CHARACTERIZATION OF SUBGRADE SOILS IN COLD REGIONS FOR PAVEMENT DESIGN PURPOSES

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This paper discusses the assessment of the effects of freezing and thawing on the stiffness of subgrade soils in an environment representative of the north central portion of the North American continent. Subgrade samples were taken in the fall of 1970 and in the spring of 1972 from a road in the province of Saskatchewan. These samples were used to determine in situ suction and resilient moduli values representative of those existing in the spring and the fall, and a laboratory test was developed to duplicate these conditions. Moduli of the undisturbed samples obtained during the spring were considerably lower then those for samples obtained in the fall, whereas moduli of the remolded samples were considerably higher than those of the undisturbed samples, probably reflecting the presence of secondary structure in the undisturbed samples. After two freeze-thaw cycles on the remolded samples, moduli were obtained similar to the values obtained for the 1972 spring samples. Suction values obtained for the undisturbed samples were lower than for remolded samples. In situ suction values appear to range between 5 and 30 psi, indicating the need for precise techniques for measurement. Applicability of the psychrometer for determination of in situ suction values was investigated; this device does not appear sufficiently accurate to measure suctions in this low range.

•PREDICTION of the response of asphalt pavements to moving wheel loads, which in turn permits an estimate to be made of fatigue damage caused by repetitive stressing in the asphalt-bound layer, requires, among a number of factors, an estimate of the dynamic or resilient response characteristics of the untreated materials comprising the pavement section. One such procedure presented by Kasianchuk (5) makes use of a resilient modulus for subgrade soils determined by means of a repeated load triaxial compression test (13). In a recent investigation (2) this procedure was used to consider fatigue distress and applied to the analysis of an existing pavement in the province of Saskatchewan. The original method was developed for conditions in which no freezing of the subgrade occurs; therefore, application of this method to a northern environment such as Saskatchewan requires consideration of the effects of freezing and thawing on the response of soils. This paper outlines the problems and describes a method for characterizing the subgrade soil for a specific section of highway, Regina to Lumsden, in Saskatchewan for such conditions.

OUTLINE OF STUDY

In a northern environment such as experienced in central Canada, the deflection response of an asphalt pavement consisting of comparatively thin asphalt concrete layer (approximately 4 in.) overlaying untreated aggregate base and subbase varies

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considerably throughout the year and will be influenced markedly by the stiffness characteristics of the subgrade soil. Figure 1 shows the seasonal variation in Benkelman beam deflection of a section of highway between Regina and Lumsden in Saskatchewan. Based on earlier studies (14), it can be argued that, if the deflection response could be predicted from laboratory tests, the fatigue distress that had actually developed in this highway (Fig. 2) could be estimated.

Accordingly, the purposes of the study reported in this paper were to determine the in situ resilient moduli of the subgrade in the spring and in the fall and to develop a laboratory procedure that would duplicate both conditions. This was accomplished by studying the subgrade soil from the Regina-to-Lumsden highway, which had been in service for several years. This road was selected for investigation because its subgrade is relatively uniform, and, as noted earlier, the study formed a part of a larger fatigue simulation program (2) to attempt to predict the distress shown in Figure 2.

During the fall of 1970 and again during the spring of 1972, 12 sites were selected for detailed study. At these sites block samples of asphalt concrete, disturbed samples of base and subbase, and undisturbed samples of the lacustrine clay subgrade were obtained. This paper is concerned with the test program for the subgrade soils, a summary of which is as follows: Two or three 4½-in. diameter Shelby tube samples were taken at each site. Sample 1 was located 0 to 2 ft below top of subgrade, sample 2 was 2 to 4 ft below top of subgrade, and sample 3 was 4 to 6 ft below top of subgrade. All samples were taken in outer wheelpath, right-hand lane. The testing consisted of plastic and liquid limits tests, moisture content and density tests, and suction and resilient modulus tests.

Water content and dry density test results for all samples are shown in Figure 3. In this figure it is interesting to note that 45 samples exhibited water contents greater than the optimum water content based on the standard AASHO compaction test, whereas only four had less than optimum water content. The average plastic and liquid limits for this soil are 30 and 75 percent respectively. When the subgrade was constructed in 1961, the soil was placed several percent dry of the standard AASHO optimum water content and at a dry density ranging from 80 to 90 lb/ft^3. The test results indicate that a significant increase in water content in the subgrade has taken place since construction. Test results, however, do not indicate a difference in water content and dry density between the fall of 1970 and the spring of 1972.

RESILIENT MODULUS TESTING

Repeated load triaxial tests were performed on all samples to determine resilient moduli. Specimens 2.8 in. in diameter by about 6.0 in. in length were used for the first few tests; however, it was soon concluded that more uniform results could be obtained by using specimens 4 in. in diameter and 8 in. long. During the repeated load testing lateral and axial deflections were measured using a Linear Variable Displacement Transducer (LVDT). In a recent study, Dehlen (3) found that 1,000 stress repetitions were sufficient to condition the specimen to avoid changes in axial deflection because of end imperfections. The same procedure was tried and found adequate for the Regina clay samples. After a stress level change it was observed that 50 or 100 stress repetitions were sufficient to eliminate significant changes in modulus on further applications of repeated loads, which is similar to the results observed for glacial till material by McLeod (7).

