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Improving snow roads and airstrips in Antarctica

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During the 1986–1987 austral summer, snow road and runway test lanes were constructed at McMurdo Station and at South Pole Station. These lanes were monitored during December 1986, January 1987, and again in January 1988. Test sections were constructed of 1) tractor-compacted snow topped with a 15-cm thick layer of rotary blower processed snow, 2) rotary processed and compacted snow in 15-cm layers to a depth of 60 cm, 3) rotary processed and compacted snow in 15-cm layers incorporating a wood sawdust additive mixed at 5% by volume, and 4) rotary-processed snow with 10% sawdust by volume. These test sections were observed and monitored by obtaining temperature and density profiles, Rammsonde hardness profiles, California Bearing Ratio and Clegg surface strength values, and testing for ability to withstand traffic. It was concluded that wood sawdust added to processed snow in amounts of 5% to 10% by volume significantly increases the strength of the resulting snow road or runway. This increase was greater at McMurdo than at the South Pole, appearing to be a function of snow temperature. Adequate strengths of the snow/sawdust mixtures were achieved for limited use by wheeled C130 aircraft, but additional processing with heat, water or added compaction appears necessary to produce a 25-cm-thick surface layer adequate for more frequent use and to accommodate wheeled C141 aircraft. At McMurdo, it was found that the sawdust was not effective in maintaining the integrity of the surface for traffic during the thawing season without additional maintenance, whereas

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19. Abstract (cont'd)

at the South Pole, thawing was not a problem since temperatures remained well below the melting point. It was concluded that the McMurdo snow roads were not constructed adequately early in the season to prevent failure and, therefore, required an unduly high maintenance effort during the warm season. It is recommended that the future roads be constructed by depth processing with a rotary miller or blower. It is also recommended that geotextile fabrics or membranes be used to divert water into culverts, and that the use of heat (or water) injection or confined dynamic compaction be investigated for creating a hard snow surface layer for use by C141 wheeled aircraft.

PREFACE

This report was prepared by Dr. Sung M. Lee and Dr. Wilbur M. Haas of the Institute of Snow Research, Keweenaw Research Center, Michigan Technological University, Houghton, Michigan, Dr. Robert L. Brown of Montana State University, and Albert F. Wuori, also of the Institute of Snow Research.

This is the final report on studies performed during the period November 1986 through June 1988 for the Operations Section, Division of Polar Programs, NSF Contract DPP8612951. This project had the objective of developing improved methods for designing and constructing snow roads and runways in Antarctica. The authors express appreciation to graduate students Mark Bott from Michigan Technological University and Mike Barber, Montana State University, for their contributions and participation in this work.

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CONTENTS

ILLUSTRATIONS

Figure

Figure Page

TABLES

Table

Improving Snow Roads and Airstrips in Antarctica

SUNG M. LEE, WILBUR M. HAAS, ROBERT L. BROWN, ALBERT F. WUORI

INTRODUCTION

The state of the art in snow compaction technology has been advanced in recent years as a result of economic development in the North and scientific exploration in Antarctica. Snow roads and airstrips for wheeled vehicles and light aircraft are a reality in northern areas such as Canada, Alaska, Scandinavia, and other regions (Adam 1978). The Soviets have developed experimental heat processing equipment for constructing hard-surfaced snow runways. However, the snow runway for wheeled cargo aircraft at U.S.S.R. Antarctic Station, *Molodezhnaya*, was constructed by repetitive compaction with rollers (Averyanov et al. 1983). The United States has only recently readdressed snow compaction technology after a period of virtual inactivity for almost 20 years. The Polar Programs Division, National Science Foundation (NSF), has recently funded some work in this area because of concern for supplying scientific activities in Antarctica and for possible reconstruction of South Pole Station.

BACKGROUND

In January 1986, the NSF funded a visit to Antarctica by two investigators from the Institute of Snow Research, Keweenaw Research Center, Michigan Technological University. The purpose of the visit was to assess the problem of snow roads and runways and to make some on-site observations and collect data on existing roads and skiways. As a result of this visit and some laboratory and field work, a report (Lee et al. 1986) was submitted to NSF in November 1986. This report described the observations at McMurdo and South Pole and assessed the possibility of improving the roads and runways. It also reported on the laboratory and field studies that indicated that the use of sawdust as an additive could be quite effective in increasing snow strength. The use of the CBR, Clegg, and other tests to develop a serviceability index for snow roads was also discussed. A proposal was made to NSF for an active field and laboratory program to further develop this technology. This proposal was funded and a field team was deployed to the Antarctic in late November 1986.

WILLIAMS FIELD AND DELTA ROAD OBSERVATION PROGRAM

This program was initiated in late November 1986 and continued through late January 1987. Five stations were located along both the Delta Road and Snow Road, beginning near Williams Field at McMurdo and continuing to the curve near the transition area (Fig.1). Both roads are of compacted snow. However, the so-called Snow Road was used by shuttle vans and other light vehicles only. The Delta Road was used by the much heavier Delta vehicles. At each station, five ram (Rammsonde) hardness profiles were obtained on the Snow Road and three profiles on the Delta Road at 10-ft intervals. Also, at each of these observation points, Clegg (CIV) measurements were made. A number of cores were taken for density measurements and a number of in-situ CBR tests were performed.

The hardness profiles (Fig. 2 and 3) on both Snow and Delta roads show values that are somewhat marginal for support of the Delta vehicles. Although the vans that use the Snow Road are lighter vehicles, their frequency of travel is greater and, therefore, more damaging. Many failures were observed as a result of traffic on these roads. This was especially serious during warm ambient conditions when the surface softened considerably. The low strengths or hardness tended to be more pronounced with distance away from Williams Field, e.g., nearer to the edge of the ice shelf and the land slopes. Surface Clegg Impact Values (CIV)

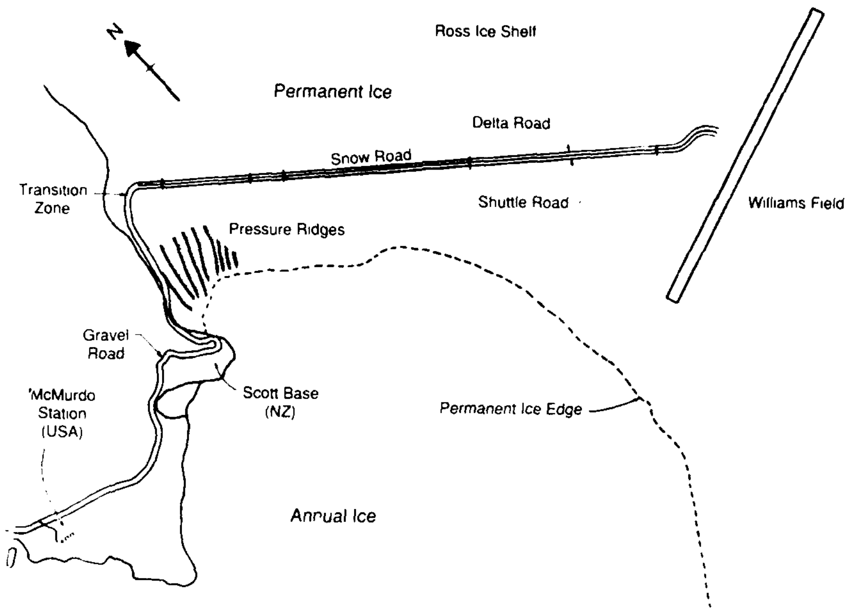


Figure 1. Test locations on Williams Field roads.

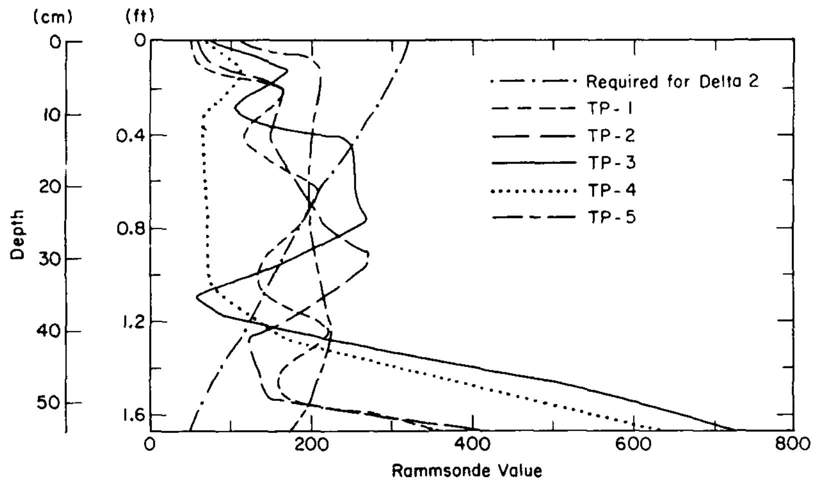


Figure 2. Snow Road hardness profiles.

