Numerical analysis of fault-slip in longwall mining using linear slip weakening law

Chunchen Wei

Chengguo Zhang

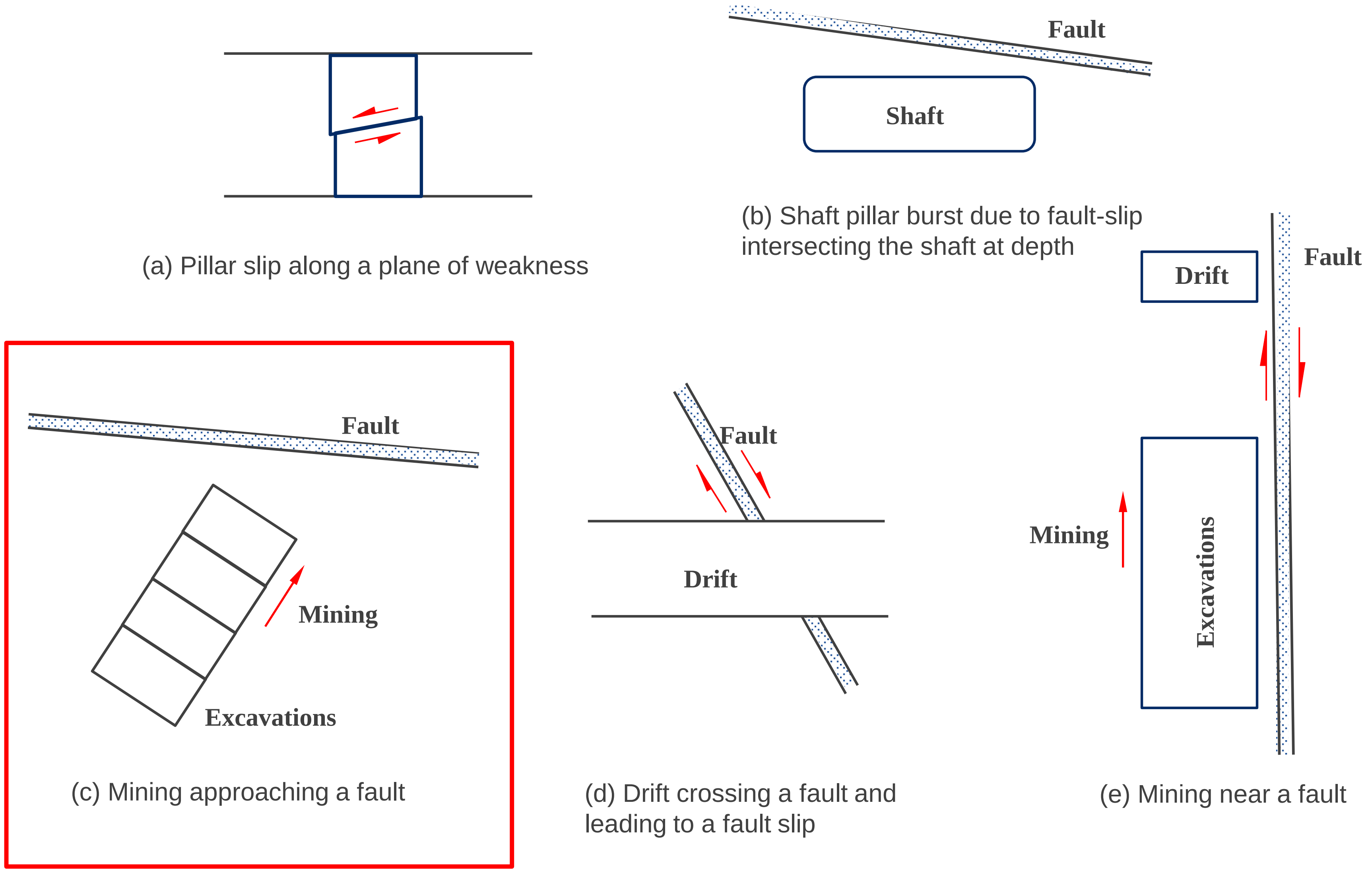
Ismet Canbulat

Fifth International Itasca Symposium, Vienna, 2020

19/02/2020

Table of Contents

Background



(a) Pillar slip along a plane of weakness

(b) Shaft pillar burst due to fault-slip intersecting the shaft at depth

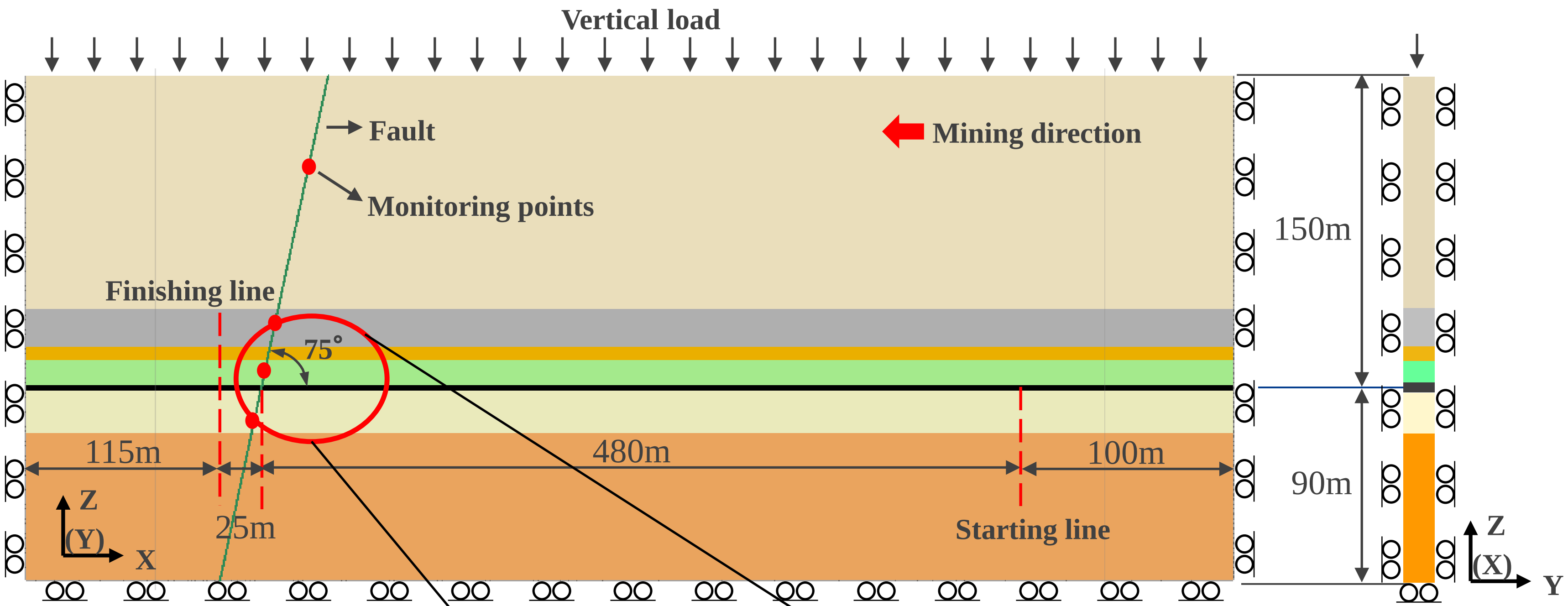
(c) Mining approaching a fault

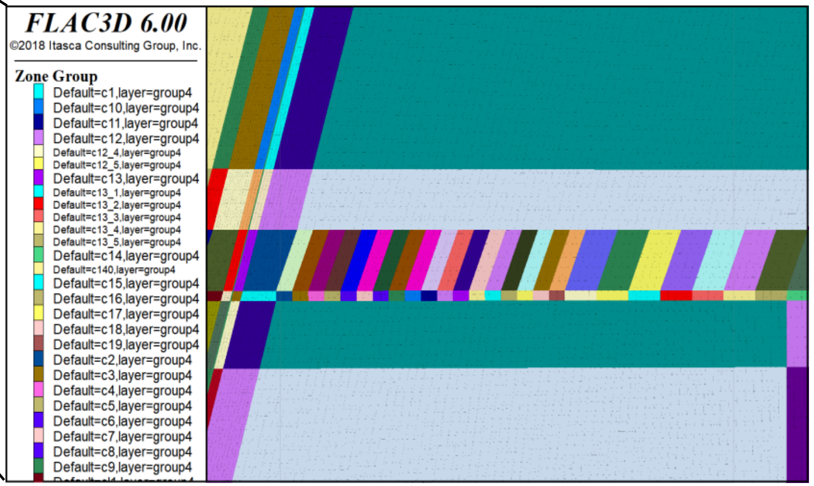
