Technical Report 153

STUDY OF THE RAMMSONDE FOR USE IN HARD SNOW

by

Landon Niedringhaus

APRIL, 1965

U.S. ARMY MATERIEL COMMAND
COLD REGIONS RESEARCH & ENGINEERING LABORATORY
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PREFACE

This work was performed as part of U. S. Army Cold Regions Research and Engineering Laboratory (USA CRREL) Project 6, Development of Trafficable Surfaces, during the 1963 test season at Houghton, Michigan, and Camp Century, Greenland.

The study was conducted by Sp5 Edward L. Niedringhaus, Civil Engineering Assistant, Applied Research Branch, under the supervision of Mr. Albert F. Wuori, Chief, Applied Research Branch.

The author was assisted in the field work by Sp4 Paul Benson, Civil Engineering Assistant, Applied Research Branch, and Messrs. James Tobolski and Edward Young under the Dartmouth College contract.

USA CRREL is an Army Materiel Command laboratory.

Manuscript received 23 December 1963.
DA Task IV025001A13001

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SUMMARY

The Rammsonde hardness instrument which is presently used by the U. S. Army Cold Regions Research and Engineering Laboratory (USA CRREL) was found to be unsatisfactory for use in processed, age-hardened snow of extreme hardness.

During 1963, studies were performed at Houghton, Michigan, and Camp Century, Greenland, to investigate various modifications of the Rammsonde and to improve its suitability for use in hard snow.

Studies were also made to determine whether such factors as hammer drop height, hammer weight, and time delay between blows had any effect on the results obtained. It was discovered that the hammer drop height had little apparent effect on the hardness values obtained, but the hammer weight and the time interval between blows had a noticeable effect on the results and must be taken into consideration when performing ram hardness tests.

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INTRODUCTION

The Rammsonde cone penetrometer was originally developed as a simple test instrument for determining the resistance to penetration of a natural snow surface (Bader et al., 1939). With the advance of snow mechanics, the Rammsonde cone penetrometer has become one of the principal test instruments in this field. It provides a quick and simple method of evaluating a snow profile.

The Rammsonde cone was originally designed for use in natural snow, where hardness values above 200 were considered unlikely. In recent years, however, it has become possible to construct snow surfaces of considerable hardness by processing (Wuori, 1962) and allowing them to age harden (Nakaya, 1959). In processed, age-hardened snow having a density of over 0.5 g/cm^3 it is not uncommon to find ram hardness numbers of 1000 or more.

A study was made of the original theory used to design the Rammsonde cone, and it was tested in snow of various hardnesses. From this study it was determined that the standard Rammsonde cone is unsuitable for use in snow of extreme hardness. The Rammsonde which is presently used by USA CRREL consists of a hollow aluminum tube, 2 cm in diameter, with a conical head having a 60° point and a 4-cm maximum diameter. On top of the tube is a metal rod to guide the driving hammer. By making several simple modifications in the design of the Rammsonde cone penetrometer, its useful range can be greatly extended and its operation simplified. The purpose of this study is to develop a standard design for a Rammsonde for use in hard snow, and to establish standard operational procedures for this instrument.

THEORETICAL CONSIDERATIONS

The ram hardness number is based on the equation $R = \frac{Wh}{s} + (W + Q)$, where:

W = weight of driving hammer (kg)
h = height of fall of driving hammer (cm)
s = depth of penetration per blow (cm)
Q = weight of penetrometer (kg)
R = ram resistance (kg).

This equation is based on the assumption of a completely elastic collision between the hammer and the penetrometer and does not reflect any effect of varying the hammer weight. However, field tests performed by the writer and others (Reese, 1955; Haefeli, 1963) have shown that the hammer weight does have a considerable effect on the hardness number obtained.

In order to account for the effect of the hammer weight, the following expression has been proposed (Haefeli, 1963):

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

where:

$$\lambda_s = \frac{r + \eta^2}{r + 1}$$

$$r = \frac{W}{W + Q}$$

η = blow-elasticity coefficient (or coefficient of restitution).

No definite value for η has been established. It appears to be dependent on the hardness of the snow surface. As hardness approaches 0, the transfer of energy between the hammer and the shaft is defined by a simple impulse momentum equation, and the value of η approaches 0. As the hardness approaches ∞, all of the energy is used for internal deformation of the shaft, and the value of η approaches 1. The need to determine η could be eliminated if the weight ratio between the hammer and the shaft remained constant. For a given snow hardness the error would remain constant, and the values obtained would be consistent. Therefore, when designing a Rammsonde for use in hard snow, it is desirable to use only one hammer weight.

The ratio $\underline{f}$ between the internal deformation energy and the effective penetration energy is given by $f = RL/2EAs$ (Bader et al., 1939) where:

- R = ram resistance (kg)
- L = length of penetrometer (cm)
- A = cross-sectional area of penetrometer shaft (cm^2)
- E = modulus of elasticity of the penetrometer shaft (kg/cm^2)
- s = depth of penetration per blow (cm).

The penetrometer shaft should be sufficiently rigid to insure that the loss due to internal deformation does not become too great. On the other hand, the shaft should be light enough so that a reasonable penetrometer to hammer weight ratio is maintained without using an excessively heavy hammer.

DESCRIPTION OF STUDY

Field tests were performed to give a better evaluation of how various physical characteristics of the Rammsonde affect the test results. The testing program was designed to give a detailed evaluation of 30° and 60° cones and steel and aluminum shaft materials. The tests were performed on processed snow having a density from 0.50 to 0.65 g/cm^3 and age hardened for a period of 2 to 4 weeks.

The testing procedures were basically the same for the evaluation of all characteristics, except for the point correction which is explained in detail later. For each characteristic to be evaluated a number of ram tests (usually 12) were made in the same area. The rams were taken on approximately 1-ft centers, equally distributed over the test area in order to minimize the inconsistencies of the snow. Figure 1 shows a typical layout for evaluating characteristics X, Y, and Z. The hardness values were recorded for each 5-cm depth increment.

One series of tests was performed at the Keweenaw Field Station, Houghton, Michigan, during February 1963. The standard 60° aluminum ram cone was compared with a 30° steel cone on a standard aluminum shaft. During the summer of 1963, three series of tests were performed at Camp Century, Greenland. In this study the standard 60° ram cone was compared with a 30° steel cone on both a standard shaft and a solid steel shaft. The Rammsondes tested are shown in Figure 2; the data are given in Appendix A. A least squares analysis was performed on the data with the aid of a Bendix G-15 electronic computer. The results are presented graphically in Figure 3.

DESIGN OF THE INSTRUMENT

The standard 60° ram cone has proved to be quite unsatisfactory for use in processed, age-hardened snow of extreme hardness because the entire ram assembly rebounds as a result of the hammer blow. Excessive vibrations were observed in the shaft, the penetration seemed to be erratic, and at times no penetration was noted after 100 blows with a 3-kg drop hammer. This procedure was extremely slow, and the results appear to be too high and unrealistic for the harder snow areas. When penetration was achieved, quite frequently the ram became stuck and was impossible to retract without augering with a core auger. This operation is time-consuming and leaves a large hole in the snow surface, which is undesirable. It was also noted that the depth markings on the standard ram shaft are difficult to read, especially in bright sun.

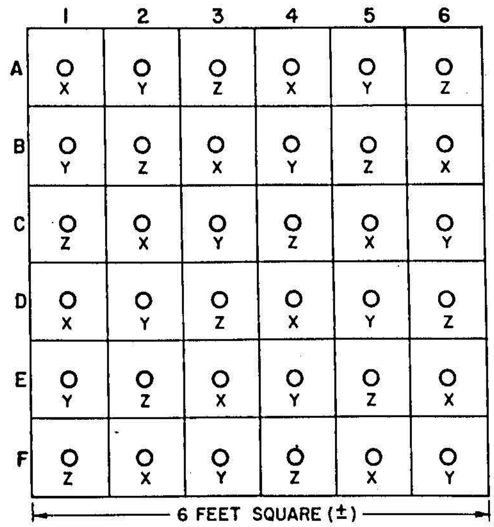

Figure 1. Test layout. Letters X, Y, and Z indicate location of positions at which the characteristics X, Y, and Z were tested.

