Proceedings of the Western Muskeg Research Meeting

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NATIONAL RESEARCH COUNCIL

CANADA

ASSOCIATE COMMITTEE ON SOIL AND SNOW MECHANICS

PROCEEDINGS

OF THE

WESTERN MUSKEG RESEARCH MEETING

MARCH 2, 1955

Technical Memorandum No. 38

OTTAWA

September 1955

FOREWORD

This is a record of the Fourth Meeting of the Muskeg Subcommittee, which was held in Edmonton, Alberta, on March 2, 1955. A list of those in attendance is included as Appendix A. The meeting was the first to be held in Western Canada, and was sponsored by the Associate Committee on Soil and Snow Mechanics of the National Research Council.

Under the direction of Dr. N. W. Radforth, the morning session was devoted to business and to the reading of progress reports of muskeg research which is now underway in Canada. The afternoon took the form of a technical session with Dean R. M. Hardy and Mr. I. C. MacFarlane acting as Chairmen. Four papers were presented and discussed.

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Appendix A - List of those present at the Western Muskeg Research Meeting

Morning Session, March 2

Section 1

INTRODUCTORY REMARKS

by

Dr. N. W. Radforth

Dr. Radforth pointed out that this was the first formal meeting of the Muskeg Subcommittee to be held in the West, and that it was long overdue. Meetings of the Subcommittee have been infrequent, the last having taken place in Ottawa late in 1951. He reported that the working arrangements of the Subcommittee have changed somewhat as business has been carried on mainly through correspondence and the exchange of experience. Although this may appear to be a strange way to approach the subject it was brought about by the diversity in the knowledge of the problems concerning muskeg. It has been only in the last three or four years that the muskeg problem has received special attention. The opening up of the North has brought special problems to light. Because of the new terms of reference with regard to muskeg, the approach to the problem has had to be changed, resulting in this meeting.

The Chairman welcomed all those present, on behalf of Mr. R.F. Legget, Chairman of the Associate Committee on Soil and Snow Mechanics. He expressed Mr. Legget's regrets that he could not be present. Although burdened with a very heavy schedule, Mr. Legget still takes great personal interest in muskeg research, and was most pleased that this meeting was taking place. Dr. Radforth recalled that it was seven or eight years ago that Mr. Legget had consulted with him on the muskeg problem, and had initiated research into that subject, maintaining a personal interest throughout the years.

Section 2

Reports

The Chairman mentioned that Mr. Martineau of the Quebec Department of Highways had been gathering information on muskeg in that province, and a report prepared by him would be presented at the afternoon session.

Report on "Some Engineering Properties of Muskeg" - by C.B. Crawford

In the absence of Mr. C.B. Crawford, Mr. I.C. MacFarlane gave a brief review of this report. He explained that the report represented the results of some preliminary tests on muskeg carried out at the Division of Building Research. Consolidation tests were performed on muskeg samples, and several determinations were made of density, water content, and unconfined compressive strength of undisturbed samples. Mr. Crawford had concluded that the compression characteristics of muskeg depend more on the dry density of the material than on whether the sample is disturbed. Mr. MacFarlane mentioned that these early test results were the beginning of a more extensive program to be undertaken by the Division.

Progress Report - by I. C. MacFarlane

In reviewing his work to date on muskeg research, Mr. MacFarlane said that most of his time had been devoted to a literature review and to the preparation of a muskeg bibliography. He emphasized that this annotated bibliography was a preliminary report. He reported also that valuable personal contacts have been established with other organizations interested in muskeg research: Defence Research Board, Muskeg Research Laboratory at McMaster University, Bord Na Mona (Peat Board) in Ireland, and University College, Dublin. A start had been made on the abridgement of Dr. Radforth's original paper on classification of muskegs for the engineer.

As for the future, Mr. MacFarlane said he planned to continue his literature review and to enlarge his bibliography. A collection of relevant field data will be started, and the information so obtained will be made available to those interested. Eventually, a program of laboratory tests will be undertaken to determine the physical and mechanical properties of frozen and unfrozen muskeg. It is hoped thereby to check the conclusions drawn from the strength tests which were carried out on Irish peats. It is also hoped to correlate Dr. Radforth's classification system with the engineering properties of the various kinds of muskeg.