Load was applied for 0.1 sec at 20 cycles per minute, and samples were tested at a confining pressure of 2 psi and a range in deviator stress of 1 to 5 psi. These stresses were selected based on analysis of typical stress conditions in the subgrade as determined by analytical techniques (2).

Results of the resilient moduli tests at $\sigma_3 = 2$ psi and $\sigma_d = 5$ psi are shown in Figure 4. Although there is considerable scatter in the data, most of the moduli are in the range 3,000 to 10,000 psi, with an average value of 8,200 psi for the fall of 1970 and an average value of 6,300 psi for the spring of 1972. These results agree reasonably well with observed pavement response in cold regions where a peak deflection is experienced in the spring probably because of a decrease in subgrade modulus (Fig. 1).

Figure 1. Benkelman beam deflection.

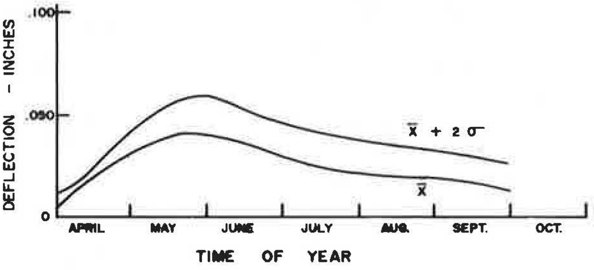
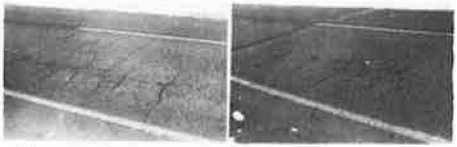
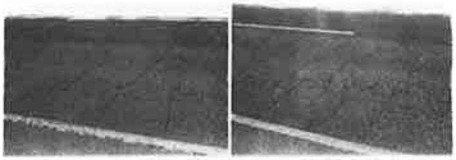


Figure 2. Fatigue and transverse cracking.



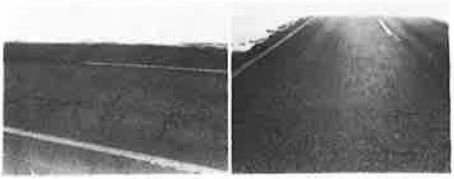
Early stages of fatigue, primarily transverse cracks in wheel path

Typical alligator pattern outside wheel path



Close-up view of fatigue

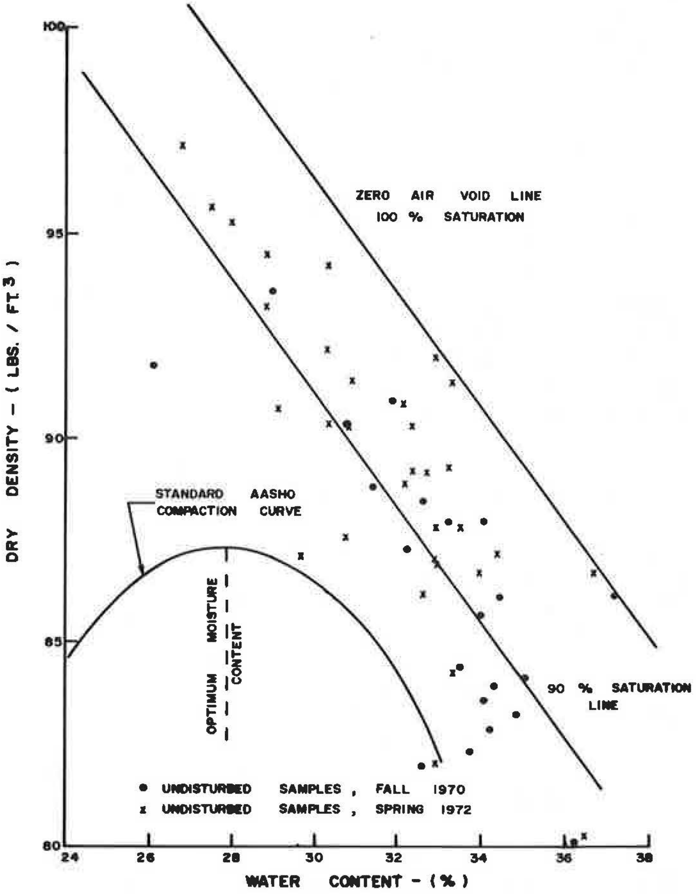
Close-up view of fatigue



Fatigue in the vicinity of a cold temperature transverse

Fatigue in isolated locations

Figure 3. Moisture-density conditions of test road samples.



