Preparation of artificially frozen sand specimens

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PREPARATION OF ARTIFICIALLY FROZEN SAND SPECIMENS

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Several specimens of artificially frozen sand (ASTM C-109) were prepared to evaluate different testing procedures and techniques used to determine the mechanical properties of frozen soils. Two methods of preparation of fully saturated frozen sand specimens, described by other investigators, were compared.

Compaction by a rodding technique and saturation under vacuum produced a uniform degree of compaction and saturation upon freezing.

The most critical part of the preparation procedure leading to physical variability between specimens was found to be the time during freezing and machining. This time span must be kept constant to minimize the effects of sublimation.

PREPARATION DE SPECIMENS DE SABLE GELE ARTIFICIELLEMENT

par T.H.W. Baker

Plusieurs spécimens de sable gelé artificiellement (ASTM C-109) ont été préparés afin d'évaluer différentes méthodes et techniques d'essai utilisées pour déterminer les propriétés mécaniques de sols gelés. Deux méthodes de préparation de spécimens de sable gelé complètement saturé, décrites par d'autres chercheurs, ont été comparées.

Le tassement par une technique de pilonnage et par saturation sous vide a produit un degré uniforme de tassement et de saturation lors de la congélation.

La partie la plus critique de la méthode de préparation pouvant mener à une variabilité physique entre les spécimens a été trouvée comme le temps de congélation et d'ajustage. Cette durée doit être maintenue constante afin de diminuer les effets de la sublimation.

PREPARATION OF ARTIFICIALLY FROZEN SAND SPECIMENS

by

T.H.W. Baker

The mechanical behaviour of frozen soil is greatly affected by such properties as specimen homogeneity, grain size, moisture content and density. In order to evaluate testing procedures and techniques for frozen soils it was found necessary to produce a large number of identical, artificially frozen, sand specimens whose preparation has been described by several investigators (1 to 18).

This paper reports on the results of a comparison of specimen characteristics of frozen sand compacted and saturated in the following ways:

1. Compaction by vibration and saturation under a head of water; and

2. Compaction by rodding and saturation under vacuum.

A uniform medium textured sand was chosen and moulded into cylindrical test specimens (75 mm dia. by 150 mm high). The sand had to be coarse enough to prevent the formation of ice lenses under normal freezing conditions. A commercially available Ottawa sand (ASTM Designation C-109) was found to be suitable. The grain size distribution is shown in Figure 1.

Specimen preparation included compaction into a mould, air evacuation and saturation with water followed by freezing.

1. Compaction

A split perspex mould with two end caps was designed and constructed for the preparation of cylindrical frozen samples 75 mm in diameter and 225 mm in height. The extra height of the moulded sample allowed removal of sublimated sections and machining and end facing the specimen to a height of 150 mm. The split mould is shown in Figure 2.

A standard Proctor compaction test showed that the optimum moisture content for this sand was between 11 and 13 per cent by dry weight.

Two methods of compacting the sand into the mould were tried. Five samples were placed in layers (36 mm thick) at a moisture content of 11 per cent and densified by vibration. A Cleveland compressed air vibrator, with a foot attachment of 1 cm^2, was passed over each layer until maximum densification was achieved. A photograph of the vibrator is shown in Figure 3. Four samples were placed in layers at a moisture content of 11.5 per cent and were rodded to the required density. Eighteen samples were rodded at a moisture content of 14 per cent which was above the optimum moisture content, but which produced samples with the highest frozen dry density. The rodding technique involved the uniform mixing of water with the sand to achieve the desired moisture content. A known weight of the sand-water mixture was placed in the mould and a rod was used to tamp a layer of the thickness required for the desired density.

2. Saturation

The vibrated samples were saturated under a head of water for two hours. This technique is similar to that used by other investigators (1, 3, 10, 11, 14).

Saturation of compacted sand samples under a vacuum (4, 13) gave excellent uniformity. It was this method of saturation that was used with the rodded samples in this investigation.

