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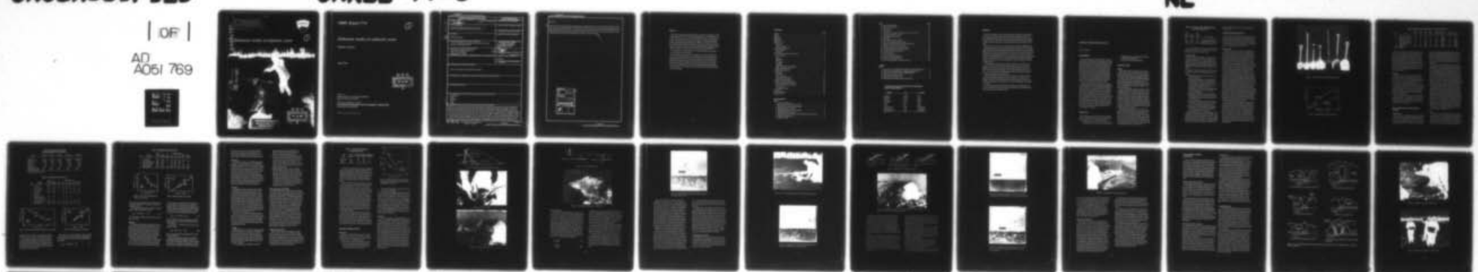

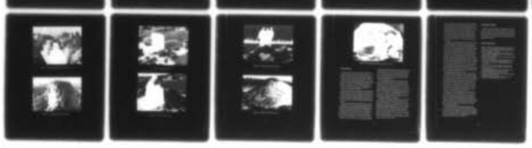

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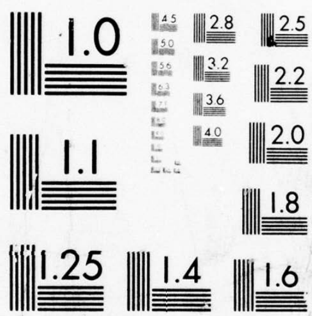

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REPORT 77-6

Defensive works of subarctic snow

CRREL Report 77-6

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Defensive works of subarctic snow

Philip R. Johnson

April 1977

Prepared for
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It has been reported that small arms projectiles are inherently unstable in snow and that snow has an unexpectedly high ability to stop them and other fast-moving projectiles. Field tests at Fort Wainwright, Alaska, carried out in March-April 1975 showed that the typical subarctic snow of interior Alaska can be used effectively to provide protection from both rifle and machine gun fire. The undisturbed snow had an average density of 0.18 g/cm^3, but simple processing, such as shoveling, increased the density to around 0.34 g/cm^3. Further processing increased the density to above 0.40 g/cm^3 but densities much above that value were difficult to obtain with simple hand equipment. Tests of the M16 rifle and M60 and M2HB machine guns showed that bullet penetration was inversely related to density – the higher the density the lower the bullet penetration. Design values for the three weapons were determined.

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A number of types of snow trenches and structures were designed and tested. They were found to provide good protection, in part since bullets showed a strong tendency to ricochet from the snow surface when striking it at a low angle. Burlap bags were filled with snow to revet structures and worked very well. Several types of Russian defensive works of snow were tested but proved unsuitable in the light, weak subarctic snow. The times required for troops to build several types of structures using only shovels and scoops were recorded.

PREFACE

This report was prepared by Philip R. Johnson, Research Civil Engineer, of the Alaskan Projects Office, U.S. Army Cold Regions Research and Engineering Laboratory. The work was carried out under the direction and with the assistance of Dr. George K. Swinzow, Geologist, of the Construction Engineering Research Branch, Experimental Engineering Division, CRREL. It was funded by DA Project 4A762730AT42, *Design, Construction and Operations Technology for Cold Regions,* Task A1, *Ice and Snow Technology,* Work Unit 005, *Construction Techniques for Expedient Protective Structures Using Cold Regions Materials.*

George Aitken, Dr. George Swinzow, and Dr. Malcolm Mellor technically reviewed the manuscript of this report.

Col. W.L. Martin, Commander, Fort Wainwright, and several organizations under his command provided support and assistance for the project field work during March and April 1975. C Troop, 5th Squadron, 297th Cavalry of the Alaska National Guard at Fairbanks, Alaska, supplied and fired the .50 caliber machine gun, making it possible to include heavy machine guns in this study. George Aitken and Dennis Farrell assisted in the final preparation and publication of this report. The assistance of these organizations and individuals is gratefully acknowledged.

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ILLUSTRATIONS

TABLES

CONVERSION FACTORS: METRIC TO U.S. CUSTOMARY UNITS OF MEASUREMENT

Multiply	*By*	*To obtain*
millimeter	0.0393	inch
centimeter	0.393	inch
kilogram	2.20	pound
centimeter^2	0.155	inch^2
meter^3	35.3	foot^3
gram	15.4	grain
meter/second	3.28	foot/second
kilogram-meter	7.23	foot-pound
gram/centimeter^3	6.24	pound/foot^3

SUMMARY

Snow has a promising role in constructing hasty and deliberate winter defensive positions in the subarctic areas of Alaska and Canada and adjacent areas to the south. Bullets generally tumble after entering snow and their total travel distance is greatly reduced – apparently because the tumbling bullet presents an increased frontal area. Bullets also tend to ricochet from the snow when striking it at a low angle.

Bullet penetration distances for the M16 rifle and the M60 and M2HB (.50 caliber) machine guns were studied in undisturbed and processed snow at Fort Wainwright, Alaska, and mean and design maximum penetration values were determined. Bullet penetration was inversely related to snow density, and methods of increasing the density of the very light subarctic snow were tested. A number of defensive positions were designed and built of snow and field tested under fire; they effectively resisted the above weapons. It was concluded that hasty and deliberate defensive positions could be built of snow in the Subarctic to protect troops from rifle and machine gun fire.

Very simple but effective snow trenches can be built in a few minutes and provide protection from low angle rifle and machine gun fire. More elaborate positions can be built by two men in an hour or less with shovels and scoops. Revetting is necessary and snow bags – large burlap bags filled with snow at the site – are easy to use and work satisfactorily. They are an obvious and logical extension of existing sand bag technology.

Russian technology was tested in the field. Their snow trenches and other positions were apparently designed for areas with dense snow subject to wind packing. They used near-vertical walls for excavations and snow blocks to revet and build up positions. Such methods do not work well with light and weak subarctic snow.

A simple igloo-like shelter was built by hollowing out a shoveled snow pile. Such a structure has most of the thermal characteristics of the true Eskimo igloo and may be useful as an expedient shelter.

DEFENSIVE WORKS OF SUBARCTIC SNOW

by

Philip R. Johnson

BACKGROUND

Snow is recognized as an effective winter fortification material. Various U.S. Army publications, including Training Film 5-2372 (U.S. Army 1956) and Field Manual 5-15 (U.S. Army 1972) point out that snow can provide protection from both the elements and hostile fire. These sources show that small arms fire penetration varies from 4 m in newly fallen snow to 0.3 m in icecrete (frozen water and soil). Swinzow (1972) pointed out that most countries with armies in temperate and cold regions instruct their soldiers to use snow as a shelter and expedient fortification material, and he reproduced drawings of expedient snow trenches selected from Russian manuals.

Swinzow (1970) observed that snow has an unexpectedly high ability to stop fast-moving projectiles and reported (Swinzow 1972) that bullets are inherently unstable in snow and often tumble. He reported that snow density is the principal parameter controlling penetration and suggested that "normalized energy," kinetic energy divided by cross-sectional area, determines projectile performance in snow. Schaefer (1975) conducted field tests of snow as a fortification material at Fort Wainwright, Alaska, during the late winter and spring of 1973. He conducted further field tests during the same period of 1974 at both Fort Richardson and Fort Wainwright, Alaska. His field notes were available to the author.

OBJECTIVES

Field studies were carried out on the machine gun range at Fort Wainwright, Alaska, between late February and mid-April 1975. The objectives were to:

1. Obtain data on manpower effectiveness in constructing deliberate and hasty snow fortifications.
2. Establish the degree of protection offered by elementary snow structures.
3. Verify or refute foreign technology.

