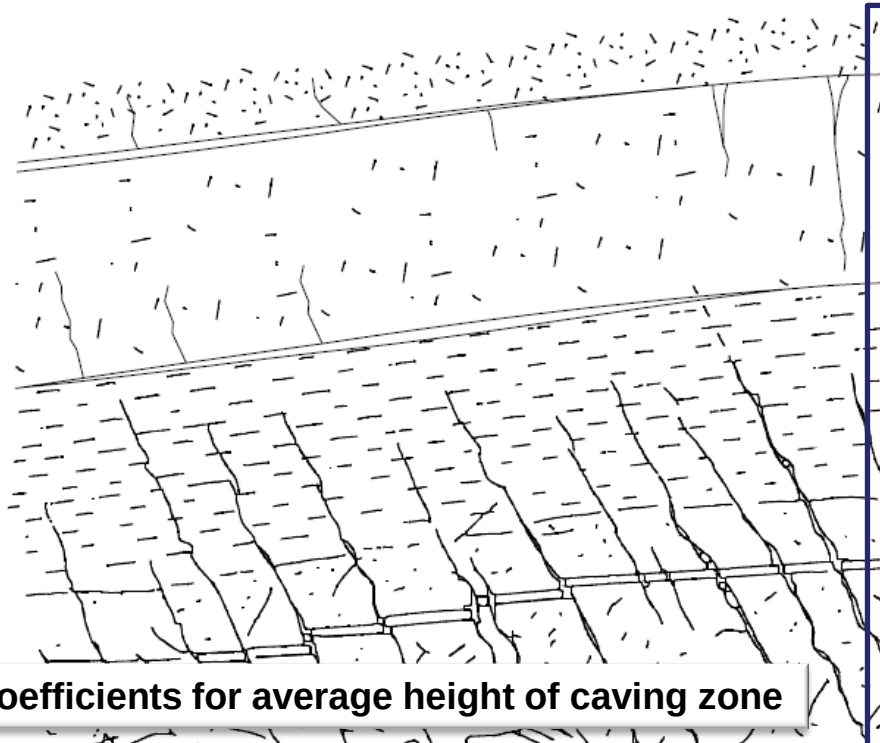


Coefficients for average height of caving zone

Strata Type	C_1	C_2
Strong and hard	2.1	16
Medium strong	4.7	19
Soft and weak	6.2	32

Modulus Updating Method

(Badr et al. ,2003)

$$K = \frac{1.75}{0.5 - \varepsilon_v}$$

K = Bulk modulus, ε_v = Vertical strain

$G = 3K(1\text{-}2\nu)/2(1+\nu)$

Caving Height

(Whittles et al., 2005)

$$Hc = \frac{100h}{C_1 h + C_2}$$

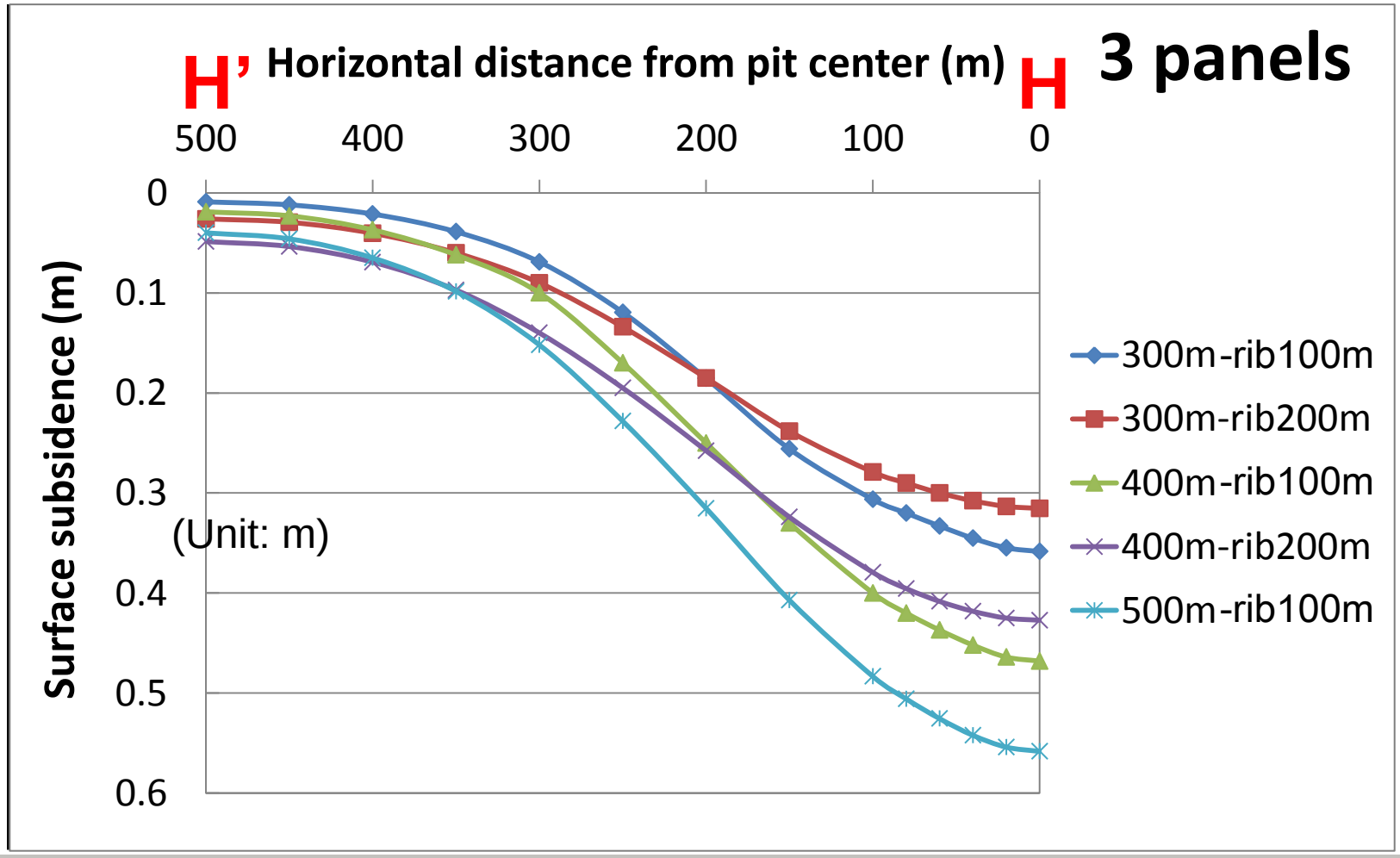
Hc = Caving height (m)

h = Mining height (m)