(d) Drift crossing a fault and leading to a fault slip

(e) Mining near a fault

Typical situations that may lead to fault-slip type of rock/coal bursts (Simon, 2001)

Model Geometry





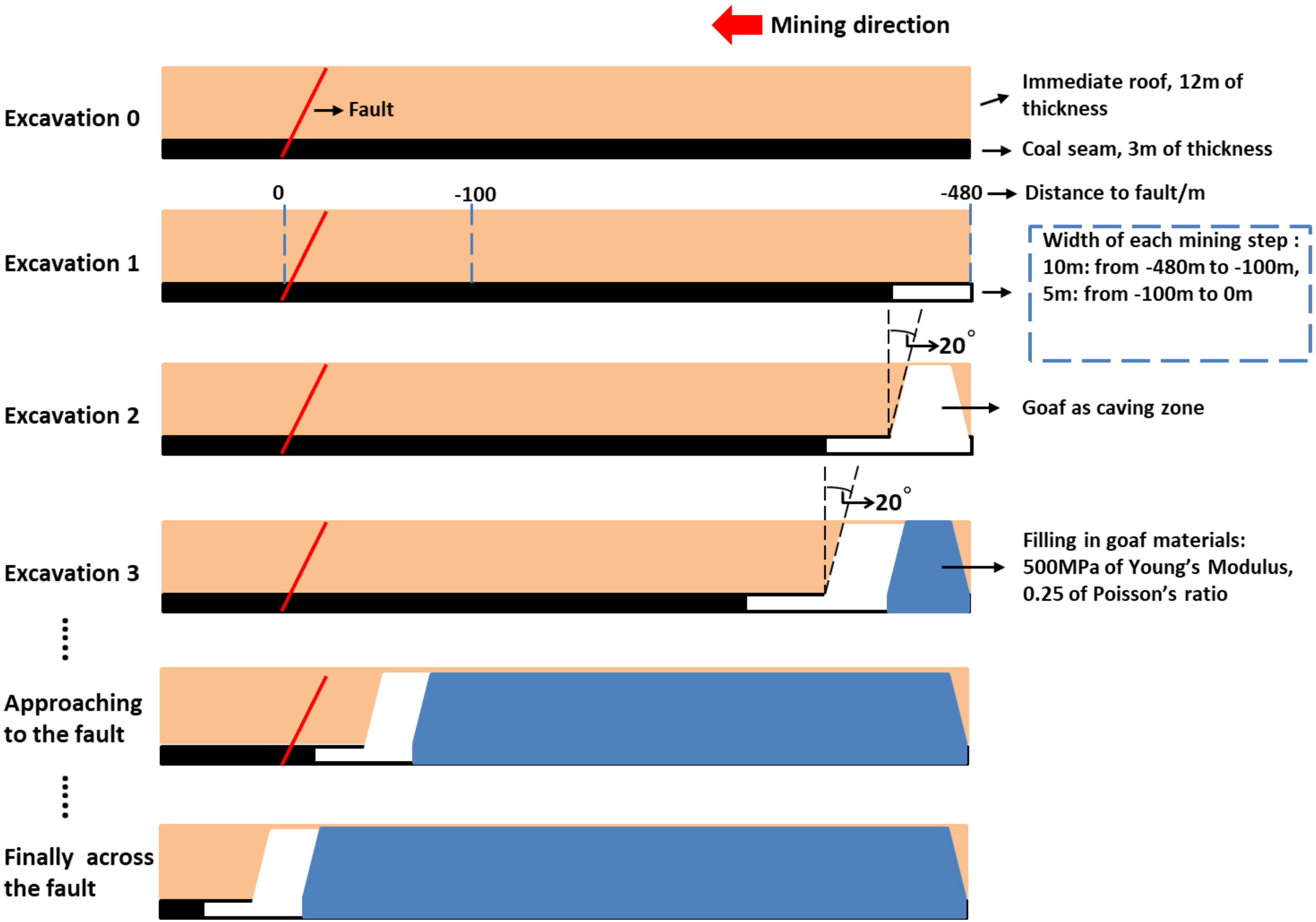
Pre-mining horizontal stress in each layer

$$\sigma_{hx} = 1.2\sigma_v + 2.6 + 0.003E$$

$$\sigma_{hy} = 1.2\sigma_v + 0.0015E$$

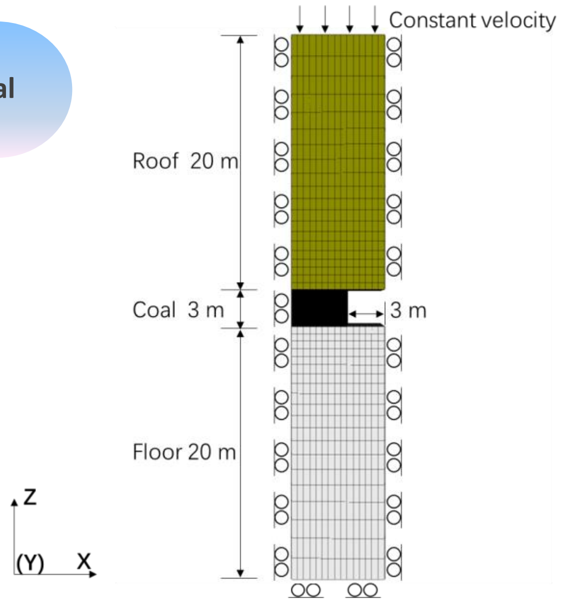
σ_v is the vertical stress in each rock layer
E is the Yong's modulus of each rock layer.
(**Esterhuizen and Mark, 2010**)

