Proceedings of the Sixth Muskeg Research Conference
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The Associate Committee on Soil and Snow Mechanics is one of about thirty special committees which assist the National Research Council in its work. Formed in 1945 to deal with an urgent wartime problem involving soil and snow, the Committee is now performing its intended task of co-ordinating Canadian research studies concerned with the physical and mechanical properties of the terrain of the Dominion. It does this through subcommittees on Snow and Ice, Soil Mechanics, Muskeg and Permafrost. The Committee consists of about twenty-five Canadians appointed as individuals and not as representatives, each for a 3-year term. Inquiries will be welcomed and should be addressed to: The Secretary, Associate Committee on Snow and Snow Mechanics, c/o Division of Building Research, National Research Council, Ottawa, Ontario.

NATIONAL RESEARCH COUNCIL OF CANADA

ASSOCIATE COMMITTEE ON SOIL AND SNOW MECHANICS

PROCEEDINGS OF THE SIXTH MUSKEG RESEARCH CONFERENCE

APRIL 20 AND 21 1960

Prepared by
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and
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TECHNICAL MEMORANDUM NO. 67

OTTAWA

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FOREWORD

This is a record of the Sixth Annual Muskeg Research Conference which was held at the Palliser Hotel in Calgary, Alberta, on April 20 and 21, 1960. The Conference was sponsored by the Associate Committee on Soil and Snow Mechanics of the National Research Council. Topics considered include road construction and transmission line structure foundations on muskeg, classification systems used by different organizations, the rôle of aerial interpretation, utilization of special vehicles in muskeg, aspects of permafrost as relating to muskeg, logistics, timing and personnel problems in the North, and muskeg in relation to northern development. A list of those in attendance is included as Appendix "A" of these proceedings. In Session I, under the chairmanship of Dr. R. M. Hardy, five papers were presented. Session II was chaired by Mr. T. A. Harwood and consisted of a panel discussion as well as three papers. Chairman of Session III was Mr. I. C. MacFarlane; two papers were presented and a short film shown. Four papers were presented during Session IV, chaired by Dr. J. Terasmae. Session V, a panel discussion under the chairmanship of Mr. R. A. Hemstock, brought the Conference to a close.

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Thursday, April 21

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IV. 1. "Some Aspects of the Permafrost Problem" - T. C. Mathews.

IV. 2. "The Engineering Aspects of Permafrost in the Petroleum Industry" - R. A. Hemstock.

IV. 3. "Some Aspects of Muskeg in Permafrost Studies" - R. F. Legget and J. A. Pihlainen.

IV. 4. "Climate, Archaeology and Permafrost" - T. A. Harwood.

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(a) J. E. Savage.

(b) Dr. J. Terasmae.

(c) W. B. Dingle.

(d) Dr. N. W. Radforth.

(e) Dr. R. M. Hardy.

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Appendix "A" - List of those present at Sixth Muskeg Research Conference.

INTRODUCTORY REMARKS

Dr. Radforth, on behalf of the Associate Committee on Soil and Snow Mechanics, welcomed those in attendance. He read a telegram from Mr. R.F. Legget, Chairman of the Associate Committee, who expressed his regrets at not being able to be present. Appreciation was expressed by Dr. Radforth for the assistance of Imperial Oil Limited and the Shell Oil Company in the arranging of the Conference, and specifically for the co-operation of Mr. R.A. Hemstock of Imperial Oil. Announcements were made pertinent to luncheon arrangements, chairmen of the sessions, and availability of N.R.C. muskeg literature.

I. 1 CONSTRUCTION EXPERIENCES IN PEAT BOGS AND MUSKEG IN BRITISH COLUMBIA

R. C. Thurber

In the pre-war years, swamps and peat bogs were avoided by engineers and by most agriculturists. The post-war expansion has necessitated a new look at the vast expanses of now valuable terrain in British Columbia. The general practice of highway engineers before the war was to avoid swamps of any size because, after placing thousands of yards of material, usually they still did not have a stable road. Since the war, however, techniques of construction such as excavating, blasting, displacement, sand drains and preloading techniques have overcome many of the problems of construction over swamps and soft ground. The problem now resolves itself into a programme of careful engineering design, with the cost depending upon the degree of perfection required. For success, a high degree of engineering skill and experience in soil mechanics are essential. Many roads and freeways and other structures are now being built with satisfactory results over unstable areas. There are probably more failures, however, than most people would care to admit. Failures are projects where not only is the structure unsatisfactory but where excessive maintenance is required and where distortion appreciably lowers the operating efficiency of the structure.

A. Okanagan Lake Dam Outlet Channel

This project involved the construction of a channel located in a swamp area adjacent to the City of Penticton and between Okanagan Lake and Skaha Lake. Soundings indicated more than 70 feet of peat and soft marine silts and organic clays underlying this area. A dam was constructed on piles, although with some difficulty. The channel connecting the dam to the lakes was begun. Excavation was completed from Skaha Lake to a point 300 feet below the dam. The channel was left full of water as work progressed and only minor failures and sloughing occurred. The type of material encountered can be described as "GK3" according to the Alberta Research Council classification of muskeg.

Three hundred feet of the downstream channel was to be excavated in the dry in order to place a gravel and rock channel lining. When the channel was almost down to grade, the large spoil banks (placed by the drag-line) suddenly started to drop and the channel bottom came up. To prevent this, the spoil banks were placed further back with a drag-line and a further unsuccessful attempt was made to excavate the channel. The suggested solution was to drive sheet piling the full length of both sides of the channel in order to hold the excavation.

A check of borings showed that a stable clay was encountered at a depth of about 75 feet. This meant that sheet piling would have to be over 75 feet long. It was apparent that piles of 50 feet or less in length would not result in a stable condition and that piles 80 to 90 feet long would be necessary to key into the firm material at the bottom and would have to be supported at the top to be stable. Although not entirely impossible, this plan would have been very expensive and would have delayed the project considerably, so alternative procedures were investigated.

Indications of cracking and an upheaval were such that it was evident that a slip circle type of failure was occurring. It was also apparent that plastic flow was taking place at depth. To arrive at tangible values of the forces involved, the failure was analysed utilizing the simple slip circle type of failure. A careful check of several individual points indicated that this assumption would produce results within an accuracy that was required for design purposes. On this basis, it was calculated that if a bed of 3 feet of gravel and rock were in place, as in the original design for rip rap, then the channel would have a low but satisfactory safety factor after being filled with water.

It was decided to excavate the channel an extra 2 feet and place a properly graded filter sand which would:-

(1) Prevent the soil from pumping up into the gravel and rock.

(2) Provide a working platform upon which to spread the gravel and rock.

A construction procedure was laid down such that the channel was excavated in six consecutive 50 foot sections. The sand acted satisfactorily as a filter; as the load was placed, instead of the muck liquefying and becoming unstable, the water was able to escape through the sand and the soil increased in strength. The job was completed without further difficulty and performance has been satisfactory since.

B. Project No. 459 (Maillardville-Coquitlam Highway)

The Maillardville-Coquitlam Highway, constructed during 1954 and 1955, is a project which may be considered a failure. Up to 1954, the Department of Highways was not organized or staffed to investigate and predict problems before they occurred. It was the policy to build the road according to past experience and, if some unusual soils problem occurred, the Materials Engineer was called in. Such was the case with Project No. 459. Following enquiries by the contractors who were worried by the great expanses of muskeg, a brief investigation was made. Penetration tests were carried out with a probe consisting of a 5/8-inch diameter steel rod, joined by thin couplings and with a bullet-shaped nose. Two men forced the rod downward; the depths reached by an estimated 100 lbs. and 400 lbs. pressure were recorded.

A few auger holes were advanced to correlate the soils encountered with the penetration results. There were two main sections to the swamp area; from Maillardville to Cape Horn - about 6,400 feet long; and the other section from Cape Horn to Essondale - about 7,500 feet long. The depth of soft material of both sections was determined. The classification was "Bc 14" and "Cd 14". (Alberta Research Council Classification).

Design calculations indicated that a grade of 8 feet with a load of about 28.1 tons per lin. foot would be on the point of shear failure and that a grade of 6 feet with a load of 19.9 tons per lin. foot would probably be safe from a shear failure. Consequently, a report was made stating that a shear failure would not occur if a grade was placed of not more than 6 feet depth. It was also suggested that if a floating road was utilized, a 1 foot lift of sand should be placed over the swamp ahead of the grade to prevent peat from permeating the fill.

It was concluded that a fill of 6 feet, although it would settle excessively, would not shear the swamp crust. However, the road would not likely be satisfactory.

Funds were not available for displacing an average of 19 feet of peat over 14,000 feet of road, so it was decided to float the road over the swamp areas. During construction, numerous culverts were placed throughout the swamp area, but on piles. In a particularly soft section, the swamp had much thinner crust and was not nearly as stable. As it was feared that a shear failure might occur, sand drains were placed in that area. About 3,000 sand drains were placed in this section extending along 1,000 feet, averaging about 30 feet deep, 18 inches in diameter, and 9 feet on centers. A closed end mandril was driven down by an air-powered pile driver. After filling with sand, air pressure was applied to force the sand out as the mandril was withdrawn.

Settlement readings were taken at the time and have been continued. After about two years a comparison indicated that the settlement was very similar in the sand drains area to that encountered elsewhere. However, there was no shear failure through that area; therefore, the sand drains were considered to have served an effective purpose.

This section of road settled considerably but the piled culverts did not. As a result, the cost of maintenance has been rather high. However, the section of road between the culverts stood up for several years fairly well under extremely heavy traffic and, apart from the culverts which continually punched through the pavement, the road performed satisfactorily.

C. Pacific Great Eastern Railway

A large number of problems were encountered in connection with the construction of the Pacific Great Eastern Railway. A study of several locations where failures had occurred, utilizing drilling, testing, and analyses, produced some interesting results and conclusions. These conclusions were successfully utilized in applying corrective and stabilizing work at the various locations.

In investigating several of these failures, it was noted that a considerable amount of peat remained under the center of the grade in spite of large quantities of inorganic soil or gravel which had been placed in an attempt to fill the area. Thus, it was possible to account for the complaint that, even after filling these swamps completely with rock or gravel, undesirable and uneven settlement and distortion of the grade later occurred.

On the basis that in new construction of a railway grade and before final ballasting and lifting of the track small settlements are not particularly undesirable, certain recommendations were made:-

(1) For grades satisfactory for high speed travel, any organic material of depths up to 6 or 7 feet should be excavated prior to construction.

(2) For depths of organic material over 6 or 7 feet, explosives should be used in the normally prescribed manner by discharging after the fill is in place.

(3) Where the grade was already built, and the track was in use, the practice of putting in granular fill in large quantities to keep the track up to grade should be discontinued. Berms should first be built to counterbalance the grade. These berms could be built of any inexpensive material, usually clay from adjacent cuts. Once such berms are built, the grade can be brought up to the proper elevation. This procedure has been successfully utilized; its main advantage being that far less material is required for equilibrium and, of course, local inexpensive soils can be used for berms.

Several of these sections have been observed to show signs of unevenness after several months of heavy traffic but this is not serious on a railway. Also, it has been noted that where ditching and drainage of the swamps had been carried out, a gradual lowering of the water table had a direct and appreciable effect on the settlement of the grade.

D. General Recommendations Regarding Construction in Muskeg

(1) No primary or secondary highway to carry heavy modern traffic should be built over any depth of peat or organic matter. Such organic material should be displaced or excavated.

(2) Soft silts and compressible clays often encountered under peat should be consolidated rapidly by sand drains and preloading if it is apparent from the testing programme that appreciable settlement can be expected after completion of the road.

(3) Corduroy or timber grillage is not necessary under roads with a grade of more than about 3 feet.

(4) Swamps will definitely carry an embankment which can be used for a railway or a highway providing it is possible to design for the differential settlement at the transition points and to design for any bridges or culverts required.

(5) A rule of thumb is that approximately 1 foot of settlement can be expected for every 10 feet of swamp depth for such floating grades.

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I. 2 MUSKEG AND PERMAFROST IN HIGHWAY DEVELOPMENT IN THE CANADIAN SUB-ARCTIC

J. P. Walsh

Permafrost as Nature's Aid in Construction over Muskeg

It does not matter what physical form a highway foundation may have if it is strong enough and stable enough. Where the subsurface can be maintained permanently frozen, that is sufficient highway support, whether the subsurface be select granular materials or of entirely organic composition. The engineer's problem is to preserve the permafrost in all foundation materials where thaw would cause a partial or total loss of support. From soil mechanics we know which inorganic soils are affected by frost action. We also know that organic soils have little strength unless frozen. At the Snag Airport on the Yukon-Alaska boundary, the soil is a coarse gravel with little or no fines and no loss in subgrade support resulted from annual thaw even though the active layer was 18 feet deep. In other areas where silt exists and where conditions were once such as to permit ice segregation, the thawing of the subsoil will cause total loss of support. When thawed, such soils are more difficult to deal with in the north than further south, for two reasons:-

(1) The soil at greater depth will remain frozen so there is no escape for excess moisture in that direction.

(2) There is less loss by evaporation in these latitudes.

In many of the areas where the soil structure is such as to permit the formation of ice lenses, this has already occurred. If these soils are allowed to thaw, support is lost due to their extremely high moisture contents. Moisture content may well be several hundred percent in inorganic soil and two thousand percent in muskeg. Physical feature examples of this is the silt hill and the pingo. North of Yellowknife, in an excavation in silt, ice lenses of two feet in thickness were exposed.

Consideration of permafrost in highway construction is only necessary when it is within construction depth. After some experience in an area, the depth to permafrost can be estimated from surface cover and topography. Between latitudes 61 and 64 the permafrost is to be found at some depth in almost any area, as has been proved by the mining industry in sinking shafts and also in oil drilling. The permafrost level is higher and the active layer shallower with increase in the density of tree growth, the presence of organic cover and the absence of free moisture in this cover. A dry muskeg has many times the insulating qualities of a saturated muskeg. Where there is some natural surface drainage within a muskeg area, the channel carrying the run-off or the ponds formed in the depressions usually cause the permafrost level to drop. Sometimes the heat conductivity allowed by this water will create an underground channel which then remains in an unfrozen condition. Ponds may have no visible drainage yet never change surface level where they have subsurface connection to a large body of water nearby.

Utilizing the Permafrozen Foundation in Highway Construction

The person responsible for the route location should be a graduate of the construction force. Any possible economy can be realized only by consideration of all factors peculiar to construction in these areas. Consider a common situation in the Yellowknife area: a three-mile section of the general route is without available embankment materials from borrow except at the extremities. The grade at any section may be over rock or muskeg. The muskeg fill section, due to submergence and other shrinkage, will require 36,000 yards of borrow per mile plus 15,000 yards of excavation for side and offtake drainage. The embankment per mile over rock would require 17,000 yards of borrow and 5,000 yards of rock excavation (which would be used as fill). After a complete analysis, including overhaul costs, it may be found that a section from each end would be built on the muskeg and the center portion along the rock.

Some recommendations for route location are:-

(1) Every standard should be brought to a common denominator. Class "A" standard for grades should not be considered when alignment can only be Class "D".

(2) The first impression of a difficult area is usually too pessimistic. The location engineer should deal with lengthy sections governed by definite control points (such as river crossings) and should bear in mind that the shortest route may be one and one-quarter but never twice the straight line distance.

(3) All muskeg sections whether wet or dry have to be drained. The grade will cause the muskeg on one side to become saturated eventually. Permafrost will always be at a shallower depth in dry muskeg and therefore the embankment quantities, and consequently the cost, will be less.

(4) Rock is safe. Unit costs may be higher but design quantities for excavation through it and for borrow for embankment over it can be maintained. Also routing along rock ridges and outcrops reduces maintenance since this enables the road to blow clear of snow.

(5) Total shrinkage will be high in grade construction over muskeg. Submergence, haul roads and increased embankment density relative to the borrow pit, in that order, contribute to an approximate average of sixty percent shrinkage in the Yellowknife area.

Some Recommendations for Construction

For the permanently frozen subsurface to be utilized as the highway foundation, the frost level must be maintained or raised, never lowered. Lowering of the frost level will result from any of the following:-

(a) Removal of the insulating cover.
This is usually the layer which undergoes the annual freeze-thaw cycle. Generally this applies to an organic soil but other soils may be the insulating medium. In the Yellowknife area, permafrost exists from two to four feet depth in silt hills which have little or no organic cover and only sparse tree growth. Due to the topography, the active layer is well drained and no free water is available for ice segregation in this layer. This depth of dry inorganic soil is sufficient insulating cover.

(b) Wetting the insulating cover. If necessary drainage is neglected in the slightest and the moisture content of the active layer is increased, then the permafrost level will drop.

(c) Disturbing the insulating cover. The ground surface in its natural state is usually in the best condition to hold the permafrost level at a static depth. Any operation of construction equipment on this surface in the summer will have bad results. The color change in the organic surface will cause heat absorption and any ruts or depressions will be collection ponds for water which will result in pockets of thaw.

The permafrost may be maintained at its natural level (or even raised) by the following methods:-

(a) Drainage. Constructing drainage ditches on both sides of the center line, at sufficient distance so that the semi-circle of thaw below them will not intercept the toe of fill, and continuing these ditches to offtakes, will improve the insulating quality of the cover. From two to two and one-half miles of ditch may be required per mile of road. If at all possible, drainage should be carried out well in advance of construction, preferably a year ahead.

(b) Use the forest cover which must be cleared for right-of-way as additional insulating cover. All trees and brush should be hand cleared and laid in a mat over which the grade will be built. This will actually raise the permafrost profile under the grade after a few seasons.

(c) As a rule, never excavate on the road line. Unless it is rock, or gravel without fines, go over it. The frost will be encountered so quickly that the quantity reduction by cut in the road width will be negligible and the exposing of the permanently frozen subsoil may cause considerable difficulty.

(d) Set culverts high so that heavy run-off will be carried and at other times the culvert will have little or no flow. By creation of a large area of pondage above the culvert, evaporation will substitute for a flow through the culvert for seasons other than break-up and after heavy rains. A continuous flow in a culvert will cause a basin of thaw below it. Another reason for setting culverts high is that glaciation will occur where there is winter flow and when it is required at the break-up; the culvert will not have a capacity above the limit of icing.

(e) Where glaciation is a problem, it usually occurs where the highway is built along a hillside for an appreciable distance. Water is trapped between the permafrost and the active layer and a head is built up. The road ditch will freeze to greater depth and lock on to the permafrost before this occurs in undisturbed ground. Under sufficient head, the water will break the surface in or just outside the ditch. A second ditch parallel to the road and at some distance up the slope from it should be excavated and the ice will pile up there safely away from the grade.

Suggested Approach to Highway Development in the Canadian North

It appears that both owners and contractors are too much influenced and guided by conventional methods in highway construction. Methods which are tried and proven for southern areas are not always correct when applied further north. Owners let, and contractors acquire, highway jobs in which completion dates, expected performance and estimated costs are quite unrealistic. The construction season at Yellowknife is from July 1st to October 31st, whereas it may be twice as long and twice as good in the Calgary area. Of the total job cost, the proportion to place men, camp, fuel and equipment on site and to supply throughout the project is much higher at a distance of one thousand miles from the nearest city (Edmonton) than for a similar highway job in more settled districts. In addition, there is less knowledge of proper methods in highway construction in the Canadian North than in almost any part of the world.

Some Suggestions:-

(1) Contracts should be large enough to reduce the move in - move out proportion of total cost as much as possible. Heavy equipment should not be sent in annually, which is the case with one-year contracts, unless this year's contractor happens to be the successful bidder on the next job.

(2) Job specifications should be written and interpreted in an applicable manner. There is no history of road construction in the North and therefore there can be no fixed specifications, since these can only be written when based on past tried and proven methods.

It is not unusual to find a young conscientious engineer attempting to apply standard specifications which are applicable to road construction in southern Canada. Also a contractor may enter a job with an equipment choice based too greatly on contract specifications and too little on field study.

(3) At this time and until many more highways are built and knowledge gained, both owners and contractors should adopt a non-rigid approach. Should one contractor become educated, he must still compete on subsequent jobs with those who still bid unrealistically due to ignorance of the problems peculiar to this area.

Since method is still to be learned, they might be learned on the job but not at the expense of it. When those factors are encountered for which correct specifications are yet to be written, then field decision based on the collective knowledge of all associated with the project should prevail.

(4) Staff should be chosen on a basis of more remuneration for a more demanding job. The employer should seek out experienced men and compensate financially for this experience as well as for isolation. Highway construction in Northern Canada should not provide just an interim position for young graduates out of engineering school or for an in-training superintendent or foreman; but the challenge is so great that experienced men properly compensated should be responsible for this work.

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I. 3 THE PRACTICAL APPLICATION OF PRECONSOLIDATION IN HIGHWAY CONSTRUCTION OVER MUSKEG

C. O. Brawner

Peat or muskeg is of limited geologic extent in British Columbia. However, in the Lower Fraser Valley area, muskeg deposits are quite numerous. About 1955, when it became apparent that several new major highways were necessary in the vicinity of Vancouver, alignment requirements and right-of-way costs indicated it would be desirable to locate portions of these highways through muskeg areas.

These deposits range in depth from about 6 to 30 feet. It was obvious that the most widely accepted construction procedures, removal or displacement of the peat, would be very expensive. Hence, the B. C. Department of Highways gave consideration to other methods that might offer greater economy and still provide high performance and low-maintenance construction.

Of the methods considered, preconsolidation, often used to stabilize soft inorganic soil, appeared to offer many advantages, particularly economical construction. If the procedure was successful, it was estimated that savings in excess of $50,000 per lane-mile could be saved compared to the removal or displacement techniques. Considering this possible saving, the Department approved detailed studies, comprising laboratory and full-scale field investigations. Two of these studies have been completed (1) (2) (3) and a third is still underway. Based on the results of these studies preconsolidation has been or is being used on three major highway projects.

It is the purpose of this paper to summarize the findings of these studies, outline experience on several highway projects and to present design and construction procedures that have been developed. It is important to note that the investigations were directed more toward practical rather than pure research.

Principle of Preconsolidation

The principle of preconsolidation is relatively simple. A load in excess of that which will finally be carried by the soft ground is placed and allowed to settle until the ultimate settlement that would occur under the final load has been reached. The excess load is then removed and road construction completed. The principle is illustrated in Figure 1. Curve 1 is a typical time-settlement curve for a 6 foot fill placed over a peat deposit. The settlement, with no surcharge, reaches 2.8 ft. in 25 years. This 2.8 feet of settlement can be obtained during the construction period by placing an 11 foot fill for about 20 days (Curve 3). After this period the excess 5 feet is removed and future settlement will be negligible.

Practical Problems Associated with Preconsolidation

While the principle of preconsolidation is relatively simple, there are several major problems that must be overcome in order for the procedure to be successful:-

(a) Construction must be carried out in such a manner that overloading of the peat and subsequent failure does not occur.

(b) Excessive settlements, generally very non-uniform, must be reduced to within tolerable limits.

(c) Deflection and rebound under heavy traffic loads resulting in high compression, tension and bending stresses in the asphaltic concrete must be maintained within tolerable limits to prevent failure.

Brief Outline of Research

Three full-scale field test sections were constructed. General location details are shown in Table I.

Location	Depth of Peat	Material under Peat	Length of Deposit
Lulu Island (Vancouver-U.S.)	Up to 11 feet	Silt and sand, clay below 70 ft.	Approx. 2 miles
Maillardville (Trans-Canada Highway)	Up to 18 feet	Medium soft clay, silt and till	Approx. 1 mile
Sperling Avenue (Trans-Canada Highway)	Up to 15 feet	Very soft clay	Approx. 1 mile

Table I - General Details of Test Section Locations

The first test section at Lulu Island was constructed to determine whether preconsolidation could be utilized for highway construction over peat. The peat at the Maillardville site was somewhat different in texture and a second test section was considered advisable.

At Sperling Avenue, clay, with a lower shear strength than the overlying peat, extended to depths up to 60 feet and created a problem of sufficient magnitude to warrant a third test section.

Prior to the construction of the test sections, field soil surveys were carried out and vane shear tests performed. Samples, disturbed and undisturbed, obtained during the soil survey, were subjected to numerous laboratory tests. Field instrumentation comprising piezometers, settlement gauges and lateral movement gauges were installed before the test fills were placed. Reading of the instrumentation was carried out while the surcharge was in place and for some time after removal. In addition, plate bearing tests were run on the preconsolidated peat. Results of the first two test sections have been published elsewhere (1) (3).

The Sperling Avenue location is the most critical, with the underlying soft clay posing a greater problem than the peat. Stability analysis revealed only 3 feet of granular material could be placed without a shear failure and settlement computations indicated 9 feet of settlement, to occur over at least 50 years, can be expected. At the test section, six to eight feet of sawdust, which will settle below the water table, was placed on the peat before the gravel to maintain the grade above ground line. In addition, vertical sand drains are being installed to determine if they will materially increase the rate of consolidation. Results of this latter study will not be complete for at least another six months.

Brief Discussion of Test Results

Detailed information regarding test results has been published previously (1)(3). A brief discussion of the most significant results follows:-

(a) Strength Characteristics and Embankment Stability

Strength determinations for peat require some special attention. Unconfined compression tests are unsuitable because of drainage during the test. Undrained triaxial tests have been carried out; however, sample preparation is very difficult. Field vane shear tests are more readily performed, providing the peat is essentially fine grained. While there is some discussion as to the validity of the vane test in peat, it has been used on several projects for strength determinations and embankment designs based on these results have not resulted in unstable conditions.

With the validity of strength tests for peat not well established, detailed theoretical stability analyses are not as yet considered justified. Accordingly, the strength is assumed to be cohesive in nature and the critical height of embankment is determined from the approximate formula

$$h_c = \frac{6c}{\gamma}$$

where h_c = critical height (feet)

c = cohesion = shear strength (p. s. f.)

γ = unit weight of fill (p. c. f.)

On actual construction, the installation of fairly simple instrumentation can be used to forewarn of impending instability. If pore water pressure in the peat exceeds about 50% of the effective pressures or if lateral movement exceeds about 3 inches, stability is considered critical.

Fortunately, the permeability of peat is generally quite high, and thus increased pressure results in a fairly rapid increase in strength. If the peat does not contain fine grained inorganic soil or if the loading is not extremely rapid, embankment stability for fills up to about 8 feet in height is not usually a problem, except where very soft clays underlie the peat.

(b) Settlement and Consolidation Characteristics

As for shear strength determination, evaluation of the rate and magnitude of settlement due to the weight of a fill is difficult. The main problem arises from the difficulty in obtaining and preparing representative samples. The Swedish foil sampler has been fairly successful in obtaining reasonably undisturbed samples. Large diameter thin wall tubes have also been used with fair success. Where sample preparation is difficult, the samples have been quick frozen and trimmed in the frozen state, placed in the consolidometer and allowed to thaw for 24 hours before testing.

Another problem concerns the selection of a suitable consolidation theory. The Terzaghi theory of consolidation (4) applies to primary consolidation where the coefficient of consolidation is assumed constant. This coefficient varies markedly for peat, hence the theory does not apply. At the same time, however, it is considered that peat consolidation is largely primary, rather than secondary, as is often suggested.

In order to evaluate the rate and magnitude of settlement it is assumed that Darcy's Law is valid. Consequently, the magnitude of the settlement is considered to vary as the thickness of the peat layer and the rate of settlement to vary as the square of the thickness. Reasonable agreement using these relationships was obtained between the laboratory and field results during the studies.

A procedure to estimate the magnitude of settlement has been prepared by Lea (3), Figure (2). Curve ABC is the calculated field load-settlement curve on which each point gives the settlement which would occur 25 years after a given load is applied. Curve DEF is a similar calculated field load-settlement curve for the allowable construction period - in this case, three months.

Curves ABC and DEF are constructed by running special consolidation tests at different pressures. Such tests are loaded at the field rate (correlated by the square law) and the load is left on for a time corresponding to 25 years. A family of curves is obtained and the 3 month and 25 year curves are plotted.

Point D indicates that if a 0.30 ton load is placed it will settle 2.5 feet in three months. Curve GDB represents the load which must be added to maintain the required finished roadway. The slope and shape of this curve are affected by the location of the water table and unit weight of the fill materials. Point B represents the ultimate condition which must be achieved and the horizontal projection of B to line DEF, point E, gives the load required to obtain the 25 year settlement in three months.

Where conditions vary, new curves must be constructed.

(c) Flexible Pavement Design

Of the pavement design methods available there appear to be only four procedures which may lend themselves to the determination of pavement thickness over preconsolidated peat.

(1) Plate Bearing Test - This test, developed by Dr. Norman McLeod for the Canadian Department of Transport, has been used very successfully in airport pavement design (5) and modified for highway design. Tests on the surface of the preconsolidated peat at various locations reveal about 40 to 48 inches of pavement (asphaltic concrete and base) are required. The results of the tests are shown in Table 2. It should be noted that the thickness of pavement determined by the plate bearing test is affected by the strength of the granular base. In the present tests "K", the base course constant varied from 50 to 65. If, however, the base is poorly compacted, "K" may be greater and increase pavement requirements.

Location	Material	Pavement Thickness Required (inches)
Lulu Island	Preconsolidated peat	45
Lougheed Highway	Preconsolidated peat	42
Maillardville Test Site	Preconsolidated peat	43
Sperling Ave. Test Site	Preconsolidated sawdust overlying peat	47

Table 2 - Pavement Requirements for Preconsolidated Peat as determined by the Plate Bearing Test.

(2) Benkelman Beam Test - Recent testing at the W.A.S.H.O. test road (6), in California (7), British Columbia and elsewhere has indicated pavement will not fail under repeated heavy traffic load applications provided deflection, as measured by the Benkelman Beam, does not exceed about 0.030 inches at temperatures near freezing and about 0.045 inches during the summer. A series of tests using the procedure developed at the W.A.S.H.O. road test were carried out to relate pavement performance and deflection to pavement thickness. The results are shown in Figure 3. Pavement thickness of about 40 inches is indicated.

(3) Shear Strength Method - This method has been used most frequently in England (8). Based on vane shear tests at Lulu Island a depth of pavement of 22 inches was indicated. This thickness is obviously too low considering pavement performance. The discrepancy may be due to the vane shear test not being reliable in peat, that peat has a moderate angle of shearing resistance, or that radius of curvature and not shear strength is the limiting design factor.

(4) Elastic Theory Method - Laboratory and full-scale tests in Sweden (9) (10) and B. C. (3), suggest that the elastic theory method, which results in a radius of curvature criterion, is also a satisfactory pavement design procedure for roads over peat. Using the method outlined in Reference 9, 48 inches of pavement is required.

The fine fibrous and granular peats in the lower mainland of B. C. have reasonably similar properties. Consequently, a pavement thickness of 40-48 inches is considered valid for preconsolidated peat in this area.

Use of Preconsolidation in B. C.

