Best Practices in Dam and Levee Safety Risk Analysis

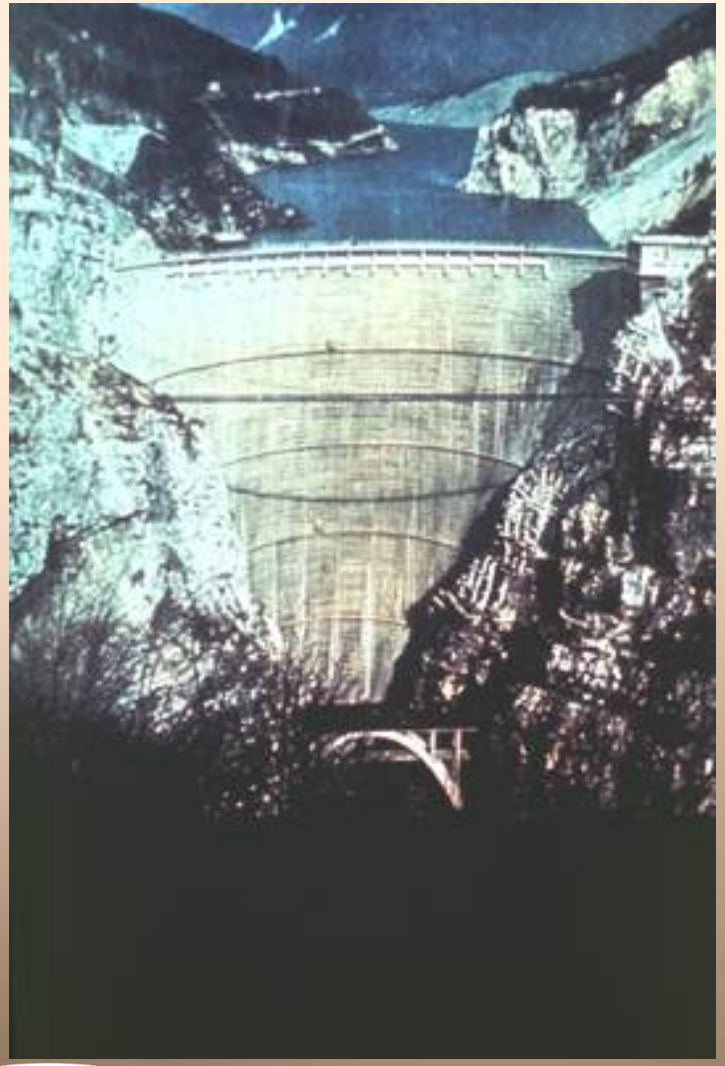
VIII-2. Landslides

27 September 2012

RECLAMATION
Managing Water in the West

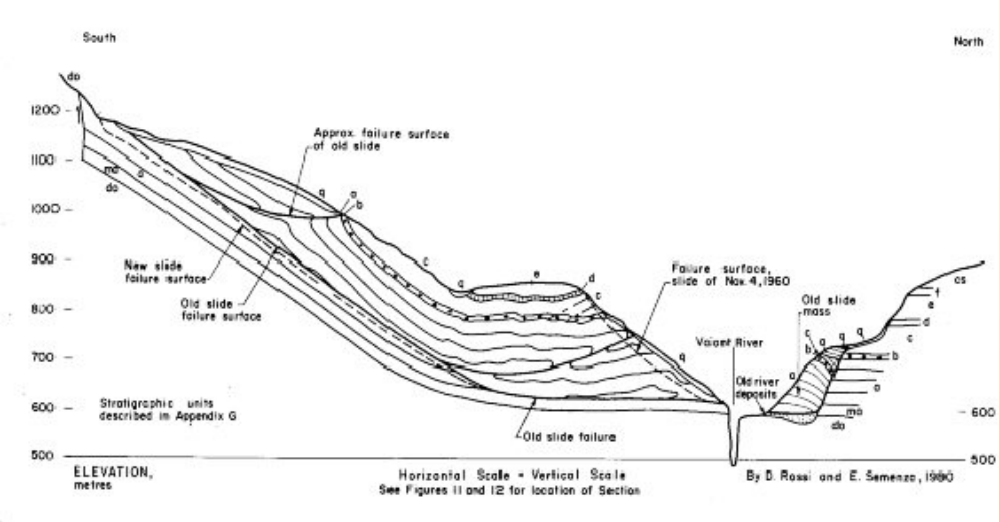
US Army Corps of Engineers
BUILDING STRONG®

Vaiont Dam, Italy



- 870’ high arch dam on Vaiont River near Longarone, Italy
- Completed in 1960
- The foundation and reservoir slopes composed of bedded limestone
- Left bank slide mass from post-glacial period

