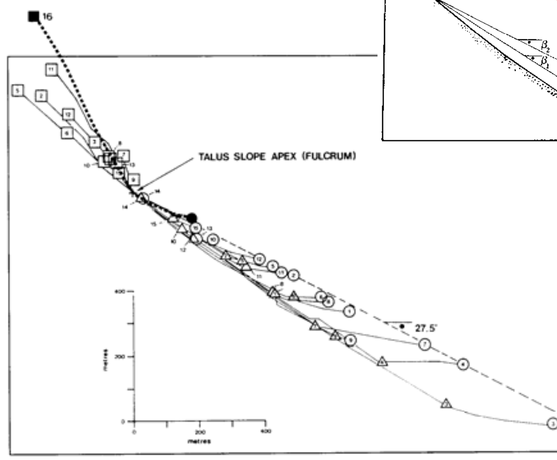
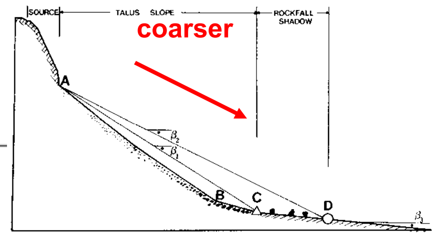

Rock Fall Hazard
Management


1) Rock fall characterization
2) Rock fall hazard priority

Talus deposits, “rock fall shadow”





β_1 = 32-38º
B_2~= 27 º

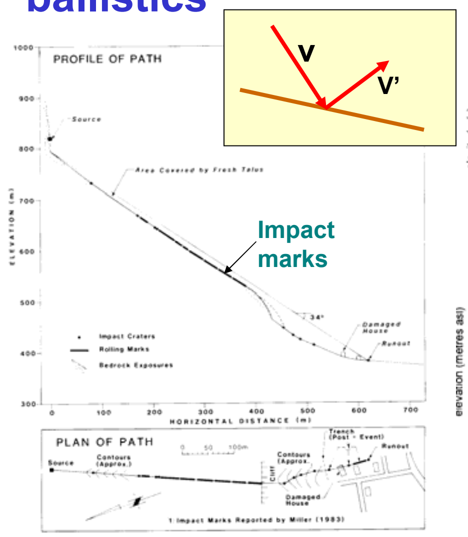
(Evans and Hungr, 1993)

FIG. 10. Profiles of 16 surveyed rockfall paths from British Columbia (modified from Hungr and Evans 1988). The profiles have been plotted with the talus apex as a common point. Δ, base of the talus slope; ○, distal margin of the rockfall shadow; □, either known source areas or the crest of the source cliff. 1, Hedley; 2, Similkameen A (Sweatlodge)*; 3, Similkameen B (rockslide); 4-Similkameen C (kame); 5-Similkameen D (Winters Creek); 6-Similkameen E (campground); 7, Similkameen F (speedway); 8, Pukaist; 9, Sunnybrae; 10, Barnhartvale*; 11, Silverhope A; 12, Silverhope B; 13, Silverhope D; 14, Silverhope C; 15, Hope North*; 16, Stawamus Chief* (asterisks denote sites where fresh debris was found in the rockfall shadow area).

Rock fall, Salmon Arm British Columbia, 1982.

Block 5x5x2 m fell and then rolled, two fatalities

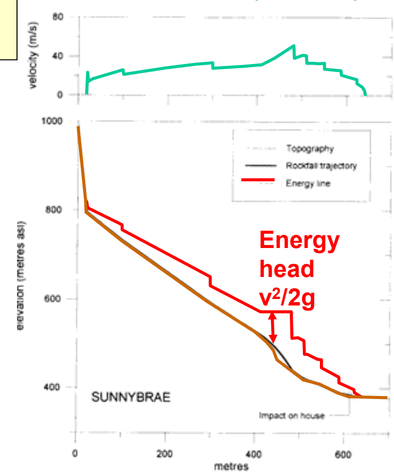
Rock fall ballistics



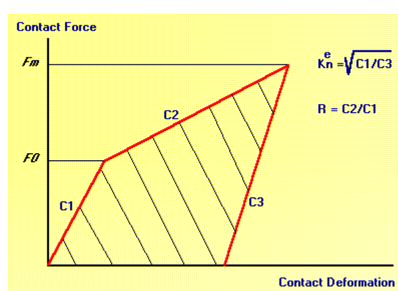
$$v'_n = v_n k_n$$

$$v'_t = v_t k_t$$

k_n, k_t = normal, tangential restitution coefficients (~0.7, 0.9)



