SNOW AVALANCHE SIZE CLASSIFICATION

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Introduction

When avalanche events are reported, it is necessary to include an estimate or measure of their size. If a simple, consistent method of sizing avalanches can be found, obvious benefits can be derived. For example, data from different storm cycles, years, or areas can be compared. People such as avalanche forecasters, observers or consultants, as well as skiers, can clearly profit from the data once a good method is established.

Unfortunately, in the great majority of cases there is no visual record of the avalanche as it falls. The observer is left with only a few measurable factors after the event. Some of these are: mass, runout distance, path dimension, depth, and spatial extent and water content of debris. In addition, there are other variables which may be estimated such as area swept out by the flowing avalanche, degree of path confinement, and damage to structures or vegetation. In this paper it is argued that a meaningful estimate of size should take into account all observables. Other measures of size proposed such as volume of snow moved, avalanche mass, and estimated kinetic or potential energy seem inadequate to describe avalanche size when taken singly. This is due to the inherent complexity of the phenomenon of avalanches in motion. In the present paper size classification systems with emphasis on the system in use in Canada are discused. Experience with the Canadian system is described by data collected at Rogers Pass, B.C.

Size Systems in Use or Proposed

1. Recommendations by the Working Group on Avalanche Classification of the International Commission on Snow and Ice (I.C.S.I.)

In a comprehensive paper on avalanche classification (de Quervain, et al. 1973), the I.C.S.I. recommended that a set of dimensional measurements be recorded when reporting events. Those measurements relevant to avalanche size are: width and thickness of fracture, length and width of avalanche path, and dimensions and volume of the deposit.

The data recommended by the I.C.S.I. are potentially very useful in determining avalanche size. However, some essential elements such as density of the deposit are not required so that avalanche mass, for example, cannot be calculated. In addition, no scheme is presented to combine the measurements into a size factor. Thus, the I.C.S.I. recommendations do not constitute a size classification system although the format prescribed is used internationally for reporting destructive avalanches.

2. U.S. Reporting System

In the U.S.A. avalanches are classified using five sizes. The sizes are based upon an estimate of the volume of snow transported down the avalanche path. The five sizes (Perla and Martinelli, 1976) are:

1. Slough or snowslide less than 50 m (150 ft.) of slope distance [approximately 25 m (75 ft.) vertical] regardless of snow volume.

2. Small, relative to path.

3. Medium, relative to path.

4. Large, relative to path.

5. Major or Maximum, relative to path.

The important feature of the system is that Sizes 2-5 are related to the path in question. This restriction produces a measure which is not compatible with the concept of size. By relating avalanche size relative to the path, the implication is that size depends on location. Specifically, the same avalanche may have a wide variation in size according to the path it falls on. In addition, the system does not make use of all the observable factors; for example, mass of the avalanche or water content of debris. Furthermore, the system is subjective and yields data which are meaningless to anyone not familiar with the paths in question.

3. Systems Proposed in Japan

Several systems have been proposed in theoretical papers by Japanese researchers. None of these, however, appears to be used systematically for reporting avalanche events.

Shoda (1965) proposed a logarithmic scale based upon avalanche potential energy, $\log_{10}MgH$, where H is the vertical drop, M is avalanche mass, and g is acceleration due to gravity.

There is some merit in Shoda's system because M and H are potentially measurable. Furthermore, the concept is valid even for the processes in a falling avalanche which contain non-conservative frictional forces. However, the system does not make use of all the observable variables; for example, volume of snow transported or depth of deposit. In addition, there is no implied velocity dependence so that a slow, wet avalanche might be classed nearly the same as a more destructive, fast moving, dry one.

Shimizu (1967) proposed three size systems. One of these is identical to Shoda's. The other two are: $\log_{10}M$ and a scale based logarithmically on destructive kinetic energy, $\log_{10}\frac{1}{2}MV_T^2$, where V_T is the avalanche terminal velocity.

The system based on mass alone suffers from the same disadvantages as Shoda's system but to a greater degree. The system based upon kinetic energy has some merit but Shimizu's actual discussion of it is phrased in terms of unknown factors and he admits it is not a usable form (Shimizu, 1967).

4. Systems Used in Switzerland

Researchers in Switzerland have proposed a variety of specific systems in various research papers. None of these, however, is used systematically in practice.

de Quervain (1975) proposed a two-class system based upon the objects that avalanches affect. Those affecting people were designated "tourist" while those affecting villages were designated "catastrophic". Föhn (1975) used a similar system in which he established the following classes: slough, slope avalanche, and valley avalanche with the latter two designations used as synonyms for tourist and catastrophic.

Föhn et al. (1977) related size to the area covered by the avalanche in a three-class system: small (sloughs), medium, and large (50000 m^2).

