

THE EFFECT OF TEMPERATURE ON THE BEARING VALUE OF FROZEN SOILS

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Many problems must be considered in the construction of buildings, roads, runways, and other structures in regions of permafrost. One plan followed in such areas is an attempt to retain the foundation soil in a frozen condition, with the idea that if such is accomplished, the frozen soil will remain firm and of high bearing value. This practice suggested the subject of this research--Is all frozen soil of approximately equal bearing value, and do the bearing characteristics vary any with changes in temperature?

Muller, in his collection of information on permafrost(1), has shown that the properties of ice are dependent upon temperature, as well as upon such other properties as orientation of ice crystals. Both the compressive strength and the shearing strength of ice increase for a decrease in temperature. Muller also cites data concerning the strength of frozen soils. In general the properties of frozen soils follow the same trend as ice for changes in temperature. The effect of soil texture and moisture content are not very clear.

In the investigation reported herein, tests were made on four soils of widely varying textures, viz., sand, sandy loam, silt loam, and clay. Each soil was tested over a range of varying moisture contents and densities. A simple penetration bearing test was made and test temperatures were varied from about 10 F. to above 32 F.

SOILS TESTED

Four soils were tested: Soil P-4602, Fairbanks Silt Loam, a gray soil from the permafrost research area of the Corps of Engineers at Fairbanks, Alaska; Soil P-4604, Lowell Sand, a material furnished by the Corps of Engineers, New England Division, is a cohesionless, siliceous sand from a glacial outwash deposit at South Lowell, Massachusetts; Soil P-4713, Ramsey Sandy Loam, a local soil from Ramsey County, Minnesota; and Soil U-4701, Gumbo Clay, a local soil from near Wolverton, Minnesota. The characteristics of the soils are shown in Table 1.

BEARING TEST

The bearing test consisted essentially of placing soil at a known density and moisture content in a cylinder with a thermocouple, freezing the sample with a vertical steel rod at the top, and finally applying a load to the steel rod while recording load, penetration and temperature. The test was arbitrarily made similar to the California bearing-ratio test in that speed of penetration and points of penetration at which loads were read were the same for both tests.

Figure 1 shows a cross-section of the test cylinder. Eleven molds were in use.

Soil was mixed to the desired moisture content and compacted into all 11 molds at the desired density.

TABLE 1

Soil No.	Textural Class		Mechanical Analysis					Modified		
	U.S. Bur. of Chem. & Soils	Corps of Engrs	Gravel Over 2.00 *	Sand		Clay Under 0.005	Liquid Limit	Plasticity Index	Opt. Moist.	Max. Den
				0.05 to 2.00	Silt 0.05 to 0.005					
P-4604	Med. Sand	SW	0.0	100.0	0.0	0.0	--	N P.	12.2	119.0
P-4713	Sandy Loam	CL	0.4	53.6	27.5	18.5	24.6	9.3	9.0	127.5
P-4602	Silt Loam	ML	0.0	7.6	80.9	11.5	34.0	N.P.	15.5	110.0
U-4701	Clay	CH	0.0	9.2	37.5	53.3	77.0	53.5	19.8	107.1