Special lucite caps were placed at the ends of the mould after the sample had been compacted. Both end caps were fitted with hose connections that contained porous stones, to prevent the loss of sand during evacuation and water saturation. Rubber tubes were connected to the end caps. The tube from the top cap was connected to a collecting bottle and a vacuum pump protected with an air drier. These can be seen to the right of the mould in Figure 4. The tube from the bottom cap, fitted with an on/off valve was connected to a reservoir of distilled water. These can be seen to the left of the mould in Figure 4. The on/off valve allowed for the separate deaeration of the mould.

During evacuation a vacuum was applied to the top of the mould with the on/off valve closed. At the same time the distilled water reservoir was placed under a vacuum to remove as much air as possible. After deaeration, the vacuum was removed from the reservoir and the on/off valve opened to allow water to flow up through the mould and saturate the sample. The water was allowed to flow until no air was observed coming out of the sample.

3. Freezing

All samples were frozen in the same manner. The top cap of the mould was removed for the freezing process and a capillary tube was attached to the hose fixture in the bottom of the mould. This was to allow collection of water expelled from the sample and to relieve cryostatic pressure during freezing. The water level was maintained at the top of the mould using the capillary tube filled with water in order to prevent drainage prior to freezing. A heater wire was placed inside the capillary tube to prevent freezing. The mould and attached capillary tube were placed in a box of vermiculite to ensure uniaxial freezing of the specimen. Freezing was carried out in a cold room at -5°C. A photograph of the specimen during freezing is shown in Figure 5.

Ice sublimation takes place at the top of the sample during the freezing process due to the low relative humidity of the cold room (approximately 37 per cent). The dry portion at the top of the sample was removed during the machining and end facing procedure prior to testing. The rate of sublimation with time is shown in Figure 6. The time necessary to completely freeze the sample was measured by a thermocouple placed in the bottom of the mould as shown in Figure 7.

Density-Moisture Content Relationships

The final dry density and moisture content of frozen sand specimens were dependent on the initial compaction in the mould, the extent of air evacuation and water saturation, and the rate of freezing. The compaction curve and history of a typical specimen are shown in Figure 8. Point #1 gives the dry density/moisture content relationship after compaction. Point #2 gives the change in the moisture content with saturation. The shift to point #3 represents the lowering of the density due to the water/ice phase change and the lowering of the moisture content due to the sublimation-evaporation of the ice.

Specimen Physical Characteristics

Moisture content, dry density, bulk frozen density, saturation and void ratio were calculated for each specimen. The formulae used to compute these values are given in Appendix A. The results for each specimen are tabulated in Appendix B. These data are grouped according to the initial compaction of each specimen. The statistical results for each group of data are also included in Appendix B.

The rodding compaction technique at a 14 per cent moisture content gave the highest average dry density and lowest void ratio with the smallest standard deviation. Moisture content and per cent saturation were more closely controlled with the vacuum method of saturation.

Conclusions

1. Compaction by rodding and saturation under a vacuum provide a more uniform degree of compaction and saturation during the preparation of frozen sand specimens.

2. The most critical part of the preparation procedure is the time it takes to freeze and machine the specimen. This time must be kept constant for each specimen to minimize variability if sublimation can occur.