After the samples had been tested, some were then frozen and retested. Prior to freezing, the samples were wrapped in a plastic film, placed in a Zonolite-insulated container, and surcharged with a 5-lb weight. The samples were frozen for 8 hours at 0 F and then thawed for 8 hours and retested. Confining pressure was not applied during freezing, nor were repeated loads applied during freezing. Typical results, which are shown in Figure 5, indicate the resilient modulus dropped considerably after one freeze-thaw cycle. The results after freeze-thaw (Fig. 5) were taken after 1,000 stress repetitions. With continued stress repetitions the modulus increased to approximately the original modulus prior to freeze-thaw. Approximately 10,000 stress repetitions at σ_d = 5 psi and a confining pressure of 2 psi were required to increase the modulus to its original value. McLeod (7) also reported significant decreases in resilient moduli of undisturbed samples of till after one freeze-thaw cycle, and he also reported, based on a very limited number of tests, that the modulus was regained after a number of repeated load applications.

After all the suction and resilient moduli tests were completed on the undisturbed samples, the soil was recombined, and remolded samples were prepared at about the same water content and density. Figure 6 shows the results of the resilient moduli tests on the remolded samples. In order to obtain resilient moduli that are more indicative of the spring value, the remolded samples were put through two cycles of freeze-thaw, and the results are shown in Figure 7. A comparison follows of the resilient moduli obtained for undisturbed samples from the spring and fall samplings with results from remolded samples with and without freeze-thaw. The resilient moduli obtained for the undisturbed samples were 6,300 psi for the spring 1972 sample and 8,200 psi for the fall 1970 sample. The resilient moduli for the remolded samples were 14,800 psi for no freeze-thaw and 6,500 psi for two cycles of freeze-thaw. The water content of the samples was approximately 33 percent. Two cycles of freeze-thaw appear sufficient to condition the samples so that stiffness values similar to those observed in situ are obtained.

SUCTION

During the past several years, numerous researchers have considered the possibility of using soil suction values for pavement design purposes (12, 15). A number of investigators have suggested procedures to measure suction both in the laboratory and in situ. Richards (10) has recommended the use of a psychrometric technique to measure total suction in the field and in the laboratory. Krahn (6) investigated the measurement of total suction by the Richards technique in the laboratory and also the measurement of matrix suction using a modified Anteus Consolidometer as developed by Pufahl (9). The results of these investigations indicate that laboratory techniques appear satisfactory. Field techniques for measuring suction over extended periods of time in cold regions, however, are still in the developmental stage.

Suctions on the Regina-to-Lumsden undisturbed samples before and after freeze-thaw were determined using the Anteus Consolidometer as modified by Pufahl (9). Following these measurements on the undisturbed samples, the soil from all test samples was combined and remolded. Suctions were then determined on remolded and recompacted samples over a range in water contents before and after freeze-thaw.

Results of all the suction tests on Regina clay are shown in Figures 8, 9, and 10. Figure 8 compares suction values on undisturbed and remolded samples prior to freeze-thaw. It is important to note that the undisturbed samples have already been subjected to several freeze-thaw cycles in the field. It is apparent from Figure 8 that the suction values on the undisturbed samples are considerably lower than for the remolded samples. It is difficult to detect a difference in suction values between the fall of 1970 and the spring of 1972. In all cases the undisturbed samples exhibit low suction values. Figure 9 shows suction values for remolded samples before and after freeze-thaw. A very significant drop in suction is evident after the freeze-thaw cycle. Figure 10 shows a comparison of suction values on undisturbed samples before and after freeze-thaw. A small but significant drop in suction occurred on the undisturbed samples after the freeze-thaw cycle. As noted previously, the undisturbed samples ob-

Figure 4. Clay resilient modulus and water content.

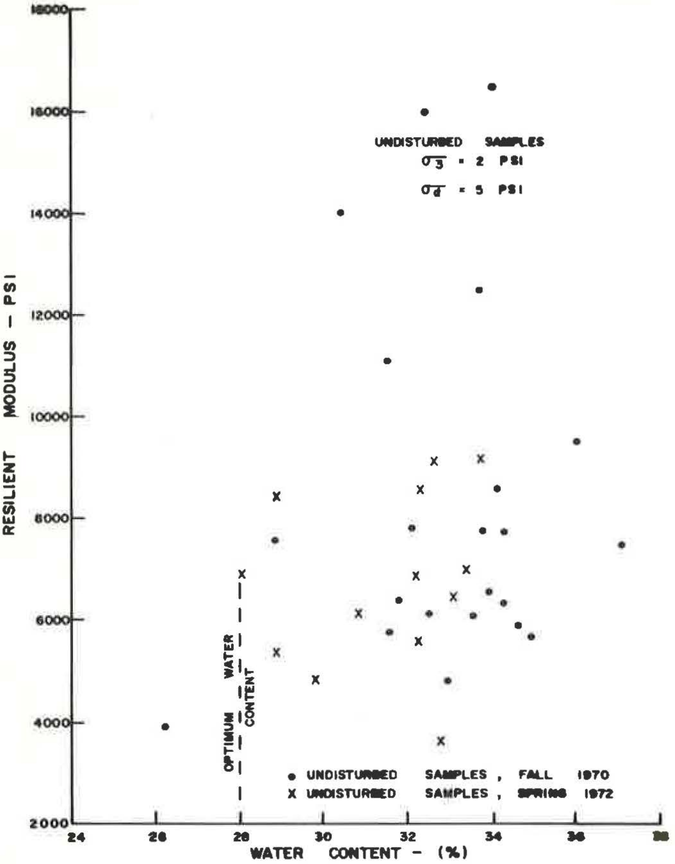


Figure 5. Resilient modulus tests, Regina clay samples, 1970.

