ESTIMATING DEPTH-LOAD VALUES IN THE SPRING ALPINE SNOWPACK

By

Donald L. Alford 1/

Introduction

Studies of the alpine snowpack are commonly concerned with the hydrologic potential of this resource. Two basic field techniques have been developed for measuring the amount of water present in any given accumulation of snow. These are: (1) the snow sampling tube, which is used to remove a core sample from the top to the bottom of the snowpack. This core sample is then weighed on a scale which normally reads directly in inches or centimeters of water-equivalent, and (2) the so-called "pit" technique in which a large number of individual samples are removed from the wall of a pit dug for that purpose, weighed individually and then averaged over the depth of the pit. This average value, when multiplied by the snow depth, gives the water equivalent present. Recent comparative studies at Mt. Hood in Oregon and in Alaska by Work, et al., (1965) have shown that in shallow (< 50 cm), low density (.1 - .25) snow covers, these two techniques produce comparable values but they also point out that in the case of inexperienced operators operator error is a significant factor in the use of the pit wall samples. The comparable accuracy of the horizontal sampling technique was not evaluated in snowpacks over 50 cm. in depth. Using a variety of vertical sampling tubes in snowpacks up to 500 cm. deep, it was found that the error increased with increasing snow depth to maximum values of 3-12% depending on tube design. Even assuming comparable accuracy from the pit technique in snow of this depth, its use is not practical due to the amount of time required to complete a measurement at a single site. From the results of the above studies, it appears that the use of a vertical coring tube is a practical means of measuring depth load values under the depth and snow type conditions described.

Under certain conditions, however, it is felt that the ability of the vertical coring tube to produce accurate data is less than the above study would indicate. In order to consistently obtain accurate water-equivalent values in the deep (< 2m.) dry snowpack commonly found in the northern Rockies, it is usually necessary to plug the bottom of the tube with soil to prevent the loss of the largely cohesionless basal depth hoar layers. It is not uncommon to find as much as 1/3 of the total pack thickness composed of depth hoar or incipient depth hoar at higher elevations in this area. At the same time, it is quite often the case that the surficial composition at the higher elevations is rock rather than soil which precludes plugging the snow tube.

Another situation in which the use of the vertical sampling tube is not wholly satisfactory is in measuring the water equivalent of the annual snow layer on an alpine glacier. While the loss of snow from the bottom of the tube is not a particularly significant factor here, the problem is to determine the exact depth of the annual layer, particularly in the upper accumulation basin. There, it is often difficult to sense the transition from the most recent annual layer to that immediately preceding it. This means that reproducibility is very greatly influenced by the ability of the operator to accurately determine the depth of this transition.

It is the purpose of this paper to discuss this problem in terms of the preliminary results of snow studies at the U.S. Army Cold Regions Research and Engineering Laboratory's Goose Lake research site in the Beartooth Mountains of southwestern Montana. Due to the preliminary nature of the study, the data are presented in graphical form and only the most obvious conclusions are drawn. A limited amount of data from another area is presented for purposes of camparison.

Nature and Location of the Research Area

Because the relationships discussed here may be unique to the environment which produced them, it is pertinent to briefly discuss the characterizing elements of that environment.

1/ Environmental Engineering Group; Endowment and Research Foundation; Montana State University; Bozeman, Montana.

During the months of April and May of the winters of 1964 and 1965, a program of snow studies was undertaken at Goose Lake (3000 m) 19 km north of Cooke City, Montana, (2330 m) on the south flank of the Beartooth Range at Lat. 45° 00', Long. 109° 55'. During April of 1965, complementary studies were made on a traverse between Cooke City and Goose Lake at six sub-equally spaced sites. A detailed description of this general area is given in Alford and Weeks (1965).

