5. DETERMINATION OF DESIGN AVALANCHE CHARACTERISTICS

5.1 General

The boundaries of the Red and Blue hazard zones, as defined in Section 1, depend upon the size, frequency, and physical characteristics of the design avalanche. The design avalanche, however, is by definition a very rare event seldom observed in any particular avalanche path. Because direct observations of the large events of interest are seldom made, and because the velocities, densities, and impact forces have very rarely been measured, we have used indirect methods to deduce avalanche sizes, frequencies and characteristics.

This section describes the methods used to determine avalanche sizes within the Municipality of Anchorage. Four different approaches were used: (1) field observations of major avalanche destruction, (2) compilation of an avalanche history, (3) terrain analysis, and (4) calibration and application of equations of motion. These four techniques are independent of one another. Therefore the results of one technique do not influence any other.

5.2 Field Observations of Major Avalanche Destruction

Although design avalanches are unusual (by definition 100-year events) in any particular avalanche path, they do occur at isolated locations at least every few years within the municipal area and the Chugach and Kenai Mountains. Because these unusual avalanches are of extreme interest in zoning applications they were studied in detail to enable more confident predictions about what could happen in similar avalanche areas that affect private land.

The areas and lengths covered by the design avalanches studied were delineated by destruction of mature trees at the boundaries. The ages of these trees could usually be approximated by counting the number of growth layers in broken stumps. Sampling several large trees in this manner provided a good estimate of the length of time since an avalanche of this magnitude had previously occurred. The method is an approximation because it provides only an estimate of the period between the last two events of this size. This period is not necessarily equal to the return period, T, because T is by definition an average interval between many such events randomly spaced through time. Avalanches of a given size may occur on successive years, or may not recur for a period of 2T, 3T, or more years. Nevertheless, estimating the order-of-magnitude return period in this way is valid as illustrated by application of encounter probability theory.

For example, if broken trees at the avalanche limit have an average age of 100 years, application of encounter probability theory shows only a 9.6% chance exists that a 10-year avalanche reached to that point, an 18.2% chance that a 20-year avalanche reached the limit, and 39.5% chance it was a 50-year avalanche. In this way a 10-year and 100-year avalanche extents were clearly separated. The boundary of the 10-year avalanche often coincides with an area devoid of mature trees. These areas will commonly support dense stands of alders or other flexible, fast-growing species.

Boundary damage studies also provided information about avalanche thickness and qualitative estimates of destructive force. The height of limb stripping above ground provided an upper-limit to destructive thickness although this is exaggerated because the avalanche may have spread on top of a deep snowpack. Where large, mature trees snapped through extreme bending stress, unit avalanche thrust loads probably exceeded 10 kPa (200 lbs/ft^2) but may have exceeded 100 kPa (2000 lbs/ft^2). Figure 5-1 is a photograph of destruction in the runout zone of a large dry snow avalanche on the north face of Mt. Alyeska. Ring counts showed that many destroyed trees were more than 200 years old.

Our study of boundary destruction suggests that design avalanches consisted of dry snow throughout the entire study area. The major avalanches in the Girdwood area in particular, and the Turnagain Arm area in general, appear to stop after traveling shorter distances on steeper slopes, as discussed earlier. However, these avalanches have been very destructive near the distal limits of their paths. This contrasts to our observations of destruction in the higher elevation avalanche paths of South Fork where design avalanches were also dry but appear to have traveled at moderate speeds for long distances on low-angle slopes. Although dry snow probably constitutes design avalanches in all areas, the coastal climates produce dense hard slab avalanches while interior climates lower density slabs that quickly fluidize and travel longer distances on lower gradients.

FIGURE 5-1. Many conifers more than 200 years old were destroyed by a large dry/snow avalanche that released from the north face of Mt. Alyeska. The starting zone was located on the face in the background. (See also Figure 5-3.)