Progress Report - by Dr. N. W. Radforth

Dr. Radforth reported that the muskeg laboratory at McMaster was interested in extending the classification system for muskeg and bringing it more into line with the problems now arising, and with the needs of the people involved with the material. There is a particular desire to assist those interested in the survey of organic terrain preceding engineering development. He felt a lack of confidence, from almost every quarter, in the problem of reporting and the use of adequate reference terms for muskeg. He hoped to bring these out of the realm of intangibility so that problems of trafficability, etc., could be dealt with. Dr. Radforth said that the McMaster Laboratory had already made some contribution to these problems, but now the basic information must be applied at his own laboratory as well as by others.

Dr. Radforth pointed out that muskeg involved not only material, but also physiographic features which must be brought into the picture and into the definition of muskeg. This is developed more fully in the paper on subsurface summer ice conditions, recently published by the Royal Society*. The size and general constitution of peaty materials and the conditions under which they were found are all important to muskeg study. He considered therefore that his approach to the muskeg problem was justified.

Reference was made to Handbook No. 1 (Organic Terrain Organization from the Air, Altitudes less than 1,000 feet) as a means of facilitating the approach to organic terrain survey. This handbook is being brought out under the auspices of the Defence Research Board, and will be available to all interested persons.

As to the future, Dr. Radforth is concerned with an extension of the classification system for muskeg and indicated that field work on specific areas, taken as type cases, should be undertaken. He also referred to his work on subsequent handbooks (No. 2, dealing with altitudes from 1,000 to 5,000 feet, and No. 3, for altitudes up to 20,000 feet). Three handbooks are necessary because as one proceeds to a higher altitude, ground patterns change and shapes take on a different meaning.

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* Radforth, N.W. Palaeobotanical method in the prediction of sub-surface summer ice conditions in northern organic terrain. National Research Council, Associate Committee on Soil and Snow Mechanics, Technical Memorandum No. 34, March 1955, 64p.

Research will also continue into subsurface conditions. Dr. Radforth recalled an observation made by Dean Hardy several years ago, to the effect that it is important not only to interpret muskeg from higher altitudes, but that the interpretation must be extended below the surface of the ground. In this regard information already available has been utilized.

In conclusion Dr. Radforth said that he thought that now was the time to bring in an important component of muskeg -- the highly mineralized matter directly beneath the peaty layer.

Report on the International Peat Symposium - by I. C. MacFarlane

Mr. I.C. MacFarlane briefly reported on the International Peat Symposium which was held in Dublin, Ireland, during July, 1954. The Symposium was sponsored by the Bord Na Mona and brought together more than 200 delegates from 19 countries to hear and discuss the 65 papers which were presented. The Bord Na Mona have since published a volume made up of the papers which were read at the Symposium. The conference covered a wide field of subjects, including classification of bogs and peats, survey methods, milled peat and sod peat production methods, combustion in large and small boiler furnaces, gas turbines, gasification plants and domestic appliances, wax extraction and reclamation of bogs with and without fuel winning. Except for one paper, little was said of the engineering properties of peaty soils. During the session on classification, the ambiguity of terminology in technical literature on peat was deplored. Recommendations were made for the establishing of an International Peat Institute tocorrelate all phases of peat research. One Canadian paper was presented by A.A. Swinnerton of the Dept. of Mines, which gave the history of the peat industry in Canada. A report from Ireland indicated that work is being done in attempting to correlate surface vegetation and subsurface conditions of a peat bog. Mr. MacFarlane pointed out that the present intense interest in peat problems is due largely to the fact that peat areas represent land which is not highly utilized. This presents a challenge to the botanist, agriculturalist, forester, industrialist, and engineer.

Section 3

Muskeg Bibliography

Mr. MacFarlane spoke briefly about the annotated muskeg bibliography which he had prepared. He re-emphasized the preliminary nature of this work, stating that he hoped it would be extended as soon as time permitted to the reading and abstracting of further literature. The 90 references included in the bibliography are selected as being somewhat representative of the literature which is available on organic soils. They are grouped into ten sections, depending upon their approach to the problem, and cover most aspects of interest in a study of organic soils. They are as follows:

Section A: Extent of Organic Terrain (4 references)

Section B: Origin of Organic Deposits (5 references)

Section C: Classification (5 references)

Section D: Surface and Subsurface Characteristics (11 references)

Section E: Properties of Organic Soils (10 references)

Section F: Road Construction over Organic Terrain (27 references)

Section G: Bog Blasting (10 references)

Section H: Trafficability Problems (1 reference)

Section J: Miscellaneous Engineering Problems (11 references)

Section K: Utilization of Organic Soils (6 references)

This bibliography has been published by the Division of Building Research as Bibliography No. 11, and may be obtained from the Publications Section of the Division.