Based on the present studies, it was considered that preconsolidation can be utilized to provide economical and stable highway construction. Consequently the B. C. Highway Department has used or is using preconsolidation on several major projects. Results of experience on several of these projects is summarized below.

(a) Lougheed Highway near Boundary Road

In 1957 it was considered necessary to widen the Lougheed Highway to four lanes. About 1,200 feet of the highway crossed a peat deposit ranging in depth up to 14 feet. The old highway was floated over the peat and was badly deformed. Excavation and replacement and vertical sand drains were initially considered but discarded in favour of preconsolidation.

The entire fill was brought to grade and a five foot surcharge placed and left for three months before removal. Immediately after removal the base gravel and asphaltic concrete were placed. No major construction difficulties were encountered.

This highway has now been in service for nearly two years and no noticeable differential settlement or pavement failure has occurred.

(b) Chilliwack By-Pass

About 2,000 feet of the Trans-Canada Highway near Chilliwack crosses muskeg ranging up to 35 feet in depth. A grade about 8 feet above ground line was utilized. Eight feet of fill was placed initially at which point lateral movements became excessive. Construction ceased for three months after which another 7 feet was placed. The surcharge was recently removed and paving will commence shortly. Again no major problems were encountered.

(c) Hart Highway

A portion of the present gravel highway, which is to be paved this year, crosses several large muskeg areas. Four to five feet of surcharge was placed on the grade last Fall and left over the winter. This surcharge will be removed and the highway paved in June or July of this year.

(d) Trans-Canada Highway near Maillardville

Preconsolidation is being used to construct over a mile of four lane divided highway near Maillardville. Generally the final grade is to be about 6 feet above ground line with the exception of an overhead crossing where the approach fills will reach 25 feet. No difficulty is being experienced with the shallow grade. However, the higher approach fills are presenting problems.

Considering settlement and surcharge a total depth of fill of about 35 feet is required. With the peat only capable of supporting about 8 feet of fill initially, stage construction is necessary. The first stage was constructed without difficulty. The second stage has had to be placed much more slowly as the rate of consolidation and reduction in pore pressures have decreased considerably from that during the first stage. One possible explanation is a marked decrease in permeability of the peat. If the rate of consolidation continues to decrease as markedly for the third and fourth stage, as much as two years may be required to place the total fill. This is obviously too long and a change in procedure such as the use of vertical sand drains, counterbalancing berms or well points may be required.

This experience suggests that preconsolidation may only be practical where the grade is up to about 6 to 8 feet above ground line.

The Practical Application of Preconsolidation

Based on the study sections, procedures were developed for the practical application of preconsolidation. In the light of experience gained on several highway projects, the initial procedures have in some cases been slightly modified. The general details of the requirement for successful application of preconsolidation are outlined in the following text. They are considered applicable where the underlying soil is stronger than the peat. Studies are presently continuing to develop procedures when the underlying strata is very soft highly compressible clay.

(a) Preliminary Studies

Preliminary studies should always include a subsurface investigation. The first step involves determination of the depth of the muskeg and contour of the firm bottom to indicate the most desirable location. This is done rapidly by forcing a 5/8" diameter sounding rod by hand through the peat to firm bottom. Notes are made to include the pressure required to force the rod into the ground at various depths. By drilling the occasional test hole at sounding points the sounding rod pressure is correlated with the general soil type and the correlation extended for all sounding points. This procedure is sufficiently accurate to provide data to select the final alignment.

On the final location, soundings are recommended every 25 to 50 feet along the center line with offset soundings every 50 to 100 feet. Test holes should be drilled every 100 to 300 feet along the center line to obtain samples for identification and determination of physical and mechanical properties. If settlement computations are to be made, undisturbed samples are required for consolidation tests.

In order to estimate the height of fill that can be placed initially, field vane shear tests at every one foot increment of depth are recommended at locations spaced 300-500 feet along the center line. The information and samples obtained from this field testing are then submitted to the laboratory and design office.

(b) Design

The first step in the design is to establish the desired grade and to designate the approximate location of any necessary culverts or structures. Based on experience gained at Maillardville it is advisable to establish the grade between 2 to 6 feet above the surface of the muskeg.

Test results indicate that a minimum pavement thickness of 3 1/2 to 4 feet is necessary for adequate pavement performance. Based on consolidation tests or other procedures, the amount of settlement and surcharge is estimated and quantities determined. A minimum surcharge of 4 feet is recommended. A depth of about 7 1/2 feet of material, which includes the surcharge, will be the approximate minimum requirement. If granular material is not economically available, the surcharge need not be gravel.

The settlement of the total depth of fill can be estimated from:-

(i) Consolidation test results (as outlined).

(ii) Moisture content-void ratio-coefficient of compressibility relationships. (1)

or if no testing is carried out

(iii) Assume settlement will approximate 1/3 to 1/2 of the depth of fill placed, with the settlement not to exceed about 1/2 of the original thickness of the peat.

Where extensive use of preconsolidation is proposed it is recommended that the first procedure be used since more accurate estimates of settlement and quantities involved will result. Where the highway must cross the muskeg for only a short distance or where a secondary road is involved, the second or third procedure will normally be adequate.

To determine quantities, the base width of the fill is increased 3 feet for every foot of estimated settlement, if 1 1/2 to 1 side slopes are used, or 4 feet for every foot of settlement for 2:1 slopes.

All material between the base of the fill and to within 6" to 12" of grade elevation (depending on the Highways Department's crushed gravel requirements) will be left in place. After the required consolidation has occurred, the surcharge is removed to grade plus a depth equal to the crushed gravel requirement. This material, if suitable, can be designated for use in the nearest fill. For purposes of the cost estimate, excavation, hauling and placing of the entire quantity must be considered plus an additional allowance for excavating and hauling the surcharge.

The maximum height of fill that can be placed initially without shear failure can be estimated from $6c/\gamma$ if field vane tests have been carried out. Alternatively a slope stability type of analysis can be used. Experience in B. C. to date is that no fill less than 8 feet in depth has caused a failure, provided very soft clay does not underlie the peat.

Where extensive use of preconsolidation may be employed, more accurate analysis methods may be used that consider the gain in shear strength of the peat as the fill is placed as well as the effects of pore water pressures.

Provision for drainage ditches should be made if they are required. These ditches, however, should not be too close to the toe of the fill to ensure the surface mat is not broken. Where culverts are necessary, the estimate should be based on placing the culvert, digging it out after consolidation, placing a granular base to establish the required grade, then replacing the culvert and backfilling.

A further cost should be included for field instrumentation required to control construction and evaluate settlement. This estimate can be computed based on the procedure outlined under construction.

Costs for base gravel and asphaltic concrete can be treated similarly to that for normal construction.

(c) Construction

During the clearing operation, all small brush should be cut and left on top of the peat. Heavy timber should be trimmed at ground level and removed from the fill area. Brush or timber should not be burned on the muskeg as it may smolder and burn for many months or even years. Grubbing is not required.

The next requirement is to lay out the center line and slope stakes. This is followed by the installation of the field instrumentation. This instrumentation should include settlement plates and piezometers placed every 100 to 400 feet on the center line. Porous stone piezometers may be preferred by some engineers due to their greater sensitivity. The settlement plates should be placed on a levelling course of sand. The elevation of the top of the gauge and water level in the piezometer is then determined and recorded about 24 hours after installation. Lateral movement gauges are recommended every 25 to 100 feet placed about 20 feet from the proposed toe.

Difficulty has been experienced in B. C. with field instrumentation being damaged or broken by construction equipment. These instruments are difficult and expensive to replace and it is suggested that the contract include some provision to the effect that if field instruments are damaged or broken by the contractor he shall be responsible for replacement at his expense.

After the field instrumentation has been installed and initial readings obtained, the contractor can commence placing the fill. Care should be taken to ensure the surface mat is not broken. Any culverts that are required should be placed at this time and can be placed directly on the muskeg. Initially 2 to 3 feet of fill will be required in one lift to act as a working mattress to support the equipment. This lift should be compacted with several passes of a wobbly wheel, rubber-tired or grid roller. The mattress should be placed over the entire length of construction before any additional fill is placed. The instrument readings should be taken 12 to 24 hours after placing the mattress and after each subsequent lift is placed. The additional lifts should not exceed 1 foot and should be carried over the entire length of the construction before each additional lift is placed to facilitate consolidation and gain in shear strength.

Placing of the fill can be continued until the required depth including surcharge is placed, unless that depth exceeds the maximum height allowed initially. In this case the contractor should not be allowed to place additional material unless the pore pressures are less than about 50% of the total effective pressure and lateral movements are less than 0.25 feet.

Construction should not be allowed to recommence until pore pressures reduce substantially, lateral movement ceases or the field time settlement curves indicate primary consolidation is 100% complete. This degree of consolidation has occurred after 25 to 35 days on projects in B. C. and on the two test sections. To facilitate later removal, the material placed as the surcharge should not be compacted.

After the grade has been completed to full surcharge height, field settlement readings are continued to determine when the desired settlement has taken place. The surcharge is then removed and if suitable can be used elsewhere. The culverts can now be dug out and replaced at the required grade. Base gravel which should be well compacted can be placed immediately followed by final paving.

Summary

1. The B. C. Department of Highways has carried out several full-scale studies in the use of preconsolidation for highway construction over muskeg.

2. Results of the studies have revealed that preconsolidation can be successfully employed and is generally less expensive than displacement or excavation for depths of peat greater than 5 to 6 feet.

3. The problems of foundation stability and differential settlement can be accommodated by the use of simple field instrumentation and proper construction procedures.

4. Pavement stability can be provided on preconsolidated peat by the use of 3 1/2 to 4 feet of granular material and asphaltic concrete.

5. Construction over peat using preconsolidation has been or is being utilized successfully on several projects in B. C.

6. Based on the studies and construction experience, highway design and construction procedures have been developed and are outlined.

7. While the investigations have been carried out only in the Vancouver area, it appears quite possible that preconsolidation can be adapted for highway construction over muskeg in other areas.

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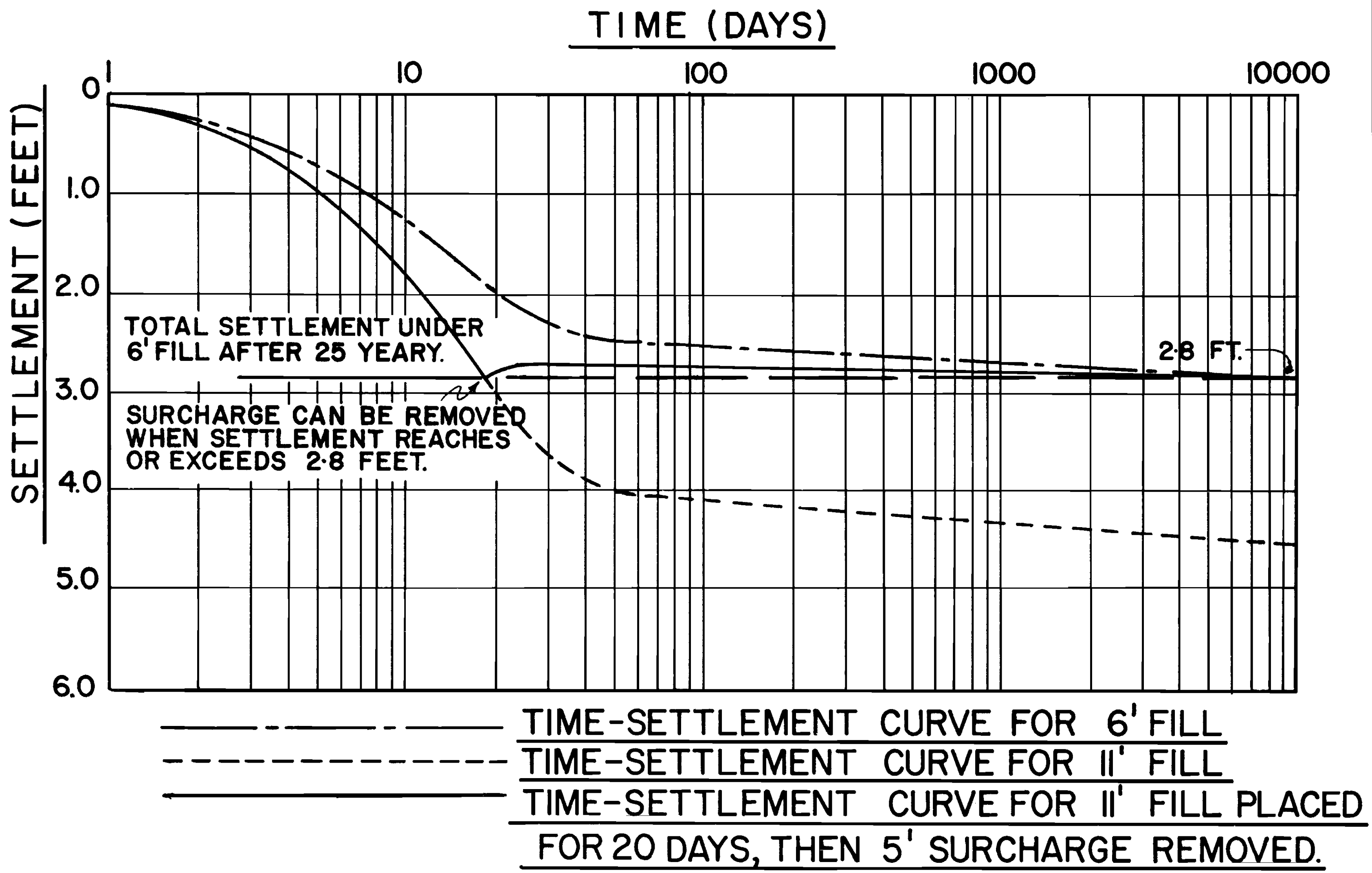

FIG. 1.-TIME SETTLEMENT CURVES ILLUSTRATING PRECONSOLIDATION PRINCIPLE.

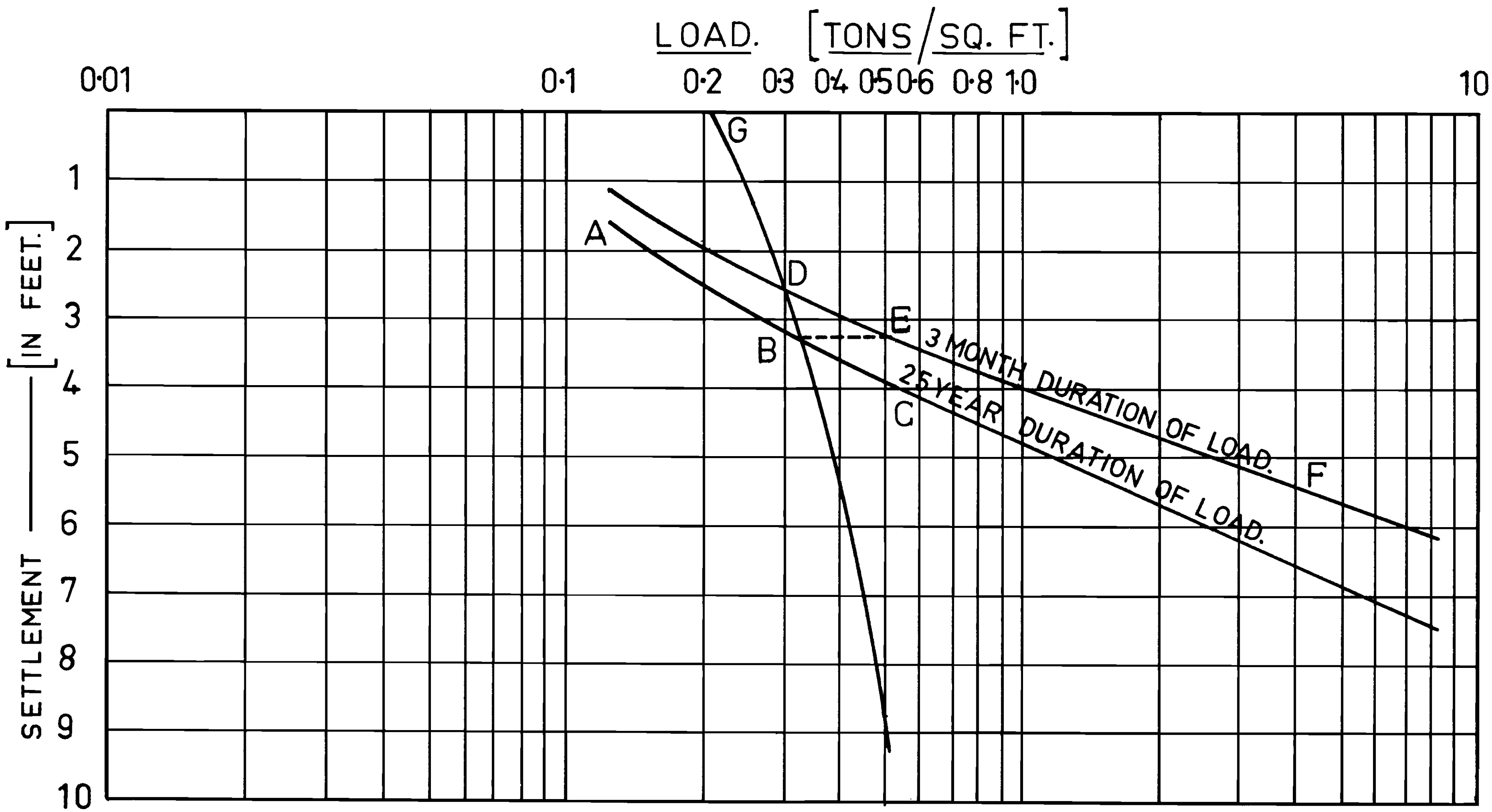

FIG. 2.

GRAPHICAL DETERMINATION OF SURCHARGE LOAD REQUIRED FOR PEAT TREATMENT BY PRECONSOLIDATION.

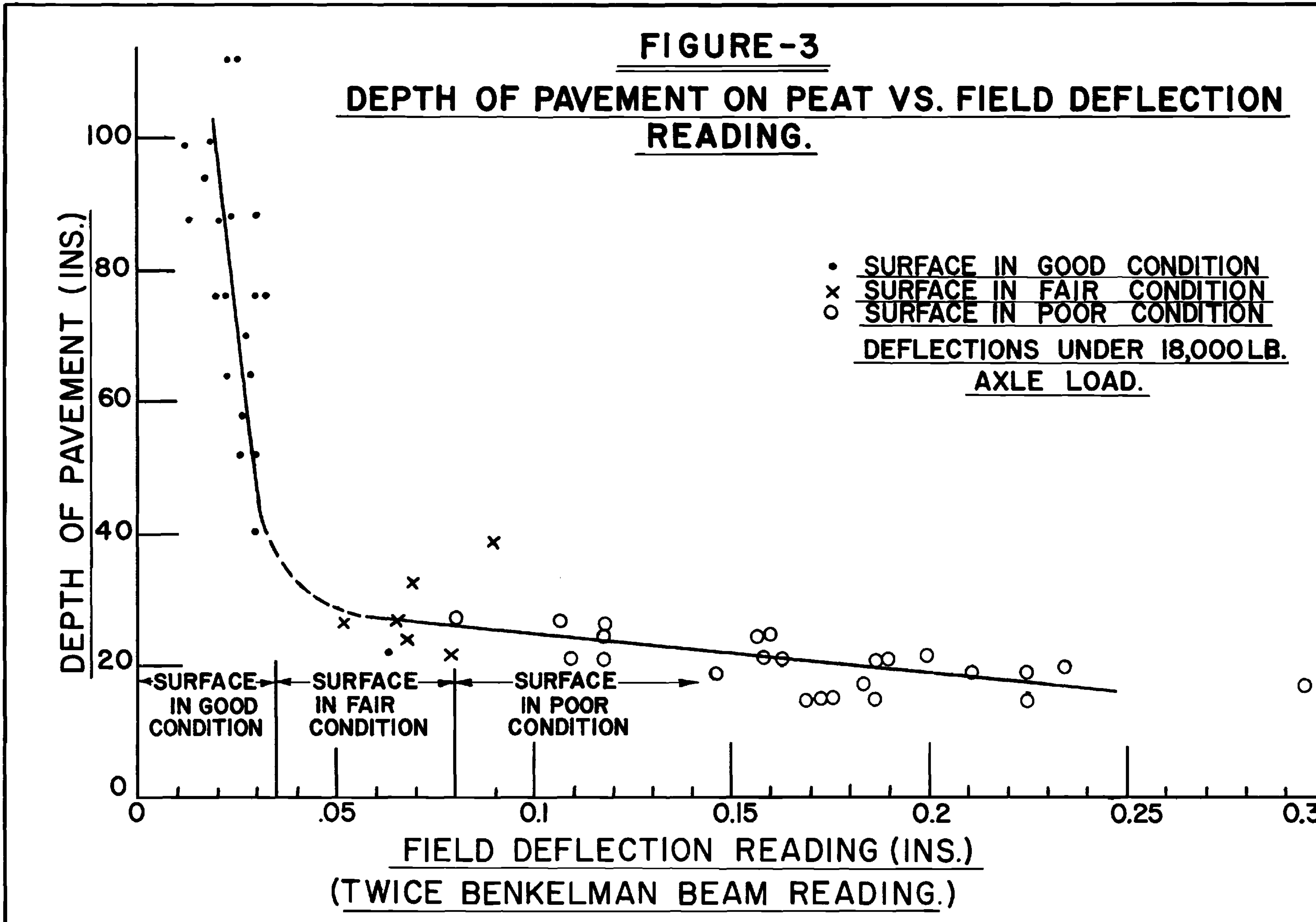

FIGURE-3
DEPTH OF PAVEMENT ON PEAT VS. FIELD DEFLECTION READING.

DISCUSSION

C. F. Ripley

Procedures being used by the B. C. Department of Highways to construct permanent roads over muskeg in the Lower Fraser Valley area, using the method of preconsolidation, have been presented in the paper by C. O. Brawner entitled, "The Practical Application of Preconsolidation in Highway Construction over Muskeg". Reports on the engineering studies and test results on which the procedures have been based, have been presented by the author to previous Canadian Muskeg Research Conferences and in other publications (1, 2, 3, 4).

The several reports indicate that permanent embankments can and have been built successfully across muskeg in the Lower Fraser Valley, using a rational method of design based on conventional soil tests, vane shear tests and consolidation tests, and supported by full-scale field test data. These experiences contrast appreciably with those of the writer, sometimes painful, on several projects involving construction of permanent fills over deep muskeg in the same area. The differences in experience are pointed out with a view to suggesting caution against hasty or over-confident reliance on either laboratory test data, field vane tests or short-term full-scale field tests on muskeg. In doing so, the writer does not wish to detract from the use and value of such test data, but merely to warn that successful application requires correct interpretation and this in turn requires careful, experienced and sound judgment.

Shear Strength

Analyses of two recent cases of shear failures which have occurred during construction of embankments over muskeg indicate that the computed average shear stresses at failure were remarkably close to the remolded vane shear strength, which was about 1/2 to 1/3 the undisturbed vane shear strength. In each case, average shear stresses were computed for the most critical circular arc passing through the observable toe and heel of the rupture surface. The vane used for determination of shear strength had a diameter of 2 1/2 inches and a length of 5 inches. It was rotated at a rate of 0.4 degrees per second. Thicknesses of peat were 34 ft at Case A and 19 ft at Case B.

The embankment at Case A failed when the total fill thickness was 6 ft only, of which 4 ft was placed in the first lift, followed by 2 ft placed five weeks after the first lift.

The embankment at Case B failed when a total thickness of fill equal to 6 ft had been placed in one lift.

Consolidation Characteristics

Settlement observations extending over a period of four years indicate that the magnitude of the long-term or secondary settlement of muskeg in this area may be a high proportion of the total ultimate settlement which occurs during the twenty-five year period referred to by the author. The author indicates that 75% of the 25 year total settlement occurred within 25 to 30 days after fill placement. One wonders as to the basis of determination of the magnitude of settlement during the 25 year period, and whether the author's estimate of the long-term settlement after the 30 day period will not be on the low side.

The following is an interesting example of the serious proportions which the long-term settlement may assume. A site underlain by 17 ft of muskeg was covered with 5 ft of fill. Settlement at the end of the so-called primary period, 50 days after completion of placing fill, was 2.6 ft. Settlement between 50 and 1200 days has amounted to an additional 1.0 ft. The slope of the time settlement curve on a semi-log plot is only slightly less during the so-called secondary period than during the primary period. Extrapolating the curve to 25 years indicates an additional future settlement of about 1 ft. Thus the long-term settlement will amount to 75% of the primary settlement or to between 40% and 45% of the total settlement. Similar behaviour in which the long-term settlement has been of the same or larger order has been noted on other sites.

For such conditions, the ultimate success of the preconsolidation method appears to be questionable. It would appear to the writer that the preconsolidation procedure recommended by the author may eliminate the primary settlement, but that the roadway may still be subject ultimately to secondary settlements of nearly the same order as the primary. The success of the recommended procedure will thus depend upon whether or not the secondary settlements will cause excessive unevenness of the finished roadway surface. The question arises whether it is possible to pre-induce the secondary settlement by preconsolidation. This would appear to depend primarily on the shear strength of the muskeg. Within the writer's experience the shear strength of the muskeg at several areas of the Lower Fraser Valley has been sufficiently low that it would not support preconsolidation thicknesses greater than the three to four feet recommended by the author, and in some cases, would not permit thicknesses that great. Where such conditions prevail, effective preconsolidation would not be feasible.

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I. 4 TRANSMISSION LINE STRUCTURE FOUNDATIONS IN WEAK SOILS

M. Markowsky N. J. McMurtrie

Although transmission engineers tend to avoid areas of weak soil conditions, they are usually forced on them by either one or both of two significant economic facts of life. First, transmission lines are often forced to locate on land not generally desirable for other uses. Second, it is usually more economical to locate a transmission line route in a straight line. Angle structures are much more expensive than the "tangent" structures used on the straight line portions of a transmission line. Therefore, many transmission lines are located in part in a swamp or muskeg area. Transmission engineers expend considerable effort looking for foundation designs which will minimize the higher costs of these applications.

In Ontario, it is planned to construct extensive transmission facilities during the next three years in connection with the power developments on the Moose River system in the James Bay area. Approximately 100 miles of these lines will be located through muskeg areas.

Although, in the past, almost all the long-distance transmission lines have crossed areas of swamp, muskeg, and marine clay, the proposed lines from the Moose River sites present special problems due to the much larger extent of muskeg, etc. The high cost of transporting suitable conventional materials presents a challenge to engineers to seek alternative designs which will minimize the need for these materials. Also, the design of transmission towers is concerned not only with bearing pressures but also with overturning forces which result in considerable uplift reactions and horizontal forces on the foundation.

Nature of the Structural Loading

High voltage transmission lines are usually supported by rigid structures but may also make use of semi-flexible structures.

The rigid towers are almost always made of steel, while the semi-flexible structures can be made of either wood or steel, with the wood predominating in practice.

Transmission line structures can also be classified into three broad groups by the type of loading or duty to which they are applied. On straight line portions "tangent" or "suspension" structures are used. These structures are loaded mainly through the action of the wind on the bare conductors, or on ice-covered conductors. Because of this, the normal "everyday" load is a relatively small percentage of the ultimate design load and is the same on each footing of the foundation.

A second category consists of "medium angle" or "semi-anchor" structures which are used at most of the angles in the line. Because the conductor tension normally amounts to several thousand pounds, the transverse component of this line tension at line angles adds considerably to the structural loading of both the tower and its foundation. At heavy angles and line terminations, a third category of structure is used known as a "heavy anchor" structure. This type of structure is used to support the full line tension of all conductors. At semi-anchor and heavy anchor locations, where the conductor tension forms a major part of the structural loading, the everyday loading is a large percentage of the ultimate design loading and, for this reason, transmission engineers take few chances in the foundation design of such structures.

Due to the obvious difference in cost between these structure types (varying in a ratio from 3/1 to 6/1), transmission lines are constructed with suspension towers wherever possible. The unusual or unorthodox approaches to foundation design are limited to this type of tower, but because it comprises 95% of the structures used in a typical line, the savings achieved by this means are multiplied many times over throughout the length of the line route.

The structural loading is transmitted to the towers and foundations by the action of wind and ice on the conductors, therefore there are problems in dealing with the stresses in the soils from bearing, uplift, and horizontal shear forces. "Suspension" structures, which are located in a relatively straight line, are therefore loaded almost entirely by the overturning force of wind either on the bare conductors or on ice-covered conductors. This complicates the foundation design to the extent that the backfill material becomes every bit as important as the soil under the foundation.

Extent of Soil Investigation

Because of the relatively low cost of a transmission line structure and foundation, it is usually difficult to justify extensive soil investigations at each site. For example, the cost of a complete soil investigation would approach the cost of a normal suspension tower foundation in good soil. Soils are examined visually during the process of selecting a route. The depth of the poorer soils which are encountered is determined by the probe method. Tower locations in poor soil areas are investigated by the standard drop hammer test but without the laboratory analysis.

It should also be borne in mind that the limitations on uniform settlement on the foundation of the transmission line structure are not severe. Differential settlement, however, is a major concern because of the additional stresses which this could introduce into the structure. Differential settlement on rigid transmission line structures is limited to 3/4" to 1".

Soil Strengths and Treatment in Design

In dealing with weak soil areas, the unconventional foundation designs are applied only to the suspension or tangent towers because, unlike the semi-anchor and heavy anchor towers, the normal everyday load on these structures is a relatively small percentage of the ultimate design load. Normally, the standard steel grillage foundation of a suspension tower is used for soils with a bearing capacity of the order of 4000 psf. However, in isolated instances, these foundations would be used in soils with bearing strength as low as 2000 psf. For the semi-anchor and heavy anchor towers, this value is limited in all instances to 4000 psf.

When the actual soil conditions at the construction site fall somewhat below these values, the bearing area under each footing is increased by a reinforced concrete mat. This device is used for soil strength down to 1000 psf in the case of suspension towers and down to 2000 psf in the case of semi-anchor and heavy anchor towers. For soils below the strength of 2000 psf, piles are used for the foundations of anchor towers. In the case of suspension towers, where the soil strength is below 1000 psf, piling is usually considered as a next step. However, since problems of access frequently make this not feasible economically, alternatives are sought.

A number of these alternative designs which have been used for suspension tower foundations can be called unconventional.

Special Types of Foundations

A "piston" foundation is shown in Figure 1. The significant feature of this type of foundation is the use of cribbing or shoring for the purpose of containing the soil down to a depth at which the stress in the soil has reduced to a safe figure. A reinforced concrete mat is also used in connection with this foundation in order to spread out the stress inside the "piston". Two sections of shoring are used, as shown. The granular material which is placed between the inside and the outside shoring is used to increase the friction between these planes for the purpose of "keying" the footing into the plane of the outside shoring. In this way, all of the backfill used will contribute to the uplift strength of this footing. The gravel or planking, which is used under the reinforced concrete mat, is simply for the purpose of providing a working surface.