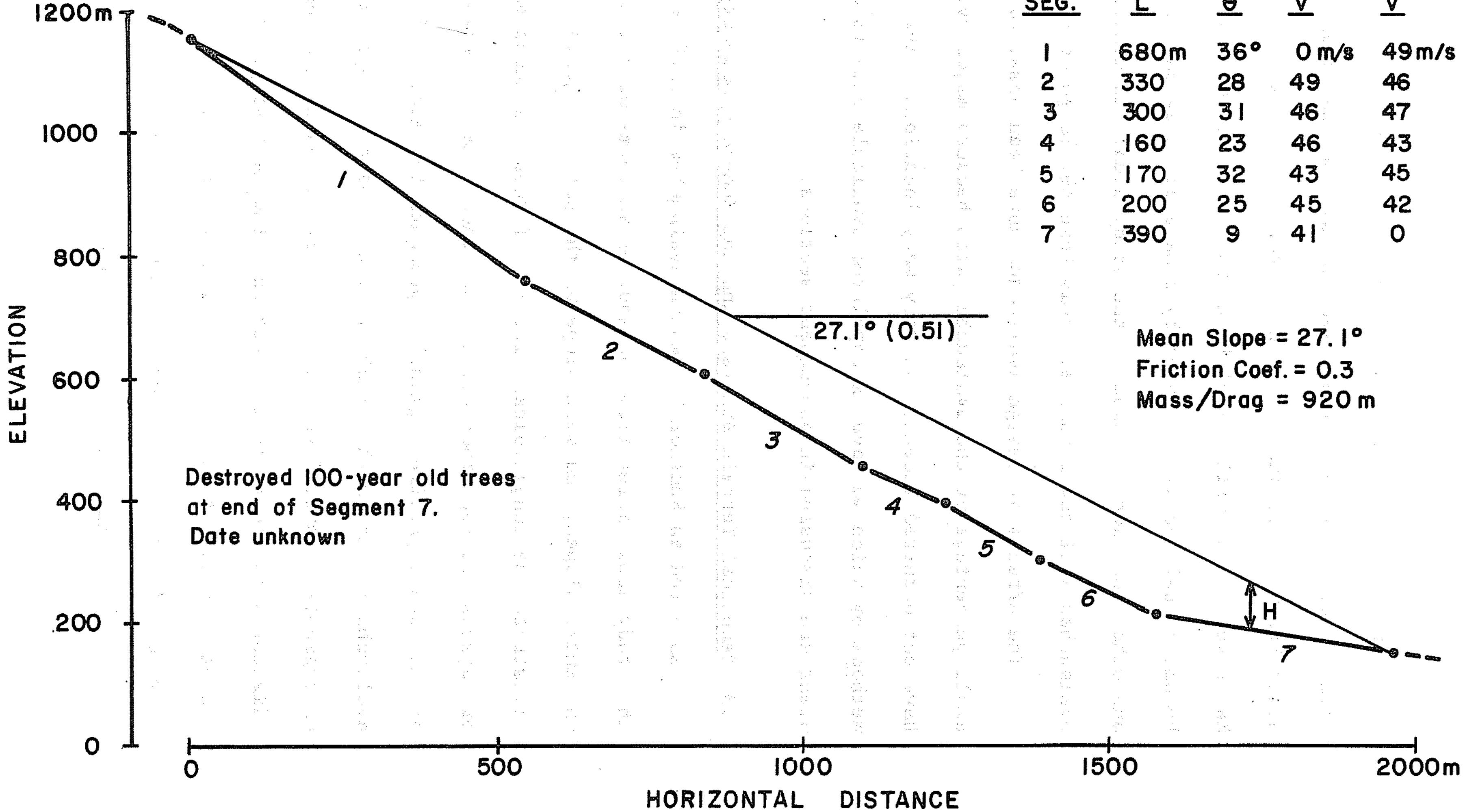
Large wet-snow avalanches also occur throughout the entire study area. Some major wet slides have reached the base area at Girdwood after becoming confined to a major channel that bisects the ski area. Major wet slides will travel long distances, especially when they become chanelized as indicated by damage at Girdwood, Eagle River, and other locations outside of the study area. In general, wet-snow avalanches will cover smaller areas than the large dry-snow avalanches.

The effects of design avalanches have been observed in only a small percentage of the avalanche paths because major events simply have not occurred recently at very many locations. The indirect methods by which we have extrapolated available data to other avalanche areas are discussed in subsequent sections.

5.3 Technical Terrain Analysis and the Red-Zone Boundary

As noted in Section 3, design avalanches in different parts of the study area differ from one another in terms of travel distances on gentle slopes, and mean slope of the path. Figures 5-2 through 5-5 illustrate the longitudinal profiles of four avalanche paths within or adjacent to the study area. The runout limit of each path (bottom of the lowest profile segment) represents the extent of the 100-year avalanche in each path. Each profile shows the length and steepness of segments, computed velocities at the beginning and end of segments (discussed in the following section), the mean slope of the path, and other relevant data. A casual inspection of these four profiles shows considerable variation in the mean slope of the path, ranging from 27.1° in the Crow Creek Road Slide near Girdwood to 19.9° in the

FIGURE 5-2
CROW CREEK ROAD (SEC. 33)