*Size in millimeters

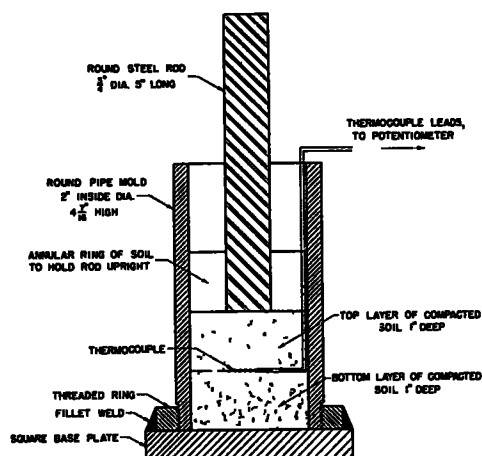


Figure 1. Cross-Section of Test Cylinder with Sample in Place

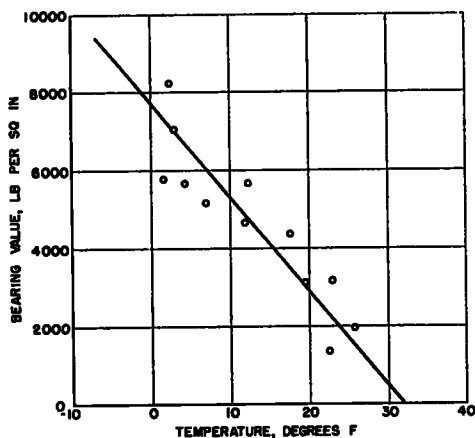


Figure 2. Bearing Value - Temperature Curve for Ice

They were placed in a cold-room at approximately -10F. for about 24 hours.

The bearing test was made in a hydraulic testing machine at a head speed of 0.05 in. per min. A cylinder was taken from the cold-room and the thermocouple leads attached to a potentiometer. Upon contact of the head with the 3/4 in. rod, an Ames dial was read to determine penetrations. Loads were read at 0.025, 0.050, 0.075, 0.1, 0.2, 0.3, 0.4, and 0.5 in. penetrations and temperatures at about the same intervals. Many of the tests were run to only a 0.2 in. penetration.

One cylinder was surrounded with granulated cork in the cold-room before being tested. This gave the lowest temperature test. Subsequent cylinders were permitted to warm up in the laboratory air before being tested. Attempts were made to have the temperatures at the time of test vary from below 0 F up to 32 F for seven or eight tests, and to have the other three or four tests made at temperatures above 32 F.

The test result selected for expression of the bearing value was the unit load at a penetration of 0.1 in. This selection was arbitrary, and no particular significance should be attached to the exact numerical values which result. A maximum unit load was usually obtained at either the 0.1 or 0.2 in. penetration. For comparative purposes the bearing value as defined above appears to be reasonable.

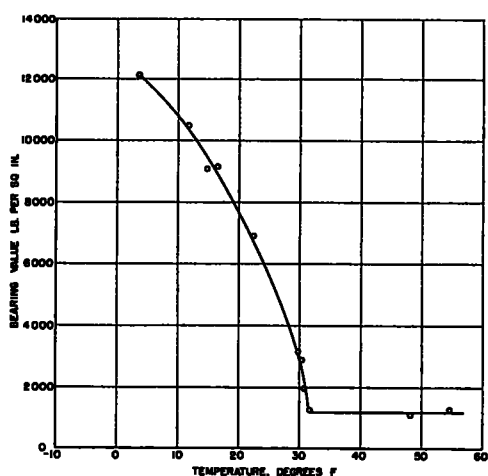


Figure 3. Bearing Value - Temperature Curve Sand, Test No. 4
Dry Density 109.8 lb. per cu. ft.
Moist. Cont. 9.0 Percent

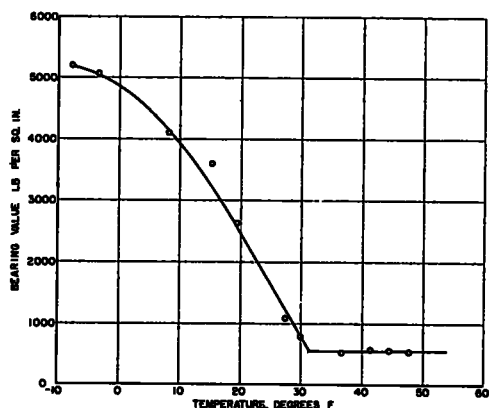


Figure 4. Bearing Value - Temperature Curve Sandy Loam, Test No. 2
Dry Density 116.3 lb. per cu. ft.
Moist. Cont. 9.6 Percent

The temperature read at the time of 0.1 in. penetration was used to correlate the bearing values with temperature.

From five to eight moisture-density conditions were tested for the four soils. It was attempted to select these so that both the effects of moisture variations at a constant

dry density and density variations at a constant moisture content could be ascertained.