None of these systems makes use of all important measurable variables. Also, it would seem that there are not enough size classes to discriminate adequately in most cases.

5. Canadian Reporting System

The system used in Canada is based upon estimated potential destructive effects. It is an extension of that originally introduced by M. Atwater in the U.S. (U.S.D.A., 1961, rev. 1968). R. Perla introduced the system into Canada and it was adopted by the Canadian Avalanche Committee in 1977.

The basic idea of the system is to estimate the potential destructive effects of the avalanche at terminal speed in approximately the middle of the path. The five sizes are listed in Table I, along with suggested values for typical associated factors. In Table I the size of the objects affected increases with size classification so there is a strong implied relation between size, avalanche mass, and area swept out by the falling avalanche.

The Canadian system attempts to integrate all observable variables associated with the events into a simple estimate of size. The disadvantage of such a system is that there is some subjective judgment involved. This is the primary reason that only five classes are used. Only approximate estimates are necessary in order to classify events in the system. Field experience shows that observers with a reasonable amount of experience will generally agree on the size of a given avalanche.

The principal objective of the system is to provide an effective vehicle for communication between the observers themselves and others (not necessarily observers) who may wish to use approximate data describing recorded events.

Factors for the Canadian Size Classification System

The factors listed in Table I are determined from data and theoretical analysis and only approximate values for each size are given.

1. Suggested Typical Mass

Figures 1-4 show mass/size data for 744 avalanches for the winters 1978-79 and 1979-80. These data are all from Rogers Pass, British Columbia and were collected by the staff of the National Research Council. Figure 1 shows that only about 6% of the avalanches were estimated as Size 4 or larger. Figure 2 shows that most avalanches estimated as Size 2 had masses in the range 10^2t-10^3t. However, the distribution is skewed toward smaller sizes so 10^2t was taken as the typical Size 2 mass. Figures 3-4 show similar results for Sizes 3 and 4.

Figure 5 depicts a mass/frequency distribution for 6534 avalanches at Rogers Pass observed by the National Research Council from 1966 to 1980. When compared to Figure 1, it can be seen that the sizing is heavily dependent on mass, as is expected. Clear differences are evident, however, and therefore, mass is not the only important variable.

It should be emphasized that the data in Figures 1 and 5 will reflect the character of the avalanches at Rogers Pass where many of the paths are frequently controlled by artillery fire which tends to reduce the avalanche masses. Also, the observations are made at the highway so that the number of Size 1 and Size 2 avalanches recorded will not be accurate. This is because many of these stop higher up on the mountain where they cannot be seen either due to weather conditions or terrain. For these reasons, Size 1 avalanches are not generally recorded by the National Research Council staff.

2. Path Factors

Destructive effects of avalanches are related to velocity as well as mass. The only dynamic model which provides velocity predictions in terms of path variables is the two parameter model of Perla, Cheng and McClung (1980). Their model implies that path length is the fundamental variable where path length is the distance along the incline from starting zone to the avalanche stop position. The model describes the motion of centre of mass of the avalanche and relates motion to friction along the path by a differential equation. Higher terminal velocities are obtained on longer paths because the driving force is applied over a longer distance (time). The Appendix of this paper gives a short derivation and an approximate estimation of the dependence of maximum terminal speed in path length. Vertical drop may be of greater practical interest due to greater ease of estimation. It is obviously related to path length for typical mountain terrain.

3. Typical Impact Pressures

The impact pressures listed in Table I were obtained from the product of expected flow density and $V_T{}^2$ for typical path lengths. This calculation is described in the Appendix. In addition, estimates of impact pressures from measurements made at Rogers Pass, B.C., as well as other estimates (e.g. Salm, 1966; Perla and Martinelli, 1976) were used. It is not intended in the classification system to estimate impact pressures before ascribing a size to an avalanche. Rather, the suggested typical values are expected to follow from the observable data associated with the events.

4. Water Content of Deposit

Water content of the avalanche deposit is usually estimated to be dry, moist, wet, or very wet as explained in the International Classification for Snow (International Commission on Snow and Ice, 1954). It may cause the size to shift downward as terminal velocity usually decreases as wetness increases. This effect is expected in spite of the fact that density increases with wetness. Field observations show that increasing wetness greatly reduces the area swept out by the flowing avalanche.

The effect of water content in the Canadian system is integrated into the size estimate by the observer. Thus, it does not appear explicitly in Table I.

Conclusion

Avalanche size classification is a potentially important variable in reporting events. Each proposed system has obvious advantages and disadvantages. Due to the complexity of the problem and the fact that in most cases few observable data are available, a dilemma results: one is faced with a somewhat subjective measure if unmeasured data are estimated or an unsatisfactory designation if measurable data are strictly adhered to.

