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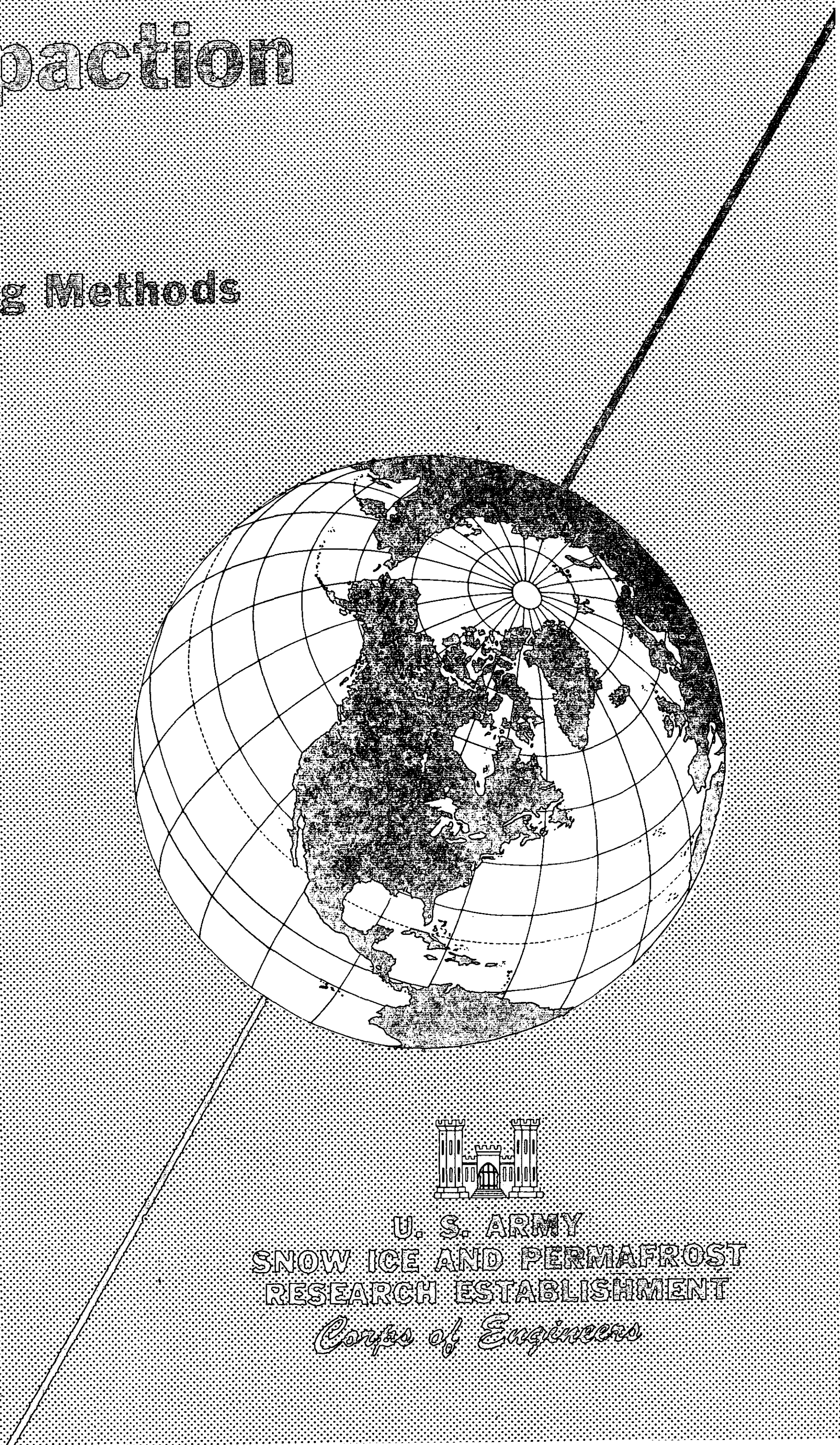
MARCH, 1959

Preliminary Snow Compaction Field Tests

Using Dry Processing Methods



U. S. ARMY
SNOW ICE AND PERMAFROST
RESEARCH ESTABLISHMENT
Corps of Engineers

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Using Dry Processing Methods

by A. F. Wuori

U. S. ARMY SNOW ICE AND PERMAFROST
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Corps of Engineers
Wilmette, Illinois

PREFACE

This constitutes an interim report on work done on USA SIPRE Project 22.2-17, Snow runway compaction, (now redesignated as Project 022.02.001, subtask h). The purpose of this investigation is to study methods of constructing runways of snow for supporting wheeled aircraft.