A spread mat foundation consists simply of the steel grillage tower footing on a reinforced concrete mat, and may look very similar to the mat which is shown as part of the piston footing in Figure 1. This method is used primarily to deal with a bearing problem. It is applied where the soil above the footing has sufficient resistance to provide the uplift strength required. A variation of this method, where a smaller increase in bearing area is required over the standard footing, uses ordinary wood planking instead of reinforced concrete. The limitation of this latter version is the relatively smaller area over which it could be used.

In some cases, soil investigations reveal the presence of relatively thin layers of stronger soils at certain levels. Under these conditions, it is sometimes possible to adjust the depth of the tower footing to be set at such a level that advantage can be taken of one of these stronger layers. In such cases, the spread mat is used together with the top or outside shoring shown in Figure 1.

It is sometimes possible to consolidate a weak soil by placing rock or broken concrete at the bottom of the foundation excavation. This has been used to advantage in certain cases to build up a sufficiently thick layer of stronger material. The footing is then treated in the same manner as above.

In both of the above cases, the size of the reinforced concrete mat is selected so that the stresses reaching the weaker layers underneath are within permissible limits.

A raft or mat foundation, which has been used to some extent in Northern Ontario on twin wood pole structures, seems to be particularly adaptable to muskeg conditions. This foundation is illustrated in Figure 2. In this application, the bearing stresses are distributed over the surface of the ground by means of the wood planking which is formed into the shape of a raft by the cross timbers. In the case of a muskeg application, this type of foundation makes very good use of the top dense fibrous layer of the muskeg which, of course, is the only part of the muskeg worth using for this purpose. As a necessary supplement to this type of foundation, the wood pole structures are guyed to each side and are held by swamp or muskeg anchors of the type shown in Figure 3. The screw anchor is employed where the swamp or muskeg is not excessively deep and where the blade of the screw can be turned sufficiently far into firm soil as to give the desired holding power. The log anchor, on the other hand, is employed where firm soil is not available at a reasonable depth. In this application, the use of the logs and stakes spreads the stress over a large area of undisturbed material.

In the applications described above, the piston type footing has been used only to a limited extent but quite successfully. The other applications have been used widely and at considerable savings in cost over the more conventional piled foundations.

Current Investigations

A relatively new, experimental footing for towers, which is presently undergoing some preliminary testing near Abitibi Canyon, is illustrated in Figure 4. This footing consists of the conventional steel grillage with the addition of bracing to give the necessary lateral support, and with the application of earth anchors to give the necessary uplift strength.

As shown in the illustration, the muskeg in this area is relatively shallow. The glacial till which underlies this muskeg has sufficient strength in bearing to support the tower adequately. However, the muskeg which has been removed from the excavation would supply very little support in uplift. As an alternative to the expensive process of importing suitable backfill material, the additional bracing and the use of earth anchors, as illustrated, are being considered.

At the present time, the anchors are being installed and tested, both singly and in groups. Various types of anchors are being testsed for this application but they consist mainly of screw anchors and expansion anchors. The main problem which is being encountered at the present time is the search for suitable methods of installing these anchors in the till. This material is mainly a clay silt and when it is disturbed during the installation of the anchors it has a relatively low remold strength. Additional soil analysis is underway at the present time to study further the soil characteristics.

Frost Problems

Over wide areas of northern Ontario, the soil which underlies the muskeg or is found near the muskeg areas varies from pure silt to clay silt. This type of soil is very susceptible to frost heaving and has caused a good deal of trouble to our transmission line structures. Where this soil is overlaid with muskeg, penetration of the frost is prevented by the insulating blanket of muskeg.

When excavating in shallow muskeg, it has been found that if the silt is allowed to be mixed with the muskeg in the backfilling operation, the frost will penetrate the silt mixture into the underlying silt and cause severe heaving conditions. Therefore precautions are taken to replace the insulating blanket of muskeg intact.

Where no muskeg cover exists, there are two methods which could be used to minimize heaving and which we are experimenting with at this time. One consists of replacing the silt surrounding the footing with granular material. The second involves coating the foundation components with low temperature grease and wrapping with plastic film to prevent leaching. Both of these methods simply overcome the adhesion between the footing and the surrounding soil.

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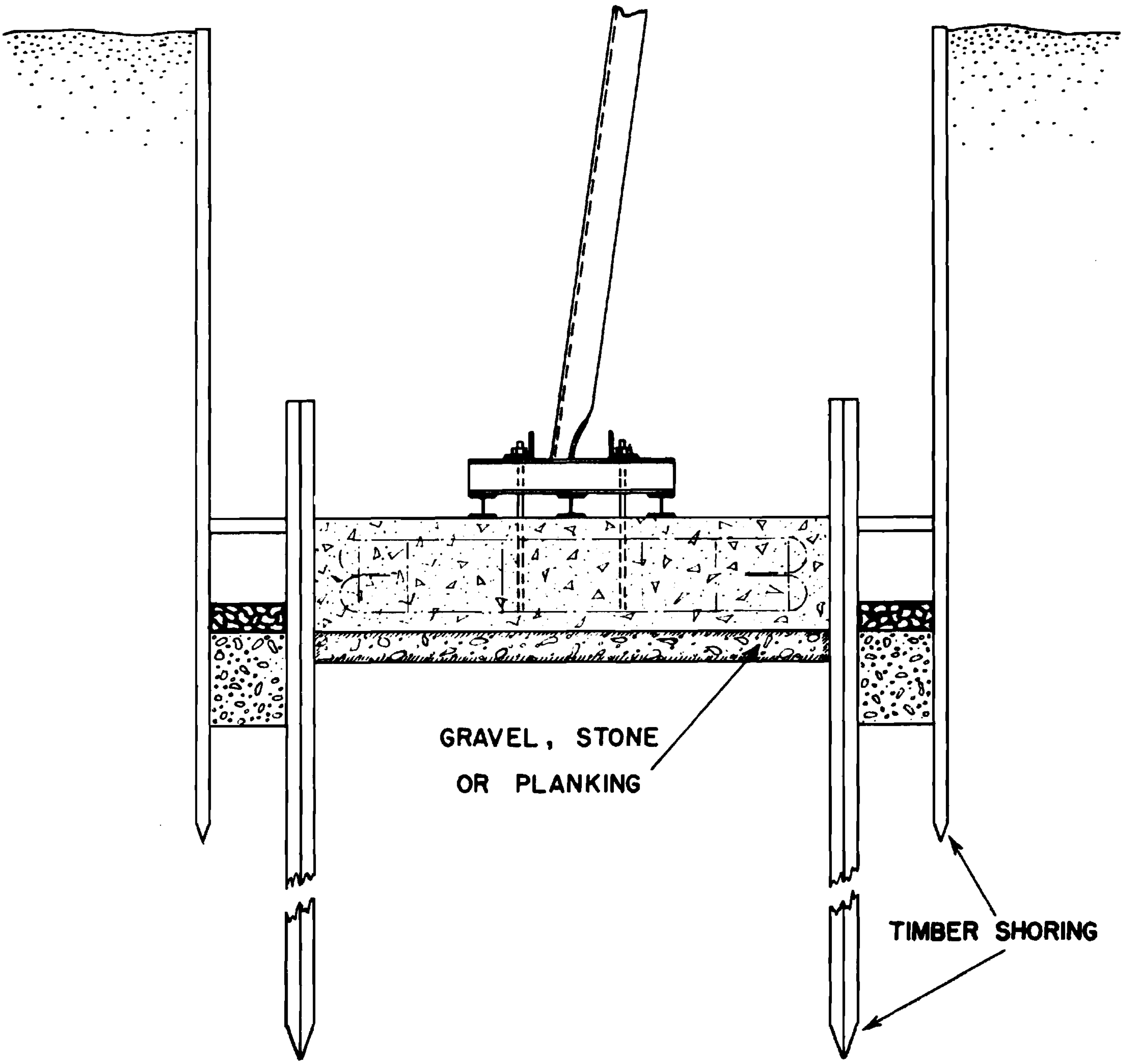


FIG I. PISTON FOUNDATION

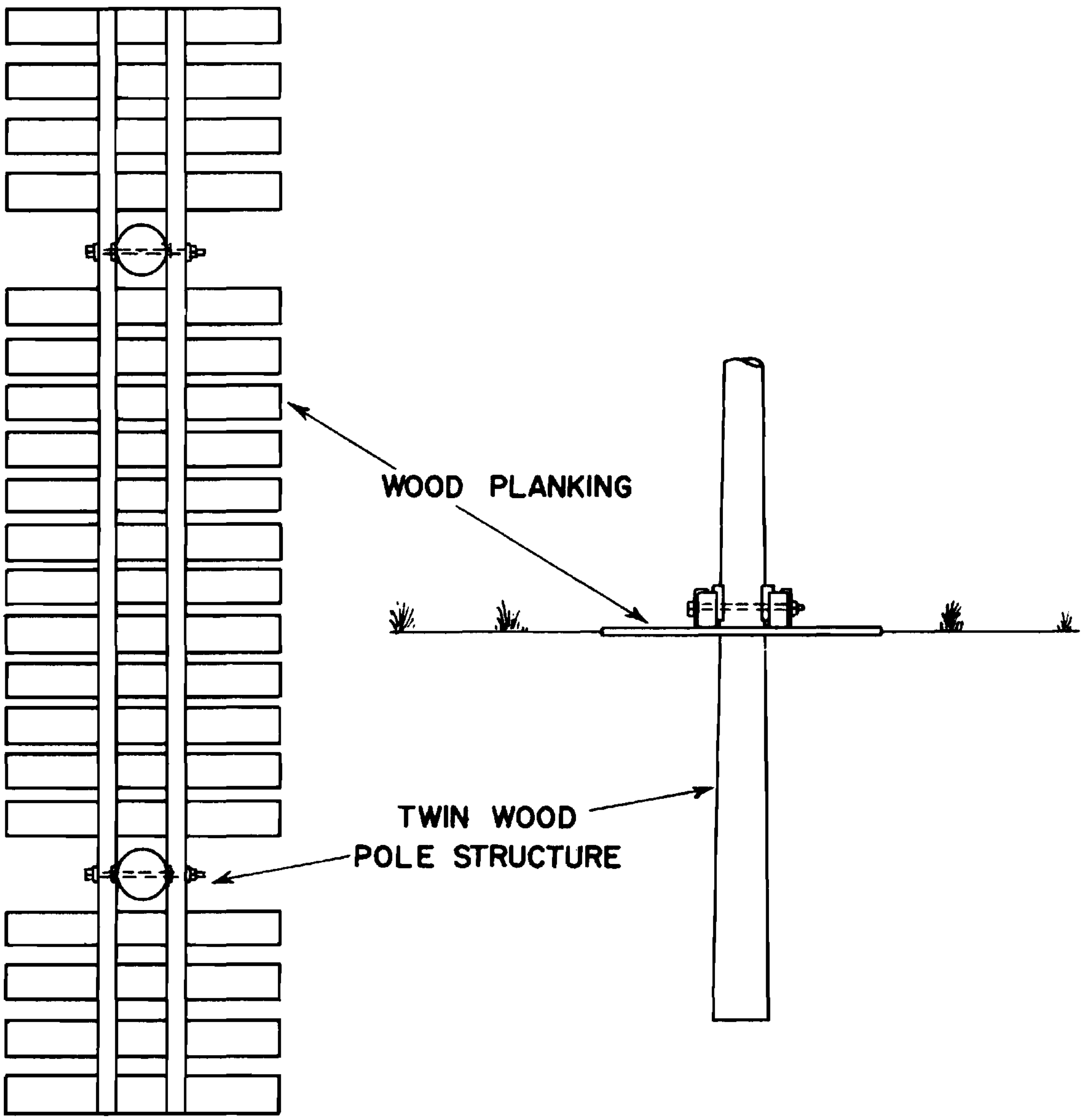


FIG 2. RAFT FOUNDATION

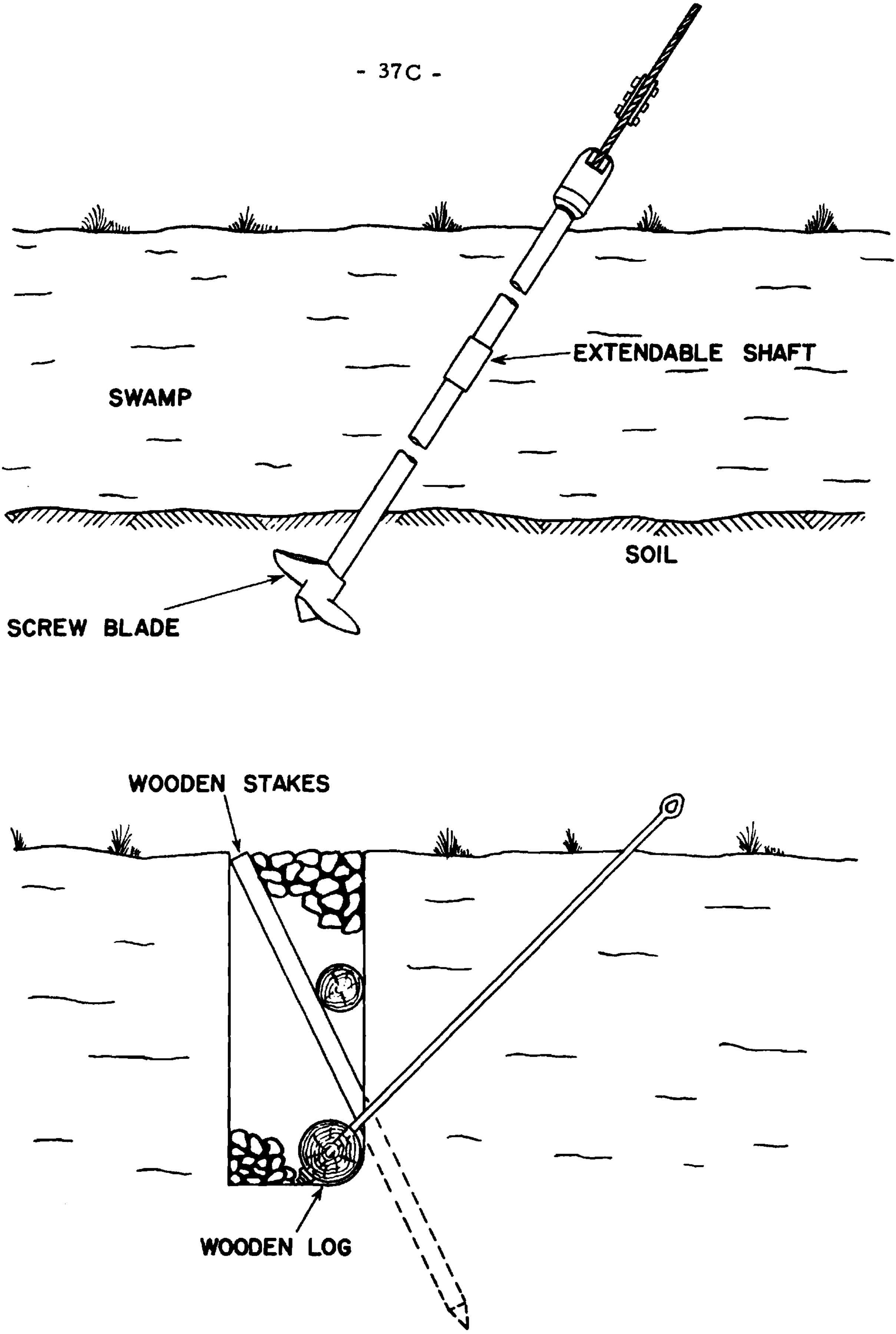


FIG 3. SWAMP OR MUSKEG ANCHORS

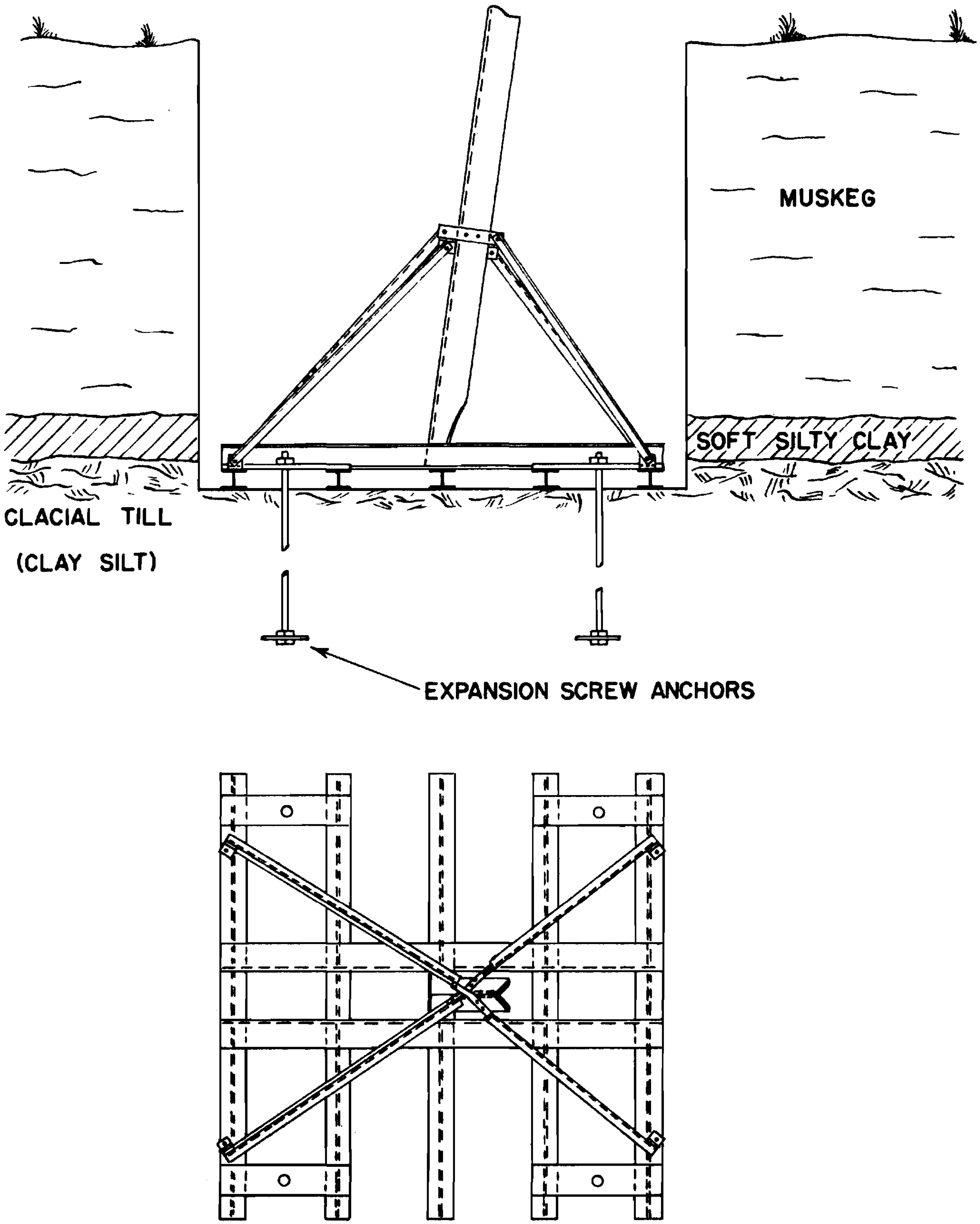


FIG 4. STEEL GRILLAGE WITH ANCHORS

I. 5 EVALUATION OF ROAD PERFORMANCE OVER MUSKEG IN NORTHERN ONTARIO - SECOND STAGE

I. C. MacFarlane

I. Review of First Stage

1. Background and Outline of Area Covered

It has been obvious to the Department of Highways of Ontario, from experience and observation, that some roads constructed over muskeg have performed very satisfactorily while others have not. It was believed that a comparison of existing successful and unsuccessful roads over organic terrain would be a useful and significant study to assist in determining some of the engineering properties of muskeg. Therefore, during the summer of 1958, the initial stage of a joint research programme was undertaken by the Department of Highways and the Division of Building Research of the National Research Council. The main object was to study the performance of existing roads over muskeg, to obtain all pertinent construction details, and then to attempt to group muskegs according to their bearing properties. In addition, a further objective was to attempt to correlate road performance with the Radforth Classification System for muskeg.

A large area was covered in a general way, extending from North Bay along Highway 11 to Nipigon, and to the Lakehead, No. 17 up to Kenora, then along Highway 71 to Emo and No. 11 to Rainy River (Figure 1).

2. Investigational Procedure

Forty-four different muskeg areas were investigated, and about 500 peat samples obtained for laboratory analysis. Field testing included the limited use of the vane shear apparatus. A series of observations were made and the road performance was assessed (based on history and present condition) relative to the performance of adjacent sections of road over mineral soil.

3. Summary of Results

Table 1 shows the pattern of performance of the 44 muskeg areas investigated; 27 sections of road are noted to be rated as "satisfactory", 17 as "unsatisfactory". Of the sections of road over muskeg in the "plain" areas (a term used to describe the flat plain type of topography), 75 percent were in "satisfactory" condition (as compared to the condition of adjacent sections of road on mineral soil) contrasted to only 38 percent in the "depressional" areas (a term used to describe muskeg occurring in a depression between rock outcrops).

A tabulation of results pertaining to coverage class, depth of fill, depth of peat, thickness of soft intermediate subsoil layer (if any), and substratum type, is given in Table II.

Due to the large number of variables involved in assessing road performance and due to the difficulty of evaluating them, it was not possible to obtain any clear-cut correlation between muskeg type and road performance, except to show generally that performance is better in muskeg areas with tall tree growth. It was suggested that factors other than muskeg type (i. e. depth of fill, traffic loads, etc.) may be the predominating influence in determining the performance of a road riding muskeg.

All the road shear failures observed occurred in areas underlain by a layer of soft clay, with the range of total unstable depth being 25 to 50 feet. It was concluded that although the soft clay may not actually have caused the failure (since both the clay and the peat have very low shear strengths) it was evident that the existence of this extra depth of soft material substantially contributed to failure. Excavation of the peat and backfilling with mineral soil was not considered to be a solution to the problem, in that the soft clay layer would then be subjected to an overburden of about 100 pounds per cubic foot bulk density rather than the original bulk density of the peat of about 65 pounds per cubic foot, which may actually aggravate the situation.

In the Clay Belt region (Cochrane-Kapuskasing-Hearst), roads over muskeg areas generally were in as good condition as roads over mineral soil.

No correlation was evident between the road condition and the type of firm mineral soil substratum.

Correlations were shown to exist between vane shear strength and depth, water content of the peat and depth, vane shear strength and water content, specific gravity of the peat and water content, as well as between acidity and carbon content of the peat.

II. Stage Two: Summer 1959 Investigations

1. Investigational Procedure

For Stage Two it was planned to select muskeg areas that were typical for a certain region (as determined from an analysis of Stage I results) and carry out a more detailed and exhaustive series of tests which would include extensive vane tests in the field, as well as to procure "undisturbed" samples of the peat for laboratory strength testing. This stage of the investigations was carried out during the summer of 1959. For purposes of comparison, three groups of two muskeg areas each were chosen for study; in each of the groups the conditions of the two sites were similar, except for a rather wide variation in the assessment of the road condition. It was the purpose to find out why the road was worse in the one location than the other. In addition to these six areas, three other sites, which were underlain by a deep layer of soft clay, were investigated in some detail, particularly from the point of view of vane testing.

The field test procedure was carried out as follows:-
1) Soundings were made along both sides of the road (in the natural muskeg) at intervals of approximately 200 feet. Also, a profile was obtained through the roadway fill, at the edge of the pavement, where possible. Generally time did not permit more than one or two soundings through the fill at a particular site. These were at the deepest point in the muskeg.

2) A comprehensive series of vane tests were carried out in the natural muskeg. Attempts were made to carry out vane tests in the peat beneath the road fill, but it was found to be impossible manually to push the vane into the ground. Three different sized vanes were used, which will be

described later. At each site and for any particular vane, three tests were carried out through the complete profile to obtain a reasonable value for the shear at that point, and also to determine whether results could be duplicated with any one vane. This represents a total of nine vane tests at a particular site.

3) "Undisturbed" samples of peat were obtained for laboratory strength testing. These were obtained by means of a specially designed piston-type sampler utilizing 2.8 inch inside diameter Shelby tubes. Samples up to 2 ft. 6 inches long were retained. In addition, disturbed samples of peat were obtained for classification testing. The D.H.O. peat sampler or a post hole auger were used for this purpose. A total of 150 disturbed and 20 tube samples were obtained for laboratory analysis.

2. Description of the Vane Testing Equipment

The vane apparatus was initially developed for use in clay soils. Recently it has been used rather extensively for determining - at least qualitatively - the shear strengths of peat. Vane shear results have been compared with shear computed from the analysis of a fill failure and have shown fairly good correlation. However, there is still some controversy regarding the validity of the vane test for a complex soil such as peat. With this in mind and with the aim of determining the effect - if any - of the size of the vane on the shear strength of peat, three different sized vanes were used in the investigations. All three vanes had conical ends, the edges were sharpened, and they were of the recommended H/D ratio of 2. Their dimensions were as follows:-

Vane	D	H	"K" Factor	Area Ratio
S	2.0 in.	4.0 in.	56	9.1%
M	2.8 in.	5.6 in.	20	13.0%
L	4.0 in.	8.0 in.	6	7.7%

The vanes were attached to "E" drill rods and were manually pushed into the ground. Torque was applied through a specially designed head attached to the end of the drill rod.

The torque was exerted and measured by means of a "Torquometer" (torque wrench) with a maximum capacity of 150 foot-pounds. No casing was used with the vane. Every effort was made to rotate the vane at a constant speed in each test, the rate of strain being about three degrees/second. Following shear failure, a remoulded test was run in the usual manner (four complete revolutions, wait one minute, then repeat test). Undrained shear strength was calculated from the following relationship: Shear = Torque x Constant "K".

III. Results Obtained

1. Road Assessment

In the first two of the areas compared, site 1 was rated as "good to very good" and site 2 as "poor to fair". The condition of the road at site 2 which contributed to the low rating was a severe dishing of the pavement; also the level of the road surface was only 0. 3 feet above the level of the muskeg at the deepest point of the muskeg. Both sites had similar predominating muskeg classification types (characterized by both tree and shrub growth), although there was less consistency in this regard at site 2. The maximum depth of peat was the same for both areas, 12 feet; the mineral subsoil in both cases was sand to sandy silt in type. The depth of peat under the roadway fill was about the same, 8 feet for site 1, 7 1/2 feet for site 2. Site 1 was well drained, whereas site 2 was quite wet and generally poorly drained. However, perhaps the most obvious variation between the two areas was the depth of the road subgrade. Site 1 had a 5 feet to 6 feet sand and clay fill, whereas site 2 had a sandy fill only 2 feet 6 inches in depth. It is fairly safe to say that the predominating factor contributing to the road condition at site 2 as compared to site 1 was the inadequate depth of subgrade. It is believed that this factor contributed substantially to the adverse condition of several of the sections of road rated as unsatisfactory. Brawner of British Columbia has recommended a minimum depth of subgrade of 3 feet 6 inches which seems to be a reasonable figure.

Sites 3 and 4 were rated as "very good" and "poor to fair" respectively. Both road surfaces were paved and both had a 5 feet depth of sandy gravel subgrade. Site 3 had a maximum depth of peat of 9 feet compared to 8 feet for site 4; both had a sandy silt subsoil. At site 3 the vegetative cover was A↔BEI, at site 4 it was B↔DEI to B↔DF. The low rating given to site 4 is due to the severely undulating surface, with an amplitude of as much as 0.7 feet maximum. The depth of the peat under the roadway at the deepest point is 7 feet for site 3, at site 4 it is only 4 feet. Site 4 was very wet and poorly drained. Conditions would indicate that perhaps the primary factor contributing to the poor condition (i.e. differential and excessive settlement) of the road at this site is the high water level, coupled with a rather less satisfactory muskeg type than at site 3.

Sites 5 and 6 when compared give rather inconclusive results. The fill material was rock so that its depth was unobtainable. Both sites are within depressional areas, with about 12 feet of peat overlying many feet of soft clay in both instances. The predominant muskeg type is generally similar for both areas, and includes both tree and shrub growth. Site 5 is assessed as "good", site 6 as "very bad" as the latter is a failure condition. The present surface of the road at site 6 is in a fairly good state of repair, but settlement is still taking place and maintenance has to be carried out each year to bring the road back up to grade. Since the depths of the respective fills could not be determined, it is not possible to suggest what might be the cause of the difference in condition between the two sites - at least with any degree of accuracy. However, it may be that the physiography has played an important part in the failure condition of site 6. The road is located near the edge of the muskeg, with a rock outcrop rising very steeply at the edge. A "mudwave" is evident on the side of the road away from the sloping rock outcrop. It is possible that there may be a sliding action down the rock face, caused by the weight of the fill.

2. Vane Testing

In peat, high deformations accompanied the development of shear. The total strain during a vane shear test was as much as 50 degrees - sometimes even more. Part of this angular rotation, however, was due to twist in the rods.

It was possible to get 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 at a given depth in any of the three profiles did not deviate markedly from the mean value (for any one vane). Sensitivity values ranged rather widely from 1.5 to 10, and for all three vanes it decreased with depth.

For those muskegs not underlain by a layer of soft clay (i.e. in the "plain" areas), there was no consistent evidence of increase in shear strength with depth. This is rather surprising since the vane test results (although limited in number) from the 1958 programme appeared to indicate an increase in strength of the peat down to a depth of approximately 6 feet, then a gradual decline in strength. In those muskegs underlain by the soft clay layer, however, it was found that there was a trend toward a slight increase in the shear strength of the peat with depth, generally reaching a maximum value at or just above the transition zone. This was followed consistently by a drop in the shear strength of the clay, sometimes to well below that of the maximum shear value of the peat layer. This is yet another confirmation of the contention that in these "depressional" areas, where the peat layer is generally assumed to be the cause of a poor highway condition, the problem in fact is not with the peat but rather with the soft underlying layer of mineral soil.

In their comprehensive report entitled "The Vane Borer", Cadling and Odenstad of Sweden 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 a very good correlation. They point out, however, that design considerations place certain limits on the practical sizes of vanes that can be used.

When the average shear strength of peat for the three different vanes was plotted against depth, there was a marked variation in the results - which was consistent for all sites investigated. The three curves all have the same shape and clearly reflect any layers of higher or lower strength, but the smallest vane on the average gives results about double those of the medium sized vane and from four to five times those of the large vane. Sample curves are sketched in Figure 2 for site 5. Each line represents the average values for a series of three tests.

At least two important factors militate to cause the wide variation between the results of the small vane and those of the other two: -

1) Torque readings for the small vane were relatively low; consequently errors in reading the dial are rather large percentage-wise. The dial is graduated in 5 ft.-lb. divisions and errors in extrapolating are magnified by the vane constant of 56.