Special tests were also made to determine the variation of temperatures in the test specimen and the bearing values for ice.

BEARING STRENGTH OF ICE

Bearing tests made on ice gave more irregular results than tests on frozen soils. (See Fig. 2.) A straight line plot through zero strength at 32 F seems reasonable. This curve is of interest for purposes of comparison with the strength of frozen soils.

BEARING STRENGTH OF SOILS

The series of bearing-value tests on the four soils gives a qualitative indication of the effects of temperature, texture, moisture content, and density. Typical test results for one series of tests on each soil are shown in Figures 3 to 6, inclusive. In any one of these series the soils were all at approximately the same density and moisture content, the only variable being the temperature at the time of the bearing test. For each of the soils

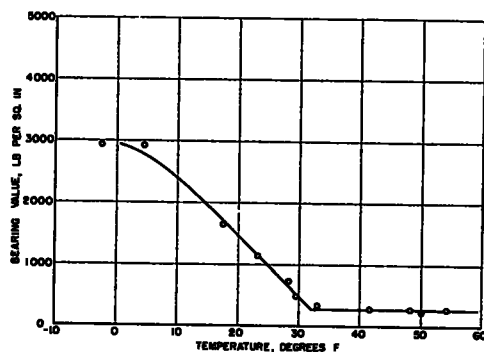


Figure 5. Bearing Value - Temperature Curve Silt Loam, Test No. 4
Dry Density 93.5 lb. per cu. ft.
Moist. Cont. 17.0 Percent

the results of tests made above freezing were about the same, and the curve is shown as a horizontal line for this temperature range. The tests on the frozen soil, however, show a wide variation, depending upon the temperature. Bearing values at 0 F, for example, are as much as 10 times those just below freezing. The increase in bearing strength with decrease in temperature is approximately a straight-line relationship with some decrease in the rate of increase-of-strength at lower temperatures.

Nearly all series of tests gave curves similar to those of Figures 3 to 6. The curves for all series of tests on each soil are plotted in Figures 7 to 10, inclusive. In Figure 7, for example, the five series of tests on the sand soil are shown. The individual test points are not shown. A study of these curves, together with the moisture contents and densities, gives an indication of the effect of the variables under consideration.

The point at which the strength curves for the temperature ranges above and below freezing intersect is of interest. For the sand (Fig. 7), this is, in general, between 31 and 32 F, for the sandy loam (Fig. 8), somewhat variable but on the average about 31 F; for the silt loam (Fig. 9), 31 to 32 F; but for the clay (Fig. 10), several of the points are below 30 F, and the average is about 29 F. This value for the clay may be the result of a depressed freezing-point for a fine-grained soil, as has been discussed by Bouyoucos, Wintermeyer, and others. From appearance the clay seemed to be frozen up to a temperature of 32 F, but curves such as those of Figures 6 or 10 indicate that no gain in strength results from freezing until a temperature of less than 28 to 30 F is reached.

The effect of the dry density of a frozen soil on its bearing value may be illustrated by a study of the strength curves for the sand, Figure

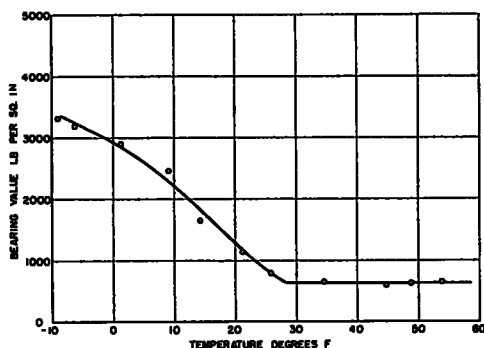


Figure 6. Bearing Value - Temperature Curve Clay Test No. 8
Dry Density 101.9 lb. per cu. ft.
Moist. Cont. 20.2 Percent

7. Test series 2 and 4 are at about the same moisture content (9.34 and 9.00 percent) but widely different densities (94.7 and 109.8 lbs per cu ft). The high-density soil has a much greater strength (Curve 4) than the low-density soil (Curve 2). Similar relationships can be noted on Figures 8, 9, and 10. On Figure 8, three series of tests on the sandy loam at 9-plus percent moisture content and at 116.3, 120.9, and 125.2 lbs-per-cu-ft. densities show, in general, an increasing strength.