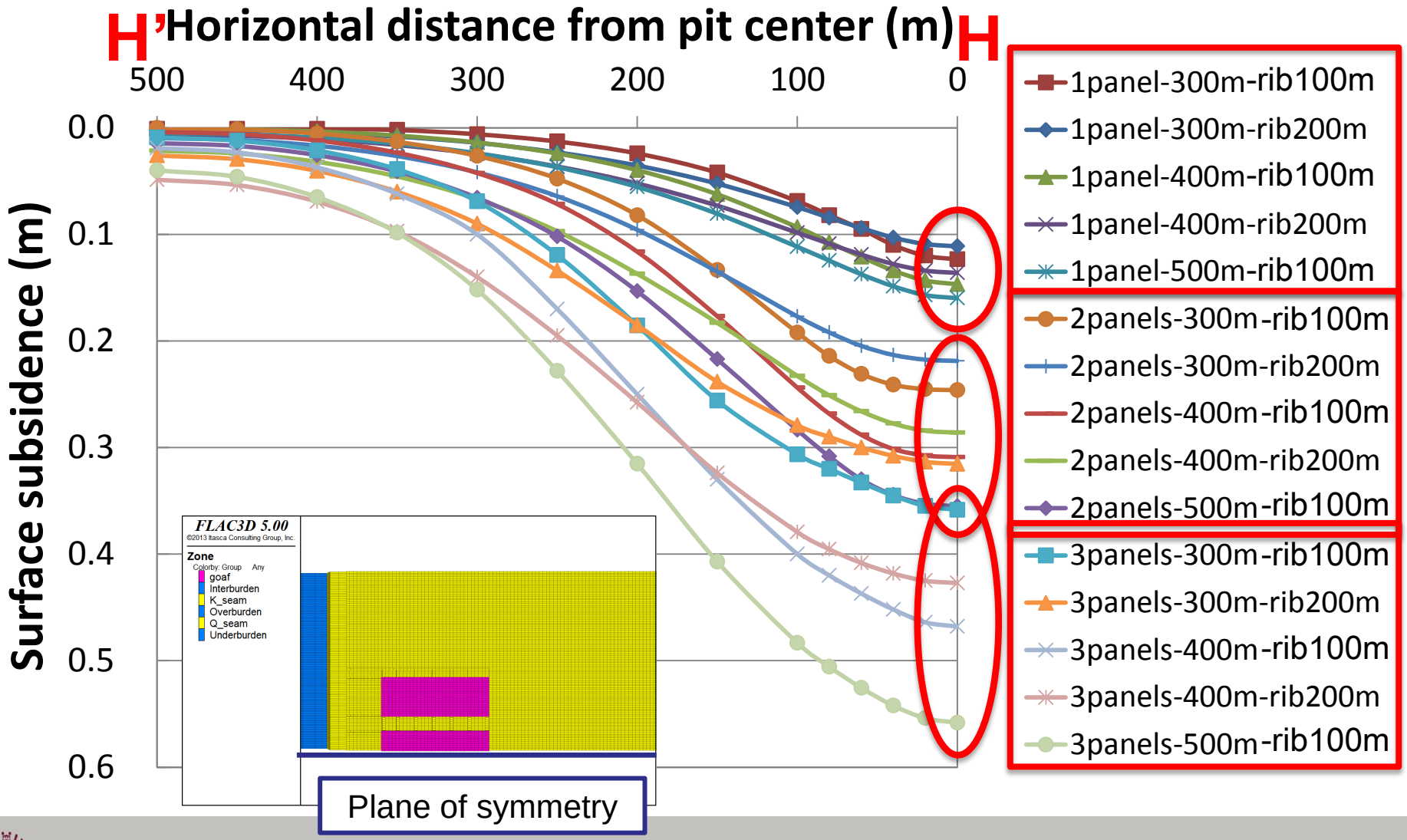
C_1, C_2 = Coefficients

Assessment of stability①

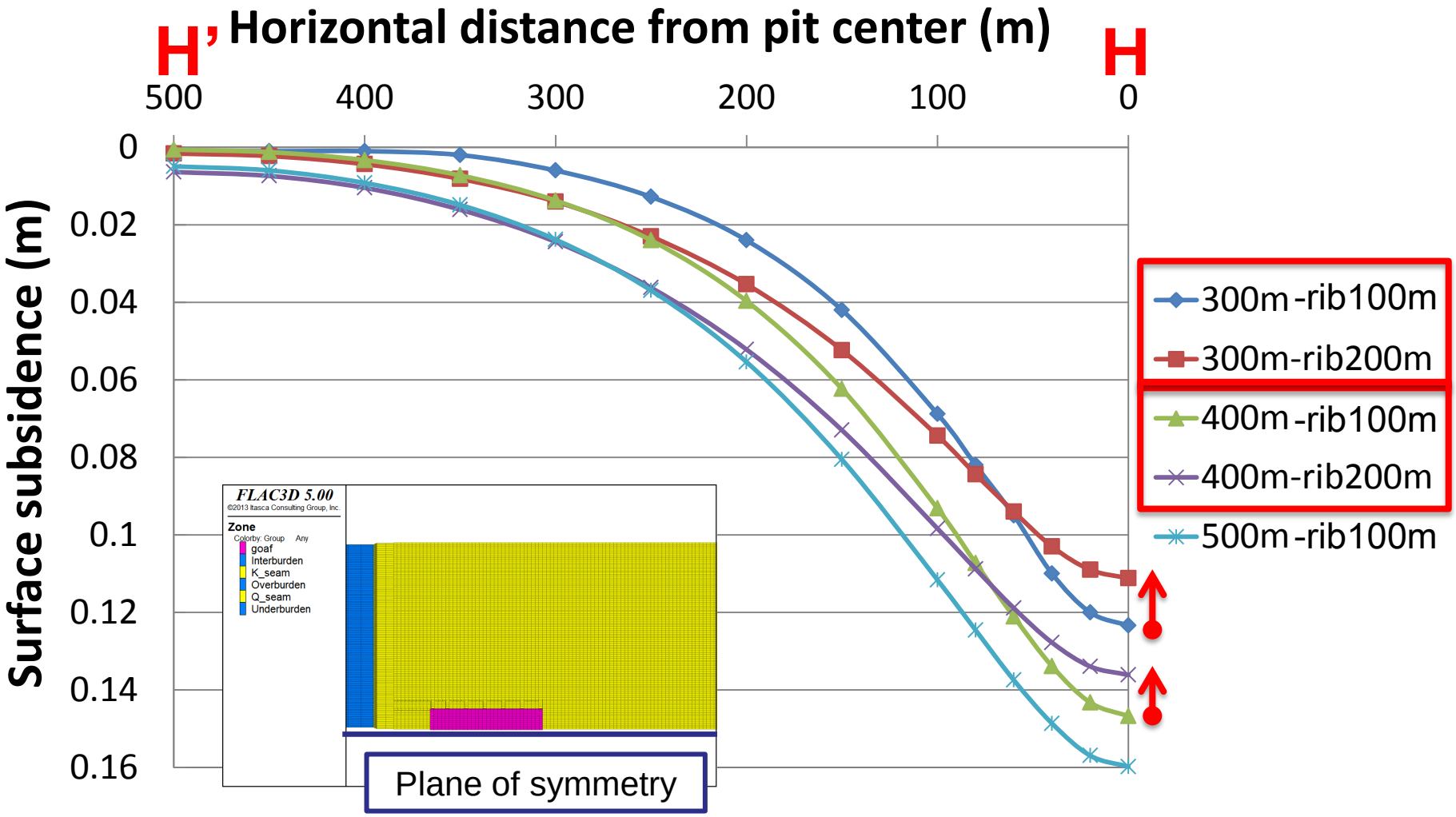
Assessment by monitoring surface subsidence.