SUBARCTIC SNOW

General

The subarctic region in this report is the zone of sparse to medium spruce and birch forest in Alaska and Canada lying north of the heavy temperate forest and south of the treeless Arctic (Johnson and Hartman 1969). Interior Alaska, including the Fairbanks area, is typically subarctic. During the winter a semipermanent high pressure system lies over the area. Due to this stable system, the high latitude and strong winter radiational cooling, the winter climate is of a cold continental type.

Snow in the Subarctic reflects the climate. It is normally light and dry when it falls and, because of low winds and forest cover, tends to remain in place until it melts in the spring. The initial density of the snow is very low, and since it is seldom subjected to wind packing or midwinter thawing, its density remains low throughout the winter. Steep temperature gradients drive recrystallization processes which convert the lower layers to a poorly bonded, large-crystal form known as depth hoar. Such snow is extremely weak and will collapse if shocked or loaded.

Table I shows the characteristics of the snow at the Fort Wainwright machine gun range during March-April 1975. Eight centimeters of loose fluffy snow lay on top of 22 cm of somewhat deeper snow underlain by 36 cm of depth hoar. The center layer, while weak, exhibited some strength and would almost support skis or snowshoes. However, the depth hoar layer would collapse when the center layer was loaded, with the result that the entire system would fail.

Table I. Snow density, Fort Wainwright machine gun range, 26 March 1975.

Ht above ground (cm)	*Density (g/cm^3)*	*Water content (cm)*	*Type/comments*
58-66	0.158	1.19	Fine-grained, light and fluffy.
36-58	0.192	4.39	Medium-grained, low strength.
0-36	0.178	6.32	Depth hoar. No strength.

The average density of the three layers of the snow was 0.18 g/cm^3 and the total water content 11.90 cm. There were no ice layers or wind crusts.

Snow processing

Swinzow (1972) and Schaefer (1975) report that total bullet penetration in snow is principally controlled by snow density – increased density reduces bullet penetration. Any disturbance of the snow increases its density as the disturbance breaks intercrystalline bonds and allows the crystals to pack more closely.

A number of methods of processing the snow were used. The processes and resulting densities were as follows:

1. Shoveling the snow increased its density from 0.18 to 0.34 g/cm^3.
2. Driving a snowmobile over it increased the average density to 0.30 g/cm^3 while packing it from 66 to 40 cm. The packed snow had a density gradient ranging from 0.27 g/cm^3 near the ground to 0.38 g/cm^3 at the top.
3. Shoveling snow, which had been knocked down with the snowmobile, into a pile increased density to 0.40 g/cm^3.
4. Running undisturbed snow through a small snowblower increased its density to 0.40 g/cm^3. Shoveling this into a pile increased density further to 0.44 g/cm^3.
5. Continuously tramping snow as it was being shoveled into a pile increased density to 0.46 g/cm^3. This required a great deal of work.
6. Shoveling snow into burlap bags, and shaking them down so that they could be well filled, gave densities of 0.40 to 0.42 g/cm^3.

It was concluded that any simple treatment, such as shoveling snow or packing it with a snowmobile, will increase the density of typical subarctic snow to values on the order of 0.30 to 0.34 g/cm^3. A second processing will further increase the density and values of 0.40 g/cm^3 can be obtained. Densities much above 0.40 g/cm^3 are difficult to reach with simple equipment and hand labor.

CONSTRUCTION PRODUCTIVITY

One objective of the study was to measure troop productivity and the time required to build simple snow structures with the equipment and supplies that troops in the field might have or easily obtain. In the absence of heavy equipment such as bulldozers, such equipment consists primarily of shovels and scoops.

Shovel capacity

A shovel will carry loose granular material such as loose snow crystals both *in* the shovel (contained by the ends and sides) and *on* the shovel (piled above its sides). The quantity *on* the shovel varies with the size, shape and angle of repose of the material as it is subjected to the acceleration forces resulting from the shoveling action. If the shape of the shovel remains constant, the total shovel volume varies as the $^3/_2$ power of the shovel area. A round shovel will carry more than a square one of the same area. A square shovel will carry more than a rectangular one of the same area. The greater the angle of repose the greater the volume.

The scoops and shovels shown in Figure 1 were tested to determine their capacity in undisturbed snow and berm snow. The undisturbed snow at the test site was similar to that at the Fort Wainwright machine gun range with a slightly higher density of 0.21 g/cm^3. It shattered into loose crystals when disturbed. The berm was of snow that had been plowed to the side of a road during the winter and had not been disturbed since. The berm snow had an average density of 0.36 g/cm^3 and a depth-hoar structure, and most of it also shattered into loose crystals when handled (although a few chunks persisted). For each test a number of shovel loads were shoveled into a container and the average weight determined. The volume was calculated from the average weight and the density of the snow. Shovel dimensions and productivity are shown in Table II.

The average shovel load weights are plotted against shovel area to the $^3/_2$ power in Figure 2. While the shovels had different shapes and depths and were used by different persons, the load follows the $^3/_2$ power fairly well for each type of snow. Productivity in the berm snow was about twice that in the undisturbed snow. A significant exception to the general rule is that the large steel scoop (shovel 7) falls well below the trend in the denser and heavier berm snow. In this case the scoop would hold more snow than a person could comfortably handle so that the shoveler did not take full loads.

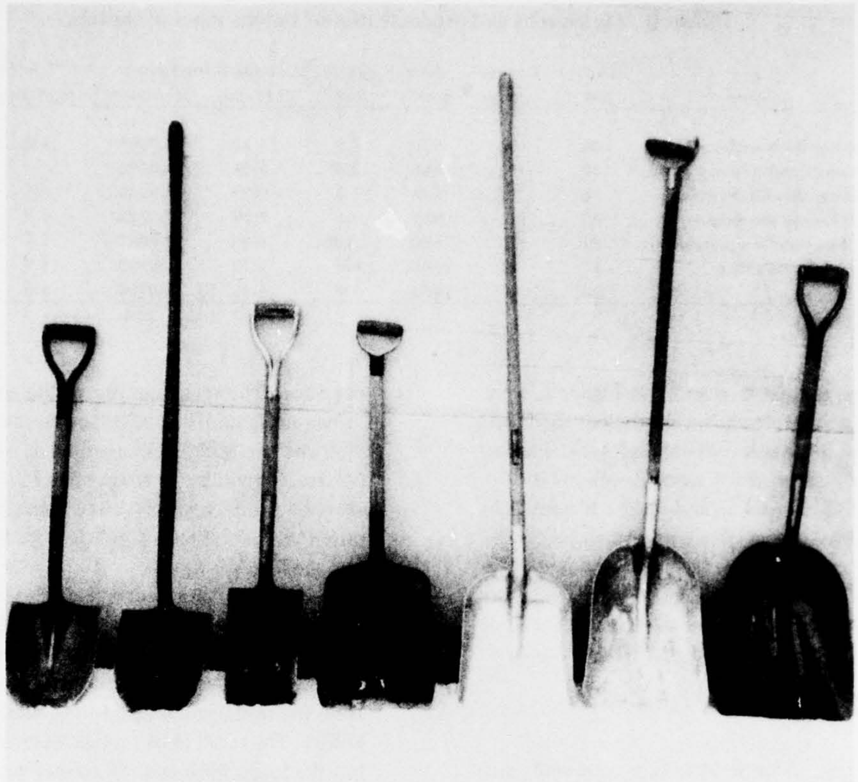


Figure 1. Types of shovels used (1-7 from left to right).

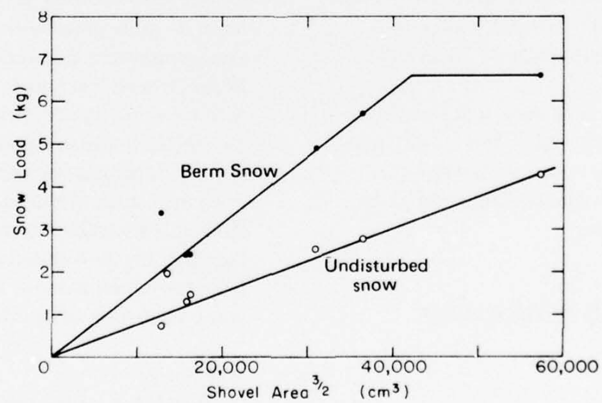


Figure 2. Average shovel load vs (shovel area)$^{3/2}$.

Table II. Dimensions and productivities of various types of shovels.