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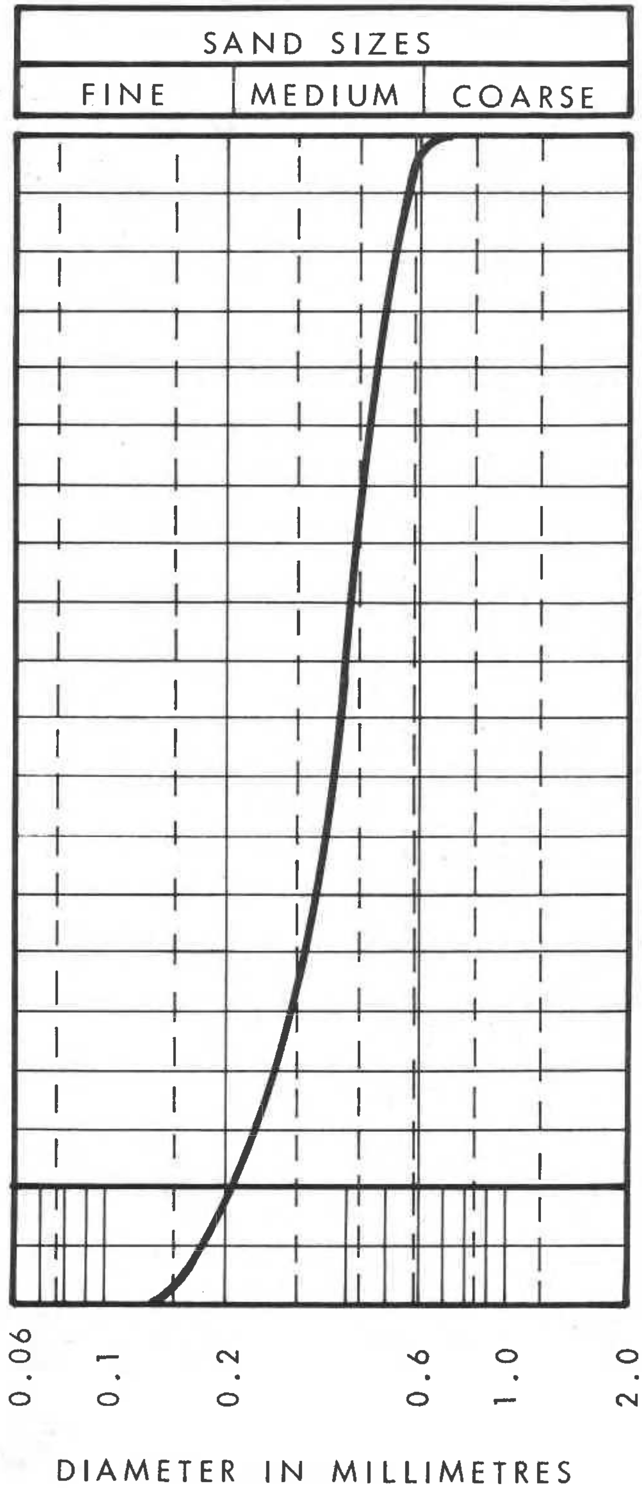


FIGURE 1

