An Evaluation of Pavement Performance over Muskeg in Northern Ontario

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This paper is a report of a cooperative research program carried out in 1958 and 1959 by the National Research Council, Canada, and the Ontario Department of Highways to study the performance of some existing roads over muskeg in northern Ontario. Investigation of close to 50 different muskeg areas included classification of the muskeg, determination of the depth and type of fill, depth of the organic deposit, and type of mineral soil substratum. Roads over the muskeg areas were assessed on the basis of performance and surface condition relative to adjacent sections of road on mineral soil terrain. Many peat samples were obtained for laboratory analyses, which included water content, specific gravity, acidity, and ash content.

During the second stage of the project an extensive series of field vane tests was carried out in certain selected muskeg areas that were typical for a certain region. Three different sizes of vanes were used. It is shown that road performance is better in muskeg areas with tall tree growth than in areas with little or no tree growth, other factors being equal. No correlation was evident between road condition and type of firm mineral soil substratum. However, an intermediate unstable layer of soft mineral soil is shown to be an important factor in road performance and condition. Although vane testing appears to be a feasible method for determining the shear strength of peat and excellent duplication of results was possible for any particular size of vane, these tests revealed a marked variation in the shear results depending on the vane size. Laboratory test results indicate correlations between moisture content and depth, specific gravity and moisture content, and acidity and carbon content.

● A LARGE PART of the total area of Canada is covered with an organic mantle known as muskeg, much of it occurring north of the main population centers. Its extent is not known precisely but it has been estimated that there are some 500,000 sq mi of muskeg in Canada, or approximately 12 percent of the total land area.

The word "muskeg" is distinctive to Canada and the northern United States and is derived from the Chippewa Indian work "maskeg" meaning "grassy bog." For engineering purposes, muskeg (or organic terrain) may be defined as "terrain composed of a living organic mat of mosses, sedges or grasses, with or without tree and shrub growth, underlain by a usually highly compressible mixture of partially decomposed and disintegrated organic material commonly known as 'peat' or 'muck'" (1). Muskeg is associated with a very high water table and is characterized by its low bearing capacity. The depth of these organic deposits varies from a few inches to many feet and they may be underlain by either marl, clay, silt, sand, gravel, or bedrock.

The whole of Ontario—in common with most of the rest of Canada—has been glaciated. As is typical of glaciated regions, muskeg areas are encountered to a greater or lesser degree depending on the physiographic formation. One of the many complex problems in Ontario highway engineering, therefore, is the satisfactory construction of roads over muskeg. In some regions, as much as 80 percent of the length of a particular road project is over muskeg of variable depth and composition. It is not unusual for this muskeg to be underlain by deposits of very soft marl, silt, or clay, thereby greatly increasing the total depth of unstable material.

It is sometimes possible to circumvent muskeg areas, but due to the high geometric standards for modern highways and also due to economic considerations, it is often necessary to construct roads directly across muskeg. The height of the embankments may vary between 4 and 40 ft. Therefore, if a satisfactory road surface is to be provided, it is evident that detailed investigations and analyses of results must be made to ensure that the proper treatments are carried out.

Generally, the tendency has been to remove or to displace the peaty material and to construct the roadbed on a more stable foundation. Because the water table is very close to the surface, backfill material must remain stable when saturated. Granular soils are the most suitable for this purpose, but in many parts of Ontario they are scarce or nonexistent. In some cases cohesive soils have had to be used for backfill because of the prohibitive cost of transporting more suitable materials.

The expanded construction program of the Department of Highways of Ontario in the northern part of the province, where muskeg is extensive and costs are high, has necessitated a particularly careful consideration of the construction of a satisfactory and economical road over muskeg. It is these northern areas that are usually associated with a scarcity of suitable granular material for use in the treatment of muskeg areas. It is therefore desirable to know something of the engineering characteristics of the muskeg encountered in order to assist in the economic design of roads.

BACKGROUND OF PROJECT

Some roads constructed over muskeg have performed quite satisfactorily while others have not. It was thought that a comparison of these existing successful and unsuccessful roads would be a useful and significant study to assist in determining some of the engineering properties of muskeg. The difficulty of establishing the success of a particular road was realized but it was thought that this could be done by reference to settlement and to qualitative standards of performance.

A joint research program was consequently undertaken by the Department of Highways of Ontario and the Division of Building Research of the National Research Council, Canada. The main object was to study the performance of existing roads over muskeg, to obtain pertinent construction details and then to attempt to group muskeg areas according to their bearing properties. A further objective was to attempt to correlate road performance with the Radforth Classification System for muskeg (2). The great extent of muskeg in northern Ontario and the many problems associated with it made this area the obvious choice for the research program. Only those roads were investigated that had been built directly on the muskeg surface, and where no special treatment of the muskeg had been undertaken.