Excavation Sequence



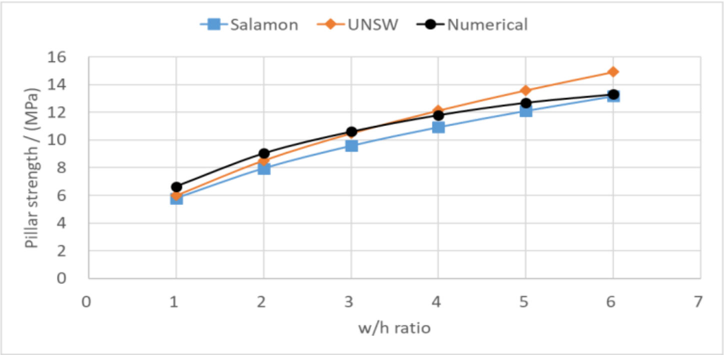
Rock Properties

Coal



$$\sigma_{ps} = 7.2 \frac{w^{0.46}}{h^{0.66}} (MPa)$$ (Salamon and Munro, 1967)

$$\sigma_{ps} = 8.6 \frac{w^{0.51}}{h^{0.84}} (MPa)$$ (Salamon et al, 1996, the UNSW Pillar Strength formula)

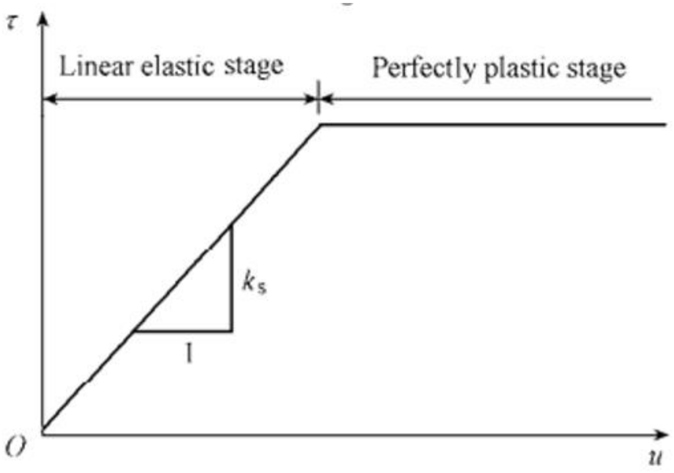


Other rock layers

	Material	thick	Lab UCS	Field UCS	E(Young's)	Poisson	Cohesion	Res. Cohesion	Friction	Tension	Res. Tension
		/m	/MPa	/MPa	/GPa		/MPa	/MPa	/°	/MPa	/MPa
Roof	Shale1	111	25	14	6	0.25	4.5	0.45	25	1.4	0
	Sandstone	18	48	27	8	0.25	8	0.8	28	2.7	0
	Shale2	6	25	14	6	0.25	4.5	0.45	25	1.4	0
Floor	Shale3	12	18	10	5	0.25	3.3	0.33	24	1.0	0
	Shale4	20	25	14	6	0.25	4.5	0.45	25	1.4	0
	Shale5	70	34	19	7	0.25	6	0.6	26	1.9	0

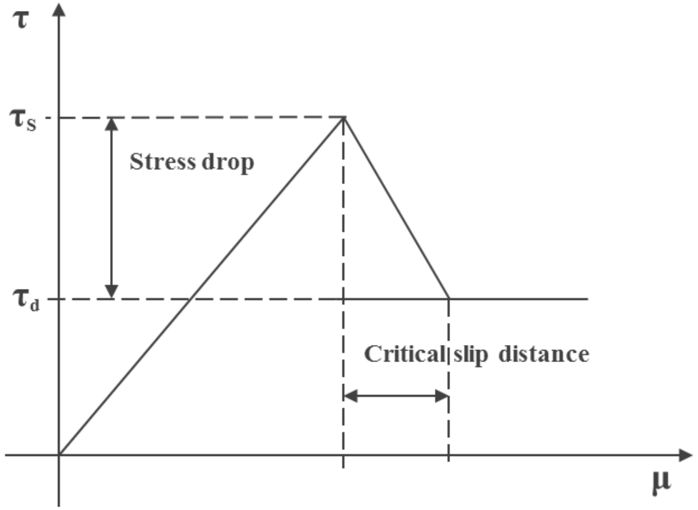
(**Zipf, 2010**)

