III.1. PERMAFROST OCCURRENCE AND ASSOCIATED PROBLEMS AT THOMPSON, MANITOBA

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This paper deals with permafrost conditions at Thompson, Manitoba. This is a new townsite which has been developed since 1957 to house and service the personnel at the mine and smelter operation of the International Nickel Company of Canada. Although extensive investigations had been carried out in connection with the mine and smelter sites, there was no evidence of the existence of permafrost in the area. However, when work was subsequently started in the townsite, permafrost was encountered at many locations.

Included in the paper is a description of the soil profile in the Thompson area, a discussion of the significance of certain test results on soil samples from the site, a brief history of construction at Thompson and finally, a review of the procedures which are being followed in engineering construction at the present time to minimize the effects which are normally associated with permafrost occurrence.

The town of Thompson is located approximately 400 miles north of Winnipeg and 250 miles southwest of Churchill. This places it roughly 150 miles south of the line which approximates the southern limit of continuous permafrost as shown in the Climatological Atlas of Canada (4). It also places it approximately 50 miles north of the southern limit of permafrost as recorded by Charles (2). The mean annual temperature at Thompson is approximately 25°F, which incidentally is close to that at Norman Wells, N.W.T., where widespread permafrost has been encountered. The mean January and July daily temperatures are about -15°F and 59°F, respectively. On the average there are about 140 frost-free days each year.

The soil profile in the Thompson area consists of varved clays overlying glacial outwash deposits of sand and gravel which in turn overlie the bedrock. Two distinct horizons exist in the varved material, differentiated by a colour change from brown to grey. The change occurs at an average depth of approximately 12 feet but has been observed as deep as 17 feet.

In the upper portion of the profile the silt to clay varve proportion is roughly 1/4 inch of silt to 3/4 inch of clay. The proportion of silt gradually increases and below a depth of about 12 feet the layers are approximately equal in thickness. Index and physical properties of the brown and grey varved materials are shown in Table 1. It will be noted that a somewhat higher than usual variation in natural moisture

TABLE 1

Index and Physical Properties

Clay Type	Moisture Content (%)			Atterberg Limits (%)				
	No. of Tests	Range	Av.	No. of Tests	Liquid Limit Range	Liquid Limit Av.	Plastic Limit Range	Plastic Limit Av.
Brown	130	28-47	34.2	25	34-80	58.0	19-32	26.0
Grey	183	19-55	31.7	25	20-77	45.2	16-29	19.5

	Unconfined Compressive Strengths		
	No. of Tests	Tons/Sq. Ft. Range	Tons/Sq. Ft. Av.
Brown	15	0.8-2.3	1.48
Grey	25	0.1-2.3	0.66

contents occurs in the clays. This is significant because it suggests that the higher moisture contents occur in sections of the profile where permafrost has only recently receded and subsequent consolidation of the clay is not yet complete.

Routine foundation investigations at several building sites have included laboratory strength and consolidation tests on undisturbed samples of both the brown and grey varved material. Shear strength was determined by means of the unconfined compression test. The average results of some 40 tests on samples from two such sites are shown in Table 1. These are typical of the results from the several sites investigated. The tests consistently showed a reduction in strength with depth. As more and more test results became available it became apparent that the unconfined compressive strength tests did not in all cases accurately assess the strength of the soil in situ. It did not seem logical to accept as valid, strength test results which showed shear strengths of only 300 to 400 pounds per square foot for samples from depths of 30 to 40 feet.

A detailed study of all the available strength data was therefore undertaken. Shear vane tests were conducted at a limited number of sites to secure a check on the in situ shearing strength of the clays, and in addition, penetration tests were run in the form of driving resistance of thin walled Shelby tubes.

No correlation was found between the natural moisture content and the strength of the varved silt-clay soils as determined by the laboratory unconfined compressive strength test. This suggests that the soil derives its shearing strength predominantly from thixotropic bonds between the soil particles, and to only a relatively minor degree from their frictional characteristics. This appears to be the case irrespective of whether or not the soil has been subjected to permafrost conditions in its recent geological history.