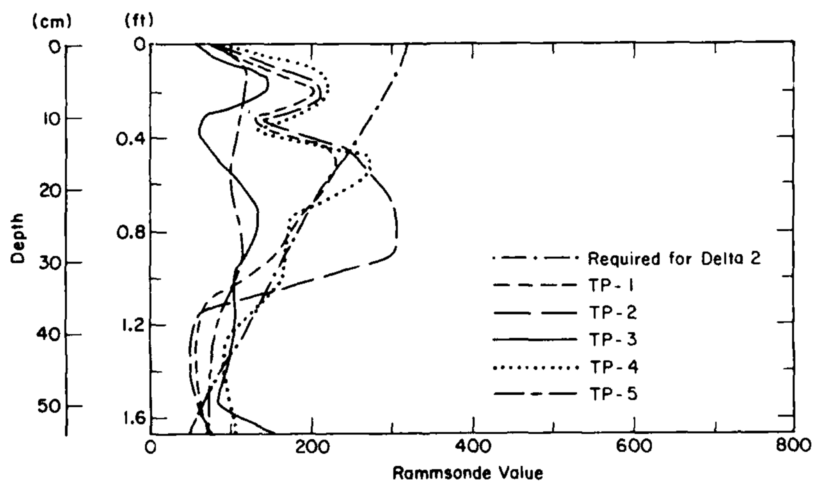


Figure 3. Delta Road hardness profiles.

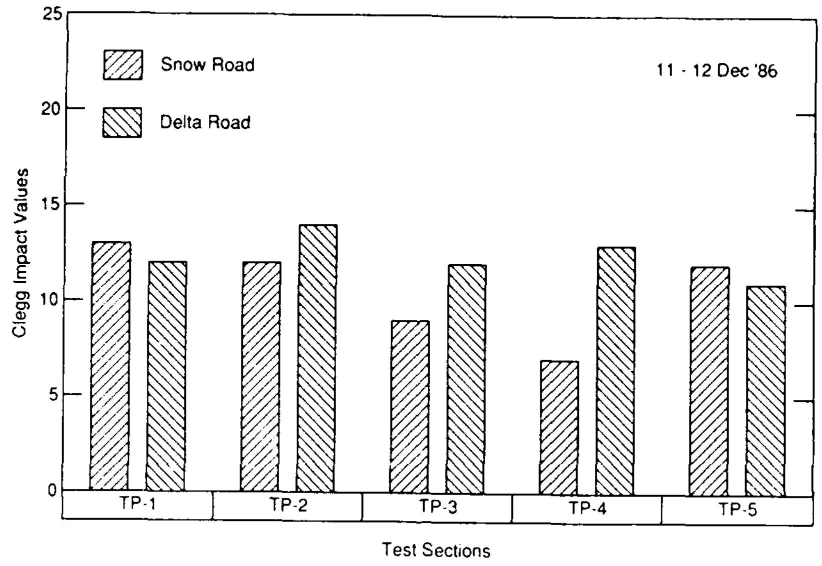


Figure 4. Clegg impact values (CIV).

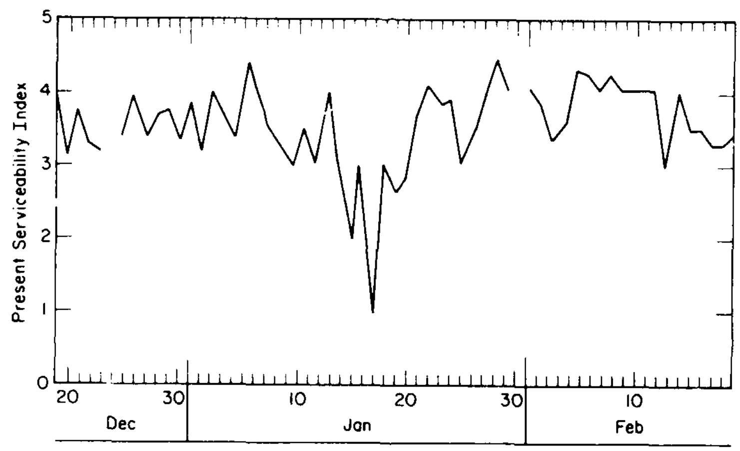


Figure 5. Present serviceability index—Snow Road.

(Fig. 4) were generally low, although somewhat higher on the Delta Road (TP 2,3,4) than on the Snow Road. Some correlations have been made between Clegg values (CIV) and the CBR for soils and base course materials for conventional roads. Similar correlations for snow have yet to be developed.

Figure 5 illustrates the Present Serviceability (PS) index of the Snow Road throughout the season. The PS index was derived from user (drivers') comments. A rating of "1" indicates a nearly impassable condition for the vans. A rating of "5" would indicate a perfectly smooth surface.

As used in conventional roads, the PS index is a subjective rating, determined by a panel of drivers who may be experienced pavement engineers, drivers selected from the general population, or a combination of these. The PS index determined in this manner may also be correlated with quantifiable items, such as length of pavement cracking per lane mile, square feet of patching per lane mile, the longitudinal pavement roughness determined from a measured profile, or vertical accelerations measured as an instrumented test vehicle is driven over the road (or airfield).

However it may be determined, the PS index of conventional roads is expressed as a function of load repetitions, or alternatively, of time. A new pavement typically begins its service life with a PS index of approximately 4.6. With time and load repetitions, the PS index gradually decreases. When the PS index reaches about 2.5, or 2.0 for less important roads, the road is resurfaced, thus bringing the PS index back up to about 4.5 or more. The road then begins another cycle. Depending on the adequacy of the design, the quality of construction, and the nature and intensity of the traffic, this cycle time may typically be from 10 to 20 years.

As applied to a snow road, the PS index is a function of the initial construction and subsequent maintenance, but most significantly of the surface temperature of the road. The surface temperature depends on the ambient air temperature and the extent to which the surface absorbs radiation. When the snow road surface temperature approaches the thaw temperature, the road rapidly loses durability and stability, resulting in rutting that becomes progressively worse. The roadway may soon become so weak that vehicles, which easily traveled on its surface at lower temperatures, now may become immobilized due to excessive rutting. Thus, the PS index may drop from an acceptable 3 or 4 down to a very risky 1 in a matter of 24 hours or less, as happened on 17 January 1987 (Fig. 5). Thus, the PS index of a snow road is very sensitive to the temperature of the road surface.

The PS index is concerned almost exclusively with "ride quality," and thus the smoothness of the surface, and does not inherently measure or indicate the strength or durability of the road surface. There is, however, a clear relationship between roadway strength and roadway smoothness, especially in the case of snow roads. The PS index of a snow road cannot remain at the 3 or 4 level unless it has first been suitably prepared, and then subsequently retains sufficient strength to resist rutting. If the strength drops below some critical level, rutting and a decrease in the PS index will certainly follow. Depending on temperature and traffic effects, the snow road may rapidly deteriorate to the point of becoming impassable. Ironically, when the road regains strength with the return to lower temperatures, the road may still have an unacceptably low PS index, as the refreezing will act to "lock in" the roughness, unless the road can be smoothed and recompacted simultaneously with the regaining of strength.

The above observations indicate that better initial snow road construction techniques are required. The continual maintenance of the roads throughout the season with a Delta vehicle towing a drag improves the surface only and has no significant effect on the underlying layers. The initial snow road construction should accomplish strengthening in depth with rotary processing equipment and compaction at the beginning of the season. Vibratory compaction would be the preferred technique, as this would result in higher densities and strengths. This observational program on the Delta and Snow roads and the analyses are described in detail in Bott (1988).

LABORATORY STUDIES ON ADDITIVES

A number of confined compression tests were performed in the laboratory in order to evaluate the effect of additives on the mechanical properties of snow. In the first series of tests, sawdust and polystyrene beads were used as the two additives. Tests were run on these two types of snow mixtures having snow/additive volume ratios of 4:1, 4:3, 2:5, and 1:0. The purpose of these tests was to first determine the relative effectiveness of these two additives. A second purpose was to determine if there existed an optimum ratio of snow and additive. The samples were initially mixed and then placed in cylindrical tubes and compacted manually by the standard free weight drop technique used in soil mechanics. The total compactive effort for each specimen was 12,375 ft-lbf (16,780 J). The samples were allowed to sinter for one day at −14°C before testing. The tests were all done in confined compression at a constant crosshead speed. Figures 6 and 7 show typical results for snow/additive mixtures. These test results were initially not very informative, other than to demonstrate that polystyrene beads were definitely counterproductive in increasing strength. The sawdust, however, showed increased strength for

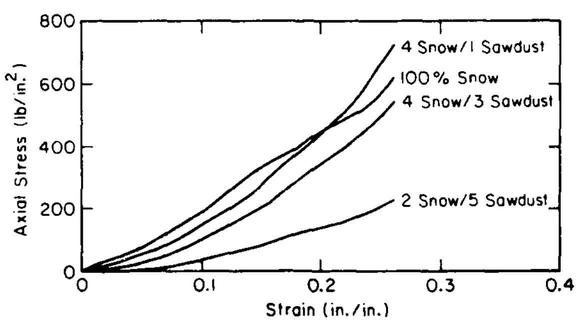


Figure 6. Stress-strain curves for various volume ratios of sawdust mixed with dry snow.