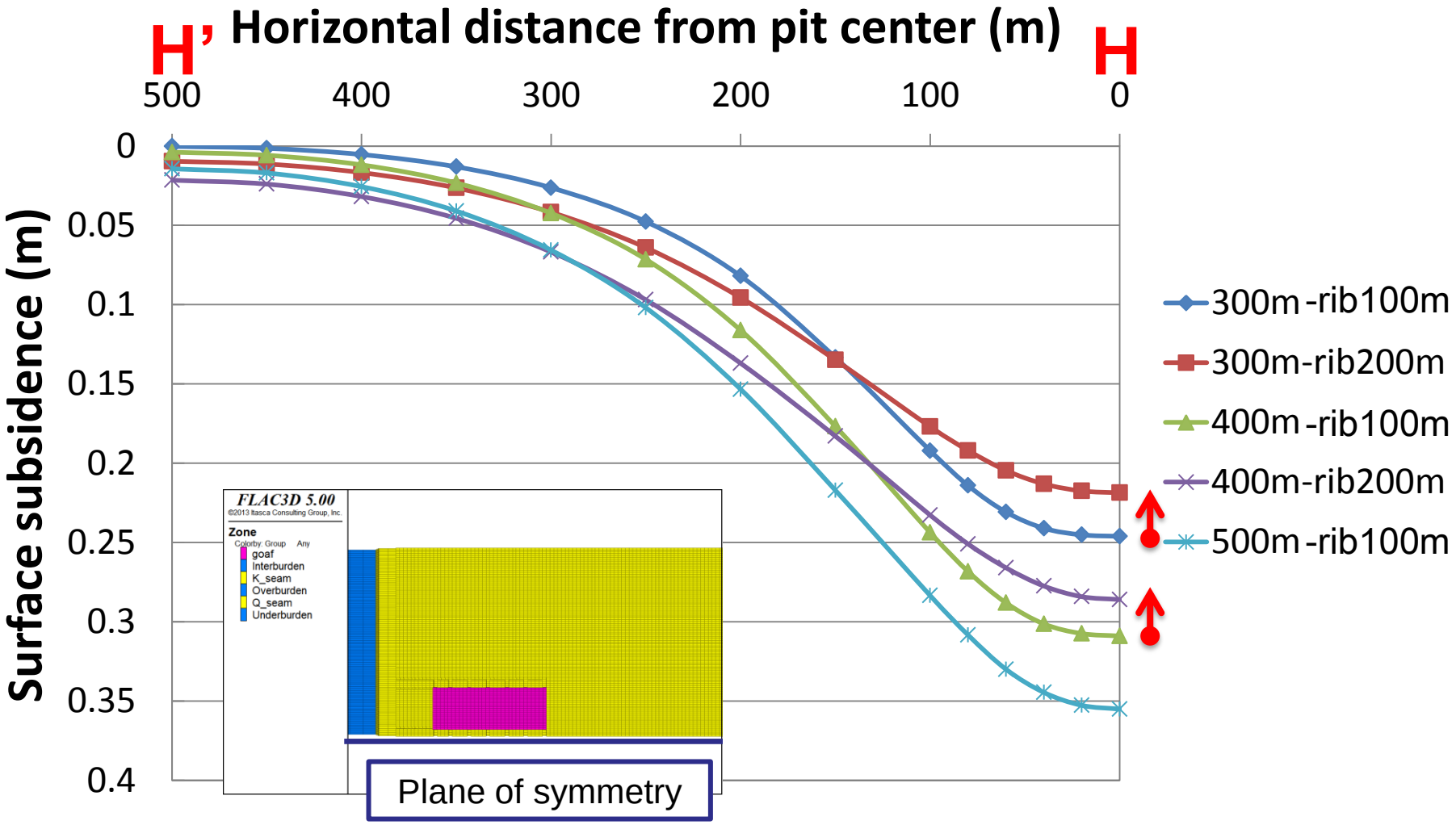
Results① - Subsidence



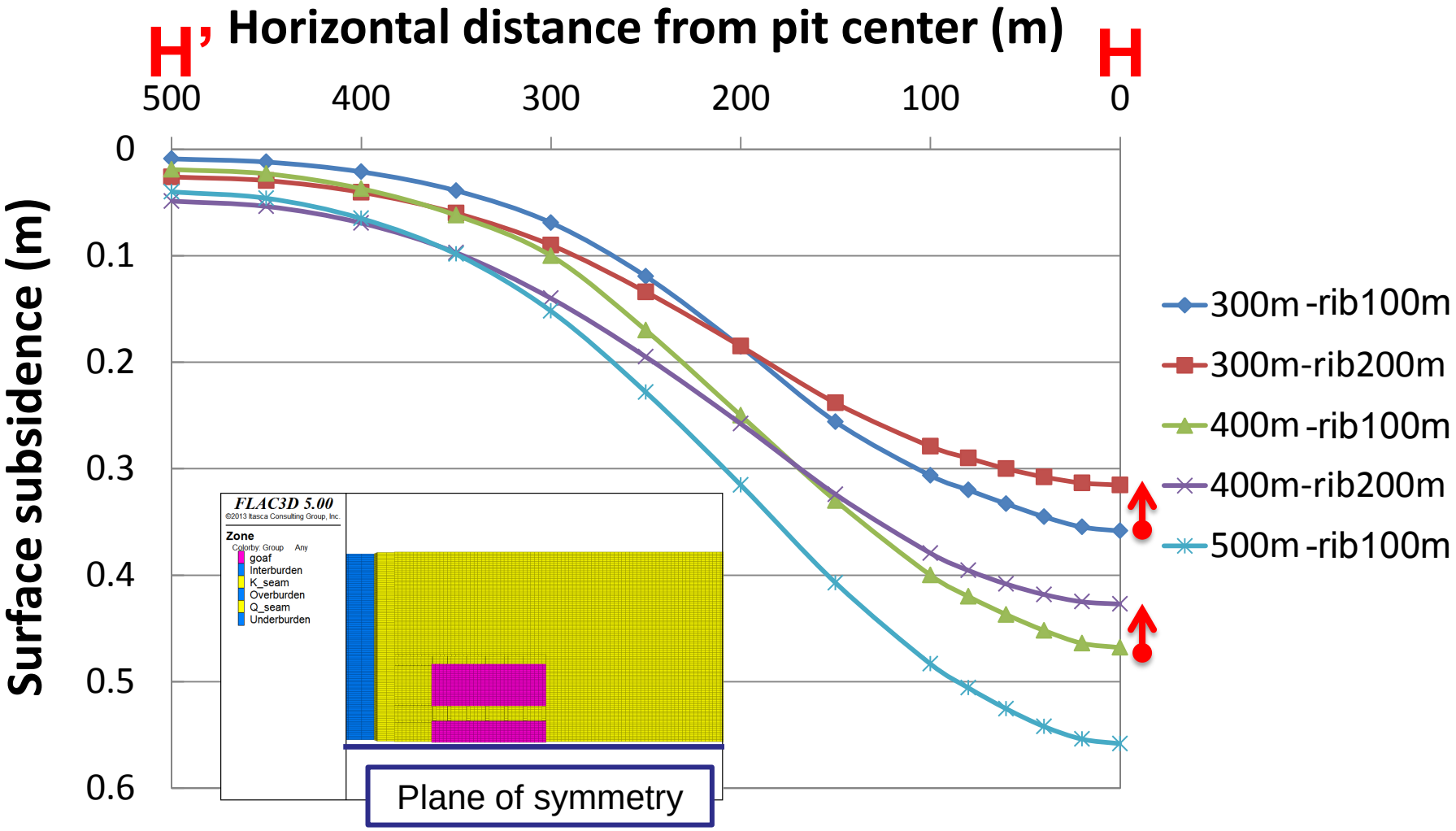
Results① - Subsidence (1 panel)



Results① - Subsidence (2 panels)

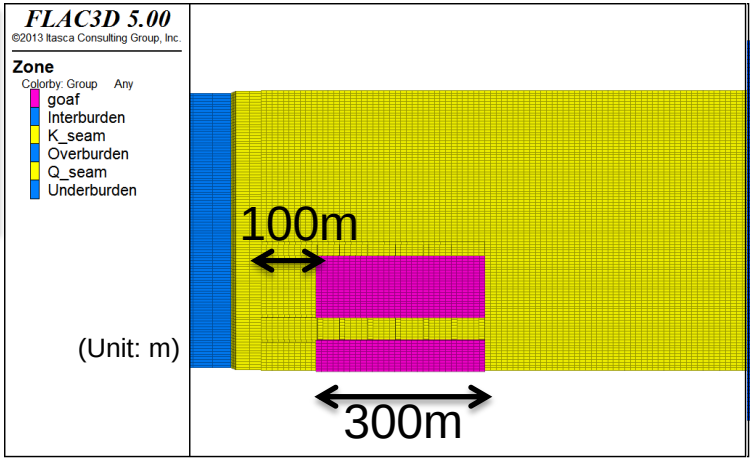
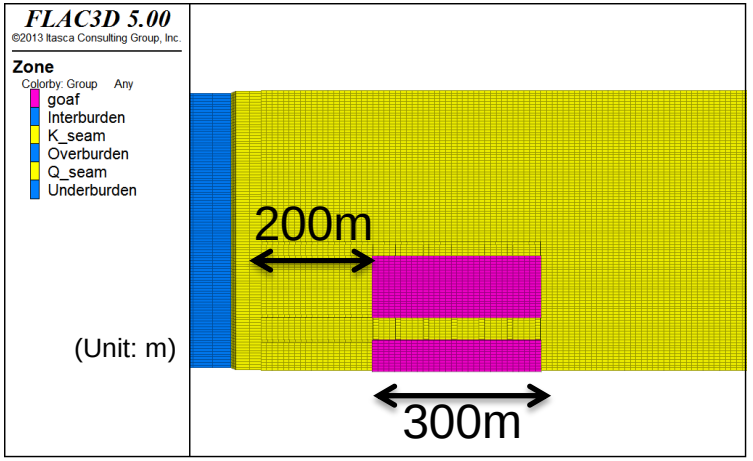
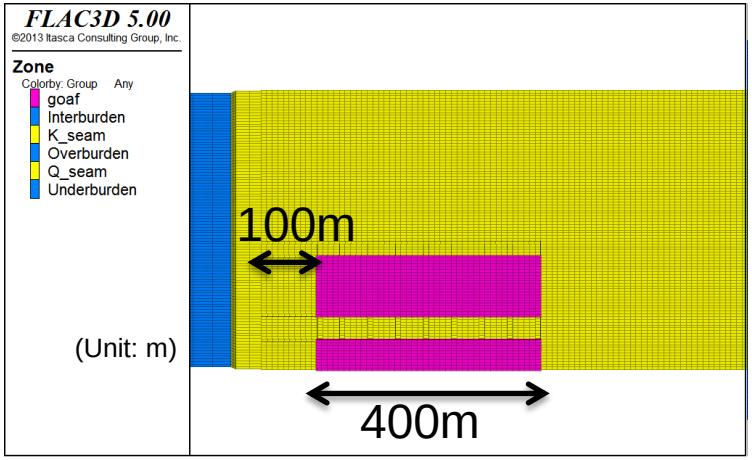
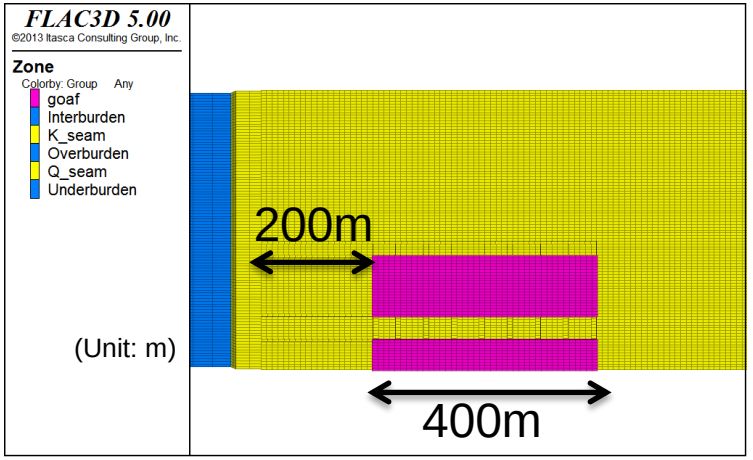


Results① - Subsidence (3 panels)



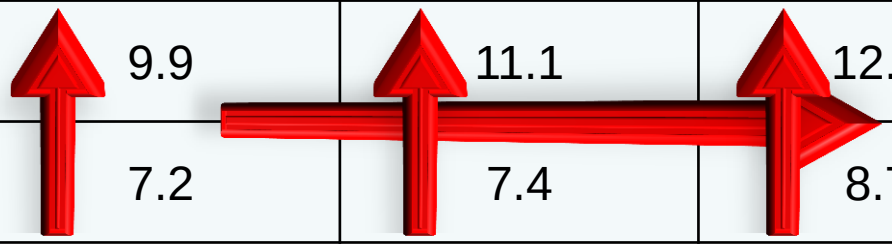
Results① - Subsidence (3 panels)

Rib-pillar length

Longwall panel length	100m	200m
300m		
400m		

Results and discussion① - Subsidence

Subsidence reduction rate (%)		Number of longwall panels		
		1	2	3
Longwall panel length (m)	300	9.9	11.1	12.0
	400	7.2	7.4	8.7