Because these were the first winter studies to be performed in the vicinity of Goose Lake, little is known of the average snow conditions found there. Based on these observations, 2.5 to 3 m. of snow seems a reasonable estimate of the snow depth there during an average winter. Snow accumulation usually starts in late September or October and melt does not begin in the spring until early in May. The weather systems supplying snow to the area come predominantly from the west and north and there is a pronounced orographic effect on accumulation between Goose Lake and Cooke City. The mean winter air temperature at 3000 m. is estimated to be between -20 and -25°C.

Instruments and Procedures

During 1964, a series of 11 pit studies was made at the Goose Lake site using the SIPRE snow density kit and standard pit techniques as described by Benson (1962). In addition, a resistance-to-penetration profile using a rammsonde penetrometer (Haefli, in Bader, et al., 1954) was made immediately adjacent to the pit wall.

In April, 1965, a traverse between Cooke City and Goose Lake produced complementary data at eight sites at intervals between 2350 and 3150 m.

At each pit, the primary measurements were density (at 5-10 cm. intervals), the temperature gradient, visual stratigraphic relationships and the rammsonde profile. Water equivalent for each pit was determined by averaging the individual density values found at 5 to 10 cm intervals over the depth interval of the pit and multiplying the snow depth by the resulting number. The individual density values are felt to be accurate to ± 0.005 g/cm^3 (Bader, 1962) and snow depth, measured at the pit wall with both a steel tape and with the rammsonde is felt to be accurate to ± 2.0 cm.

The ramm hardness number is expressed in units of force. When it is integrated over a depth interval the resulting quantity is the work done on the snow as the penetrometer moves through a stated interval. In practice this integration is performed by multiplying each depth increment, Δz_i, by its hardness number, $\underline{R}_i$, and adding these values from z = 0 at the snow surface to the base of the pack. The total work done by the penetrometer in moving from the snow surface to a stated depth zj may be written as

$$Rj = \int_0^{zj} R dz$$

In the present study, values for Δj are taken at 5 cm. intervals to the base of the pack.

Observations and Discussion

1. Figure 1 shows the relationship which was found to exist between the load, in g/cm^2 and integrated ramm number for maximum values of Δz at each pit. The minimum load was 36 g/cm^2 at an elevation of 2350 m. The curve has been arbitrarily extrapolated through the zero point.

As a check on the usefulness of the curve, load and integrated ramm values at 1 and 2 meter intervals in northwest and central Greenland were also plotted. These values were taken from Benson's (1962) graphical data sheets for his pit series from 4-0 to 4-350. Considering the difficulties of estimating the values from the graphical data presentation with accuracy, the agreement is felt to be quite good.

2. A limited number of vertical cores, using a federal sampler, were taken in conjunction with the pit studies during both 1964 and 1965. Agreement between the two techniques was poor, with the vertical sampler measuring only 70-75% of the load as determined in a pit wall. A purely subjective evaluation of this discrepancy indicated that it resulted from the inability of the federal sampler to retain the essentially cohesionless depth

hoar in the absence of an earth "plug". It was impossible to get such a plug as the surficial composition of the study site was largely morainal, with a high percentage of large stones.

Conclusions

The use of the rammsonde to determine load values in snowpacks with significant thicknesses of depth hoar and on glaciers where the thickness of the annual layer cannot be readily identified with a vertical coring tube appears feasible enough to warrant further study. At the present time, the best technique for obtaining water-equivalent in both these cases is by pit-wall measurements. The effort involved in pit studies means that only a limited amount of points can be sampled at any one time.

An additional advantage of the rammsonde is that it produces a wider range of useful data than the vertical coring tube. While most of the correlations are quite empirical at the present time, ramm number has been related to unconfined compressive strength (Abele, 1963), and density (Bull, 1956; Keeler and Weeks, 1966). The rammsonde will also delineate the vertical stratigraphy of the pack on a qualitative basis and should be capable of detecting the difference between snow less than one year old and iced firn from the preceding year on a glacier.

The data discussed here are preliminary and this technique cannot be used with confidence until much additional work is done. They do suggest, however, that an alternative to vertical coring or pits may exist for use in those areas where those two techniques are either too time-consuming or inaccurate to be profitably used.

