SNOW MECHANICS

Thesis for the Degree of B. S.
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William L. Myers
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SNOW MECHANICS

A Thesis Submitted to

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AGRICULTURE AND APPLIED SCIENCE

by

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THESIS

INTRODUCTION

Snow mechanics, or the science of the laws of matter and motion in relation to snow, is the problem on which I have been working. The purpose of my study has been to compile and determine data to give a basis of scientific study to snow removal.

I wish to take this opportunity to thank Professor C. L. Allen, Head of the Civil Engineering Department of Michigan State College, Mr. E. A. Finney and Mr. Burke of the Michigan State Highway Department and Mr. G. W. Radimershy of the Foreign Language Department for their valuable aid and advice in the preparation of this thesis.

ACCUMULATED DATA

In my search, I was surprised at the scarcity of data on the mechanics of snow. Most of the heads of state highway departments recognized that there existed different types of snow having different characteristcs, for their reports on the costs of various snow removal jobs varied with the atmospheric temperature and type of snow. V.R. Burton, of the Michigan State Highway Department, in a report, "The Cost Analysis of Snow Removal," "found a remarkable variation in cost per inch mile as shown by the classification according to temperature. It should be remembered that this cost variation is due to the product of two factors: first, depth of drifting, and second, the cost of removing the particular class of snow encountered through the drift. It can be easily seen then that there may be a temperature at which a minimum cost may occure due to the minimum product and not the minimum of either factor.

Throughout all ranges of topography and wind conditions the cost per inch mile from seventeen different counties with a mean daily temperature of 20° to 22° is consistently less than for a temperature either above or below this temperature range. Drifting is not so serious at this temperature as it is at the lower temperature, and the cost of moving an inch of drifted snow is not so high as it is in the temperature above. We have here then the condition of snow removal at the minimum cost per inch mile.

As the temperature drops below 20° the amount of drift increases faster than the decreased cost of moving a lighter snow and we get increased costs. As the temperature goes above 22° the snow gets heavier and more difficult to move since thaws are more frequent. The cost of moving this type of snow increases faster than the decreased amount of drifting."[1]

In 1936 the Four Wheel Drive Auto Company, a manufacturer of trucks for snow plows, experimented on different shaped plows to facilitate the removal of snow. J.R. Shannon of the Engineering Department of the Company, who wrote the article "The Truck Manufacturer Looks at Snow Plows," was interested primarily in the snows of Wisconsin. The counties there own most of the road maintenance equipment; therefore, "the state roads are opened first, the county roads next, and where the townships have no equipment of their own, their roads are opened last. As a result, the latter sometimes remain closed for a week or more during which time the snow becomes hardpacked. Often these roads have high frozen banks on each side caused by previous plowing. This condition is one of the most difficult that a snow removal unit is called upon to meet. It requires a truck with plenty of power and traction and a plow with the right mold board shape to lift the snow over the bank.

It was under these conditions that Mr. Shannon studied the action of a number of makes of plows. He took measurements of them and built accurate models on a scale of ½ inch to the foot. Powdered air-slaked lime, slightly dampened

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[1]Burton, V.R., "The Cost Analysis of Snow Removal," <u>American City</u>, April, 1926.

with kerosene, was used as snow.

A long narrow box, having no removable partitions running lengthwise, and made to represent banks six feet high and fourteen feet apart according to the scale used, representing a stretch of snow-blocked highway. The bottom of the box was corrugated so that the plowing medium would stick to the bottom and not slide endwise under the pressure of the plows. The artificial snow was packed between the model snow banks to a uniform depth on each trial. A stout cord, wound onto a small winch drum, operated by an electric motor through a reduction gear, pulled the models through the artificial snow at a uniform plowing speed. The spring scale used to obtain the reading was interposed between the models and the winch. Five tests were run on each model. The average pull required was as follows: Plow A - seven pounds, B - 7.6 pounds, C - 9.5 pounds, D - 9.6 pounds. The widest plow, D, required the most power, while the narrowest, A, required the least.

Another model was constructed of plow D but narrowed down to an eight foot width at the cutting edge, the same as plow A. Upon testing this plow, he found that it took almost as much power as the full size plow D model. From this he concluded that the power required to push the snow plow depends as much, if not more, upon the shape as upon the width at the cutting edge. He concluded too that it would be possible to build a ten foot plow requiring very little more power than an eight foot plow if the shape were correct."[2]

While the Four Wheel Auto Company held the snow constant and varied the shape of the plow, I decided to have a single shaped plow and to use it in varying density snow. This article is of interest for it gives data on snow removal equipment.

Dr. J.E. Church, father of snow surveying and meteorologist at the University of Nevada, in his article "The Human Side of Snow" tells of the experiences of J.D. MacVicar, Maintenance Engineer for the State of Washhington. Mr. MacVicar found that the highest sliding resistances occurred when snow is slightly wet and still retains its needle-like structure. Upon losing the latter its sliding resistance is low. Still higher resistances would probably occur at very low temperatures.

Dr. Church had included in his article the recommendations of George J. Klein of the National Research Council, Ottowa, Canada, for improving the snow characteristics of skis under all conditions. These recommendations, I believe, could be applied to snow plows.

"1. The skis should be made of a material which resists wear and has a low tendency to wet, and which gives a low surface tension drag. Bakelight fills all three requirements most satisfactorily.

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[2]Shannon, J.R., "The Truck Manufacturer Looks at Snow Plows," Roads and Streets, February, 1937.

2. A high unit loading improves the snow characteristics of skis under all conditions. A unit loading of between 400 and 500 pounds per square foot is recommended instead of 200 pounds per square foot, which is the present general practice.

3. The ratio of length to breadth should be at least six. High ratios are particularly important for highly loaded skis and low temperature snow.

4. Flexible construction assists unsticking."

The first requirement is the main disadvantage of steel, for it has a high tendency to wet and a high surface tension. Bakelight is too brittle a material to use for a snow plow. It may be possible to use a plastic glass that would have the required properties but not have bakelight's brittleness.

I read an article headed "Glass Replaces Vital Materials" that told of glass's new qualities. "One reason for the new importance of glass is the shortage of many materials. Glass by the nature of its ingredients is plentiful and will remain so. As a result it is being used to replace such varied metals as steel, stainless steel, iron, tin, aluminum, nickel and copper.

Tough, fine fibers of glass, stronger than steel wire of the same dimensions, are now being woven into a fireproof fabric for covering th wings of light trainer planes. Walls of glass blocks are daylighting new war production plants and are also used to replace worn-out steel sash in converted factories. Concrete is being reinforced with glass instead of with steel.

The same glass that goes into the most delicate of hand-blown stemware can be made as heavy and tough as cast iron, volume for volume. It can be transparent, translucent or opaque. Glass can be taken from an oven and plunged into icy water without breaking. It can be toughened to a point where it will stop a machine gun bullet fired point blank."[3]

There also appeared in the article the statement that "unconsolidated snow weighs from five to twelve pounds per cubic foot, whereas compacted snow weighs from fifteen to fifty pounds per cubic foot."[4]

J.D. MacVicar, who was mentioned by Dr. Church, published an article, "Snow Types Encountered in Highway Removal." He found that snow weighing 6.25 pounds per cubic foot, with a water content of 10% when pushed by a plow, is so compacted that its weight increases five-fold. The weight of the compacted snow is 29.5 pounds per cubic foot and its water content is 46%.[5]

E.A. Finney, head of the Michigan State Highway Research Department, has performed many experiments on the drifting of snow. In an article, "Snow Control on Highways," he branched off a bit to touch on snowfall and density. He found data to the effect that "freshly falling snow "maybe

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[3]"Glass Replaces Vital Materials" The State Journal of Lansing Michigan, March 7, 1943.

[4]Church, J.R., "The Human Side of Snow," Scientific Monthly, March, 1942.

[5]MacVicar, J.D., "Snow Types Encountered in Highway Removal," Roads and Streets, September, 1940.

of the light feathery type, the powdery type, or the wet clinging type, depending on local conditions at the time of the storm. The factors which affect the type and density are the temperature, altitude, time of day and season of the year, compactness of the snow crystals, water content and foreign bodies collected by the falling snow.

Freshly fallen snow will have a water equivalent of about three to ten per cent, depending upon the type of snow. The light feathery type will have from three to five per cent, the powdery type, five to seven per cent and the wet, clinging type, from eight to ten percent. In terms of density the range may be anywhere from 0.03 to 0.2, depending upon altitude and air temperature.

Accumulative snow rapidly becomes of high water equivalent because of compaction by its own weight, absorption of the sun's rays, settling by wind and heat from the earth. Tests show values of water equivalent from 20% to 60%. A curve showing the relation between the depth of snow and water equivalent is given in Figure 1. This curve is based on readings taken at Summit, California by H.F. Alps.

There exists a relation between snow density and air temperature. It is quite apparent that air temperature has a decided influence on the density of freshly fallen snow. The light feathery snows occur under low temperatures, while high temperatures produce heavy snows. A curve showing this relation may be found in Figure 2. This is an average curve based on the results of A. Lancaster, and

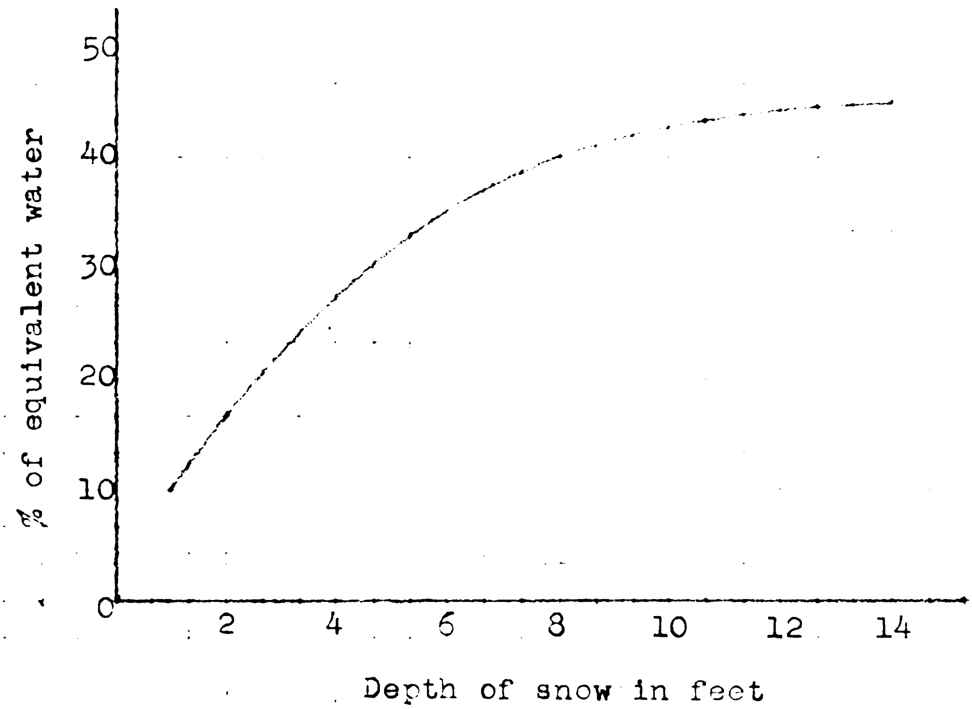

Fig. 1

Relation between depth of snow and water equivalent

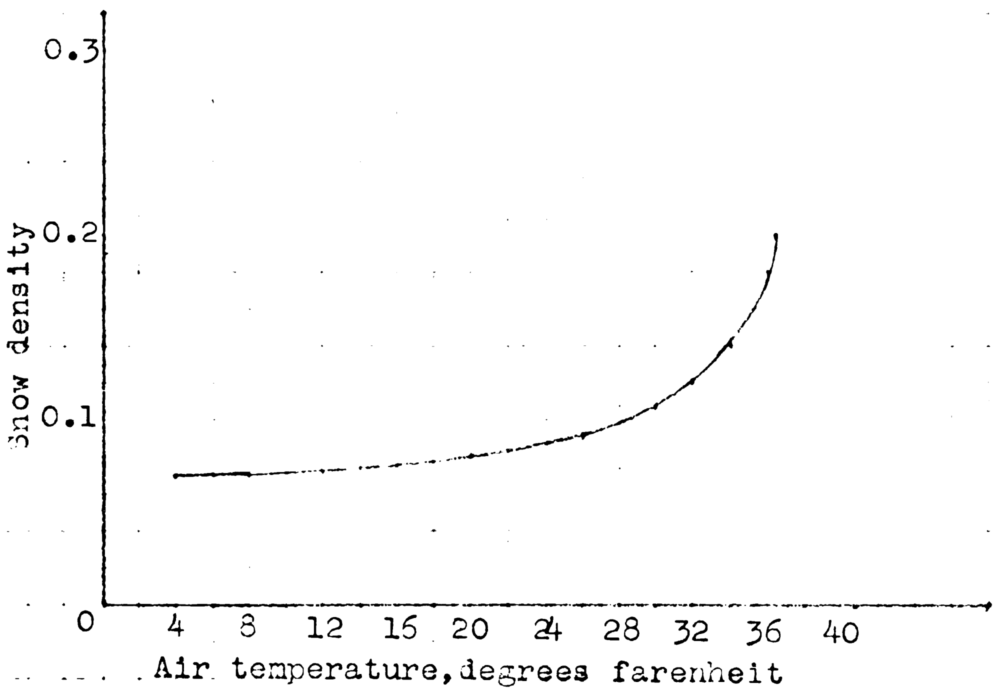

Fig. 2

Relation of snow density to air temperature

Fritz Wengler, who have made a study of this relation over a period of years. Their observations were made at different localities, but check very closely."[6]

Snow density and cohesion has been made an active project by R.A. Wock of the Division of Irrigation. In a report written by him of the Crater Lake Experiments, he observed that building up of ice on the ground under conditions as shown in Table I.