Shovel	Type	Width (cm)	Length (cm)	Area (cm^2)	Depth (cm)	Undisturbed snow (kg/load)	Undisturbed snow (m^3/load*)	Berm snow (kg/load)	Berm snow (m^3/load*)
1	D-handle round point	24	30	630	2.5	1.33	0.0064	2.4	0.0067
2	Long handle round point	22	30	568	2.5	2.01	0.0096	–	–
3	D-handle square point	18	30	548	1.3	0.73	0.0035	3.4	0.0093
4	D-handle square point	27	37	987	3.8	2.54	0.0122	4.9	0.0136
5	Long handle square point	23	28	640	3.8	1.45	0.0068	2.4	0.0068
6	Aluminum scoop	27	43	1100	6.3	2.79	0.0133	5.7	0.0190
7	Steel scoop	36	43	1485	7.6	4.27	0.0204	6.6	0.0184

*Before shoveling.

The two large shovels, 6 and 7 in Figure 1, were large enough to effectively shovel undisturbed snow, but they were too weak to break out packed snow. The ruggedly built shovel 4 worked well in hard-packed snow. Shovels 1, 2 and 3 were too small to be effective while shovel 5 was too small for undisturbed snow and too weak for packed snow. Snow work in the Subarctic can be carried out using two types of shovels, a large scoop similar to 7 for undisturbed snow and a strong sharp shovel similar to 4 for hard-packed snow.

Snow piles

Various types of snow structures were built during the study and the time required for their construction is noted in the sections describing the structures. However, several piles of snow were built by the troops to measure general productivity.

One pile was built by shoveling undisturbed snow into a pile with a volume of 7.41 m^3 and a calculated weight of 2550 kg. The troops took turns, with only two men shoveling at a time. The pile was built in 40 minutes, giving a production rate of 32 kg and 0.09 m^3 per man-minute.

A second pile was built with snow that had been knocked down with a snowmobile. This 3.1-m^3 pile was built by two men in 20 minutes. It weighed a calculated 1240 kg. The production rate was 31 kg and 0.08 m^3 per man-minute.

BULLET BEHAVIOR AND PENETRATION IN SNOW

Test procedure

Three weapons, the M16 automatic rifle, the M60 machine gun and the M2HB .50 caliber machine gun, were used to test bullet penetration in snow. They were fired into undisturbed snow and into snow piles constructed by different methods to secure different densities. The specifications of the ammunition are shown in Table III. The linked ammunition for the M60 and the M2HB had a sequence of four ball and one tracer rounds. In some cases the tracers were removed so that only ball rounds were fired, but in other cases the tracers were also fired and tabulated separately.

In each test a number of rounds were fired into the vertical face of a snow pile or undisturbed snow, and the snow was then excavated to locate the bullets. The total penetration of each bullet was measured from the initial snow face to the final position of the bullet. The small M16 rounds were difficult to locate but the larger M60 and .50 caliber rounds were relatively easy to find. Several of the troops working on the project became extremely proficient in finding bullets in the snow. Success in finding bullets increased as the snow density increased, since the bullet did not penetrate as far and had less opportunity to scatter.

The density of each target was measured with the CRREL snow density kit using standard procedures. Since all snow piles showed some density variation, average values in the area of bullet travel were used. Hardness tests were made but hardness varied greatly with time and location within a snow pile and proved impossible to use as a parameter. Hardness was often greatest at or near the exterior surface, dropping toward the center of the pile. In a few cases firing the M60 and .50 caliber machine guns into a snow pile densified the core material which then settled away from the harder exterior shell. These cases are noted in the discussion of individual tests.

M16

The M16 is a light rifle which will fire in either a semi-automatic or fully automatic mode. Single shots were generally fired to avoid interference between successive rounds. Table IV shows the type of snow treatment, the number of bullets fired and found, the snow density and age, and the range of penetration.

Table III. Ammunition specifications (from AMCP 700-3-2, U.S. Army 1967).

Weapon	*M16 rifle*	*M60 MG*	*M60 MG*	*M2HB MG*	*M2HB MG*
Caliber, mm	5.56	7.62	7.62	12.7 (.50 cal)	12.7 (.50 cal)
Designation, type	M193 ball	M80 ball	M62 tracer	M33 ball	M17 tracer
Bullet wt, g	3.63	9.66	9.46	42.87	41.67
Jacket wt, g	1.13	3.37	4.24	15.23	29.16
Slug wt, g	2.17	6.29	4.67	25.92	13.41
Propellant wt, g	1.65	2.98	2.98	15.23	14.58
Muzzle velocity, m/s	991	838	807	887	872
Muzzle energy,* kg-m	182	346	314	1729	1617

*Calculated from the above data.

Table IV. M16 bullet penetration in snow.

Test	*Snow treatment*	*Fired/ found (no.)*	*Density (g/cm³)*	*Age (days)*	*Penetration (cm) Min*	*Max*	*Mean*	*Std dev*	*Coeff. var. (%)*
1	Undisturbed	Unk/7	0.18	30+	163	188	172	11.4	9.7
2	Piled w/shovels	10/9	0.33	7	84	94	89	3.3	3.7
3	Piled w/shovels	10/4	0.34	7	76	81	79	2.5	3.2
4	Packed, then shoveled	10/9	0.40	7	48	66	61	6.4	10.4
5	Piled after going through a snowblower	10/3	0.42	1	53	61	58	–	–
6	Tramped while piled	10/6	0.46	0.25	53	69	61	6.4	9.5
7	Piled w/shovels	10/7	0.35	1	84	112	102	9.7	9.5

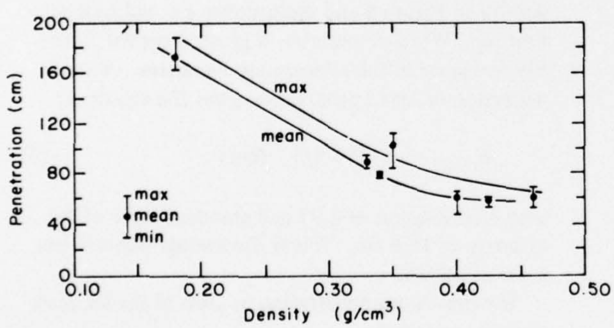


Figure 3. M16 (5.56 mm) bullet penetration vs snow density.

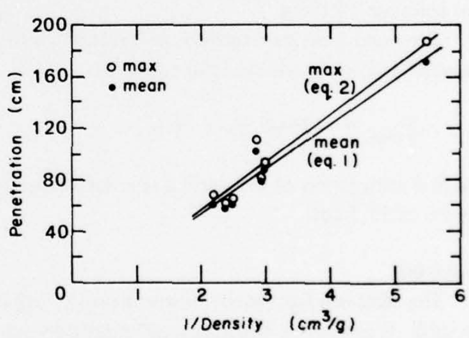


Figure 4. M16 penetration vs 1/density.

The coefficient of variation, the standard deviation divided by the mean, relates scatter to distance traveled.

The minimum, mean and extreme penetrations for each test are plotted against snow density in Figure 3. The relationship is curvilinear with penetration decreasing as density increases. The data are generally consistent, but test 7 penetrations were, for some reason not known, greater than the pattern.

When penetration is plotted against 1/density (Fig. 4) the data fall into a relatively straight line, suggesting that this relationship can be used. A linear regression gives the equation:

$$P_{mean} = -20 + 35.8/\rho \quad \text{(cm)} \qquad (1)$$

Table V. M60 bullet penetration in snow.

Test	Snow treatment	Fired/found (no.)	Density (g/cm³)	Age (days)	Penetration (cm) Min	Max	Mean	Std dev	Coeff. var. (%)
1	Undisturbed	15/6	0.18	30+	310	361	343	18.5	5.4
2	Piled w/shovels	10/5	0.33	8	114	137	130	9.4	7.3
3	Packed, then shoveled	10/3	0.40	8	127	132	132	–	–
4	Piled and tramped	41/44	0.46	1	84	125	107	9.4	8.7
5	Piled w/shovels	10/8	0.35	2	132	163	152	9.7	6.3
6	Piled w/shovels	40/9	0.34	0.25	104	191	130	29.7	22.9

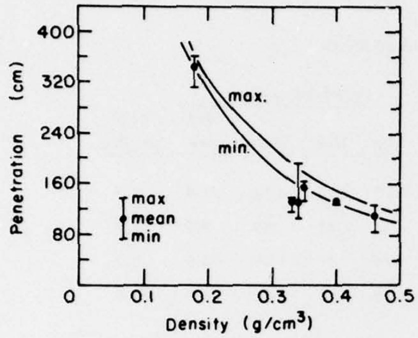


Figure 5. M60 (7.62 mm) bullet penetration vs snow density.