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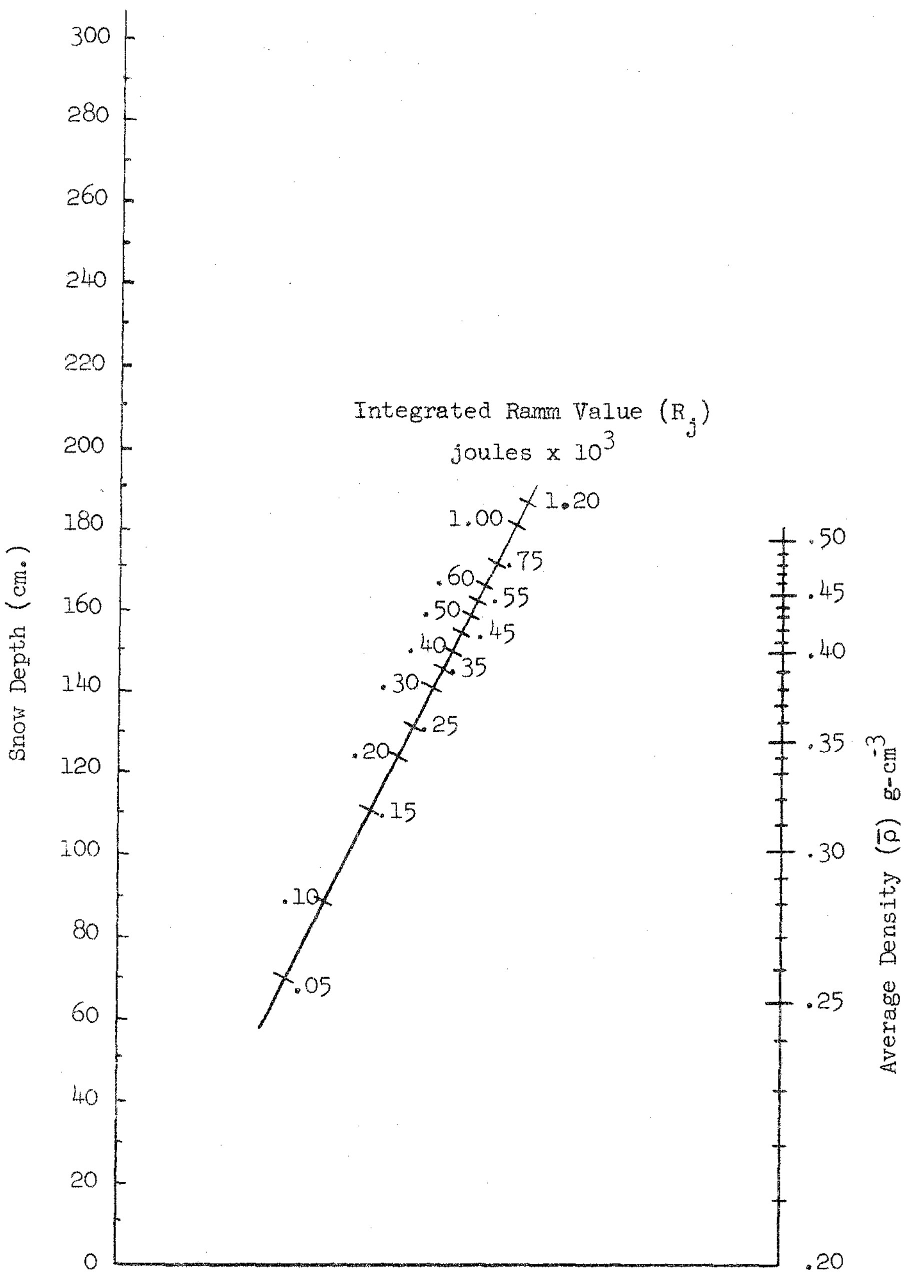

A nomograph, based on the empirical curve in Figure 1, for the conversion of Integrated Ramm values (R_j) to average snowpack density ($\bar{\rho}$) .