Table I.

Date	Snow Depth	Range Temp. in Snow F.	Soil temp. $1\frac{1}{2}$" below surface F.	Thickness of ice on ground "	Remarks
Apr.15	103.0	31.7-32.0	32.6	none	Amount of water from snow beginning
Apr.28	83.0	31.8-32.0	32.3	0.25	Amount of water from snow underway
May 13	68.0	31.9-32.0	32.0	0.37-0.50[a]	

a- with some parts of ground-surface not covered with ice.

Mr. Wock writes "the ground was frozen under the snow on all of the above dates. The ice on the ground on May 13 was porous, that is, water passed through it. No doubt there is some simple explanation for this icing phenomenon but none occurs to me just now. I might add that this ice building on the ground has been previously observed by snow

[6]Finney, E. A., Bulletin #57, Michigan Engineering Experiment Station.

surveyors in this state. I have observed it myself on several occasions; however such ground-icing does not _always_ occur."[7]

The previous data has been more on snow density, generalities and observations of snow pecularities. It has shown that there exists some relation between density, compaction and temperature of snow.

The deformability of snow and its variation with the depth of the overlying snow have been studied by Mr. Kuroda of Tokyo.

Mr. Dorsey's review of Mr. Kuroda's work is as follows; "For measuring the tensile strength he used telescoping sheet-metal forms of the general shape of the axial section of metal specimens intended for similar tests. One of these forms was pressed into a layer of undisturbed snow carefully taken up on a glass plate, and the force required to pull it apart was measured.

For obtaining the shearing strength he used a flat block sliding snugly in a slot cut in another block; through the center of the compound block and perpendicular to the plane of the sliding one was cut a rectangular hole. By means of a suitable sheet-metal form, prisms of snow that filled the hole could be cut out and placed in it; the force then required to withdraw the sliding block was measured.

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[7]Work, R.A., A report in the "Transactions of 1941 of the American Geophysical Union".

He gives curves showing the grain size, the density, D, and the temperature, throughout the thickness of a natural snow-blanket 9 meters thick. The size of the grains varied but little until the ground was approached, where the snow was several months old; the density varied brom 0.35 g/cm^3 at a depth of 50 cm. to 0.65 at 700 cm; from a depth of 200 cm to that of 700 cm. the hardness was essentially constant; the temperature was lowest (-0.9°C) at mid-depth.

The variation of the hardness of snow with its depth in a snow blanket is indicated by the surface diameter (D) of the conical indentation produced by dro pping a brass-tipped wooden cone, vertex angle = 90°, from a stated height (h) above the surface of the snow under study. By carefully removing the overlying snow, that surface was placed at any desired depth (d) below the undisturbed suffface of the natural snow-blanket; h = 0 indicates that the cone was placed gently upon the surface and sank under its own weight. Values are given for two blankets; those in the first column hv= 0 refer to one, and the others, to the other. In the original papers the values of h and d for the second blanket appears to have been interchanged. They are the reverse of those here given.

Table I. unit of h, d, and D = 1 cm.

h	0	0	5	10	20
d	D		D		
0	16.8		16.0	19.2	
2	14.0				
10	10.0		4.7	9.1	11.7
15	4.4				
20	4.3		4.6	8.0	12.0
30	4.0				
40	4.5	3.4		7.6	12.0
50	4.0				
60	5.0				
70	3.3	3.0		5.4	8.0
80	3.6				

To determine the effect that tamping has on the hardness of snow, carefully remove the overlying snow so that the surface under study can be brought to any desired depth (d) below the surface of the natural snow blanket. The hardness of one portion of the surface so cleaned was determined at once; another portion was tamped by dropping from a height H of a load of 2700 g with a rectangular base 18x27 cm, and the hardness was then determined. D and h have the same significance as the above table. Two snow blankets were studied; temperature of the snow, about -11°C.

Table II. h = 20 cm. Unit of H, d, D = 1 cm.

H	U^a	20	U^a	40	60
d		D		D	
0	4.5		14.0		
10	8.5		8.0		
12	8.5	4.0			
13			5.5	2.0	1.5
16	6.0	3.0			
19	6.5	3.0			
20	5.2		4.5	2.5	2.0
22	5.2	4.8			
25	4.5		4.0	3.3	3.0
26	4.0	3.5			
30	3.0	3.0	3.5	3.5	3.5
45	4.5	4.5			

U^a = untamped

Strength and Hardness of Snow.

T = tensile strength, S = shearing strength, D = hardness as in Table I, t_s°C = temperature of the snow.[8]

Unit of D = 1 cm., of T and S = 1 gm/cm^2.

Snow	A	B	C	D	
t_s	9.0	0	-2.0		A = fresh and Powdery.
T	63.	33.	93.		B = wet and soft.
S	3.	2.5	20.	43.	C = surface crust.
D	20.	20.	155.		D = surface more crusted than C.

N. Ernest Dorsey also wrote a short article on the density of snow.

"The density of freshly fallen snow varies greatly, depending upon the aerodynamic conditions attending its dposition; the density at any point of a snow blanket increases with the age of the blanket, even in the absence of fusion. The density in a natural blanket of snow increases nonlinearly with the depth. Values as low as 0.004 have been recorded for freshly fallen snow.

The density of the persistent néve in the Pyrenees at altitudes of 2.5 to 3.4 km. varies from 0.51 to 0.59 g/cm^3 in August to September, and from 0.53 to 0.65 in October. Devaux thought that this apparent increase was real. The samples were probably taken from the near surface. E. Sorge has found that the density of the néve on the inland ice-sheet of Greenland is 0.51 g/cm^3 at depths of 30 to 118 cm, varying inappreciably with the depth."[9]

[8&9] Dorsey, N.E., Properties of Ordinary Water Substances.

Mr. Dorsey also had an article on the adhesiveness of ice.

"J.W. McBain and D.G. Hopkins have reported that the freezing of a thin film of water between 2 plates of fused silica produces a joint that is "very strong" in shear. The freezing was done with solid CO_2, and the test was presumably made at that temperature."[10]

The Department of Soil Mechanics in the Research Institute of technology at Zurich, Switzerland has gone far in their research on snow. Their main object was to combat the avalanche menace in the Swiss mountains. In order to do this they have spent years on snow research. The findings of the Institute have been published by R.Haefeli under the title "Schneemecanik" ie. Snow Mechanics.

The book which is written in scientific German, covers very thoroughly the subject of snow mechanics. A translation of the contents is given below:—

Laboratory Experiments;

I. General conditions of experiments
   - A. testing room
   - B. testing materials

II. Plastic deformation and sliding of homogeneous snow specimens under the action of known outer forces.
   - A. compressibility
     1. arrangement of tests

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[10]Dorsey, N.E., Properties of Ordinary Water Substances.

2. General behavior of settlement

3. basis of comparison

4. influence of forms

5. comparison of compressibility of different snows

6. influence of loading

7. influence of temperature

B. Extensability as compared with compressability

1. arrangement of experiment

2. general characteristics of extension as compared with settlement

3. basis of comparison

4. comparison of extensability of different snows

5. ration of extensability to compressability for differetn snows

6. influence of loading

7. influence of temperature

C. Sliding

1. fundamental conceptions

2. arrangement of experiments

3. comparative investigation and general characteristics of sliding

4. influence of shear stresses on the velocity of sliding

5. influence of normal stresses on the velocity of sliding

6. special cases

D. Sliding processes and discontinuation planes.

1. fundamental conceptions and arrangement of experiments

2. friction as a function of temperature

3. friction as a function of velocity of sliding

4. friction as a function of pressure

5. conclusions

III. Strength characteristics of homogeneous snow specimens.

A. General data

B. Strengths in compression

C. Strengths in tension

D. Strengths in shear, cohesion and inner friction

1. fundamental conception

2. arrangement of experiments

3. measurement of cohesion

4. shear strengths and the seeming inner friction as a function of pressure.

IV. Comparatuve tests with ice.

A. General fundamental principles

B. Plastic, compressibility, extensability

C. Plastic sliding

D. Strengths in compression and tension

E. Possible applications

Field Tests.

I. Measurement of the resistance to ramming and the taking of ram profiles.

  A. Purpose - fundamental conception and arrangement of experiments

  B. Theoretical bases

  C. Applications

II. Creep measurements.

  A. Purpose, fundamental conception, methods

  B. Measurements on snow surface

  C. Measurements on inside snow

III. Measurement of snow pressure.

  A. Arrangement of tests

  B. Variation of pressure in time

  C. Effect of pressure

Investigation of the seeming equilibrium of snow.

I. Physical underlying principles.

II. Stress theory.

  A. General characteristics of stress

  B. Dead load stresses of horizontal snow

  C. Conditions of equilibrium of inclined snow

    1. special characteristics of stress in the case of snow with low cohesion

    2. general condition of stress prevailing with cohesive snow

D. Dead load stress characteristics of inclined snow.

1. special case of stress
2. general case of stress
3. influence of topography
4. various influences

E. Example computation of snow pressure

1. continuous wall
2. isolated pier
3. applications and general rules of levying prevention

III. Investigation of a special type of reviens.

A. Reviens - Haupterta1i

B. Reviens - Weibfluh

C. Reviens - Strelahalde

D. Reviens - Schwarzhorn

E. Reviens - Scheahorn

F. Final remarks.

The following are some tables and graphs taken from "Schneemecanik".

Comparison of different types of snow from the same snow profile.

Average experimental temperature, t_1 = -5°C (air)
6 - 5 kg/dm^2

Depths of lower surface cm. cm.	Snow temp. in profile C°	Age of snow	Vertical pressure in snow cover Kg/dm^2	Space weight Kg/m^3	Index of permeability by air cm/sec	% of compaction. %
0		0	0	49		67.0
35	-5.8	18	0.78	308	47	8.02
67	-4.7	54	1.60	307	182	2.24
99	-3.4	56	2.75	421	44	0.97
131	-2.2	100	3.85	362	155	0.69

As the age of the snow, the number of days between snowfall and beginning of the experiment are designated.

Index of compaction for various pressures.

Exp. no.	Average space weight Y_{so} kg/m^3	Average porosity number %	Average air permeability K_o cm/sec	Temp. of air t_1 C°	Index of compaction s_1 in % (24 hrs) for 6 in kg/dm^2: 2	5	10	20	40
1	376	59.0					2.67	4.56	9.24
2	306	66.6	8.3	-4			5.90	10.05	10.20
3	292	68.2	69	-5	3.48	6.45	9.25		

Index of compaction in the function of the temperature for 6 = 6.4 kg/dm^2 (compare fig. 8)

Exp. number	Sp. Gr.	Air permeability.	Temperature of medium	Index of compaction
1	318	125.5	-1.6	5.46
2	318	127.5	-3.9	4.16
3	315	123.0	-5.5	3.08
4	316	128.5	-8.1	2.73
5	319	120.5	-11.0	1.88
6	313	136.5	-17.5	1.28

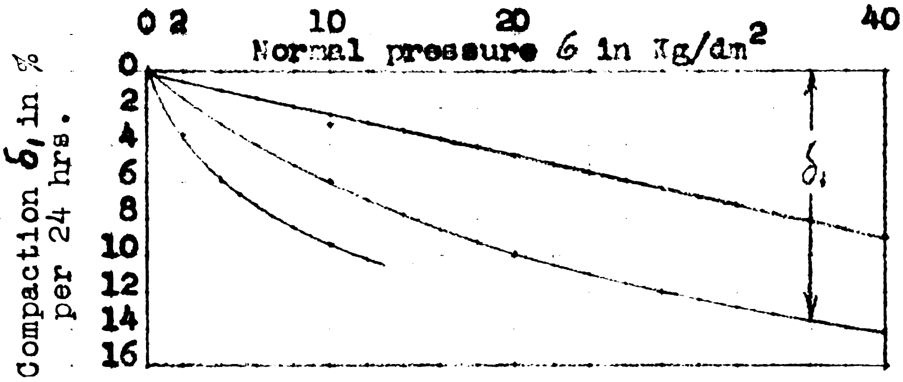


Fig.7

Index of compaction δ_1 in the function of normal tension б for various types of snow.

