THE EFFECT OF ADMIXTURES ON THE FREEZING POINT OF A SUBGRADE

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The Effect of Admixtures on the Freezing Point of a Subgrade

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INTROUCTION

Most persons living in the northern section of the United States or in a location with a similar climate and who drive motor vehicles are well aware of the havoc that may be wrought on highways as a result of frost action. Some roads are broken up quite a bit, others are affected little. Gravel roads and roads with bituminous surfaces are usually affected greater than concrete highways. The reason for this will be shown later. Particular sections of a road surface may be raised an amount up to six inches due to frost action. Usually the surface breaks up if the heave is greater than one and one-half inches to two inches. The heaving is due to ground water freezing and expanding. The use of admixtures to reduce the freezing point will consequently reduce the amount of frost action. It is the purpose of this paper to show what admixtures will lower the freezing point the greatest and how they react to frost action when finally frozen.

THEORY

Frost heave is due to the freezing and subsequent expansion of moisture in the soil. The freezing forms layers of ice caused by the growth of ice crystals in the direction of heat transfer. The layers of ice sometimes form in the shape of lenses, hence the term ice lenses. The ice crystals in growing exert pressure on the particles around them and since there is less resistance above, the soil begins to heave or erupt. This eruption is often called a "frost boil." When the frost "goes out" of the ground, the ice in the frost boil turns to water and flows out of the frost boil, leaving a void which has little supporting power. Damage to a road surface is done both upon eruption of the surface and also when a vehicle sinks in the void left by the frost boil. The repair of a gravel road after such action has taken place is not costly or involved, but when the frost action takes place under a bituminous or concrete surface the repair may prove to be costly.

There are various conditions which are necessary before frost heave can occur. These are:

(1) The soil must be saturated.

(2) The soil must have an ample supply of water within itself or have a supply of water to draw on.

(3) The soil grains must be of size as to facilitate "sucking-up" of water to the zone of freezing.

(4) There must be a formation of layers of ice. The formation of these layers depends on

  (a) The rate of temperature change.
  (b) The moisture content of the soil before freezing.
  (c) Nearness of additional water.
  (d) The rate at which capillary action takes place.
  (e) The density of the solution.
  (f) Depth to ground water.
  (g) Air dry water content.

(5) The ice crystals, in growing, must exert enough pressure to cause heaving.

In addition, previous experiments have found that the more colloidal material in the soil, the greater the danger of heaving. Pulverzer-compacted clay has a greater amount of heave than undisturbed clay. The most severe heaving of clay occurs at a density of 102-107 pounds per cubic foot. There is also much heave when the air dry water content is between three and five percent. Lastly, a non-uniform soil results in a greater heave than a uniform soil.

In an experiment reported by A. W. Johnson,[1] the relation of the texture of soil to the amount of frost heave was given by the following table:

(1) "Frost Action in Subgrades and Bases" A. W. Johnson Roads and Bridges Sep. 1947 p. 104

Texture of Soil	Height of Heave (inches)
Silt	6
Very fine sand and silt	5
Silty clay	5
Very fine sand	4
Sandy clay	3

The reason for the great height of heaving in silt is the fact that silt has a high capillarity and therefore contains a high degree of water. This water upon freezing, increases its volume. Since the silt has the greatest amount of water it will have the greatest amount of volume change (or heave) upon freezing.

There have been attempts made to reduce the amount of frost heave by completely eliminating the silt in a soil. If this is impractical or impossible, a lessening of the severity may be had by being certain of good drainage. This would eliminate the supply of water, one of the conditions necessary for frost action. Another remedy may be through the use of admixtures in the subgrade. These admixtures combine with the water to form a solution which is more dense than just plain water. This increase in the density of the solution lowers the freezing point and the vapor pressure and increases the surface tension and the viscosity. The lowering of the freezing point lessens the severity of the frost heaving. This paper deals with certain admixtures, why they are used, and results obtained from using them.

Some of the admixtures currently used in soil stabilization are ammonium chloride, sodium nitrate, sodium chloride, calcium chloride, potassium carbonate, potassium dihydrogen phosphate, limestone dust, tar (TC), emulsified asphalt (AES-1) and liquid asphalt (MC-1). Due to the shortage of time, samples were only tested which contained as admixtures sodium chloride, calcium chloride, lime, and emulsified asphalt. These were picked because they are most commonly used now in stabilization practice and they are both plentiful and economical.