2) The ratio of the area of the rod in contact with the ground and the area of the sheared cylinder is much greater for the small vane than for the other two. Consequently, friction is a more important factor.

Further series of tests are planned by the Division of Building Research during the summer of 1960 to evaluate some of the presently unknown variables such as the effect of friction on the rod at different depths as well as the effect of twist in the rod. Even though the vane test results cannot yet be completely evaluated, it appears quite clear that due to the unusual nature of peat, the size of the vane does have some effect on the shear strength. Indications are that it is advisable to use vanes somewhat larger than frequently used for clays; the optimum size is not yet known.

3. Soundings Through "Mudwaves"

At three different sites where a shear failure had resulted in mudwaves being pushed up on one or both sides of the road, hand borings were made through the center of the mudwaves - usually by means of a post-hole auger - as well as through the natural muskeg. Levels were made of the ground surface and the elevation of the peat-soft clay interface was plotted from this information. This revealed that the mudwave extended into the soft clay layer as well; in other words, shear failure appeared to have taken place in this layer.

4. Laboratory Testing

The laboratory testing programme is not yet complete and cannot be reported at this stage. Classification tests are now underway on the undisturbed samples. A programme of various strength tests is also planned for the tube samples. A joint National Research Council-Department of Highways paper is planned for the 1961 Highway Research Board meeting, at which time laboratory results will be more fully reported.

IV. Summary

1. It has been shown that the cause of highway shear failures in areas underlain by a soft clay layer is due chiefly to this layer and not necessarily to the peat.

2. Poor condition of the road is sometimes due to an inadequate depth of subgrade. The British Columbia recommended minimum of 3 1/2 feet depth seems a reasonable figure.

3. Shear strength of the peat does not appear to be a problem in the stability of highway embankments on muskeg not underlain by soft clay. Excessive and differential settlement is a more serious problem and, in highway design, consideration should be given to this factor.

4. In some areas, a low-lying road and a high water level are important contributing factors to the deterioration of the road surface.

5. Sections of road built over muskeg types with tall tree growth exhibit better performance than in those areas with little or no tree growth - if most other factors are equal or similar.

6. Series of field vane tests show good reproducibility of results. However, vane size is apparently a factor to be considered and further research on this aspect seems advisable.

7. Generally, there is no evidence of increase in shear strength with depth. At some sites this phenomena was exhibited but it was not consistent.

TABLE I

PERFORMANCE OF MUSKEG AREAS INVESTIGATED

Physiography	Condition of Road							
	Satisfactory				Unsatisfactory			
	Excellent	Very good	Good	Fair	Poor	Bad	Very Bad	Total
Plain Areas	-	2	9	10	5	1	1	28
Depressional Areas	1	1	2	2	4	1	5	16
Totals	1	3	11	12	9	2	6	44

TABLE II

SURFACE AND SUBSURFACE CHARACTERISTICS OF AREAS INVESTIGATED

Road Performance	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	5-11 1/2	0-6	5-18 1/2	Clay; sand
Poor (9)	A⟷BEI B⟷DFI	12-60	5 1/2-14	0-18	5 1/2-32	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

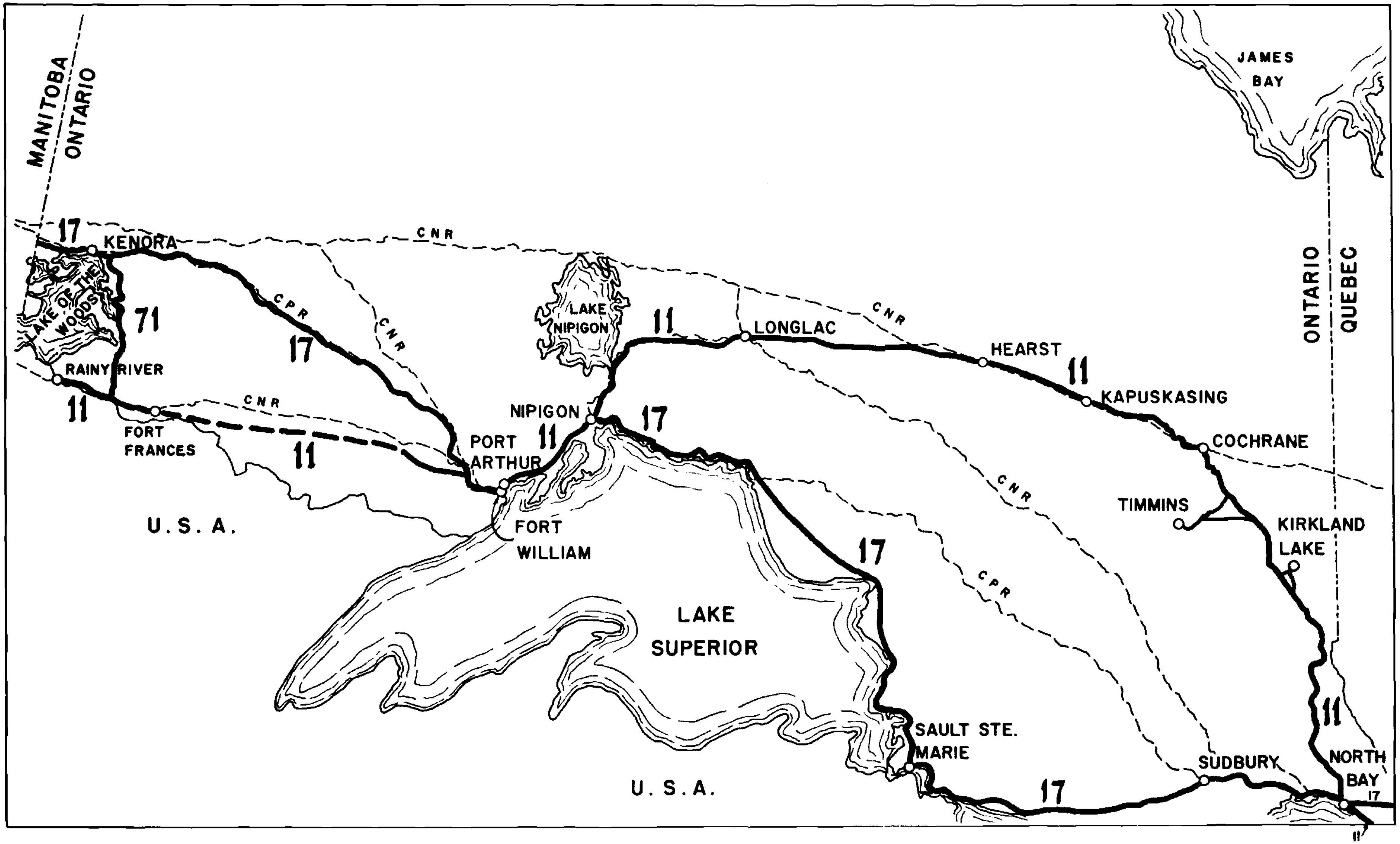
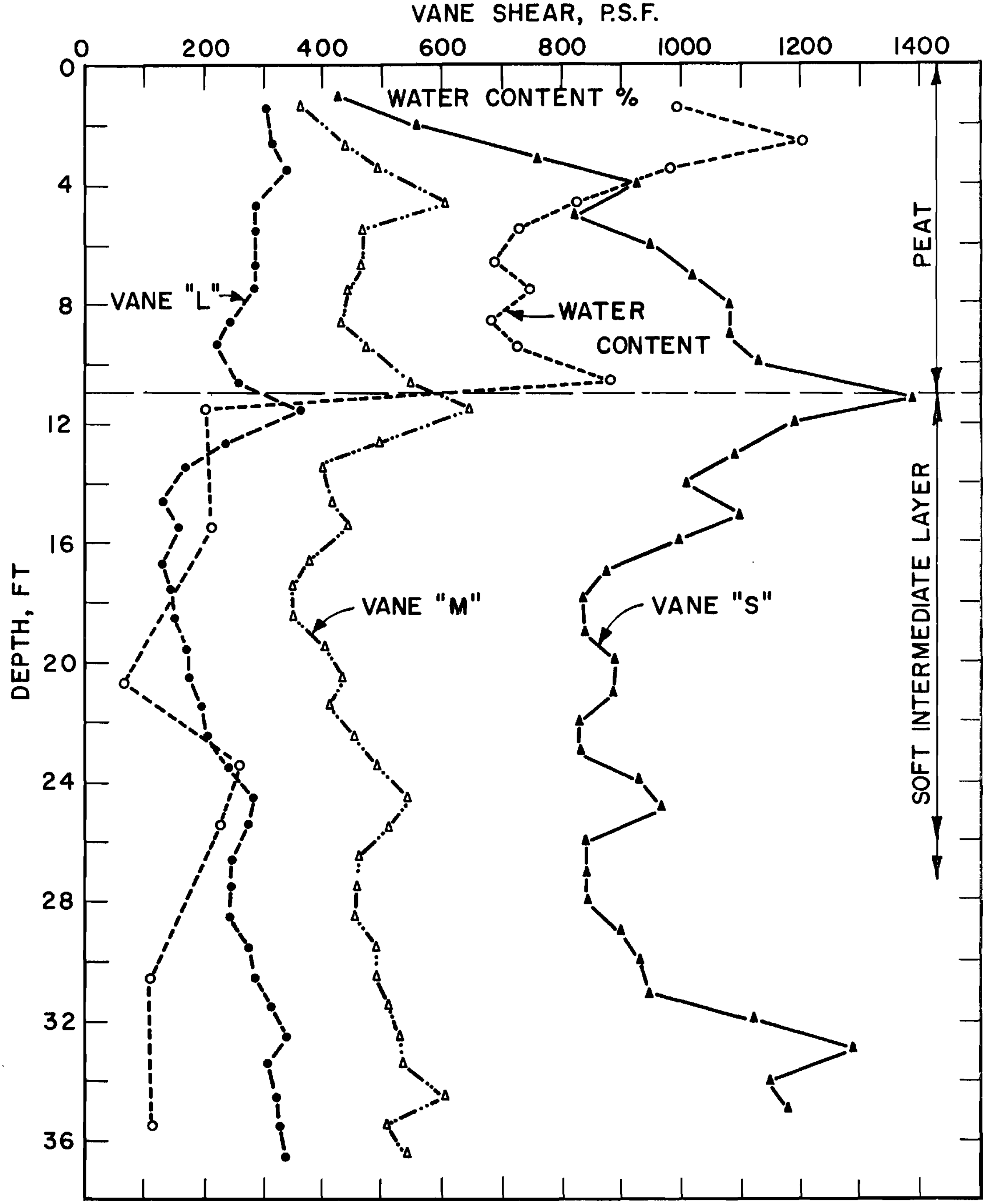

MANITOBA
ONTARIO
JAMES
BAY
ONTARIO
QUEBEC
17
KENORA
CNR
LAKE OF THE WOODS
71
CPR
17
CNR
LAKE
NIPIGON
11
LONGLAC
CNR
HEARST
11
KAPUSKASING
RAINY RIVER
11
FORT
FRANCES
CNR
11
NIPIGON
17
PORT
ARTHUR
11
COCHRANE
TIMMINS
KIRKLAND
LAKE
CNR
U.S.A.
FORT
WILLIAM
17
CPR
LAKE
SUPERIOR
SAULT STE.
MARIE
11
U.S.A.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

FIGURE I



VANE SHEAR & WATER CONTENT VS DEPTH

FIGURE 2

DISCUSSION

(For Session I)

Major Charles (C. N. R.) referred to the discussion in the proceedings of the Fifth Muskeg Conference (T. M. 61) regarding the drainage problem. Speaking from the railways' viewpoint, he asserted that muskeg definitely should be drained. The evidence from the Hudson Bay Railway - which has been in operation for 46 years - has shown that drainage should be carried out and the drainage system maintained. The cost of drainage is less than the cost of periodically repairing embankments where no drainage has been provided. He stated emphatically that without drainage the area will "go back to the jungle". He endorsed the idea of berms and believes that they are most important. Brigadier Connelly (Department of Northern Affairs and National Resources) asked Major Charles how far out from the railroad center line should the drainage system be constructed. Major Charles replied that this would depend upon the height of fill, but drains should be well out from the center line. If necessary, extra right-of-way should be cleared to provide for ditches. No formula exists, each case must be treated separately.

A question was posed regarding the recommended minimum distance to the ditches. Mr. Thurber thought that the ditches should be 40 to 50 feet from the center line of grade. He supported Major Charles' contention that the water table has to be controlled.

Session II: Classification and Exploration

II. 1. Panel discussion on Muskeg Classification -

(a) Dr. N. W. Radforth, McMaster University.

(b) D. G. Stoneman, Shell Oil Company Limited.

(c) W. C. Bridcut, Spartan Air Services.

(a) RADFORTH CLASSIFICATION SYSTEM

(Summary)

Dr. N. W. Radforth

Classification is essential to interpreting and solving problems in different types of muskeg. When one first looks at muskeg it appears completely disorganized. However, patterns can be seen on closer examination and if it can be organized then we can determine what we are dealing with and begin classification. Because of its biological origin, muskeg is quite complex. Owing to this complexity it was originally thought that perhaps no constant relationship existed between various factors of the terrain. However, extensive examination of the fossilized pollens and spores preserved in peat samples from various locations across Canada proved that certain qualitative relationships do exist and this furnished a basis for the development of a classification system. The complexity of organic terrain requires several subsidiary systems but used together they adequately classify the terrain. The Radforth System attempts to record a three-dimensional problem and is based on surface vegetation which occurs above the ground, topographic features which occur along the ground, and on composition and structure of the subsurface material which occurs in the ground. All of these features at least must be taken into account to obtain a reasonable evaluation of the terrain. Colour of the surface vegetation also is often a distinguishing factor of various muskeg types.

Surface vegetation is the first factor to be observed in a particular muskeg area and is also the easiest factor to assess. The surface coverage system utilizes nine pure classes of vegetation. These are described in the literature. The pure classes seldom exist by themselves but are in combination with other classes. Only about 25 such combinations occur very frequently in northern Canada. Terrain unevenness is important in the appraisal of organic terrain. Changes in topography are sometimes caused by irregularities in the mineral substrata but much of the unevenness of the surface is due to structural changes within the organic material itself. The topographic characteristics of muskeg areas are designated by lower case letters and are also to be found in the literature. Description of the subsurface material (peat) is also very important. Sixteen categories of peat have been established. The structure of the subsurface material can be related to the organization in the surface structure. In aerial interpretation of muskeg, therefore, it is possible to predict qualitatively the subsurface conditions through recognizing the surface coverage classes. It is now possible to refer to large muskeg areas from elevations up to 30,000 ft.

(b) SHELL MUSKEG CLASSIFICATION

D. G. Stoneman

The Shell muskeg classification was drawn up for the initial vehicle testing programme in the summer of 1957. From this testing programme it was hoped to learn how the various types of muskeg would withstand the repetitive traffic necessary to haul a drilling rig and supplies and how the vehicle would perform in these various types. With the realization that performance would vary with muskeg type, a search was made for a muskeg classification system to serve as a basis for the testing programme. Dr. Radforth's system was found to be the only classification available. It was decided that the Radforth system was more detailed than necessary for the purposes of this testing programme. As a result a classification was set up which would give the desired performance data within the limited time available for testing and which could be used by field personnel.

The Shell muskeg classification system is based upon the surface cover of the muskeg. In this system all muskegs are classified into four types, each of which has a predominant surface coverage feature that is readily identifiable in field reconnaissance. These predominant coverage features can also be recognized from aerial photographs after sufficient ground reconnaissance has been made to establish the ground to photo control. Although this method of classification does not take into consideration the depth of the muskeg, generally the depth will vary inversely as the magnitude of the surface cover, i. e. black spruce swamps are usually shallow, while floating or grassy bogs are deep. However, since the reverse is occasionally encountered, surface cover cannot be used as an absolute indication of muskeg depth.

Each type of muskeg was given a common name identifying the predominant feature, which would enable the field personnel to tie their identification to the system. A description of the Shell Muskeg Classification follows:-

Type I muskeg is recognized as a black spruce or tamarack swamp. The live timber varies from 5 to 15 feet high, is small in diameter and occurs in dense stands. The brush undergrowth is light and quite often non-existent. The surface mat of the muskeg is composed of a thick layer of moss interwoven with the boughs of fallen timber. Quite often the surface mat of the muskeg is uneven. In general, Type I muskeg is relatively shallow.

Type II muskeg is recognized as a willow bog. The live woody growth consists of a dense willow bush up to 10 feet high. The surface mat is usually a tightly interwoven thick grass cover. This type of muskeg is usually accompanied by considerable standing dead timber and deadfall loosely imbedded in the surface mat. Willow bog usually borders intermittent streams and in many cases covers large areas the length of the stream and several hundred yards wide. Type II generally is of medium depth, ranging from 3-6 feet deep.

Type III muskeg is recognized as brown moss and is the most commonly occurring muskeg type. The live timber consists of a scattered and stunted spruce growth, as well as a low shrub cover. The surface mat is a thick tough moss layer occurring in mounds and hummocks. The uncleared moss is a purple grey colour when wet, but when cleared and dry it takes on a readily recognized brown tone. Type III is also characterized by small diameter standing dead timber up to 15 feet high as well as considerable small diameter deadfall. Type III often occurs adjacent to Type II with overlapping of classifications at the boundary. Type III muskeg is found in large areas with no recognizable pattern of occurrence. The depth of brown moss is also inconsistent, varying from a few inches to many feet.

<u>Type IV</u> muskeg is recognized as a floating bog. This type is the most severe muskeg class and approaches a swamp condition. There is generally no timber or woody vegetation present. The surface cover consists of tall grass and moss occurring in clumps or mounds, with the water table at or near the surface. Type IV muskeg is usually found within Type III muskeg areas where it occurs as a pocket, a few hundred feet in diameter and several feet deep.

The Shell Muskeg Classification is summarized below:-

Type	Common Name	General Description
I	black spruce or tamarack swamp	timber (black spruce or tamarack) 5-15 feet high, little or no brush cover.
II	willow bog	dense willow bush up to 10 feet high, grassy, deadfall common.
III	brown moss	cleared muskeg brown in colour uncleared muskeg purple grey in colour, mossy mounds and hummocks, standing dead timber up to 15 feet high, deadfall small in diameter.
IV	floating bog	grassy, water table at or near surface, no woody vegetation or timber.

This classification system was adequate for the purposes of the testing programme. With a minimum of testing, data was obtained which has enabled a prediction, with reasonable accuracy, of vehicle performance for summer transportation operations in other muskeg areas.

The Shell Muskeg Classification is not intended to replace the Radforth Classification. For research and engineering studies, a more complete muskeg description is required than that provided by our classification. As muskeg interest expands, and as it becomes beneficial and necessary for individuals interested in muskeg to meet and discuss their problems, the need for a universal muskeg language becomes apparent. This need can better be filled by the Radforth Classification System.

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(c) METHODS OF INTERPRETATION, ANALYSIS AND PRESENTATION OF MUSKEG ACCESS

W. C. Bridcut

Aerial photo analysis of organic terrain and soil types can be applied directly to the problem of oil exploration and development access (1). For geophysical surveys and for travel to drilling sites, off-the-road access is frequently necessary. Interpretation of stream and river crossings, general topography, upland soil types and muskeg vegetal coverage types can assist in selection of the best route, provided the vehicle type and some idea of the period of year is known.

Prior studies made on a systematic basis can contribute considerably to the success of any operations conducted in the north. The chief contributions of these studies for exploration or development are (1) to present geographically the relative locations of surface obstacles in a given area, and (2) the degree of interference that these features may present to the carrying out of a particular programme.

Modern techniques of air photo interpretation and mapping from vertical aerial photographs are an important first approach to the study of these features that will either aid or act as obstacles to a given operation.

Muskeg or Organic Terrain as it Applies to an Area Interpretation

During an initial field reconnaissance, inspection and identification of muskegs and beaver meadows are carried out together with the upland landform classification. For area mapping (in comparison to route analysis where start and end points are known), as a first approximation the muskegs are classified on a drainage and structure basis.

The broad groupings used in area mapping are the shallow peat swamps, the deep peat swamps, and the bogs. These groups are numbered according to a relative drainage scale in sequence with the drainage scale for upland terrain. This drainage relationship holds true only in the wetter seasons. In other seasons (for example, late summer) the sedgy sloughs which are included in the bog category may dry up, whereas the shallow peat swamps, having three to six feet of peat, may retain a water-table in the peat. In the Spring, the bogs are flooded whereas the shallow or the deep peat swamps are not.

The main differences in the three types are the nature of the organic material as to depth and kind of peat, as follows:-

Shallow Peat Swamps:

Averaging three feet of peat; fibrous and woody peat having a high shear strength and good carrying capacity. The shallow peat swamps carry closed black-spruce forests with lesser vegetation of scattered dwarf shrubs and moss. After fire a dense tall shrub may develop or a mixture of tall and dwarf shrubs.

Deep Peat Swamps:

Averaging over six feet of peat; less woody and more fine-fibrous and amorphous peat having lower shear strength and less carrying capacity than the peat of the shallow swamps. The vegetation is short and open black spruce-larch, with dwarf shrub and moss or scattered tall shrub-lichen-moss and some sedge. Fire may alter the cover to chiefly dwarf shrub but the sedges remain more abundant than on the shallow peat swamps and hummocks of short shrub-lichen frequently stand out.

Bogs:

Variable in depth of peat - may be a floating fine-fibrous and amorphous mat of a mixture of organic matter and mineral soil. The main characteristic is flooding or complete saturation during wet seasons and drying-up in drought seasons. The vegetation types are short shrub-sedge, or moss-sedge; the floating variety may support hummocks of short shrub-lichen.

Various combinations of the three main types occur, in which case patterns are mapped; combinations of mineral soil types and any of the three muskeg types may also be present. In situations where a seepage water-table moves slowly through a swamp or bog the nature of the organic material, the fluctuations in the water table, and the vegetation cover, may alter from the above suggestions. The change in vegetation is a result of the peat being enriched by the telluric or seepage water. Dense, tall shrubs, for example, may dominate a deep peat swamp after fire whereas this vegetation type is more commonly found on the shallow muskegs.

The photo interpretation is based chiefly on the vegetation cover and to a lesser extent on the surface micro-topography. Therefore great care must be taken with the relationships between fire, history, vegetation type, and topography. Other features which are sometimes helpful are the shape of the overall muskeg, and the pattern of the vegetation types when the muskeg is complex.

Upland and Muskeg Classification Scales for Area Mapping

Local topographic symbols are diagrammatic and indicate the predominant pattern within each soil type.

Drainage is classified into categories based on the degree of internal and external drainage, combined. The categories are numbered from 1 to 9 (excessive to flooded) with No. 2 as the standard at the well drained position (a gently sloping site with good internal drainage). The No. 4 category (imperfect) is a glei type with an internal or perched seasonal (spring) water-table, usually due to a depression position, seepage, or impermeable internal strata. The No. 6 category is saturated to the surface of the mineral soil for much of the frost-free period; it may dry up in August and September of drought years and is common in sloughs and drainage ways, where peat is usually very shallow. Nos. 7, 8 and 9 categories are muskeg with deeper peat. Nos. 0, 3 and 5 are transitions used only in very detailed mapping. Where drainage is extremely variable and individual categories cannot be mapped out, patterns are indicated by combined symbols.

Texture is indicated by letter symbols for clay, silt and sand arranged in order of abundance in the case of mixtures such as sandy silts, etc.

For muskeg, the drainage symbol only is given, with the depth and type of the peat automatically included, as described above and in the accompanying Table.

There is a relationship between the broad classification described previously and the Radforth system of classification. It must be kept in mind that the broad types may have critical small areas of difficult organic terrain included. With present advancement in vehicle development for muskeg travel, however, the smaller areas of varied muskeg are not as critical as they once were.

Dr. Radforth has tabulated seven cover formulae most commonly encountered in planning for access over organic terrain (2). These seven more common cover formulae in groups of two, three and two are related to these broad area types as follows:

The general relationship between the Broad Area Type 7, i. e. shallow peat swamp are the Radforth Coverage formulae AH and AEH. The Broad Area type 8 or deep peat swamps may be related to coverage formulae D, DBE and EH. Also the Broad Area type 9 or bogs may be related to coverage formulae HE and FI.

The broad approach to muskeg classification is adequate for determining off-the-road access for tracked vehicled. However, following the analysis of the soil types and organic terrain for a whole area, main access roads may have to be planned. Should these roads pass through organic terrain, the analysis of muskeg portions in more detail is recommended, but probably no further than grouping it into the seven more commonly encountered coverage classes.

REFERENCES

1. Brown, W. G. E. and Boultbee, J. - "Oilfield Access Planning", The C. I. M. M. Bulletin, February 1959.

2. Radforth, N. W. - "Muskeg Access, With Special References to Problems of the Petroleum Industry, The C. I. M. M. Bulletin, July 1956.

SOIL TYPE LEGEND

Local Topography

Steep slopes (direction of arrow indicates moderate downgrade)

Gentle

Scarp

Hill or ridge

Gentle knoll

Gently undulating

Strongly undulating

Flat

Trough

Depression

Elevated flat

Depressed flat

Channels

Drainage & Accessibility

Mineral Terrain

1. Excessive drainage; good for all-weather roads.
2. Good drainage; good for all-weather roads.
4. Imperfect drainage; artificial drainage, except in dry season.
6. Poor drainage; normally saturated or submerged. Unsatisfactory for all-weather roads.

Organic Terrain Classification

7. Organic material up to 3 ft. deep.
8. Organic material up to (on the average) 10 ft. deep.
9. Flooded or floating.

BM Beaver meadow
OBM Old beaver meadow

Texture

G - Gravel

S - Sand (MS=medium FS=fine)

ST - Silt

C - Clay

P - Peat

Notes

(a) Sporadic occurrence $\frac{(ST)}{C}$=sporadic patches of silt over clay.

(b) Combined texture "ST. S. C." = combination of silt, sand and clay with last shown being most prevalent.

Notes on Drainage and Accessibility

Mineral Terrain

(a) A pattern is indicated "2-4", etc. The first is the most abundant.

(b) Sporadic occurrence of non-typical but significant drainage is indicated by brackets "4(-6), etc.

Organic Terrain Classification

(a) 7 and 8 muskeg when unimproved are usually only passable by tracked vehicles; 9 requires buoyant vehicle in wet spring months.

(b) Seepage water in muskeg is indicated by underlining "<u>7</u>", etc.

(c) Muskeg patterns are indicated "7-8", "7-9", etc.

DISCUSSION

Mr. Harwood (Defence Research Board) asked if all members of the panel agree with the three different approaches put forward. He said that he could see a common denominator in all. Dr. Radforth replied that perhaps everyone was disappointed that there was no basic disagreement in approach. He thought that Mr. Stoneman need not have been apologetic in his final remarks; the important thing about classification is that it must work and fulfil the need for which it was set up. If it does, then it is a good classification system. However, there is a need for some sort of reconciliation in the use of certain expressions, e. g. "black spruce swamp", "deep peat swamp", etc. There should be further questioning of such terms. The "black spruce" swamp in reality may be tamarack or larch. On the periphery of a muskeg area there may be very large spruce rather than the dwarfed structure common to the rest of the muskeg area. From mid-April until the middle of June, the worse condition is in the region of the tall spruce, due to ice knolling. This points up the need for a detailed survey prior to construction, access, etc. Dr. Radforth said that in the final analysis the three panel members are talking about the same thing.

Mr. Harwood agreed that it is a good thing to get out of the qualitative into quantitative terms. He expressed his appreciation for the NRC booklet on muskeg identification.

Mr. Keeling (Imperial Oil Limited) mentioned that he has not as yet experienced any muskeg types "G" or "C" in his operations. This leaves only seven pure classes to be concerned about. In trying to find an operational method of approach to classification, they have been using their seismic surveyors in noting the classification of muskeg areas encountered. They have had but one hour's instruction from the muskeg booklet and the results have been excellent. He said that there is no need to be frightened by the Radforth Classification System. However, he wondered about the accuracy of classification of the lower peat layers by untrained field personnel. Dr. Radforth pointed out that Mr. Keeling's remarks served to emphasize the need and importance of the initial survey.

Mr. Harwood concluded by remarking that few people fully appreciate the value to Canadians of the extensive aerial photographic coverage of Canada.

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II. 2. OPERATING IN MUSKEG AND PERMAFROST IN THE EAGLE PLAINS AREA OF THE YUKON TERRITORY

W. G. Campbell

During the last eight years exploration programmes for oil and gas have been undertaken by Western Minerals Ltd. and their associates in the Conwest Exploration group in the Northern Yukon and Northwest Territories. Most detail work has been concentrated in what is known as the Eagle Plains Area, straddling the Arctic Circle between 66° and 67° north latitude. This section of the Yukon is bounded on the east, west and south sides by mountain ranges. A minor range of mountains permitting easy access to the Northern Arctic coast forms the north boundary.

The area is a natural basin of sedimentary rocks, exhibiting neither glacial deposition or erosion. The topography exhibits gently rolling hills of 300 to 500 feet relief, generally covered with a growth of stunted spruce and birch trees and interlaced with meandering streams and rivers of various sizes. Temperatures range from 70°-80° F during the summer months to 60°-70°below zero during the winter months.

In addition to the three coverage found on the Eagle Plains, there exists an almost 100% coverage of moss, varying from a few inches to several feet in thickness. In the low areas, such as along valleys and drainage systems, it tends to develop a greater thickness than upon the hill tops and ridges. It is straw coloured, heavily interlaced, disintegrates readily when handled, and has little or no ability to support weight. It provides a very much needed layer of insulation which protects the subsurface from the heat of the summer sun.

Beneath the moss are various thicknesses of permanently frozen silty soils and ice lenses which, but for the presence of the moss, would become a sea of watery silt and mud during the summer months. As long as the moss coverage remains undisturbed, no more than an average of 18" to 2 feet of the surfaces loses its frost during these months.

The moss in the Eagle Plains area can be described as muskeg type "BI" and of Contour types "a", "b" and "c". That is, woody, 5 feet to 15 feet high, consisting of young or dwarfed tree or bush (in this case, spruce and birch trees), as well as non-woody up to 12"-18" of soft velvety mosses.

There is very little peat development beneath the muskeg; only in the flats of the larger rivers and in the broad valleys near them does deeper vegetation appear to develop. In these local areas adjacent to the rivers, permafrost would seem to be absent, presumably due to the warming effect of flowing water winter and summer. Vegetation, for this reason, appears to thrive at greater depths.

The presence has been mentioned of frozen soil and lenses of ice occurring beneath the moss, frozen the year round, and this is permafrost. Permafrost is that part of the subsurface which is at all times below the temperature of $32^{o}F$. The Eagle Plains area is almost completely underlain by it. Investigations have indicated that permafrost may exist to as great a depth as 1500 feet and may not exist at all beneath rivers and deep lakes. Tests indicate that the actual temperature of the permafrost may be little more than three or four degrees below freezing, which is very significant.