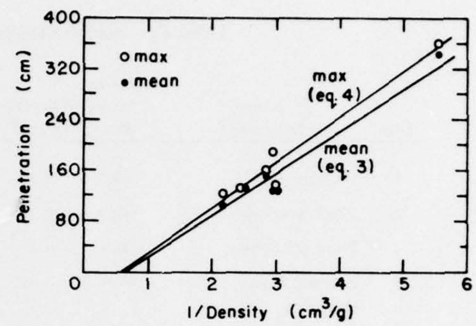


Figure 6. M60 penetration vs 1/density.

where P_{mean} is mean penetration and ρ density. The correlation coefficient is 0.95 and the standard error of estimate 12.0 cm.

The maximum penetrations in Table IV, also fitted against 1/density, yielded the equation:

$$P_{max} = -42+44.5/\rho \quad \text{(cm)} \qquad (2)$$

with a correlation of 0.96 and a standard error of estimate of 33.5 cm.

M60 ball

The M60 is a light machine gun firing a 7.62-mm round. It cannot be fired semi-automatically, so most firing was in short bursts of 2-3 rounds. It was fired the day following the M16 tests and, in most cases, at the same snow targets. Tracers were removed for all tests except test 4. Table V shows test number, snow treatment, rounds fired and found, snow density and age, and penetration data for the M60.

In most tests the weapon was fired at a close range of 4.5 m, except test 5 which was at 45 m and test 6 at 25 m. Test 6, fired at a snow pile that had little time to set up, shows the greatest scatter, indicating that the setting up process affects the uniformity of bullet penetration. Penetration is plotted against density in Figure 5 and again shows a curvilinear relationship. When penetration is plotted against 1/density in Figure 6, the relationship linearizes. A linear regression of mean penetration gives the equation:

$$P_{mean} = -61+71.4/\rho \quad \text{(cm)} \qquad (3)$$

with a correlation of 0.97 and standard error of the estimate of 19.8 cm. This is the average penetration to be expected.

The maximum penetration of each of the six tests gives the equatio[illegible]

$$P_{max} = -44+7[illegible].9/\rho \quad \text{(cm)} \qquad (4)$$

with a correlation of 0.97 and standard error of the estimate of 22.6 cm.

Atypical bullet behavior (not shown in Table V) was observed when firing the M60 at a pile of snow that had been tramped while piled to achieve a density of 0.46 g/cm³. Firing was conducted the day following construction. The first 10 rounds curved upward and exited from the top of the pile after traveling about 125 cm. Another 10 rounds were fired of which 5 passed through the 1.8-m-thick pile. A further 10 were fired of which 4 passed through the pile.

M60 tracers

The linked ammunition for the M60 machine gun consisted of a repeated sequence of four M80 balls followed by an M62 tracer. The tracers were removed for all tests but test 4. The 11 tracer rounds recovered from this test were well-grouped and traveled an average distance of 84 cm, compared to an average of 107 cm for the ball rounds fired at the same time. As Table III shows, the two types of ammunition have similar weights and velocities. The principal difference is that the tracer is longer (31.7 vs 24.2 mm) and has a greater profile area. Since projectiles present their profile when tumbling, the greater profile area of the tracers may explain the shorter travel distance.

.50 caliber

The M2HB .50 caliber machine gun fires a heavy slug with high velocity and muzzle energy. Thirty rounds were fired fully automatically into a one-day-old snow pile with a density of 0.34 g/cm^3. Under this heavy point-blank fire, the center of the pile collapsed slightly and left a void under the outer shell. Sixteen rounds were recovered of which 4 had apparently traveled in this void and achieved penetration distances of 229-264 cm. The remaining 12 had traveled 157-231 cm – these were used to establish a tentative pattern for this weapon. They had a mean penetration of 193 cm with a standard deviation of 25 cm and a coefficient of variation of 13%.

This group of 12 establishes a tentative behavior pattern for this weapon. In snow of 0.34 g/cm^3 density the mean penetration is 193 cm and the maximum is 231 cm. This information should be used with caution, but the test did demonstrate that this weapon can also be defeated by snow despite its heavy bullet and high kinetic energy.

Tumbling

Bullet tumbling was not a subject of primary study in the 1975 field work, but evidence of tumbling was observed whenever possible. The tests confirmed Swinzow's (1972) observation that bullets become unstable and tumble in snow. With the exception of the atypical M60 tests described above, tumbling was general and perhaps universal. Several types of evidence were observed:

1. The orientations of the sixteen .50 caliber rounds reported above were recorded. No bullets or cores recovered in the snow were aligned in the direction of bullet travel.
2. Most of the M16 and M60 penetration data were extremely consistent in that many bullets fired into the same snow target would come to rest at about the same penetration distance. For example, 9 of 10 bullets were recovered in test 4 of the M16 series. All except one round penetrated between 56 and 66 cm.
3. Bullets generally showed evidence of having tumbled. All the bullets in test 4 of the M16 series, as well as the 44 recovered in test 4 of the M60 series, showed evidence of having tumbled. The cases were flattened to some extent. Core material had extruded from the open base of each bullet and then had bent around the end of the bullet due to spinning motion. Striations on the exposed core material also showed that the bullets had spun around a short axis.

Bullet deformation and breakage

All bullets recovered from disturbed snow (density 0.30 g/cm^3 or greater) were visibly deformed. The thin-walled M16 bullet invariably flattened and extruded core material from its open base. The M60 bullets also flattened and extruded core material, but deformation was less severe than with the M16. On rare occasions a bullet from either caliber would break at the point where the jacket was crimped to the core during manufacture.

The M33 .50 caliber bullet of the M2HB machine gun behaves more spectacularly. The 25.92-g steel core is placed within a 15.23-g gilding metal jacket, and a small void in the nose is filled with 0.97 g of sodium carbonate monohydrate. The jacket nose is poorly supported and bends or breaks off. The jacket splits longitudinally where the rifling has scored and weakened it and, due to the spin of the bullet, begins to peel off. It often rips where it is crimped to the core, tearing apart into two or more pieces which are relatively large and badly deformed and which travel along with, but independent of, the steel core.

Design penetration values

Table VI shows maximum penetrations to be expected from bullets from the M16, M60 and M2HB weapons in subarctic snow of three common densities. The values were calculated from eq 2 and 4 and rounded for the M16 and M60 weapons. These values can be used for design purposes. The relationships developed in this section are shown in Figure 7 where penetration is plotted against density for the three calibers.

Table VI. Bullet penetration design values, subarctic snow.

Snow type	*Density (g/cm³)*	*Maximum design penetration (cm)*		
		M16	*M60*	*M2HB*
Undisturbed	0.18	200	360	–
Piled	0.34	90	170	230
Packed	0.40	70	140	–

The M16 was easily defeated by snow. Penetration was low and the bullets tumbled and flattened. The M60 was somewhat more effective in penetrating farther than the M16 but it was also easily defeated. The M2HB .50 caliber machine gun with its tremendous muzzle energy, heavy bullet and fairly high muzzle velocity could only penetrate 40% farther than the M60.

A brief look at the hazard presented by a bullet in terms of penetration and transfer of kinetic energy as it travels through snow is of interest. The frontal area is drastically increased once the bullet tumbles, immediately reducing its ability to penetrate. Kinetic energy is proportional to the square of the velocity so that, as velocity drops, kinetic energy drops much faster. When velocity has decreased by one-half, kinetic energy has decreased by three-fourths. While a high-speed tumbling bullet is undoubtedly dangerous, a low-speed tumbling bullet lacks both energy and penetrating ability. Heavy winter clothing should provide good protection against such bullets. Materials such as wood or metal would also be effective in stopping tumbling bullets when used to line defensive works of snow.

Swinzow (1972) suggested that inhomogeneities in the snow cause tumbling. The snow used during these tests was generally free of inhomogeneities. It had no wind or ice crusts. Snow piles were built of well-mixed loose snow crystals without hard chunks of snow or other anomalies. It appears that tumbling is normal behavior, not the result of inhomogeneities.