Vaiont Dam



From Hendron and Patton

- Entire mountain slid into the reservoir on October 9, 1963
- Filled the entire reservoir for a mile upstream of the dam creating huge wave
- Sliding occurred on clay-filled bedding planes with phi = 10 to 12°

Vaiont Dam

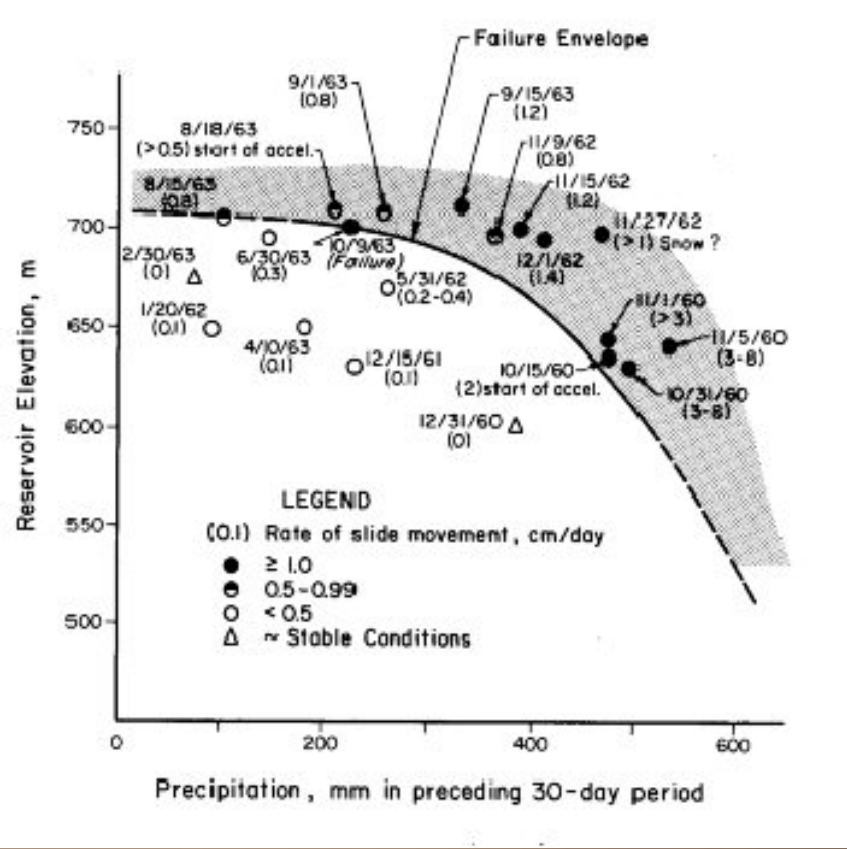
Slide sent wall of water 330’ high over the top of the dam downstream (dam survived)

2600 fatalities in the village of Longarone downstream

Vaiont Dam

From Hendron and Patton

Res (m)	Rain	F.S.
710	High	1.00
710	Low	1.10
650	High	1.08
650	Low	1.18
None	High	1.12
None	Low	1.21