Constitutive Model used for fault-slip



Linear elastic-perfectly plastic Coulomb shear strength criterion

$$\tau = \sigma_n \tan(\phi) + c$$



Linear Slip Weakening Law

$$\tau = \tau_s - (\tau_s - \tau_d)\frac{u}{D_C}, (u \le D_C)$$

$$\tau = \tau_d, (u > D_C)$$

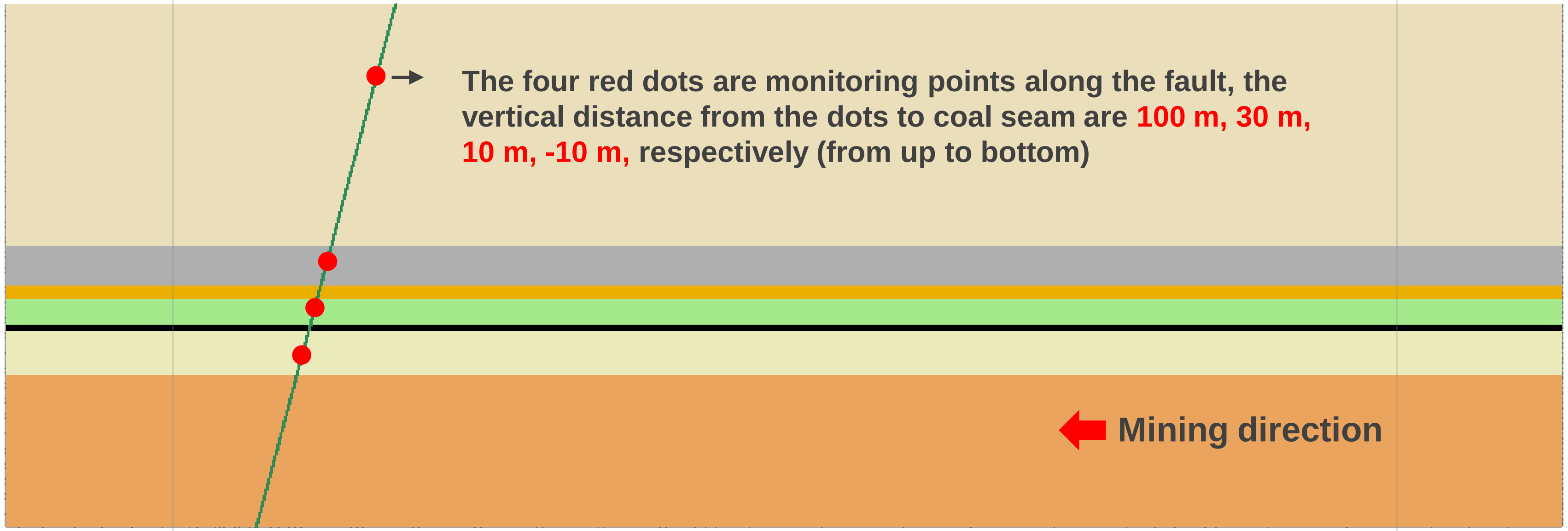
Where τ is the shear strength of the fault, τ_s is the static shear strength, τ_d is the dynamic shear strength, u is the slip distance, D_C is the critical slip distance

Parametric Study

Model design used for the parametric study

Model	Static friction/°	Dynamic friction/°	CSD/m
1	25	18	0.001
2	25	18	0.01
3	25	18	0.05
4	25	18	0.075
5	25	18	0.1
6	25	18	0.25
7	25	18	0.5
8	25	18	0.75
9	25	18	1

Evaluation Method



$$\Delta\sigma = \frac{1}{A}\int_s [\sigma(t_2) - \sigma(t_1)]dS$$

Δσ represents the stress drop defined as average difference between the stress on a fault before a seismic event and the stress after the event

$$E_s = 0.5\Delta\sigma DA$$

E_S represents the sudden energy released along the faulting area ”A” subjected to the slip “D”

$$M_o = GDA$$

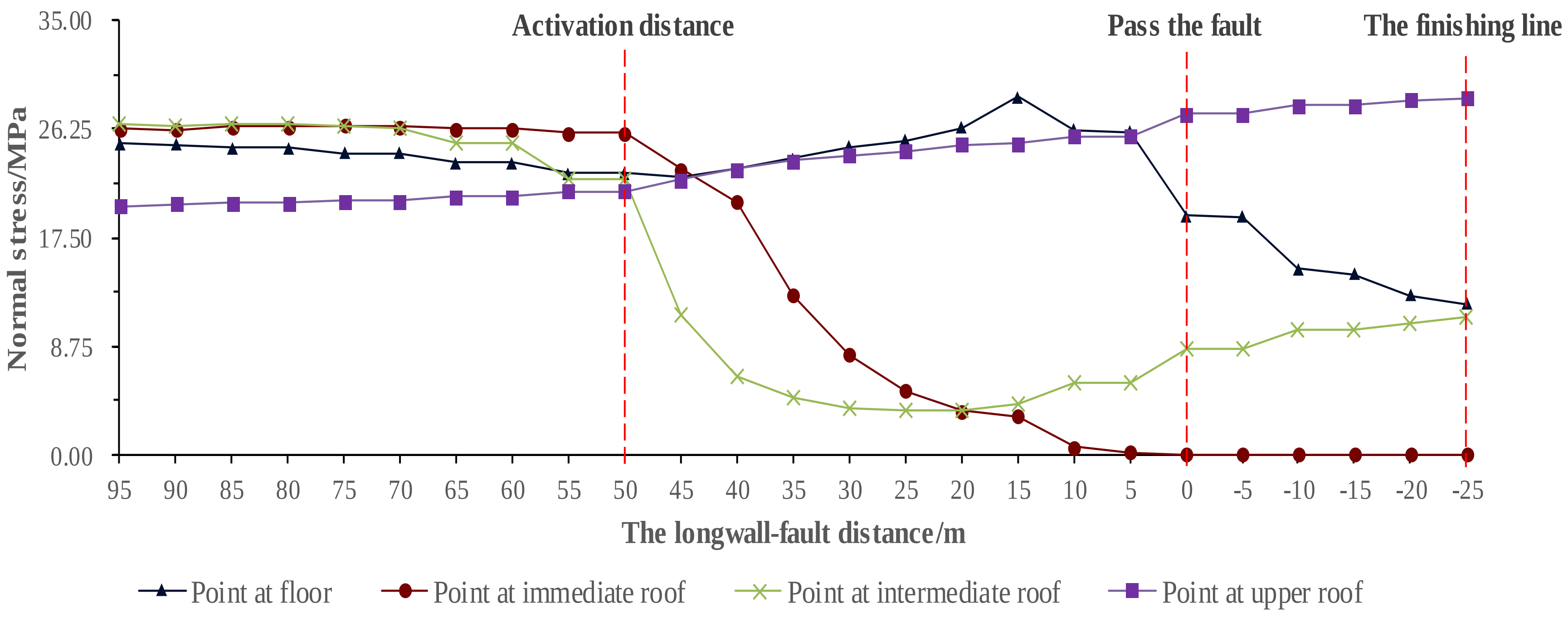
M_o is the seismic moment; D is the average shear displacement; A is the area sliding takes place.