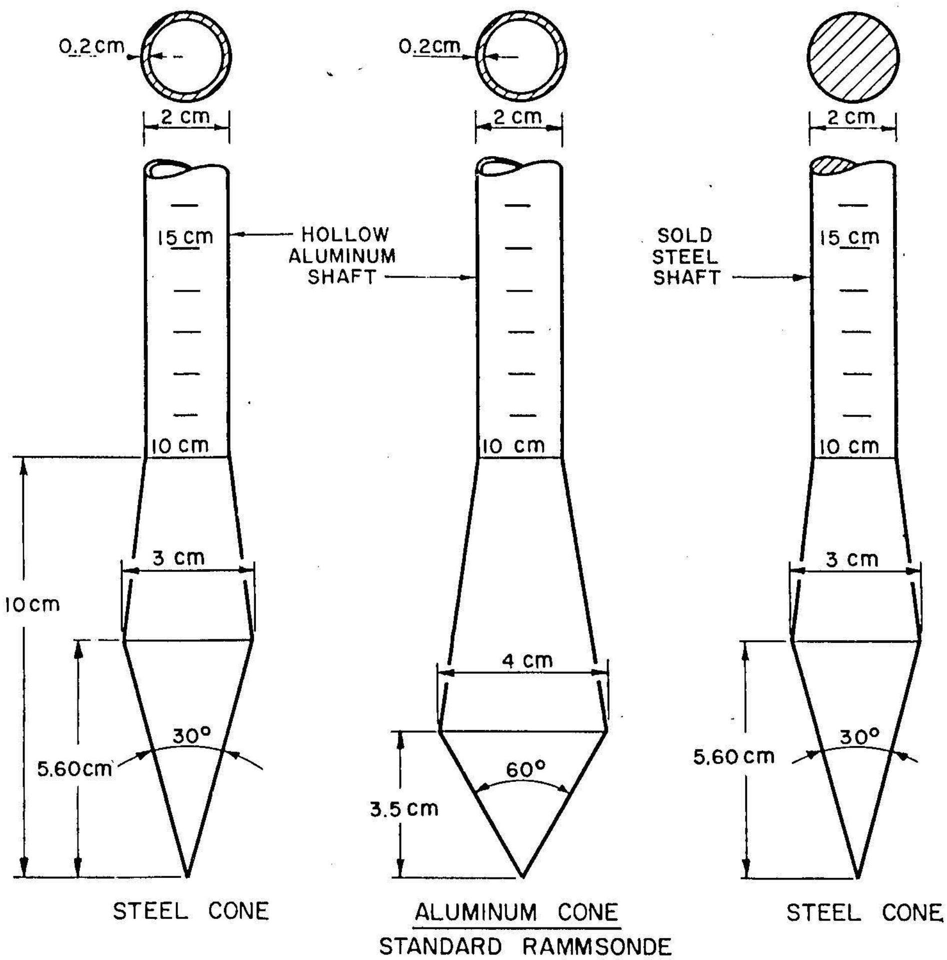

Figure 2. Rammsondes tested.

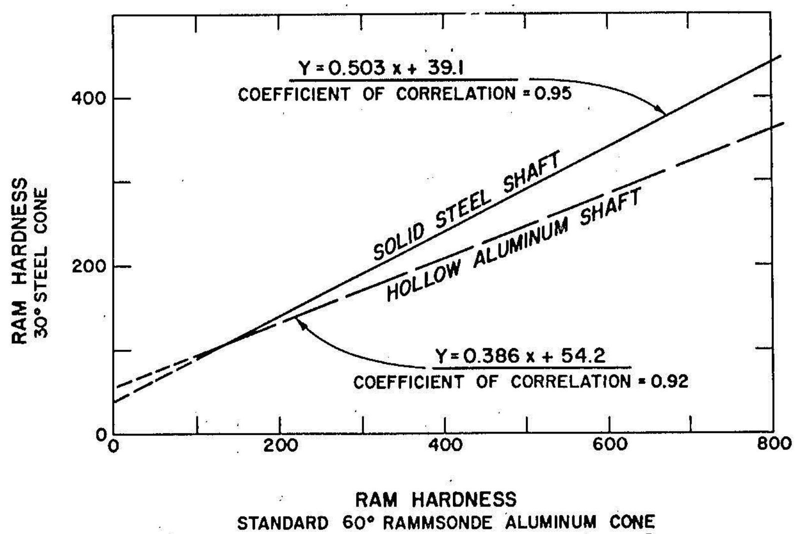

Figure 3. Correlation between results obtained with 60° and 30° cones.

The performance of the 30° cone with both the steel and aluminum shafts proved to be satisfactory. The penetration was smooth and could be held within reasonable limits. The penetrometers with the 30° cones were also easily retractable after the test. From Figure 3 it can be seen that, for snow of a given hardness, more energy is required for penetration with the steel shaft than with the aluminum shaft. It appears that the loss due to the ratio of hammer and penetrometer weights has a greater effect than the loss due to internal deformation. Therefore, the aluminum shaft would seem to be the logical choice for general use in processed, age-hardened snow.

It is recommended that the Rammsonde apparatus for use in processed snow be constructed as follows (see Figure 4):

1. The cone should be made to the exact dimensions of the 30° cone used in the above tests.

2. Aluminum should be substituted for steel as the material for the cone, as steel only adds unnecessary weight to the instrument and does not give any advantage over aluminum. However, it may be desirable to provide the cone with a hardened tip.

3. The shaft should be made of aluminum tubing with the same dimensions as the standard ram. However, a slightly greater wall thickness may be desirable.

4. Five cm wide bands of contrasting colors should be anodized on the shaft to facilitate reading.

5. The depth markings should be stamped in the aluminum shaft at 120° intervals around the shaft to facilitate penetration readings from any position.

6. The hammer guide should remain similar to the one which is presently being used.

7. The 1-kg weight should be eliminated from the kit. Only the 3-kg weight should be used. Variations required in the input energy should be made by adjusting the drop height.

At the present time there is very little need for the use of extensions when testing processed snow. However, if they are required, they should be similar to the extensions which are presently being used.

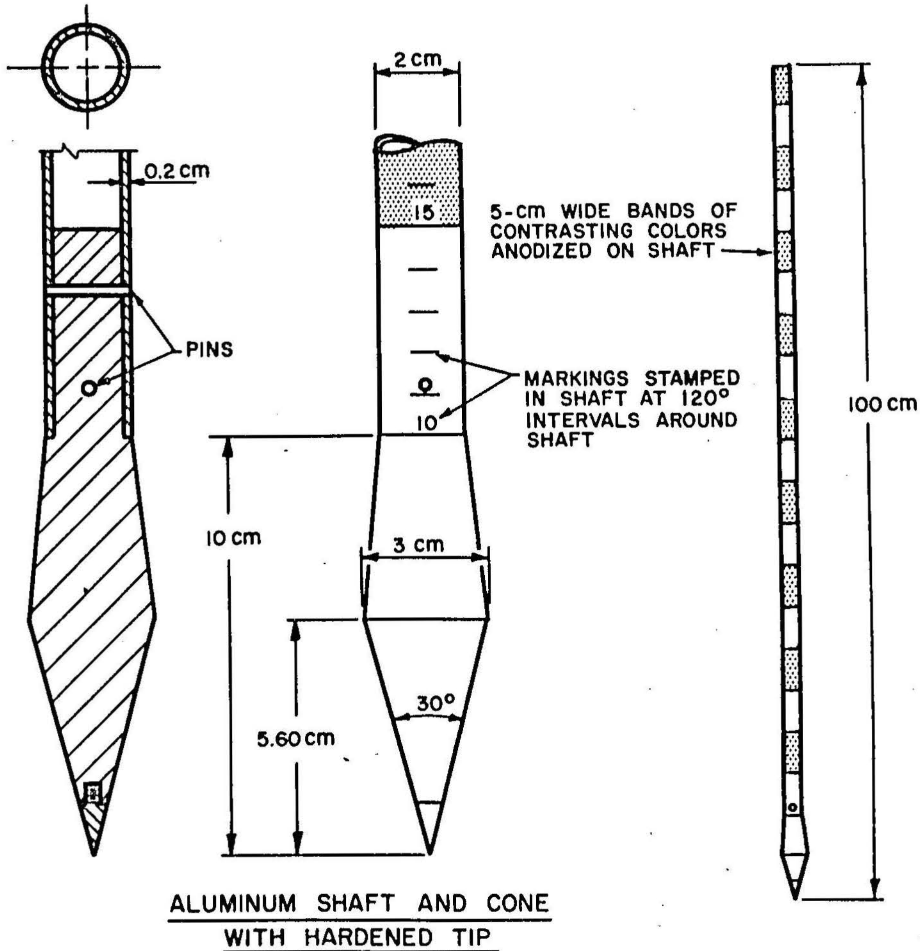

Figure 4. Proposed Rammsonde.

