Muskeg Studies in Alberta

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This paper discusses the development of muskeg research studies in Alberta, with particular reference to vane shear testing. Correlations of vane shear strength, water content, and classification are presented. Limited conclusions are drawn from an evaluation of flexible pavements constructed in muskeg areas. A sampler for use in very soft fibrous peat is also described.

●IN RECENT years marked advances have been made in solving the engineering problems encountered with muskeg or "organic terrain." A thorough review of this development was presented by MacFarlane in 1959 (1). This paper is intended to trace the development of muskeg studies in Alberta, as fitting into the Canadian picture as a whole, and to report on results of recent investigations not available in 1959.

As in most areas of Canada and the U.S.A., there has been a particularly active program of highway construction and improvement following a period of relative inactivity from 1940-45. In Alberta, as of 1948 the total mileage of highways and district and local roads was 81,823 mi, and only 656 of the 4,753 mi of main and secondary highways were bituminous surfaced. During the succeeding 10 year period to 1958 (2), the paved mileage increased fourfold to a total 2,758 mi. This highway construction program necessitated by a high vehicle-population ratio of 1 to 2.9 in 1957, together with a sharp increase in movement of materials by truck transport, has resulted in surfaced main highways being constructed over practically all types of terrain. Expansion of the petroleum industry into previously inaccessible areas has also resulted in many miles of secondary highways and access roads being built.

To comprehend the existing situation better, a brief description of the physical features of the Province has been compiled:

> Alberta is a plateau averaging more than 300 mi from east to west and 800 mi from south to north, a total of 255,285 sq mi. This region is a widely inclined plain deeply cut by rivers and marked by plateaux, merging in the west with the foothills of the Rocky Mountains. The southern half of the province rising toward the west, lies at a general elevation of 2,000 to 4,000 ft. In the northern half the slopes descend until elevations well under 1,000 ft are reached at Lake Athabasca in the northeast corner. (2)

Most of the area has been glaciated, the effects of which have influenced the surface features and resulted in widely distributed surface materials. Figure 1 is an outline map of Alberta showing the general area in which occurrences of muskeg deposits are fairly prevalent.

Figure 2 shows the surface transportation facilities and population distribution. Because vast undeveloped areas in the northern part of the Province are in predominantly muskeg territory, agricultural and forestry developments as well as oil and mineral explorations are impeded by the muskeg problem.

A small percentage of the main highways with a much larger percentage of the lower access-type roads have been built in areas predominantly covered by muskeg. This problem of working in muskeg areas was common to governmental agencies and industry alike and prompted studies by those concerned.

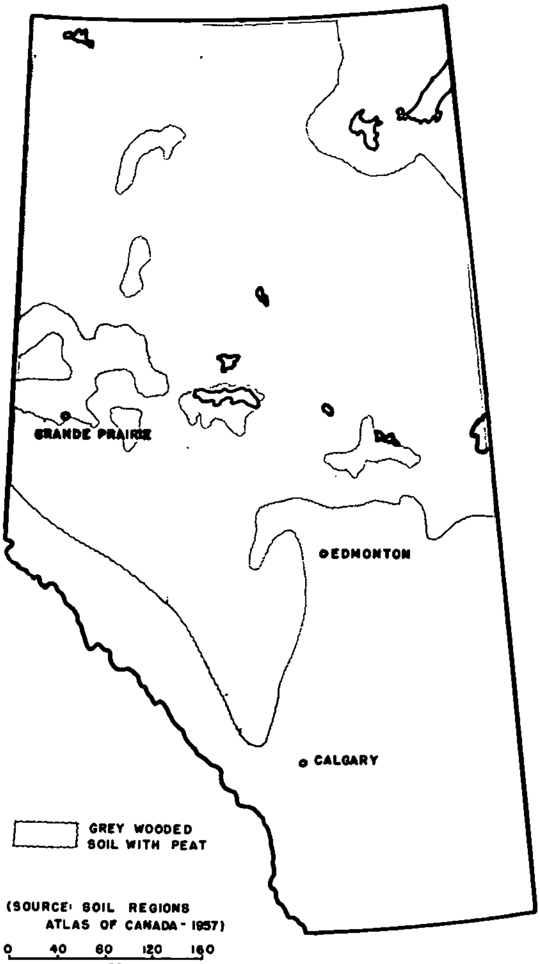

Figure 1. Map of Alberta showing areas where muskegs (peat) commonly occur.

