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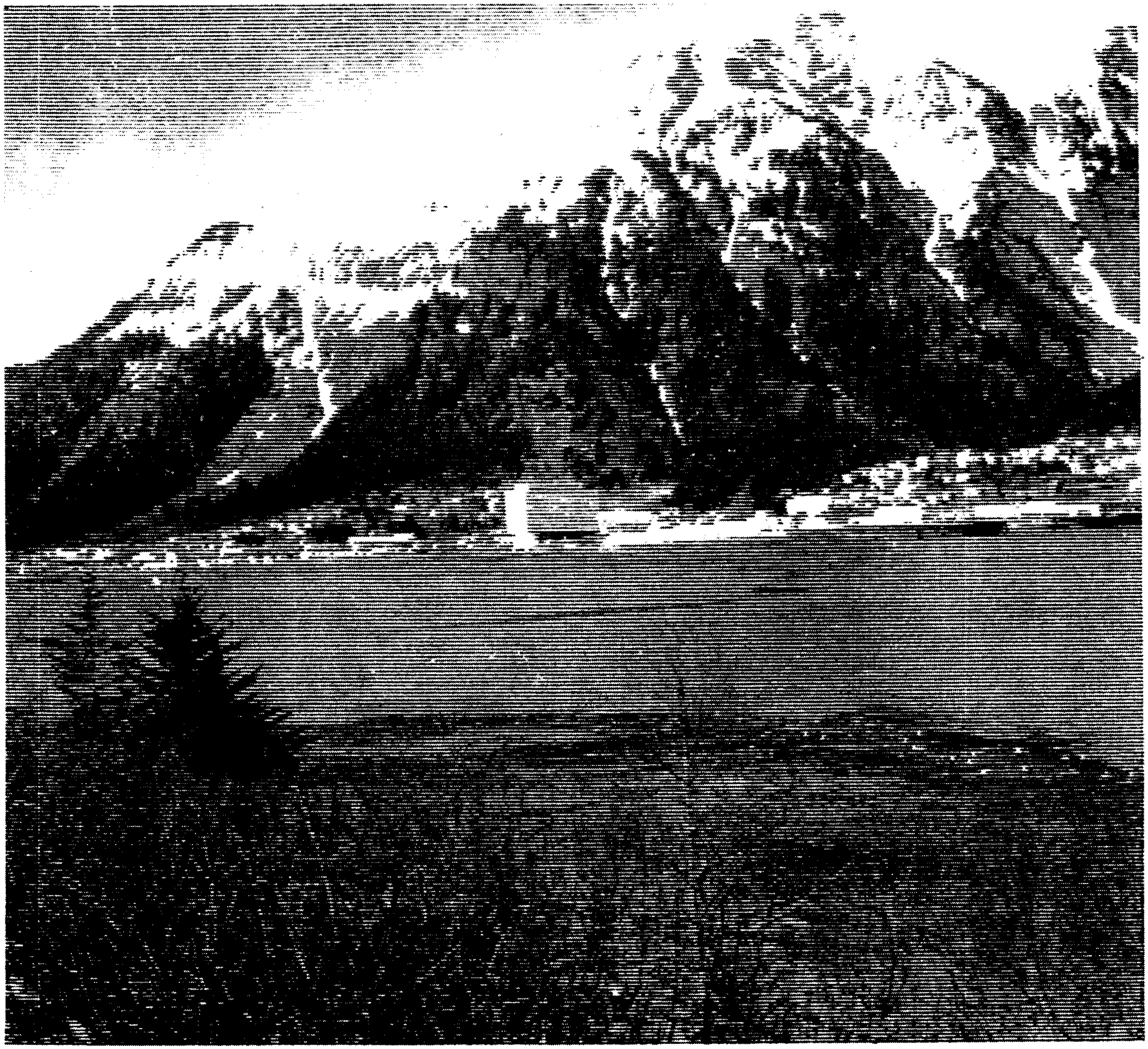

GEOPHYSICAL HAZARDS INVESTIGATION FOR THE CITY AND BOROUGH OF JUNEAU, ALASKA

TECHNICAL SUPPLEMENT

October 1972

The preparation of this report was financed in part through a comprehensive planning grant from the Department of Housing and Urban Development, under the provisions of Section 701 of the Housing Act of 1954, as amended.

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INTRODUCTION

This Technical Supplement to the Summary Report of Findings of the Geophysical Hazard Investigation for the City and Borough of Juneau, Alaska presents in appendix form a record of the work performed during the course of this investigation. Included are the reported findings of each of the specific hazards investigated: seismic hazard, mass wasting hazard and avalanche hazard. To complement these three investigations, four additional appendices are included: copies of the Hart Report (1967), the La Chapelle Report (1968), and the Hart Report (1968), and an appendix of excerpted structural avalanche defense measures.

Two additional items have been added as appendices. The first is a structural review and recommendations related to seismic hazards and the second is a file memorandum describing the citizen's information program which was conducted during the field work in Juneau. These items are included for the purpose of fully describing the work that was accomplished during the course of this investigation.

Reproducible copies of the mass wasting and avalanche hazard maps contained herein have been provided to the Planning Commission Staff of the City and Borough of Juneau under separate cover.

APPENDIX I

SEISMIC HAZARD INVENTORY AND LAND USE CONTROL FOR THE CITY AND BOROUGH OF JUNEAU

Report to the
City and Borough of Juneau
Juneau, Alaska

Prepared by: Alaska Geological Consultants, Inc.
Anchorage, Alaska

June, 1972

SEISMIC HAZARD INVENTORY AND LAND USE CONTROL FOR THE CITY AND BOROUGH OF JUNEAU

INTRODUCTION

The City and Borough of Juneau, located within the active circum-Pacific seismic belt, called the "ring of fire", has experienced many earthquakes in the past and must be prepared for them in the future. The past earthquakes felt in the Juneau area provided a few thrills and considerable conversation, but no significant damage. The minor intensities of these historical earthquakes, however, should not be used as a basis to forecast future seismic events. Juneau could well be compared to other Alaskan cities such as Anchorage, Whittier, Valdez, Cordova, and Kodiak, which never suffered measurable earthquake damage prior to the "Good Friday" earthquake of March, 1964. A potentially damaging shock could also strike the Juneau area.

A growing knowledge concerning earthquakes gained through study of previous seismic events is taking much of the previous fatalism out of the realm of earthquake hazards. The destructive potential can be greatly minimized by intelligent planning, zoning, land use control, and by designing buildings, utilities and other facilities to withstand the effects of earthquakes. A highly important factor in the design of earthquake resistant structures is thorough knowledge of the subsurface geologic conditions upon which the facility will be built. The damage from a high magnitude earthquake can always be correlated with the local geology and with how well man has built his structures. Buildings on bedrock can often be expected to escape major damage while those on deep alluvial soils or filled ground may be severely damaged. It could be said that the Biblical directive about building one's house on rock appears to be sound seismology.

The purpose of this report, therefore, is to inventory the potential seismic hazards of the urbanizing City-Borough area and to make recommendations for measures to minimize these hazards.

ACKNOWLEDGEMENTS

Most of the data for this study were obtained from the just-released U.S. Geological Survey open-file report authored by Robert D. Miller of the Survey's Engineering Geology Branch. This report, entitled "Surficial Geology of the Juneau Urban Area and Vicinity, Alaska, with Emphasis on Earthquake and other Geologic Hazards", is a complete and comprehensive study of the subject. The investigation leading to the report was part of a U.S. Geological Survey program to evaluate earthquake and other geologic hazards of Alaskan coastal cities. The sur-

ficial geology map and the transparent overlay depicting the quality of foundation conditions, which are a part of Miller's report, represent many months of painstaking investigations. The detail shown is excellent. We therefore are adopting it as the basis for the task of assigning seismic hazards to urban and urbanizing portions of the City and Borough. It is particularly noteworthy here to point out that Robert D. Miller was the co-author of U.S. Geological Survey Bulletin 1093 which so clearly and fully warned of the potential for earthquake-triggered landslides in the Anchorage area. The report was published in 1959. Unfortunately the warning went unheeded and when the March 27, 1964 earthquake shook Anchorage, massive destructive slides occurred in the areas where he had predicted.

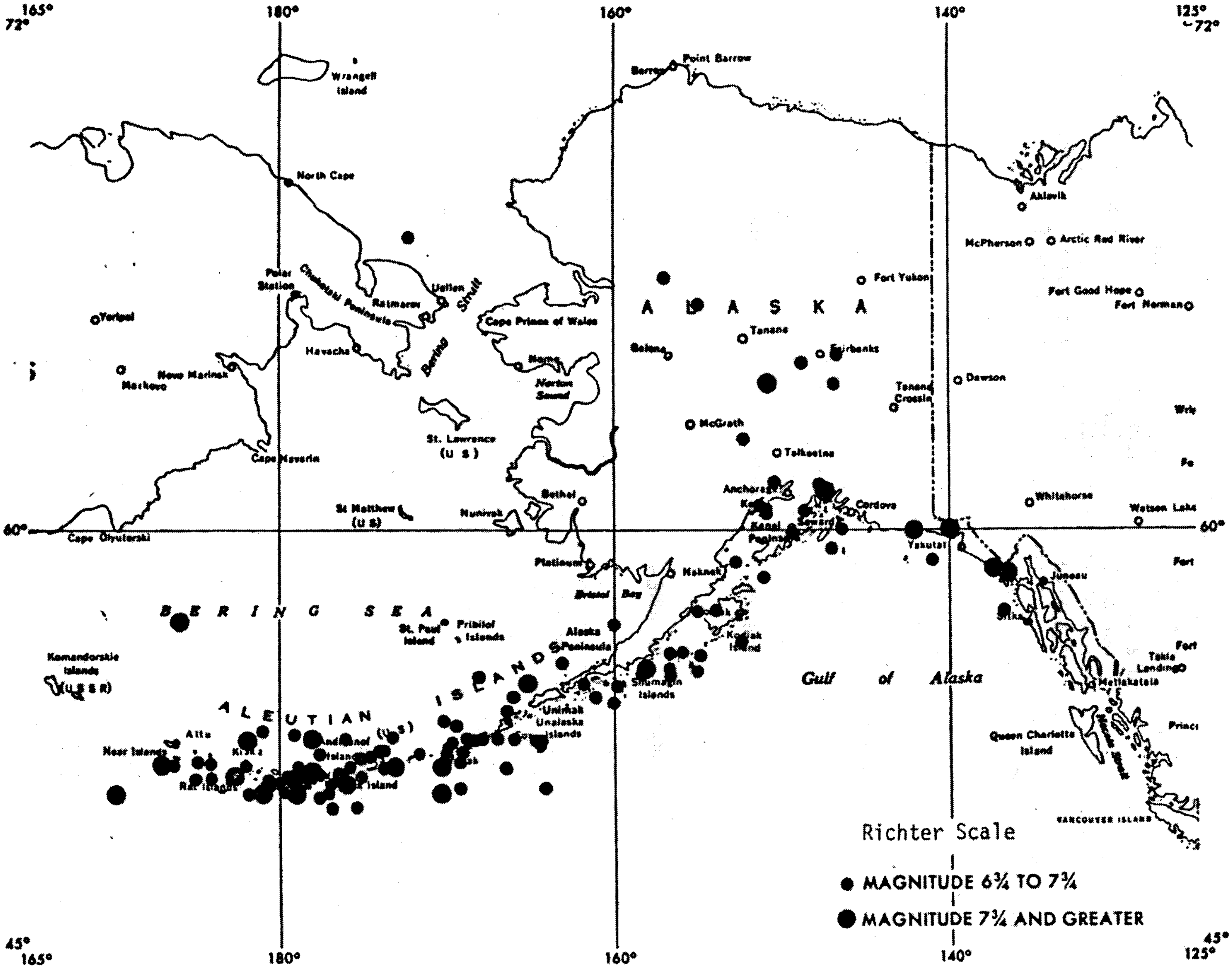
Other valuable information was contributed by Dr. Douglas Swanston, a long-time Juneau resident and a member of the Geophysical Hazards Study Team assigned to the landslide and mass wasting inventory. Dr. Swanston's wide knowledge of the local geology and geography was a great asset during investigations of the Juneau area. Special thanks is also due to Keith Hart, Senior Planner of the City-Borough for his cooperation and advice throughout the duration of the study. We are also very grateful to the DMJM staff, a group of competent hard working professionals which provided technical and logistical support to the study team.

HISTORY OF EARTHQUAKES IN JUNEAU

Instrumental recordings of the larger earthquakes of Alaska have only been obtained since the beginning of the century. The overall record reveals that roughly 4 percent of the energy annually released by all earthquakes has an Alaskan source. There are two principal earthquake zones in Alaska which together form a part of the active seismic belt which rings the Pacific Ocean. The most important of these two zones is the one of the Aleutian Islands, which is a 200-mile wide zone extending from Fairbanks, Alaska, through the Kenai Peninsula to the Near Islands. This zone is nearly a classical island arc with shallow focus earthquakes associated with an oceanic foredeep and with intermediate depth earthquakes under and behind the volcanic islands. The other zone extends from north of Yakutat Bay southeastward to the west coast of Vancouver Island. Seismic activity in this zone is that which is felt in Juneau.

The epicenters of earthquakes with magnitudes 6.75 and larger on Richter scale are plotted in Figure 1.

Miller (1972) has compiled a list of all earthquakes felt in Juneau dating back to 1847. There were 84 events and the record reveals that the greatest intensity of these quakes in Juneau was about VI on the modified Mercalli scale of intensity. Intensity refers to the observed qualitative effects of earthquake forces (that is, principally in a lateral direction). These vary from area to area,



ALASKAN EARTHQUAKES THRU MARCH 1964 MAGNITUDE 6¾ AND GREATER

AFTER U.S.C.&G.S. 1964 MAP

ALASKA GEOLOGICAL CONSULTANTS

FIGURE 1

depending upon the local geology and distance from the epicenter. The chart shown in Table 1, shows the modified Mercalli scale in comparison with other scales. The magnitude of an earthquake is a measure of the amplitude of the seismic waves and is related to the amount of energy released. The most common magnitude scale used today is the Richter Scale.

The historical record reveals that only two earthquakes with epicenters within fifty miles of Juneau have occurred since the turn of the century. Earthquakes felt in Juneau in the past occurred generally along the very active Fairweather-Queen Charlotte Islands fault which extends up the coast roughly 100 miles to the west of Juneau. Earthquake magnitudes of up to 8.6 have been recorded along this fault zone. The largest recent earthquake along this zone occurred on July 10, 1958. This event had a spectacular affect on Lituya Bay, and was accompanied by significant fault movement.

FUTURE EARTHQUAKE PROBABILITY

Investigators in many earth science disciplines have been pursuing the elusive goal of earthquake prediction with little success. However, given a historical seismic record for a region for several centuries, it is possible to formulate the statistical probability that an earthquake of a given magnitude will occur in a region within a specific interval of time. Unfortunately, Juneau does not have the necessary multi-century history to establish seismic probability. There are several other factors, however, which can be used to determine the seismicity of the area. Miller (1972, p. 10) refers to the large rockslide avalanche deposits along lower Gold Creek and on Douglas Island as well as landslide deposits in Lemon, Salmon and Nugget creeks as evidence of a seismically active recent past. He points out that other conditions could have precipitated the slides, but earthquake activity is the most probable cause.

The location of geologic faults in the area is evidence that considerable ground movement has occurred in the past. Faults are often classified as active faults or dead faults. Active faults are faults along which there has been movement in historic or recent geologic time, or along which recurrence of movement is likely to occur; dead faults are those along which there is no indication of movement in historic or recent geologic time and no reason to predict a recurrence of movement. These distinctions, of course, are very subjective. Faults in seismic areas, even without a history of movement, are more likely to slip than faults in regions without a history of seismic activity.

R. D. Miller (1972, pp. 7, 8, 9 and 10) has described the many faults within the Juneau Borough as well as those occurring throughout the southeastern Alaska Region. The location of these faults is shown in Figure 2. The faults which lie within the City and Borough of Juneau as follows:

FIGURE 2

THE MODIFIED INTENSITY SCALE OF 1931*

Scale Degree	Effects on Persons	Effects on Structures	Other Effects	Rossi-Forel Equiv.	Equiv. Shallow Magnitude
I	Not felt except by few under favorable circumstances			I	
II	Felt by few at rest		Delicately suspended objects swing	I-II	2.5
III	Felt noticeably indoors		Duration estimated	III	
IV	Felt generally indoors		Cars rocked, windows rattled	IV-V	3.5
V	Felt generally	Some plaster falls	Dishes, windows broken pendulum clocks stop	V-VI	
VI	Felt by all, many freightened	Chimneys, plaster damaged	Furniture moved, objects upset	VI-VII	
VII	Everyone runs outdoors, felt in moving cars	Moderate damage		VIII	5.5
VIII	General Alarm	Very destructive and general damage to weak structures. Little damage to well-built structures	Monuments, walls down, furniture overturned. Sand & mud ejected.Well water level changes	VIII-IX	6.0
IX	Panic	Total destruction weak structures, cons. damage well-built structures	Foundations damaged, underground pipes broken	IX	
X	Panic	Masonry and frame structures commonly destroyed. Only best buildings survive	Ground badly cracked, rails bent. Water over on banks		
XI	Panic	Few buildings survive	Broad fissures, fault scarps. Underground pipes out of service	X	8.0
XII	Panic	Total destruction	Acceleration exceeds gravity.Waves seen in ground.Lines of sight & level distorted, objects thrown in air		8.5

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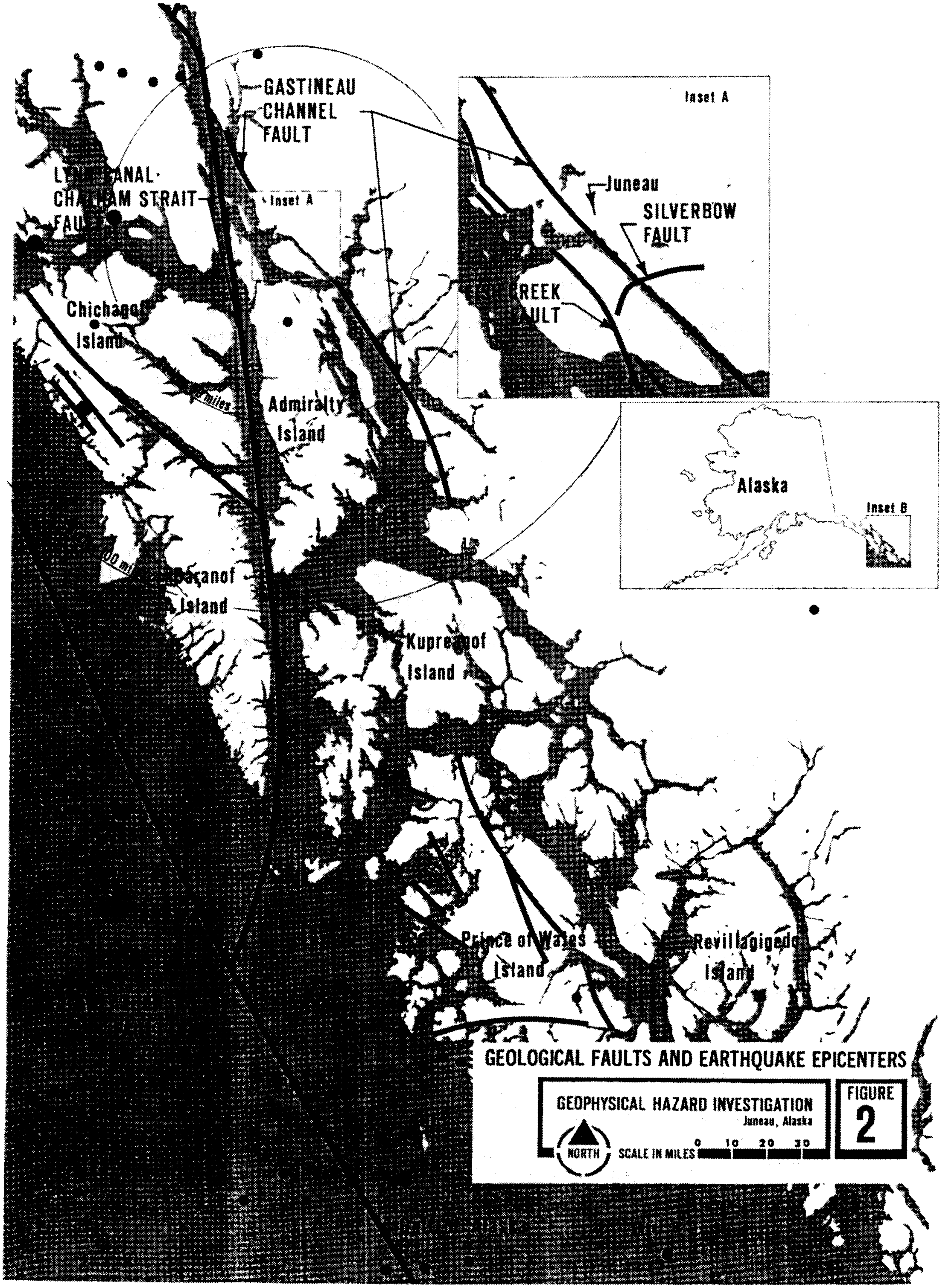
*Howell, 1959 - Simplified for this report.



GEOLOGICAL FAULTS AND EARTHQUAKE EPICENTERS

GEOPHYSICAL HAZARD INVESTIGATION
Juneau, Alaska

FIGURE 2

1. Gastineau Channel-Berners Bay Fault
2. Silverbow Fault
3. Fish Creek Fault on Douglas Island
4. Lynn Canal-Chatham Strait Fault

Miller reports no evidence of movement along these faults in Pleistocene or recent time. The Lynn Canal-Chatham Strait fault and the Gastineau Channel-Berners Bay fault are southeasterly extensions of the Denali fault. The lack of activity in these southeastern extensions of the otherwise active Denali fault has been attributed to a shifting of seismic activity from the Denali fault to the Fairweather fault by way of the Totschunda fault near the Alaska-Yukon border. Miller cautions against assuming that the Lynn Canal-Chatham Strait fault is tectonically inactive because of the absence of historic earthquakes with epicenters related to it. He cites work by Tobin and Sykes which suggests that the long period of seismic quietude along the fault may be an indication that strain is being accumulated which could be released as an earthquake. This also applies to other seemingly inactive faults which lie in the Juneau area.

The very active Fairweather-Queen Charlotte Island fault has been the scene of numerous major quakes in historic time. In the years of 1899 and 1900 there were four earthquakes with magnitudes ranging from 6.0 to 8.1. Based upon this historical record, it is reasonable to predict that earthquakes strong enough to affect Juneau will occur along this fault.

Records indicate that where earthquakes have occurred in the past they will probably recur, and that the intensity of the recurrence can be much greater than that of previous quakes. Some believe in the probability that an earthquake will recur increases proportionately as time elapses, but this has not been proved conclusively.

SEISMIC ZONING

The Uniform Building Code of the International Conference on Building Officials places seismic zones on particular areas based upon the largest probable earthquake magnitude for the area. There are three zones; 1, 2, and 3 corresponding to minor damage, moderate damage, and major damage respectively. Juneau was included in Zone 3, where major damage could be expected, until the 1970 edition of the Uniform Building Code was published. The 1970 edition has placed Juneau in Zone 2. This in effect relaxes the building code for earthquake resistant construction. Miller (1972, p. 18) proposes that the Zone 3 classification should be adopted for Juneau until the seismic activity, or lack of it, in the Lynn Canal area is better understood. It is very difficult to disagree with this thinking in view of the relatively short historical record in the Juneau area. Experience has shown that many buildings in Anchorage designed and constructed in accordance with the code under seismic Zone 3 did not suffer irreparable damage from lateral acceleration during the March 27, 1964 earthquake.

REACTION OF GEOLOGIC UNITS TO EARTHQUAKE SHOCKS

The existence of a relationship between earthquake damage and local geology has been recognized by geologists and seismologists for many years. Simply stated, each geologic unit of geography responds differently to the shaking and vibrations of earthquakes. Experience gained from damage studies of many large earthquakes has shown that structures on soft ground often suffered damage five to ten times as great as similar structures on hard-rock foundations. Water filled alluvium or saturated filled ground tends to magnify the amplitude of earthquake shock waves and transmit them further than bedrock or other extremely competent non-bedrock material. The importance of solid rock foundations in minimizing earthquake damage was clearly illustrated in the San Francisco earthquake in 1906 and equally so by the "Good Friday" Alaska earthquake of 1964. In San Francisco, building damage was consistently greatest on land that had been recovered from the bay or filled in over old swamps and river beds. Proximity to the fault was much less important than the character of the foundation soil. Uncompacted fill also lurched and settled unevenly, causing streets to crack and often total collapse of buildings. Similarly, the 1964 Alaskan earthquake also demonstrated the effect of site conditions on earthquake effects. This was especially dramatized in Whittier which is located approximately 40 miles from the epicenter of the earthquake. High-rise buildings in Whittier, built on bedrock, were undamaged. Anchorage, however, located approximately 80 miles from the epicenter, is built upon thick unconsolidated soils. Many buildings there were damaged severely by the intense shaking and some suffered total collapse. The major damages in Anchorage, however, were the result of landslides in soils which underwent a fluid reaction to earthquake vibration. Similar fluid reactions resulting in destructive landslides occurred in Valdez and Seward, Alaska.

Thick beds of loose, saturated cohesionless alluvium react to earthquake shaking by granular response. This type of response consists of densification or compaction of the cohesionless materials under vibratory loading, resulting in differential settlements of structures founded thereon.

Brittle response to dynamic loading occurs in otherwise competent geologic units located in precipitous areas of mountains and hilltops. This type of response consists of rapid breaking off of glaciers, rock falls and rock fall avalanches as well as earthslides from steep slopes.

Bedrock and other extremely competent materials have an elastic reaction to earthquake vibrations. These elastic-reacting foundation materials generally constitute the "good ground" of an urban area insofar as response to earthquake loading is concerned. The non-elastic, reacting materials constitute "bad ground" geologically speaking.

The response of the various geologic units to earthquake loading generally results in mapping of areas of good ground and bad ground. It then follows that the bad ground should be avoided by anyone contemplating building construction. Unfortunately, the physical make-up and environment of most modern urban areas does not always allow the luxury of avoiding "bad ground" which, other than its susceptibility to damage from earthquakes, may have every other conceivable advantage of location. Perhaps because of the complex nature of the problem, the Uniform Building Code does not address itself to the effect that soil has on the action that an earthquake produces on a structure.

Many of the so-called areas of bad ground can be utilized if the soil conditions are thoroughly investigated and the specific character of the foundation soils and subsurface conditons are considered in the foundation design. The design of the foundation has an important structural effect on the intensity that might be experienced by structures during an earthquake. If the grip on the structure is good, the greater is the assurance that the structural action will match that of the foundation, and hence be more predictable. Therefore, the better the design, that is, the deeper the piles, the more piles that are present, the more rigid the foundation.

FOUNDATION MATERIALS OF THE JUNEAU AREA AND THEIR PROBABLE RESPONSE TO EARTHQUAKE LOADING

The surficial geology map of the Juneau area prepared by R. D. Miller shows the distribution and character of the surficial deposits. He has also made an evaluation of the relative quality of foundation conditions throughout the area. (See Fig. 3) Miller has rated the various foundation materials from poorest to marginal to most acceptable. The most acceptable areas are further subdivided as follows:

Sub-area 1 -- Best foundation material - bedrock

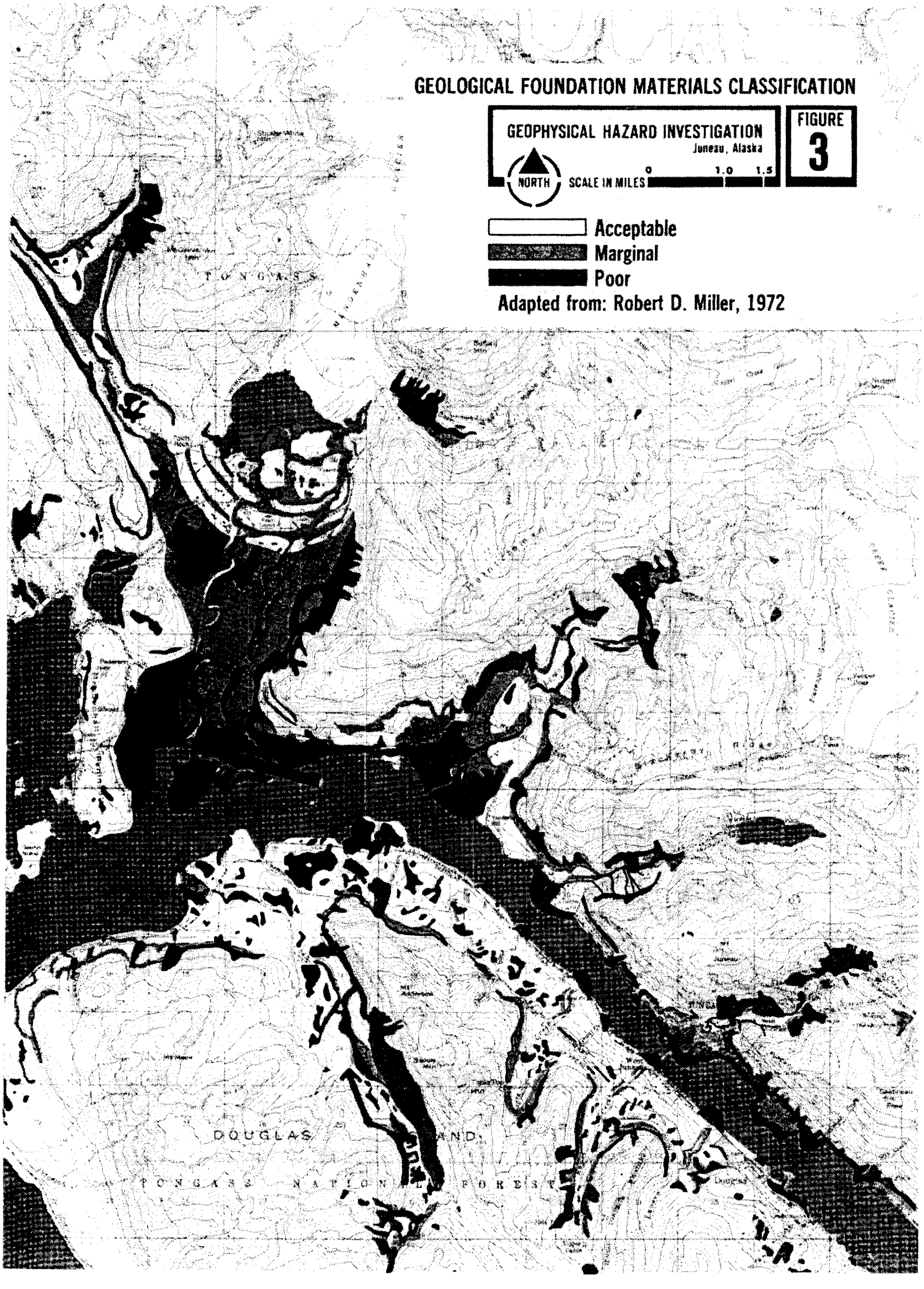
Sub-area 2 -- Very good - dense or well-compacted

Sub-area 3 -- Satisfactory

The relative suitability of the various foundation materials was judged by Miller principally from the expected behavior of those deposits during a severe earthquake. His map was compiled on parts of the Juneau A-2, B-2 and B-3 quadrangles and encompasses the urban portions of the Juneau Borough.

In addition, Miller has made an inventory of the areas known or believed to be susceptible to the effects of landslides. In view of the fact that landslides are often triggered by earthquakes, the data contained on the surficial geology map and the two analyses constitutes a nearly complete inventory of seismic-related geophysical hazards of the area.

We recommend that the information contained in Miller's report and Fig. 4 be used as the basis for the seismic-hazard rating in the land use plan, the zoning ordinance, and the building code. Not mentioned in Miller's report, but considered by this writer to be a probable hazard is the potential for earthquake-triggered landslides descending into



GEOLOGICAL FOUNDATION MATERIALS CLASSIFICATION

GEOPHYSICAL HAZARD INVESTIGATION
Juneau, Alaska

FIGURE 3

☐ Acceptable
▨ Marginal
■ Poor

Adapted from: Robert D. Miller, 1972

the Salmon Creek Reservior. A landslide terminating in the reservior would result in extreme hydrostatic pressure on the circa 1915 dam which could result in total failure of the structure. The developed portion of Salmon Creek Valley would therefore be subjected to disastrous flooding. The landslide potential on the steep slopes surrounding the reservior has been judged by Dr. Douglas Swanston[1] as very high. (Oral Communications, June 10, 1972). If not already accomplished by the Corps of Engineers in a flood hazard study, I strongly recommend that the integrity and soundness of the dam be determined as soon as possible. Periodic examination of the facility should, of course, be made.

SUMMARY OF SEISMIC HAZARDS

Miller (1972, p. 21) has tabulated the relative probability of occurrence of earthquakes and selected hazardous geologic events in the Juneau area within 100 years. This table, Table 2, presents a concise summary of the potential seismic hazards for the area including Tsunamis (seismic sea waves). To this table this writer would add the previously mentioned possibility of landslides in the Salmon Creek Reservoir. A probability of 4 should be placed on this event. The probability of dam failure caused by a landslide in the reservoir could only be determined by a detailed investigation of the structure and its foundation. Such an investigation was beyond the scope of this study.

RECOMMENDATIONS

At the present time, the best protection against earthquakes is to employ earthquake resistant construction techniques and to avoid construction in high risk areas. Our first recommendation is, therefore, to adopt a seismic zone 3 for the Juneau Borough. We further recommend that building permits for larger structures or for public buildings should not be issued unless the plans have been checked by a structural engineer qualified in the field of earthquake engineering. To ensure good construction practices in conformance with the earthquake code, we recommend that field inspection by the local governmental building official be religiously performed.

The highest risk areas in the Juneau Borough are those that are subject to landslides. This particular hazard is treated in detail in the mass-wasting portion of the geophysical hazard study. We are of the opinion that the areas of poorest foundation materials with respect to response to earthquake loading do pose a problem but need not be avoided. Most of these areas are underlain by geologic units which have a granular response to earthquake loading with the possibility of differential settlement. With properly designed foundations utilizing one of a number of foundation

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[1] Dr. Douglas Swanston performed the Landslide Investigation for the Juneau Geophysical Hazards Study.

TABLE 2

RELATIVE PROBABILITY OF OCCURRENCE OF EARTHQUAKES AND SELECTED HAZARDOUS GEOLOGIC EVENTS IN THE JUNEAU AREA WITHIN 100 YEARS

Earthquakes	Probability[1]
Earthquake of magnitude 6 or greater with epicenter at Juneau	1
Earthquake of magnitude 6 or greater with epicenter within 50 miles of Juneau	3
Earthquake of magnitude 6 or greater with epicenter within 100 miles of Juneau	5
Type of Hazard	
Movement along faults in Juneau area	1
Massive landslides in glaciomarine deposits similar to landslides that occurred in the Bootlegger Cove Clay in the Anchorage area during the March 1964 earthquake	1
Delta-front slides into water as result of earthquake, causing waves with rapid runups in excess of 5 feet	3
Tsunamis in Gastineau Channel with rapid runups in excess of 5 feet	2
Tsunamis in Lena Cove, Auke Bay, Fritz Cove, Tee Harbor, and along North Douglas Island and rapid runups in excess of 5 feet	3
Debris flows along existing or new channels on mountain slope above the Gastineau Avenue-Franklin Street area	5
Massive rockslide-avalanches along mountain fronts	4
Isolated rockfalls along existing talus cones, and as unexpected occurrences elsewhere	5
Damage from severe shaking caused by earthquake of magnitude 6 or greater with epicenter within 100 miles of Juneau	3
Compaction and settlement of water-saturated deposits from shaking of ground in response to earthquake of magnitude 6 or greater with epicenter within 100 miles of Juneau	3

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[1] Probability ranges from 1 (almost impossible) to 5 (almost certain)

Source: Miller, 1972.

treatments, the problem can be overcome. We therefore recommend that major structures proposed for these areas should have detailed soils and geology investigations. The filled areas along the Juneau waterfront, including the mine-tailing dumps can be developed for most structures by employing pile foundations. Piles should extend through the fill and should terminate in bedrock or other competent materials as determined in the preconstruction geologic and soils investigation.

We recommend that waterfront construction in Auke Bay, Lena Cove, Fritz Cove, Tee Harbor and North Douglas Island be designed to withstand the effects of seismic sea waves.

One of the principal dangers to life and property accompanying earthquakes is that of fire. Failure of the water supply often occurs. Major structures should, therefore, have an auxiliary fire fighting capability.

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APPENDIX II

MASS WASTING HAZARD INVENTORY AND LAND USE CONTROL FOR THE CITY AND BOROUGH OF JUNEAU

Report to the
City and Borough of Juneau
Juneau, Alaska

Prepared by: Douglas M. Swanston, Ph.D.
U.S. Forest Service
Forest Services Laboratory
Corvallis, Oregon

June, 1972

A REPORT ON THE MASS WASTING (LANDSLIDE)
HAZARDS IN THE URBAN AND
URBANIZING AREAS OF
THE CITY AND BOROUGH OF JUNEAU, ALASKA

General Stability Characteristics

Land form in the Juneau area is in a dynamic stage of geomorphic development. The area is geologically young and is actively rising due to faulting and uplift. Recent glaciation (less than 10,000 years ago) has over-steepened the slopes and withdrawl of the 5,000 to 6,000 feet of ice which existed over the area during the Pleistocene Epoch has caused an isostatic rebound or uplift, presently occurring at the rate of 1.3 cm per year (Miller, 1971, p. 83).

Bedrock is composed predominantly of interbedded slate, phyllite (a more highly altered form of slate) and andesite (volcanic flow rock) which have undergone extensive metamorphism. Bedrock strike in the area is to the northwest, approximately parallel to the Gastineau Channel with a variable dip to the northeast at 30° to 75°. Two major joint surfaces or planes of breakage in the rock dominate the slopes above the Juneau urban and urbanizing areas. One strikes perpendicular to the slope and dips northwestward at 55° to 80°. The other strike is parallel to the slope and dips southwestward in the same direction as the slope gradient at about 65° (Miller, 1971, p. 24).

These joint surfaces, in combination with the strike and dip of the bedrock have resulted in a ready production of platy fragments and large blocks of rock which become loosened and unstable on the slopes and move downward, primarily under the force of gravity, accumulating as talus or colluvium on the slopes below.

Controlling Factors

These geologic conditions have produced the following slope and soil characteristics which control the inherent instability of the slopes in the Borough area.

Oversteepening of the slopes, due to glacial erosion and active uplift, have produced gradients far above the stable angle of the materials on them. For soil materials of the type found on the slopes in the Juneau area (Tolstoi-McGilvery stony silt loam)[1] these stable slope angles may

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[1] Soils of the Juneau Area, Interim Report by Dale B. Schoephorster and Clarence E. Furbush, U.S.D.A. Soil Conservation Service, Palmer, Alaska.

range from 28^{0} to 37^{0}, but probably lie near the upper end of the range. Measured slope angles in the field have averaged around 40^{0} and have gone as high as 70^{0} on the upper slope.

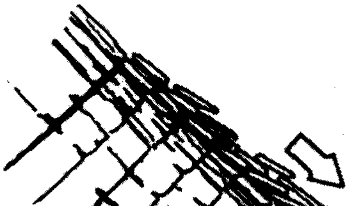
Slope soils are youthful, shallow (usually less than 2 feet), and coarse-grained with little cohesion or internal binder to hold them together. Densities are low, averaging 79.6 pounds/f^{3}. These are colluvial soils produced by mechanical weathering and gravity accumulation of local materials on the slope.

While the bedrock dips into the slope, the dominant jointing has produced planes of breakage or weakness parallel to or inclined in the same direction as the slope and independent of the bedding. Miller (1971), has hypothesized that such parallel jointing is primarily due to stress release, or release of pressure of the overlying ice with withdrawal of continental glaciers from the area. These joints provide zones of weakness along which both mechanical and chemical weathering can take place producing colluvial soil materials and unstable rock units. The joint surfaces also provide excellent planes of failure for overlying colluvial materials and potential sliding surfaces for fragments and blocks of rock.

Fragments of slate and phyllite, which dominate the colluvial soil matrix, are characteristically hard, platy and high in mica content. When accumulated on the slope, they tend to orient parallel to the slope in a shingled fashion (overlapping) (Figure 1) producing small, discrete failure planes where fragments overlap. These planes are low in frictional resistance due to the smooth surfaces and the occasional lubricating effect of the mica weathering to clay, thus greatly decreasing overall stability of the colluvial soil.

FIGURE 1

--Diagramatic cross-section of a slope showing the shingling effect of overlapping slate and phyllite fragments.



Gullies and V-notch channels in the bedrock, produced by differential erosion along fractures and joints, occur frequently on the slope. These serve to concentrate run-off from the slope and frequently channel snow and earthslides onto the lower slope. They also function as areas of temporary accumulation for debris, both organic and soil, produced by earth sliding higher up on the slope. These debris deposits may be temporarily stabilized behind natural dams in the channels, created by jammed logs and rocks, but ultimately reach the bottom of the slope as massive earth flows when the dams fail. This is a frequent cause of destructive earthslides in the Juneau area.

Contributing Factors

Important contributing factors to the relative stability on the slope include vegetation cover and the climatic conditions prevalent in the area.

Vegetation cover exerts its influence mainly through tree rooting effects on soil stability. Tree roots exert a dominantly stabilizing influence through:

a) the anchoring effect of roots growing through the shallow soil and into joints and cracks in the bedrock beneath;

b) intertwining with adjacent root systems to provide a more-or-less continuous long fiber binder to the soil mass over broad slope areas;

c) the spreading of long lateral roots across zones of weakness and into more stable areas; and,

d) the buttressing effect of tree root masses holding the soil up-slope in place.

Vegetation cover and tree rooting can also function to decrease slope stability by:

a) loosening of soil and rock by the waving of trees in the wind and more drastically by tree blow-down;

b) the wedging and loosening of blocks of rock and fragments from cliffs and open rock slopes; and,

c) the damming of channels and gulleys by limbs, trunks and root masses, producing concentrations of debris in the channel which may fail during periods of high run-off.

The relative stability of the slopes in the Borough area is strongly affected by local weather conditions. Juneau weather is characterized by frequent intense rainfalls of fairly long duration, during the months of September, October, November and December. Storms with rainfall in excess of 2 inches in 24 hours are a yearly occurrence and storms with rainfall in excess of 4 inches in 24 hours have a predicted five-year recurrence interval (Miller, p. 163). Heavy snowfall at higher elevations is also common and serves to store precipitation for delayed release and high melt-water run off during warming periods. Winters are generally moderate with frequent periods of melting and freezing and strong winds result from large pressure gradients produced between opposing air masses and gravity drainage from the Juneau Icefield.

These dominating weather characteristics produce frequent saturation of soil masses on the slope and within gullies with resulting temporary increases in weight of the soil mass and active pore-water pressure development due to high rainfall, snow-melt or a combination of both. Active frost wedging of bedrock fragments and blocks by diurnal freeze and thaw add to the unstable conditions on the slope by loosening individual bedrock units and mobilizing rock debris. Wind-throw or blow-down also mobilizes soil and rock material on the slope through the ripping-up of roots and dislodgement of the soil mass.

Principal Processes Operating on the Slope

With these natural factors operative on the slope, soil mass wasting, or the down-slope movement of rock, soil and organic debris, primarily by gravity, stands out as the dominant process of slope erosion and reduction in the Juneau area.

Slopes with gradients above the stable angle of the materials on them (corresponding to the angle of internal friction[2] for the slope soils in this area) must be considered as highly unstable under the best of conditions and any disrupting influence, whether a natural catastrophic event such as an earthquake or storm, or the activities of man is a potential initiator of renewed mass wasting activity.

Dominant mass wasting processes on the Juneau area slopes can be divided into three groups:

a) Soil creep, or the slow, almost imperceptible down slope movement of rock and soil by small increments of slipping, sliding and rolling is everywhere present on the slopes. This is a natural process and the principal process in colluvial soil formation and movement. It can be recognized on the slopes in the Juneau area by re-curved trees, "cat-steps"[3], small slumps and short soil and debris slides on the open slope. Movement is due mostly to the application of gravitational stress in increments great enough to cause small movements but not great enough to cause massive failure.

b) Rockfalls, rockslides and rock avalanches are also common in the Borough area and have been identified as frequent initiators of major earthslides. Probably most of the massive earthslides that have occured in the area prior to Juneau settlement resulted from initial failure of sections of the upper slope due to rockslides and rock avalanches. These may be initiated by hydrostatic pressure between and along bedding and joint planes, by the loosening action of alternate freeze and thaw cycles which lift individual blocks and fragments and greatly reduce their frictional resistance or by earthquake vibrations. Velocities are usually high and movement

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[2] Angle of internal friction-an expression of the degree of friction or interlocking between individual soil grains. The angle is directly related to the degree of frictional resistance of the soil mass.

[3] "Cat-steps"-narrow, generally backward tilted micro-terraces on steep hillsides produced by slumping.

ranges from free-fall to sliding, bounding and rolling rock. The rock that initially falls or slides may start as one block or several but repeated impact generally causes it to disintegrate as it moves downslope producing a rock avalanche. If enough soil and organic material become incorporated, a debris avalanche or debris flow may result.

c) Debris slides, debris avalanches and debris flows constitute the most important mass wasting processes active in the Juneau area. These are landslides produced by translational failure of the shallow residual or colluvial soils above an impermeable bedrock surface. The soils are essentially cohesionless and range in depth from several inches to four or five feet. Movement may be triggered by surface loading, increase in soil water levels or removal of the mechanical support of the soil mass downslope. Velocities of movement are variable, probably ranging from as high as 40 ft./sec., to as low as 5 ft./sec. Velocities are highest on the steep portions of the slope and within channels and decrease rapidly at the slope base as energy is dissipated through increased internal friction in the slide mass and impact with trees, brush and other obstructions. Several eyewitness reports of landslides in the Juneau urban area describe houses moving downslope more or less intact following impact indicating that many of these slides are moving at a relatively slow rate of speed by the time they reach the urbanized zone.

Rockfalls, rock slides, rock avalanches, debris slides, debris avalanches and debris flows will collectively be called landslides in the remainder of this report.

Volume of material moved or size of landslide depends on a number of variables including width and depth of failure zone, length of slope on which the landslide developed and the amount of debris accumulated in failure channels. A landslide which occured in 1936 on the slope above the Juneau Cold Storage Plant, piled up against the building approximately 10 feet above the level of South Franklin Street. The estimated volume of this landslide is approximately 1,248 cubic yards. At an assumed density of 79.6 pounds per cubic foot [4], this is a total weight of 1,341 tons. As a comparison, the estimated volume and weight of one of the massive landslides which occured before Juneau settlement (the landslide deposit on which the old Home Hotel was situated) is 66,000 cubic yards at a total weight of 66,825 tons.

Small debris avalanches and debris flows occur yearly throughout the Borough area, on open slopes and within gullies and channels on the slope. These are rarely observed or noted since they usually flow a short distance and are temporarily stabilized behind trees, logs or stumps on the slope or jammed within the channels. The ultimate effect, however, is frequently the accumulation of large masses of earth, rock and organic debris in the

---

[4] This is the average undisturbed soil density and in actuality slide density could be considerably higher although it is highly variable depending on the amount of organic debris included in the slide mass.

channels which may fail as large scale destructive debris avalanches.

Larger debris avalanches and flows are usually the result of massive failures of rock and soil on the upper slope or failure of accumulated debris deposits in the gullies.

MECHANICS OF LANDSLIDING

How do these landslides develop?

Periodically high soil water content and oversteepened slopes are the controlling parameters. Bedrock geology and structure, general climatic conditions and the influence of vegetation are important contributing factors. The stability of a shallow, coarse-grained, cohesionless soil overlying an impermeable bedrock surface can be expressed in a highly simplified way as the ratio between shear strength (S) or resistance of a soil to the downslope component of gravitational stress (T) and the gravitational stress itself. This ratio expresses the "factor of safety" (F) of the soil mass or its ability to resist slope failure.