Figure 1 shows plots of laboratory unconfined compressive strengths, field penetration tests and in situ shear vane tests each plotted against depth below the surface. Ground temperature readings are also plotted against depth in Figure 1. These data are composite results from several test holes at two typical sites in the townsite area.

It will be noted from Figure 1 that shear vane tests, both ultimate and remoulded, show substantially greater strengths at depth for the soil than is indicated by the laboratory unconfined compressive strength tests. As would be expected the curve for shear strengths indicated by the penetration tests closely match the remoulded vane shearing strength curve over the portion of the depth where the two curves overlap. The plots for the vane shear strength tests appear to reflect the effect of recent thawing of the permafrost in that the minimum strengths occur over the depth where permafrost is known to exist at present in the area of these sites. The laboratory unconfined compressive strengths were all characterized by comparatively high rates of strain at failure stress and by a decrease in modulus of deformation with depth of sample.

The strength-depth relationship from laboratory unconfined compressive strength tests, as shown in Figure 1, is not consistent with currently accepted principles governing the shearing strength characteristics of clay soils. It is recognized that desiccation may produce increased soil strength with a gradual decrease to the depth of undesiccated soil. This factor could only affect the soil strength to a shallow depth of a few feet, however, in view of the location and recent geological history of the Thompson area.

A more valid explanation is suggested on the basis of research done in recent years on Norwegian normally consolidated varved clays as well as work on normally consolidated glacial lake deposits of varved clays in Canada (1). The Norwegian workers found that for the Norwegian sensitive varved clays ordinary sampling procedures produced a partial destruction of the soil structure. This resulted in a loss in strength and an increase in strain at failure as measured in laboratory strength tests. The effect increased with depth of sample and appears to be associated with sample disturbance by the sampling equipment plus rapid release of stress in removing the sample from its natural environment. This latter factor, of course, increases with greater depth of sample. The Norwegian work indicated that "per cent strain at failure" in the laboratory strength tests was a positive measure of the degree of sample disturbance, and "failure strains" exceeding 3 per cent were indicative of appreciable strength loss due to sampling.

Experience during the past few years with normally consolidated glacial lake bottom varved clays at Steep Rock Lake in Western Ontario has shown these same soil characteristics to exist (5). Extensive laboratory strength tests on samples secured by conventional sampling methods showed loss of strength and increased strain at failure with depth of sample. In situ shear vane strength tests indicated that the laboratory strength test results were unrealistic as a measure of the in situ strength, and demonstrated that there was, in fact, an increase in strength with depth. These results have been confirmed by the subsequent performance of dredged slopes in the lake bottom material, which extend to vertical heights of as much as 400 feet. These were designed on the basis of the increase of strength shown by the in situ vane tests, and would not be standing if the in situ shear strengths were only the values indicated by the laboratory strength tests on conventionally extracted samples.

The evidence is, therefore, that the laboratory shear strength test results on samples from the Thompson sites are subject to the same limitations as indicated by the Norwegian findings and the experience at Steep Rock Lake. The fact that laboratory shear strength tests underestimate to a substantial degree the in situ strength of the clays at depth at the Thompson sites is of considerable practical importance. It is significant in the design of foundations that must be carried through permafrost or through zones where the permafrost has only recently receded. The results of in situ vane tests would seem to be more reliable in assessing the true soil strengths below the permafrost or even within the zone of recently thawed permafrost.

It is of some interest to assess the effect of the formation of permafrost in the Thompson varved silt-clays in disturbing the structure of the soil. One might well expect that the cycle of freezing and thawing would produce complete remoulding and therefore result in almost complete loss in strength. However, the available data do not confirm this. While some effect of freezing and recent thawing is evident in Figure 1 it is considerably less than appears to result from soil sampling and rapid stress release. It may be speculated that the reason for this is that the glacial lake varved deposits in the Precambrian Shield area of Canada appear to be subject to comparatively rapid formation of thixotropic bonds between the soil particles (3).