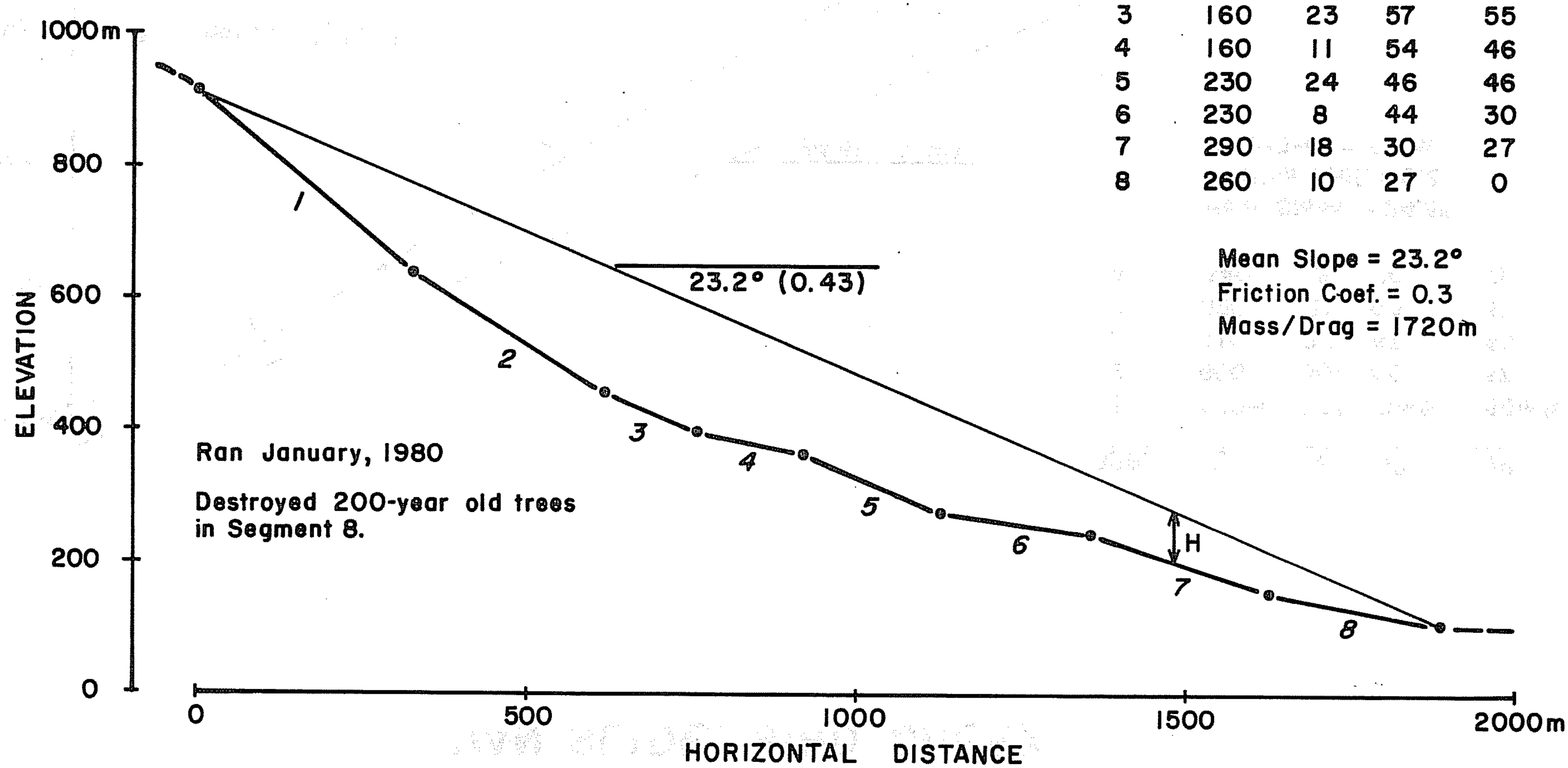


SEG.	L	θ	V^a	V^b
1	680m	36°	0 m/s	49m/s
2	330	28	49	46
3	300	31	46	47
4	160	23	46	43
5	170	32	43	45
6	200	25	45	42
7	390	9	41	0