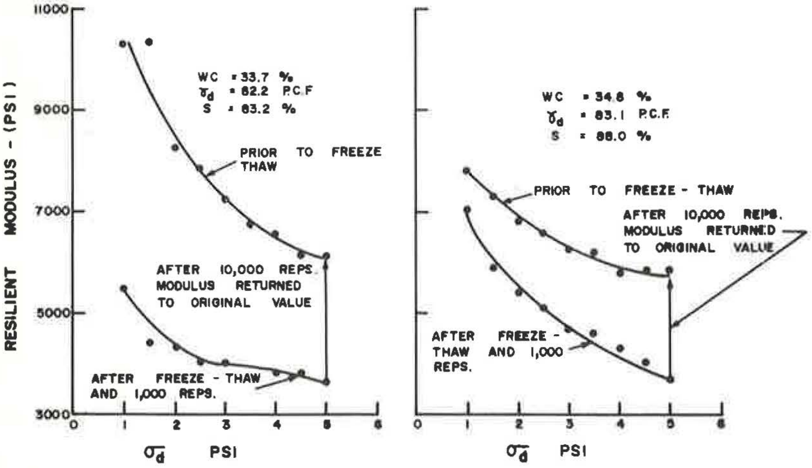


Figure 6. Resilient modulus of subgrade and water content of remolded Regina clay samples (σ_3 = 2 psi and σ_d = 5 psi).

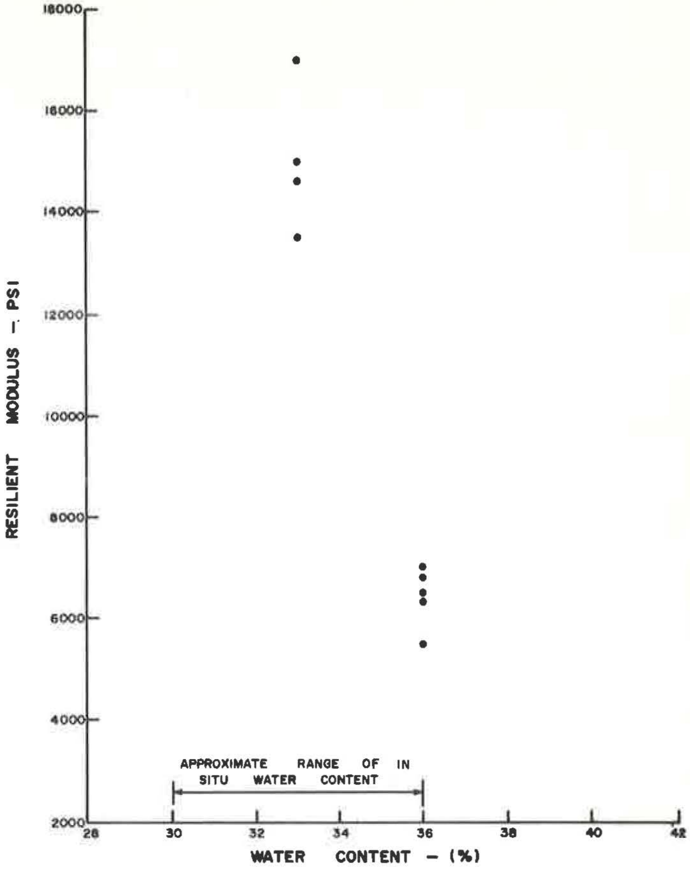


Figure 7. Resilient moduli of remolded samples after two freeze-thaw cycles (σ_3 = 2 psi and σ_d = 5 psi).