Description Of Equipment And Technique

In performing the research for this thesis, soils representing the worst possible soil conditions and the best possible soil conditions were used. A sample consisting of 100% silt was used to represent the worst condition. A sample consisting of 7.5% silt, 15% clay, and 77.5% sand, was used to represent an ideal road sub_base sample. It would have been much better to have used several samples of different combinations but the limited length of time in which to perform the experiment made it implausible to use more than the two samples.

The admixtures used were ones that are economical and easily obtained. The percentages of the admixtures used were based on what has already been economically used in soil stabilization practice. The following admixtures were used in the percentages shown:

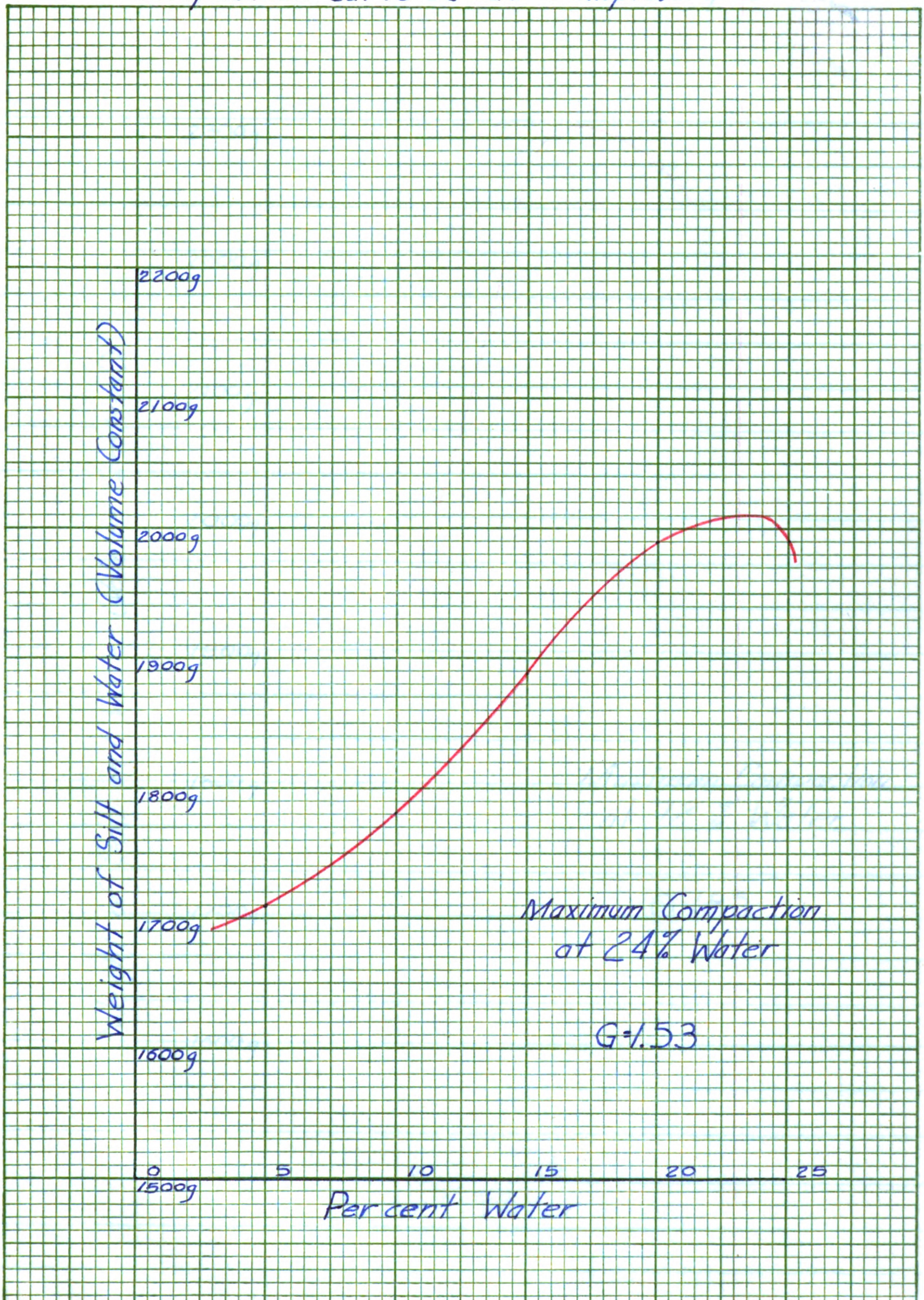
Calcium Chloride ---------- 1% (Ideal sample)
" ---------- 2% (Silt)
Sodium Chloride ----------- 1% (Ideal sample)
" " ----------- 1% (Silt)
Crushed Limestone ---------50% (Ideal sample)
" " -------- 50% (Silt)
Emulsified Asphalt -------- 5% (Ideal sample)
" " -------- 5% (Silt)
Sodium Chloride -----------10% (Ideal sample)