$$M = \frac{2}{3}\log M_o - 6$$

M is the moment magnitude

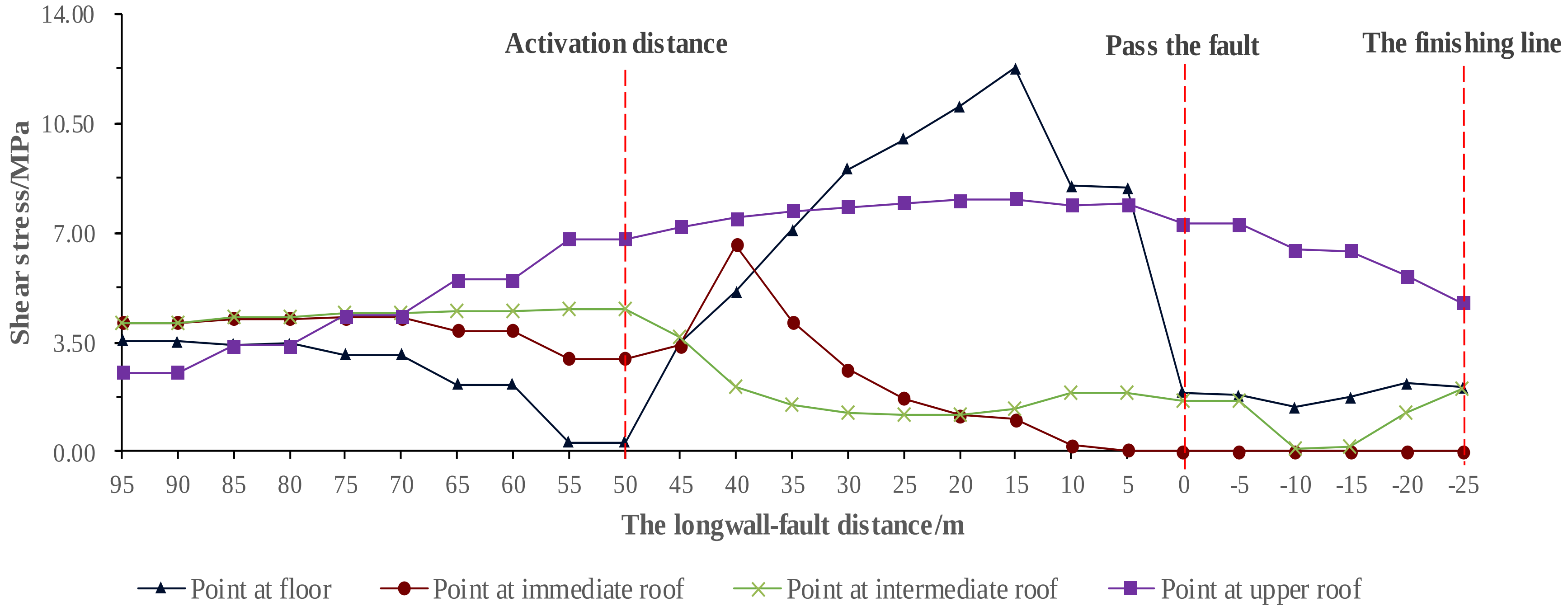
(Aki and Richards, 2002)

Normal Stress



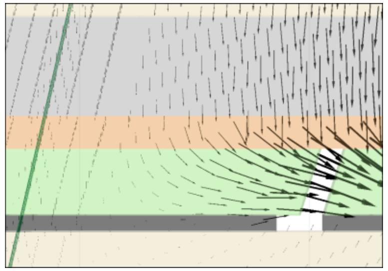
Development of normal stresses of the four monitoring points

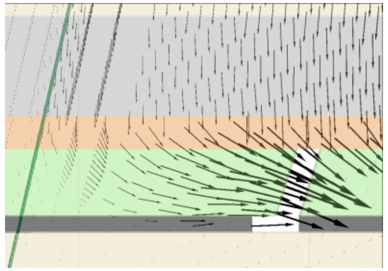
Shear Stress

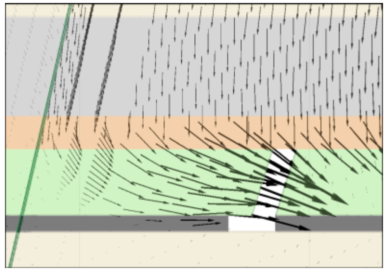


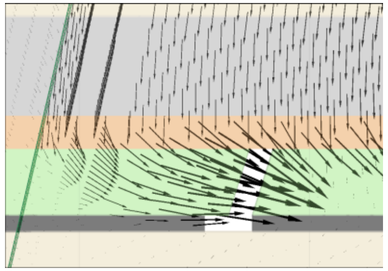
Development of shear stresses of the four monitoring points