Mean Slope = 27.1°
Friction Coef. = 0.3
Mass/Drag = 920 m

FIGURE 5-3

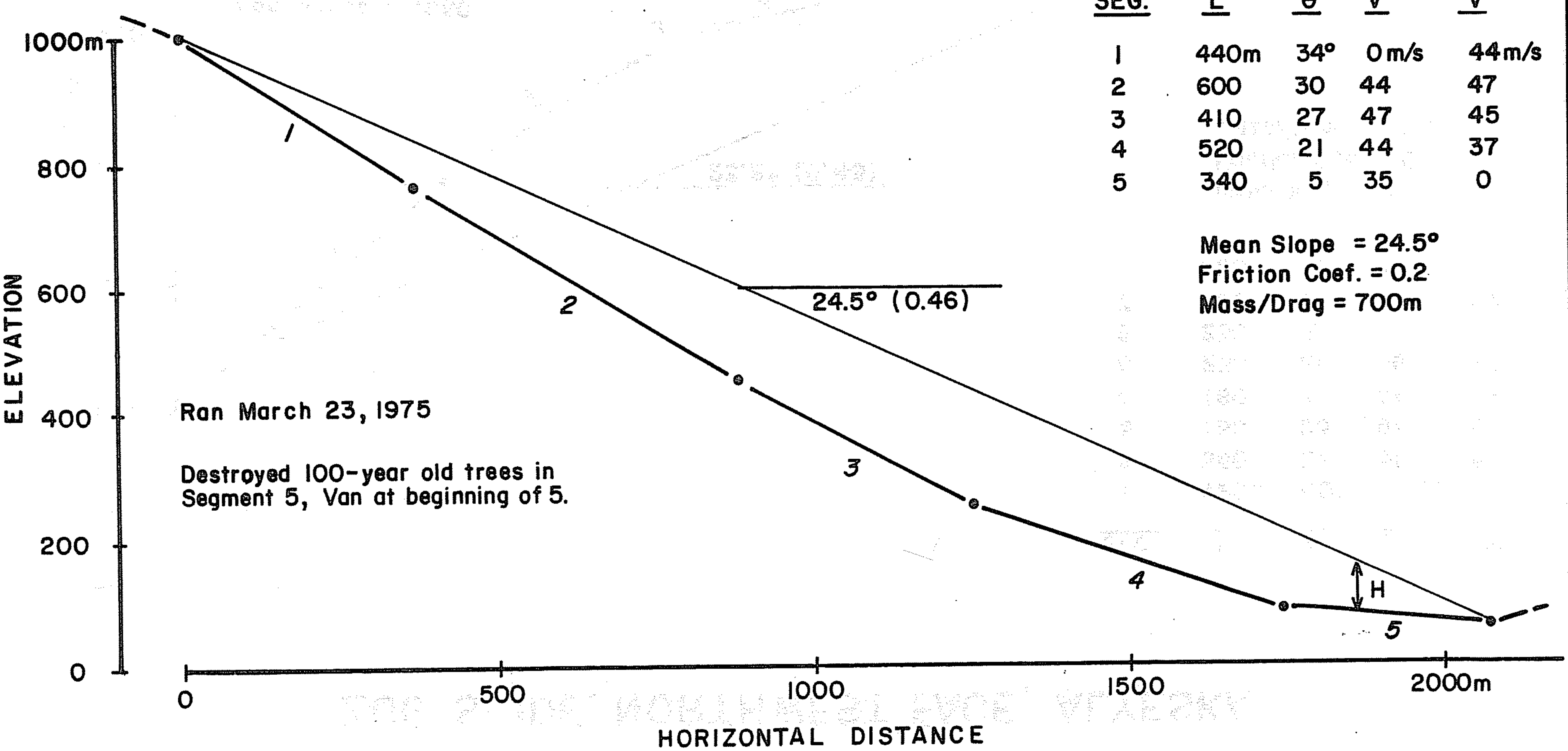
ZUG SLIDE, NORTHWEST FACE, ALYESKA



SEG.	L	θ	V^a	V^b
1	420m	40°	0m/s	52m/s
2	340	32	51	57
3	160	23	57	55
4	160	11	54	46
5	230	24	46	46
6	230	8	44	30
7	290	18	30	27
8	260	10	27	0

Mean Slope = 23.2°
Friction Coef. = 0.3
Mass/Drag = 1720m

FIGURE 5-4
VAN SLIDE, BIRD CREEK



SEG.	L	θ	V^a	V^b
1	440m	34°	0 m/s	44m/s
2	600	30	44	47
3	410	27	47	45
4	520	21	44	37
5	340	5	35	0

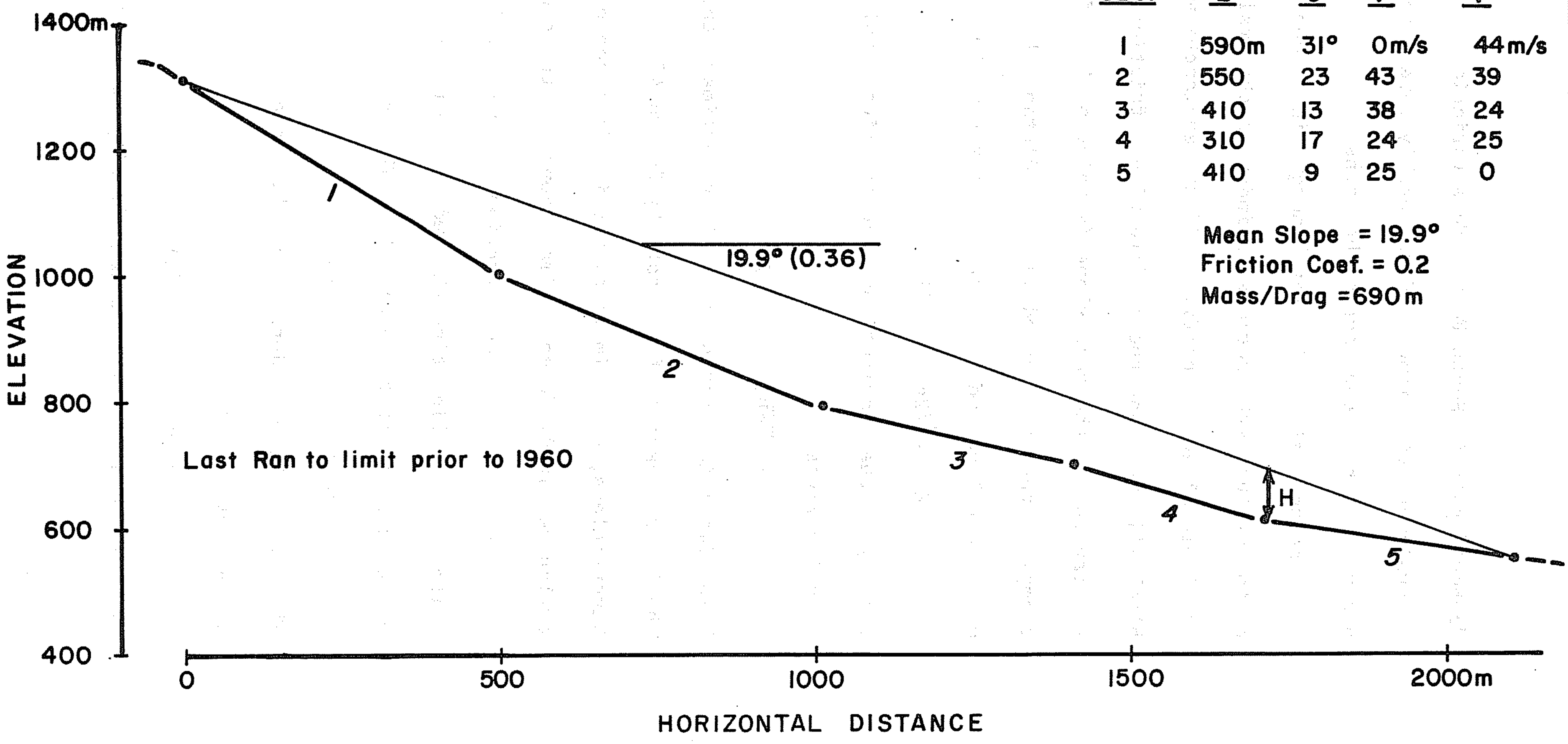
Mean Slope = 24.5°
Friction Coef. = 0.2
Mass/Drag = 700m