When extensions are used, additional errors are introduced due to both the added weight and the added length of the shaft. Conversion charts should be prepared to give the corrected ram value for the number of extensions used.

USE OF THE INSTRUMENT

General considerations

One of the most important considerations for insuring reliable results with the Rammsonde is the proper use of the instrument. Besides the more obvious requirements, such as accurate reading and recording of the penetration and hammer drop height, and keeping the penetrometer vertical, there are other factors which have to be considered.

A field study was made of the effects of the 30° cone entering the snow surface, hammer drop height, hammer weight, and time interval between hammer drops.

Effect of cone entering surface

In order to obtain accurate results, it is necessary to make corrections for the 0 to 5 cm and 5 to 10 cm penetration of the ram cone to compensate for the varying resistance while the cone is entering the snow. Although the maximum diameter of the cone is only slightly more than 5 cm from the tip, the pressure bulb below the cone is apparently not fully developed in the 0 to 5-cm layer, so that a correction is needed in the 5-10 cm layer also.

In order to determine the proper correction factor, two areas with a vertical face of at least 50 cm were tested at Camp Century. The first area was located at the northeast entrance of the Project 6 trench, where a Peter plow had made a vertical cut while clearing the entrance to the trench. The second area was located in trench 12 at a vertical face near the thermal drill. A ram hardness test was made in the normal manner to a depth of at least 50 cm, approximately 1 ft from the edge of the vertical face in order to eliminate edge effects. The hardness values were recorded in 5-cm increments for the entire depth. This is shown as A in Figure 5.

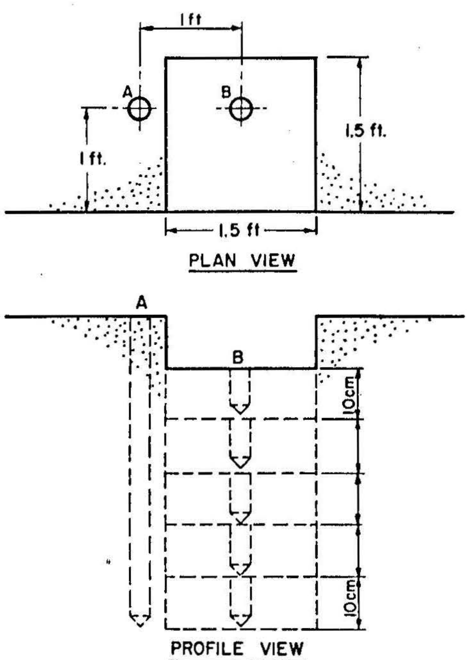

Figure 5. Layout for point correction tests.

The snow adjacent to A was then removed to a 10-cm depth, and a ram test, approximately 1 ft from A, was made starting at the new snow surface which was now 10 cm below the original surface. This is shown as B in Figure 5. The ram hardness was recorded for the 0 to 5 and 5 to 10-cm layers. Then this 10-cm snow layer was removed and another ram test made to a depth of 10 cm below the previous one. This process was repeated until the depth equalled that of the normal ram test A. The hardness numbers in the top 5 cm of each 10-cm layer of test B were totalled. This total was compared with the total of the corresponding layers of the ram test made in the normal manner to obtain the correction factor for the 0 to 5-cm layer. Likewise, the hardness values of the bottom 5 cm of each 10-cm layer were totalled, and the results were compared with the corresponding layers of the ram test made in the normal manner to obtain the correction factor for the 5 to 10-cm layer. The results are given in Appendix B and summarized in Table I. Test 4 was omitted because ice was encountered during the test. Tests 1 to 7 were made at the northeast entrance to Project 6 trench, using a ram with an aluminum shaft. Tests 8 to 11 were made in trench 12 using a ram with a steel shaft.

The test results show a correction factor of 4.17 for the 0 to 5-cm layer and 1.62 for the 5 to 10-cm layer. The mean deviation was 0.627, or 15% of the mean, for the 0 to 5-cm layer and 0.164 or 10.1% of the mean, for the 5 to 10-cm layer.

Effect of hammer drop height

In processed snow, a very wide range of hardness may be encountered. At times it would be very desirable to be able to control the amount of energy per blow delivered to the cone, to keep the penetration per blow within reasonable limits. One method of controlling the energy is to vary the drop height of the hammer. The purpose of this study is to determine if varying the drop height of the hammer has any effect on the ram hardness value obtained. Two test areas on the airstrip at Camp Century were used. In test area 1 the standard 60° ram and a 3-kg hammer weight were used; in test area 2 a ram with a 30° cone on a steel shaft and a 1-kg hammer weight were used. The testing was performed as shown in Figure 1 and explained on p. 2. The results are given in Appendix C.

Table I. Point correction test results.

Test no.	0-5 cm correction	5-10 cm correction
1	4.35	1.59
2	6.33	1.58
3	3.98	1.67
5	4.36	1.57
6	3.92	1.73
7	3.41	1.10
8	3.49	1.46
9	3.45	1.65
10	4.75	1.84
11	3.61	2.05
Avg	4.17	1.62

Mean deviation 0-5 correction .627 or 15.0% of mean
Mean deviation 5-10 correction .164 or 10.1% of mean

Table II. Drop height test results, test area 1.

Depth (cm)	Total energy (kg-cm), all tests		
	20-cm drop height	40-cm drop height	50-cm drop height
5	1440	2040	1500
10	3120	2520	3300
15	2580	3600	2700
20	8700	8520	8700
25	21180	18960	18450
30	13140	12000	12000
35	8040	7200	7800
40	5700	4920	5550
45	5040	4920	4950
50	4020	3360	4050
55	2820	2520	2400
60	2100	1800	2100
Total	77890	72360	73500

Table III. Drop height test results, test area 2.

Depth (cm)	Total energy (kg-cm), all tests		
	20-cm drop height	40-cm drop height	50-cm drop height
5	620	720	750
10	7140	3760	3800
15	22300	12920	12750
20	22960	14320	13950
25	12520	10400	10850
30	7920	7480	7750
35	5280	5760	5600
40	4560	4600	4400
45	4100	3920	3600
50	2520	2440	3100
55	2240	2200	2000
60	1880	2400	1950
Total	94040	70920	70500

The total energy for all 12 tests from each drop height was compared in each test area (Tables II, III). The data compared favorably, except in the case of the 20-cm drop height in test area 2. The data were then examined for each 5-cm layer. It was observed that the greatest difference in energy occurred when an exceptionally large or small number of blows was required for penetration of a given 5-cm layer. It was also observed that the most reliable range appeared to be when the number of blows per 5 cm of penetration was between 6 and 26. For each 5-cm depth interval which had at least two points in the 6 to 26 blows per 5-cm penetration range, the mean deviation was determined. A similar study was also made on those points which did not fall in this range. The average mean deviation of the points which fell in the 6 to 26 blows per 5-cm penetration was 2.5%, whereas the mean deviation of the points which did not fall in this range was 10.2%.

Effect of hammer weight.

The ram hardness value is based on the amount of energy required for unit penetration. As pointed out earlier, there is a loss of energy in the transfer when the hammer strikes the ram assembly. The amount of energy delivered to the system does not equal the potential energy of the system before the hammer is dropped. The ratio of the potential energy to the kinetic energy actually delivered to the system appears to be related to the ratio of the weights of the ram assembly and the hammer. As examples, field data were obtained in Greenland during the summer of 1963, using a hammer weight of 1 kg, the weight of ram assembly 1.13 kg, and drop heights of 40 and 50 cm. The results show that the total potential energy for 720 cm of penetration using a 40-cm drop height was 70,920 kg-cm, and the total potential energy for 720 cm of penetration using a 50-cm drop height was 70,500 kg-cm. This indicates that when the weight ratio between the ram assembly and the hammer is constant, the resulting ram hardness values appear to be consistent. Another test was performed using a 3-kg hammer weight from a 20-cm drop height and a 1-kg hammer weight from a 50-cm drop height. The potential energy required for 720 cm of penetration with the 1-kg weight from 50 cm was 83,050 kg-cm, while the potential energy required for 720 cm of penetration with the 3-kg weight from 20 cm was 61,740 kg-cm. These results indicate that when the weight of the ram assembly is kept constant and the hammer weight is increased (assuming drop height has no significant effect, as shown earlier), there is a decrease in the hardness value obtained.