Afternoon Session, March 2

Section 4

Primary and Secondary Access over Muskeg in Forestry Practice

by

W. C. Harrison

I have been asked to say something about "Primary and Secondary Access over Muskeg in Forestry Practice". In simpler terms, this could be stated as "Road Building in the Bush". I have found out by bitter experience that the problems are numerous, the worries are endless, and the costs are dumbfounding. I have no knowledge concerning the terms of reference of your Committee; neither do I know its objectives. If the Subcommittee on Muskeg arrives at a method of dealing with organic terrain, as I understand muskegs are now called, the industry I represent would be very interested.

My experience is limited to the muskegs of the northern Ontario clay belt region and floating bogs of northeastern Manitoba. Of the two, I believe the latter is the worse.

When I first went to the bush of northern Ontario and spent long periods in locating roads, with the least amount of grade, to extract pulpwood, I believed that muskegs were depressions in th general topography of the area. This, of course, was before the bush was cut off. Later, I discovered that they were saucer- or disk-shaped areas, each with a slight incline before the actual edge of the muskeg was reached. This, then, was the greatest excuse to avoid crossing a muskeg; but it was not always possible. I am talking now of a situation when winter roads were constructed simply by cutting off the trees flush with the ground, keeping the snow tramped down to allow frost penetration, and maintaining a hard surface to haul on. This was during the time that logging operations started in November or after freeze-up and finished around the middle of March.

A change of conditions has been brought about by many factors, particularly since the end of World War II. For example, logging operations have been pushed back from water delivery systems. Labour has a different attitude towards woods work. There is the advent of specialized equipment; the use of helicopters, and the change-over from sleigh hauls to truck trailer hauls. There is also the need for better fire detection and suppression systems; even the needs of the tourist industry must be considered. All of these factors, and probably many that I have overlooked, are demanding better roads throughout the forest.

I would like to spend a few minutes now to talk about primary access roads. The type of road that is built in the paper industry depends on the use to which it is to be put. For example, if it is to be used as an access road only with no hauling of heavy loads of pulpwood over it, the standard of construction is much lower than if the road is to be a combination access and haul road. When I speak of construction standards, I refer to those which are set by each company in our industry because each pulp and paper company for the most part pays for the construction of its own roads within its timber holdings or pulpwood limits. These are basically private roads over which the company concerned has complete control. In constructing an access road, we choose the best location possible, are not too particular about the amount or extent of the grades, and try to avoid crossing muskegs. This type of road usually follows a river where there is always some type of building material immediately adjacent to the drainage. This material is used to build up the grade and provide an 18- to 20-~~foot~~ inch crown, with a 3:1 slope which is the angle of repose for clay. Construction can be done almost entirely by machinery, by using bulldozers to clear and grub, draglines to throw up the grade, scrapers to touch up the rough spots, graders to level and shape the crown, and front-end loaders and trucks to carry out the gravelling. The use of manual labour is confined almost entirely to the preparation for and installation of culverts. We have found that such a road might be longer and more crooked than the shortest distance between two points, but it is usually a stable, relatively low-cost road.

If a road is to be used for both access and hauling, much more thought and care must be given to its location, the standard of construction is much higher, and perhaps most important of all, grades must be held to a maximum of 2 per cent. In this case, it is desirable to have as many long tangents as possible and as few curves as possible. Faced with these requirements, in many cases it is not possible to avoid crossing a muskeg. I have found that it is useless and more costly to try to build directly on top of the muskeg, say by placing corduroy and hauling in fill material to build up the grade. When it is necessary to cross a muskeg, it is important to study the physical characteristics. Although muskegs look alike, there are tremendous variations in their composition and depth even above the permafrost. There may be shallow spots which can be located by observing the tree cover as well as by actual testing. It is important to make this study of the physical characteristics because in locating a road, one would not deliberately run through a lake 50 feet deep, and many muskegs are worse. We have found that extra time spent in road location and muskeg testing can save many thousands of yards of fill and, consequently, many dollars.