GEOLOGY OF THE AREA

The general area covered in the investigations extended from North Bay along Highway 11 to Nipigon and to Port Arthur and Fort William, up Highway 17 to Kenora, then Highway 71 to Emo and along Highway 11 to Rainy River (Fig. 1). Basically, there are two different types of terrain in the area investigated, both located within the Pre-Cambrian shield. The topographic feature of the rocky terrain (characteristic of the Kenora region) is its ruggedness and the countless number of lakes and depressional areas, the latter being filled in with soft clay or marl and peat. The other type of topography is the extensive flat areas of clay plain with depressional areas containing very soft clays and peat, located primarily between Kirkland Lake and Longlac. Figure 2, which denotes the geomorphic subprovinces of northern Ontario, shows these features in more detail.

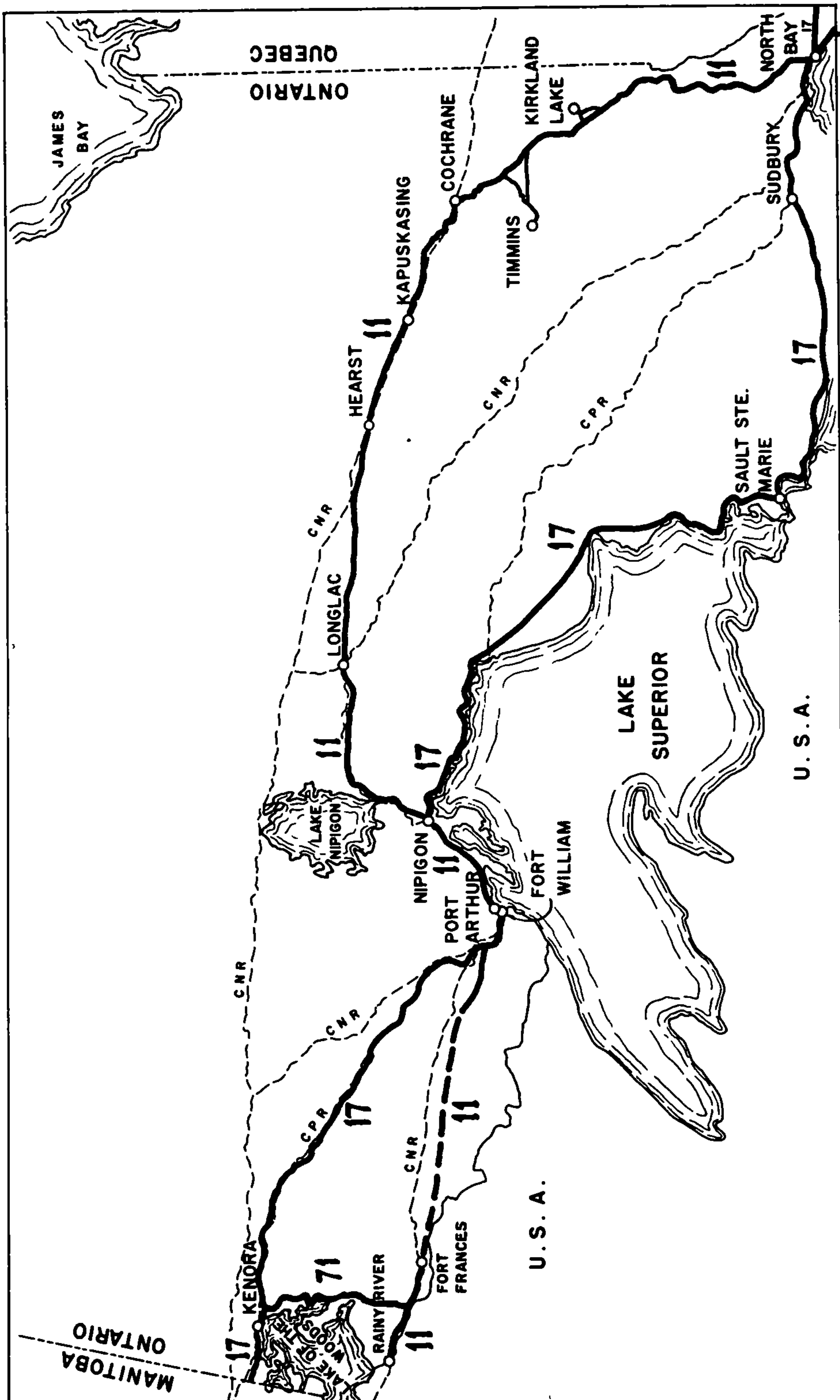
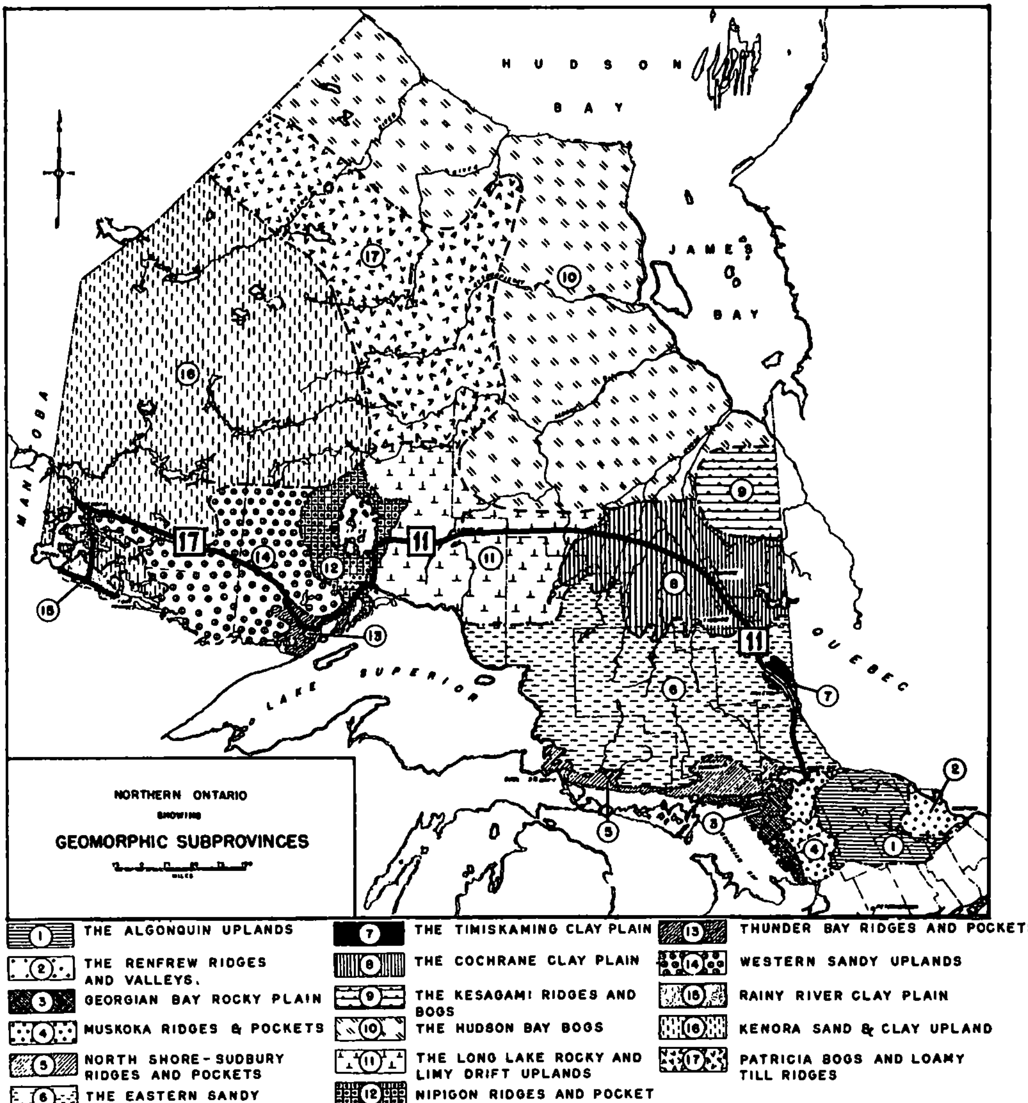