In another test a 1-kg hammer weight, a drop height of 50 cm, and ram assembly weights of 1.39 and 3.01 kg were used. The 1.39-kg ram assembly required 65,300 kg-cm for 720 cm of penetration, while the 3.01-kg ram assembly required 75,920 kg-cm for 720 cm of penetration. The data indicate that when the hammer weight is kept constant and the weight of the ram assembly is increased, the hardness value is increased (Table IV).

Data for all tests are given in Appendix D.

It appears that the weight ratio of the hammer and the ram assembly has a significant effect on the ram hardness value obtained. Therefore, as recommended earlier, one standard hammer weight should be established, and any necessary changes in energy should be made by varying the drop height.

Effect of time interval between hammer drops

In order to improve the technique of making ram hardness measurements, a study was performed to determine the effect of time interval between hammer drops on the resulting hardness values.

Two separate studies were made, each study being performed in the manner shown in Figure 1. Ram tests in this study were performed by: 1) dropping the hammer, returning it to the original drop height, and allowing it to drop again as quickly as possible; 2) dropping the hammer, allowing it to remain down approximately 1 second before returning it to its original drop height, and then allowing it to drop again; 3) dropping the hammer, allowing it to remain down approximately 5 seconds before returning it to its original drop height, and then allowing it to drop again. The first series of tests

Table IV. Hammer weight test results.

Conditions		Energy required for 720 cm of penetration
Hammer weight	1.00 kg	
Ram weight	1.13 kg	70920 kg-cm
Drop height	40 cm	
Hammer weight	1.00 kg	
Ram weight	1.13 kg	70500 kg-cm
Drop height	50 cm	
Hammer weight	3.00 kg	
Ram weight	1.13 kg	61740 kg-cm
Drop height	20 cm	
Hammer weight	1.00 kg	
Ram weight	1.13 kg	83050 kg-cm
Drop height	50 cm	
Hammer weight	1.00 kg	
Ram weight	1.39 kg	65300 kg-cm
Drop height	50 cm	
Hammer weight	1.00 kg	
Ram weight	3.01 kg	75920 kg-cm
Drop height	50 cm	

was made using the standard 60° ram cone. The second series of tests was made in an area of harder snow using a 30° ram cone. For each test the total energy required for 60 cm of penetration was recorded. Data are given in Appendix E. The total energy for all tests of the same hammer drop frequency is shown in Tables V and VI.

The results indicate that much more energy is required for penetration when the delay between hammer blows is increased. Using the 0-sec delay as a standard, test 1 shows that 16.4% more energy is required with a 1-sec delay and 19.0% more energy is required with a 5-sec delay. Test 2 shows that 14.7% more energy is required with a 1-sec delay and 18.4% more energy is required with a 5-sec delay.

There appears to be an area of disaggregated snow below the point of the ram cone (Fig. 6). Constant ramming will keep this area disturbed, but even a slight delay will result in interlocking and possibly some bonding of these particles, resulting in a harder snow and thus requiring more energy for penetration. In order to obtain consistent hardness values, a uniform hammer blow frequency must be used. Although mechanical hammering is desirable for precise laboratory work, it is not considered practical for field work. It is believed that a satisfactory uniform rhythm can be established in the field without mechanical aids. It is recommended that the hammer be dropped as rapidly as possible, as it is easy to establish a uniform motion in this manner.

CONCLUSIONS AND RECOMMENDATIONS

The ram which is presently being used by USA CRREL was not designed for use in processed, age-hardened snow, and is not satisfactory for use in this material. Field tests have shown that a ram with a 30° cone penetrated the snow in a smoother manner and was much easier to extract when used in hard snow than a ram with a 60° cone. The addition of color bands to the penetrometer shaft aided greatly in reading the depth of the ram. The height from which the hammer was dropped apparently had little effect on the resulting hardness value as long as the rate of penetration was kept within reasonable limits. However, the hammer weight and time delay between hammer blows had a noticeable effect on the hardness values obtained.

Further testing should be performed with the 30° ram cone to learn more about the action of the instrument in very hard snow.

Table V. Time delay test results, 60° ram cone.

Depth (cm)	Total energy (kg-cm), all tests 0-sec delay	1-sec delay	5-sec delay
5	2580	2880	2820
10	7320	10560	10380
15	12750	17250	15000
20	9750	9600	11250
25	5100	5850	5850
30	3750	4950	5100
35	3450	3300	3600
40	3000	2700	4050
45	2850	2550	2550
50	1650	1950	1800
55	2100	1800	2250
60	1950	1950	2250
Total	56250	65340	66900

Table VI. Time delay test results, 30° ram cone.

Depth (cm)	Total energy (kg-cm), all tests 0-sec delay	1-sec delay	5-sec delay
5	2040	1860	1860
10	8820	11040	9900
15	18750	20850	19650
20	23850	28800	27750
25	22650	26550	28950
30	19050	23850	25500
35	17100	19500	20100
40	15000	15300	18000
45	12900	16050	16050
50	13950	14400	15300
55	13200	12600	14850
60	12150	12150	14700
Total	179,460	205,950	212,610

More data are needed for the point correction, since the values had a wide distribution. A more detailed study of the effect of hammer weight may provide data which would give a better understanding of penetration into snow. A correlation of unconfined compressive strength and ram hardness with the 30° cone under controlled laboratory conditions would also be desirable.

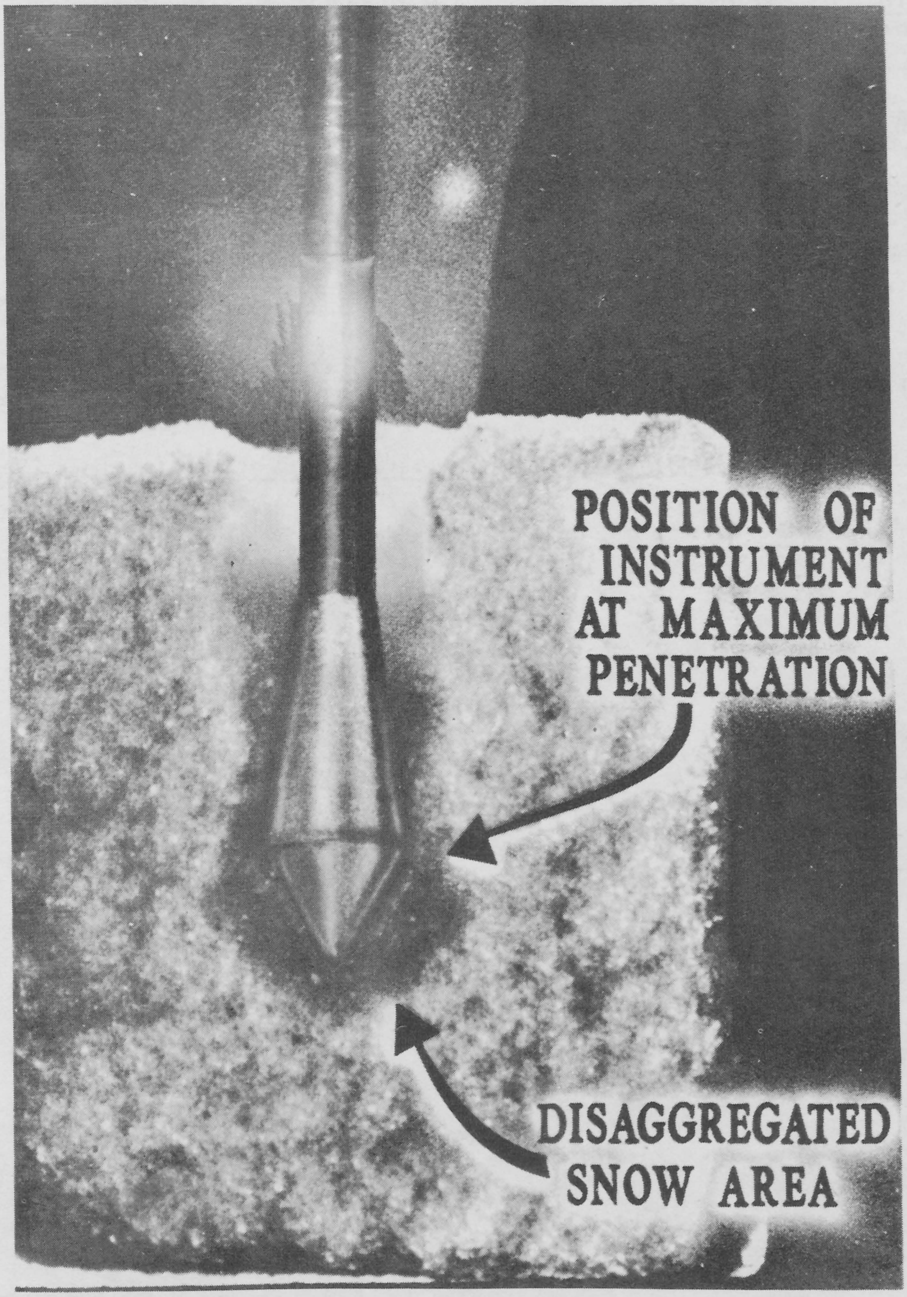

Figure 6. Disaggregated area beneath ram point.