The effect of a variation in moisture content with an approximately uniform dry density can be studied in a similar manner. For

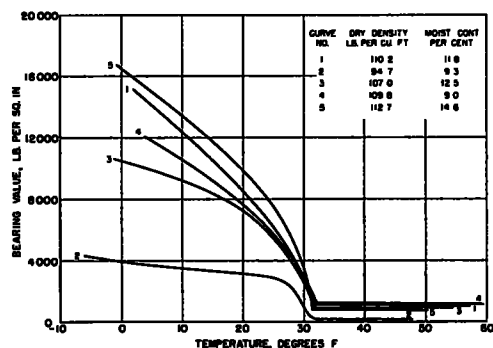


Figure 7. Summary of Bearing Value-Temperature Curves Sand

example, on the sand soil, Figure 7, test series 4, 1, and 5 are within 3 lbs. per. cu. ft. of the same density with moisture contents of 9.00, 11.78, and 14.55 percent. In the frozen range, the bearing strength shows an increase with this increase in moisture. The silt-loam soil (Fig. 9) shows a similar increase for test series 5, 3, and 1, which have moisture contents of 9.88, 16.55, and 22.62 percent for a density of about 101 lb. per. cu. ft. The sandy loam and clay soils do not show such distinct increases.

The bearing value of frozen soil is apparently also dependent upon the texture of a soil. (See Fig.11.) The bearing-value temperature curves for each soil at the moisture-density test condition closest to the modified optimum moisture content and maximum density have been plotted together with the curve for ice as shown in Figure 2. It will be noted that the order of soils from lowest to highest strength is clay, silt loam, sandy loam, and sand. This is the order which might be expected according to the normal bearing characteristics of these soils. The strength of the frozen clay is appreciably less than that of the ice; that of the silt loam and sandy loam is approximately the same as ice; and that of the sand is two or more

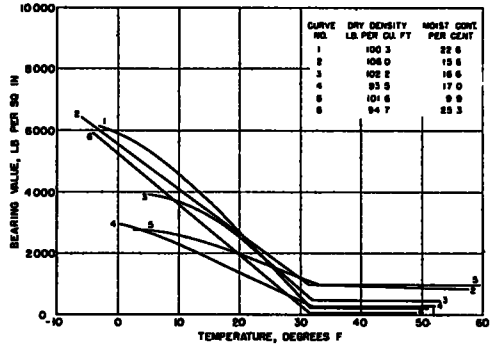


Figure 9. Summary of Bearing Value-Temperature Curves Silt Loam

times greater than ice. The strength of the sand in the unfrozen state is low because of the lack of any appreciable surcharge in the bearing test as run.

VARIATION OF TEMPERATURE WITHIN SPECIMEN

It is realized that in the test method followed the temperature of the soil was changing as the penetration test was in progress and that the temperature was not uniform throughout the soil specimen. For tests made at low temperatures (0 F, plus or minus), the temperature, as measured at the center of the soil specimen, might change as much as 5 to 10 degrees during the