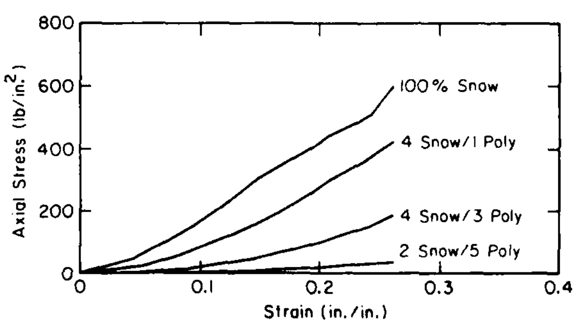


Figure 7. Stress-strain curves for various ratios by volume of polystyrene beads mixed with snow.

the lowest ratio tested (4 parts snow/1 part wood). However, no conclusions regarding an optimum ratio of sawdust to snow could be arrived at from these test results. Note, however, the relative curves of the 100% snow and the 4 parts snow/1 sawdust mixtures. The 100% snow sample initially showed a higher strength but was substantially lower in ultimate strength. This will be discussed later.

The second set of laboratory tests was more comprehensive. In this case a computer-operated servohydraulic testing machine with a higher crosshead speed capability was used. Samples were again prepared by mixing snow and sawdust in prescribed ratios (0, 2.5%, and 10% sawdust by volume). These ratios were selected, because the earlier tests indicated that higher proportions of sawdust did not enhance strength. After mixing, the snow mixture was placed in waxed concrete sample holders having a diameter of 25.4 cm (10 in.). These samples were then placed in the testing machine and compressed at a rate of 0.1 in./s (0.25 cm/s) until a load of 2500 lbf (approx. 32 psi or 0.2 MPa stress) was reached. This stress was then held constant for 10 seconds and then released. All samples were prepared by this method. They were all aged for 27 days and then tested. Prior to testing, the sample was cut from its sample holder, cut down to 20.3-cm (8-in.) diameter and placed in an instrumented aluminum cylinder for the confined compression tests. The crosshead speeds were either 1 in./s or 0.1 in./s, and the test temperature was −14°C.

The results are shown in Figures 8–10 as stress-strain curves. Figure 8 demonstrates the rate dependency of snow, which shows an increased stress response with strain rate. The mean density was 0.532 g/cm³ ±0.007 g/cm³ for the two tests illustrated. This trend was found to also hold for the samples containing sawdust.

Figures 9 and 10 illustrate the relative stress-

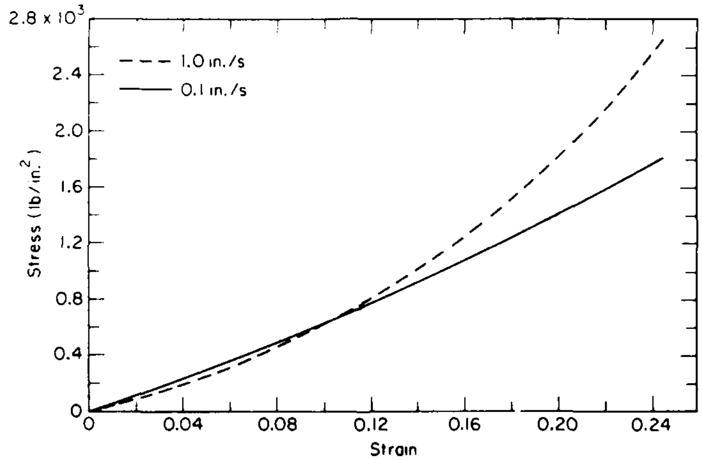


Figure 8. Stress-strain curves for compacted snow.

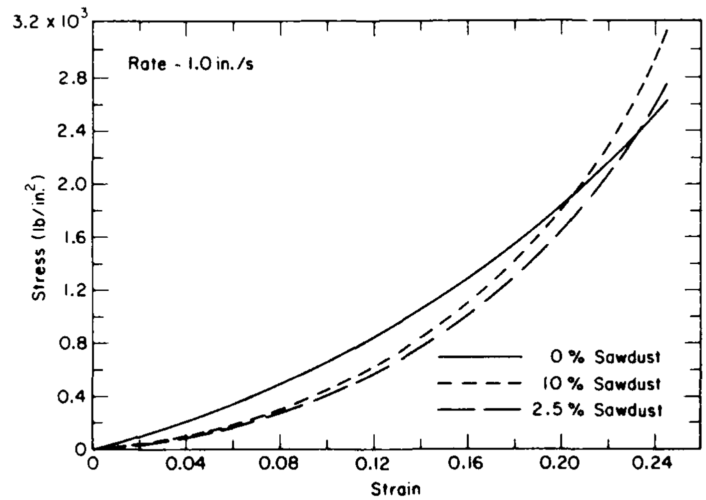


Figure 9. Stress-strain curves for snow/sawdust at fast rate.

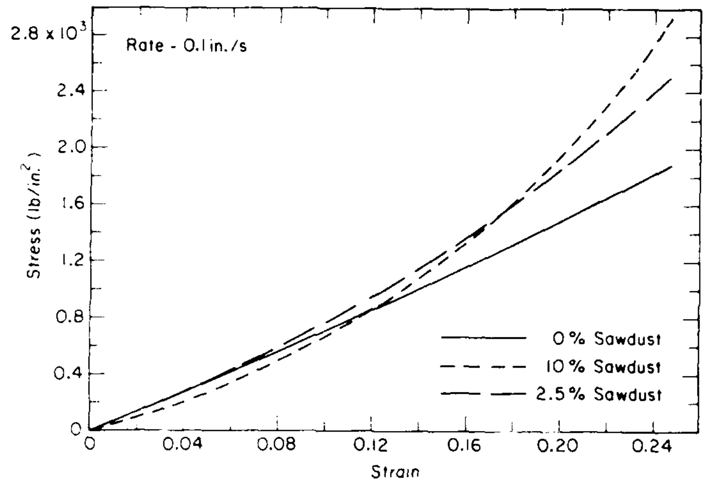


Figure 10. Stress-strain curves for snow/sawdust at slow rate.

strain curves for the snow mixtures of 0%, 2.5%, and 10% sawdust. Figure 9 is for the high rate (1.0 in./s) and Figure 10 is for the slow rate (0.1 in./s). Both figures indicate that the 10% sawdust mixture gives the greatest strength at strains above 0.2. However, the 100% snow samples had the highest initial stiffness and continued to have the higher strengths until strains of approximately 10% to 20% were reached. This is consistent with the earlier test results shown in Figure 6.

The higher initial strength of the pure snow may be explained partially in terms of sintering and adhesion processes. Apparently after mixing, sintering between the ice particles takes place at a higher rate than adhesion between the sawdust and ice particles. After the 27-day sintering period the interparticle bonding was more fully developed in the pure snow samples, since all particle contacts were between ice particles. Upon starting the deformation, the superior intergranular (or interparticle) bonding for the 100% snow results in higher initial stresses. As the deformation proceeds, the intergranular bonding breaks down due to fracture of the bonds (both between the ice particles and between the ice and wood particles). As this proceeds, the greater strength of the wood, its elastic behavior, and the more complicated geometrical shape of the wood chips combine to increase the strength of the mixtures above that of the pure snow.

The effect of adding sawdust to snow on the stiffness (or Young's modulus, E), of the mixtures can be illustrated more dramatically by plotting the slope of the stress-strain curve vs strain. Differentiating $d\sigma/d\varepsilon$, the equations of the stress-strain curves shown in Figures 9 and 10, results in the slope (the tangent modulus at any strain) vs strain curves shown in Figures 11 and 12. (Note that the stress values in Figures 9 and 10 are shown in terms of 10^3 psi, while the slope, $\Delta\sigma/\Delta\varepsilon$, or E, values in Figures 11 and 12 are shown in terms of MPa, the strain ε being a nondimensional value.)

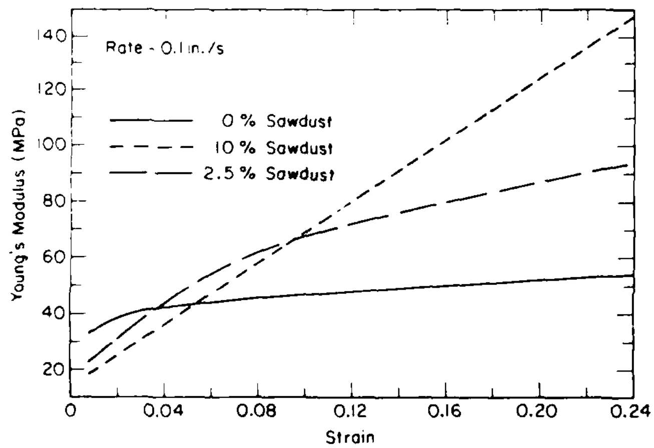


Figure 11. Young's modulus at low strain rate.

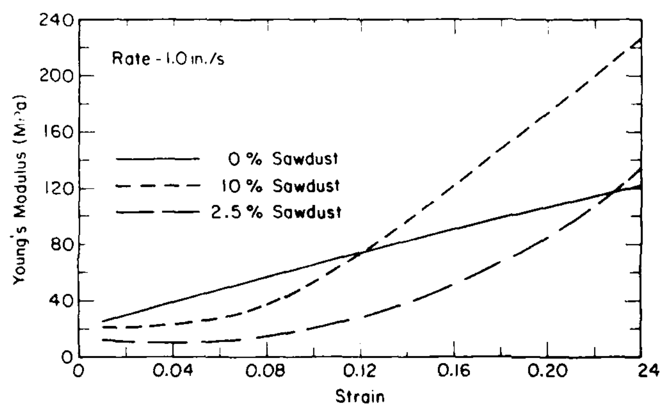


Figure 12. Young's modulus at high strain rate.