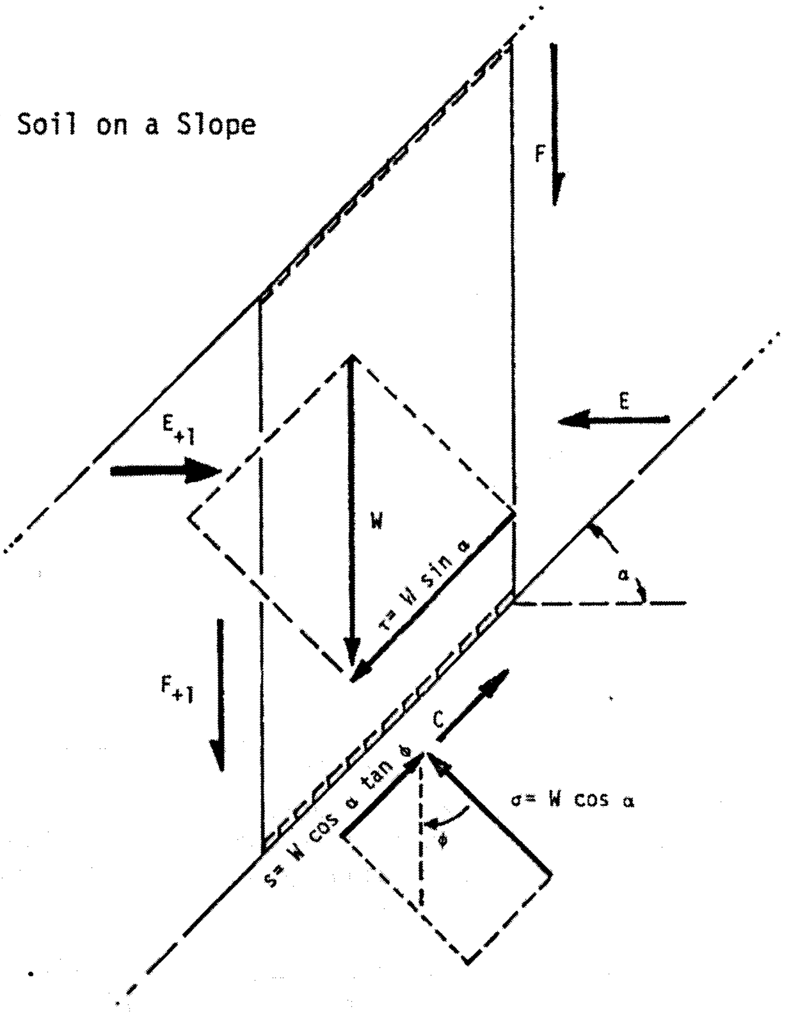
Thus: $$F = \frac{S}{T} = \frac{\text{Soil strength or resistance to sliding}}{\text{Downslope component of gravitational stress}}$$

Ideally, as long as the factor of safety remains greater than 1 (resistance to sliding is greater than the downslope pull of gravity), the slope will remain relatively stable. When the factor of safety equals one, the slope is on the verge of failure.

Landslides result from changes in the soil-shear strength--gravitational stress relationship at the point of failure. This may involve a mechanical readjustment between individual units or particles, as in rockfall, rockslide or talus creep; or a more complex interaction between intrinsic soil properties, ground water movement and external factors acting on the slope (roots, rockfall, artificial damming, etc.).

Figure 2 depicts the principal forces acting on a unit mass of soil on a slope in the Juneau area.

Figure 2
Forces Acting on a Mass of Soil on a Slope



E, E_{+1} = Equal and opposite normal forces acting on the soil mass

F, F_{+1} = Equal and opposite shear forces acting on the soil mass

W = Weight of the soil mass

α = Inclination of the sliding surface

τ = Sheer stress = $W \sin \alpha$

c = Cohesion, a soil property

σ = Normal stress on the sliding surface = $W \cos \alpha$

ϕ = Angle of internal friction, a soil property

s = Frictional resistance = $W \cos \alpha \tan \phi$

For simplicity, the lateral and shear forces acting on the mass are assumed equal and opposite and therefore cancel. The driving forces tending to cause downslope movement then consist of the weight of the soil mass (W) and its tangential component (τ) or sheer stress. Resisting forces consist of cohesion (c)[5] which is independent of the frictional forces and frictional resistance (s) which is proportionally related to the normal component of the soil weight (W cos α) through the angle of internal friction (ϕ).

Gravitational stress (τ) or the downslope component of gravity acting on the soil mass, is the resultant of the weight of the soil mass (W) acting along the sliding surface.

Thus: $\tau = W \sin \alpha$

For shallow soils of the type on the slopes above Juneau, the slope surface can be considered approximately parallel to the sliding surface. Thus, slope gradient becomes equivalent to the angle of the sliding surface (α) and a controlling factor in the downslope component of gravity. Any increase in soil weight or angle of slope will increase the gravitational stress acting on a soil.

For coarse grained soils of the Tolstoi-McGilvery type, cohesion can be considered negligible and soil shear strength (S) or resistance of a soil mass to sliding becomes a product of friction between the soil mass and the sliding surface and the friction between soil grains. Friction along the sliding surface is also controlled by slope gradient (α) and the weight of the soil mass (W) and is strongly influenced by pore water pressure development[6] (μ) which acts to reduce the weight of the soil mass. Friction between, and the mechanical interlocking of, soil grains is expressed as an angle of internal friction (ϕ).

Thus: $S = (W-\mu) \cos \alpha \tan \phi$

The stabilizing influence of external factors such as roots may add considerably to the overall resistance of a soil to failure but must be considered as an added influence independent of the above mathematical model.

Resistance to sliding is overcome by:

a) Saturation, which increases the weight of the soil mass and therefore the component of gravity acting to pull the soil downslope;

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[5] Cohesion is the ability of individual soil particles to stick or adhere together through the action of capillary tension, cementation or weak electrical bonding of clay minerals and organic colloids.

[6] Pore water pressure is pressure produced by the head of water (its vertical height above an impermeable base) in a saturated soil and transferred to the base of the soil through the pore water.

b) Active pore water pressure development in the soil, produced by rising free water levels, which decreases frictional resistance along the sliding surface, decreasing soil shear strength;

c) Hydrostatic pressure produced by seepage of water along cracks and joints in the rock which also decreases frictional resistance between overlying rock masses and joint surfaces;

d) Freeze and thaw action which pries out blocks and fragments of rock along joints and fractures, loosening the materials and mobilizing them in a downslope direction;

e) Destruction of stabilizing root systems by decay or breakage due to windthrow or timber harvesting activities;

f) The loosening effect of the prying action of root growth into joints and cracks and the working of roots by trees swaying in the wind, and;

g) Rapid surface loading from rockfall, rock avalanching or debris avalanching which increases the downslope component of gravity; produces temporarily high pore water pressures during periods of high soil water content due to rapid compression and release of water between soil grains and breaks and shears roots and other binders by force of inpact.

LANDSLIDE HAZARD IDENTIFICATION AND RATING

General Hazard Rating

Triaxial shear tests performed on soil samples taken from undisturbed portions of the unstable slopes behind the Juneau urban area[7] indicate that the soil is essentially cohesionless with an effective angle of internal friction of 36°. Slope angle and angle of internal friction play major roles in determining relative stability of a soil mass with these characteristics. In the absence of active pore water pressures, the ratio between resistance to sliding and gravitational stress, or more correctly, the "factor of safety" of the slope can be approximated by the ratio between the angle of internal friction and the angle of slope.

$$F = \frac{\phi}{\alpha}$$

Since the angle of internal friction is normally fixed at a specific value or within a certain range, slope angle becomes a prime indicator of the relative stability of these soils in place. Whenever the slope gradient equals or exceeds the angle of internal friction of the soil, the slope must be considered unstable and highly susceptible to occurrences or activities which tend to alter the factors contributing to soil shear strength.

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[7] Samples analyzed by J. R. Bell of the Civil Engineering Department, Oregon State University. A report of his findings is included in Appendix A.

While the angle of internal friction is ideally a single value for a specific soil type, under natural conditions engineering experience has indicated (Terzaghi and Peck, 1960) a considerable point to point variability. For soils of the type on the Juneau area slopes, these values range from a maximum of approximately 37° to a minimum of 28°.

The effective value of (ϕ) obtained from triaxial shear tests for these soils was 36°. However, since the angle of internal friction is so highly variable for natural, non-homogenous soils of this type, it is more realistic to consider zones of stability when rating slopes for purposes of hazard identification. Thus, slopes with gradients above 37° can be classified as highly unstable in terms of the susceptibility to events which might alter or reduce the delicate balance of forces operating on the slope. These are slopes which are subject to sliding whenever disturbed and may serve as major sources of landslide material during catastrophic events such as earthquakes or exceptional storms. Great care should be taken to prohibit urban development within or immediately below such areas. Road building and timber harvesting activities must be prohibited for the protection of the areas below the highly unstable zone and no dwellings should be allowed in the area.

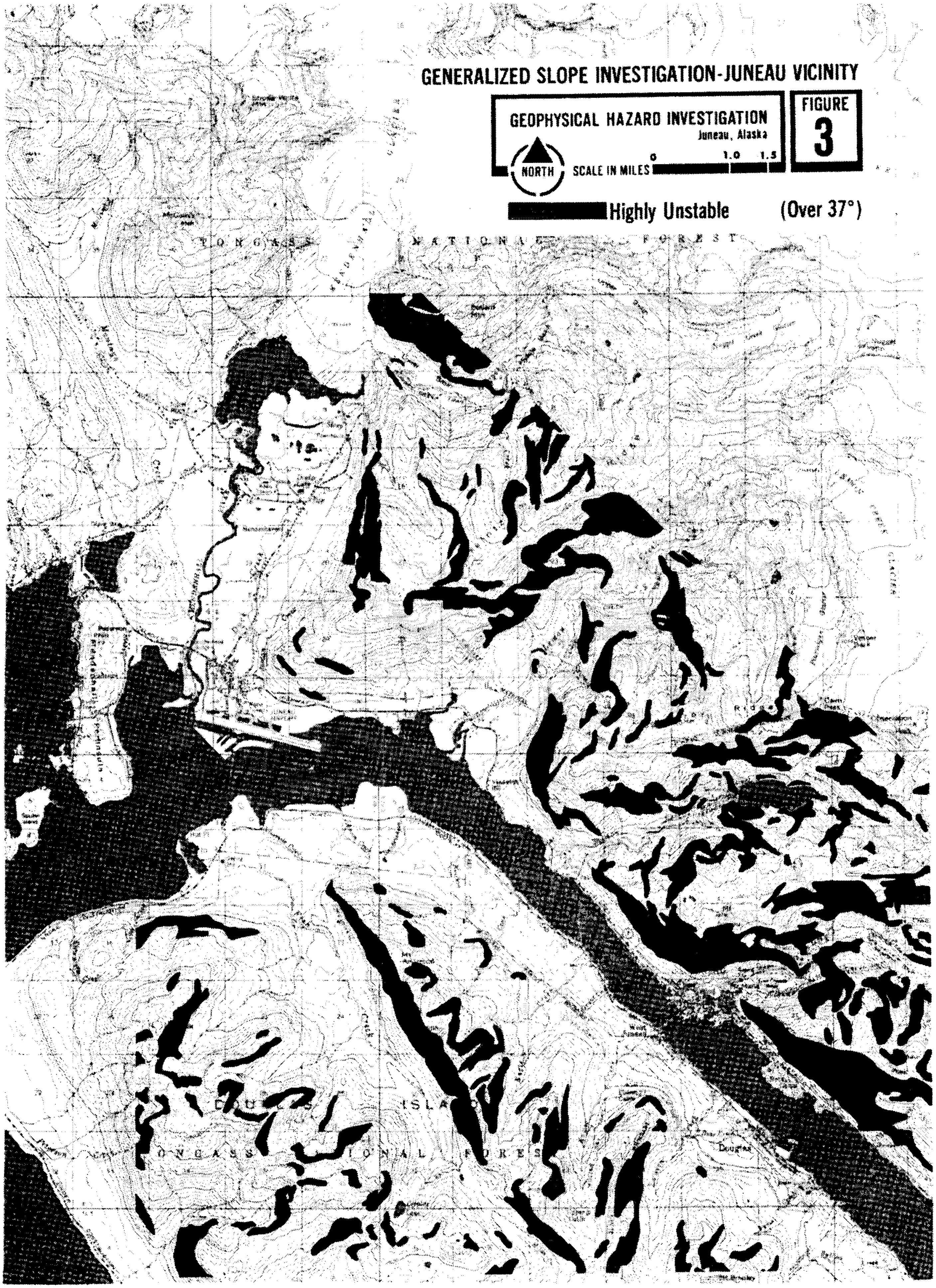
Slopes with gradients between 28° and 37° are classified as potentially unstable and should receive minimum development with full realization that local areas within this zone may be in a highly unstable state. It is essential that natural vegetation cover be maintained wherever possible. No timber harvesting or massive land clearing should be allowed in this zone. The potential danger of landsliding from the highly unstable slopes above this zone is always present and should be kept in mind at all times when development is being considered in this area.

Figs. 3 and 4 show the stratification of most of the slopes in the Juneau Borough into zones of highly unstable and potentially unstable ground on the basis of slope gradient.

Specific Hazard Identification

Landslide deposits occur at frequent intervals along the Mt. Juneau and Mt. Roberts slopes. The most massive of these are pre-Juneau settlement in age and support old growth stands of Sitka spruce and western hemlock indicating an occurrence 250 to 300 years ago. A substantial number of lesser but still destructive landslides have occured since the settlement of Juneau and can be traced as linear ridges and recently re-vegetated strips on the slopes behind the city. Most of these have been documented in the city newspapers, copies of which are included in Appendix X. A few have been dated approximately by dendrochronological methods.

All are indicators of active or dormant instability and of potential landslide recurrence. As a result, each of the landslide tracks have been carefully mapped, their probable points of origin indicated and the entire slope assessed in terms of immediate or potential hazard. The results of this investigation are shown in Figures 5, 6 and 7. Pre-settlement landslides and post-settlement landslides are shown in Figure 5.



GENERALIZED SLOPE INVESTIGATION-JUNEAU VICINITY

GEOPHYSICAL HAZARD INVESTIGATION
Juneau, Alaska

FIGURE 3

GENERALIZED SLOPE INVESTIGATION-JUNEAU DOUGLAS AREA

GEOPHYSICAL HAZARD INVESTIGATION
Juneau, Alaska

FIGURE 4

HISTORIC LANDSLIDE DEPOSITS

GEOPHYSICAL HAZARD INVESTIGATION
Juneau, Alaska

FIGURE
5

NORTH

SCALE IN MILES 0 .25 .50

(P) Prehistoric (Before 1880)
(11) Historic (After 1880)

ESTIMATED AGE OF DEPOSIT

1-1912
2-1932
3-1892
4- --
5-1922
6- --
7-1918
8-1935
9-1918
10-1936
11-1949
12-1920
13-1932
14-1936
15-1952
16-1952
17-1935

Broad areas of high and potential hazard from landslide damage are shown in Figure 6. Specific gullies and channels with a known or indicated history of past debris avalanche and debris flow activity are mapped in Figure 7.

Gullies with a high hazard rating exhibit substantial accumulations of organic debris, rocks and soil in their channels and have had a past history of debris avalanche-debris flow activity. These are mapped in Figure 7. Those with a potential rating do not exhibit substantial accumulations of debris, but extend to the upper slope and exhibit some evidence of past debris avalanche-debris flow activity. Table 1 summarizes the major historical landslides in the Juneau area with dates of occurrence, approximate location, associated 24-hour rainfall and damage.

URBAN AREA SOUTH OF GOLD CREEK TO THE CITY LIMITS (See Fig. 8)

Mt. Roberts Slope

By far the most hazardous area in terms of potential destruction of property and loss of life from landslides is that area at the base of the Mt. Roberts slope extending from the corner of 3rd and Harris Streets to the beginning of Thane Road. Eleven major debris avalanche-debris flow deposits have been identified and mapped on this slope. Three of these are massive in size and occured before Juneau settlement. The remaining eight were smaller but still destructive in size. All are identifiable on the ground and the eight post-settlement slides were well documented by local newspapers at the time of their occurrence (Appendix X).

Pre-settlement Landslides

The three pre-settlement landslides occur as major topographic features expressed as linear ridges extending approximately 700 feet through gullies in a cliff above the A.J. tram (approximately 400 feet elevation) and terminating at the beach. These deposits range from 20 to 50 feet thick and average about 200 feet wide. In every case, the debris deposit passes through or overlaps a lower cliff or bluff at the 400 foot level indicating an origin from a rock slide or soil failure on the upper slope. The gully through which the deposit passes must have served to channel the material onto the lower slope.

One of these massive landslide deposits crosses the southern terminus of Gastineau Avenue, one crosses Gastineau Avenue at the site of the A.J. bunkhouse foundation and one extends downslope from the southern end of the A.J. tramline. Many other pre-settlement landslides have occurred in the area and are indicated by deposits of mixed logs, rock and soil exposed in banks and foundation excavations between Gastineau Avenue and South Franklin Street, but are not recognizable as distinct units.

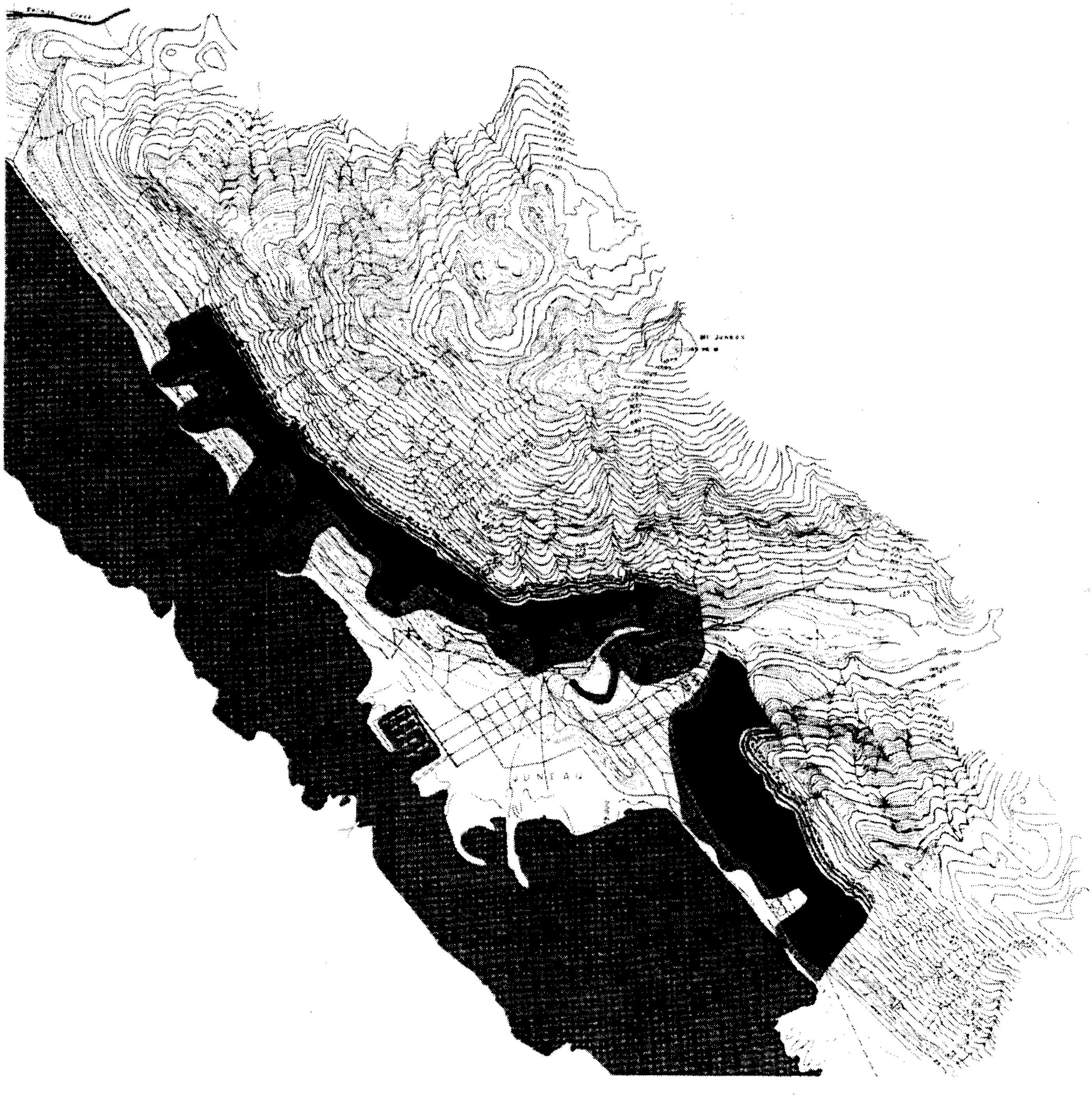
MASS WASTING HAZARD AREAS

GEOPHYSICAL HAZARD INVESTIGATION
Juneau, Alaska

FIGURE
6

NORTH
SCALE IN MILES 0 .25 .50

▨ Potential Hazard
■ High Hazard



MASS WASTING CHANNELS AND ROCK SLIDE AREAS

GEOPHYSICAL HAZARD INVESTIGATION
Juneau, Alaska

FIGURE
7

NORTH

SCALE IN MILES
0 .25 .50

▤ Rock Slide Hazard Areas

TABLE I

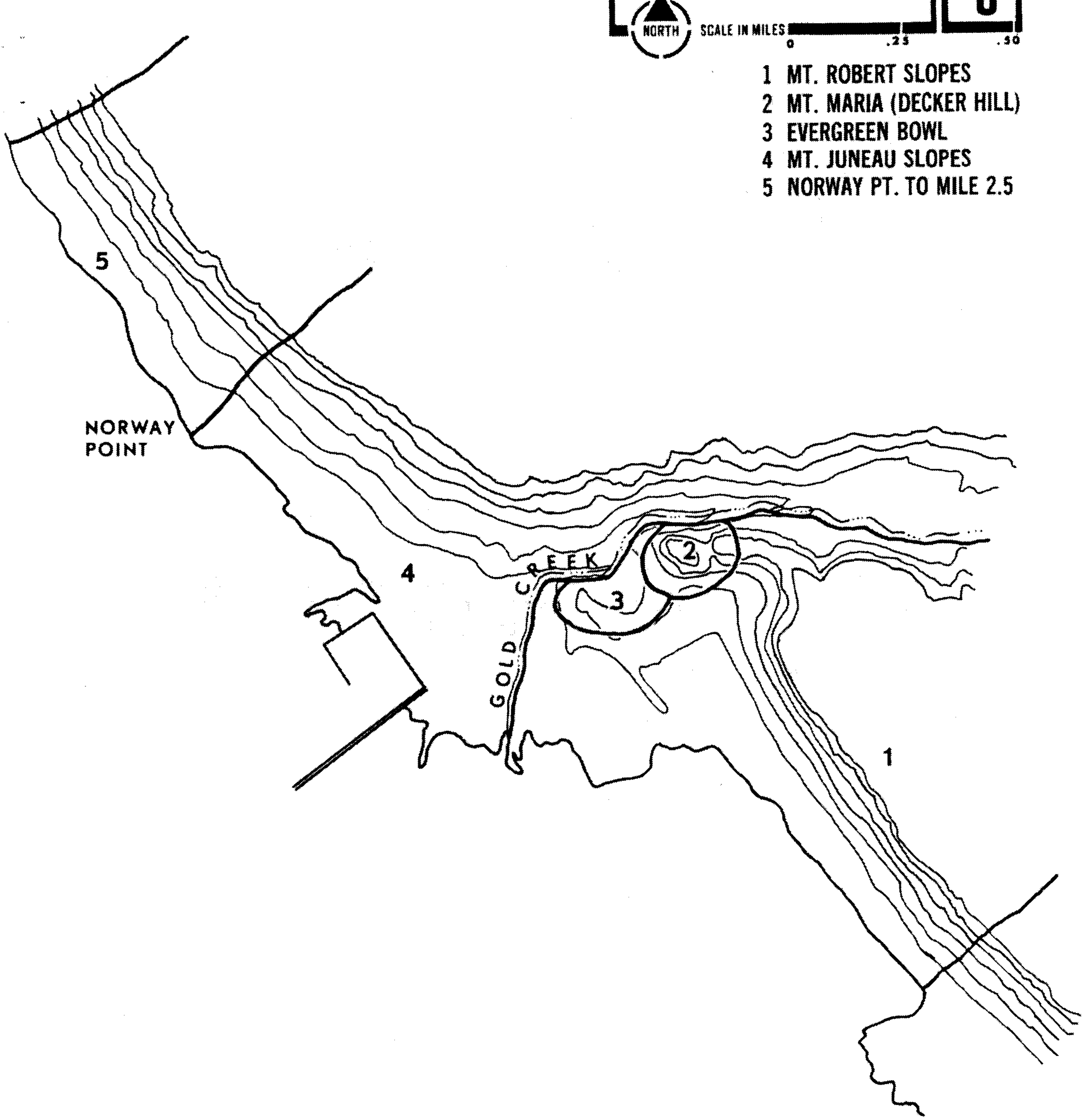
LANDSLIDES LOCATED IN THE JUNEAU, ALASKA AREA

DATE	TIME	RAINFALL (inches/hrs)	TYPE	LOCATION	DAMAGE	COMMENTS	REFERENCE
10-18-1913	2100	3.5/24	rockfall, rockslide	Mt. Maria on Basin Road	homes damaged	5 landslides reported in Perserverence Basin, 1 landslide at Tredwell	Alaska Daily Dispatch, October 18, 1912
9-25-1918	--	6.32/24	debris avalanche	slope behind Gastineau Hotel	apt. building destroyed-Gastineau Hotel damaged $25,000	Swept apt. downhill and across Gastineau Ave., broke in back wall of Gastineau Hotel, small slide followed	Daily Alaska Empire September 28, 1918
9-25-1918	--	6.32/24	debris slide	7th and Goldbelt into Evergreen Bowl	cabin destroyed	Carried small cabin into Evergreen Bowl	Same as above
9-25-1918	--	6.32/24	debris avalanche	Gastineau Hts.	none	Other slides reported above Gastineau Hts., but not recorded	Same as above
1-2-1920	1130	warm weather, melting snows and heavy rain 1.79/24	debris avalanche	Gastineau Hts.	3 people killed, $50,000 damage	Destroyed boarding house, three homes, twelve cabins, broke into Goldstein's store, overflow of A.J. Flume	Daily Alaska Empire January 2 and 3, 1920
9-27-1935	--	2.89/24	debris avalanche	S. Franklin at A.J. oil tanks	road blocked	--	Daily Alaska Empire September 27, 1935
11-27-1935	1530	3.35/48	debris avalanche	Third Avenue above Harris	2 homes wrecked one damaged	Slide due to damming of gully by debris	Daily Alaska Empire November 29, 1935
11-27-1935	--	3.35/48	slump	5th Street above Kennedy	none	Slide possibly due to saturation of marine beach deposit in area	Same as above
11-27-1935	--	3.35/48	debris slide	Evergreen Bowl	none	A serious slide reported at Evergreen Bowl-no details	Same as above
10-16-1936	0800	1.43/3	debris avalanche	Gastineau Hts.	one woman injured, 2 houses damaged, Alaska Hotel damaged	Slide came down Mt. Roberts crossed Gastineau Ave. and broke in back of Alaska Hotel	Daily Alaska Empire October 16, 1936
11-22-1936	1930	3.89/24	debris avalanche	Gastineau Hts., above cold storage plant	14 died, 9 injured, apt. house, boarding house, 2 homes ruined	Slide resulted from slope failure below flume. Tension crack noticed	Daily Alaska Empire November 23, 24, 25, 27, 28, 30, 1936
11-30-1936	--	--	debris avalanche	Thane Road near Standard Oil	road closed	--	Daily Alaska Empire November 30, 1936
10-31-1949	--	2.36/24	debris avalanche	Gastineau Hts.	home destroyed	Moved 700 feet downslope, piled into home on Gastineau Avenue	Daily Alaska Empire October 31, 1949
10-1-1952	--	1.85/24	debris avalanche	S. Franklin by old Columbia Lumber Co. kiln	road closed	--	Daily Alaska Empire October 2, 1952
10-1-1952	--	1.85/24	debris avalanche	Gastineau Hts., piled behind 475 S. Franklin	home destroyed	--	Daily Alaska Empire October 2, 1952
10-1-1952	--	1.85/24	debris avalanche	Above Johnson Bldg., 261 Gastineau Avenue	home destroyed	--	Daily Alaska Empire October 2, 1952
12-16-1954	--	warm weather snow melt 2/24	debris avalanche	Irwin Street before Gold Creek.	1 home badly damaged	2 earthslides 1 hour apart near Gold Creek bridge	Daily Alaska Empire December 17, 1954

MASS WASTING HAZARD INVESTIGATION SUB-AREAS

GEOPHYSICAL HAZARD INVESTIGATION
Juneau, Alaska

FIGURE
8



1 MT. ROBERT SLOPES
2 MT. MARIA (DECKER HILL)
3 EVERGREEN BOWL
4 MT. JUNEAU SLOPES
5 NORWAY PT. TO MILE 2.5

Historical Landslides (Refer to Table 1)

The eight major landslides which have occurred since Juneau was settled are expressed as linear ridges near the base of the slope or as bulked deposits above Gastineau Avenue and South Franklin Street. Five of these reached South Franklin Street but did little damage on the beach side of the street (side nearest the harbor) since most of their energy was dissipated by damage and destruction above South Franklin. Three terminated on Gastineau Avenue.

Six of the historic landslides or about 75% of the total occurring, originated in or were channeled by gullies and V-notch channels which extend from the upper slope. At least three of these probably originated from slope failure above the cliff where slopes exceed 70° in gradient. The rest occured as a direct result of failure of accumulated debris in the gullies.

The two remaining historical landslides apparently resulted from open slope failure just below the A.J. tram. One was apparently triggered by rapid addition of water to an already saturated soil mass due to overflow of the A.J. water flume on January 1, 1920. The other occurred as a result of failure, just below the tram and above the Cold Storage building on November 22, 1936. This later landslide was initiated during a period of exceptionally high rainfall (3.89 inches in 24 hours) and was probably triggered by active pore-water pressure development due to leakage of surface water into tension cracks developed at the outer edge of the tram. Unsubstantiated reports state that such tension cracks existed in the tram above the point of failure prior to the landslide.

Recent Landslide Activity

The last major landslide occurred on the Mt. Roberts slope on October 1, 1952 but small debris avalanches and debris flows have continued to occur up to the present. For the most part these are small, flow only a short distance and have not reached into the urban zone. These are currently building up behind rocks, logs and other jammed debris in the gullies and constitute a continuing debris avalanche hazard to the area (Figure 4).

At least two small debris flows occurred within gullies above Gastineau Avenue last fall. One in a gully above Ewing Way which terminated temporarily at the A.J. tram and remains as a future hazard to the slopes below. The other occurred in a gully above the 1st Street stairs and flowed downslope until it was stopped behind the cable hand-rail along the old A.J. access trail to the Harris Street stairs.

In summary, 21 gullies have been mapped on the Mt. Roberts slope above the city; 15 identified as having a high debris avalanche-debris flow hazard. Considering the extremely steep slopes, unstable bedrock and soil conditions, numerous high hazard gullies extending directly into the urban area and its past history of landsliding, most of the Mt. Roberts slope above South Franklin Street and Gastineau Avenue must be considered as highly hazardous in terms of damage and potential loss of life from landslides.

Mt. Maria (Decker Hill)

Several landslides of major proportions have occurred in this area during post-settlement times.

A combination rockfall-rock avalanche occurred on October 18, 1913 from the open cliff face of Mt. Maria (Decker Hill) destroying several houses and creating a deposit of angular rock fragments exposed above Basin Road between 6th and 7th Streets. Similar small deposits of angular rock fragments and talus occur above 6th Street from Basin Road to Nelson Street. A talus cone at the base of a small cliff occurs behind a home at the corner of 6th and Nelson Streets.

The area directly below the open rock cliff above Basin Road lies in a high rockfall-rock avalanche hazard zone. While the bedrock exposed in this cliff dips into Last Chance Basin, it exhibits well developed fracturing and jointing along vertical planes and is highly susceptible to additional failures produced by freeze and thaw and the lubricating action of water in the cracks. The small cliff above the corner of 6th and Nelson Streets is fractured in a similar manner, and while the volume of materials would not be large, the area directly below it must be considered as a high rockfall hazard area. The cliffs of broken slate dipping downslope and at an angle to the road cut along the backside of Mt. Maria (the trestle portion of Basin Road) must also be considered a high hazard area for falling rock.

Evergreen Bowl

The slopes into Evergreen Bowl are greatly oversteepened and bedrock dips into the Bowl making the slopes potential areas for landslide damage, especially to buildings and property along the upper edge of the Bowl and adjacent to Basin Road, Gold Belt Avenue and 7th Street. A landslide occurred on this slope in September 1918 beginning near the corner of 7th Street and Gold Belt and carried a cabin down into Evergreen Bowl. A serious landslide in Evergreen Bowl was also reported on November 27, 1935 but no details were provided.

A potential rockfall hazard exists above Calhoun Street between Dixon Street and 6th Street.

URBAN AREA NORTH OF GOLD CREEK TO MILE 2.5 (See Fig. 8)

Mt. Juneau Slope

The slopes of Mt. Juneau, from Gold Creek to Mile 2.5 Glacier Highway exhibit the same oversteepened slope gradients, cohesionless soils and bedrock jointing patterns found on the Mt. Roberts slope. A lower cliff or bluff at about 500' in elevation extends intermittently along the entire slope length and is broken only occassionally by gullies and V-notch channels. Each of these gullies serves to channel snow, rock and soil debris from the very steep slopes above the bluff to the slope below and there is much evidence of repeated snow and soil avalanching along these gullies and into the timber. Between these major gullies there is little evidence of large scale landsliding although numerous small slips and minor debris slides occur between the trees. Small debris and rock slides have occurred repeatedly on the bluff face and on the slope immediately below, but these have traveled relatively short distances into the trees before being stabilized by the timber cover. Large blocks of rock are scattered on the slopes below the bluff and within the timber indicating frequent local rockfalls but these do not penetrate far because of the stabilizing effect of the vegetation.

There are a number of shallow linear depressions and small gullies dissecting the slopes below the bluff and between major slide paths. These must have served at one time to channel snow and soil debris but are dormant or completely stabilized now; many having mature timber growing in them. For the most part, major landsliding activities have been confined to the principal gullies passing through the bluff.

Massive landsliding (rock and debris avalanches) have occured on this slope in the past and at least 11 landslides or landslide run-out zones can be recognized in the field as distinct linear ridges rising above the normally flat slope surface. The majority have terminated in the timber well above the urban and urbanizing areas, but in at least 5 cases these have reached the beach or extended into an urban zone.

Unfortunately, there is no record of the time of occurrence of most of these landslides, but an indirect age was obtained on many of them using an increment borer to determine the age of trees growing on the landslide deposit. Using this method, estimated ages of landslides ranged from 18 years for an alder growing in a landslide track above Evergreen Avenue to greater than 200 years for hemlocks growing in a stabilized, linear slope depression west of Norway Point.

As on the Mt. Roberts slope, the oldest and most extensive landslide deposits are pre-settlement in age and are covered by old growth Sitka spruce and western hemlock forests with an estimated age of greater than 250 years. All began by shallow rock and soil avalanching from the extremely steep slopes above the lower bluff and were funneled onto the lower slope through major gullies. Repeated sliding has taken place in most of these gullies and at several locales multiple deposition has created massive deposits of undifferentiated landslide debris. Where these deposits have been dissected locally by running water high banks of mixed rock, logs and soil material are exposed above the present stream channel. It is almost impossible to date these multiple landslides accurately because of the lack of established vegetation in the active zone of redeposition. This problem is compounded by the fact that most of these landslide tracks also function as active snow avalanche zones.

Norway Point to Mile 2.5

The largest landslide deposit in be urban area forms the ridge constituting Norway Point. This is a pre-settlement landslide which must have originally extended well out into Gastineau Channel. The lower part of this deposit is covered with old growth spruce-hemlock forest indicating a depositional age for the main slide mass in excess of 200 years.

A channel or series of channels leading from a break in the lower bluff and extending to the lower slope, is still very active and both snow and debris avalanching occur at frequent intervals from the slope above the bluff. This channel is classified as a high hazard debris avalanche track. The active state of these channels and the large potential source area for rock and debris above the lower bluff, make the major part of the Norway Point deposit and a zone extending a minimum of 100 feet into the timber for landslide run-out purposes, a high hazard area. Based on past history of massive sliding and the large source area for the origin of a potentially massive failure, the remainder of the area covered by the Norway Point deposit must be classified as potentially hazardous. It is vital that existing timber cover be maintained to serve as a protective screen for existing dwellings in the area, otherwise the high hazard zone would have to be extended to the beach.

Immediately west of and adjacent to the Norway Point landslide deposit is a second massive deposit of pre-settlement age forming a distinct linear ridge terminating in the trees above Glacier Highway. This deposit has an old growth spruce-hemlock forest growing at its lower end but is bare of major vegetation above about 200 feet in elevation due to frequent snow avalanching. The deposit passes upward through a main break in the lower bluff and has been dissected by the present stream forming a deep gully leading to the lower slope. This gully is currently active, primarily as a snow avalanche path but does carry soil and debris and must be considered a high debris avalanche hazard. Again, due to the large potential source area for landslide materials above the lower bluff and the active state of the V-notch channel, the open area of the deposit and a run-out zone of at least 100 feet into the timber below must be classified as a high hazard area. The intervening slope between the Norway Point deposit and the remainder of this deposit to the beach lies within a potential hazard zone.

A third massive deposit reached the beach in the vicinity of the Johnson Children's Home. This deposit also originates at an opening in the lower bluff and has also been dissected by stream cutting. It is pre-settlement in age with old growth timber at its lower end but shows much evidence of active snow and debris avalanche activity in its upper reaches. A recent debris flow has occurred within the active zone and extending 100 feet into the timber. The rest of the depositional area extending to the beach is classified as a potential hazard area. The channel dissecting the deposit in its upper reaches is classified as a high hazard debris avalanche track.

A fourth deposit terminates at the beach between Mile 2 and Mile 2.5 on the Glacier Highway. This landslide track also functions as a major snow avalanche track and the entire slide area is devoid of trees except for some alder growing near the highway. Unvegetated talus and landslide deposits occur at the lower end of the landslide track and there is evidence of repeated landsliding and active talus creep within the deposition zone. Because of the active nature of this landslide track and the absence of trees or protective vegetation to control landslide run-out, the entire landslide zone is classified as a high hazard area extending to the beach.

The intervening slope areas between these landslide tracks are classified as potential and high hazard areas using the method for general hazard rating.

Norway Point to Gold Creek

Two massive landslide deposits emanating from major breaks in the bluff and three smaller deposits beginning at small gullies occur above the urbanized area extending from Norway Point to Gold Creek. Both massive deposits show evidence of repeated sliding and at least one destructive debris flow has been channeled into the urban area along Gold Creek.

The slope between Norway Point and the Behrends Avenue snow avalanche track is free from major landsliding. Unstable conditions exist on the slope, however, and there is much evidence of active creep and small scale sliding and slumping within the timber. Several shallow, partially stabilized gullies and a small V-notch channel leading through a small opening in the bluff dissect the slope in the area. These serve primarily to channel snow into the timber on the lower slope, but minor debris avalanching has also occurred in the V-notch channels. Because of the general unstable condition of the slope and the presence of channels which could function to carry landslide debris to the lower slope if massive failure occurred, the entire slope area above 28^{0} (maximum stable angle from the general hazard rating) and including a minimum strip of 100 feet of timber below the major break in slope is classified as a potential hazard area.

A landslide deposit occurs within the Behrends Avenue snow avalanche track, beginning at an elevation of about 500 feet, at the base of a small gully in the lower bluff and extending downslope along the west side of the snow avalanche zone. It terminates at an elevation of about 350 feet. An increment core taken from a lone spruce growing on the lower end of the deposit indicates an age of approximately 60 years. A channel extends along the western edge of this deposit beginning at the gully and may serve to carry additional landslide material downslope. This channel is classified as a high hazard debris avalanche track.

The Behrends Avenue avalanche track itself has functioned as a landslide path repeatedly and extensive deposits of talus and landslide debris are found at the lower end.

At least two major gullies or channels pass down the center of the track and function to channel landslide materials to the lower slope. These are rated as high hazard debris avalanche paths and the entire open zone of the Behrends Avenue track above the lower timber zone must be considered as a high hazard area in terms of landsliding. A potential hazard area extends to Behrends Avenue.

Immediately southeast of the Behrends Avenue snow avalanche track is a massive landslide deposit extending from the lower bluff and terminating in the timber at an elevation of about 350 feet. This is a multiple deposit consisting of a major lobe, with two smaller lobes superimposed on top of it. At least three periods of landslide deposition are represented. The oldest was the most massive and is covered near its lower end by an old growth spruce-hemlock forest. The second lobe did not extend as far downslope. A core taken from an alder growing on this mass indicates a deposition age greater than 80 years before present. The current channel dissects these deposits exposing rock and organic debris along its sidewalls. Two levees or small ridges of fresh debris on either side of the channel and down the length of the landslide deposit, and fresh debris deposited near the lower end of the multiple lobes, indicate the most recent episode of debris avalanche activity, probably within the last 10 years. This deposit is clearly active and although the deposits have all stabilized within the timber, they do represent a potential hazard to the urban area immediately below. A high hazard zone extends the length of the landslide deposit and includes 100 feet of timber below the lower end. Maintenance of timber cover on and immediately below this zone is essential for protection of the urban development already present.

Small debris avalanches and individual rockfalls are of frequent occurrence on the lower bluff face above Coleman, Willow and Evergreen Avenues; but in general, the timber cover on the slope below prevents these materials from moving very far downslope. Most of the rock and debris becomes stabilized a short distance below the bluff. Several shallow, stabilized gullies dissect the slope in this area and lead directly into the urbanized zone. Most of these presently have timber growing in them but could function to channel landslide material into the urban area if massive failures at or above the bluff occurred. Only one active gulley of any size cuts through the bluff and this has a small talus slide deposited in it at the bluff base. A narrow channel which could serve to carry landslide material downslope leads through the timber toward Willow Street and is marked as a potential debris avalanche track. Due to the unstable nature of the slope gradient above this urbanized area and the presence of the gullies extending through the timber, this slope is rated as a potential hazard with the lower limit of the potential hazard zone determined by the minimum stable slope angle (approximately 28^{o}) and the presence of dwellings which may be damaged by landslide activity. Maintenance of the remaining timber cover on this slope is essential to help stabilize the slope and protect the dwellings already in the area.

An area of recurring rockslides and debris avalanches has removed the old growth timber above the central part of upper Evergreen Avenue, opposite Pine Street.

This exposes the dwellings immediately below the area to the direct impact of additional landsliding from the slope and open rock faces above. This is an actively unstable area with no natural protection from major vegetation on the slope. Small debris avalanches and rock falls occur at any time. This is a high hazard area extending to Evergreen Avenue with a potential zone of damage reaching to the lower end of Pine Street.

Four landslide deposits, one of massive size, occur at the southeasterly end of upper Evergreen Avenue. Two originated within a major gully which serves as a frequent snow avalanche track and were deposited along the eastern slope of the present channel. Both are pre-Juneau settlement in age and are partially superimposed. The other two originated in minor gullies in the bluff just west of the major avalanche track. The age of one of these deposits is approximately 50 years.

The major gully has functioned repeatedly as a path for landsliding as indicated by the superimposed deposits along the channel. As recently as 1954, this same gully channeled two debris avalanches, an hour apart, down onto Erwin Street at the Gold Creek Bridge, badly damaging a home, and filling the street with mud. This channel must be rated as a high hazard avalanche track, with a high hazard zone extending from the channel opposite the eastern end of Evergreen Avenue to the Gold Creek channel.

The channels from the smaller gullies lead down into the gravel quarry above Martin Road. These must be rated as potential debris avalanche tracks and the slopes in this area as potential hazard areas.

PREDICTION AND PROBABILITIES OF LANDSLIDE RECURRENCE

It is difficult to accurately predict the time of occurrence or interval of recurrence for landslides in the Juneau area due to the lack of long-term records of sliding events and closely associated weather conditions. This problem is compounded by widely differing rainfall and run-off characteristics between measuring stations and the point of initiation of the slope failures.

Some idea of these factors can be obtained, however, by a careful consideration of the documented landslide occurrences, observed field conditions, area-wide rainfall characteristics and the known stability characteristics of the slope.

An inspection of Table 1 shows that 17 destructive or potentially destructive landslides have occurred in the Juneau urban area during 11 major storms over a 41-year period from 1913 to 1954. This is an average rate of occurrence of one landslide-producing storm every 4 years during the period, although the actual time interval between events is quite variable. The last landslide of major consequence was recorded in 1954, 18 years ago.

Of the 17 landslide events recorded during the most active period, 11 or 64% occurred on the Mt. Roberts slope above South Franklin Street, most during the years of active mining and mill operation (1918-1944). Machinery vibrations and blasting undoubtedly added to the total numbers and frequency of occurrence of landslides in the area. The fact remains, however, that destructive earthslides occurred before mining activities and at least four have occurred since mining ceased. At the present time, landslide conditions are developing on the slope and it is only a matter of time before another occurs.

The occurrence of landslides is closely related to major storm events or periods of rapid snowmelt, producing excess flow in channels, saturation of the soil mass and active pore water pressures, all important contributors to landslide development. An inspection of the "Probable Maximum

Precipitation and Rainfall Frequency Data for Alaska" (Miller, 1963) reveals the following interesting probability relationships in terms of the recurrence of storm events capable of triggering landslides in the Juneau area. The highest probabilities of intense, 24-hour rainfall occur in September, October, November and December. All but one of the documented landslides within the urban area occurred as a result of major storms during this period. The one exception occurred early in January as a result of heavy rain associated with abnormally warm weather and rapid snow melt on the upper slopes. On a yearly basis, the probabilities work out to be a 25% chance of occurrence in October, an 18% chance in September and a 15% chance in November. The probabilities of intense 24-hour rainfall drop off rapidly to 9% in December and only a 4% chance in January. October is the most likely month for a landslide producing storm to occur followed by September and November. In fact, 88% of all destructive earth slides in the Juneau area have occurred during this 3-month period, most in October and November.

The probable maximum 24-hour rainfall intensity for the Juneau area on a yearly basis is 2 inches in 24 hours; for a 5-year period, 4 inches in 24 hours. Most of the major landslide events in the urban area have occurred during rainfall intensities of greater than 2 inches but less than 4 inches in 24 hours. Thus, storm events capable of triggering landslides occur frequently in the area and can be expected at a 2 to 5 year return interval. Such a high recurrence interval reflects the natural susceptibility of these slopes to sliding given the right soil and slope conditions. These conditions exist on the urban area slopes at the present time.

In view of the current build-up of debris in the channels above the urban area and the naturally unstable conditions extant on the slopes, the continued occurrence of destructive landslides in the designated hazard areas has a very high probability, emphasizing the necessity of careful consideration of the landslide potential in future urban planning and development.

Measures for Landslide Prevention and Control

Landslides of the type occurring in the Juneau area are natural processes of erosion and slope reduction. They develop under the highly unstable slope and soil conditions prevalent in the area, triggered by excess soil water supplied by naturally high precipitation levels. Under such conditions, maintenance of slope integrity is prerequisite to preventing or controlling earthslide occurrence in urban and urbanizing areas. This means, at a minimum protection of all hazardous slopes from large scale timber cutting, land clearing or construction activities which may disrupt an already delicately balanced stability situation.

Reduction or elimination of major damage and loss of life can be best accomplished by either:

--avoiding areas with indicated landslide hazard;
--controlling damage resulting from landslides; or,
--limiting types of land use within hazard areas.

Hazard Area Avoidance

Avoiding areas with indicated landslide hazard is probably the simplest and most effective method in the long run and can be accomplished by careful land use planning and responsible and effective zoning regulation. This is especially applicable to the presently urbanizing areas of the city.

