# VEHICULAR TRAFFICABILITY OF SNOW

BY

MARVIN DIAMOND

SIPRE
CORPS OF ENGINEERS, U.S. ARMY
WILMETTE, ILL.

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M. DIAMOND

## INTRODUCTION

The Department of the Army is directly interested in the relation of vehicle performance over snow. This is a vital problem in the movement of combat forces and combat support forces in snow covered areas.

The ability of a vehicle to operate over a snow surface is dependent in part upon the mechanical properties of the snow. These properties are largely a function of the meteorological phenomena to which the snow cover has been subjected since its deposition.

The influence of snow properties and certain meteorological phenomena on the trafficability of a snow surface has been studied in the high mountains of California and in Northern Michigan. Tests were conducted by the Snow, Ice and Permafrost Research Establishment during the winter and spring of 1951-52 at the Central Sierra Snow Laboratory, California, and during the winter of 1955 at its Keweenaw Field Station located near Houghton, Michigan. Both the Central Sierra Snow Laboratory and the Keweenaw Field Station are U.S. Army Corps of Engineers installations

Lightweight, low ground-pressure, track-type vehicles capable of travelling at comparatively high speeds were used in these studies.

## TEST VEHICLES

The snow tractors used in the trafficability studies were: *M-7 Ordnance*, half-track vehicle with wide pad tracks and a ski-steering front, referred to in this report as the "M-7". Without load it has a unit ground pressure on the tracks of 0.71 psi.

*Tucker Sno-cat*, Model 421, of the half-track type with a ladder track system on two pontoons and a ski-steering front end, referred to in this report as "T-2". It has a unit ground pressure on the pontoons of 0.49 psi when not loaded.

*Tucker Sno-cat*, Model 443, with a ladder track system on four pontoons, with front and rear drive and front and rear hydraulic steering, referred to in this report as "T-4". Unit ground pressure is 0.73 psi on the front pontoons and 0.60 on the rear pontoons, unloaded.

Pertinent specifications for the vehicles are listed in Table I and photographs of them are presented in Plates 1 to 3. All of the vehicles were maintained in optimum mechanical condition during the tests.

## INSTRUMENTATION AND TEST PROCEDURE

### CALIFORNIA TESTS

The "dead load" drawbar pull of the tractors was obtained by means of a dynamometer provided with a set hand and attached to a cable between the tractor and a tree. Measurements of maximum drawbar pull prior to or just after the start of track slippage and drawbar pull under steady track slippage were made during most tests. Instrumentation used did not permit an accurate determination of the beginning of track slippage. The maximum drawbar pull was determined from the reading of the set-hand on the dynamometer after definite slippage was observed and drawbar pull decreased.

### NORTHERN MICHIGAN TESTS

Drawbar pull was measured with a Baldwin strain gauge load cell having a range of 0-30,000 lb. The drive shaft torque of both the M-7 and T-2 was measured with a Baldwin SR4 type Torque pickup with a range of 0-20,000 lb-in. Values of both torque and drawbar pull were recorded on a Brown "Electronik" recording potentiometer which was installed in a console on a sled towed by the test vehicle. An Esterline-Angus Operations Recorder installed on the console was used to record distance travelled by track and vehicle and depth of rut produced by vehicle Track slippage was computed from distance travelled by both track and vehicle.

The test vehicle was connected through the dynamometer sled to a braking vehicle (Pl. 4). During each trial an increase in drawbar load was obtained either by decreasing engine speed or by braking the towed vehicle.

## SNOW TESTS AND METEOROLOGICAL MEASUREMENTS

Density, temperature, and hardness of the undisturbed snow cover were measured at various depths before the trials and in the rut produced by one pass of the test vehicle. A detailed description of the instruments used in making these measurements is given in SIPRE Report 7 (1952) and SIPRE Instruction Manual 1 (1954). Continuous records of air temperature, dewpoint, wind velocity, and incident and reflected solar radiation were available from the concurrent snow metamorphism-meteorological research project in the vicinity of both test sites.

## RESULTS OF TRAFFICABILITY TESTS

"Drawbar coefficient", which has been defined as the ratio of the drawbar pull of a vehicle to its weight, has been used in soils trafficability work to compare the tractive ability of vehicles of different weights. In the Michigan tests it was observed that when drawbar pull (P) was plotted against the weight (V) of the loaded vehicle, the resulting points fit reasonably well a straight line which goes through the origin:

$$P = bV \qquad (1)$$

where b is constant. The plots of drawbar pull against weight for some of the tests are shown in Figure 1. The drawbar coefficient is then equal to the slope of the line or:

$$b = \frac{P}{V} \qquad (2)$$

A plot of the drawbar coefficients against track slip for a number of trials when very good records of track speed and vehicle travel distance were obtained is presented in Figure 2. The curves show that the maximum drawbar coefficient was obtained within a range of 20 to 40% track slip. This is evidence that the trafficability of snow may be a function of its dynamic (kinetic) friction. The distribution of points around the curves for the several tests with the M-7 emphasize the difficulties that may be expected in any attempt to associate small changes in track slip, of the order of 5% with vehicle performance.

The 1955 trials were limited to two periods, 2-5 February and 9-11 March, which made it difficult to establish a relationship between many snow properties and trafficability. However, as shown in Table 2, higher drawbar coefficients were obtained in March when the snow was harder and denser than in February.

## RELATIONSHIP BETWEEN SOME SNOW PROPERTIES AND DRAWBAR PULL

### DENSITY

The density of the undisturbed snow appeared to be one of the more important properties affecting trafficability. To determine the effect of the initial density and some of the other physical properties of the snow cover on trafficability, the depth to which the snow cover was affected by the passage of a vehicle was measured. A study of one of the snow-profile measurements made immediately before and after the passage of the test vehicle, shown graphically in Figure 3, indicated that only the top 15 in. of the snow cover was affected by the vehicle, so only the density of this top layer was used in evaluating the results of the trafficability tests.

For comparison purposes, curves showing the relationship between density and the maximum drawbar coefficient for the trials at both locations are shown in Figure 4. In the trials in Northern Michigan, the drawbar coefficient at a given density was less than that obtained in the California tests.

The difference in compressibility of different types of snow may account for the difference in the apparent tractive capacity of the M-7 snow tractor in the two different climatic areas. The snow at the Central Sierra Snow Laboratory was a maritime type in which density increases rapidly after deposition due to metamorphism at high temperature. Depth hoar does not usually occur in this type of snow or, if it does, it is at too great a depth below the surface of the deep pack to influence vehicle performance. The continental-type snow in which metamorphism at low temperature predominates and in which depth hoar is a common phenomenon is characteristic of Northern Michigan.