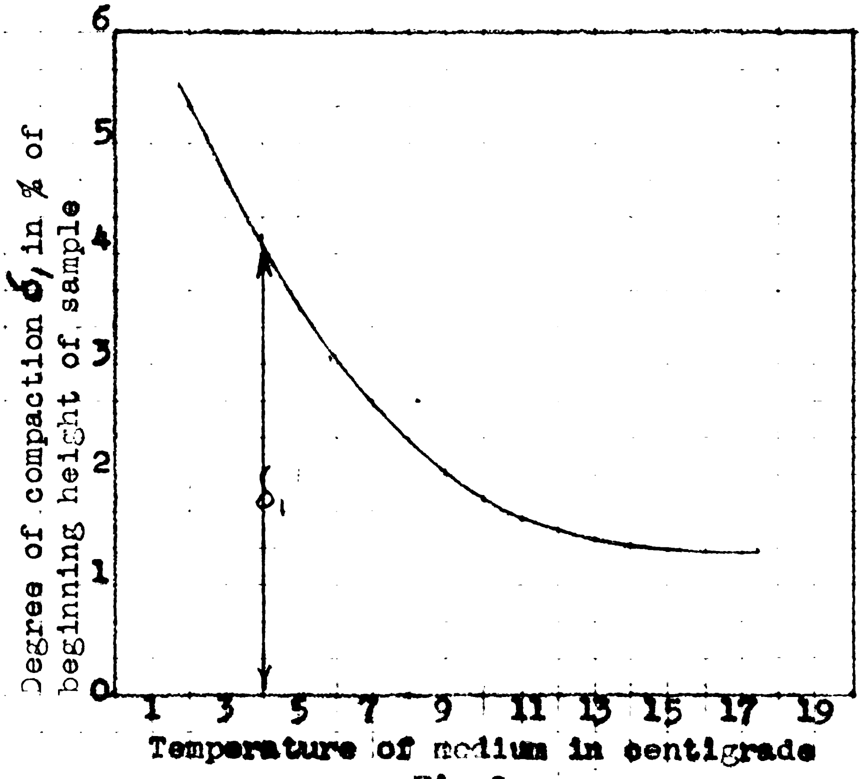
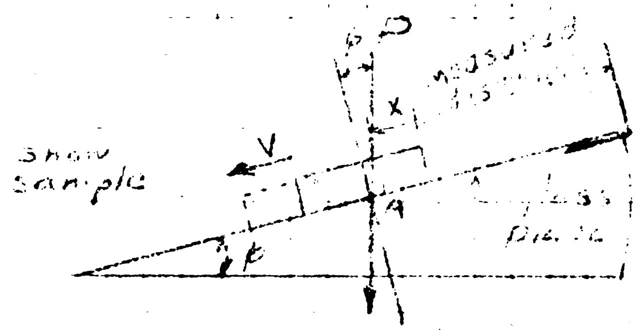


Fig.8

Experiment Arrangement



Sliding Diagram

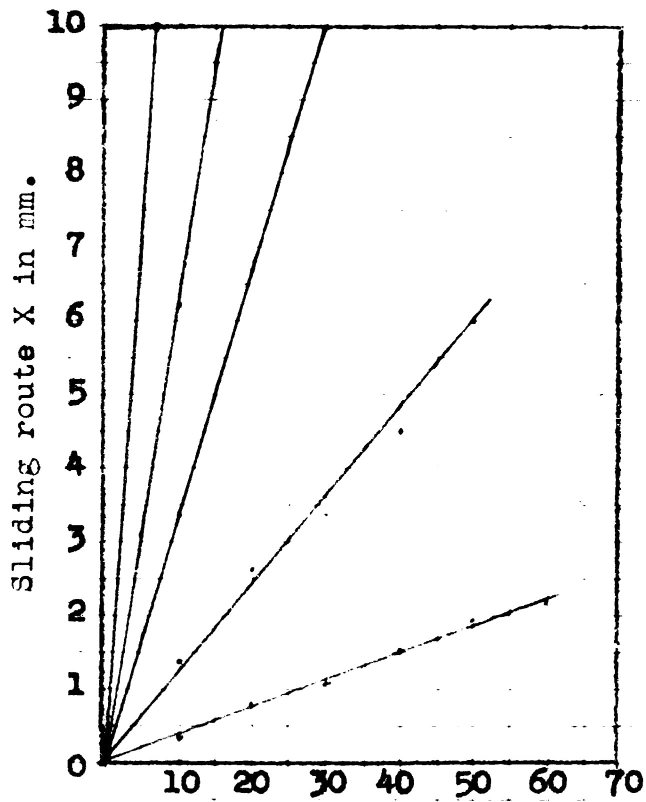


Fig. 24
Gliding experiment with snow on glass
temperature-=0°

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Schneemecanik - R. Haefeli

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EXPERIMENTS

There entered into my experiments many offshoots which went more into the physical properties of the snow than the mechanical. The mechanical properties are directly dependent upon the density of the snow and the atmospheric temperature.

The first draft of the outline of work that I proposed to accomplish, as I soon found out, was too long for the determination of definite data. The time required for devising and constructing equipment and in preforming the experiments proved to be far more than I had allowed. There also entered in, the disappointments of the inability of equipment to perform as desired. I did however obtain from these failures, negative knowledge. I have included herein the experiments that were failures.

Cans used in the experiments.

Number	Weight in grams	Depth	Diameter	Volume in cu. cm.
1	94.0	7.78	12.70	985.03
2	95.6	7.78	12.70	985.03
3	95.9	7.78	12.70	985.03
4	85.5	7.78	12.70	985.03
5	94.0	7.78	12.70	985.03
6	94.0	7.78	12.70	985.03
7	94.0	7.78	12.70	985.03
8	96.0	7.78	12.70	985.03
9	96.0	7.78	12.70	985.03

Method of Obtaining a Sample of Snow.

There are two conditions under which samples were taken: 1 - newly falling snow and 2 - fallen snow. To collect newly falling snow, the cans, chilled to atmospheric temperature, are set out during a snow storm in a protected place so that the wind, will not blow the snow out of the can. In the collection of fallen snow more skill is required. The equipment, ie., cans and a steel plate ~~to~~ which is wider than the diameter of a can, are chilled to atmospheric temperature. At some level place the can is carefully pushed down into the snow with a rotating or twisting motion, open end first, until the bottom of the can is level with the surrounding snow. Cut the snow away from the sides of the can until about one-half of the rim is visible. Slide the flat piece of steel along the rim of the can, using the other hand to prevent the can from being disturbed. Remove the metal plate, can and snow together and turn right side up. Remove the plate by sliding it off.

Temperature Reading.

The temperature readings marked trailer were taken from a thermometer hung inside a non-heated trailer owned by the Michigan State Highway Research Department. The trailer protected the thermometer readings from direct sunlight and direct winds which would have caused variations in the temperature readings.

The trailer in which temperatures were read and some experiments preformed.

Types of Snow.

1 - dry, fluffy snow powder

2 - dry, heavy powder

3 - damp powder

4 - wet snow

5 - thawing snow

6 - slush

These types appear under three conditions;

1 - newly fallen snow

2 - old snow

3 - drifted snow

A group picture os some of the equipment
used in my experiments.

EXPERIMENT NUMBER 1.

Density and Water Content in Snow.

OBJECT: To determine the density and water content for different types and conditions of snow.

EQUIPMENT: Cans of known weight and volume to put the snow into. A flat steel plate (approximately 12' x 6'). Scales. Thermometer.

PROCEDURE: A sample of snow was obtained as described under "Method of obtaining a sample of snow". Record the atmospheric temperature at the time the sample was taken, and the type of snow from which the sample was taken. Wipe the outside of the can to remove any clinging snow. Weigh the can and the snow and subtract the weight of the can to determine the weight of the snow in the can.

COMPUTATIONS:

$$\text{Density of snow} = \frac{\text{weight of snow}}{\text{volume of snow}}$$

$$\text{Water content in \%} = \frac{\text{volume of water}}{\text{volume of snow}} \times 100$$

$$\text{water equivalent in cm. of depth} = \frac{\text{volume of water}}{\text{cross-sectional area of can}}$$

water equivalent in inches of depth

$$= \frac{\text{volume of water}}{\text{cross-sectional area of can} \times 2.59}$$

Date January 20, 1943

Temperature in trailer $6^{\circ}F$.

Atmospheric temperature

Snow storm - when January 18 & 19

Snow characteristics

Type of snow in sample regular

Remarks previous weather -6° to $-10^{\circ}F$.

DATA:

		DENSITY			wt. of snow	density	WATER CONTENT			
trial	can no.	vol. can c.c.	wt.of can + snow grams	wt.of can grams	~~grams per c.c.~~	~~#/ft.~~ grams per c.c.	vol. water c.c.	water equiv. cm. of depth	water equiv. in. of depth	% of water by vol.
1	1	985.0	169.0	94.0	75.0	.076	75.0	.59	.23	7.6
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										

Date January 20, 1943

Temperature in trailer 10°F.

Atmospheric temperature

Snow storm - when January 18 & 19

Snow characteristics

Type of snow in sample regular

Remarks previous weather -6 to -10 F.

DATA:

			DENSITY		wt. of snow	density	WATER CONTENT			
trial	can no.	vol. can c.c.	wt. of can + snow grams	wt. of can grams	~~grams per c.c.~~	~~#/ft.~~ grams per c.c.	vol. water c.c.	water equiv. cm. of depth	water equiv. in. of depth	% of water by vol.
1	2	985.0	209.0	95.6	113.4	.115	113.4	.90	.35	11.5
2	1	"	219.0	94.0	125.0	.127	125.0	.99	.38	12.7
3	5	"	209.1	94.0	115.1	.117	115.1	.91	.35	11.7
4	4	"	205.0	88.5	116.5	.118	116.5	.92	.36	11.8
5	6	"	211.8	94.0	117.8	.120	117.8	.93	.36	12.0
6		"								
7		"								
8										
9										
10										
11										
12										

Date January 20, 1943

Temperature in trailer 9°F.

Atmospheric temperature

Snow storm - when January 13 & 19

Snow characteristics

Type of snow in sample regular

Remarks previous weather -6° to -10°F.

DATA:

		DENSITY					WATER CONTENT			
trial	can no.	vol. can c.c.	wt. of can + snow grams	wt. of can grams	wt. of snow ~~grams per c.c.~~	density ~~#/ft.~~ grams per c.c.	vol. water c.c.	water equiv. cm. of depth	water equiv. in. of deoth	% of water by vol.
1	2	985.0	202.0	95.6	106.4	.108	106.4	.84	.33	10.8
2	4	"	228.5	88.5	140.0	.142	140.0	1.11	.43	14.2
3	6	"	221.5	94.0	127.5	.129	127.5	1.01	.39	12.9
4	5	"	224.0	94.0	130.0	.132	130.0	1.03	.40	13.2
5										
6										
7										
8										
9										
10										
11										
12										

Date January 21,1943

Temperature in trailer 13° F.

Atmospheric temperature 12° F.

Snow storm - when January 21,1943

Snow characteristics dry heavy powder

Type of snow in sample drifted

Remarks snow flakes-definitely shaped crystals

DATA:

trial	can no.	vol. can c.c.	DENSITY wt.of can + snow grams	wt.of can grams	wt. of snow ~~grams per c.c.~~	density ~~#/ft~~ grams per c.c.	WATER CONTENT vol. water c.c.	water equiv. cm. of depth	water equiv. in. of depth	% of water by vol.
1	5	935.0	219.0	94.0	125.0	.127	125.0	.99	.33	12.7
2	1	"	228.0	94.0	134.0	.136	134.0	1.06	.41	13.6
3	2	"	227.0	95.6	131.4	.133	131.4	1.04	.40	13.3
4	4	"	213.0	83.5	129.5	.131	129.5	1.03	.40	13.1
5	6	"	234.5	94.0	140.5	.142	140.5	1.11	.43	14.2
6										
7										
8										
9										
10										
11										
12										

Date January 21, 1943

Temperature in trailer 14.5°F.

