SOME RESEARCH PROBLEMS

IN

SNOW MECHANICS AND THERMODYNAMICS

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I Introduction

In the far west, research on snow has been confined largely to the hydrologic field with emphasis on forecasting of runoff and development of criteria for the design of structures for storage of snow melt water. Basic research has been limited almost entirely to heat budget problems in an effort to improve upon such empirical concepts as the degree-day factor. The efforts to balance the heat budget have included some research on heat supplies from both long and short wave radiation and from condensation and evaporation.

In all snow-covered areas and particularly in the Subarctic and Arctic, civilian economy and military logistics are dependent upon the mechanical and thermodynamic properties of snow. The areas in which the physical properties of snow affect the living and working conditions of mankind greatly exceed those where snow hydrology is of primary importance. At present, because of agricultural and industrial demands, the economy of the North American Continent is more closely associated with snow hydrology than with such mechanical properties as the bearing strength and friction of a snow surface. The rapid development of civilian and military establishments in the areas north of the 57th parallel as well as the increased emphasis on maintenance of uninterrupted air, rail, and highway traffice in our northern states and the Canadian Provinces during the winter season has created a demand for more basic information on the mechanical properties of snow and the thermodynamic processes which affect those properties.

II Physical Properties of Snow

If snow consisted of an isotropic crystal aggregate of unvarying structure and texture, the strength could be computed from the simple Coulomb equation

$$S = C \qquad \tan 0$$

where S = the shear strength, the normal stress, 0 the angle of internal friction, and C the shear strength at zero normal stress.

Snow, however, is such a morphologically heterogeneous material that its shear strength is a function of many variables. Both immediate and antecedent temperatures and the frequency of temperature cycles influence the strength of snow. The nascent crystal of new snow and the morphological product, resulting from the time - temperature and internal pressure relationships within the snow pack affect the strength of the snow. The size, type, and cohesive bonding of the crystals may have as great an influence upon the shear strength and supporting capacity of a snow pack as the density of the snow. The very process of measuring the shear strength, under stress, may in itself cause physical changes within the matrix of the snow sample with more pronounced effects upon the measured value than would be obtained with a material subject to lesser metamorphism such as a sample of quartz sand.

Several investigators have measured the tensile strength of snow and report extremely wide variations in their results.

Bucher (1) in 1948, working with snow between 38.5 and 44.3 percent density, found, for 23 samples, tensile strength values between 400 and 1000 gm/cm^2. A review of the data from the report by Bucher indicates that there was little relationship between density and tensile strength within the range covered by these samples.

The University of Minnesota (3) reported tensile strengths varying between 320 and 940 gm/cm^2 for measurements on 8 samples of 40 percent density snow. Haefeli (4) studied the effect of age on the cohesive strength of snow and found that a day-old snow of 15 percent density, with a cohesive strength of 17 gm/cm^2 increased, after 7 days of ageing to 33 gm/cm^2 without change in density.

The change in cohesive strength of snow with time, even for short intervals, following disturbance of the snow is remarkable. A few tests at the Central Sierra Snow Laboratory indicate that the bearing strength of snow, as measured with a cone penetrometer, following compaction by the treads of an M-7 snow tractor, with a weight distribution of about one pound per square inch, continued to increase for several hours after passage of the tractor. The ultimate strength of the tractor-compacted snow, achieved several hours after compaction, was four to five times that measured within a few minutes after passage of the snow tractor. The increase in shear strength, cohesiveness or bearing capacity with age is a product of thermodynamic processes of a type not usually considered important in the stabilization and compaction of other granular materials.

As the snow tractor moves over the surface of the snow, both individual crystals and the solid bonds between single crystals are broken while, at the same time, the size of the air voids are reduced. The disturbance and compaction exposes many new crystal faces and edges to the vapor-saturated air in the voids. For a very brief period following compaction, there may be a supersaturated vapor condition in the voids. As the vapor is condensed on the exposed crystal surfaces, further instability is caused by the release of latent heat of condensation or of sublimation.

The physicist will here recognize that entropy probably plays a part in the metamorphism of a snow matrix following compaction or other mechanical disturbance. As small as entropic energy may be, it is effectively large in terms of the enormous number of snow crystals displaced or fractured by even a single footprint in the snow. The physicist recognizes also that the metamorphic processes which induce the changes in the physical and mechanical properties of snow operate continuously, isopiestically and isothermally but that such metamorphism is accelerated by fluctuations in temperature and vapor pressure changes within the snow matrix.

Some of the problems in snow mechanics are analogus to those in soils, but in many cases snow reacts oppositely to soil for a given force. Whereas pressure dehydrates a soil and thereby may contribute to its stability and supporting capacity, snow at or near the freezing point will melt slightly, under pressure, and the resultant water films acting as a lubricant between grains may decrease the shear strength and trafficability of the snow. Conversely, the release of pressure on a soil may permit water to enter it and increase the plasticity whereas the release of pressure on snow, near the ice point, will cause free water between the grains to freeze and decrease the plasticity.