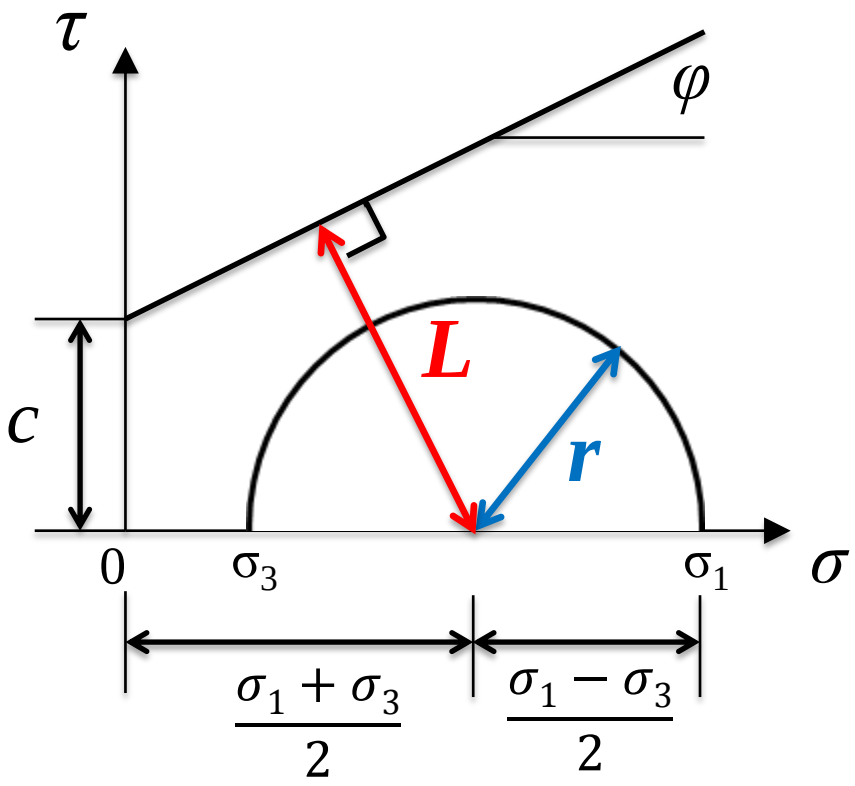


(□In the case that the rib-pillar length is extended from 100m to 200m)

- ✓ The more longwall panels, the more effectiveness of longer rib-pillar appears on the surface subsidence.
- ✓ Shorter longwall panel length, more effectiveness of longer rib-pillar can be expected.

Assessment of stability②

Assessment by contours of strength factor based on the Mohr-Coulomb failure criteria.

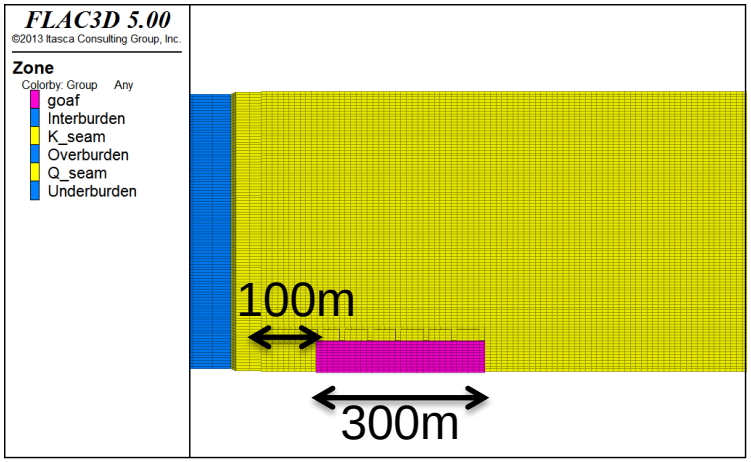
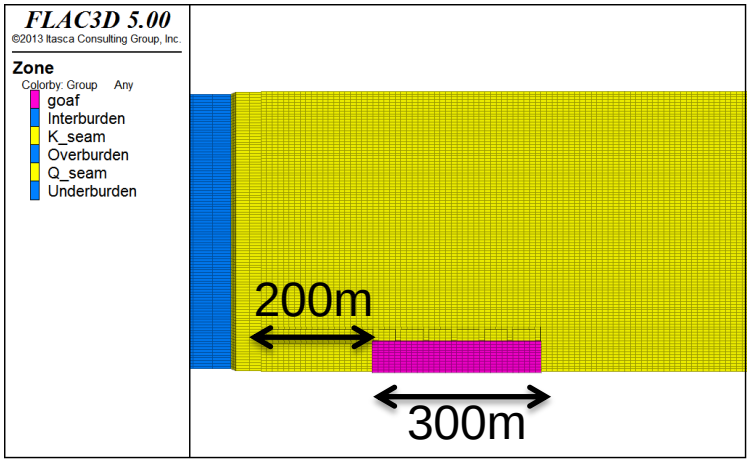
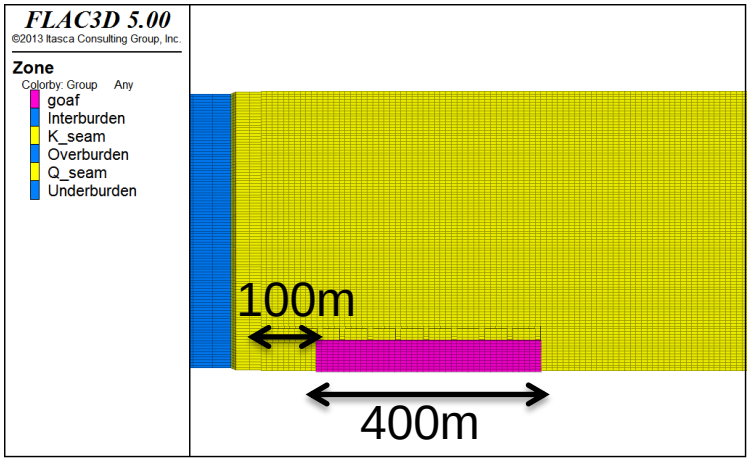
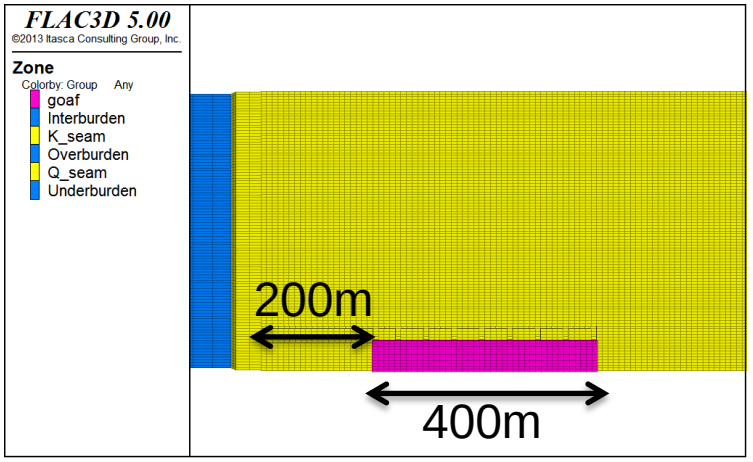


Strength factor

$$= \frac{c\cos\varphi + \frac{\sigma_1+\sigma_3}{2}\sin\varphi}{\frac{\sigma_1-\sigma_3}{2}}$$

Results② - Strength factor (1 panel)

Rib-pillar length

Longwall panel length	100m	200m
300m		
400m		

Results② - Strength factor (3 panels)