Atmospheric temperature 10°F.

Snow storm - when 10:30 A.M. January 21

Snow characteristics dry heavy powder

Type of snow in sample caught in cans

Remarks snow flakes had definitely shaped crystals

DATA:

		DENSITY					WATER CONTENT			
trial	can no.	vol. can c.c.	wt. of can + snow grams	wt. of can grams	wt. of snow ~~grams per c.c.~~	density ~~#/ft~~ Grams per c.c.	vol. water c.c.	water equiv. cm. of depth	water equiv. in. of depth	% of water by vol.
1	7	889.1	163.3	94.0	69.3	.078	69.3	.547	.211	7.8
2	8	819.3	157.0	96.0	61.0	.075	61.0	.481	.186	7.5
3	9	889.1	162.5	96.0	66.5	.075	66.5	.525	.203	7.5
4										
5										
6										
7										
8										
9										
10										
11										
12										

Date January 22, 1943

Temperature in trailer 17.5 F.

Atmospheric temperature

Snow storm - when

Snow characteristics

Type of snow in sample regular

Remarks

DATA:

	DENSITY						WATER CONTENT			
trial	can no.	vol. can c.c.	wt. of can + snow grams	wt. of can grams	wt. of snow ~~grams per c.c.~~	density ~~#/ft.~~ grams per c.c.	vol. water c.c.	water equiv. cm.	water equiv. in.	% of water by vol.
1	2	985.0	210.5	95.6	114.9	.117	114.9	.91	.35	11.7
2	4	"	207.5	88.5	119.0	.121	119.0	.94	.36	12.1
3	7	"	214.5	94.0	110.5	.112	110.5	.87	.34	11.2
4	6	"	209.0	94.0	115.0	.117	115.0	.91	.35	11.7
5										
6										
7										
8										
9										
10										
11										
12										

Date January 24, 1943

Temperature in trailer 17.5 F.

Atmospheric temperature

Snow storm - when

Snow characteristics

Type of snow in sample regular

Remarks

DATA:

			DENSITY				WATER CONTENT			
trial	can no.	vol. can c.c.	wt. of can + snow grams	wt. of can grams	wt. of snow grams ~~per~~ ~~c.c.~~	density ~~#/ft.~~ grams per c.c.	vol. water c.c.	water equiv. cm.	water equiv. in.	% of water by vol.
1	7	285.0	259.0	94.0	165.0	.168	165.0	1.30	.50	16.8
2	8	"	249.0	88.5	160.5	.163	160.5	1.27	.49	16.3
3	5	"	244.5	94.0	150.5	.153	150.5	1.19	.46	15.3
4	1	"	235.0	94.0	141.0	.143	141.0	1.11	.43	14.3
5										
6										
7										
8										
9										
10										
11										
12										

Date January 25, 1943

Temperature in trailer 32°F.

Atmospheric temperature

Snow storm - when

Snow characteristics

Type of snow in sample old snow

Remarks snow crust ½" thick

DATA:

			DENSITY		wt. of snow	density	WATER CONTENT			
trial	can no.	vol. can c.c.	wt. of can + snow grams	wt. of can grams	~~grams per c.c.~~	~~#/ft.~~ grams per c.c.	vol. water c.c.	water equiv. cm. of depth	water equiv. in. of depth	% of water by vol.
1	5	985.0	301.3	94.0	207.3	.210	207.3	1.64	.63	21.0
2	7	"	300.0	94.0	206.0	.209	206.0	1.63	.63	20.9
3	7	"	307.0	94.0	213.0	.216	213.0	1.68	.65	21.6
4	8	"	295.0	96.0	199.0	.202	199.0	1.57	.61	20.2
5	5	"	300.0	94.0	206.0	.209	206.0	1.63	.63	20.9
6										
7										
8										
9										
10										
11										
12										

Thesis for Winter Term, 1945

Snow Mechanics - Willaim L. Myers

The Design of a Municipal Airport - Harlan E. Pitcher

Steel Design for Extension of the Boom of Steamer Carl D. Bradley ---
Frederick Neil Jackson

A Design and Cost Estimate of a Trailer Coach Park - Malcolm H. Cooper, Jr.

Date January 26, 1943

Temperature in trailer 16°F.

Atmospheric temperature

Snow storm - when

Snow characteristics

Type of snow in sample crusted snow; old snow

Remarks warm Jan.23 & 24; cold Jan.25 &26
cans #1 & 2-regular; cans #4 & 6-drifted snow

DATA:

			DENSITY		wt. of snow	density	WATER CONTENT			
trial	can no.	vol. can c.c.	wt. of can + snow grams	wt. of can grams	~~grams per c.c.~~	~~#/ft.~~ grams per c.c.	vol. water c.c.	water equiv. cm. of depth	water equiv. in. of depth	% of water by vol.
1	1	985.0	301.0	94.0	207.0	.210	207.0	1.63	.63	21.0
2	2	"	284.0	95.6	198.4	.201	198.4	1.57	.61	20.1
3	4	"	312.0	88.5	223.5	.227	223.5	1.77	.68	22.7
4	6	"	324.0	94.0	230.0	.233	230.0	1.82	.70	23.3
5										
6										
7										
8										
9										
10										
11										
12										

Date February 11,1943

Temperature in trailer 24°F.

Atmospheric temperature

Snow storm - when February 11,1943

Snow characteristics dry fluffy snow

Type of snow in sample drifted snow

Remarks strong wind

DATA:

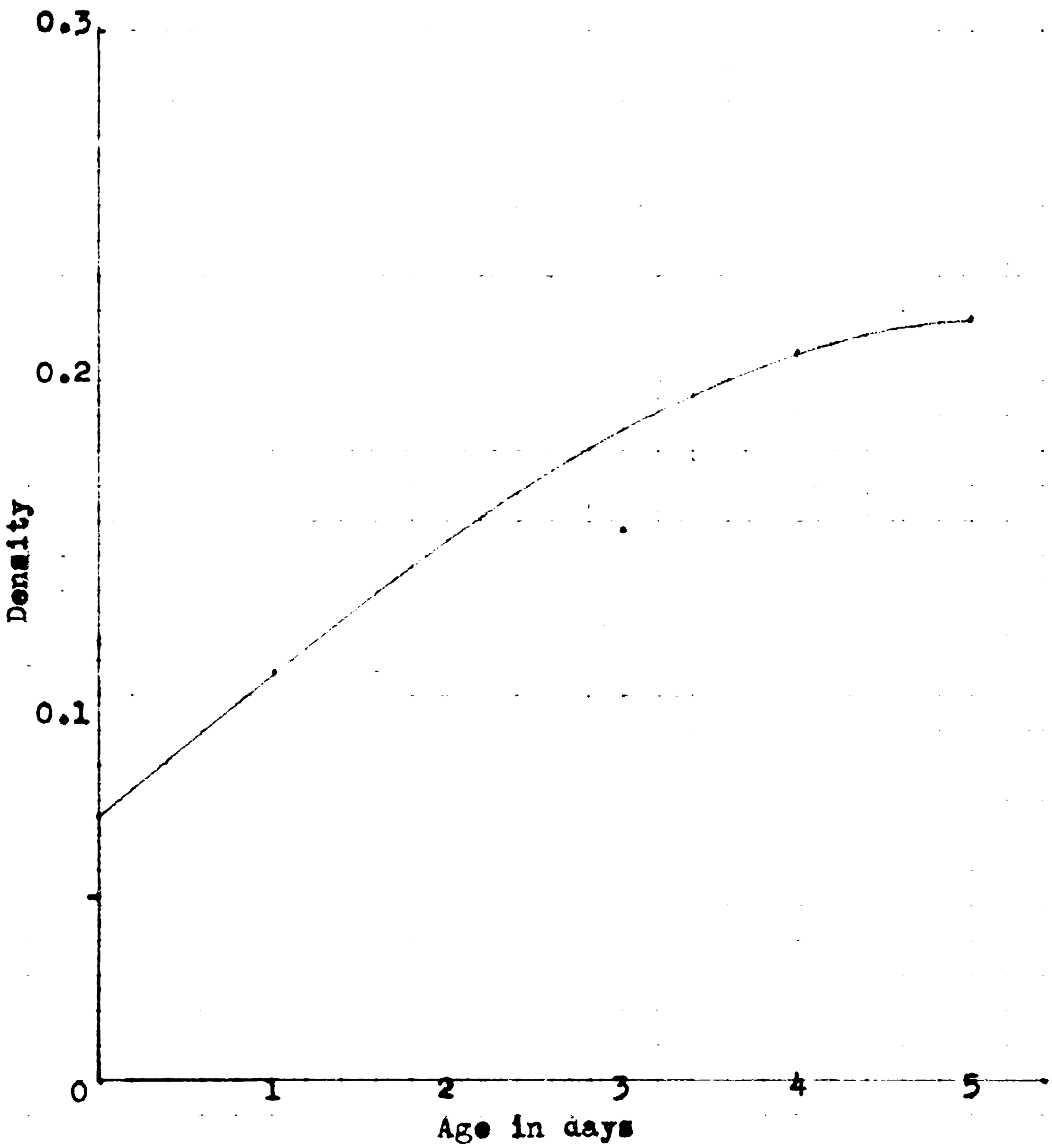
			DENSITY		wt. of snow	density	WATER CONTENT			
trial	can no.	vol. can c.c.	wt.of can + snow grams	wt.of can grams	~~grams per c.c.~~	~~#/ft.~~ grams per c.c.	vol. water c.c.	water equiv. cm. of depth	water equiv. in. of depth	% of water by vol.
1	4	985.0	158.0	88.5	69.5	.071	69.5	.55	.21	7.1
2	8	"	167.0	96.0	71.0	.072	71.0	.56	.22	7.2
3	5	"	189.0	94.0	95.0	.096	95.0	.75	.29	9.6
4	9	"	198.0	96.0	102.0	.104	102.0	.81	.31	10.4
5	4	"	188.0	88.5	99.5	.101	99.5	.79	.31	10.1
6	5	"	195.0	94.0	101.0	.103	101.0	.80	.31	10.3
7	8	"	195.0	96.0	99.0	.101	99.0	.79	.31	10.1
8	9	"	201.5	96.0	105.5	.107	105.5	.83	.32	10.7
9										
10										
11										
12										

Snow characteristics dry fluffy snow

Type of snow in sample

Remarks

DATA:



Relation of snow density to age in days

RESULTS: The curve obtained by plotting density against age in days is very similar to the curve obtained by H.F. Alps from his readings at Summit, California. His curve was a relation between percent of water equivalent and depth of snow. His percent of water equivalent corresponds to my density and his depth of snow is similar to my age in days. The further down you go in a snow drift the older the snow. My data showed that drifted snow is from 1.5 to 2 times more dense than non-drifted snow.

CONCLUSION: The curve obtained can be used to determine rapidly the approximately density of snow from its age.

I was unable to obtain a relation between the density of snow and atmospheric temperature for I did not have the equipment required to control the temperature.

Sidelights on the Density and Water Content Experiments.

In a pamphlet published by the U.S. Weather Bureau, the following was given as a way to measure the density of snow; "The snowfall collected in the overflow attachment is measured after placing the vessel in a warm room until the snow is melted. The water is then carefully poured into the measuring tube just as though it were rainfall."