Thus, with the location of the road carefully selected through a study of aerial photographs and a painstaking field investigation, we proceed with the construction. Having chosen the best location across the muskegs that cannot be avoided, we now must deal with the muskeg. Up until now, construction has proceeded reasonably well, but new procedures must be developed. For instance, the muskeg will have to be cleared by hand as it is too risky to send a 20-ton tractor over an open muskeg in summer or even in winter if there is an insulating blanket of snow covering the ground. The dragline must be equipped with pads, which are made from five logs, 8 to 10 inches in diameter and 16 feet long, cabled and bolted together. These pads are placed under the tracks of the dragline and provide some footing and a distribution of the weight. The dragline must cast off all the muskeg covering from both the centre of the road and the ditches, digging down until the subsoil is reached. It is only then that the operator can start thinking about building up the grade. The height of the grade is determined by the gradient on the road, the necessity to obtain drainage, and the desire to obtain quick drying.

Offtake ditches are required and we do not hesitate to build these as we have found that they are worthwhile. The frequency, size, and length of offtakes depend on the general conditions, and I cannot give any set rule for putting them in except to say that they are an important adjunct to the road and should never be neglected.

What I just described holds true mainly for road building over the muskegs of northern Ontario. Elsewhere in the location line, the problems are the usual ones, i.e., removal of trees, clearing to the subsoil, building up the grade above the waterline, ditching, installing culverts, removal of boulders, cutting down to the required gradient, and surfacing. If we can find an esker on the location line, we follow it as this type of ground affords the cheapest construction cost.

We have found that the cost per mile over muskeg is about triple that for constructing a road over ordinary swamp country, highland, and sandy areas.

Gravel pits are usually hard to find and never seem to be close to the road job, and the search is for cheaper surfacing material. Although gravel is excellent surfacing material for our type of bush roads and the cost high, it is still cheaper than other types. However, we have considered other treatment of the surface, such as soil cement, calcium chloride, waste sulphite liquor from our own mills, and others, but we always come back to gravel. The other types of surfacing are much more costly at first, besides being high for maintenance as they require specialized equipment. Gravel can be hauled from out-of-the-way places in winter and stock-piled for summer use or even put in place during the winter.

I would like now to talk about the equipment that is used over these roads and the loads that they must bear. If the road is used for access purposes only, i.e., freighting in camp building materials, moving equipment, handling camp supplies, transporting men, moving gas and oils, etc., the loads are relatively light and not frequent. For example, 3- or 4-ton trucks are used hauling loads of 6 to 7 tons, tractors weighing 20 tons are moved on low beds, light trucks and cars travel the road. Mainly, the use is not constant and trips with one type of unit may only be twice a week. In wet weather, trips may be conveniently postponed and the muskeg road allowed to dry out. In this way, we are able to keep maintenance costs down to a minimum. Of course, in winter there is no problem for, once the frost sets in, it becomes a matter of keeping the snow off to permit easier travelling. The purely access road will allow speeds of 20 to 25 miles per hour in summer and slightly higher in winter, depending on conditions.

There is a trend in our industry to carry out summer hauling of pulpwood over the all-weather roads that have been built as combination access and haul roads which, as I have pointed out, do cross muskegs. Specially designed trucks and semi-trailers are being brought into use, which in themselves weigh 20 tons or more. On the semi-trailers, we load seven to eight cords of green pulpwood, each weighing about $2\frac{1}{2}$ tons, or a total load of $17\frac{1}{2}$ to 20 tons. The total impact on the road then is around 40 tons and might be greater. There would be several such units, each making four or five trips per day over the road. The speed of these hauling units is usually limited to a maximum of 15 miles per hour while under load and 20 miles per hour during the return trip. Therefore, you will see that our muskeg haul roads take a lot of abuse and must be properly designed and built to withstand the heavy loads.