Permanent road building and air strip construction is very difficult and very expensive to undertake in the area under discussion. During the winter season, construction of roads and air strips is accomplished in a method similar to that being used in Northern Alberta and British Columbia. However, with the approach of summer, roads and air strips built during the winter become unusable.

Consideration has been given to building permanent or all-year-round roads and air strips but very little, if any, gravel exists and no other "fill" material is readily available. Attempts have been made to build roads by bulldozing moss from the sides of the right-of-way up on to the top of the undisturbed moss in the center of the right-of-way. Some success was achieved using this technique and tracked vehicles were able to travel successfully over them. However, it is unlikely that such roads would stand up with continued use.

This also applies to air strip construction and the economics of building one for larger aircraft is simply not reasonable. This is especially true where operations are still in the exploration stage; it would be unwise to build a permanent air strip at great expense only to find later that the main activity is to be some miles away.

Recently, studies have been made of the possibility of building small air strips suitable for large-tire Piper Super Cub aircraft. A strip of only 700 feet by 30 feet is required and by using heavy mesh wire fencing or corduroy as a base, a suitable strip may be built. Due to the lack of large lakes in the Eagle Plains area, it was necessary to shuttle 35 miles or more between a lake and the base of operations by helicopter. This was very expensive. The shuttle service provided by Super Cubs would result in considerable savings.

Rather than expend great sums of money in building permanent roads or air strips at this particular stage of an oil and gas exploration programme and, if time is not too much a factor, it is better to restrict movement of major tonnages and supplies to the winter seasons, late fall or early spring, when frost is in the ground and ground transportation can be used. It has been found to be feasible and relatively cheaper to freight all heavy tonnage by tractor train during the winter months. The extreme cold weather does not materially affect the type of equipment used and the ground is solid enough and the rivers frozen over sufficiently that heavy tonnages can be handled on sleighs without too much trouble. In addition to being the most efficient method of transportation, it is the surer way of getting supplies over long distances and over difficult country.

The absence of road building materials and the swampy nature of the terrain in the Eagle Plains area make any overland movement of freight practically impossible except in the winter. However the development of low ground bearing vehicles built primarily for use during the warmer months has been watched with interest. This year experiments are being carried out with one of the larger tracked vehicles designed for movement of heavier tonnage over soft muskegs. Such vehicles are superior to straight wheeled vehicles no matter how big the wheel or soft the air pressure contained. However, low ground pressure tracked vehicles have comparatively low load factors and this, as well as other factors, makes it inadvisable to attempt to move large tonnages greater distances than 20 to 25 miles. Winter transportation is still the best method of moving large tonnages over long distances.

During the years 1955 and 1956 two broad areas of seismic reconnaissance and one detailed project were completed. Equipment used was a mixture of sleighs, bombardiers, tractor vehicles and large-tire North King trailers. During the spring and early summer, fair mobility was sustained. However, once the frost was gone from the surface, the operation became very unwieldy. None of the equipment had particularly low ground bearing pressure characteristics but the bombardiers fared better than the others.

Experience then and since has shown that during the summer months wheeled vehicles are of no particular use in traversing wet, slippery, moss-covered "tussocks". Something which provides traction and spreads the load over large areas is required. To maintain a high degree of mobility for all phases of seismic operation, it is probably advisable to mount all equipment on tracks, including the camp; but certainly the personnel carriers, instrument vehicles, surveyors, drills, water trucks and blasting crew vehicles. This adaptation of tracks to all equipment was successfully used in Alaska during the last two summer seasons.

The ideal season for seismic is during the months of March, April and May, when the frost is still in the ground and the days are longer, with the severe cold season behind, but if tracked vehicles of suitable design and strength are used, the season of seismic operations can be increased to as much as 10 months of the year in some parts of the Yukon.

In brief, seismic operations can be efficiently operated for 6 to 10 months of the year provided suitable tracked equipment is used. The costs will be greater than in the more accessible areas because of the increased transportation costs of supplying the operation, but the operating expenses themselves should not show an increase because of operating difficulties alone.

The effect of permafrost and muskeg on the deep drilling operations is interesting. In the drilling of Eagle Plains No. 1, there was considerable "guesstimating". Information was available from the drilling operations undertaken by the American Navy on the Naval Reserve near Point Barrow in Alaska. Data are also available from Imperial Oil in relation to its drilling experiences near Norman Wells. However, no experience of any account was available for the immediate area of the Eagle Plains. It was known that permafrost was present but the extent was unknown. The first hole was drilled with such a degree of operational success, however, that the same basic programme was used on the second hole.

Five or six major factors should be pointed out which are important to consider in planning to drill in country where permafrost exists:-

1. Disturb as little of the moss covering as possible where the rig is to be located.

2. The rig and all auxiliary equipment should be placed on piles.

3. Drill as much of the surface hole as possible, if not all of it, with air.

4. Use a liberal amount of conductor pipe.

5. Set the surface casing below the permafrost.

6. Make use of the readily available moss for insulation purposes.

Disturbing the moss and the results of doing so have already been discussed. Pilings are essential. It is impossible to keep from disturbing the moss when rigging up a drilling unit and when the summer sun warms the surface it will quickly erode away beneath the rig, around the rig, and anywhere where insulation has not been provided. With the use of insulation and of piles, there is almost complete insurance that the rig will always remain standing firm. The procedure has been adopted of using timber pilings in the ground for the main rig foundation. A wooden plank platform is built over the piles; under it a good supply of moss is located for additional insulation.

Piling holes are easily drilled using air and a seismic drill, usually being 20 feet deep. After the piles are placed in the hole, drilling mud or water is added and they become frozen in permanently. The substructure, motors, tool house, and boilers, should all be placed on piles.

It has been found that by drilling the conductor pipe hole and surface hole with air much of the risk has been eliminated of creating caverns and cavings within the soil and ice lenses which could result from the use of drilling mud.

Because it was possible to bottom the conductor pipe hole of both wells in solid rock, they could be cemented in the hole using the normal cementing methods. This was due in part to the temperature of the rock in the permafrost zone being only a few degrees below freezing. By drilling the last few feet in the rock with drilling mud, the permafrost was driven back from the bore hole and the cement was pumped around the conductor pipe and was set before the permafrost moved back into the bore hole. It has been apparent that once permafrost has been driven out of a zone, it takes considerable time for it to return. This has been borne out by the fact that only two to three feet of ice was found on top of the drilling mud in the first well after work had been suspended over the winter months.

However, the practice is still followed of setting surface casing well below the indicated permafrost where it is much more certain that a good bond between the cement, pipe and rock will occur.

As far as drilling is concerned - or for that matter any operation requiring a good base - the use of moss as an insulator has proven itself time and time again. There is an unlimited supply of this material in the country. It is therefore no problem to harvest huge volumes and cover everything which is to remain stationary over the summer months.

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II. 3 GUIDES FOR THE INTERPRETATION OF MUSKEG AND PERMAFROST CONDITIONS FROM AERIAL PHOTOGRAPHS

J. D. Mollard

Private industry and government agencies, both currently spending large sums of money on northern exploration and development, must take a hard look at any tool that can aid in outlining varying amounts and conditions of organic terrain and permafrost. This tool is airphoto interpretation, which is doubly important in the north where few, if any, usable terrain maps have been published.

It is true that the photo interpreter has an important responsibility to his employer. The interpreter should ensure that the better -- i. e., the more economic and more feasible -- transportation routes and construction sites are selected. To do this he must delimit boundaries of landforms having significantly different construction qualities. The photo interpreter must continually make comparisons and weigh alternatives. He should always list the reasons for the choices he has made. Certainly he must offer acceptable answers to questions asked by his employers. For they have every right to demand: "Why is the chosen route located where it is?" and: "Does the route avoid all the troublesome ground it is feasible to avoid -- project objectives duly considered?"

To cope with his task the airphoto interpreter should be able to identify, classify and delineate muskeg and permafrost conditions with competence and assurance. He should also be able to identify, classify and delineate landforms and assess surface and near-surface characteristics affecting northern construction.

To carry out these functions at the highest level the interpreter seldom relies solely on his own experience. Wisely he will consider the pertinent literature dealing with permafrost mode of occurrence and with the environmental factors controlling permafrost distribution and problems. Similarly he will consult the growing volume of accumulated data on muskeg -- more correctly termed "organic terrain". The literature contains much useful information that guides and disciplines the airphoto interpreter's thinking and thus the inferences he draws during his study of aerial photographs.

In large part this paper summarizes data and interrelationships that the photo interpreter uses when assessing terrain conditions in areas containing muskeg and permafrost.

Naturally in a paper of this kind it is not possible to show more than a few airphotos depicting muskeg and permafrost features. Therefore, if the reader is interested in obtaining a selected group of photos showing a variety of muskeg and permafrost patterns, he should write to the author, who will provide a list of photos which in turn may be ordered from respective airphoto libraries.

Literature Sources

Many mistakes in the airphoto interpretation of northern terrain could be avoided and more useful data could be obtained if the observer were familiar with the literature on permafrost and organic terrain. Specifically the interpreter should cull the literature dealing with case histories, with diagnostic environmental relationships, and the photo-identifying features of organic terrain and permafrost conditions. In particular he should be familiar with the relationships that muskeg and permafrost occurrence and character bear to different surficial deposits, to topographic position, and to drainage and vegetative cover. Because the interpreter must first compare alternatives and then make a selection, he must have a basic understanding of engineering and construction techniques followed in handling problems associated with permafrost and muskeg. Where is he likely to find this assistance in the literature?

One of the better sources of material is the Division of Building Research, National Research Council, Ottawa.

In addition, the interpreter should obtain relevant works published by the Arctic Construction and Frost Effects Laboratory of the U.S. Army Corps of Engineers, Boston. Two noteworthy publications (24) are Volumes I and II titled "Evaluation of Soils and Permafrost by Means of Aerial Photographs".

Reports and papers issued by the Snow, Ice and Permafrost Research Establishment, Wilmette, Illinois, often provide valuable assistance to the photo interpreter.

In 1954 Robert F. Black (1) reviewed the permafrost literature. This review provides a concise reference to the more important published works up to that time.

Too numerous to list separately are the many good articles and case histories published almost monthly in magazines that report on construction and engineering activities in Canada.

The Photo Interpreter and Photo Interpretation

The interpreter must be able to recognize a variety of airphoto patterns that reveal different classes of organic terrain and different permafrost conditions. Equally as important is his ability to recognize different surficial deposits in aerial photos. If landforms possessing varying construction qualities cannot be reliably recognized and delimited, the role played by photo interpretation is greatly diminished.

Individual project objectives vary considerably. Consequently there must be close coordination between the photo interpreter and the project supervisor or superintendent -- whether the latter be in the oil industry or a supervising engineer in a highway department.

In a given locality and at a particular season of the year open moss-covered muskeg may afford optimum conditions for traversing by the Nodwell Transporter (or by a similar machine). Here locality and seasonal aspects are important. They must be considered because trafficability across muskeg and permafrost areas is greatly affected by both. While moss-covered muskeg favors use of the Nodwell Transporter, other classes of organic terrain -- e.g., tall dense trees with a shallow peaty layer -- offer decidedly superior potentialities as permanent roadbeds. In short, objectives and type of organic terrain desired or to be avoided are closely related.

The quality of photo interpretation and the usefulness of the results often vary over a wide range. To a large extent the quality and value of terrain analysis is a matter of judgment based on experience.

A working knowledge of environmental factors that control the formation and determine the occurrence of muskeg and permafrost is essential. Ordinarily the observer is concerned with "total" environment and so he must be familiar with climatic, geologic, topographic, and drainage settings that regulate the formation of organic deposits and permafrost conditions.

In Canada it is generally true that as one travels southward in regions affected by permafrost (e. g. , from continuous to sporadic permafrost areas) the effects of frost action become less apparent in aerial photographs. In the sporadic permafrost belt, for example, the interpreter depends largely on clues furnished by known and suspected relationships.

Airphotos showing relics of permafrost patterns in regions that at one time contained permafrost can lead to erroneous interpretations. The interpreter should therefore be cautious in these regions and should consider the effect of present-day climate.

Photo interpretation of course must always be closely integrated with field work. Whenever an airphoto study is carried out in the office it must be appropriately field checked. Where the two are properly integrated, they cut field survey and construction costs and reduce time very substantially.

In a comprehensive airphoto study (12) of a region containing both muskeg and permafrost the landscape was divided into eight photo-identifiable classes based on estimated highway construction costs. These estimated costs ranged from \$10,000 to \$80,000 a mile. Until the landscape units were outlined on airphotos and until estimated costs per mile on the several alternate routes were aggregated and compared, the location engineer had little concrete evidence that the best line had been chosen for ground study. Even before the comparative cost-estimating study was made there was the task of selecting a logical number of better possible routes.

<u>Useful Background for Studying Organic Terrain in Airphotos</u>

Following are background data intended to assist the beginning interpreter:-

1. When studying organic terrain in aerial photographs four factors should be interpreted:

(a) Origin and probable depth of the original depression, now partially or wholly infilled with organic deposits.

(b) Origin and nature of adjacent surficial materials and topography.

(c) Hydrologic history of the depression containing organic material as well as hydrology of the surrounding area.

(d) Vegetative cover -- especially its stature and density (see Radforth's cover formulae).

2. In temperate and subarctic climates hydrophytic plants may "colonize" ponds occupying undrained depressions -- for example, deep kettleholes in glacial outwash. Following in succession, the peat-forming plants grow progressively inward from the perimeter of ponds. In time the entire pond may be filled with dead plant remains. Finally the bog might be invaded by trees and, to one degree or another, transformed into a forested depression. Such forested depressions can be very deceptive to the unwary location engineer.

In the subarctic and throughout the boreal forest for that matter, bogs of regional extent may actually engulf forests and replace them by succession -- first by forest mosses, then Sphagnum. Forest floor mosses spread until ensuing wet conditions kill the forest and shallow bogs are formed (2).

In perennially frozen regions where a break develops in the moss carpet (by fire, animal trails, frost cracking, or the action of running water or man), thawing of near-surface ground ice may be initiated. Eventually thermokarsts ("thaw lakes") are formed and a sequence of progressive organic accumulation may follow.

In Newfoundland the author (9) has observed and mapped "raised" bogs. Here many Sphagnum bogs have low dome shapes. The surface of these convex forms contain one or more small ponds clustered near the center of the bog. Indeed the bog surface may actually build up to the point where it will finally burst. Water for the living mat is supplied by rainfall, the capillary action of the underlying peat and dew condensate. These intriguing organic features are easily recognized in airphotos (9).

3. Bogs occurring on level to gently sloping surfaces are underlain by materials or conditions that impede subsurface drainage. Frequently the position of the water table can be inferred from aerial photos. Seemingly the original free-water surface controls the bog surface in many cases. Indeed, topographic and related drainage considerations seen in the photos provide useful indicators of probable depth of organic material. That is to say, deeper organic materials are usually found in deeper original hollows in the mineral terrain.

4. In temperate and subarctic areas containing considerable organic terrain, the taller and denser stands of forest commonly offer better prospects for permanent highway systems than do areas of stunted or dwarfed sparse vegetation. Also dwarfed vegetation areas normally offer better prospects for a permanent roadbed than does open muskeg. According to Radforth (23) a cover class of AEH might be expected to offer the highest bearing strength while FI represents the lowest. For road-building purposes, AH, AHE and AE cover classes (8) are generally associated with better terrain and HE, EH and EI are associated with poor terrain. Incidentally these celebrated formulae for vegetal cover were set up for use in aerial interpretation (5).

In the arctic forest-tundra belt, trees are regularly confined to sheltered depressions and drainageways. In these low tracts the peaty layer is actually much thicker than on the surrounding treeless, windswept and relatively dry tundra upland. Because of adverse topographic and drainage conditions in this vegetative fringe area, these depressions, even though treed, are poor places for roadways, runways, and building sites.

5. Radforth has found that the peat in organic terrain is usually the fossil remains of the same type of vegetative cover that now inhabits the present surface (5). Stated another way, present-day vegetal-cover classes show a direct relationship with the underlying dead organic remains. According to Hughes (6) this correspondence is valuable in road-location studies because one can select the "better" muskegs to cross when planning to float a road. Stoeckeler (private communication), however, states that the present vegetative cover shows a relation to the dead layer only where the peat is 5 or less feet thick. The relation indicated above, he says, is not necessarily true for deeper peat deposits.

6. Thick stands of pine and aspen poplar also suggest well-drained subsoils that quite commonly are granular in texture.

7. In the heavily forested belt of northern Canada the photo interpreter often observes the peculiar effects of downslope movement of subsurface fluid in deep open muskeg deposits. Apparently this movement produces a frictional drag on the stronger overlying organic mat causing it to tear apart in a series of subparallel strips. In these situations the narrow moss-covered bog ridges -- often with some brush or trees -- seem always to be elongated at right angles to the direction of local land slope. The ridges are separated by swales covered with sedgy or grassy vegetation, or with standing water. This pattern can be seen on numerous muskegs in northern British Columbia, Alberta, Saskatchewan, and east of Lake Winnipeg in Manitoba. These patterns are associated with the central part of fairly deep elongate muskegs. In construction work these areas should be avoided wherever possible.

Where bog ridges are very widely and non-uniformly separated and are irregular in trend, the land slope is almost always flat. In such instances the "strings" in the pattern may be caused or accentuated by wind and wave action.

8. In extensive bog and swamp flats, small over and tear-shaped elongate "islands" covered with trees and brush frequently appear oriented in the direction of surface drainage flow. The long axes of these islands are parallel to the direction of local slope. In these areas it is believed that periodic flow of flood water is responsible for the streamlined patterns seen in airphotos. This pattern is sometimes very well expressed in areas of present-day extensive alluvial-fan accumulation.

9. From airphotos it is usually possible to give indications of variability in the depth of organic terrain (9, 11, 16). In some instances depths of muskeg may be reliably predicted. Moreover, several types of organic terrain may be identified from the air (9, 11, 15, 17).

Useful Background for Studying Permafrost Areas in Airphotos

In permafrost regions photo interpretation is used in predicting and avoiding areas containing interstitial ice, segregated ice lenses and ice wedges, and frost-susceptible soil conditions. Airphoto study by experienced personnel aids materially in understanding the regional and local physiographic setting. As a result, methods for handling unavoidable permafrost problems (13, 18) may be indicated at once.

Landform and associated engineering materials and problems are evaluated in the light of past and present climate, geology, vegetal cover, topographic form and position, and drainage -- that is to say, "total" environment. Usually permafrost conditions in the subarctic are inferred from environmental circumstances. Hence the beginning interpreter must be familiar with customary relationships occurring between permafrost and its surroundings.

Background information useful to the photo interpreter is listed below. To make really effective use of this information the interpreter should be able to competently identify landforms and vegetal-cover types in aerial photographs.

1. General

Three variables that determine the character of permafrost are grain-size distribution of soil materials, availability of water and rate of freezing.

As pointed out by Pihlainen (personal communication) permafrost, first of all, is a condition of material and not a material itself. Ice may fill interstices in soil deposits and so bond particles into a rock-like mass. Or, as is often the case, the ice may occur as segregated lenses and wedges.

Secondly, permafrost is highly sensitive to environmental changes. Difficult engineering problems, for example, result from upsetting the thermal regime -- e. g., by removing the vegetal cover or by making open cuts in frozen fine-textured soil deposits (7, 14, 18).

Thirdly, permafrost is impervious and this property affects surface runoff and thus the evolution of landforms, particularly in the Arctic.

Landscapes composed of organic and inorganic silty materials are especially susceptible to frost-action phenomena. In silt strata, probably owing to very slow freezing, pockets of clear ice up to 10 or more feet may form. Therefore, in selecting construction routes and sites, the photo interpreter looks for granular deposits and topographic settings that give rise to well-drained subsoils. Permafrost below 15 feet in sand and gravel strata seems to be inconsequential in engineering investigations. Essentially level landscapes that require very little grading and disturbance during construction operations are also preferred.

Theoretically in fine-grained mineral and organic soils where the active layer seasonally joins the permafrost table, the greatest depths of seasonal freezing and thawing follow approximately the 0°C mean annual isotherm. This is a useful consideration even though in practice one observes local exceptions.

Obviously, aggradation of ice lenses above the permafrost table produces heaving while degradation (melting) produces irregular settlements.

2. Geologic Landforms

Landforms composed of fine-grained organic and inorganic waterlaid and icelaid materials are especially susceptible to frost action and to the development of segregated ice lenses in the active layer (4). Examples of landforms especially noted for their association with adverse permafrost conditions are lower coastal plains, extensive delta plains, former lakebeds, former alluvial flood plains, the less steep lower slopes on colluvial deposits and alluvial fans and landforms composed of silty and clayey glacial till. One should also add any poorly drained depressional area found in coarse-textured landforms. Noteworthy examples are back-swamp and slackwater areas on granular terraces, kettleholes in granular morainic areas, and fossil channels in glacial outwash deposits. In these instances a relatively deep overburden of organic fine-textured soils commonly overlies the granular substratum. Also the water-table is usually near ground surface.

On the other hand, elevated well-drained landforms composed of granular materials are either unfrozen or dry frozen near ground surface. Examples of this group of landforms are the upper slopes and crests of sand dunes, eskers and kames, the outer (riverward) portions of granular terraces, and the more elevated portions of outwash plains.

3. Topography and Drainage

In parts of the arctic islands and along the adjoining mainland in the continuous permafrost belt, surface runoff and mass-wasting processes have resulted in smoothly rounded topographic forms. Hillsides are mantled with unconsolidated fine to coarse clastic debris.

Topographic settings that favour permafrost occurrence are poorly drained depressions, flat areas, and low-gradient slopes (3).

Slope exposure is important in determining the presence or absence of segregated ice in the active layer.

Adjoining principal watercourses and along active flood plains subject to periodic inundation, deposits are usually unfrozen near ground surface owing to the thawing action of moving water.

A beaded, or buttonhole, type of drainage pattern is often seen in permafrost regions (19, 24). This development, however, occurs most frequently in tundra areas.

4. Erosion Characteristics

In the continuous permafrost zone an impervious sheet of frozen ground prevents percolation of water and promotes surface runoff. In the arctic islands, slopes underlain by all but the most durable rock types tend in time to be smooth and rounded owing to long-continued downslope migration of fine to coarse rock waste. This surficial material ultimately enters drainage systems and, as a result, stream-beds are choked with debris. Braided and anastomotic drainage patterns develop.

Solifluction is a conspicuous mass-wasting process in the arctic and its effects can usually be observed in airphotos. Its various manifestations depend on slope, thickness of the affected layer, and the volume and distribution of ice in the affected layer. Solifluction activity is rarely seen in temperate climates (except for alpine regions) because slopes in these areas are usually well drained above the capillary fringe.

Gully cross-sections, often used as indicators of soil texture and soil permeability in temperate regions, must be used with considerable caution in areas where permafrost is prevalent. Many gullies in the arctic and subarctic tend to have V or U shapes regardless of the grain size of material into which these gullies have been cut.

In ice-wedge polygon areas, caving of frozen cutbanks around lakes and along streams frequently gives these banks a serrated appearance in aerial views.

5. Vegetative Cover

Thick peaty surface layers act as insulators and aid in the development and preservation of permafrost conditions. Where the natural insulation is the thickest, the permafrost table is ordinarily nearest ground surface.

Of course, any reference to vegetation as an indicator of subsurface conditions should specify a fairly small area over which the macroclimate is similar. In local areas, such as portions of a watershed, vegetation can be used as an indicator when considered in relation to "total" environment. But it must be stressed that vegetation is dynamic and vegetation-permafrost relationships are subject to continual change.

While vegetation alone should not be used as an indicator of permafrost conditions, still a few observations concerning vegetative cover-permafrost relationships are worth noting. They are especially valuable when carrying out field investigations.

Sager (19) says willow and aspen indicate the absence of permafrost to a depth of 10 feet or more; balsam poplar to a depth of at least 6 feet; paper birch to a depth of 3 to 8 feet; and black spruce and tamarack to a depth of 2 feet. White spruce, as a rule, will indicate 1 foot of unfrozen soil for every 10 feet of tree height. Some types of muskeg and tundra vegetation are good indicators of permafrost as close to the surface as 12 to 18 inches.

Stoeckeler (21, tables 2 to 7) observed the following relationship along one major river valley in the subarctic: white spruce and paper birch forests occur on both frozen and unfrozen soils; black spruce-tamarack stands grow on frozen muskegs; and aspen poplar occurs on dry unfrozen south-facing slopes; balsam poplar stands are confined to sites adjacent to active streams having moist sandy soils to a depth of at least 10 feet or more; and pure alder brush occurs in wet peaty soils frozen at a depth of 30 inches.

Pihlainen, reporting (14) on permafrost studies in the Upper MacKenzie Valley region of the Northwest Territories, claims that aspen poplar will not grow on frozen ground; pines indicate reasonably well-drained soils and a low permafrost table; willows indicate a very low permafrost table and the likelihood of underground water; balsam poplar and birch indicate a low permafrost table and well-drained subsoils; while moss, tundra vegetation and stunted spruce suggest poorly drained subsoils and a high permafrost table.

Airphoto Identifiable Features Commonly Associated with Permafrost Conditions

A whole series of downslope flow markings and terracettes are developed along the sides and lower slopes of hills in the arctic. Depending on their form and soil-instability processes that shaped them, these microforms are called soil terraces and soil lobes, lobate terraces, and tundra mudflows by Sigafoos and Hopkins (20). Other workers (4, 19, 22, 24) use the terms flow markings, earth-flow markings, earth runs, stepped and striped ground to describe a variety of frost-induced microforms.

The airphoto observer can also often detect a range of diagnostic mound forms having varying sizes, varying shapes and varying origin and occurrence. Among these forms are so-called earth hummocks, mud boils, humpies, peat mounds, frost mounds and pingos (4, 19, 24).

Also a series of distinctive hydrographic features, observable in good quality photos, are prevalent in regions containing permafrost. Depending on local circumstances one frequently observes braided, anastomotic, horsetail, subparallel, and rectangular drainage patterns. Asymmetric valleys, "dry" valleys, and beaded drainage are other aspects of permafrost conditions seen in airphotos (4, 11, 12, 24). But it must be pointed out that experience is necessary when interpreting the significance of these hydrographic features because they also occur in non-permafrost areas as well.

Airphotos showing lower coastal plain arctic regions reveal circular, oblong and elliptical lakes. Thaw lakes, "cave-in" lakes, tetragonal lakes, "sinks", and thermokarst lakes are names given to water-filled basins resulting from the thawing of subsurface ice. In ice-wedge polygon areas, serrated shorelines are commonplace on thermokarst lakes. In airphotos showing the subarctic, "leaning" trees and the local slumping of cliffs may commonly be seen around the edges of these small lakes.

Other features observed in aerial photos warn of potential permafrost conditions. They are raised-center ice-wedge polygons (also called channel-type polygons) and depressed-center polygons. These celebrated features vary from 20 to 200 feet across (24).

Tilted trees -- the "drunken" forest -- may be seen in places where a break has been formed in the vegetative cover. Tilted sand terraces may also suggest the presence of permafrost (19).

For more complete discussions on the origin of these features the reader is referred to several well-known works (1, 3, 4, 19, 20, 24). Considerably more research is required to establish the origin and occurrence of some of the features listed above. Suffice it to say that in northern areas they are commonly associated with frost-action phenomena and, where they can be reliably identified in aerial photographs, they serve to warn of potential permafrost conditions.

Conclusion

Before effective use can be made of aerial photos in areas containing muskeg and permafrost the observer must be able to do a competent job of identifying landforms found in non-permafrost regions. He must also appreciate the factors that affect the formation and occurrence of organic terrain and permafrost conditions. Moreover he should be familiar with their engineering significance.

In general the two principal functions of the photo interpreter studying areas containing muskeg and permafrost in northern areas are to (a) avoid adverse ground conditions where better conditions exist in the vicinity; and (b) delineate granular borrow deposits for use in foundations and for use as aggregate material.

The analysis of terrain from airphotos is particularly important in northern regions because there exist no sufficiently detailed terrain maps to allow intelligent route or site selection. Photos are nearly always the only means available for assessing the merits of alternative routes and for planning the collection of field data for design and construction purposes.

Despite progress in predicting ground conditions from aerial photos in areas containing muskeg and permafrost, much research remains to be done. Especially needed is a widely accepted nomenclature for various types of patterned ground and terms relating to permafrost conditions.

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Fig. I. This airphoto shows the progressive "colonizing" of kettle-holes, first by bog plants and finally by trees. Kettleholes 1 to 9 demonstrate a successional sequence from open water to a forested depression. The interpreter should be able to recognize other landscape features recorded in this photo.

Letter A shows a high bedrock slope; B, incipient sink holes indicating the rock type here is limestone. G, points to bedrock slopes that have been oversteepened by glacier-ice erosion. Letter D shows the location of faint current scars, indicative of gravelly subsoils while E shows the regular dotted pattern of an orchard. F is a gravel pit, located in a kame; K, a kettlehole. In stereovision, the area around I shows hilly topography, F. K, and I are located along the outer margin of a valley-loop end moraine. A hypothetical road location following the route B-3-C would intercept rock at G, cross highly compressible peat and muck deposits at 3, and overlie gravelly well-drained subsoils at C (between 8 and 9).

-- Photo courtesy U.S. Conservation Service

Fig. 2. Airphoto showing the wavy bog-and-tree covered ridges on a so-called "string" bog. The elongate ridges seen here are much more widely spaced and much more irregular in form than those found on classic areas of string bogs east of Lake Winnipeg and south of Lac La Ronge, Saskatchewan. East of Lake Winnipeg the pattern of bog ridges and bog hollows is usually confined to the deeper central portion of elongate organic-filled channels.