DEFENSIVE WORKS OF SNOW

Revetments

Defensive works normally have vertical or nearly vertical interior walls but such walls cannot be built of subarctic snow. Consequently, the structure must be revetted in one of the following ways:

1. Snow blocks or chunks can be piled in a wall.
2. Poles, brush, lumber, plywood, sheet metal or other materials can be used following standard military engineering techniques.

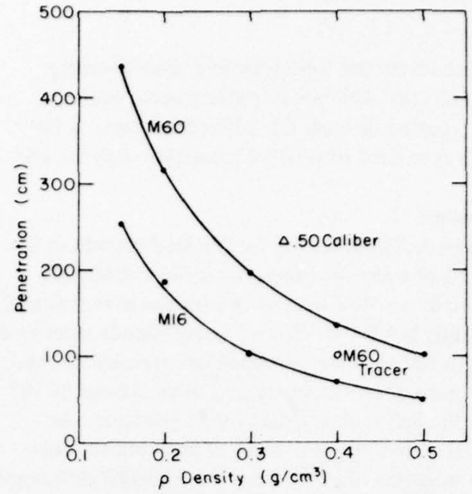


Figure 7. Design penetration distance for various calibers in subarctic snow. Curves for M16 and M60 from eq 2 and 4.

3. Bags can be filled with snow and piled in a manner similar to sandbags.

All of the methods are feasible under the right conditions, although snow suitable for blocks or chunks is seldom found in the Subarctic. (Snow blocks are discussed in more detail later in this report.) Figure 8 shows a log and snow breastwork from Field Manual 5-15 (U.S. Army). This type of structure is feasible in the Subarctic, since logs, poles, boughs and other similar materials are locally available. The planks or round timbers facing the breastwork would be effective in stopping tumbling bullets which penetrated the snow. Snow bags proved to be a simple, fast and versatile means of revetting.

Snow bags

The use of snow bags – bags filled with snow – is an obvious and logical extension of the well-developed sand bag technology. TF-5-2372 (U.S. Army 1956) briefly mentions the use of snow-filled sand bags and Schaefer (1975) built several structures of them. Since snow is lighter than sand, the bags can be larger than sand bags and still easily handled. One hundred-pound burlap potato bags were used and worked well. They could be filled by a team of two men at the rate of three bags in five minutes (see Fig. 9). When laid (Fig. 10 and cover) each bag formed a structural element 23 cm high, 41 cm wide and 60 cm long, with an effective frontal area of 0.14 m^2. After the bags were laid, the snow in the bags hardened and that between the bags bonded to the bags, cementing them together. The result was a relatively hard and strong monolithic wall.

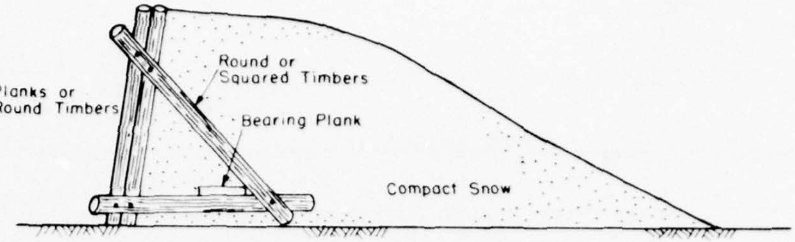


Figure 8. Log and snow breastwork (from FM-5-15).

Figure 9. Filling snow bags.

Figure 10. Snow bag breastworks.

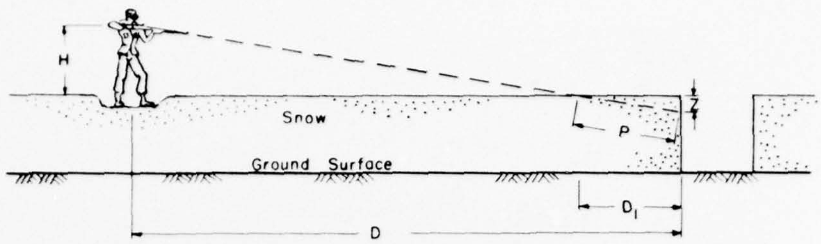


Figure 11. Snow trench geometry.

Figure 12. Snow trench. The front is to the left.

The snow trench

A trench in the snow will provide protection from small arms fire if the weapon is firing at a shallow angle to the surface. Because of the geometry, bullets from the weapon are unable to penetrate deeply into the trench. This is demonstrated in Figure 11 which shows a rifleman at a distance D from a trench in the snow. Table VI and Figure 7 indicate the distance P that the bullets will penetrate through the snow. When the angle between the bullet path and the snow surface is small, P is approximately equal to D_1, the horizontal distance of bullet travel in the snow. When the rifle is at a height H above the snow surface Z, the maximum distance below the snow surface that bullets will reach can be calculated by similar triangles:

$$\frac{Z}{P} \approx \frac{H}{D-P} \tag{5}$$

$$Z \approx \frac{HP}{D-P}. \tag{6}$$

Bullet penetration can be determined for any combination of weapons, distances and snow types. For example, the M16 rifle held at 1.5 m above the ground and 18 m from the trench yields a value of Z of 0.18 m, when P is 1.90 m. If the M60 is 0.3 m above the surface and 90 m from the trench, Z is 1 cm. This geometry was used to design snow trenches.

A trench in the snow can be built very rapidly and several were built large enough (1 m wide, 4 m long) for 2-4 persons by one soldier in 5-8 minutes. Figure 12 shows a simple snow trench of which two were built and tested under fire. Note that the snow from the trench was thrown to the rear of the position.

The simple snow trench provided protection from low-angle rifle and machine gun fire. Even heavy fire from the .50 caliber machine gun proved unable to blast into the trench. All bullets showed a tendency to ricochet from the snow surface, greatly reducing their effectiveness. The individual tests are described below.

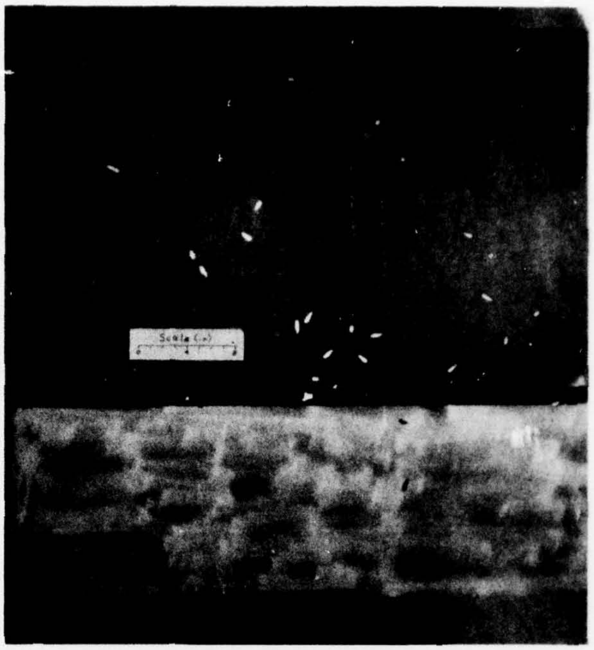


Figure 13. M60 (7.62-mm) target. Fifty rounds were fired at snow trench from 15 m.

M16 tests. The M16 was relatively ineffective against the snow trench. Twenty rounds were fired from 18 m in the first test by a standing rifleman with the weapon 1.5 m above the surface. The vulnerable zone, calculated from eq 5, was 18 cm. This proved difficult to hit and most rounds entered the snow below this zone, stopping in the snow. Five rounds struck the witness board 2-15 cm below the snow line. In the second test 40 rounds were fired from 15 m by a standing rifleman. Similar difficulties were encountered during the second test. The witness board was struck by only two bullets below the snow line. Eight tumbling bullets struck the witness board above the snow line and are considered to be ricochets. Twelve were fired high and struck the target without striking the snow; the balance stopped in the snow.