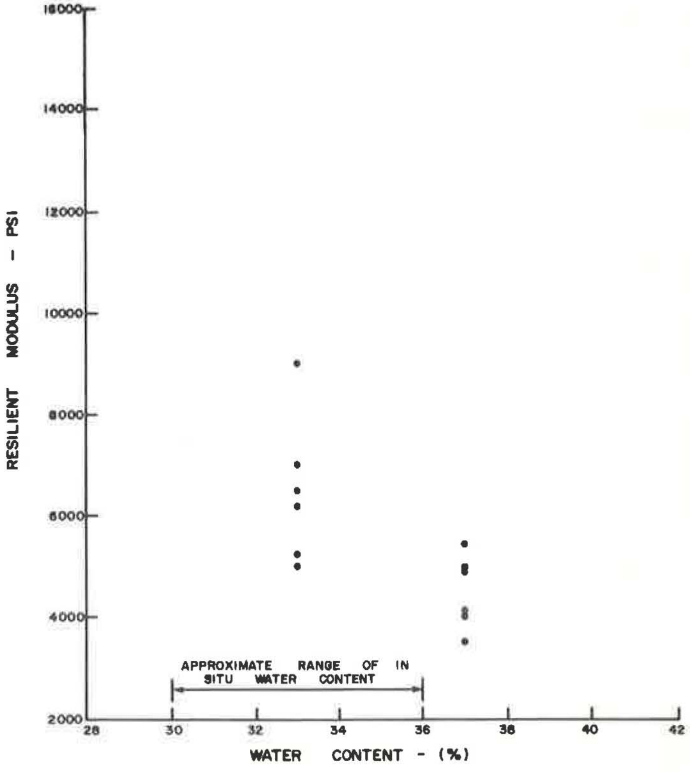


Figure 8. Soil suction values of undisturbed and remolded samples, no freeze-thaw.

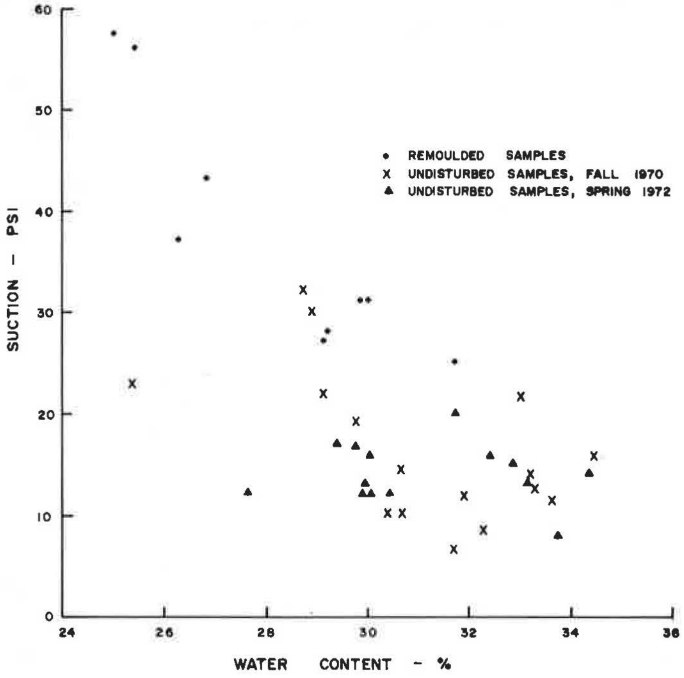
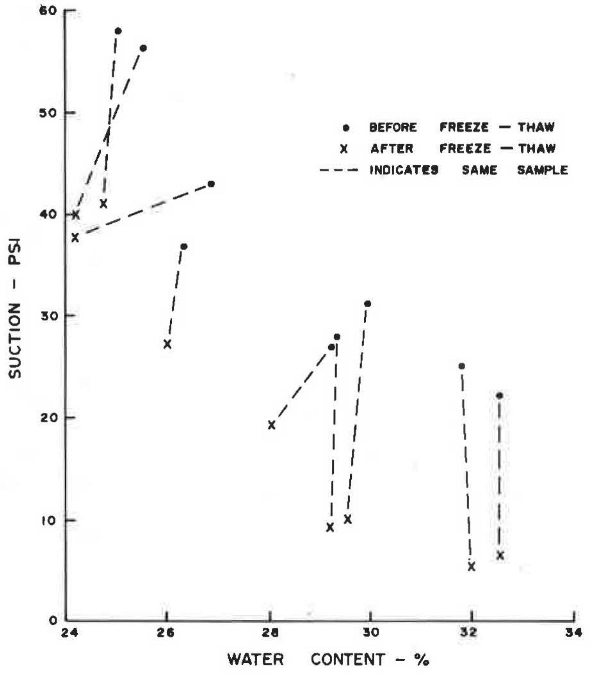


Figure 9. Soil suction values of remolded samples before and after freeze-thaw, fall of 1970.



tained during the fall of 1970 have been subjected to several cycles of freeze-thaw, but since the last cycle the roadway has been subjected to considerable truck traffic.

A well-defined secondary structure was present in the undisturbed samples (Fig. 11), and definite ice segregation was evident in the samples as observed by breaking three undisturbed samples in the frozen state. The average suction value of the undisturbed samples of Regina clay was 15 psi. Six of these samples were subjected to one cycle of freeze-thaw, and an average suction of 5 psi was measured after thawing (Fig. 10). This may represent in some way what happens in the subgrade between fall and spring in a cold region.

Mickleborough (8) also did suction tests using a pressure plate device on remolded Regina clay (the same material as tested in this investigation), and found that freeze-thaw cycles reduce suction values (Fig. 12). In this same investigation Mickleborough found that freeze-thaw reduced the resilient modulus by 50 percent at water contents greater than about 28 percent. The possibility of secondary structure affecting the suction was advanced as a possible explanation.