Leaving now the questions of soil types and characteristics, let us consider the nature and occurrence of the permafrost in the Thompson area. Over the course of four separate drilling programmes carried out between November 1957 and February 1962, 171 test borings have been put down in an area approximately 7,000 feet square. Permafrost in one form or another has been encountered in 75 of these borings. A study of a plan showing the location of all borings shows that the permafrost is patchy and occurs in scattered islands, the largest of these permafrost islands being approximately 1,500 feet by 2,500 feet. The transition from permafrost zones to frost-free zones is very abrupt. At one particular location, for example, one boring showed 24 feet of permafrost while another boring only sixty feet away showed no permafrost whatsoever even though there was no great difference in surface topography and tree cover between the two sites.

Not only is the permafrost patchy in occurrence in the horizontal direction but it also varies considerably with depth. In a few cases discontinuities were observed, a portion of the boring showing ice crystals, then unfrozen soil for a few feet, then ice crystals again. These crystals were approximately 1/8 inch on a side and had the appearance of commercial rock salt. Most of the evidence of ice segregation which was found was in the form of clusters although some evidence of the formation of lenses of clear ice was observed. The maximum size of crystal recorded was 3/4 inch and the maximum thickness of ice lenses about 1/4 inch.

Not only did visual observations of the nature of the permafrost indicate that retrogression was taking place, but in the earlier work, where hand auger methods were used, there was a very marked variation in the resistance to penetration encountered in extending the borings. In some cases, augering was relatively easy, but where the frost was continuous progress was very slow.

The maximum depth to which permafrost has been observed is 30 feet but generally it does not extend below a depth of about 14 feet. It is interesting to note that of those borings which were carried beyond a depth of 14 feet the bottom of the permafrost was encountered between depths of 13 and 15 feet in approximately half of them. The maximum depth of continuous permafrost which was encountered was 22 feet.

Since the time when the first investigation was completed in 1957 the town of Thompson has enjoyed a substantial development. There are now over 700 houses, a modern hotel and hospital, a large completely enclosed Shopping Centre, two schools and many other small commercial and service buildings. The foundation performance of the great majority of these has been satisfactory but, at some sites and particularly where no preliminary soil investigations were conducted, foundation troubles have developed. As might possibly be expected the major problems have been in connection with buildings which cover a substantial area. An example of this is the case of the first school building erected. At this school site, where four test borings were put down and where permafrost was found to underlie the entire building area, a heavily reinforced structural concrete slab was used without a foundation wall. Subsequently, extensive settlements have taken place in the building and differential movements of as much as 18 inches have been measured.

Movements have also occurred in a number of house foundations, resulting in extensive damage. It is now a requirement that at least one test boring be put down on each lot before constuction is permitted to proceed to ensure that permafrost is not present.

The history of foundation movements in Thompson is that they occur quickly and this supports other evidence that the permafrost is disappearing very rapidly. Sufficient information is available to suggest that the permafrost will thaw during one summer from a cleared piece of ground, but complete reconsolidation of the soil within the frozen zone may not be complete in this time.

There have been a number of types of foundations used at Thompson. In areas where the dense sand and gravel strata are within economical pile length, point-bearing timber, or concrete piles have been used and have proven satisfactory. In other areas, where permafrost has been encountered, drilled cast-in-place concrete piles are being used, the length of the pile depending on the depth of the permafrost. It has been the general practice to assume no support down to a depth equal to twice the depth of the permafrost and then assume a pile loading capacity equal to between 300 and 500 pounds per square foot of pile surface area. By providing an extra length of pile equal to twice the depth of the permafrost, allowance is made for the negative skin friction effect produced when the permafrost melts and the unfrozen soil begins to consolidate. The comparatively low skin friction values which have been used for design purposes reflect the low values secured in laboratory strength tests.

Spread footings have also been used in the design of a number of structures. An example of this is the shopping centre which covers an area of approximately 90,000 square feet and which is completely enclosed. It is carried on pad footings with adjustable columns being provided to take up any differential movements that may occur. The maximum movement recorded to date is about 6 inches. Spread footings are now being recommended in those areas where the soil moisture content profile does not show any abnormally high values which would indicate very recent permafrost, and where the shearing strength of the varved silt and clay material is not less than one-half ton per square foot.