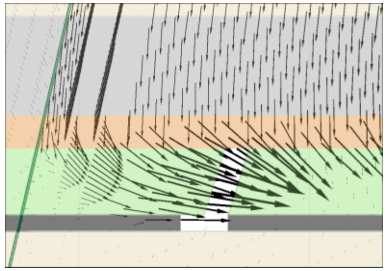
Fault slip process

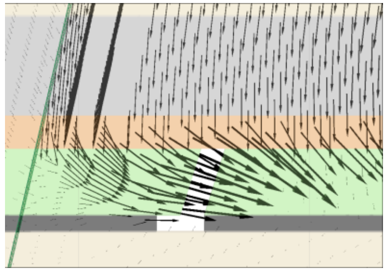

(a) 50 m


(b) 45 m

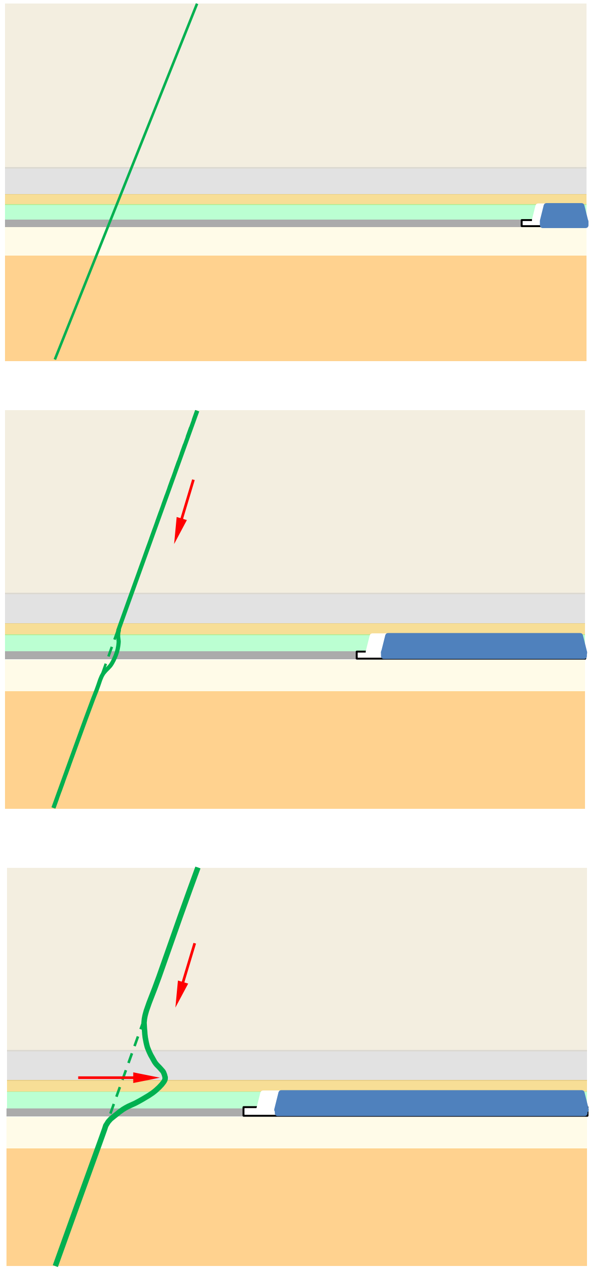

(c) 40 m


(d) 35 m

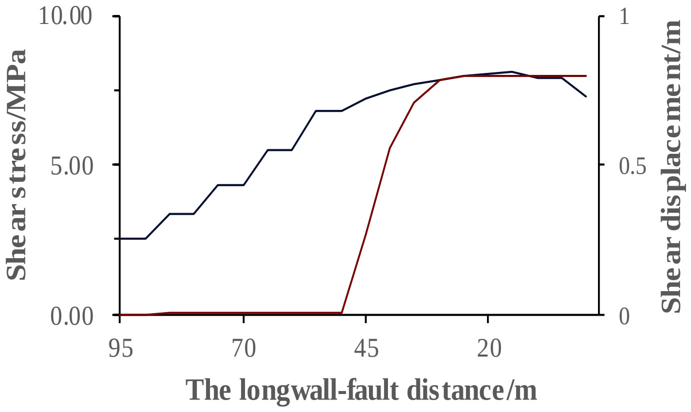

(e) 30 m


(f) 25 m

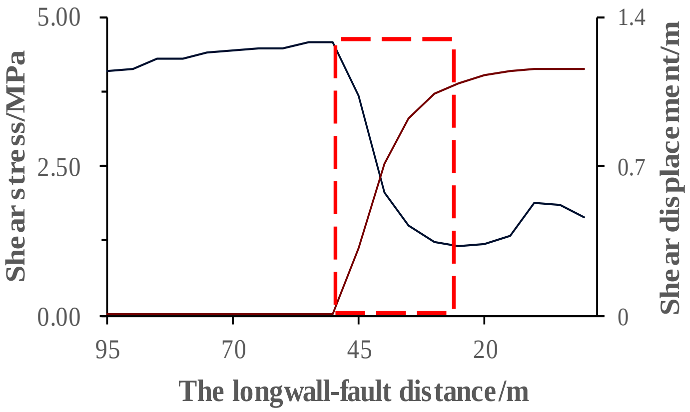
Zone Displacement Vectors



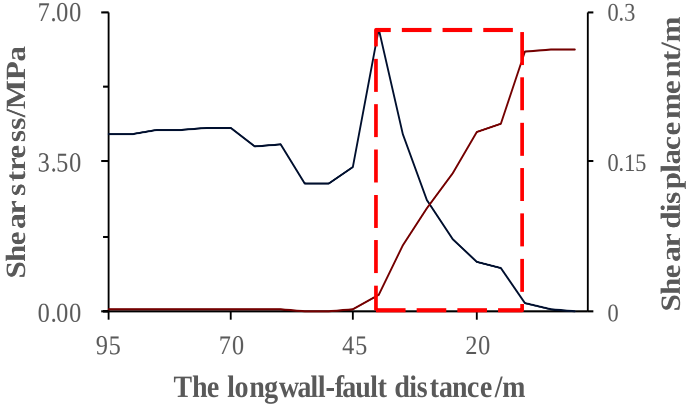
Seismic Events



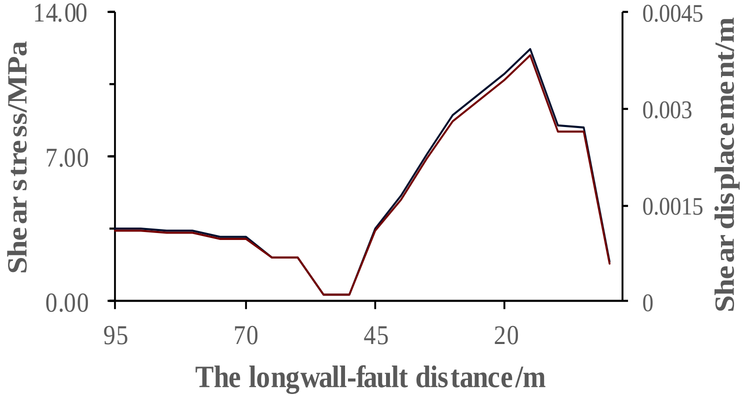
(a) Point at upper roof



(b) Point at intermediate roof



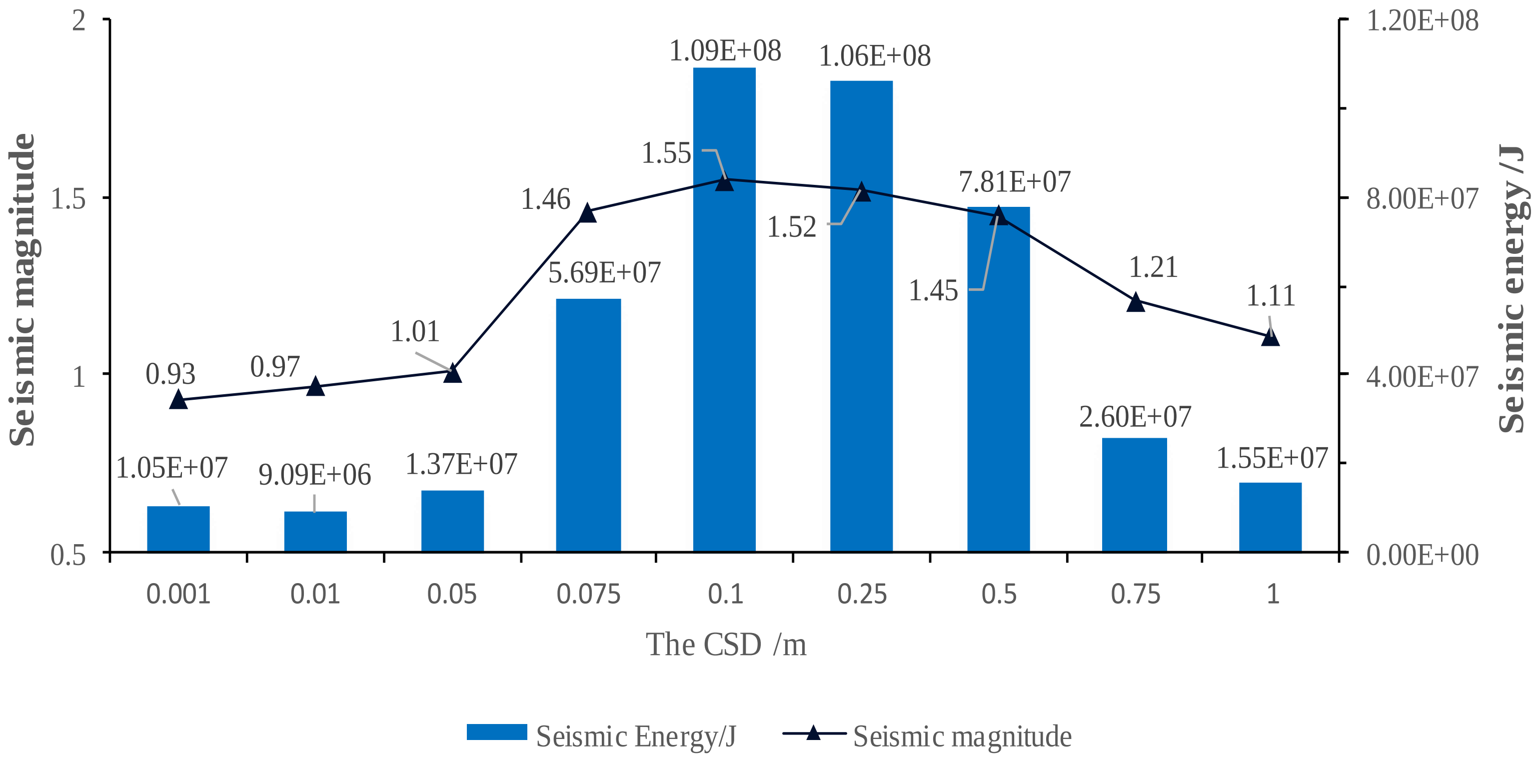
(c) Point at immediate roof



