Application of *UDEC* to a stress-related mine slope failure at Leigh Creek, South Australia

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Background

- Leigh Creek: open pit brown coal mine in South Australia - 3 Mt of coal/year; up to 220 m deep
- Lowwall failed when Upper Series pit mined to 100 m depth; final length about 600 m around pit
- Failure involved slip on bedding shear beneath lowwall (dip 30°), yield through intact rock at toe
- Safety implications of sudden failure - require understanding of cause

Stress-related mine slope failure

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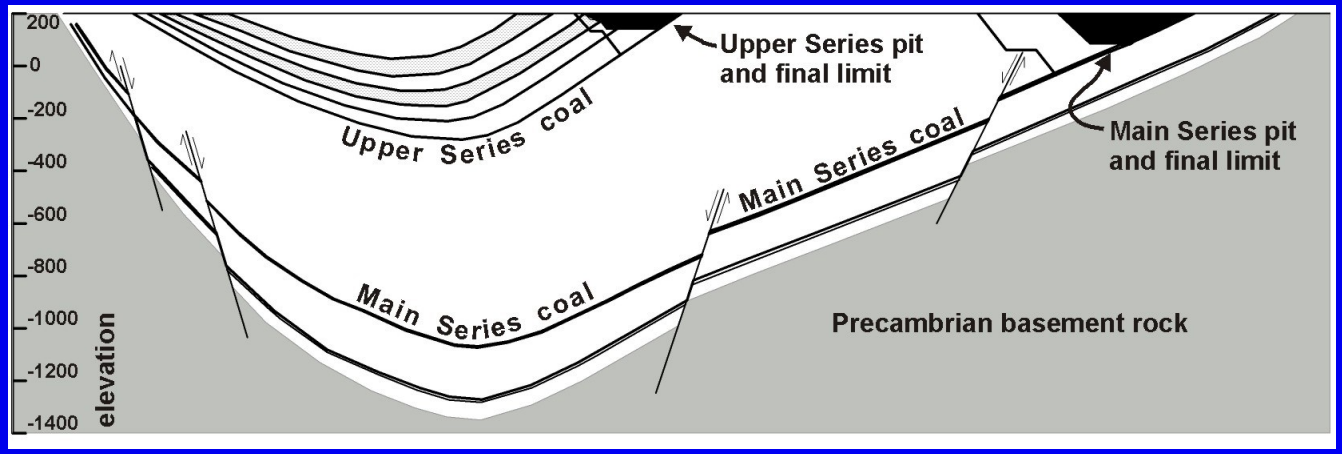
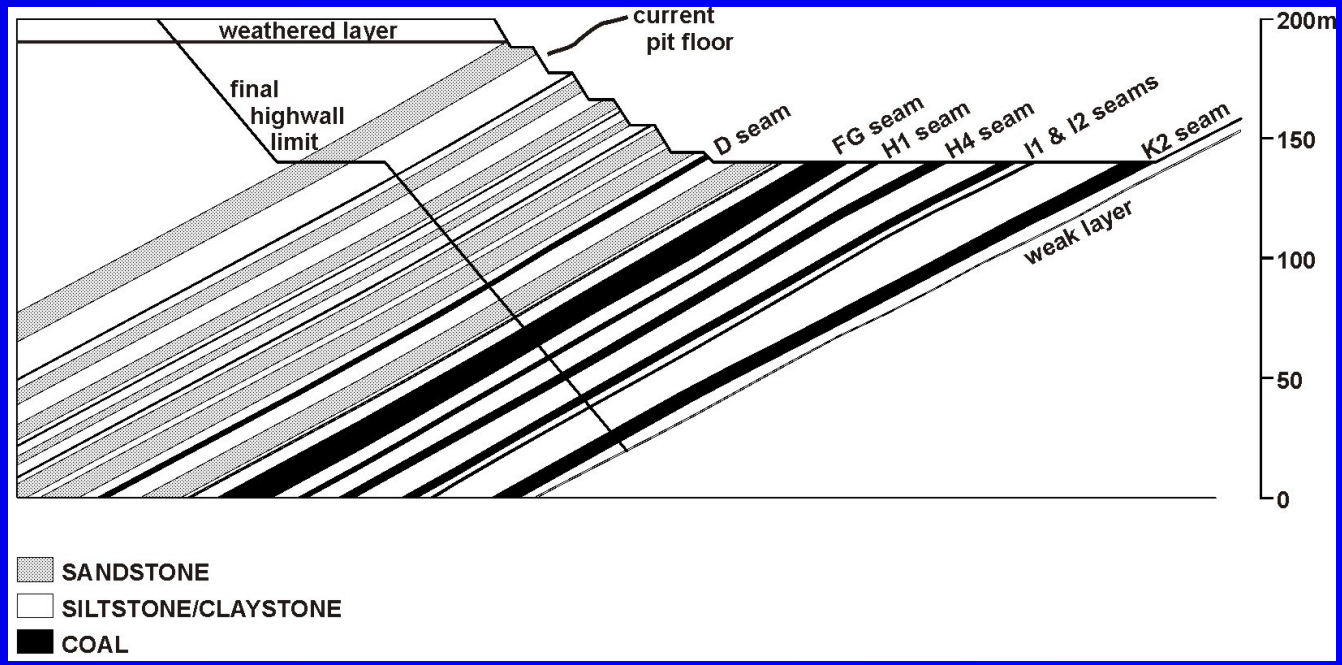
Site Geology