Some portion of this difference is the maximum drawbar coefficient obtained for the M-7 tractor in the two sets of trials may be due to difference in instrumentation and trial procedures. At the Keweenaw Field Station the drawbar pull on the test vehicle was increased uniformly by a back-up vehicle. At the Central Sierra Snow Laboratory the maximum drawbar pull was obtained by attaching the tractor to a tree, through a slack cable and dynamometer, the drawbar pull being recorded by a set hand on the dynamometer. The maximum drawbar pull under the break-traction test procedure used in California was measured at low track slippage. The recorded maximum drawbar pull for the pull-slip test methods used in Northern Michigan was found to occur within a track slip of 20%-40%. The trials are comparable to the extent that in each case the drawbar pull was a product of the dynamic friction of the snow.

### HARDNESS

The relationship between tractor performance and surface snow hardness is clearly demonstrated by the plot of drawbar pull vs. torque for the M-7 tractor for two of the late season trials at the Keweenaw Field Station, (Figure 5). Trials 42 and 54, plotted in this figure, were made in essentially the same area about 24 hr. apart. Since there was no change in snow density at the test site, the increase in hardness as measured with the drop cone could be attributed to a marked drop in temperature during the night preceding trial 54. An additional 200 lb-in. of torque was required to move the same load over soft snow with a drop cone hardness of 11 than over a hard snow with a drop cone hardness of 80.

## RELATIONSHIP BETWEEN DRAWBAR PULL AND METEOROLOGICAL CONDITIONS

### DRAWBAR PULL VERSUS SNOW AND AIR TEMPERATURE

Diurnal values of maximum and steady drawbar pull, snow temperatures, air temperature, and track depth for the tests made on 6, 14, and 15 May, 1952 are plotted in Figure 6. The results of these tests indicate that values of maximum drawbar pull were generally low when snow temperatures were at 0°C and high if snow-surface temperatures were less than 0°C. When snow-surface temperatures are at 0°C, maximum drawbar pull varies inversely with air temperature. This reduction in drawbar pull as air temperature increased above a spring snow surface probably shows the effect of free water on trafficability, since the high air temperatures increased the amount of melting. As additional evidence of the influence of liquid water in the snow cover on trafficability, the evening drop in snow surface temperature to below freezing levels on 14 and 15 May resulted in a large increase in drawbar pull. A drop in snow-surface temperatures from 0°C to -0.5°C between 2000 and 2300 hr. on 15 May was accompanied by an increase of more than 100% in drawbar pull of the M-7 tractor. During this period, the air temperature 4 ft. above the snow surface did not drop below 5.0°C. Since the sky was clear during the night when this diurnal study was conducted, the drop in snow-surface temperature and the improved trafficability may be attributed to long-wave radiation heat losses from the snow. It is probable that long-wave radiation may have an important effect on trafficability, but whether it can be evaluated from such readily observable parameters as air temperature and cloud cover has not yet been determined.

The analysis of the data for air and snow-surface temperatures shows that, during the winter, trafficability was not affected by the temperature of the snow surface, while, during the spring trials, the correlation between snow-surface temperature and trafficability was highly significant, with an inverse relationship indicated. The analysis indicates also that, during the winter, trafficability may improve as air temperatures rise, while, during the spring, falling air temperatures are associated with improvement in trafficability.

The higher trafficability achieved when air temperatures are high during the winter may be associated with an improvement in compaction of the snow as the warm air is brought into more intimate contact with the cold snow by the action of the vehicle tracks. The lower trafficability during the spring when air temperatures are high may be attributed to the reduction in cohesive strength of the snow caused by increased amounts of melt water serving as a lubricant between the grains.

### DRAWBAR PULL VERSUS ABSORPTION OF SOLAR RADIATION

Effective amounts of solar radiation can penetrate snow to as much as 18 in. The absorbed radiation will raise the temperature of the upper layer of snow and cause the bonds between snow grains as well as the grains themselves to become weaker, producing an adverse effect on drawbar pull. Figure 7 shows that an increase in absorption of solar radiation is accompanied by a decrease in drawbar pull. The advection of warm air with resultant higher air temperature during the test period undoubtedly influenced the measured drawbar pull, since air temperatures were sufficiently high to cause melting during part of the day. These tests did not demonstrate, however, that the simple measurements of air temperature will provide an index to trafficability when large amounts of solar radiation are available.

## APPLICATION OF COULOMB'S EQUATION TO PREDICTION OF DRAWBAR PULL

The results of the variable load tests in Northern Michigan have shown that drawbar pull (P) is related to load (V) by the equation

$$P = V \tan \theta$$

This equation is similar to Coulomb's equation for a cohesionless material

$$S = \sigma \tan \theta$$

where:

$S$ = frictional resistance, psi

$\sigma$ = normal pressure, psi

$\theta$ = angle of internal friction (kinetic friction)

This indicates that the snow in these tests acted as though it had little or no cohesion, and in such a material its resistance to motion is a function of its kinetic friction. Further evidence that the trafficability of snow is related to its internal (kinetic) friction may be deduced from the fact that the maximum drawbar coefficient was obtained at 20-40% slip.

## SUMMARY

The Department of the Army is directly concerned with the ability to manoeuver in snow-covered areas. The affect of a number of factors on the vehicular trafficability of a snow cover are reported in this paper.

Three light snow vehicles of the personnel carrier type were used to test the trafficability of the snow cover in the high mountains of California and the Keweenaw Peninsula of Northern Michigan. The former location is under the influence of a maritime climate while the latter is dominated by a continental climate.

It was found that the maximum drawbar coefficient (drawbar pull/vehicle weight) was obtained at a track slip of 20 to 40%, indicating that the drawbar pull is a function of the frictional resistance of the snow. For track-slip of less than 10%, the variation in the drawbar coefficient is too large to permit any evaluation of low-slip performance.

The physical and mechanical properties of the top 15-20 in. of snow determined the trafficability of the snow cover for light-weight tracked vehicles. The thickness of the effective layer was determined largely by its density, but even in snow of 0.12 to 0.20 g/cm3 density the passage of a snow tractor did not appear to produce any change in the snow at depths greater than 20 in. It is probable that, for a snow cover less than 20 in. thick, trafficability may be a function of the thickness of snow and the nature of the underlying surface, to which some of the load may be transferred.

Differences between the maritime deep warm snow of the California mountains and the cold, continental-climate snow of Northern Michigan is indicated by the higher drawbar coefficient obtained with the M-7 in the California trials.

More power was required to produce the same drawbar pull in soft snow than in hard snow, indicating that some of the vehicle's power is expended in compacting or displacing the snow.

During the spring, trafficability is inversely related to both air temperatures and snow-surface temperatures. The variation of trafficability during the day appears to be inversely related to the amount of solar radiation absorbed by the snow cover.