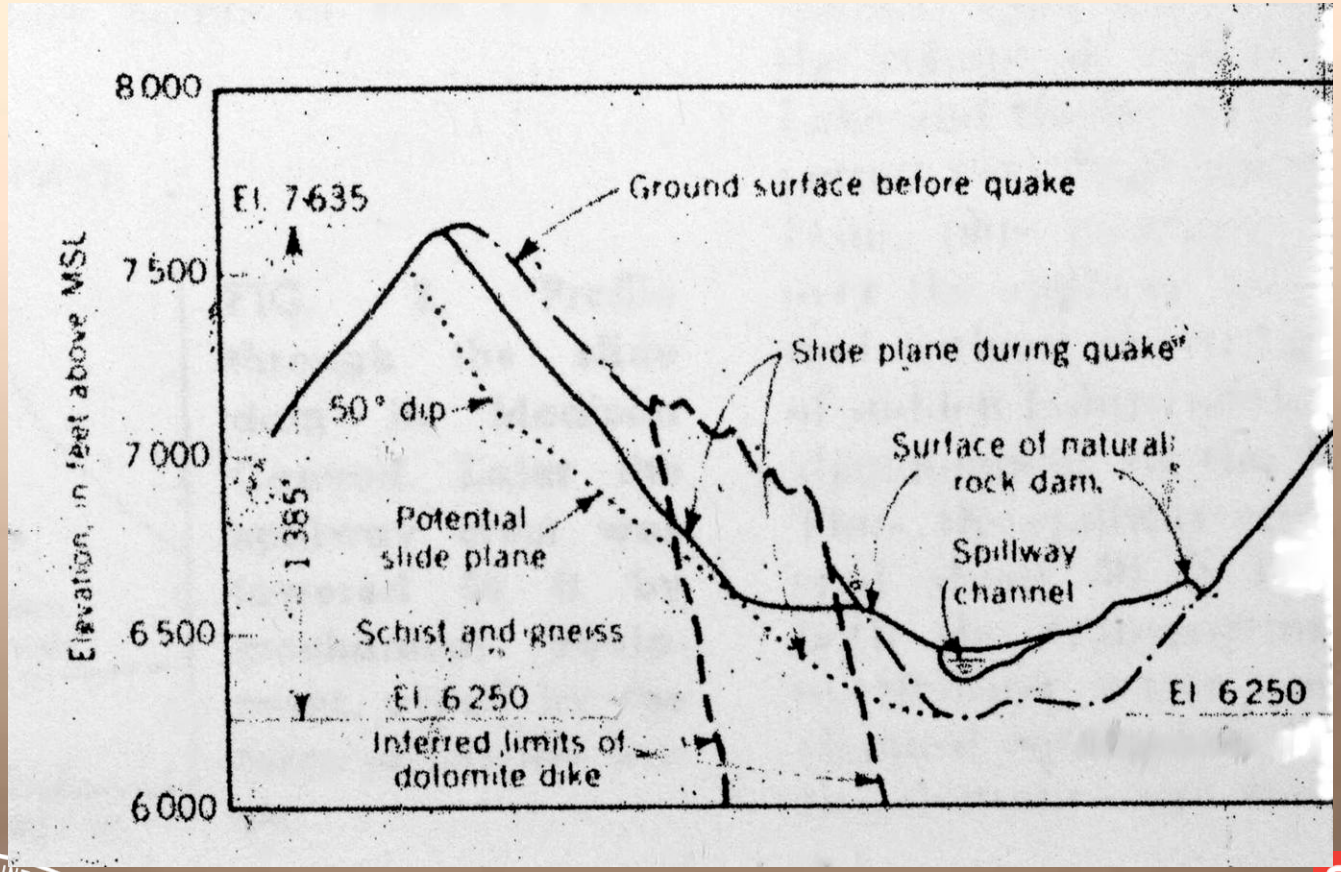
Combination high reservoir and high rainfall caused slide

Quake Lake Landslide

- Triggered by August 17, 1959 Hebgen Lake E.Q.
- M7.5-7.8 in SW part of Yellowstone Park
- 43,000,000 c.y. slid across canyon and up opposite side nearly 400’
- 27 fatalities in campground on opposite side of river

Quake Lake Landslide

- Buttress of jointed dolomite collapsed
- Sliding occurred along 50° foliation toward canyon



Quake Lake Landslide

- Landslide debris dam 4,000’ long and 200’ high across Madison River d/s Hebgen Dam formed “Quake Lake” - leakage to ~ 200 cfs
- Hebgen Lake nearly full at the time and dam was damaged by earthquake (inspection desirable)
- Volume in Hebgen Lake nearly 4 times that which could be accommodated in Quake Lake
- In time allowed, spillway notch 250’ wide cut through slide with capacity of 10,000 cfs
- Simultaneous armoring with 2-3’ rock

Key Concepts

- Many dams in mountainous terrain where landslides are common
- Landslides can be triggered by
  - Heavy rainfall
  - Snowmelt
  - Reservoir drawdown
  - Large earthquake

Key Concepts (cont.)

- Landslide failing rapidly into reservoir can create an overtopping wave
- Landslide can occur downstream of a dam, blocking the river and creating threat if releases from dam overtop and fail debris
- If dam abutments are on a landslide, movement can create cracking and internal erosion (embankment), or structural distress (concrete)
- Landslides can block spillway when needed for releases to prevent dam overtopping

Landslide Stability

- Important to understand
  - Geology (including 3-D effects)
  - Groundwater conditions
  - Movement surveys
  - Reservoir operations
  - Limit equilibrium (including reliability analyses or other analyses)