The field work was carried on at the Keweenaw Field Station, Houghton, Michigan, during the winter of 1956-57 by Mr. A. F. Wuori, Project Engineer, Snow and Ice Applied Research Branch, under the general supervision of Mr. R. W. Waterhouse, then acting branch chief. Mr. H. C. Brunke, Civil Engineer, Snow and Ice Applied Research Branch, assisted in the work and in the analysis of the data.

This report has been reviewed and approved for publication by the Office of the Chief of Engineers.

Walter H. Parsons Jr.

WALTER H. PARSONS, JR.
Colonel, Corps of Engineers
Director

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Department of the Army Project 8-66-02-400

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SUMMARY

During the winter of 1956-57 at Houghton, Michigan, several test lanes were constructed of dry processed snow in order to determine the feasibility of constructing runways of snow processed without the addition of heat or water. The test lanes were composed of snow disaggregated by and discharged from rotary snowplows. The surfaces of the leveled snow deposits were additionally processed by rolling or vibratory compacting. It was found that the vibratory compactor was effective in densifying and strengthening the surface layer when used on freshly processed snow and less effective when age hardening of the snow had taken place. Rolling was most effective when the snow temperature was near the melting point. There may be a significant difference in the properties of disaggregated snow dependent on the mechanical and operating characteristics of the different snowplows used.

PRELIMINARY SNOW COMPACTION FIELD TESTS USING DRY PROCESSING METHODS

by

A. F. Wuori

INTRODUCTION

Studies have been made by USA SIPRE for the past two years regarding the feasibility of constructing runways and roads of processed snow capable of supporting heavy wheeled aircraft and vehicles.

During the 1955-56 winter season at the Keweenaw Field Station, Houghton, Michigan, a number of snow test sections were constructed by using disaggregated snow for the base course, followed by treatment with water and slush-ice to form a wearing surface and load distributor. These studies were continued on the Greenland Ice Cap during the summer of 1956, using different amounts of water on each test section to produce snow-ice pavements of varying thickness.

The construction methods requiring the use of water showed promising results, but the difficulty lies in producing large quantities of water in the Arctic. For this reason, stabilization of test sections using "dry" processing methods has been initiated. The feasibility of such methods is the subject of this report.

During the winter of 1956-57, several test sections were constructed at Houghton, Michigan, using snow disaggregated with rotary plows to produce the base course. Additional surface processing was accomplished by rolling or vibratory compaction.

The effectiveness of the different processes was evaluated in terms of density increase, grain-size distribution, final hardness, and bearing capacity of the processed snow.

EQUIPMENT

Snowplow, rotary—Klauer Sno-Go, Model TU-3. Mounted on an Oshkosh truck, Model W1700-15

Snowplow, rotary—crawler, Peter Jr. Snow Miller.

Snowplow, rotary, wheel type—Rolba Sno-Boy, Model 2005/100

Compactor, vibratory, electrically operated, hand controlled—Jackson. 26 in. wide vibrating base; weight 240 lb; delivers up to 4500 - 1¾ ton blows per minute

Roller, snow, corrugated, Canadian. Length 10 ft. Diam 5 ft. Weight 4000 lb. Made of corrugated steel plate.

Roller, road, wheeled, rubber-tired, 13 tires—William Brothers Model 67-W. Weight 5600 lb.

Roller, sheepsfoot, 48″ diam drum, weight 2925 lb including towing apparatus.

Grader, road, towed-type, hand-controlled, 10-ft mold board—Adams Model 124-S.

Tractor, crawler, Caterpillar, D-7, diesel.

CONSTRUCTION OF TEST LANES

Six snow fences were planted at the beginning of the snow season to aid the accumulation of deep snow in the testing area. The fences consisted of 1 ft wide horizontal strips of Sisalkraft paper spaced 1 ft apart and attached to wooden poles at 8-ft intervals. The fences were 6 ft high and during the season the snow accumulated to over a 4-ft depth. At the time of testing, the snow pack consisted of four distinct layers of varying thickness separated by thin ice layers.

Seven test sections were constructed at different times during the season. Each consisted of a base course of snow deposited by a rotary plow. The snow was blown into a prepared trench by the plow and then leveled. Surface processing consisted of rolling or vibratory compaction to densify and strengthen the surface layer. The test sections varied from 8 to 18 ft in width and 50 to 100 ft in length. The layer of processed snow varied from 18 to 42 in. deep (45 - 105 cm) and rested on a concrete runway surface. Table I summarizes the methods of processing and the resulting density and hardness.