The Canadian system, which is described in this paper, provides a reasonable compromise between the alternatives. The disadvantage of the subjectivity involved is more than outweighed by the advantage of the communicable estimate of size that results. Experience with the system thus far shows that it is useful and practical. The qualitative size estimates yield data which are useful to avalanche specialists and non-specialists alike as well as for applied purposes. The observers who produce the data must be experienced and they must be checked for consistency.

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TABLE I

Canadian Snow Avalanche Size Classification System and Typical Factors

Size	Description	Typical Mass	Typical Path Length	Typical Impact Pressures
1	Relatively harmless to people	<10t	10 m	1 kPa
2	Could bury, injure or kill a person	10^2t	100 m	10 kPa
3	Could bury a car, destroy a small bldg. or break a few trees	10^3t	1000 m	100 kPa
4	Could destroy a railway car, large truck, several bldgs. or a forest with an area up to 4 hectares (40000 m^2)	10^4t	2000 m	500 kPa
5	Largest snow avalanches known; could destroy a village or a forest of 40 hectares	10^5t	3000 m	1000 kPa

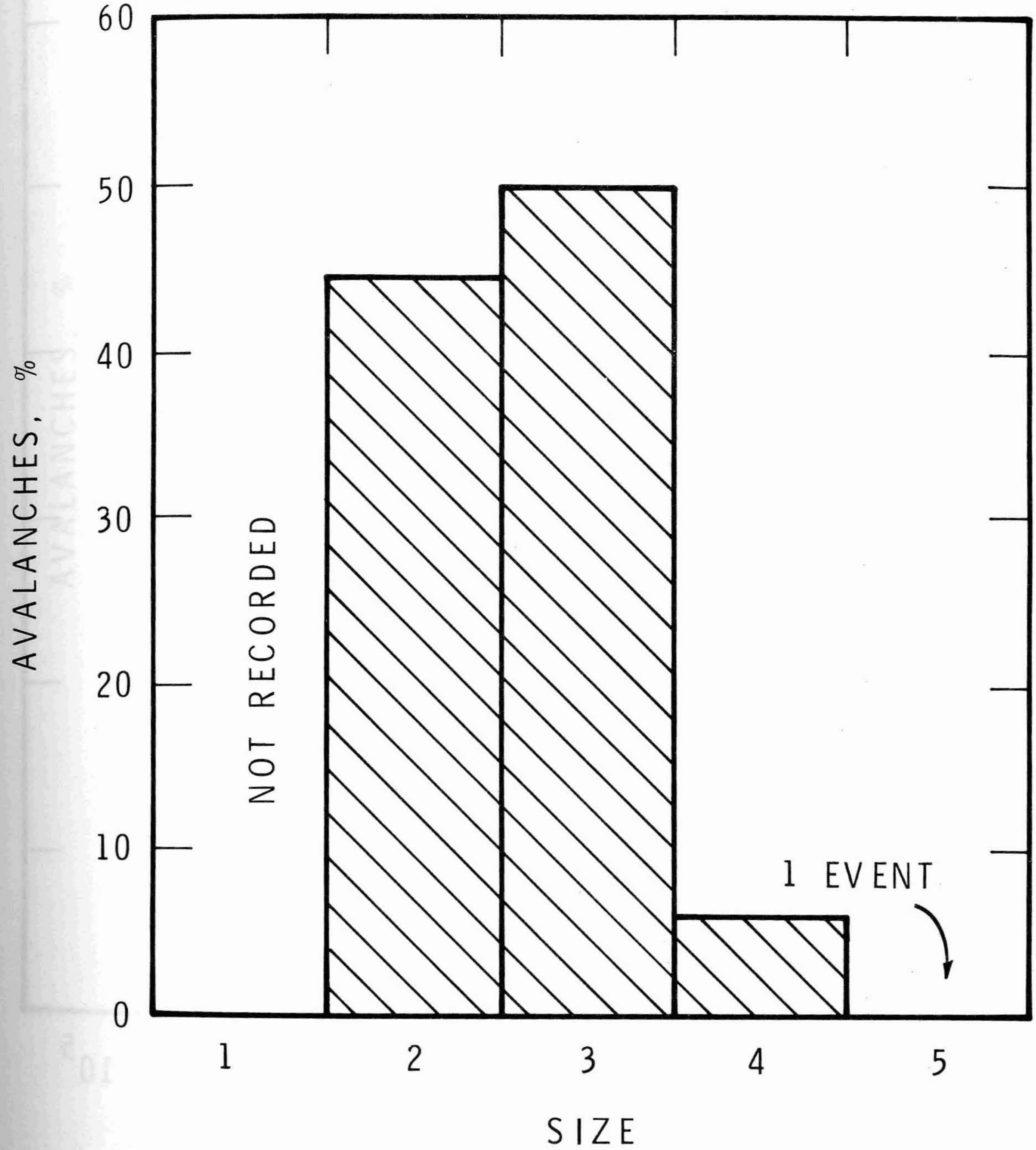

FIGURE 1

FREQUENCY VS SIZE FOR 744 EVENTS FROM ROGER'S PASS, B.C.