A modification of the Coulomb law was shown to express a relationship between tractive effort and vehicle. The mean angle of internal friction, $\theta$, was found to be 28° and varied between 26-32°.

## REFERENCES

Snow, Ice and Permafrost Research Establishment (1951) *Preliminary investigations of some physical properties of snow*, Report 7, Corps of Engineers, U.S. Army, 48 pages.

Snow, Ice and Permafrost Research Establishment (1954) *Instructions for making and recording snow observations*, Instruction Manual 1, Corps of Engineers, U.S. Army.

### TABLE I

Distribution of Weight and Pressure of Three Snow Tractors

| Make of Vehicle | | Ordnance | | Tucker Commercial | |
|---|---|---|---|---|---|
| Model or designation | | M-7 | Model 421 (T-2) | Model 443 (T-4) | |
| Total Weight of Vehicle (Empty), lb. | | 2710 | 2250 | 4000 | |
| Distribution of Weight | | | | Front* Pontoon | Rear* Pontoon |
| On Tracks or Pontoons | Proportion of Total Weight Supported, % | 68 | 65 | 55 | 45 |
| | Actual Weight Supported, lb. | 1843 | 1462 | 2200 | 1800 |
| | Effective Bearing Area, in$^2$ | 2580 | 3000 | 3000 | 3000 |
| | Pressure, psi | 71 | .49 | .73 | .60 |
| On Skis | Proportion of Total Weight Supported, % | 32 | 35 | | |
| | Actual Weight Supported, lb. | 867 | 788 | | |
| | Effective Bearing Area, in$^2$ | 770 | 1500 | | |
| | Pressure, psi | 1.13 | .52 | | |

*Tucker Model 443 (T-4) is equipped with 4-pontoon drive and steering.

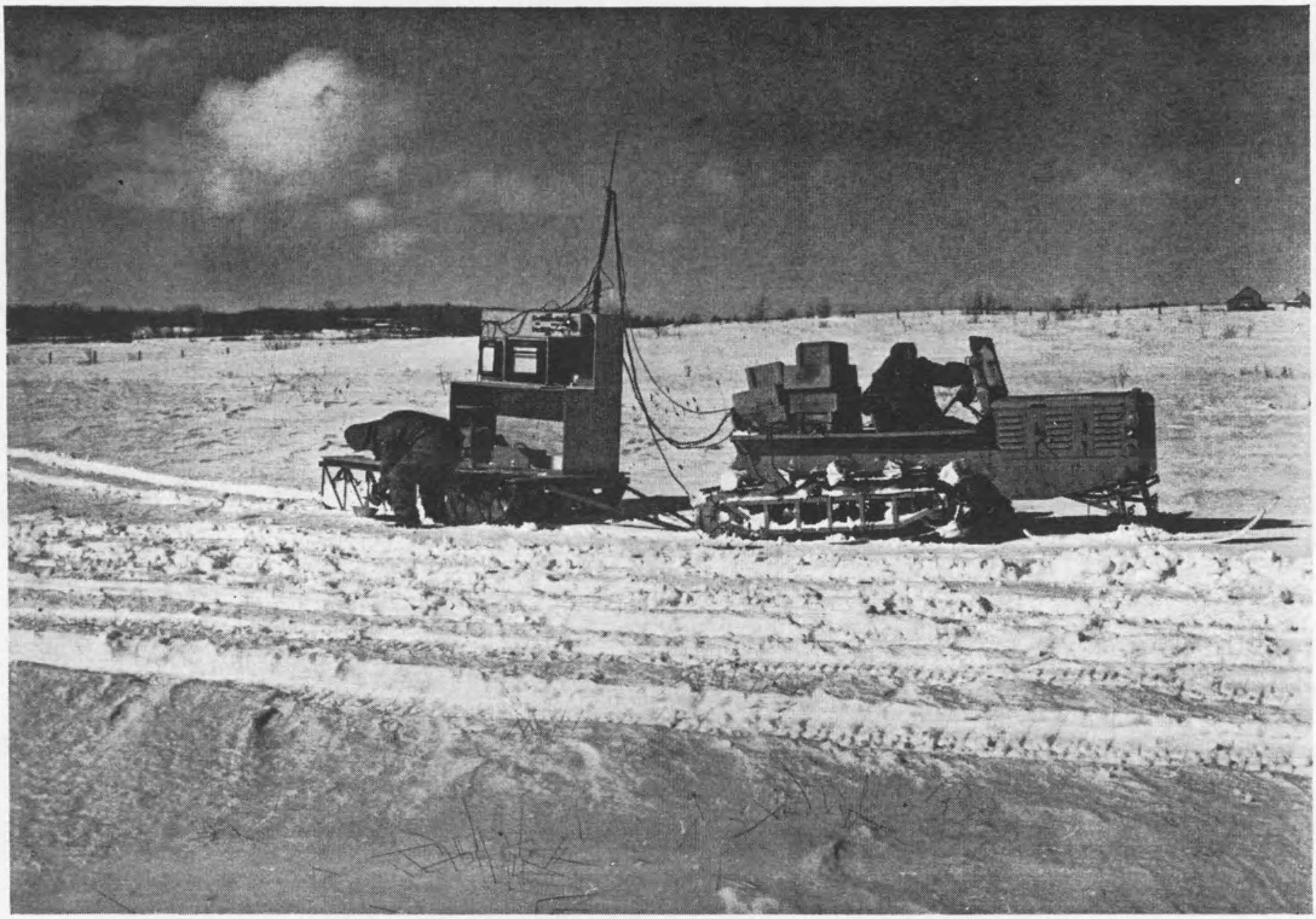

PLATE 1 — The M-7 half-track snow tractor. In this picture it is shown with a 1000 pound load and with Kamm-type grousers installed on every third track plate.