-- Photo courtesy Alberta Dept. of Lands and Forests

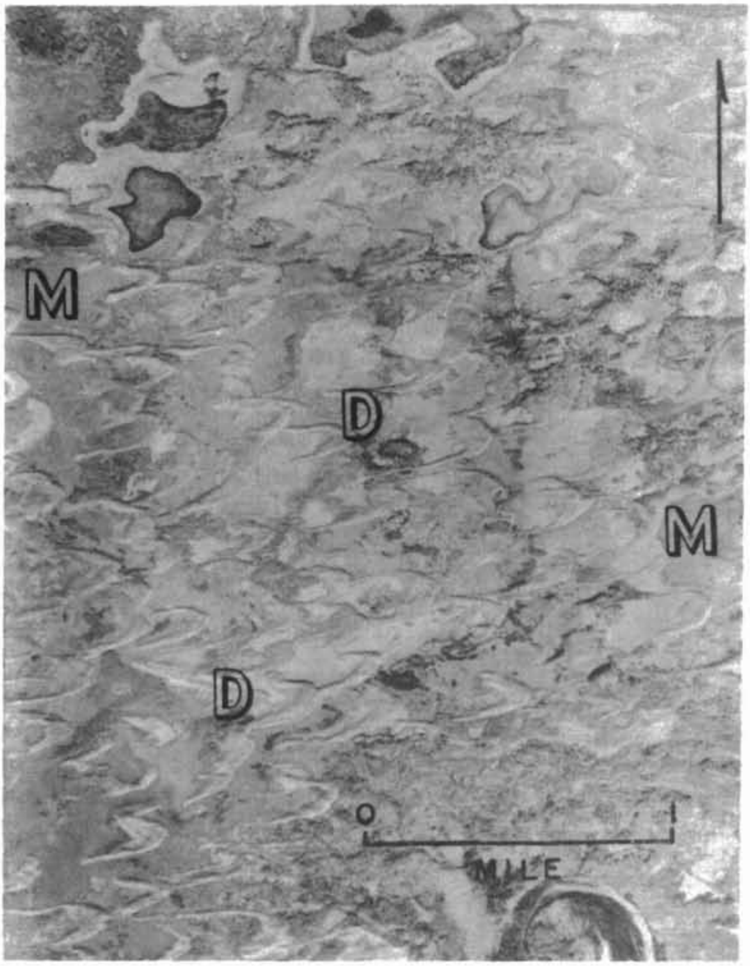

Fig. 3. In early postglacial times when the ground in this area was dry, sandy materials from lakebed and outwash plains were shifted into dunes. With eventual build-up of the water table, deep Sphagnum bogs accumulated in the interdune flats. The distribution of U-shaped dunes and muskeg is clearly seen in this illustration showing an area near Grande Prairie, Alberta.

Photo courtesy Alberta Dept.
of Lands and Forests

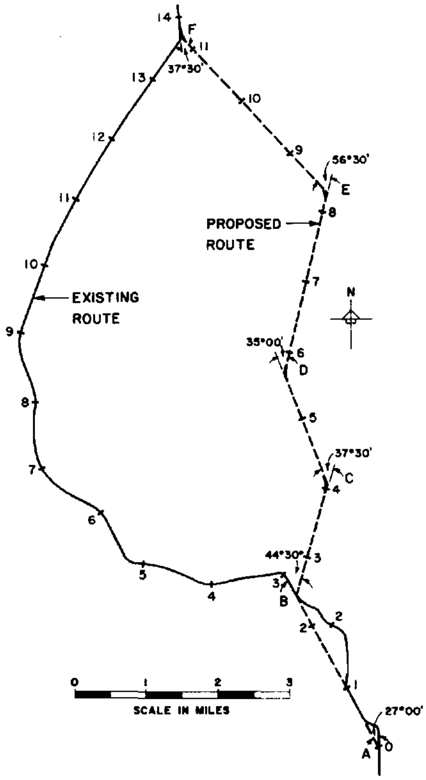

FIGURE 4

Fig. 4. This map shows the results of a two-day airphoto study. Purpose of the study was to relocate a portion of highway north of Glaslyn, Saskatchewan. The land here is uncultivated. The vegetal cover consists of a complex pattern of mixed forest and open muskeg. Following are data derived from this photo study:

Route between A & F	Length (Miles)	Organic Terrain (Miles)	Character of Organic Terrain	No. of Curves
Existing route	14.0	1.5	mixed shallow & deep	24
Shortest (straight line from A to F)	10.7	2.0	mainly deep	2 (at A & F)
Proposed route	11.5	0.5	shallow	6

A proposed highway for this region costs about $10,000 a mile for earthwork alone. In addition, every mile saved in relocation means an approximate yearly saving of $800 in maintenance costs and $12,000 in road-user's costs. The role of photo interpretation in this type of study is therefore immediately apparent.

II. 4. THE PROCUREMENT OF PHYSICAL AND MECHANICAL DATA FROM ORGANIC TERRAIN

N. W. Radforth and K. H. Ashdown

Introduction

Peat, a major component of organic terrain (muskeg), has a biologically controlled organization (1). To classify it effectively one must work in accordance with certain biological trends. Procurement of data, usually an extension of classification, must also proceed in accordance with the biological trends if measurements are to signify valid organization.

In biological studies of muskeg there is need for quantitative data to indicate physical values characterizing the structural features of peat. The features of structure are exemplified by categories (loc. cit. pp. 54-59) but the properties of these features are expressed only qualitatively.

It seems reasonable to investigate whether persistence (or change) of biological trend (loc. cit.) which is associated with difference in the structural category of the peat is correlated with the density and water content which possibly characterize given categories. There would be important application if such correlation could be established. Distribution of muskeg cover would be better understood. Reclaiming of muskeg would be more effectively achieved. Engineering planning and design could be effected with more confidence than at present.

To procure the data it is desirable to work with undisturbed peat. Unfortunately, though prediction of the structural categories can be achieved in the field there is no reliable way to obtain data on the density and water relations of these categories.

This paper is therefore concerned with the development of an approach which will provide for direct measurement of density and water content of the muskeg. The approach depends upon the possibility of exploiting molecular conditions in the peat with the aid of radioactive agents. (2)

A brief outline of the basic principles of method is offered prior to considerations on instrumentation.

Density (cf. Fig. 1.)

(The term "Density" here refers to weight per unit volume and not to specific Density.)

All matter is composed of atoms and the density of a material is a function of its atomic concentration per unit volume.

Its constituent electrons also serve to give an indication of density and the use of a method of determining electron concentrations of a number of media of known densities will result in a series of values which may be used to construct a calibration curve from which densities of other materials (lying within the calibrated range) may be found.

If material be interposed between a source of gamma radiation and a suitable detector, quanta of radiation will enter the material and, colliding with a proportion of its electrons, will be scattered. Each collision results in a reduction of the energy level of the quantum of gamma radiation, the balance of energy being transferred to the electron involved which is ejected from its atom (3).

At low electron concentrations the probability of collision, scattering, and consequent energy reduction is less than that obtaining for higher concentrations and the number of quanta arriving at the detector per unit of time will vary inversely with density (4).

The arrival of a quantum of radiation at the detector will initiate a reaction that will provide a signal which may be used to operate a recording device.

Water Content (cf. Fig. 2.)

Reasoning similar to that applying for density may be used in determining water-content. In this case the source must emit fast neutrons and the detector be responsive to the arrival of slow neutrons.

Fast neutrons involved in collisions with the nuclei of atoms in the material are scattered at reduced velocities owing to kinetic energy losses. Repeated collisions will reduce the energy level of fast neutrons to the average kinetic energy level of the atoms in the material.

The neutrons are then said to be slow. (4)

Two factors govern the rate at which this energy reduction proceeds:-

(a) Collisions involving nuclei of atoms of low atomic weight result in large reductions in the kinetic energy of neutrons and a rapid decline to the slow neutron state. (4)

(b) The probability of a neutron colliding with a nucleus is proportional to the scattering cross-section value of the atom involved. This value varies inversely with neutron energy levels and for most elements is low. (4) (11).

Of all elements most commonly found in mineral soils, hydrogen, present as a constituent of water, can be regarded as providing the most rapid moderating effect on fast neutrons because of its low atomic mass (almost equal to that of a neutron) and its large scattering cross-section value. Thus a count of slow neutrons arriving at the detector per unit of time will be proportional to the hydrogen atom concentration of a mineral soil and, after calibration, may be used to give an indication of water-content.

In peat, owing to the presence of hydrogen other than as a constituent of water the preceding reasoning was initially thought to be inapplicable for determining water-content but it is now hoped that the following suggestions will lead to a reappraisal.

Approach

Whether for density or for water content, the reasoning relies upon elemental considerations of the material under investigation. It is appropriate therefore to examine peat on this basis.

A number of investigators have made elemental analyses of selected peat samples obtained from various localities and shown results in tabular form. P. N. Kropotkin (5) has plotted results graphically and we have taken the liberty of transferring data of Feustel and Byers (6), Lin and White (7) and Miller (8) to a similar graph (Fig. 3). The pertinent portion of the graph has been amplified in Fig. 3a, where we may now compare analyses of selected peats from the U.S.S.R., U.S.A. and Eire.

A line drawn through a point in the triangle (Fig. 3) and parallel to the "O + N + S" scale will intersect the "C" scale at a point indicative of the carbon content as a percentage of the total weight of ash-free peat. Similarly, lines drawn through a point and parallel to the "C" and "H" scales will intersect the "H" and "O + N + S" scales respectively and show the weight percentages of hydrogen and oxygen + nitrogen + sulphur.

The constancy of the hydrogen percentage, by weight, about the 5.5% value is immediately apparent and forms the basis for a method to be suggested.

Before accepting analysis involving only five elements as a working basis let us examine the possible effects of other elemental constituents of peat on neutron energy dissipation.

D. E. Lea (3) has shown that energy dissipation in an organic tissue is proportional to $\sum \frac{p\,\sigma}{(1 + A)^2}$ for all elements present,

where p is the fractional content by weight of the particular element in the tissue, σ is its atomic cross-section for neutron scattering and A is the atomic weight of the element.

For purposes of biological radiation Lea suggests comparison between the figures obtained for tissue and that for H_2O and we think that a similar comparison may be made between the figures obtained for peat and that for H_2O to discover if energy dissipation caused by minor elemental constituents is significant.

These constituents are recovered from the "inorganic matter" (ash-content) of peat.

Ash-content values vary widely and the degree to which a minor constituent is present in peat may depend upon the composition of the mineral sub-layer, aerial contamination and/or drainage from other areas. (6) Some samples obtained near the mineral sub-layer give results that indicate a degree of intermixing. For example, in (6) a peat is described as "Dark-brown to black, partly fibrous with considerable white sand present", has insoluble SiO_2 present as 95% of the "inorganic constituents of ash" and an ash-content of 75%.

Average values of ash-content expressed as a percentage, by weight, of anhydrous peat are (6) 8.81%; (8) 2.4% (one value - an average); (7) 10%; (9) 11.25%; and (10) 7.91%.

For discussion purposes we shall assume an ash-content value of 10%.

The elements heading the columns in TABLE I may not all be present in all peats but the figures shown represent percentages, by weight, in an air-dried example of peat of 10% ash-content and are adjusted averages taken from (6).

Energy dissipation ratios are also shown and may be compared with those for "organic" constituents shown in Table II. (11)

It is apparent that hydrogen will provide the greatest fast neutron moderating effect in peat and that other elements have little influence on the total energy dissipation ratio when present in the quantities indicated.

The high energy dissipation ratio of hydrogen, which allows the use of a fast neutron moisture meter for mineral soils, should justify attempts at calibration in which slow neutron counts may be translated into hydrogen atom concentrations expressed as hydrogen density in grams per cubic centimetre.

Calibration

Although peat of a uniform structure and density might be used to establish calibration points on the gross density curve it does not seem to be suitable for establishing hydrogen density calibration points.

An ideal medium would be one in which hydrogen occurred as approximately 5.5% by weight and in which the whole range of dry-peat densities could be simulated. It would then be necessary to find a method of introducing water to the sample in a calibration chamber, to provide various water-content values, in such a way as to obtain uniform distribution. Such a medium may exist, as will be discussed later, but the latter provision does not seem possible at present.

However, the entire gross density and hydrogen density ranges might be covered by the use of several media and TABLE III (an abbreviated version of Table I (6)) will serve to give an indication of the range to be provided for in gross density calibration procedures.

The names in column one of the table are sometimes used to infer structural characterization of the peat. Actually they designate generic relationship at best empirical and structural connotation is vague and apt to be misinterpreted. It is thus difficult to equate them with the categories of structure used by the authors (1). It can be stated, however, that in terms of structure they would be well within the limits of range represented by our categories 1 to 16 and therefore all the values in the right-hand four columns of Table III show limits that are justifiably assumed to apply for categories 1 to 16.

It would seem possible to effect calibration by the use of several organic compounds of known formulae and suitable density.

Thus cellulose acetate ($C_{12}H_{16}O_8$) (in the form of powder, granules or pellets) might be placed in a suitable calibration chamber, its density calculated from the results of repeated "free-drop" placements and slow neutron counts obtained and expressed as hydrogen density in gm/cc. For example, cellulose acetate with a "free-drop" density of x gm/cc. has a hydrogen density of 0.0599 x gm/cc. In other words, hydrogen represents 5.99% of the total weight of cellulose acetate.

Similarly, sucrose ($C_{12}H_{22}O_{11}$) with a "free-drop" density of y gm/cc. would have a hydrogen density of 0.0648 y gm/cc. (hydrogen 6.48% by weight) and be used to furnish other calibration points.

Demineralized water might be used to provide another value or, by the admixture of carefully weighed amounts of sucrose, another series of values for hydrogen density.

Gross density calibrations, using the gamma-radiation source density meter, should be made concurrent to each hydrogen density measurement. If the calibration media mentioned above fail to provide a sufficient range of values for gross density calibrations, other organic media, for example, sawdust, cork (powder or granules) or well-shredded peat, might serve to reproduce lower density values, although it is possible their use may be criticized because of the difficulty of establishing a completely uniform density. However, repeated "free-drop" placements should help establish satisfactory calibration points.

Similarly, cellulose acetate, in the form of spun fibre, might serve as the one calibration medium capable of reproducing the entire range of peat density, when subjected to pressure, but might suffer from the same objection. However, its possible use should be examined.

The advantage of using organic media is apparent when we observe the position, in Fig. 3, of the values for coals, lignites and woods in relation to the line representing 5. 5% hydrogen and realize that we might expect to obtain similar percentages in the media mentioned above and so avoid discrepancies that might arise if we substituted non-hydrogenous or highly-hydrogenous materials.

Owing to its No. of electrons/Atomic weight ratio, hydrogen has a greater electron density than most elements and to an instrument that has been calibrated upon normal electron densities will appear to be approximately twice as dense as it actually is.

Gross density measurements obtained from hydrogenous material will therefore provide erroneous information unless corrected. See TABLE IV.

In the formulae to follow gross density will be indicated by γ and hydrogen density by γ_H.

Thus a correction must be applied to γ measured to arrive at the true value for γ. It is apparent that $\gamma = \gamma$ measured $- \gamma_H$.

Method of Assessing Water-Content

Assuming that the calibration procedures prove satisfactory and that it is possible to obtain gross density and hydrogen density curves a method of assessing water-content may now be suggested.

The two measurements obtained may be illustrated graphically as in Fig. 4.

The horizontal scale indicates density in gm/cc. The density of water is assumed to be 1 gm/cc. and although the organic material illustrated has been assigned a density of 0.5 gm/cc. this value does not need to be known and will be termed γ_d in the formulae to follow.

The vertical scale represents a volume of one cubic centimetre and is used to indicate the fractional content, by volume, of water and of organic material; and for the mixture illustrated has been given a value of 0.5 for each. In the formulae to follow the volumetric fraction occupied by water is represented by V_w and that occupied by organic material by $1 - V_w$.

The fractional content, by weight, of hydrogen in peat is denoted by h.

By application of the formula H_2O it is found that the fractional content, by weight, of the hydrogen in water is 0.111.

Gross density is indicated by γ and hydrogen density by γ_H

It is seen that hydrogen density in gm/cc. γ_H may be expressed as

$$\gamma_H = 0.111\,\gamma_w V_w + h\gamma_d \quad (1 - V_w) \qquad \text{Eq. 1}$$

and gross density γ as

$$\gamma = \gamma_w V_w + \gamma_d (1 - V_w) \qquad \text{Eq. 2}$$

Multiplying the whole of Eq. 1 by 1/h and solving the simultaneous equations for $\gamma_w V_w$

$$\gamma_w V_w \quad \frac{\gamma_H - h\gamma}{0.111 - h} \qquad \text{Eq. 3}$$

Weight of water in one cubic centimetre of peat insitu is seen to be $\gamma_w V_w$; where γ_w = density of water in gm/cc. Eq. 4

Water as a percentage, by weight, of the insitu sample will be

$$\% \, H_2O = \frac{100 \, \gamma_w V_w}{\gamma} \qquad \text{Eq. 5}$$

or, if water expressed as a percentage of dry weight is required then

$$\% \, H_2O = \frac{100 \, \gamma_w V_w}{\gamma - \gamma_w V_w}$$

The symbols used in this paper conform generally to those suggested in 1941 by the American Society of Civil Engineers, although exceptions are made where it is necessary to represent new terms. (12)

Equation 3 is seen to require three values for solution; γ, γ_H and h.

γ and γ_H will be provided after results (counts) obtained by each instrument are applied to the respective calibration curves. The derivation of h will be examined in detail later but, to provide a value to be used in the following numerical example, we will assume a peat in which hydrogen as a percentage of the organic constituents of peat (hereinafter referred to as h_o) is 5.5% and the ash-content is 10%. Hydrogen as a percentage of the total weight will then be 4.95%, or a value for h of 0.0495. This is approximated to 0.05 in the example.

Assume $\gamma = 0.5$ gm/cc. $\gamma_H = 0.05$ gm/cc

$h = 0.05$ $\gamma_w = 1$ gm/cc

Substituting in Eq. 3

$$\gamma_w V_w = \frac{0.05 - 0.025}{0.111 - 0.05}$$

$$= 0.41 \text{ gm/cc} \qquad \text{Eq. 4}$$

Substituting in Eq. 5

$$\%H_2O = \frac{41}{0.5} = 82\%$$

Substituting in Eq. 6

$$\%H_2O = \frac{41}{0.5 - 0.41} = 455.6\%$$

Discussion and Conclusion

Three values have been assumed in the foregoing; that the density of water is 1 gm/cc., that the hydrogen content of peat is 5.5% of the weight of the "organic" constituents and that ash-content is 10% of the total weight of a dry peat sample.

Slight departures from the assumed values are likely to be found in naturally occurring peats and, if so, correction factors will be required.

The density of water varies little over a wide temperature range and, for the temperature conditions expected in peat deposits during those periods of the year when field measurements are most likely to be made, correction factors are not thought necessary. However temperature measurements may be made prior to γ and γ_H determinations in the chosen location and a correction factor obtained from appropriate tables.

The value of h is influenced by the value of hydrogen as a percentage of the organic constituents of peat (h_o) and by the value of the ash-content as a percentage of the total weight of dry peat.

Upper and lower limits of h_o (Fig. 3a) are 7.0% and 4.8%. From the literature cited (disregarding those samples obviously affected to a considerable extent by the proximity of the mineral sub-layer) ash-content is found to lie between approximately 50% and 1.5%.

The limits for the value of h may be defined by assuming a peat with $h_o = 4.8\%$ and an ash-content of 50%, and a peat with $h_o = 7.0\%$ and an ash-content of 1.5%. The value of h for the former will be 0.024 and for the latter h=0.072.

Fig. 5 indicates the value of Eq. 5. $\frac{100\gamma_w V_w}{\gamma}$

found by using the assumed value h=0.05 and the values that would obtain if the actual value of h was as indicated by the appropriate curves.

Water content is plotted against the ratio γ/γ_H and use of this ratio will indicate the probable range of error.

It is apparent that while it might be feasible to obtain adequate approximations to the first two variables (density of water and h_o) by field observations, assessment of ash-content values will be difficult in the field.

If calibration can be successfully achieved according to the developed approach density and water-content of the recognized sixteen categories of peat structures (1) can now be attempted. Probably values of "h" will have to be determined in the laboratory to achieve this.

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TABLE I

ENERGY DISSIPATION RATIOS & WEIGHT PERCENTAGES OF INORGANIC ELEMENTS OF PEAT											
Element	Na	Mg	Al	Si	P	S	K	Ca	Ti	Mn	Fe
% Wt	0.069	0.39	0.445	1.76	0.08	0.28	0.067	1.54	0.036	0.016	0.428
$\frac{p\sigma}{(1+A)^2}$	4.70×10^{-6}	2.19×10^{-5}	7.96×10^{-6}	3.55×10^{-5}	3.88×10^{-6}	2.8×10^{-6}	6.28×10^{-7}	8.68×10^{-5}	6.0×10^{-7}	1.16×10^{-7}	3.55×10^{-5}

TABLE II

ENERGY DISSIPATION RATIOS & WEIGHT PERCENTAGES OF ORGANIC ELEMENTS OF PEAT							
	C		H		O + N + S		$\sum \frac{p\sigma}{(1+A)^2}$
	%	$\frac{p\sigma}{(1+A)^2}$	%	$\frac{p\sigma}{(1+A)^2}$	%	$\frac{p\sigma}{(1+A)^2}$	
PEAT A Fig. 3a	64	0.0182	5.5	0.522	30.5	0.00488	0.54508
PEAT B Fig. 3a	57	0.0162	5.5	0.522	37.5	0.00589	0.54409
PEAT C Fig. 3a	50	0.0142	5.5	0.522	44.5	0.00691	0.54311
H_2O	-		11.1	1.055	88.9	0.0129	1.0679

TABLE III

SOME PHYSICAL PROPERTIES OF PEAT (AFTER FEUSTEL AND BYERS)					
Description of Sample	Depth (Inches)	Volume * Weight	Apparent, S. G.		Absolute S. G.
			Saturated	Oven-Dry	
Sphagnum Peat	3-6	0.486	1.012	0.14	1.588
" "	24-36	0.645	1.016	0.06	1.501
Heath Peat	3-6	0.851	1.047	0.51	1.491
White Cedar Forest Peat	36-42	1.158	1.074	0.90	1.557
Saw Grass Peat	63	0.985	1.039	0.39	1.560
" " "	94-96	1.028	1.024	0.51	1.490

* Weight of 1 cc of Peat in Natural Condition.

TABLE IV

ELECTRONS PER GRAM (AFTER LEA)			
Element	Z	A	Electrons per gm. x 10^{-23}
H	1	1.008	5.975
C	6	12.01	3.009
N	7	14.01	3.010
O	8	16.00	3.012
Na	11	23.00	2.881
Mg	12	24.32	2.972
Al	13	26.97	2.903
Si	14	28.06	3.005
H_2O			3.343

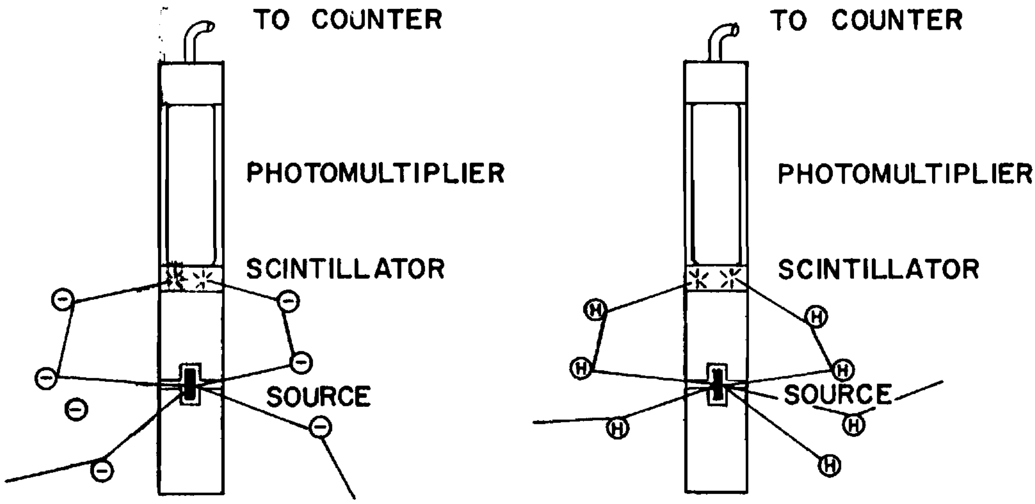

FIGURE 1 FIGURE 2

DIAGRAM ILLUSTRATING BASIC PRINCIPLES OF DENSITY AND WATER-CONTENT DETERMINATIONS

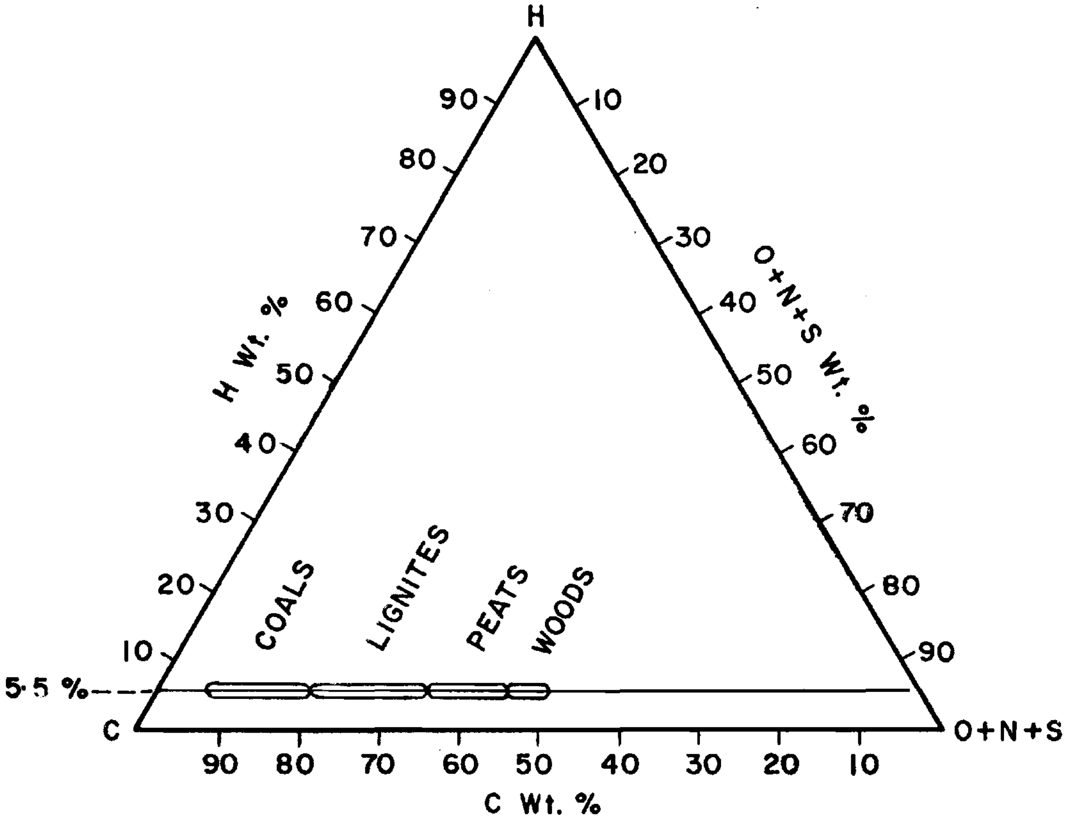

FIGURE 3

ANALYSES OF CERTAIN PEAT SAMPLES

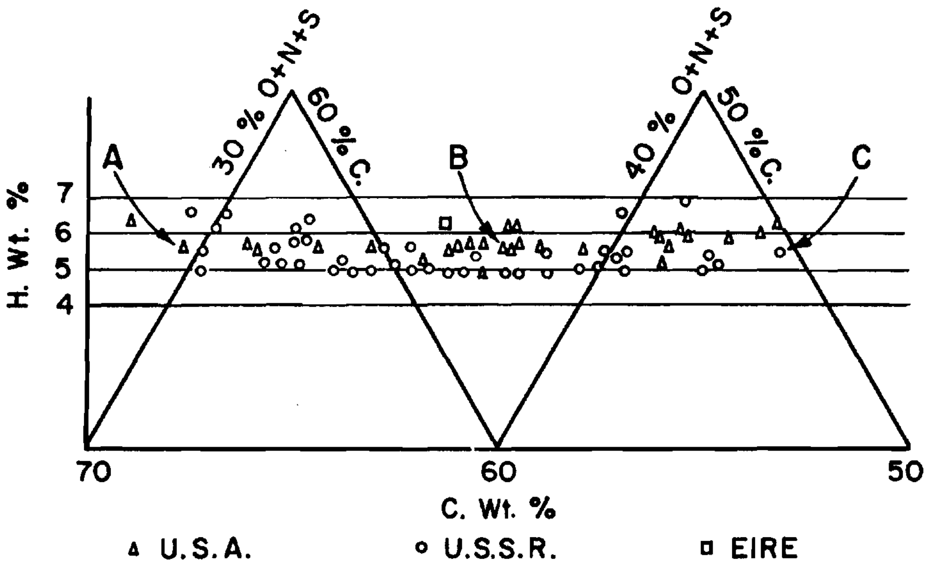

FIGURE 3a
ANALYSES OF CERTAIN PEAT SAMPLES

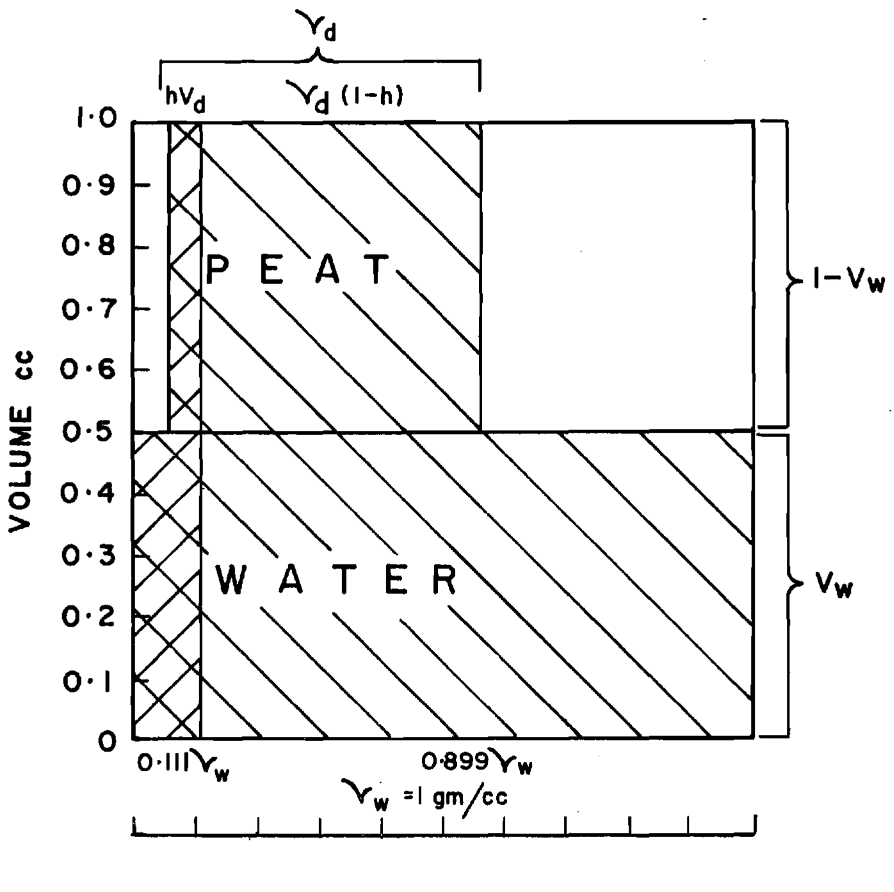

FIGURE 4
DERIVATION OF FORMULAE

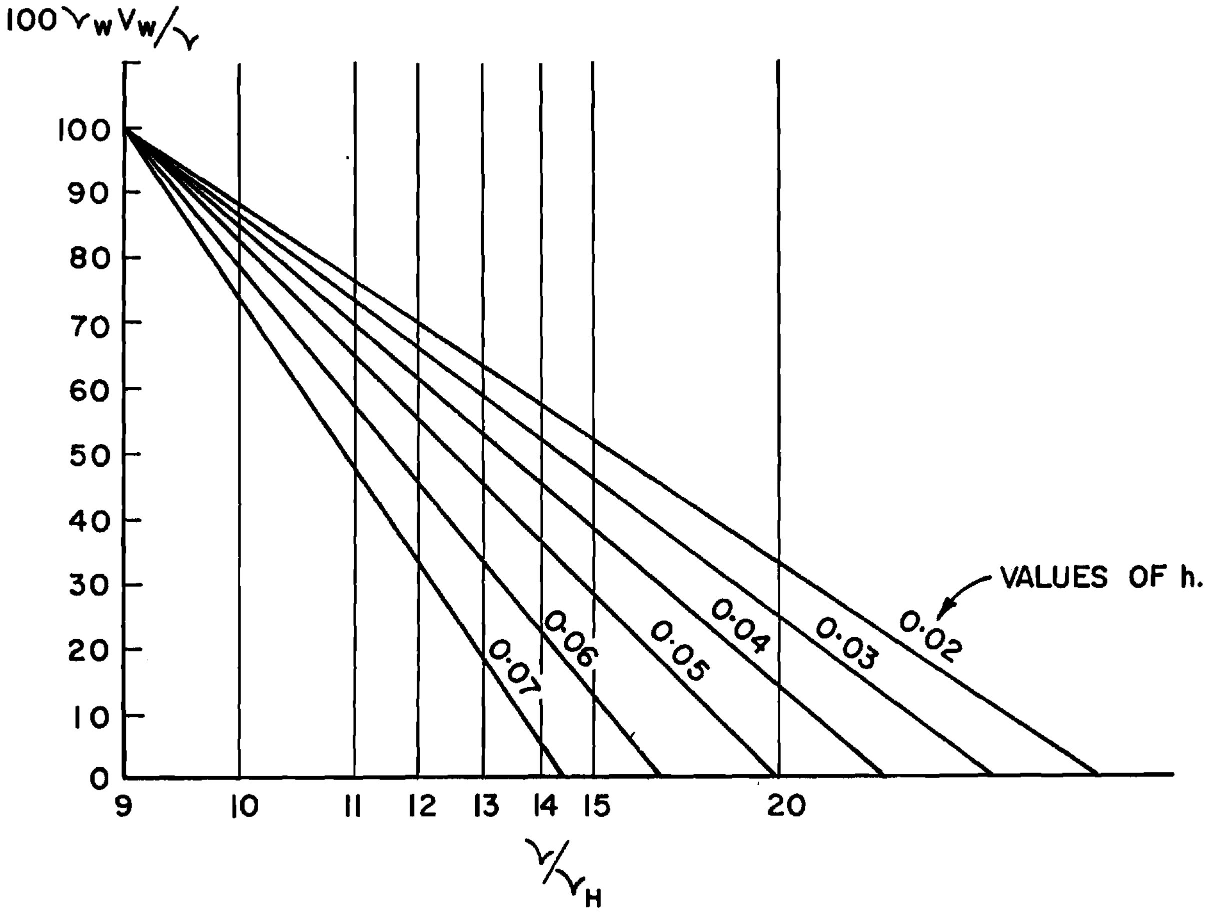

FIGURE 5

VARIATION OF 100 $\gamma_W V_W/\gamma$ WITH h AND γ/γ_H

Session III: Miscellaneous Papers

III. 1. THE SUCCESSFUL USE OF TRACKED TRANSPORTERS IN SHELL'S SEARCH FOR OIL IN THE MUSKEG OF NORTHERN CANADA

D. G. Stoneman

The general inaccessibility of much of Northern Canada is a major problem confronting the oil industry as the search for oil spreads northward. In the past, attempts have been made to use conventional equipment in unfrozen muskeg terrain, but for the most part these were expensive failures. As a result, access by conventional equipment has been restricted to the winter months. In order to enable operation in muskeg terrain during the unfrozen months, it has been necessary to develop off-highway transportation equipment to meet the requirements of muskeg service.