JAMES BAY
QUEBEC
ONTARIO
COCHRANE
KIRKLAND LAKE
NORTH BAY
TIMMINS
KAPUSKASING
HEARST
SUDBURY
SAULT STE. MARIE
C N R
C P R
LONGLAC
LAKE SUPERIOR
U. S. A.
LAKE NIPIGON
NIPIGON
PORT ARTHUR
FORT WILLIAM
KENORA
RAINY RIVER
FORT FRANCES
LAKE OF THE WOODS
MANITOBA
ONTARIO
11
17
71

Figure 1.

VARIABLES

The condition of a particular section of road constructed over muskeg will depend on a large number of variables which include:

1. Traffic loads and volume;
2. Age of road;
3. Depth and type of roadway fill;



(COURTESY ONTARIO DEPT OF LANDS & FORESTS)

Figure 2.

4. Type of road surface (gravel, prime, hard surface, etc.);
5. Extent of maintenance;
6. Muskeg type;
7. Muskeg depth;
8. Depth of unstable mineral soil layer (if any) beneath the organic material;
9. Type of firm mineral soil substratum;
10. Drainage regime of the muskeg, both natural and man-made.

The procedures followed in this investigation were established in an effort to evaluate as many of these variables as possible.

INVESTIGATIONAL PROCEDURES

General

The research program was undertaken in two stages, each taking one summer. Stage I (Summer 1958) provided the more general information and covered as large an area as possible. The muskeg was classified, the depth to firm substratum determined, and the type of mineral subsoil was established. Samples of the peat in each area were obtained, classified, and retained for routine laboratory analysis. The type and depth of the roadway fill was also determined. Finally, the performance and condition of the road in a particular area was assessed on a qualitative basis and relative to the condition of adjacent sections of the road over mineral soil. Evaluation of the roads ranged from excellent through very good, good, fair, poor, bad (representing severe settlement or deterioration of the surface) to very bad (representing a shear failure at some time in the road's history as evidenced by the presence of "mud waves"). Some 44 different muskeg areas were investigated in the first stage and results reported (3).