TESTING

Testing of the various sections included:

1. Standard USA SIPRE snow pit studies for density and temperature data.
2. Standard Rammsonde tests for hardness profiles.
3. Sieve analysis for particle size determination.
4. Plate-bearing tests.

The snow pit studies and most of the sieve analyses were made immediately after a base course was laid. The sieve analysis procedure is described in the appendix. The Rammsonde tests were made at intervals during the ageing of the sections. Plate-bearing tests were made on test sections 6 and 7 after most of the age hardening was completed and the results have been reported elsewhere in detail.*

Air temperatures were taken throughout the season and are shown in Figure 20.

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* Wuori, A. F. (1957) Plate bearing tests on compacted snow surfaces, Michigan College of Mining and Technology, Unpublished thesis.

Table I. Test lane summary.

Test lane	BASE COURSE				SURFACE LAYER					RAM HARDNESS (Days after final processing shown in parentheses)	
	Processing	Total thickness (cm)	Avg density (g/cm³)	Avg snow temp at time of deposition of base course (C)	Processing	Age of base course (hr)	Temp of surface layer (C)	Thickness (cm)	Density (g/cm³)	Surface layer[1]	Base course[2]
1	Klauer Sno-Go	105	0.47	—9.8	None	--		20	0.47	170 (19)	130 (19)
					Vibrated (3 passes)	2	—10.0	20	0.49	250 (19)	125 (19)
2	Klauer Sno-Go	75	0.49	—8.0	None	--	--	10	0.49	230 (12)	330 (12)
					Vibrated (3 passes)	24	—10.8	10	0.51	310 (12)	330 (12)
3	Rolba Sno-Boy	45	0.50	—6.0	None	--	--	30	0.50	150 (21)	300 (21)
					Vibrated (3 passes)	½	—7.0	35	0.57	350 (21)	330 (21)
					Vibrated (3 passes)	1½	—7.5	30	0.53	500 (21)	370 (21)
4	Peter Jr. Snow Miller	45	0.47	—5.0	None	--		20	0.47	70 (10)	55 (10)
					Vibrated (1 pass)	½	—4.0	20	0.52	145 (10)	200 (10)
					Vibrated (3 passes)	½	—4.0	25	0.53	225 (10)	200 (10)
5	Klauer Sno-Go	60	--	—5.5	Corrugated roller (2 passes)	½	--	--	--	100 (15)	275 (15)
6	Klauer Sno-Go	105	0.51	—6.0	Sheepsfoot roller (1 pass) Wobble-wheel roller, empty (2 passes) Corrugated roller (2 passes)	½	—6.5	35	0.52	300 (8)	250 (8)
7	Klauer Sno-Go	90	0.54	—3.0	Wobble-wheel roller, 2000 lb load (1 pass) Corrugated roller (1 pass) Wobble-wheel roller, 6000 lb load (2 passes) Corrugated roller (2 passes)	½	—2.5	40	0.59	480 (8)	270 (8)

[1] Average ram hardness for thickness shown in col. 9

[2] Average ram hardness for processed snow layer beneath surface layer.

Table II. Properties of freshly deposited base-course snow.

Properties	Rolba snow	Klauer snow	Peter Jr. snow
Average density (g/cm^3)	0.51	0.50	0.47
Uniformity coefficient, C_u	2.33	2.23	1.87
Average mean grain size, D_m (mm)	0.496	0.427	0.451

TEST RESULTS

Densities and particle size distribution

The undisturbed snow ranged in density from 0.30 to 0.36 g/cm^3. Processing with the rotary plows increased the density to the values shown in Table II. The snow processed with the Rolba plow became denser than that processed with either of the other plows, and it compacted to a higher density by vibration. Figures 2 to 19 describe depth-density, depth-hardness and time-hardness characteristics of the test lanes.

Figures 13 to 19 show the general trend of ram hardness. The erratic rise and fall of the plotted points beyond the 5-day period may represent a particular effect of the age hardening process. Figure 1 and Table II summarize the particle size data of the various snows.

The uniformity coefficient is used in soils work to indicate how well a soil is graded.

$$\frac{D_{60}}{D_{10}} = \text{uniformity coefficient } (C_u)$$

Where D_{60} = largest diameter of the finest 60% of grains

D_{10} = largest diameter of the finest 10% of grains.

A high uniformity coefficient indicates that the soil is well graded for maximum compaction. This parameter can also be usefully applied to snow. The Rolba snow has the higher uniformity coefficient, but simultaneous tests with the three plows must be made to prove or disprove the superiority of Rolba snow. The difference in uniformity coefficient of the various snows is very small. In soils, such a small difference would seem hardly significant as the uniformity coefficient can vary from 1.1 to several hundred. However, the range of particle sizes of snow is very small and a small difference in uniformity coefficient may be significant.