BR 6104-1

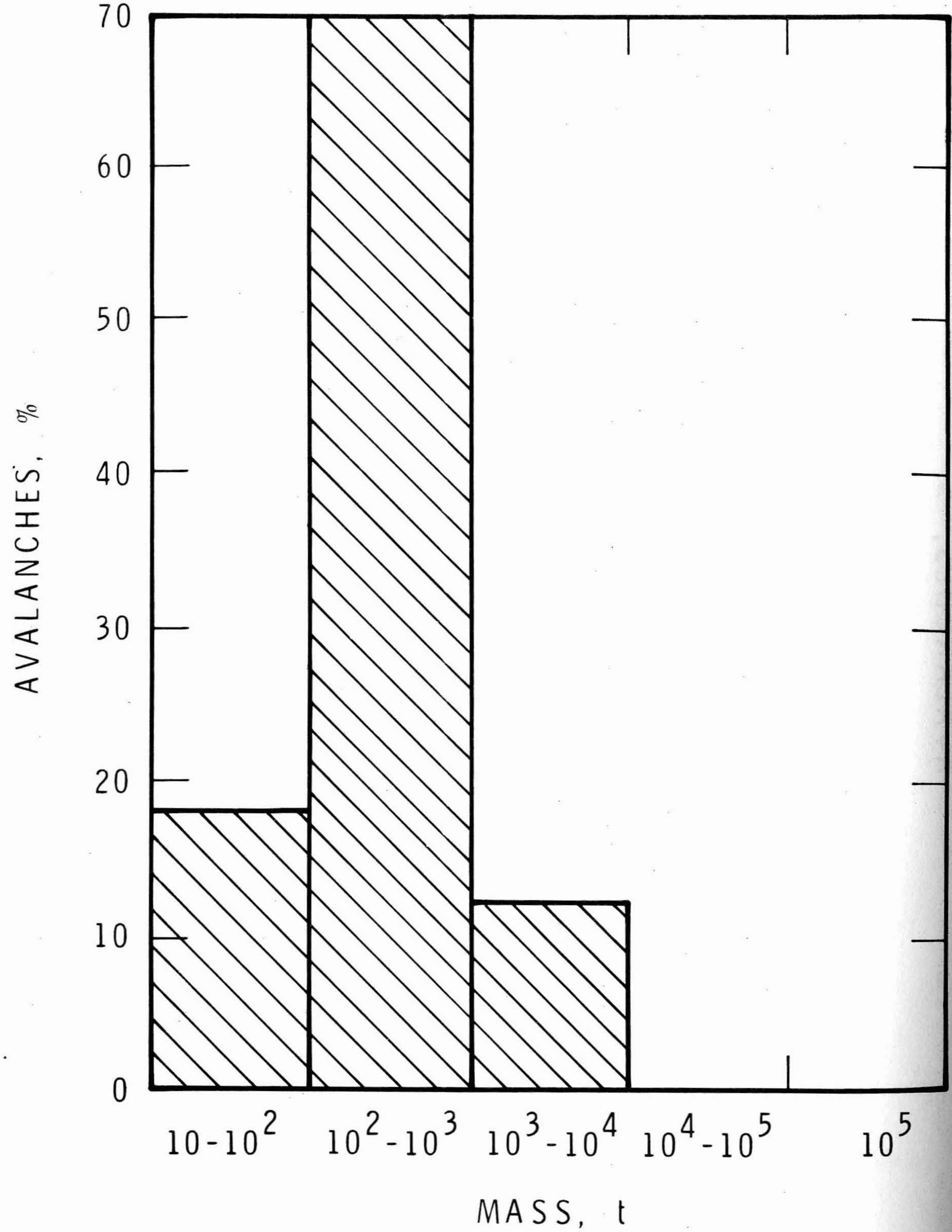

FIGURE 2

FREQUENCY VS MASS FOR 330 EVENTS ESTIMATED AS SIZE 2 FROM ROGER'S PASS, B.C.