Rock fall ballistics
Plastic impact model (Falcetta, 1985, Hungr and Evans, 1989)



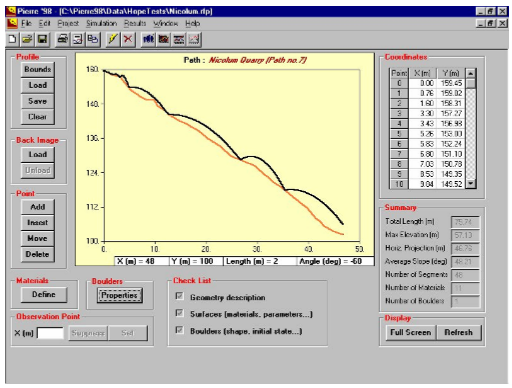
Elastic Impact (Contact force $<F_0$)

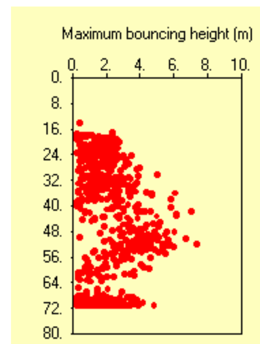
$$k_n^e = -\sqrt{\frac{C_1}{C_3}}$$

Plastic Impact (Contact force $>F_0$)

$$k_n^p = k_n^e \sqrt{\frac{C_2}{[C_1 + (\frac{F_0}{F_m})^2 (C_2 - C_1)]}}$$

Program “Pierre” (work in progress)





CRSP - COLORADO ROCKFALL SIMULATION PROGRAM

(Colorado School of Mines Colorado Geological Survey Colorado Department of Transportation)

Features:

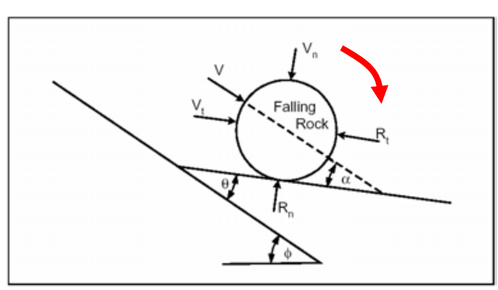
-Acounts for both rotational and translational energy

-Some allowance for plastic yielding

-Allows for random surface roughness

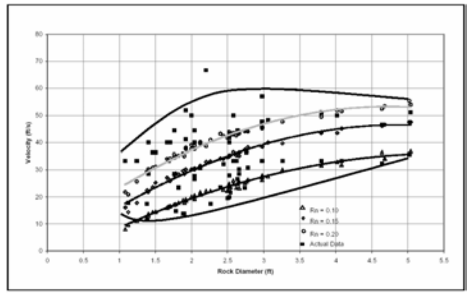
-Calibration data available

-Public domain

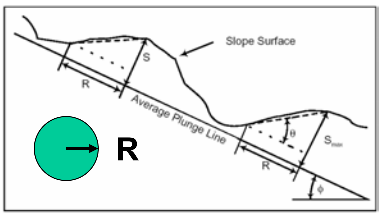


CRSP

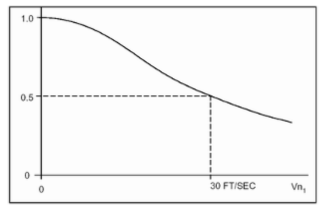
Typ. calibration result



Roughness definition



Plastic energy loss

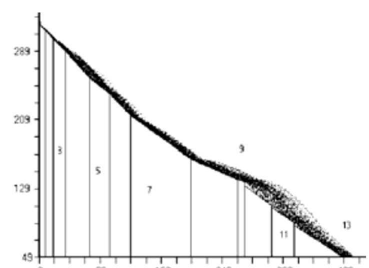


Impact velocity

Table 5. Suggested Normal Coefficient Input Values.