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APPENDIX A: DATA FOR COMPARING RAMS

Keweenaw Field Station, 18 Feb 1963

Card no.	Test position	Type of ram	Ram hardness Depth (cm) 5	10	15	20	25	30	35	40	45	50	55	60
1		60°	640	640	394	394	394	304	214	214	214	184	184	154
2		30° AL	300	352	244	214	184	124	154	124	94	94	124	124
3		60°	584	1655	484	454	604	544	514	424	364	244	244	274
4		30° AL	188	218	214	214	244	394	304	214	274	244	184	124
5		60°	752	660	604	724	574	364	304	274	274	274	184	154
6		30° AL	300	275	214	364	334	274	214	154	154	124	94	64
7		60°	584	718	454	664	664	484	334	244	184	154	154	124
8		30° AL	300	237	244	334	214	184	184	184	154	94	94	64
9		60°	357	621	274	244	364	334	274	274	214	184	184	184
10		30° AL	188	218	154	214	184	214	184	154	124	94	94	94
11		60°	584	448	334	364	304	244	274	274	304	214	94	154
12		30° AL	244	256	184	214	214	214	214	184	154	184	154	94
13		60°	364	874	514	574	604	574	454	364	304	274	214	244
14		30° AL	244	198	634	424	364	304	244	274	184	154	124	124
15		60°	752	833	364	484	484	334	484	394	364	304	244	214
16		30° AL	244	257	244	424	364	364	274	244	214	244	184	154
17		60°	752	871	484	514	544	574	544	394	304	244	154	154
18		30° AL	357	257	214	274	244	274	274	244	184	154	124	94
19		60°	978	1100	454	454	424	544	514	484	424	274	244	214
20		30° AL	244	314	214	214	364	304	244	274	244	184	124	124
21		60°	1504	602	1144	934	634	514	424	334	274	304	244	244
22		30° AL	557	525	424	274	304	214	184	184	124	124	124	94
Camp Century, 1 July 1963														
160	A-1	60°	188	525	454	424	484	484	484	394	274	214	184	274
161	A-2	30° AL	132	102	154	184	334	334	364	274	184	184	94	94
162	A-3	30° ST	132	198	274	214	304	304	304	334	244	94	154	94
163	A-4	60°	300	179	334	454	454	604	544	364	184	154	94	124
164	A-5	30° AL	132	102	124	214	304	274	184	154	124	124	124	154
165	A-6	30° ST	75	198	184	304	394	334	304	184	124	123	154	154
166	B-1	30° AL	132	122	184	304	274	364	334	364	214	94	154	184
167	B-2	30° ST	75	102	184	244	244	274	274	154	94	124	94	124
168	B-3	60°	132	294	364	484	514	454	244	124	124	94	94	154
169	B-4	30° AL	75	64	184	304	274	274	244	124	154	124	94	64
170	B-5	30° ST	75	45	124	244	244	214	154	184	154	184	124	154
171	B-6	60°	132	64	244	364	394	334	274	214	244	184	154	184
172	C-1	30° ST	132	88	214	124	184	244	214	184	154	124	124	214
173	C-2	60°	188	88	244	394	364	274	124	64	124	124	124	184
174	C-3	30° AL	75	45	124	184	184	214	154	94	94	124	154	124
175	C-4	30° ST	132	160	184	184	214	214	154	154	154	214	184	184
176	C-5	60°	132	172	394	394	334	304	214	244	214	184	214	304
177	C-6	30° AL	75	26	94	214	184	184	154	184	154	184	184	304
178	D-1	60°	132	160	154	184	214	154	124	154	124	94	154	214
179	D-2	30° AL	75	83	64	94	154	124	154	124	154	124	124	124
180	D-3	30° ST	75	26	64	214	214	214	244	184	124	154	154	124
181	D-4	60°	132	122	244	334	274	244	184	244	184	184	124	124
182	D-5	30° AL	75	83	64	94	124	94	94	94	124	154	154	184
183	D-6	30° ST	75	26	34	64	94	124	94	64	124	214	184	184

Camp Century, 1 July 1963 (Cont'd)

Card no.	Test position	Type of ram	Ram hardness Depth (cm) 5	10	15	20	25	30	35	40	45	50	55	60
184	E-1	30° AL	75	64	64	94	124	94	64	94	64	64	94	94
185	E-2	30°ST	75	45	64	64	94	94	124	94	94	94	94	124
186	E-3	60°	75	45	94	124	94	64	64	64	154	154	214	244
187	E-4	30° AL	75	26	64	34	64	64	94	64	94	154	154	154
188	E-5	30°ST	132	64	64	64	64	34	94	64	124	154	214	154
189	E-6	60°	75	102	64	64	154	154	154	124	124	274	304	274
190	F-1	30°ST	75	45	64	34	64	34	94	94	124	154	124	94
191	F-2	60°	75	102	94	94	64	64	94	94	94	184	214	244
192	F-3	30° AL	75	26	34	94	64	64	64	94	64	124	154	94
193	F-4	30°ST	38	13	64	124	64	34	64	64	64	154	184	184
194	F-5	60°	75	26	64	64	184	124	124	124	154	214	244	244
195	F-6	30° AL	38	13	64	64	94	94	124	124	154	124	154	154

Camp Century, 15 July 1963

Card no.	Test position	Type of ram	5	10	15	20	25	30	35	40	45	50	55	60
431	A-1	60°	244	371	154	124	124	214	274	274	304	154	244	214
432	A-2	30° AL	132	102	94	94	64	154	214	154	184	124	124	154
433	A-3	30°ST	75	83	154	64	94	94	154	184	184	124	154	154
434	A-4	60°	300	288	154	124	124	184	274	334	274	154	214	184
435	A-5	30° AL	188	102	94	64	94	64	184	184	124	124	124	184
436	A-6	30°ST	188	160	94	94	64	94	154	184	154	154	154	184
437	B-1	30° AL	188	141	124	124	64	124	94	154	184	154	124	154
438	B-2	30°ST	244	102	124	94	94	94	124	214	184	184	124	154
439	B-3	60°	357	237	154	154	154	124	184	274	274	184	184	274
440	B-4	30° AL	188	122	94	64	94	64	124	184	154	154	94	154
441	B-5	30°ST	188	122	94	94	64	64	154	184	184	184	94	184
442	B-6	60°	244	237	124	94	154	124	274	244	274	214	214	274
443	C-1	30°ST	75	102	274	364	184	154	124	244	214	184	94	214
444	C-2	60°	414	333	184	184	124	124	154	274	214	274	184	304
445	C-3	30° AL	407	160	124	94	64	64	94	154	154	154	94	184
446	C-4	30°ST	188	160	94	124	64	94	124	184	184	184	64	244
447	C-5	60°	414	294	154	154	94	124	214	304	184	244	154	304
448	C-6	30° AL	188	102	94	64	64	64	124	184	124	124	124	154
449	D-1	60°	584	314	184	124	124	124	154	244	334	274	184	274
450	D-2	30° AL	244	83	94	94	94	64	94	124	184	154	154	124
451	D-3	30°ST	188	64	94	124	94	64	94	184	184	184	154	124
452	D-4	60°	300	141	154	154	124	124	154	274	274	274	214	304
453	D-5	30° AL	244	102	94	124	94	94	94	154	154	94	94	94
454	D-6	30°ST	132	83	94	94	94	64	124	184	154	154	94	244
455	E-1	30° AL	244	160	64	94	94	64	94	154	154	214	184	94
456	E-2	30°ST	300	122	94	94	94	94	64	154	184	214	184	94
457	E-3	60°	300	256	154	154	184	194	124	244	244	274	244	244
458	E-4	30° AL	188	102	94	94	94	64	64	124	154	154	154	124
459	E-5	30°ST	244	141	94	124	94	94	154	154	154	124	64	124
460	E-6	60°	300	275	124	154	154	94	184	244	214	244	154	304
461	F-1	30°ST	527	160	64	94	94	64	94	124	184	184	214	184
462	F-2	60°	470	294	124	154	154	94	124	214	334	274	274	124
463	F-3	30° AL	470	141	94	94	64	94	64	94	124	214	154	124
464	F-4	30°ST	527	179	94	94	124	64	64	124	154	184	184	124
465	F-5	60°	696	486	124	184	124	124	184	214	214	184	154	124
466	F-6	30° AL	244	122	64	64	64	64	94	124	154	154	124	124