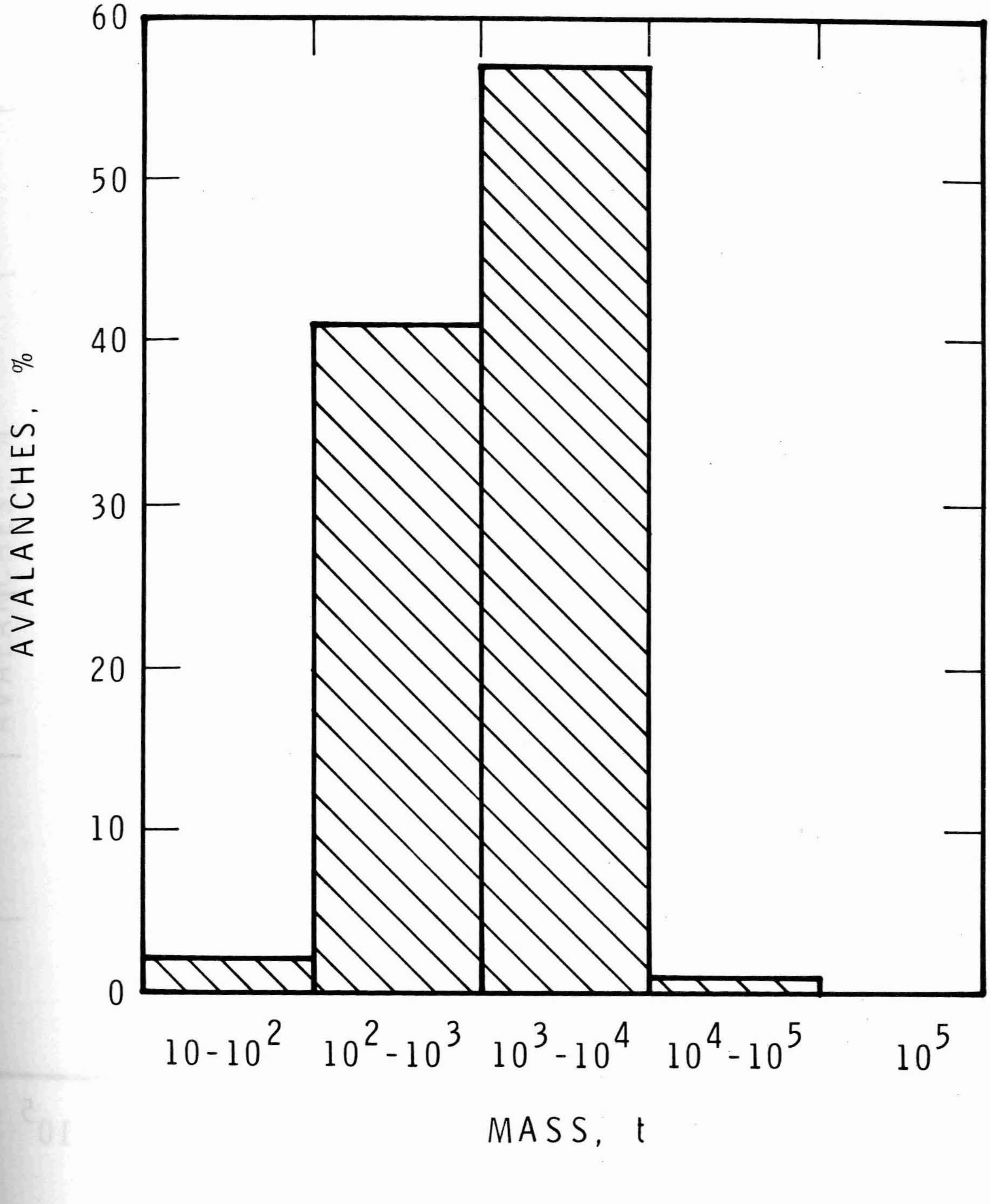

FIGURE 3

FREQUENCY VS MASS FOR 368 EVENTS ESTIMATED AS SIZE 3 FROM ROGER'S PASS, B.C.