Damage Control

Damage in urbanized hazard areas can be controlled by:

- --construction of barriers in the lower end of debris avalanche channels to reduce landslide velocities and trap some of the landslide debris; and
- --improve building design requiring stable foundations anchored in bedrock and either reinforced concrete structure, buttressed concrete backwalls, or skeletal reinforced concrete structures with facework walls which can be punched out by landslide impact.

Some relief from damage by landsliding can probably be obtained by construction of retaining walls consisting of open metal or concrete cribbing anchored in bedrock and placed at the lower end of debris avalanche channels. These would serve as effective barriers to small landslide occurrence in the channels and reduce velocity of flow and spreading of large landslides. These should be open skeletal structures allowing free drainage through them and carefully designed and anchored in the bedrock to resist major slide impact. Great care must be taken to keep them clean and free of debris accumulations so they do not actually dam the stream channel or create a massive deposit which may later fail during a critical event. The most logical areas of installation for structures of this type would be above and adjacent to existing roads (for example, Gastineau Avenue) where access for construction and cleaning is easy and damage to the slope is minimal.

Reinforced concrete is apparently an effective construction medium for buildings in high hazard areas. The only buildings along South Franklin Street that have survived impact from large landslides without major structural damage were of reinforced concrete. These include both the Gastineau Hotel and the Juneau Cold Storage Plant. At the very minimum, any construction in high hazard areas should require buttressed, reinforced concrete walls on the upslope side of the building.

These are not areas for minimum design and construction. Engineering-geological information for foundation conditions should be obtained for each site and foundations anchored firmly in bedrock. Packaged or precut buildings should be prohibited unless specifically designed for conditions in the area. The design or structural engineer in every case should be informed of foundation conditions and landslide potential and aksed to design the building for an impact load produced by a landslide with a density of approximately 80 pounds per cubic foot, moving at a velocity of 3 feet per second.

An effective technique for multi-storied construction has been used successfully in Czechoslovakia (Zaruba and Mencl, 1969) and may be applicable in landslide hazard areas within the Borough of Juneau. This type of construction consists of a well-founded reinforced concrete skeletal structure designed to withstand the anticipated impact loads from landsliding. This structure is covered with facework walls which can be punched out by earthslide impact. If an earthslide occurs, the walls will collapse, filling the lower floor or floors but the structural integrity of the building remains intact. Repair can be easily effected by removing the landslide materials and replacing the face-work. The lower floors of such a building should be used for non-dwelling purposes such as parking or storage.

Land Use Limitations

Potential damage and loss of life in urbanizing areas classified as high landslide hazard areas can be greatly reduced if the land is designated for temporary use only such as for parks, recreation or parking.

SUMMARY RECOMMENDATIONS

The following recommendations are made based on field investigations and analysis of landslide hazard in the Juneau Borough area:

1. No new dwelling construction or reconstruction should be allowed in high hazard areas.
2. Land clearing, road building and logging operations should be prohibited in high hazard areas and on any slopes with gradients above 37°. All existing natural vegetation must be retained.
3. In potential hazard areas, and on any slopes between 28° and 37°, as much natural timber cover as possible must be retained for stabilizing purposes. Large scale land clearing and extensive road building and logging should be prohibited.
4. In newly urbanizing areas, no construction of dwellings should be allowed in potentially hazardous zones.
5. In benched areas, a buffer strip of timber, a minimum of 100 feet wide should be left between the base of the steep slope and any development to serve as a screening area and run-out zone for potential landslides.
6. At no time should dwellings be allowed to be constructed within or directly below any outflow channels of gullies which may serve as debris avalanche paths.
7. Residents currently living in high hazard and potential hazard areas should be warned in writing of the potential landslide hazard and provisions made so that future buyers of these properties will be so informed.

8. If possible, high hazard areas should be designated for use as city parks or for parking areas. Use of these areas for dwelling purposes should be prohibited in high hazard zones and strongly discouraged in potential hazard zones unless buildings are adequately designed.

9. Construction of buildings with high dwelling density (multi-family dwellings) should be prohibited in high hazard areas and discouraged in potential hazard areas.

10. If buildings are to be constructed in these hazardous areas they must be carefully designed to withstand anticipated loading stresses from landslide impact and the foundation firmly anchored, preferably in bedrock, to prevent displacement.

11. Buildings in high hazard areas should be entirely of reinforced concrete either solid wall or skeletal frame with face work. If the latter, the lower two floors should be reserved for parking.

12. Some relief from major damage from landsliding in gullies may be obtained by construction of open crib-walls anchored firmly in bedrock. These would be effective mainly in stopping small landslides and reducing velocity and impact of major landslides. To be effective, these crib-wall dams must be anchored adequately and cleaned frequently to prevent build-up of materials in the gully. If these provisions are not taken care of such dams could serve as the focus of major landsliding due to pile-up of debris and ultimate failure.

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Report of Strength Testing of Juneau, Alaska Soil Samples

for
Douglas N. Swanston

by

J R. Bell
Corvallis, Oregon
July 1972

Four representative, disturbed soil samples at natural water content were received from D. N. Swanston. The soils were gravelly sandy silts of very low plasticity. The insitu moisture density conditions were provided with the samples and are tabulated in Table I.

Samples 1 and 2 were slightly different but were considered representative of the bulk of the soil and were used for the strength tests.

TABLE I. Insitu Moisture Density

Sample No.	Dry Unit Weight (lb/ft^3)	Water Content (%)
1	63.3	27.3
2	77.6	31.4
5	62.6	25.1
6	110.2	14.6

The soils were tested in consolidated undrained triaxial compression with pore pressure measurements to determine the effective stress strength parameters c' and ϕ'. The test specimens were prepared by molding the soils at insitu moisture and density. Then they were saturated and consolidated under the desired stress. Finally they were sheared without drainage, and pore pressures were measured during shear.

To investigate the effects of overconsolidation and stress-path to failure, five specimens were tested under a variety of conditions as indicated below.

Specimen 1 - Soil 1, consolidated under 5 psi and sheared with a 5 psi confining pressure.
Specimen 2 - Soil 1, consolidated under 6 psi and sheared with a 10 psi confining pressure.
Specimen 3 - Soil 2, consolidated under 10 psi and sheared with a 10 psi confining pressure.
Specimen 4 - Soil 2, consolidated under 15 psi and sheared with a 15 psi confining pressure.
Specimen 5 - Soil 2, consolidated under 15 psi, allowed to expand under 5 psi and sheared with a 5 psi confining pressure.

The results are presented as Figures 1 and 2 and Table II. Figure 1 shows the stress-strain curves for the several tests. Taking 10% strain as failure, the conditions at failure are tabulated in Table II. Plotting the effective stress data from Table II yields the effective stress envelope shown on Figure 2. The results are very consistent,

TABLE II. Failure Conditions

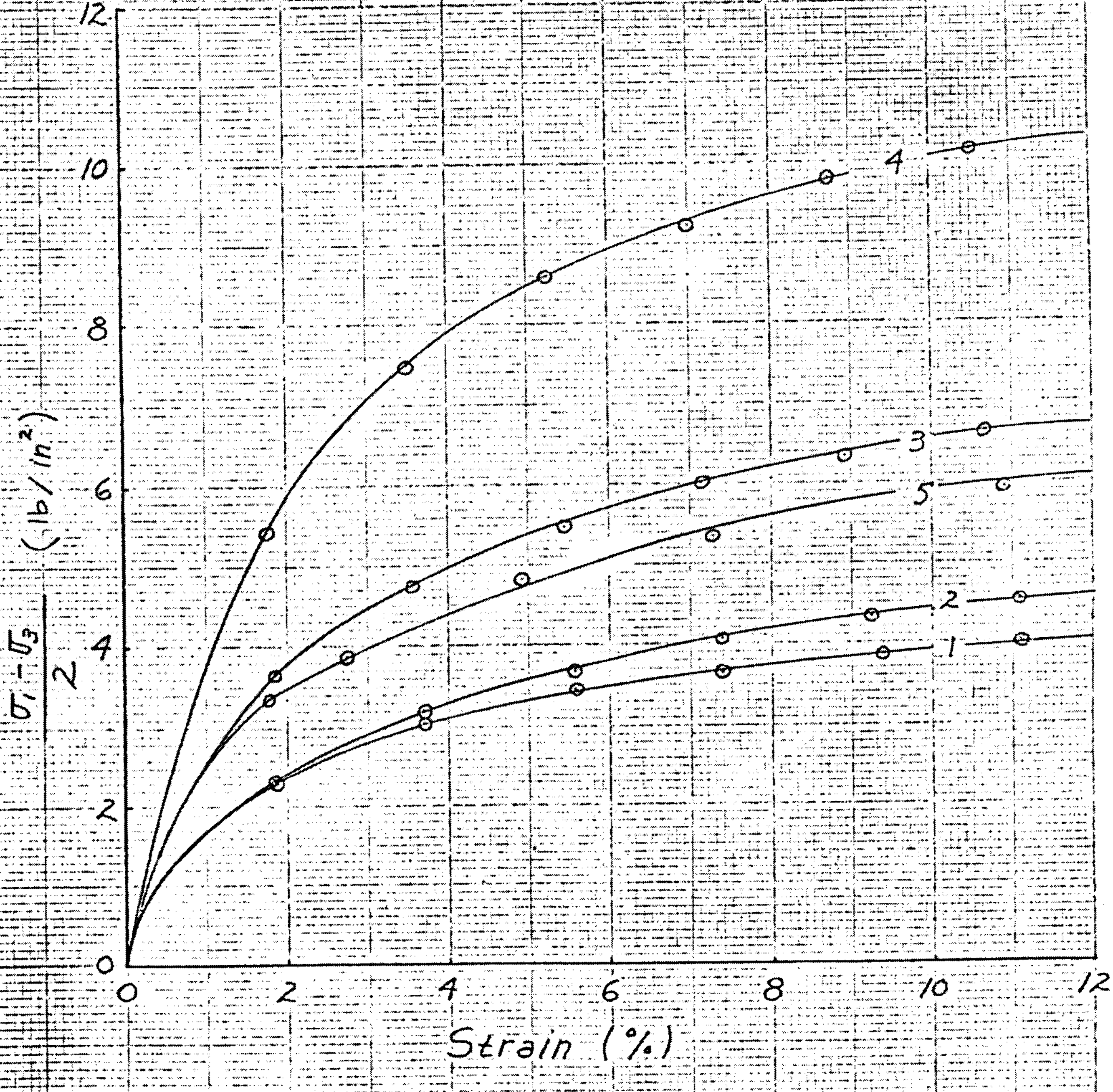
Specimen No.							
1	5	12.8	2.0	3.0	10.8	67.8	49.2
2	10	18.8	6.8	3.2	12.0	63.2	46.6
3	10	23.2	5.3	4.7	17.9	77.2	37.6
4	15	35.1	8.2	6.8	26.9	82.8	36.9
5	5	16.9	1.0	4.0	15.9	77.5	39.3

and = Total major and minor principal stresses (psi)
and = Effective major and minor principal stresses (psi)
= pore pressure (psi)
= dry unit weight (lb. per cu. ft.)
= water content (%)

producing a $c' = 0$ and $\phi' = 36°$. The strength of this soil can be represented by $s = \sigma' \tan 36°$. In the stress range tested, this is independent of overconsolidation or stress-path to failure.

REGISTERED PROFESSIONAL ENGINEER
OREGON
NOV. 6, 1934
J. RICHARD BELL

FIG. 1 - Stress - Strain Curves

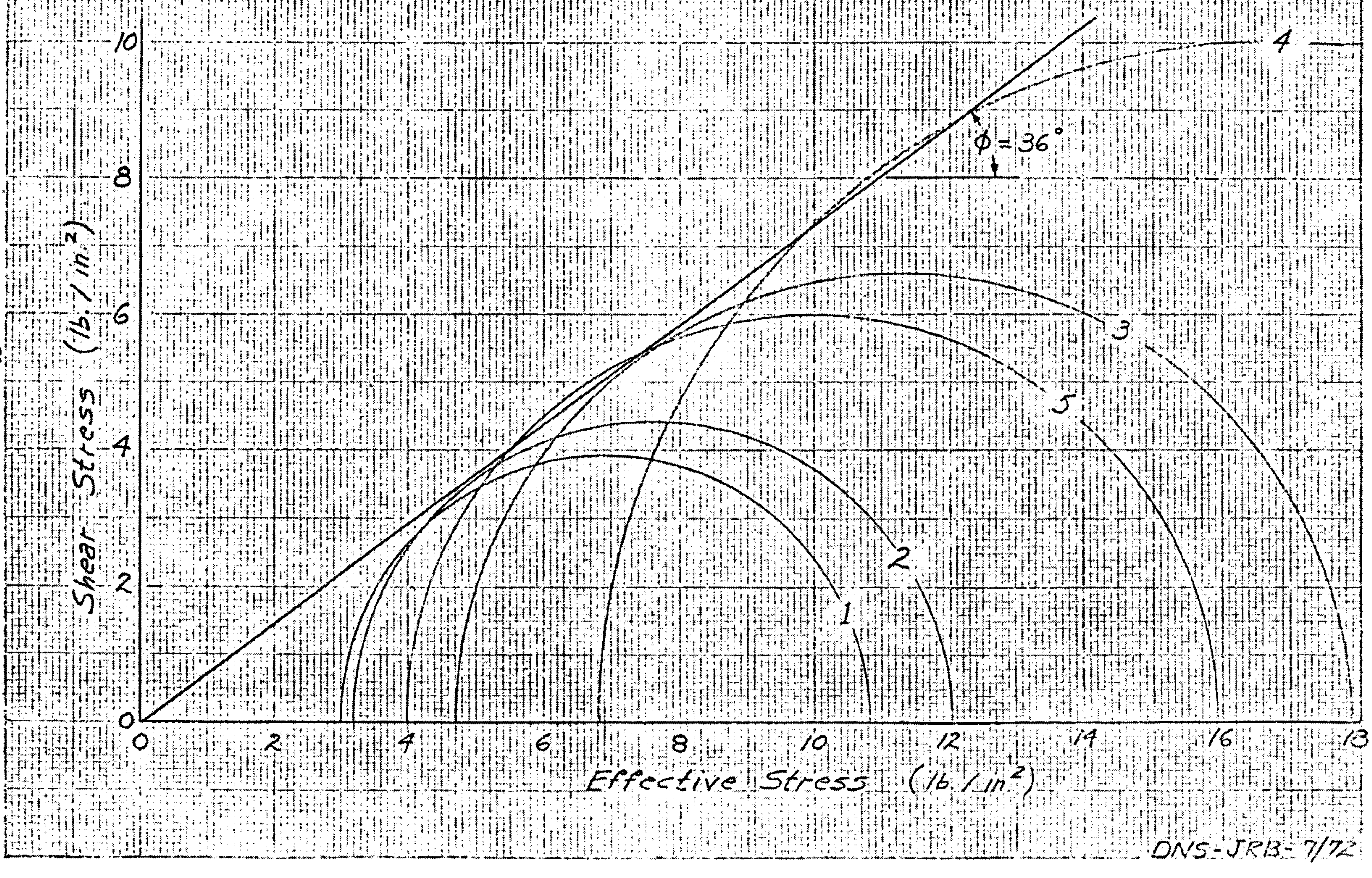


DNS- JKB-7/72

Form No. 620 : 20 Squares to Inch

Form No. 620 : 20 Squares to Inch

FIG 2- Effective Stress Strength Envelope



APPENDIX III

AVALANCHE HAZARD INVENTORY AND LAND USE CONTROL FOR THE CITY AND BOROUGH OF JUNEAU

Report to the
City and Borough of Juneau
Juneau, Alaska

Prepared by: Hans Frutiger
Swiss Federal Institute for Snow
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June, 1972

AVALANCHE ZONING
FOR THE CITY AND BOROUGH OF JUNEAU, ALASKA

GENERAL REMARKS

Structural avalanche control is subsidized in Switzerland by Federal funds up to 80% of total costs. This high rate was granted after the disastrous winter of 1950-51 as a reparation for the damage due to immense avalanching. At the same time this support was granted, the Swiss Federal Department of the Interior issued a decree in 1952 which read as follows:

> "The preparation of avalanche zoning plans and avalanche cadasters is indispensable if future loss of life and property is to be prevented. The Federal Government cannot grant contributions to resettlement or structural control if the building site was chosen without regard to the avalanche zoning plan and avalanche cadaster, or if such are lacking, warnings of building commissions were disregarded."

Avalanche zoning started with this decree 20 years ago. In fact, to know where avalanches occur or may occur and to stay out of such places would prevent any avalanche hazard. Avalanches give rise to no problems unless human activity is spread out to these places. Unfortunately too many avalanche problems already exist and have to be considered. Whether the question is to stay out or to solve already existing problems the need to know exactly the places endangered by avalanches is evident. The base for any preventive or protective measures is the avalanche zone map.

Avalanche mapping and avalanche zoning is still in the development and improvement stage. There is a world-wide need for a standard method to perform the task. The purpose of this report is to show in a practical example how we do it in Switzerland and to broach the question. It is hoped that the avalanche zoning of the City and Borough of Juneau will serve as a model for future development of the matter in the United States.

A more detailed presentation of the findings and practical experiences already made in other places will be found in the following reports:

AVALANCHE ZONING
Unpublished report on the Twin Lakes Disaster of January 21, 1962
Rocky Mountain Forest and Range Experiment Station
Fort Collins, Colorado, July 1962

THE AVALANCHE ZONING PLAN
U.S.D.A. Forest Service, Alta Avalanche Study Center
Wasatch National Forest, Translation No. 11, July 1970

The present report strictly concentrates on avalanche zoning. It does not deal with other possible protective measures like avalanche warning, artificial release, structural control or resettlement. It is a contribution to a more general Geophysical Hazard Study Project carried out by Daniel, Mann, Johnson, & Mendenhall under contract with the City and Borough of Juneau, the major scope of it being the background for safe planning of urban development. The work was performed according to the task descriptions of August 1971 and May 2, 1972; the latter first brought to my attention on May 22, 1972.

AVALANCHE MAPPING

The base of any avalanche hazard evaluation is an accurate inventory of existing avalanches in a specific area. This inventory is the so-called Avalanche Cadaster (AC). The results of the AC complemented by studies on potential avalanching is shown in the so-called Avalanche Zone Map (AZM). It shows in detail the areas subject to avalanching. Avalanche Mapping considers mainly the following factors:

- topography
- climate
- vegetation
- records of past avalanching

An accurate large scale topographic map is needed. The scale should not be smaller than 1:5000 to 1:10,000 (1 inch to 400 feet / 1 inch to 800 feet), with contour line intervals of 5 to 10 meters (15 to 30 feet), the latter depending on the general steepness of the slopes. The AZM is a general presentation of avalanche zones. It is not self-sufficient because it has to help make decisions on whether a projected building is endangered or not. Therefore the AZM must show enough reference points to allow a later transfer of the avalanche zone limits to the large scale subdivision maps and single plats. These reference points may already be existing buildings, roads, power lines, single trees and prominent terrain features which allow an orientation. The map should be waterproof; this is especially true for Southeast Alaska coastal conditions.

Climatic factors influence to a large extent the occurrence, the type and the magnitude of the avalanches for given terrain features. The evaluation of potential big and long term avalanches becomes very questionable when climatic data for the regions where avalanches start are not available. This, in fact, is the case for the Juneau region. Our actual knowledge on significant climatic factors leading to avalanching is very poor. If one is to know about the delicate relationship between temperature and snow quality or wind action and avalanche release it becomes evident that there is a great need to know more about winter conditions in this region.

A first examination of U. S. Weather Bureau data of the Juneau No. 2 station (Subport) for the winters 1917-18 through 1971-72 yielded some very valuable information on storm activity. Almost no data on snow cover conditions are available. Only four tests on resistance to penetration of the years 1962 (March 30) and 1966 (February 14, March 31 and May 10) at the Mt. Juneau Behrends avalanche test site are known. The U. S. Weather Bureau operated for the years 1916 through 1921 a station at Perseverance Camp at an elevation of 1400 feet, not high enough to represent starting zone conditions. Attempts have been made to operate two weather stations on Mt. Roberts at elevations of 1800 and 3500 feet and there were some precipitation and temperature readings obtained between July 1922 and October 1923 but it appears that the stations were soon given up.

The actual timber distribution is a very helpful indicator for mapping the frequent avalanches. However, more could be done in evaluating long term changes in vegetation cover by comparing photographs of different times. To find old pictures is very time consuming but that effort must be spent. Because of lack of time, no thorough inspection of the age of the timber stands in the neighborhood of avalanche tracks was made. This would be most important to detect past avalanche occurrence. A quick inspection of the timber thrown by the Mt. McGinnis 1972 avalanche indicated an age of 75 years, raising to 268 years for some single individual trees (see Table 1, Appendix A).

The dates of past avalanches given in previous reports are incomplete. To know the year of occurrence may be good enough to evaluate a return period. However to relate avalanches to weather conditions, the exact date (day and months) of occurrence is needed. Tedious searches in old newspaper files yielded some results. The time needed to go through the past 50 years would be far beyond what be afforded in the short time that was given me to complete the study.

The Swiss Federal Institute for Snow and Avalanche Research developed a calculation method used in avalanche mapping. This method uses topographic and climatic parameters to compute significant values of a given avalanche. It is not an exact method by far because there is very little known about avalanche dynamics. However we have the feeling that avalanche zoning should be based on numerical values rather than be a matter of mere estimate. The method becomes more valuable with an increasing understanding of avalanche dynamics and the better the parameters used are known the better will be the result. In the case of avalanches in the Juneau region, the topographic factors can be studied well on the large scale map whereas the knowledge of the significant climatic and snow cover factors is very poor.

Under the reservations stated above, the method was used for five avalanches in the area studied, the main purpose being to set an example. (See Table 2a through 2e--Appendix A). The unusual steepness of the slopes, the low altitude combined with heavy precipitation and adequate abundant vegetation and the intricate weather pattern makes the use of known standard parameters almost impossible. See, for example the exceeding steepness of the Thunder Mountain Avalanche No. 405 shown on Table 5e and Figure 5d. The average slope angle of the 4.0 ha (10 acre) starting zone is 133%. Although it is hard to believe that snow sticks on such a steep slope, there is evidence of avalanching.

RESULTS

A detailed avalanche mapping has been carried out for the areas defined in the original scope of work and as indicated, on the Geophysical Hazard Study Areas map of February 25, 1972. The total area inspected is 1313 hectares (ha) (3244 acres). (See Figure 1, Table 3, 4 and 5a through 5e, Appendix A.)

The Avalanche Zone Map (Fig. 2) shows three different zones:

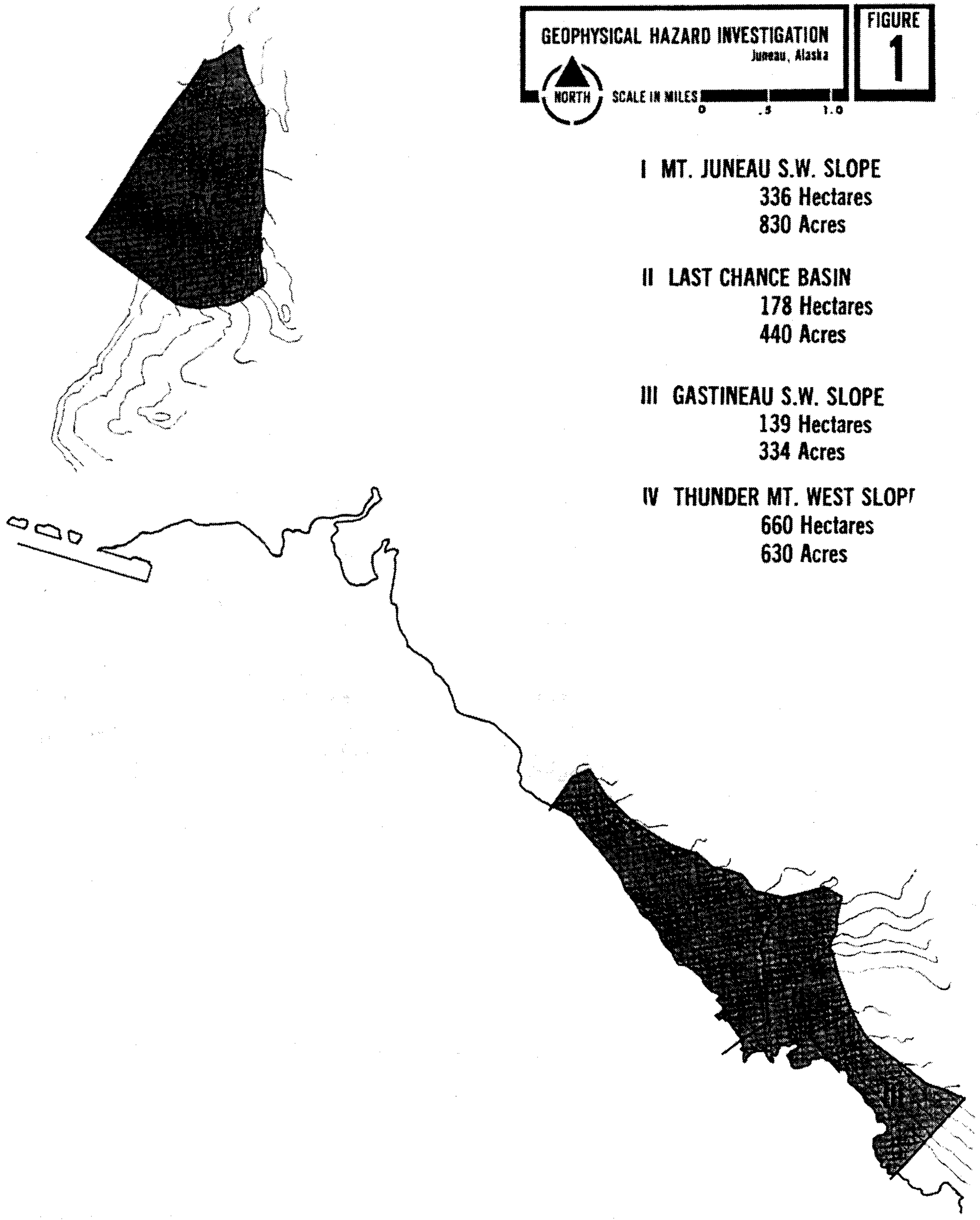
White Zone: (i.e. no hazard)	Terrain is free of avalanche hazard. It might be affected by the air blast of dust avalanches the pressure of which does not exceed 100 kilograms (kg) per square meter (20.5 pounds per square foot).
Blue Zone: (i.e. potential hazard) (Shown medium grey)	The blue zone is a transition zone between white and red. This area is affected only seldom or slightly by avalanches. This means avalanches have; --a pressure of more than 3 tons per square meter (over 600 pounds per square foot) and a return period of more than 90 years; --a pressure of 1 to 3 tons per square meter and a return period of more than 30 years; --a pressure of 0.1 to 1.0 tons per square meter (20 to 200 pounds per square foot).
Red Zone: (i.e. high hazard) (Shown dark grey)	Terrain which is exposed to frequent and powerful avalanches. This means avalanches with; --a pressure of 1 to 3 metric tons per square meter (200 to 600 pounds per square foot) and a return period of 30 years or less; --a pressure of more than 3 tons per square meter and a return period of 90 years or less

According to the task description of May 2, 1972 which says "any other potential avalanche hazard areas outside the planning area which

SNOW AVALANCHE HAZARD INVESTIGATION SUB-AREAS

GEOPHYSICAL HAZARD INVESTIGATION
Juneau, Alaska

FIGURE
1

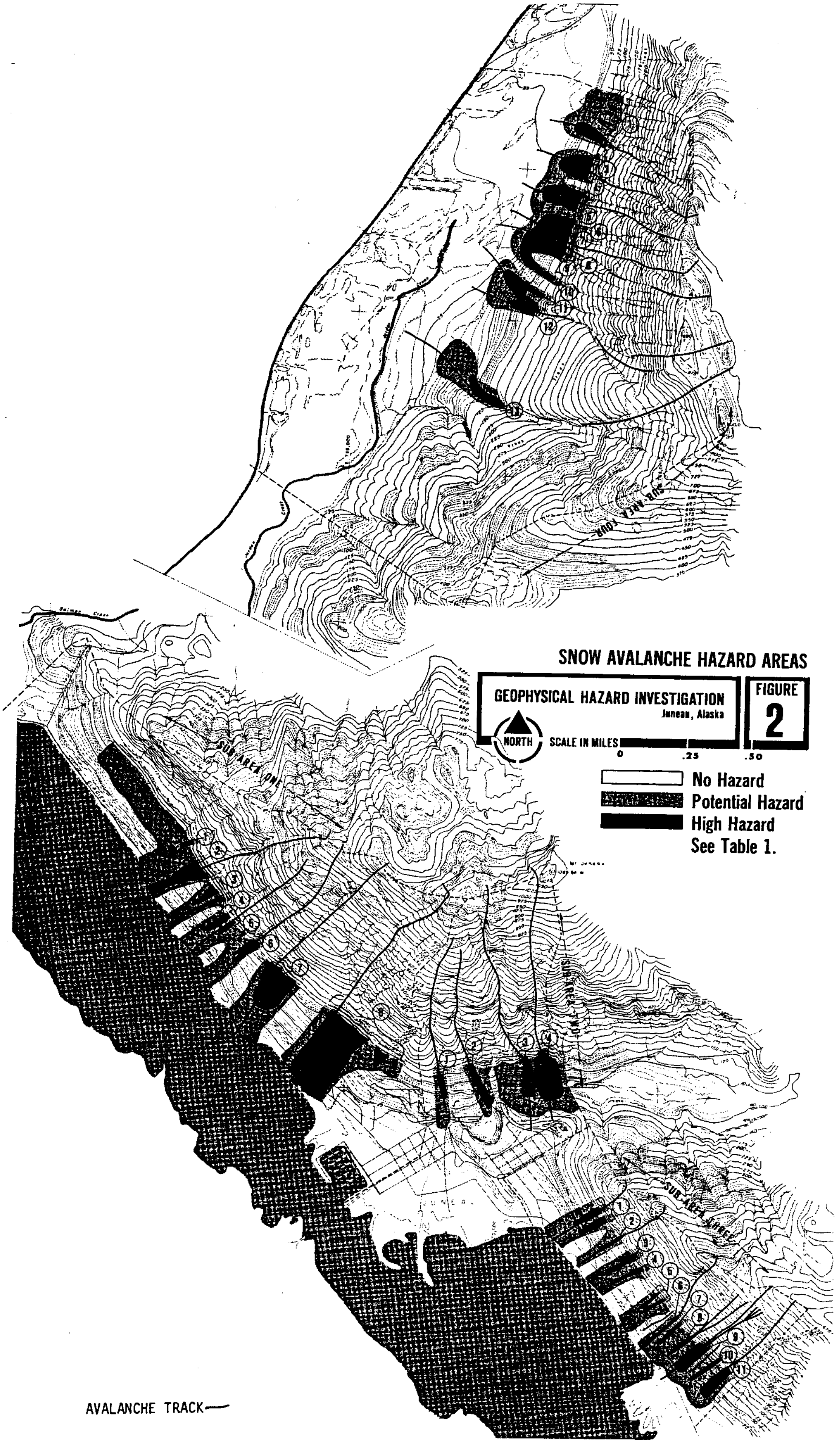


I MT. JUNEAU S.W. SLOPE
336 Hectares
830 Acres

II LAST CHANCE BASIN
178 Hectares
440 Acres

III GASTINEAU S.W. SLOPE
139 Hectares
334 Acres

IV THUNDER MT. WEST SLOP
660 Hectares
630 Acres



SNOW AVALANCHE HAZARD AREAS

GEOPHYSICAL HAZARD INVESTIGATION
Juneau, Alaska

FIGURE 2

might affect urban development" has to be considered. Urban development, i.e., especially housing, is expected along the four major arterial roads, namely Glacier Highway (41 miles), Thane Road (5.6 miles), Douglas Road North (9 miles) and Douglas Road South (3.7)miles). A superficial survey indicated that there exists avalanche hazard only on the Thane Road. This is the only road affected directly by avalanches and where housing development would create essential hazard (see Figures 3 and 4). The hazard affects both housing and traffic.

No survey was made in the valleys not accessible by means of roads, i.e., all the valleys on Douglas Island leading to higher elevations, Salmon Creek Valley, Lemon Creek Valley and so forth. No survey was made along Gold Creek Road beyond the bridge at the entrance of Last Chance Basin.

As already discussed the special conditions under which avalanches in the Juneau region have to be studied makes it difficult to define accurately the hazardous zones. In case of doubt, it was advisable to act rather cautiously and to assume the more unfavorable case. The AZM of course have to show the hazard for the most unfavorable case possible, in other words, to take into account an extreme situation which may occur very seldom. Nobody knows when such a situation will occur. The avalanche of January, 1972 which took off trees as old as 270 years shows drastically that such situations have to be considered. It is also obvious that the lack of exact data on the occurrence of past avalanches makes it impossible to use the distribution of snow storms leading to avalanching as a means to establish "possible return periods".

RECOMMENDATIONS

1. Avalanche Zone Planning

The heavy building activities in recent years gave rise to local planning activities. These have to take into account the identified avalanche areas. Avalanche zoning thus is a permanent part of local planning by means of which avalanche hazard can be prevented. In this respect the term "avalanche zone plan" has to be understood. Avalanche zones do not arise from the desires of planners but are imposed on them as natural forces independent - at least at first - of human influence. Avalanche zone planning includes the whole complex of tasks involved in preventing avalanche hazards which are addressed to technical as well as to legal and administrative measures.

The Swiss Federal Institute for Snow and Avalanche Research is starting to work on General Directions for Avalanche Zoning (see Appendix B). A modified copy of those directions could be adopted for U. S. avalanche zoning. It is high time to stop the hazardous building in avalanche-prone areas. The right to enact legislation to protect the safety, welfare, peace and lives of people comes

FIGURE 3

1: 250 000

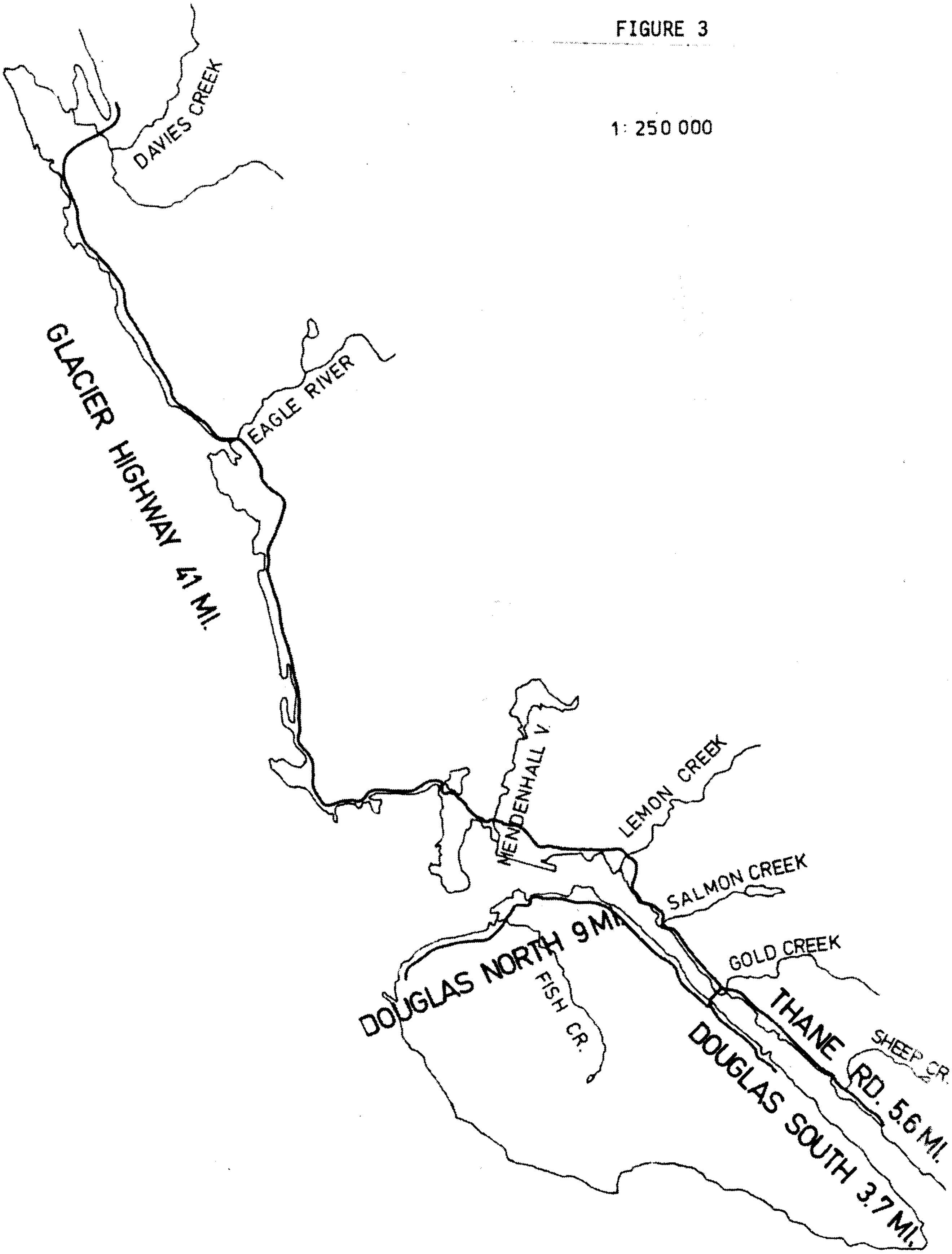


FIGURE 4

AVALANCHE HAZARD INVESTIGATION
GENERALIZED HAZARD AREAS

under police power. Although this does interfere with private rights and does seem to take them away, no compensation should be necessary. We know that some land developers - a small number among the responsible ones - may disregard the dangers of development in an avalanche hazard area as a result of ignorance or as a result of subordinating their responsibility to the community to their desire to make a profit. An efficacious stop to this possibility must be found.

In general, building or zoning regulations are enforced under the police power without compensation to the property owners. The Planning Commission, advised by the Planning Department of the City and Borough, has to recommend to the governing board, which land is to be designated as subject to avalanches. The Avalanche Zone Plan (or the Avalanche Zone Map) in the scale of 1:10,000 is the base for such recommendations. It is an official document. The City and Borough of Juneau should find means to bring the AZM to public notice. Avalanches are a restriction on land. It is a naturally imposed restriction in a deed and affects the land adversely, and is called a deed restriction. At the conveyance of any land this restriction should be made evident. Any Subdivision Ordinance should provide means to show the restriction on the U. S. survey serving the transfer of property, in the Land Description and on the plats. By this means property buyers can be warned.

What can be done in the case of already existing hazards such as the case of Behrends Avenue? Proposals have already been made as to how to handle it. Reference is made to the Hart Report (1) p. 19 and the LaChapelle Report (2) p. 10, 16-17.

(1) Keith Hart: Report of the Preliminary Evaluation of the
Behrends Avenue Avalanche Path
Conducted for the City of Juneau, Alaska
January 1967

(2) Edward R. LaChapelle: The Behrends Avenue Avalanche and Other Avalanche Hazards in the Greater Juneau Borough. A report based on an inspection trip to the Juneau area on August 29-31, 1968, submitted to the Chairman of the Greater Juneau Borough November 7, 1968

2. Avalanche Warning

This is more commonly referred to as "Avalanche Forecasting". To prevent at least losses of life in places where buildings in avalanche zones already exist, the efforts to improve avalanche forecasting should be continued.

All technical, legal and administrative measures serving as avalanche warning are comprised in the so-called "Avalanche Service", a term used widely in Europe. It consists in collecting data on avalanche occurrence (avalanche cadaster, avalanche occurrence chart), on the snow cover and weather conditions leading to avalanching (snow studies, snow measurements, snow conditions, storm plots), in assigning properly instructed technical people and the responsible authorities to prepare a warning system and an evacuation plan (administrative), and in establishing the necessary organization to guarantee a quick, effective and alert evacuation in case of emergency. It might be advisable to also be prepared to do rescue work.

There is a technical and financial problem in finding suitable snow study plots. The future Fish Creek Ski Area has already been taken into consideration. It is doubtful if it would represent the particular and specific "Taku Wind" conditions, which might be especially dangerous for the slopes facing southwest. A closer inspection of the following two places might be of some value:

--Heintzleman Bowl on the headwaters of Steep Creek;
--Twin Lakes, ½ mile northwest of Mt. Juneau.

A telemetering system will never replace man-operated study plots, although some elements like wind and temperature might be telemetered. The forecaster must personally have the opportunity to periodically make a thorough study of the snow cover.

Snow studies conducted in the Juneau region, in a standard manner, accurately and permanently, would not only be of value for the benefit of the residents but would also be of scientific interest. Contact should be established with other agencies interested in those snow studies like the Snow and Avalanche Research Section of the Rocky Mountain Forest and Range Experiment Station at Fort Collins, Colorado, or the University conducting the Juneau Ice Field Research Project. Collaboration or even partial support might be possible. The RMFRES at Fort Collins is the headquarters of the Nationwide Snow and Avalanche Reporting Network.

Reference to standard snow observation and avalanche reporting is given in Appendix C. Detailed technical instruction is available through the U. S. Avalanche School. If needed, details can be made available on the administrative portion of the task by following the example of the Davos Avalanche Service.

It is obvious that artificial avalanche release ("Avalanche Shooting") cannot be considered in residential areas.

3. Structural Avalanche Control

I agree with the fundamental arguments regarding structural control of the Behrends Avenue avalanche in the Hart Reports (1) p. 6-10, 17 and (3).

(3) Keith Hart: A Defense Construction Plan for the Terminal Zone of the Behrends Avenue Snow Avalanche Path, Juneau, Alaska. Juneau, April 17, 1968

Considering the details of the proposed diversion, retarding and arresting structures, however, I would suggest building one to two big dams (catching dams) rather than to split the works into many smaller structures as provided (2 small diversion dikes and 18 to 57 small earthen mounds). An upper dam, very likely about 250 meters long and horizontally laid out and about 12 meters high would be situated at the 60 meter (200 foot) level, a lower one with the same dimensions at the 25 meter (80 foot) level. (Altitudes do not coincide on the 1:10,000 and the 1" to 200' maps). There would be some advantage for this plan over Hart's plan with respect to a water collector system, maintenance and cost.

The longitudinal profile of the Behrends Avenue avalanche track (No. 108, Figure 5a) shows the run-out distance between the break in the terrain at the 100 meter level and the Behrends Avenue homes as only 320 meters and the average slope angle as high as 28% (16^o). Those terrain features are not particularly favorable for the placement of retarding and catching structures.

As stated in the reports mentioned above, it is out of the question that the Behrends Avenue avalanche be controlled by supporting structures in the starting zone. The latter shows an extent of 17.5 ha (43 acres) and an average slope angle of 74%. About 10 kilometers (6.2 miles) of permanent supporting structures (steel snow bridges) would be needed to control the snow in the starting zone.

APPENDIX A

APPENDIX A
TABLE 1

DETERMINATION OF THE AGE OF TREES KNOCKED DOWN BY THE AVALANCHE OF MT. MCGINNIS ON JANUARY 19 (?), 1972 WITH THE INCREMENT BORER

Date: June 20, 1972

Crew: Keith Hart
Tom Laurent
Craig Lindh
Hans Frutiger

Lower Portion of the Track

Species	Diameter (in inches) at Breast Height	Age (in years) (estimated*)
Sitka Spruce	15.6	65
Sitka Spruce	17.8	79
Sitka Spruce	21.1	80 *
Sitka Spruce	16.6	68 *
Sitka Spruce	28.1	80 *
Sitka Spruce	25.0	60 *
Sitka Spruce	23.4	73
Sitka Spruce	21.5	83
Sitka Spruce	27.6	78 *
Sitka Spruce	22.9 (7.0 ft.)	87 *
Average	22.0	75

Upper Portion of the Track

Species	Diameter (in inches) at Breast Height	Age (in years) (estimated*)
Western Hemlock	7.0 ft 32.2	230
Sitka Spruce	7.0 ft 33.0	138
Sitka Spruce	6.5 ft 44.6	268
Average	36.6	212

NOTE: The tree growth varied from 1.2 mm per year (annual ring width) to 5.8 mm per year; most common annual ring width was 3.4 to 3.6 mm per year.

TABLE 2a

No.: I Region: MT. JUNEAU SW

No.: 102 Name: White Subdivision

Starting zone

Elevation (~~ft~~ m.above m.s.l.) from 725 to 325

Area (ha): 7.6 (19 acres)

Slope angle (%):

	Area(ha)	%
medium	7.6	100
minimum	1.2	46
maximum	2.6	138

Depth of snow breaking away (m): 2.0

Discharge volume (m^3): 152'000

Coefficient of friction μ : 0.20

[Table: $v^2 = \xi . h_0(\sin\psi_o - \mu . \cos\psi_o)$]

Velocity of flowing snow (m/sec): 24

Flowing distance (m): 600

Flowing time (sec): 25

Passage volume (m^3/sec): 6'100

Avalanche track

Section (~~ft~~ m.above m.s.l.): from 100 to 25

Grade of track (%): 57

Cross section of track: well pronounced gulley U-40

[Table: $v^2 = \xi . R(\sin\psi - \mu . \cos\psi)$]

Avalanche depth (m): 6.2

Avalanche velocity (m/sec): 25

Runout zone

Grade of runout zone (%): 21

Cross section of avalanche: 50 m wide

Avalanche depth (m): 6.2

Avalanche velocity (m/sec): 25

Runout distance (m): 20% : 1300 m
0% : 130 m

[Table: $s = \dfrac{v^2}{2g\{(\mu . \cos\psi - tg\psi) + \dfrac{v^2}{2\xi . h_a}\}}$]

coefficient of friction	runout distance(m)
$\mu = 0.10$	s =
$\mu = 0.15$	s =
$\mu = 0.20$	s = 1300/130

TABLE 2b

No.: I Region: MT. JUNEAU SW

No.: 108 Name: Behrends Ave.

Starting zone

Elevation (~~ft~~ m.above m.s.l.) from 900 to 600

Area (ha): 17.5

Slope angle (%):

	Area(ha)	%
medium	17.5	74
minimum	—	—
maximum	—	—

Depth of snow breaking away (m): 2.0

Discharge volume (m^3): 350'000

Coefficient of friction μ : 0.15

[Table: $v^2 = \xi . h_0 (\sin\psi_o - \mu . \cos\psi_o)$]

Velocity of flowing snow (m/sec): 21

Flowing distance (m): 560

Flowing time (sec): 27

Passage volume (m^3/sec): 13'000

Avalanche track

Section (~~ft~~ m.above m.s.l.): from 300 to 100

Grade of track (%): 68

Cross section of track: ⌊250⌋ unconfined area avalanche

[Table: $v^2 = \xi . R (\sin\psi - \mu . \cos\psi)$]

Avalanche depth (m): 2.3

Avalanche velocity (m/sec): 23

Runout zone

Grade of runout zone (%): 28/0

Cross section of avalanche: ⌊250⌋

Avalanche depth (m): 2.3

Avalanche velocity (m/sec): 23

Runout distance (m): 28%: unlimited
0%: 120 m

coefficient of friction	runout distance(m)
$\mu = 0.10$	s =
$\mu = 0.15$	s =
$\mu = 0.20$	s = ∞/120

$$\left[\text{Table}: s = \frac{v^2}{2g\left((\mu . \cos\psi - tg\psi) + \frac{v^2}{2\xi . h_a}\right)}\right]$$

TABLE 2c

No.: II Region: LOST CHANCE

No.: 204 Name: ?