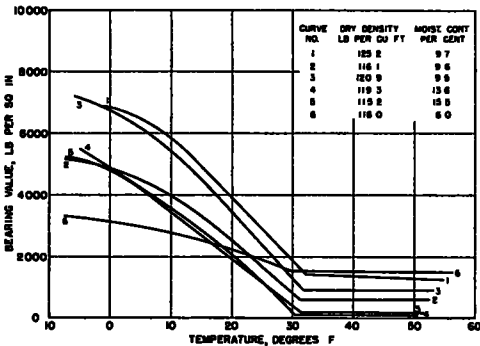


Figure 8. Summary of Bearing Value-Temperature Curves Sandy Loam

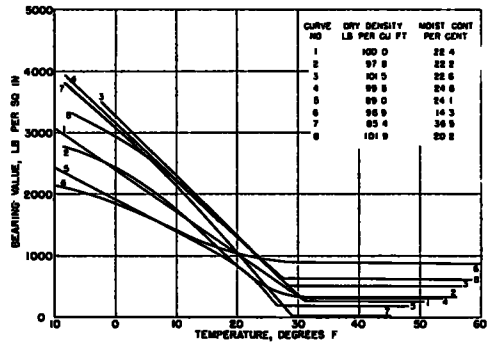


Figure 10 Summary of Bearing Value-Temperature Curves Clay

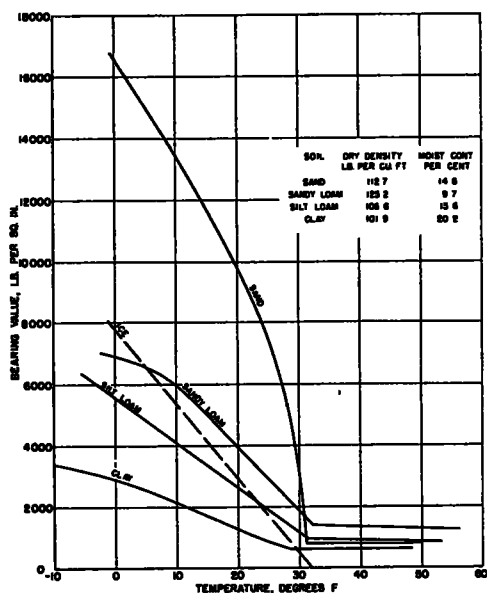


Figure 11. Bearing Value - Temperature Curves

Soil Approximately at Modified Optimum Moisture Content and Maximum Density

attainment of 0.1 in. penetration. For tests just below the freezing point the rate of temperature change was much slower.

Some special tests were made with five or six thermocouples placed in the specimen at various depths. Thermocouples in actual contact with the base plate or the 3/4-in. rod gave higher temperatures than those not in contact with the metal; the difference was in the nature of 10 degrees. Thermocouples within the soil and more than 1/8 in. from the metal bottom or plunger showed variations in the neighborhood of 5 degrees. Such tests suggest that the exact temperatures given in the various graphs should be considered only as approximate. The depth of soil beneath the plunger, which controls the penetration, is not known. Whatever this depth might be there would be some temperature

variation within it; exact determination of an average would be difficult. The qualitative nature of the graphs is still held to be essentially correct. More exact temperature control and measurement might result in a shifting of such curves as shown in Figures 3 to 10 to the right or left, but their general form would not change.

SUMMARY AND CONCLUSIONS

An arbitrary test procedure has been developed and tests on four different soils at a wide range of moisture contents and densities have been made at temperatures from about 0 F to above 32 F. The test was a penetration type similar in character to the California bearing-ratio test but using much smaller equipment.

The soils tested cover a wide textural range, viz., sand, sandy loam, silt loam, and clay. The following conclusions seem warranted:

1. The test procedure was sufficient to portray the effects of differences in density, moisture content, soil texture and temperature on stability. The numerical values of the bearing value are for comparative purposes only and are not considered directly applicable to other conditions.

2. The bearing power of frozen soils varies markedly with their temperature. The bearing value increases as the temperature decreases below approximately 32 F. The strength at 0 F may be several times that at 30 F.

3. The bearing power of a frozen soil at a given moisture content and temperature increases with an increase in density.

4. The bearing power of a frozen soil at a given temperature and dry density increases, in general, with an increase in moisture content. For thawed soils an increase in moisture content results in a decrease in bearing value.

5. The bearing power of frozen soils may vary considerably according to their texture. The order of strengths of the four frozen soils tested in this program from least to greatest was clay, silt loam, sandy loam, and sand. The bearing strength of ice as compared to the soils was greater than the clay, about the same as the silt loam and sandy loam, and less than the sand.

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REFERENCES

(1), Muller, S. W., 'Permafrost or Permanently Frozen Ground and Related Engineering Problems.' U. S. Geological Survey, Special Report, Strategic Engineering Study No. 62.