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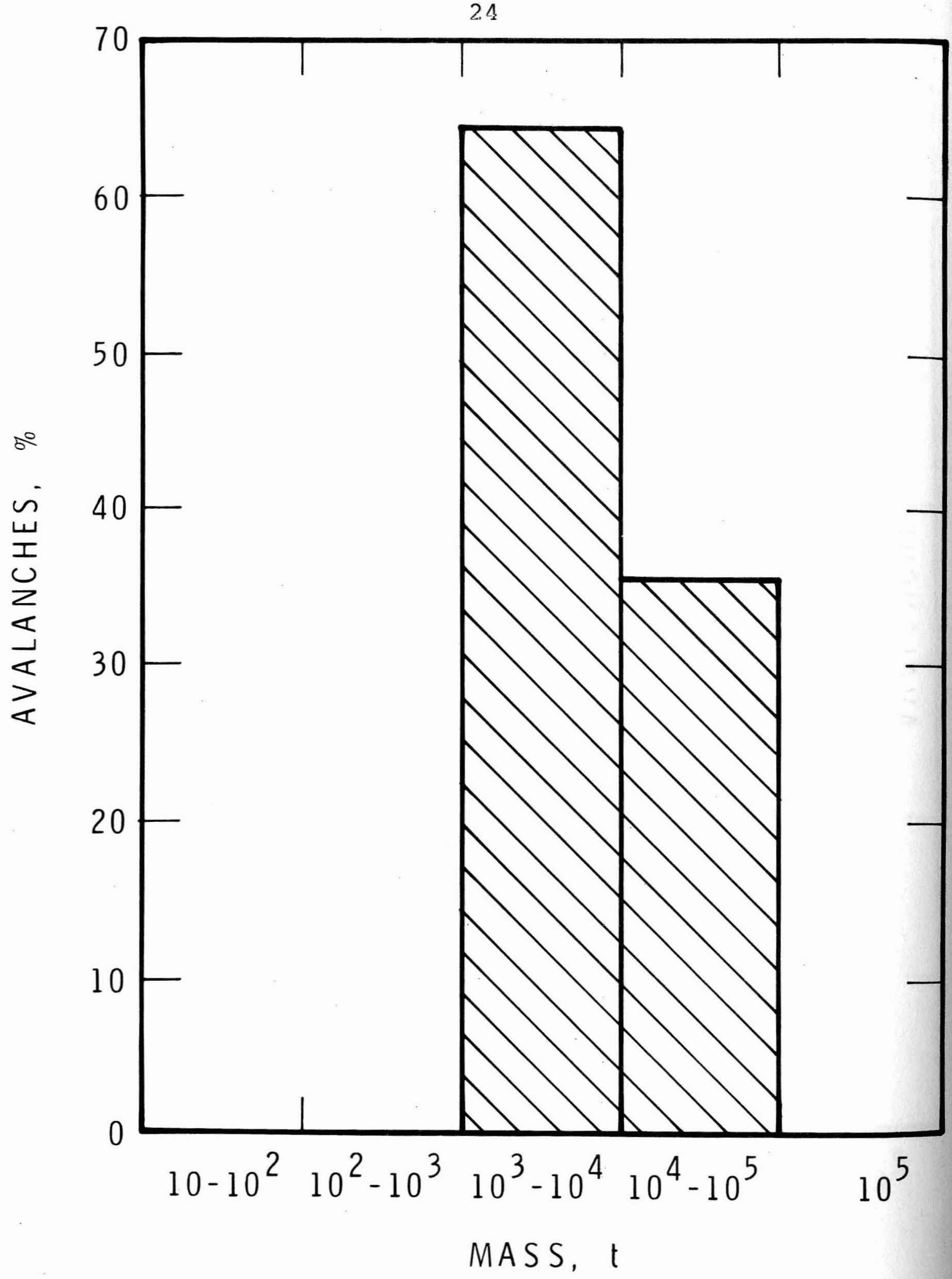

FIGURE 4

FREQUENCY VS MASS FOR 45 EVENTS ESTIMATED AS SIZE 4 FROM ROGER'S PASS, B.C.