Section through coal measures and pits



Upper Series stratigraphy



Site Geology

- Upper series: several coal seams, up to 8 m thick
- Interburden rocks: mudstone, siltstone, sandstone
- Lowwall: base of K2 seam; 28-30° dip
- Planar bedding joints, parallel to surface, around 1 m apart, continuous
- Bedding shears: differential movement associated with some bedding joints; very low strength

Geotechnical investigations

- Importance of bedding shears in lowwall recognised in 1980s
- Thorough testing of rock units and weak layers
- In situ stresses measured at mine 150 km away - K_{0x}=1.6, K_{0z}=1.3 for plane of *UDEC* model
- Further testing in 1997 - detailed locations of shears, shear strengths; instrumentation installed (piezometers, extensometers)

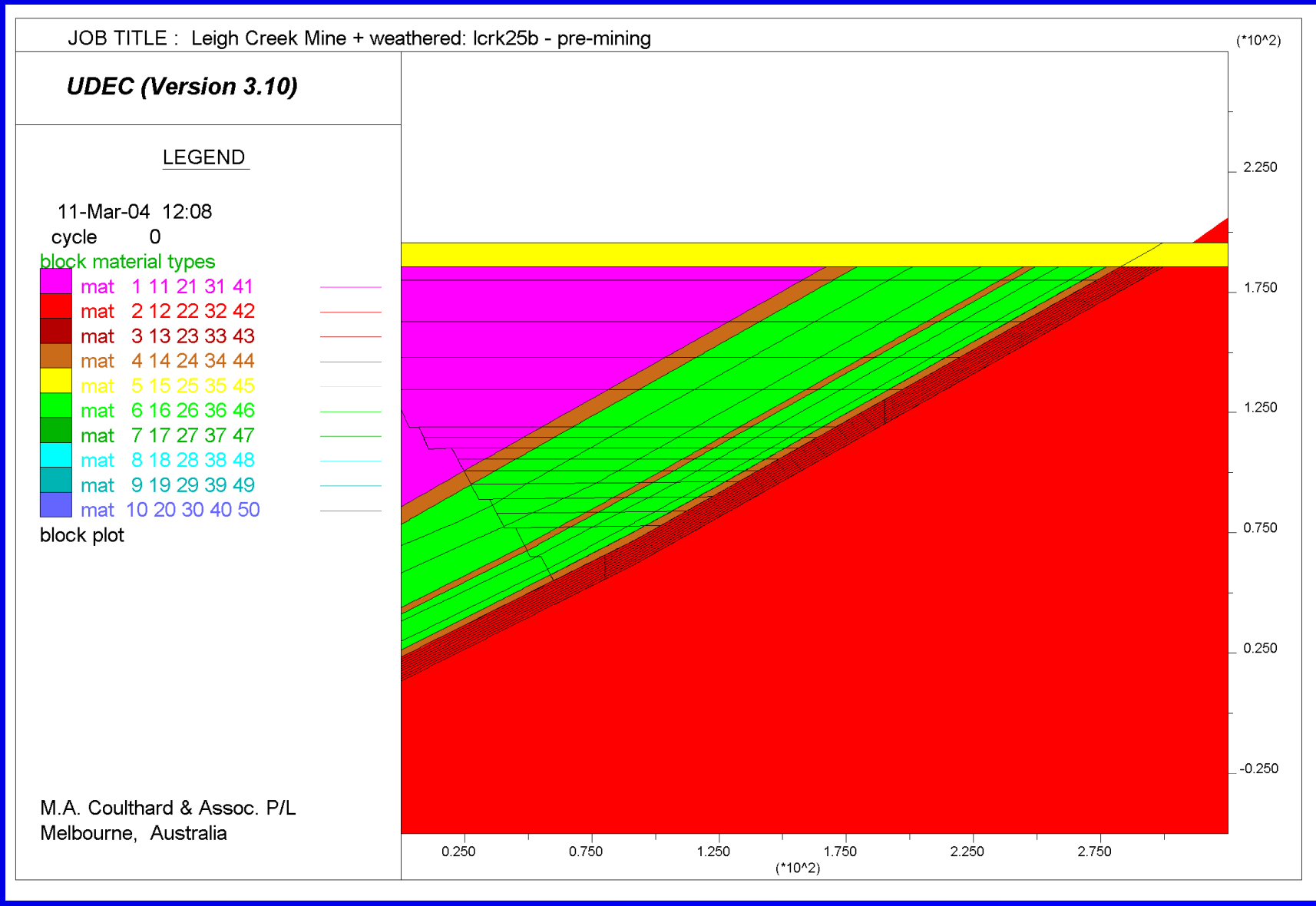
Stability analyses

- **Limit equilibrium sliding analysis predicted slope would have been stable unless:**
  . toe rock strength much less than measured; or
  . toe substantially undercut over significant length of pit
- **Buckling analysis also did not explain the failure**

UDEC modelling strategy - 1

- Geology and geometry of failure effectively 2D
- Model includes 3 coal seams explicitly, others as joints; bedding joints and weak layer
- Mining in 15 m benches at top, then 5 m benches
- Finer zoning in immediate lowwall
- Initial in situ stresses as measured set, then equilibrated

Stress-related mine slope failure



UDEC modelling strategy - 2

- Excavate 5 stages, placing overburden dump behind lowwall crest at stage 2
- Convert rock units in lowwall from Mohr-Coulomb to strain-softening; re-equilibrate
- Continue mining until failure develops, or reach current depth
- Two-part analysis of each excavation stage, to avoid spurious yield via transient stresses

