SURFACE MINING

Traditionally two General Subdivisions:
- Hard Rock and
- Soft Rock.

But
- "all geotechnical materials are part of one continuous spectrum";
- "one continuous science extending from soft soils to hard rocks; all geotechnical materials behave according to the same engineering principles";
- "differences a function of degree rather than fundamental nature" (Johnston 1991).

OPEN CUT MINE SLOPE DESIGN

Application of scientific methods and engineering principles to the materials of the earth’s crust for the solution of engineering problems.

MINE SLOPE DESIGN:
- Soil mechanics,
- Rock mechanics,
- Hydrogeology and
- Geology.

Geologically based science.
Fundamental corner stone of all mine slope design is geology.
Success with mine design depends on the ability to understand the geology.
In particular, the Patterns, Subtleties and Variations.

ENGINEERING AND SCIENTIFIC DISCIPLINES

What are the general slope design rules?

"achieve an optimum design — a compromise between a slope which is steep enough to be economically acceptable and one which is flat enough to be safe" (Ross and Bray, 1981).

What is the practical reality to statements such as:
- "steep enough to be economically acceptable" or
- "flat enough to be safe".

The other general definition of the optimum pit slope design is:
- "The best design is the one which falls down the day that the last truck leaves the pit".
**SIMPLE GEOLOGY – RISK?**

- How effectively can we understand the geology?
- Comparison of drilling and interpreted faults

**COMPLEX GEOLOGY – RISK?**

**TECHNICAL COMPLEXITY AND RISK?**

**MINE GEOMETRY AND RISK?**

**MINE GEOMETRY AND RISK?**
MINE GEOMETRY AND RISK?

EXCAVATING A SLOT NEXT TO AN UNSTABLE HIGHWALL
"...slopes seldom fail without giving adequate warning" (Hoek and Bray 1974)

Five Scales Of Problem:
• Very Large Post Failure Deformations
• Large Blocky Failures and Collapses – Highwalls and dump
• Bench Failure
• Rockfall
• Small Individual Blocks
z 21st October 1966.
z 144 deaths, including 116 children.

- Colliery waste had been dumped above the village for more than 20 years.
- Two previous dump failures had occurred: 1944 and 1963. The 1963 failure was in the same location as the 1966 failure.
- Because mine personnel were not injured and the downstream environment was not significantly damaged, the 1944 and 1963 slides were ignored.
SUMMARY OF ISSUES AND FINDINGS

GEOTECHNICAL FACTORS

Dump formed over springs, led to softening of the toe. Dumped materials a mixture of rock, coal slurry and water. High moisture content of dump material lead to liquefaction. Failure took a few minutes.

CONCLUSIONS OF INQUIRY

"...the Aberfan Disaster is a terrifying tale of bungling ineptitude by many men charged with tasks for which they were totally unfitted, and of total lack of direction from above. Not villains but decent men, led astray by foolishness or by ignorance or by both in combination, are responsible for what happened at Aberfan."

THREDBO LANDSLIDE 1997
18 DEATHS

LOCATION IN THE VILLAGE

LANDSLIDE MASS
ONLY 1300 m³

VIEW OF TOP OF SLIDE

"LOST FORGOTTEN OR IGNORED"

- Over 40 year history of similar but infrequent slides in the area.
- Site originally classified as "unstable and unbuildable"
- Loose dumped fill at 40° over an old landslide.
- High pressure water pipeline
  - Asbestos cement with simple push couplings
  - Approved and constructed through the site.
2007 MITSUBISHI LECTURE

Part 3
Large Blocky Failures
Highwalls
And
Benches

CARTENGA COAL MINE COLUMBIA
DRAGLINE
SPOIL DUMP
BRIDGE

LOADER

TOE OF FAILURE

OVERALL VIEW OF HIGHWALL FAILURE
SHEAR ALONG JOINT PLANES

PREVIOUS FAILURE OF SAME TYPE IN THE SAME SLOPE AT HIGHER ELEVATION ALSO AFFECTING HAUL ROAD

TRI-STAR COAL MINE
MARYLAND USA

17th April 2007 – 2 killed

OVERALL VIEW OF HIGHWALL COLLAPSE

KIDSTON – OVERALL VIEW

CABLE BOLTED FOOTWALL STEEPENED BELOW HAUL ROAD

PRE-SPLIT DRILL RIG
DRILLING SECOND LIFT OF TRIPLE BENCH

Drill rig located here Failure plane and collapse
CHARACTER OF FAILURE PLANE

HOLES HALF FULL OF GROUT AND CABLES NOT GROUTED

COAL MINE

UNCONTROLLED PLACEMENT OF WET TERTIARY IN DUMP

EQUIPMENT DAMAGE

LOSS OF PRODUCTION
Catastrophic failure of a portion of the western wall of the Fairyland open pit occurred near an excavator that was digging and loading ore into haul trucks. An ore control technician directing the activities of the excavator was fatally injured when buried under the rockfall.

Immediate suspension of mining and mobilisation of the Mine Rescue Team. Notification of all relevant authorities. An investigation by the Western Australian Police commenced immediately and by the Department of Mineral and Petroleum Resources early the next day. Nature of the failure prevented immediate rescue attempts. Recovery of the body 41 hours after the event.

Earlier inspection of the wall shortly before the event by a geotechnical consultant and other staff gave no indication that failure was imminent.

Cause: proximity to pit wall.
Part 4
Rockfall Issues
And
Conclusions

Diagrama de sucesos
Accidente Fatal
29 de octubre de 2003
Operaciones Mina Rajo Abierto
División Mantos Blancos

Diagrama frontal del sector del suceso:

Zona de posible desprendimiento de la roca.