Effect of vibratory compaction

The compaction using the single Jackson vibrator on a freshly laid base course was quite effective. The tests show that the vibratory compaction should be done almost immediately after the snow has been processed by the rotary plows. If it is allowed to age-harden, the effect of the vibratory compactor becomes less. Damping is quite apparent in snow which has age-hardened for 1 hr or longer. A section of test lane 3 which was vibrated immediately after processing had a surface layer density of 0.57 g/cm^3, while another section which was vibrated over 1 hr after processing had a surface layer density of 0.53 g/cm^3 (Table I, Fig. 4). In this case, however, the latter section became harder (Fig. 15). Snow vibrated 24 hr after processing showed no appreciable increase in density (Fig. 3). The effect of the vibration was a softening of the top 4 in. (10 cm) of the surface, and the surface did not harden again as well as a surface not touched by the vibrator (Fig. 14). However, the surfaces of sections which were vibrated soon after processing hardened considerably more than non-vibrated surfaces.

The first pass of the vibrator gave the most compaction (Fig. 5, 16). Each successive pass became less effective and beyond 2 passes the additional effect became negligible.

The compaction of the base course surface layer by the vibratory compactor was aided by lateral confining action of the snow trench walls.

Effect of rolling

Three types of rollers were tested for surface processing. The sheepsfoot roller was found to be quite ineffective on a new base course. The effect was somewhat the same as in sand, the snow being displaced instead of compacted. This roller was found to be a little more effective in snow which had aged for an hour or so and developed some cohesion. Slight increases in the surface density were noted.

The corrugated roller, used alone, was effective in compacting a new surface layer of about 4 in. (10 cm) by approximately 4%. The wobble-wheel roller compacted snow to a greater depth, especially when several passes were made, the load being increased with each pass. The best results were obtained when the wobble-wheel and corrugated rollers were used in sequence (test lane 7; Fig. 6, 12, 19). The corrugated roller compacted the ridges left by each pass of the wobble-wheel roller. In this way density increases of about 8% were achieved in the top 10 in. (25 cm). On partially age-hardened snow, the degree of compaction was reduced considerably.

It was also noted that the higher the snow temperature, the easier it was to compact by rolling. This was especially true with test lane 7 (see Figure 6). The air and snow temperatures at the time of rolling were only a few degrees below freezing, and a high density resulted.

Plate bearing tests

A large number of plate bearing tests were made on test lanes 6 and 7. The effect of size and shape of plates on the bearing capacity was investigated and a comparison of behavior of compacted snow and cohesive soil was made.

It was found that the initial deformation of the snow pavement under a loaded plate was elastic up to a fairly well-defined yield point followed by plastic deformation and subsequent shear failure. It was also found that as the bearing area was increased, the unit load required to cause failure decreased, indicating that if bearing plates are to be used for determining the bearing capacity of compacted snow surfaces, the size of bearing area must be taken into consideration.

This study has been described in a previous report. (Wuori, op. cit).

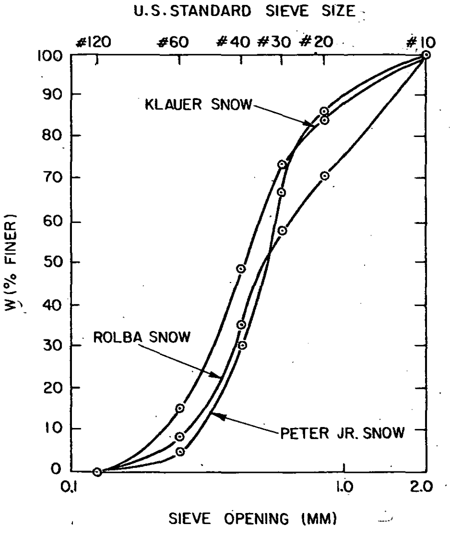

Figure 1. Sieve analyses of freshly deposited base course.

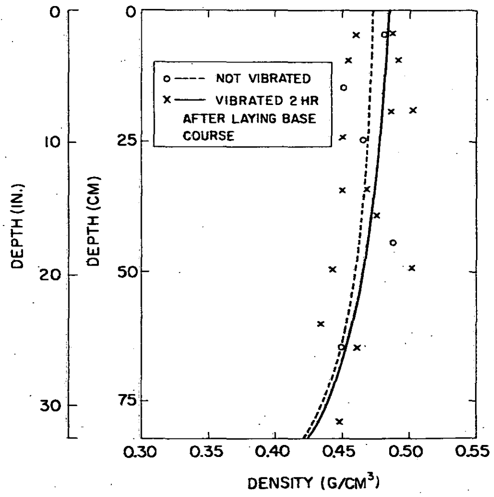

Figure 2. Density profiles of test lane 1, Klauer-snow base course.