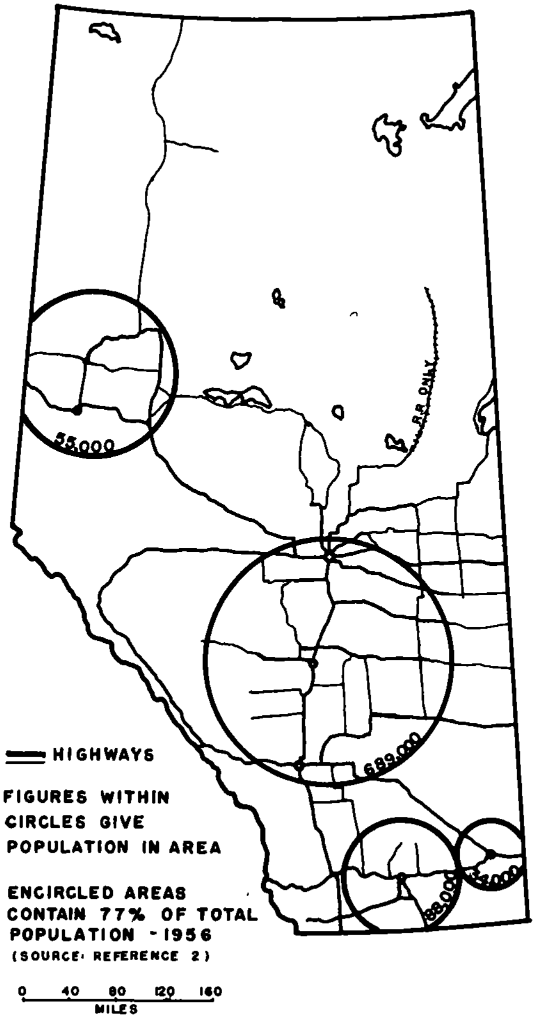

Figure 2. Surface transportation facilities and population distribution in Alberta.

SHEARING STRENGTH OF PEAT

Development of Vane Shear Apparatus

The locations of several main highway routes planned for construction and improvement early in this expansion period were in areas where numerous muskeg deposits occurred. Because complete avoidance was not possible and depths were such that complete excavation was not considered economical, the technique of floating the road fill on the muskeg was adopted and used in most instances. The hazards involved such as shear failure of the underlying material were recognized but were difficult to predict because little information was known of the physical properties of this material. Due to the nature of the peat and soft underlying inorganic material, conventional methods of sampling and laboratory testing were unsuccessful.

One method of determining the average shearing strength of these very soft organic and inorganic soils would be to analyze the stability of embankments in instances where shear failures had developed. One such case is on record (3) where an estimate of the safe embankment height was made and subsequently proven to be correct within an accuracy of about 10 percent by failure of the embankment where the computed height was exceeded.

This same case enabled a computation of the average shearing strength of the organic cover and wet silt within the zone of failure to be in the order of 80 lb per sq ft.

Because the shearing strength can only be determined by computation following a survey of failed sections, this method has severe limitations for design purposes in that the number of failures of this type are few and widely scattered.

To secure some relative indication of strength prior to construction, the provincial Department of Highways began using a penetrometer in 1950. This probe consisted of ½-in. diameter steel rods, the lower rod being fitted with a conical tip. The resistance to penetration was transmitted through a hydraulic piston attached to the top rod, the driving force being manually applied to a set of handles on the piston. A gauge on the piston indicated the pressure required to force the penetrometer steadily downward into the soil.

This tool was very useful in establishing the depth of soft soil, but did not give a direct measurement of the shearing strength of the material tested. At best, it was able to provide a relative indication of the strength of various muskegs.