McLeod (7) performed suction tests on undisturbed till samples (Fig. 13) from a subgrade that had been in service for 3 years, and he found similar trends.

A possible explanation for the drop in suction after freeze-thaw is that the water accumulates in the secondary structure during the winter, and then on thawing the free water in the secondary structure controls the suction as measured in the laboratory. During the summer, with repeated stress applications and an internal suction gradient, the moisture is redistributed, and the suction as measured in the laboratory increases.

The suction test results on undisturbed samples from the highway section between Regina and Lumsden and the section of highway studied by McLeod (7) indicate that the suction of undisturbed field samples varies between 5 and 20 psi. It is possible, based on limited freeze-thaw test results, that the maximum suction during the spring is only about 20 psi. In the majority of the cases, the water content was above the standard AASHO optimum and also above the plastic limit. It is apparent that, in order to measure suction in the field, the technique must be precise enough to detect changes in suction in the range between 5 and 50 psi.

Details of a water content study completed during the fall of 1970 at a typical cross section on the Regina-to-Lumsden highway are shown in Figure 14. All water contents are higher than the plastic limit of 29.8 percent and the optimum moisture content of 27.8 percent as determined by the standard AASHO compaction test. A change in water content across the section or with depth is not evident. These data indicate that the suction value in all areas of the roadbed is probably less than 20 psi.

An extensive amount of field work has been carried out to determine the suction under covered areas in regions of moderate temperature. DeBruijn (4) reported a soil suction of 2.8 to 3.8 pF (2 pF = 1.42 psi, 3 pF = 14.2, and 4 pF = 142 psi) under covered areas in South Africa. Richards (10) reported soil suctions between 3 pF and 4 pF in a number of areas studied in Australia. The suction measurements reported (Fig. 8) are much lower than those reported by DeBruijn (4) and Aitchison and Richards (1). Low suction values are difficult to measure in the laboratory and are extremely difficult, if not impossible, to measure in the field with present technology under extremely adverse climatic conditions.

Sauer (11) measured matrix suction under thin pavements (1 in. of asphalt concrete on subgrade) using gypsum blocks during the fall of 1966 in the province of Saskatchewan. Suctions that were measured 2 ft below the pavement on centerline are given in Table 1. Water contents were well below the plastic limit, but still the suction values were very low. Based on work reported on remolded samples (Fig. 9) if the water content for lacustrine clay is 5 percent below the plastic limit the suction should be about 100 psi, but Sauer (11) reported suctions in the order of 10 psi. These observations are in agreement with observed suctions on undisturbed samples from the highway between Regina and Lumsden, as discussed previously. These field observations substantiate the differences found in the laboratory between suction measured on remolded samples and that measured on undisturbed samples.

Figure 10. Soil suction values of undisturbed samples before and after freeze-thaw, fall of 1970.

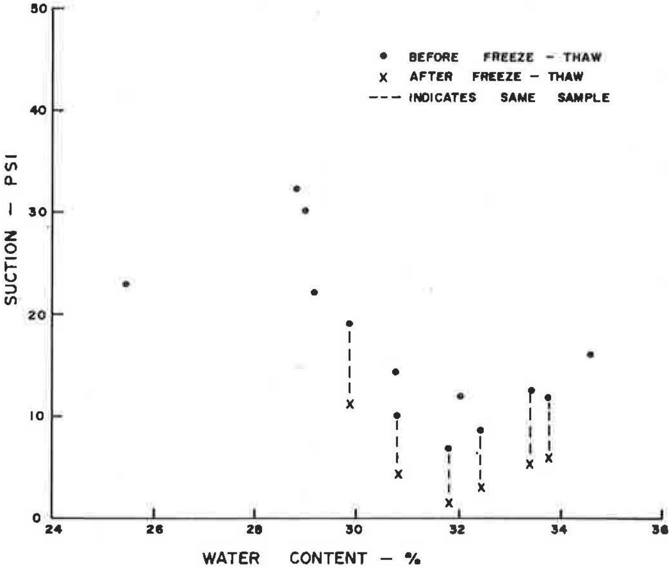
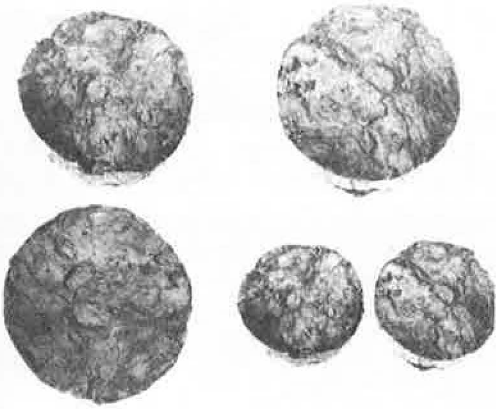
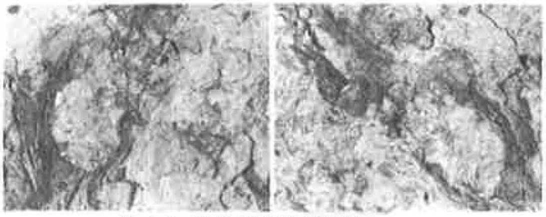


Figure 11. Undisturbed samples of Regina subgrade clay.



