LANDSLIDES AND MASS WASTING (20)

I Main Topics
   A Landslides and mass wasting
   B Major events of the 20th century
   C Costs of mass wasting
   D Natural factors affecting mass wasting
   E Case history: Nevado Huascaran, Peru, May 31, 1970

II Landslides and mass wasting

   A Mass wasting: gravitationally driven processes that move solid and solid/liquid masses downslope
   B Examples of mass wasting
      1 Landslides
      2 Debris flows
      3 Avalanches
      4 Rock falls
      5 Toppling failures
      6 Creep failures
   C Glaciation excluded from mass wasting phenomena
D Pantia Remis Landslide
Tin Mine, Perak, Malaysia, 10/21/1993

https://www.youtube.com/watch?v=H6Ma05VjMHA

III Major events of the 20th century
http://www.canadacollege.net/galloway/haz.9.html

<table>
<thead>
<tr>
<th>Year</th>
<th>Country</th>
<th>Name and Type</th>
<th>Triggering process</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>1911</td>
<td>Tadzhik Republic</td>
<td>Usoy rock slide</td>
<td>Usoy earthquake M=7.4</td>
<td>54 killed</td>
</tr>
<tr>
<td>1919</td>
<td>Indonesia (Java)</td>
<td>Kelut lahra (volcanic mud flow)</td>
<td>Kelut volcano (eruption)</td>
<td>5,100 killed 106 villages destroyed</td>
</tr>
<tr>
<td>1920</td>
<td>Ningxia (China)</td>
<td>Haiyuan landslide</td>
<td>-</td>
<td>~100,000 killed</td>
</tr>
<tr>
<td>1921</td>
<td>Kazakhstan</td>
<td>Alma-Ata debris flow</td>
<td>Snow melt</td>
<td>500 killed</td>
</tr>
<tr>
<td>1933</td>
<td>Sichuan (China)</td>
<td>Deixi landslide</td>
<td>Deixi earthquake M=7.5</td>
<td>6,800 killed; 2,500 drowned when dam failed</td>
</tr>
<tr>
<td>1939</td>
<td>Hyogo (Japan)</td>
<td>Mount Rokko slide/mud flow</td>
<td>Rain (typhoon)</td>
<td>505 dead, 130,000 homes destroyed</td>
</tr>
<tr>
<td>1949</td>
<td>Tadzhik Republic</td>
<td>Kait rock slide</td>
<td>Kait earthquake M=7.5</td>
<td>12,000 to 20,000 killed, 33 villages destroyed</td>
</tr>
<tr>
<td>1953</td>
<td>Wakayama (Japan)</td>
<td>Arita River slide/mud flow</td>
<td>Rain (typhoon)</td>
<td>460 dead, 4,722 homes destroyed</td>
</tr>
<tr>
<td>1953</td>
<td>Kyoto (Japan)</td>
<td>Minamiyamashiro slides/debris/mud flow</td>
<td>Rain (typhoon)</td>
<td>336 dead, 5,122 homes destroyed</td>
</tr>
<tr>
<td>1958</td>
<td>Shizuoka (Japan)</td>
<td>Kanogawa slide/debris/mud flow</td>
<td>Rain (typhoon)</td>
<td>1,094 dead; 19,734 homes destroyed</td>
</tr>
<tr>
<td>1962</td>
<td>Ancash (Peru)</td>
<td>Nevado Huascaran debris avalanche</td>
<td>-</td>
<td>4,000 to 5,000 killed most of Ranrahirca village destroyed</td>
</tr>
</tbody>
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### Major events of the 20th century