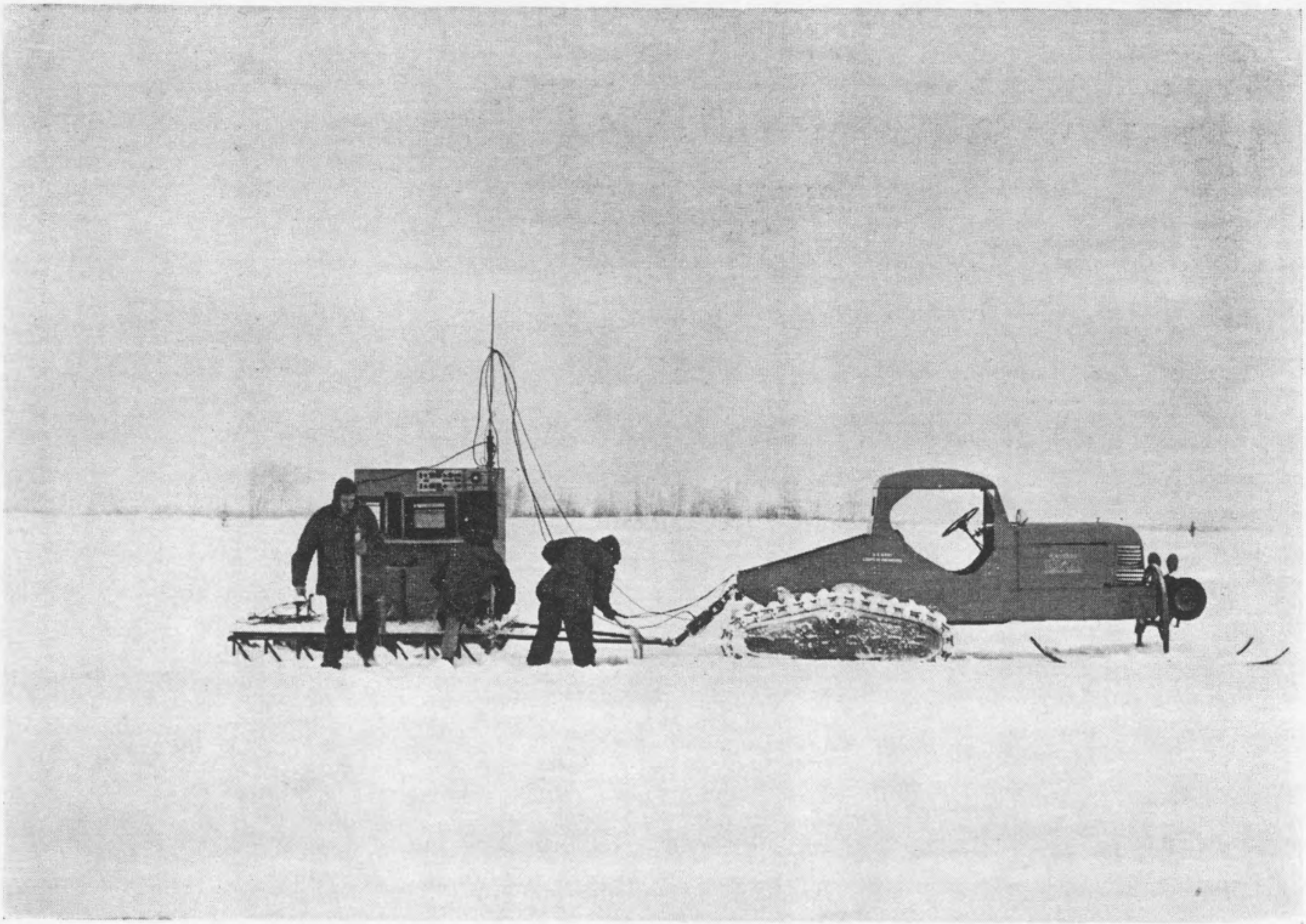

PLATE 2 — The two-pontoon, Model 421 Tucker Snow-cat, (T-2) with the instrument sled as operated in the trafficability tests.

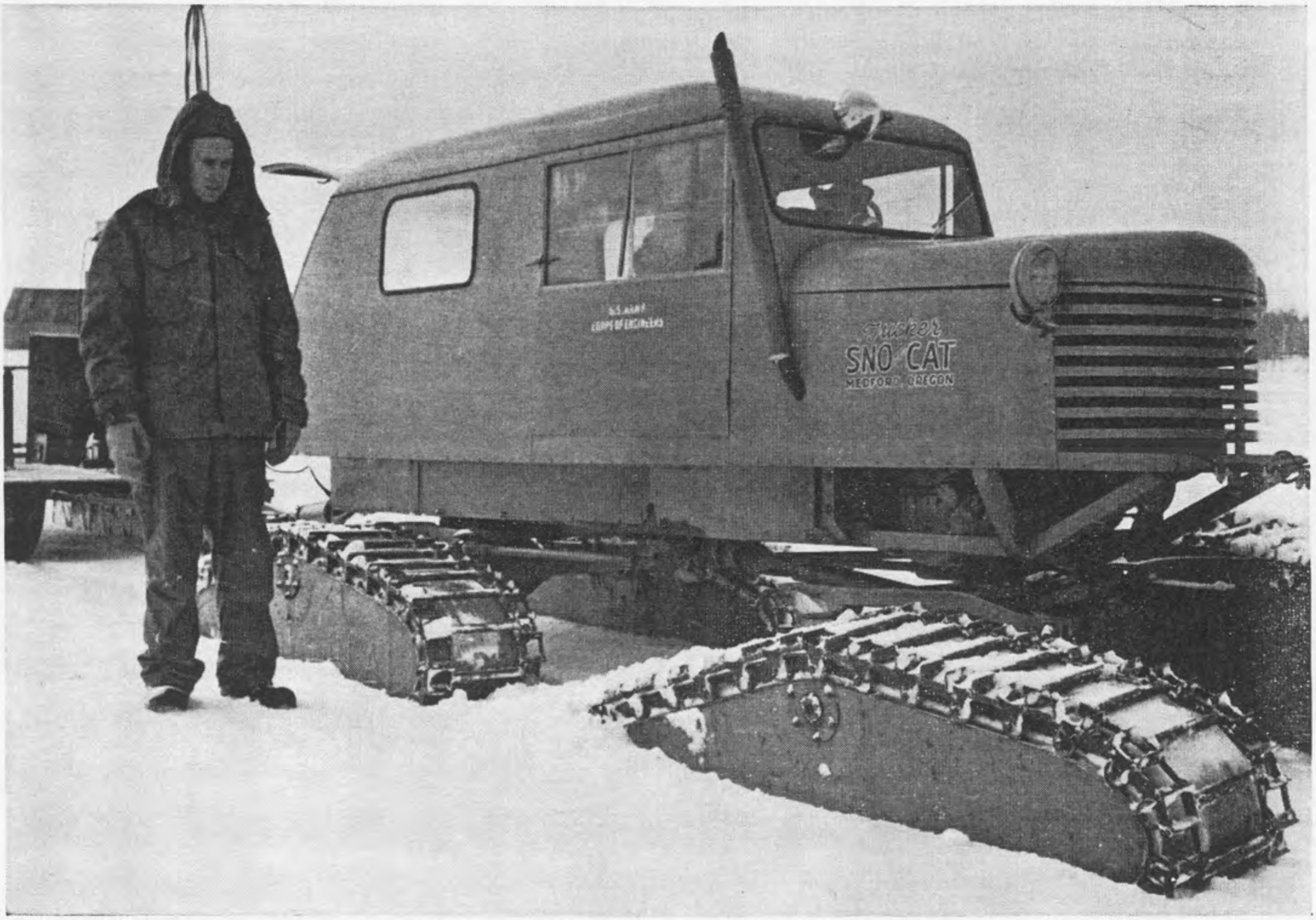

**PLATE 3** — The 4-pontoon, Model 443 Tucker Sno-cat, (T-4), used in the 1955 trafficability trials. In this photograph the vehicle has become immobilized by 100% slip of the right front pontoon. Although able to move ahead after being disconnected from the light instrument sled, it was unable to pull any load when immobilized by penetration of any one track into the loose layer of depth hoar at 8-12 in. below the snow surface.