In the second stage (Summer 1959) muskeg areas were selected that were typical for a certain region (as determined from an analysis of results of stage I) and a more exhaustive series of tests were carried out. These included extensive vane testing, together with the procuring of a number of "undisturbed" tube samples of peat for laboratory testing. For purposes of comparison, areas were chosen that had similar terrain conditions (such as muskeg type and depth) but that had a wide variation in the assessment of road performance. Three pairs of such areas were compared, in an attempt to learn why the road was unsatisfactory in one location and satisfactory in another. An additional three sites, where a shear failure had occurred, were investigated with regard to determining the profile of the peat-soft clay interface.

Vane Testing

Three different sizes of vanes were used; each had conical ends and sharpened edges and were of the recommended H/D ratio of 2. Table 1 shows their dimensions.

TABLE 1

Vane	Diameter (in.)	Height (in.)	"K" Factor
S	2.0	4.0	56
M	2.8	5.6	20
L	4.0	8.0	6

The vanes were attached to aluminum "E" drill rods and manually pushed into the ground. To maintain reasonable portability, no casing was used. Torque was applied through a specially designed head attached to the end of the drill rod. Torque was measured by means of a torque wrench with a maximum capacity of 150 ft-lb. Every effort was made to rotate the vane at a constant speed in each test, the rate of strain being about 3 deg per sec. Following shear failure, a remoulded test was run in the usual manner (four complete revolutions, a 1-min wait, then a repeat of test). At each location under investigation, three tests were carried out with each vane through the complete peat profile and into the soft mineral soil sublayer, when this was present. Undrained shear strength was computed from the relationship

$$S = K \times \text{torque}$$

RESULTS

Road Assessment

Those roads rated as fair or better were considered to be satisfactory; those rated as poor or worse were considered to be unsatisfactory. Of the 44 areas investigated in stage I, 27 were classed as satisfactory, 17 as unsatisfactory. In the flat plain type of topography characteristic of the Kapuskasing region, 75 percent of the over-muskeg road sections investigated were classed as satisfactory (compared to adjacent sections of the road on mineral soil terrain). In contrast, in the type of topography characterized by a rugged rocky terrain, with the depressions between rock outcrops being either lakes or muskeg (typical of the Kenora region), only 38 percent of the road sections investigated were classed as satisfactory. It is in this type of topography that a deep layer of soft clay beneath the organic cover was observed most frequently.

A summary of the general information obtained in stage I is given in Table 2, which shows the relation between road performance, muskeg coverage class, depth of fill, depth of the organic material and of the soft mineral soil sublayer (if any), as well as the type of firm mineral soil substratum. All sections of road assessed as very bad were underlain by a soft mineral soil layer. The range of total unstable depth for these shear failures was 25 to 50 ft. No shear failure was observed for a depth of unstable material of less than 25 ft.

Table 3 presents a summary of the relationships observed between the three pairs of muskeg areas investigated during stage II. An analysis of the results indicates that the main factors contributing to the unsatisfactory condition of the road at site 2 as compared to site 1 were the inadequate depth of fill and poor drainage conditions. At site 4, the unsatisfactory condition of the road was indicated by excessive and differential settlement, giving it a "roller-coaster" effect. Poor drainage and a less satisfactory muskeg type than at site 3 are the possible reasons for this condition.

Road and muskeg features at sites 5 and 6 were so similar that it was difficult to see the reason for the difference in road performance. Part of the answer, however, may be the location of the road at site 6, which is constructed quite close to a sharply sloping rock outcrop. The manner of the road failure would indicate that the fill may be slipping along the plane of the rock face.

At three different sites where a shear failure had resulted in mud waves being pushed up on one or both sides of the road, hand borings were made through the center of the mud waves, as well as through the natural muskeg, to determine the depth to the soft intermediate zone. Levels were made of the ground surface and from this information the elevation of the soft clay-peat interface was plotted. It was found that this soft clay-peat interface followed the general contour of the surface mud wave, indicating that the failure zone extended down into the soft mineral soil layer.

Vane Tests

In peat, high deformations accompany the development of shear. The total strain in the vane shear tests was frequently as much as 50 deg, and occasionally reached 90 deg. It was greatest for the small vane, least for the largest vane. Part of this angular rotation was due to twist in the rod although this was observed to be generally less than about 5 deg. It was possible to obtain an excellent reproducibility of results for each vane in a series of tests at any particular site. Apart from an occasional exceptionally high value due to the vane striking a root, the shear values for any one vane at a given depth did not deviate markedly from the mean value. Sensitivity values ranged from 1.5 to 10, and for all three vanes sensitivity decreased with depth.