Rib-pillar length

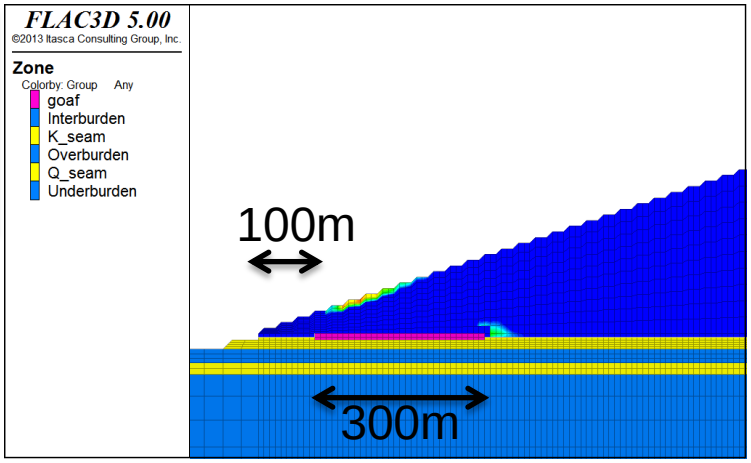
100m

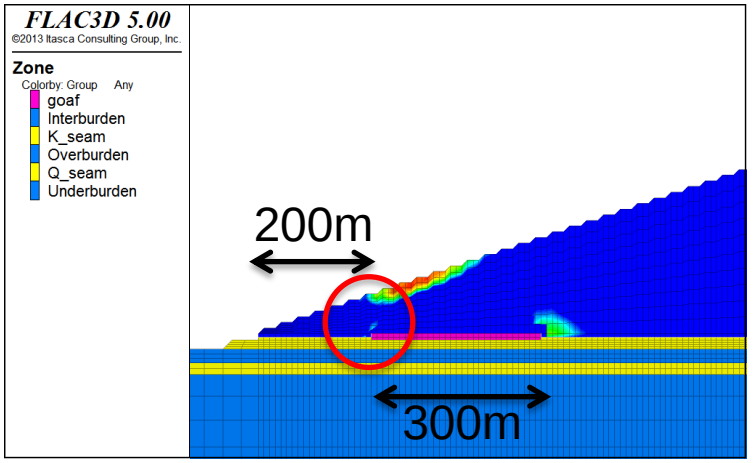
200m

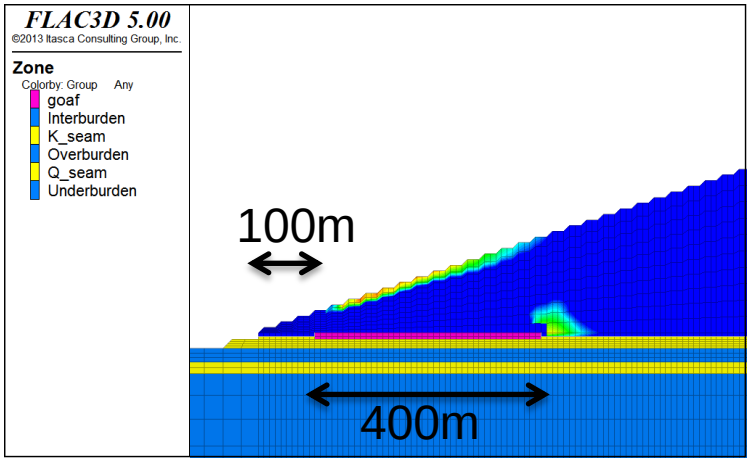
Longwall panel length

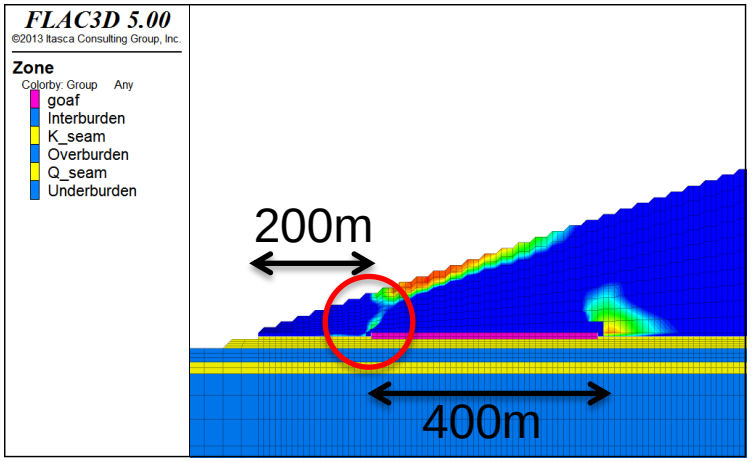
300m

400m









Results② - Strength factor

- ✓ **No stress influence over adjacent longwall panels (Single panel, or wide enough barrier-pillar)**

  The slope stability improves with extending the length of rib-pillar as well as the behavior of subsidence.

- ✓ **Stress influence over adjacent longwall panels (With influence of stress superposition)**

  The slope stability deteriorates with extending the length of rib-pillar since the overburden gets high and shear stress around rib-pillar becomes excessively large.

For further research

- The spatial relationship between the width of barrier-pillar and that of longwall panel needs to be taken into account.
  - Wider barrier-pillars to decrease the stress superposition.
  - Shortwall mining method.

- Backfilling methods should be considered to enhance the stability.
  - Using industrial wastes from the adjacent power plant, such as flue-gas desulfurization gypsum and fly ash.

Conclusions

- Surface subsidence can be reduced by extending the length of rib-pillar.
- In the case that stress superposition occurs, shear stress on the slope surface becomes large regardless of whether rib-pillar is extended to 200m.
- In this pillar conditions, extracting several longwall panels is not accepted. Further research is needed to develop the planning of longwall mining method.

Thank you for your attention.

FLAC^{3D} - Advantage

1. An “explicit” solution scheme is used. Explicit schemes can follow arbitrary nonlinearity in stress/strain laws in almost the same computer time as linear laws, whereas implicit solutions can take significantly longer to solve nonlinear problems.
2. FLAC^{3D} is robust in the sense that it can handle any constitutive model with no adjustment to the solution algorithm; many finite element codes need different solution techniques for different constitutive models.

$FLAC^{3D}$ – Material properties

Material properties of rocks

Materials	Density (kg/m³)	Young's modulus (MPa)	Poisson's ratio	Internal frictional angle (°)	Cohesion (MPa)	Tensile strength (MPa)
Clay stone	1,950	10,000	0.25	20	1.75	1.0
Coal	1,430	500	0.28	22.3	0.5	0.5

(Courtesy of EGAT)

Material properties of coal used in simulations

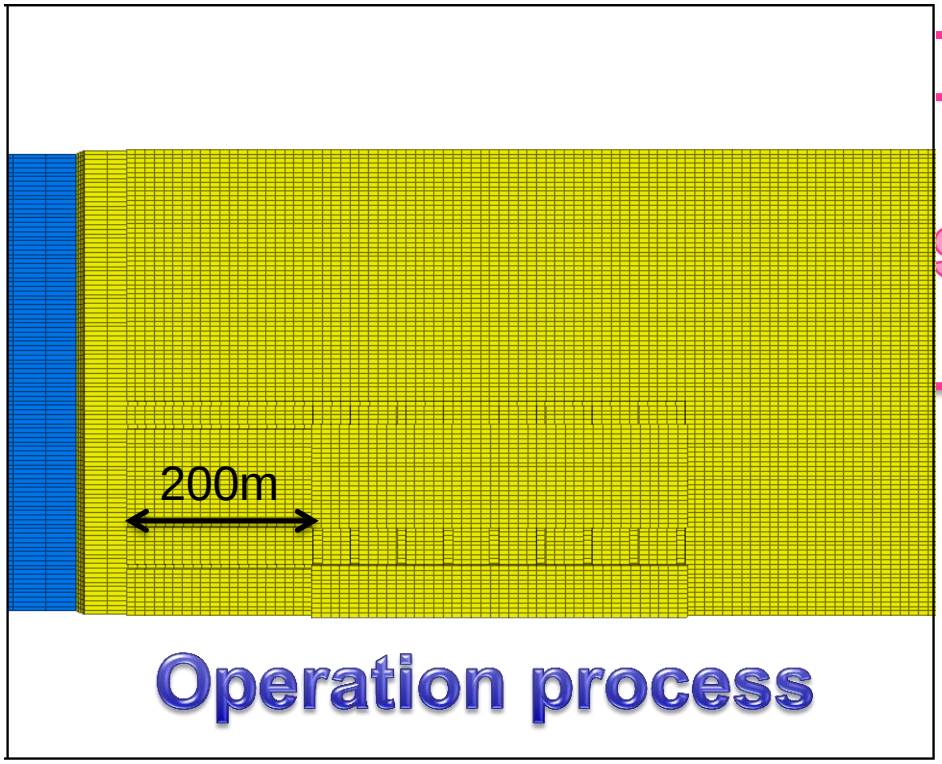
Location	Density (kg/m³)	Young's modulus (MPa)	Poisson's ratio	Internal frictional angle (°)	Tensile strength (MPa)	UCS (MPa)
Australia	1,400	2,000	-	25	0.6	7.6
U.S.A	1,350	3,000	0.25	-	-	7.6

Remedy - Backfilling

Backfilling can enhance slope stability.