Starting zone

Elevation (~~ft~~ m .above m.s.l.) from 1000 to 650

Area (ha): 9.8

Slope angle (%):

	Area(ha)	%
medium	9.8	75
minimum	—	—
maximum	—	—

Depth of snow breaking away (m): 3.0

Discharge volume (m^3): 294'000

Coefficient of friction μ : 0.15

[Table: $v^2 = \xi . h_0(\sin\psi_o - \mu . \cos\psi_o)$]

Velocity of flowing snow (m/sec): 27

Flowing distance (m): 580

Flowing time (sec): 21

Passage volume (m^3/sec): 14'000

Avalanche track

Section (~~ft~~ m .above m.s.l.): from 200 to 50

Grade of track (%): 38

Cross section of track: ⌊100⌋ unconfined area avalanche

[Table: $v^2 = \xi . R(\sin\psi - \mu . \cos\psi)$]

Avalanche depth (m): 5.7

Avalanche velocity (m/sec): 25

Runout zone

Grade of runout zone (%): 38

Cross section of avalanche: ⌊150⌋ unconfined area avalanche

Avalanche depth (m): 5.7

Avalanche velocity (m/sec): 25

Runout distance (m):
Runout zone is Gold Creek Gulley and opposite slope of Mt. Maria

[Table: $s = \dfrac{v^2}{2g\{(\mu . \cos\psi - tg\psi) + \dfrac{v^2}{2\xi . h_a}\}}$]

coefficient of friction	runout distance(m)
μ = 0.10	s =
μ = 0.15	s =
μ = 0.20	s = —

~~TABLE 2d~~

No.: III Region: GASTINEAU SW

No.: 309 Name: ?

Starting zone

Elevation (~~ft.~~ m above m.s.l.) from 575 to 200

Area (ha): 3.2

Slope angle (%):

	Area (ha)	%
medium	3.2	88
minimum	0.8	60
maximum	0.8	103

Depth of snow breaking away (m): 2.0

Discharge volume (m^3): 64'000

Coefficient of friction μ : 0.15

[Table: $v^2 = \xi . h_0(\sin\psi_o - \mu . \cos\psi_o)$]

Velocity of flowing snow (m/sec): 24

Flowing distance (m): 530

Flowing time (sec): 22

Passage volume (m^3/sec): 2'900

Avalanche track

Section (~~ft.~~ m above m.s.l.): from 125 to 10 (Thane Road)

Grade of track (%): 46

Cross section of track: 60 unconfined area avalanche

[Table: $v^2 = \xi . R(\sin\psi - \mu . \cos\psi)$]

Avalanche depth (m): 2.6

Avalanche velocity (m/sec): 17

Runout zone

Grade of runout zone (%): 46

Cross section of avalanche: 80 unconfined, 80 m wide

Avalanche depth (m): 2.6

Avalanche velocity (m/sec): 17

Runout distance (m): 46%: unlimited
0%: 70 m

[Table: $s = \dfrac{v^2}{2g\{(\mu . \cos\psi - tg\psi) + \dfrac{v^2}{2\xi . h_a}\}}$]

coefficient of friction	runout distance (m)
$\mu = 0.10$	s =
$\mu = 0.15$	s =
$\mu = 0.20$	s = ∞/70

TABLE 2a

No.: IV Region: THUNDER MT.

No.: 405 Name: ?

Starting zone

Elevation (~~ft.~~ m .above m.s.l.) from 825 to 525

Area (ha): 4.0

Slope angle (%):

	Area(ha)	%
medium	4.0	133
minimum	1.0	100
maximum	3.0	155

Depth of snow breaking away (m): 1.0

Discharge volume (m^3): 40'000

Coefficient of friction μ : 0.20

[Table: $v^2 = \xi . h_0(\sin\psi_o - \mu . \cos\psi_o)$]

Velocity of flowing snow (m/sec): 20

Flowing distance (m): 380

Flowing time (sec): 19

Passage volume (m^3/sec): 2'100

Avalanche track

Section (~~ft.~~ m .above m.s.l.): from 250 to 50

Grade of track (%): 68

Cross section of track: detritus cone 150 m wide

[Table: $v^2 = \xi . R(\sin\psi - \mu . \cos\psi)$]

Avalanche depth (m): 1.0

Avalanche velocity (m/sec): 14

Runout zone

Grade of runout zone (%): 10

Cross section of avalanche: alluvial cone 150 m wide

Avalanche depth (m): 1.0

Avalanche velocity (m/sec): 14

Runout distance (m):

[Table: $s = \dfrac{v^2}{2g(\mu . \cos\psi - tg\psi) + \dfrac{v^2}{2\xi . h_a}}$]

coefficient of friction	runout distance(m)
$\mu = 0.10$	s =
$\mu = 0.15$	s =
$\mu = 0.20$	s = 76

AVALANCHE ZONING FOR THE CITY AND BOROUGH OF JUNEAU

TABLE 3

AREA STATISTICS

Section Number	Name	Total Area		Area Covered by Avalanche (starting zones only)	
		ha	acres	ha	acres
I	Mt. Juneau SW Slope	336	830	57.4	142
II	Last Chance Basin	178	440	34.8	86
III	Gastineau SW Slope	139	344	22.7	57
IV	Thunder Mt. W Slope	660	1630	59.2	147
	Total	1313	3244	174.1	432

TABLE 4

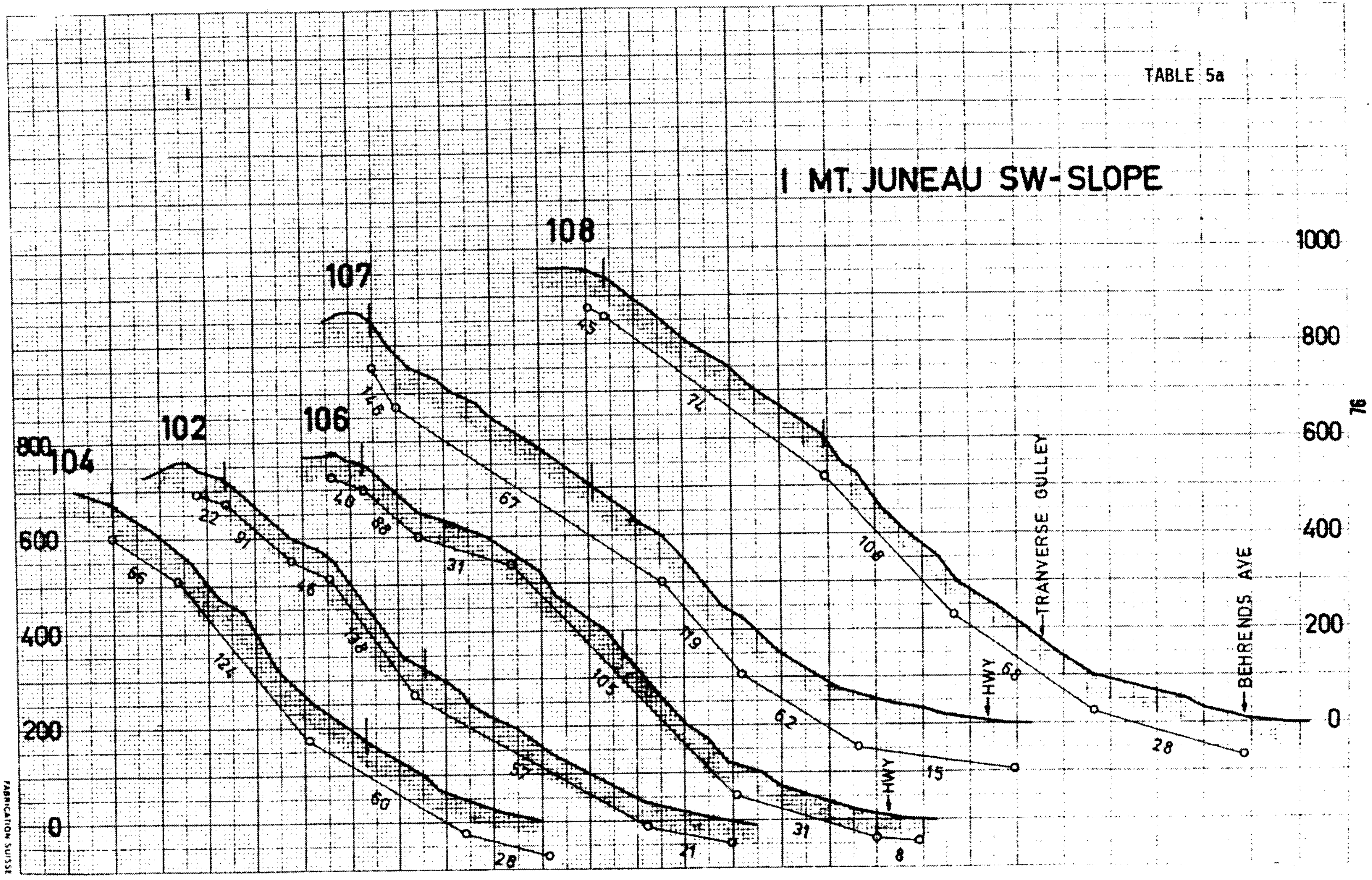
TRACK STATISTICS

Number	Name or Location, Remarks	Area of the Starting Zone		
		ha	acres	
101		2.4	6	
102	White Subdivision	7.6	19	
103	Childrens Home	2.8	7	
104		5.5	14	
105		1.7	4	
106		6.4	16	
107	Norway Point	13.5	33	
108	Behrends Avenue	17.5	43	
109	Diffuse snow avalanching from cliffs, stops in heavy timber above Highland Drive and Evergreen Avenue	--	--	
		57.4	142	Sub-total, Section 1
201	12th Street	6.9	17	
202	Evergreen Bowl	6.4	16	
203		11.7	29	
204		9.8	24	
		34.8	86	Sub-total, Section 2
301	Hospital, diffuse starting zones in timber snow falls into channels	1.9	5	
302	Shed, end of S. Gastineau	1.0	3	
303	North end Tailings	2.6	6	
304	Tailings	1.5	4	

TABLE 4 (Continued)

305)	Two	0.4	1	
305)	Narrow channels south of mine	0.5	1	
306	Along tramway	3.3	8	
307	Tramway crossing	0.7	2	
308	Tramway crossing	2.9	7	
309		3.2	8	
310		1.3	3	
311		3.4	8	
		22.7	57	Sub-total, Section 3
401	5 channels in timber	--	--	
402		3.0	7	
403	Small narrow avalanche	--	--	
404		2.8	7	
405		4.0	10	
406	Andrew	5.2	13	
407	Katherine	6.3	16	
408	Daniel	4.4	11	
409	Stephen	3.9	10	
410		2.9	7	
411		2.4	6	
412		13.5	33	
413		10.8	27	
		59.2	147	Sub-total, Section 4

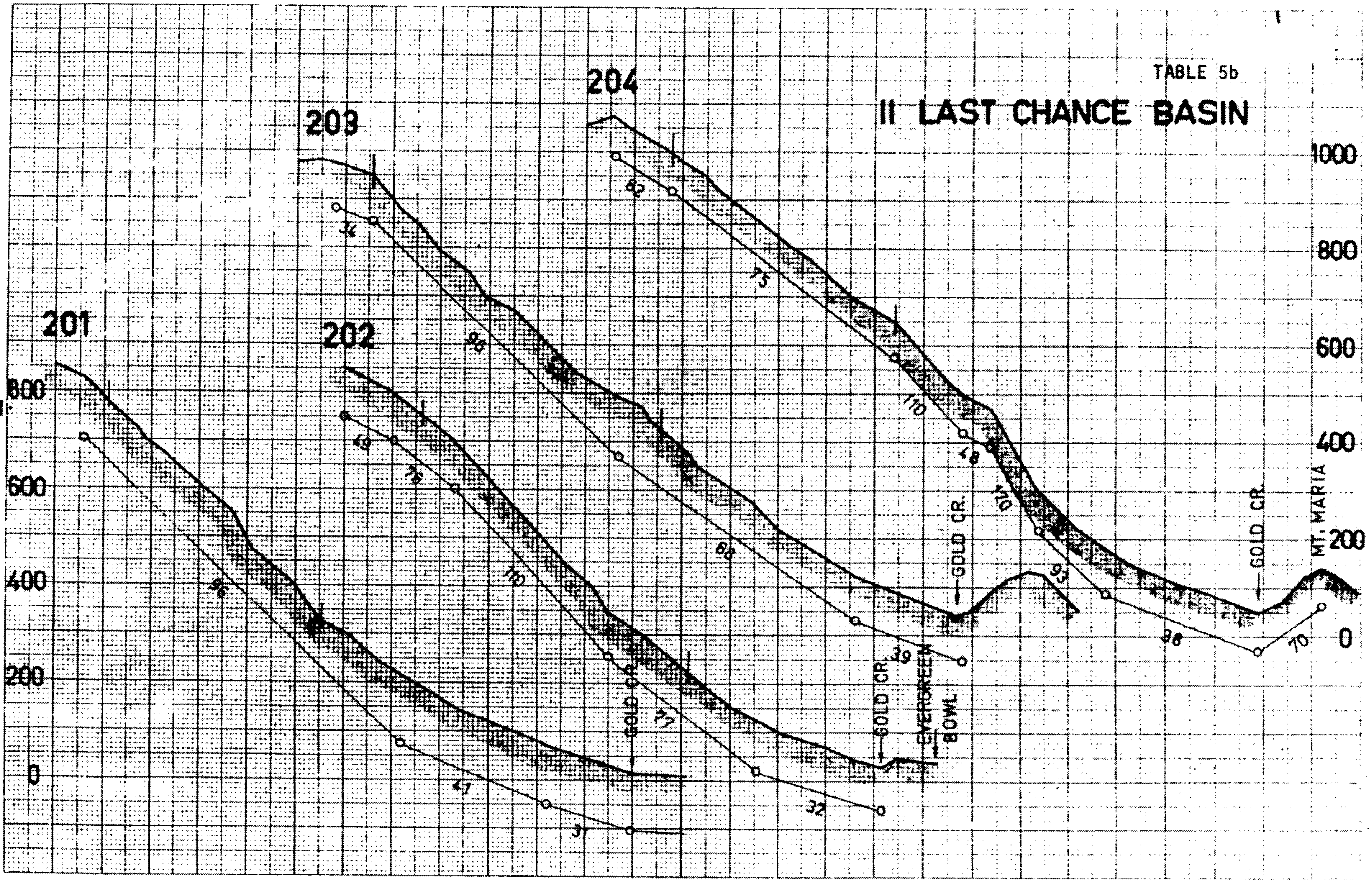
TABLE 5a



I MT. JUNEAU SW-SLOPE

TABLE 5b

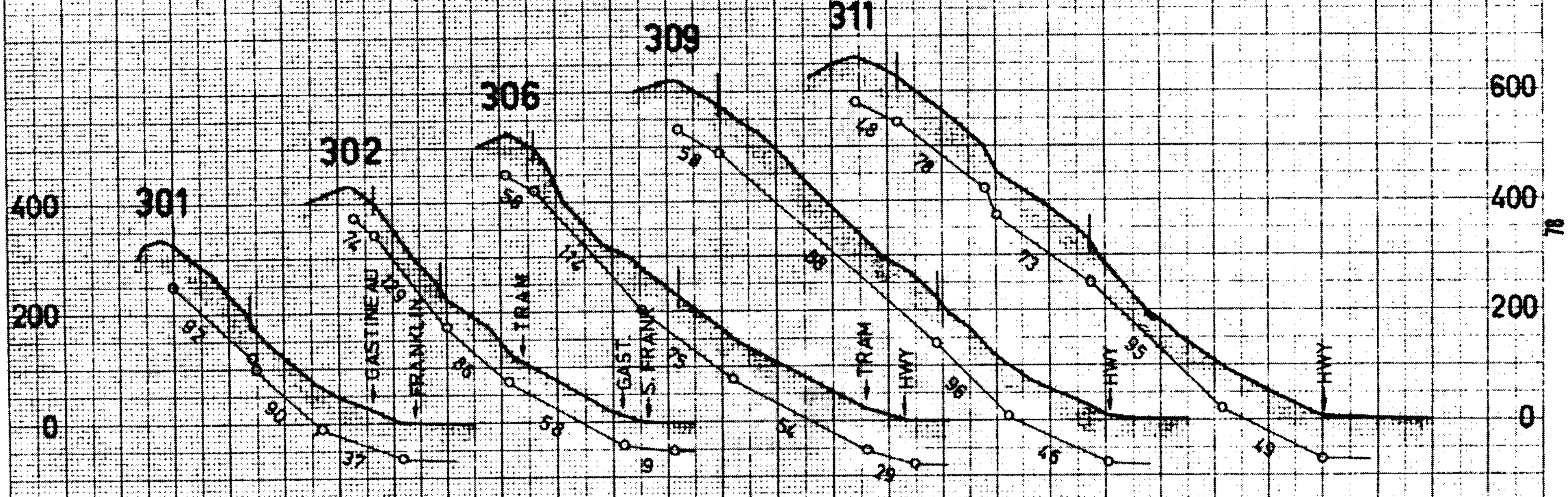
II LAST CHANCE BASIN



FABRICATION SUISSE

TABLE 5c

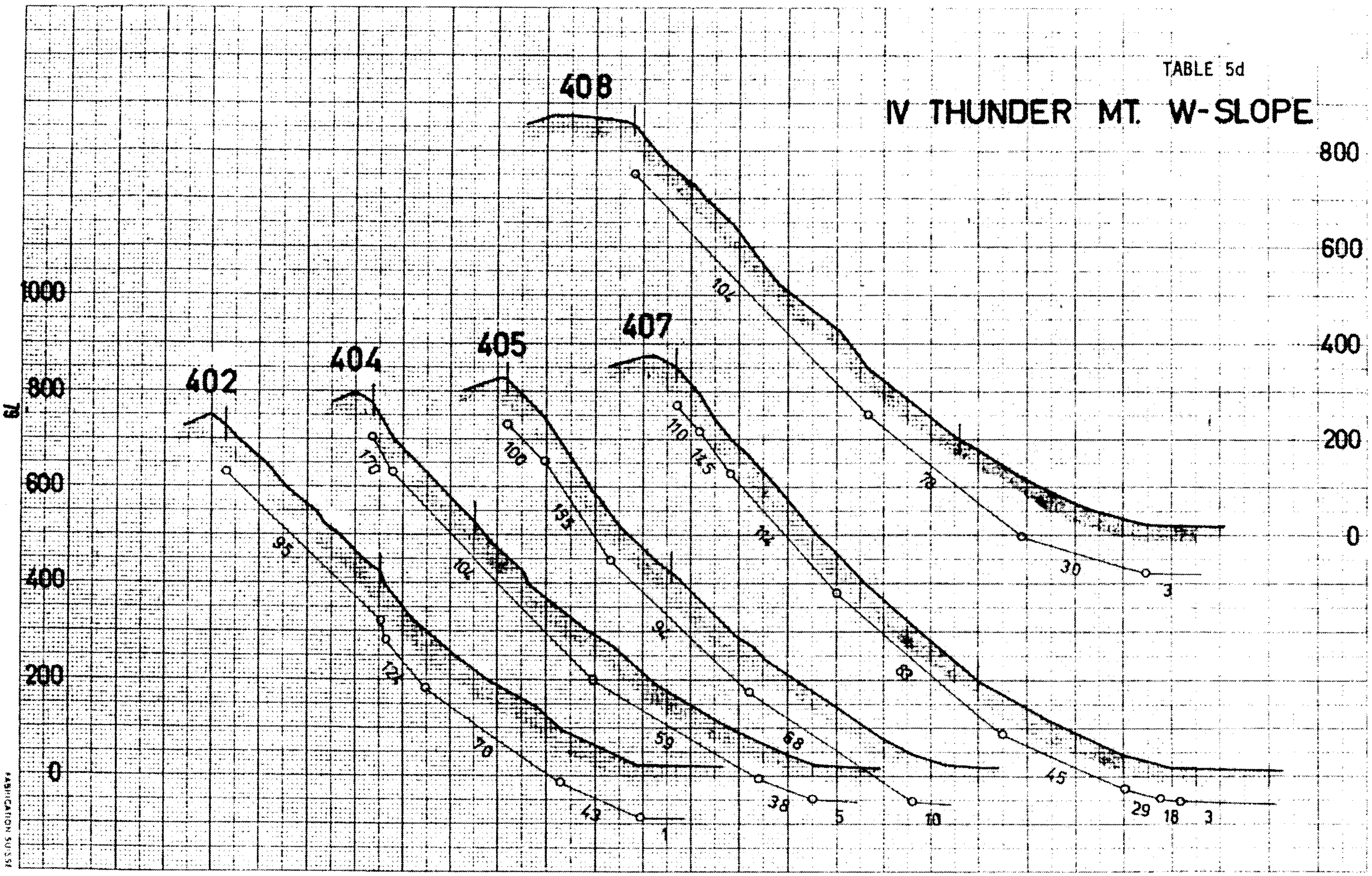
III GASTINEAU SW-SLOPE



FABRICATION SUISSE

TABLE 5d

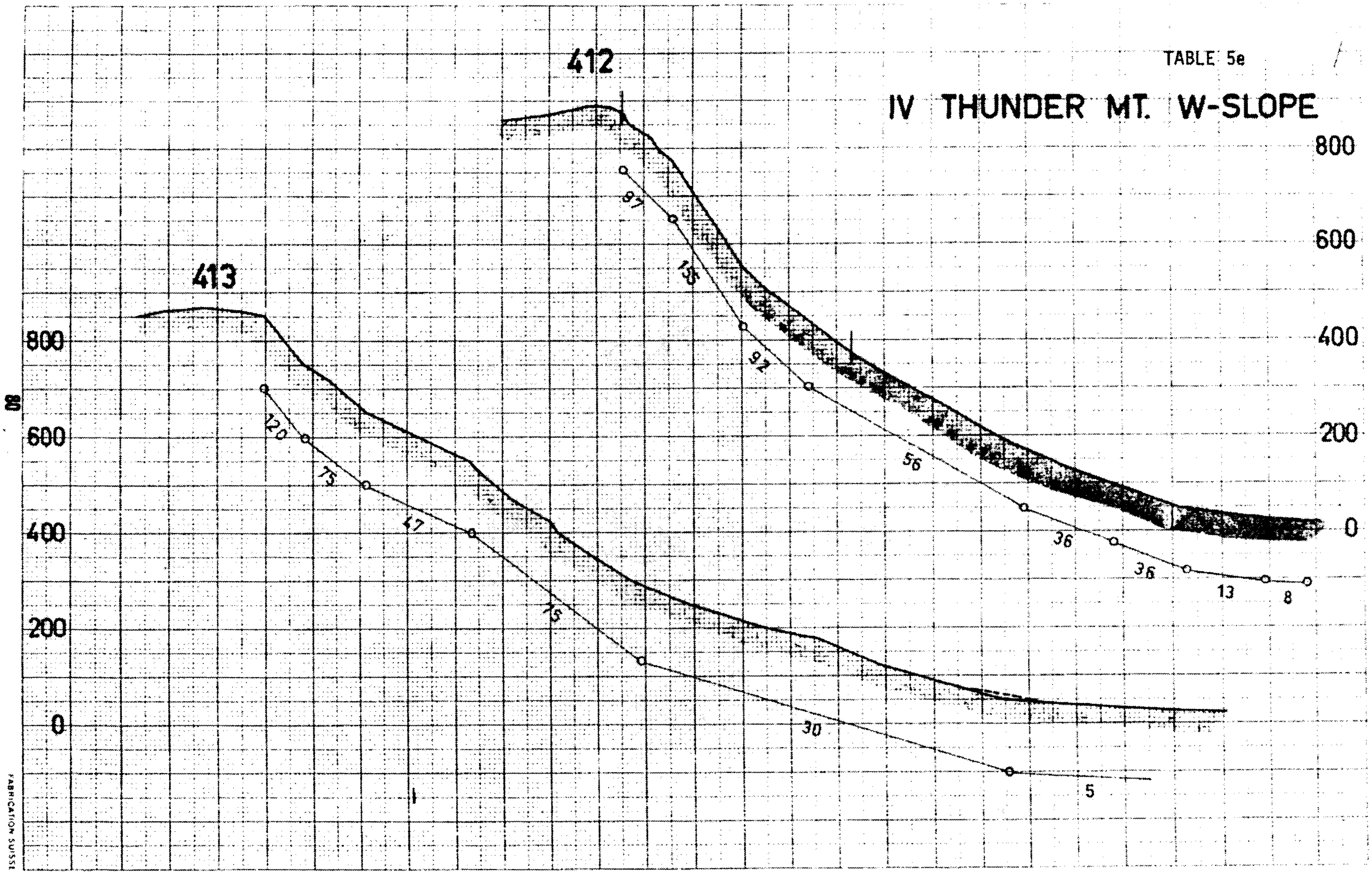
IV THUNDER MT. W-SLOPE



FABRICATION SUISSE

TABLE 5e

IV THUNDER MT. W-SLOPE



FABRICATION SUISSE

APPENDIX B

APPENDIX B

The FUNDAMENTALS OF AVALANCHE DYNAMICS used in the present engineering application have been published in the following items:

VOELLMY, A. 1955
On the destructive force of avalanches: U.S.D.A. Forest
Service, Alta Avalanche Study Center
Translation No. 2, March 1964.

SOMMERHALDER, E. 1965
Avalanche Forces and the Protection of Objects. Published in:
Annual Report of the Swiss Federal Institute for Snow and
Avalanche Research No. 29 1964-1965 and, U.S.D.A. Forest
Service, Alta Avalanche Study Center
Translation No. 6, November 1967

The units of measurement and symbols used in the metric system are the following:

-meter (m) = 39.37 inches or 3.28 feet
-square meter (m^2) = 10.76 square feet or 1.196 square yards
-cubic meter (m^3) = 35.3 cubic feet
-hectare (ha) = 2.47 acres
ψ slope angle, grade of longitudinal profile in percent (%)
μ coefficient of friction
ξ flow coefficient, velocity coefficient
h_0, h snow depth, flow depth
v velocity of flowing snow, avalanche velocity
R hydraulic radius
g acceleration due to gravity

Specific terms in avalanche research are defined in:

SNOW AVALANCHES 1961
A handbook of forecasting and control measures
U.S.D.A. Forest Service Agricultural Handbook No. 194

FRUTIGER, H. and MARTINELLI, M. 1966
A manual for planning structural control of avalanches
U.S.D.A. Forest Service Rocky Mountain Forest and Range
Experiment Station Research Paper RM-19, May 1966

RECOMMENDED AVALANCHE ZONING FOR THE CITY AND BOROUGH OF JUNEAU BASED ON ZONING PRACTICE IN SWITZERLAND

General Directions for Avalanche Zoning

1. General

1.1 Avalanche zoning provides a base for a safe development of a region with respect to avalanche hazard.

1.2 The avalanche hazard of a defined area is represented by the so-called avalanche zone map. It serves the urban planning, planning of communications and recreation resorts, building regulations and helps the local avalanche hazard forecaster make protective decisions.

1.3 Avalanche activity may result in burying persons and/or damaging real value. The grade of the hazard varies considerably depending on place and time. The avalanche zone map represents the whole variety of hazard. It considers in particular the avalanches occurring seldom, that is, those with long return periods.

1.4 Avalanche activity is recorded by the Avalanche Cadaster (AC). It is an inventory of all known avalanches of a defined region. It gives particulars on every single avalanche; i.e., on its time of occurrence, its volume, its run-out distance and eventual damage to life and property.

1.5 The Avalanche Zone Map (AZM) is based on the AC supplemented by estimating possible avalanche hazard from those avalanches for which former records are not available. For both the known and unknown avalanches the estimation of possible hazard which may result from extreme snow conditions is based on climatic conditions and local topography.

1.6 Possible damage from settling, creeping and gliding snow is not considered by the avalanche zone map.

2. Avalanche Zone Map (AZM)

2.1 The AZM is part of the local extension and alignment plan. It represents the extent of the avalanche terrain at a large scale.

2.2 As a rule, the AZM shows three different zones. These consider the intensity and frequency of the avalanche which are:

--the possible avalanche pressure on a wall exposed to the avalanche,

--the estimated return period of the avalanche

2.2.1 Red Zone (i.e. High Hazard)

The red zone shows terrain which is exposed to avalanches occurring frequently and powerfully; this means avalanches with:

--a pressure of 1 to 3 tons per square meter (t/m^2) and a return period of 30 years or less

--a pressure of more than 3 tons per square meter and a return period of 90 years or less.

2.2.2 Blue Zone (i.e. Potential Hazard)

The blue zone shows terrain affected only seldom or slightly by avalanches; this means avalanches with:

--a pressure of more than 3 tons per square meter and a return period of more than 90 years

--a pressure of 1 to 3 tons per square meter and a return period of more than 30 years

--a pressure of 0.1 to 1.0 tons per square meter

2.2.3 White Zone (i.e. No Hazard)

Terrain that is free of avalanche hazard. It might be affected by the air blast of dust avalanches, the pressure of which does not exceed 100 kilograms per square meter.

2.3 The topographic base map for the AZM should not be inferior to a scale of approximately 1:10,000.

2.4 The AZM is a base for planning structural avalanche control.

3. The Avalanche Zone Plan (AZP)

3.1 The AZP fixes the extent of the area which, with regard to avalanche hazards, can be used for building purposes or on which certain precautionary measures are necessary or on which buildings are not permitted at all.

3.2 The AZP is based on the AZM considering planning principles also. As a rule, it shows the three zones of the AZM. With regard to building regulations, the three different zones have the following definitions:

3.2.1 Red Zone: On red zones buildings are not permitted. This rule does not apply to buildings which can neither be damaged nor destroyed by avalanches and the use of which does not bring avalanche hazard on persons or animals. The risk of damage to real value should not exceed reasonable proportions. These are matters of insurance techniques.

3.2.2 Blue Zone: In the blue zone buildings are permitted provided that precautionary measures be taken. These might refer to:

--the kind of building
--its arrangement and its proportions
--its stability and strength.

Domestic buildings are also permitted insofar as they do not raise the risk by inducing heavy traffic or gatherings of people. This would be the case especially with schools, restaurants and so forth.

During periods of avalanche hazard, the local avalanche service takes preventive measures like closures and evacuations to prevent at least the loss of lives in case of avalanche occurrence.

3.2.3 White Zone: In the white zone no restrictive regulations regarding snow avalanches exist.

3.3 The limits of the different zones of the AZM and the AZP may differ. The differences are due to safety measures and reduction of complicated boundary lines to simpler lines. Small zones which are not endangered might be designated as hazardous because the access is not safe.

4. Administration and Enforcement of Law

4.1 Avalanche zoning is a duty of the community authority. The AZP comprises the whole territory of the community. Regions without any economical value might be exempted. In preparing avalanche zoning, preference is given to regions which are development areas.

4.2 The Cantonal Planning Office gives exact directions to those communities for which avalanche zoning is necessary. It decides on the priority schedule.

4.3 The Cantonal Forest Service is engaged to advise the community authorities on the technical task of compiling the AZM.

4.4 The forested area is exempt from the avalanche zoning because the Federal Law on Forestry Police does not permit any use of forest land for building purpose.

4.5 The avalanche zones are incorporated into the Federal Land Register. The avalanche hazard is shown for each particular parcel of real estate. An eventual obligation to evacuation is annotated. The location of every particular parcel relative to the hazard zones is clearly shown on a large scale land register map.

4.6 The land register can give the avalanche zone plan the necessary publicity and thus assure safety in property transactions.

4.7 The avalanche zone plan induces a legal restriction of the rights of the landowner. The AZP must be approved by the local government. The approval procedure is prescribed by Cantonal law.

4.8 Amendments of the AZP are subject to legal approval procedure.

APPENDIX C

APPENDIX C

Standard snow observations and avalanche reporting

REFERENCES

1. 1961 U.S.D.A., Forest Service
"Snow Avalanches", Agricultural Handbook No. 194
Washington, D. C. January 1961

NOTE: From the Wasatch National Forest, Utah the following notice: "Ron Perla has transferred to the RMFRES. His first task there will be a comprehensive revision of the U. S. Forest Service Handbook "Avalanche Control", U.S.D.A. Bulletin No. 194"

2. 1968 Swiss Federal Institute for Snow and Avalanche Research
"Instructions for Observers" (Avalanche Service)
Weissfluhjoch/Davos (Switzerland), August 1968

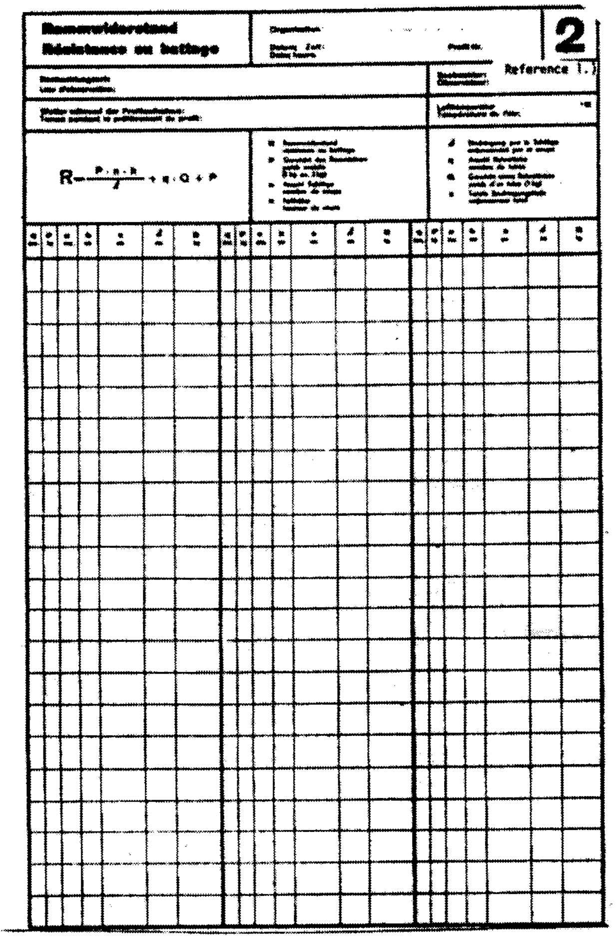
3. 1970 UNESCO, Iash, Wm.
"Seasonal Snow Cover", A Contribution to the International Hydrological Decade
Paris, Place de Fontenoy, 1970

4. 1970 NRC of Canada, A. Judson
"A Pilot Study of Weather, Snow and Avalanche Reporting for Western United States"
NRC Technical Memorandum No. 98, 1970

5. 1970 U.S.D.A., Forest Service
"Artillery Control of Avalanches Along Mountain Highways" by N. C. Gardner and A. Judson
Rocky Mountain Forest and Range Experiment Station
Fort Collins, Colorado, October, 1970

The following pages are excerpted from the above listed references:

Reference 1) 2, 3, 4, and 5
Reference 2) P. 27
Reference 3) P. 130, 131
Reference 4) P. 23

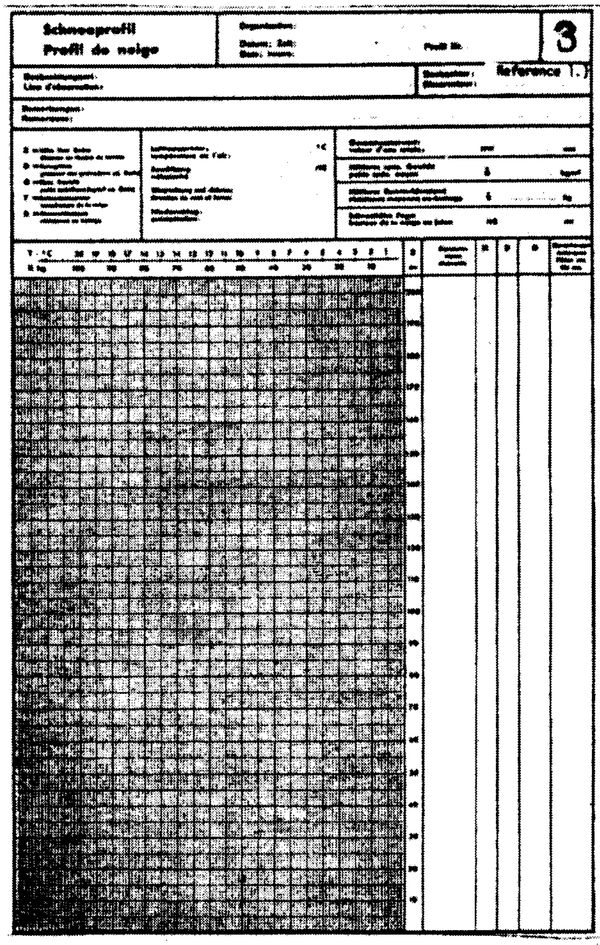


Rammwiderstand
Résistance au battage

2

Reference 1.)

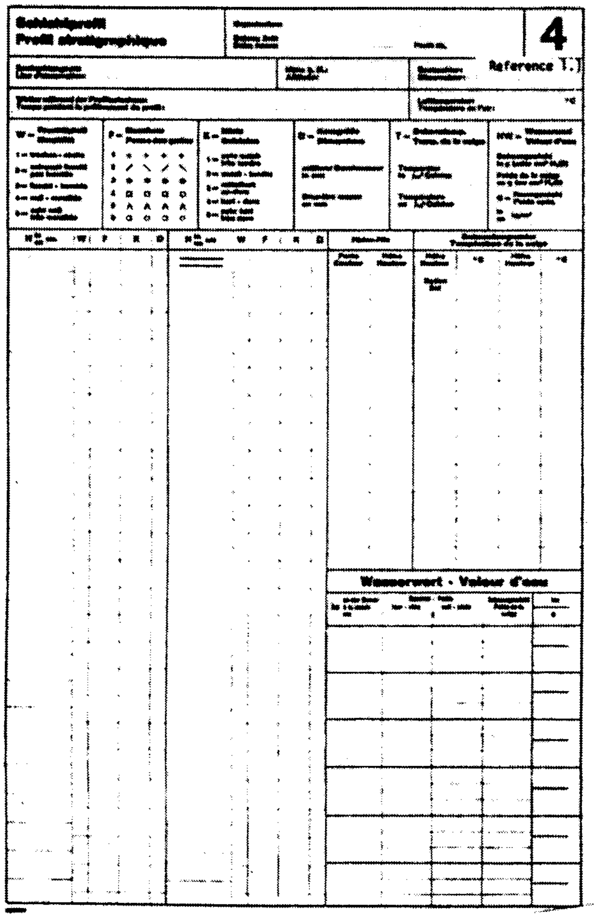
$R = \frac{P \cdot n \cdot h}{e} + q \cdot Q + P$



Schneeprofil
Profil de neige

3

Reference 1.)



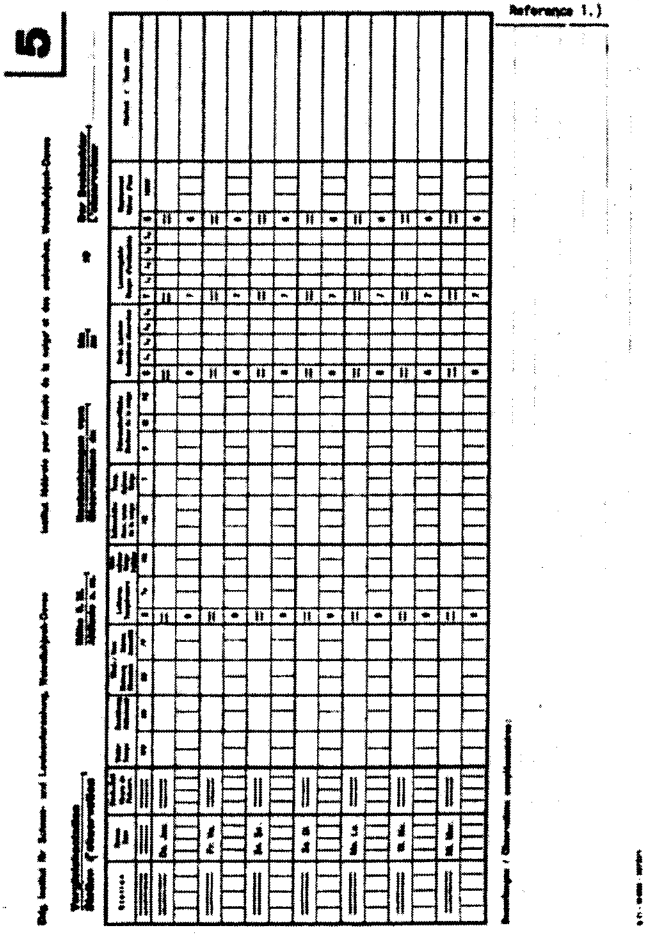
Schichtprofil
Profil stratigraphique

4

Reference 1.)

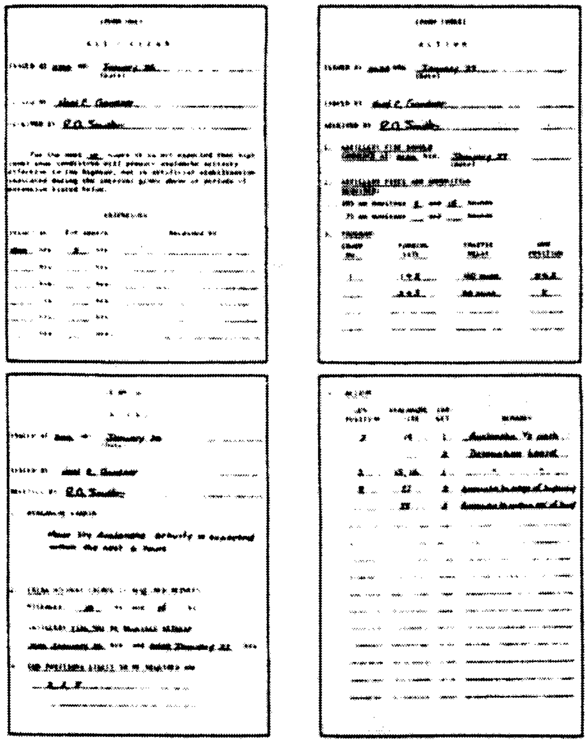
Wasserwert - Valeur d'eau

Reference 1.)

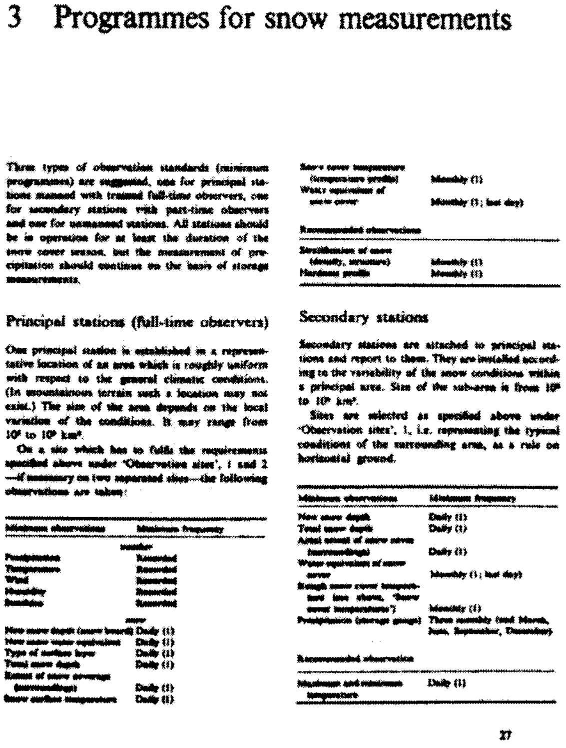


5

Reference 4.) p.23



Reference 2.) p. 27



3 Programmes for snow measurements

Three types of observation standards (minimum programmes) are suggested, one for principal stations manned with trained full-time observers, one for secondary stations with part-time observers and one for unmanned stations. All stations should be in operation for at least the duration of the snow cover season, but the measurement of precipitation should continue on the basis of storage measurements.

Principal stations (full-time observers)

One principal station is established in a representative location of an area which is roughly uniform with respect to the general climatic conditions. (In mountainous terrain such a location may not exist.) The size of the area depends on the local variation of the conditions. It may range from 10^3 to 10^4 km^2.

On a site which has to fulfil the requirements specified above under 'Observation sites', 1 and 2 —if necessary on two separated sites—the following observations are taken:

Minimum observations	Minimum frequency
weather	
Precipitation	Recorded
Temperature	Recorded
Wind	Recorded
Humidity	Recorded
Sunshine	Recorded
snow	
New snow depth (snow board)	Daily (1)
New snow water equivalent	Daily (1)
Type of surface layer	Daily (1)
Total snow depth	Daily (1)
Extent of snow coverage (surroundings)	Daily (1)
Snow surface temperature	Daily (1)
Snow cover temperature (temperature profile)	Monthly (1)
Water equivalent of snow cover	Monthly (1; last day)

Recommended observations	
Stratification of snow (density, structure)	Monthly (1)
Hardness profile	Monthly (1)

Secondary stations

Secondary stations are attached to principal stations and report to them. They are installed according to the variability of the snow conditions within a principal area. Size of the sub-area is from 10^2 to 10^3 km^2.

Sites are selected as specified above under 'Observation sites', 1, i.e. representing the typical conditions of the surrounding area, as a rule on horizontal ground.

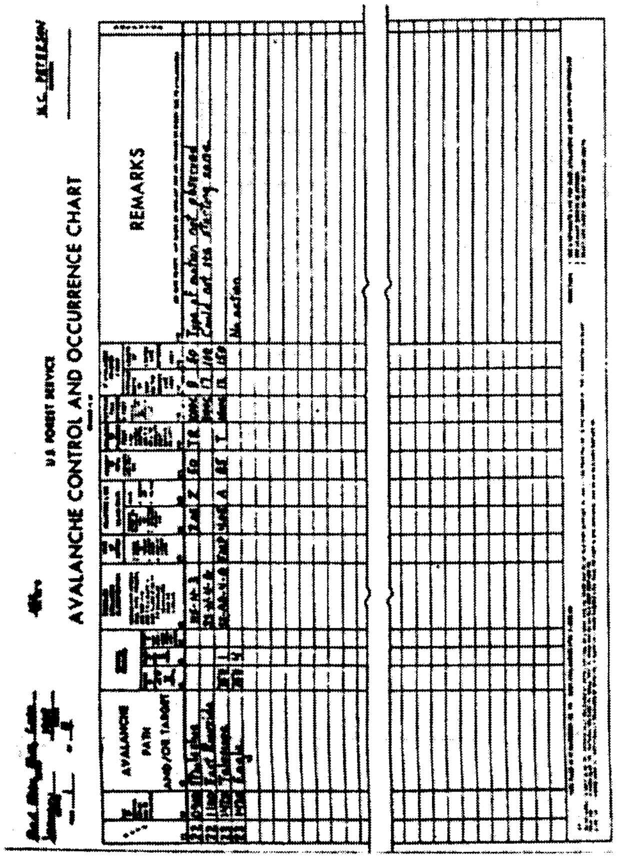
Minimum observations	Minimum frequency
New snow depth	Daily (1)
Total snow depth	Daily (1)
Actual extent of snow cover (surroundings)	Daily (1)
Water equivalent of snow cover	Monthly (1; last day)
Rough snow cover temperature (see above, 'Snow cover temperature')	Monthly (1)
Precipitation (storage gauge)	Three monthly (end March, June, September, December)

Recommended observation	
Maximum and minimum temperature	Daily (1)

27

-131-

Reference 3.) p. 131



AVALANCHE CONTROL AND OCCURRENCE CHART

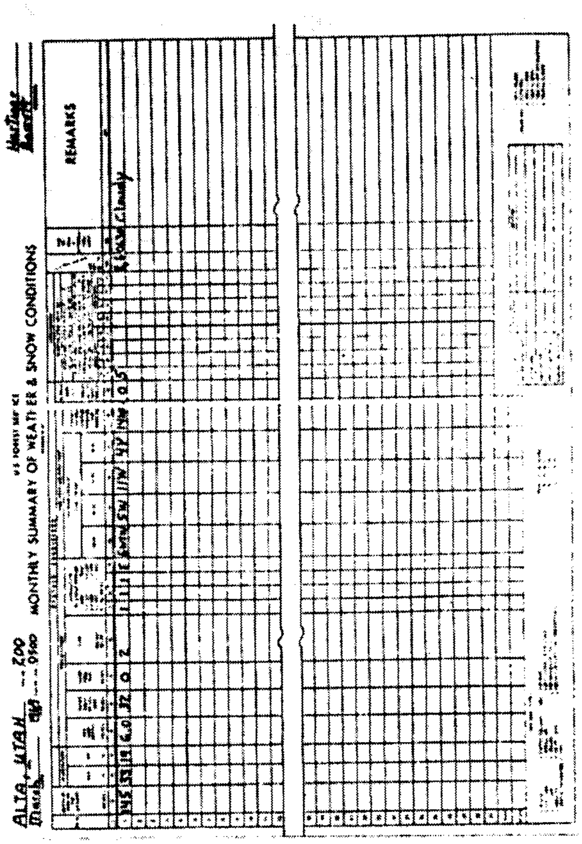
US FOREST SERVICE

REMARKS

FIGURE 3 AVALANCHE CONTROL AND OCCURRENCE CHART

Reference 3.) p. 130

-130-



MONTHLY SUMMARY OF WEATHER & SNOW CONDITIONS

U S FOREST SERVICE

ALTA, UTAH

REMARKS

FIGURE 2 THE WEATHER FORM USED AT NETWORK STATIONS IN 1969. ACTUAL SIZE IS 28 BY 36 CM

APPENDIX IV

STRUCTURAL DESIGN REVIEW OF SEISMIC HAZARD INVESTIGATION

R. EVAN KENNEDY, STRUCTURAL ENGINEER
921 S. W. Washington Street
Portland, Oregon 97205

August 15, 1972

Daniel, Mann, Johnson, & Mendenhall
921 S. W. Washington Street
Portland, Oregon 97205

Subject: Juneau Geophysical Hazards Study

Gentlemen:

The report submitted to you by Alaska Geological Consultants of Anchorage has been reviewed. As a result, I have the following three comments for your consideration:

1. The reasons given for suggesting the Zone 2 Uniform Building Code seismic probability rating to be changed to Zone 3 are in my opinion valid. This zone change from 2 to 3 on the part of the Uniform Building Code in recent years was I believe ill advised and a move taken upon review of much less seismic data than is represented by this report. I therefore concur with the recommendation of changing this zone from 2 to 3.