TABLE 2

SURFACE AND SUBSURFACE CHARACTERISTICS OF AREAS INVESTIGATED

Road Performance	No of Roads	Predominating Cover Class	Depth of Fill (in.)	Depth of Peat (ft)	Depth of Soft Subsoil (ft)	Total Unstable Depth (ft)	Type of Substratum
Excellent	1	AEI	Rock (depth unknown)	17	10	27	Sand
Very good	3	AE	60-66	9-20	0-12	9-32	Clay, sand, rock
Good	11	AEI	12-24	4-11	0-30	4-41	Clay, silt, sand, rock
Fair	12	A-BEI B-DFI	12-45	5-11½	0-6	5-17½	Clay, sand
Poor	9	A-BEI B-DFI	12-60	5½-14	0-18	5½-32	Clay
Bad	2	Inconclusive	24 (1 only)	2-10	0	2-10	Clay, sand
Very bad	6	B-DFI	Rock (depth unknown)	13-19	6-34	25-47	Clay, silt

TABLE 3

			Road Features				Muskeg Features				Average Shear Value
Site	Topography	Drainage	Performance	Surface	Depth of Fill (ft)	Type of Fill	Classification	Max Depth of Peat (ft)	Depth Under Road (ft)	Subsoil Type	(Vane M) (psf)
1	Flat plain	Well drained	Good to very good	Paved	5-6	Sand, clay + sand	A-BEI	12½	8	Sandy silt	844
2	Long flat area between rock outcrops	Very wet, poorly drained	Poor to fair	Paved	2½	Sand	A-BEI B-DEI	12	7½	Sand	534
3	Flat plain	Well drained	Very good	Paved	5	Sand and gravel	A-BEI	9	7	Silty clay	626
4	Flat plain	Fairly wet	Poor to fair	Paved	5	Sandy gravel	B-DEI	8 11	4	Sandy silt	455
5	Depressional area	Quite wet	Good	Paved	Not obtainable	Rock	B-AEI	11 to 41(soft clay) 41 (Refusal)	Not obtainable	Silty clay	484 (Peat) 467 (Clay)
6	Depressional area	Very wet	Very bad	Paved	Not obtainable	Rock	B-DF AEI	12 12 to 33 (Soft clay) 33 (Refusal)	Not obtainable	Sandy silt	543 (Peat) 456 (Clay)

There was a marked variation in the shear results between the three vanes. When the average shear value for each vane is plotted against depth, all three curves have a similar shape and clearly reflect any layers of higher or lower strength. The small vane, however, gave results about double those of the medium size vane and from four to five times those of the large vane. This was consistent for all sites investigated. There was no strong evidence of a correlation of shear strength with muskeg classification type, although the upper range of shear values obtained were generally in muskeg types having tall tree growth (classes A and B).

In those muskeg areas not underlain by a soft mineral soil layer, the vane tests did not consistently indicate an increase in shear strength with depth. In fact, the shear strength remained fairly constant throughout the depth of the deposit. In those muskegs underlain by a soft mineral soil layer, however, there tended to be a slight increase in shear strength with depth, reaching its maximum value at, or just above, the transition zone. This was followed consistently by a drop in the shear strength of the soft mineral soil layer. On the average, the shear strength of this soft mineral soil layer was found to be 77 percent of the shear strength of the peat. Figure 3 gives vane test results from one site and shows the consistent relationship that obtains between the three vanes throughout depth. These curves are generally indicative of the trend at the other sites investigated. When all values of vane shear were plotted against water content, no clear correlation was evident.

Laboratory Results

The water content of peat varies over a wide range and may even exceed 1,000 percent of the dry weight. When water content was plotted against depth for each site, a curve was produced similar in shape to the vane shear curves (see Fig. 3 for a sample curve). Peat generally exhibits an acidic quality, the acidity (as measured by pH) being proportional to the organic content (or ignition loss) as shown in Figure 4.

Figures 5, 6, and 7 show an apparent critical zone for the peat samples studied. This zone is indicated for organic contents greater than 75 percent, specific gravity values of soil solids less than about 1.6, and water contents greater than approximately 600 percent. Higher values of organic content represent the "pure" peats, with comparatively little admixed mineral matter. Therefore, beyond this critical zone (i.e., in the "pure" peats) there is no evidence of correlation between the organic content, specific gravity of soil solids, and water content. Up to this zone, however, it is seen that as organic content increases, specific gravity values decrease and water content increases. The void ratio will correspondingly increase with increased organic content and consequently the compressibility of the peat will also increase.

In Figure 5, that part of the curve below the critical zone agrees closely with the results of Cook (4) regarding the relationship between water content and specific gravity.

A consolidation test program has been started at the Division of Building Research on the tube samples of peat in an effort to determine when the primary phase of peat consolidation is completed and also to determine how much of the settlement is due to secondary consolidation.