GRAIN SIZE DISTRIBUTION

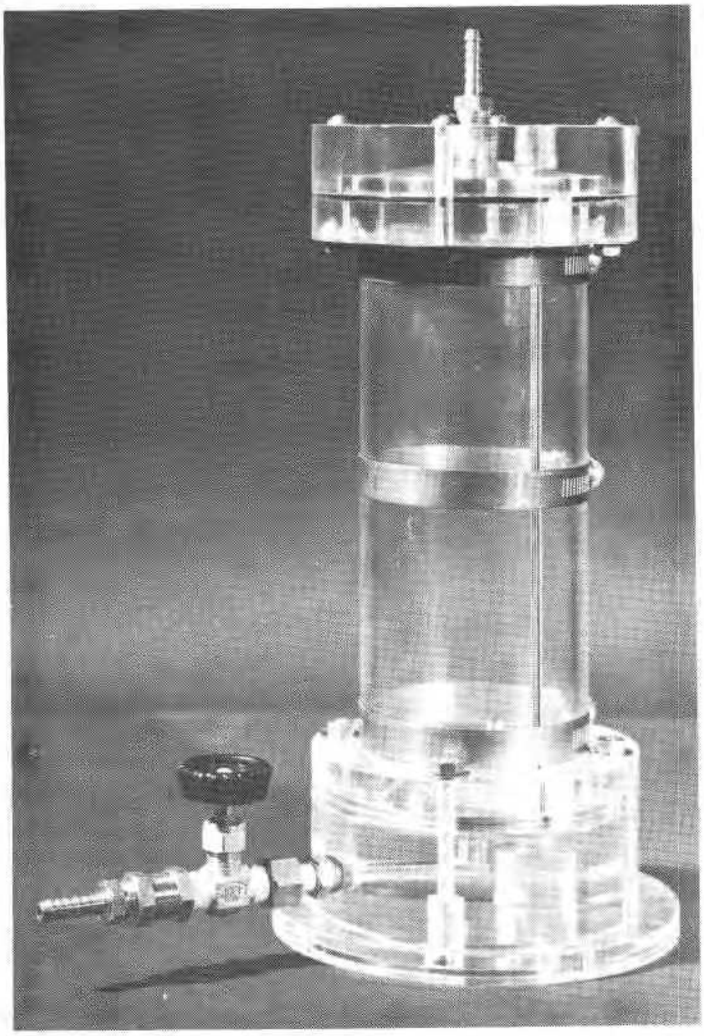
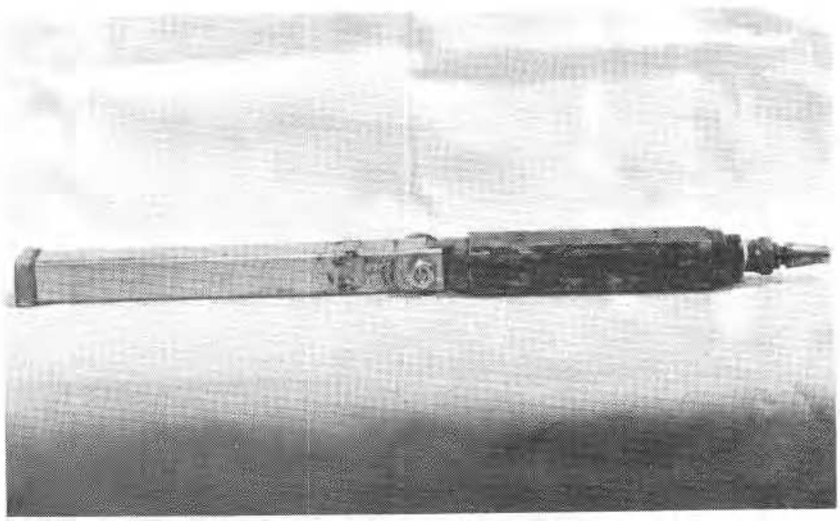