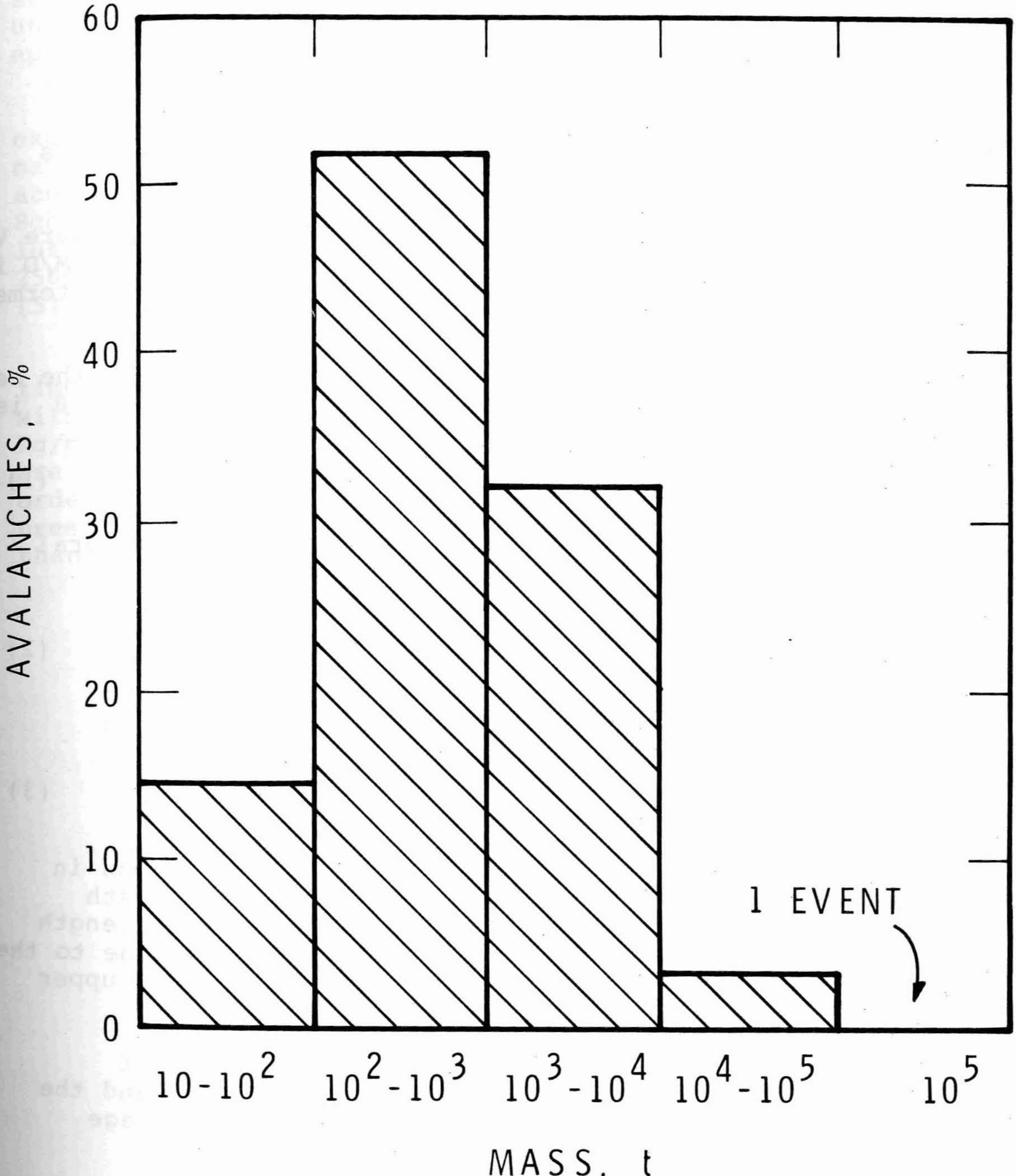

FIGURE 5

FREQUENCY VS MASS FOR 6534 EVENTS FROM ROGER'S PASS, B.C.

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APPENDIX

Estimates of Maximum Terminal Velocity

The centre of mass model (Perla, Cheng, and McClung, 1980) contains essentially the same boundary condition physics as the widely used Voellmy model. This results in a two-parameter representation with drag expressed as the sum of a constant term (coefficient of sliding friction), μ, and of a term depending on V^2 (where V is the instantaneous velocity) which is written M/D. M/D is the ratio of mass to V^2 drag and is the sum of several terms for some of which D may depend on M.

The differential equation for the motion of the centre of mass along an increment of path ds with inclination θ is:

$$\frac{1}{2}\frac{dv^2}{ds} = g(\sin\theta - \mu\cos\theta) - \frac{D}{M}V^2 \qquad (1)$$

with μ and M/D constant over the entire path, the general solution to (1) is (with V = O at S = O):

$$V = \left[e^{\frac{-2DS}{M}} \int_0^S 2g(\sin\theta - \mu\cos\theta)e^{\frac{2D}{M}S'} ds'\right]^{\frac{1}{2}} \qquad (2)$$

Now if M/D>>S, we find sensitivity to M/D is lost and

$$V \approx \left[\int_0^S 2g(\sin\theta - \mu\cos\theta)ds'\right]^{\frac{1}{2}} \qquad (3)$$

In reality, sensitivity of V_T to variations in M/D is nearly lost when M/D is close to So, total path length (e.g. Bakkehøi et al. in press), where path length means distance along the slope from the starting zone to the avalanche stop position. Thus, M/D has a practical upper limit near So.

Assume the path is broken into segments of constant averaged slope angle, i.e. the track (t) and the runout zone, as in Perla (1980). For constant average incline in the track, θ_t, (3) yields:

$$V \approx \sqrt{S}\sqrt{2g(\sin\theta_t - \mu\cos\theta_t)} \qquad (4)$$

If terminal speed is reached on about half the total path length, So/2, then an appropriate upper limit for V_T is:

$$V_T \approx \sqrt{S_o}\left[\sqrt{g(\sin\theta_t - \mu\cos\theta_t)}\right] \qquad (5)$$

Typically, expected numerical values for the second square root term in brackets are in the range 1-2 (mks units) and therefore we see that maximum V_T scales approximately as $\sqrt{So}$.