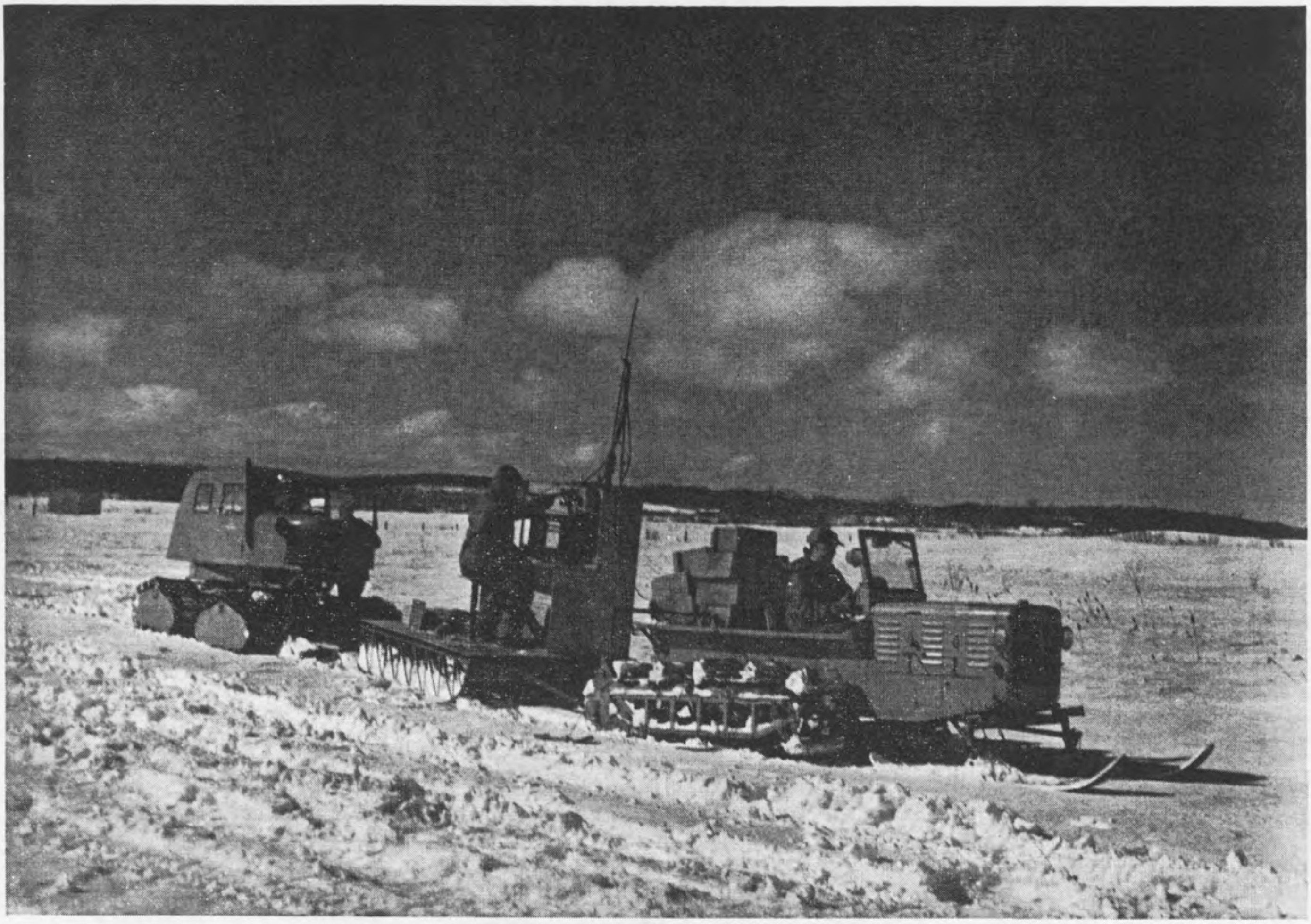

PLATE 4 — The start of a test run with the T-4 being used as a braking vehicle through the instrument sled to the M-7. The snow is not as shallow in the test area as the cat tails in the background appear to indicate.