In order to obtain more quantitative information on the shearing strength of the underlying peat, various methods of in-situ testing were investigated. The method of determining the shearing strength of soil in-situ by means of a rotating vane was receiving considerable attention at that time (4, 5). In 1955, a program was initiated at the University of Alberta to determine whether the vane shear principle could be applied to the investigation of muskeg soils. This work was undertaken as a M.Sc. thesis project (6, 7), with the field tests in cooperation with the Canadian Army, Northwest Highway System (who are charged with maintenance of the Alaska Highway in Canada).

A somewhat crude, portable vane shear apparatus was developed using a 4-in. diameter by 4.5-in. long vane. The applied moment was measured by means of a calibrated spring attached to a cable pulley and torque wheel assembly. From this preliminary investigation it was concluded that the organic material comprising the muskeg was susceptible to vane shear testing. Fairly good correlation was obtained between results from the vane and unconfined compression tests run in the laboratory. Additional work was considered necessary to establish the accuracy of the vane test and evaluate factors such as the fibrous nature of the material.

Further investigations were conducted in 1956 in an attempt to correlate the measured vane shearing strengths with depth, muskeg classification, moisture content and ash content (8). Field work was carried on in the Pembina oil fields, located 80 mi southwest of Edmonton, an area of approximately 1,000 sq mi of which 30 percent is estimated to be muskeg. The vane apparatus differed from the previous investigation in that a larger 4.5-in. diameter by 10.1-in. long vane was used and the applied moment measured by a 0-300 ft-lb torque wrench. Use of the torque wrench greatly increased the portability and ruggedness of the equipment.

Results from this study indicated that the shearing strengths of the muskeg varied directly with depth and inversely with moisture content and appear to vary directly with angular deformation and ash content.

To determine the validity of the vane shearing strengths for use in stability computations, a further study was undertaken in 1958 (9). This involved the construction of a test fill to failure and the comparison of the computed shearing strengths with the measured vane shearing strengths obtained before construction. Results indicated that the vane shear test does give a satisfactory value for the shearing strength for at least some types of peat and can be used in the stability analysis of fills constructed on muskeg.

Factors Influencing the Shearing Strength of Peat

As stated by Tresidder (10),

> It is undoubtedly an oversimplification to refer to the complex rheological properties of peat under the general heading of "shear strength." As far as

> the practicing road engineer is concerned, however, it is convenient to regard shear strength as representing in practical terms one important aspect of the behavior of peat under load.

Deformation under load is influenced both by elastic and viscous properties of the peat, the relative effect of each being dependent on the rate of application of load and the drainage condition. Many others have stated that very large deformations normally occur before a maximum load is reached, which is also supported by this work. What point is actually considered as failure is therefore dependent on the allowable deformation for the particular case. In the case of embankments constructed on peat, localized deformations of high magnitude usually occur and if loading continues to increase without a corresponding gain in strength, such as by consolidation, complete slippage or shearing takes place. Because of this progressive or plastic action it is felt that the shearing strength of peat as determined at maximum load, even though at high deformation, is a valuable indication of its behavior under load.

The author's studies consider the principal factors influencing the shearing strength of peat to be (a) texture, (b) moisture content, and (c) inorganic soil content. Variations in each of these three factors significantly affect the shearing strength of the peat.

Radforth (11) has reported that a definite correlation exists between the surface vegetation and the subsurface organic material. Thus for a given type of surface cover, as defined by the Radforth Classification system*, the general type of peaty material and its relative bearing potential may be predicted with reasonable assurance.

Quantitative measurements of shearing strength using the vane apparatus on a limited number of different muskeg classification types generally support this prediction. Shearing strength has been found to increase with increasing stature of surface cover. The lowest shearing strengths have been on F1 type muskeg (i.e., sedges, grasses, mosses) and generally range from 100 to 200 lb per sq ft.

