Implications of Earthquakes on the Stability of Tailing Dams

Introduction

- Increase of insured earthquake damages
- No special regard on the mining industry
- Direct motivation:
  - Baja Mare, River Danube, Romania
  - Wismut GmbH, Uranium Tailings, Germany

- Studies about earthquake exposures and their impact for industries
## Ranking of Natural Catastrophes

<table>
<thead>
<tr>
<th>Year</th>
<th>County, Region</th>
<th>Event</th>
<th>Economic Losses $^1$</th>
<th>Insured Losses $^1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>USA</td>
<td>Hurricane Kathrina</td>
<td>125,000</td>
<td>60,000</td>
</tr>
<tr>
<td>1995</td>
<td>Japan, Kobe</td>
<td>Earthquake</td>
<td>&gt; 100,000</td>
<td>3,000</td>
</tr>
<tr>
<td>1994</td>
<td>USA, California</td>
<td>Earthquake</td>
<td>44,000</td>
<td>15,300</td>
</tr>
<tr>
<td>1998</td>
<td>China</td>
<td>Floods</td>
<td>30,700</td>
<td>1,000</td>
</tr>
<tr>
<td>2004</td>
<td>Japan, Niigata</td>
<td>Earthquake</td>
<td>28,000</td>
<td>450</td>
</tr>
<tr>
<td>1992</td>
<td>USA</td>
<td>Hurricane Andrew</td>
<td>26,500</td>
<td>17,000</td>
</tr>
<tr>
<td>1996</td>
<td>China</td>
<td>Floods</td>
<td>24,000</td>
<td>445</td>
</tr>
<tr>
<td>2004</td>
<td>USA, Caribbean</td>
<td>Hurricane Ivan</td>
<td>23,000</td>
<td>11,500</td>
</tr>
<tr>
<td>1993</td>
<td>USA</td>
<td>Floods</td>
<td>21,000</td>
<td>1,270</td>
</tr>
<tr>
<td>2004</td>
<td>USA, Caribbean</td>
<td>Hurricane Charley</td>
<td>18,000</td>
<td>8,000</td>
</tr>
</tbody>
</table>

$^1$ Original losses in Million US$

Munich Re 2005, 2006
Funding and Data Acquisition

- Munich Reinsurance (Munich)
- Federal Institute for Geosciences and Natural Resources (Hannover)
- Deutsche Montan Technologie (DMT) (Essen)
- Foundation Library of the Ruhr (Bochum)
- Institute for Geophysics (Münster)
- Geological-Palaeontological Institute (Münster)
Reinsurance

Policyholder

Primary insurer (Ceding company)

Reinsurer (Accepting Company)

Insurance contribution

Cession

Retrocession
Earthquakes in Germany

- Earthquakes in Germany
  - Regions
  - Noticed intensities
  - Special events

- Mining in Germany
  - Hard coal
  - Brown coal
  - Salt
  - Former uranium
Earthquake Zonation of Germany

- **Magnitude**
  - Local magnitude $M_L$
  - Quantifies the amount of seismic energy released by an earthquake

- **Intensity**:
  - Quantifies the effects of an earthquake on the earth's surface, humans, objects of nature, and man-made structures
  - Scale of 1 (weak) to 12 (complete destruction)
## Examples of Tailing Damages

<table>
<thead>
<tr>
<th>Date</th>
<th>Location</th>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
</table>
| 19. July 1985 | Stava, South Tyrol, Italy | Collapse of a dam of a fluorite mine  
- Mass movement of 180,000 m³ of mud plus 40,000 m³ to 50,000 m³ erosional material  
- 268 fatalities  
- Minor environmental contaminations  
- Cause: wrong angle of the slope  
- Costs: 15 million US$ | STIFTUNG, STAVA 19985 |
| 25. April 1998 | Aznalcollar, Spain | Collapse of a dam of lead-zinc mine  
- Semioxidised pyrite plus additional toxic material  
- Cause: collapse of a separating dam and shearing along a underlying clay horizon  
- Severe environmental contaminations  
- Costs: 100 million US$ to 200 million US$ | WISE, URANIUM, PROJECT 2002 |
| 30. January 2000 | Baia Mare, Rumania | Collapse of a dam of gold mine  
- 100,000 m³ of wastewater including 120 t cyanide and other heavy metals contaminated the rivers up to the Danube  
- Severe environmental contaminations  
- Cause: soaking of the dam material and spilling  
### Earthquake Damages on Tailings