As can be seen, at low strains, the initial E values for pure snow are somewhat higher than those for the snow/sawdust mixtures, but as the strain increases, the E values for the snow/sawdust mixtures exceed those for the pure snow.

The values of E are much lower than those that would be found from the more acceptable technique of dynamic testing. However, these data give a good measure of the relative value of Young's Modulus E for the various sawdust contents at various strains. These results demonstrate that ice bonds more slowly to wood than it does to itself. However, it is possible that the eventual adhesive strength between wood and ice could be high. Future work will investigate the use of mixture theories to model the behavior of the sawdust/snow mixtures. In addition, work at Montana State University is now underway to correlate ram hardness profiles with material properties measured in this laboratory testing program.

CONSTRUCTION OF TEST SECTIONS

WIlliams Field Road test sections

Four test sections were constructed adjacent to the Williams Field Road during the period 6–8 December 1986. Ambient temperatures ranged from –5° to –10° C and snow temperatures from –5° to –5° C. The sections were each made 6 m (20 ft) wide and 12 m (40 ft) long, laid end to end, with transition zones to the Shuttle Road to permit trafficking (Fig.13).

The general construction procedure began by excavating undisturbed snow with a bulldozer tractor to a depth of 1 m where there was a layer of dense snow-ice. The trench was then filled to within 60 cm of the surface with snow placed and compacted with a bulldozer, sheepsfoot roller and drag. Then 15-cm-thick layers of snow were blown into the trench using a small driveway-type rotary snowblower This was followed by 15 compaction coverages of the bulldozer tracks. This procedure continued until the test sections were filled to final grade and leveled by backblading.

Since there were four different test sections and two transition areas, the above procedure was modified as follows. The first test section was filled with snow and compacted by the bulldozer to within 15 cm of grade. The remaining 15 cm of trench was then filled with snow blown in by the rotary blower and compacted with the bulldozer. The second test section was constructed as described by the general procedure, all snow blown in 15-cm lifts. The third section was constructed as described by the general procedure except that with each lift a measured amount of wood sawdust was spread on each lift and reprocessed or mixed into the snow with the snow blower so that the top 60 cm resulted in a layer of snow/sawdust mixture of 20:1 by volume. The fourth section was the same except that the amount of sawdust was doubled resulting in a snow/sawdust mixture of 10:1 by volume (Fig. 14). The transition zones to the shuttle road were constructed by compaction and leveling with the bulldozer.

The above construction procedures were followed because of equipment limitations. Specifically, the small snowblower was inadequate for a more efficient construction procedure. A large rotary snow blower or processor would have greatly reduced time and effort.

Williams Field taxiway test sections

These test sections were constructed on 18 December in the same manner as the road sections, except that their dimensions were 9 × 7.5 m each to accommodate possible trafficking or taxiing by C130 aircraft. Also, these sections were covered with a thin layer of pure snow to minimize the chance of loose sawdust being blown about. The ambient and snow temperatures were higher than those at the Williams Field Road test sections, –1.0° to +1.0°C and 0.0 to –8.0°C, respectively.

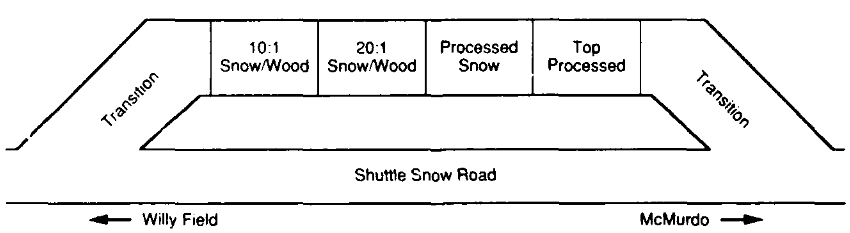


Figure 13. Williams Field Road test sections.

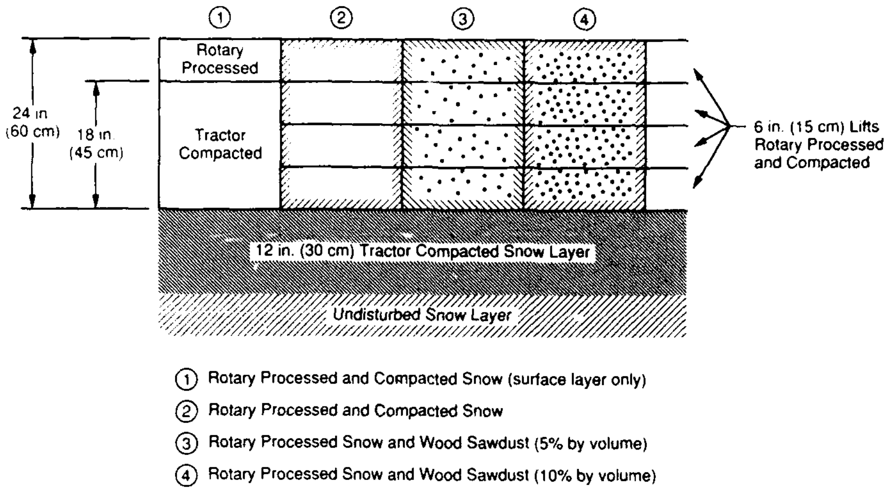


Figure 14. Cross sections of test lanes.

South Pole cargo berm test sections

Two test sections were constructed on 1 December '86 near the cargo berm, an area of snow disturbed and somewhat compacted by cargo traffic. The ambient temperatures were –30° to –40°C and the snow temperatures were –30° to –49°C. Wind chill factors were –80°C. One test section was constructed of processed snow only, after excavation first to a 60-cm depth and then blowing in 15-cm lifts, compacting each lift with the tractor to finish grade. The second test section incorporated wood sawdust with a snow/wood ratio of 20:1 by volume. The small snowblower performed inadequately at the 2800-m elevation, resulting in incomplete processing and mixing. Therefore, some chunks of unprocessed snow and unmixed sawdust were noted. This also resulted in uneven compaction.

South Pole taxiway test sections

Three sections were constructed on the taxiway near the aircraft parking area on 2 December 86. The ambient and snow temperatures were approximately the same as those on 1 December. One test section was of processed snow only, again in 15-cm lifts, another incorporated sawdust with a snow/wood ratio of 20:1, and the third section 10:1 by volume.

TEST RESULTS

Types of testing

Generally, the test sections were subjected to the following series of tests conducted at prescribed intervals from immediately after construction to the end of January. Temperature and density profiles were obtained from snow pits or cores. Rammsonde penetrometer hardness profiles were obtained at regular intervals to 65-cm depth. The ram hardness numbers are based on the equation:

$$R = \frac{Wh}{S} + (W + Q)$$

where W = weight of hammer (kg)
h = height of hammer fall (cm)
S = depth of penetration (cm)
Q = weight of penetrometer (kg)
R = ram resistance (kgf).

While the cone is entering the surface, the resistance varies because of the increasing diameter (0 to 4 cm) and, therefore, a surface layer correction factor has to be applied. For the standard cone (60° included angle) the correction factor is 4.7R for a depth of 0 to 5 cm, and 1.6R for a depth of 5 to 10 cm. In hard snow, as in these studies, a Rammsonde instrument with a 30° cone may be used. In this case, correction factors of 4R and 1.6R are applied to the surface layers of 0–5 cm and 5–10 cm, respectively (Niedringhaus 1965). Also, because the 30° cone with a maximum diameter of 3 cm encounters less resistance than the 60° cone (4-cm diameter), a correction factor of 1.5R for each R value for the entire snow depth has been calculated from empirical data to convert 30° cone readings into equivalent 60° cone readings (Abele in prep.).

The California Bearing Ratio (CBR) laboratory test, used extensively for conventional road and airport work, has also been used for snow roads.

The field version of the CBR test was performed along the edges of the snow road. The hand-driven loading jack with penetration piston was mounted on the front portion of the frame of a Tucker Sno-Cat. The SnoCat provided the necessary reaction for the loading jack, as well as a means of transport between test locations. The loading jack was removed from its mounting on the SnoCat for longer travel distances, such as from the test plots back to McMurdo.

Because of the aggressive nature of the tracks on the SnoCat, tests were limited to one edge of the Williams Field Snow Road. To prevent damage to the Snow Road, plywood sheets were laid down on the snow for the tracks to rest on. As the setup, testing and demobilizing for this test required a 30-minute cycle, it was not practical to run a large number of tests in the time available. These tests were performed only on the Delta and Snow roads and Williams Field Road test sections. The test was not used at South Pole.

The Clegg impact device was used on the Delta and Snow roads, Williams Field Road test sections and the South Pole taxiway test sections. This device has been developed to complement the CBR in road and airfield work. Compared to the CBR field test, it is much more portable and requires considerably less time to perform. In its standard form, the Clegg device measures the deceleration of a drop hammer as the hammer strikes the soil (or snow). Expressed as the Clegg Impact Value (CIV), the deceleration value increases as the strength or stiffness of the soil or snow increases. In conventional use, the CIV reported is the reading taken after the fourth successive hammer blow.