The process of melting the snow to water is very slow and an error will occur in the determinations due to the evaporation of the water at room temperatures. It is sufficient, knowing the size and weight of containers to measure the depth of the snow in them and to weigh the container and the snow. The weight of the snow is the volume of the water in the snow. I recorded a few smaples of snow to determine this:

Can	Weight of can and snow before melting	after melting	Temperature of water
#5	219	218.5	88°F
#1	228	227.5	71°F
#2	227	226.5	82°F
#4	218	217.4	73°F
#6	234.5	234.	72°F
#7	259	259	12°F

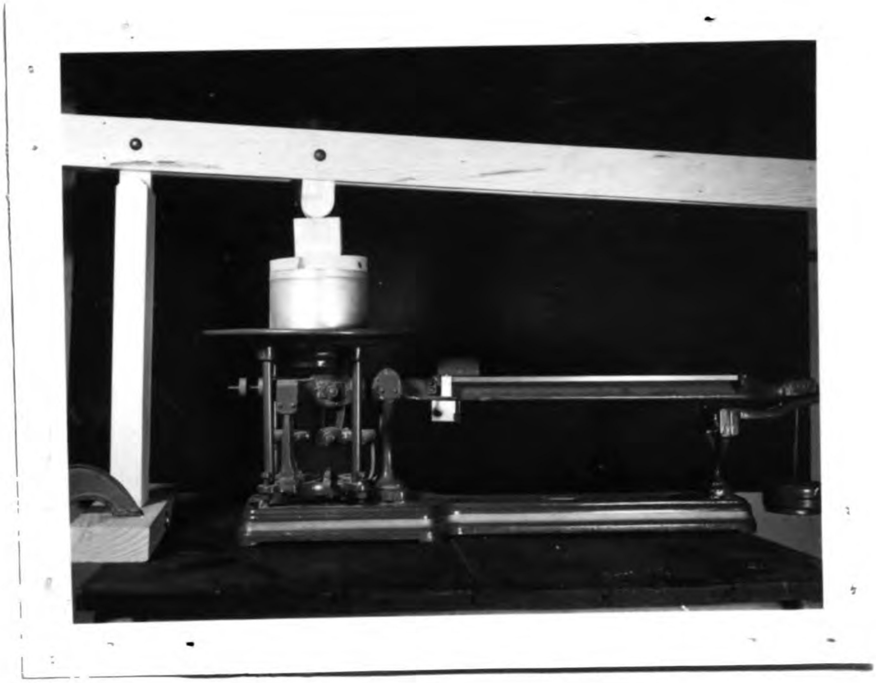
EXPERIMENT NUMBER 2.

Compactibility.

OBJECT: To determine the percent of compaction of snow of different density and type when it is confined in a container of known size.

EQUIPMENT: Thermometer. Cans of known size. Scales to weigh cans of snow. Steel plate. Scales to determine load applied to snow wooden plunger. Ruler for measureing. Clamps to hold equipment in place.

PROCEDURE: The samples of snow were obtained as described under "Method of obtaining a sample of snow". Record atmospheric temperature and type of snow from which the sample was taken. A can of snow was placed on the scales and the scales balanced. Place the plunger carefully on top of the s now and add a weight to the scales. Using the arm, apply sufficient pressure to balance the scale. Remove the plunger and measure the distance that the snow was compacted. Repeat for different weights. Weigh the can and the snow and determine the density of the snow.



The apparatus used to compact the sample
of snow with a known weight in experiment
number 2.

Date January 21,1943

Temperature in trailer 14.5°F.

Atmospheric temperature 10°F.

Snow storm - when 10:30 A.M. January 21

Snow characteristics dry heavy powder

Type of snow in sample caught in cans

Remarks snow flakes were definitely shaped

DATA.;

can no. 7 depth of can 2 3/4 in.

volume of can 53.07 cu.in. density of snow .073

wt. applied kilo.	compaction in in.	% of compaction
1 1.13	15/16	34.0
2 2.13	1 3/16	43.2
3 3.13	1 5/16	47.7
4 4.13		
5 5.13	1 8/16	54.5
6 7.13	1 10/16	59.1
7 9.13	1 11/16	61.4
8 11.13	1 11/16	61.4
9 13.13	1 11/16	61.4
10		
11		
12		

Date January 21,1943

Temperature in trailer 14.5°F.

Atmospheric temperature 10°F.

Snow storm - when 10:30 A.M. January 21

Snow characteristics dry heavy powder

Type of snow in sample caught in cans

Remarks snow flakes were definitely shaped

DATA.;

can no. 9 depth of can 2 3/4 in.

volume of can [illegible].27 cu.in. density of snow .075

wt. applied kilo.	compaction in in.	% of compaction
1- 1.18	14/16	31.8
2- 2.18	1 4/16	45.5
3- 3.18	1 5/16	47.7
4- 4.18	1 8/16	54.5
5- 5.18	1 9/16	56.8
6- 7.18	1 9/16	56.8
7- 9.18	1 11/16	61.4
8-11.18	1 11/16	61.4
9-13.18	1 12/16	63.6
10		
11		
12		

Date January 21,1943

Temperature in trailer 14.5°F.

Atmospheric temperature 10°F.

Snow storm - when 10:30 A.M. January 21

Snow characteristics dry heavy powder

Type of snow in sample caught in cans

Remarks snow flakes were definitely shaped crystals

DATA.;

can no. 8   depth of can 2 1/2 in.

volume of can [illegible] cu.in.   density of snow .075

wt. applied kilo.	compaction in in.	% of compaction
1- 1.18	12/16	30.0
2- 2.18	1 4/16	50.0
3- 3.18	1 6/16	55.0
4- 4.18	1 7/16	57.5
5- 5.18	1 8/16	60.0
6- 7.18	1 9/16	62.5
7- 9.18	1 9/16	62.5
8-11.18	1 9/16	62.5
9-13.18	1 10/16	65.0
10		
11		
12		

Date January 25, 1943

Temperature in trailer 32°F.

Atmospheric temperature

Snow storm - when

Snow characteristics

Type of snow in sample old snow

Remarks snow crust $\frac{1}{4}$" thick

DATA.;

can no. 7 depth of can 3 1/16"

volume of can 60.12 cu. in. density of snow .209

wt. applied kilo.	compaction in in.	% of compaction
1-2.18	1/16	2.1
2-4.18	1/16	2.1
3-6.18	8/16	16.3
4-8.18	14/16	28.6
5-10.18	15/16	30.6
6-12.18	15/16	30.6
7		
8		
9		
10		
11		
12		

Date January 25, 1943

Temperature in trailer 32^{o}F.

Atmospheric temperature

Snow storm - when

Snow characteristics

Type of snow in sample old snow

Remarks snow crust ⅛" thick

DATA.:

can no. 7

depth of can 3 1/16 in.

volume of can 60.12 cu.in.

density of snow .216

wt. applied kilo.	compaction in in.	% of compaction
1- 2.18	none	none
2- 4.18	1/16	2.1
3- 6.18	10/16	20.4
4- 8.18	11/16	22.5
5-10.18	13/16	26.5
6-12.18	13/16	26.5
7		
8		
9		
10		
11		
12		

Date January 23, 1943

Temperature in trailer 32° F.

Atmospheric temperature

Snow storm - when

Snow characteristics

Type of snow in sample old snow

Remarks snow crust 1" thick

DATA.;

can no. 8 depth of can 3 1/16 in.

volume of can 60.12 cu. in. density of snow .202

wt. applied kilo.	compaction in in.	% of compaction
1- 2.18	none	none
2- 4.18	1/16	2.1
3- 6.18	14/16	28.6
4- 8.18	15/16	30.6
5-10.18	1 1/16	34.7
6-12.18	1 1/16	34.7
7		
8		
9		
10		
11		
12		

Date ~~January 25, 1943~~

Temperature in trailer ~~32°F.~~

Atmospheric temperature

Snow storm - when

Snow characteristics

Type of snow in sample ~~old snow~~

Remarks ~~snow crust ¼" thick~~

DATA.;

can no. 5

depth of can ~~3 1/16 in.~~

volume of can ~~60.12 cu.in.~~

density of snow ~~.209~~

wt. applied kilo.	compac- tion in in.	% of compaction
1. 2.13	none	none
2. 4.13	1/16	2.1
3. 6.13	3/16	6.1
4. 8.18	12/16	24.5
5. 10.18	13/16	26.5
6. 12.18	13/16	26.5
7		
8		
9		
10		
11		
12		

Date January 26, 1943

Temperature in trailer 16°F.

Atmospheric temperature

Snow storm - when

Snow characteristics

Type of snow in sample Crusted snow; old snow; drifted snow

Remarks warm Jan. 23 & 24; cold Jan. 25 & 26

DATA.;

can no. 6

depth of can 3 1/16

volume of can 60.12

density of snow .233

wt. applied kilo.	compaction in in.	% of compaction
1 - 2.18	none	none
2 - 4.18	1/8	4.1
3 - 6.18	3/16	6.1
4 - 8.18	3/8	12.2
5 - 10.18	9/16	18.4
6 - 12.18	7/8	28.6
7		
8		
9		
10		
11		
12		

Date January 26, 1943

Temperature in trailer 15°F.

Atmospheric temperature

Snow storm - when

Snow characteristics

Type of snow in sample Crusted snow; old snow; drifted snow

Remarks warm Jan. 23 & 24; cold Jan. 25 & 26

DATA.;

can no. 4 depth of can 3 1/16

volume of can 60.12 cu. in. density of snow .227

wt. applied kilo.	compaction in in.	% of compaction
1 - 2.18	none	none
2 - 4.18	1/8	4.1
3 - 6.18	1/4	8.2
4 - 8.18	1/2	16.3
5 - 10.18	7/8	28.6
6 - 12.18	15/16	30.6
7		
8		
9		
10		
11		
12		

Date January 26, 1943

Temperature in trailer 16° F.

Atmospheric temperature __________

Snow storm - when __________

Snow characteristics __________

Type of snow in sample Crusted snow; old snow; regular

Remarks warm Jan. 23 & 24; cold Jan. 25 & 26

DATA.;

can no. 2

depth of can 3 1/16 in.

volume of can 60.22 cu. in.

density of snow .201

wt. applied kilo.	compaction in in.	% of compaction
1 2.18	1/8	4.1
2 4.18	7/16	14.3
3 6.18	3/4	24.5
4 8.18	15/16	30.6
5 10.18	1 "	32.6
6 12.18	1 "	32.6
7		
8		
9		
10		
11		
12		

Date January 2[illegible].1943

Temperature in trailer 16° F.

Atmospheric temperature ____________

Snow storm - when ____________

Snow characteristics ____________

Type of snow in sample crusted snow;old snow;regular

Remarks warm Jan.23 & 24;cold Jan.25 & 26

DATA.;

can no. 1 depth of can 3 1/16 in.

volume of can 60.12 cu.in. density of snow .210

wt. applied kilo.	compaction in in.	% of compaction
1- 2.18	none	none
2- 4.18	6/16	12.2
3- 6.18	7/16	14.3
4- 8.18	9/16	18.4
5-10.18	12/16	24.5
6-12.18	12/16	24.5
7		
8		
9		
10		
11		
12		

Date February 11, 1943

Temperature in trailer 24° F.

Atmospheric temperature

Snow storm - when February 11, 1943

Snow characteristics dry fluffy snow

Type of snow in sample drifted snow

Remarks strong wind

DATA.;

can no. 9 depth of can 3 1/16 in.

volume of can 60.12 cu.in. density of snow .107

wt. applied kilo.	compaction in in.	% of compaction
1- 2.18	1 2/16	36.7
2- 4.18	1 5/16	42.9
3- 6.18	1 8/16	49.0
4- 8.18	1 9/16	51.0
5-10.18	1 10/16	53.1
6-12.18	1 10/16	53.1
7		
8		
9		
10		
11		
12		

Date February 11,1943

Temperature in trailer 24°F.

Atmospheric temperature

Snow storm - when February 11,1943

Snow characteristics dry fluffy snow

Type of snow in sample drifted snow

Remarks strong wind

DATA.;

can no. 8 depth of can 3 1/16 in.

volume of can 60.12 cu.in. density of snow .101

wt. applied kilo.	compaction in in.	% of compaction
1- 2.18	1 2/16	36.7
2- 4.18	1 7/16	46.9
3- 6.18	1 9/16	51.0
4- 8.18	1 10/16	53.1
5-10.18	1 10/16	53.1
6-12.18	1 11/16	55.1
7		
8		
9		
10		
11		
12		

Date February 11, 1943

Temperature in trailer 24°F.

Atmospheric temperature ______

Snow storm - when February 11, 1943

Snow characteristics dry fluffy snow

Type of snow in sample drifted snow

Remarks strong wind

DATA.;

can no. 5 depth of can 3 1/16 in.

volume of can 60.12 cu.in. density of snow .103

wt. applied kilo.	compaction in in.	% of compaction
1-2.18	1 3/16	38.8
2-4.18	1 7/16	46.9
3-6.18	1 9/16	51.0
4-8.18	1 10/16	53.1
5-10.18	1 10/16	53.1
6-12.18	1 11/16	55.1
7		
8		
9		
10		
11		
12		

Date February 11, 1943

Temperature in trailer 24° F.