There are other, more complicated thermodynamic and metamorphic processes which take place within the snow pack such as the development of depth hoar or "schwimmschnee". The loose fragile, hoarfrost type of crystals apparently develop by sublimation processes as definite horizons during periods when large temperature gradients prevail within the snow-pack.

On level areas the layers of depth hoar create both immediate and potential traffic hazards. Foot troops or vehicles break through the crusted snow surface and become as effectively immobilized as in loose dry sand. Because of their peculiar crystallographic and physical properties, the layers of depth hoar cannot be readily compacted and persist as pockets and sink holes in compacted roadways and air strips.

In mountain areas the layers of depth hoar provide shear planes or layers of discontinuity which serve as the base for snow slides and avalanches, hence the German appellation, "Schwimmschnee". It is possible that some forms of the so-called "corky snow" encountered by snow surveyors in the Sierra may consist of a form of depth hoar although it is more common in arctic and alpine climates where greater temperature differences persist between the soil and the snow surface.

The foregoing discussion of some of the mechanical and thermodynamic properties of snow indicates the difficulties which may be encountered in the construction of a snow road or compacting snow for an air landing strip.

The derivation of a traction index from the measurable mechanical properties of snow or the forecastable degree of metamorphism is complicated by the inconsistency of the frictional resistance of the snow surface.

Palmer (5, 6) has discussed several of the frictional resistance mechanisms which may apply to snow. Among these mechanisms are:

1. The intermeshing of surface roughness or irregularities of the two surfaces; this includes the plowing action when a rough hard surface is in contact with a smooth or softer surface.

2. The cohesion of surfaces through molecular attraction.
3. The electrical attraction induced by the separation of negative and positive electrons as two surfaces rub together.

Since the basic theories neither individually nor in combination account for the low but extremely variable coefficient of friction for snow, there have been many supplemental theories proposed. Most of these are based upon the narrow temperature range which separates the three phases, liquid, vapor and solid in snow.

Reynolds (7) more than 50 years ago suggested that the pressure of the bearing surface caused the melting of a thin layer of water which served as a lubricant between ice and the sliding surface.

Bowden (8) believed that a lubricating film of water was produced by frictional heat induced by the object sliding over a snow surface.

McConica (9) suggests that a vapor film serves as a lubricant, developing his idea from the proven theory for the lubricating properties of graphite which was shown by Savage (10) to be due to a vapor film and a function of the water vapor pressure.

Seligman (11) advanced the idea of a ball bearing action of the snow particles as a basis for the low coefficient of friction for snow. Studies reported by Nakaya (12) give some support to this theory.

That none of the theories alone provide a satisfactory explanation or basis for computing or forecasting the coefficient of friction for a snow surface is indicated by the many exceptions to each theory.

Bowden (8) found that brass with a high thermal conductivity had a higher coefficient of friction than wood. This would be in agreement with the frictional melting theory since a material with a high thermal conductivity would conduct the heat away from the contact surface and reduce the melting of snow. However, McConica (9) has shown that magnesium with a very high thermal conductivity has a very low coefficient of friction and very fast skis have been made of magnesium. He attributes the low coefficient of friction for magnesium to a chemical affinity between the water vapor in snow and the magnesium or its oxidation product. Klein (13), on the other hand, has shown that Bakelite with a low thermal conductivity was one of the best materials for airplane ski. The freeze-down phenomena which influences the take-off power requirements of a plane may be associated with the thermal conductivity of the ski material.

If water or vapor films serve as a lubricant, the fact that the coefficient of friction for a wet snow is higher than for a dry snow at or near the freezing point complicates the lubricating film theories. The increase in the coefficient of friction with an increase in load on wet snow as reported by Bucher (2) which has been attributed to a rupture of the lubricating film by the heavier loads is contradictory to the pressure and frictional melting theories. The rupture of vapor films is the cause of increased friction at low temperatures according to McConica (9).

It is possible that a satisfactory compromise can be derived for the sliding friction coefficient with, of course, a suitable adjustment for variations in the mechanical properties of snow. However, both the physico-chemical nature of the sliding object and its shape or displacement must be included in any coefficient for the object itself. Saito (14) has pointed out that there is a head resistance and side resistance for any moving object which sinks into snow. Klein (13) has shown that an object made of monel metal may have a static friction coefficient on snow varying between 0.20 and 0.85 and a sliding coefficient between 0.10 and 0.17.

III SUMMARY

The Snow, Ice and Permafrost Research Establishment is engaged in a broad field of basic research, both directly and by contract with other research institutions, on the mechanical properties and thermodynamic processes in snow. It is hoped that these investigations will lead to an improved understanding of the causes of the enormous variation in the presently reported and used values for physical constants in snow. The Establishment's low temperature laboratories at Wilmette, Illinois will be completed by 15 May 1952 and instrumented for a program of controlled basic research which will supplement the field investigations. The problems discussed in this brief paper are but a small fraction of those which will be investigated. The results eventually should be of value to civilian economy as well as to military strategic and logistic planning.

In the preparation of this paper, free use has been made of the material contained in Report No. 4, "Review of the Properties of Snow and Ice", prepared by the University of Minnesota, for the Snow, Ice and Permafrost Research Establishment.