2. The present building code does not refer to the problem every structural engineer has to face, of analyzing the way his building is going to work with the foundation upon which it is resting. This is true in respect to both vertical as well as horizontal loading and is because the relationship between structure and soil is an extremely complex one which takes understanding on the part of each specialist to perceive the problems of the other specialist, and to cooperatively arrive at what they think is the best solution. This complex relationship has never been able to be satisfactorily phrased in a building code to the satisfaction of many who have tried it and even many more who have reviewed those attempts. It is however true that the structural considerations made in the design of any building should in fact take into consideration the foundation upon which that building is resting. It is therefore my suggestion that a paragraph should be inserted in the Uniform Building Code as adopted by the Borough of Juneau, which would be in effect Section 2314-M, as follows:

   (m) Foundation compatibility. Each building or structure shall be designed so that the loads it imposes upon the supporting geological structure do not impose pressures upon the geologic structure greater than allowable pressures recommended by a competent soils engineer. Both horizontal and vertical seismic and gravity loadings shall be taken into consideration.

3. It is recommended that in the case of frame construction as usually utilized in dwellings, at least four walls, only two of which can be roughly parallel, should be sheathed with either plywood or with sheathing that is arranged diagonally to form a bracing pattern against seismic loading, or with particleboard specially constructed for use as a diaphragm. If ordinary sheathing is used and placed in a horizontal direction as is common, the building will be subject to racking by earthquake action. It is therefore important that this diagonal sheathing be placed at an angle of approximately 45° with the horizontal, or that a material similar to plywood or particleboard be used, and that it be of exterior quality if exposed to the weather.

Very truly yours,

R. Evan Kennedy

REK:so

APPENDIX V

1967 REPORT ON THE BEHRENDS AVENUE AVALANCHE PATH

REPORT OF THE PRELIMINARY EVALUATION OF THE BEHRENDS AVENUE AVALANCHE PATH

Conducted for
The City of Juneau, Alaska

Prepared by: Keith Hart
Avalanche Specialist

January, 1967

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Maps

P.O. Box 152
Douglas, Alaska

January 27, 1967

The Honorable Lauris Parker, Mayor,
and The Council of the City of Juneau
Juneau, Alaska 99801

Gentlemen:

Submitted herewith is one copy of a confidential study entitled a Report of the Preliminary Evaluation of the Behrends Avenue Avalanche Path. The study was requested by Mayor Parker thru Mr. George Davidson, then Public Works Director, in December 1965, with the very limited field program commencing February 14, 1966.

Due to an unusually heavy workload at my office and combined with some very uncooperative weather, it was impossible to collect snowcover data in the avalanche breakaway zone at two-week intervals as planned. The Field data collected, however, will be of value to any future investigators.

The excellent cooperation and assistance of the Department of Public Works is gratefully acknowledged.

Sincerely yours,

Keith Hart

Keith Hart
Avalanche Specialist

Introduction

At a few minutes past five a.m. on Tuesday, March 22, 1962, a fast-moving, largely airborne dry-snow avalanche slammed into the western part of Juneau's Highland district inflicting varying amounts of damage upon two dozen or more homes. Luckily, because of the hour, only one person was injured. Within a few weeks nearly all signs of the damage were gone: new roofs had been placed on some houses, a number of homes sported patched roofs and siding, a few had new chimneys, and new power and telephone poles replaced those snapped off by the avalanche.

Residents of the affected area had two things to be thankful for: one, and most basic, that they were not killed or seriously injured; and two, that the insurance adjustors chose not to call the avalanche an avalanche. By an exemplary rationalization, the insurance adjustors--under considerable pressure, of course--determined that the damage was caused by "the wind" and not the avalanche. As a consequence, nearly all repairs were covered by the homeowners' insurance.

This report will show that the 1962 avalanche was not a freak natural disaster which most likely will never again occur, but that future avalanches should be expected and, most important, to recommend means of eliminating or reducing the hazard to life and property in the affected area.

Snow Avalanches - A Nontechnical Discussion

A normal snowcover consists of a number of distinct strata, each representing one snowfall or snowdrifting period. In the Juneau area, many of the snow strata are separated by ice lenses which are the result of rain, sleet or thaw between snowfalls. As in a chain, the weakest link (i.e., snow stratum) determines the breaking point of the snowcover. If the weakest stratum happens to be at or near ground level, any resulting avalanche may involve the entire snowpack; whereas a weak stratum near the surface will, most likely, involve only that stratum and those above it. It is obvious that if the weak stratum is at or near the ground the degree of hazard is considerably greater than if it is at or near the surface.

On steep slopes much of the newly deposited snow slides during or shortly after falling, thereby reducing the opportunity for avalanches of major proportions. In an ordinary winter--1965-66 was such--there will not be any particularly large avalanches occurring because of these frequent small slides.[1] This is not to say, however, that there is no danger from these so-called direct-action, surface avalanches. Within this northern temperate, maritime province heavy snowfalls are not uncommon and snowfalls greater than 24 inches occur rather frequently at elevations above 2,000 feet. A 24 inch snowfall in the accumulation zone above Behrends Avenue adds about one-quarter million cubic yards of snow. A not insignificant quantity.

Avalanches are classified by a number of different criteria (Table 1). Most of the larger avalanches in the study area are of the slab type; the

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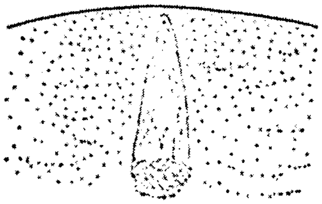
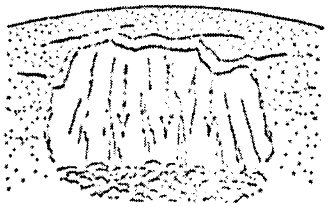
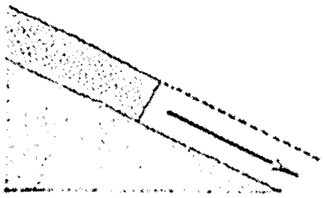
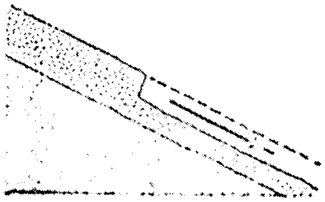
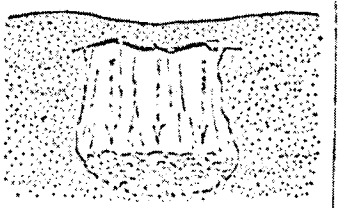
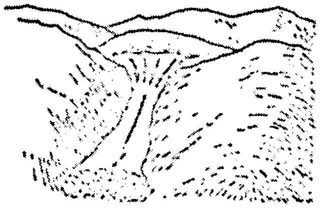
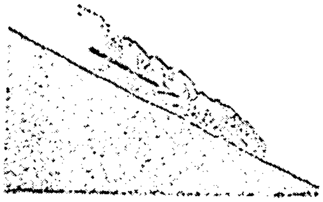
[1] Another factor favoring stability was that there were no weak layers deep in the snowcover during winter 1965-66.

TABLE 1

AVALANCHE CLASSIFICATION SYSTEM

Avalanche Definition: Dislocation of the snow cover over distance greater than 50 metres.

	CRITERION	ALTERNATIVE CHARACTERISTICS AND NOMENCLATURE	
1	TYPE OF BREAKAWAY	From Single Point  LOOSE-SNOW AVALANCHE	From Large Area Leaving Wall  SLAB AVALANCHE
2	POSITION OF SLIDING SURFACE	Whole Snow Cover Involved  FULL DEPTH AVALANCHE	Some Top Strata only Involved  SURFACE AVALANCHE
3	HUMIDITY OF THE SNOW	Dry DRY-SNOW AVALANCHE	Wet WET-SNOW AVALANCHE
4	FORM OF THE TRACK IN CROSS SECTION	Open Slope  UNCONFINED AVALANCHE	In a Gully  CHANNELLED AVALANCHE
5	FORM OF MOVEMENT	Through the Air  AIRBORNE-POWDER AVALANCHE	Along the Ground  FLOWING AVALANCHE

After the system proposed by Prof. R. Haefeli and Dr. M. de Quervain of the Swiss Federal Snow and Avalanche Research Institute in 1955.

March 22, 1962 avalanche was one. The loose-snow type is most common in the spring after rain, warm wind and sun have largely destroyed the cohesive properties of the individual snow crystals through destructive metamorphism. Most avalanches are combinations of the characteristics shown on Table 1 .

The March 22, 1962 avalanche moved down its well-defined path as an airborne-powder avalanche, the form which some regard as the most devastating of all avalanches. Observers in Switzerland have measured the velocity of this type at about 200 miles per hour. It is believed that internal cross-gusts within the slide may move twice as fast as the slide itself. A pressure wave of snow-free air precedes the airborne-powder avalanche. It was this pressure wave or wind-blast that, undoubtedly, did much of the damage in 1962. An avalanche of this type during the same winter but in Switzerland, levelled between 240 and 250 acres of forest and buried one and one-half miles of roadway.

Wet-snow avalances may occur during or following wet-heavy snowfalls, rainstorms or periods of above freezing weather. These avalanches travel at relatively slow speeds; unless of course, they fall free over cliffs. Because wet-snow avalanches move on the ground, they follow natural channels such as stream gullys. Most of the wet-snow slides falling from above the Behrends Avenue area travel down the prominent west to east trending gully (apparent in some of the photographs included in this report).

Avalanches are caused by those factors which reduce the shear strength or increase the shear stress of the snow. Shear strength is reduced by destructive metamorphism of the individual snow crystals through moisture migration toward the crystal nucleus, i.e., the interlocking spikes and branches of the newly

Fallen snow crystals largely disappear. Temperature rise, especially when the snow temperature is near the freezing point, is effective in weakening shear strength. Rain, a warming agent, is an effective destroyer of crystal bonding and in addition, acts as a lubricant. Constructive metamorphism, the formation of cup crystals by moisture migration to the crystal edge, can lead to the formation of deep avalanches since these fragile new crystals commonly occur near ground level. Gradual overloading by snowfall, snowdrifting, or rain is the most common means of increasing shear stress in a snowcover.

In addition to these gradual causative influences, avalanches may be released by external forces or "triggers" such as falling cornices, snowfalls, rocks, animals or humans. In the subject slide area it seems likely that most avalanches are caused by the gradual influences discussed in the preceding paragraph.

For a more thorough discussion of avalanche causes and forms, the reader is referred to the Bibliography and especially to Colin Fraser's, The Avalanche Enigma, Rand McNally & Company, 1966.

Avalanche Defenses

Today there are a variety of defense measures being used to protect life and property from avalanches. These range from simple ordinances to extremely costly snow retention structures. There are two broad concepts of avalanche control: one, the passive, presupposes that avalanches will fall and is, therefore, concerned only with limiting the amount of damage or injury; the other, active control is concerned with the prevention of avalanches.

Land Classification and Zoning - Prior to any construction, known or suspected avalanche areas are investigated by a qualified avalanche specialist. If the land is classified unsafe, it is then zoned by the responsible government to prevent its use for residential and commercial purposes. In certain cases, the hazard may be such that avalanche resistant construction could be used. Governmental regulation of tree cutting in potential avalanche areas is another means of reducing the chances for future avalanches.

Forecasting and Evacuation - In the Alps a number of villages having inadequate structural defenses, rely upon evacuation plans which are based upon hazard forecasting. For example, when a certain depth of new snow falls and when certain other conditions are met, the avalanche forecaster will recommend that persons and livestock within the area move to places of safety. Evacuation is mandatory only in a few villages.

There are at least two serious defects in the evacuation scheme: first, it is always possible that a slide will occur without the benefit of being forecast; and secondly, if the forecaster predicts slides that do not happen—crys "wolf", so to speak--the actual slide will, most likely, catch a number of doubting Thomases. This is not idle conjecture, there are quite a few tragic examples.

Forecasting in the Juneau area is unusually inexact due to the greatly differing conditions between sea level, where the forecaster is, and the avalanche formation or breakaway zone some 2,000 to 3,000 feet above. Here, anyone claiming forecasting reliability above 50 percent is either clairvoyant or given to exaggeration.

Passive Structural Defenses - Included in this category are structures which deflect and arrest avalanches as well as buildings specially built to withstand avalanches.

The road or railroad snowshed is probably the best known example of a deflecting or diverting structure. For obvious reasons it is unsuitable as a defense for residential areas, although the principle is used in the design of some buildings. The deflectors commonly used to protect structures are walls and splitters. The walls or dikes are constructed of earth, sometimes being faced with concrete or stone. The principle of the wall or dike is to channel the moving snow away from the object or objects being defended; this works best when the wall is a continuation of a natural channel. One problem inherent with these defenses is that they will become ineffective once earlier slides have filled the channel. Splitters are designed to cleave or split the descending avalanche around the defended object. Splitters vary from simple earthen mounds to elaborate wedges shaped much as the prow of a ship.

Arresting defenses perform best when located on transitional grades where slide velocity is being reduced naturally. Arresters include dams, terraces and breakers. Dams are generally built across channelized slide paths, the idea being to catch as much of the slide as possible. Few dams can be built large enough to contain one season's avalanches. Wide terraces are sometimes useful in checking or containing slides, but, generally, have little effect against large, fast moving avalanches. The most effective of the arresting structures are the so-called avalanche breakers, consisting of two, three or more rows of 15 to 20-foot high earthen mounds. The mounds are so spaced that an avalanche striking them is broken or divided into a number of small currents which are then directed against each other.

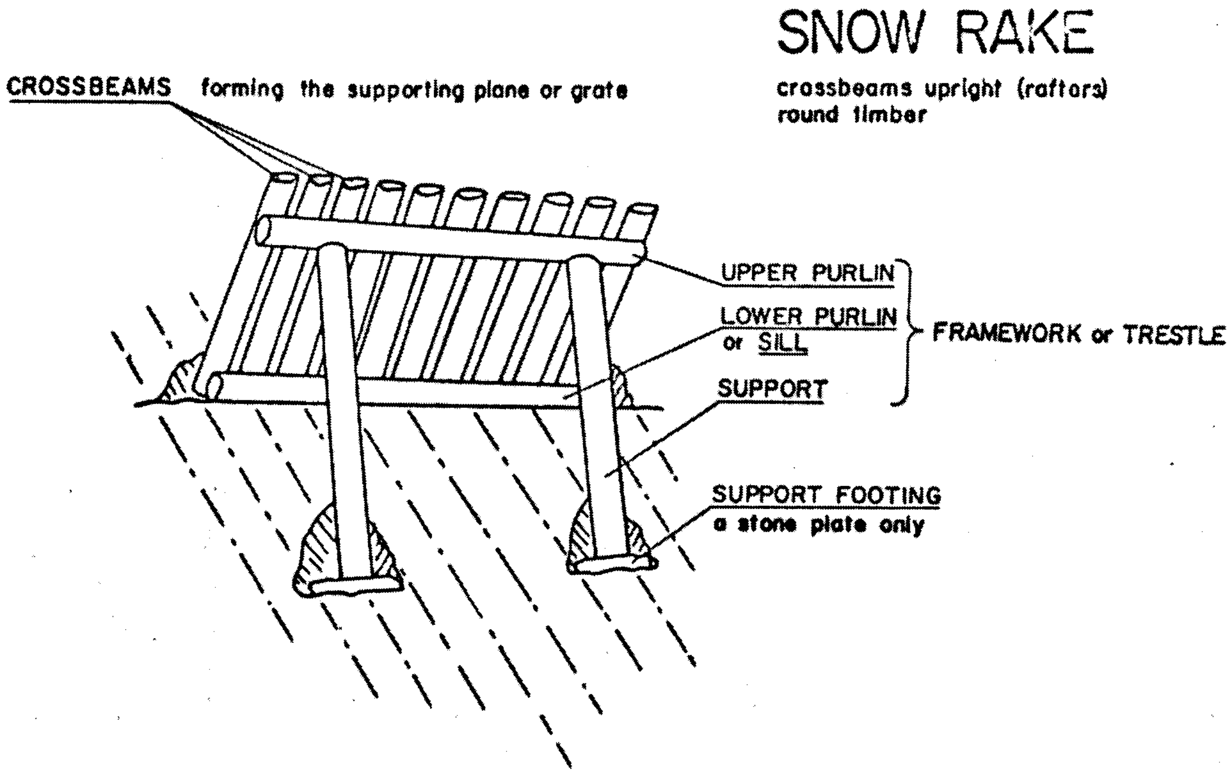
Buildings in slide areas (e.g., mines, power and communication stations, etc.) are often constructed to withstand avalanches. Measures used include the shed roof, reinforced concrete or masonry upslope walls and no openings in upslope walls. In addition, there may be a splitting mound or diversion dike above the building.

All of the passive defense structures discussed, except for the snowshed, are subject to avalanching which may exceed their capabilities. Early season slides can fill channels, cover dams, walls and dikes or load breaker systems and thus pave the way for later slides to travel unimpeded. None of these structures, snowsheds excepted, offer adequate protection against high-velocity, airborne-powder avalanches.

Active Structural Defenses - Snow retention in the breakaway zone is accomplished by means of fence-like structures, nets and reafforestation. Wind baffles are used to prevent the formation of stress-susceptible snowslab, while snowdrift fences reduce deposition in the breakaway zone.

Evolution of snow retention structures has followed this pattern: 1) earth terraces; 2) earth terraces and dry masonry walls; 3) wooden fences; and presently 4) lightweight metal barriers and steel or nylon nets. Because of the continually rising cost of manual labor, metal barriers and nets are now favored. (see Tables 2 & 3)

TABLE 2


SNOW RAKE
crossbeams upright (rafters)
round timber
CROSSBEAMS forming the supporting plane or grate
UPPER PURLIN
LOWER PURLIN
or SILL
SUPPORT
FRAMEWORK or TRESTLE
SUPPORT FOOTING
a stone plate only

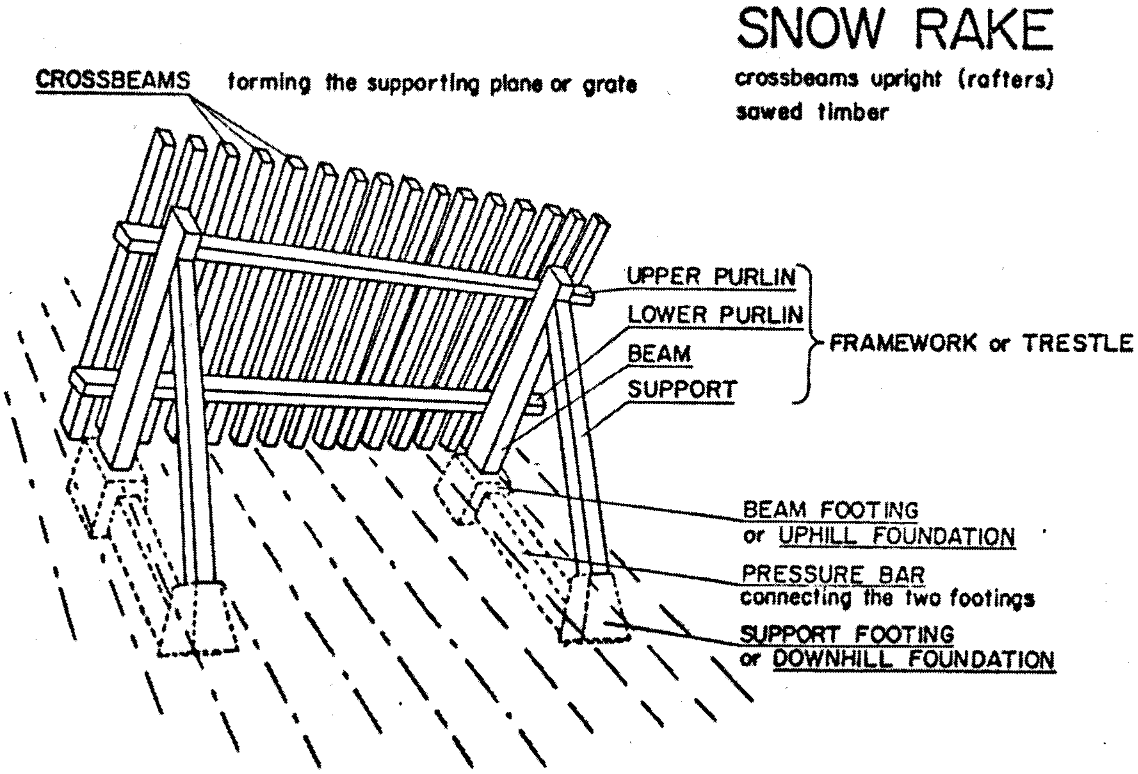
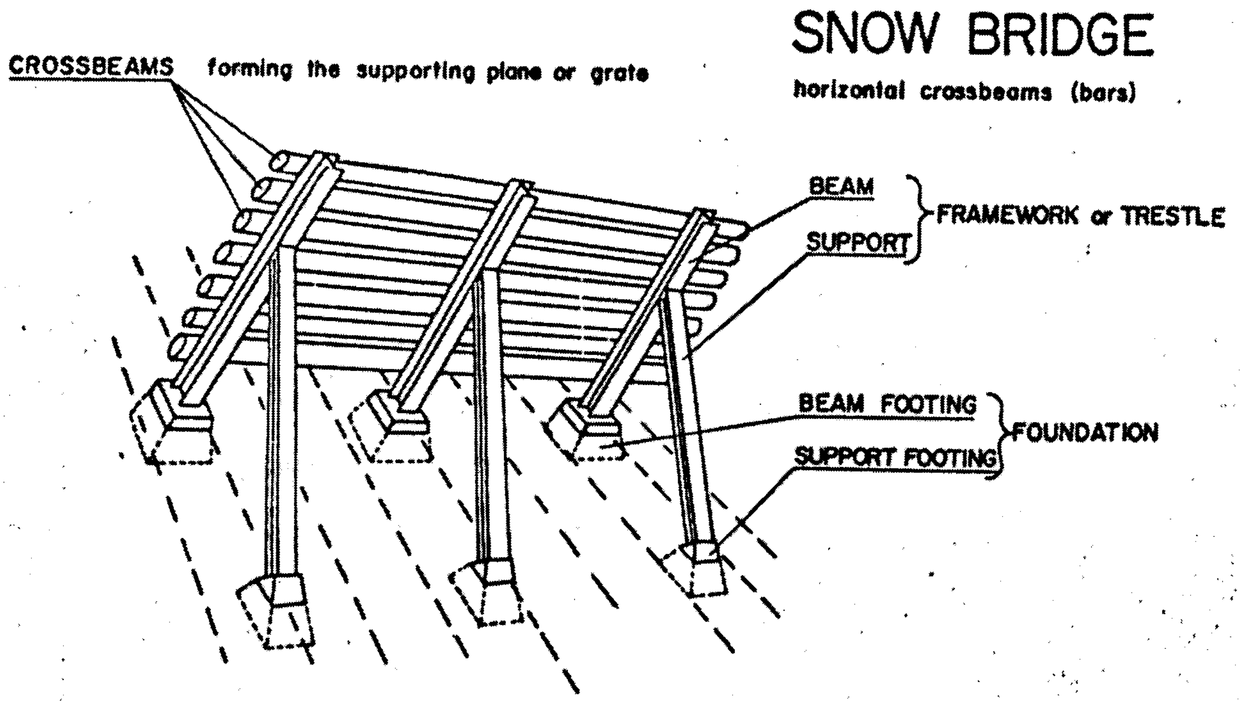
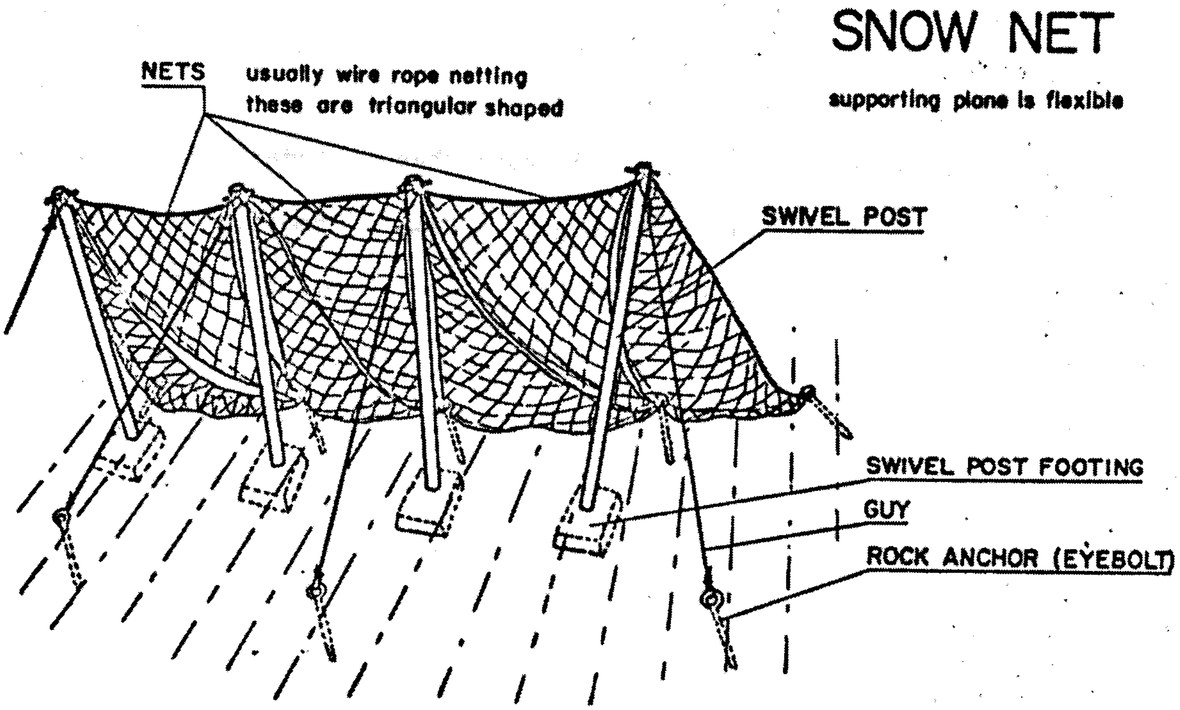

SNOW RAKE
crossbeams upright (rafters)
sawed timber
CROSSBEAMS forming the supporting plane or grate
UPPER PURLIN
LOWER PURLIN
BEAM
SUPPORT
FRAMEWORK or TRESTLE
BEAM FOOTING
or UPHILL FOUNDATION
PRESSURE BAR
connecting the two footings
SUPPORT FOOTING
or DOWNHILL FOUNDATION

TABLE 3


SNOW BRIDGE
horizontal crossbeams (bars)
CROSSBEAMS forming the supporting plane or grate
BEAM
SUPPORT
FRAMEWORK or TRESTLE
BEAM FOOTING
SUPPORT FOOTING
FOUNDATION


SNOW NET
supporting plane is flexible
NETS usually wire rope netting
these are triangular shaped
SWIVEL POST
SWIVEL POST FOOTING
GUY
ROCK ANCHOR (EYEBOLT)

The purpose of barriers and nets is to prevent the formation of potentially destructive avalanches by interrupting and holding the snowcover. These barriers, called bridges if the crossbeams are horizontal or rakes if the crossbeams are upright, and nets are very costly. The installed, per meter costs in Switzerland are: aluminum bridge - $255; and steel cable net - $135. In certain slide paths many hundred meters of structure may be required to provide the necessary control. Very rough estimates of the cost of these defenses installed in the subject area are from 3-5 million dollars. A thorough study of snowcover, and soil conditions is necessary before these defenses can be designed and installed. Wherever possible reafforestation is accomplished shortly after the barriers have been installed, since a dense forest is regarded as the most permanent defense possible.

Other measures for limiting the build-up of avalanches include: 1) the use of wind baffles to disrupt the snowcover-- prevent slab formation; 2) drift fences to prevent overloading and slab formation; 3) chemical inhibition of depth hoar (cup crystal) formation*; 4) mechanical compaction of the snow by skiers, walkers or machines; and 5) the premature release of avalanches by skiers or explosives. Only items 1) and 2) appear to merit serious consideration as possible defense measures for the subject slide area.

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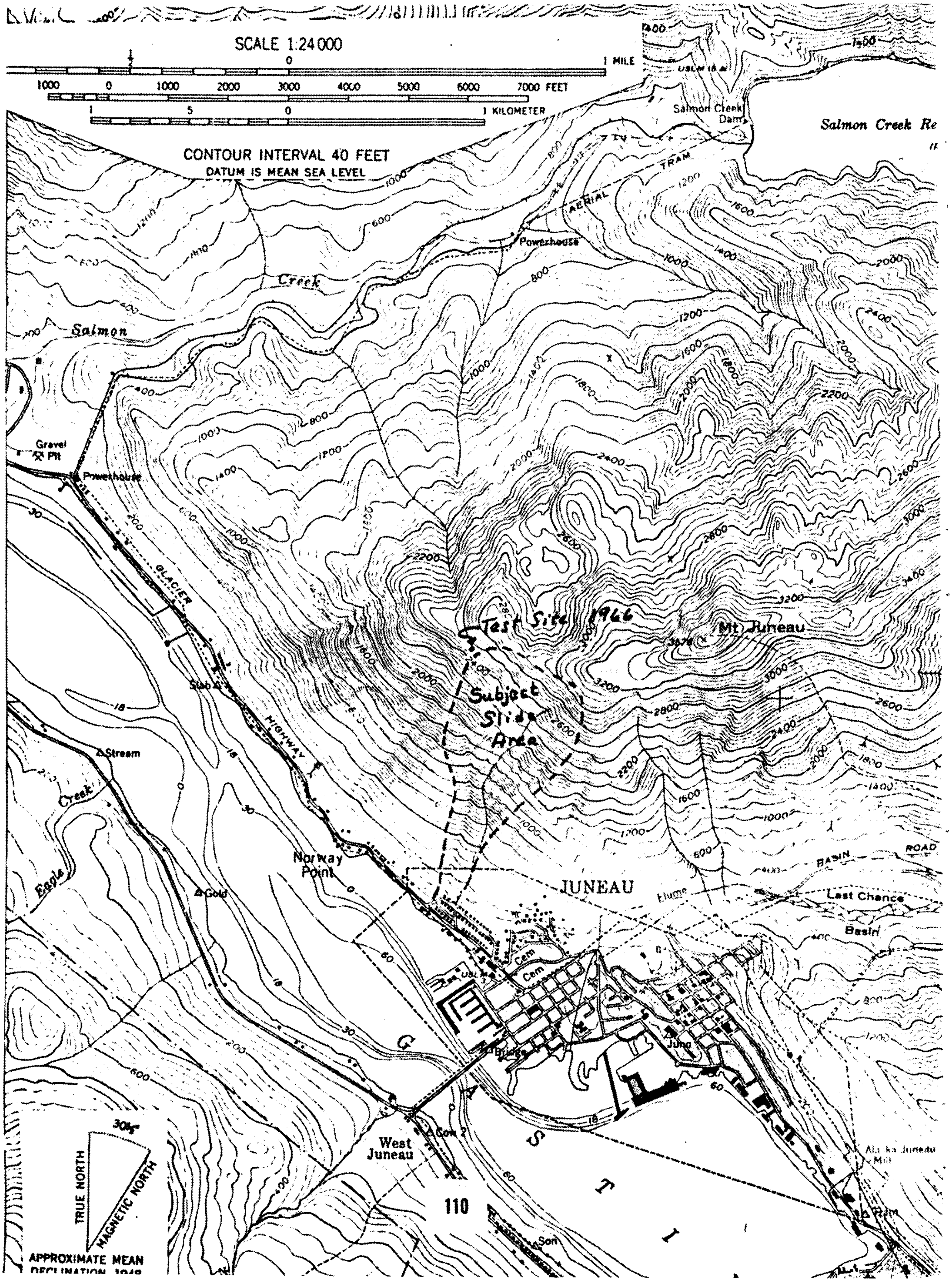
* Still in the experimental stage.

The Behrends Avenue Avalanche Path

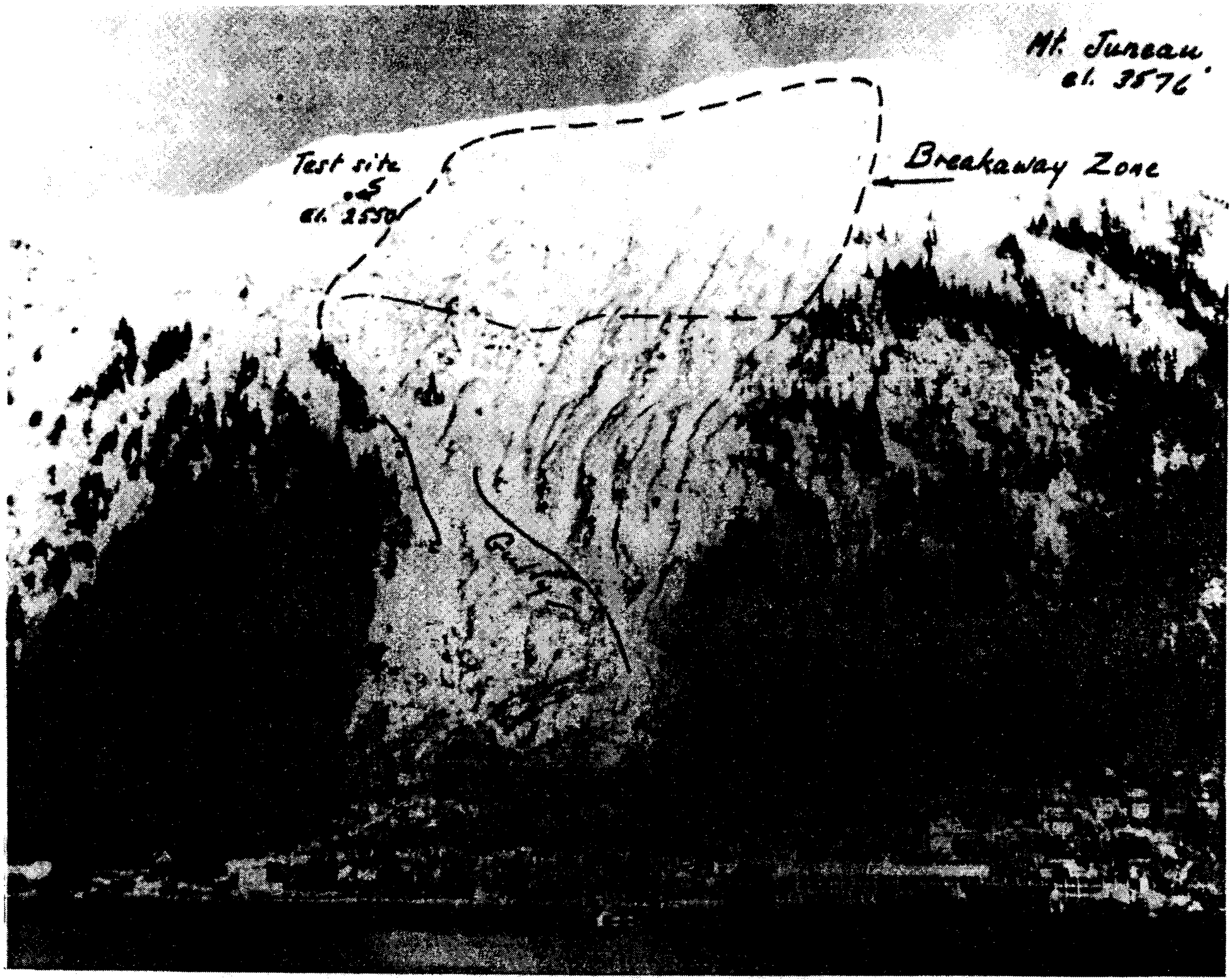
Certainly one of the strongest impressions received by the first-time visitor to Juneau is that of dynamic nature -- rushing streams, rugged glaciers, dense forests and mountains plunging abruptly to the water. Shortly following this overview, he begins to notice the violently irregular forest pattern on the mountain slopes. If he happens to be an avalanche specialist, he knows that it is an area subject to frequent, very large snowslides. (see photos, particularly 1961 oblique aerial)

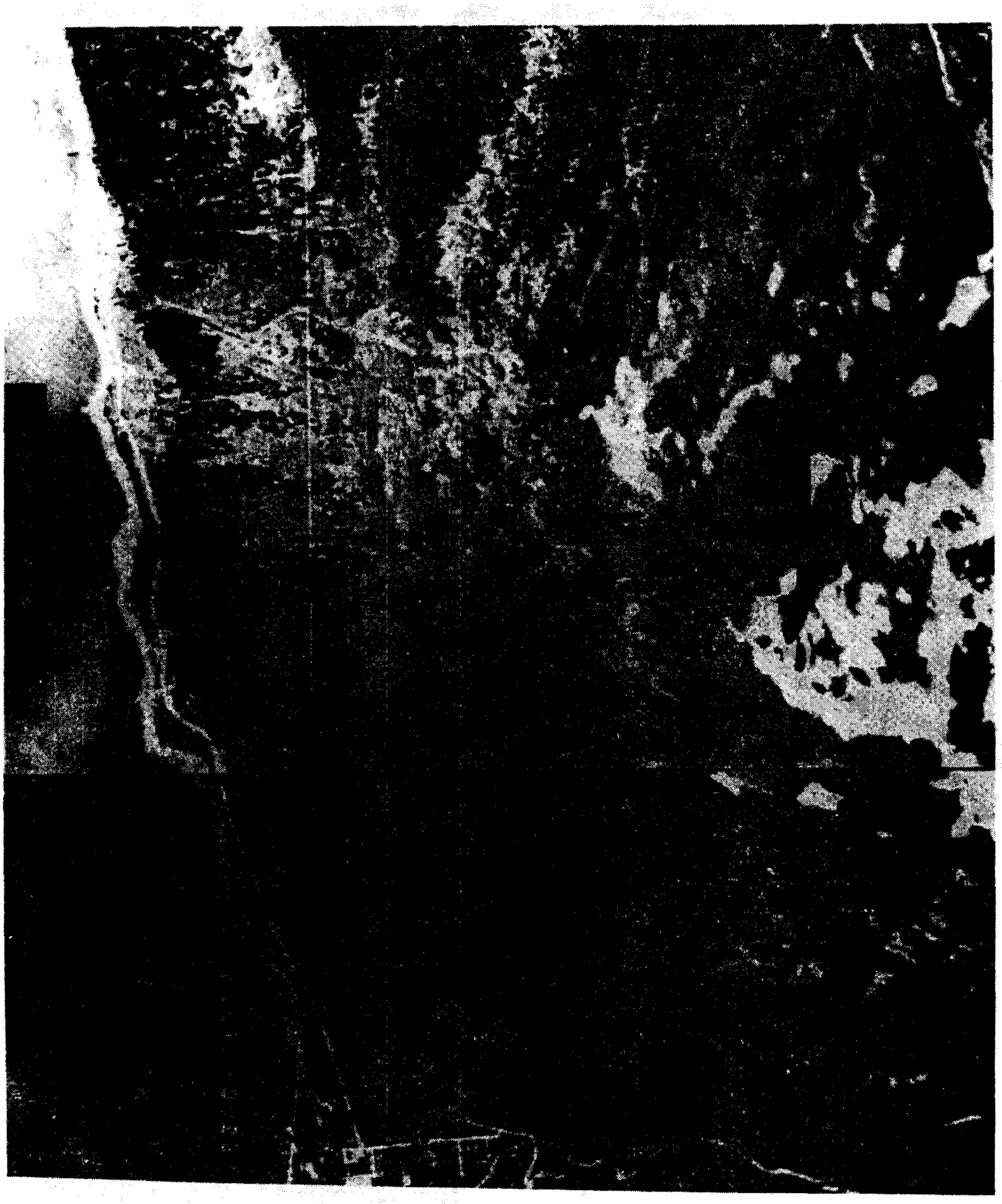
An avalanche track in a forest can reveal a number of important clues. First, the limits, both lateral and terminal are indicated -- this is no assurance, however, that later slides will not enlarge the clearing. Second, if the trees are broken off some distance above the ground, an airborne-powder avalanche was the likely villain. Third, if the broken trees are sizable, it was probably a fairly long-cycle avalanche. And last, if alder, grass and berries are the primary vegetation in the slide swath, it is reasonably certain that avalanches occur frequently even though they do not often reach the timber.

The Behrends Avenue Avalanche path exhibits all of these characteristics. (see photos of 1962 slide damage). In addition, a number of the scientists who have been associated with the continuing Juneau Icefield Research Project have identified the Behrends Avenue area as a major avalanche path. One of these, Mr. Edward LaChapelle, now avalanche Hazard Forecaster for the U.S. Forest Service and regarded as the leading U.S. avalanche authority remarked in a recent letter to the writer: "..that this was a possible avalanche danger zone was known all along by a number of people in Juneau. I, among others, pointed this out to Forest Service officials more than ten years ago, but some of the local residents were already aware of the fact, even then." The writer

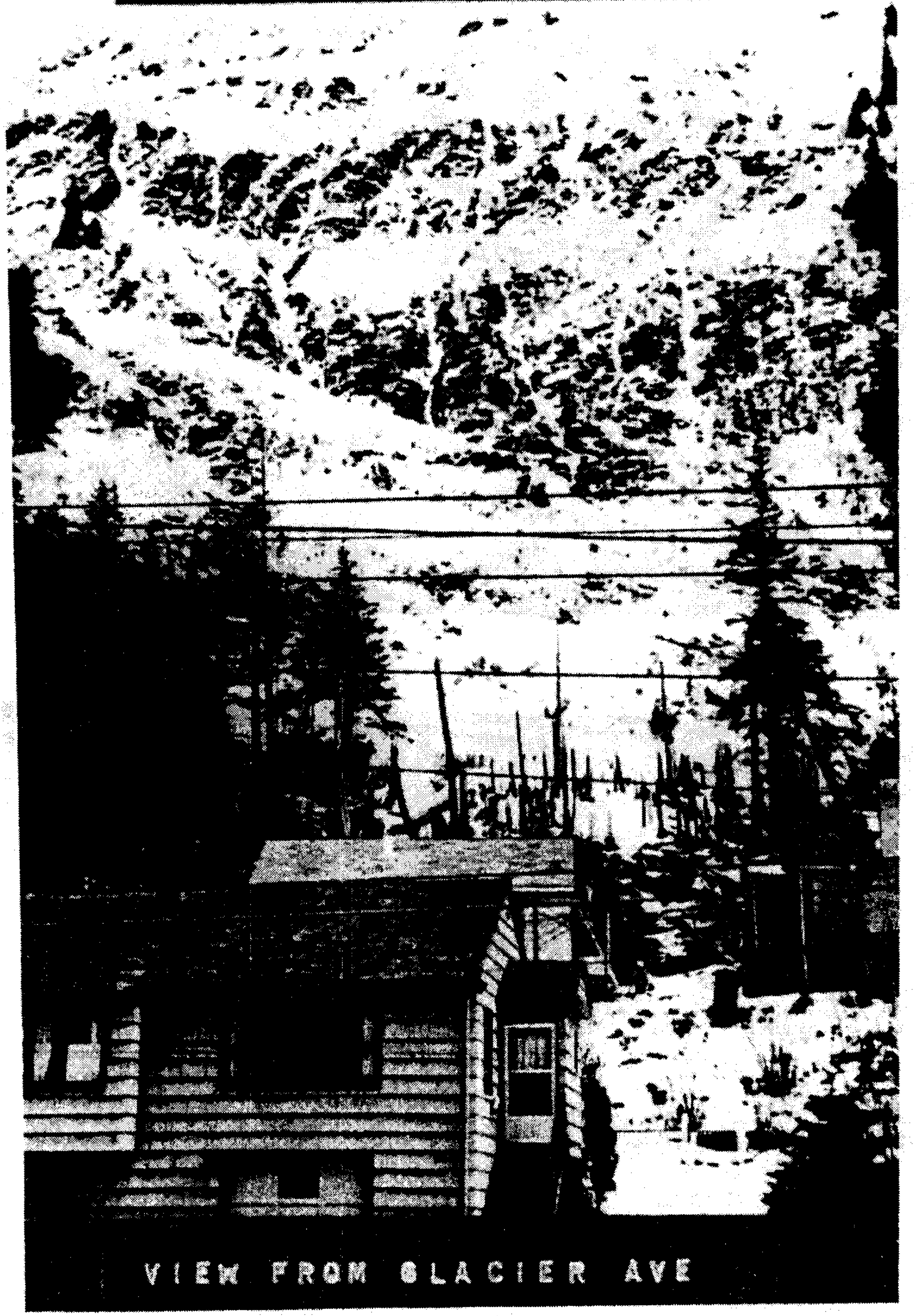

SCALE 1:24 000
1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 KILOMETER
CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL
Salmon Creek Dam
Salmon Creek Re
AERIAL TRAM
Powerhouse
Creek
Salmon
Gravel Pit
Powerhouse
GLACIER
HIGHWAY
Slab
Stream
Creek
Eagle
Gold
Norway Point
Test Site 1946
Subject Slide Area
Mt Juneau
3576
JUNEAU
Flume
BASIN ROAD
Last Chance
Basin
Cem
Bridge
Juno
G
A
S
T
I
West Juneau
Cow
Alaska Juneau Mill
Son
TRUE NORTH
MAGNETIC NORTH
30½°
APPROXIMATE MEAN DECLINATION 1948


5-2-66
1966 PHOTO

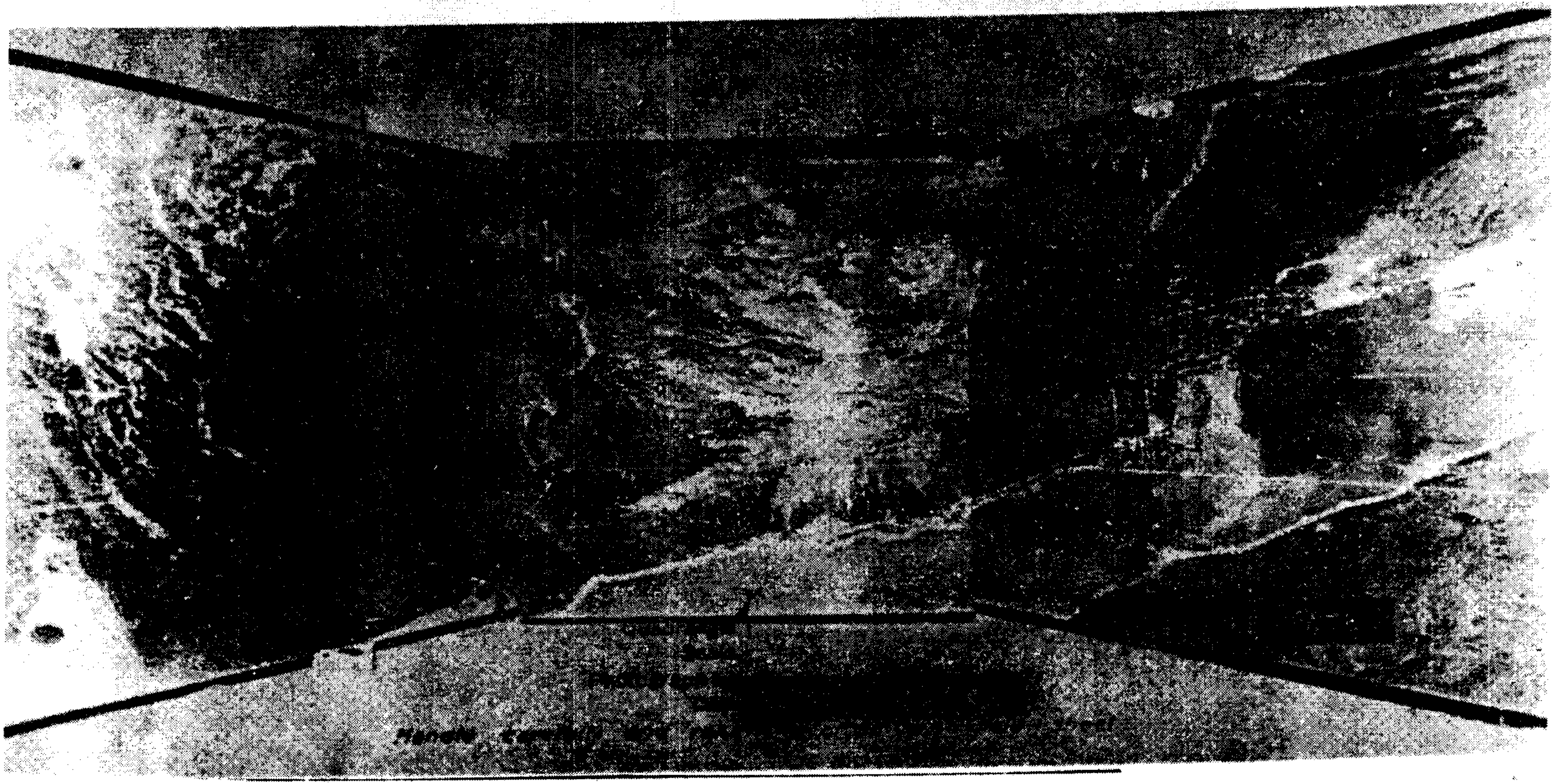

Mt. Juneau
el. 3576'
Breakaway Zone
Test site
#5
el. 2550'
Gully



SHORTLY AFTER 1962 AVALANCHE



[illegible] AVALANCHE



has also been advised that the avalanche potential of the area was discussed when the area--with houses already built--was being annexed by the City of Juneau.