Description of Slope	Normal Coefficient (R_n)	Remarks
Smooth hard surfaces and paving	0.60 – 1.0	-For short slopes try lower values in applicable range.
Most bedrock and boulder fields	0.15 – 0.30	
Talus and firm soil slopes	0.12 – 0.20	-If max. velocity/KE* are design criteria, use lower values in range; if avg. velocity/KE* are design criteria, use higher values in range.
Soft soil slopes**	0.10 - 0.20	

*KE = kinetic energy
**Soft soil slope coefficients were extrapolated from other slope types due to lack of data.



"Each of the graphs listed above used a constant surface roughness of 0.5 feet. Although no field measurements of surface roughness were performed on any of the slopes used for the calibration, a surface roughness of 0.5 feet appears to be reasonable for each of the slopes based on the slope descriptions and pictures provided by the investigators supplying the data."

Rock Fall hazard assessment

Purpose:

1) **Absolute hazard assessment: is the hazard acceptable? Is mitigation needed?**

2) **Absolute risk assessment: is the risk acceptable? Is mitigation needed (cost-benefit analysis?**

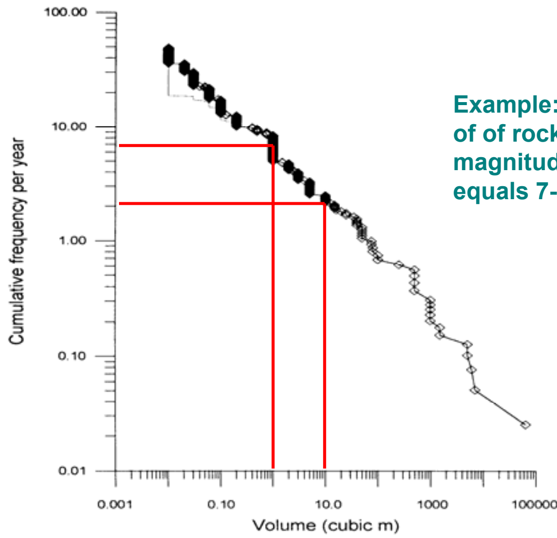
3) **Relative assessment: What locations should have the highest priority?**

Example: Relative risk assessment The Oregon Rock Fall Hazard Rating System

CATEGORY			RATING CRITERIA AND SCORE: POINTS 3	POINTS 9	POINTS 27	POINTS 81
SLOPE HEIGHT			25 FT	50 FT	75 FT	100 FT
DITCH EFFECTIVENESS			Good catchment	Moderate catchment	Limited catchment	No catchment
AVERAGE VEHICLE RISK			25% of the time	50% of the time	75% of the time	100% of the time
PERCENT OF DECISION SIGHT DISTANCE			Adequate site distance, 100% of low design value	Moderate sight distance, 80% of low design value	Limited site distance, 60% of low design value	Very limited sight distance, 40% of low design value
ROADWAY WIDTH INCLUDING PAVED SHOULDERS			44 feet	36 feet	28 feet	20 feet
GEOLOGIC CHARACTER	CASE 1	STRUCTURAL CONDITION	Discontinuous joints, favorable orientation	Discontinuous joints, random orientation	Discontinuous joints, adverse orientation	Continuous joints, adverse orientation
GEOLOGIC CHARACTER	CASE 1	ROCK FRICTION	Rough, irregular	Undulating	Planar	Clay infilling or slickensided
GEOLOGIC CHARACTER	CASE 2	STRUCTURAL CONDITION	Few differential erosion features	Occasional erosion features	Many erosion features	Major erosion features
GEOLOGIC CHARACTER	CASE 2	DIFFERENCE IN EROSION RATES	Small difference	Moderate difference	Large difference	Extreme difference
BLOCK SIZE / QUANTITY OF ROCKFALL/EVENT			1 FT / 3 cubic yards	2 FT / 6 cubic yards	3 FT / 9 cubic yards	4 FT / 12 cubic yards
CLIMATE AND PRESENCE OF WATER ON SLOPE			Low to moderate precipitation; no freezing periods, no water on slope	Moderate precipitation or short freezing periods or intermittent water on slope	High precipitation or long freezing periods or continual water on slope	High precipitation and long freezing periods or continual water on slope and long freezing periods
ROCKFALL HISTORY			Few falls	Occasional falls	Many falls	Constant falls

(Pierson et al., 1990)

Cumulative Frequency –Magnitude (CFM) curve



Example: annual frequency of of rock falls in the magnitude range 1 to 10 m^3 equals 7-2=5