Procedure

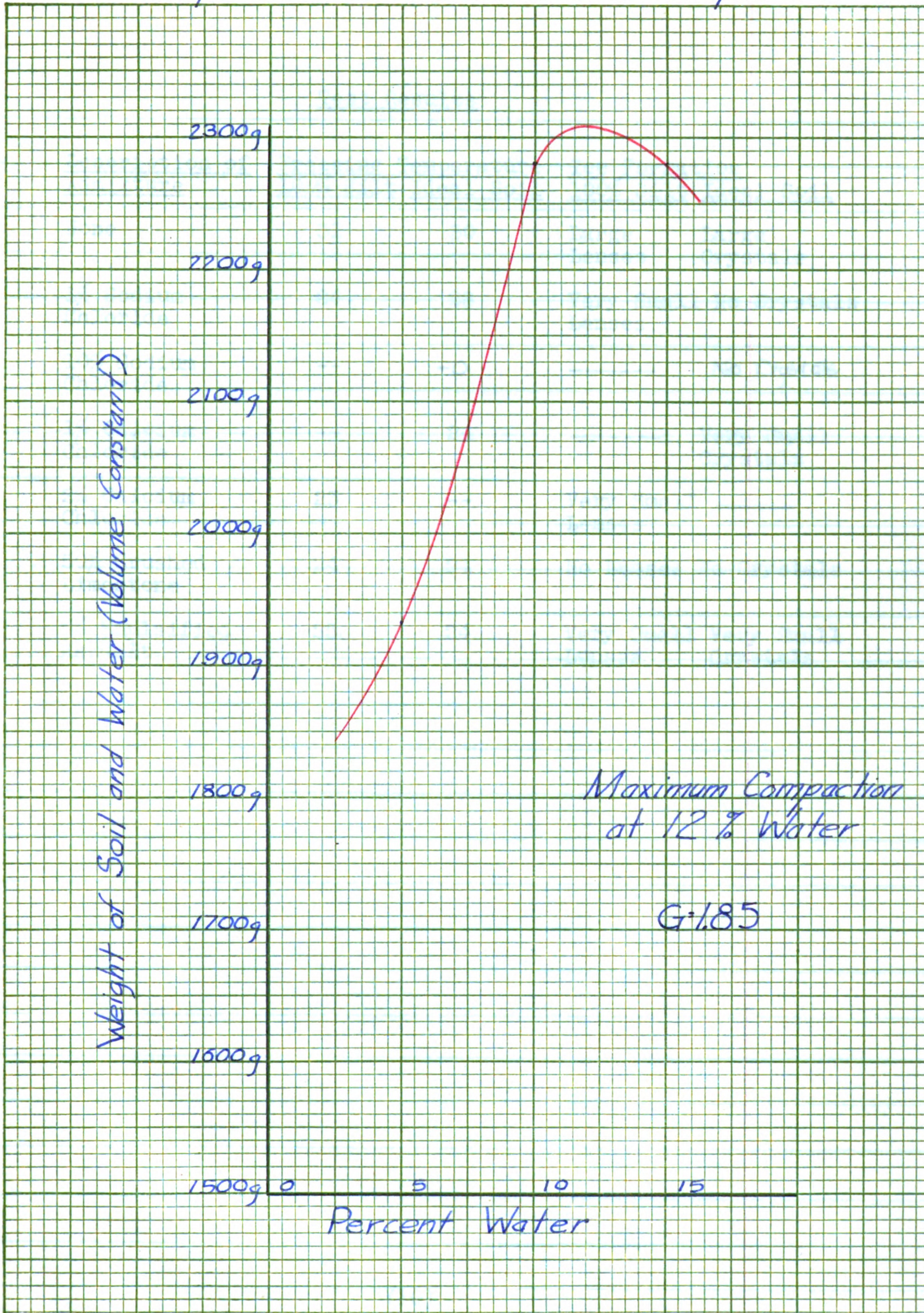
The first step was to obtain the soil samples. Boichot 2DS sand was used. The clay was obtained from the excavation for Robert Shaw Hall and the silt was obtained from the college gravel pit. The soil samples were dried with a Brunsen burner and the ideal sample was prepared using the percentages by weight as previously mentioned. A compaction curve (Proctor) was made for both the silt and the ideal mixture to determine the percentage of water contained by the soil when it had reached its maximum density. The dry density of each sample was also obtained.