Figure 2

Perspex Mould

Figure 3

Vibrator



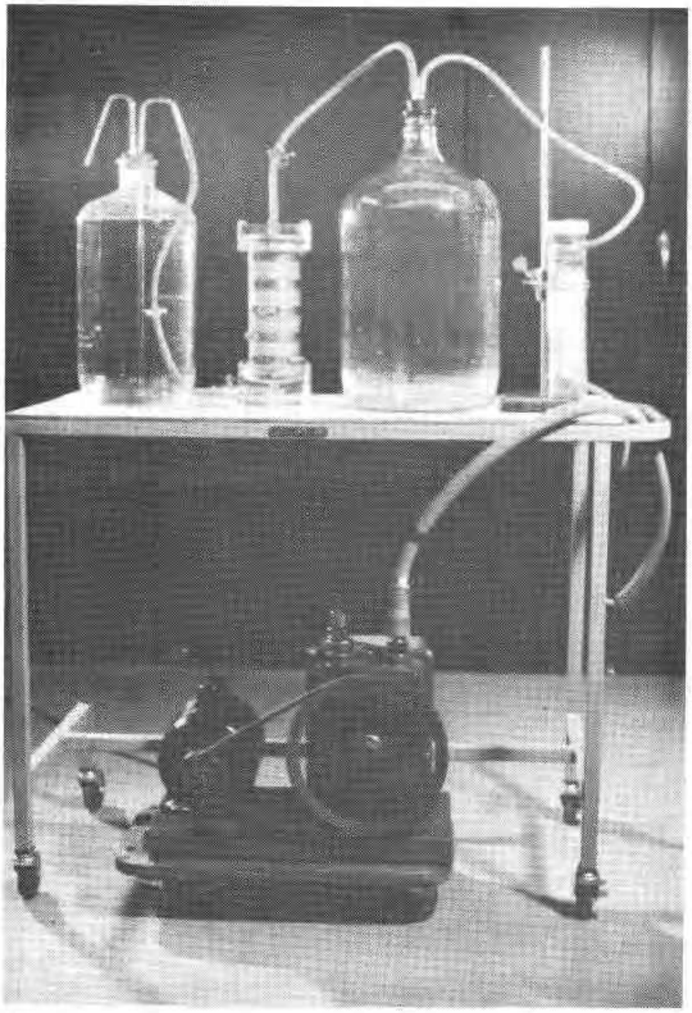
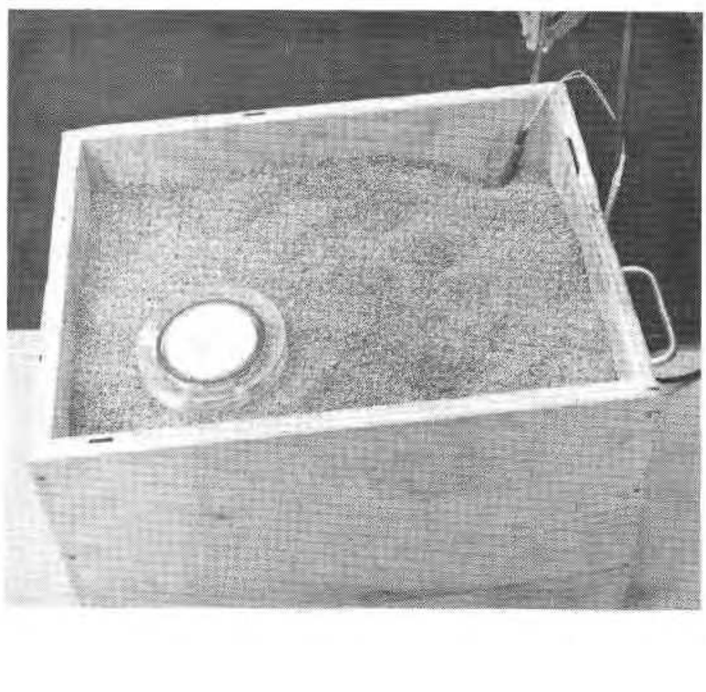