<table>
<thead>
<tr>
<th>Date</th>
<th>Location</th>
<th>Magnitude</th>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
</table>
| 10. January 1928 | Chile         | 8.3 (?)   | - Flood wave of 2,800,000 m³ tailing material  
- 500 m wide gap in the 61 m high dam  
- 54 fatalities  
- Cause: Liquefaction | ICOLD 2001       |
| 28. March 1965 | El Cobre,    | $m_L = 7.1$ | - Collapse of two dams of El Cobre copper mine  
- Two flood waves of 350,000 m³ (new dam) and of 1,900,000 m³ (old dam)  
- Downstream flow of 12 km  
- The town of El Cobre destroyed  
- More than 200 fatalities | CASE WESTERN RESERVE UNIVERSITY 2007 |
| 19. March 1971 | Chungar, Peru | $m_L = 4.8$ | - Landslide causes the break of a tailing dam  
- Tailing mud destroyed the surface facilities of the mine and ran into the shafts  
- Only 25 miners survived | SÜDDEUTSCHE ZEITUNG 22. MARCH 1971 |
| 17. January 1994 | Northridge, USA | $m_L = 6.7$ | - Collapse of the 24 m high dam of the Tapo Canyon Tailing  
- 60 m wide breach  
- Downstream flow of extended hundred meters in an incised canyon  
- Considerable losses for the owner and a downstream water treatment facility | STEWART ET AL. 1996 |
| April 1995     | Philippines   | $m_L = 6.2$ | - Collapse of a dam of the Surigao del Norte gold mine  
- Several earthquakes damaged the internal structure of the dam  
- Crest of the dam was a road  
- Soaking of internal structure of the dam with infiltrating liquids (water)  
- Collapse with a time lag | BGRM 2000  
MR199504A039  
NEIC 1995 |
Damage scenarios

- **Surface**
  - Fractures and breaches
  - Liquefaction
  - Slumping
  - Spilling

- **Subsurface**
  - Flooding of the mine
  - Destruction of the facilities for the subsurface operations

- **Surface loss scenarios** depending on the structure of the dam and the tailings
- **Linking of loss scenarios** between surface and subsurface
- **Environmental damages**
Example Germany

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after Munich Re 2000
Swarm Earthquakes in SE-Germany

Observed highest magnitude in 1986: $m_L = 4.6$
Input Parameters

- Earthquake scenarios

<table>
<thead>
<tr>
<th>Monitored Earthquakes</th>
<th>Earthquake Scenario 1 (No collapse of the dam)</th>
<th>Earthquake Scenario 2 (No structural damages)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnitude $M$</td>
<td>4.6</td>
<td>5.4</td>
</tr>
<tr>
<td>Intensity $I$</td>
<td>VI to VII</td>
<td>VIII</td>
</tr>
<tr>
<td>Hypocenter $h$</td>
<td>10 km to 5 km</td>
<td>10 km</td>
</tr>
</tbody>
</table>

- Volume
  - 40 million m$^3$ tailing mud
  - 5 million m$^3$ free water

- Tools
  - NOAA: Simplified Dam Break (SMPDBK)
  - ArcGIS
Implications of Earthquakes on the Stability of Tailing Dams

Collapse of the Tailing Dam

1.

2.

3.

4.
Flow Chart

Seismic Effect → Loss Scenario → Consequences

Seismic Event
- Earthquake
- Tremor
- Aftershock

Fractures and breaches
Liquefactions
Slumping
Spillings

Collapse of the dam

Subsurface loss scenario

Damage/Loss:
- Blocking
- Burying
- Wash-outs

Environmental Modifications
- Water balance
- Flow regimes

Environmental Impact
- Contaminations through tailings
- Contaminations of rivers
- Contaminations of aquifers
- Contaminations of objects (e.g., buildings)
- Formation of dust
- Regional transport of the contaminations

Economic consequences
- Business interruptions (Down time)
- Repairs and maintenance
- Clean-up
- Claim for compensations (Liability)

Fatalities and casualties
Diseases

Implications of Earthquakes on the Stability of Tailing Dams
Conclusion

- Special exposure of Germany
- Main loss scenarios
  - Fractures and breaches
  - Liquefactions
  - Slumpings
  - Spillings
  - Subsurface loss scenarios
- Severe environmental damages and contaminations (local and regional)
- Economic losses
- High expenses for
  - Business interruptions (Down-time)
  - Repair and maintenance
  - Clean-up
  - Claim for compensations (Liability)