Shuttle vans and Delta vehicles normally used on the Williams Field road were diverted onto the Williams Field Road test sections. A C130 taxied with wheels down on the taxiway section. Visual observations including photographs, notes, etc., were made on all roads, airstrips, and test sections. Table 1 shows significantly higher temperature at the 30- to 50-cm depth in snow/wood sections, indicating high absorption of solar energy by sawdust. The surface cooled to ambient (Fig. 15). Note the significantly higher densities in the snow/wood sections (Fig. 16).

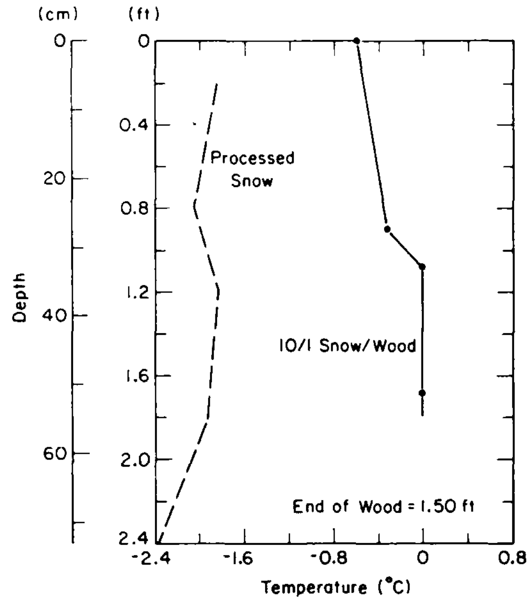


Figure 15. Williams Field Road test lane temperature profiles.

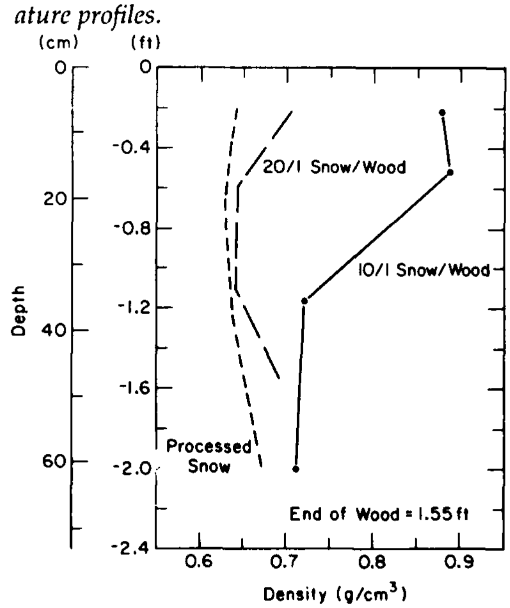


Figure 16. Williams Field Road test lane typical density profiles.

Table 1. Williams Field Road test sections—significant results.

Temperature profiles, 26 January 1987

10:1 snow/wood	−0.5°C at surface to 0.0° C at 40 cm
20:1 snow/wood	−2.2°C at surface to 0.2° C at 70 cm
Processed snow	−1.8°C at surface to −2.2°C at 70 cm
Top processed	−0.8°C at surface to −0.2°C at 70 cm

Density profiles, 26–27 January 1987

10:1 snow/wood	0.87 g/cm³ at surface to 0.71 g/cm³ at 60 cm
20:1 snow/wood	0.72 g/cm³ at surface to 0.70 g/cm³ at 50 cm
Processed snow	0.65 g/cm³ at surface to 0.67 g/cm³ at 60 cm
Top processed	0.60 g/cm³ at surface to 0.60 g/cm³ at 70 cm

Rammsonde profiles	*Average (15 days)*	*Maximum (15–45 days)*	*Predominant range (15–45 days)*
10:1 snow/wood	700	2000	800 to 1200
20:1 snow/wood	500	800	700 to 1000
Processed snow	300	1500	500 to 700

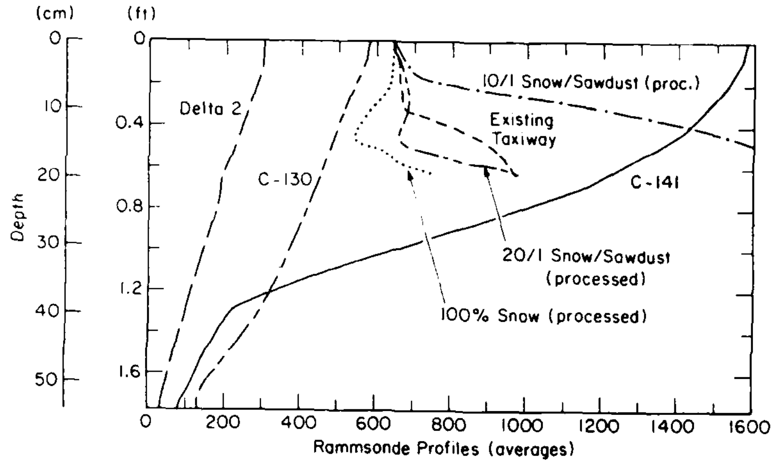


Figure 17. Williams Field Road test section Rammsonde hardness.

Note the significantly higher ram hardnesses (5- to 40-cm depths) in sections with wood additives, especially the 10:1 ratio; 0 to 5-cm depth *R* values are unreliable and are not listed. Profiles show increasing hardness with depth. Figure 17 illustrates profiles of sections compared with required profiles for the Delta vehicle* and the C130* and C141 aircraft* developed earlier by CRREL (Abele et al. 1968). The profiles indicate that all of the test sections can support the Delta 2 vehicle and the wheeled C130 aircraft. The C141 needs a harder surface layer of 15-cm thickness on the base course of 10:1 snow/sawdust. It would need a 25-cm-thick pavement layer on the 20:1 base and close to a 30-cm-thick hard layer on the processed-only snow base.

The field CBR at 0.1-in penetration (30 days) was as follows:

10:1 snow/wood	2.5 to 25.0 CBR, %
20:1 snow/wood	18.0 to 23.0 CBR, %
Processed snow	17.5 CBR, %
Top processed	1.5 to 13.0 CBR, %

Note that the highest CBR values were observed on the 10:1 snow/wood section. The second highest were on the 20:1 snow/wood test section followed by the processed snow only test section. The lowest values were on the top processed test section. The trends of the CBR tests were, therefore, consistent with the other tests. As a point of reference, crushed rock is the standard of 100% at 0.1 in penetration.

A typical CBR curve on the snow is shown in Figure 18. The field Clegg values (average) were as follows:

10:1 snow/wood	24 CIV
20:1 snow/wood	27 CIV
Processed snow	21 CIV
Top processed snow	19 CIV

Figure 19 shows the final stage of preparation of the taxiway test sections—covering the sections with pure snow to minimize the chance of sawdust being blown around the parking area. Trafficking by shuttle vans, and occasionally Delta vehicles,

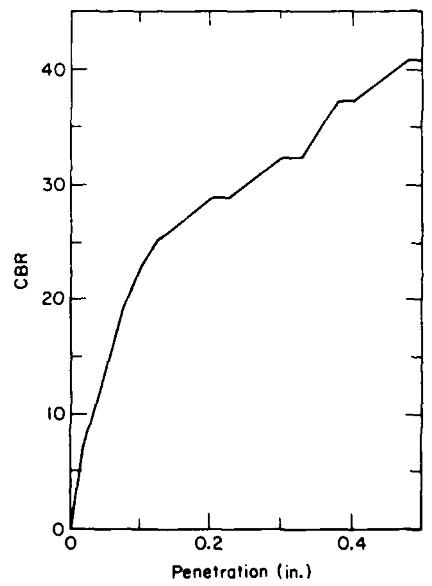


Figure 18. Williams Field Road test lane CBR test.

*The Delta vehicle has a wheel load of 11,000 lb and a tire inflation pressure of 18 psi. The C130 aircraft has a wheel load of 28,500 lb and a tire inflation pressure of 70 psi. The C141 aircraft has a wheel load of 40,000 lb and a tire inflation pressure of 150 psi.