What I have said mainly applies to northern Ontario. The muskegs in northeastern Manitoba are much worse inasmuch as the entire forested area is broken up with very large floating bogs which have little or no tree growth on them. So far, there are not very many all-weather roads built in this section of the Province, but muskegs and bogs have been avoided in their route. In my Division, we have only one all-weather access road, built by the Company, which follows a river drainage. There are soft areas even in this location from which we have had to discard the top organic material and get down to the solid clay soil. You are perhaps aware that the best farming soil in Manitoba is a heavy black muck, which is very fertile. This type of subsoil extends into the forested areas and is not at all like the gumbo or podsol soil of the clay belt. I was surprised to note that forested areas, cleared off in the fall or winter, were growing an agricultural crop the following summer. This will give you some idea of the growing qualities of this soil. Due to the usually low annual rainfall, which is 16 to 17 inches, and lack p.10 line 1 read "... There are a lot of roads in Manitoba that are only graded clay."

of gravel, ~~there are a lot c~~
Our access road is gravel surfaced only in the worst spots, and we have found that by having the right-of-way cleared to 150 feet, drying is very rapid, and we experience very few delays during the open season due to the condition of the road. This is important because with a low annual rainfall, the forest fire risk is greatly increased and we have to be able to get in with men and equipment with the least possible delay.

The general topography in our part of Manitoba is flat, with rock ridges which can be circumvented when a winter haul road is being located. The timber is not too heavy and winter haul roads can be bulldozed for as little as $150 per mile. It is our practice to do this work in winter as it is impossible to do summer bulldozing over the muskegs and particularly floating bogs. Vegetation is completely cleared off and stumps grubbed out. Thus we have a surface which can be easily levelled once the frost has set in. We keep the snow cleared off, and as a result, cars and trucks can run anywhere over these bulldozed roads in the winter. Pulpwood is hauled by truck, truck and semi-trailer, truck and sleigh trains, and by tractors. We have found that this type of road construction is the cheapest and so far we have been able to avoid costly construction of graded roads over the muskegs.

However, there is one problem that faces us each year, and that is the breaking out of these winter haul roads after the snow has come and before the frost has a chance to penetrate. The muskegs and bogs do not freeze to any appreciable degree if there is an insulating blanket of snow. Last fall an abnormal amount of rainfall was experienced which left the swamps supersaturated; the snow arrived before the frost. Faced with preparing a road, we were doubtful as the advisability of sending a snowmobile over the bog, and so we sent men with snowshoes in to tramp down the snow. Then, after some frost came, a snowmobile was passed over it. While waiting for the road to freeze, progressively heavier tractors were sent over it but this was discontinued after a tractor sank in the bog, and later a truckload of pulpwood was forced off. The extraction of these units meant a loss of time, money and production. I mention these things so that you can appreciate why ours is basically a winter operation in Manitoba.

Suffice it to say that all-weather roads built to date are access roads. Haul roads are bulldozed and only used in the winter time, and we are very careful in the use of equipment to break out roads until we are sure that a good solid bottom has been prepared.

Now I would like to say something about secondary access, which in my mind, is simply a question of making what we call a tote road. In our business, a tote road is just a trail that has to be used in the open season for infrequent trips to supply a camp, or construction job, but may also be used to transport fire fighting equipment. It always follows the line of least resistance and stays pretty much to the high ground. It may be crooked or straight, depending on the lay of the land, but invariably is never over 30 feet wide. A team and wagon may be used on it or a small tractor with a jumper or sloop. The loads never exceed a ton and are usually much less. There are several units being developed by various equipment manufacturers for use on such roads. It was my privilege to see one of these units, which I think would be useful to us, being tried out last summer, near Chip Lake just west of Edmonton. The manufacturers of Bombardiers have turned out a small light tractor-type snowmobile, which they are calling the J 5. This is a one-man unit, which can haul a wagon, sleigh, or sloop, and I believe is strong enough to haul pulpwood in the winter. I am greatly interested in this unit. Weighing slightly over a ton, it can be used not only for toting, but also to break out the winter haul roads over the bogs without too much danger of becoming marooned because it is supposed to float. There are hand tractors on the market which can handle fire fighting equipment and which can be assembled and disassembled in a matter of minutes by one man.

These developments, I believe, are limited in use to the tote road phase of our operations as the trend is toward more and better all-weather roads to speed up operations, improve efficiency, and increase production.

Methods of building a tote road have not changed very much in the last few years. They are usually cut by hand, with the trees cut flush to the ground. The reasons for this are that, in the first place, the surface is not disturbed and secondly, the root system of spruce being shallow, a bearing surface is provided. When it is necessary to cross a swamp or muskeg with a tote road, all the brush from the tree tops and even the main stems of the smaller trees are thrown right across the road. This provides a bearing surface for the freighting unit and helps hold it up. Sometimes it is necessary to lay corduroy in the road in the really bad places, but this is usually avoided as it is costly and must be kept in good repair.