DISCUSSION OF RESULTS

The problem of evaluating objectively the many variables involved in assessing road performance creates some difficulty in correlating the road performance with muskeg type. It is evident that factors other than muskeg type are influential in determining the performance of a road constructed over muskeg. Consequently, the clear-cut pattern hoped for at the

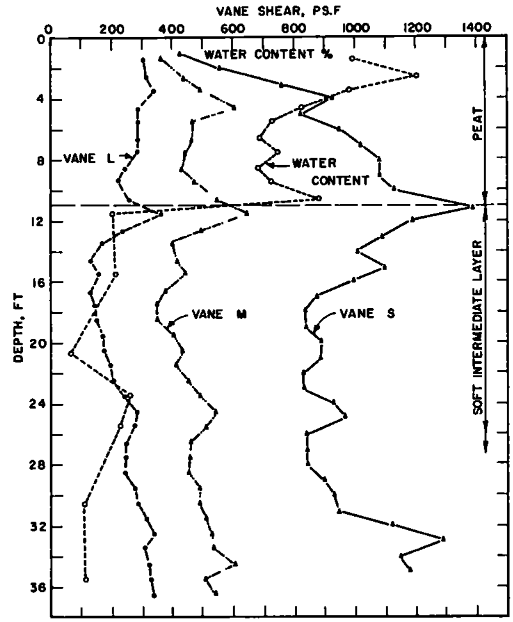


Figure 3. Vane shear and water content vs depth.

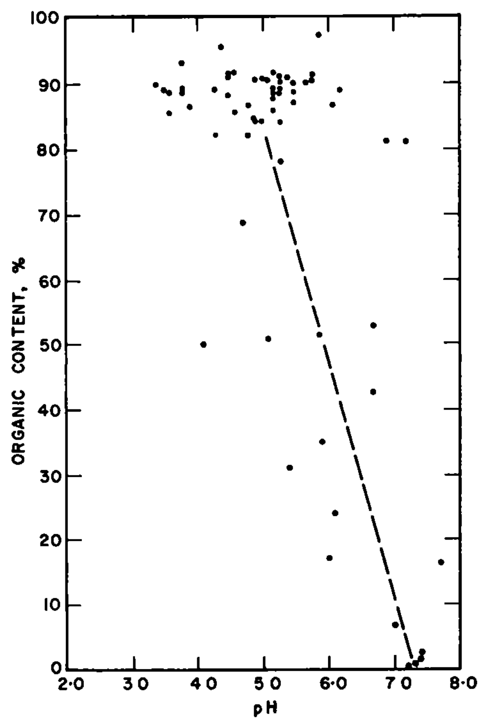


Figure 4. Organic content vs pH.

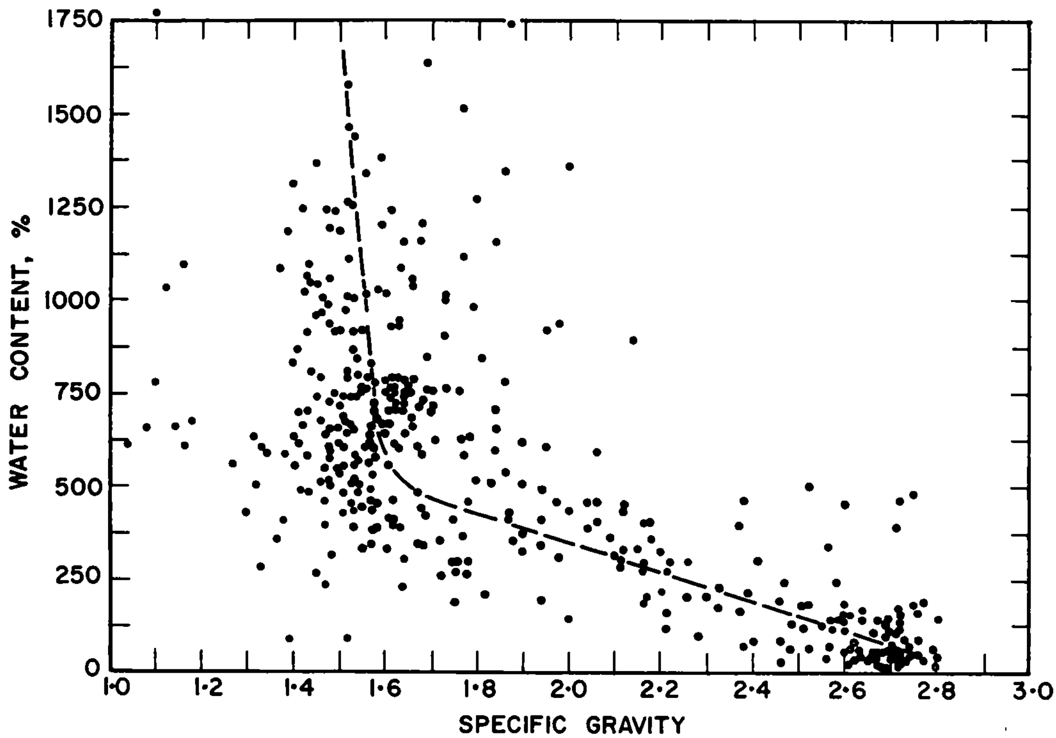


Figure 5. Water content vs specific gravity.

beginning of the research project did not emerge. Nevertheless, it can be seen from Table 2 that, although there is considerable overlap in muskeg type in the different road assessment categories, a trend is observed from tall trees to dwarfed trees and shrub growth as the road assessment drops from excellent to very bad. This is especially true for those muskeg areas directly underlain by a firm mineral soil substratum (i. e., no intermediate soft layer). It may be concluded, therefore, that roads constructed over muskeg types containing tall tree growth (classes A or B in the coverage formula) performed more satisfactorily than those on muskeg types with little or no tree growth. No correlation was evident between road performance and the type of firm mineral soil substratum.