Shell has used the 10-ton Transporter for the past two summer seasons. The vehicle was developed and built by Bruce Nodwell Ltd. , now Robin-Nodwell Mfg. Ltd. of Calgary. The Transporter is powered by two engines, one mounted in the cab which drives the front tracks, and one mounted at the front of the deck which drives the rear tracks. The two pairs of 48-inch-wide rubber belt tracks give a total projected track area of 28,000 square inches, resulting in a ground bearing pressure of 2.0 psi at the rated payload of 10 tons.

During the summer of 1958, three of these units were used to move and supply an 8,000 foot capacity drilling rig for two exploratory drilling operations. Although the units were capable of traversing all but the most severe types of muskeg, various mechanical difficulties seriously restricted the entire operation.

In the winter of 1958-59 a development-testing programme was conducted and the mechanical performance of the vehicles is now very good. No major mechanical difficulties have been encountered, and with proper preventative maintenance a reasonable mechanical reliability is enjoyed. Because of the severe operating conditions under which these vehicles are used, higher maintenance requirements and lower component life can be expected than for conventional equipment.

During the summer and fall of 1959, over a four-month period, the modified Transporters were used to move all drilling equipment and supplies for a four-hole exploratory drilling programme in the Clear Hills area of Northwestern Alberta. Through this operation the vehicles travelled a total of 5,839 miles, hauling 1,490 tons in 1,028 operating hours. The length of haul varied from 7 to 31 miles.

Vehicle Performance

The ability of the Transporter to traverse muskeg is very good. The units operated continuously in all types of muskeg (with the exception of Type IV) without difficulty. Type IV, or floating bog, will only support one or two vehicle passes and then amphibious equipment is required for further travel. In general it was found that this severe type of muskeg could be circumvented, and as a result was avoided. Performance in the other types of muskeg was without incident. The vehicles performed and handled well even at deep penetration.

It has been found that certain types of muskeg make very good Transporter trails and are preferred to some inorganic soils. Type III, brown moss, is relatively smooth, does not deteriorate rapidly, and because of the light surface cover requires little or no clearing.

Besides traversing muskeg, the units worked in gumbo mud, sand, gravel, the freeze-thaw conditions of the fall freeze-up, snow, and ice. Of particular interest was the operation in gumbo mud. This extremely viscous mud would pack around the frame and running gear and be carried on the tracks. The unit was weighed, and it was found that the machine was carrying, in addition to its 10-ton payload, in excess of 10 tons of mud. Under these conditions top speeds were considerably reduced, but otherwise the operation of the vehicle was not restricted.

Climatic conditions on the operation varied from 80° above in August to 25° below in mid-November.

Route Selection and Trail Construction

One of the most important aspects of the entire operation was the selection and preparation of the Transporter trail. Tentative routes were first selected from aerial photographs. From the photographs the various types of muskeg could be recognized and the route then selected to avoid the severe type and take advantage of the more durable types. The tentative routes were then finalized by an on-the-ground reconnaissance. Existing seismic lines were used wherever possible. However, it was found that where these winter cut lines crossed muskeg, the trail would not withstand the repetitive traffic and detours through the muskeg were necessary.

Two International Harvester TD-142 crawler tractors fitted with 34-inch wide tracks were used for all trail preparation. On firm ground the surface cover was stripped and dozed to the side to make a 20 foot wide trail. In the muskeg the timber and brush were "high-bladed" and then tramped into the muskeg surface mat. Only trees larger than 8" in diameter were removed from the trail. To avoid driving into the tops of the fallen timber, two one-way trails were prepared (one in each direction) so that the vehicles could always travel with the lay of the timber. These low-standard trails were adequate for Transporter travel. The TD-142's were also used to prepare the drillsite and load and unload the Transporters.

Costs

At present, summer transportation in muskeg terrain is an expensive undertaking. As improvements are made to the equipment and operating techniques, the costs will be reduced. For example, operating costs for the 1959 operation were $24 per hour as compared with $38 per hour for the 1958 programme. The $24 per hour operating cost gives an average hauling rate of $1.75 per ton-mile. The ton-mile rate varies considerably depending upon the haul distance. At Clear Hills the rate varied from $1.38 to $2.30 per ton-mile.

In addition to the unit operating costs, there are the operation support charges, which include base camp charge, personnel carriers, and extra communications. At Clear Hills the support charges were approximately $5,000 per month.

Trail construction costs averaged $300 per mile. Winter trail preparation costs in the same area averaged $700 per mile. Summer road costs to carry conventional units are estimated at a minimum of $2,000 per mile. Summer drillsite preparation costs were comparable to winter costs.

Conclusions

After two years' experience in operating in muskeg terrain during the summer months, some conclusions are:-

1. The use of lightweight tracked Transporters is a practical solution to the access over muskeg problem;

2. Summer operation costs are approximately 10 - 20% higher than equivalent winter operation costs;

3. Equipment is available to move medium range drilling equipment over any terrain, with the exception of areas requiring amphibious vehicles;

4. Some of the advantages to be gained through summer operations in muskeg terrain are:-

   (a) exploration lands can be evaluated at three to four times the present rate;

   (b) by extending operations over a 12-month period, peak requirements for men and equipment are reduced;

   (c) if required by lease sales or drilling commitments, drilling can be conducted during the summer months;

   (d) in development areas lacking all-weather roads, the Transporters can be used to support drilling operations beyond the normal winter season and through the spring breakup period.

5. Summer drilling costs are lower and efficiency higher through elimination of cold weather problems.

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TRANSPORTER HAULING DRILLING EQUIPMENT IN NORTHERN ALBERTA
SUMMER, 1959

PHOTO COURTESY OF SHELL OIL CO. OF CAN. LTD. CALGARY, ALBERTA.

DISCUSSION

Major Charles asked about the approximate cost of the Transporter. Mr. Stoneman replied that it cost about $65,000. Mr. Keeling enquired as to how many loads were required for spudding and how many for the whole operation. Mr. Stoneman said that a total of 45 loads into and out of the site were required and 30 loads to spud. It took 7 to 10 days to move the entire rig from the marshalling area to the drilling site.

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III. 2. TIMING, LOGISTICS AND PERSONNEL IN NORTH COUNTRY OPERATION

B. W. Gillespie

1. Timing

There is a correct time for anything and everything that is done in the North.

World Economics, as applied to oil or gas exploration, should play an important part in determining the correct time to invest large sums of money in regions that are practically inaccessible, particularly where pay-out, in terms of years, is directly tied in with the need for abnormally large discoveries and some assurance of access to markets which will not be unduly affected by floods of low-cost oil or gas.

Transportation has a direct bearing on proper timing. Transportation costs alone can contribute materially to the economics of any north country project.

Assuming that world conditions justify serious consideration of exploration in isolated regions of the North country, land must be acquired. Certain things should be considered.

Even with modern equipment, several years of intense exploration may be necessary before thought can be given to the selection of a drill-site.

The seas, the lakes and the rivers, which dominate the timing of water transportation, may, in some instances, be completely closed to navigation. Off-highway transportation, although improving, is still a matter of timing. In some years, ideal winter hauling is frustrated by early heavy snowfalls and late freezing.

Summer movement over most of the country lying in the North is an exasperating, frustrating and economic nightmare.

Drilling a well under northern conditions requires an understanding of the fact that the drilling time will usually be much longer unless it is carried out near sources of supply and under more favourable weather conditions. Regardless of the many obstacles which have been overcome, weather still has its effect on timing.

Experience has shown that almost anything can be accomplished under sub-zero conditions, providing the pocket-book can stand the strain. Working against the weather most certainly subjects even the healthiest pocket-book to a severe strain.

2. Logistics

Logistics, according to the military definition, is the science of moving, supplying and supporting troops. To expand this definition, it is the act of planning for a movement, the housing and supporting of personnel and heavy machinery, its proper timing and careful support both during normal and emergency periods. Logistics also includes the establishing of all possible forms of communications necessary to tie in all ground operations with air or other supporting media, as well as contact with points of policy-making in order to keep lost time, due to a lack of instructions, at a minimum. Good communication is good economy.

Logistics is a problem which increases with distance between the sources of supply and the project site. The problems of transportation, of climate, and of road-building (often where road-building materials do not exist) all have a direct bearing on the importance of carefully worked out Logistics.

Transhipping is another nightmare to the Logistics planner. Each handling of drums, crates and vital tubular goods and machinery increases the chances of smashing, twisting, bending, or losing some vital item.

3. Personnel

The proper selection of people to carry out the logistics and, later, the operation, becomes the most important part of the whole task. The programmed procedure to carry on a vital project under abnormal conditions must be so detailed that no single person is improperly selected. The success of a project, as well as the lives of the personnel, rests in the hands of the planners.

There are many people in Canada and in Alaska who possess considerable experience and knowledge of cold country operations. These people are familiar with weather conditions, they understand muskeg and the problems of permafrost. They know what psychological characteristics are to be looked for in men who are working in isolation during the long nights and the unusually long days. These men also recognize the basic need of incentive for a person to do his best under such abnormal conditions. They will be the first to admit that good talent is not imperishable and that it must be used properly or it will stagnate.

4. Summary

1. A desire should be built up in industry to establish a clearing-house for the knowledge about the north which is now scattered all over North America.

2. Select personnel with great care.

3. For drilling crews, the benefits of two 12-hour work periods as against three 8-hour shifts should be studied. This can mean greater pay incentive for the man.

4. Twelve months do not make an Arctic year. Timing should be arranged so as to work with the weather - not against it.

5. Transportation should be planned with a minimum of trans-shipments. Package properly.

6. Logistics must provide for situations which would be classified as emergencies anywhere else but which in the North country are everyday occurrences.

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Session IV: Permafrost

IV. 1. SOME ASPECTS OF THE PERMAFROST PROBLEM

T. C. Mathews

To a great extent engineers have tended to over-design structures placed on permafrost because they have had to incorporate a large safety factor to cover their ignorance of basic physical factors involved. Enlightened design must begin with an accurate knowledge of the heat budget applicable to the area under consideration. The variables involved in the heat budget equation are predictable only to an approximate degree.

A. H. Lachenbruch has recently made a very significant contribution to the solution of the heat budget problem in U. S. Geological Survey Bulletin No. 1052B. Lachenbruch has derived equations and rather simple solutions to three dimensional heat conduction in permafrost beneath heated buildings. The method is applicable to any source-sink heat problem. To intelligently use this method, temperatures of both source and sink must be accurately known or predictable. This accentuates the knowledge or lack of knowledge of the overall heat budget with its wide amplitudes introduced by climate, weather, natural cover, precipitations and man-induced soil and cover disturbances.

Approaching the frozen ground problems from physical fundamentals, it becomes apparent that it is the change of moisture from a frozen to thawed state or vice-versa that generates the disruptive forces which must be dealt with. If the moisture state can be predicted, the design can be straightforward. Moisture control in Northern latitudes is usually rendered more difficult by the presence of surface accumulations of silt. The fine capillary sizes in silt soils exert forces which cause moisture migration at below freezing temperatures. Silt must be removed from foundations if methods of moisture control are to be incorporated in the design.

A worthwhile field for research lies in the investigation of moisture properties when changed by chemical additives to depress the freezing point below expected temperatures, the use of chemicals to modify the capillary pressures in silt soils, and the possibility of the use of hydrophobic surfaces to which ice will not adhere.

Soil types vary greatly in their ability to retain moisture. In many areas permafrost appears to be a fossil condition maintained in its present state by the negative heat budget produced by a surface cover of moss and spruce forest. Removal of the surface cover results in progressive thawing of the underlying material which is often supersaturated silt having no shear strength in the thawed condition. Roads have been successfully constructed through such areas by adding moss and trees to the existing surface to a compacted depth of at least two feet for the road width and covering the mat with one to two feet of pervious ballast. Such construction will support the heaviest trucks. The low temperatures inhibit decay of the mat. Frost boils are non-existent because insitu materials remain frozen.

Granular soils having low moisture retention may often be thawed and drained to provide a suitable foundation base. It is often possible to change the heat budget by surface modification to yield a naturally thawed and drained base in an area which was originally permanently frozen.

Clays in permafrost areas usually remain unfrozen and can be dealt with by methods of design similar to those used in temperate climates. Moisture migration through clay does not appear to be the problem that it is in silts. However, clays will retain their moisture in spite of any efforts to drain and will remain subject to plastic deformation at low unit loads.

It is apparent that there is a great need for more knowledge of ground temperatures in Northern latitudes. It seems logical that the weather bureaus should gather data on ground temperatures along with other weather observations.

Ground temperatures dictate proper design in dealing with frozen ground. Remembering that the primary concern is with moisture properties, the reason becomes apparent when the physical properties of ice are considered between 17°F. (a ground temperature to be expected in the Arctic) and 32°F. which may be expected in the southern fringes of the permafrost zone. Ice becomes increasingly plastic as 32°F. is approached and at the 32°F. point the ice in the ground may have lost any portion of its heat of fusion of 80 calories per gram. The amount of heat which the ice may tolerate can only be that which can be absorbed as specific heat and heat of fusion. The rate at which the heat may be absorbed depends upon the ground conductivity. These two factors are interdependent.

The effects of temperature on adfreeze strength, shear strength, bearing and conductivity of frozen soils were extensively investigated in the Laboratory at Point Barrow during the U.S. Navy drilling operations to determine design factors for drilling rig pile foundations in silt soils of high moisture content. Many slurry additives were tested but in all cases an ice film was found in contact with the pile. Strength and plasticity were that of the ice bond and independent of properties of the additives, with the exception of clay additives which lowered the strength.

Minus 5°C. was found to be a critical temperature for loadings over an extended period of time. Strengths were also affected by the time of loading after freezing. Several days of aging were required to develop full strength.

Ultimate strengths of adfreeze for loadings over a period of several days were found to be as follows:-

Degrees Centigrade	Pounds per square inch
-1	69
-2	108
-3	123
-4	157
-6	179
-7	200

At minus 5°C. a maximum adfreeze strength of 40 pounds per square inch was found for loadings of three months' duration.

Bearing and shear tests revealed similar variation with temperature and time. At minus 5°C. a safe bearing strength of 1,000 pounds per square inch was found for short duration loads. For shear strengths at the same temperature, the apparent angle of internal friction was found to be 20° - 38° with apparent cohesion of 80 pounds per square inch.

Conductivity of frozen 28 percent moisture sandstone yielded a K of 13. The dry sandstone yielded a K of 12. Unconsolidated samples of frozen silt of frozen density of 105 pounds per cubic foot and dry density of 85 pounds per cubic foot yielded K values of 10 to 13. Conductivities were much less at -1°C. than at -5°C.

Since ice properties are being considered in handling permafrost, economics dictate that design is only for the time period of use and maximum advantage taken of the properties which nature has provided. Continuing research should be directed toward the accumulation of nature's data, especially as regards properties of the various soil types, moisture, ground temperature and the heat budget at various latitudes and cover types.

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IV. 2. ENGINEERING ASPECTS OF PERMAFROST IN THE PETROLEUM INDUSTRY

R. A. Hemstock

SUMMARY

(This paper has been published in full in "Oil in Canada", Vol. 12, No. 40, pp. 50-54, August 1, 1960).

Permafrost occurs over about one-fifth of the land area of the world. More than one-third of Canada is underlain by permafrost which occurs in those areas where portions of the ground remain frozen throughout the year. Permafrost is not a new material but is the frozen equivalent of bedrock, gravel, sand, silt, clay, organic material or water. The three principal properties which are important in permafrost are:-

1. the ice content;

2. the thermal sensitivity; and

3. imperviousness to water.

The petroleum industry faces several problems in the exploration for and development of petroleum resources in the North. These are:-

1. Transportation.

   (a) Tracked vehicles. These are being developed for travel over muskeg and will be suitable for permafrost.

   (b) Roads. The "passive" method of construction is usually employed, which involves retention of the permafrost layer beneath the road. A common problem in Arctic roads is "icings" or "glaciers" which are caused by sheets of ice formed by successive layers of water which freeze as they seep from the ground.

(c) Pipelining. Pipelines are required to bring products from the oilfield to the market. They are usually laid on the ground surface.

2. Drilling. Problems which may be encountered can be summarized as a matter of heat exchange.

3. Building foundations. Three main factors are important:-

   (a) Texture and structure of the ground.

   (b) Temperature of the effected permafrost zone.

   (c) Hydrology of the area.

4. Sources of adequate water supply. These are usually limited to the larger lakes and rivers or even to wells drilled through the permafrost layer.

5. Water distribution and other service lines. Usually all service lines are installed in "utilidors", which are well-insulated boxes laid to grade on the surface of the ground, and which may be founded on piles, if necessary.

6. Adequate sewage disposal. Special methods of sewage treatment may be required since biological and chemical reduction of organic material proceeds very slowly at low temperatures.

DISCUSSION

Major Charles wondered about the problems arising from the permafrost transition zone. Mr. Hemstock said that special problems are involved in the transition zone as it is more difficult to maintain a stable thermal regime for engineering works in the transition zone than in continuous permafrost.

Dr. Radforth asked if the present practice is to use single poles for power lines rather than tripods. Mr. Hemstock replied that after their experience with single poles tripods have been used.

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IV. 3. SOME ASPECTS OF MUSKEG IN PERMAFROST STUDIES

R. F. Legget and J. A. Pihlainen

Permafrost in Canada

Permafrost may be defined as any part of the earth's crust that remains below 32°F. for a number of years. It cannot be over-emphasized that permafrost is not a material but the condition of material. Permafrost may therefore be rock, gravel, sand, silt, clay, peat or any mixtures of these materials when they exist below 32°F.

This subsurface condition is found beneath about one-half the land area of Canada, underlying most of the Northwest and Yukon Territories and the northern parts of all provinces except three Atlantic Provinces. The depth or vertical extent of permafrost varies with location, being naturally deeper in the Far North. At Resolute Bay, on Cornwallis Island of the Arctic Islands, it is estimated to be approximately 1300 feet deep; at Norman Wells on the Mackenzie River 90 miles south of the Arctic Circle, it is approximately 200 feet deep; and at Hay River on the southern shore of Great Slave Lake, some patches of permafrost only a few feet thick have been encountered.

The problem of mapping the southern limit of permafrost is of great practical importance but of equal difficulty, in view of the area to be covered and the fact that the boundary generally occurs in areas remote from normal access. The Division of Building Research of the National Research Council regards the mapping of this boundary as a major responsibility. Some progress has been made towards a more accurate delineation of the boundary than has been available up to recently. A questionnaire has been prepared and circulated throughout the North with a view to obtaining as much information as possible from those who live on or adjacent to permafrost areas.

Thermal Regime of Permafrost

The climate, past and present, is the principal variable in the formation of permafrost. In non-permafrost areas, the results of climate are reflected in a mean annual ground temperature which is above 32°F; in permafrost areas, the mean annual ground temperature is below 32°F. Such a comparison of annual ground temperatures may be utilized further to note that in non-permafrost areas, winter air temperatures below 32°F. may produce a seasonal depth of freezing; in permafrost areas the summer air temperatures above 32°F. produce a seasonal depth of thawing, sometimes known as the "active layer".

Unfortunately, these simple concepts of climate and ground temperatures are not adequate to explain the more detailed aspects of permafrost. The southern limit of permafrost in Canada, for example, cannot be correlated directly with the mean annual 32°F. isotherm. Such difficulties lead to consideration of an energy concept of the formation of permafrost in which the attempt is made to evaluate the effect of climatic energy pulses that produce freezing in the winter and thawing in the summer and which are influenced by terrain controls.

The prediction of the energy change between the terrain surface and the atmosphere cannot be readily reduced to a simple basis. The dominant weather elements affecting this energy change are sunshine, air temperature and wind. In addition, the relief, orientation, the presence of adjacent objects as well as the absorptivity and emissivity characteristics of the ground surface enter into the problem. Additional complication is provided by the effects of rain, condensation, evaporation and plant transpiration. Even if all these individual factors are measured, there remains the problem of re-combining these variables in the calculations of total net energy gain or loss to the atmosphere. There is another source of energy, although small, that affects the degradation of permafrost at its lower extremity: heat radiation from the centre of the earth. This amounts to about 40 cal. per sq. cm. per year and for a soil with 30 per cent ice by volume would mean a recession of the lower boundary of permafrost upward at a rate of approximately 2 cm. per year, if considered without reference to other factors.

Studies of some phases of these energy exchanges have been initiated by the Division of Building Research of the National Research Council. The results of such studies will not be immediately applicable to construction, but the research approach to these problems serves as a useful reminder of the many variables that may influence the simplified concepts necessarily utilized in dealing with construction problems.

Properties of Perennially Frozen Soil

Permafrost as defined on a temperature basis must be re-examined for an evaluation of its engineering characteristics. Only in a few instances is temperature below 32°F. in rock or in dry sand and gravel of significance to construction. More important to engineers is the presence of ice in soil. For the purpose of this paper, the word "permafrost" will be used to designate a perennial condition below 32°F. while the more cumbersome term "perennially frozen soil" will be used to denote frozen fine-grained soils with ice content.

The three principal properties of perennially frozen soil which give rise to construction difficulties are its ice content, its thermal sensitivity and its imperviousness to water. The ice in a frozen soil acts like a cement, bonding the individual soil particles. The result is a material with considerable, often rock-like strength. The ice can take the form of layers or lenses ranging from hairline size to 3 and 4 feet thick or as coatings over soil particles. Some of the most spectacular ice deposits occur as chunks, wedges or blocks buried in perennially frozen soil. It will be readily understood that excavation or any embedment of foundations into perennially frozen soil can be difficult and costly. This is further complicated by the fact that the volume of ice may be as much as six times that of the soil solids. Such materials, if thawed, turn into a slurry and this simple fact is probably the worst "practical" problem that permafrost presents.

An organic mantle at the surface forms a natural insulator for permafrost from the thawing effects of summer. This function may be thought of as two processes - insulation and what may be termed apparent insulation. Dry peat, moss, or lichen, composed of organic fibres, particles and many minute air spaces will act as conventional insulation, retarding the seasonal pulse of energy which produces thawing. When such organic material is wet, it acts like a sponge, retaining large amounts of water. The apparent insulating effect of this wet organic material is given by the fact that much of the seasonal pulse of energy which produces thawing will be expended in thawing the large amounts of ice contained in the organic material and in evaporating the resulting large quantities of water.

This general thermal balance is so delicate that the permafrost table is always adjusting to variations of climate and even to variations in the type of vegetation. The thermal sensitivity is well illustrated by game trails which become slightly depressed paths as the perennially frozen soil beneath them thaws a little more under the compacted moss than under the surrounding terrain. Some appreciation of the insulating value of the organic mantle can be gained by some observations in an area at Inuvik, N. W. T., which developed a 2 foot depth of thaw (or "active layer") in the undisturbed condition. After 12 to 18 inches of living vegetation and peat had been stripped off, the depth of thaw in the underlying granular material increased to 8 feet during the following summer.

The third property of perennially frozen soil, and one which is most directly associated with organic terrain, is its imperviousness to water. Rainfall and water from melting snow cannot drain into the ground and tend instead to form irregular drainage channels or stagnant pools. This environment is excellent for the development and formation of organic terrain and explains in part the relatively lush surface vegetation of this arid region. Could the earlier extension of permafrost far to the south of its present boundary account in part for the large expanse of muskeg in the North?

The Field Description of Muskeg in Permafrost Areas

Some extension of the present field description of organic terrain appears to be necessary when permafrost is present.* Desirable modifications are best discussed under the subdivisions used in the field description of organic terrain -- of terrain features above, along and below the ground surface.

(a) Above-Ground Features

The vegetative cover is described by qualities such as height, degree of woodiness, growth habit and texture. It is suggested that some attempt should be made at the identification of species. In many cases, particular species or plant associations are invaluable for the inference of terrain properties in permafrost areas, particularly in exploratory engineering surveys. The identification of species may at first appear formidable. Fortunately the most apparent indicators are trees and the number of northern species is limited to about seven. Shrubs are not generally regarded as important indicators but in any case the number of northern species is also limited. Small, non-woody plants are numerous but apart from some exceptions, their indicator value is in the plant associations or communities that they form.

(b) Along Ground Features

Terrain features along the ground, described as topographic features and including sixteen terrain situations in the existing field description of organic terrain should be enlarged in permafrost areas. In such areas the organic cover is much more extensive and is not confined principally by relief. In permafrost areas, it has been found useful to describe and identify the large-scale landform. After this, small-scale or micro-relief features are described with particular emphasis on slope, exposure to solar radiation and micro-drainage details.

(c) Below the Ground

A first extension of the existing description of the subsurface organic material concerns the amount and form of the ice. In the description of ice in frozen soils, it has been found useful to subdivide frozen soils into three groups in which the ice phase is (a) not visible by eye; (b) visible by eye with individual ice layers

*Radforth, N. W.; "Suggested Classification of Muskeg for the Engineer". The Engineering Journal, Vol. 35, No. 11, Nov. 1952.

less than 1 inch thick; and (c) visible by eye with individual ice layers greater than 1 inch thick.

A subsurface observation of considerable value in permafrost areas is a record of the seasonal depth of thaw. Although observations of the depth of thaw deal with a subsurface property, thaw depth variations have been found to be initiated by surface conditions such as vegetation, relief and drainage. Because considerable deviations in the depth of thaw are possible in an area as small as a 5 foot square, it has been found useful to make many random observations in areas of differing terrain. Maximum, minimum and average depths of thaw should be recorded. It should be noted that the seasonal depth of thaw is the thawed zone for an environment in a locality at some particular time during the thawing season. Only at the time of its maximum depth (autumn) can it correspond to what is known as the "active layer".

Special Construction Problems

(a) Overland Trafficability

Permafrost provides some additional factors for consideration in the problems of overland trafficability. It is difficult to visualize terrain conditions in permafrost areas which are more severe for vehicles than those which have been experienced and solved in muskeg areas farther south. The presence of perennially frozen soil at a shallow depth may actually be welcomed. When perennially frozen material is found at a shallow depth, it can provide a firm bearing for tracked vehicles. Even in an undisturbed condition, however, large variations of potential significance to the performance of vehicles can be expected. Of more significance is the fact that when the organic mantle is disturbed by repeated traffic, the permafrost table recedes quickly, leaving a saturated mass of peat and sloppy soil. Since the underlying perennially frozen soil is impervious, this saturated condition of the peat is widespread and usually unaffected by any conditions other than exceptionally favourable natural drainage conditions.

(b) Road Construction

As with most construction in permafrost areas, the design of roads must be based on the preservation of permafrost.