M60 tests. The M60 was less effective against the snow trench than eq 5 would indicate. In the first test 20 rounds were fired from 18 m with the weapon 1.4 m above the snow surface. The zone of vulnerability should have extended to 33 cm, but only three bullets struck the witness board at 0, 5 and 18 cm below the snow line. In the second test 50 rounds were fired from 15 m with the bipod-mounted weapon 0.3 m above the surface. The zone of vulnerability was 10 cm. Only two rounds struck the witness board below the snow line at 4 and 18 cm. It is suspected that the one round followed a path through the snow that curved downward. Twenty tumbling ricochets struck the witness board above the snow line as can be seen in Figure 13.

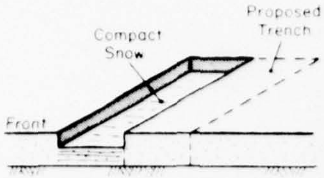
.50 caliber tests. The .50 caliber machine gun was also relatively ineffective against the snow trench, showing poor penetration and a strong tendency to ricochet from the snow surface. In the first test 21 rounds were fired from 18 m with the tripod-mounted weapon 0.4 m above the snow surface. Figure 14 shows the gun in position. One tumbled round struck the target 5 cm below the snow line, three struck as tumbling ricochets above the snow line, and three untumbled rounds, fired high, struck the target directly. In the second test, 50 rounds fired from 15 m yielded three bullets which struck the witness board, shown in Figure 15, a maximum of 15 cm below the snow line. Many ricochets struck the witness board above the snow line.

The hardened snow trench

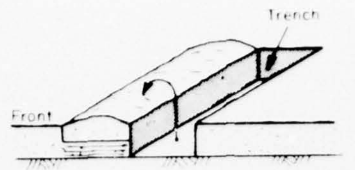
The snow trench can be made more effective by increasing the density and hardness of the snow in front of the position. Increased density reduces the distance of bullet travel and thus the depth of penetration into the trench. A harder snow surface should increase the tendency of bullets to ricochet.

Figure 14. .50 caliber machine gun positioned to fire at snow trench.

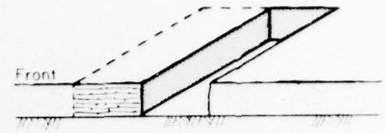
Figure 15. .50 caliber (12.7-mm) machine gun target. Fifty rounds were fired at snow trench from 50 ft.



Step 1. Pack the snow in front of the trench.



Step 2. Place snow excavated from the trench in the packed snow.



Step 3. Smooth and level the packed snow.

Figure 16. Building the hardened snow trench.

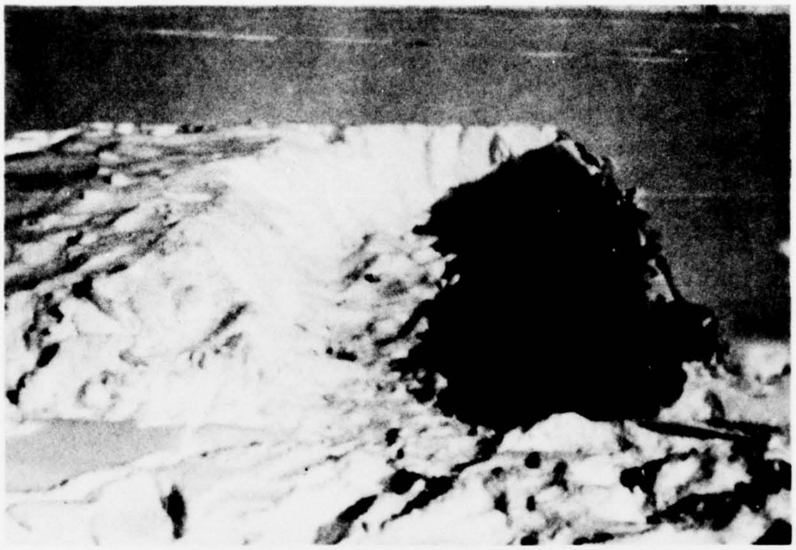


Figure 17. First hardened snow trench. Because the packed snow in front was not smooth and level, it lost some effectiveness.

A simple form of an improved or hardened snow trench was built by packing the snow in front of the trench and then throwing the snow from the trench onto the packed snow. Figure 16 shows these steps. Two hardened trenches 4.5 m long were built, each by 2 men in 15 minutes. The packed snow in front of the first, shown in Figure 17, was poorly leveled and some bullets penetrated into the trench. When the snow in front of the second trench was carefully leveled, the trench was highly successful in resisting bullet penetration.

M16 tests. The M16 was fired against both trenches. In the first test, 20 rounds were fired from 18 m with a weapon height of 1.5 m. Three bullets struck the target below the snow line at a maximum depth of 15 cm. Bullet fragments struck the target above the snow line, showing that some bullets were breaking up when striking the packed snow. The angle of incidence of the bullets was 6°. No ricochets were observed from the rough snow surface.

In the second test, 60 rounds were fired from 18 m with the weapon 1.5 m above the snow surface. No bullets struck the witness board below the snow line but five ricochets struck it above the snow line. The angle of incidence was 5°. Some bullets broke and the fragments struck the witness board.

M60 tests. Twenty rounds were fired from the M60 at the first hardened trench from 18 m with a weapon height of 1.2 m. Three bullets penetrated below the snow line with a maximum penetration of 8 cm. Three tumbling ricochets struck the witness board above the snow line, and most bullets were absorbed in the snow. The angle of incidence was 4°.

In the second test, 60 rounds were fired from 15 m, with the weapon 0.3 m above the surface, giving an angle of incidence of 1°. Figure 18 shows that no rounds penetrated below the snow surface but many ricochets struck the witness board.

.50 caliber tests. Fifty-eight rounds were fired against the first hardened trench with the weapon 0.4 m above

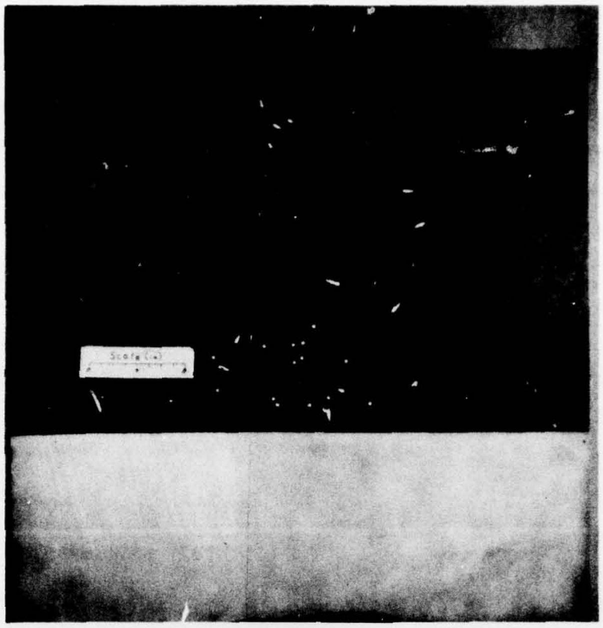


Figure 18. M60 (7.62-mm) target. Sixty rounds were fired at hardened snow trench from 15 m. Note the many ricochets.

Figure 19. .50 caliber (12.7-mm) machine gun target. Fifty-five rounds were fired at hardened snow trench. Note the many ricochets.

Figure 20. Snow trench revetted with snow bags.

the snow. The witness board showed a maximum penetration of 10 cm below the snow line, although the heavy sustained firing dug a 30-cm-deep trench in the loose snow ahead of the packed snow. Several ricochets occurred. The angle of incidence was 2°.

Fifty-five rounds were fired against the second hardened trench. Figure 19 shows that no rounds penetrated below the snow line but that bullets ricocheted badly from the snow surface. Several rounds shed their jackets before they struck the witness board. The angle of incidence was 1°.

Breastworks and bunkers

Snow trenches, particularly when hardened, can provide effective hasty shelter from small arms and machine gun fire. However, unless the snow is several feet deep, the individual must lie on the ground to be sheltered. Other types of positions where troops can kneel or sit are needed for weapon positions and breastworks. Several small structures were designed, built and tested using snow bags for revetting the position and, in some cases, as breastworks. Figure 20 shows a position revetted with snow bags on both front and back. It was faced with piled snow, giving a total thickness, including the snow bags, of 2 m at the top and increasing toward the bottom. This 4-m-long structure was built by four men in one hour. It was tested by firing 20 rounds from the .50 caliber machine gun at close range. There were no penetrations and the position was judged successful.