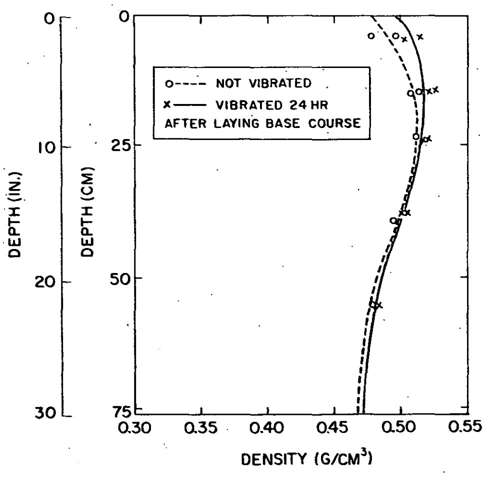

Figure 3. Density profiles of test lane 2, Klauer-snow base course.

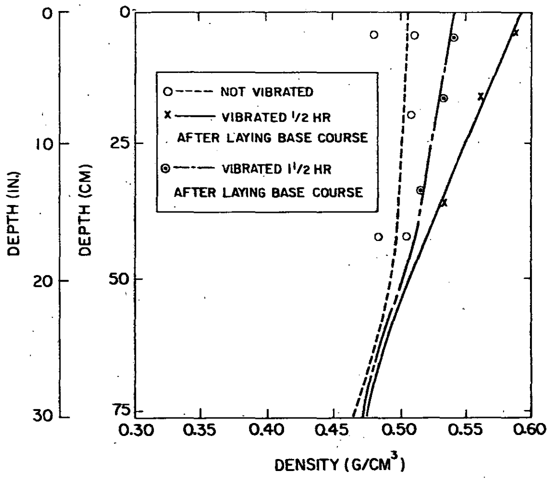

Figure 4. Density profiles of test lane 3, Rolba-snow base course.

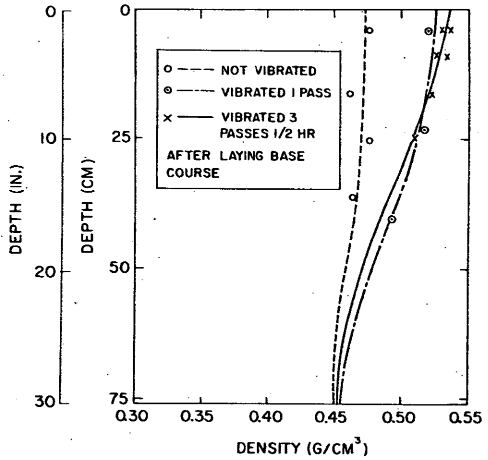

Figure 5. Density profiles of test lane 4, Peter-snow base course.

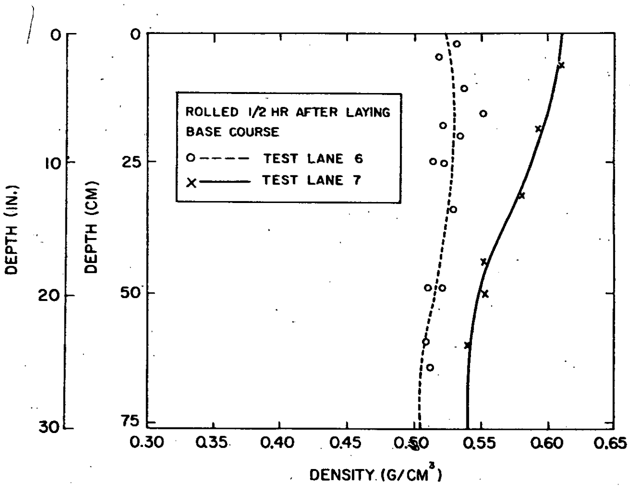

Figure 6. Density profiles of test lanes 6 and 7, Klauer-snow base courses.

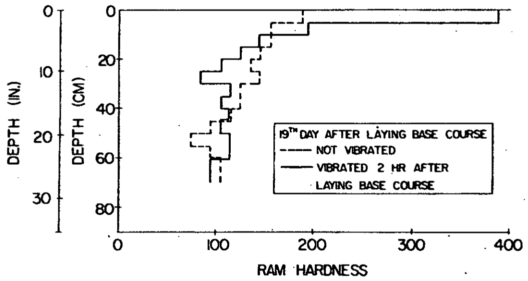

Figure 7. Rammsonde profiles of test lane 1, Klauer-snow base course.