Traffic loads and volume are important to the performance of any road. In this investigation, where performance of roads over muskeg was compared to the performance of adjacent roads over mineral soil terrain, traffic loads could safely be assumed to be the same for both sections of road and were not therefore considered further.

The cause of shear failures in muskeg areas underlain by a soft mineral soil layer is due largely to this layer rather than to the peat itself. The shear strength of this layer was generally less than that of the peat overlying it and it would seem the zone of failure is in this soft subsoil. Consequently, from the point of view of both consolidation movements and embankment stability, the greatest difficulties in road construction over muskeg can be expected in these depressional-type muskegs.

Table 3 indicates that an inadequate depth of fill and a high water level (acting together or separately) contribute to the poor performance of a road on muskeg. In some cases, peat was observed to be "pumping" through a very shallow fill subjected to heavy truck traffic. In at least one instance, stumps were noted to be puncturing through the asphalt surface of a road. Lea and Brawner (5) have recommended a minimum depth of fill on preconsolidated peat of 3½ ft. These investigations confirmed that a depth of fill of this order is desirable.

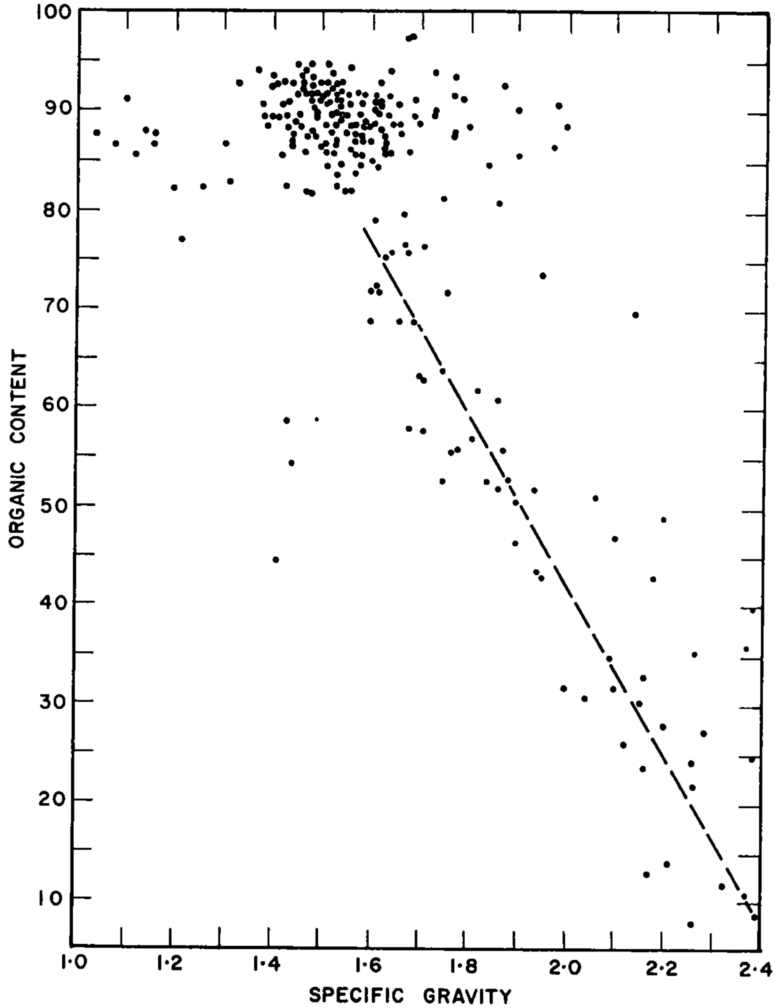


Figure 6. Specific gravity vs organic content.

The vane apparatus, although initially developed for use in clay soils, has been used extensively recently for determining the shear strength of peat. There is still some question, however, regarding the validity of this apparatus for such a complex soil as peat. In their comprehensive report, Cadling and Odenstad (6) concluded (after investigating three sizes of vanes) that the influence of the vane dimensions does not appreciably affect the shear results for clays. When the average shear strength for the different vanes was plotted against depth, they showed very good correlation. The authors point out, however, that design considerations place certain limits on the practical sizes of vanes that can be used.

It is reasonable to assume that for a fibrous material such as peat, the particle size relative to the vane size is significant. This might account for some of the variation between the results for the three sizes of vanes used in this investigation. Another factor—the effect of which has not yet been fully assessed—is rod friction. It was thought that the extremely wet condition of peat together with the disturbance caused by periodic vane rotation reduces rod friction to a negligible value.