BE1 type muskeg (i.e., with woody growth 5 to 15 ft in height, low woody shrubs 0 to 2 ft high, and non-woody moss up to 4 in. high) has given shearing strengths from 210 to 1,090 lb per sq ft. The texture of the peat in F1 muskegs would be fine-fibrous to amorphous, whereas the BE1 muskeg would give a woody fine-fibrous peat held in a coarse-fibrous structure.

Figure 3 shows the variation of shearing strength with depth for two typical surface coverage types, the texture of the peat in both cases being fine-fibrous. The F1 type shows a fairly consistent increase of strength with depth. The BE1 muskeg shows a loss in strength down to a depth of 5 to 8 ft, then an increase with greater depth. In both cases the water level was within several inches of the surface.

Figure 4 shows the variation in moisture content with depth for the same two types of muskeg. For the peat, in the case of the F1 type, the moisture content decreased going from the 1- to 3-ft depth, increased to the 5-ft depth, and then decreased again to the 11-ft depth.

The common definition of moisture content has been used, that is, the loss is weight expressed as a percentage of the dry material after the original sample has been dried for 24 hr at 110 C.

The trend in the BE1 type was to an increase in moisture content from the surface to the 5- to 8-ft depth, then a decrease with greater depth. It is considered that the primary reason for the difference in moisture profile with depth is the varying amount of evapotranspiration of water by the different types of surface vegetation.

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*This system considers the vegetal coverage, the topographic features and subsurface constitution of the peaty material. For engineering purposes the coverage classification is considered most important, the vegetation being divided into nine classes from A to I, with descriptive information as to the qualities of vegetation such as stature, degree of woodiness, external texture, and certain easily recognized growth habits. A complete description of this system can be found in MacFarlane (1) and Radforth (11).

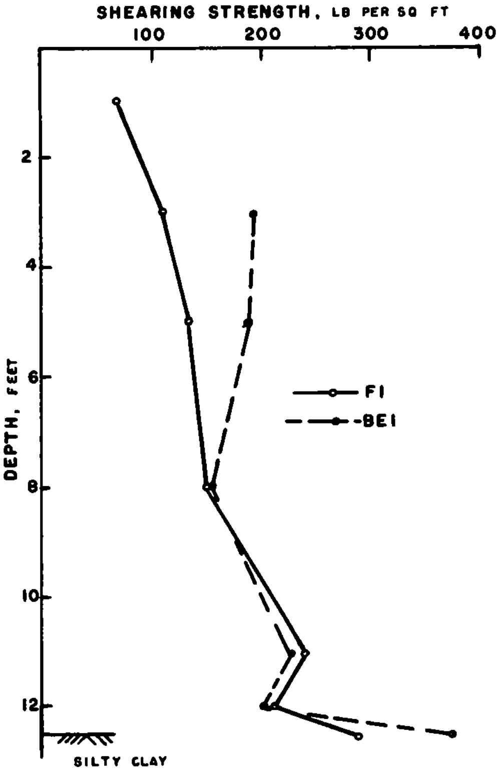

Figure 3. Variation of shearing strength with depth.

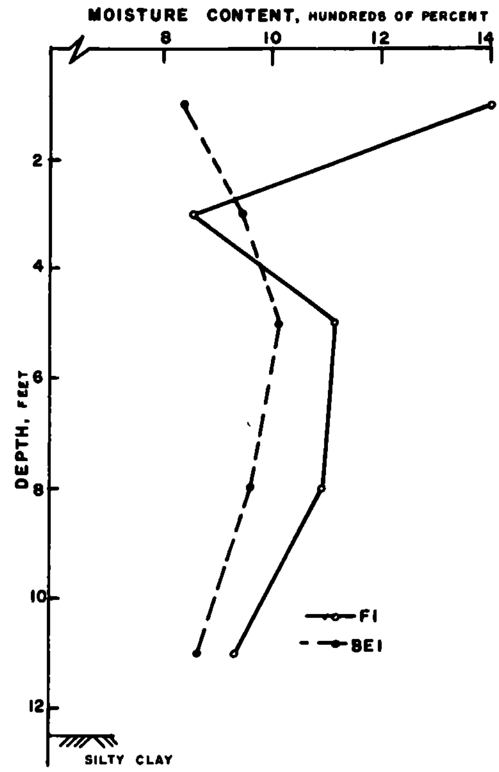

Figure 4. Variation of moisture content with depth.