(d) Point at floor

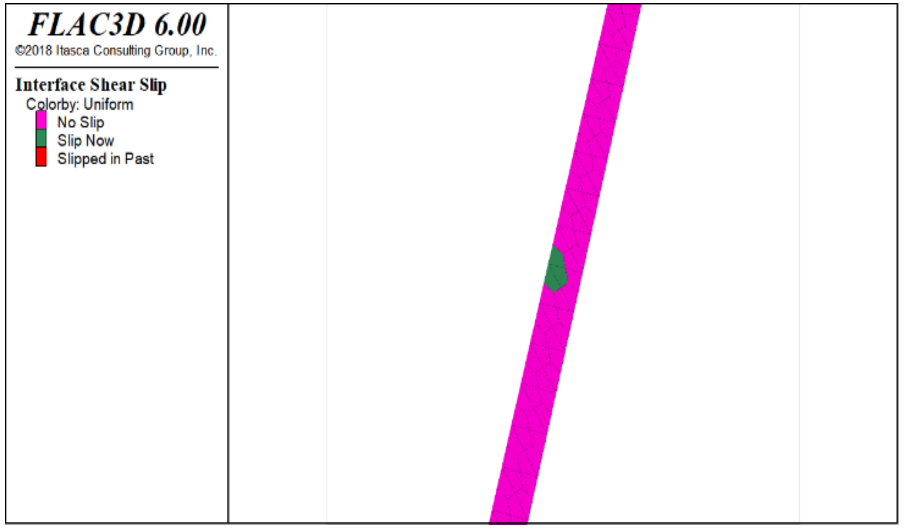
*The red line and blue line are the shear displacement and shear stress of the monitoring points

Seismic Energy



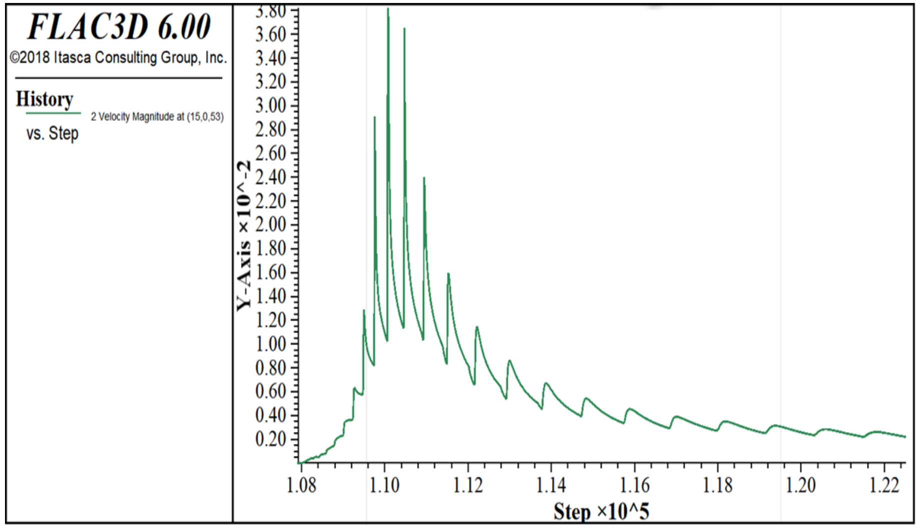
Seismic energy and magnitude of the largest seismic events in models

Dynamic analysis



The initiation position of fault-slip

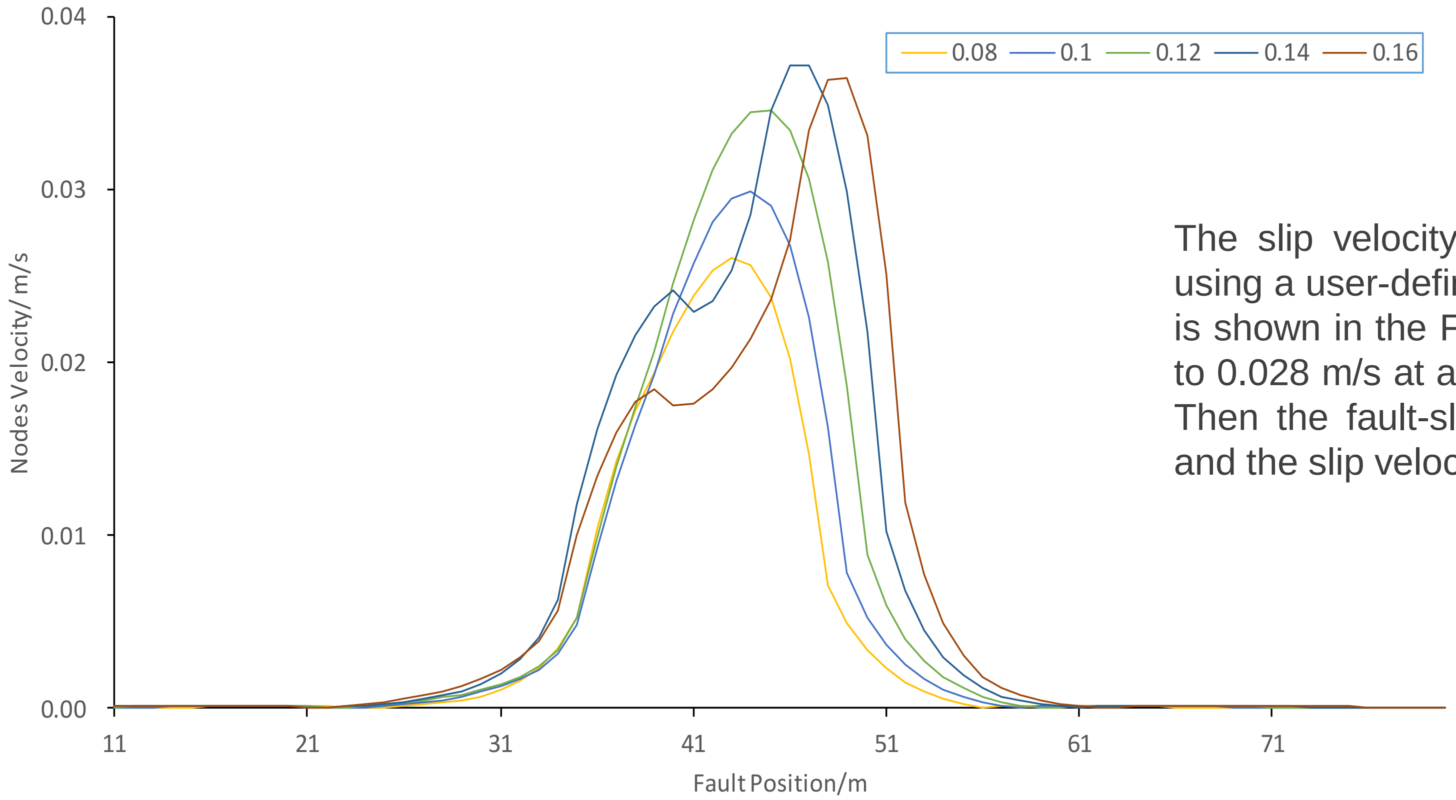
The fault began to slip when the longwall face was 50 m away from the fault. The fault-slip area appeared firstly at approximately 39 m above the coal seam.