Pole tracks and plank roads were considered a satisfactory means of crossing muskegs with tote roads, and for some places, they were the best methods. I imagine you can still see the remains of some of the old pole tracks and plank roads that were in use by the Eastern Canadian pulpwood industry. These types were costly to build and expensive to maintain and, as a result, were only used when no other method could be found. I am not aware of any pole tracks or plank roads presently in use in Eastern Canada, although there may be some in a few very isolated spots. The trend is more and more to all-weather access roads which, even though by comparison costly to construct, are cheaper in the long run because of the resulting increased volume and production.

It could be safely said that winter roads over muskegs are secondary access even though their prime purpose is for the extraction of pulpwood. If we consider them as such, then the following points are of interest.

With the long, cold Northern Canadian winter with no real thaws until break-up, the muskegs do make the best haul roads because they are generally flat and straight roads can be laid out. Once cut, they do not grow up again for at least 50 years and perhaps more. They can be cleared very cheaply. Provided an operator is willing to take a chance with his equipment in breaking the road, the wetter the muskeg, the better the road because all the holes fill with water and freeze like a lake. In this condition, they will support heavy loads because of the fibrous material that freezes into the ice. Without cold weather, freezing conditions and long winters, the Eastern Canadian pulpwood industry could not take off its annual harvest of about 10,000,000 units. Consequently, the pulpwood logging operations are mainly winter propositions.

Access roads over muskeg for logging operations serve as a means of fire protection as well, and for this purpose there are not enough roads throughout the forests of Canada. Industry is constructing as fast as conditions will permit and governments are doing their part, but it is not fast enough as witness the huge areas that are burned annually because they cannot be reached quickly by men with equipment. All large fires are small ones at the start, and it is important to attack them when they are small. It is true that aircraft plays an important part, and of recent years, the helicopter has become a fire fighting unit. But think how much more effective man could be if the forests were accessible through an adequate network of roads. The time will come no doubt when such will be the case, but in the meantime, we must content ourselves with fighting the muskegs, and, until some economical solution is found to the problem of getting across them, we will go on "fighting" them.

In conclusion I would like to make a few general observations.

We have found that roads should be cut a year ahead of operations as bulldozing usually makes the frozen crust of the muskeg or bog very rough and we have found this will settle down during the summer.

Any snow at all, even 2 inches, will retard the freezing of a muskeg. In fact, we have found that a muskeg with no snow cover and exposed to extreme low temperatures might not freeze because any moss protruding above the general water-level makes perfect insulation.

Snow or no snow, muskeg roads have to be packed down until the water comes up. This is for a winter haul road. For an all-weather graded road, we have found that the grade has to be 5 to 6 feet above the water-level.

Packing the road down to obtain a bottom is the first and most important operation in preparing a winter haul road.

Once the muskeg is frozen down 4 to 5 inches, we plow off any excess of snow that has not been frozen hard.

The road has to be dragged to cut off the high spots and fill the holes. Several trips with the drag are required, with increases in weight being added after each trip, to complete the bottom for a perfect road.

Just as it pays to go out of your way to avoid deep muskegs on a graded road, we have found that it pays to follow these with a winter haul road.

Since the war, aerial photographs have become the loggers' maps. The species of timber can be easily discerned. A logger's knowledge of trees can usually tell him the depth and nature of the soil they are growing on. This is important because it eliminates costly field investigation.

Our access requirements over muskeg, whether primary or secondary, are unique in that they must first of all serve a prime function which is pulpwood logging. We are interested in the cheapest construction methods, which at the same time will be lasting for the tenure of the areas that we have under license. Our traffic is controlled, and our equipment might be called specialized. Unlike public highways, we can set up our own standards to meet the conditions we have to work with. Thus I would not promise to give advice on how to build roads in muskegs because our policy of following drainages for all-weather roads and adequate location surveys have kept us away from the spectacular problems that require spectacular solutions and costs.

Discussion

The Chairman thanked Mr. Harrison for this report and opened the meeting for discussion. Dr. Radforth brought to light different techniques used in road building over muskeg. He stated that various companies adopt certain methods to deal with their own problems, and use those methods which seem best for their individual needs.