Figure 4

Evacuation-Saturation Apparatus

Figure 5

Specimen During Freezing



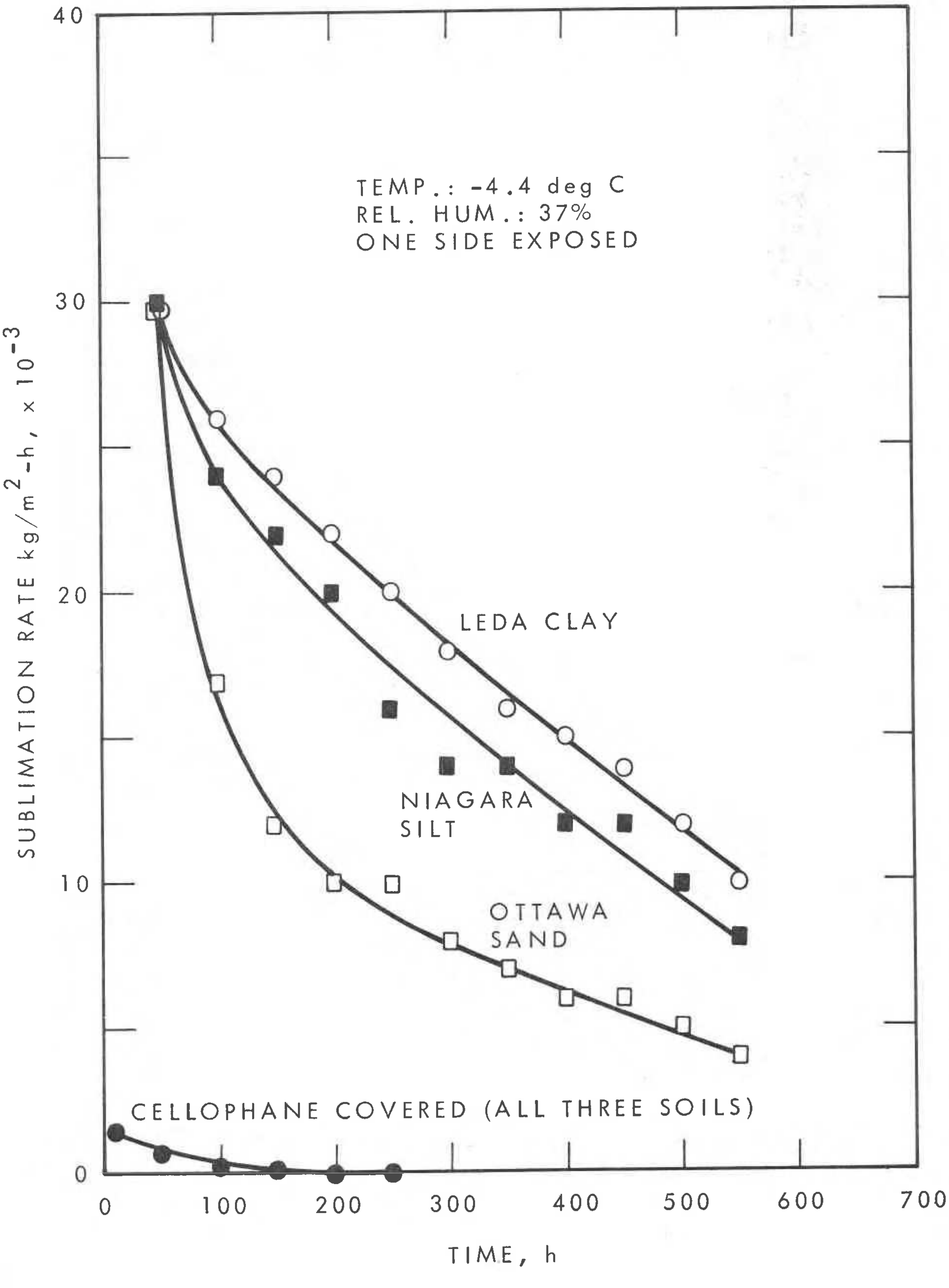


FIGURE 6

SUBLIMATION OF SOME FROZEN SOILS

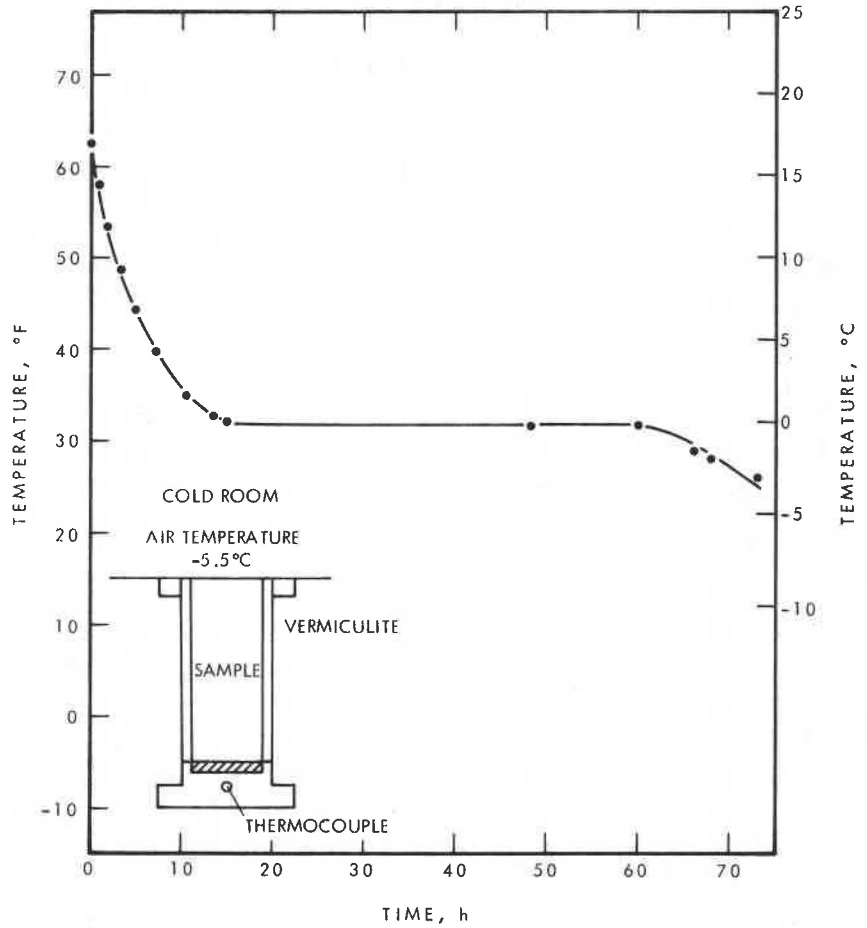