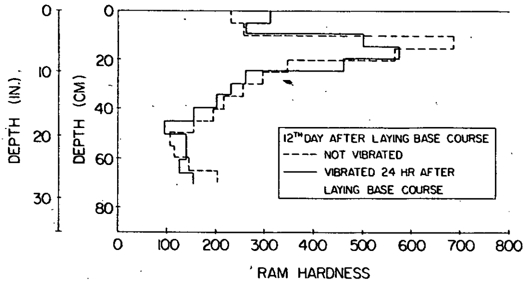

Figure 8. Rammsonde profiles of test lane 2, Klauer-snow base course.

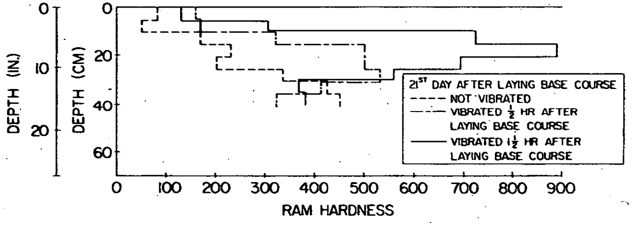

Figure 9. Rammsonde profiles of test lane 3 Rolba-snow base course.

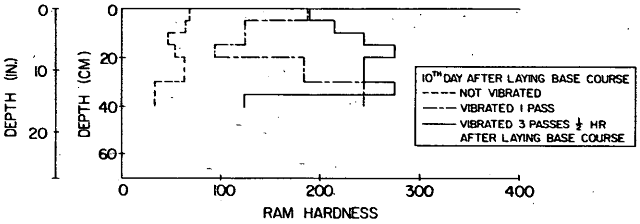

Figure 10. Rammsonde profiles of test lane 4, Peter-snow base course.

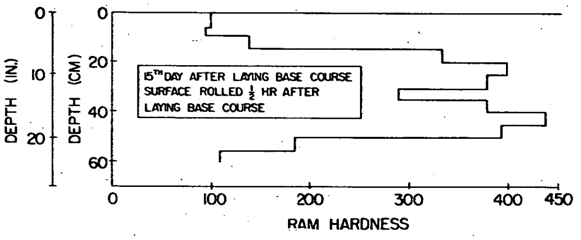

Figure 11. Rammsonde profiles of test lane 5, Klauer-snow base course.

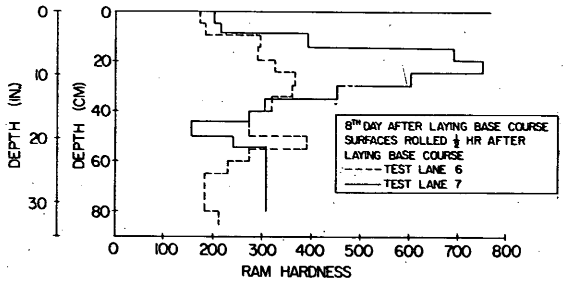

Figure 12. Rammsonde profiles of test lanes 6 and 7, Klauer-snow base courses.

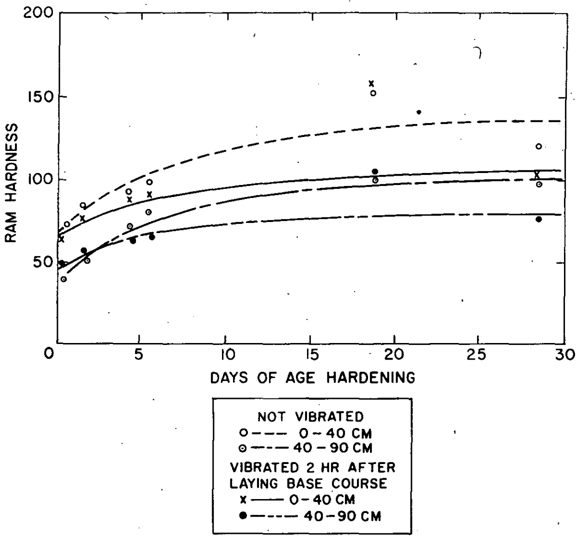

Figure 13. Age hardening of test lane 1, Klauer-snow base course. Each point represents the average ram hardness for the depth indicated.