To make samples of a convenient size for these experiments round, waxed, one pint, card board containers were obtained. The soil was mixed with the proper percentage of water so that it would be at its maximum density and then mixed with the proper percentage of admixture. Two samples each of silt and ideal soil were made with no admixture and six samples using each admixture for both silt and ideal soil were made. The mixtures were firmly packed in the containers by filling the containers in increments of one third and tamping twenty five times. Ten or twelve holes were punched in the bottom of each container. The samples were then set in a large pan containing enough water to cover the holes. The silt samples, which have fast capillarity, were left in the water seven days and the ideal soils were left in the water for at least ten days. The samples were then placed in a freezing chamber and subjected to temperatures varying from thirty two degrees Fahrenheit downward in increments of one degree. As each sample froze it was removed from the freezer and broken to see if frost lenses or crystals had yet been formed. If lenses or crystals had been formed the temperature was recorded and the sample photographed. The samples were left in the freezer for at least one day before being broken.

Compaction Curve (Silt Sample)



Compaction Curve (Ideal Soil Sample)



Test Results

Description of Admixture	Freezing Temperature 100% Silt	Freezing Temperature Ideal Soil	Ice Formation 100% Silt	Ice Formation Ideal Soil
None	31	30	Large Lenses	Large Crystals
1% Sodium Chloride	24	23	Very Small Lenses	No Crystals
10% Sodium Chloride	--	-0	------	No Crystals
1% Calcium Chloride	--	24	------	Very Small Crystals
2% Calcium Chloride	23	--	Very Small Lenses	------
50% Crushed Limestone	24	24	No Lenses	No Crystals
5% Emulsified Asphalt	25	24	Very Small Lenses	Very Small Crystals

100% Silt, No admixture
Froze at 31° F, large ice lenses

Ideal Soil, No admixture
Froze at 30° F, large ice crystals

100% Silt, 1% Sodium chloride

Froze at 24^{o}F, Small ice lenses

Ideal Soil, 1% Sodium chloride

Froze at 23^{o}F, small ice crystals

100% Silt 2% Calcium chloride

Froze at 23° F, Small ice lenses

Ideal Soil, 1% Calcium chloride

Froze at 24° F, Small ice crystals

100% Silt 50% Crushed limestone
o
Froze at 24 F, No ice lenses

Ideal Soil, 50% Crushed limestone
o
FrozeFat 24oF, No ice crystals

100% Silt, 5% Emulsified Asphalt

Froze at 25 ^{o}F, Small ice lenses

Ideal Soil, 5% Emulsified Asphalt

Froze at 24 ^{o}F, Small ice crystals

Ideal Soil, 10% Sodium chloride
Froze at -0°F, No ice crystals

Interpretation of Results

The results obtained were very satisfactory. All of the admixtures used lowered the freezing point of the sample below the lowest temperature to be expected, 26 degrees Fahrenheit.

With no admixture present, the sample containing 100% silt froze at 31 degrees Fahrenheit, one degree below the freezing point of water. Due to the high capillarity, a large volume of water was present. This volume was so large that the sample froze at almost the same temperature as water. Also due to the large amount of water held in capillary action was the formation of ice lenses. Since this soil froze at the highest temperature it can be seen that it would be the most unsatisfactory for a subgrade. Due to the ice lenses formed, it can also be seen that a subgrade containing silt would have the most frost heave due to volume change.

The ideal soil containing no admixture froze at 30 degrees Fahrenheit with the formation of no ice lenses but with the formation of large ice crystals. Thus, a subgrade of this material would be unsatisfactory since it freezes at a relatively high temperature with the formation of ice crystals.