In areas where recent clearing has resulted in the decay of the permafrost, but comparatively high natural moisture contents still exist due to incomplete reconsolidation in the permafrost horizon, displacement piles such as creosoted timber piles appear to offer advantages. The driving of these piles will have a consolidating effect in the former permafrost zone, and there appears to be no reason to assume that negative skin friction will develop. If the strength of the clay below the permafrost zone is assessed by means of in situ vane shear tests, and the piles are assumed to act as friction piles in the clay, they can be designed very economically. They need not be extended to the depth of the underlying sand and gravel. Where site conditions are such that permafrost thawing has occurred only a few months previous to construction, it is considered advisable to use structural basement floors carried on piles similar to those used for the foundations.

A surprisingly wide variety of foundation types have been successfully used in the Thompson area, but there appears still to be ample scope for further investigations and study. The records and data available at the present time undoubtedly provide a valuable source of knowledge, and even the preparation of this paper, which involved a review of old files, has pointed out new avenues for study. For example, it would be interesting to determine what effect the freezing and subsequent thawing of soil has had on the swelling characteristics of the clays. Detailed studies of the moisture content profiles in recently thawed permafrost areas to determine the moisture migration pattern, as well as studies of the degree of distortion to the soil skeleton resulting from the freezing and thawing cycle would provide data which would be both interesting and of practical value.

There is no question but that the Thompson area can provide a tremendous amount of useful information regarding permafrost conditions, information which will be of great value in the ultimate development of the Canadian North.

REFERENCES

1. Bjerrum, L. Geotechnical Properties of Norwegian Marine Clays. Geotechnique, Vol. IV, 1954. pp. 49-69.
2. Charles, J. L. Permafrost Aspects of Hudson Bay Railroad. A.S.C.E. Paper 2319, 1959.
3. Hardy, R.M. and Legget, R.F. Boulder in Varved Clay at Steep Rock Lake, Ontario, Canada. Bulletin Geol. Soc. of America, Vol. 71, January 1960, pp. 93-94.
4. Thomas, M.K. Climatological Atlas of Canada. National Research Council Public. No. 3151, 1953.
5. Whitman, E.W., Reipas, S.A. and Hardy, R.M. Unusual Problems in the Development of the Caland Mining Operation at Steep Rock Lake. Presented to Annual Meeting E.I.C., June 1960. In press.

Discussion

G. J. Sladek commented that permafrost occurs at Thompson in scattered islands underlying somewhat less than 50 per cent of the townsite area. In some of these frozen areas, it is neither practical nor desirable to maintain the soil in the perennially frozen state. He asked if it is possible, with present techniques of field investigations, to predict the rate at which the permafrost can be expected to degrade either in undisturbed or disturbed areas. The author replied that it is not possible.

R. G. Howard enquired whether any precautions were taken when pouring cast-in-place concrete piles in permafrost to prevent freezing of the concrete. C. A. Nesbitt stated that no precautions were taken. After the holes were drilled, reinforcing steel was installed and then the concrete was placed.

H. G. Dutz wished to know what effect the destructive qualities of permafrost on housing have on the prospective purchasers. C. A. Nesbitt's answer was that under controls enforced by the Central Mortgage and Housing Corporation and the town authorities, the developers have repaired the damage to houses at their own costs in all cases.

The author remarked that the National Research Council has been making ground temperature measurements in the Thompson area. G. H. Johnston added that temperatures to depths of 25 feet measured by thermocouples have ranged from 31°F to 31.5°F.

J. R. Lotz wished to know what extent the settlement and movement of buildings caused by the thawing of permafrost have caused people occupying houses to complain, to leave the town, or to avoid buying and building their own houses. In other words, how much social disruption has been caused by this physical disruption? C. A. Nesbitt replied that before 1958 there was a problem because drilling was not undertaken on each house lot to determine whether or not permafrost was present. Since 1958, this has been a requirement and lots having permafrost were not used for houses.