Cut sections should be avoided and fill sections are to be preferred since they are also easier to maintain during the winter. Present practice is to place an additional insulating layer of organic material on the undisturbed road location. Although a major design consideration of roads is settlement (due to thawing of perennially frozen soil), the implications of drainage with potential thermal disturbance are almost as great. Longitudinal subgrade drainage is best supplied by utilizing natural drainage with a minimum of ditching at some distance from the shoulder. Low areas may be drained by lateral ditches which direct potential ponding areas to some distance from the road.

(c) Construction Design

The principal guide for construction design in permafrost areas is to avoid or to minimize the disturbance of the natural organic cover. Although the implications of perennially frozen soil are not as critical to temporary as to permanent construction, much is to be gained in operational efficiency if the potential problems of perennially frozen soil can be anticipated. In all cases, some disturbance of permafrost is inevitable. For temporary construction, such as camp buildings, additional moss and peat may be used as insulation to keep the depth of thaw to a minimum. For permanent construction, the design may be more elaborate and may incorporate several methods for minimizing thawing or dealing with expected results of thawing. The most successful results can be achieved by proper site selection.

Conclusion

Muskeg is a most important factor in maintaining the natural stability of perennially frozen soil. The exact mechanism by which muskeg provides natural insulation to underlying frozen material is an active field of research in Canada today. Enough is known of the interaction of muskeg and permafrost to point to the eminent desirability of disturbing muskeg to the absolute minimum extent possible. This general rule applies in all engineering operations in northern areas featured by perennially frozen fine-grained soils covered with a muskeg mantle.

DISCUSSION

In reply to a question from Dr. Mawdsley (University of Saskatchewan) regarding ice lens formation in permafrost, Mr. Pihlainen said that ice lens formation does not occur in permafrost. Ice lens formation is in the active layer only. The exact mechanism of ice lensing is still being investigated. Mr. D. Beckett (RCAF) remarked that Mr. Pihlainen had suggested that it is not good practice to ditch or excavate the organic material and to put this organic material (peat) on the roadbed. On the other hand, Mr. Hemstock had indicated that this had been done at Norman Wells with good results. He wondered if there is an optimum distance ditches should be kept from the center line so as to get no deterioration of the permafrost under the roadbed. Mr. Pihlainen replied that the recommended minimum distance is six times the anticipated depth of thaw. The National Research Council tends to be conservative in recommending no ditching.

Mr. C.A. Meadows (C.A. Meadows, Ltd.) said that it is worth taking a good look at creating a permanent frozen condition the year round by mechanical means. His experience in all-year skating rinks indicates that this may be the answer to foundation problems. It should be economical to maintain a frozen condition under a building by refrigeration.

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IV.4. CLIMATE, PERMAFROST AND ARCHAEOLOGY

T.A. Harwood

ABSTRACT

This paper is an attempt to draw together some evidence for a fairly exact dating of a climatic change in the Middle Ages. It is pointed out that whatever may have been the cause, the fact remains that two human catastrophes - one at Lake Hazen (Ellesmere Island) at 82°N., the other at Herjolfsnes (Greenland)

at 60°N. - took place at almost the same time. There is conclusive evidence that the permafrost level was creeping upward during the latter part of the Norse period at Herjolfsnes. It can be shown that increased frost action between the first and second stages of the Eskimo occupation at Hazen was splitting the houses. This indicates, therefore, that the rate of thermal cooling was increasing. A remarkable correlation can be discerned between events at and about the same time in Japan, Formosa, Scandinavia, the Alps and the Ward Hunt Ice Shelf. The conclusion is made, therefore, that the climatic change which has been shown to have taken place was certainly hemispheric, if not world-wide, since it occurred in areas widely separated by latitude (44°N. to 82°N.) and by longitude (98°W. to 110°E.)

Thus there is good evidence that there was a sharp climatic deterioration which commenced in Northern Ellesmere Island, in Greenland, and in Northern Europe in the early 1400's, and which continued and deepened, probably with fluctuations, until 1740-60. From recent historical and climatic records, at least since 1890, the climate throughout the northern and western hemispheres has changed somewhat for the better.

If some indication of the mean depth of the active layer in permafrost areas prior to this great climatic deterioration, at any given latitude, could be obtained, it would be possible to work back to a mean annual isotherm for that period and for that latitude. It is therefore suggested that any clue from archaeological, botanical, or soil evidence which could be dated (as, for instance, graves as Herjolfsnes) and which would indicate positively the depth of the active layer at that time, is well worth recording.

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(This paper has been submitted for publication in a technical journal).

Session V: Panel Discussion on "Muskeg in Relation to Northern Development"

(a) J. E. Savage.

(b) Dr. J. Terasmae.

(c) W. B. Dingle.

(d) Dr. N. W. Radforth.

(e) Dr. R. M. Hardy.

Mr. Hemstock introduced the subject of muskeg in relation to northern development. He pointed out that each of the participants had come to say how muskeg and permafrost are a problem from the point of view of economics and engineering in his own sphere of interest.

(a) ECONOMIC FACTORS ARISING FROM PRESENCE OF MUSKEG

J. E. Savage

The relative importance of muskeg in highway construction to some extent depends on the class of road to be constructed. For territorial development roads the Department of Public Works believes that it is generally desirable to have a standard of road which can be used by passenger cars and light trucks during summer, except during prolonged wet spells; and in good periods of weather would carry heavy trucks. The embankment would be constructed to a width of 18 ft. to 24 ft. with a gravel surface. In good travel conditions, this would permit passing of standard vehicles at restricted speed. The more heavily-travelled roads, such as the Mackenzie Highway Extension, are built to a somewhat higher standard than this.

In the Northwest Territories the Department of Public Works is attempting to build the maximum number of miles of development road for the least dollars and this consideration is uppermost when planning work. To achieve the desired economy the location or construction procedure is "tailor-made" in each area. The problems arising from muskeg and permafrost are many. On location studies, ground transportation over muskeg is generally difficult and expensive for most of the year. Therefore, to keep costs down an attempt is made to obtain as much information as possible from a study of maps and aerial photos before placing any engineering parties in the field. The reconnaissance group usually consists of only two or three men. An attempt is made to carry out the first field reconnaissance when the ground is sufficiently frozen to support the weight of tractors or other track vehicles. If a tractor is being used at this stage, then normally a narrow pilot line is cleared along the route. This line is widened in spots to act as a landing strip for small aircraft. Clearing of a pilot line means real savings in dollars, since it materially speeds up the work of the main location group that follows.

In muskeg areas, if there are numerous lakes and rivers and if the work must be carried out in the summer months, aircraft have been found to be the cheapest means of transportation rather than fighting unfavourable ground conditions. For example, on location surveys east of Yellowknife last year, three major location groups operating from light fly camps were employed. Ten or fifteen miles of location work was performed from each setup and then the entire crew and camp was moved by float plane. All crews were provided with canoes and motors to take the maximum advantage of existing watercourses. On the Precambrian shield east of Yellowknife with muskegs, boulder sections, steep terrain and hundreds of lakes, there was no single type of ground transport that would have been suitable for all surface types.

Where it is necessary in muskeg country to move personnel and supplies by ground transport during the summer, track vehicles are a must. At present a number of full track vehicles with a rated payload capacity of 5,000 lbs. are being used. These have proven to be very valuable on construction engineering work as well as on location engineering work. Track trailers are also useful for moving fuel and equipment over muskeg. The Department owns 25 camp trailers, all on wheels. At times the possibility has been considered of converting some of these units to tracks but because of conversion costs and the necessity of wheels on certain types of terrain, no conversions have been carried out to date.

Where it is necessary to carry out engineering studies in muskeg country, first consideration should be given to carrying out the work when the ground is frozen - the problems connected with shorter days and low temperatures are often compensated for by increased mobility on frozen ground. If the work has to be done in summer, then the use of aircraft or boats should be considered; and as a third alterate, for year-round use in areas not lending themselves to air or water transport, track equipment is recommended.

It is important to avoid rigid rules for construction through muskeg country. The field engineer must be highly adaptable and avoid preconceived notions. Very rarely is it possible to completely drain muskegs along northern highways, yet it is usually desirable to drain off as much free water as possible before placing fill material. This is particularly true in permafrost areas, since drainage can increase the bearing capacity of the muskeg, permits the use of lower class embankment materials and yields a more stable grade, not as susceptible to damage during periods of peak run-off.

There should be a wide berm between the embankment and side ditches in permafrost areas so that the side ditches will not thaw out the foundation under the embankment.

In the Northwest Territories, depending on location conditions, on occasion muskeg has been stripped from the right-of-way and at other times additional insulating material has been piled on top of the muskeg before placing embankments. For example, sixteen miles of the Mackenzie Highway extension south of the Mackenzie River were through a low area covered by approximately 18 inches of wet muskeg. The underlying soils were clayey and permafrost was generally well below the surface. It was not economically feasible to haul in select borrow so after preliminary drainage the muskeg was stripped back and the underlying soils used to construct embankment. North of Fort Providence permafrost was also generally well below excavation depths. Here muskegs were intermittent and, where possible, were drained. Borrow material was used to fill across the muskeg. Muskegs are frequent in the area north of Yellowknife and permafrost is generally only a foot and a half or two feet below the surface, so the clearing debris is piled along the center line in a flattened windrow, as added insulation, before placing borrow excavation as embankment. In permafrost areas such as this it is also important to remember the lack of vertical drainage when designing drainage structures. Aside from evaporation nearly all water movement is horizontal. During breakup flash floods are common and drainage structures must be larger than normal to accommodate the short term peaks.

DISCUSSION

The question was raised as to whether any of the roads in the north were being built in co-operation with the oil companies. Mr. Savage said that while there may be cost-sharing agreements, this is not done on the construction level. Brig. Connelly pointed out that normally cost-sharing agreements are carried out between the Federal Government and the provinces rather than between private agencies and the Federal Government. Mr. Thurber asked if it was possible to do much of a preliminary soil testing programme prior to the construction of these northern roads. Mr. Savage replied it is possible but such investigations are limited on a low-cost road, being chiefly visual. Again it is a dollar question - how much money do you want to spend? His Department, in building development roads, discourage too much preliminary survey. Mr. Hemstock asked if aerial photography is utilized in the preliminary survey for any of the standard roads constructed by the Department. Mr. Savage stated that aerial photographs have been invaluable. He believed that there are cases where, if aerial photos had not been used, the increase in engineering costs would have been of the ratio 100 to 1.

Mr. Hemstock referred to a condition where the permafrost is below the construction depth and the muskeg is stripped, thereby altering the thermal regime. He wondered if this would cause excess water to be released which would collect at the base of the fill, causing sliding, etc. Mr. Savage explained that they had had no difficulty in this regard since in the Fall prior to construction the area is cleared and an attempt made to establish preliminary drainage with several lateral ditches. Sometimes it is necessary to supplement this drainage system in the Spring. In the construction of the Hay River - Providence Section of the Mackenzie Highway, permafrost was encountered only at one spot, a mile from the Mackenzie River. Dr. Mawdsley asked if he understood rightly in that it was stated that no permafrost was encountered north of the Mackenzie River. Mr. Savage felt that he may have given the wrong impression. The actual condition was that, for the practical purposes of their construction, there was no permafrost - apart from isolate pockets - in that there was none in the top six or eight feet.

(b) THE USE OF PEAT, ORGANIC DEPOSITS AND PERMANENTLY FROZEN GROUND (PERMAFROST) IN STUDIES OF GLACIAL GEOLOGY

J. Terasmae

Several reasons can be given why a Pleistocene geologist should be interested in muskeg and permafrost. Most important of all is this. Both organic deposits and the permanently frozen ground preserve evidence of past animal and plant life. A striking example of this are the frozen mammoths found in Siberia and Alaska which show an amazing degree of preservation - there is no decay whatever. Other less remarkable fossils are preserved in great numbers in peat and permanently frozen ground. Peats preserve fossils because of their acid and non-oxidizing environment.

Based on a study of fossils, it is possible to reconstruct changes in plant and animal life for many thousands and, in fact, many millions of years and from this evidence infer the probable climatic conditions and changes.

Presently it is possible to use organic deposits for absolute age determination by studying the decay of radio active carbon isotope (C-14) in these samples. Ages up to 65,000 years before present have been determined by this method.

Outside of these applications it is desirable, from a geological point of view, to know something about the muskeg since it may be one of the most extensive surficial map-units for some regions.

The possible economic uses of organic deposits should not be neglected. It may be interesting to note that in suitable areas peatlands purchased for $7. 50 an acre, and now under proper intensive cultivation, are valued at $700. 00 to $1,000. 00 per acre in southern Ontario.

A study and dating of peat deposits has aided glacial geologists in studies of ice retreat and advance, assuming that peat accumulation began shortly after ice melted from an area. Knowledge of climate, life and length of interglacial intervals has been gathered from studies of buried peat deposits.

A knowledge of past forest history has shown that certain predictions can be made for the future of forest growth in some regions. A study of forest history, based on investigation of pollen and spores in peat in the James Bay lowlands, has also shown that drainage conditions were better in early post-glacial time and have deteriorated since.

Archaeological studies of human history have quite clearly shown that a knowledge of past climates and geologic events is important for these investigations.

In conclusion, it can be stated that muskeg (including peat and other organic deposits) and permanently frozen ground are just as important to a Pleistocene geologist as is a reference library from which he can obtain information for his studies.

DISCUSSION

Professor Anderson remarked that there is some speculation as to whether the surface features of muskeg accurately reflect its characteristics throughout depth. For instance, the present surface coverage of a muskeg deposit may be "FI". However, taking samples throughout the depth of the deposit (say 10 ft.) one sometimes finds peat of a type inconsistent with the surface cover, perhaps woody fibrous. He wondered if there has been any change in the surface cover over the past several thousands of years. Dr. Terasmae replied that in some cases there has been a change in surface vegetation cover. This is especially true where the muskeg is a filled-in lake. It has gone through perhaps all stages from a floating bog to black spruce. On the other hand, if the muskeg developed through a poor drainage condition, there might not have been much change; the vegetation may be much the same as it has been for hundreds or thousands of years.

(c) MUSKEG AND PETROLEUM EXPLORATION ECONOMICS

W. B. Dingle

In Canada, muskeg and climate cannot be separated. The problems are intensified in that the terrain, in addition to having a high percentage of muskeg, is also interspersed with lakes, rivers, streams, hills, boulders, bedrock, gravel, and sand. On the surface there are various types of soil transformed by rains and snows into muds of every conceivable viscosity and consistency, together with shrubs, trees, and timber. It is varying combinations of all these, together with greatly varying climatic conditions, that create the problems. In the field of transportation (and exploration depends on transportation), vehicles have been designed to overcome any one, or many, of these conditions but it is doubtful if there is a vehicle to overcome them all, when they occur in one area, and at one time.

Transportation as it concerns exploration in the hinterlands must be by air transport of one sort or another, supported by good roads to some reasonably adjacent area. In recent years great advancements have been made in various types of surface vehicles, but the area is so large and conditions vary so drastically, that it appears that all-purpose land vehicles are somewhat "down the road". Advancements in large-capacity work-horse type aircraft of one sort or another bring the era of all air transportation closer. Certainly, one factor which has worked against the use of large load capacity work-type aircraft of modern design and performance has been their lack in this area at reasonable rental rates. High capital costs and spasmodic or spot requirements have kept individual companies from operating their own equipment. Lack of assured continuing business has restricted public carriers from making this type of aircraft available.

Large helicopters or special fixed-wing aircraft could move drilling equipment from local staging points to exploratory sites and maintain the rigs during operations, but aircraft such as these are expensive to buy and to operate, unless the volume of business is large. To do this, companies interested in this type of service would have to jointly guarantee the minimum amount of business to have such an aircraft or aircrafts available in the country permanently. Whether arrangements such as this will come to fruition is a moot point, but it is something that deserves consideration. Certainly, any move along these lines should result in improved economics in exploration work in muskeg country.

This envisions 100 per cent use of air transport in the interests of exploratory drilling in inaccessible areas. Substantial economies can be obtained by taking maximum assistance from the cold weather, utilizing detailed planning, and giving adequate consideration to other economic factors affecting exploration.

There seems to be an ingrown fear amongst operators in this country who carry out programmes in muskeg territory that, under no circumstances, should a drilling rig ever be trapped in the muskeg over the summer - or that an attempt should be made to operate one over the summer in this type of country - the reason being that it is too expensive. Perhaps the truth is that it is too expensive not to do it, when all facts are considered.

It is true that paying standby time on a rig for months or supplying a rig by air, together with airstrip construction costs, can be expensive. However, the end result should be analyzed of allowing these costs to influence decisions. Many exploratory holes are spotted on inadequate information in order to move a rig in, drill the hole, and get the rig out during winter months. Perhaps three more months of technical work would have resulted in a more advantageously located hole and a successful completion to an exploration programme. It could well be that a million-dollar exploration programme has been jeopardized by fear of $100,000 additional costs.

There are other factors that might justify deliberate plans to operate in muskeg country in summer months. For instance, Imperial Oil held a number of reservations in a country heavily covered by muskeg, bisected by major streams but with dry ridges on which a suitable airstrip could have been built. The reservations were in late stages with reasonably heavy retention costs. The whole area was sparsely explored. A hurried effort was made to get a rig in, hole drilled, and rig out, before break-up. The plan was to surrender the reservations if the hole showed no leads, to save substantial retention costs. Unforeseen lost circulation fouled this up. Late in the winter there was no airstrip and no time to build one and it became apparent that the project could not be finished. Muskeg terrain conditions, large rivers to cross, and no airstrip, made it inadvisable to endeavour to keep the rig operating. The rig was brought out and then went back in the next year. Additional land rentals on large spreads of surrounding acreage had to be paid to retain it until drilling could be completed. These additional costs amounted to over $175,000. A planned operation to move the rig in on frost and an adequate airstrip for necessary additional supplies, standby time paid on the rig after completion until freeze-up, and reduced rental payments through acreage surrender at an earlier date, would not have exceeded this $175,000.

Time, as well as transportation, are important factors in exploration, and time, abetted or hindered by climate, is a major factor in dealing with muskeg. In Western and Northern Canada areas, where muskeg is a major factor, land regulations - particularly in the reservation stage - require considerable work in relatively short periods of workable time. It is here that muskeg problems and time are vitally important. Muskeg in this country is not too great a problem in exploration if advantage is taken of frozen conditions in the winter. This necessitates that time be on the side of exploration companies, and this is where regulations and conditions of oil exploration are diametrically opposed.

A physical change in Canadian exploration has been taking place in the last decade; that is, a trend from exploration in accessible areas to more remote localities. Industry has been brought face to face with the major problem of this country's peculiar topographical and climatic conditions. An economic means of conducting year-round operations over muskeg is the largest unsolved problem of its kind. Muskeg has been considered a difficulty in this country for some years but the Industry has tended to look upon it largely as a physical problem and not as one which has long-range economic effects, or one which controls exploration planning. The seasonal operation results in high cost of labour and of equipment which is seldom encountered as severely elsewhere. The operator has to conduct an intensive programme at abnormally high costs for a short period of the year and be content with the results until the following winter.

This planning, cost, and operational disadvantage has not been offset by existing legislation. The legislation in most of Canada has attempted to deal with the problems created by muskeg by allowing for extensions to exploration reservations, based on inaccessibility and difficult terrain. Unfortunately, the regulations enable the operator to obtain extensions for short periods only, albeit frequently. Because there is seldom any assurance of more than one year's extension period, the company is prevented from making long-range exploration plans. This tends to cause the operation to be conducted in a sporadic, unplanned fashion. Because of this and because also of the long-term leases granted by most governments, an operator can merely go through the motions of exploration in order to obtain a lease position which he hopes to explore eventually, or one which he hopes will appreciate in value because of another company's work or a future land shortage.

The operator's difficulty in planning an exploration programme is influenced by another problem which results from legislation. This is the large amount of land held by long-term Crown leases. The granting of long-term leases gradually resulted in an inflexible land position, particularly in the more promising areas. The effect of a relatively inflexible land situation is twofold:-

(1) It cuts activity by failing to provide a means of acquiring wholly-owned holdings, the existence of which is historically one of the basic reasons for a high level of exploration activity;

(2) It results in joint operations, especially in the more prospective areas. When there is no other means to acquire an interest in the area, companies resort to agreements among themselves, wherein the exploration programme is controlled by the terms of the deal, and inherently the programme becomes rigid and difficult to change.

If the more remote areas are examined, it can be seen that they are not receiving intensive exploration in spite of large holdings, grouping arrangements, and the granting of frequent extensions to reservations. The reason for the lack of exploration activity appears to be the involvement of an insufficient number of companies. Not enough companies are involved because the access costs are high, the rental costs are high during the exploration period, and the land is not available except through joint deals. Therefore, flexibility in planning, lower costs during the exploration period, and more rapid turnover of the land in the lease stage, would provide more encouragement.

It is apparent that a substantial rental charge during the exploration phase is detrimental to incentive. It puts a charge against the operator before he has an opportunity to know whether he likes what he bought. This effect is heightened in this age of technology by the relatively long period of time needed to evaluate exploration work properly. Not only is the operator burdened by the substantial rental payment during the early stages of exploration, but his expensive tools (such as modern seismic equipment) provide data which require time-consuming interpretation and study, thereby forcing the operator into more extensions which become increasingly expensive in rentals. Since these extensions usually are granted at the Minister's discretion, the operator must risk his cumulative investment, unsure that he can have adequate time to complete exploration or even make a lease selection scientifically. Of greater importance to some operators is their inability under these circumstances to make long-range exploration plans.

In some areas, the regulations force the operator to conduct actual exploration work in the form of geophysical or geological crews on the reservation lands and give no credit toward continuation of the reservation for work which the operator may have purchased or obtained by trade.

Finding a solution to the muskeg problem is a prerequisite to exploration of much of Canada's unexplored sediments. This is partly a matter of co-operation in transportation and research between Industry and Government, but it is also a problem for consideration by the various authorities who administer minerals. Only by establishing the kind of regulations conducive to co-operation in the transportation and research field, and rich enough in incentive to the exploration investor, can this be accomplished. The policies which govern the disposition of basic economic units of oil exploration, namely, the units of exploration rights to mines and minerals, are the policies which will determine the amount of money invested and the methods employed.

What changes in land regulations would encourage exploration expenditures and result in efficient methods in inaccesible areas?

The first is a shorter term lease. If foreign and Canadian capital are to be attracted for exploration, the opportunity must exist for the operator to acquire wholly-owned lands and not merely farmouts, or high-cost, short-term, obligation-loaded drilling reservations. A short-term lease would enable the land to turn over more rapidly and be available for acquisition as an exploration reservation again. If established operators could foresee more rapid turnover of land, they would be less likely to hold onto their leases so tenaciously. There would be fewer joint agreements and more exploration would be done.

The second would be more flexibility in the regulations during the exploration phase. Reassessment of the obligations with due consideration to time, rentals, work commitments, and terrain, is essential. In some jurisdictions, the rigidity of the regulations forces an operator to do work he does not need to maintain his reservation. More flexibility would allow programmes to be less dependent on terrain conditions and other factors of the northern climate.

DISCUSSION

Brig. Connelly asked for a further explanation of the comments regarding a larger exploration period and a shorter lease time. Mr. Dingle said that in muskeg terrain it is difficult to carry on an efficient exploration programme in the time allotted. Extensions are granted only by dispensation of governmental authority and cannot be counted on. Leases should be more flexible. Also, they should decrease the time that a lease can be held after exploration is completed. This would prevent companies from "sitting" on oil properties.

(d) CONTRIBUTION BY DR. N. W. RADFORTH

Muskeg represents a complex of situations and it must be remembered that they are all related. If one main problem appears solved and consideration of all the secondary problems is forgotten, then it will likely be found that the solution will not stand up for long.

McMaster University has been working on muskeg since late 1945. The success which has been achieved is due to the organization factor of muskeg analysis. If this factor of organization can be established, then one has a basis on which to predict, not simply in terms of physical conditions and matter, but in terms of the actual kind of operation that will be appropriate in a particular area. Basically it is necessary to travel on muskeg, in it, or over it, whichever method can be devised because of the continuing need for a short haul. No one vehicle can be developed to deal with all problems encountered. This is not necessary as various kinds of vehicles can be suited to different situations as determined by appropriate surveys. The essential thing is to think nationally and not just about local muskeg problems. Too much attention can be paid to summer access problems at the expense of the Fall and winter problems which really are the most serious of all.

(e) CONTRIBUTION BY DR. R.M. HARDY

(1) Discussion on Drainage Ditches

The concensus is that they are pretty essential. This opinion is based on valuable experience going back many years. Drainage has been discussed at several of these conferences; the only reason why there has been no rebuttal to opinions expressed this time is because the "opposition" was not in attendance. There is no question that on the basis of valuable authentic experience drainage is essential. However, it is possible to postulate where it is not necessary - for example, in preconsolidation. The type of drainage used elsewhere may not be applicable here. A certain amount of empirical information has been acquired; one of the difficulties which arises is to make the proper generalization from the empirical information which is available. Arising out of discussions at these conferences should be permissible and valid generalizations so that a person without the empirical experience could make an analysis of a particular situation. In northern problems, it depends to whom you go what answers you get to the same problem.

(2) Preconsolidation

There are two schools of thought in this matter of preconsolidation: what is primary and what is secondary consolidation of peat? It may be that arising out of a study of this problem, very significant information may be acquired applicable to organic soils. In the last two days, records extending over a total of 55 years have been mentioned. In one instance it was reported that in primary consolidation there is no settlement problem but that there is for secondary consolidation, in that secondary consolidation is three or four times primary.

(3) Shear Strength vs. Depth

It was reported by Mr. MacFarlane that he found no variation in shearing strength with depth. This is at variance with tests made elsewhere and again is a problem to be reconciled. It is necessary to establish which is right, which is wrong, and, if both are right, then why is this so? If one is to make a rational analysis, this is an extremely important point to be positive about.

(4) Roads on Permafrost

The solution to the problem of road building at Inuvik, for instance, is quite different to the solution to the problems of access at Eagle Plains.

(5) Permafrost Classification

The definition for permafrost as given by Mr. Pihlainen is too general - it is about as general as the word "soil" to designate unconsolidated material. There is a great need for something to be done on sub-classification for permafrost as different materials below freezing act quite differently. We need a "Moses" to lead us out of the wilderness regarding subdivisions for permafrost material, as Dr. Radforth has done in the field of muskeg.

(6) Southern Boundary of Permafrost

There has been some work carried out in the past few years by the Associate Committee on Soil and Snow Mechanics to determine the southern boundary of the permafrost line. There has not always been progress in this direction. In Muller's book, published in 1945, the southern boundary of permafrost was shown. Subsequent discussion questioned the accuracy of the line shown therein, especially the finger coming south as far as Banff. However, permafrost has been observed at Banff in November at 5000 ft. elevation. A good deal of effort was expended to establish this so-called southern boundary of permafrost. The Division of Building Research eventually took its courage in both hands and in the National Building Code put a dotted line across the northern part of the country to represent this permafrost line. However, it only covers the prairies and, in any case, is too high. For instance, at the Thompson development sporadic permafrost has been encountered and this is well below the dotted line. The southern boundary of permafrost surely is a zone, 200 to 300 miles wide, in which it can be expected that sporadic permafrost will be found. The existence of sporadic permafrost depends upon cover, exposure, altitude, etc. It is every bit as important to know where sporadic permafrost occurs as it is to know where continuous permafrost exists. There is an idea that the further north one goes the worse the permafrost problems are. In fact, the reverse is true and thinking should be changed around accordingly.

(7) Heat Transfer

Finally, the matter that needs the most attention "engineering-wise" is the problem of heat transfer conditions in permafrost.

The foregoing remarks are not intended to be particularly critical. Rather, they are intended to point up the discrepancies which exist and the need for further research.

DISCUSSION

Mr. Pihlainen pointed out that there are as many problems in classifying permafrost as there were in muskeg. As a start he suggested looking at two points regarding classification of permafrost:-

(1) Aerial distribution of Permafrost

There have been several attempts at an aerial classification of permafrost (particularly in Russia). There are two types of permafrost:-

(i) Continuous - found everywhere under ground surface; extending to depth.

(ii) Discontinuous - broken by thawed areas. If one goes far enough south, he will find predominantly thawed ground with islands of permafrost.

The line as drawn on maps and referred to by Dr. Hardy represents the southern limit of continuous permafrost. It does not recognize areas of sporadic permafrost. The comments by Dr. Hardy are well taken and the matters he raised are in fact being acted upon. Any line of the sort referred to should be a probability curve. The one shown in N. R. C. publications tends to be on the conservative side.

(2) Classification of Perennially Frozen Soil

There is a classification for frozen soil put out by the U. S. A. Corps of Engineers which is used in a restricted sense in Canada. At the present time, a revised version of this classification of frozen soil is being considered. Within a year there will be some form of classification of frozen soil issued for use in Canada.

Mr. Pihlainen agreed that the greatest problems will occur in the more southern areas of sporadic permafrost. However, it is largely a matter of economics. Successful northern construction has to take into account materials and methods of construction as well as terrain conditions. Dr. Hardy suggested that Roman numerals, or perhaps Greek letters, are required for a classification system. He thought that the whole approach is wrong in establishing a permafrost line on the basis of geographic conditions when it should be defined on the basis of climatological data. For instance, it can be predicted from the climatological atlas that permafrost will exist at Thompson, which is south of the line designating the southern boundary of permafrost.

SUMMARY

In summarizing the discussion, Mr. Hemstock pointed out that Mr. Savage had emphasized that muskeg and permafrost cannot be isolated from one another in the north. He warned that people should be adaptable, they they should work with natural conditions and not against them. Dr. Terasmae has shown how history can be traced from muskeg areas, which may have economic importance. Mr. Dingle referred to going over muskeg, not on it, by means of aircraft. He referred to the time factor and how important it is. His remarks may be summarized under three main headings: Research, Engineering, and Legislation. Dr. Radforth reviewed his long research in muskeg. Now that muskeg has been classified, new avenues of research are opened up. He referred also to the work he was doing in interpretation of muskeg from the air. Dr. Hardy emphasized the lack of information and has warned that engineers should not generalize too much since every case is different.

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CLOSING REMARKS

Dr. Radforth said he felt that progress has been made during this conference. While controversial matters have been raised, he pointed out that we - like the turtle - cannot make progress unless we stick our neck out. He expressed appreciation for the assistance of Mr. Hemstock in helping to organize the conference and in making local arrangements, and also of Miss J. Rogers of Imperial Oil Ltd., who assisted in registration, etc. Dr. Radforth announced that the 1961 conference would, in all probability, be held at McMaster University, Hamilton, Ontario.

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APPENDIX "A"

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A list of Technical Memoranda of the Associate Committee on Soil and Snow Mechanics may be obtained from the Secretary, Associate Committee on Soil and Snow Mechanics, c/o The Division of Building Research, National Research Council, Ottawa, Canada.