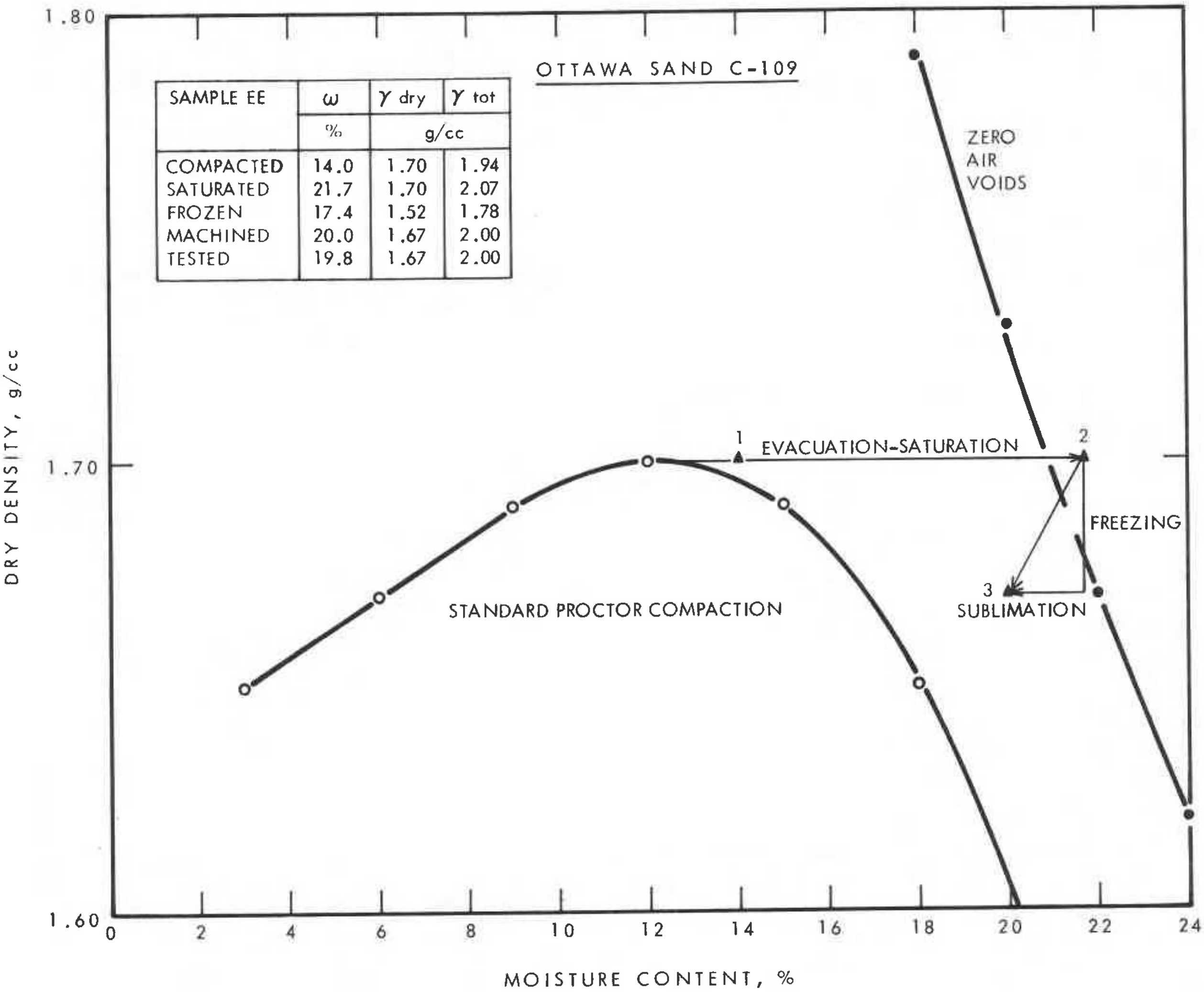


FIGURE 7
UNIAXIAL FREEZING OF FINE SAND SPECIMEN



SAMPLE EE	ω	γ dry	γ tot
	%	g/cc	
COMPACTED	14.0	1.70	1.94
SATURATED	21.7	1.70	2.07
FROZEN	17.4	1.52	1.78
MACHINED	20.0	1.67	2.00
TESTED	19.8	1.67	2.00