FIGURE 5-5

"3-BOWL", SOUTH FORK EAGLE RIVER

SEG.	L	θ	V^a	V^b
1	590m	31°	0 m/s	44 m/s
2	550	23	43	39
3	410	13	38	24
4	310	17	24	25
5	410	9	25	0

Mean Slope = 19.9°
Friction Coef. = 0.2
Mass/Drag = 690 m



"3-Bowl" path in South Fork. This variation in mean slope is an index of avalanche efficiency. Considerably more frictional retardation occurs in the steeper avalanche paths.

The mean slope line (or "energy line") connecting the top and bottom of the path provides an index of the avalanche kinetic energy available along the profile. If the avalanche were modeled as a rigid block sliding along the profile with a friction coefficient equal to the tangent of the mean slope (a value of 0.43 in the Zug Slide, for example), then the scaled vertical distance H, from the ground to the mean slope line can be written in terms of the velocity, V, as

$$H = V^2/2g, \qquad (1)$$

where g is the gravitational acceleration. Solving equation (1) for velocity gives

$$V = \sqrt{2gH}. \qquad (2)$$

This simplified expression will overestimate the computed velocity in the lower segments of the path by 20% to 40%, as discussed later. Nevertheless, this simple expression is a convenient way of comparing avalanches in different climate zones of the study area.

Because limited construction is possible in the blue zone, a criteria for delineating the red/blue boundary is based on the kinetic energy density of the avalanche. The energy density, P, is equal to

$$\tfrac{1}{2}\rho V^2 \qquad (3)$$

Where ρ is the mass density of the avalanche. Substituting in equation (1) we have

$$P = \rho g H, \qquad (4)$$

an index of the kinetic energy density or impact pressure at various points on the profile. A height H = 80 m is chosen as the boundary between the red and blue zones, because our experience in calculating avalanche forces and observations of destruction suggests extremely large avalanche forces can be expected where H > 80 m.

The actual impact pressure used in design of structures in the blue zone will, in general, differ from P, because avalanche velocity will be less than that obtained by equation (2). Furthermore, the value for avalanche density, ρ, will differ considerably from one location to another. The variables, velocity and density, must be chosen carefully in final design. For these reasons, engineering criteria for a given structure are site and design specific and must be analyzed on an individual basis. The relationships between avalanche velocity and energy density are discussed in terms of a 2-component model in Section 5.5. Avalanche defense design is discussed in Section 6.

5.4 History of Avalanches Affecting Property in Anchorage

The following compilation of historical avalanche data was compiled by Mr. Doug Fesler of Chugach State Park. We have subdivided the data into two categories. The first category includes part of Eagle River and South Fork drainages and are mapped on a 1:25,000-scale USGS topographic map (Figure 5-6). Figure 5-6 shows the known extents of avalanches and indicates the starting zones with dashed lines where exact boundaries are unknown. Avalanches are numbered 1 through 17 as indicated on Figure 5-6 and described below. The Eagle River avalanches all occurred in 1979 and 1980. Inspection of the avalanche paths indicate that the events represent "10-year" avalanches. The "100-year" design events would extend considerably farther downslope in all cases and would also include areas that did not avalanche in 1979 or 1980.

The second category includes avalanches in the Turnagain Arm area including Indian and Bird Creek, Girdwood, and Crow Creek. These avalanches are numbered 18 through 31. When the avalanche path locations are known and they have been shown by number on the topographic map (Figure 1-2).