The samples containing admixtures froze below 26 degrees Fahrenheit, the lowest soil temperature that is apt to be encountered in a subgrade. This indicates that a subgrade that a subgrade containing any of the admixtures would result in a subgrade that would not freeze, and subsequently, have no icd lenses.

The test sample containing 5% emulsified asphalt in silt froze at 25 degrees Fahrenheit with the formation of ice lenses so small as to be barely discernable. The emulsified asphalt evidently broke up the capillary action of the silt to a great extent. Frost heave in a road having a subgrade of silt treated with emulsified asphalt would be negligible since the volume change due to the formation of the tiny lenses would be negligible. The same result was found in the ideal soil sample which froze at 24 degrees Fahrenheit. Very small crystals were found which would cause very little volume change. The freezing point was 1 degree lower than that of the sample containing silt since silt has a greater capillarity and therefor a greater amount of water.

The silt sample with 50% crushed limestone froze at 24 degrees Fahrenheit with the formation of no ice lenses. The ideal soil sample containing 50% crushed limestone also froze at 24 degrees Fahrenheit with no formation of ice lenses or crystals. A subgrade containing this admixture would therefore have no frost heave due to the formation of ice lenses and crystals.

Silt containing 2% calcium chloride froze at 23 degrees Fahrenheit, the lowest temperature recorded for a silt sample. Hence, from the standpoint of the lowest freezing

temperature, the best admixture to use with silt would be calcium chloride. Small lenses were formed, however, and therefore there would be a slight heave upon freezing. The soil sample with 1% of this admixture froze at 24 degrees Fahrenheit, one degree higher than the silt sample. This is adnormal since all the other samples tested the silt samples froze before the ideal soil samples, however, this could have been due in part to the extra 1% of the admixture present in the silt. Small ice crystals were formed and hence a small volume change would occur upon freezing.

Silt containing 1% sodium chloride froze at 24 degrees Fahrenheit with the formation of very small ice lenses. The ice lenses were so small as to present little volume change. The Ideal soil sample froze at 23 degrees Fahrenheit, the lowest temperature recorded for the regular samples. The only sample with a lower freezing point was the soil sample containing 10% sodium chloride, an impractical mix. This sample froze at -0 degrees Fahrenheit. From the standpoint of the lowest freezing point it may be concluded that a 1% sodium chloride mixture would be the best for a subgrade. Since there were no ice crystals or lenses formed, this admixture would also be best from the standpoint of volume change and subsequent frost heave.

The ideal soil sample containing 10% sodium chloride froze at -0 degrees Fahrenheit with the formation of no ice crystals or lenses. As was before stated, this was an impractical mix and was used purely for experimental purposes.

CONCLUSION

From the results obtained, several conclusions con be drawn:

(1) A subgrade composed of silt will freeze sooner than a subgrade of ideal soil containing 7.5% clay, 15% silt, and 77.5% sand.

(2) Since ice lenses are more detremental than ice crystals, a subgrade containing silt will heave greater than one or ideal soil.

(3) A silt subgrade containing 2% calcium chloride as an admixture would have the lowest freezing point.

(4) A silt subgrade containing 50% limestone would have the least amount of heave due to ice formation.

(5) A 1% sodium chloride admixture in ideal soil would lower the freezing point the greatest.

(6) An ideal soil would have no heave due to ice formation if the admixture used was either crushed limestone or sodium chloride.

(7) Using current prices (May 16, 1949), and quantities as indicated previously, the most economical admixture that could be used is sodium chloride.

<u>Prices as of May 16, 1949</u>

Sodium chloride	$ 9.30 per ton
Calcium chloride	$23.36 per ton
Crushed Limestone	$35.50 per ton
Emulsified Asphalt	$ .11 per gallon

Based on the foregoing conclusions, the authors recommend the use of sodium chloride as the admixture which will be the most effective in the prevention of frost heave with regards to lowest freezing temperature, least formation of ice lenses and crystals, and lowest unit cost.

There is still much to be done along the lines of this experiment. Many of the admixtures listed in the text of this thesis could not be tested due to the lack of time. A check should be made on the results by performing an experiment determining volume changes upon freezing using the various admixtures. Only two different soil types were used where as it is known there are many more in existence. Various percent ages of the admixtures should have been used in determining the most effective from the standpoint of frost heave. Therefore, while the authors hope they have contributed something to the knowledge of the effect of admixtures on frost heave, there is a large extensive program which must be carried out before the problem of frost heave can finally be overcome.

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