Since the conclusion of this project, a few further vane tests have been carried out in order to evaluate the effect of rod friction. Although not extensive enough to

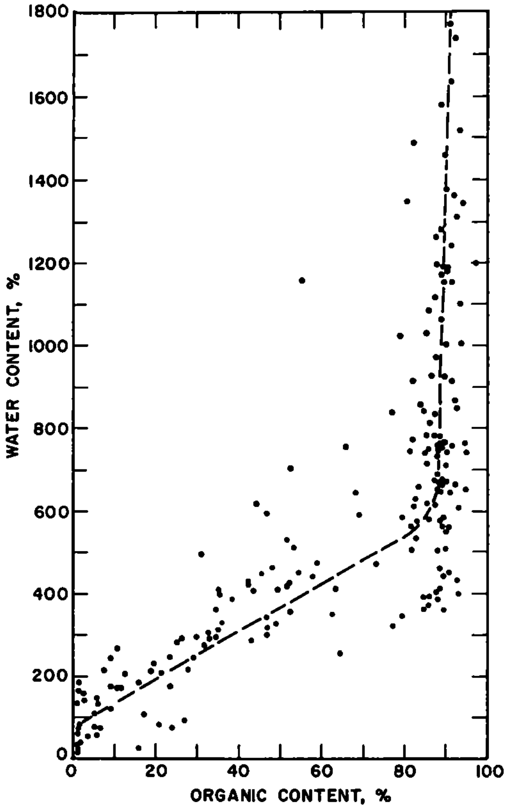


Figure 7. Organic content vs water content.

justify definite conclusions, the tests indicated that for the initial 5 or 6 ft of depth, rod friction is a fairly negligible factor. For greater depths, however, it appears to have some effect on the vane shear results, particularly in the case of the small size vane. A further series of tests is planned.

SUMMARY

1. Sections of road built over types of muskeg that support tall tree growth exhibit better performance than those over areas with little or no tree growth, if most of the other factors are equal or similar. However, road performance cannot be generally correlated with muskeg classification type alone.
2. There was no evident correlation of vane shear strength with muskeg type, except that the upper range of shear values was generally in muskeg types with classes A or B in the coverage formula.
3. Series of vane shear tests show good reproducibility of results. Vane size is apparently a factor to be considered and further research to determine the optimum size seems justified.
4. There was no consistent evidence of increase in shear strength of the peat with depth. On the average, the shear strength remained fairly constant throughout depth.
5. In general, no significant relationship was evident between vane shear strength and water content of peat.
6. Shear strength of peat does not appear to be a problem in the stability of highway embankments on muskeg not underlain by a soft sublayer. Excessive and differential settlements are the more serious problem.
7. Unsatisfactory road performance is sometimes due to an inadequate depth of subgrade. The recommended minimum of 3½ ft appears to be a reasonable figure.
8. A low-lying road and a high water level in the muskeg were important contributing factors in some areas to the deterioration of the road surface.
9. The vane shear strength of the soft mineral soil sublayer was found to be generally less than the shear strength of the overlying peat.
10. Shear failures in areas underlain by a soft mineral soil layer (clay, silt, or marl) are due chiefly to this layer and not necessarily to the peat.
11. Peat becomes more acidic with an increase in organic content.
12. As the organic content of peat increases, there is a corresponding increase in the water content and a decrease in the specific gravity of soil solids, up to a certain critical zone beyond which these three characteristics have no clear relationship.

ACKNOWLEDGMENTS

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Discussion

PHILIP KEENE, Engineer of Soils and Foundations, Connecticut Highway Department—The authors are to be congratulated on their excellent paper, containing a large amount of factual data on the projects involved and well-founded conclusions where they felt these were justified. Their efforts represent another example of the skilled and competent work being done by engineers and other scientists of Canada on the problems involving muskeg.

The authors have noted that when slides occurred, resulting in the familiar rapid subsidence of the embankment and the formation of mud waves beyond the toe of embankment slope, the zone of rupture always went through a soft mineral stratum located below the peat. The mineral layer is described as clay or silt or both.

The authors state that high deformations accompany the development of shearing in peat. In contrast, deformations due to shear stresses in soft mineral soil are relatively much smaller. Hence, it is probable that as an embankment was being placed and shear stresses were being developed in the underground, the peat furnished very small shearing resistance while the deformations were small, and consequently a large share of the shearing resistance was borne by the silt-clay. Just before the time of rupture, the silt-clay was stressed to its ultimate shearing strength, with a shearing strain of perhaps 2 or 3 in., while the peat was resisting, at that strain, at perhaps 50 percent of its maximum ultimate shearing strength. After the silt-clay failed, the peat then must resist nearly all the shearing force and because it was unable to do so, it then failed. Hence, this progressive failure explanation would be based on large differences in stress-strain characteristics between peat and soft mineral soil rather than on ultimate shearing strengths of both materials.