FIGURE 8

DENSITY-MOISTURE CONTENT RELATIONSHIP

Appendix A

Calculations used in determining sample characteristics

Moisture Content

$$\omega = \frac{W_w}{W_d}$$

Bulk Frozen Density

$$\gamma_f = \frac{W_f}{V_f}$$

Dry Density

$$\gamma_d = \frac{W_d}{V_f} = \frac{\gamma_f}{1+\omega}$$

Void Ratio

$$e = \frac{V_v}{V_s} = \frac{V-V_s}{V_s} = \frac{V-\frac{W_d}{G}}{\frac{W_d}{G}}$$

Degree of Saturation

$$S_r = \frac{V_w}{V_v}$$

$$V_w = \frac{W_d\ (\omega-\alpha)}{0.917} + \frac{W_d\alpha}{1.0}$$

$$V_v = eV_s = e\,\frac{W_d}{G}$$

$$S_r = \frac{W_d \left[\frac{(\omega-\alpha)}{0.917} + \alpha \right]}{e \, \frac{W_d}{G}}$$

$$S_r = \frac{\frac{G(\omega-\alpha)}{0.917} + G\alpha}{e}$$

where:

W_w = weight of water

W_d = weight of dry soil (oven dried)

W_f = weight of frozen soil mass

V_f = volume of frozen soil mass

V_v = volume of voids

V_w = volume of water

V_s = volume of dry soil

G = specific gravity of dry soil

0.917 = specific gravity of ice

1.0 = specific gravity of water

α = grams of unfrozen water per gram of dry soil

Appendix B

Vibrated Samples Compacted to 11% m.c.
Saturated Under Head of Water

Sample	Final ω %	γ_d/cc	γ_f/cc	S_r %	e
A	19.7	1.67	1.99	96.2	0.592
B	21.1	1.63	1.97	96.6	0.631
C	21.4	1.63	1.96	96.2	0.643
D	20.1	1.66	1.99	97.1	0.598
E	22.7	1.53	1.88	89.5	0.733
n=5					
Average	21.0	1.62	1.96	95.1	0.639
Standard Deviation	1.18	0.06	0.05	3.16	0.06
Standard Error	0.53	0.02	0.02	1.41	0.03

Rodded Samples Compacted to 11.5% m.c.
Vacuum Saturated

Sample	Final ω %	γ_d/cc	γ_f/cc	S_r %	e
K	19.2	1.67	1.99	94.7	0.586
L	20.2	1.67	2.00	97.9	0.596
M	21.3	1.61	1.95	94.8	0.649
N	20.1	1.64	1.92	94.6	0.614
n=4					
Average	20.2	1.65	1.97	95.5	0.611
Standard Deviation	0.86	0.03	0.04	1.60	0.03
Standard Error	0.43	0.01	0.02	0.80	0.01

Rodded Samples Compacted to 14.0% m.c.
Vacuum Saturated

Sample	Final ω %	γ_d/cc	γ_f/cc	S_r %	e
S	17.9	1.69	2.00	91.7	0.564
T	19.3	1.68	2.01	97.0	0.575
V	18.7	1.70	2.02	96.5	0.560
W	17.3	1.74	2.04	95.0	0.526
Y	18.8	1.69	2.00	96.8	0.561
Z	18.1	1.68	2.00	96.5	0.575
AA	17.8	1.71	2.02	93.9	0.548
BB	18.5	1.71	2.02	96.3	0.555
CC	19.2	1.69	2.02	98.0	0.566
DD	18.6	1.70	2.02	95.8	0.560
EE	19.8	1.67	2.00	97.3	0.588
FF	19.6	1.68	2.01	97.8	0.579
HH	18.4	1.71	2.03	97.2	0.547
II	20.3	1.65	1.99	97.1	0.604
JJ	18.5	1.70	2.02	95.8	0.558
KK	20.0	1.67	2.00	97.6	0.592
LL	18.7	1.71	2.03	97.7	0.553
MM	19.4	1.68	2.01	98.0	0.572
n=18					
Average	18.8	1.69	2.01	96.4	0.566
Standard Deviation	0.81	0.02	0.013	1.62	0.018
Standard Error	0.19	0.01	0.003	0.40	0.004