The relationship of shearing strength with moisture content is shown in Figure 5. In one particular muskeg location comprising F1 and BE1 types, a direct inverse variation was found ranging from 225 lb per sq ft at 800 percent to 100 lb per sq ft at 1,400 percent moisture content.

Although there is considerable scatter in the individual points, a reasonably well-fitted curve close to a straight line can be drawn through the points on a moisture content vs log shearing strength plot. This is similar to shearing strength relationships established for clays (12). Much of the scatter can be attributed to the difficulty in obtaining reliable samples particularly at the high moisture contents.

An indication of the inorganic or mineral soil content has been taken as the weight of ash residue after drying at 300 C divided by the weight of dry sample after drying for 24-hr at 110 C. The above shearing strengths have been on peats having ash contents of 10 to 25 percent.

Contamination of a deposit of peat with mineral soil will reduce the apparent moisture content and increase the shearing strength out of line with the previously shown relationship (Fig. 5). In this particular case the EF1 muskeg deposit was located in a drainage course adjacent to a mountain slope. In view of this, the range of shearing strengths as predicted from surface coverage type, may have to be modified for particular cases depending on the likelihood of mineral soil contamination.

Excessive deformation or remolding will reduce the shearing strength of peat. Remolded vane shearing strengths were taken by rotating the vane quickly four revolutions immediately after the maximum reading had been obtained, waiting a period of 1 min, and then repeating the procedure as for the undisturbed strength test. The sensitivity, or ratio of undisturbed to remolded strengths, ranged from a low of 1.5 to a high of 3.7.

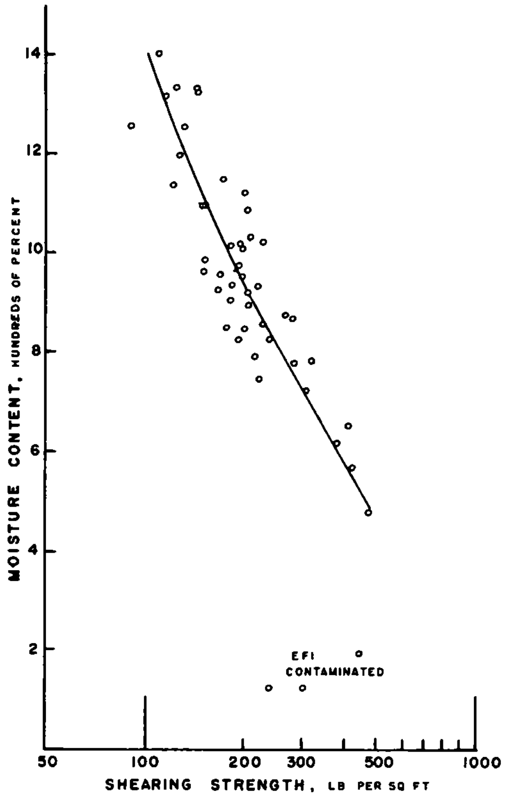

Figure 5. Correlation of shearing strength with moisture content.

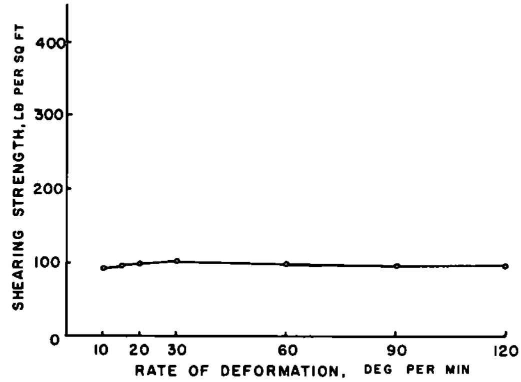

Figure 6. Effect of varying rates of deformation on shearing strength.