http://www.canadacollege.net/galloway/haz.9.html

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<tr>
<td>1963</td>
<td>Fruili-Venezia-Griulia (Italy)</td>
<td>Vaiont rock slide</td>
<td>Filling of Vaiont Reservoir</td>
<td>~2,000 killed; city of Longarone damaged ~ $970 million (1994 U.S. dollars)</td>
</tr>
<tr>
<td>1965</td>
<td>Yunnan (China)</td>
<td>Rock slide</td>
<td></td>
<td>~444 dead; 4 villages</td>
</tr>
<tr>
<td>1966</td>
<td>Rio de Janeiro (Brazil)</td>
<td>Rio de Janeiro slides/avalanches/ debris/mud flows</td>
<td>Heavy rain</td>
<td>~1,000 dead</td>
</tr>
<tr>
<td>1967</td>
<td>Serra das Araras (Brazil)</td>
<td>Serra das Araras slides/ avalanches/debris/mud flows</td>
<td>Heavy rain</td>
<td>~1,700 dead</td>
</tr>
<tr>
<td>1970</td>
<td>Ancash (Peru)</td>
<td>Nevado Huascaran debris avalanche</td>
<td>Earthquake M=7.7</td>
<td>18,000 dead; town of Yungay destroyed and Ranrahirca partially destroyed</td>
</tr>
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<td>1974</td>
<td>Huancavelia (Peru)</td>
<td>Mayunmarca rock/slide/debris/ avalanche</td>
<td>Rainfall</td>
<td>Mayunmarca village destroyed failure of 150 m-high landslide dam caused major flooding downstream</td>
</tr>
<tr>
<td>1980</td>
<td>Washington (United States)</td>
<td>Mount St. Helens rockslide/ debris avalanche</td>
<td>Eruption of Mt. St. Helens</td>
<td>World's largest historic landslide 23-km-long debris avalanche with average velocity of 125 km/hr; surface remobilized into 95-km long debris flow</td>
</tr>
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<td>1983</td>
<td>Utah (United States)</td>
<td>Thistle debris slide</td>
<td>Snow melt and heavy rain</td>
<td>Total losses ~$400 million in 1994 U.S. dollars</td>
</tr>
<tr>
<td>1985</td>
<td>Tolima (Columbia)</td>
<td>Nevado del Ruiz debris flows</td>
<td>Eruption of Nevado del Ruiz</td>
<td>&gt;20,000 dead; four towns destroyed; ~100-km long debris flow</td>
</tr>
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III Major events of the 20th century
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<td>1986</td>
<td>Papu New Guinea</td>
<td>Bairaman rock slide/avalanche</td>
<td>Bairaman earthquake M=7.1</td>
<td>Village of Bairaman destroyed. Debris avalanche formed 210-m-high dam that impounded 50-million cubic meter lake; dam failed, causing 100-m-deep debris flow downstream</td>
</tr>
<tr>
<td>1987</td>
<td>Napo (Ecuador)</td>
<td>Reventador landslide</td>
<td>Reventador earthquake M=6.1 and M=6.9</td>
<td>~1,000 killed $1.3 billion (in 1994 U.S. dollars)</td>
</tr>
<tr>
<td>1994</td>
<td>Cauca (Columbia)</td>
<td>Paez landslides</td>
<td>Paez earthquake M=6.4</td>
<td>271 dead; 1,700 missing; 32,000 displaced; villages destroyed</td>
</tr>
</tbody>
</table>

Modified from Table 1, Schuster, R.L., 1996, in Landslide, Chacón, Irigaray and Fernández, eds., A.A. Balkema/Rotterdam

III Costs of mass wasting

1 Mass wasting in the U.S.
   a Est. annual cost in U.S. as of 1978: $1 B (x 2 for 1991)
      Actual losses in 13 California slides: $3.5 B
   c Portugese Bend (1956-1959): $10 M (x 5 for 1991)
   d Utah (1983*): $250 million*
   e S.F. Bay Area January, 1982 storm: 18,000 landslides!
III Costs of mass wasting

2. Human activity as a contributing factor
   a. Contra Costa County, California: 80%
   b. Allegheny County, Pennsylvania: 90%

3. Improved geotechnical practices can greatly reduce slide costs:
   b. Los Angeles 1968-1969 storm: 97% reduction vs. pre-1952
   c. State of CA (Beach Leighton): 95-99% reduction

IV Natural factors affecting mass wasting

A. Geologic Factors
   1. Geomorphology: Topography; processes of erosion & deposition and deformation that create topography
   2. Composition: Rock types and weathering products
   3. Structure: Distribution of flaws (e.g., bedding and fractures) and rock types (controls geometry of failure surface)
   4. Seismicity
   5. Geologic History (Time): Past is key to future

B. Environmental Factors
   1. Climate and Hydrology: Rainfall, surface/ground water flow
   2. Vegetation (Very sensitive to all factors above)
V Artificial factors affecting mass wasting

A Deposition
B Cutting slopes
C Alteration of environmental factors
   1 Groundwater levels
      a Leaking pipes
      b Dams
      c Pumping ground water
   2 Diversion of surface water
      a Road construction and paving
      b Culverts (drainage ditches)
   3 Destruction of vegetation
      a Fires
      b Logging