Atmospheric temperature ____________

Snow storm - when February 11, 1943

Snow characteristics dry fluffy snow

Type of snow in sample drifted snow

Remarks strong wind

DATA.:

can no. 4

depth of can 3 1/16 in.

volume of can 60.12 cu.in.

density of snow .071

wt. applied kilo.	compaction in in.	% of compaction
1- 2.13	1 8/16	49.0
2- 4.13	1 13/16	59.2
3- 6.13	1 15/16	63.3
4-3.13	2	65.3
5-10.13	2 1/16	67.4
6-12.13	2 1/16	67.4
7		
8		
9		
10		
11		
12		

Date Febuary 11, 1943

Temperature in trailer 24 °F.

Atmospheric temperature ____________

Snow storm - when Febuary 11, 1943

Snow characteristics dry fluffy snow

Type of snow in sample drifted snow

Remarks strong wind

DATA.:

can no. 4

depth of can 3 1/16

volume of can 60.12 cu.in.

density of snow .101

wt. applied kilo.	compaction in in.	% of compaction
1- 2.18	1 3/16	38.8
2- 4.18	1 7/16	46.9
3- 6.18	1 9/16	51.0
4- 8.18	1 10/16	53.1
5-10.18	1 11/16	55.1
6-12.18	1 11/16	55.1
7		
8		
9		
10		
11		
12		

Date Febrary 11,1943

Temperature in trailer 24°F.

Atmospheric temperature

Snow storm - when Febrary 11,1943

Snow characteristics dry fluffy snow

Type of snow in sample drifted snow

Remarks strong wind

DATA.:

can no. 9 depth of can 3 1/16 in.

volume of can 60.12 cu.in. density of snow .104

wt. applied kilo.	compaction in in.	% of compaction
1- 2.13	1 2/16	36.7
2- 4.13	1 6/15	44.9
3- 6.13	1 7/16	46.9
4- 8.13	1 9/16	51.0
5-10.13	1 10/16	53.1
6-12.13	1 11/16	55.1
7		
8		
9		
10		
11		
12		

Date February 11, 1943

Temperature in trailer 24°F.

Atmospheric temperature ____________

Snow storm - when Febuary 11, 1943

Snow characteristics dry fluffy snow

Type of snow in sample drifted snow

Remarks strong wind

DATA.;

can no. 5 depth of can 3 1/16 in.

volume of can 60.12 cu.in. density of snow .095

wt. applied kilo.	compaction in in.	% of compaction
1- 2.18	1 3/16	38.8
2- 4.18	1 7/16	46.9
3- 6.18	1 10/16	53.1
4- 8.18	1 11/16	55.1
5-10.18	1 12/16	57.1
6-12.18	1 12/16	57.1
7		
8		
9		
10		
11		
12		

Date Febuary 11,1943

Temperature in trailer 24°F.

Atmospheric temperature

Snow storm - when Febuary 11,1943

Snow characteristics dry fluffy snow

Type of snow in sample drifted snow

Remarks strong wind

DATA.;

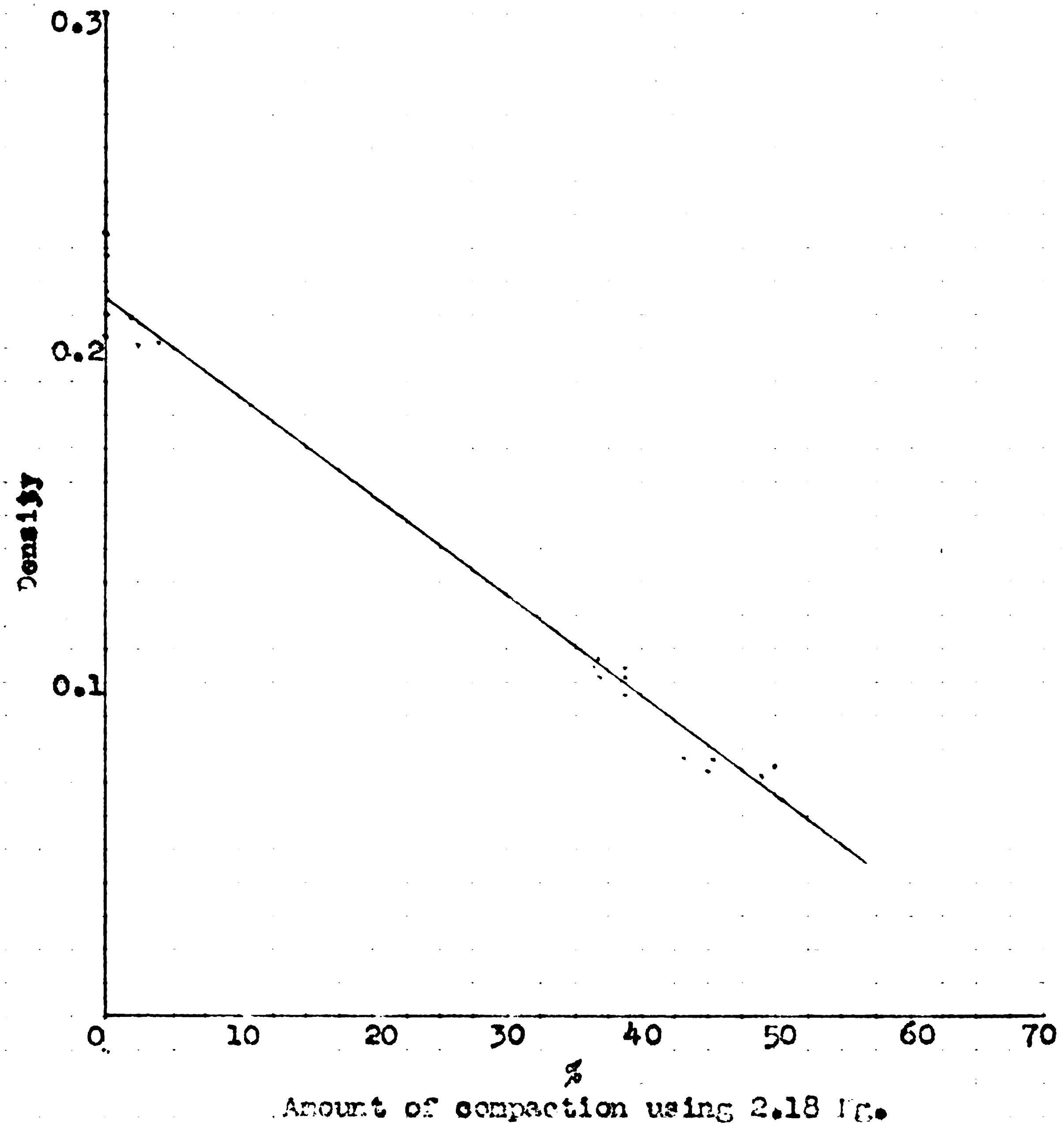
can no. 8

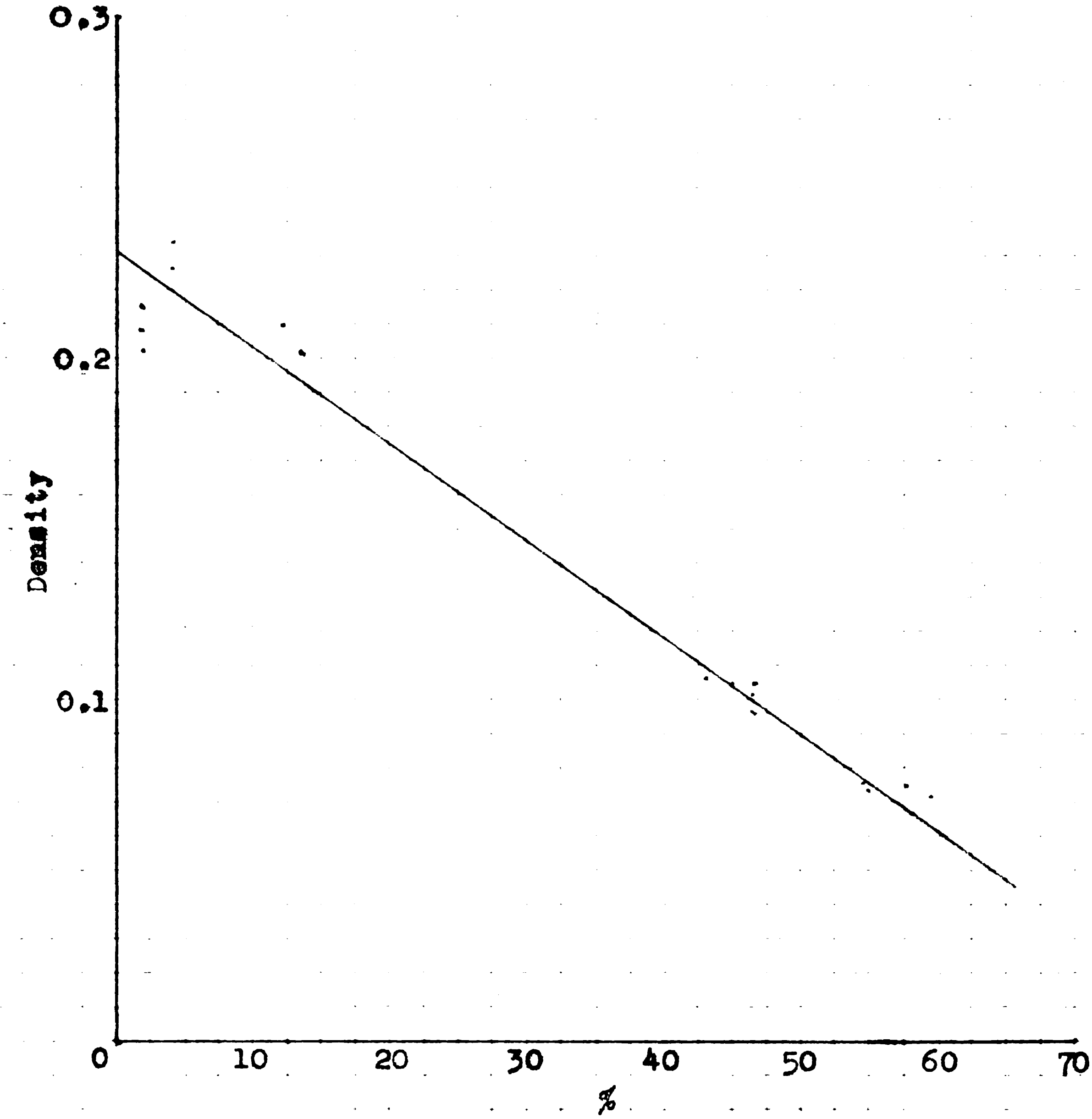
depth of can 3 1/16 in.

volume of can 60.12 cu.in.