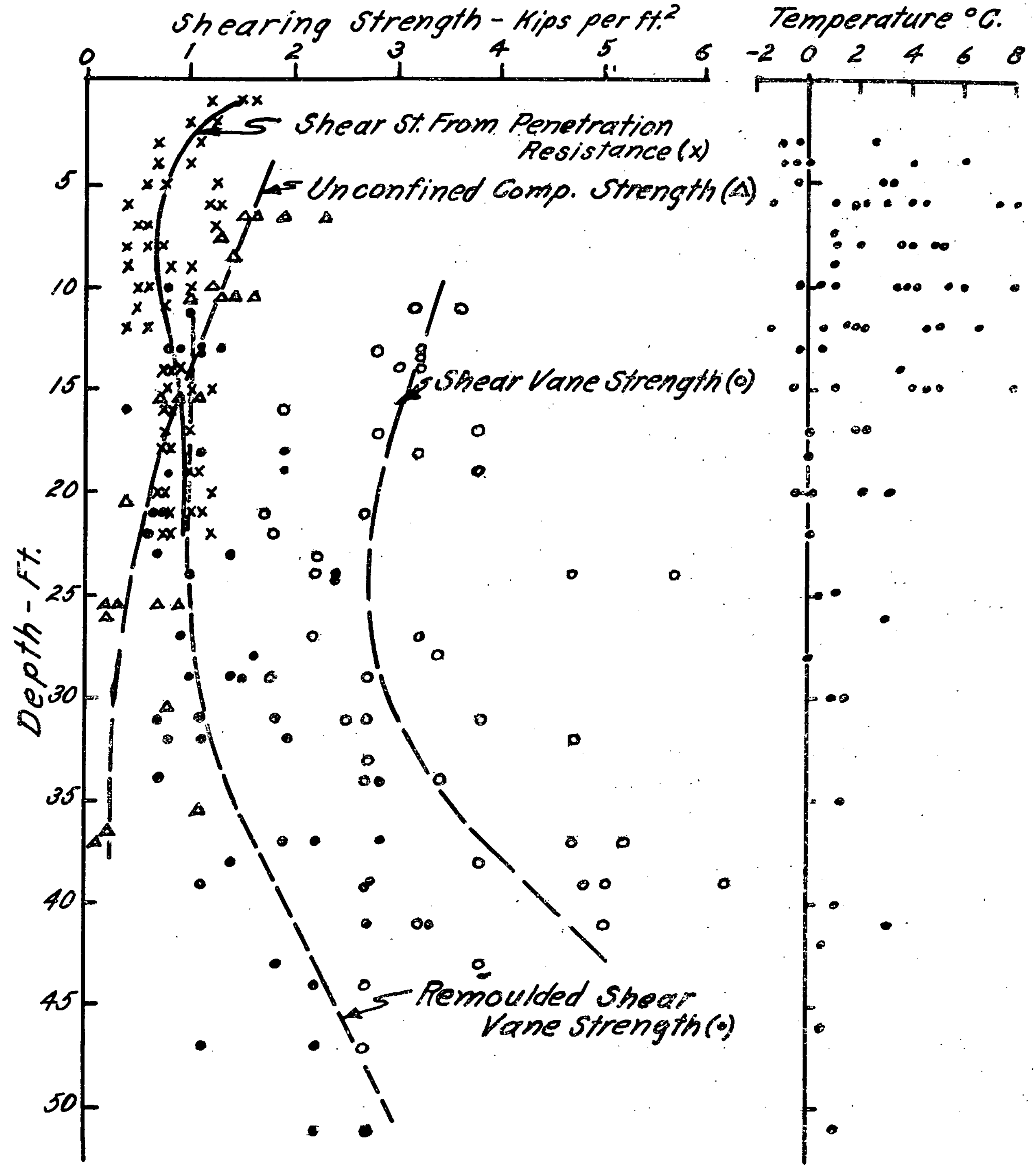
Shearing Strength - Kips per ft.^{2}
0
1
2
3
4
5
6
Temperature °C.
-2
0
2
4
6
8
Shear St. From Penetration Resistance (x)
Unconfined Comp. Strength (△)
Shear Vane Strength (○)
Remoulded Shear Vane Strength (•)
Depth - Ft.
5
10
15
20
25
30
35
40
45
50

FIGURE 1