ex) 3panels,

Longwall panel length=400m, rib-pillar length=200m



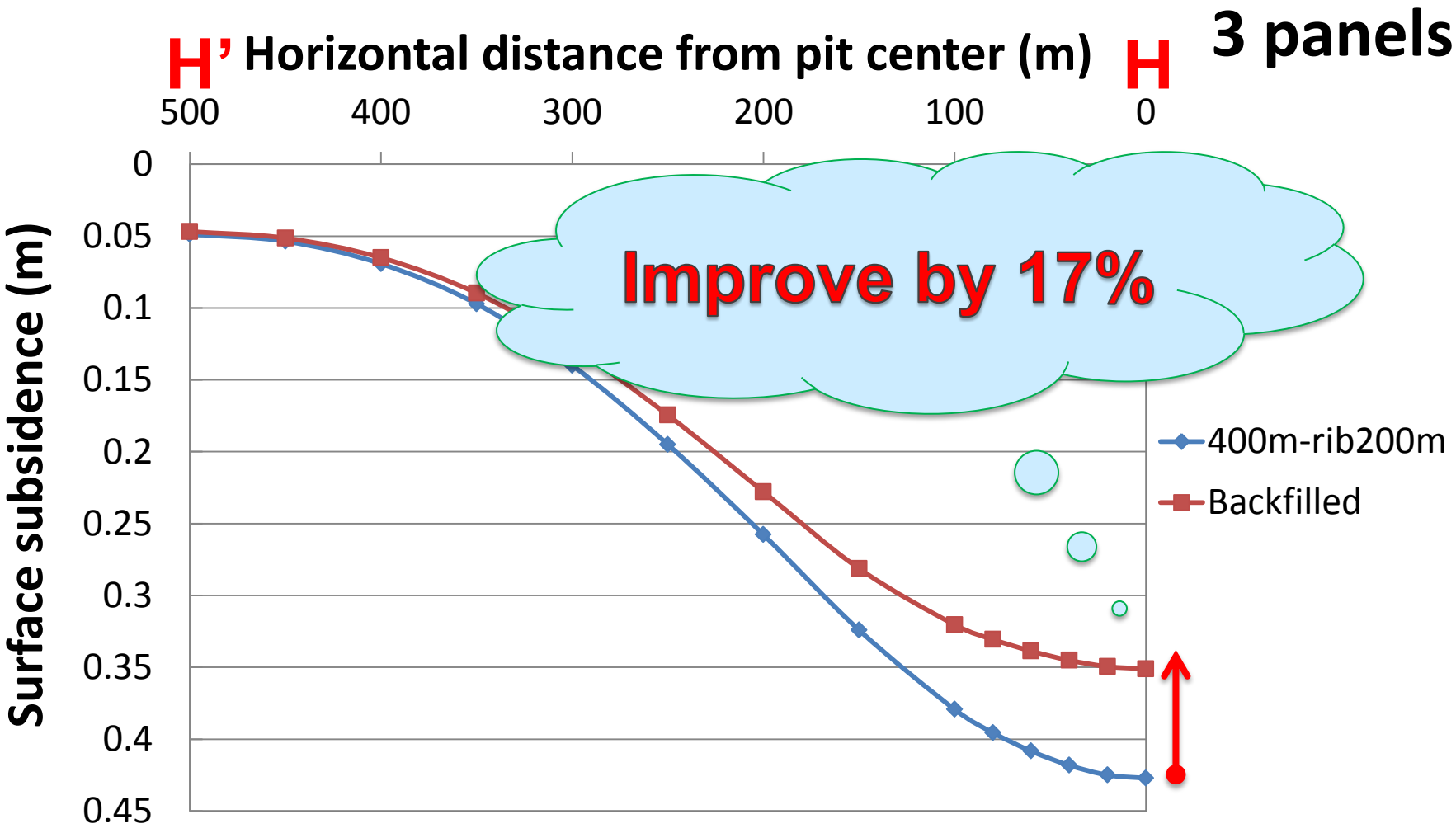
st panel

Remedy - Backfilling

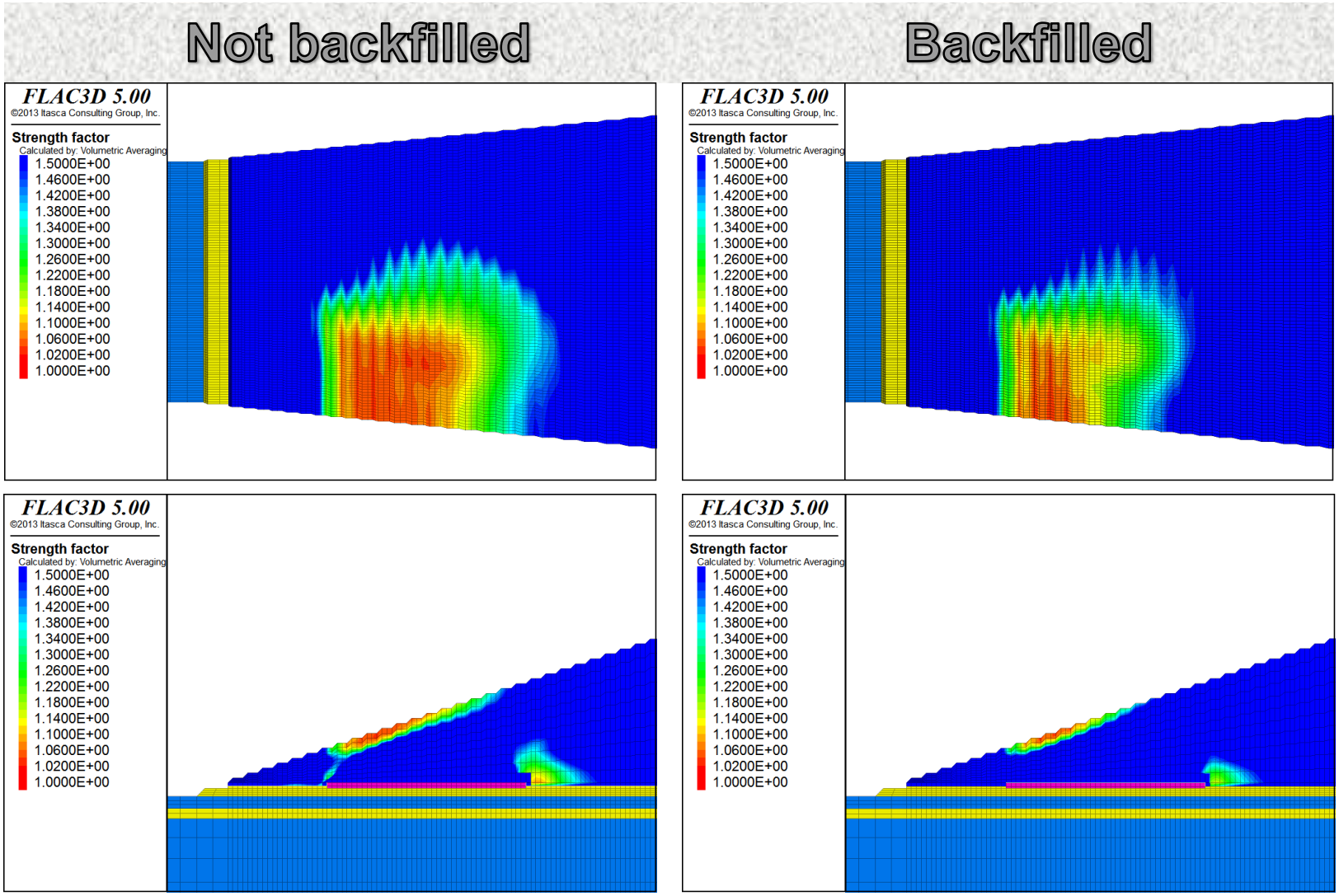
Backfill properties used in numerical simulations (cemented material)

Property	Value
Density (kg/m^3)	2,000
Young's modulus (MPa)	200
Poisson's ratio	0.20
Internal frictional angle (deg)	35
Cohesion (MPa)	0.5
Tensile strength (MPa)	0

Results of backfilling - Subsidence

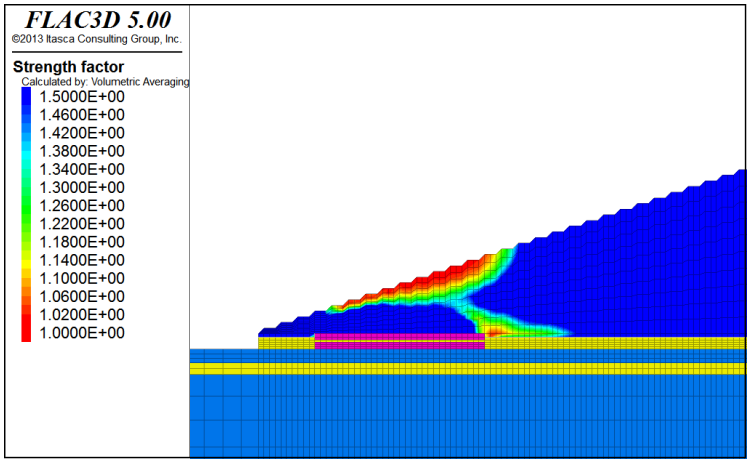
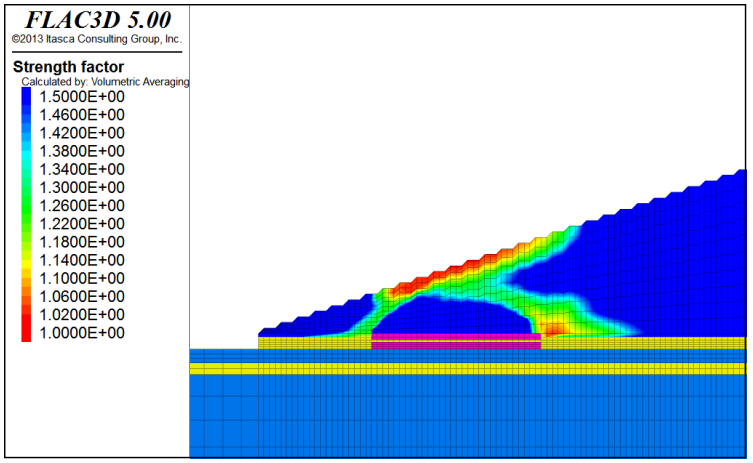
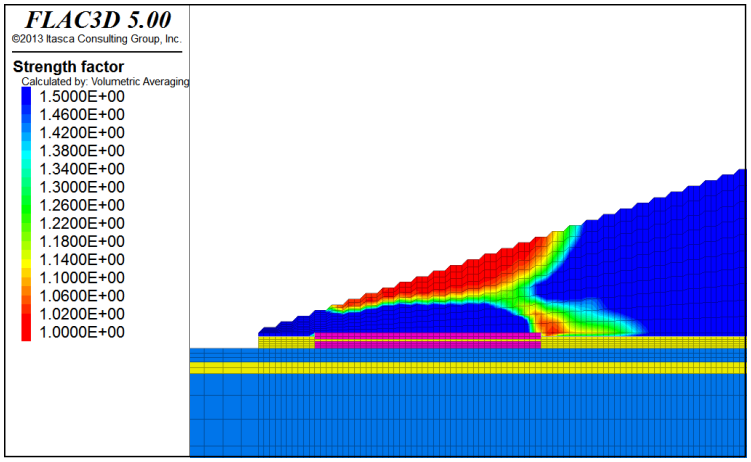
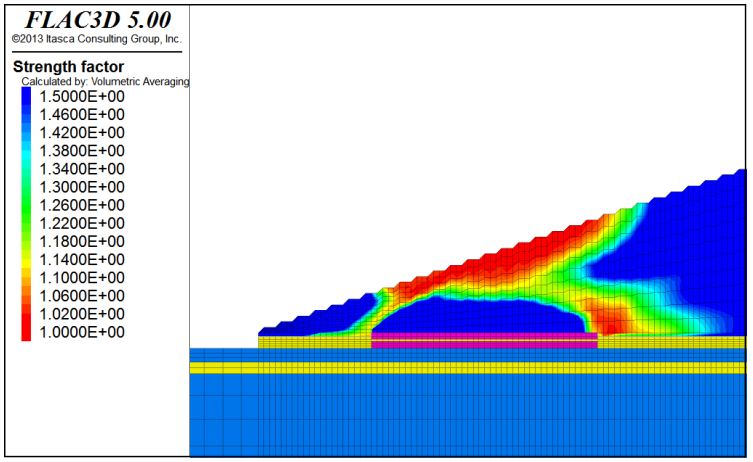