Section 5

Engineering Characteristics of Western Muskeg

by

Dean R. M. Hardy

This paper will review what is known of the engineering properties of muskeg and attempt to delineate that which is not known but might be of value to those concerned with problems of access over muskeg areas. It is also intended to direct attention to research that might be undertaken on the subject.

Organic terrain, as defined by Dr. N.W. Radforth, is the result of the growth of organic material under conditions of excessive moisture and with only slight oxidation of the dead material. The wet conditions conducive to muskeg growth are the result of poor drainage in soils of silty or fine sandy types immediately below the ground surface. These are usually underlain by highly impermeable soil types such as clay, shale or rock, so that a "perched" water table exists above the hard bottom.

A wide variety of muskeg conditions are encountered in nature with degrees of supporting power ranging from that of a heavy slurry to that of soft mud. The depth to the hard bottom is a factor of considerable interest and it has been found that this varies widely in different areas. In Ontario the Department of Highways has reported that the depth to hard bottom seldom exceeds 15 feet. However, in Alberta the petroleum exploration people have found it to extend to depths of 50 to 60 feet and, occasionally, even more. At a location west of Edmonton the hard bottom was computed to be at a depth of 150 to 160 feet.

It is characteristic of saturated fine sands and silts in a loose state that they have low shearing strength and are readily liquefied by disturbing forces. They tend to "quick" when distorted or disturbed under vehicle loads. This is one reason why roads floated on the top of muskeg get out of shape so quickly.

The phenomenon of liquefaction is of considerable interest and one about which very little is known concerning its fundamental causes. A road built over loose saturated silt or fine sand may be capable of satisfactorily carrying a single pass of a vehicle with no apparent damage to the road-bed. However, if say ten vehicles, one after the other, are moved along the road gradual liquefaction of the subsoil may occur and finally the road becomes impassable. With such a loading condition - that is, several vehicles travelling on a close time interval - the best remedy for the liquefaction effect is to remove the traffic from the road for a period to permit the soil to "set up" again. There is a real need for research into the mechanics of the liquefaction of loose saturated silts and fine sands.

The fine sands and silts characteristic of soils supporting muskeg growth are of a type ideal for ice segregation, that is for the formation of ice lenses in the soil, under freezing conditions. Thus road-beds built on muskeg are subjected to severe heaving during the winter, and the formation of serious frost boils during and immediately after the spring break-up.

The fine sands and silts also constitute the most treacherous forms of permafrost in far northern regions. In these soils the formation of the permafrost is usually accompanied by the growth of substantial ice lenses. The muskeg cover in such areas provide an excellent insulation for the permafrost and consequently the thickness of the active layer, that is, the depth of thawing in summer, may be only a few inches below the organic cover. However, if the muskeg is removed or if it is compressed by a road-bed fill, its insulation value is lost and an active layer several feet thick may develop in the summer with disastrous results to the road. Accurate data on the insulation characteristics of muskeg are not available and here again is a field for research.

Standard techniques for road construction in muskeg areas involve floating the road-bed on top of the muskeg with or without the use of "corduroying" or "punchin"; displacing the underlying unstable material, thus sinking the road embankment to a stable bottom by means of blasting, hydraulic pressure or simply weight of embankment; or by pre-consolidating the underlying unstable material by the use of sand drains and a surcharge of embankment material.

The hazards in floating the road-bed on the muskeg are, first, that if a certain limiting height and cross-sectional dimension of embankment are exceeded then the underlying material will be failed in shear; second, large and irregular settlements are to be expected and third, serious damage from frost action may occur. If the soil underlying the muskeg is failed in shear then at such locations the construction has, of its own accord, reverted to a case where the displacement technique must be used.

A shearing failure develops by displacement of the soil below the road-bed extending down to the top of the hard bottom material. The soft soil is displaced laterally and forms a series of mud waves for a considerable distance on both sides of the road-bed.

Theoretically, the safe embankment height against a shearing failure and the magnitude of settlement to be expected can be computed but such computations require a knowledge of the physical properties of the muskeg material. A height of 10 feet was arrived at in one such computation in my own experience. This was subsequently proven to be correct within an accuracy of about 10 per cent by failure of the embankment where the computed height was exceeded.