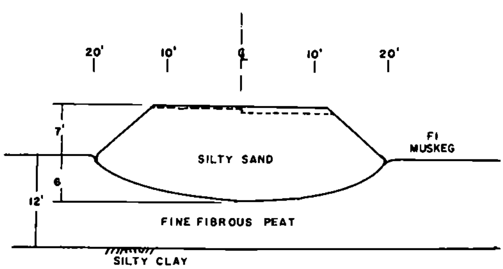

Figure 7. Cross-section of test fill at failure.

A factor of concern in any strength test is the possible effect of varying rates of strain. To overcome an uneven application of torque, the rate of deformation of 30 deg per min was adopted after trial (8) and has subsequently been used. This rate is faster than usually used for gear of winch-driven vane assemblies, the rate used by Thomson (6) being 6 deg per min. To check the possible effect of this, a series of vane tests were run at the same depth at closely spaced intervals on a uniform F1 muskeg. Results of varying the rate of strain from 10 to 120 deg per min are shown on Figure 6. Considering the reproducibility of each individual test numerically being no less than the vane constant, it is concluded that there is no significant change in strength over this range of strain and the previously adopted rate of 30 deg per min is valid.

The effect of vane size theoretically should not affect the measured shearing strength. Recognizing the nonhomogeneous and fibrous nature of peat, however, the possible influence of roots can give erroneous results. In order to decrease such possible effects and increase the accuracy, as large a vane as practical should be used. For this reason the 4.5- by 10.1-in. size was used. This size gives a vane constant or multiplication factor of 5.0 times the torque reading in foot-pounds when the shearing surface is the bottom and sides of a cylinder, and 4.7 including the top surface, used to calculate the shearing strength in pounds per square foot.

Shear Strength from Failure Analyses

In order to determine the validity of the measured vane shear strengths, a suitable area was tested and instrumented prior to construction of a test fill. The site chosen was located approximately 70 mi southwest of Edmonton at an elevation of 2,775 ft above sea level. The muskeg area was of a closed pond form extending about 1 mi in length and ½ mi in width, the water level being at the surface of the muskeg. Using the Radforth classification system, coverage types of F and 1 were most prevalent with varying amounts of B, D, and E. The depth of the muskeg ranged from 10 to 12 with a maximum of 14 ft. The peat was fine-fibrous ranging to amorphous, the lower 2 ft being well decomposed. The mineral underlying soil was a blue silty clay of medium to high plasticity.

Instrumentation consisted of 2-ft square settlement platforms, porous stone tube piezometers, guide stakes, and flexible plastic tube slide surface detectors.

The fill material was a silty sand of low plasticity and was placed by being end-dumped from trucks and spread by dozer.

Figure 7 shows a cross-section of the fill at failure. Because the actual surface of failure could not be established definitely, the particular mode of failure was inconclusive. In view of this, the failure was analyzed by four common methods; (a) circular arc, (b) sliding block, (c) plastic equilibrium theory, and (d) computation of stresses by the theory of elasticity.

The circular arc and sliding block analyses appeared to satisfy the actual conditions at failure. Assuming the shearing resistance of the peat to be purely cohesive (i.e., $\phi = 0$) the computed value from the circular arc analysis was 160 lb per sq ft. Using the sliding block analysis the average shearing resistance ranged from 95 to 235 lb per sq ft, depending on assumed hydrostatic pressures with the more probable limits being 140 to 235 lb per sq ft. The average shearing stress along a critical arc by elastic theory computations was 150 lb per sq ft.

The measured vane shearing strengths of the F1 surface cover peat before construction of the fill varied from 125 to 225 lb per sq ft at the 3- and 11-ft depths respectively. From this it can be seen that the vane shearing strengths are of the same order of magnitude as the computed average shearing resistances and therefore seem to be applicable to stability analyses.

Because no shear failures have occurred with actual highway embankments on muskeg since this test fill in 1958, other comparisons of computed shearing resistance with vane shearing strengths before construction are not available.