Results② - Strength factor (3 panels)



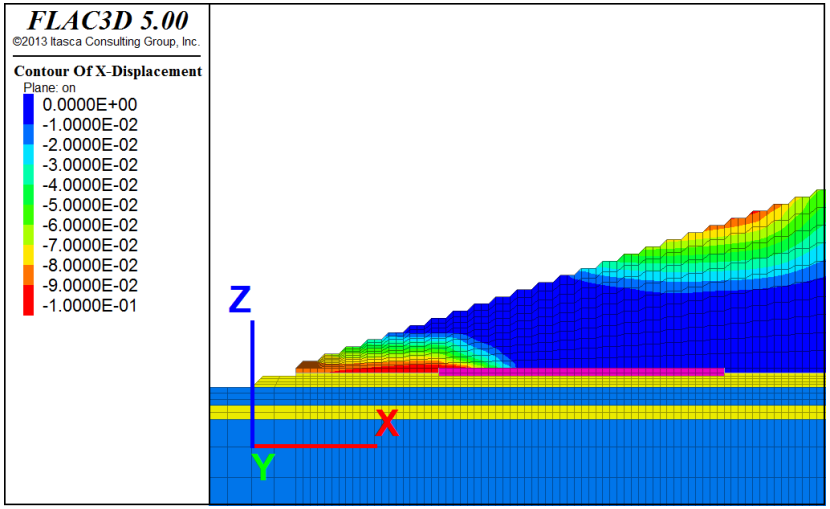
Results② - Strength factor (6 panels)

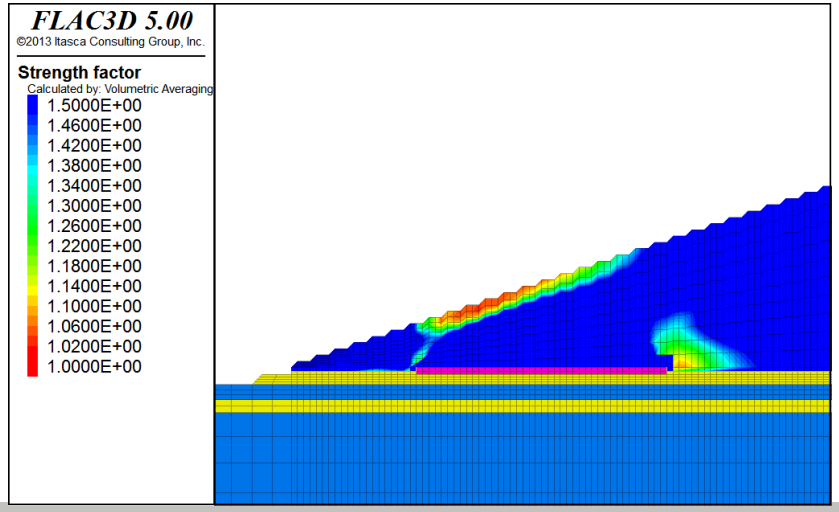
Rib-pillar length

Longwall panel length	100m	200m
300m		
400m		

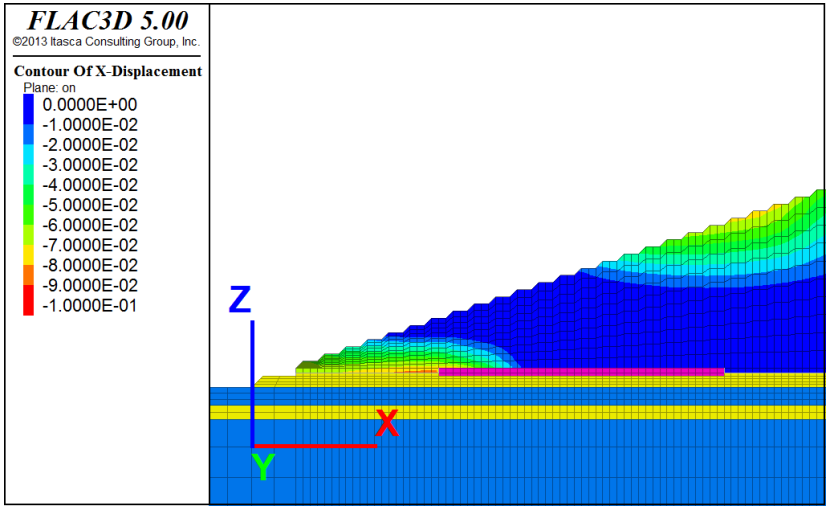
Results② - X-displacement (3 panels)