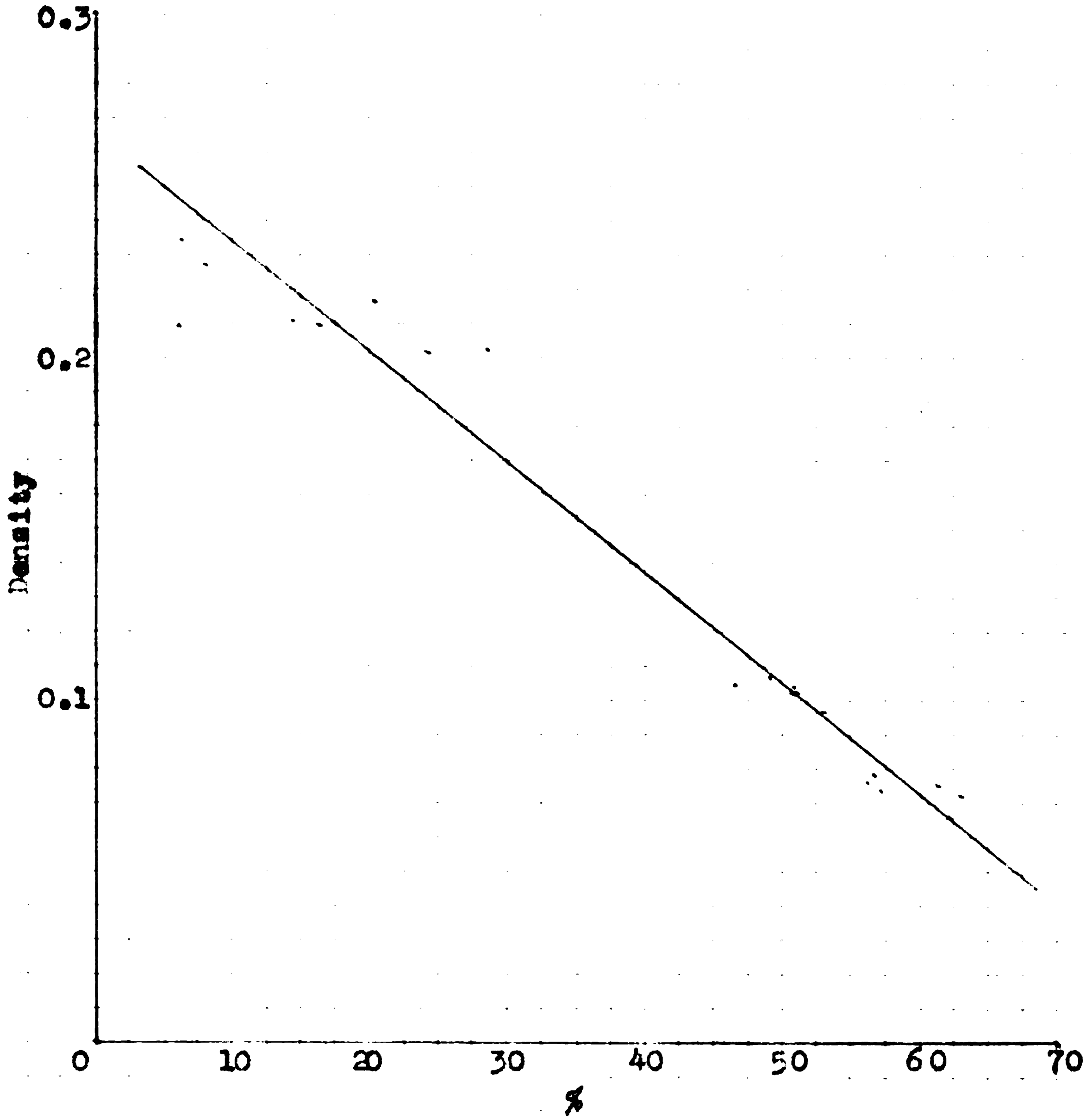
density of snow .072

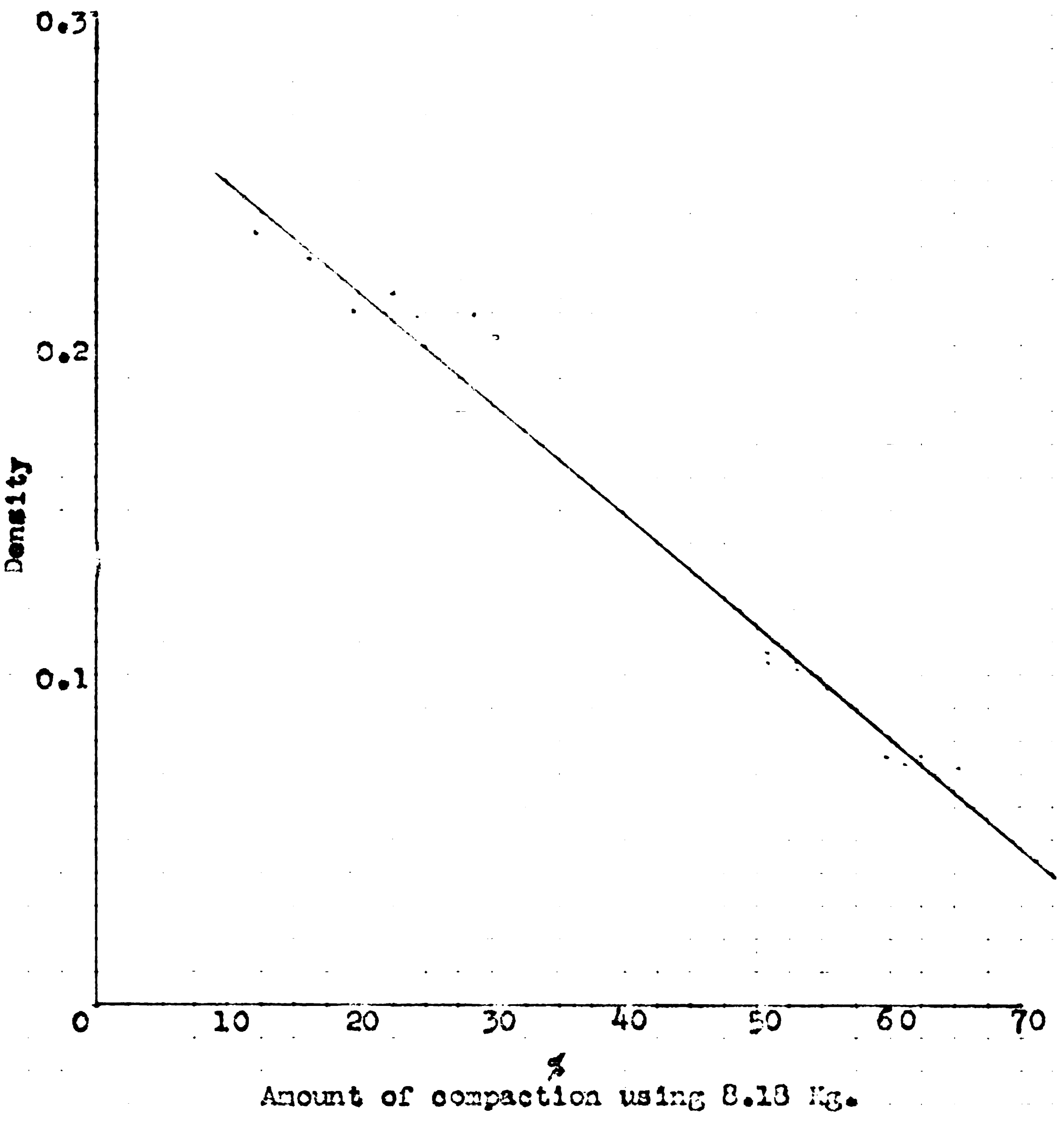
wt. applied kilo.	compaction in in.	% of compaction
1. 2.13	1 6/16	44.9
2. 4.13	1 11/16	55.1
3. 6.13	1 12/16	57.1
4. 8.13	1 14/16	61.2
5. 10.13	2	65.3
6. 12.13	2	65.3
7		
8		
9		
10		
11		
12		


0.3
0.2
0.1
Density
0
10
20
30
40
50
60
70
%
Amount of compaction using 2.18 Kg.

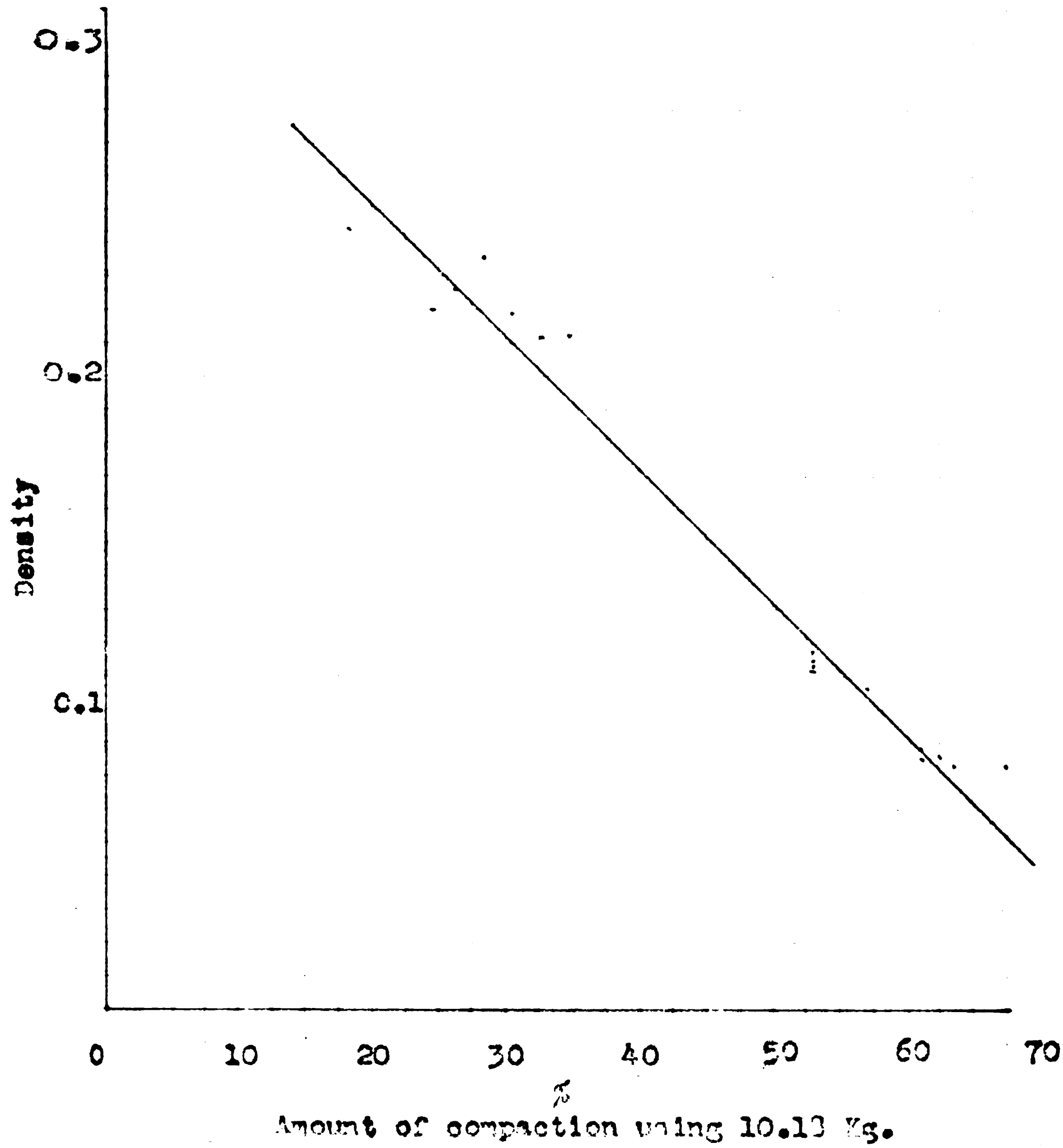


Amount of compaction using 4.18 Kg.

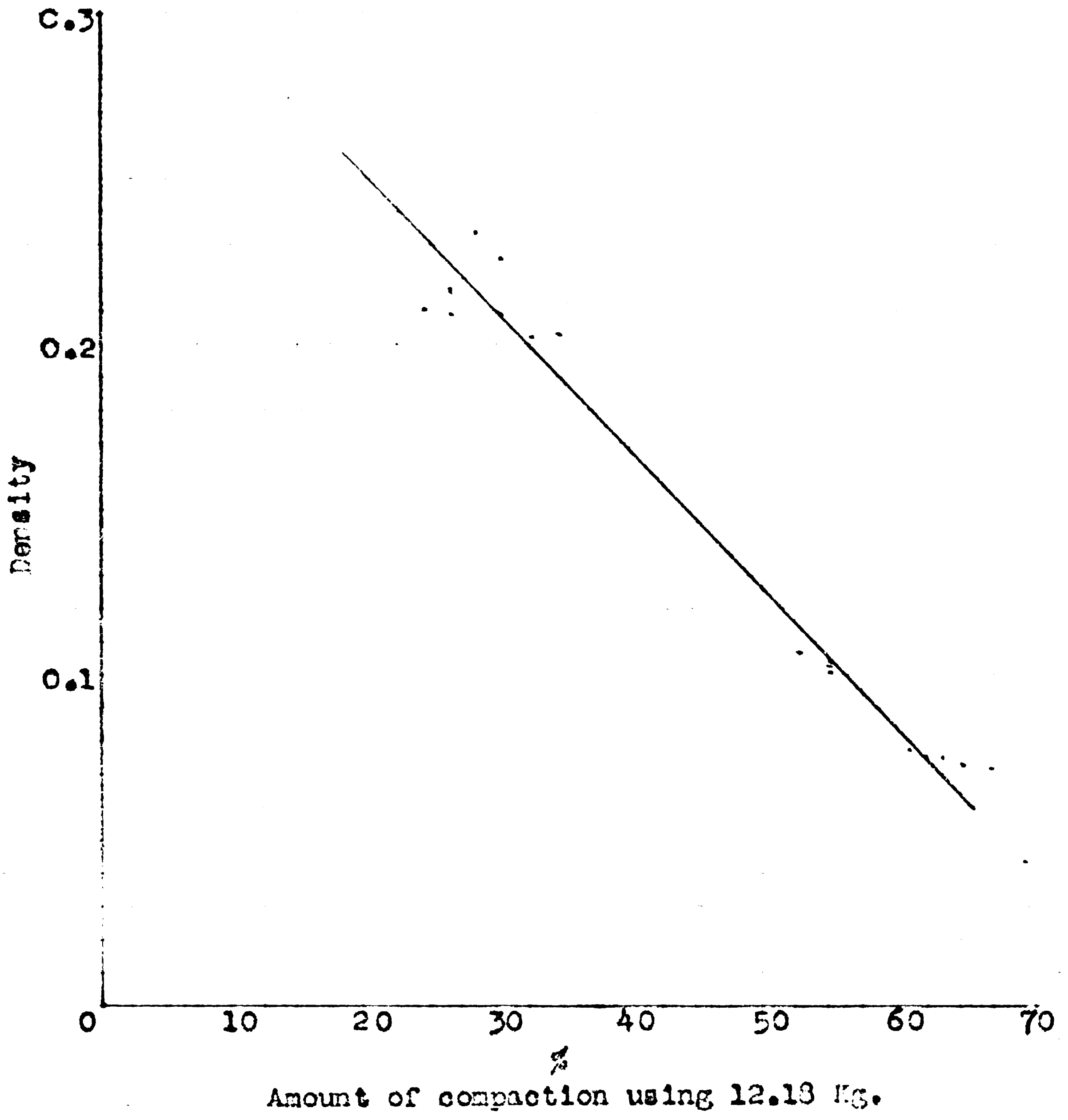

0.3
0.2
0.1
Density
0
10
20
30
40
50
60
70
%
Amount of compaction using 6.13 Kg.