A similar position was built and 100 rounds of .50 caliber ammunition were fired at close range immediately after it was built. Under this heavy fire, with snow that had not yet hardened, some of the snow bags were driven into the position and several rounds penetrated.

A breastwork, shown in Figure 10, was built of two rows of snow bags and 0.2 to 0.5 m of facing snow. It was tested after it had aged one day. Twenty rounds of M16 fire at close range failed to penetrate. When 40 rounds were fired from the M60 at close range, one bullet penetrated. The .50 caliber machine gun at a similar distance was effective in both penetrating the position and driving some of the snow bags into it.

Successful breastworks and bunkers can be built of subarctic snow. It should be noted that these structures will normally rise above the relatively shallow snow in the area and will present a face too steep to cause bullets to ricochet. Consequently, they must interpose sufficient snow to stop the bullets. The criteria of Table VI should be used for designing these structures.

The breastworks and bunkers should normally be revetted; snow bags work very well. Such bags are rapid to fill and easy to lay. After the snow sets up, they become relatively hard and bond together. Three rows of snow bags and facing snow are necessary to withstand M60 and .50 caliber fire.

EVALUATION OF FOREIGN TECHNOLOGY

Swinzow (1972) in a literature review points out that most countries with armies in temperate and cold regions instruct their soldiers to use snow as a shelter and expedient fortification material. He found the most prolific military literature on snow fortifications to be in Russian and redrew typical Russian expedient snow trenches. These drawings, with captions in English, are shown in Figure 21. He also selected various expedient and deliberate Russian snow structures for possible evaluation in the field during this study.

Russian expedient snow trenches

The Russian expedient snow trenches shown in Figure 21 are built by excavating the natural snow cover and then building up the position with shoveled snow, possibly compacted. Snow blocks and chunks are used to revet the structure in some cases, but in others the snow stands without support. A snow block corbeled roof or free-standing snow arch may cover the trench.

The free-standing walls of the natural snow cover and the extensive use of snow blocks suggest that this technology was developed in and for areas with relatively strong, dense snow subjected to sufficient wind to form drifts from which snow blocks can be cut. As was pointed out earlier, snow of sufficient density and strength to yield snow blocks is rare in the Subarctic. Trenches such as those in Figures 21d and 21e can be built if forms are used for shaping the trench. On the other hand, structures such as 21a, 21b and 21c use snow blocks and cannot be built using readily available material; this technology cannot be applied directly in the Subarctic.

Snow blocks and block structures

If subarctic snow is packed, it will age harden so that snow blocks can be cut from it. Figure 22 shows blocks being quarried from an area packed with a snowmobile, and Figure 23 shows them being carried to a site where a snow block structure was being constructed. The partially built structure is shown in Figure 24 and the completed structure in Figure 25.

Manufactured snow blocks are a poor construction material. The time required to pack the snow, allow it to harden, and then quarry and carry the blocks is excessive. The blocks are relatively weak and soft and do not wear well. They require a moderate amount of skill and understanding before they can be used to advantage; few troops possess this skill and understanding.

The snow arch

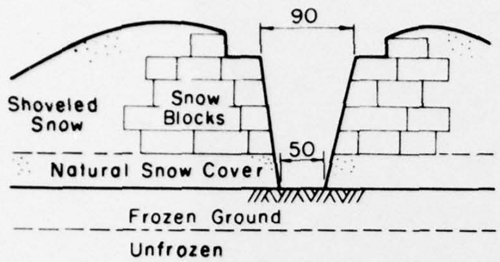
The snow arch shown in Figure 21f recalls the snow arches developed and used extensively by the U.S. Army in construction of Camp Century on the Greenland Ice Cap in 1959-60 (Mellor 1968). Trenches cut into the snowfield were covered with light corrugated steel arch forms, which were in turn covered with snow. The snow set up and became self-supporting, and in some cases, the forms were removed (U.S. Army 1962, p. 203). Snow, particularly in an arch shape, is often sufficiently strong to support itself, and the snow arch is an obvious means of covering expedient trenches and other structures.

A plywood snow arch form was built and tested. The bare arch is shown in Figure 26. It was covered with 18-25 cm of snow (Fig. 27) and slipped forward when it was judged that the snow had set up sufficiently to be self-supporting. Set-up time varied from as little as 1 hour with the air temperature above -7°C to more than 18 hours when the temperature was below -18°C. The amount of packing affects set-up time. The arches are strong, as Figure 28 shows, and forms could be improvised in the field. As two soldiers can cover a form in two minutes, the labor costs are very low. The snow arch is far superior to the corbeled block roof shown in Figures 21b, 24 and 25.

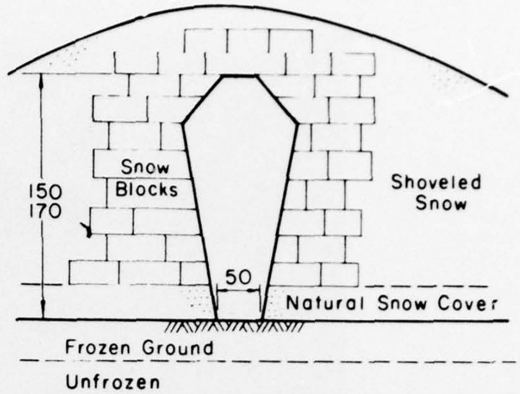
An expedient shelter

Field operations during the winter create a requirement for an expedient shelter from the elements. The Eskimo snow igloo is an excellent shelter built wholly of snow, but it is not adapted to the Subarctic since snow with the necessary mechanical properties is rare or nonexistent. Holes and caves in the snow are proposed in FM 5-15 (U.S. Army 1972) and FM 31-70 (U.S. Army 1968) but again, snow which can be excavated for shelter in the Subarctic is rare. Successful shelters are built using poles, tarps, boughs and a snow cover. One further type, the excavated snow pile, may have some utility.

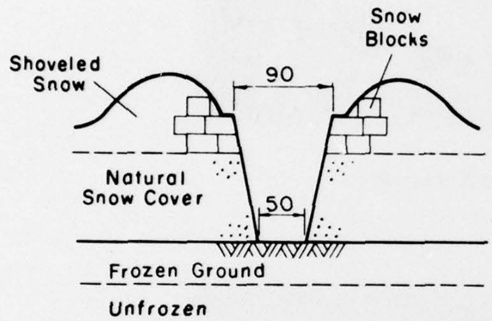
Troops with scoops can rapidly build relatively large snow piles. The pile will harden and can then be hollowed out to form an igloo-like structure suitable for emergency shelter or temporary living quarters. Figure 29 shows a snow pile built by four soldiers in 30 minutes. The pile was allowed to set up overnight and was partially excavated on the following day. While the troops inside the snow pile, shown in Figure 30, are cramped, the interior could have been easily enlarged by further excavation. This type of structure can be built by troops with a low degree of skill. It will have the thermal advantages of the igloo if provided with a proper door covering.



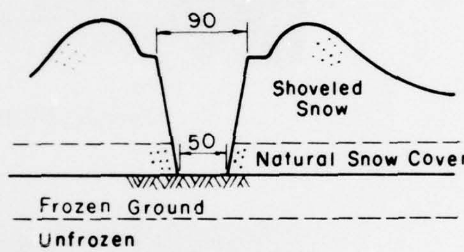
a. Uncovered trench in snowdrift using cut blocks.



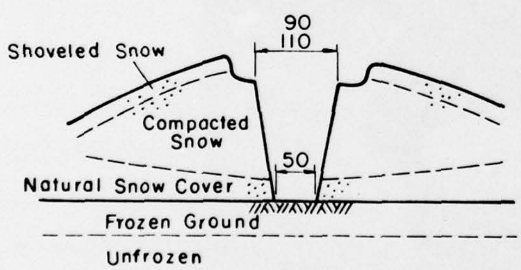
b. Covered trench in deep snowdrift.



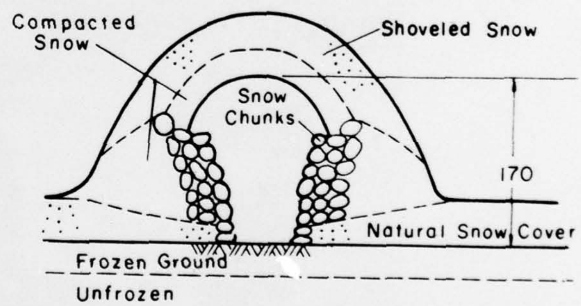
c. Hasty trench in medium snow.



d. Hasty trench in shallow snow.



e. Open trench in compacted, reworked snow.



f. Covered trench in compacted snow using snowballs and chunks.