KNOWN AVALANCHES AFFECTING STRUCTURES AND PRIVATE LAND IN EAGLE RIVER AND VICINITY

1. Circa January 1980, Mile High Subdivision, Eagle River: Avalanche entered private land and crossed road two times. Source: Personal observations and photos (Fesler).

2. Circa January 1980, Mile High Subdivision, Eagle River: Avalanche entered private land and crossed road three times. Source: Personal observations and photos (Fesler).

3. Circa January 1980, Mile High Subdivision, Eagle River: Avalanche entered private land and crossed road two times. Source: Personal observation and photos (Fesler).

4. Circa January, 1980, Mile High Subdivision, Eagle River (same site as #5 below): Avalanche entered private land crossing road two times. Source: Personal observations and photos (Fesler).

5. Circa March 1979, Mile High Subdivision, Eagle River (same as site #4, above). Avalanche entered private land crossing road five times. Source: Personal observations and photos (Fesler).

6. Circa 21 March 1979. Myrtal Drive, Eagle River: Avalanche stopped 75' short of a private residence after destroying a chain link fence. Source: Personal observation and photographs (Fesler).

7. Circa 21 March 1979, Myrtal Drive, Eagle River: Avalanche stopped within 200' of hitting a private residence. Source: Personal observations (Fesler).

8. 27 April 1979, Wallace residence #1, Eagle River: One house, its contents, and one vehicle totally destroyed by a slide which stopped short of three other buildings (including two residences). Source: Personal observation and photos (Fesler) and personal conversations (R. Wallace and M. Rodak).

9. 18 January 1980, Wallace residence #2, Eagle River (same path as #8 above): Extensive damage to an occupied residence caused by soft slab avalanche which followed main gully. This is the second residence within 10 months in the same path to be destroyed or damaged. Source: Personal observation and photos (Fesler) and personal correspondence (R. Wallace).

10. 21 March 1979. Berryhill Road, Eagle River. One residence (A-frame) was totally destroyed and most of the contents lost in a slide which originated on W aspect of the South Buttress of (unnamed) peak 4500', (1.5 miles NE of Berryhill Road and stopped at Berryhill Road. Source: Personal observation and photos (Fesler).

11. Circa 21 March 1979. .5 mile E of Berryhill Road, Eagle River. Avalanche recorded as reaching and affecting private land presently undeveloped. Source: Personal observations and photos (Fesler).

12. Circa 21 March 1979. Mile 9 Eagle River Road (Moose Pond Slide), Eagle River. Avalanche stopped against the rear wall of a private residence (A-frame) causing no known damage. Source: Personal observations and photographs (Fesler).

13. Circa January 1980, Mile 9 Eagle River Road, Eagle River (same site as #12 above): Avalanche stopped a couple of hundred feet above private residence. Source: Personal observations and photo (Fesler).

14. 1979 or 1980. Avalanche identified on aerial oblique photograph by D. Fesler, details unknown.

15. 18 January 1980, Long Homestead, South Fork of Eagle River: One utility trailer hit, overturned, and damaged. This is the first reported avalanche to have occurred at this site since the land was homesteaded in the early 60's. Source: Personal communication (W. Long), report "Avalanche Hazard Evaluation at Long Homestead" (J. Riehle) and personal observation (Fesler).

16. Circa 1960's, Ken Moon Homestead, South Fork of Eagle River area, (specific site and date unknown): One homestead cabin (A-frame) reportedly hit and destroyed. Source: Personal correspondence (Diane Brenan of Anchorage and Mrs. Axesmith, South Fork Eagle River).

17. Circa January 1980, .5 miles E Eagle River Visitor Center, Eagle River: Avalanche stopped just short of private residence (newly built). Source: Personal observation and photos (Fesler).

KNOWN AVALANCHES AFFECTING STRUCTURES AND PRIVATE LAND IN TURNAGAIN ARM AND VICINITY

18. February 1932, Peter Strong mining claim, Indian, (Specific site and date unknown at this time): One occupied cabin was hit, partially damaged, and moved downhill. Some of the contents were damaged. Source: Anchorage Daily Times, 12 February 1932, p. 8, Col. 1.

19. March 1979, Chugach Electric poerline, Powerline Pass area: Three major transmission line poles for 115 kv line were totally destroyed in first recorded avalanche at that site since the construction of the powerline circa 1962. Source: Personal observation (Fesler) and conversations (Shompers/Chugach Electric).

20. Winter 1975-76, USCS Snow Course Site, Indian Creek Pass area. Antennae and structure housing instrumentation and telemetry equipment was damaged and subsequently moved. Source: Personal Observations (Fesler) and conversations (Clagett).

21. 21 March 1979, MP 105 Seward Highway near Indian: First recorded avalanche at this site to reach (and block) the highway since its construction in 1951. Source: Personal observations and photos (Fesler).

22. 23 March 1975. Van Slide, Penguin Creek. Major dry-snow powder avalanche destroyed Ford Econoline Van by wrapping it around a tree. Trees destroyed at runout limit were 80-100 years old.

