COMPACTIBILITY OF NEWLY FALLEN SNOW IN EASTERN CANADA*

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Abstract. The critical density of newly fallen snow was measured during the 1956-57 winter season at two stations: Montreal Road Laboratories of the National Research Council, Ottawa, and the University of New Brunswick, Fredericton, New Brunswick. The relative compacted density or compactibility of newly fallen snow was found to depend on undisturbed density and snow temperature. A statistical equation was developed relating snow temperature and undisturbed density to the compacted density of the snow sample. Additional tests under cold room conditions indicate that grain size and grain-size distribution also have an appreciable effect on compacted density.

Résumé. Pendant la saison d'hiver 1956-1957 on a mesuré, près de deux stations, la densité critique de la neige fraîchement tombée. L'une de ces stations se trouvait dans les laboratoires du Conseil National des Recherches, route de Montréal à Ottawa, tandis que l'autre était située a l'Université du Nouveau-Brunswick, à Fredericton, dans la province du Nouveau-Brunswick. On s'est aperçu que la densité relative de compaction ou "compactibilité" de la neige fraîchement tombée dépendait de la densité naturelle de cette neige et de sa température. On a mis au point une équation statistique établissant un rapport entre la température d'une parcelle de neige et sa densité naturelle d'une part et sa densité de compaction d'autre part. D'autres essais effectués en chambre froide, ont permis de déceler l'effet sensible qu'ont la dimension des grains et leur répartition sur la densité de compaction.

Information on snow compaction is essential in solving many practical problems related to snow such as the development of over-snow vehicles, snow clearing by mechanical means and compacting snow for road construction. Although there have been some fundamental studies on snow compaction,[1] apparently no effort has been made to develop a means of measuring the variation in the compactibility of new snow under different climatic conditions. This report presents a simple method for measuring the compactibility of newly fallen snow. These compactibility measurements were taken for the Division of Building Research during the 1956-57 season. While the emphasis in this report is on newly fallen snow the principles could probably be applied to other snow types.

Different procedures have been used for describing snow cover in terms of grain size, shape, density, and hardness.[2,3] These measurements, however, do not always describe snow adequately from an engineering viewpoint. It is considered that a snow classification which treats the snow mass as an aggregate is more useful for engineering purposes than one based on individual constituents of the snow mass. This implies that the behaviour of a snow type can be predicted more readily from observations of how the snow mass behaves under various tests than by observations of grain size, shape, and distribution. Measurements on undisturbed density and hardness are measurements which treat the snow mass as an aggregate but few attempts have been made to relate these to the qualitative behaviour of snow.[4]

In the field of soil mechanics attempts to relate grain-size characteristics to soil constants such as permeability have been consistently disappointing.[5] The trend has been to study the maximum and minimum porosities of granular soil in order to bring the complex phenomena of soil behaviour to a common basis.[6,7]

In studies by Nuttal and Finelli,[8] the term "critical density" has been applied to snow types. In this paper the authors suggest that below this critical density snow will absorb normal stresses primarily through packing; above this critical density the snow cover will fail hydrodynamically. The work of Kragelski,[9] indicates that there is a critical density for snow types, beyond which a great deal of additional energy is required to obtain a small increase in density.

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Fig. 1 compares the densities Kragelski obtained for the number of passes of a float, to the densities the author obtained by dropping a 1000 gm. weight through a height of 10 cm. on confined snow samples. Both sets of data indicate that the critical density is dependent on snow temperature and is a measurable snow property. It was thus decided to measure the critical density along with other snow characteristics of newly fallen snow under a range of snow conditions.

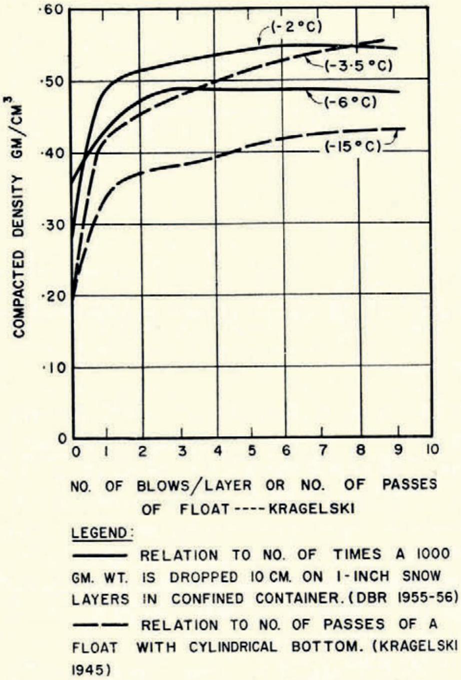

Fig. 1. Typical curves showing relationship between compacted snow density and different methods of compacting

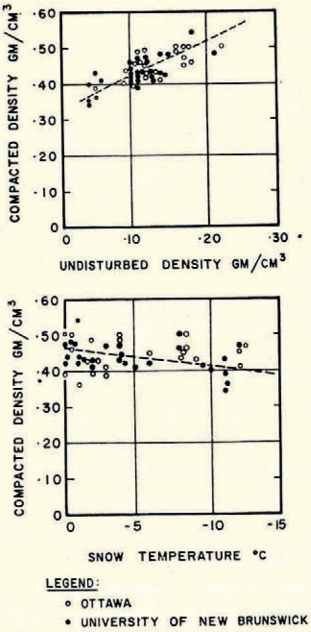

Fig. 2. Relationship between compacted density and undisturbed density and snow temperature

EXPERIMENTAL PROCEDURE

The physical properties of newly fallen snow were investigated during the 1956-57 winter season at two snow survey stations: the Montreal Road Laboratories of the National Research Council, Ottawa, and the University of New Brunswick at Fredericton, N.B. The following snow properties were recorded: snow temperature, undisturbed density, compacted density and snow hardness. In addition, the amount of each snowfall, general type of snow and air temperature were recorded.