By means of interviews a rough history of the subject slide path has been developed back to the year 1890. In reading this brief chronology, the reader should bear in mind that prior to about 1946 the only structure in the slide path above Glacier Highway (now Avenue) was the so-called "pest house" a long abandoned, World War I vintage, smallpox isolation building. This is on important consideration because there could have been, and likely were, avalanches which did not reach the highway and therefore were unobserved. A brief history of the observed avalanches follows.

<u>1890</u> - This was an extremely large avalanche which terminated in Gastineau Channel, where the Aurora Basin small boat harbor is now located. The late Mr. Gene Nelson, manager of the A-J Corporation's Juneau facilities, possessed a photograph of the avalanche. Information from Mr. W.S. Twenhofel, Geologist, U.S. Geological Survey, Denver, Colorado.

<u>1917</u> - This was a very large avalanche which crossed the road (then little more than a trail) and ended just short of the shoreline. A great number of trees were destroyed; the broken trees prevented the early reopening of the road which was used by a dairyman. The slide probably fell in March or April; it was believed to have been an airborne-powder type. Information from Captain L.H. Bayer, then a school child living at Norway Point. Also recalled by Mr. George Skuse.

<u>1926</u> - This was a large avalanche that flowed around the old "pest house." From descriptions given, it is believed that it was a wet snow avalanche, a type which moves on the ground. It probably occurred in late March or April.

Information supplied by Mr. Joseph McLean and Mr. Robert Killewich. Mr. Killewich recalled that one part of it reached tidewater. From the type of slide, it can be inferred that the part reaching tidewater probably traveled down the stream gulley which now intercepts Ross Way.

1935 - There is not much information available regarding this avalanche which was reported by Mr. George Danner. It did, however, cross the highway.

1946 - This was the last sizable avalanche reported in the Behrends Avenue area prior to the one in 1962. Mr. R.E. (Randy) Randall observed that this avalanche terminated in the trees above the old shop building at 1735 Glacier Avenue. The slide reached at least as far downslope as Behrends Avenue. It probably was a wet snow type with motion confined to the ground and of such low velocity that it flowed around the trees without breaking them.

1962 - This avalanche is well documented. According to Mr. R.E. (Randy) Randall who was possibly the only eye-witness, the airborne-powder avalanche travelled completely across Gastineau Channel terminating near the Treadwell Ditch at elevation 750 feet. As some of the photos show, the avalanche destroyed some 10 acres of spruce-hemlock timber, some of the individual trees as large as 18 inches in diameter. Branches, limbs and parts of tree trunks were hurled into tidewater at the location of the new Aurora Basin small boat Harbor. Damage to the houses included: removal of roofs; collapsed walls; buildings off foundations; chimneys broken off, and windows broken out. A few 60 pound chimney blocks were blown 135 feet onto houses fronting on Glacier Avenue. Damage estimates ranged from a high of $250,000* to a low of $150,000; the true figure, no doubt, lies somewhere between.

* Newspaper article: The Alaska Empire, Juneau, Alaska, March 22, 1962

The Juneau newspaper reported the following damage: F.G. Nottingham house (229 Behrends) knocked from foundation and one wall torn out; Harvey Willson house (226 Behrends), back window blown out and 18 inch diameter tree "...tossed across roof.;" J.A. Herdlick house (245 Behrends), "Roof ... completely gone." and windows facing mountain blown out; Cecil Willis house (241 Behrends), roof off and windows facing mountain blown out; and W.W. Hackwood house (1736 Glacier Avenue), "...had a large hole in the roof caused apparently by a tree hitting it." From the same newspaper: "The full force of the avalanche caused wind seemed to hit the Highlands area between Ross Way on the North and about 221 Behrends, although traces of heavy snow and scattered tree branches were farther south on Behrends."

Future Avalanches - Unless Juneau's climate becomes tropical or sub-tropical, it seems reasonable to expect future avalanches. In the 76 years covered by this report, there have been at least six large avalanches reported in the Behrends Avenue area, or if averaged one about each 13 years. Unfortunately, however, avalanches--especially long-cycle--do not wait for the "count of three" to begin shooting. Between 1890 and 1917, 27 years passed between slides. The next avalanches, 1926 and 1935, occurred nine years apart; the 1946 avalanche 11 years later; while the 1962 avalanche waited 16 years.

The writer will not hazard a guess (and that is all that it would be) as to when the next avalanche will fall; but given the past history of the area and the long-term climatological forecasts which say that colder winters are in the offing, the possiblity of destructive avalanches seems real.

Some Possible Defense Measures for the Behrends Avenue Area

The following are possible courses of action to be followed for reducing the hazard to persons and property in the affected area.

1) The area indicated on the City Map and Photomap would be declared a high hazard area. All homeowners and others having an interest (e.g., tenants, mortgage holders, insurance companies) would be so advised. Sellers would be required to advise prospective buyers of the hazard classification; failure to do so would be a criminal offense. No further construction would be allowed in area if purpose of construction is to house additional persons. In case of destruction of existing house, no replacement would be allowed.

2) Establish an avalanche forecasting service and prepare an evacuation plan. Evacuation to be mandatory or optional?

3) Require that walls of houses facing avalanche be reconstructed of reinforced concrete, braced and without openings or else require that a separate reinforced concrete deflection wall be built a few feet from each house. Establish standards for these constructions.

4) Construct avalanche breakers and diversion dikes at base of slope and above houses. Reafforest.

5) Construct snow retention devices in the formation and breakaway zone.

6) Require removal of all houses in affected area. Rezone land for summer recreational use.

Course of action 6) is the only one which would completely eliminate the hazard. Course of action 5) in conjunction with 4) and 3) would probably reduce the hazard to tolerable levels. Courses of action 1) and 2) together should be regarded as the minimum level of effort. While no definite cost estimates are available, it appears reasonable to guesstimate that course 6) might cost 250,000 to 350,000 dollars whereas courses 4) and 5) combined may run to as much as five million dollars.

It is rather obvious that any of these courses of action will raise financial, legal, political and moral questions (and not necessarily in that order). However, to do nothing may lead to consequences too terrible to contemplate.

Conclusion and Recommendations

There is every reason to expect future major avalanches in the Behrends Avenue area. In order that tragedy will be averted, the following recommendations are made.

1) That as a first step the area within the lines on the enclosed City Map and Photomap (1) be declared a high hazard area; (2) be publicized as such; and (3) be zoned to prevent further construction, and reconstruction if damage[1/] repairs amount to 50 percent or more of the value of the structure.

2) That an avalanche hazard forecasting service and evacuation plan be established.

3) That an engineering study be conducted by some qualified individual or organization to determine the cost of a structural defense system. The writer recommends consideration of the Federal Institute for Snow and Avalanche Research,

   Weissflujoch/DAVOS, Switzerland
   (Dr. Marcel de Quervain, Director)

4) That a study be made to determine where the buildings can be relocated and the cost of relocation.

5) That a study be made for financing the recommended measures.

6) And based upon the results of the studies recommended above, 3), 4) and 5), that either a structural defense system be constructed or the houses be removed.

7) Additionally, it is recommended that the City of Juneau through the Greater Juneau Borough, strive to prevent the use of avalanche susceptible land for building sites in areas likely to be annexed by the City.

[1/] Damage from any cause.

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APPENDIX A

Avalanche Forecasting - A Modern Synthesis

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ABSTRACT

Avalanches are generated by structural weaknesses in the snow cover. Some of these weaknesses can be observed and measured by investigating snow stratigraphy in pits or with instruments. This method offers reliable data from direct observation, but it is time-consuming. It is most effective when forecasting climax avalanches caused by snow metamorphism or a sequence of snowfalls.

Many avalanches fall during or immediately after a single storm. Time usually does not permit stratigraphic investigation, which is difficult in fresh snow. These direct-action avalanches can be forecast by an analysis of meteorlogical factors prevailing during the period of snow deposition. This indirect evidence is less reliable, but can be more easily obtained and often is the only forecasting guide available.

The accuracy of such forecasts is checked by practical field tests for the existence of tensile stresses leading to slab avalanche formation. Tests are made by disrupting the snow in potential slab zones with skis, with explosives, or with artillery fire, according to the character of the snow and accessibility of the test zone.

In practice, these methods are combined, weight being given to one or another according to circumstances largely determined by climate. This determination is illustrated by examples from different climate zones in the western United States.

Definition of Terms

Avalanche forecast------------- Either an *evaluation* of current avalanche conditions or a *prognostication* of future ones, the latter depending on mountain weather forecasts.

Climax avalanche--------------- This type falls as the result of internal structural weaknesses within the snow cover which may develop over long periods of time. It may be triggered by a new snow fall, but involves snow layers at the release point deposited by more than one storm.

Direct-action avalanche-------- This type falls during or within 24 hours after a storm, and involves only the snow of that storm at the release point.

Hard slab---------------------- The constituent snow of a slab avalanche with a high degree of internal cohesion. Sliding snow usually remains in chunks or blocks.

Soft slab---------------------- The constituent snow of a slab avalanche with a low degree of internal cohesion. The sliding sonw breaks up into an amorphous mass and may resemble loose snow.

Introduction

Avalanches are caused by structural instability in the snow cover. The concept of an avalanche forecast is predicted on the assumption that this instability can be recognized and interpreted. Recognition may be based on direct observation (snow pits, test instruments), or it may be based on indirect evidence (meteorological records). Interpretation in terms of possible avalanche release is largely empirical, being based on general knowledge accumulated by the forecasting profession plus personal experience of the forecaster with a given area of climate zone. Though today the basis exists for a good theoretical understanding of the physics and mechanics of the snow cover which leads to an informed interpretation of conditions causing snow avalanches, operational practice in day-to-day forecasting nevertheless still depends on the subjective element of personal experience. The interacting mechanical forces involved in avalanche release, together with the physical processes which determine them, are far too complex to allow a timely, exact, analytical or numerical evaluation.

An avalanche forecast may assess instability with considerable accuracy for a given area, but it cannot foretell the exact time of avalanche release on a given slope. More precisely, it is a hazard forecast which evaluates or foresees the probability of avalanche release, natural or artificial.

This paper attempts to state systematically the principles applied today in forecasting avalanche hazard, and to relate the variations of these to variations in climate. Winter avalanche situations only are considered; the forecasting of spring avalanches is reserved for a separate and later treatment.

Forecasting form Direct Evidence

The condition of snow stability is most readily inferred from direct examinations of snow cover structure. The techinques of such observations have been highly developed over the past thirty years, particularly in Switzerland. The standard techniques of snow pit investigations and the use of such instruments as the ram penetrometer (Haefeli rammsonde) have served as the basis for snow studies in such diverse applications as snow road compaction and assessment of annual accumulation on polar ice caps. Today their application to avalanche forecasting, the original reason for their development, is also widespread.

According to the concepts developed in this paper, snow structure observations are primarily applicable to forecasting climax avalanches. Such avalanches frequently, but not necessarily, originate as hard slabs. Unstable conditions which develop slowly, (such as depth hoar formation), or those depending on a sequence of snowfalls or other meteorological events, allow sufficient time for pit excavations and for instrument studies of changing snow properties. The structural conditions leading to climax avalanches usually can be detected well in advance of the actual avalanche release. These may illustrate a currently unstable snow cover, or, more commonly, one which will become unstable when overloaded by additional snow accumulation.

Certain relations of snow stresses and strength properties are amenable to quantitative analysis (Roch, 1956). Such analysis provides criteria for estimating avalanche hazard, but solves only a part of the complex mechanical problem of avalanche release. In forecasting avalanches from structural observations, everyday practice depends on the empirical comparison of existing snow structure patterns with those known to produce avalanching. (Fracture line observations are the most fruitful source of the latter.) This empirical approach has been explicitly adopted where climate and snow conditions are appropriate (Vrba and Urbanek, 1957).

Structural characteristics of the snow cover ultimately are a product of the meteorological environment. If the physical processes of weather influince on snow deposition and metamorphism are clearly understood, it should be theoretically possible to predict snow cover structure from a sufficiently detailed weather history. In practice this is done in general terms, but not with sufficient precision for reliable comprison with avalanche-producing structure patterns. Again, empirical experience and the observer's familiarity with local climate play an important role. An attempt to formulate a basis for quantitatively predicting the important structural feature of depth hoar formation has met with only partial success (Giddings and LaChapelle, 1962).

Where the climate causes climax avalanching to predominate, snow structure analysis providos good forecasting accuracy in the hands of a forecaster whose experience can be developed only by a substantial investment of time and training. Structural analysis loses its effectiveness in those climates which minimize climax avalanching.

Forecasting from Indirect Evidence

Soft slab avalanches usually run in newly-fallen snow (direct-action avalanches), often involve only the surface snow layer, and may fall over extensive areas of mountainside with only limited reference to wind direction. The avalanche hazard may develop rapidly in a few hours during intense storms, with the new snow sliding off a stable snow cover which does not become involved except where it is swept away by large surface avalanches already in motion. Rapid hazard development and the difficulty of measuring strength properties in newly-fallen snow preclude a meaningful examination of snow structure. Indirect evidence of instability must be sought instead.

Direct-action, soft slab avalanches are forecast primarily from meteorological evidence. Empirical experience has taught that there are a number of contributory weather factors which determine the stability of newly-fallen snow. Forecasting methods have been developed which depend on the sometimes subjective weighing of these contributory factors (U.S. Forest Service, 1961). Eight are recognized as a regular part of forecasting procedures: wind velocity, air temperature, snowfall intensity, precipitation intensity, and new snow depth, crystal type, density and settlement. Other factors appear to be involved as well, such as the degree of riming on falling snow crystals, but satisfactory criteria for their evaluation have not been established. Precipitation intensity has a dominant influence in many situations of hazard development (Atwater, 1952). The depth and surface condition of the existing snow cover are also considered in estimating the hazard from soft slabs.

Avalanche forecasting by meteorological analysis also produces good results in favorable climates and in the hands of an experienced forecaster, who again must be trained at some length. This method alone does not give information about hidden structural weaknesses which may give rise to climax avalanches.

Stability Tests in the Field

It is the view of avalanche forecasters in the United States that the application of these two basic methods of forecasting, singly or in combination according to climate, does not furnish sufficiently accurate information upon which sound operational decisions can be based. Maintaining a high degree of public safety in ski areas or on highways requires a higher degree of certainty about snow conditions than can be achieved by formal forecasting procedures in the present state of the art. To imporve this certainty, the hazard evaluation is tested in the field.

The basic criterion of snow instability adoped for these tests is the existence of tensile stress in potential slab layers. Though the mechanical conditions determining this stress may be complex, its existence, and its approximate magnitude, are readily indicated by the manner in which cracks form when snow is disturbed on an inclined surface. The propagation of fracturing in snow away from the point of disturbance, whether an avalanche is released or not, shows the existence of tensile stress. Extent and distance of the fracturing shows its relative magnitude. Practical experience has taught that there is a high degree of correlation between snow which so exhibits tension and the formation of slab avalanches. The recognition of this fracturing under tensile stress can readily be taught to untrained personnel. In fact, skill in this aspect of avalanche forecasting is acquired much more readily than that required to interpret snow structure and weather conditions.

The test for tensile stress is more readily applied to soft slabs, where the passage of a ski usually provides sufficient disruptive force to initiate fracturing. Correlation between stress evidence and soft slab avalanching is high only in those circumstances where structural evidence of instability is dufficult to obtain. Field-testing for stresses in soft slabs thus provides the direct evidence to supplement that gained indirectly by meteorological observations. Such testing customarily is done on short, steep test slopes whose slope angle and exposure imitate those of the large and more dangerous avalanche paths. Stringent safety precautions are observed to reduce the possibility of accident in case of avalanche release.

Field-testing of hard slabs requires a more vigorous disruptive force. Explosives are usually required to obtain a more satisfactory test. The results sometimes are less clearly related to general snow stability, but valuable information still is gained to supplement structural observations. It has become accepted practice in the United States to use artillery as well as hand-placed charges for this purpose. Gunfire thus is sometimes deliberately used to test stability as well as to eliminate known hazard conditions.

Where circumstances permit, soft slabs as well as hard slab conditions are also tested in this fashion. In both cases, test by artillery offers the advantage of rapid access to distant of dangerous slopes. It is useful only during good visibility, when the results (fracturing as well as avalanche release) can be closely observed. The judicious interpretation of results from test skiing or exploratory artillery fire depends on accurate records of avalanche occurrence, for slopes which earlier have been relieved of their burden of snow will react differently than those which have not.

The Synthesis and its Relation to Climate

Avalanche forecasting today is a practical systhesis, based on both direct and indirect evidence of snow stability which may be further checked by field tests. The fact of this synthesis has been recognized in the design of modern avalanche forecasting and control methods (Schaerer, 1962). On the other hand, there have been occasions when mininterpretation of forecasting principles has led to wrong observation methods for a particular climate. The latter is especially true of forecasting from indirect evidence, when the limitations of this method have not been recognized, or its application has been too formalistic. Difficulties also arise when overemphasis is placed on structural investigation to the point of excluding consideration of winter storm characteristics.

The relative weight which should be given to these methods of avalanche forecasting is largely determined by climate. Diverse examples of this determination are found in the mountain regions of the Western United States, which extend over nearly 15° of latitude and encompass both maritime and continental climates. Roch (1949) recognized three major snow and avalanche zones in the western United States: High Alpise, Middle Alpine and Coastal

Alpine. These broadly correspond to areas 3, 4 and 1. respectively, in Figure 1. The subsequent compilation of data from these areas on snow cover and avalanche characteristics furnishes the following examples of the relation between climate and forecasting methods.

<u>The Pacific Coast</u>, Mountain altitudes are generally under 2500 meters, except in parts of the Sierra Nevada Range, precipitation is heavy, and winter temperatures mild. Annual snowfall varies from 15 to 25 meters, large quantities may fall in a single storm, and snowfall intensities as high as 30 cm per hour have been observed. Snow covers are deep and often very firmly consolidated. Direct-action soft slab avalanches are common. Rain may fall at any time during the winter, and a significant cause of major avalanching is rain which immediately follows a deep fall of new snow. Avalanches which slide off a rain-generated ice layer in the snow cover are also frequently seen. High storm winds and extensive rime formation are encountered above timberline (1500-2500 meters). Lower layers of the snow cover achieve ram resistances of several hundred kilograms by mid-or late winter. The ram penotrometer thus is useful for collecting snow structure data only in the upper snow layers.

Forecasting of both dry soft slabs and rain-induced avalanching is predominantly based on weather ovservations. Air temperature telemetry from mountain tops is considered an essential forecasting aid, for it warns of the onset of thaw or rain accompanying a warm front. The principal concern about snow structure is for ice layers which may provide a good sliding surface.

Lower temperatures at altitudes above 3000 meters in the Sierra Nevada Range modify these conditions in spite of the low latitude.

The Coastal Transition Zone. This zone encompasses some eastern parts of the coast ranges (not shown separately in Fig. 1) the Blue Mountains of Oregon, and Northern Idaho and northwestern Montana. The winter climate is drier and colder than along the Pacific Coast, but snowfall is still moderately heavy. Snow covers tend to be stable and direct-action avalanches predominate, but climax avalanches occasionally fall. Winter rain is much rarer than in the coastal mountains. Forecasting depends mainly on the analysis of weather factors.

The Rocky Mountains. This zone includes much of Colorado, and parts of Wyoming and Montana. Altitude range is 2500 to 4000 meters, annual snowfall generally less than 8 meters, and very low winter temperatures are common. Timberline is around 3200 meters in Colorado. High winds are frequent, both during snow storms and in fair weather. In all but sheltered valleys, snow drifting is extensive. Depth hoar formation is almost universal throughout this region. Heavy snowfalls are rare, but very deep wind drifts may accumulate in a few hours. Principle avalanche type is a hard, wind-drifted slab sliding off poorly consolidated snow or depth hoar. Avalanching is markedly confined to lee slopes. Slab avalanches may originate in surprisingly thick stands of trees below timberline.

Similar, though less cold and severely continental, climate is found in southern Utah. A peculiar precipitation pattern there brings maximum snowfall in the autumn and spring, but very little in mid-winter. Depth hoar formation is extensive.

Avalanche forecasting depends heavily on observations of structural weaknesses in the snow cover. Comprehensive studies on the relation of snow structure to avalanche formation in the Colorado Front Range have demonstrated that in this climate ram profiles furnish an accurate picture of snow cover stability (Borland, 1952-1960). Recording anometers are also essential, for, given a weak existing snow structure, the immediate cause of most hazard is the deposition of hard slabs by wind.

The Intermountain Zone. This zone is located in Utah, Idaho, Southwestern Colorado, and Western Wyoming, between the Rocky Mountains and the Coast Ranges. Altitudes vary from 2000 to 3000 meters. Annual snowfall averages 7.5 to 15 meters, temperatures are mild compared with the Rocky Mountains, but in mid-winter thaws or rain are rare. Wind storms are distinctly less frequent and less intense than in the high Rockies. Snow cover stability varies widely from season to season. Soft slab, direct-action avalanches are very common, while structural weaknesses leading to climax avalanche formation occur in about half of the winters. Major avalanching tends to be extensive, rather than confined to lee slopes. Hazard conditions form frequently, but do not persist as long as in the Rocky Mountains due to the milder temperatures.

Avalanche forecasting in the Intermountain Zone depends on both structural evidence and weather ovservations, the emphasis shifting from year to year according to snow conditions. Because snow accumulation is deep and soft, ram resistance is often low and ram profiles provide only limited information on structural weaknesses leading to climax avalanches.

<u>Figure I</u>

Predominate avalanche types and applicable forecasting methods in the mountainous areas of the Western United States. 1) Generally deep and stable snow covers. Extensive surface avalanching, with possibility of melt or rain throughout the winter. Avalanching forecasting by meteorological observations. 2) Often stable snow covers, extensive surface avalanching, melt or rain rare in mid-winter months. Forecasting largely by meteorological observations. 3) Shallow, unstable snow covers with depth hoar formation comman and climax, hard slab avalanches frequent. Forecasting largely by snow structure analysis. 4) Conditions of 2) and 3) may overlap, with one or the other usually predominating in a giver winter. Forecasting actively combines meteorological and snow structure observations.

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APPENDIX B

Rammsonde Profiles 1962 & 1966

Because only three rammsonde tests were made in 1966, the data is not sufficient for analysis. It is interesting, however, to note that total snow depth on March 31, 1966 is slightly greater than in 1962 at about the time of the avalanche.

APPENDIX C

U. S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE
WASATCH NATIONAL FOREST

ALTA AVALANCHE STUDY CENTER
Miscellaneous Report No. 10

ENCOUNTER PROBABILITIES FOR AVALANCHE DAMAGE

Edward R. LaChapelle
Avalanche Hazard Forecaster
Wasatch National Forest

March 1966

A common problem in selecting sites for mountain construction or development is determining the probability of avalanche damage. Prudent planning dictates that sites should be completely free of avalanche danger if at all possible. This should be the inflexible standard for buildings and lodges in recreation developments, but a slight exposure to avalanche hazard is sometimes acceptable for ski lifts or parking areas. In the case of mining construction or other industrial enterprises where the character of hazard exposure can be more strictly controlled, a more substantial risk of damage may sometimes be acceptable. This risk is known as encounter probability.

The problem normally is not posed by large avalanches which run frequently (annually or oftener). These present such obvious prospects of repeated damage and destruction that they must either be avoided entirely or else defended or eliminated by what may be prohibitively expensive construction. More often a proposed site lies within or adjacent to a slide path where normal avalanche activity is limited and non-destructive, but which shows evidence of infrequent avalanches of potentially destructive proportions.

The situation is similar to that posed by other geophysical hazards---earthquakes, floods, tidal waves, hurricanes---which recur in destructive size at long and irregular intervals. The concept of a "20-year flood" or "100-year flood" is familiar to the hydrologic engineer. The avalanche specialist is faced with the similar problem of evaluating prospective damage from a "20-year avalanche" or a "100-year avalanche". It often is undesirable or too costly to avoid completely the prospects of damage from an avalanche which may fall only once a century. In some circumstances, such as the exposure of a large number of people, the only acceptable hazard may be zero and there is no choice but to seek another and safer location. There sometimes is economic justification for accepting a limited amount of risk for buildings or other installation, especially mining or other enterprises where a definite and limited building life can be projected. Such risks can logically be taken only if their size can be reasonably estimated. This report presents methods for making such estimates, or encounter probability.

Large, infrequent avalanches, like large, infrequent river floods, are the product of unforseeable weather and climate. For purposes of statistical analysis they are considered to occur at random even though there may be some evidence for their association with short-term (in the geologic sense) climate cycles. The average time between a number of such random events is called the return interval. For the kind of avalanches under discussion, typical return intervals might be 25, 50 or 100 years. Most installations are designed for a useful estimated life which depends on such factors as economics, construction materials and rate of obsolescence. When such an installation is exposed for its estimated life to the threat of damage from an infrequent avalanche of a given return interval, there is a definite encounter probability which describes the chance that the avalanche will damage the installation during its estimated life.

Table 1 and 2 enumerate these encounter probabilities for the given values of return interval and estimated life. They are derived from a paper by Borgman (1) which treats the subject of geophysical risks in considerable depth. The design engineer seeking a more sophisticated treatment is referred to this paper.

In using these tables, it is important to consider the restrictions imposed on their construction. First, and in general, statistics treat the relations between numbers or groups of numbers. These relations may or may not describe physical reality. They predict probable consequences but do not assign causes. Second, both tables are based on the assumption that occurrences of the event in question (in this case major avalanches) are random and independent. This means that the encounter probability does not change because the event occurs. This is another way of stating the gambler's maxim: "The laws of chance have no memory."

Table 1 is calculated on the assumption that the events occur only at integers on the time scale. This may seem an arbitrary and impractical restriction, but in the case of avalanche hazard it has some useful applications. If most avalanches of a damaging size are known to occur at a given site in, say, January, then such events will fall close to the time scale integers if the convenient time unit of a year is chosen.

Table 2 removes this restriction, allowing the events to occur at any point on the time scale. The following mathematical restrictions, however, have been observed in calculating Table 2: The process is stationary, possesses independent increments, and has a time-independent average. Two or more events cannot occur simultaneously.

Allowing the events to occur at any point on the time scale gives a more realistic flexibility to the calculations, but does raise another problem when dealing with avalanches in time units of years. Avalanches do not occur at any point on such a time scale; they occur only in the winter. This difficulty may be circumvented if the chosen time unit is winter months for both the return interval and the estimated life. The estimate of encounter probability is then based on a continuous time scale made up of years consisting of those four or five winter months when avalanche damage is possible. The balance of each year when avalanche occurrence is zero is ignored along with that same portion of the estimated life.

Note that for long return intervals and low encounter probabilities the two Tables give very similar or identical figures.

TABLE 1.-ENCOUNTER PROBABILITY, E_1, VERSUS ESTIMATED LIFE, L, AND RETURN PERIOD $\bar{T}_1$. $\left[E_1=1-\left(1-\frac{1}{\bar{T}_1}\right)^L\right]$

$\bar{T}_1$ / L	5	10	15	20	25	30	40	50	60
1	0.200	0.100	0.067	0.050	0.040	0.033	0.025	0.020	0.017
2	0.360	0.190	0.129	0.098	0.078	0.066	0.049	0.040	0.033
3	0.488	0.271	0.187	0.143	0.115	0.097	0.073	0.059	0.049
4	0.590	0.344	0.241	0.185	0.151	0.127	0.096	0.078	0.065
5	0.672	0.410	0.292	0.226	0.185	0.156	0.119	0.096	0.081
6	0.738	0.469	0.339	0.265	0.217	0.184	0.141	0.114	0.096
7	0.790	0.522	0.383	0.302	0.249	0.211	0.162	0.132	0.111
8	0.832	0.570	0.424	0.337	0.279	0.238	0.183	0.149	0.126
9	0.866	0.613	0.463	0.370	0.307	0.263	0.204	0.166	0.140
10	0.893	0.651	0.498	0.401	0.335	0.288	0.224	0.183	0.155
12	0.931	0.718	0.563	0.460	0.387	0.334	0.262	0.215	0.183
14	0.956	0.771	0.619	0.512	0.435	0.378	0.298	0.246	0.210
16	0.972	0.815	0.668	0.560	0.480	0.419	0.333	0.276	0.236
18	0.982	0.850	0.711	0.603	0.520	0.457	0.366	0.305	0.261
20	0.988	0.878	0.748	0.642	0.558	0.492	0.397	0.332	0.285
25	0.996	0.928	0.822	0.723	0.640	0.572	0.469	0.397	0.343
30	0.999	0.958	0.874	0.785	0.706	0.638	0.532	0.455	0.396
35	0.999+	0.975	0.911	0.834	0.760	0.695	0.588	0.507	0.445
40	0.999+	0.985	0.937	0.871	0.805	0.742	0.637	0.554	0.489
45	0.999+	0.991	0.955	0.901	0.841	0.782	0.680	0.597	0.531
50	0.999+	0.955	0.968	0.923	0.870	0.816	0.718	0.636	0.568

	80	100	120	160	200	250	300	400	500
1	0.012	0.010	0.008	0.006	0.005	0.004	0.003	0.002	0.002
2	0.025	0.020	0.017	0.012	0.010	0.008	0.007	0.005	0.004
3	0.037	0.030	0.025	0.019	0.015	0.012	0.010	0.007	0.006
4	0.049	0.039	0.033	0.025	0.020	0.016	0.013	0.010	0.008
5	0.061	0.049	0.041	0.031	0.025	0.020	0.017	0.012	0.010
6	0.073	0.059	0.049	0.037	0.030	0.024	0.020	0.015	0.012
7	0.084	0.068	0.057	0.043	0.034	0.028	0.023	0.017	0.014
8	0.096	0.077	0.065	0.049	0.039	0.032	0.026	0.020	0.016
9	0.107	0.086	0.073	0.055	0.044	0.035	0.030	0.022	0.018
10	0.118	0.096	0.080	0.061	0.049	0.039	0.033	0.025	0.020
12	0.140	0.114	0.096	0.072	0.058	0.047	0.039	0.030	0.024
14	0.161	0.131	0.111	0.084	0.068	0.055	0.046	0.034	0.028
16	0.182	0.149	0.125	0.095	0.077	0.062	0.052	0.039	0.032
18	0.203	0.165	0.140	0.107	0.086	0.070	0.058	0.044	0.035
20	0.222	0.182	0.154	0.118	0.095	0.077	0.065	0.049	0.039
25	0.270	0.222	0.189	0.145	0.118	0.095	0.080	0.061	0.049
30	0.314	0.260	0.222	0.171	0.140	0.113	0.095	0.072	0.058
35	0.356	0.297	0.254	0.197	0.161	0.131	0.110	0.084	0.068
40	0.395	0.331	0.284	0.222	0.182	0.148	0.125	0.095	0.077
45	0.432	0.364	0.314	0.246	0.202	0.165	0.140	0.107	0.086
50	0.467	0.395	0.342	0.269	0.222	0.182	0.154	0.118	0.095

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APPENDIX VI

THE BEHRENDS AVENUE AVALANCHE AND OTHER AVALANCHE HAZARDS IN THE GREATER JUNEAU BOROUGH

Edward R. LaChapelle

November, 1968

THE BEHRENDS AVENUE AVALANCHE AND OTHER AVALANCHE HAZARDS IN THE GREATER JUNEAU BOROUGH

A report based on an inspection trip to
the Juneau area on 29-31 August 1968

Submitted to the Chairman of the
Greater Juneau Borough 7 November 1968

Edward R. LaChapelle
Visiting Associate Professor
Department of Atmospheric Sciences
University of Washington

Hart Report

In January 1967, Mr. Keith Hart submitted to the City of Juneau a "Report of the Preliminary Evaluation of the Behrends Avenue Avalanche Path." This report examined the history and character of avalanche hazard in the Behrends Avenue and presented several recommendations and alternatives for ameliorating the hazard.

I concur in all essential points of this report and judge that Mr. Hart has made an accurate appraisal of the character of the Behrends Avenue Avalanche.

My own report below will amplify certain aspects discussed by Mr. Hart and will suggest an additional safety measure. It will also review the prospects for forestalling similar problems in the Juneau area.

Additional Evidence

Additional evidence about the Behrends Avenue avalanche path has come to light since Hart submitted his report in 1967.

A photograph is reported to exist of the 1890 avalanche. Because this apparently is the largest avalanche to be observed in this path, such a photograph would be exceptionally valuable in determining damage potential. Attempts are being made by Margaret Fritsch, Planning Chairman of the Juneau Borough, to obtain a copy of this photograph. If and when it is received, a supplementary report will be sent evaluating the evidence it offers.

would have to be provided for the existing springs in the area. It must be emphasized once again that even such a large barrier cannot guarantee 100% protection for the dwellings below, for the capricious behavior of high-velocity avalanche snow might lead to overrunning of the barrier in one fashion or another. Nevertheless, the substantial gain in safety might make such construction worthwhile.

The only way to assure positive elimination of hazard from the Behrends Avenue Avalanche is to remove completely the buildings presently in the slide path. This would assure a permanent solution to the problem. The present type of land use - residential area and motel - is just the one which offers the maximum exposure of hazard in respect to injuries or fatalities, for a number of persons are certain to be found in the area at almost any time of day or night throughout the year. An alternate and limited use of this slide area which might safely be contemplated is restricted industrial development with a strict building code confining structures to low profiles, reinforced roofs and uphill barriers. Such construction would minimize the prospects of avalanche damage, and restricting occupancy of the area to normal working hours of 8 to 5 weekdays would immediately reduce the human hazard by a factor of four.

It should be noted that this avalanche path also offers the possibility of substantial property damage to boats moored in the Aurora small-boat harbor. Any sliding snow which reaches tide water at this point, aside from causing damage by direct impact, would very likely generate a seiche within the basin enclosed by the breakwater. This could extend the area of damage well beyond the zone of direct snow impact. An avalanche which reached the boat basin in this fashion would of course inflict severe damage during its passage through the residential area and carry a large amount of debris into tidewater. The 1890 avalanche appears to be the only one of historical record which falls into this category.

Avalanche Paths at the Western End of Mt. Juneau

A number of smaller avalanche paths exist above the Glacier Highway west of Norway Point. This zone encompasses the so-called "White Subdivision" and extends as far as the prominent gulley adjacent to the Aurora Wrecking Company. The avalanches concerned originate on a lower shoulder of Mt. Juneau than the Behrends Avenue Avalanche; hence they do not gather as much snow or fall with the same destructive force as the latter one. Nevertheless they do present possible danger to this area along Glacier Highway. Hart reported during our inspection of this area that there were records of avalanches reaching the highway here during the 1930's.

Along much of the zone encompassing the White Subdivision there is a substantial screen of timber between the Highway and the open and steeper slopes on the flank of Mt. Juneau. There is relatively little transition zone of gentler slopes between these and the Highway. This timber screen is the primary protection from avalanche activity for the area just above the highway. Much of it is a substantial stand of timber which does not show evidence of penetration by major avalanches in the recent past. There are also several open gulleys or paths through the timber which are the obvious product of snow avalanche activity. These probably are the sites of any snow which slid to the Highway in the 1930's.

Residential construction in the White Subdivision area seems a reasonable risk as long as it is confined to the zone immediately above the Highway and does not encroach far enough up the mountainside to destroy the existing timber shield. Maintenance of this screen of relatively mature timber is essential to protection of the slopes below. Specifically, residential construction would appear feasible along the Highway from the Children's Home west. The zone for about 100 yards east of the Children's Home is exposed to one of the open slide paths through the timber and definitely should not be the site of any construction above the Highway. This restriction also applies to the open gulley at the western end of the area under discussion - the previously-mentioned gulley adjacent to the Aurora Wrecking Company.

A recently-built house at Norway Point, is located appreciably higher up the mountainside than other houses in the area. There is little timber screen above it, and such timber as does exist is noticeably smaller than that either east or west, suggesting that an avalanche may have at one time penetrated this area and destroyed the earlier timber stand. This house would appear to be exposed to avalanche hazard during winters of exceptional snowfall or avalanche activity.

Preventing Future Problems

Counting the 1949 school site letter, this present report is the third formal survey of the Behrends Avenue Avalanche problem presented to the City or Borough of Juneau. All three reports agree in their major thesis: This avalanche path is an unsuitable site for residences or public buildings. Although construction in this area has raised the problems which occasioned the last two reports, there does not seem to be at present any clear-cut legal inhibition placed on further construction of buildings. Presumably the 1962 avalanche and subsequent information stemming from the Hart report have served notice to the public that a problem does exist, but it should be borne in mind that public memory for such problems is all too short. I strongly urge that the Greater Juneau Borough, and the City of Juneau, explore all possible means to place a formal limitation in further development in the Behrends Avenue area. The problem is sufficiently serious now, without it being allowed to compound through more construction. The new motel occupying the previously rejected school site represents an unfortunate trend in the hazard zone which ought to be reversed.

The first step in dealing with the Behrends Avenue problem obviously is to prevent it from getting any bigger. But this problem is only part of the larger one of widespread geophysical hazards within the Greater Juneau Borough. This larger problem deserves close attention, for other endangered areas are apt to arise as the population rapidly expands, sometimes into potential and readily recognizable avalanche, earth slip, flood or rockfall areas. The Juneau area is probably unique in this respect among rapidly developing cities of its size in the United States, for a large number of geophysical hazards are concentrated in a relatively small area.

During my past 18 years of active research and management in the field of snow avalanche hazards, there is one overriding lesson I have repeatedly learned as I worked in many places in both North America and Europe. This is the fact that most practical avalanche hazard problems arise through carelessness, ignorance, oversight or deliberate disregard. Once they have arisen, usually by construction of houses, highways, mine buildings, ski lifts or other structures in danger areas, the solution, if a practical one exists, is invariably expensive. Most avalanche problems can be avoided by foresight and careful planning. Foresight is a free commodity. Planning is cheap, compared with the cost of moving structures, building defenses or drastically altering existing enterprises. Except for the Behrends Avenue Avalanche, where it comes too late, some careful planning at this stage of the Borough's development will reap rewards for many years to come in elimination of future problems and possible future disasters.

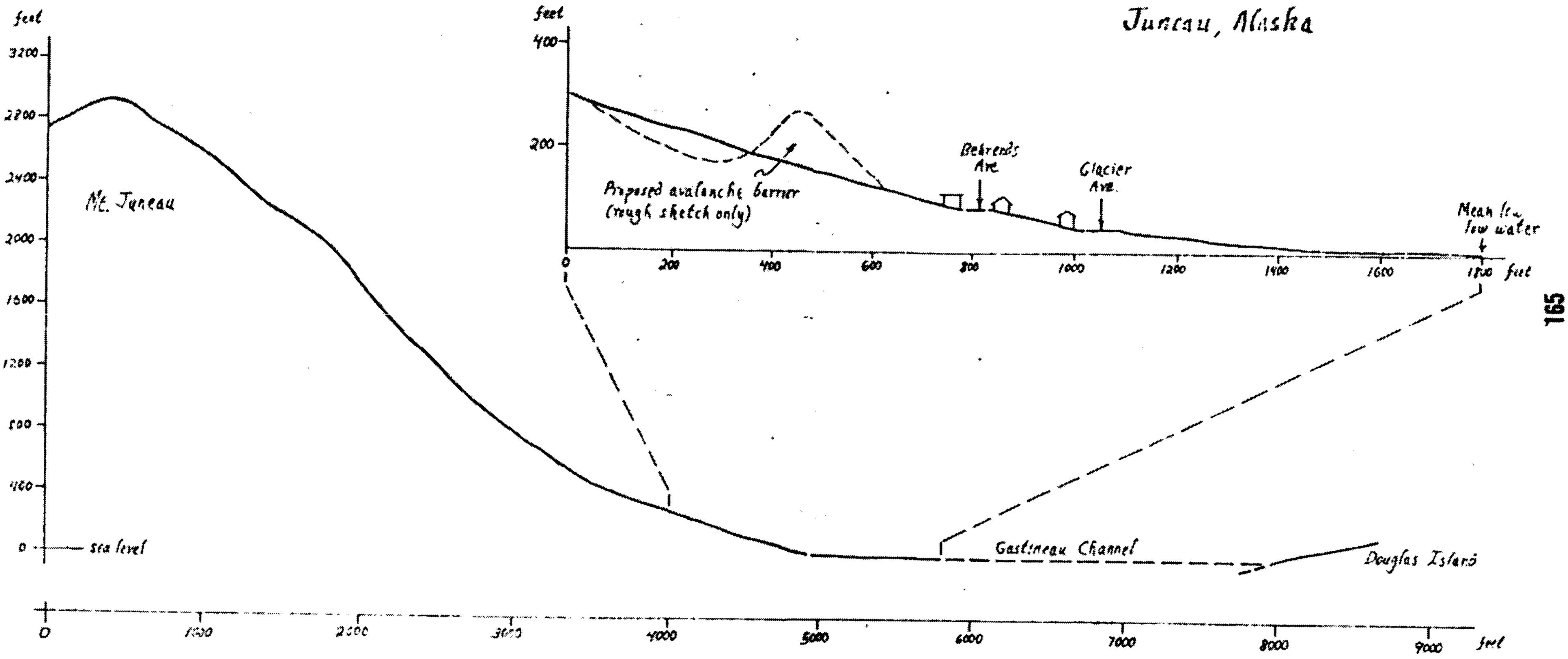
I recommend that the Greater Juneau Borough initiate immediately a survey of geophysical hazards within the Borough, employing such experts as necessary to itemize the danger areas, to delineate them accurately on maps, and to file with the Borough professional appraisals of the nature of the dangers and any recommended measures for their amelioration. The current survey of soil stability being conducted by Dr. Miller of the U. S. Geological Survey already represents a big step toward this goal, for earthslide problems are one of Juneau's serious concerns. When the advance version of Dr. Miller's report becomes available, it can form the excellent basis for development of a full geophysical hazards survey.

A hazard survey should begin without delay. It is especially important that the survey receive wide publicity from its inception. A vigorous publicity campaign will produce several advantages:

(1) It can encourage citizens to come forward with information about

Fall Line Profile Through Center of Behrends Avenue Avalanche

Juneau, Alaska



Sept. [illegible]

present and past experience with hazards. This may uncover data which would otherwise be difficult to locate.

(2) It will advertise the Borough's stance as a forward-looking organization which acts effectively to protect the public interest.

(3) Through steps (1) and (2), it will lay the groundwork for ultimate public acceptance of zoning ordinances or other legislation. If the latter appear suddenly on the scene following an unpublicized hazard survey, there is apt to be substantial public resistance.

I recommend establishing immediately a file or archive in the Borough office for the collection of data pertaining to geophysical hazards. This should include past records and photographs of such events as snow avalanches or earth slides. When such events occur in the future, as they inevitably will, every effort should be made to obtain photographs and collect all pertinent documentation, including statements from eyewitnesses. This is an activity well within the capability of the present Borough staff. It will serve to form the basis for a hazard survey, and it will provide a continuing record to keep the results of such a survey up to date. Responsibility for maintaining the file should be clearly assigned to one of the Borough staff positions.

Once a geophysical hazard inventory has been completed, there are several methods of utilizing it to protect the citizens of the Greater Juneau Borough. There is little precedent in this field, but interest currently exists in developing such protection at several localities. A summary is presented below. At this point I wish to advocate the minimum protective measure which could benefit the public. This is compilation of an accurate and large-scale map of the Borough showing extent and nature of the recognized geophysical hazards. This map should be given wide publicity and should be readily available for inspection by any interested party. The minimum measure, in short, is to make available information readily accessible to the public. A step further would be to make it accessible on a more or less compulsory basis. For instance, a property-owner's signature showing he had inspected the hazard map might be required as a condition for recording title anytime property changes hands. This might not eliminate all future problems, but it would serve to give property buyers fair warning.

To my knowledge, the following localities are studying the avalanche hazard problem, or at least are confronted with such a problem.

A substantial avalanche hazard exists in the western canyons of the Wasatch Mountains in Utah. This hazard is rising rapidly as recreation use from the Wasatch Front area (Ogden south through Salt Lake City to Provo) follows the population increase. The problem is most concentrated in Salt Lake County. Several years ago, County officials enlisted aid from the U. S. Forest Service to identify the principal danger zones with a view toward establishing a zoning ordinance to control or prohibit construction under avalanche paths. To date no zoning ordinance has been enacted, but the County has used the fact that one is under study to exert influence on real estate developments. Officials have found that a substantial amount of control can be exercised through the County's authority to grant or deny permits to subdivide. Factors such as snow avalanches, earth slides, sanitation and watershed management are all considered in determining whether a permit will be granted. A subdivision application in Little Cottonwood Canyon was recently rejected on the grounds of exposure to rockfall. This tactic of course does not control the individual property owner, but it does forestall problems like the one on Behrends Avenue.

The heavy demand for mountain recreation property in Washington has generated a recent and rapidly rising avalanche hazard problem in some of the passes through the Cascade Mountains. In some cases the real estate developers have on their own initiative sought professional advice and directed their subdivision efforts accordingly. In others they have not, leading to some potentials for disaster. The State government in Olympia has for some time been exploring means to protect the public from unethical real estate operators. The problem originally came about from sale of land unsuitable for reasons other than avalanche danger, but the latter has now been added to the list. Current thinking leans toward consumer protection legislation, rather than zoning ordinances. A bill requiring real estate developers to post bond to protect their customers failed to pass the last session of the legislature, but a similar one probably will be submitted again in January. There is a possibility that in the case of actual compromise to public safety, such as from snow avalanches, some control may be possible through public health laws. Further information can be obtained from Mr. Douglas Toms, Director, Department of Motor Vehicles, Olympia, Washington. (In the State of Washington, this Department includes professional licenses.)