Camp Century, 17 July 1963

Card no.	Test position	Type of ram	Ram hardness Depth (cm) 5	10	15	20	25	30	35	40	45	50	55	60
495	A-1	60°	922	1466	754	604	484	304	334	244	244	214	184	184
496	A-2	30°ST	300	506	604	754	484	304	154	154	154	214	154	124
497	A-3	30°AL	244	333	364	484	364	244	184	184	154	124	124	94
498	A-4	60°	414	1408	754	484	394	304	304	244	244	214	214	184
499	A-5	30°ST	470	429	304	334	304	214	184	184	214	184	184	154
500	A-6	30°AL	300	275	394	394	304	184	214	214	154	94	94	124
501	B-1	30°ST	300	486	544	604	484	214	184	154	154	124	94	124
502	B-2	30°AL	357	333	484	454	364	244	184	64	94	124	124	94
503	B-3	60°	357	890	1054	2404	1564	544	454	334	214	184	154	124
504	B-4	30°ST	188	390	484	334	304	184	214	154	154	154	124	124
505	B-5	30°AL	300	294	304	244	244	244	244	154	154	124	154	154
506	B-6	60°	300	486	754	664	574	484	454	334	244	274	184	274
507	C-1	30°AL	244	333	364	274	304	244	214	154	154	154	124	124
508	C-2	60°	414	756	724	574	394	394	274	184	184	214	244	244
509	C-3	30°ST	188	257	394	424	304	214	184	154	154	154	154	154
510	C-4	30°AL	188	256	274	244	274	244	154	184	94	94	94	94
511	C-5	60°	414	640	424	484	424	394	364	274	274	214	184	154
512	C-6	30°ST	300	506	334	364	364	334	304	214	244	214	124	94
513	D-1	60°	527	371	484	604	304	244	274	214	184	184	214	184
514	D-2	30°ST	300	122	274	484	244	184	154	184	124	154	124	64
515	D-3	30°AL	244	314	364	604	334	274	214	154	124	124	94	94
516	D-4	60°	584	852	544	454	304	304	274	184	154	184	124	184
517	D-5	30°ST	244	371	364	274	214	244	154	124	124	124	94	124
518	D-6	30°AL	244	256	274	274	304	274	244	214	154	124	94	64
519	E-1	30°ST	132	256	634	634	454	364	334	244	214	154	184	184
520	E-2	30°AL	188	256	394	544	424	244	214	214	154	154	124	94
521	E-3	60°	527	602	814	694	574	514	334	244	214	214	214	214
522	E-4	30°ST	244	256	394	394	364	274	244	184	154	184	154	184
523	E-5	30°AL	188	333	364	364	334	304	274	214	184	154	154	94
524	E-6	60°	527	718	484	544	514	454	454	364	274	244	184	214

Test 4 was omitted because ice was encountered during the test. Tests 1 to 7 were made at the northeast entrance to Project 6 trench, using a ram with an aluminum shaft. Tests 8 to 11 were in trench 12 using a ram with a steel shaft.

Test no. 1

Camp Century, 8 July 1963

Depth	Ram normal		Ram 10-cm layers	
	For 0-5 cm correction	For 5-10 cm correction	For 0-5 cm correction	For 5-10 cm correction
15	222		52	
20		252		122
25	192		22	
30		132		62
35	82		22	
40		72		62
45	62		42	
50		82		92
Total	558	538	138	338

0-5 Correction $= \frac{558}{138} = 4.35$

5-10 Correction $= \frac{538}{338} = 1.59$

Test no. 2

15	130		18	
20		214		62
25	178		18	
30		98		54
35	102		22	
40		50		42
45	46		14	
50		50		102
Total	456	412	72	260

0-5 Correction $= \frac{456}{72} = 6.33$

5-10 Correction $= \frac{412}{260} = 1.58$

Test no. 3

Camp Century, 8 July 1963

Depth	Ram normal		Ram 10-cm layers	
	For 0-5 cm correction	For 5-10 cm correction	For 0-5 cm correction	For 5-10 cm correction
15	92		22	
20		134		82
25	90		30	
30		54		54
35	70		10	
40		62		46
45	114		30	
50		138		50
Total	366	388	92	232

0-5 Correction $= \frac{366}{92} = 3.98$

5-10 Correction $= \frac{388}{232} = 1.67$

Test no. 5

15	66		18	
20		106		74
25	106		22	
30		106		58
35	50		6	
40		30		18
45	22		10	
50		46		34
Total	244	288	56	184

0-5 Correction $= \frac{244}{56} = 4.36$

5-10 Correction $= \frac{288}{184} = 1.57$

Test no. 6

15	96		22	
20		136		66
25	106		22	
30		86		46
35	46		14	
40		26		26
45	34		14	
50		70		46
Total	282	318	72	184

0-5 Correction $= \frac{282}{72} = 3.92$

5-10 Correction $= \frac{318}{184} = 1.73$

Test no. 7

Camp Century, 8 July 1963

Depth	Ram normal For 0-5 cm correction	Ram normal For 5-10 cm correction	Ram 10-cm layers For 0-5 cm correction	Ram 10-cm layers For 5-10 cm correction
15	74		22	
20		96		74
25	154		30	
30		50		78
35	38		10	
40		26		22
45	34		26	
50		66		42
Total	300	238	88	216

0-5 Correction = $\frac{300}{88}$ = 3.41

5-10 Correction = $\frac{238}{216}$ = 1.10

Test no. 8

Camp Century, 15 July 1963

15	64		16	
20		64		52
25	52		28	
30		64		64
35	88		28	
40		124		52
45	160		28	
50		124		76
55	124		40	
60		160		124
Total	488	536	140	368

0-5 Correction = $\frac{488}{140}$ = 3.49

5-10 Correction = $\frac{536}{368}$ = 1.46

Test no. 9

Camp Century, 15 July 1963

Depth	Ram normal For 0-5 cm correction	Ram normal For 5-10 cm correction	Ram 10-cm layers For 0-5 cm correction	Ram 10-cm layers For 5-10 cm correction
15	52		28	
20		64		40
25	64		28	
30		76		64
35	124		28	
40		160		76
45	148		28	
50		124		76
55	136		40	
60		184		112
Total	524	608	152	368

0-5 Correction = $\frac{524}{152}$ = 3.45

5-10 Correction = $\frac{608}{368}$ = 1.65

Test no. 10

15	76		16	
20		52		40
25	76		16	
30		64		52
35	124		28	
40		148		76
45	196		28	
50		184		64
55	136		40	
60		184		112
Total	608	632	128	334

0-5 Correction = $\frac{608}{128}$ = 4.75

5-10 Correction = $\frac{632}{334}$ = 1.84

Test no. 11

15	64		28	
20		64		40
25	76		28	
30		88		40
35	88		28	
40		148		76
45	172		28	
50		184		76
55	148		40	
60		196		100
Total	548	680	152	332

0-5 Correction = $\frac{548}{152}$ = 3.61

5-10 Correction = $\frac{680}{332}$ = 2.05

APPENDIX C: DATA FOR EFFECT OF DROP HEIGHT

Camp Century, 29 June 1963. Test area 1, standard 60° ram, 3-kg hammer.