Snow temperature, snow hardness and undisturbed density were measured using the same general procedure used in the Snow Survey of Canada.[10] The compacted density was determined by dropping a 1000 gm. weight from a height of 10 cm. on snow packed in layers in a 250 cm.^{3} container. This technique was developed for measuring the free water content of wet snow.[11]

In addition to measuring the properties of newly fallen snow, some compaction tests were made on granular snow in the cold room of the Division, in order to determine the effect of grain size and grain-size distribution on the density to which snow can be compacted.

EXPERIMENTAL RESULTS

Fig. 2 shows the relationship between compacted density and undisturbed density; and between compacted density and snow temperature. These scatter diagrams indicate a general straight-line relationship between these variables.

Using the methods of correlation analysis outlined by Ezekiel,[12] a statistical analysis was made of the data shown in Fig. 2.

The equation:

$$Y = 0{\cdot}347 + 0{\cdot}750X_1 + 0{\cdot}0005X_2 \tag{1}$$

was obtained using:

Y = compacted density in gm./cm.^{3}
X_1 = undisturbed density in gm./cm.^{3}
X_2 = snow temperature (° C.)

The standard error of estimate for this equation was found to be equal to 0·025 gm./cm.^{3} which measures the closeness with which the estimated values agree with the original values. In other words, by knowing the undisturbed density and snow temperature, it is possible to estimate the compacted density within ±0·025 gm./cm.^{3} approximately 70 per cent of the time.

The coefficient of multiple correlation was calculated to be equal to 0·77. This figure gives a measure of the proportion of the variation in the compacted density which can be explained by variation in snow temperature and undisturbed density values. While this coefficient is not high it must be remembered that these data were obtained under field conditions by independent observers, and therefore some of the variation is probably due to experimental techniques.

The main value of equation (1) is that the relative compacted density or compactibility of newly fallen snow can be estimated and compared by making two simple snow measurements: undisturbed density and snow temperature.

Two variables which were not measured but which might affect the compacted density are grain size and grain-size distribution. In newly fallen snow it is difficult to make any objective measurement of these two variables. It is possible that undisturbed density does give a measure of their effect. To evaluate the effect of grain size and grain-size distribution, compaction tests were conducted in the laboratory on granular snow, screened to different grain sizes and grain-size distribution.

Table I records the results of these compaction tests under constant cold room temperature of +14° F. (−10° C.). Sample No. 2 compared with No. 4 indicates that the finer grain size can be compacted to a higher density than the coarse grain size. Sample No. 1 compared

TABLE I. THE EFFECT OF GRAIN SIZE AND GRAIN-SIZE DISTRIBUTION ON COMPACTED DENSITY OF GRANULAR SNOW. COLD ROOM TEMPERATURE +14° F. (−10° C.)

SAMPLE NO.	COMPACTED DENSITY GM/CM^3					
	INDIVIDUAL TEST RESULTS					MEAN
1	0·476	0·478	0·464	0·475	0·466	0·472
2	0·478	0·488	0·483	0·505	0·507	0·492
3	0·500	0·519	0·505	0·520	0·524	0·513
4	0·528	0·528	0·531	0·541	0·541	0·532

SNOW SAMPLE NO.		MESH OPENING
1 = GRAIN-SIZE DISTRIBUTION	40%	·078 –·055 SQ. IN.
	60%	·055 –·039 SQ. IN.
2 = GRAIN-SIZE DISTRIBUTION	100%	·078 –·055 SQ. IN.
3 = GRAIN-SIZE DISTRIBUTION	60%	·055 –·039 SQ. IN.
	40%	< ·039 SQ. IN.
4 = GRAIN-SIZE DISTRIBUTION	100%	< ·039 SQ. IN.

with sample No. 3 indicates that the proportion of fines in the material also can affect the compacted density. A comparison of sample No. 1 and sample No. 2 indicates that this is not necessarily true. Probably some measure of grain shape is also needed to analyse these tests properly. In general this result is similar to porosity determinations of granular materials, which indicate that the higher the proportion of smaller particles the denser the packing of the material.[13] It should be emphasized that this laboratory experiment was with old granular snow and the results do not necessarily apply to freshly fallen snow.

CONCLUSIONS

The measurements made on the properties of newly fallen snow indicate that the density to which freshly fallen snow can be compacted by a standard technique is largely dependent on the snow temperature and the undisturbed density. These tests were made on dry snow.

It has been shown [11] that the compacted density of wet snow depends on the amount of free water held in the wet snow. Further tests might indicate that a modified form of equation (1) would be valid for wet snow conditions.

The measurements required are simple and can readily be done under field conditions. The data obtained indicate that reasonably consistent results can be obtained by observers located several hundred miles apart.

It has also been shown that the smaller the proportion of fine, granular snow, the higher the compacted density. It is possible that the undisturbed density term in equation (1) gives some measure of the grain size and grain-size distribution effect.

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