Some definite avalanche hazards are developing in recreation areas of the Sierra Nevada in California. The major and responsible developers have taken these into account, but in some instances on private land others have not. At the moment I do not know of any activity by county or state officials to deal with the problem.

Avalanche hazards also exist in Colorado. Following an avalanche disaster at Twin Lakes, Colorado several years ago, in which houses were destroyed with accompanying fatalities, there was a flurry of interest in zoning. The Forest Service submitted two reports recommending zoning to the State of Colorado, but no action has been taken. A copy of one of these, by Hans Frutiger, has already been forwarded to the Borough. I have recently learned that avalanche zoning is presently a dead issue in Colorado. There has been some recent interest in identifying and marking danger areas along routes frequently used by oversnow vehicles, whose recreational use has risen very rapidly in the past two years. To my knowledge no action has yet been taken on this proposal.

Although avalanche hazard problems have existed for centuries in the Alps, the legal controls over them even today are very limited. Switzerland has in recent years attempted to set up zoning ordinances to define hazard areas and either prohibit building in them or impose constraints on building design. These efforts have met with a great deal of resistance and very few ordinances have actually been promulgated. (At this writing I have not yet been able to obtain copies of such ordinances as do exist, but will forward them to the Borough if received.) The problem has been accentuated of late by mountain peasants selling off their known avalanche paths to city folk seeking recreation property. It appears the Swiss peasants consider this a legitimate way to get rid of their low-value land, especially if the buyer is a foreigner, preferably German.

One of the best developed avalanche protective systems, and one of the few areas zoned for avalanche dangers in Switzerland, is the community of Davos. But even here the avalanche problems are very serious and many are still unsolved. In January 1968, a large avalanche fell from an area protected by extensive defense structures. It was the largest to occur at this site in some 200 years. Within the city of Davos, it destroyed 14 houses, damaged 25 more, and caused some 30 fatalities. It also destroyed a masonary railway viaduct and just missed the public school. It had previously been planned to build a new school at this same site, but now the community is uncertain whether to build there or in a safer spot. There is also an acute crisis over whether to permit private landowners to rebuild their destroyed houses in the same places, and, in fact, how such authority can be exercised if it is deemed in the interest of public safety not to rebuild them. I have not yet learned how the problem is being dealt with - at last report, some three months ago, it had not been resolved. I cite this as an example of the problems that can develop when residences and public buildings are allowed to grow up unchecked in area of known or even marginally questionable avalanche danger. The citizens of Davos thought they were quite safe - after all, they enjoyed protection from a modern avalanche defense system and had recorded no avalanche of the magnitude since the 18th century. Compare this with the situation on Behrends Avenue, where no defense structures exist and the known return interval is 13 years.

Apparently there are no existing zoning or other ordinances in the United States which pertain directly or indirectly to snow avalanche hazards. It appears that the Greater Juneau Borough may have to serve as the pioneer in this country. This can profitably be regarded as a challenging opportunity for leadership, rather than an obstacle. If my visit to Juneau will assist you in organizing an inventory of geophysical hazards which leads to workable guarantees of public safety by your local government, then this may in the long run profit all of us more than any specific solutions I can suggest for the Behrends Avenue problem.

Edward R. LaChapelle

Edward R. LaChapelle

Seattle, Washington
7 November 1968

April 6, 1949

Superintendent of Schools
Juneau Independent School District
and
Mayor, City of Juneau

Gentlemen:

We, the undersigned, have inspected the site of the proposed grade school in Block F of the Highlands Subdivision.

After careful inspection of the slide area, we think its influence would be extreme in the north end of the building and the playground area. It is our opinion that the north end of the proposed site is in a position which might be covered by a snow or rock slide and even if it were not covered by a slide, the air blast from a small slide might seriously damage the covered playground, the windows of the building, and cause injury to the occupants of the building.

It is our unanimous recommendation that a safer and more suitable site be selected to insure the future safety of the school children of the Juneau Independent School District.

Respectfully,

William S. Twenhofel, Geologist

[illegible] EM. ME.

E. G. Nelson M.E.

[illegible] McNamara, City Eng.

APPENDIX VII

DEFENSE CONSTRUCTION PLAN FOR THE BEHRENDS AVENUE TERMINAL ZONE

By: Keith Hart

April, 1968

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GRAPHICS

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MAPS

INTRODUCTION AND BACKGROUND

On March 22, 1962, a major snow avalanche fell onto some two dozen homes in the Highlands area of the City of Juneau, Alaska. Shortly following this disaster, the Department of Highways, at the request of city officials, sent two avalanche specialists[1/] from the avalanche research center near Girdwood to Juneau to determine what immediate defense measures, if any, might be utilized. Their brief study[2/] recommended against further development of the subdivision within the avalanche path and called for construction of defenses at the base of the cliff above Behrends Avenue.

In September 1962, the writer transferred to the Department of Highways Headquarters in Douglas, bringing with him the knowledge that some 100 residents of Juneau's Highlands area continued to live in a major avalanche path.

The present paper is a continuation of that concern which was first formalized in a talk given before the Juneau Chapter of the American Society of Civil Engineers on the subject of snow avalanches and the Behrends Avenue problem. An outgrowth of the talk was a request to the writer from the Juneau Public Works Director to evaluate the continuing avalanche hazard, to determine possible defense measures and to recommend specific courses of action.

The confidential Report of the Preliminary Evaluation of the Behrends Avenue Avalanche Path, dated January 1967, established that major snow avalanches had occurred on the average of once every 13 years from 1890 to 1962. The report as requested, outlined a number of possible defense measures and recommended a variety of plans ranging from removal of exposed buildings to avalanche hazard forecasting and evacuation during critical periods.

[1/] The writer then also an avalanche specialist remained at Girdwood.

[2/] Unpublished report entitled Mount Juneau Avalanche, March 1962. Prepared by the Planning and Research Section, Department of Highways, Girdwood, (April) 1962.

SCOPE

The scope of this paper is limited to designing a structural defense system for the terminal zone of the Behrends Avenue snow avalanche path. The as yet confidential report to the City of Juneau provides most of the necessary supporting information.

OBJECTIVE

The objective is to design an effective passive defense system which will fulfill the site requirements and can be constructed and maintained at low cost.

LIMITATIONS OF PROPOSED DEFENSE SYSTEM

The proposed defense system will be most effective against small to moderate size damp and wet snow avalanches where downslope motion is confined to the ground. It will be less effective against large or very large avalanches traveling on the ground, and it will be largely ineffectual where large, high-velocity airborne avalanches are involved. As most of the reported major avalanches seem to be those types which travel on the ground, the writer believes that a system consisting of diversion dikes and earthen mounds is appropriate.

The proposed system is only one of a number of necessary measures which must be utilized if the hazard is to be reduced to tolerable levels. See the Report of the Preliminary Evaluation of the Behrends Avenue Avalanche Path (hereafter called the Behrends Avenue report), especially the sections on Avalanche Defenses, beginning page 6, and Some Possible Defense Measures..., beginning page 17.

THE PROPOSED DEFENSE SYSTEM

In 1955 the Alaska Road Commission constructed a few experimental earthen-mound, avalanche breakers in the terminal zones of avalanche paths near Girdwood and on Pioneer Peak about nine miles south of Palmer. The first of their kind in

North America, they soon proved themselves by reducing the number and size of snowslides reaching the highway. Continued observation of the avalanche breakers has shown that their effectiveness can be increased greatly by adding to their height and by adding a third or even fourth row. See Figures 1 and 2 for profile and diagram.

Alaska's first avalanche diversion dikes were built in 1961 on Pioneer Peak in the main slide path above what is now called the Old Glenn Highway. Until the dikes were built, avalanches annually closed the highway. The closures sometimes lasted a full day, as the slide may have deposited snow some 50 feet deep and 200 feet wide on the highway. Now seven years old, the dikes have kept all but one snowslide off the road. That one was excusable; it was triggered by the Good Friday earthquake in March 1964, and is the largest slide ever observed there.

The obvious success of these two types of low cost defenses in a comparable climatic zone and similar geologic setting indicates their suitability for the Behrends Avenue area.

Site Details and Considerations

The proposed construction site is on the transitional slope at the base of the glacially truncated, southwestern face of Mount Juneau. See Map 1. Slope angle at the proposed dikes averages about 19 degrees and is somewhat less steep (about 17 degrees) at the proposed breaker locations. An adequate amount of suitable borrow material is available at the construction sites. Because of the high frequency of avalanches, vegetation for the most part consists of berry bushes, devils club and alder.

Somewhat below the upper dike and breaker system there is an existing system of stream collectors and a large culvert which carries the water to the

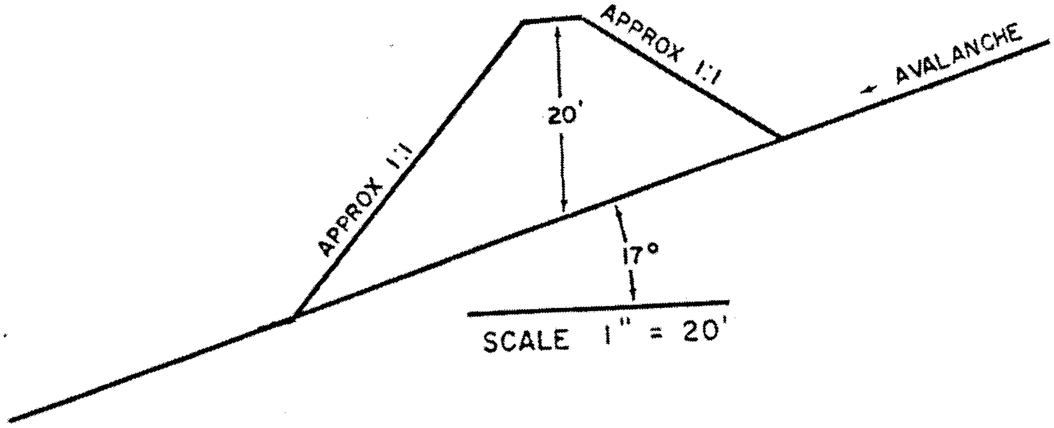


FIGURE 1 - PROFILE OF PLANNED AVALANCHE BREAKER

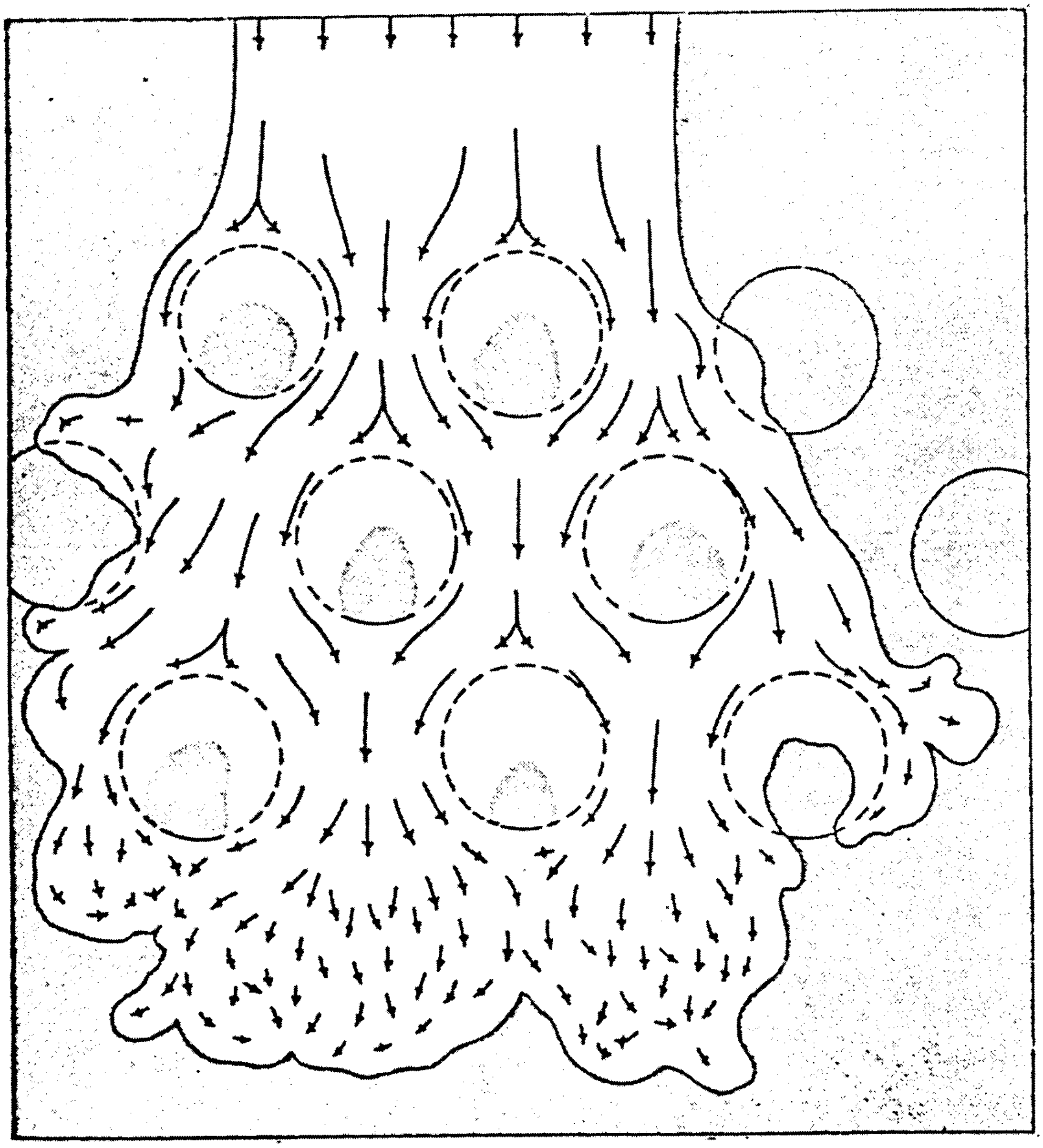
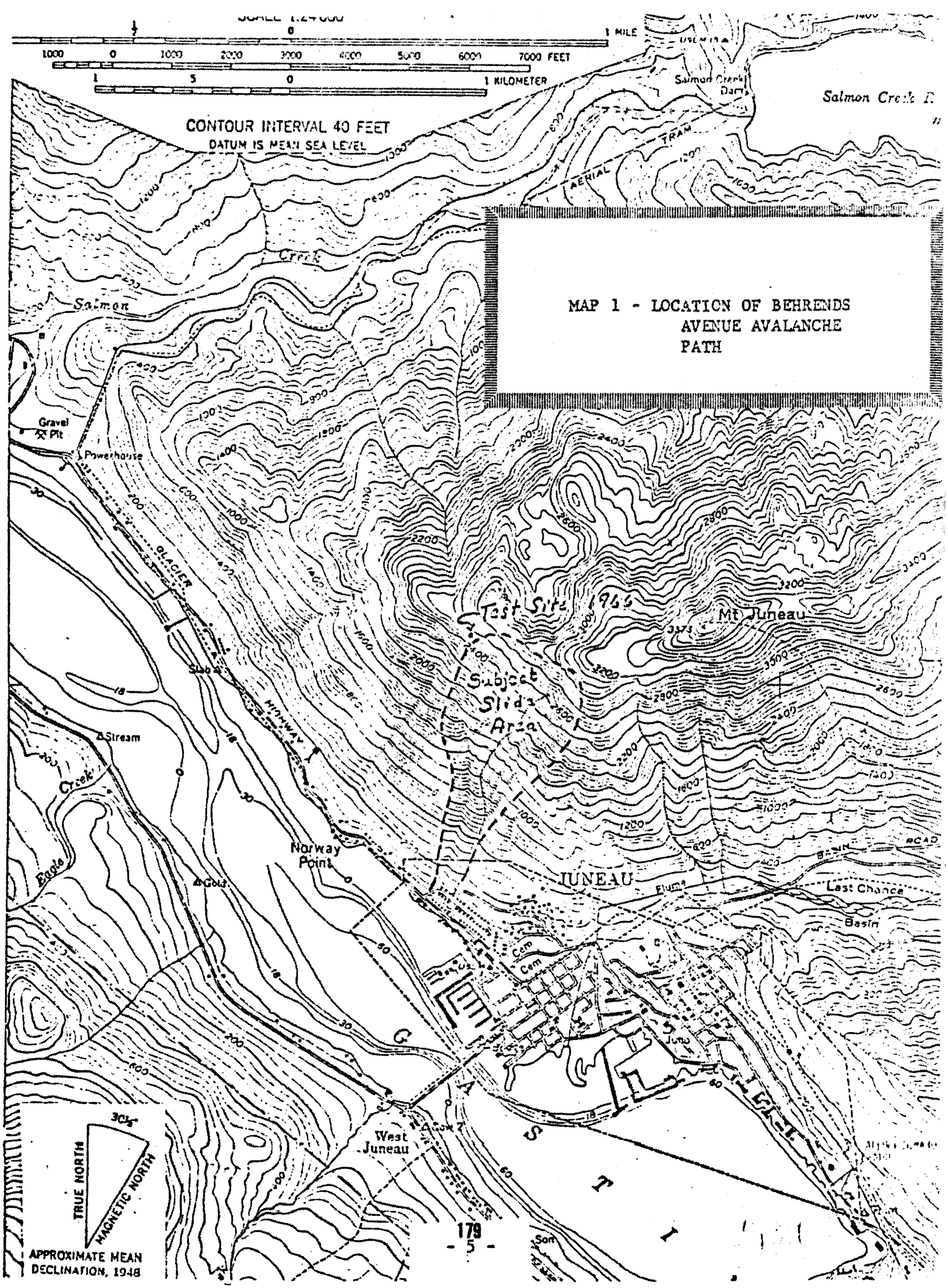


FIGURE 2 - SIMPLIFIED DIAGRAM SHOWING SPLITTING ACTION OF AVALANCHE BREAKERS



MAP 1 - LOCATION OF BEHRENDS AVENUE AVALANCHE PATH shoreline. Equipment operating in the area will have to avoid damaging the collector system and must not change the stream patterns. It will also be necessary that construction equipment does not unnecessarily destroy the natural protection afforded by the terrain and vegetation.

The land where the defenses are to be constructed is under governmental ownership or control. Therefore, there should be no great difficulty in obtaining permission to install the defense system.

Diversion Dikes

A dike sometimes may be used to deflect avalanches away from the object being defended or, as in the case of the proposed defense system, it can divert the avalanche to an area where avalanche breakers can arrest it. See Figure 3. Plan of Dike and Breaker System. The experience gained from the Pioneer Peak project has helped to establish site requirements and design criteria.

Possibly the most basic requirement is that wet and damp snowslides predominate as the airborne, high velocity type will not be controlled by a dike. Other requirements are that the avalanches must be at least partially confined at the point of intersection with the dike and that there must be an adequate depositional area. All of these requirements are met at the selected site.

Dike design criteria include the following:

a. The angle of interception between the diversion dike and the natural path must be slight, probably not greater than 30 degrees, otherwise snowslides will overrun the dike. However, once the slide direction has been changed, it is possible to alter its course rather sharply.

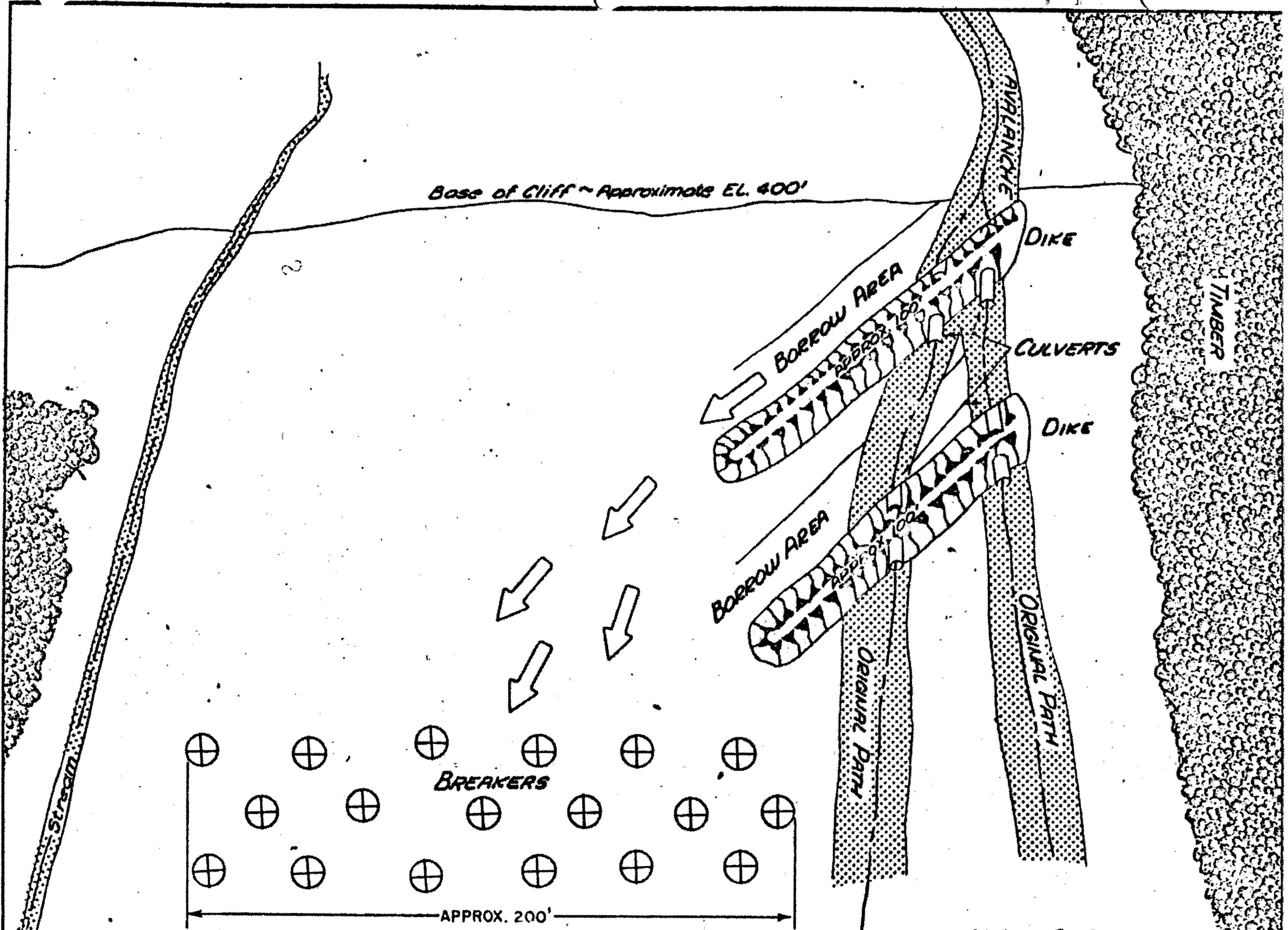


FIGURE 3 PLAN OF DIKE AND BREAKER SYSTEM

b. Whenever feasible, dike material should be borrowed upslope, thus increasing the effective depth of the new avalanche path while shaping it to obtain minimum resistance.

c. Dike height will vary with location, but 15-20 feet has proved adequate.

d. Greatest height of the dike should be at the point where the avalanches are intercepted. At this point the dike may be 25 feet or higher.

e. Slide velocity should not be appreciably reduced, otherwise deposition will occur in the diversion system and its effectiveness against later slides will be impaired.

f. Premature deposition will be minimized if the artificial path is made steep and narrow. At Pioneer Peak, the upper part of the artificial path is about 22 degrees gradient, whereas the original slope was only 1½ degrees steeper. Width of the Pioneer Peak diversion channel varies from about 35 feet at the top to about 25 feet at the lower end. Narrowing the channel apparently reduces surface friction and thus helps maintain slide velocity beyond the dike.

Avalanche Breakers

As Figure 2 shows, avalanche breakers divide the descending snow mass into smaller streams which are then redirected against one another and against the mounds or breakers in succeeding rows. The braking action of well placed earthen mounds is considerable.

The breakers should be built 20 feet high and be as closely spaced as possible, usually a bulldozer blade apart at the base. Material is borrowed from the upslope side of the mound.

It is recommended that seedling, native spruce and hemlock trees be planted on the lee slopes of the breakers. In time the trees will provide additional avalanche protection.

Periodic maintenance will be necessary to keep the breaker system free of debris and to maintain the mounds. The breakers at Girdwood and Pioneer Peak did not require maintenance for the first 10 years.

COST ESTIMATES

The costs are based upon construction near Girdwood and on Pioneer Peak some years ago and, therefore, should be regarded as being very rough. A D-9 Caterpillar tractor was used to build the diversion dikes and D-6 to D-8 size tractors were used to construct the breakers.

Diversion Dikes		
200 L.F. of earthen dike @ $12/L.F.[1]	$2,400	
160 L.F. of 36 in. Dia. C.M.P. @ $12.50/L.F.[2]	2,000	
Diversion Dikes Total		$4,400
Avalanche Breakers		
16 @ $400 each[3]	$6,400	
Avalanche Breakers Total		6,400
SYSTEM TOTAL		$10,800

---

[1] Fifty percent higher than 1961 Pioneer Peak project.

[2] It may be possible to reduce the diameter of the pipe and/or to combine the two streams which could reduce the costs.

[3] One hundred percent higher than Girdwood area breakers cost in 1956. The Girdwood breakers are only 12 feet tall but are located on much more difficult terrain.

CONCLUSIONS

The proposed defense system, consisting of two diversion dikes and possibly 16 avalanche breakers, will appreciably reduce the hazard from medium to moderately large, damp and wet type snow avalanches. It probably will not greatly reduce the danger from very large slides of these types; and it will be no deterrent to the large, high-velocity, airborne avalanches of the type that fell on March 22, 1962.

However, it is a structural defense system that appears to be within the financial capability of the area. Even if it stops only one potentially destructive avalanche, it will have repaid the initial investment many times over.

RECOMMENDATIONS

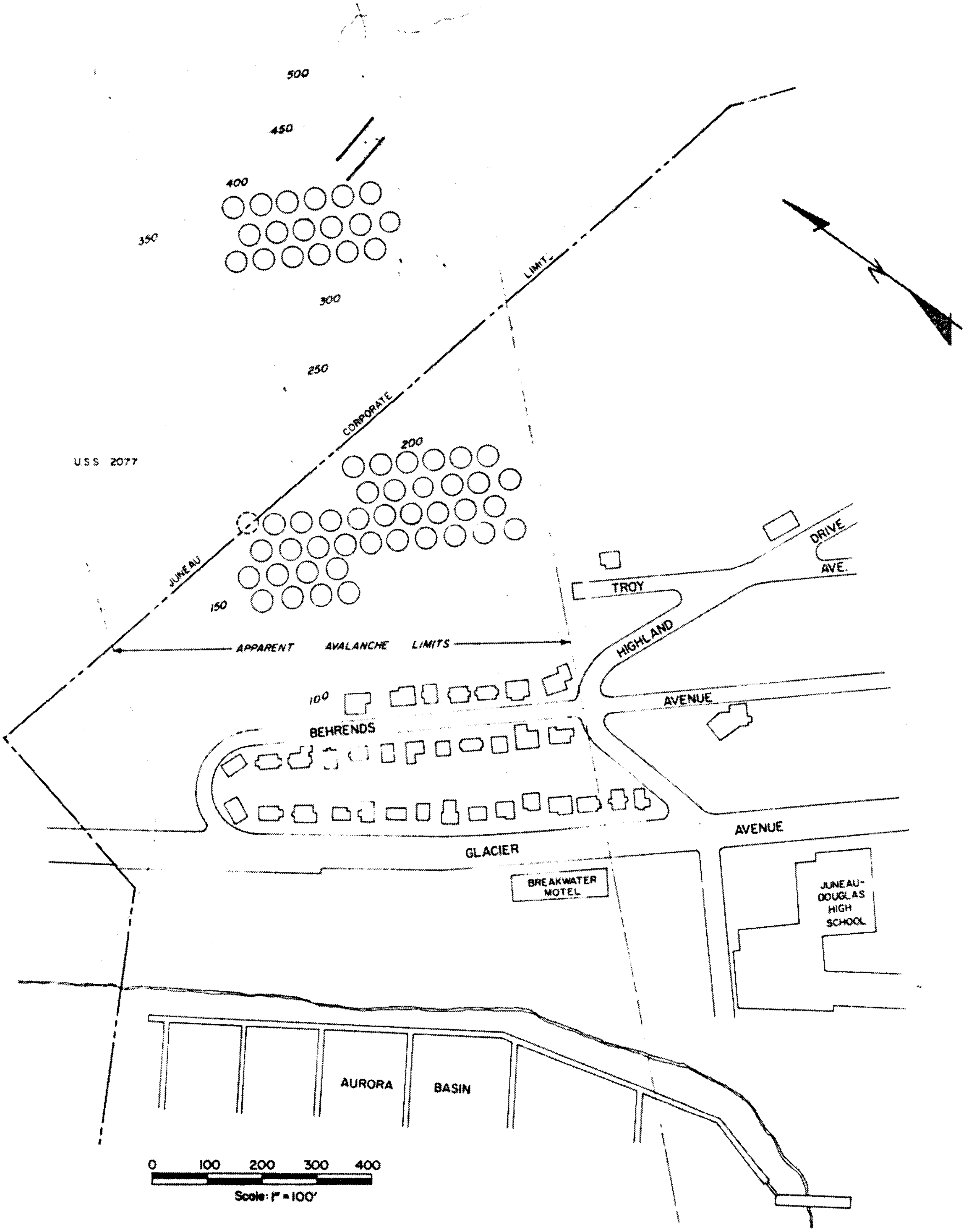
It is recommended that the City of Juneau and the Greater Juneau Borough make plans to implement this proposed defense plan as soon as possible.

It is recommended also that the appropriate governmental body determine if the cost of the proposed defenses should be borne wholly or at least in part by the benefitted property owners.

Further, it is recommended that an additional breaker system somewhat as shown on Map 2 be built as soon as possible. This second system is not of such high priority as the other. Ideally, they would all be built at the same time and preferably during summer 1968.

REFERENCES

The references are listed on page 20 of the Behrends Avenue report.



MAP 2

TERMINAL ZONE OF BEHRENDS AVENUE AVALANCHE PATH SHOWING APPROXIMATE LOCATION OF PROPOSED DEFENSES.

APPENDIX VIII

SELECTED AVALANCHE STRUCTURAL DEFENSES

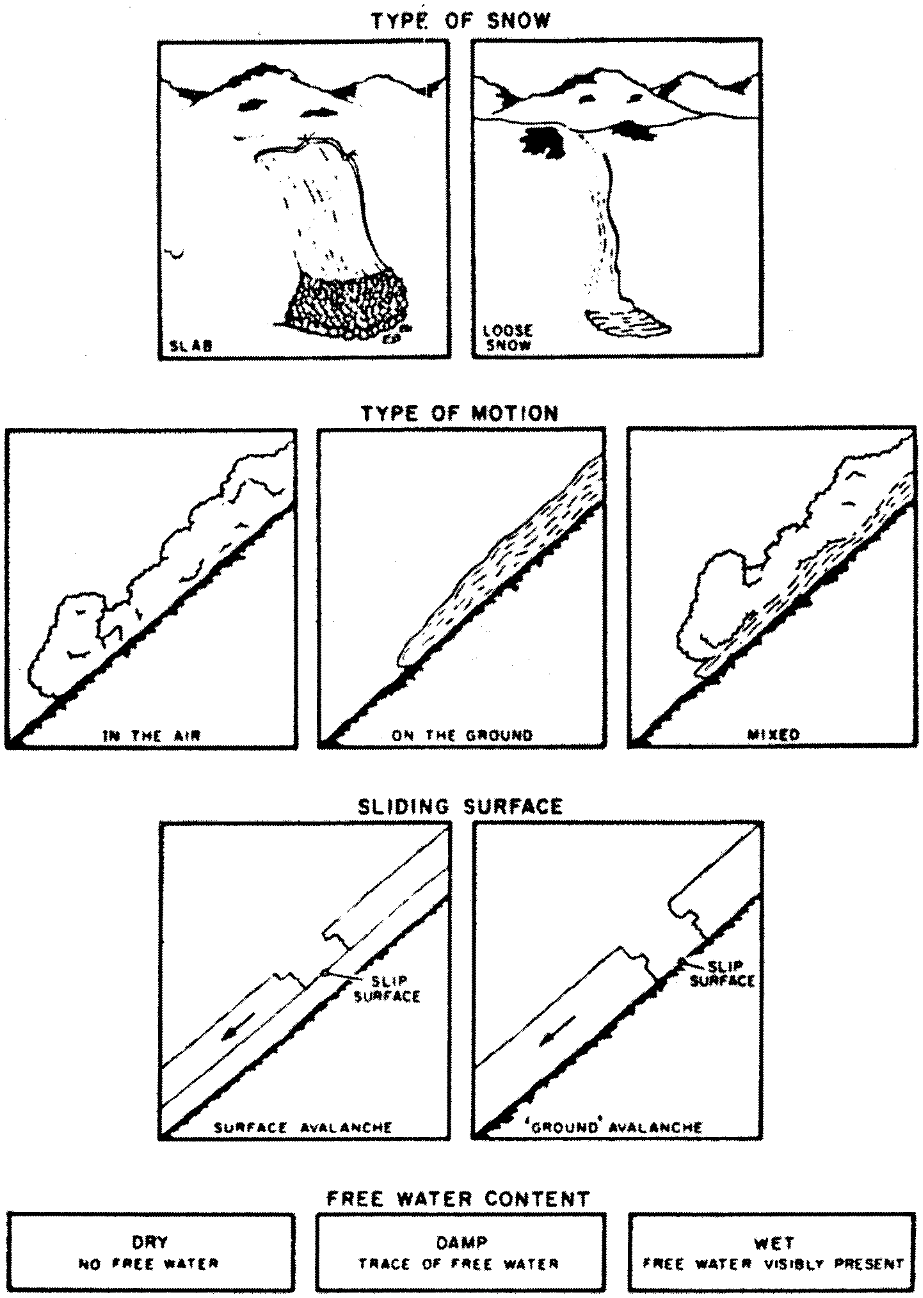


Figure 12. Current U.S. Forest Service avalanche classification.[124] It is conceivable that this classification might be modified in the future to conform more closely with the scheme given in Table II. The term "ground avalanche" should probably be changed to "full-depth avalanche."

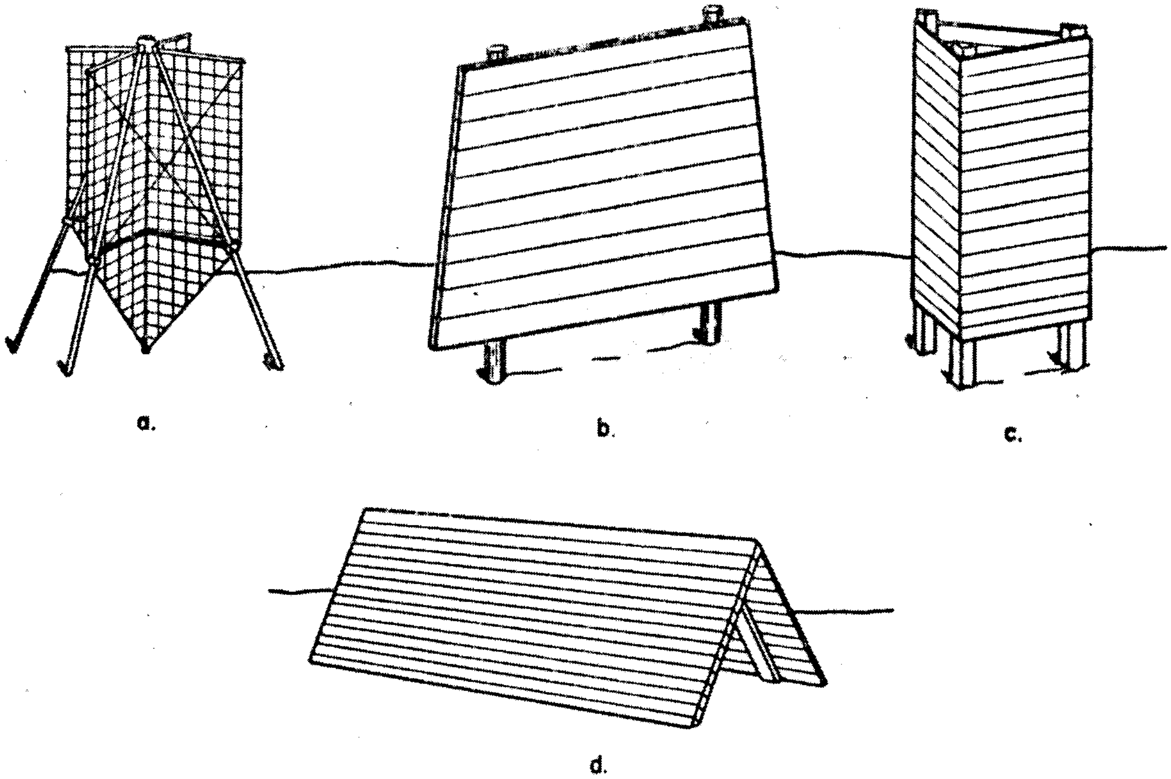
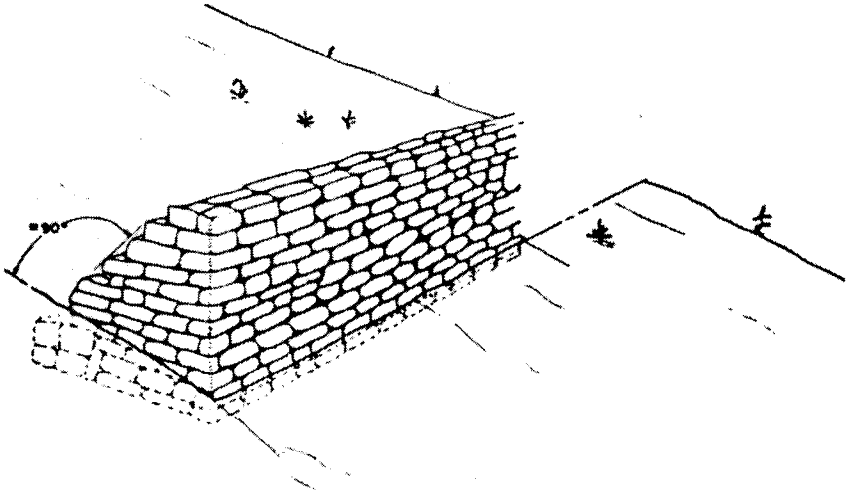
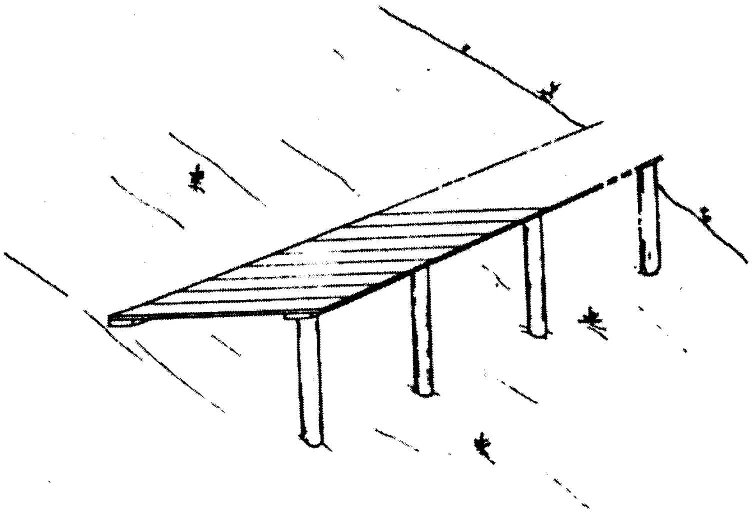


Figure 23. Wind baffles for modification of snow deposition patterns. (a) cruciform baffle (Treibschneekreuz), (b) "billboard" baffle, (c) triangular screen, (d) "tent" baffle.

Supporting works take a variety of forms, but most of them can be put into one of two categories: (a) retaining barriers whose support surface is inclined approximately normal to the slope plane, (b) steps or terraces whose support surface is close to horizontal. Early stabilizing structures included masonry retaining walls (Fig. 24a), cut-and-fill terraces (Fig. 25), timber barriers (Fig. 26a), and wooden terracing platforms (Fig. 24b), all laid out in ranks aligned at right angles to the line of greatest slope. Nowadays the favored type of supporting structure is a retaining barrier erected with its support face tilted some 15° downslope from a perpendicular to the slope plane. Manufactured materials such as steel and aluminum sections, precast concrete members, and steel or nylon netting are now widely used, although wood is still an acceptable material, especially in combination with metals. Obviously, natural barriers are much to be desired, and so the reestablishment of tree growth is an important long range goal in many schemes for the support of snow in avalanche starting zones. Reforestation is in itself a complicated problem, involving ecological considerations and introducing requirements for special structures (fences, tripods, terraces, etc.) to protect new growth.[65]



a. Masonry retaining wall - inclination of the supporting surface varying roughly from the vertical to a direction perpendicular to the slope plane.



b. Wooden ramp or platform - supporting surface close to horizontal.

Figure 24. Old-style supporting structures.

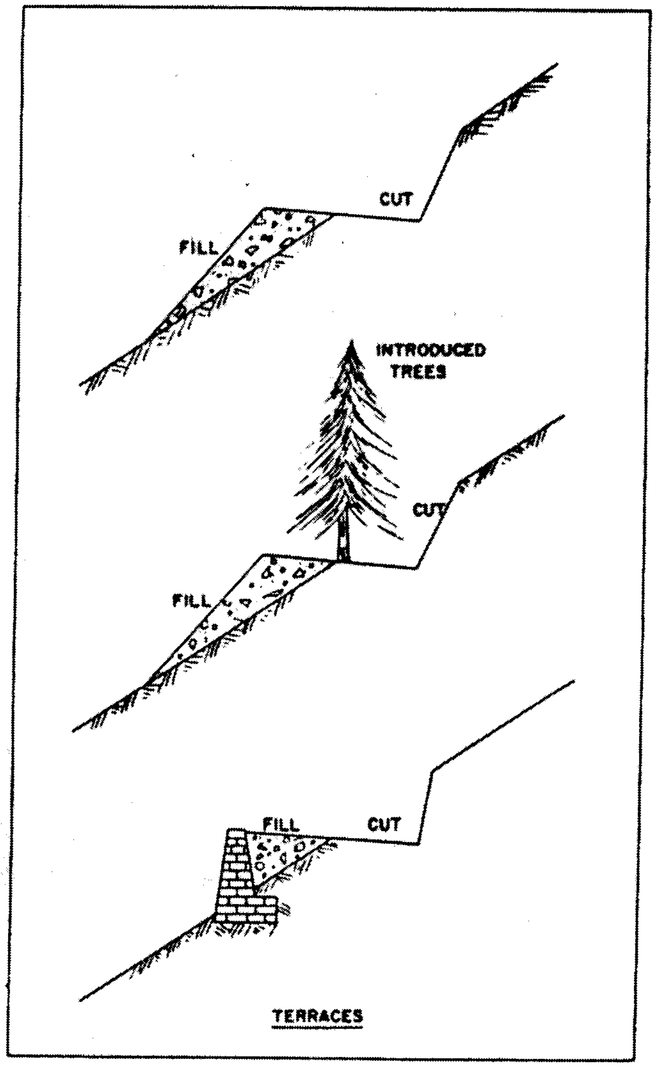
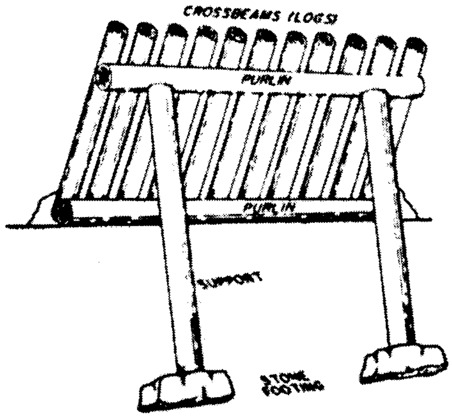
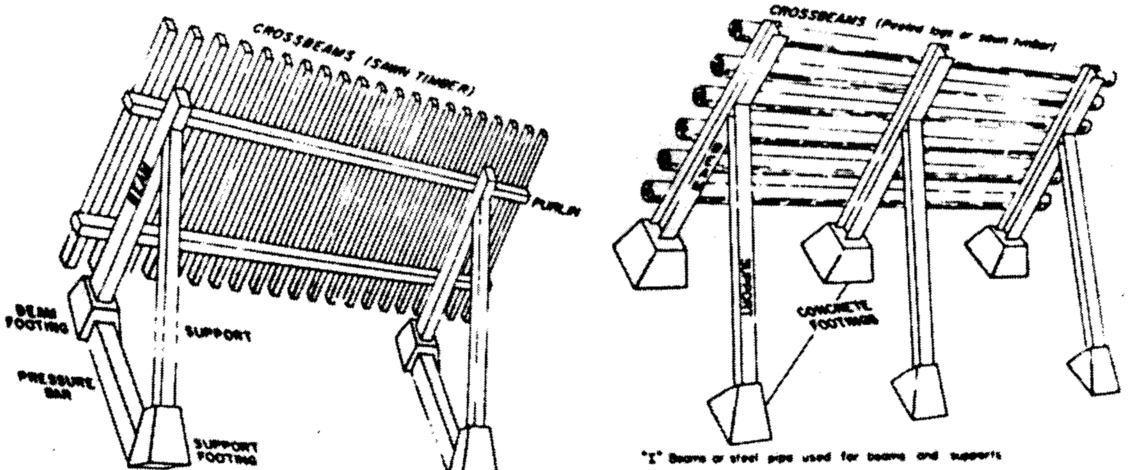


Figure 25. Cut-and-fill terraces.

A good supporting structure has a threefold purpose: (a) to provide direct support to the deposited snow, thus relieving downslope shear stresses; (b) to break the continuity of the snow cover along the fall line, hence limiting the effects of longitudinal strain; and (c) to check incipient slides. In order to meet this triple need, a structure must have the strength to resist both the static forces induced by creep and glide of the snow and the dynamic forces which may be imposed by snow slides which start between successive ranks of barriers; it must also extend from the general ground plane far enough to divide the snow cover. Considering these things it appears that, while terraces may occasionally be expedient and economical, fabricated structures erected approximately perpendicular to the slope will generally be the most efficient and economical answer to the problem. The design of these structures is considered separately later.



a. Simple snow rake (crossbeams upright) built from round timber.



b. Snow rake built from sawn timber on a concrete foundation.

c. Snow bridge (crossbeams horizontal) with concrete foundation, steel frame, and timber crossbeams.[120]

Figure 26. Supporting structures for avalanche starting zones. Rakes are more resistant to thrust concentrated near ground level, and they are less susceptible to damage from dense snow which slides after melting back from the barrier in spring.