One section on which a failure occurred during construction before that date has been analyzed in the light of vane shearing strengths taken this past summer. With the low strength measured of 90 to 250 lb per sq ft, the predicted allowable height of embankment would be less than 8 ft. The present embankment height through the failed area is approximately 7.5 ft. Detailed records at the time of failure are not available; however, this case appears to substantiate the validity of using the vane shearing strengths for stability analyses.

OTHER INVESTIGATIONS

Another aspect of the problem of road construction on muskeg that has been investigated is the effectiveness of plastic and asphalt membranes in preventing the movement of moisture into fills constructed on muskeg (9).

Membranes, one type consisting of 4-mil thick polyethylene plastic and another of fibreglass mat impregnated with blown asphalt were placed directly on the muskeg after all growth larger than 2 ft in height was cut off at the surface. Fill was then placed on the membrane by truck end-dumping and spreading. Quantities of fill used and subsequent settlement observations were taken.

Results of this test showed that the membranes were punctured by small roots and cut-off brush and were therefore ineffective in preventing moisture from entering the fill.

As MacFarlane reported (1), Imperial Oil is carrying out research into vehicle mobility performance on various tracked vehicles used in over-muskeg travel (13). Basic design principles have been developed and incorporated into specially designed vehicles for use over muskeg. A transporter capable of carrying a payload of 20 tons through muskeg and soft clay has been in service since April 1959. An interesting feature of their work has been a tentative correlation between muskeg shear strength and net vehicle performance, and that the shear vane produces a strength profile compatible with the vehicle pull-slip curve.

A current investigation under way is an over-all determination of the performance of flexible pavements constructed in muskeg areas. This is being done as a cooperative research program under the Highway Division of the Research Council of Alberta, the Department of Highways of Alberta, and the University of Alberta.

Tentative conclusions are that the over-all performance of flexible highway pavements in muskeg areas is considered to range from fair to good. This rating was based on personal observations as to riding quality, together with attention to the type and extent of pavement defects. Generally, the riding quality of these pavements in muskeg areas was slightly poorer than in adjacent areas of mineral soil. Observed differences were larger with older pavements. The relative performance of a pavement section in muskeg was found to be better where the original surface cover consisted of large tree growth, the grade was constructed high with wide berms, and where drainage and offtake ditches were used.

The difficulty of obtaining satisfactory undisturbed samples of peat for laboratory studies has been encountered by all faced with this task. Work has been under way to develop a sampler particularly for use at shallow depths in very soft fibrous peat. The requirements of such a sampler are that it must (a) advance into the fibrous peat without pushing aside or compressing the material, (b) not be filled with disturbed material before reaching sampling depth, (c) obtain a sample without developing high side friction, and (d) retrieve the sample without loss. A sampler has been designed with retractable piston, liner, and check valve to satisfy requirements b, c and d using standard sampler designs. The first requirement is the most difficult and it is felt that the most suitable method for fulfilling this is to use a rotary saw-tooth cutting edge. A simplified version has been constructed to determine the merit of this principle. Field trials to date have been promising, but further development is necessary.

CONCLUSIONS

The conclusions drawn from these muskeg studies are the following:

1. The vane shear principle can be used to determine the shearing strength of peat, a useful indicator of its behavior under load.
2. Principal factors influencing the shearing strength of peat are (a) texture, (b) moisture content, and (c) inorganic soil content.
3. General ranges of shearing strength can be predicted on the basis of surface vegetal cover or Radforth classification.
4. Different types of surface cover influence the moisture content vs depth profile through evapotranspiration of water near the surface.
5. An inverse relationship exists between moisture content and shearing strength and approaches a straight line on a semilog plot.
6. Comparison of measured vane shearing strengths with computed shearing resistances from an instrumented test-fill failure indicates these values to be of the same magnitude.
7. Membranes consisting of either plastic or asphalt impregnated fibreglass placed on the muskeg surface were ineffective in preventing moisture from entering fills constructed on the membranes.
8. Over-all performance of flexible highway pavements in muskeg areas range from fair to good.

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