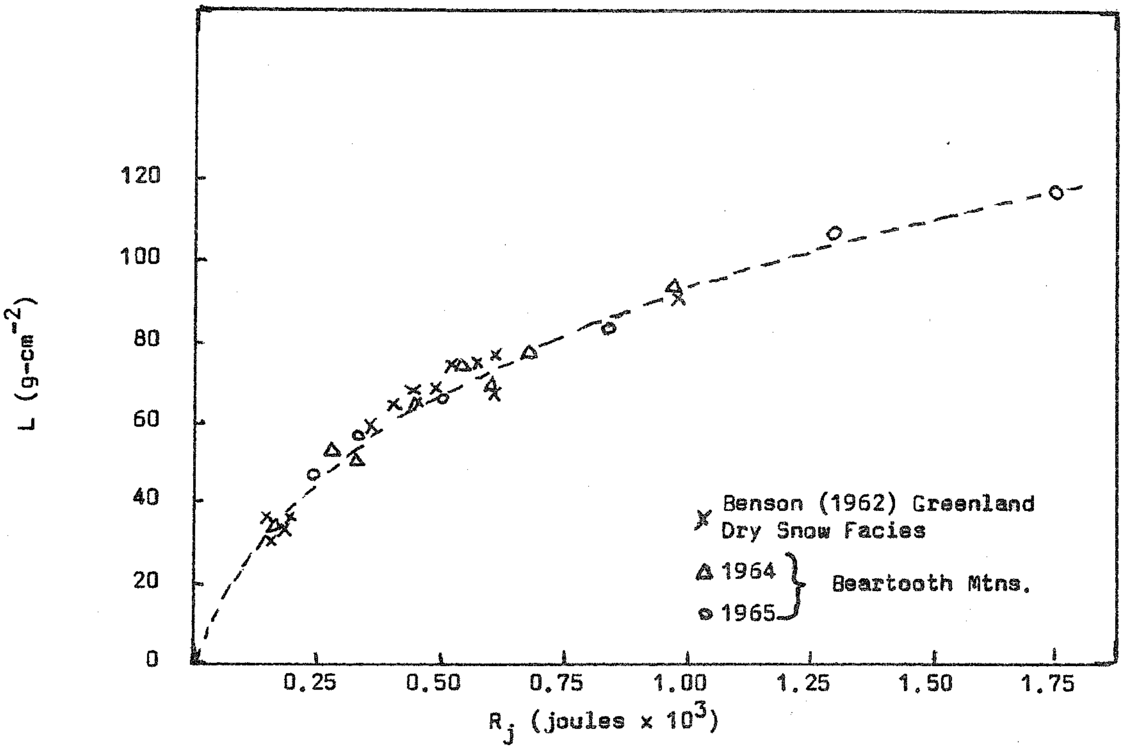

Figure 1. The empirical relationship found to exist between load (L) and integrated ramm. number (R_j) in dry snow deposits in the Beartooth Mountains of southwestern Montana and in central Greenland.

APPENDIX A

It is not felt that there are as yet sufficient data to warrant fitting an equation to the curve in Figure 1. For those who may wish to examine this relationship in more detail at other field sites, the following table is appended to this paper, presenting the values upon which the curve in Figure 1 is based.

L (g-cm^{-2})	R_j (joules x 10^3)	L (g-cm^{-2})	R_j (joules x 10^3)
0.0	0.00	67.5	0.47
35.0	0.17	70.0	0.45
36.5	0.14	71.0	0.55
36.5	0.15	73.0	0.50
38.0	0.16	75.0	0.50
38.0	0.21	75.0	0.55
39.0	0.18	76.0	0.65
40.0	0.20	82.0	0.76
44.0	0.23	82.0	0.77
47.0	0.29	90.0	0.95
51.0	0.27	90.0	1.00
53.0	0.35	98.0	1.15
61.5	0.40	104.0	1.28
64.0	0.40	115.0	1.75
66.5	0.50		