Density
0.3
0.2
0.1
0
10
20
30
40
50
60
70
%
Amount of compaction using 8.18 Kg.



0.3
0.2
0.1
Density
0
10
20
30
40
50
60
70
%
Amount of compaction using 10.13 Kg.



0.3
0.2
0.1
Density
0
10
20
30
40
50
60
70
%
Amount of compaction using 12.18 Kg.

RESULTS: The relation of density to compactibility is a straight line curve.

CONCLUSIONS: The older or more dense a snow is, the harder it is to compact and therefore the harder it is to push off a road.

If the amount of compaction of a snow is known, then the space a given amount of it will occupy can be determined and the size of equipment needed to move this snow can be approximated.

EXPERIMENT NUMBER 3.

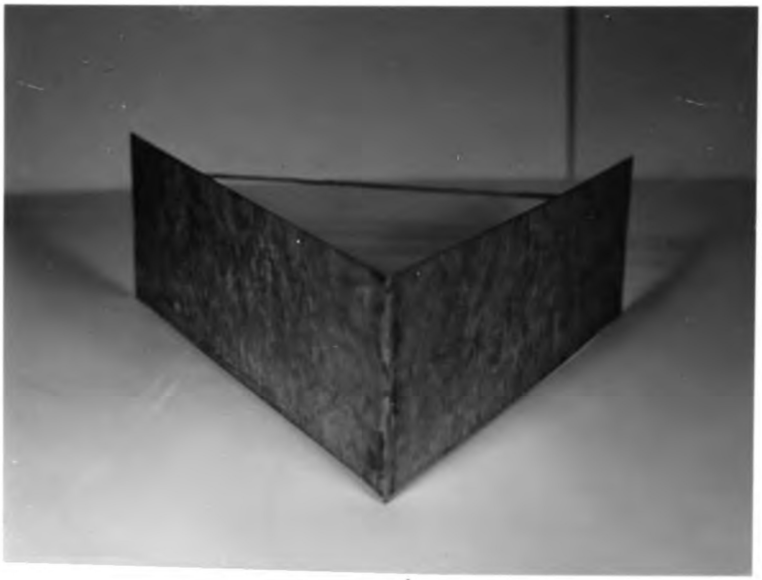
Snow Plow.

OBJECT: To determine the forces acting on a V-shaped snow plow.

EQUIPMENT: Model V-plow. Spring scale. Thermometer; Cans of known weight and volume. Scales.

PROCEDURE: The V-plow was allowed to come to atmospheric temperature. It was then placed in a level stretch of snow of a meaured and recorded depth. The spring scale was attached to the eye in the nose of the plow and a steady pull applied.

CONCLUSION: This test proved a failure for the plow had a tendency to vear back and forth making a wavy path in the snow. The test was discarded.



The model snow plow used in experiment number 3.

EXPERIMENT NUMBER 4.

Coefficient of Friction.

OBJECT: To determine the coefficient of friction between snow and steel.

EQUIPMENT: Thermometer. Sheet metal with a device to measure the angle at which the metal is set. Cans of known volume and weight. Scales. Scale.

PROCEDURE: The equipment was set out in the trailer so that it would be at atmospheric temperature. The temperature inside the trailer was recorded. The sample of snow of known size was placed on the steel plate. The plate was then slowly raised until the snow sample slid off. The snow sample was again set on the plate and the plate carefully raised and held at each successive degree. The snow was carefully slide perpendicular to the angle of inclination brought to rest and released. The angle at which the snow slid off the plate was recorded. The snow was put in a can and weighed. The weight and density of the sample were determined.

The equipment used as a sliding plane
in experiment number 4.

DATA: Temperature in trailer = 32°F.

Can no.	Sample size	Can + sample	weight of can	Angle of sliding: place on plate	Angle of sliding: rubbed before releasing	Coefficient of friction
1	2x2x1½	123.0	94.0	50°	45°	.119
4	2x2x1-3/8	119.0	88.5	54°	90° *	.138
9	2x2x2-1/8	133.0	96.0	34°	44°	.068
				36°		.073
				37°		.075
8	2x2x1-3/4	124.0	96.0	46°		.103
				33°		.067
5	2x2x1-3/4	126.0	94.0	37°	60°	.075
				32°	56°	.063

* At 90° the snow didn't slide.

CONCLUSION: The variations in results was due to the temperature 32°F. At this temperature any sample of snow, if allowed to sit on the steel plate, formed a film of water with the plate causing adhesion between the snow and the plate.

The samples that were slid perpendicular to the angle of the plate form these films of water and had a definite tendency to adhere to the steel.

EXPERIMENT NUMBER 5.

Coefficient of Friction between Snow and Steel.

OBJECT: To determine the coefficient of friction between snow and steel.

EQUIPMENT: A steel plate turned up at one end so that it looks like a sleigh. Weights. Spring scale. Cans of known volume. Scales.

PROCEDURE: The sliegh was allowed to come to atmospheric temperature. Atmospheric temperature was recorded and a sample of the snow taken for density determination. The sleigh was carefully placed on a level stretch of snow and weights applied to it. The spring scale was attached to the loop provided on the sleigh and the pull in pounds required to move the sleigh at a uniform steady speed was read and recorded.

DATA: Temperature of snow = - 4°C in all trials

Temperature in trailer = 17.5°F

TRIAL 1.

Sun shining on snow; 3 trials; sleigh and shot weighed 3 pounds; pull required = 3/4 pound; density of snow = .168 grams/cc.; coefficient of friction

TRIAL 2.

Performed in shade; 5 trials; sleigh, wood and shot weighed 3 pounds; pull required = ½ pound; density of snow = .163 grams/cc.; coefficient of friction

TRIAL 3.

Performed where sun shone on the snow; 5 trials; sleigh, wood and shot weighed 3 pounds; pull required = $\frac{1}{8}$ pound; density of snow = .153 grams/cc; coefficient of friction

TRIAL 4.

Performed in shade; 4 trials; sleigh, wood and shot weighed 3 pounds; pull required = $\frac{1}{8}$ pound; density of snow = .143 grams/cc.; coefficient of friction

TRIAL 5.

3 trials; sleigh, wood and shot weighed 6 pounds; With the weight of 6 pounds the sleigh sank into the snow. Remove part of the weight to make the total new weight 5.47 pounds.

TRIAL 6.

5.47 pounds; pull required = 1 5/16 pounds; density of snow = .117

TRIAL 7.

5.47 pounds; pull required = 1 5/16; density of snow = .121

TRIAL 8.

5.47 pounds; snow wouldn't hold up sleigh; density of snow = .112

TRIAL 9.

5.47 pounds; snow wouldn't hold up sleigh; density of snow = .117

The sleigh set up as used in experiment number 5.

It had been warm for 2 days; there was a crust of ½" thickness on the snow and the temperature in the trailer was 32°F.

TRIAL 1.

Weight of sleigh, wood, and shot = 4 pounds; 2 trials; average pull = ½ pound; density of snow = .210

TRIAL 2.

Weight of sleigh, wood and shot = 4 pounds; 2 trials; average pull = ½ pound; density of snow = .209

TRIAL 3.

Weight of sleigh, wood and shot = 5.47 pounds; 2 trials; average pull = 3/8 pound; density of snow = .216

TRIAL 4.

Weight of sleigh, wood and shot = 5.47 pounds; 2 trials; average pull = 3/8 pound; density of snow = .202

TRIAL 5.

Weight of sleigh, wood, and shot = 5.47 pounds; 2 trials; average pull = 3/8 pound; density of snow = .209

RESULTS: Coefficients of friction.

Part 1. Trial #		Part 2 Trial #	
1	.25	1	.125
2	.167	2	.125
3	.167	3	.069
4	.167	4	.069
5	______	5	.069
6	.24		
7	.24		
8	-----		
9	-----		

My results have a ~~varied~~ range from .063 to .25. They range mainly about .07.

CONCLUSIONS: The coefficient of friction between snow and steel depends upon the temperature because of the adhesion of the snow to the steel caused by the creation of a water film.

EXPERIMENT NUMBER 6.

SHEAR.

OBJECT: To determine the pounds of force necessary to shear one square foot of snow. The snow at different densities and atmospheric temperatures.

EQUIPMENT: A box-shaped affair without top or bottom made of sheet metal. A spring scale reading 50 pounds maximum. Cans of known volume and weight. Thermometer. Scales.

PROCEDURE: The equipment was set outside to allow it ot be brought to atmospheric temperature. The thermometer in the non-heated trailer was read for atmospheric temperature. A small thermometer was stuck in the snow to find the temperature of the snow. The snow in which the experiment was performed was deep enough so that there would be no interfe rence between the earth and the snow. The box-shaped affair was placed on the snow so that it would enclose a square foot of open end first. It was carefully pushed into the snow being careful not to compact the snow inside. The snow surrounding it was removed parallel to the sides of the box to a depth of 3" below the lower edge of the box. The hook on the scales was inserted in the loop and a uniformly increasing pressure applied until complete shear occurred. Maximum pull in pounds was recorded. 2 cans of snow were obtained as in the density test and compactiblity and the density of the snow determined.

The box-shaped device used for shearing in experiment number 6.

CONCLUSION: The first piece of equipment used in this test was of 1/16" sheet metal. The apparatus was square being 12" on a side and approximately 3" deep. There was a loop soldered mid-way on one side. When this was used in a test it proved to be made of too thin a material. The 1/16" metal was pulled out of shape before any shearing of the snow took place.

The design of the apparatus remained the same in the second instance but 3/32" sheet metal was used approximately 3" deep. The first trial equipment was firmly soldered on top of the second. A loop was soldered mid-way on one side.

The first test using this second apparatus proved a failure, for with the application of 28 pounds the loop gave way.

A stronger loop with a stronger weld replaced the broken one, but the tests were never completed due to the lack of snow.

EXPERIMENT NUMBER 7.

Adhesion of Ice to Concrete.

OBJECT: To determine the pounds per square inch of tension and shear needed to break the bond between ice and concrete.

EQUIPMENT: Scales reading maximum of 50 pounds. Wire loops to freeze into the ice. Forms 2", 3", 4" square.

PROCEDURE: Snow and water were mixed to a damp mass. Just enough water was added to wet the snow, but not enough to cause it to become slush. This mixture was put in metal forms with the wire loops embedded in the mass, and the whole thing was set outdoors on a concrete block. The metal forms were removed and the mixture was allowed to stand over night to freeze. The hook of the scale was inserted in the wire loop and pull applied. The number of pounds required to move a given block was recorded.

CONCLUSION: I set out three blocks to experiment on the possible poundage of pull needed. The 2" block had not started to move when my 50 pounds scale was reading past its maximum.

EXPERIMENT NUMBER 8.

The Angle of Repose of Snow.

OBJECT: To determine the angle of repose of snow.

EQUIPMENT: Very small shovel. Device for measuring the angle.

PROCEDURE: Fallen snow was collected and carefully piled. The arm of the device was set to coincide with the slope of the snow pile.

DATA: January 20, 1943

Trial	Angle of repose	Temperature in trailer °F.	Density of snow.
1	50°	6	.076
2	53°	9	.108
3	48°	9	.142
4	52°	9	.129
5	52°	9	.132

CONCLUSION: The data presented is in itself valueless. It may, however, serve someone else as a comparison for tests that they may preform.