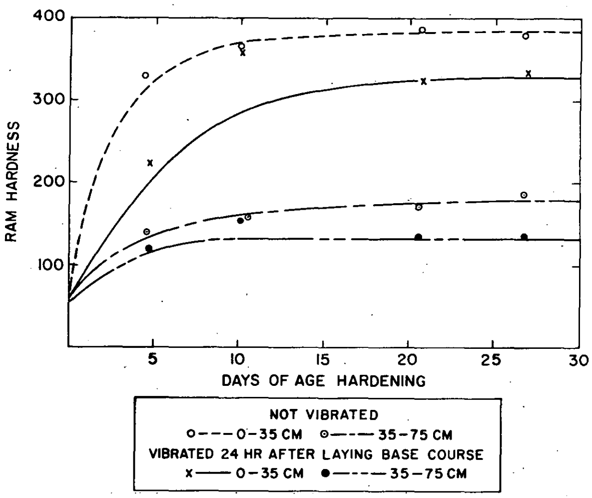

Figure 14. Age hardening of test lane 2, Klauer-snow base course. Each point represents the average ram hardness for the depth indicated.

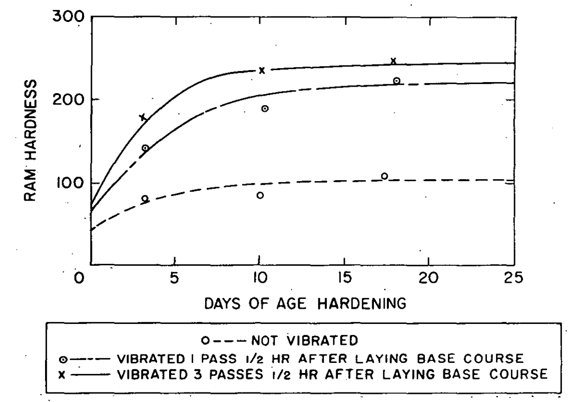

Figure 16. Age hardening of test lane 4, Peter-snow base course. Each point represents the average ram hardness for the entire processed layer.

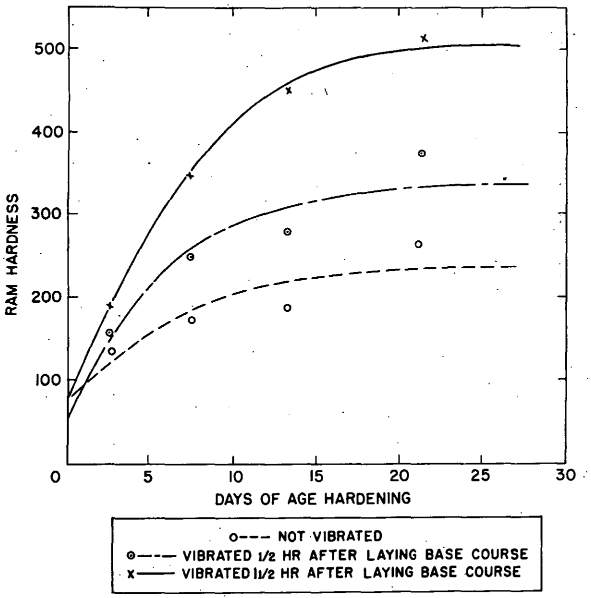

Figure 15. Age hardening of test lane 3, Rolba-snow base course. Each point represents the average ram hardness for the entire processed layer.

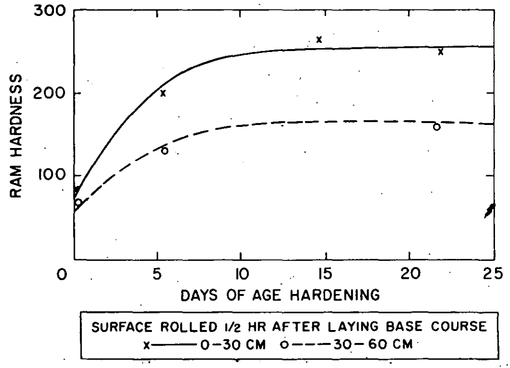

Figure 17. Age hardening of test lane 5, Klauer-snow base course. Each point represents the average ram hardness for the depth indicated.

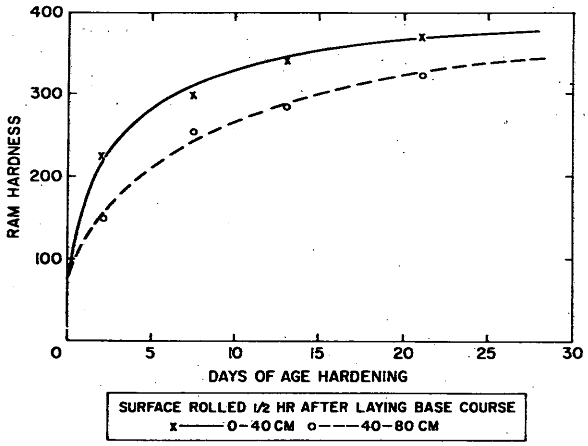

Figure 18. Age hardening of test lane 6, Klauer-snow base course. Each point represents the average ram hardness for the depth indicated.