VI Case history: Nevado Huascaran, Peru, May 31, 1970

- On May 31, 1970 the most catastrophic known avalanche in history descended from Nevado Huascaran, the highest peak in the Peruvian Andes. The avalanche caused ~18,000 casualties*, including 15,000 of 17,000 resident of the city of Yungay. The avalanche was triggered at 3:23 PM by a great earthquake (M=7.7) off the coast of Peru; the epicenter was 130 km west of Nevado Huascaran. The avalanche occurred at end of wet season, when snow cover was near a maximum and the snow had begun to melt. The avalanche originated from a partially overhanging cliff (average slope of 70-80°) at 5400-6500 m elevation, where the fractured granitic rock of the peak was covered by a 30-m-thick glacier. The avalanche had a volume of ~50-100 million cubic meters and traveled 16 km to Rio Santa with a vertical drop of 4 km. The avalanche shot over a 230m-high ridge on its descent, launching boulders as large as 60 metric tons as far as 4 km from the ridge. The average speed of the 1970 avalanche was 280 km/sec– peak speeds probably reached ~1000km/hr. A previous avalanche from the same peak in 1962, with a volume of 13 million cubic meters, caused 4000 fatalities. That event prompted a prediction that an avalanche even larger than the 1962 could fall from the peak and threaten Yungay. The hazard posed was thus recognized, partially characterized, and partially evaluated. Mapping after the 1970 event revealed deposits from an substantially larger pre-Columbian (pre 1492) avalanche that might have attained average speeds of 315-355 km/hr.

- * Evans et al. (2009) set the fatality figure at 7,000
Map of central western Peru

- Black dot shows epicenter of $M = 7.7$ earthquake of May 31, 1970
- Nevado Huascaran is site of avalanche
- Dashed line marks approximate extent of earthquake damage

From USGS Circular 639

Aerial view of west face of Nevado Huascaran

Aerial view of west face of Nevado Huascaran showing avalanche source area


Aerial view to east of avalanche source and path, with towns of Yungay and Ranrahirca

- Two avalanches, 1962 and 1970
- Both had similar sources
- Why did the 1970 avalanche hit the town of Yungay, when the 1962 avalanche did not?

View to the east of the west face of Nevado Huascaran (1948)

A  Highly jointed granodiorite
B  Summit glacier
C  Glacier 511
D  Terminal moraine

Physiographic diagram of Nevado Huascaran, view to east

Locations
A  Source of 1970 avalanche
B  Toe of Glacier 511
C  Bend in channel between moraines
F  Point nearly in line with pts. A, B, C
Generalized map and profile of 1970 Huascaran avalanche

From Plafker and Ericksen, 1977

Largest known impact crater

33m long, 15m wide, 7-8m deep

From Plafker and Ericksen, 1977
Boulder and impact crater

From USGS Circular 639

Boulders at Ranahhirca after the mud has washed away

From Plafker and Ericksen, 1977  From USGS Circular 639
Oblique view of Ranhahirca (R), Yungay (Y), and Cemetary Hill (C)

Lake formed upstream of landslide dam on Rio Santa

https://www.sciencebase.gov/catalog/item/51dda162e4b0f72b4471de8d

From USGS Circular 639
Images of 1962 and 1970 avalanches

(a) Evento 1970
(b) Evento 1962


View southwest along the track of the 1962 avalanche

• Debris rose up valley bends at A and B
• Debris almost overtopped Cerro de Aira at G
• Yungay = Y
• Ranrahirca = R
• Photo from Charles Sawyer

Some of the larger 1970 avalanche followed a straighter path than the 1962 avalanche

Data for avalanches at Nevado Huascaran

<table>
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<tr>
<th></th>
<th>1962</th>
<th>1970</th>
<th>48,000 yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area covered (km²)</td>
<td>6</td>
<td>22.5</td>
<td>&gt;30</td>
</tr>
<tr>
<td>Volume (million m³)</td>
<td>&gt;13</td>
<td>50-100</td>
<td>100-200?</td>
</tr>
<tr>
<td>Average velocity (km/hr)</td>
<td>170</td>
<td>280</td>
<td>315-355</td>
</tr>
<tr>
<td>Runup height at Rio Santa (m)</td>
<td>30</td>
<td>83</td>
<td>123</td>
</tr>
<tr>
<td>Velocity at Rio Santa (km/hr)</td>
<td>&gt;60</td>
<td>&gt;120</td>
<td>&gt;140</td>
</tr>
<tr>
<td>Casualties</td>
<td>4000</td>
<td>&gt;18,000</td>
<td>?</td>
</tr>
</tbody>
</table>