Línea de perfoación.

Cargador frontal 8703, operado por Jorge Campos, al quien se le iba a entregar el material de limpieza.

Posición final del camión siniestrado.

Barra de perforación, con 6 metros de avance aproximadamente.

Imagen tomada desde el banco 756.
Distancias de la camioneta hasta el talud y berma delimitadora de distancia.

Imagen tomada en el banco 684, sector del incidente.

Zonas de impacto de la roca (cabin).

Zona de posición final de la roca.

Zona de impacto directo de la roca en la camioneta.
SMALL RAVELLING FAILURE
EVEN SMALL ROCKS CAN BE A PROBLEM

RESULTANT VEHICLE DAMAGE

PLACEMENT OF 
SUMPS AND PUMPS
CONTROL OF 
PERSONNEL 
ACCESS

PROCEDURES AND CONTROLS FOR LIGHT 
VEHICLE ACCESS

LARGE EXCAVATING EQUIPMENT
USUALLY A PRODUCTION ISSUE

LARGE EXCAVATING EQUIPMENT
USUALLY A PRODUCTION ISSUE
BUT IT DEPENDS ON CIRCUMSTANCES
FIXED INFRASTRUCTURE

OPERATOR ESCAPED UNINJURED

ROCKFALL: WHO IS AT RISK?

ANCILLARY EQUIPMENT?

LOCATION OF SUMPS AND ANCILLARY EQUIPMENT, ACCESS ON FOOT?

OPERATORS AND LIGHT VEHICLES?
SLOPE FORM EXACERBATES ROCK FALL PROBLEMS – NO EFFECTIVE BENCHES

STEEP BENCH SLOPES POTENTIAL FOR SUDDEN FAILURE

ROCK FALL FENCES FALSE SECURITY?

ACCESS CONTROLS

IMPORTANCE OF PROCEDURES AND CONTROLS

LARGER SCALE WALL FAILURES CONTRIBUTING FACTORS

<table>
<thead>
<tr>
<th>INCIDENT</th>
<th>PRINCIPAL CAUSE</th>
<th>MINOR CAUSE</th>
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</thead>
<tbody>
<tr>
<td>Slope failure</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Large pit wall failure</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Highwall failure</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Failure leads to mudflow</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Failure undercuts equipment</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Loss of equipment over pit edge</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Large pit wall failure</td>
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<td>•</td>
</tr>
<tr>
<td>Failure to appreciate significance of previous incident (history)</td>
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</tbody>
</table>

Note 1: Failure to appreciate significance of previous incident (history)
LARGER SCALE FAILURES

- The contributing factors in order of decreasing frequency:
  - Geotechnical Issues – 14 cases.
  - Access, Procedures and Controls – 3 cases.
  - Warnings Ignored – 2 cases.
  - Open Cut Design Issues, including implementation of design – 2 cases.

Important conclusions are:
1. The overriding influence of geotechnical issues in these serious larger scale failures.
2. The concern that specific warnings apparently went unheeded in two of the cases.

ROCKFALL CONTRIBUTING FACTORS TO FATALITIES AND SERIOUS NEAR MISSES

- Rockfall onto drill
- Rockfall onto truck and excavator
- Rockfall hits light vehicle
- Ravelling rockfall on light vehicle
- Rockfall through windscreen
- Rockfall below cutback
- Bench failure and rockfall
- Inadequate separation between unstable area and access location
- Location of sumps, pumps, and ancillary services
- Inadequate awareness and access controls
- Poor control of cutback excavation
- Berm loss
- Poor blasting practices
- Inadequate support of poor rock mass zone
- Slope too steep for geotechnical conditions
- Inadequate catch fence design

ACCESS PROCEDURES AND CONTROLS

EXCAVATION PRACTICES

DESIGN ISSUES

DEEP OPEN CUT MINE SLOPE DESIGN ELEMENTS

AND RISK AREAS

SLOPE DESIGN ELEMENTS

DRAGLINE MINE DESIGN ELEMENTS
SHALLOW OPEN CUT DRAGLINE MINE
SLOPE DESIGN ELEMENTS AND RISK AREAS

<table>
<thead>
<tr>
<th>SLOPE DESIGN ELEMENT</th>
<th>COMPONENT</th>
<th>CONTROLLING OR INFLUENCING FACTOR</th>
<th>RISK AREA</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Environmental Issues</td>
<td>Mining/Exploration Issues</td>
</tr>
<tr>
<td>HEADROLL</td>
<td>Angle</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Height</td>
<td></td>
<td></td>
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<tr>
<td>LOW WALL</td>
<td>Angle 1</td>
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<tr>
<td></td>
<td>Height</td>
<td></td>
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<tr>
<td>SPoil Dump</td>
<td>Angle</td>
<td>●</td>
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<tr>
<td></td>
<td>Height</td>
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LESSONS LARGE FAILURES
- Role of HISTORY.
- Importance of overall GEOLOGICAL SETTING.
- Experience with MOVING SLOPES.
- Critical role of pore pressure responses.
- Understanding POST FAILURE BEHAVIOUR AND DEFORMATIONS.
- Experience base used to predict future performance, is it adequate or appropriate?
- MONITORING must be right.
- If the environment is different will the performance be the same; climate, stress, blasting?

LESSONS FROM SMALLER FAILURES
- Potential risks at all scales.
- Not feasible to completely remove the risk.
- Those most at risk are people on foot, ancillary equipment and light vehicles.
- Importance of:
- AWARENESS, PROCEDURES and CONTROLS.