NOTE: Prominent secondary structure in above samples



Close-up view of secondary structure

Figure 12. Soil suction and water content of Regina clay.

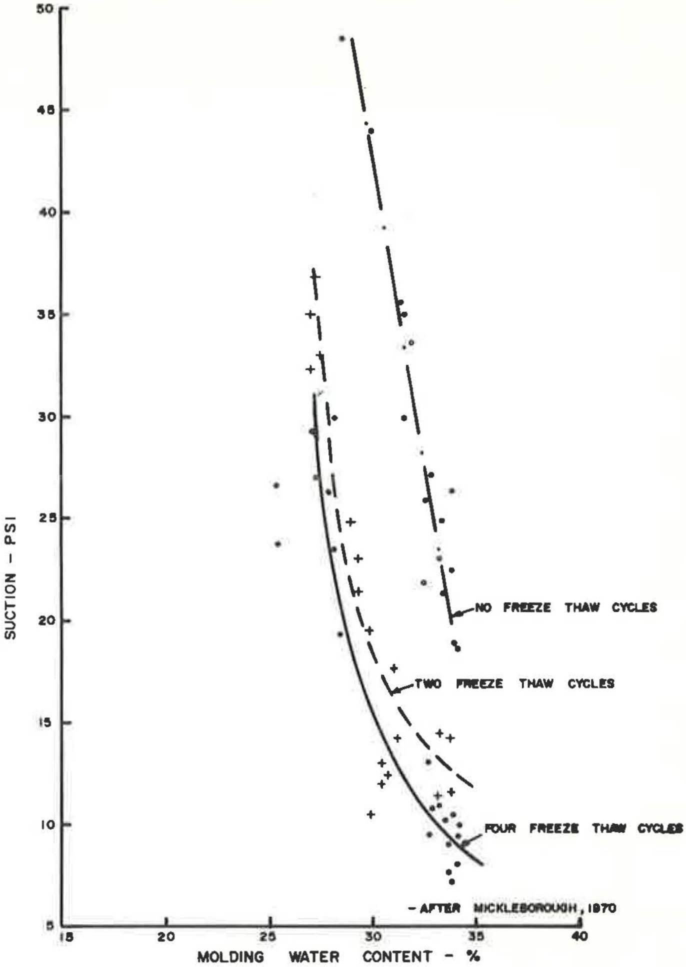


Figure 13. Soil suction and water content of original samples of till subgrade.

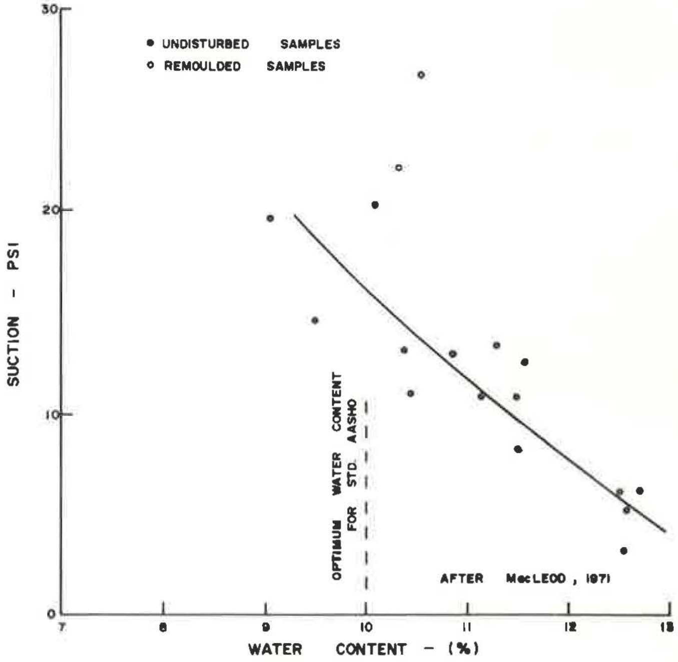
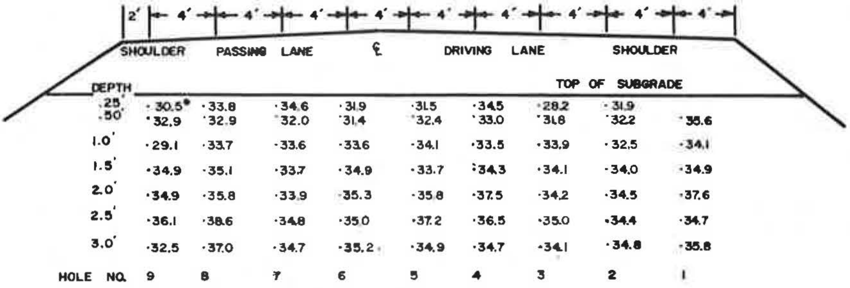


Figure 14. Moisture distribution in the subgrade.