Zone velocity close to fault

A monitoring point was set up close to the initiation fault-slip area. The maximum slip velocity at this area was approximately 0.04 m/s during the dynamic analysis.

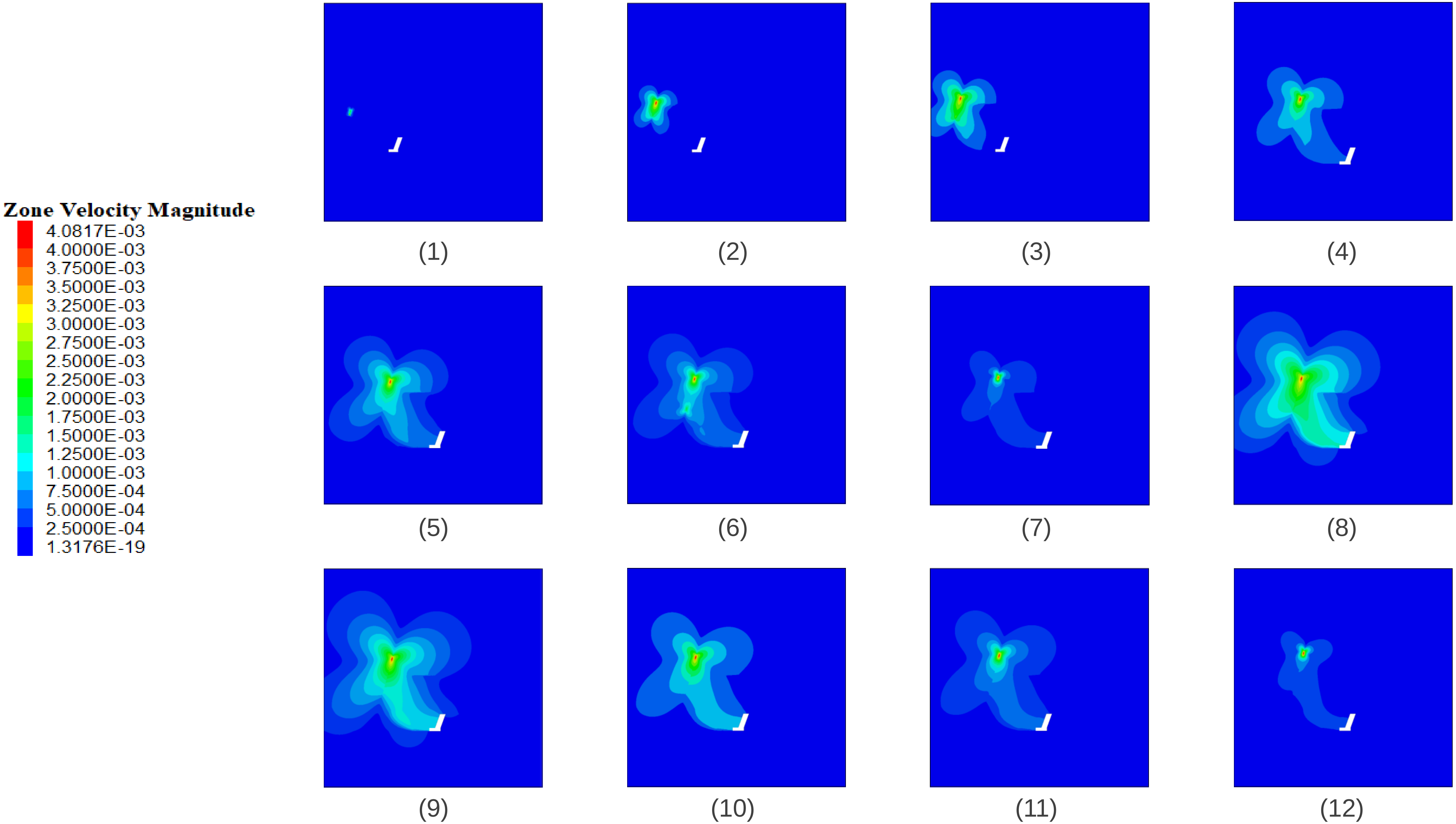
Dynamic analysis



Fault-slip process along the fault

The slip velocity of the interface nodes was monitored using a user-defined FISH program. The fault-slip process is shown in the Figure. At 0.08s, the slip velocity reached to 0.028 m/s at approximately 40 m above the coal seam. Then the fault-slip front moved upwards along the fault and the slip velocity reached to 0.04 m/s at 0.16 s.

Dynamic Analysis



Conclusions

- Seismic events mostly occurred at 0 m to 50 m above the coal seam along the fault, where this area experienced dramatic drop of normal stresses while other fault areas did not.

- The dynamic friction and the critical slip distance (CSD) influenced the occurrence trend of the seismic events.

- The model with 0.1 m of CSD produced the greatest magnitude of seismic energy.

- In dynamic analysis, the seismic wave with butterfly-pattern was produced by the fault-slip. The seismic wave gradually propagated to the longwall excavation and generated dynamic impact on the excavation boundaries.

Suggestions and Questions?

Thank you!

chunchen.wei@unsw.edu.au

UNSW SYDNEY