This analysis along with expected flow densities explains the path length and impact values in Table I. It may be noted that even though (5) is simplistic it is in accord with estimated speed data at Rogers Pass, B.C. (e.g. Schaerer, 1975). Measured speed data there are actually less than 10 m/sec and 50 m/sec for path lengths 100 m and 2500 m. Apparently the ideal maximum values predicted by (5) are rarely achieved, if at all.

The specification of impact pressures (density times V_t^2) in the classification system is also consistent with (5). Flow densities of interest are in the range 1-400 Kg/m^3 (2 orders of magnitude) while path lengths of interest are in the range 10 m to an absolute maximum of 10^4 m (3 orders of magnitude). However, the extremes will not be present together so that the impact pressure range is less than 5 orders of magnitude.

Discussion

Daffern:

One of my reasons for coming to these kind of workshops, as well as furthering my own knowledge, is to take some of the material back and try and apply it to the teaching of back country skiers. I think this is one piece of information that we are going to have to be very careful with. The thing that bothers me is the word "harmless" in your Size 1 avalanche classification. As far as the back country skier is concerned, there are only two sizes of avalanches--one that can kill him and one that can't. To my mind a slough can be just as deadly by causing a person in the mountains to lose his footing as can a large amount of snow that can come down and bury him. I just urge people to use caution in using this classification with back country education classes.

McClung:

That is an excellent point. As I mentioned, this system is not for use by people without experience.

Fesler:

I think it is a good idea to recognize that we are only able to establish the mass and volume within an order of magnitude because often field measurements aren't taken under the best of conditions for obtaining accurate measurements. One further comment I have is on relating the parallel categories of mass and pressure potential. It has been my experience that some of the very largest avalanches, in terms of the mass, aren't necessarily the ones that would have produced the highest pressures because they may not have had the highest velocities associated with them. I would say that we don't necessarily have a correspondence between the mass and the pressure potential.

McClung:

I did not mean to emphasize mass so much as other factors are definitely important. The two graphs that I showed--percentage of events versus mass and percentage of events vesus size--don't look the same in the case where there are other factors affecting the system. Mass is one important factor; others are: how far the avalanches run, whether it is wet or dry.

Stethem:

I am interested in the use of the system in terms of field forecasting because avalanche occurrences are one of the most important inputs a forecaster has. One of the problems I have encountered in correlation of data after the fact in improving a system is that if you have twelve Class 1's and you try and establish an index for the day's activity you can add them up and call it 12. If you have four Class 3's, you add them up and call that 12. The two things are very different. What do you think of the idea of some form of a multiplier for each of 1, 2, 3, 4, 5, for example, .1 for 1, .5 for 2, 1 for 3, 2 for 4, and 5 for 5, so that this index added daily means more to the forecaster when he is analyzing his data.

McClung:

I see what you mean. That is directed at a specific research-oriented application. I don't really have any guidelines for you on that.

Stethem:

The problem is that, in Canada, this system is what we are teaching in the schools and it is what everybody is using. If people come to the point, like I have, where they have to try and correlate the data by simply adding up those numbers, they are going to have trouble. Maybe somebody should think about introducing some multiplier.

McClung:

Well, that is a possibility. Or perhaps you could give an explanation of the complexity of the problem and tell him it is not that simple.

Cronmiller:

In the guidelines that were sent out, you mention that we have to look at the deposit after the avalance in order to fill out an occurrence report. Well, I go down into the deposit and I measure and I kind of have to equate it with the objects I am looking at in the debris. I take my measurements that way and then mail in the occurrence reports accordingly.

McClung:

I would submit that you are not taking your measurements correctly or you are not classifying your sizes correctly if you are doing that. What you have to do is visualize if you can the point on the path where the greatest damage would occur; that is, at terminal velocity. It is just not the mass of the deposit. You have to look at the avalanche path, the runout--whether it is wet or dry, whether the path is confined or unconfined--and any destructive effects you can see which are rare.

Stevens:

Size classification is a very subjective thing. It is going to be important for the forecaster to spend a fair amount of time with his people in the field so that the system establishes some credibility.

Stoneman:

One thing that has bothered me for years is that there are no guidelines here. It has been very difficult to have patrolmen reporting their avalanches since everybody has a different idea of size. It seems that this is the one major thing we have to work on and get some guidelines.

McClung:

That is what we are trying to do. If you noticed, Ed LaChapelle referred to Size 4 avalanches. That was the USFS system which I didn't discuss but those Size 4 avalanches meant nothing to anybody in Canada that did not know the system. I submit that if you didn't know the specific avalanche paths that he was talking about, it didn't mean anything even to those people from the U.S.A., so I agree that development of some sort of standard is important and we are trying to work toward that goal.