23. 27 March 1964, Mt. Alyeska, Girdwood: First avalanche recorded to have reached the base area of Mt. Alyeska Ski Resort since operation started. Earthquake induced avalanche started from the back side of Max's Mountain and the Saddle area, moved through the canyon, ran under the chairlift at Tower #1 and came to rest against the old lodge (present office building). Source: USFS Snow Avalanche Report dated 12 April 1969, page 3 and personal communication (David Scott).

24. 21 February 1969, Mt. Alyeska, Girdwood: Second avalanche recorded to have reached the base area of Mt. Alyeska Ski Resort, with the base area being hit by wind blast and the debris stopping 500' short. This artillery induced slide originated in the area of the Palasades, Alyeska Chute, the Sun Spots, and Alyeska Park and caused no damage to the base. However, four patrolmen and one civilian were hit by wind blast, two receiving

minor injuries. Source: USFS Monthly Avalanche Report Supplement by Charles O'Leary, dated 4 April 1969.

25. 12 April 1969, Mt. Alyeska, Girdwood: Third avalanche recorded to have reached base area of Mr. Alyeska Ski Resort. This artillery released slide originated in the shadows area coming to a halt at the base after plowing through the lift control building and the support columns of the lift terminal. It came to rest against the ticket shack. Source: USFS Snow Avalanche Report dated 12 April 1969, pp. 1-3 and Snowy Torrents, 69-17 by Knox William and personal observations (Fesler).

26. 14 April 1973, Mt. Alyeska, Girdwood: Lower terminal of chair #2 and one tower were destroyed with several chairs and cable damaged. Slide originated in the Sun Spots area at approximately 3,000 feet elevation.

27. 9 May 1975. Mt. Alyeska, Girdwood: The poma lift was derailed and trees uprooted in a large slide off of NW face of Max's Mountain (Mt. Baumann) which stopped approximately 300' short of the day lodge and parking area. Source: Personal conversations and photographs (Saxton, Lee).

28. March, 1981, Zug Slide, N. Face Mt. Alyeska, Girdwood: Skier-triggered slide destroyed many trees in excess of 200 years old.

29. Winter 1932-33, Girdwood Mining Company, Crow Creek area, Girdwood (exact date unknown): One building was totally destroyed, three cabins were slightly damaged, and one bridge hit but not damaged. Source: Alaska Road Commission photographs dated 3 June 1933 (State Historical Library).

30. 1917, Crow Creek area, Girdwood. (Specific site and date unknown at this time): the bunkhouse of the mining camp was hit and damaged (tipped slightly on end). No injuries reported. Source: Letter, written by Axel Lindblad dated 27 March, 1923 (Tohey, Girdwood).

31. March 1923, Crow Creek area, Girdwood (same site as #30 above): Two buildings, the bunkhouse and the main building (offices, storeroom, kitchen, and living rooms) were totally destroyed and two other cabins apparently were hit, but received minor damage. The majority of the equipment and supplies were lost or damaged. Source: Letter, written by Axel Lindblad dated 27 March 1923 (Tohey, Girdwood).

Many of the large avalanches listed here are representative of the "10-year" avalanche size. All of the Alyeska avalanches (numbers 23-27) were 10-year avalanches while number 28 was a 100-year avalanche.