Equations for Quick Estimates

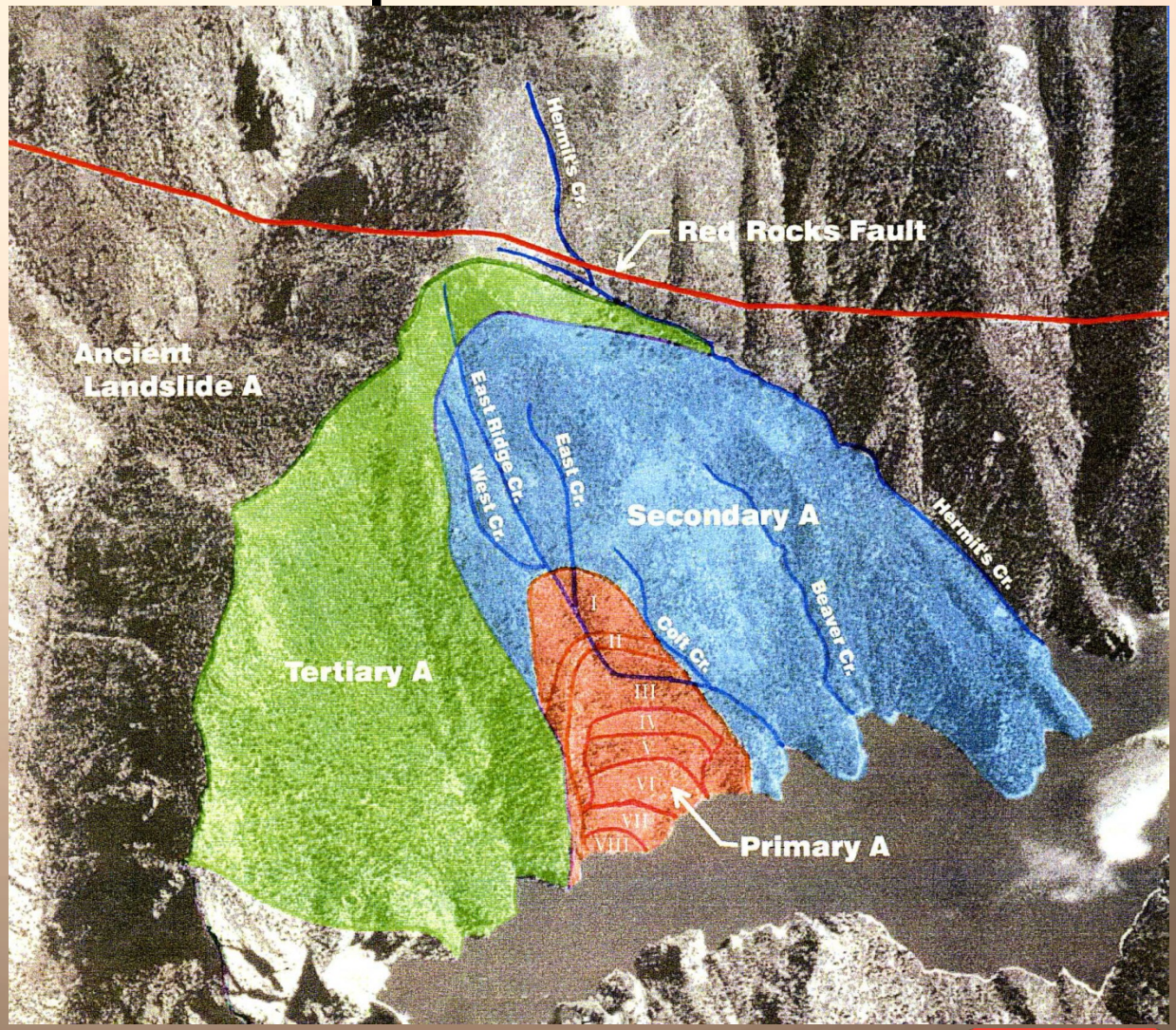
- Displacements during earthquake shaking
  - Jibson (2007) based on yield acceleration and magnitude
- Wave heights generated by landslides moving into reservoirs
  - Pugh and Chang (1986) block slides based on Morrow Point
  - Huber and Hager (1997) debris slides
  - Perez (2006)