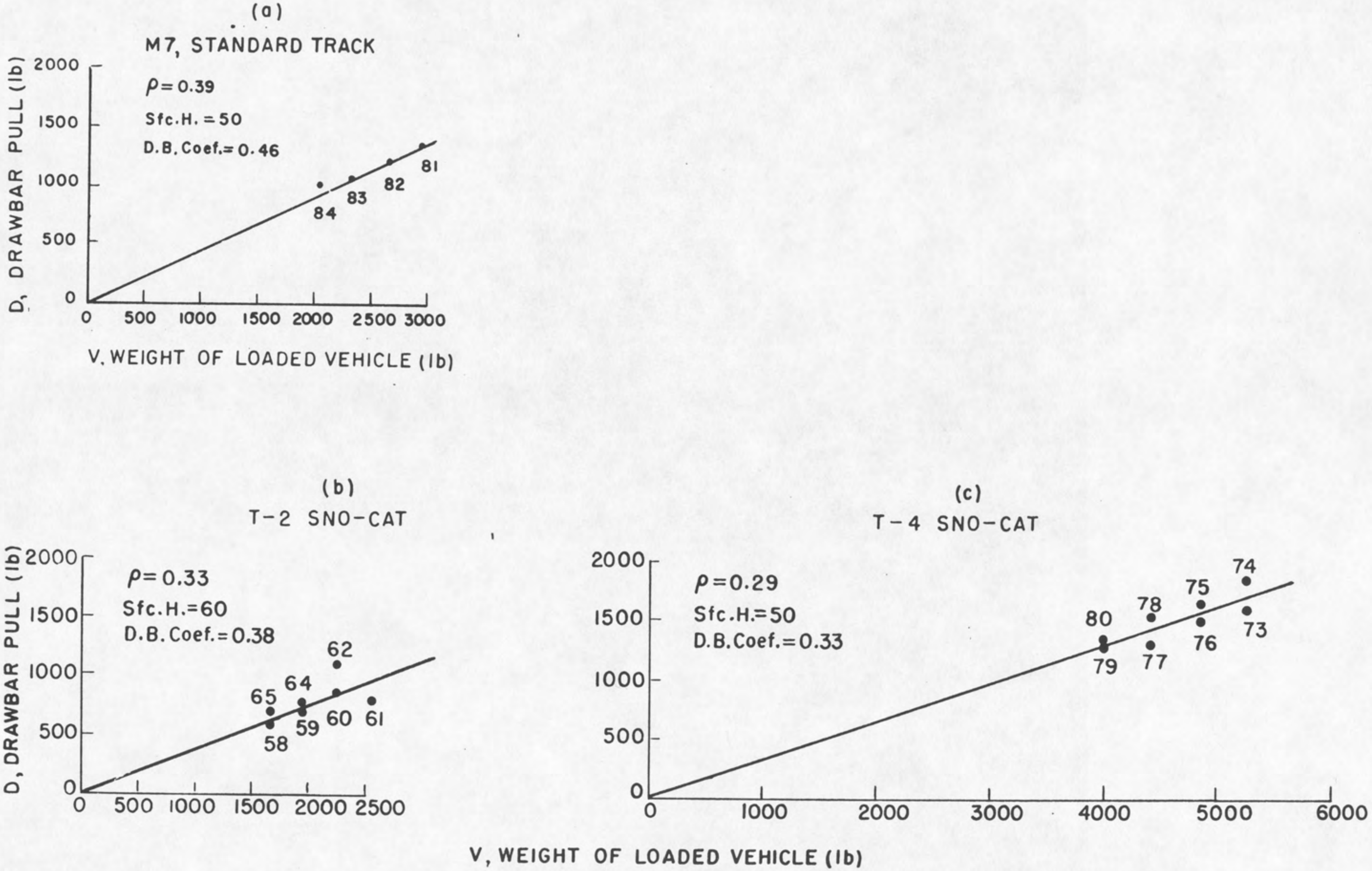

FIGURE 1 — Drawbar pull vs. weight of vehicle.

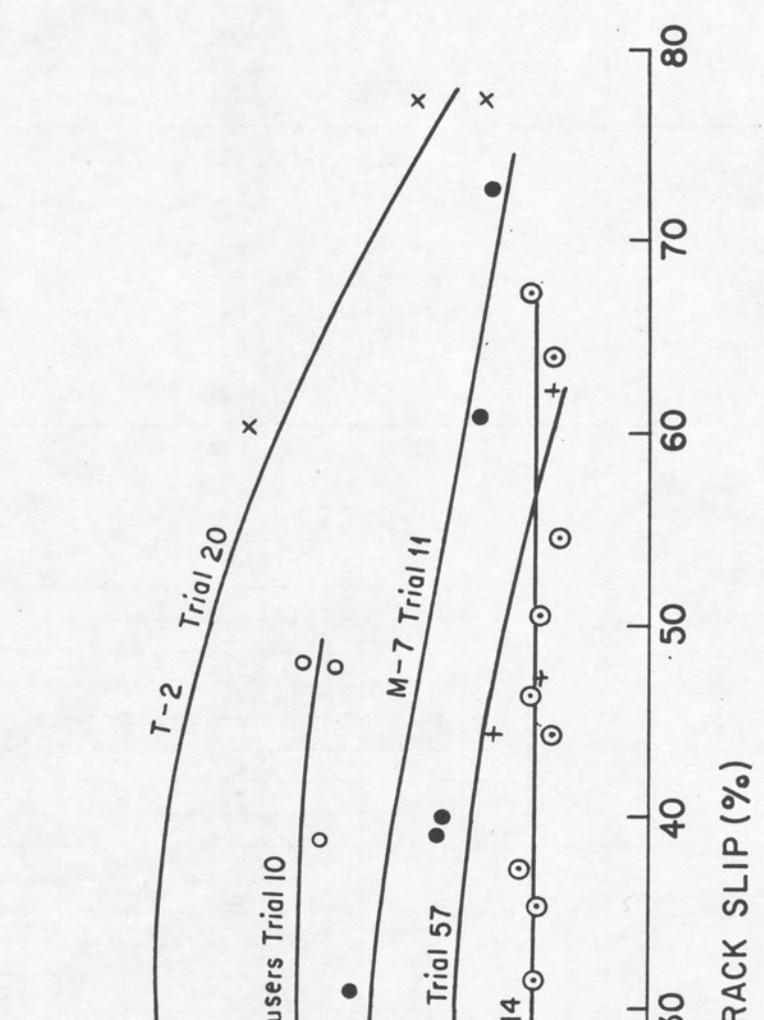

FIGURE 2 — Relationship between track slip and drawbar coefficient.

## TABLE II

Drawbar Coefficient of M-7 and the Properties of Undisturbed Snow in the Test Area

| | Drawbar Coefficient M-7 | Track Depth | Snow Density | Hardness | | Snow Temperature |
|---|---|---|---|---|---|---|
| | | | | CNRC | Drop Cone | |
| Date | Db/Wt. | in. | gm/cm$^3$ | gm/cm$^2$ | gm/cm$^2$ | C° |
| 2 Feb. | 0.26 | 8 | 0.13 | 30 | 3 | —6 |
| 3 Feb. | 0.29 | 8 | 0.20 | 40 | 4 | —5 |
| 4 Feb. | 0.31 | 6 | 0.21 | 40 | 4 | —5 |
| 9 March | 0.39 | 1-2 | 0.30 | 300 | 9 | —1 |
| 10 March | 0.41 | 1-2 | 0.33 | 150 | 80 | 0 |
| 11 March | 0.47 | 1-2 | 0.39 | 200 | 50 | —1 |

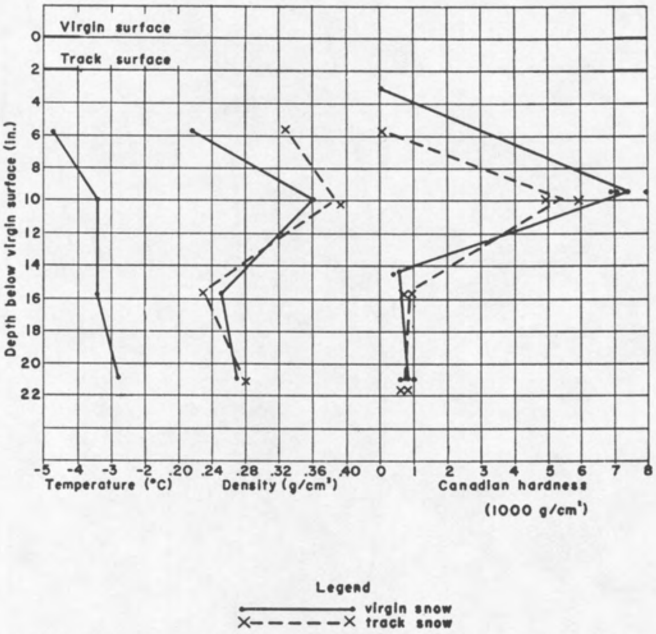

FIGURE 3 — Snow profile, 7 February 1952. Track depth 2.0 inches.