DEPTH									
.25'	30.5*	33.8	34.6	31.9	31.5	34.5	28.2	31.9	
.50'	32.9	32.9	32.0	31.4	32.4	33.0	31.8	32.2	35.6
1.0'	29.1	33.7	33.6	33.6	34.1	33.5	33.9	32.5	34.1
1.5'	34.9	35.1	33.7	34.9	33.7	34.3	34.1	34.0	34.9
2.0'	34.9	35.8	33.9	35.3	35.8	37.5	34.2	34.5	37.6
2.5'	36.1	38.6	34.8	35.0	37.2	36.5	35.0	34.4	34.7
3.0'	32.5	37.0	34.7	35.2	34.9	34.7	34.1	34.8	35.8
HOLE NO.	9	8	7	6	5	4	3	2	1

* NUMBERS INDICATE PERCENT WATER CONTENT

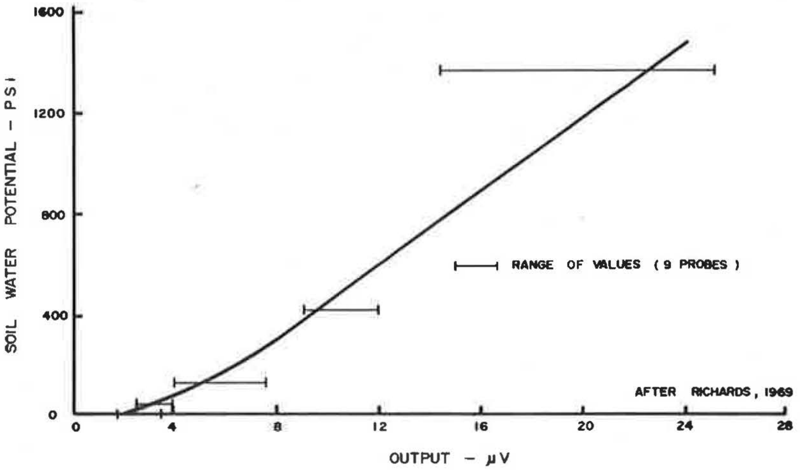
PLASTIC LIMIT = 29.8 %

OPT. WATER CONTENT STANDARD AASHO = 27.8 %

Table 1. Suctions measured by gypsum block (11).

Material	Test Site Number	Suction (psi)	Water Content (percent)	Plastic Limit (percent)
Lacustrine clay	GB-1	10	20	25.5
	GB-9	10	22	25.4
Till	GB-2	13	13	16.8
	GB-4	15	17	11.4
	GB-8	17	18	20.7
	GB-3	2	18	15.6
	GB-7	8	8	16.6
	GB-10	2	10	16.5

Figure 15. Calibration of in situ probes selected at random.



More recently Richards (10) proposed a psychrometric technique for measuring total suction. This type of installation was tried on the section of highway from Regina to Lumsden. The in situ psychrometer was designed and calibrated as outlined by Richards (10). The psychrometers were installed immediately below the outside wheelpath, and psychrometer readings were continued during April, May, and June 1971. The problem in taking such small electrical measurements (μV, microvolt) in the field makes the procedure very sensitive to error. Output readings ranged from 0 to 3 μV with the variation probably caused by measuring problems rather than differences in suction readings. Richards (10) reported the average calibrations for 9 in situ psychrometers as shown in Figure 15. This calibration is almost identical to the calibration of the psychrometers that were installed in the field on the Regina-to-Lumsden section. It is quite easy to see from the calibration why trouble was experienced in trying to detect a suction of about 10 psi or variations between 5 and 20 psi. Richards (10) suggested a psychrometric accuracy of ±15 psi or 25 percent, whichever is greater, but he also suggests that this may be improved somewhat with individual calibration. Krahn (6) used in the laboratory a psychrometer like the one used by Richards (10) and suggested that the psychrometer was not accurate at low suctions. Based on test results and other research presented in the section, the application of a psychrometer to measurement of suction in situ in cold regions does not appear to be sufficiently accurate for the range in suction expected based on findings presented here.

SUMMARY AND CONCLUSIONS

1. In cold regions the resilient modulus of the subgrade exhibits a significant seasonal change.
2. After one freeze-thaw the undisturbed samples decreased significantly in resilient modulus, and after 10,000 applications of load the modulus was regained. It was suggested that behavior reflects what happens in the roadway during spring and summer with repeated truck loading.
3. Testing of remolded samples does not duplicate field conditions in cold regions. For Regina clay, approximately two cycles of freeze-thaw are required to obtain a moduli value indicative of the spring condition.
4. Suctions measured on undisturbed Regina clay were considerably lower than measured suction for remolded Regina clay. It was suggested that this difference could be caused by the development of secondary structure.
5. Field suction values appear to be between 5 and 25 psi for the roads investigated in Saskatchewan. This indicates a need for precise measuring techniques to determine in situ suction values. The psychrometer is not sufficiently accurate for determination of such low suctions.

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