Card no.	Test position	Drop height (cm)	No. of hammer blows depth (cm) 5	10	15	20	25	30	35	40	45	50	55	60
119	A-1	20	1	6	4	8	32	23	10	8	8	8	6	2
120	A-2	40	1	2	1	5	18	8	5	3	4	3	3	1
121	A-3	50	1	1	1	3	9	6	4	2	2	2	2	1
122	A-4	20	2	3	4	10	29	22	11	7	6	5	4	3
123	A-5	40	2	1	6	12	11	5	4	3	3	2	1	1
124	A-6	50	1	1	1	3	9	7	5	3	3	3	2	1
125	B-1	40	1	1	1	5	15	8	4	2	3	2	2	1
126	B-2	50	0	1	0	4	7	4	3	3	2	1	1	1
127	B-3	20	1	2	5	6	25	12	7	7	6	4	2	2
128	B-4	40	0	1	1	6	15	9	5	3	3	1	2	1
129	B-5	50	0	2	2	5	10	7	4	3	2	2	1	1
130	B-6	20	0	4	4	13	26	21	12	7	6	5	3	3
131	C-1	50	1	1	1	2	7	5	4	1	2	2	2	1
132	C-2	20	1	5	4	7	16	15	7	5	5	3	3	2
133	C-3	40	1	2	3	4	8	7	3	3	3	2	1	1
134	C-4	50	1	2	2	5	10	6	4	3	3	2	1	1
135	C-5	20	1	4	3	15	36	16	17	12	8	6	4	3
136	C-6	40	1	1	2	5	10	8	6	4	4	2	3	1
137	D-1	20	2	3	3	4	19	17	8	7	5	6	4	3
138	D-2	40	1	2	2	4	9	8	4	2	3	2	1	1
139	D-3	50	0	3	1	3	8	7	4	4	3	2	1	1
140	D-4	20	3	5	5	13	26	18	12	6	6	4	3	3
141	D-5	40	1	2	2	5	14	9	6	3	4	2	1	2
142	D-6	50	1	2	3	6	11	7	4	4	3	2	2	2
143	E-1	40	2	3	4	6	14	11	7	4	4	2	2	1
144	E-2	50	2	2	3	6	13	8	6	4	3	4	1	1
145	E-3	20	3	6	6	15	46	24	14	10	9	8	5	3
146	E-4	40	1	2	4	9	20	12	6	5	2	3	1	2
147	E-5	50	1	3	2	12	20	9	5	4	4	3	1	1
148	E-6	20	4	4	7	27	52	25	17	13	13	10	7	3
149	F-1	50	1	2	1	2	9	6	4	3	2	2	1	1
150	F-2	20	3	5	5	7	22	13	9	7	7	4	3	3
151	F-3	40	1	2	2	2	12	8	6	4	4	3	2	2
152	F-4	50	1	2	1	7	10	8	5	3	4	2	1	2
153	F-5	20	3	5	4	20	24	13	10	6	5	4	3	5
154	F-6	40	1	2	2	8	12	7	4	5	4	4	2	1

APPENDIX C

Camp Century, 1 July 1963. Test area 2, 30° cone on a steel shaft, 1-kg hammer.

Card no.	Test position	Drop height (cm)	No. of hammer blows depth (cm) 5	10	15	20	25	30	35	40	45	50	55	60
204	A-1	20	2	16	52	42	52	79	60	40	60	20	9	8
205	A-2	40	1	3	25	29	19	17	24	15	18	11	4	4
206	A-3	50	1	2	12	12	11	10	22	14	10	10	4	3
207	A-4	20	2	14	40	37	18	27	34	26	20	25	20	8
208	A-5	40	1	5	22	50	32	18	14	14	10	11	7	6
209	A-6	50	1	1	12	18	18	15	18	9	10	10	6	4
210	B-1	40	1	5	28	35	22	19	23	11	10	4	4	4
211	B-2	50	1	8	21	26	20	9	6	4	3	2	3	3
212	B-3	20	4	20	90	92	60	26	18	11	9	5	5	8
213	B-4	40	1	4	15	27	19	9	8	5	4	3	3	6
214	B-5	50	2	6	17	22	21	10	7	7	5	5	2	3
215	B-6	20	3	37	51	64	81	36	16	14	13	12	7	7
216	C-1	50	1	8	25	29	18	10	5	8	5	6	4	2
217	C-2	20	1	23	100	98	40	22	20	20	12	6	8	9
218	C-3	40	2	12	35	26	20	12	10	10	7	3	4	6
219	C-4	50	1	7	19	20	17	11	7	7	6	3	2	4
220	C-5	20	3	28	140	70	37	20	13	18	14	7	7	6
221	C-6	40	4	15	32	29	22	12	9	8	7	3	3	5
222	D-1	20	5	118	136	63	57	34	23	20	20	14	10	9
223	D-2	40	2	9	37	52	34	20	12	12	10	8	4	4
224	D-3	50	1	12	50	40	31	20	13	9	9	8	5	4
225	D-4	20	2	25	150	130	60	42	25	20	14	12	16	8
226	D-5	40	1	6	16	13	16	16	9	7	7	3	4	4
227	D-6	50	1	7	23	30	20	10	5	3	6	5	2	3
228	E-1	40	1	8	39	40	35	17	16	14	12	6	6	4
229	E-2	50	2	7	18	33	22	18	13	15	8	5	3	3
230	E-3	20	2	11	70	155	77	48	20	22	19	12	9	9
231	E-4	40	1	10	18	18	17	17	7	11	8	5	5	5
232	E-5	50	2	6	19	17	16	13	5	6	6	5	4	3
233	E-6	20	2	18	122	260	95	33	19	26	16	6	8	7
234	F-1	50	1	7	27	15	11	6	5	4	3	2	3	3
235	F-2	20	1	17	84	77	25	15	11	10	7	5	6	9
236	F-3	40	1	8	23	19	11	8	4	3	2	2	3	5
237	F-4	50	1	5	12	17	12	5	6	2	1	1	2	4
238	F-5	20	4	30	80	60	24	14	5	1	1	2	7	6
239	F-6	40	2	9	33	20	13	11	8	5	3	2	8	7

APPENDIX D: DATA FOR EFFECT OF HAMMER WEIGHT

Camp Century, 1 July 1963. 1-kg hammer, 1.13-kg ram assembly.

Totals for 12 ram tests

Depth	Number of blows 40 cm	Number of blows 50 cm	Total energy (kg-cm) 40 cm	Total energy (kg-cm) 50 cm
5	18	15	720	750
10	94	76	3760	3800
15	323	255	12920	12750
20	358	279	14320	13950
25	260	217	10400	10850
30	187	155	7480	7750
35	144	112	5760	5600
40	115	88	4600	4400
45	98	72	3920	3600
50	61	62	2440	3100
55	55	40	2200	2000
60	60	39	2400	1950
		Total	70920	70500

Camp Century, 10 July 1963.

Totals for 12 ram tests

Drop height	Depth	Number of blows 1 kg hammer 1.39-kg ram	Number of blows 1 kg hammer 3.01-kg ram	Total energy (kg-cm) 1 kg hammer 1.39-kg ram	Total energy (kg-cm) 1 kg hammer 3.01-kg ram
20-cm drop height	5	20	19	400	380
	10	100	97	2000	1940
	15	61	86	3050	4300
	20	159	191	7950	9550
50-cm drop height	25	283	356	14150	17800
	30	263	289	13150	14450
	35	159	209	7950	10450
	40	101	98	5050	4900
	45	67	78	3650	3900
	50	67	71	3650	3600
	55	46	50	2300	2500
	60	39	43	1950	2150
			Total	65300	75920

Camp Century, 13 July 1963

Total for 12 ram tests

Depth	Number of blows 3-kg hammer 20-cm height	Number of blows 1-kg hammer 50-cm height	Total energy (kg-cm) 3-kg hammer 20-cm height	Total energy (kg-cm) 1-kg hammer 50-cm height
5	38	50	2280	2500
10	71	93	4260	4650
15	146	228	8760	11400
20	207	366	12420	18300
25	206	357	12360	17850
30	121	193	7260	9650
35	70	125	4200	6250
40	44	74	2640	3700
45	38	44	2280	2200
50	32	42	1920	2100
55	31	46	1860	2300
60	25	43	1500	2150
	Total		61740	83050

APPENDIX E: DATA FOR EFFECT OF HAMMER DROP FREQUENCY

Camp Century, 2 July 1963. 60° standard ram cone.