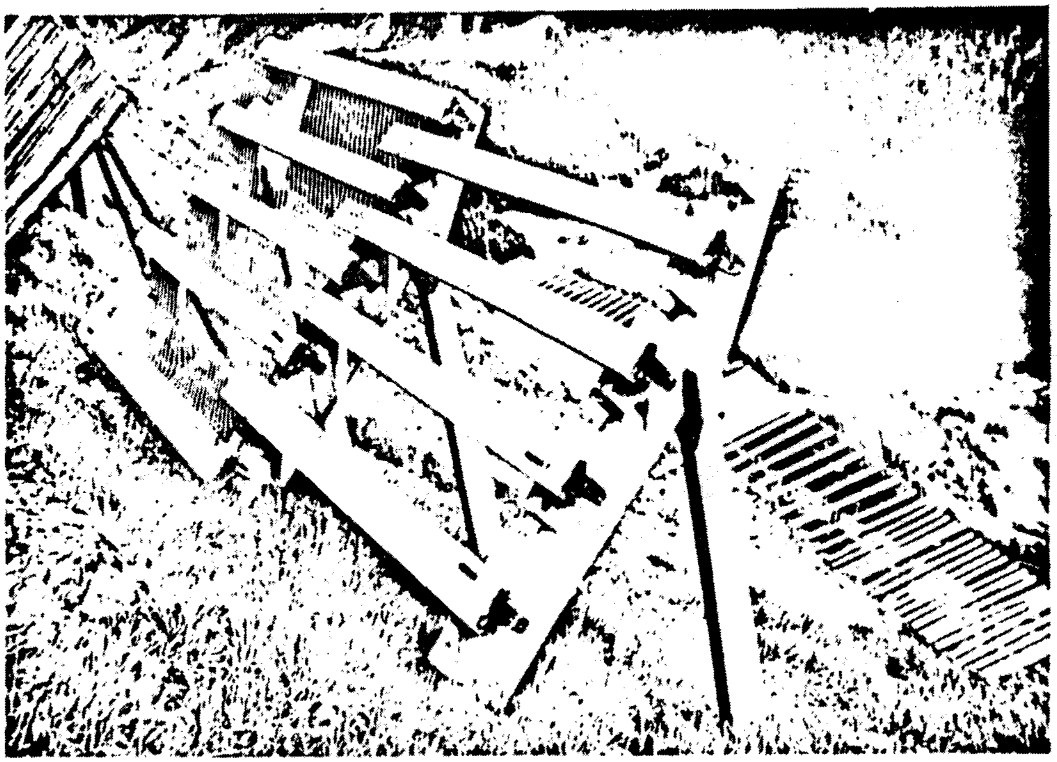
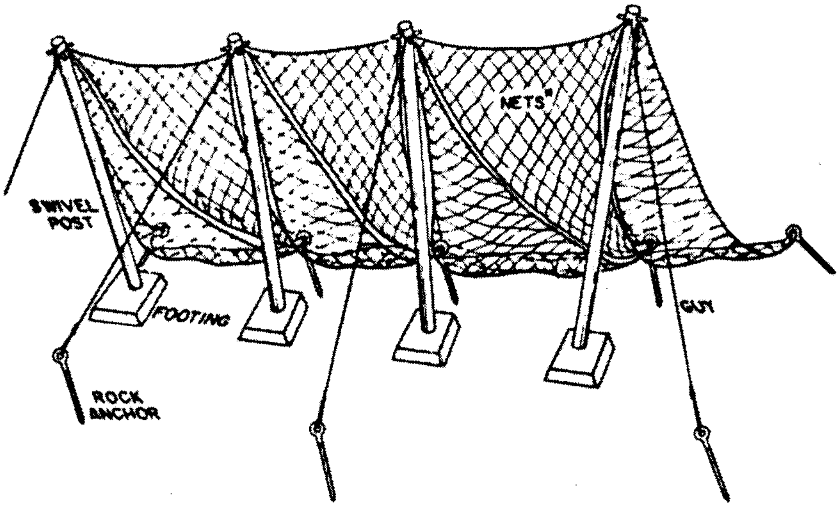
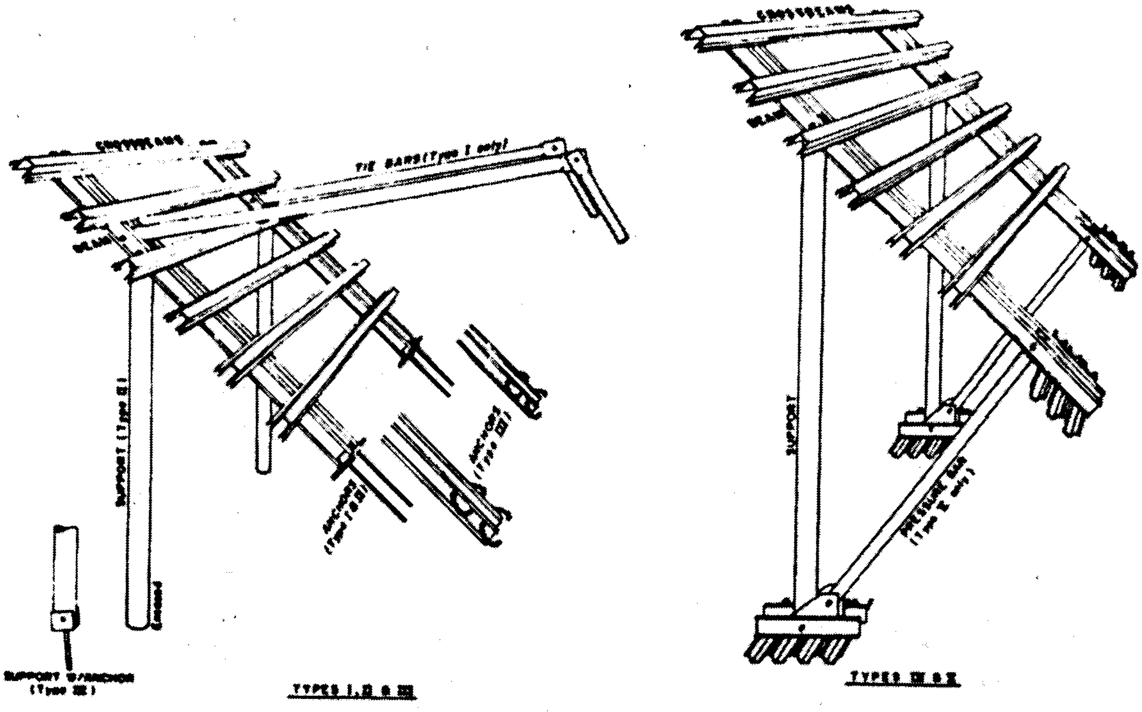


Figure 27. Prestressed concrete supporting structure at the Dorfberg experimental site, Davos, Switzerland. (Photo by E. LaChapelle.)

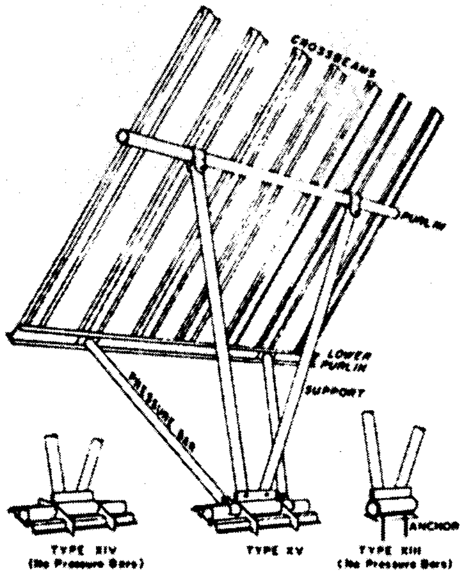


*Wire rope, netting, usually triangular shaped

Figure 28. Snow net. Nets are usually wire rope, about 8 mm (≈0.3 in.) diam with 12 mm (≈0.5 in.) diam edge ropes. Nylon nets (of the kind used as aircraft arresters) have been used, but prolonged exposure to ultraviolet radiation is thought to cause deterioration. Mesh size is about 20 to 25 cm (8 to 10 in.). Common sizes for triangular nets are (base x height): 1.7x2.5, 2x2, 3x3 and 3x4 m (≈5.6x8.2, 6.6x6.6, 9.8x9.8, 9.8x13.1 ft). Typical sizes for rectangular nets are 1.5x2.0 and 2.0x2.5 m (≈4.9x6.6, 6.6x8.2 ft). Posts are 3 to 4 m (9.8 to 13.1 ft) long, 10 to 17 cm (3.9 to 6.7 in.) diam, and anchor ropes are 1.3 to 1.6 cm (0.51 to 0.63 in.) diam. (For design, see ref. 28, 97.)

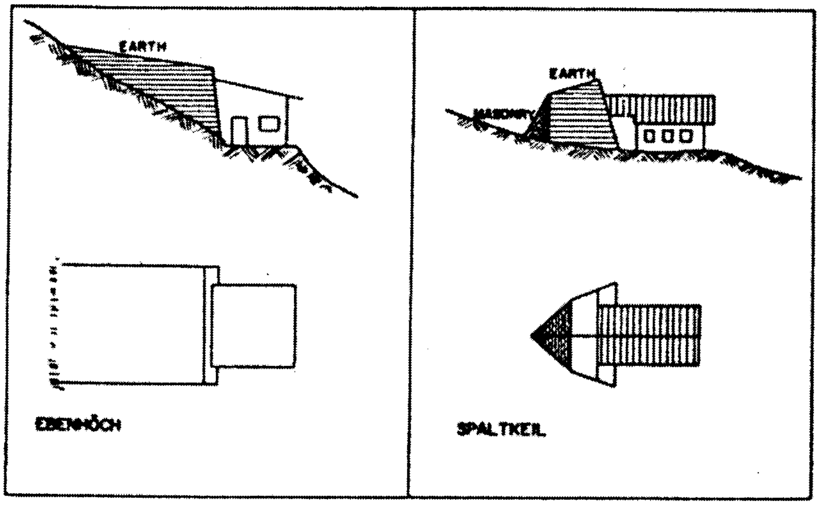


a. Snow bridges.



b. Snow rakes.

Figure 29. Designs for construction of supporting structures in aluminum and steel. (After Guler.[39])



a. Protective ramp. b. Protective wedge.

Figure 31. Deflecting structures.

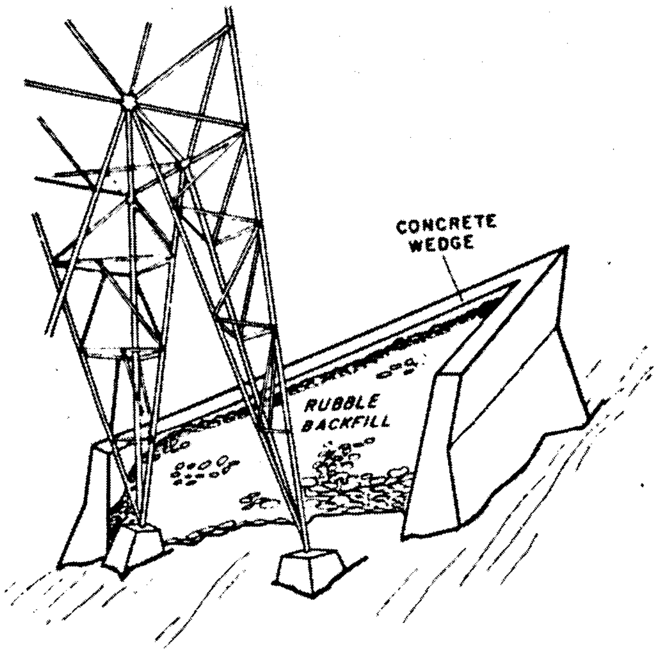


Figure 32. Concrete wedge for the protection of a pylon.

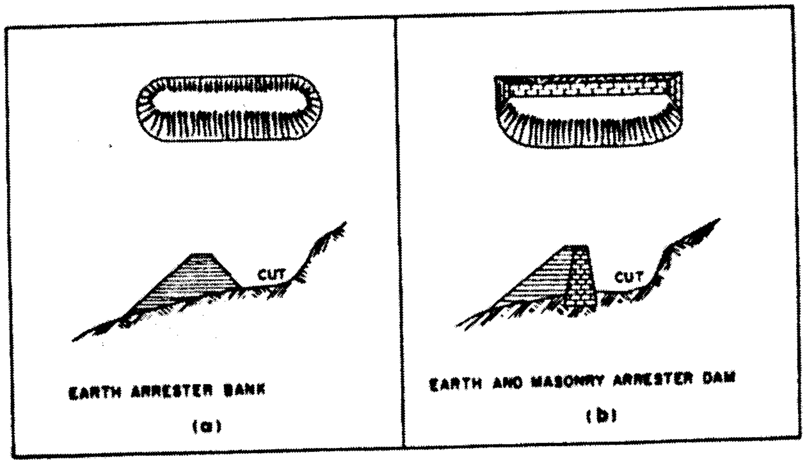


Figure 34. Cut-and-fill arrester dams, typically 3 to 5 m (10 to 15 ft) high. Arrester dams have not proved to be very reliable.

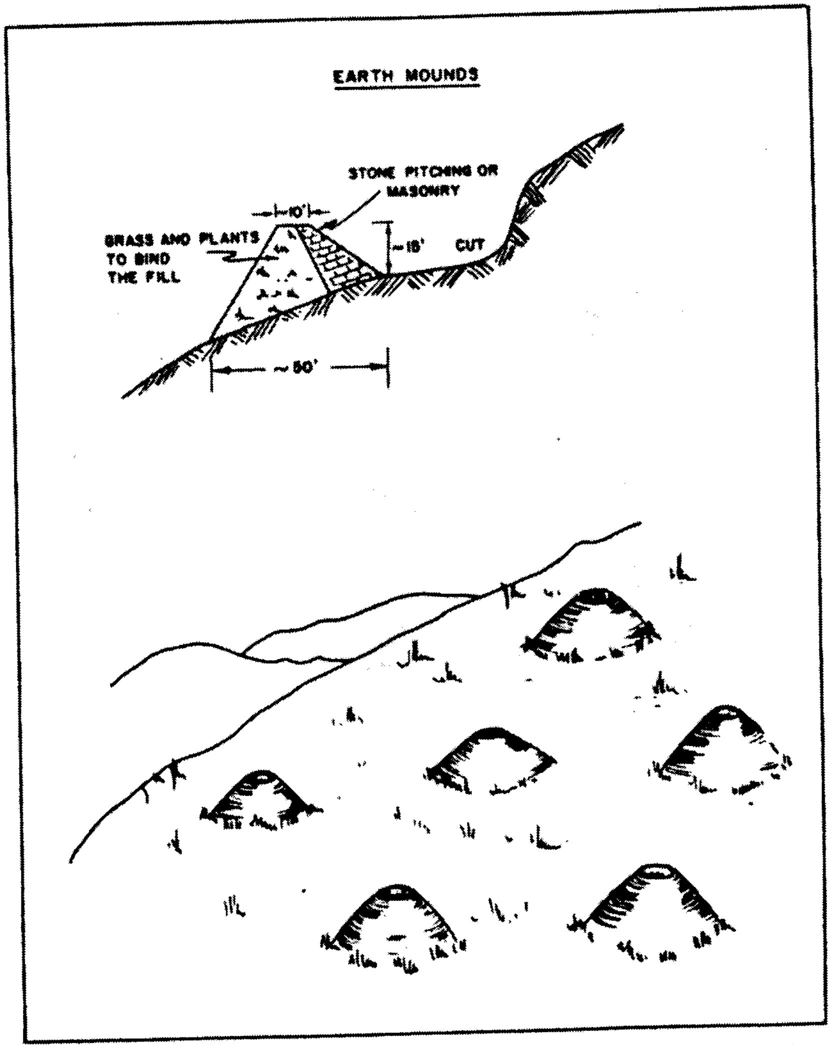


Figure 35. Earthen mounds for retarding or arresting slides.

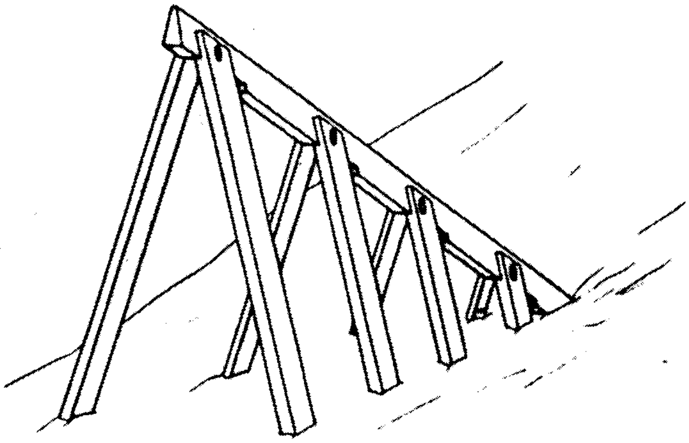


Figure 36. Precast concrete breaker ("concrete tripod").

Mounds are most effective against avalanches whose motion is largely on the ground (Fliesslawinen). Large, dry snow avalanches with much airborne motion tend to override them.

If it is undesirable to tear up the slope surface to build mounds, breakers can be built of other materials. Figure 36 shows a breaker built from precast concrete members ("concrete tripod").

Controlled release of avalanches

In sparsely populated areas and along lightly traveled highways it may be economically impossible to undertake avalanche defense construction, although human life still has to be protected. Under these circumstances the best solution appears to lie in deliberate release of avalanches while the danger zones are evacuated. This approach is widely used throughout the western United States and in Alaska by Forest Service personnel, highway departments, resort operators, and industrial concerns.

Whenever significant accumulation occurs in avalanche starting zones, access to slide paths is barred and attempts are made to dislodge the snow, usually by means of explosives. Not only does this ensure that slide paths are clear during avalanche descent, it also prevents the development of very large avalanches by periodically removing snow which might otherwise accumulate to dangerous proportions.

"Triggering" of avalanches, both natural and artificial, is discussed later.

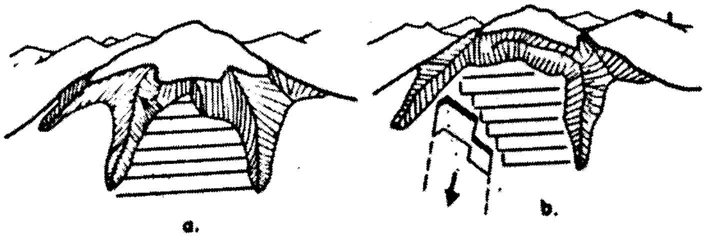
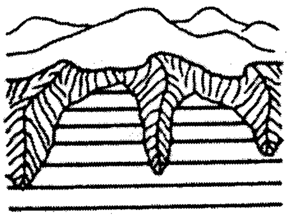
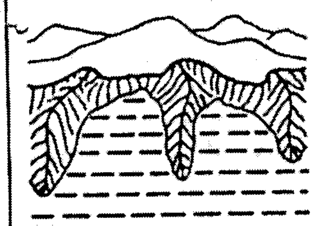
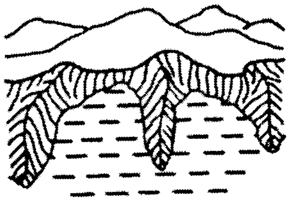
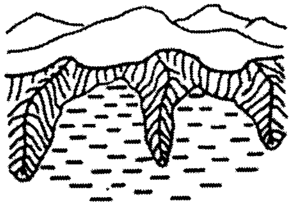
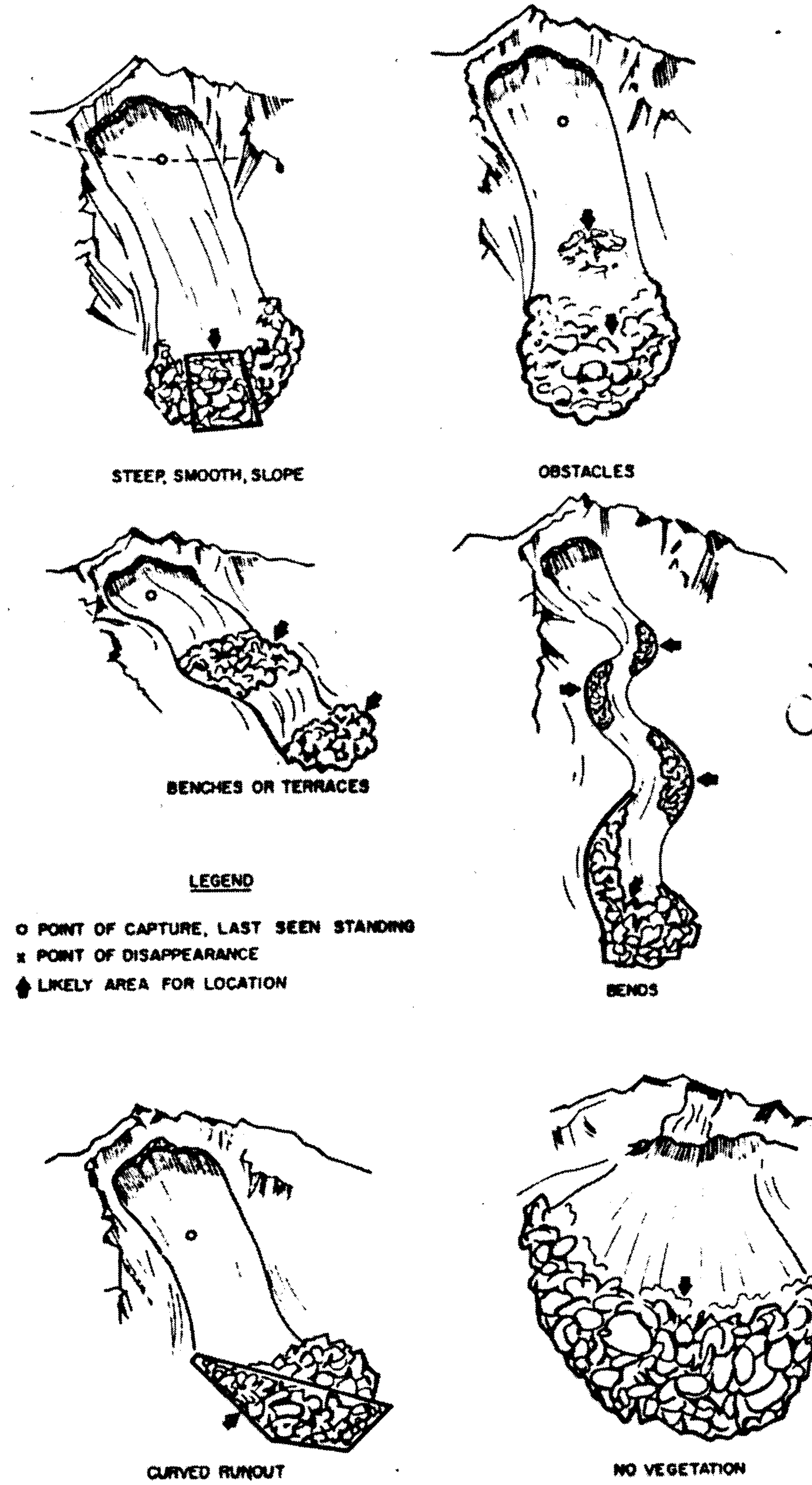


Figure 38. Schematic plans of defense works. (a) Complete protection extending laterally to natural terrain boundaries, (b) partial control with rows staggered to avoid slide damage at the free end.

Table VI. Arrangement of supporting structures (from Swiss Guidelines).

Arrangement	Advantages	Disadvantages
 Continuous	Continuous obstacle for loose snow slides. Tension stresses in the snow cover seldom develop. End forces are reduced to the ends of the work ranges (total snow pressure stresses are minimized).	Limited applicability on irregular terrain or broken ground and when the snow depths change locally. Large continuous areas of snow still exist where tensile and shear stresses can develop. Damage may be propagated laterally.
 Interrupted	A good fit to terrain configuration and to local changes in snow depths is possible. Damage from moving snow will be localized to single sections. Cheaper than the continuous arrangement in certain cases.	Loose snow can flow through the intervals. Each individual structure is subject to end forces.
 Echelon and staggered  Combination of discontinuous arrangements	Most adaptable to the terrain configuration in all directions. All permanent tensile and shear stress zones are divided. Gliding of snow cover between the works is reduced.	Stressing by end force corresponds to an isolated structure. Cost per unit length of structure is higher than the continuous and the interrupted arrangements.



Channelled

open-slope

Figure 70. Probable areas for the location of bodies buried in avalanche debris. The diagrams show possible effects of terrain features and capture locations on deposition pattern. (After ref. 9.)

APPENDIX IX

CITIZEN'S INFORMATION PROGRAM

MEMORANDUM

To: File

Date: June 28, 1972

From: Michael Mann

Reference: Juneau Hazards

Subject: Citizens Information Program

Following is a list of activities providing citizens information for the Juneau Hazards project.

		Participants						
1972		KH	MM	DS	HF	HM	ES	GP
May 25	Interviewed by Juli Chase of Empire	x	x	x	x			
26	Article published S.E. Alaskan Empire	x	x	x	x			
26	KINY Television interview 20 mins. with Bill Wally	x	x					
30	Rotary Club luncheon program		x	x	x			
30	KINY Radio interview 55 mins. with Bill Wally		x	x	x			
30	Interviewed by John Stringer, editor S.E. Alaskan Empire	x	x	x	x			
June 5	KINY Television interview by Bill Wally			x	x	x	x	
8	Chamber of Commerce luncheon program			x	x	x	x	x
9	Article published S.E. Alaskan Empire on Chamber meeting			x	x	x		
12	Planning Commission meeting public hearing		x	x	x	x		
13	Article published S.E. Alaskan Empire on PC meeting		x	x	x	x		

The initials designate the following participants:

KH	Keith Hart
MM	Michael Mann
DS	Doug Swanston
HF	Hans Fruitiger
HM	Harry Moening
ES	Ed Storms
GP	George Palmer

APPENDIX X

A SELECTION OF HISTORICAL NEWSPAPER ACCOUNTS

ANDREW WALLIN DIES FROM INJURIES RECEIVED IN SLIDE AND LOWRY MAKI AND HENRY JAEGER ARE STILL MISSING

Dead

ANDREW WALLIN, a blacksmith formerly employed at the C. W. Young Co. died at 5:30 last night. He was in the kitchen of the Koskey house when the accident occurred. He was taken out of the wreckage further down the hill suffering from a fracture of the left leg and cuts as well as internal injuries. He died at St. Ann Hospital.

Missing

LOWRY MAKI, 25 years old, native of Finland; employee of the Alaska Juneau mine.

HENRY JAEGER, miner formerly of Nome; moved from the Occidental Hotel five days ago to the Koskey boarding house. Was an old-timer of Alaska and owned mining property in this vicinity. He was about [illegible] years of age.

Injured

ST. ANN HOSPITAL

MRS. PETER KOSKEY, condition very serious. Today her pulse was stronger, but she is suffering from several fractured ribs which are pressing against the lung.

EMIL KAJANDER. Has dislocated hip and bruises about the head and body. He is in considerable pain. He is a brother of Otto Kajander, who owned the house which was destroyed. He was stopping at the Larson house.

VIANO KALLIO. Very badly bruised and cut about the head. He was asleep in the second story of the Larson residence. He remembers nothing until he woke up in the hospital. He will recover.

HENRY HEIONEN. Was asleep in the Larson house. He was carried down by the slide. He hung by his head, being jammed between some timbers for over two hours. He says he heard people talking all around him but could not move. He is badly bruised about the head and his body, and can move only his left arm. No bones are broken. Was the last man taken out.

JOHN NEIMI. Back strained and one finger cut. Was asleep in the second story of the Larson house and escaped through the roof when it broke up. Not badly hurt. He says his partner got out the same time that he did without any injuries. Both men came out in their underclothes.

AT DAWES HOSPITAL

PETER KOSKEY. Very seriously injured. Has internal injuries, an injured lung and a dislocated shoulder. His condition is considered serious.

JOHN LARSON. Has some cuts about the head and is bruised. His condition is not considered serious.

Estimated Property Loss

$3,000—John Larson house.
$8,000—Koskey house and belongings of roomers.
$12,000—I. Goldstein, loss of stock, cabins and apartment house.
$5,000—City of Juneau, loss of street and various items.
$3,000—Kajander house.
$500—Frank Oja house.
[illegible] personal property and to buildings on Front Street.
$31,000—Estimated Total.

Detailed Story of the Slide

The scene of the slide today presented a changed appearance. Every piece of wreckage had been turned over in the thorough search made for the bodies of the two missing men. It is the positive belief of the searchers and city officials that the bodies are not in the wreckage of the houses. Lines of hose have been laid and the whole hillside in the path is being ground sluiced by high pressure of water. If the bodies are there it will be only a question of time until they will be found as every foot of gravel and silt is being turned over and washed through an opening in Front street to the beach.

Recover Valuables

Careful search is being made of all the effects for personal property and articles of value when found is carefully watched and placed in a safe place under the direction of City Clerk J. W. Cole. A committee will have charge of identifying the property and giving it to its rightful owners. Many articles are being recovered. Considerable money and jewelry was in the wreck and much of it will be recovered.

Workers Are Busy

A gang of men from the Alaska Juneau Mining Company in charge of George Getchell continued active today in the work of clearing away the wreckage and sluicing away the gravel. They followed up the work done last night by the other men who were engaged in rescue work.

There is also a crew of men under the direction of Street Commissioner E. M. Polly clearing away wreckage from the vicinity of Gastineau avenue and making preparation to immediately reconstruct that [illegible]. This work was authorized by the [illegible] council at their meeting last night.

First to See Slide

Most probably the first man to see the slide was Lee Rice. He broke in the fire alarm box and sounded an alarm. Not waiting for the department to arrive he armed himself with an axe and flashlight and rushed into the mass of wreckage and rescued the first imprisoned victim. At this time cries and groans were issuing from all parts of the splintered mass of wreckage.

This individual rescue work was carried on until the arrival of the fire department which then took charge of the rescue work. The department was handicapped for a time for the lack of sufficient tools with which to work but soon these were coming from every source and with volunteers the men in charge soon began to get the imprisoned people out and send them to the hospital.

Three in Charge

The rescue work was quickly systematized into three distinct cooperating groups. The Juneau fire department which quickly responded to a general alarm was directed by Chief Jim Freeman, who was on the job all the afternoon and was [illegible] the night.

Fifty men of the Alaska Juneau joined the rescuers at 12 o'clock [illegible] a half hour after the slide. They were in charge of George [illegible] foreman and [illegible] on the job until six [illegible] they were joined by [illegible] men. These under charge of Foreman [illegible] Gerbeck. At 1 a. m. another [illegible] of Alaska Gastineau [illegible] making 115 from the company. [illegible] of them returned [illegible] at midnight and the others remained until relieved this morning [illegible]

Among those who worked hard and faithfully were men from the [illegible] Chief of Police [illegible] W. [illegible] Street Commissioner E. M. Polly [illegible] and [illegible]

WORST SLIDE IN HISTORY OF JUNEAU TEARS DOWN HILL TO FRONT STREET AND TAKES ALONG SIX BUILDINGS IN ITS PATH

THE INJURED

MRS. PETER KOSKI—Injured very badly internally and broken ribs.

PETER KOSKI—Badly injured internally.

ANDREW WALLIN—Left leg broken and left hand badly bruised. He was in the kitchen of the Koski house at the time of the slide.

VIANO KALLIA — Badly bruised. He was asleep in the second story of the Larson House.

VIANO FAJANTERI—Dislocated right hip. Badly bruised about the body. Was in Larson house.

JOHN NEIMI—Injured back. Was in Koski house.

HENRY NEIMI—Bad cut on head and bruises about the body. Was in Larson house.

JOHN LARSON—Badly injured, in Larson house.

ONE IS MISSING

LOWREY MAKI—Was rooming in the Larson house.

With eight injured and in the hospital, one missing and six buildings destroyed and others damaged, [illegible] estimated at $28,000, one of the worst [illegible] the history of Juneau took place at 11:30 a. m. [illegible] melting snows and heavy rains, for a distance of approximately 500 feet, starting below the flume of the Alaska-Juneau [illegible] and tearing its way down to Front Street, and jamming the buildings which were carried down the hill against the rear of I. Goldstein's store and James Russell's gun store. In the Koski boarding house which the slide struck about 200 feet after it started, were ten or fifteen inmates, most of whom were sleeping, who were carried down with the house. Several of them were injured and were taken to the hospital after they chopped out by gangs of rescue workers.

The mass of rocks and rock and mud carried along several houses which jammed against the Front street business houses and piled up behind into a tangled mass.

[illegible] Koski boarding house [illegible] side of Gastineau avenue. This was a two-story house with from [illegible] inmates. [illegible]

Houses Crash Together

[illegible]

Several Eye-Witnesses

[illegible]

[illegible] taken to the hospital while it was the work of hours to get others out. Men and women could be heard groaning in places where the rescuers could not reach at once. Volunteers assisted greatly in moving the wreckage so that the injured could be taken out.

Have Narrow Escapes

Many inmates of the wrecked houses had narrow escapes. This was certainly true of [illegible] escaped from the [illegible] with [illegible] and dirt and [illegible] way from the scene [illegible] man who was asleep [illegible] the accident occurred [illegible] in his [illegible] other man left the Koski a few minutes before it.

Big Storm [illegible]

The storm that has [illegible] this time of [illegible] southeaster has [illegible] with heavy rains that [illegible]

DELAYED BY [illegible]

[illegible]

ALASKA ALSO DELAYED

The steamer Alaska which arrived [illegible] was delayed in arriving from Westward points by a [illegible] storm. The boat brought [illegible] passengers to Juneau: [illegible] A. Barclay, [illegible] Johanna, Mrs. [illegible] Elmer B. Bange, [illegible] Lovell, Mr. and Mrs. [illegible] A. McGettman, F. [illegible] Walter and L. [illegible] with the passengers [illegible]

(Continued on Page Eight)

WORST SLIDE IN HISTORY JUNEAU IS EXPERIENCED

(Continued from Page One)

[illegible] Mrs. Paul [illegible] H. R. Tucker [illegible] Mrs. [illegible] Thompson [illegible] Fred A. [illegible] Frank [illegible] Tucker, H. [illegible] Mrs. C. H. [illegible] Mrs. W. [illegible] Wm. [illegible]

WORST STORM OF JUNEAU'S HISTORY WAS YESTERDAY'S

GOLD CREEK MOUNTED TO HIGHEST CREST ON RECORD

Rainfall for Twenty-four Hours is Over 3 Inches. Downpour Starts Slides. Douglas House Moves

[illegible]

[illegible] One Visiting

[illegible] Saturday night was [illegible] the bluff opposite the [illegible] was [illegible] amazed when the house came to a stop six or twenty feet away from its location. The house would very likely have gone into the bay had it not hit the Japanese bar[illegible] Japanese [illegible]

THE DAILY ALASKA EMPIRE, FRIDAY, NOV. 27, 1936

LAST RITES FOR SLIDE VICTIMS BEING ARRANGED

Seven Will Be laid Away in Juneau — One Body Taken to Sitka

Arrangements for final rites of several of the [illegible] have been made as follows:

Forrest Beaudin, Saturday morning, 9 o'clock from the Catholic Church. The Rev. W. G. Le Vasseur will conduct the services. Pallbearers are to be Pete [illegible], Wendel Schneider, Charlie [illegible], Ted Smith, Wesley Turner and Elbert Beyer.

Mr. and Mrs. James Hoag, Saturday afternoon at 1:30 o'clock at the Charles W. Carter Mortuary Chapel. Pallbearers: Clyde [illegible], Harvey [illegible], [illegible], Guy Mayer, O. H. [illegible] and Dave Barnett. Music by Mrs. Fred [illegible], Joseph McCormick and Walter Peterson.

Mr. and Mrs. Hugo Peterson, Sunday morning at 10 o'clock from the Charles W. Carter Chapel. Rev. Robert K. [illegible] will officiate.

Mrs. Gust Erickson, Sunday afternoon at 1 o'clock from the Charles W. Carter Chapel. Rev. John A. Glasse will conduct the services.

Mrs. Lena Peterson, Sunday af-

2 MORE BODIES ARE RECOVERED OVER HOLIDAY

Mr. and Mrs. Hugo Peterson Found in Wreckage of Own Home

(Continued from Page One)

is possibly a third person, an elderly man, still buried in the debris. He has not been identified, but the Mayor said today reports persisted that such a man lived in the Nickinovich Apartments and probably is dead somewhere in the wreckage.

If the three bodies are found, the death toll will reach the appalling total of 15 persons.

Speeding Work

The work of clearing away and searching for bodies is progressing at top speed through the 24 hours of each day and the Mayor emphasized it was being pushed in the hope of clearing it up and recovering all bodies before a possible sudden freeze or cold weather comes on which would make the work particularly difficult if not stopping it entirely.

Possessions of the victims are being continually found in the debris and among the articles found yesterday was a woman's purse containing [illegible]. The purse was be-

[illegible] DOWNPOUR LOOSENS MT. JUNEAU HILLSIDE

Two earth slides an hour apart yesterday evening badly damaged a residence at Erwin Street next to the Gold Creek bridge and a mother and two children fled in panic from a debris filled living room.

Mrs. Dorothy Spence, [illegible] Erwin Street, and her two children, [illegible] and Michael [illegible], narrowly escaped when the slide thundered down the hillside and smashed in their living room window flinging mud and rock into the house two feet deep.

In the basement of the Spence home a new washing machine and new drier were buried to their tops.

A first slide came down the steep hill across the street about five o'clock yesterday evening, cutting wires and setting off a single blast of the fire horn.

A second slide came down an hour later and filled the street to an estimated 15 feet deep with mud, large boulders and stumps.

The residence of Mr. and Mrs. Bob Rogers, adjoining the Spence home, suffered little damage, although a newly prepared lawn area in the front yard is filled today with over a foot of gooey mud.

Rogers, an employee of Lemon Creek and Gravel Company, today ruefully surveyed his front yard

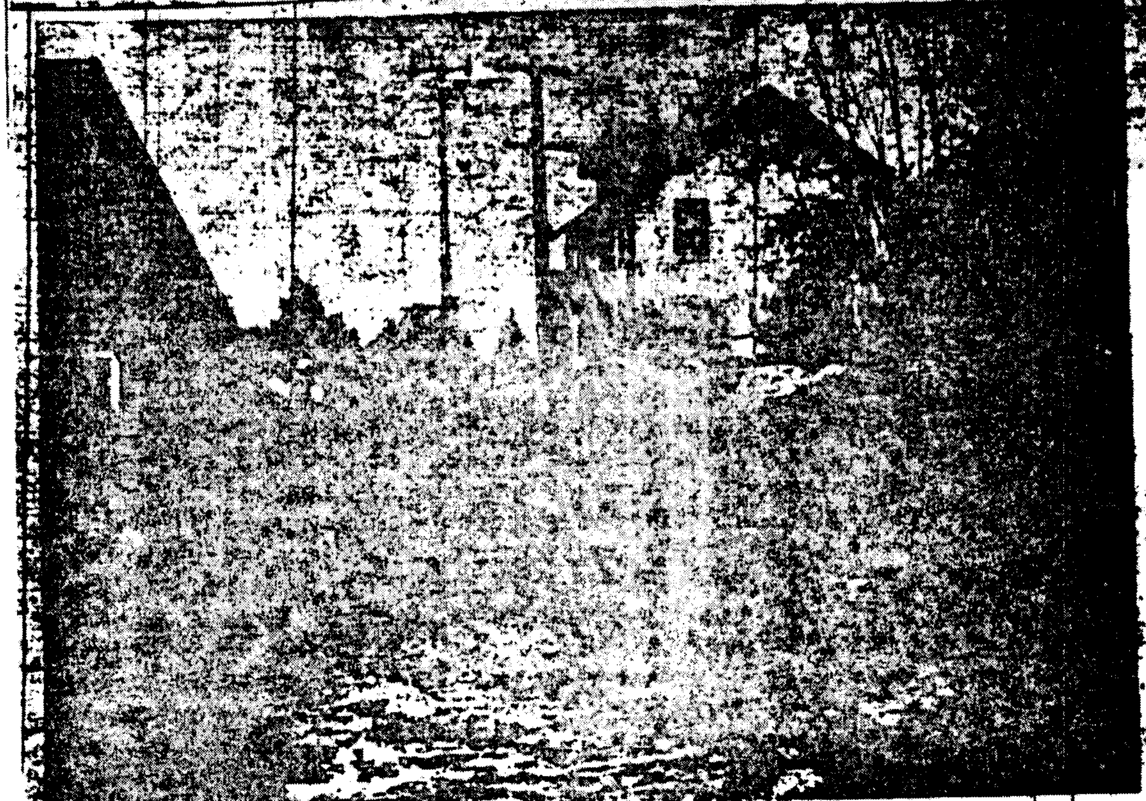
[illegible]

So badly torn and mutilated was the body of [illegible] when found that it required the [illegible] by close friends and a lodge card found in his clothing to make positive his identity. The widely known [illegible] man probably never knew just what happened. He must have been killed instantly.

A 24-hour day of three shifts each is being maintained at the scene of disaster in an effort to locate the remaining bodies. It is felt virtually certain now that at least eight are still buried somewhere in the mass of ruins. Hope for finding any living has passed, those at the digging report.

Those reported still missing are
Mrs. Lena Peterson
Mr. and Mrs. Hugo Peterson
Mrs. Fred Matson
Joe Vanalt.
An elderly man who lived in the Nickinovich apartment, whose name has not yet been ascertained.

The dead are
Mrs. Gust Erickson.
Mr. and Mrs. James Hoag
Forrest Beaudin
Lorraine Vanalt
Pete Bettelo
Mrs. Joe Vanalt



Damaged House Shown at Left

[illegible] JUNEAU—The picture above was taken from the Gold Creek Bridge this morning as work crews continued to clear the debris that last night's slide piled high on Erwin street, completely blocking traffic and damaging residences in the area.

City Swept by Severe Rain Storm

2.89 Inches Falls in 24 Hours—Third Wettest September Fall

Reviving memories of the terrific rain storm of September, [illegible] which flooded downtown [illegible] damage and [illegible] swept in all the city this [illegible] recording a total fall of 2.89 inches in 24 hours ending at 3 a. m. [illegible] morning. At noon today the fall was 3.[illegible] inches [illegible] p. m. Wednesday, [illegible] the present deluge [illegible]

[illegible]

It is the [illegible] rainfall in the [illegible] Weather [illegible] was established [illegible] and [illegible] of [illegible] inches of [illegible] high mark for 1932.

The total [illegible] since September, [illegible] 6.89 inches, [illegible] er Bureau, the [illegible] September is [illegible]

Drains [illegible] [illegible] by the [illegible] streets and sew[illegible] enough to carry [illegible] was below [illegible] of Fifth and [illegible] and [illegible] [illegible] today at the [illegible] drains and [illegible]

This morning [illegible] near the A. J. [illegible] Front Street [illegible] ed the street.

Rain Unusual

The specially [illegible] banks of Gold [illegible] very well. During [illegible] month ago [illegible] rock bank [illegible] waters but the [illegible] by city work[illegible] subsided and [illegible] holding the [illegible] ly, it was [illegible]

[illegible] heavy rains [illegible] area from [illegible]

Elton Spence had other problems today, in addition to his wrecked home. The slide disrupted schedules of Spence's city busline which normally makes the swing around 12th street and over the Gold Creek Bridge.

City street crews labored all night on the slide, but it was not believed the street area could be opened to traffic until late this evening.

The Erwin Street slide was not [illegible]

[illegible] and slides endangered the highway at several points.

On the Glacier Highway, a number of streams jumped their courses and a few minor slides were reported.

Although rainfall records at the airport showed less than two inches of rain in the past 48 hours, it was estimated that the rain gauges on the Federal Building here would show closer to four inches of fall, with a driving southeast wind and sheets of rain piling up the total at presstime.

Weather forecasters pointed out that unseasonably warm temperatures that went up to 48 degrees at the airport today added to the flow of runoff water with heavy melting of snows on the mountains.

Freezing level was estimated [illegible] around 3,000 feet altitude and [illegible] temperatures should melt all [illegible] up to 2,000 feet.

By [illegible] weatherman [illegible]

[illegible] and

ANDREW WALLIN DIES, TWO ARE STILL MISSING

(Continued from Page One)

[illegible] men, laborers [illegible] men and people from every walk of life [illegible] in the frenzied effort and those who could be found [illegible] and crying.

Along the Workers

At [illegible] open [illegible] for the purpose of [illegible] making a place where [illegible] warm [illegible] [illegible] [illegible] [illegible] going [illegible] gloves [illegible]

[illegible] all night.

Sensational [illegible]

[illegible]

When the slide hit the rear of the house, Crosby woke up. He said the walls all seemed [illegible] and then the whole house was falling to pieces around [illegible]

The elder Crosby's bed[illegible] and most of the rest of the house [illegible] swept down the hill [illegible] but the back bedroom [illegible]

[illegible]

LIST OF DEATH GROWS AS WORK MOVES FORWARD

Lorraine Vanali, Pete Bottello, Mrs. George Lee Found in Wreckage

CHILD LIVES TWO HOURS AFTER RESCUE

Pitiful Tale of Suffering Revealed with Locating of Small Child

The body of Oscar Lahe of Sitka, who had been rooming at the Mohawk Boarding House while here for medical treatment, was found shortly after 1 o'clock this afternoon in the slide wreckage. The recovery [illegible] at Carter's.

[illegible] have been [illegible] wreckage on Lower [illegible] in the wake of [illegible] bringing the [illegible] and leaving [illegible] to hope [illegible] alive [illegible] [illegible] death [illegible] persons.

[illegible]-year-old daughter of Mrs. Joe Vanali [illegible] body having [illegible] was [illegible] at [illegible] Ann's Hospital [illegible] victim of exposure [illegible]

[illegible] the body of Mrs. [illegible] found in the same [illegible]

Suffered Terribly

The child must have suffered beyond comprehension. The huge timber held her arm fast, and the small place she was in gave her no place to move her tiny body. Examination later revealed blisters on the back of her little legs showing that flames had licked viciously and

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[illegible] family had [illegible] had escaped [illegible] dirt slide [illegible]

[illegible] Charles A. [illegible] was asleep in the [illegible] Apartment building when the slide occurred. He said he did not know the slide [illegible] and he and his wife and son [illegible] went to the [illegible]

Mrs. [illegible], who lives with her husband at the [illegible] and she [illegible] away from the Light [illegible], said they were not awakened by the slide.

"We heard it hit. That was all," she said. "By this time it was too late to be afraid."

They remained in their home after the [illegible]

[illegible]

This morning Mayor Walter [illegible] surveying the wreckage [illegible] city crews had been working [illegible] He said each [illegible] to keep the storm drains [illegible] and prevent slide-causing saturation of the hillside.

He said the city would help clear up the wreckage.

Street crew men on storm-drain [illegible] at the time of the slide were [illegible] Harris and John [illegible]

EARTH SHOCK

PETERSBURG, Alaska, Oct. 31—(AP)—A light earthquake shock was felt here yesterday at 3:46 p.m. (PST). No damage is reported.

SEATTLE, Oct. 31—(AP)—Two [illegible] were registered on the [illegible] of Washington seismograph yesterday. They were estimated to have occurred about 1,000 [illegible] [illegible] starting at [illegible] PST, lasted 45 minutes. It [illegible] moderate strength. A second [illegible] described as weak, started at [illegible] lasted seven minutes.

[illegible] Faster, faster flew the [illegible] Hard and calloused men [illegible] have flirted with death [illegible] to feverish heights [illegible] as they heard that plaintive little voice call for "Mother."

[illegible] was rekindled. There was still life in that [illegible] mass of [illegible] rock and trees.

Around the town went the report that a child was being found alive. From all directions came men, women and children [illegible] [illegible] buoyed up by hope of recovery of a little child.

Men Worked Like Mad

Experts at such work declared it was a job of from two and a half to three hours to reach the child. The crowd grew bigger and quieter. Men shoveled and dug like mad. Nothing could deter them [illegible] [illegible]

[illegible]

Over the prison of little Lorraine [illegible] close friend of the Vanali family and "pal" of Lorraine, tried to converse with the child as he labored unceasingly with his companions, many of them hard rock miners from the A. J., others from various walks of life.

Battle Goes On

On and on went the battle. Dinner time came and passed but the desperate efforts moved with quickest [illegible]

ANDREW WALLIN DIES FROM INJURIES RECEIVED IN SLIDE AND LOWRY MAKI AND HENRY JAEGER ARE STILL MISSING

[illegible] to the waiting ambulance. Dr. Dismon climbed in with her and away to the hospital rolled the vehicle.

The tension was broken. Men tacked on in search of others. [illegible] at 9:30 [illegible] hours after the avalanche had [illegible] [illegible] [illegible] the city.

FLOOD OF 1918—This picture, taken by George Messerschmidt of the Purity Bakery here, shows how the flood of 1918 damaged the same area on Gold Creek as yesterday's slide. The flood of 1918, which resulted in a power failure for about five days, was estimated to have inflicted damage up to a quarter of a million dollars. This slide at the site of the present Gold Creek Bridge occurred in September of 1918.