Example

Primary A most active

Secondary A less active

Tertiary A stable



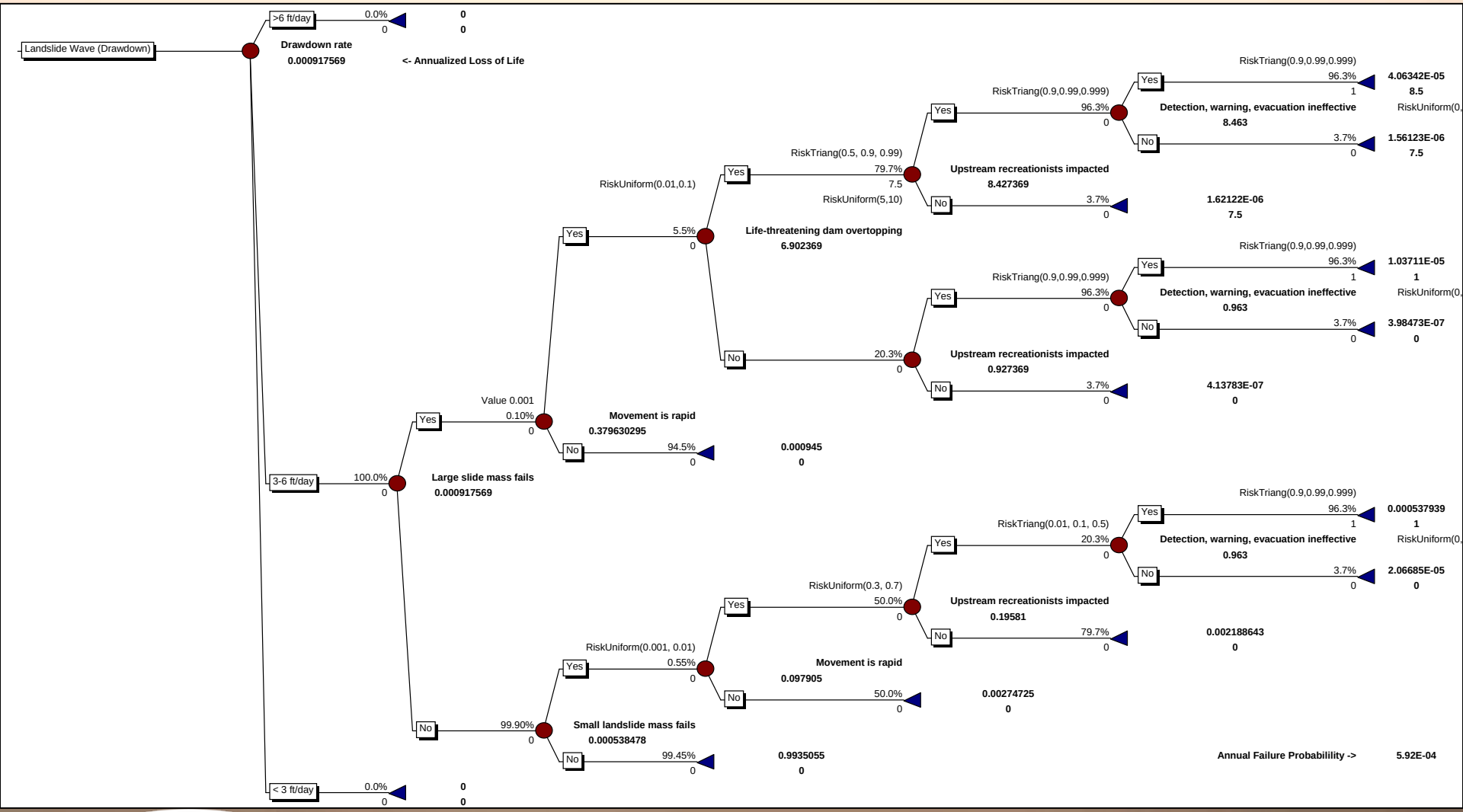
Example Event Tree

- Concrete arch dam
- Reservoir drawdown planned for maintenance
- SOP limits drawdown to 2 ft/day, but 3-6 ft/day needed for maintenance schedule
- Large landslide on right bank of reservoir less than a mile upstream of dam
- Lower part of slide moving under normal conditions
- Upper part of slide appears to be stable
- Wave height from lower portion failing rapidly unlikely to overtop dam
- Wave height from larger mass failing rapidly likely to overtop dam

Example Event Tree (cont.)

- Dam failure unlikely, but wave could affect:
  - Boaters and fishermen on the lake
  - Workers at the dam
  - People downstream including visitors, recreationists, and campers
- Note consequences in middle of tree (people on reservoir would be impacted whether wave went over dam or not)

Example Event Tree



See Pg. 28-8

Rockfall Can Also Be Damaging

Exercise

- From the description of the landslide for the Vaiont case history in the manual, calculate the expected wave height. How does it compare to what was actually observed?

Possible Exercise Solution

Reservoir depth, D =	870	ft		
Slide volume, V =	350,000,000	cy		
Slide volume, V =	9,450,000,000	ft^3		
Distance from slide to dam, L =	870	ft approx		
SQRT(V/D^3)	3.788			
10^((L/D)/58)	1.040			
Wave Height =	443	ft approx	0.14*D1*D5/D6	
Actual Height =	330	ft over dam		
Note: If roughly the mid-point of the slide is used as the distance from the				
dam to the slide, the predicted wave height at the dam is about 410 ft				