Card no.	Test position	Time delay (sec)	Number of blows 3-kg hammer depth (cm) 5	10	15	20	25	30	35	40	45	50	55	60
240	A-1	0	4	7	7	5	2	1	2	2	1	1	1	2
241	A-2	1	4	9	9	4	2	2	2	2	1	1	1	1
242	A-3	5	8	10	5	3	2	2	1	1	1	1	1	2
243	A-4	0	3	13	6	4	2	1	1	1	1	1	1	1
244	A-5	1	4	15	9	4	1	2	1	0	1	1	1	1
245	A-6	5	2	17	9	4	3	3	2	2	2	1	2	1
246	B-1	1	7	25	7	4	1	2	1	1	1	1	1	1
247	B-2	5	7	17	6	4	1	1	1	1	1	1	1	1
248	B-3	0	5	16	7	3	2	1	1	1	1	1	1	1
249	B-4	1	6	23	9	6	3	2	2	1	2	1	1	2
250	B-5	5	6	19	10	6	3	1	2	1	1	1	2	1
251	B-6	0	6	9	9	4	2	1	1	1	1	1	1	1
252	C-1	5	4	14	8	7	2	2	1	2	1	1	1	1
253	C-2	0	4	14	5	6	2	2	2	2	1	1	1	1
254	C-3	1	5	7	14	5	3	2	2	1	1	1	1	1
255	C-4	5	5	14	7	7	3	2	2	2	1	1	1	2
256	C-5	0	4	11	7	4	2	3	1	1	2	1	2	1
257	C-6	1	4	10	7	5	3	2	1	1	2	1	1	1
258	D-1	0	2	7	7	5	3	3	4	2	0	1	1	1
259	D-2	1	2	10	7	5	5	5	2	2	1	1	1	2
260	D-3	5	2	12	6	3	3	3	2	2	1	1	1	1
261	D-4	0	6	12	5	3	2	2	2	3	2	1	1	1
262	D-5	1	5	19	8	5	4	4	3	2	1	1	1	1
263	D-6	5	4	23	8	5	3	5	2	2	1	1	1	1
264	E-1	1	3	12	9	7	4	4	3	3	2	1	1	1
265	E-2	5	3	9	7	9	6	5	4	3	2	1	1	1
266	E-3	0	1	3	3	5	5	2	4	2	2	1	1	1
267	E-4	1	5	23	9	2	3	2	1	1	1	1	1	1
268	E-5	5	3	9	7	3	2	2	2	1	1	1	1	1
269	E-6	0	4	14	6	2	2	2	1	1	1	1	1	1
270	F-1	5	2	14	14	13	6	4	3	7	3	1	2	1
271	F-2	0	3	8	11	11	5	3	2	3	3	1	2	1
272	F-3	1	2	10	14	10	5	3	3	3	2	2	1	1
273	F-4	5	1	15	13	11	5	4	2	3	2	1	1	2
274	F-5	0	1	8	12	13	5	4	2	1	3	1	1	1
275	F-6	1	1	13	13	7	5	3	1	1	2	1	1	1

20 cm Drop (5–20 cm) — 50 cm Drop (25–60 cm)

APPENDIX E

Camp Century, 11 July 1963. 30° ram cone.

Card no.	Test position	Time delay (sec)	5	10	15	20	25	30	35	40	45	50	55	60
371	A-1	0	2	12	14	19	14	6	5	3	3	5	6	7
372	A-2	1	1	9	11	18	17	10	6	6	7	9	5	4
373	A-3	5	2	13	8	16	17	10	9	7	7	10	12	13
374	A-4	0	2	8	11	18	14	10	9	8	9	12	11	9
375	A-5	1	2	7	7	21	11	12	12	12	9	10	7	6
376	A-6	5	1	11	9	18	21	15	14	10	9	10	10	10
377	B-1	1	4	19	13	20	23	19	16	16	14	9	6	7
378	B-2	5	4	19	13	24	23	20	13	10	10	13	13	13
379	B-3	0	3	11	8	13	17	13	12	10	10	9	8	8
380	B-4	1	3	14	12	23	23	22	20	18	12	12	10	9
381	B-5	5	3	14	9	14	22	19	14	14	14	12	10	9
382	B-6	0	2	9	9	13	17	19	17	15	13	13	12	10
383	C-1	5	3	13	16	20	21	23	16	14	12	8	7	8
384	C-2	0	3	18	13	11	15	16	13	8	7	7	8	8
385	C-3	1	2	10	9	12	20	21	16	13	13	10	11	9
386	C-4	5	2	8	9	19	21	20	19	16	12	10	7	6
387	C-5	0	3	10	9	13	14	15	14	16	14	13	10	10
388	C-6	1	3	16	14	10	8	11	10	11	12	13	12	13
389	D-1	0	2	8	12	13	11	7	6	5	4	4	5	5
390	D-2	1	2	17	15	16	13	12	9	7	8	6	6	6
391	D-3	5	2	14	9	13	15	15	9	8	9	8	10	10
392	D-4	0	3	13	7	11	13	10	10	7	5	5	6	7
393	D-5	1	3	14	9	16	16	12	12	11	10	9	6	6
394	D-6	5	2	10	8	13	12	8	9	10	8	9	9	8
395	E-1	1	3	19	17	22	18	11	9	8	5	5	6	5
396	E-2	5	4	17	12	13	10	9	7	6	5	4	5	5
397	E-3	0	4	13	8	12	10	7	6	6	4	5	4	3
398	E-4	1	2	25	10	11	10	9	6	7	5	5	5	7
399	E-5	5	5	12	9	10	8	7	7	9	7	7	6	5
400	E-6	0	4	13	14	15	11	10	10	11	8	9	9	5
401	F-1	5	2	22	19	15	13	14	11	9	7	6	5	5
402	F-2	0	4	18	13	11	8	8	6	7	5	7	5	5
403	F-3	1	3	18	9	12	9	11	9	7	6	4	5	5
404	F-4	5	1	12	10	10	10	10	6	7	7	5	5	6
405	F-5	0	2	14	7	10	7	6	6	4	4	4	4	4
406	F-6	1	3	16	13	11	9	9	5	6	6	4	5	4

20 cm Drop   50 cm Drop

APPENDIX F: SUGGESTED RAM FORMULA REVISIONS

By making several modifications to the ram formula it may be possible to obtain reliable predictions of the failure of a snow surface under both static and dynamic loads. The ram formula presently being used is

$$R = (qQ + W) + \frac{Whn}{s}$$

where:

R = Ram hardness number
q = Number of tube lengths
Q = Weight of one tube (kg)
W = Weight of hammer (kg)
h = Height of fall (cm)
n = Number of blows
s = Penetration resulting from n blows.

The formula would be more realistic if it was modified as follows:

$$R = (qQ + W) + \frac{Whn}{s} \alpha \beta \gamma$$

where:

α = reduction factor to correct for the amount of energy lost in the hammer blow due to the weight ratio of the hammer and penetrometer assembly.

β = reduction factor to correct for the amount of energy lost in internal deformation of the shaft.

γ = correction factor to reduce the effect of the cone to an equivalent circular plate.

This expression would give a truer indication of the actual amount of energy delivered to the snow surface. The impulse of energy tends to induce a velocity, V_0, to the ram assembly. The resistance of the snow reduces this velocity from V_0 to 0 in a distance s. From the formula $V = V_0 + 2as$, when $V = 0$, $V_0 = -2as$; acceleration a may be found when V_0 and s are known.

The term (qQ + W) indicates whether or not the snow surface has the capability to support the weight of the apparatus, i.e., if the surface will support the load at 1G. The value a as described in the preceding paragraph is divided by the acceleration of gravity g to give the added number of G's at which the surface will support the given load (qQ + W). Therefore, the load carrying capacity R' of the surface in terms of a given load will be: $R' = 1 + a/g$. R' multiplied by the load (qQ + W) and divided by the maximum cross-sectional area of the penetrometer will give the resistance to penetration R of the snow in kg/cm^2. This value of R could be compared with various dynamic loadings and possibly a reliable correlation would be established. Likewise, static loadings such as footings could be analyzed to predict settlement. In a typical test, a plate of a given diameter D would be loaded to certain specified percentages of R, and plates of several multiples of D would be loaded to the same percentages of R. The results could then be analyzed to determine how much settlement would occur in each layer of a given depth with a given percentage of R loading.

With the addition of one more term Δ, a skin friction factor, it may be possible to predict the amount of energy required to drive a pile and the supporting capacity of that pile.