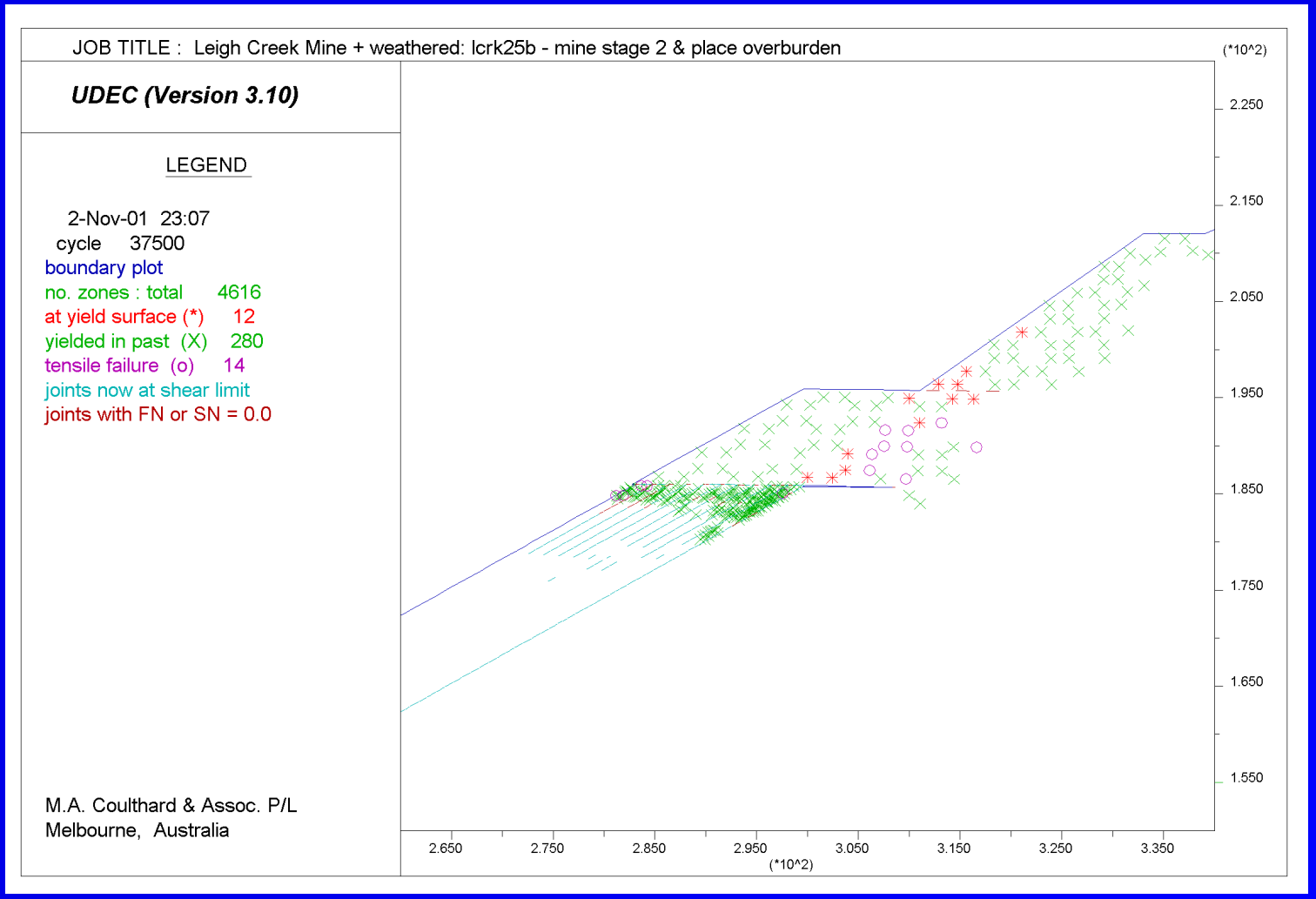
Material properties

Property	Initial value	Back-analysed value
Lowwall mudstone		
Peak/residual cohesion (kPa)	1000/10	1400/10
Peak/residual friction angles (°)	25/21	25/21
Peak/residual tensile strength (kPa)	350/0	350/0
Shear strain for residual strength (%)	1	10
Bedding joints		
Peak/residual cohesion (kPa)	10/0	1000/0
Peak/residual friction angles (°)	21/15	27/25
Peak/residual tensile strength (kPa)	20/0	20/0
Weak layer		
Cohesion/tensile strength (kPa)	0/0	0/0
Peak/residual friction angles (°)	19/15	19/15