Projected velocity of pre-Columbian event (48,000 yr)

Results here from Plafker and Ericksen, 1977
Potential Energy

<table>
<thead>
<tr>
<th>Estimate of minimum velocity at Rio Santa based on runup height</th>
<th>Potential energy release from 1970 avalanche</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta P.E. = mg\Delta h$</td>
<td>$m = \rho V$</td>
</tr>
<tr>
<td>$K.E. = (1/2)mv^2$</td>
<td>$m_{\text{min}} = (2.7\times10^3 \text{ kg/m}^3)(50\times10^6 \text{ m}^3)$</td>
</tr>
<tr>
<td>$(1/2)mv^2 = mg\Delta h$</td>
<td>$m_{\text{max}} = (2.7\times10^3 \text{ kg/m}^3)(100\times10^6 \text{ m}^3)$</td>
</tr>
<tr>
<td>$v = (2g\Delta h)^{1/2}$</td>
<td>$g = 9.8 \text{ kg/m}^3\text{e6}$</td>
</tr>
</tbody>
</table>

1962
For $\Delta h = 30\text{m}$, $v_{\text{min}} = 87 \text{ km/hr}$

1970
For $\Delta h = 83\text{m}$, $v_{\text{min}} = 145 \text{ km/hr}$

Pre-Columbian
For $\Delta h = 123\text{m}$, $v_{\text{min}} = 177 \text{ km/hr}$

1970
For $\Delta h = 30\text{m}$, $v_{\text{min}} = 87 \text{ km/hr}$

Could the 1970 event have been predicted?

- In 1962 two American scientists, David Bernays and Charles Sawyer, had reported seeing a massive vertical slab of rock being undermined by a glacier, which threatened to fall and cause the obliteration of Yungay.
- According to Sawyer, when this was reported in the *Espreso* newspaper (27 September 1962), the government ordered them to retract or face prison, and they fled the country.

From Pfafker and Ericksen, 1977
Evaluation and Assessment (from Evans et al., 2009)

- Risk scenarios for Yungay–Ranrahirca area using societal risk criteria. ALARP = As Low as Reasonably Practicable. ISR = Intense Scrutiny Region. Based on Fig. 4 of Fell et al. (2005).
- Black squares: scenarios for the Ranrahirca fan. Maximum (A1 and A2) and minimum (B1 and B2) existing hazard scenarios for 500 and 1000 deaths respectively.
- Red dots: retroactive risk for a single event in 48,000 years at Yungay (Y), i.e., the 1970 event, and two events in 48,000 years at Ranrahirca (R), i.e., the 1962 and 1970 events.
- See http://faculty.washington.edu/kramer/522/522SOA1_Fell_et_al_Vancouver.pdf

Report from a survivor

- Among these survivors was the engineer Mateo Casaverde who was accompanied by French geophysicist G. Patzelt and his wife. He recalls: "We were driving from Yungay to Caraz while, passing the cemetery of Yungay the earthquake started. You could see clearly the vertical part of the seismic waves rolling along the asphalt of the highway. We abandoned the car when the earthquake was just finishing. We heard a deep noise, different from the earthquake, but not so much so. It was coming from Huascarán and we saw between the mountain and Yungay a giant cloud of dust. The quake had caused an avalanche. Part of Huascarán was falling. The only place where we were that offered any protection was the cemetery. It was built on an artificial hill, the remains of the pre-Inca pyramid. We ran about 100 metres from the highway before entering the cemetery, which had also suffered from the effects of the earthquake. I turned to look at Yungay. At that moment you could see a giant wave, about 60 metres high, about to hit the left hand side of the city. This wave was certainly not dust. We ran up the stairs. We reached the 3rd level of the structure, which was more damaged, and found a man, a woman and three children trying to get up higher. We turned to the right, and ran along the third level. It was then that the wave hit. The avalanche reached the cemetery hitting the frontal part, practically at the same height as the third level. It passed us just below out feet, maybe about 5 metres away. The sky went dark. We looked around. Yungay and its many thousands of inhabitants had disappeared." http://www.thehuaraztelegraph.com/2012/06/yungays-disaster-of-1970/
Reference Material

- Rahn, P., Engineering Geology.