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TABLE II

SHAVER LAKE SNOW MELT TEST

MARCH, 1952

				PLOT #1		PLOT #2		PLOT #3		PLOT #4	
		Temperature		Untreated		3 qts. or 27 oz.		1-1/2 qts or 13-1/2 oz.		3/4 qt. or 6-3/4oz.	
Date	Weather	Max.	Min.	8:00 A	5:00 P	8:00 A	5:00 P	8:00 A	5:00 P	8:00 A	5:00 P
3/26	Clear	63	25	*60	59	*53	51-1/2	*55	53	* 55	53-1/2
3/27	Clear	62	28	58	55	51	43	52-1/2	44	53	44-1/2
3/28	Pt. Cloudy	62	28	55	52	43	36-1/2	43-1/2	37	44-1/2	37-1/2
3/29	Pt. Cloudy	58	28	51-1/2	49	36-1/2	31	36-1/2	31	37-1/2	32-1/2
3/30	Cloudy	53	28	49	47	31	26	31	26	32-1/2	27
3/31	(AM Clear (PM Cloudy	57	26	46-1/2	44	25	19	25	18-1/2	27	20-1/2
4/1	(AM Pt. Cldy. (PM Clear	60	26	44	42	19	14-1/2	18-1/2	14	20-1/2	15-1/2
4/2	Clear	56	30	42	40	14-1/2	9	14	8	15-1/2	10
4/3	Clear	60	27	40	37	9	4	8	3	10	4
4/4	Clear	67	31	36	34	4	(Bare 2 PM)	3	(Bare 11:30 AM)	4	(Bare 2 PM)

* First readings are at 3:00 PM, March 26.

Note: The readings for Plots 2, 3 and 4 have been corrected to ground level datum. Readings for Plot 1 are subject to an unknown correction of approximately 6 inches for depth of stake in ground. At 9:00 AM, April 15, plot #1 snow depth was 21 inches.

W. A. Lang/ca
April 15, 1952

DISCUSSION

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The results obtained by Mr. Lang in using one of the procedures recently classified as "Unconventional Methods of Snow Removal" is not only interesting but exceptionally timely as far as the Snow, Ice and Permafrost Research Establishment is concerned. This Establishment has been asked to lead a discussion on "Unconventional Methods of Snow Removal" before a panel of civilian and military personnel representing all branches of the Armed Forces in Washington following this meeting of the Western Snow Conference.

Although the literature on this subject is not very extensive, some of the available reports indicate that covering a snow surface with a foreign material in an effort to increase the heat absorption and hasten melting may actually defeat the intended purpose.

Soot, fine powdered coal and black organic matter in the form of dry muck or peat have thermal conductivities in the order of 10^{-4} gm. cal./cm^2/sec. This is about the same as for a good rock wool insulation commonly used in house construction to prevent passage of heat. If soot is spread too thickly over snow, the solar heat which it absorbs at the surface may never reach the snow. Also, since solar radiation can be expected to penetrate not much more than one foot of snow, that amount of new snow over the soot would eliminate any gains to be obtained from the application.

A non-verifiable reference indicates that prior to or in the early stages of World War II the Russians tried to speed up the melting of snow on cultivatable lands in the sub-arctic. After obtaining a limited success on a small scale with light applications of black muck and coal dust they decided that if a little was good, a lot was better and spread such thick layers of black organic soil with such high insulation capacity that snow persisted under the artificial cover until the next winter.

Dr. Roberts (1) of the Scott Polar Institute describes in detail some of the pre-war and early war efforts of Russia to clear roads and airfields, speed up the availability of agricultural lands and increase the supply of melt water for domestic and irrigation purposes by use of black, radiation absorbing materials.

Landsberg (2) in 1940 discusses the use of finely powdered coal to increase the melting rate of ice by increased absorption of solar radiation. He applies his ideas to the possibility of decreasing the katabatic flow of cold glacier winds and increasing the growing season on agricultural lands in the valleys below glaciers.

Ellickson has discussed the possibility of using nuclear energy to melt the Polar Ice Cap. His calculations show that it would require 4 billion tons of U-235 costing $10,000.00 per pound to melt the ice cap in one million years.

The best and most complete reference on the use of supplemental materials to accelerate the melting of snow and ice by solar energy is a report from the Armour Research Foundation. This report shows the air temperature must be above 32° F and the solar energy about 1000 BTU per day to induce any appreciable amount of increased melting from the application of supplemental solar energy absorbers. With such conditions, industrial wastes such as slag increased the melting rate 2 to 3 times but at a maximum of only about 2 inches of water equivalent snow or ice per day.

A review of the data in Langs report indicates that he was operating under conditions similar to those suggested by the Armour Foundation as most ideal. We, in SIPRE are interested in how to accomplish the rapid removal of snow under any condition but primarily in the arctic where neither high ambient temperatures or appreciable amounts of radiant energy are available until late summer. We hope that Lang and his co-workers will continue with these experiments and possibly provide us with some information that will indicate the extent of applicability of this unconventional method of snow removal.

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