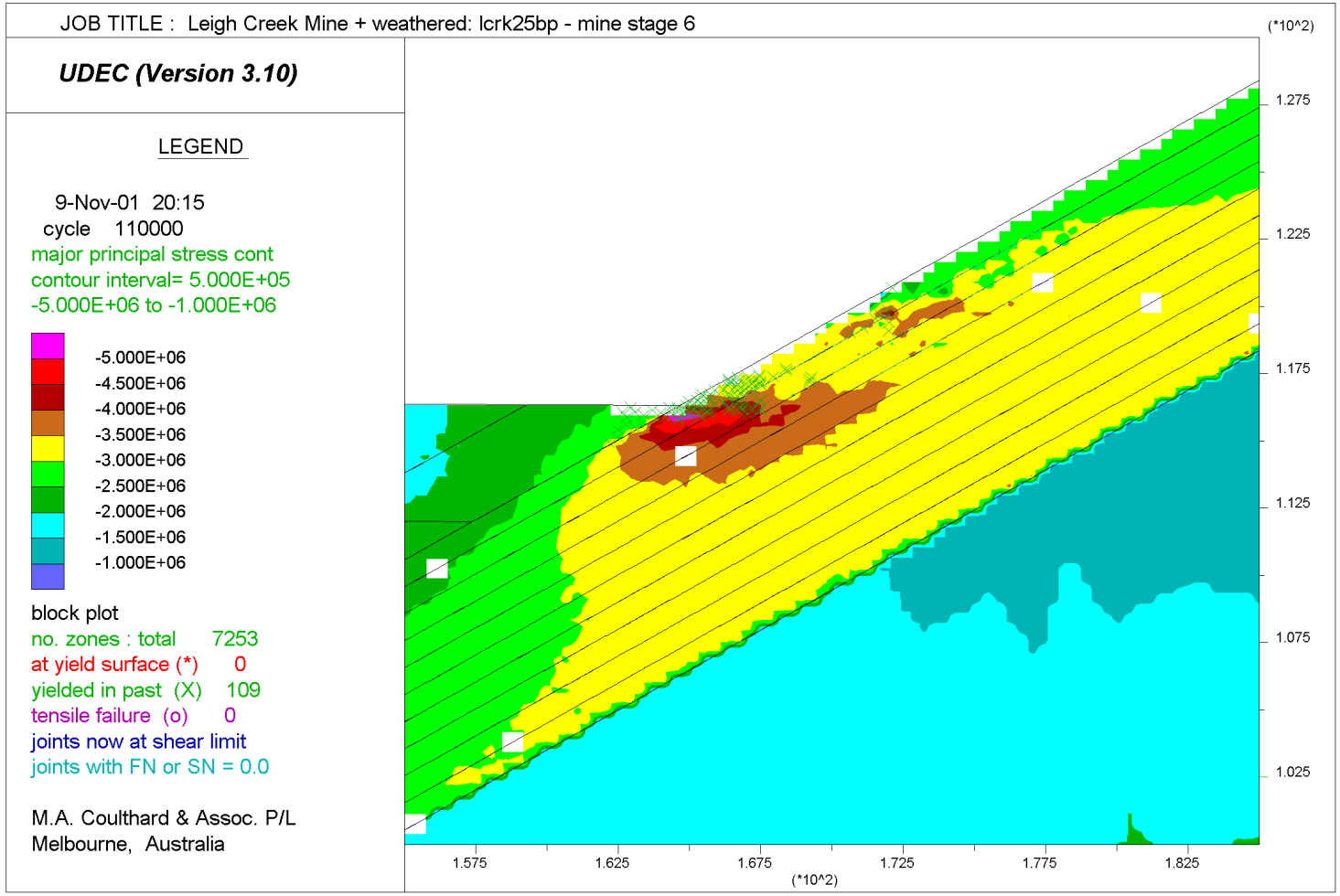
Back analysis

- Properties of critical components adjusted, within plausible ranges, until model failed with similar mechanism to real failure, and at similar pit depth
- Final parameter values were consistent with laboratory tests, where available, or with rational assessment otherwise
- Shear strain for residual strength was adjusted; this was the only parameter not supported by laboratory testing