Figure 21. Types of Russian expedient snow combat trenches (from Swinzow 1972). Dimensions (not to scale) are given in centimeters.

Figure 22. Mining a snow block in packed snow.

Figure 23. Carrying snow blocks to construction site.

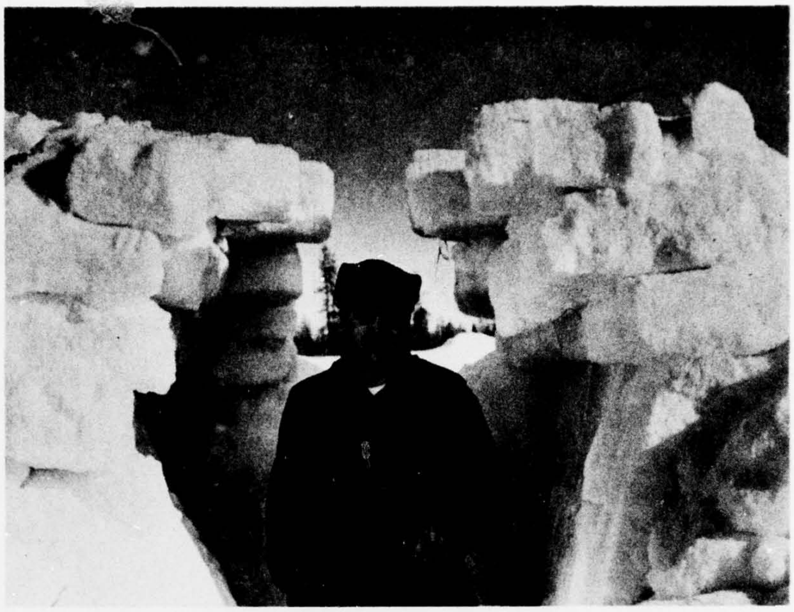


Figure 24. Partially completed snow block structure.

Figure 25. Completed snow block structure.

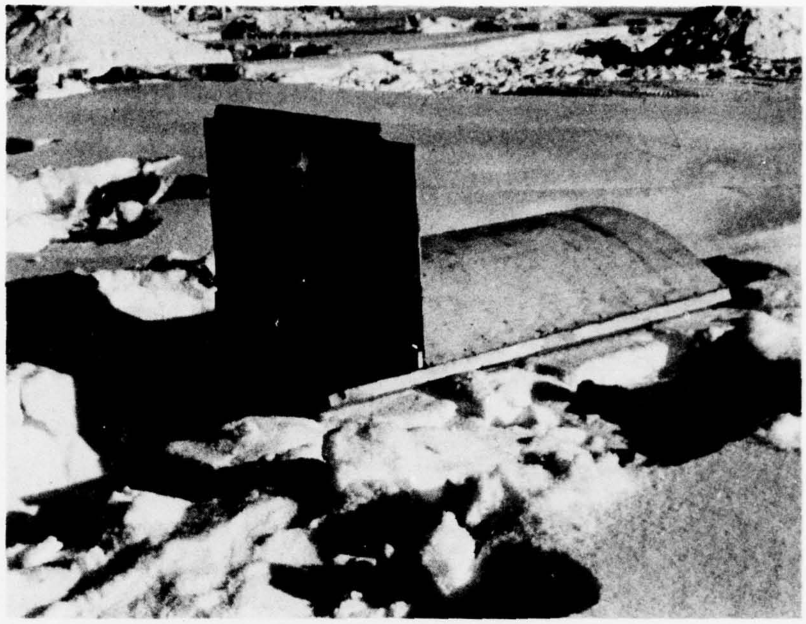


Figure 26. Snow arch form.

Figure 27. Snow arch form in use.

Figure 28. Snow arch after age hardening.

Figure 29. Partially excavated snow pile.

Figure 30. Troops inside partially excavated snow pile.

CONCLUSIONS

Snow in the Subarctic is generally available from November through April, although the quantity on the ground varies from year to year and place to place. Total snowfall is moderate but snow which falls tends to remain in place throughout the winter. It is of extremely low density when it falls, and since it is seldom subjected to melting or wind drifting, its density remains low throughout the winter. Structurally, it is very weak and will neither support equipment nor provide snow blocks for structures.

Snow can be useful in building hasty and deliberate defensive works to provide troops in the field with protection from small arms fire. Digging into the ground is difficult because of deep seasonal frost and widespread permafrost, so the defensive works must be above the ground surface. Snow is widely available and easy to work.

Undisturbed subarctic snow normally has a density of 0.20 g/cm^3 or less, but shoveling, packing or other processing increases the density to around 0.34 g/cm^3. Further work will increase the density to 0.40 g/cm^3 or slightly higher but densities much above 0.40 g/cm^3 are difficult to achieve with simple hand equipment. Total bullet penetration proved, as reported earlier by Swinzow (1972) and Schaefer (1975), to be strongly controlled by snow density. Increased density reduces the length of bullet travel. Simple linear relationships were found between the distance of bullet travel and the reciprocal of density for the M16 and M60 weapons. The penetration-density relationship is fundamental in the design and construction of defensive works of subarctic snow.

A tumbling bullet loses much of its penetrating power in traveling partially or completely sideways through the snow as it presents a large, blunt frontal surface rather than a small pointed one. Its energy drops rapidly (since kinetic energy is a function of the square of the velocity) and drops much faster than velocity. Consequently, a tumbling bullet in snow near the end of its travel probably presents little hazard and could be stopped by heavy clothing or a wooden or metal lining installed in a bunker.

Several types of defensive positions were built and tested. The simplest, a trench dug in the snow with excavated snow cast to the rear, provided protection from weapons ranging from the M16 to the .50 caliber machine gun when the bullet path was at a low angle with the snow surface. When the angle of incidence was low, the snow was adequate to stop the bullets from penetrating deeply into the trench, and the larger bullets showed a tendency to ricochet from the snow surface. Such snow trenches can be built in a very few minutes with a shovel or scoop.

Snow trenches can be easily improved by packing and smoothing the snow in front of the trench. The increased density reduces total bullet penetration and thus the depth they can penetrate in the trench. The increased hardness of the surface strongly increases the tendency of bullets, fired at a low angle, to ricochet. Hardened snow trenches proved almost invulnerable to low-angle small arms and machine gun fire. They can be easily built in a short time with scoops or shovels.

Effective breastworks and bunkers can also be built of snow and would be suitable for machine gun positions and similar uses. Several were built and tested under fire. Some were effective in resisting even heavy close range .50 caliber machine gun fire; others failed under such fire but simple measures would have improved them to the point where they would withstand such fire. Such structures require revetting and the Subarctic provides a plentiful supply of trees, branches and other forest products which can be used. An even simpler method uses bags filled with snow for revetment purposes. Sand bags have been used but are too small for a lightweight material such as snow. One hundred-pound burlap potato bags were found to work very well. A snow bag technology could be easily developed, based on sand bag technology and an understanding of the properties and behavior of snow.

Published Russian literature on hasty and deliberate snow structures was examined and the concepts tested in the field. Russian structures are built by excavating the natural snow cover to the ground and then building up the position with shoveled snow. They often use snow blocks or chunks to shape the position and contain loose snow. They may cover the trench or other structure with a corbeled snow block cover or a cast snow arch. They may also break through the ground frost and extend the structure downward.

Generally, the Russian designs are not suitable for the Subarctic, due to deep seasonal frost, permafrost and the characteristics of subarctic snow. Other designs and construction techniques must be developed and used. However, the experiences of Schaefer (1975) and the author indicate that this would not be difficult. Much basic data required are available and workable structures have been built.

An expedient shelter from the elements was constructed by shoveling a snow pile, allowing the snow to harden and then excavating the interior. With a suitable door covering, such a shelter is equivalent to the Eskimo igloo which requires snow of a special density and hardness not normally found in the Subarctic.

RECOMMENDATIONS

Work to date, including that of Schaefer (1975) has developed a great deal of basic information on the feasibility and design of snow fortifications in the Subarctic. The concept is promising and further field work should be carried out to develop and test both expedient and deliberate structures.

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