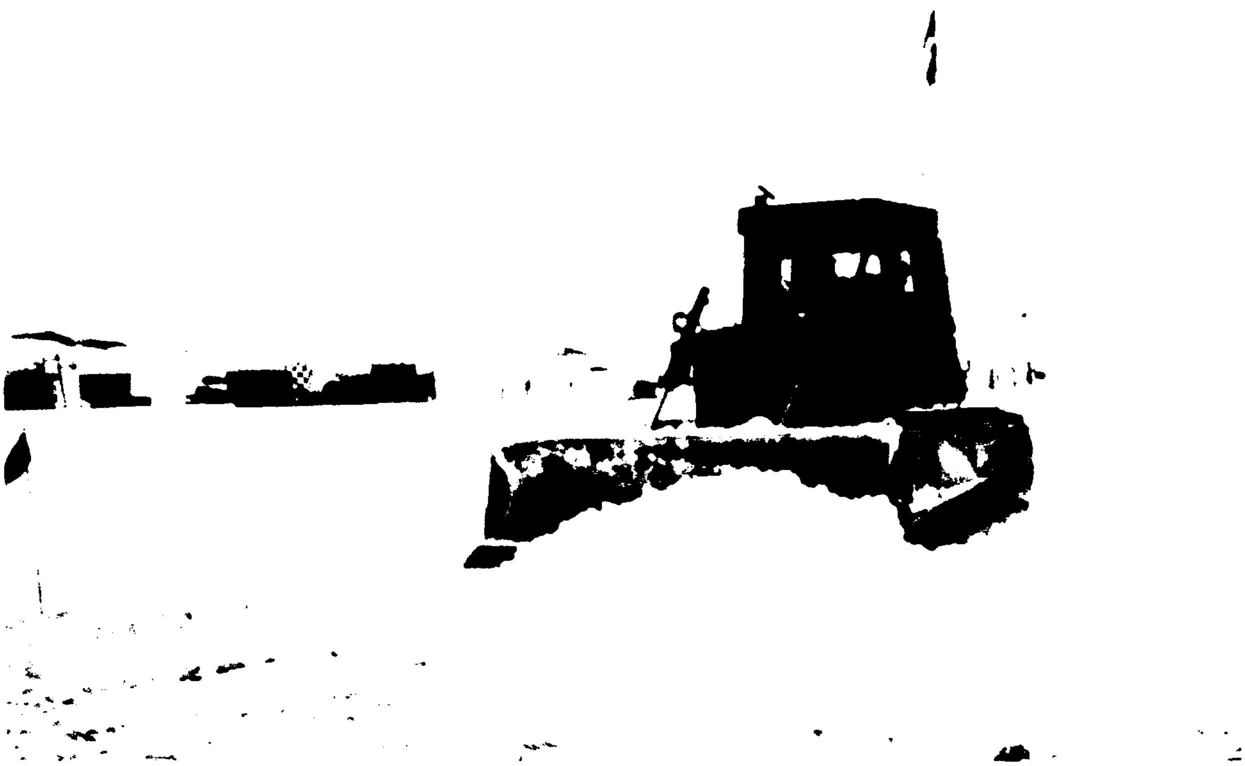


Figure 19. Williams Field taxiway sawdust test sections covered with thin layer of snow.

began on 26 December with the following results:

10:1 snow/wood	late Jan.	7- to 10-cm ruts
20:1 snow/wood	late Jan.	2- to 8-cm ruts
Processed snow	late Jan.	little rutting
Top processed	late Jan.	2- to 8-cm ruts

All test sections experienced some surface failure after 1 month of trafficking. Transition zones (made with bulldozer) began to fail after 2 days of trafficking. No base failure occurred on processed snow but sawdust sections experienced some surface rutting as a result of solar radiation and traffic. Note the higher temperatures in snow/sawdust sections although the profile or gradient is reversed from road sections (Fig. 20). Note the extremely high densities in wood sections (Fig. 21).

Table 2 shows the significantly higher ram hardnesses in the 10:1 snow/sawdust section. Profiles show increasing hardness with depth. Figure 22 illustrates profiles of test sections and required profiles for wheeled aircraft. Again, these show adequate hardness for support of Delta vehicles and the C130. The C141 would need a harder surface layer of about 25-cm thickness.

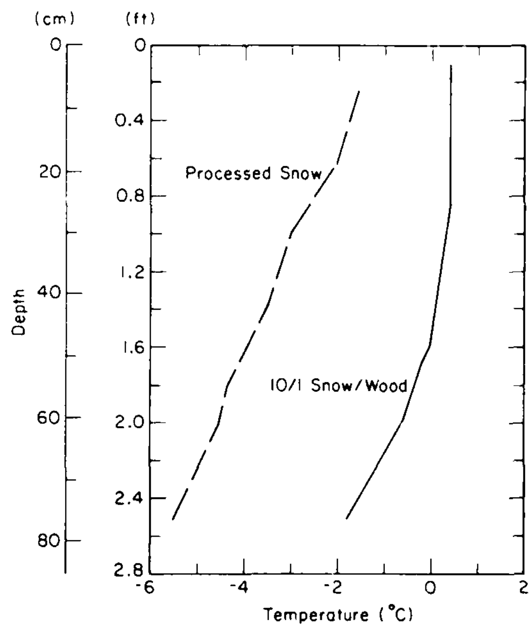


Figure 20. Williams Field taxiway test lane typical temperature profiles.

Table 2. Williams Field taxiway test sections—significant results.

Temperature profiles, 27 January 1987

10:1 snow/wood	+0.5° C at surface to −1.0° C at 70 cm
20:1 snow/wood	−0.5° C at surface to −3.0° C at 70 cm
Processed snow	−1.5° C at surface to −5.0° C at 70 cm

Density profiles, 26–27 January 1987

10:1 snow/wood	0.72 g/cm³ at surface to 0.86 g/cm³ at 40 cm
20:1 snow/wood	0.71 g/cm³ at surface to 0.65 g/cm³ at 50 cm
Processed snow	0.60 g/cm³ at surface to 0.63 g/cm³ at 50 cm

Rammsonde profiles	*Avg. (15 days)*	*Maximum (15–45 days)*	*Predominant range (5–45 days)*
10:1 snow/wood	700	1300	700 to 900
20:1 snow/wood	500	1000	600 to 800
Processed snow	300	800	500 to 700

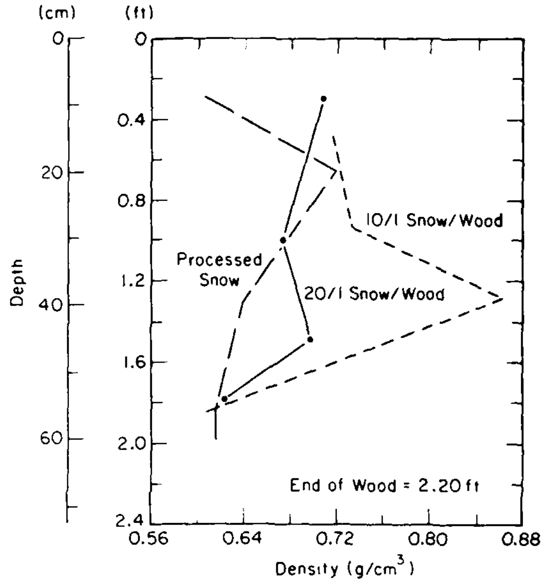


Figure 21. Williams Field taxiway test lane typical density profile.

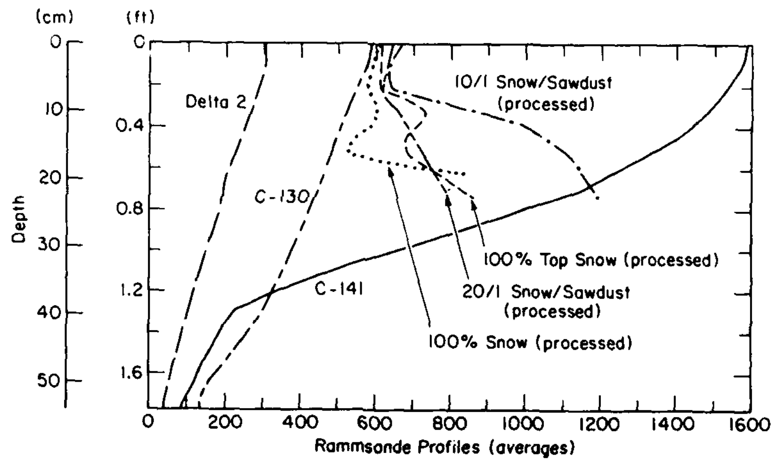
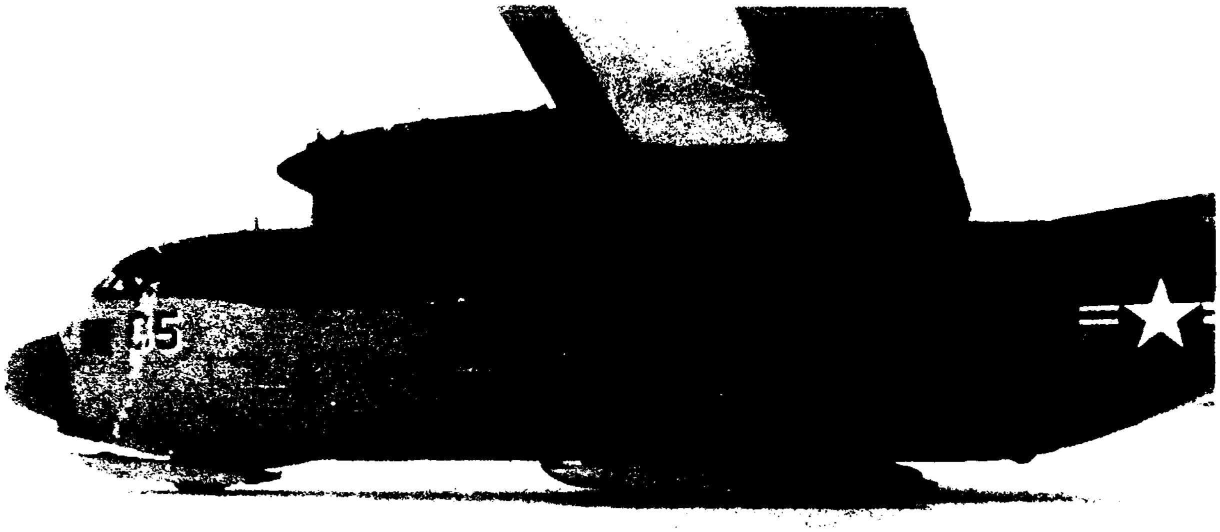


Figure 22. Williams Field taxiway test section hardness profiles.