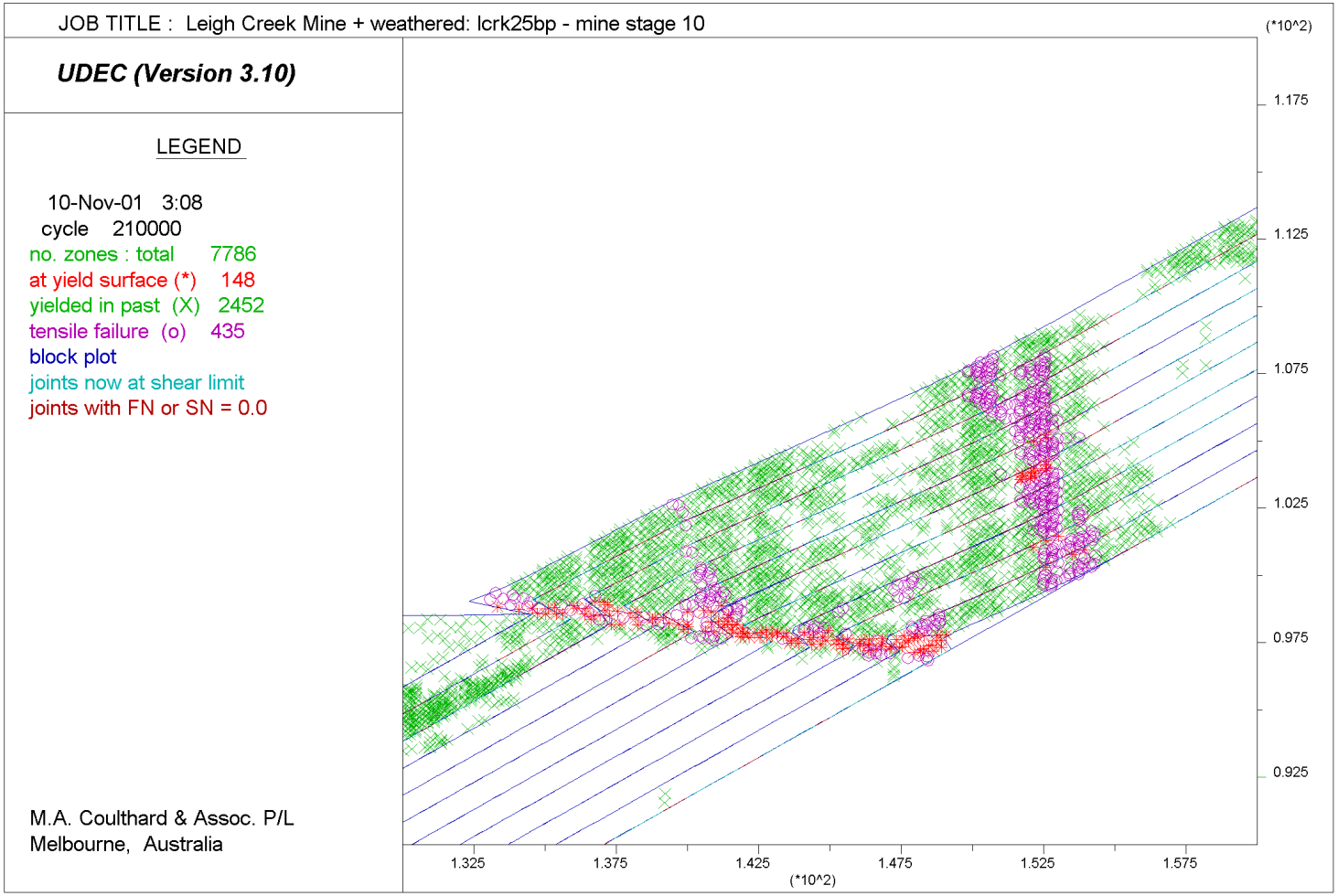
Development of failure mechanism - 1



Development of failure mechanism - 2



Development of failure mechanism - 3



Predictions for future mining

Properties from back analysis used to examine:

- effect of weak layers at different depths, in other parts of the mine;
- factor of safety of slopes at mining stages prior to failure;
- different mining and stabilisation options

Weak layer depth

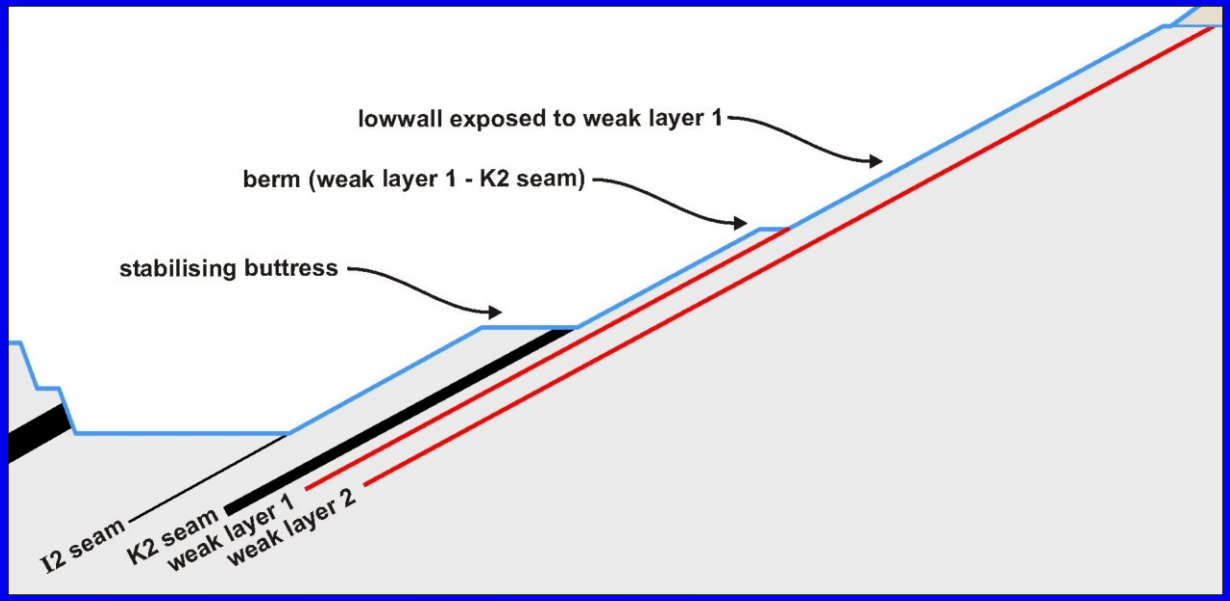
- Weak layer at 6 m and 4 m depth led to same mechanism, when pit 6 m and 9 m shallower respectively
- Deeper weak layer known to exist elsewhere, but analyses showed that it would not influence failures

Factor of safety

- *FISH* coding used to progressively reduce strengths in stable slope until failure develops
- Predicted FoS=1.20 when pit 10 m shallower than depth at failure
- Weak layer at 6 m, as in future mining areas, led to FoS=1.20 when pit 16 m shallower than for current failure

Stabilisation options

- Supporting buttress: required to be 40 m wide to mine below level for FoS=1.2
- Mining to first weak layer: reduces stress at toe, so can mine deeper before buttress required



Monitoring

- **Measurements to confirm model predictions:**
  - Uplift of berm by slip on the exposed weak layer;
  - Stress accumulation below pit floor, between weak layers.
- **Mining to the *UDEC*-designed lowwall profile, with displacement monitoring:**
  - Radar and prism monitoring;
  - *UDEC* predicts bulging of toe prior to failure.

Conclusions

- Leigh Creek: stress-induced failure developed in a shallow open pit mine
- Limit equilibrium methods are widely used to analyse such slopes, but did not predict failure in this case
- *UDEC* model explained failure mechanism
- Back analysis parameters used to design adjacent slopes