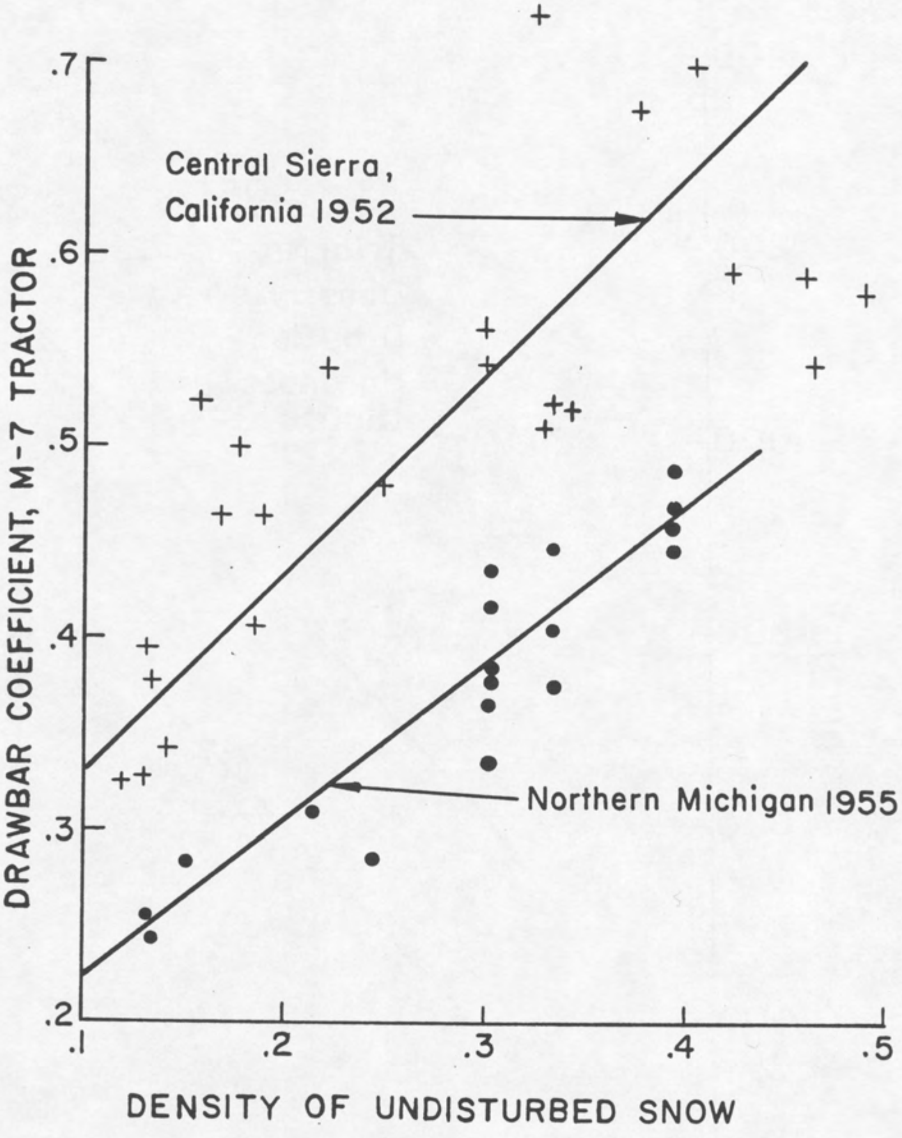

FIGURE 4 — Climatic influence on drawbar coefficient of M-7 tractor.