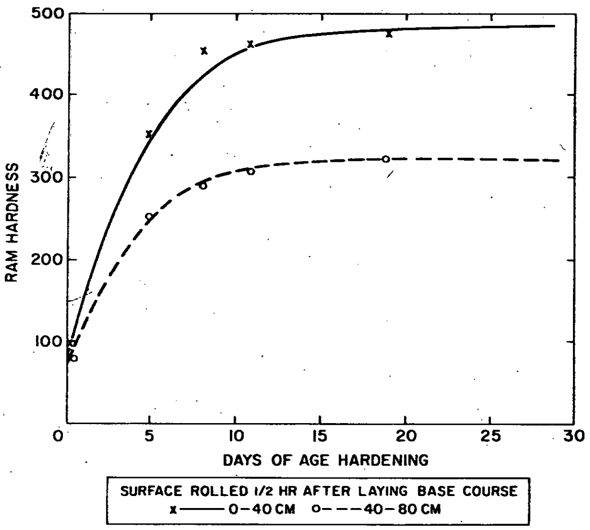

Figure 19. Age hardening of test lane 7, Klauer-snow base course. Each point represents the average ram hardness for the depth indicated.

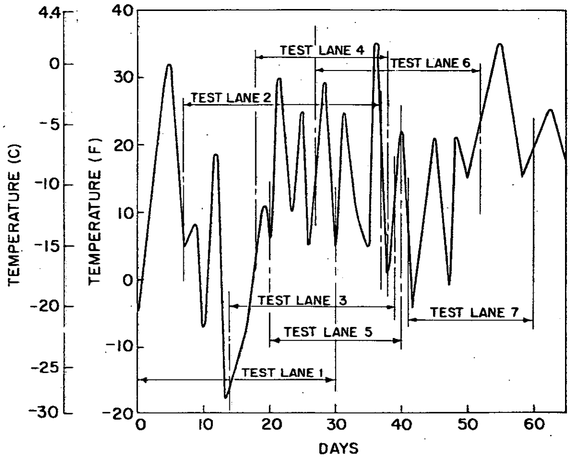

Figure 20. Air temperatures at Keweenaw Field Station.

CONCLUSIONS

The vibratory compaction of granular, cohesionless, dense snow shows promising results. A base course can be constructed of snow having a density of over 0.50 g/cm^3 by disaggregation with a rotary plow. If this snow is immediately compacted with the vibratory compactor, it is possible to densify the upper 9 in. or so by over 10%. This forms a stronger upper layer which is necessary for supporting and distributing high unit pressure loads. Because of the few tests made, it is not yet possible to evaluate the usefulness of such a method for constructing airstrips.

The use of rollers to compact disaggregated snow was not as effective as vibration, except when the snow temperature was close to the melting point. However, significant density increases were noted, especially with the combined use of a loaded rubber-tired roller and a corrugated roller.

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APPENDIX: SIEVE ANALYSIS PROCEDURE

A nest of five sieves of the U. S. Standard Sieve Series was used. Various snow sample sizes were experimented with and a 50-g sample was found to be the most convenient to use. The sieving was done in a shelter near the field test site with the air temperature varying from -6C to -15C.

The sample of freshly processed snow was sieved manually with a circular rocking motion for a sieving time of 3 min. The snow retained on each sieve was then weighed and tabulated. This procedure was used consistently for all tests so that a comparison of the various types of processed snow could be made.

Table A1. Sieve analyses summary.

Sieve no.	Rolba snow			Klauer snow			Peter Jr. snow		
	Percent finer			Percent finer			Percent finer		
	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
10	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
20	71.6	70.1	71.2	85.2	82.8	84.0	88.3	84.3	86.3
30	60.9	48.5	57.5	75.9	71.6	73.8	69.3	64.5	66.9
40	41.5	23.2	35.6	51.0	46.1	48.6	34.1	27.6	30.4
60	11.2	2.5	8.6	16.2	14.7	15.4	5.5	3.7	4.6
120	0.5	0.0	0.2	0.0	0.0	0.0	0.3	0.0	0.2
Pan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Uniformity coefficient	2.46	2.12	2.33	2.29	2.19	2.23	1.94	1.84	1.87
Mean grain diam. (mm)	0.510	0.480	0.496	0.434	0.413	0.427	0.468	0.438	0.451