Trafficking

To evaluate the effectiveness of the taxiway test section under conditions approximating the actual operational situation, an LC130 aircraft was used as a loading device for a field trial performed on 24 December 1986. The aircraft was taxied to the approach to the test section, utilizing the aircraft's skis, as the snow in the apron and taxiway area were not capable of supporting aircraft on wheels, even when the aircraft were not loaded. With the airplane in place on the test plot, the skis were lifted and the plane was taxied on wheels across the two test plots. The snow in the test plot showed ruts of less than about 1 cm resulting from the wheels (Fig.23). When the wheels went off the test plot, however, they created ruts 20 to 25 cm deep, and the aircraft's skis had to be used to continue taxiing. Figure 24 shows the temperature profiles at the South Pole cargo berm test sections. Table 3 shows that the South Pole cargo berm had higher values in the snow/sawdust section below 15 cm (Fig. 25). Figures 26 and 27 show, respectively, temperature and density profiles for the taxiway test sections. Figure 28 shows ram hardnesses that are nearly adequate for support for the Delta and C130. The C141 would require a 35-cm surface layer of greater hardness.



95

Table 3. South Pole test sections—significant results, 17 January 1987, 47 days after construction.

Cargo berm test sections	
Temperature profiles (see Fig. 24).	
Density profiles	
20:1 snow/wood	0.62 g/cm³ at surface to 0.66 g/cm³ at 40 cm
Processed snow	0.64 g/cm³ at surface to 0.69 g/cm³ at 40 cm
Rammsonde profiles	
20:1 snow/wood	1000 average, 800 –1500 range
Processed snow	900 average, 600–1100 range
Taxiway test sections	
Temperature profiles (see Fig. 26)	
Density profiles (Fig. 27)	
10:1 snow/wood	0.59 g/cm³ at surface to 0.55 g/cm³ at 40 cm
20:1 snow/wood	0.63 g/cm³ at surface to 0.58 g/cm³ at 40 cm
Processed snow	0.58 g/cm³ at surface to 0.58 g/cm³ at 40 cm
Rammsonde profiles (Fig. 28)	
10:1 snow/wood	715 average,500–1000 range
20:1 snow/ wood	600 average, 500–700 range
Processed snow	600 average, 550–650 range.

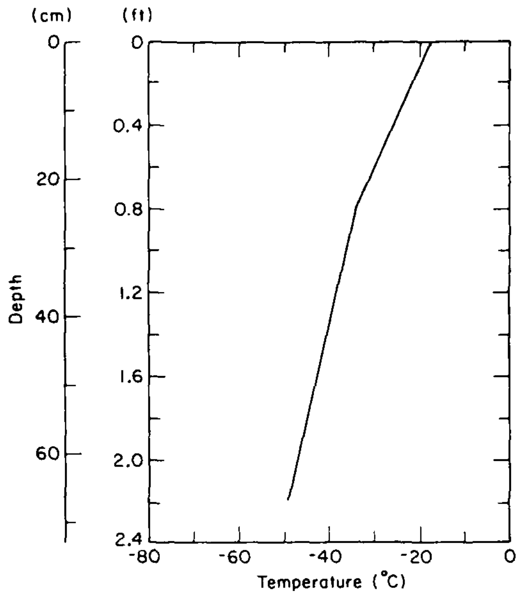


Figure 26. South Pole taxiway test section temperature profiles.

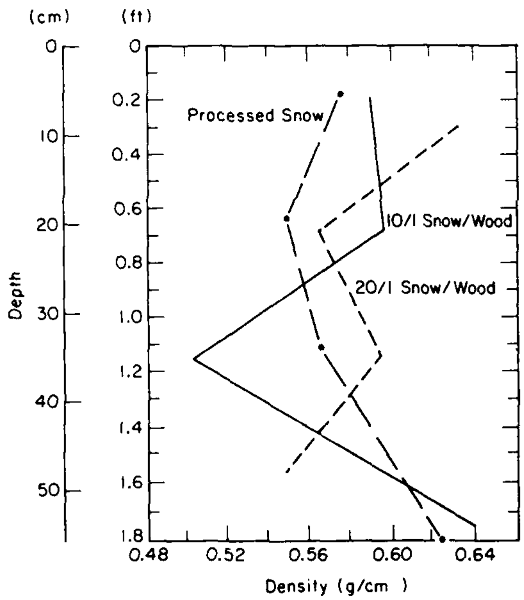


Figure 27. South Pole taxiway test lane typical density profile.

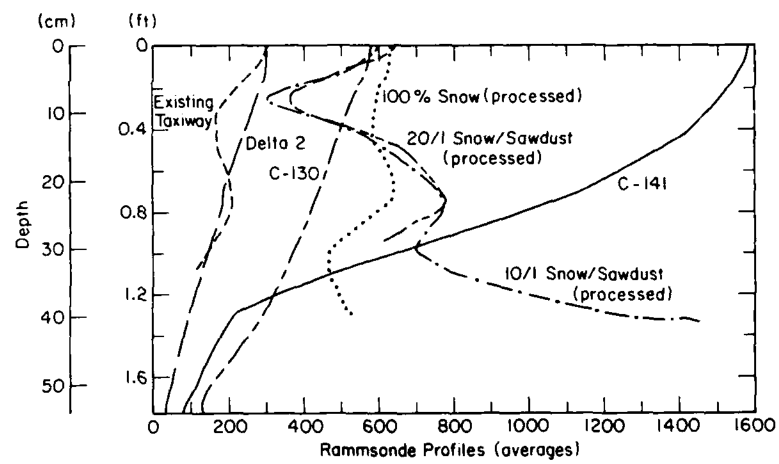


Figure 28. South Pole taxiway and test section hardness profiles.

TEST RESULTS ONE YEAR LATER

During January 1988, a visit was made to Antarctica to examine the state of the test plots at McMurdo and South Pole stations that were established a year earlier. The objective was to take Rammsonde data and examine the core samples from the test lanes to determine what changes, if any, had occurred during the winter season.

McMurdo

Williams Field taxiway

The test sections at the taxiway had approximately 60 cm of snowdrift over the top layer of the previous year's snow surface. The drift condition was worse at this location than at other nearby sites due to its proximity to the Williams Field buildings. It was decided that no useful data could be obtained from these test sections.

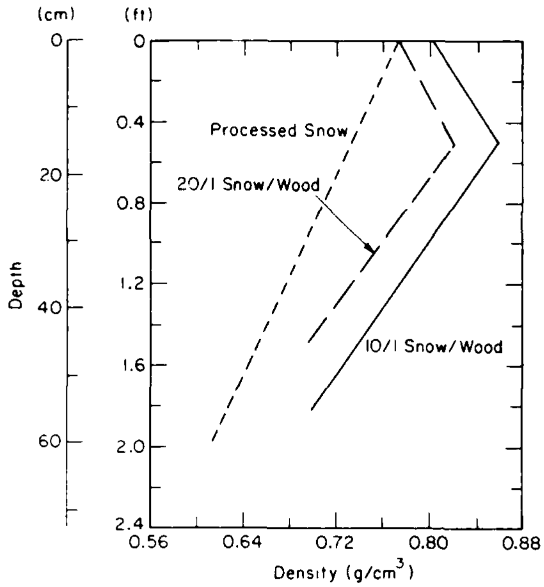


Figure 29. Williams Field Road test lane—one year later (density).

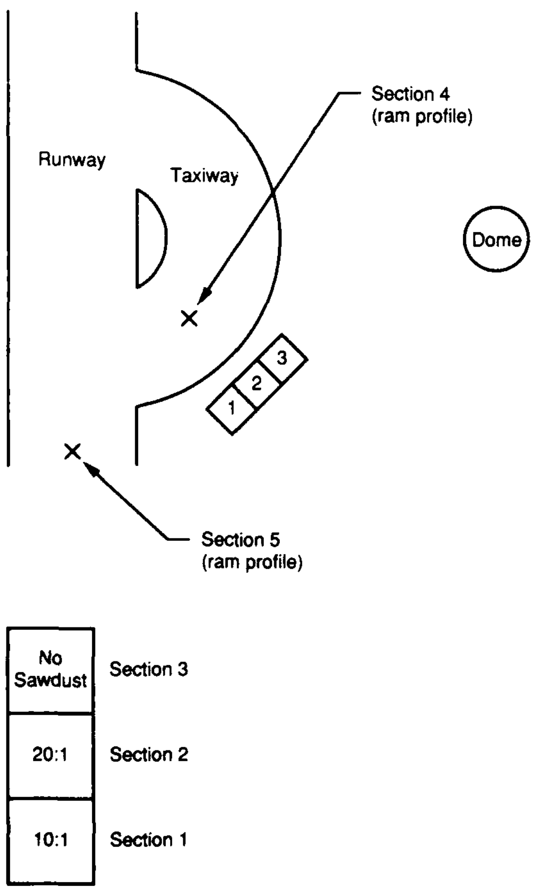


Figure 30. South Pole taxiway test sections.

Snow road

The test sections along the McMurdo-Williams Field snow road (Fig. 13) had approximately 15 cm of snowdrift over the top layer. However, it was relatively easy to identify the top layer of the previous year's surface. It was observed that in sections 2, 3, and 4, which had been processed in 15- cm lifts, the snow had hardened considerably during the winter. The extreme hardness made it impossible to take the Rammsonde data. Examination of the core samples showed that, at several depths, the snow was at a density similar to that of ice. The fourth section, which was processed only at the surface, did not show the same level of hardness or density. The data values from this test plot are shown in Figure 29.