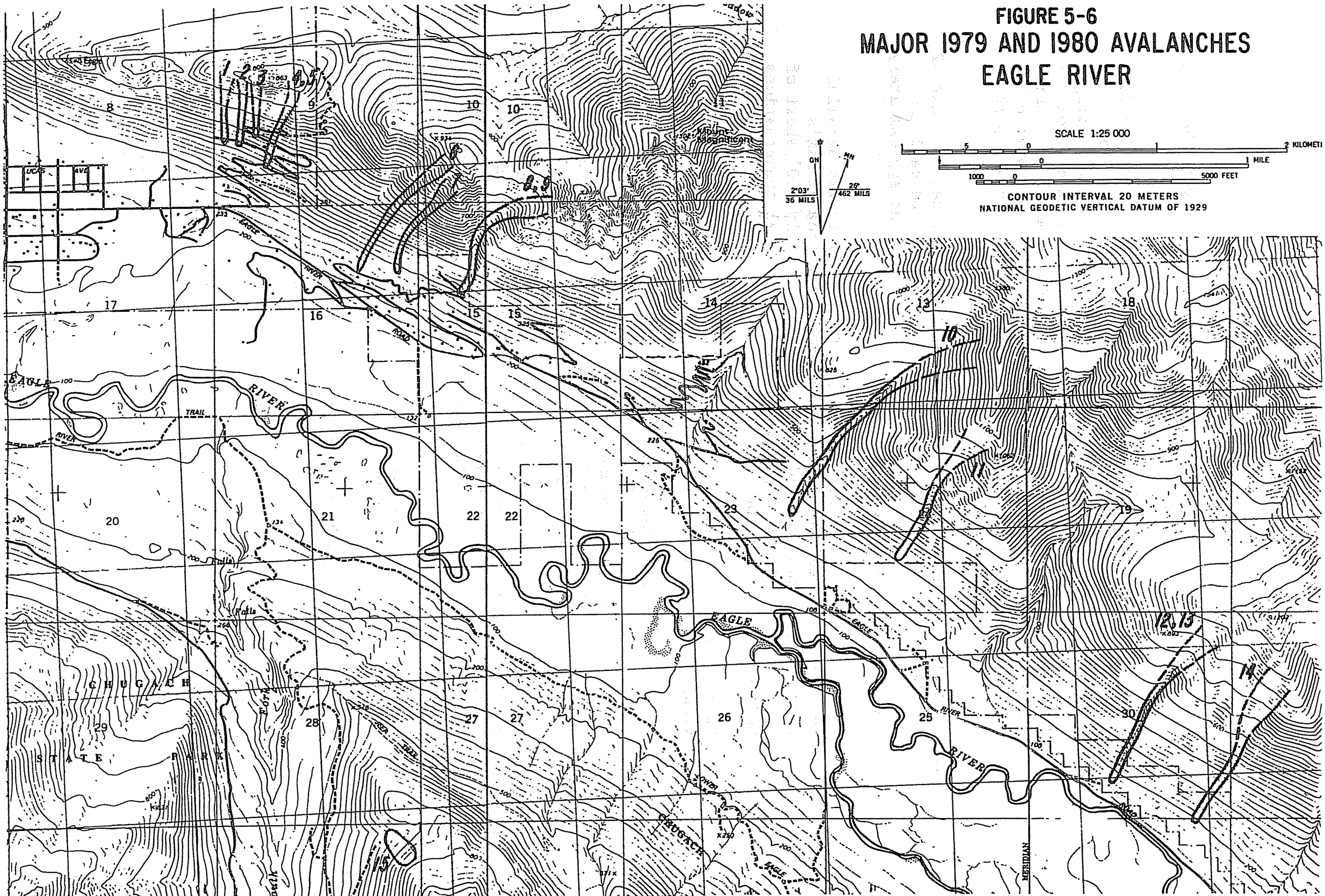


FIGURE 5-6
MAJOR 1979 AND 1980 AVALANCHES
EAGLE RIVER

Insufficient data exist to speculate about the return period of other historical avalanches listed above.

5.5 Use of Avalanche-Dynamics Equations

Equations of avalanche motion were used to compute the velocities, accelerations, and stopping positions of design avalanches in selected paths with known starting and stopping positions. This derived information was used to delineate the end of the blue zone, define the red/blue boundary in terms of avalanche energy, and to provide a cross check on the other methods used to determine avalanche size.

In each avalanche area (South Fork of Eagle River, for example), certain avalanche paths were chosen for analysis because they represent terrain and snow conditions for several adjeacent and similar paths. The computational procedure used for each of the selected paths was as follows:

(1) A longitudinal path profile was drawn in which the path was subdivided into several segments of lengths L and inclination θ. The lengths and angles were taken from topographic maps. Examples of path profiles are shown in Figures 5-2 through 5-5.

(2) A 2-component model of avalanche motion was applied to each path. This model, described in Perla and Others (1980), assumes motion resistance is of the form $R = A + BV^2$, where A is a constant sliding friction term, B is an inertial (mass-to-drag) term, and V is the avalanche velocity.

(3) Trial-and-error fits were made by choosing various (A,B) pairs until the known stopping position of a previous large avalanche was predicted. This (A,B) combination was then used to compute the stopping positions and velocities at the beginning and end of each segment in other adjacent paths.

The results of this computational procedure are shown in Figures 5-2 to 5-5 where the computed velocities at the beginning and end of each segment (V^a and V^b) are tabulated. The assumed friction coefficient and mass-to-drag ratio are also given. Our observations of avalanche terrain and destruction throughout the study area suggest that avalanche equations are best fit by assuming a friction coefficient of 0.3 in the Girdwood coastal snow climate and 0.2 in high elevation areas where dry snow is more likely throughout the path. The larger assumed friction coefficient enables the computed avalanche to stop on steeper slopes and produce the destruction characteristic of high velocity avalanches. The mass-to-drag ratio increases with avalanche path length, or the area of the path with slopes in excess of 30^o.

The destructive potential of an avalanche is closely related to the energy head, H, as defined previously. Our computatons show that within the lower 20% of the path, the energy head H' characteristic of avalanches computed using the 2-component model, is roughly half the H-value obtained using the straight-line energy head. Thus, kinetic-energy density in the lowest segment is more accurately estimated as

$$\rho g H' \qquad (5)$$

where

$$H' = H/2.$$

Therefore, a first estimate of the energy density that must be dissipated through use of defense structures can be obtained from the path profile and the mean slope line and can be written

$$P = \frac{\rho g H}{2} \qquad (6)$$

where ρ is avalanche mass density, g is gravitational acceleration, and H is the vertical distance from the profile surface to the straight-line energy head. This approximation is valid only in the lower 10% to 20% of the path and should be used to assess the feasibility of defense construction. We re-iterate that detailed site-specific analysis is required for final design.