Rockfall records, BC Hwy 99 Vancouver-Squamish

(Guttenberg-Richter method)

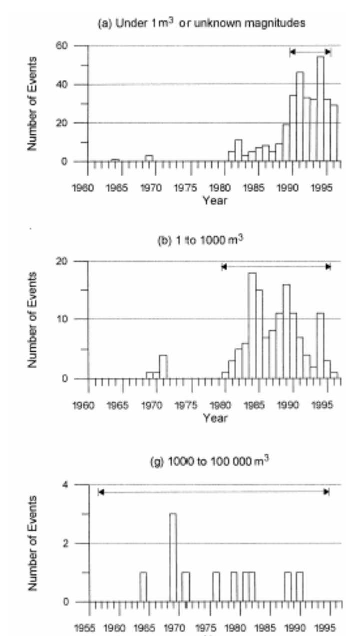
$$f_i = \frac{1}{T_i}$$

Incremental frequency

$$F_i = \sum_{i=1}^{j} f_i$$

Cumulative frequency

(Hungr et al., 1998)



Range of magnitudes

30 m³

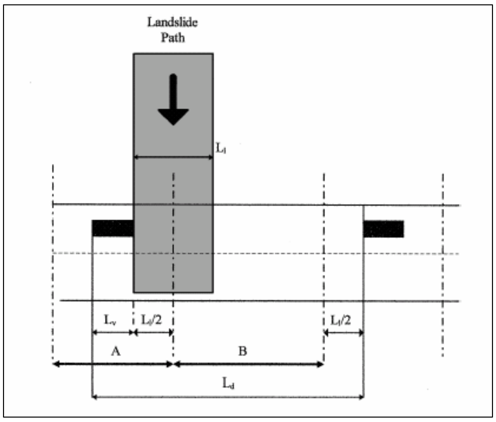
60 000 m³

Annual probability of an accident

$$P(A) = f_h P(S{:}H) P(T{:}S) P(I{:}S) P(L{:}I)$$

$P(A)$ is the annual probability of an accident involving the death of at least one occupant of a vehicle;
f_h is the annual frequency of landslides within the given sector of road, in a single magnitude category;
$P(S{:}H)$ is the longitudinal encounter probability, the probability of a vehicle being present in the damage corridor at the time of the landslide
$P(T{:}S)$ =1.0 is temporal probability (continuous traffic)
$P(L{:}I)$ is the probability of death, given an impact (vulnerability).

Longitudinal encounter probability



L_l = Landslide damage corridor width
L_v = Vehicle length
L_d = Average vehicle spacing in each lane

Encounter probability (in each lane):

$$P(S:H)_1 = \frac{A}{(A+B)} = \frac{L_v + L_l}{L_d}$$

Encounter probability (both lanes):

$$P(S:H)_2 = 2\frac{L_v + L_l}{L_d}$$

Risk calculation

Table 4. Example calculation of the risk of a fatal accident for a segment of a highway in the Howe Sound – Lillooet corridor with 100 rock falls per year, a traffic intensity of 5000 vehicles per day, and a design speed of 80 km/h.

Rock fall magnitude class[a] (m^3)	Annual cumulative frequency F_i	Annual incremental frequency f_h	Corridor width L_l (m)	Encounter probability $P(S{:}H)$ (Fig. 14)	Lateral impact probability $P(I{:}S)$	Probability of death $P(L{:}I)$	Probability of fatal accident $P(A)$	Return period R (years)
0.001	100.000	—	—	—	—	—	—	—
0.01	36.813	63.187	0.1	0.01	0.1	0.05	0.005	221
0.1	13.552	23.261	0.1	0.01	0.2	0.1	0.007	150
1	4.989	8.563	1	0.02	0.4	0.2	0.011	88
10	1.837	3.152	2	0.02	0.6	0.5	0.018	55
100	0.676	1.160	5	0.03	0.8	0.8	0.020	50
1 000	0.249	0.427	10	0.04	1	1	0.017	58
10 000	0.092	0.157	30	0.09	1	1	0.014	69
		0.092	50	0.14	1	1	0.013	76
Total							0.106	9

Note: Slope *b* of the MCF relationship in eq. [3] is assumed as –0.434 for all magnitude classes.
[a]Lower limit of the magnitude class.