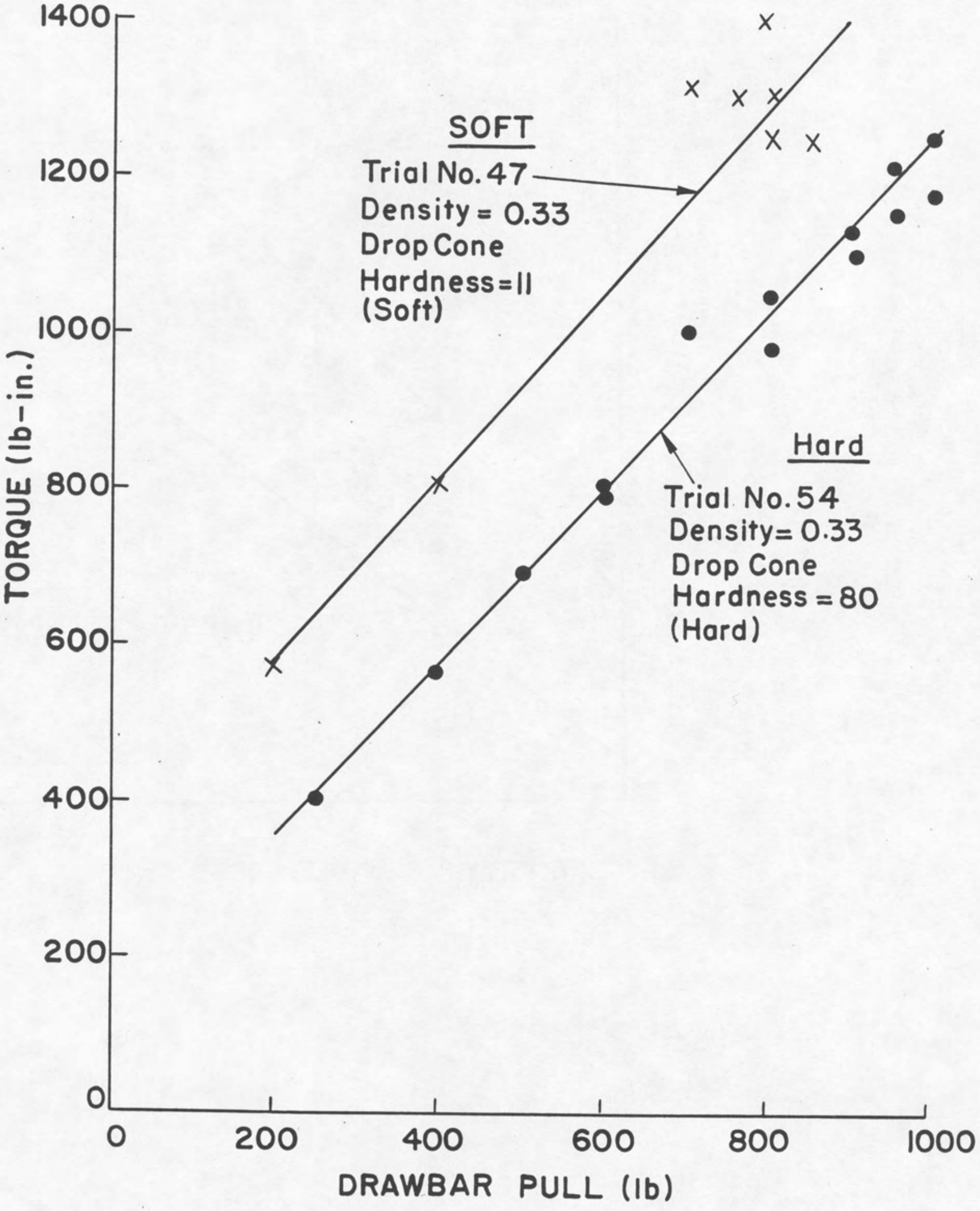

FIGURE 5 — Effect of snow hardness on performance of M-7 tractor.

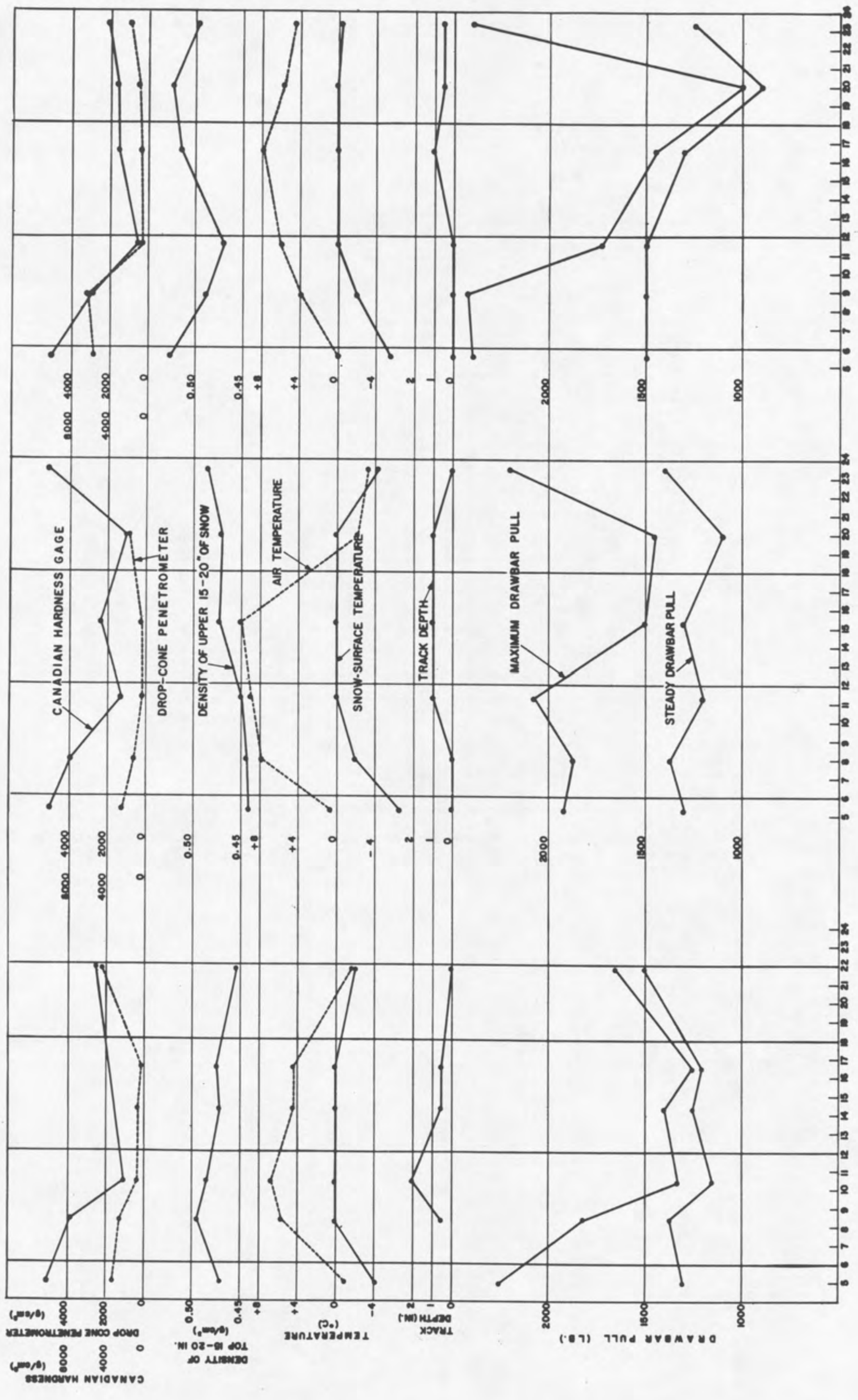

FIGURE [illegible] DIURNAL CHANGES OF MAXIMUM AND STEADY DRAWBAR PULL, M-7 SNOW TRACTOR
As related to diurnal changes in air temperature and to certain physical properties of the upper layers of snow.

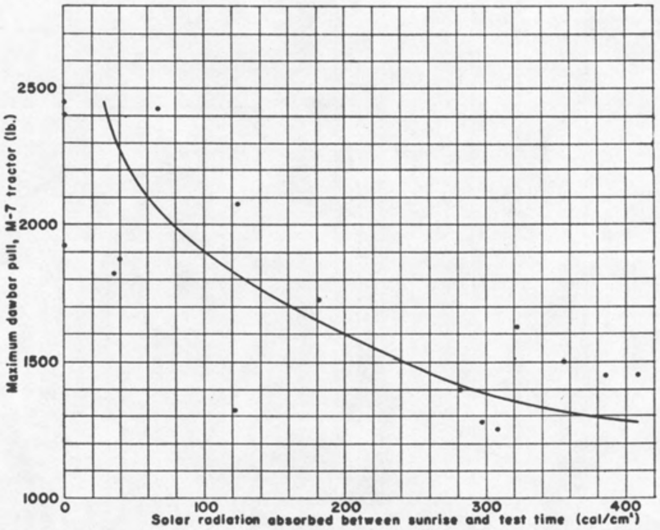

FIGURE 7 — Maximum drawbar pull, M-7 snow tractor vs. absorbed solar radiation, 6, 14, 15 May 1952. Does not include tests later than 2000 hours.