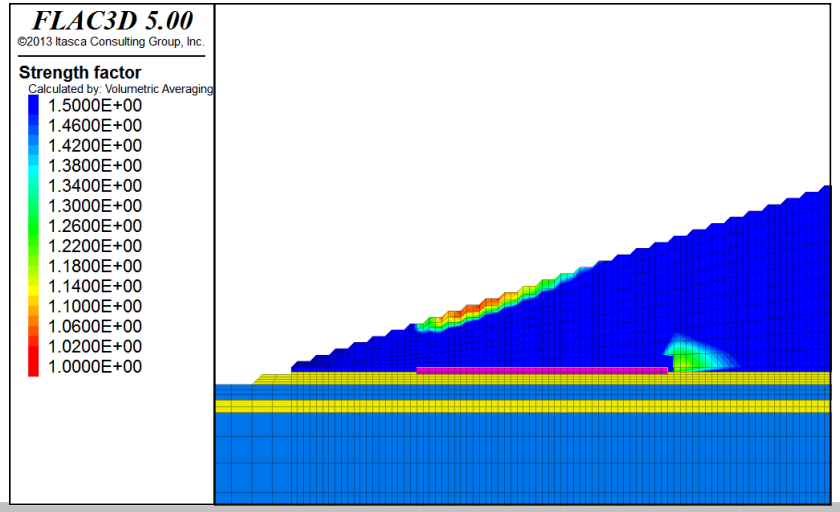
Not backfilled





Backfilled





Coal properties

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Type	Lignite	Sub-bituminous	Bituminous
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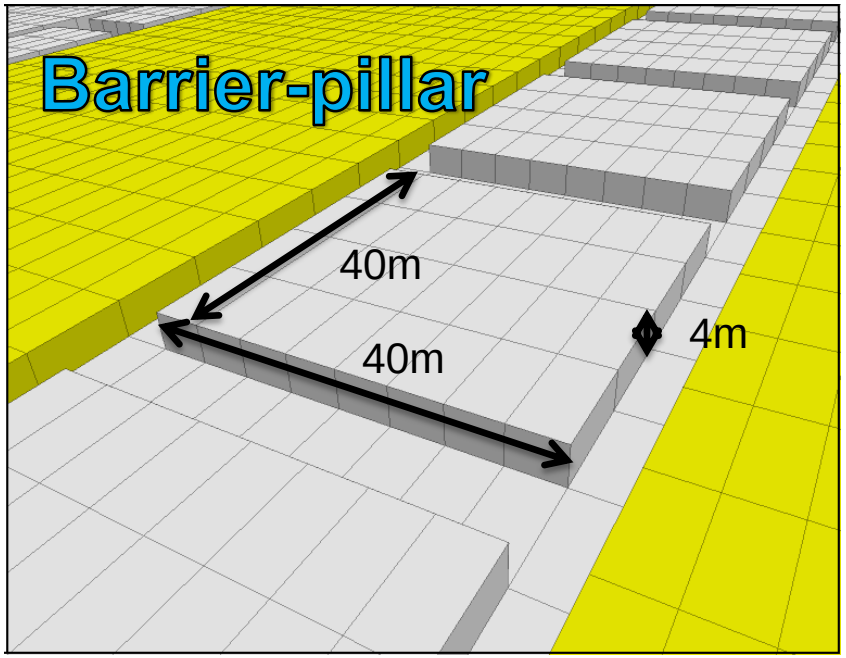
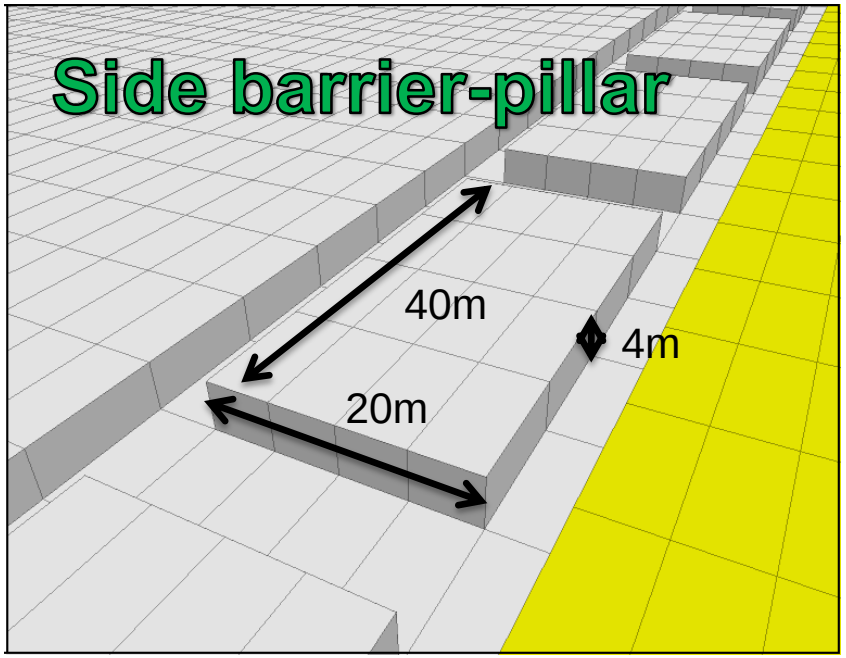
FLAC^{3D} – Barrier-pillars model geometry





Mark-Bieniawski empirical strength formula:

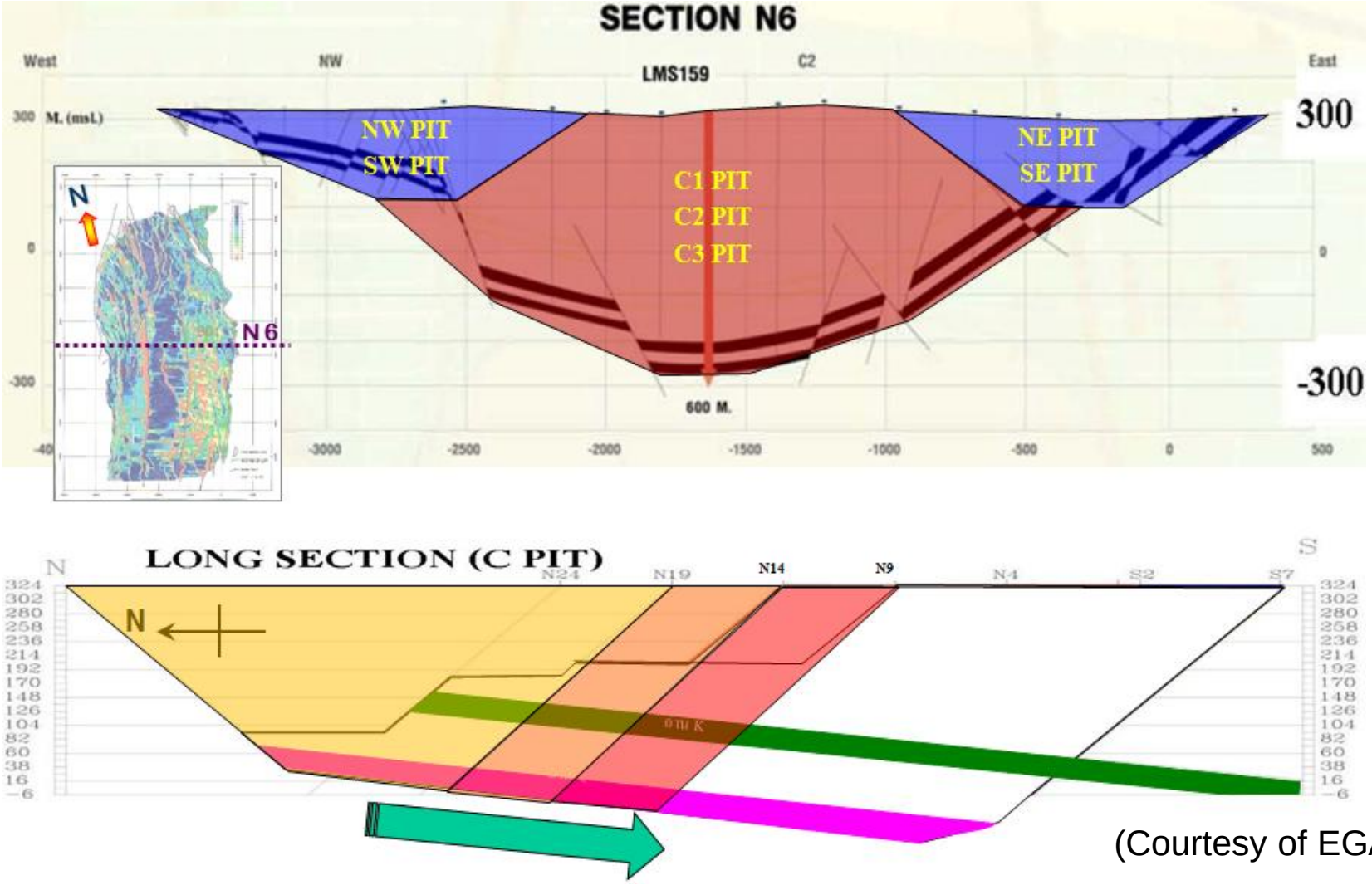
$$\sigma_p = \sigma_1 \left[0.64 + 0.54\left(w/h\right) - 0.18\left(w^2/hL\right)\right]$$

Barrier-pillar	Side barrier-pillar
σ_p = 17.4 (MPa)	σ_p = 11.9 (MPa)

σ_1 = 4.11 (MPa) (Courtesy of EGAT)

σ_p = Pillar average strength
σ_1 = In-situ strength
w = Narrowest pillar width
h = Pillar height
L = Pillar length

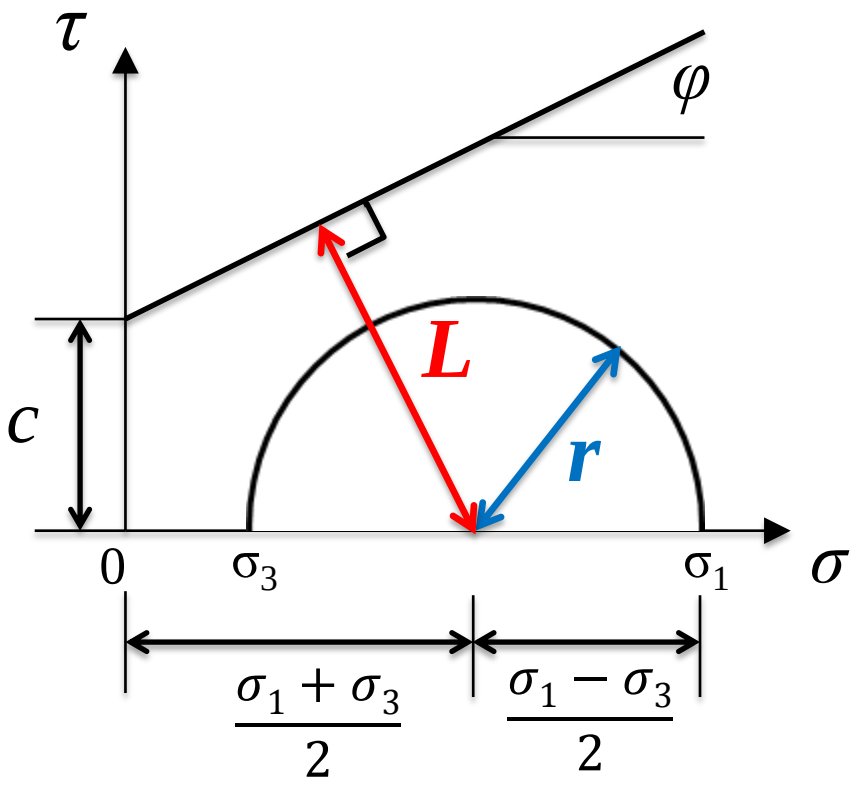
Shift to underground mining



(Courtesy of EGAT)

Assessment of stability②

Assessment by contours of strength factor based on the Mohr-Coulomb failure criteria.



Strength factor

$= L / r$