South Pole

Taxiway

The test sections at the South Pole Station taxiway (Fig. 30) showed similar phenomena as those at the McMurdo (Williams Field Road) test sections, although the hardness was lower than that at McMurdo. This probably was the result of the much colder climate at South Pole. Another contributing factor was that the processing of snow was not as efficient at South Pole as at McMurdo due to the equipment problem. The core samples showed clearly the uneven processing and mixing of the snow which resulted in a similarly uneven hardness at a depth of approximately 24 cm. The data taken from this test plot are shown in Figures 31 and 32.

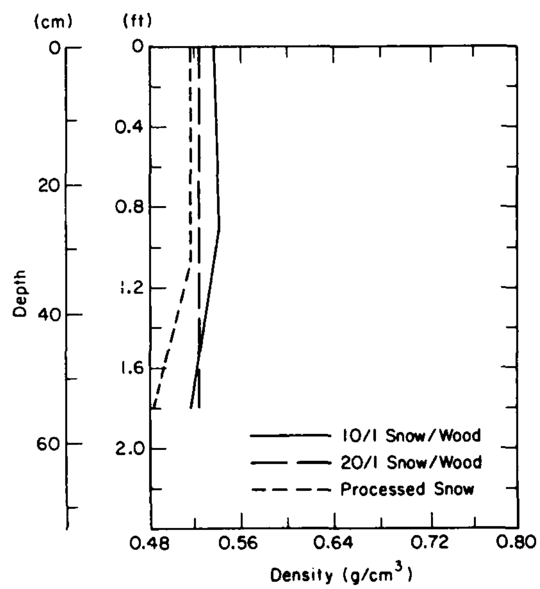


Figure 31. South Pole taxiway test sections—one year later (density).

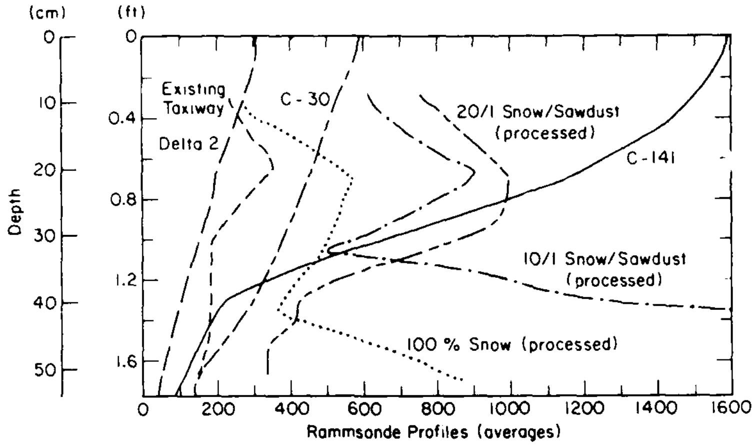


Figure 32. South Pole taxiway and test sections—one year later (Rammsonde profiles).

Cargo berm

The test sections at this location were completely obliterated by the continuous snow removal activities in that vicinity. It was decided that no useful data could be obtained from this test plot.

OBSERVATIONS ON TRANSITION AREA

Observations were made throughout the season on the transition zone between the built-up gravel road and the Delta/Snow roads on the ice shelf near Scott Base at McMurdo. This area is subject to severe degradation problems and subsequent heavy maintenance efforts during the austral summer, usually beginning in early December and continuing through late January. The major problem is that of accelerated thawing due to a low albedo surface (dirty snow) and subsequent water drainage across the road. These factors cause vehicles to become mired in soft snow, slush and mud. Frequent maintenance by blading in surrounding clean snow and opening drainage channels with a bulldozer is required. Another problem, which occurs only during some years, is the excessive movement of the perennial ice, causing ridging and breakup of the ice in the proximity of the road. This can cause catastrophic failure of the roads in this area and has required relocation of the roads in the past.

The problem of excessive thawing and poor drainage, however, can be alleviated considerably by providing better drainage. Although no testing has been done, it is believed that by using geotextile membranes and constructing a swale or ditch to intercept the widespread sheet-flow from the slope, much of the problem can be solved. The water should be directed into culverts beneath the road. These culverts should have heating pipes permanently installed to open them whenever necessary. The use of propane pipe heaters or a steam generator should be adequate for reopening the culverts.

CONCLUSIONS

Wood sawdust or small wood chips used as additives are significantly effective in increasing density and strength or hardness of processed snow roads and runways. These wood additives used in concentrations of 5% to 10% by volume and mixed well into the snow, while processing or disaggregating the snow, will produce a road or airstrip of higher strength than would result from processing the snow only. The strengthening effect is greater at McMurdo than at South Pole. It appears that the sawdust is more effective as a binder material at higher ambient and snow temperatures especially when direct solar radiation can bring the snow/wood mixture to or close to the melting point. This conclusion is supported by the higher temperature and density profiles of the wood/snow mixtures, resulting in extremely high hardness values. However, it is also evident that while strengths are significantly higher at some depth, the surface strength is not sufficient to support C141 wheeled aircraft. This conclusion is also supported by the CBR, Clegg, and traffic tests. Ram hardness profiles show that strengths of a processed snow layer with wood additives, and in many cases only processed and compacted snow, are adequate for support of the Delta 2 and the C130. However, it must be noted that while the profiles show adequate strength for a C130 wheel load based on required profiles for 2 wheel coverings (tandem landing gear) (Abele et al. 1968), frequent use would require a stronger surface. The CBR, Clegg and ram hardness profiles all indicate that the top 25 cm is deficient in strength and would result in surface failure with aircraft such as the C-141. Therefore, additional processing of the top layer would be required, most likely by addition of heat or water or possibly by greater surface compaction. The reduced strengths in the top 25 cm were observed on all test plots at both the South Pole and McMurdo, and are probably due to the solar radiation. This effect was augmented at McMurdo by the substantially higher temperatures, which brought the upper sections to the melting point. This would also explain the deeper ruts on the sections with sawdust, since the sawdust absorbed more radiation. However, below this 25-cm layer, the snow/sawdust sections continued to exhibit substantially higher strengths. Therefore, the base courses constructed of wood sawdust mixed with snow were considerably stronger than processed and compacted snow base courses.

The absorption of solar radiation by the sawdust-treated test sections at McMurdo, especially the Williams Field Road test lanes, resulted in sublimation of the snow at the surface, thus tending to concentrate the sawdust. This phenomenon was not uniform in its intensity. As a consequence, this ablation of the surface resulted in a rougher riding roadway surface than expected. It should be thoroughly understood, however, that the remaining sawdust-treated snow had more than sufficient strength and resistance to traffic. Therefore, thought should be given to surface maintenance during this limited period of a few days to bring the road back to acceptable smoothness.

The laboratory tests helped to confirm the field evaluations that sawdust can significantly increase snow strength. However, the field evaluations indicated a greater benefit due to sawdust additive than did the laboratory tests. In addition, the field tests indicated that sufficient time to increase strength by sintering is needed, particularly at the South Pole where temperatures remain quite low.

Construction effort and time could be reduced greatly by using a large rotary snow blower or processor to simultaneously process and mix the snow/sawdust materials rather than the small driveway-type rotary blower.

In regard to the Snow and Delta roads to Williams Field, the test results with Rammsonde, CBR and Clegg indices indicate that only the very surface of the roads was being maintained by trafficking with the Delta vehicle towing a drag. The maintenance had little to no effect at a depth of 15 to 65 cm, where the snow was relatively soft. The original preparation of the base course was not adequate. A layer of snow 60 to 90 cm thick should be depth-processed with a rotary miller or blower and compacted with tractor and roller to a density of 0.55 g/cm^3. After allowing a hardening time of two to three weeks, the road should be able to accommodate the shuttle and Delta traffic throughout the season with far less maintenance.

In regard to the transition area near Scott Base, which deteriorates seriously throughout the warmer season, the most serious problem is that of drainage. This may be aided by the use of geotextile fabrics or membranes to divert and channel water from the slope into culverts, which can be kept open with heating tubes. Sawdust does not appear to be a solution; however, it has not been tried at this location.

RECOMMENDATIONS

It is recommended that additional work be performed on additives such as sawdust on a larger scale. Larger test lanes should be constructed with large rotary millers to assess the feasibility of constructing an entire road or runway in a reasonable time. Also the present studies were not able to incorporate the taxiing of a heavy aircraft with wheels down, except for one short test at Williams Field. This test showed much promise and indicates that larger scale loading tests should be incorporated in future programs. These wheel tests should be done at both McMurdo and South Pole.

It is strongly recommended that work be started on developing the technology necessary to further strengthen the surface layer of a processed snow or snow/sawdust base course to accommodate the C141 aircraft as well as the C130 for safe operation. Three types of processing should be investigated: heat, water injection, and confined-impact or vibratory compaction. Present studies indicate that this type of processing is needed for only the top 25 cm of a cold, dry processed base course in order to land wheeled C141 and other similar large aircraft. This type of study would also indicate whether or not an additive such as sawdust is really needed for the base course. Depth processing the snow with a snow miller, in combination with water or heat injection (or dynamic compaction of the top layer), may be adequate.

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