This same case permitted a computation to be made for the average shearing strength of the wet silt within the zone of failure below the muskeg. It worked out to be 82 to 84 lb. per square foot. This is an exceedingly low shearing strength and means that the soil is so soft that it cannot be successfully sampled and subjected to laboratory strength tests with any of the conventional methods of sampling and testing. The shearing strength therefore can only be determined by computation following a survey of sections which have failed under load or by in-place shearing strengths using a vane borer or penetration tests. However, only a very few such strength determinations have been undertaken and only the most meagre data are available concerning the range of shearing strengths of muskeg soils. The successful application of analyses of the safe height of road embankments placed on muskeg awaits the results of further research on the strength of the soft saturated soils underlying the organic cover. In-place tests using the Swedish vane borer or alternatively penetration tests appear to offer the best possibilities for determining the shearing strength of the soft saturated soils below the organic cover. However, despite the lack of soil data the floatation procedure offers the most economical method at the present time for the construction of low cost or temporary access roads over muskeg areas.

The question is frequently asked: what is the effect of placing "corduroying" or "punchin" on top of the muskeg before building up the fill? It will have no value in increasing the stability of the embankment against a shearing failure in the soft wet subsoil. However, it will help to distribute the load over the surface of the muskeg, thus preventing local failure by rutting, and it also will have a beneficial effect in reducing the susceptibility of the underlying soil to liquefaction from vehicle loads on the road.

There are, in general, four displacement methods which have been successfully used in building road embankments over muskeg. The first of these involves raising the height of the embankment until a shearing failure occurs in the soft wet subsoil. Additional fill is added until the soft material is completely displaced and the embankment rests on the hard bottom. The procedure is somewhat wasteful of fill material and does not produce a particularly stable embankment. Considerable settlement and distortion usually follows but it is less than would occur by floating the fill on the muskeg. The economical use of the method is usually confined to conditions where an embankment is required of a height such that the subsoil would be failed in shear in any event.

The second displacement method involves the placing of dynamite charges in the soft subsoil below a fill floated on the muskeg. The dynamite blast displaces the soft soil laterally and the embankment fill drops to the hard bottom. A more stable fill results than with the method of gravity displacement. The method is also applicable to conditions where the height of embankment required is not enough to produce a shearing failure of the wet subsoil and when a more stable embankment is required than could be secured by floating the fill on the muskeg.

The third method is identical with the second procedure except that hydrostatic pressure produced by pumping into grout points below the fill is used to displace the soft subsoil and permit the fill to drop to the hard bottom.

The fourth method involves the use of vertical sand drains in the soft subsoil with a surcharge loading the embankment fill. Rapid consolidation and increase in shearing strength of the wet subsoil is induced after which the surcharge load is removed. More specifically 12- to 18-inch diameter casing is driven vertically through the soft subsoil, the casing is cleaned out and the hole fitted with coarse sand as the casing is withdrawn. These vertical sand drains are placed on a spacing of approximately 10 to 12 feet. A sand blanket is then placed on the surface and the embankment fill built up on top of the blanket to a greater height than the finished grade. The exact height of fill is computed on the basis of the subsoil characteristic, the spacing of the drains, and the number of months that the surcharge load can be left on consistent with the construction schedule. After several months the surcharge load is removed and placed elsewhere. The procedure can produce a highly stable road surface but it requires a high degree of engineering skill to successfully apply the method. It is also expensive. It has been successfully used on sections of the New Jersey Turnpike in the U.S.A., as well as on a number of industrial plant sites. However, to the best of my knowledge it has never been used in Canada.

Failure conditions in the soft subsoil are always accompanied by substantial deformations in the soil and surface of the embankment fill. In highway work the criterion that is used for the design of asphalt pavements is a surface deflection under wheel loads not exceeding 1/2 inch, or even less for high quality roads. However, on muskegs a much greater surface deflection can be produced by a wheel load without it necessarily breaking through into the soft subsoil. Taking this factor into consideration leads to the possibility of using very flexible surface mats on muskeg to spread the wheel loads to the soft subsoil. A "basket" or a "membrane" effect is secured in spreading the load. This principle has been taken advantage of in the design of some of the tracked equipment presently used by the petroleum exploration people in muskeg areas.

Satisfactory theoretical analyses are not available to permit the spread of load from a wheel through a highly flexible mat to be computed. This problem offers one of the most promising avenues for research to assist the petroleum exploration people in their problems of access over muskeg.

In conclusion, I would like to emphasize that in my opinion the first step which should be taken in working on the problem of access over muskeg is have an exchange of ideas and experiences between the practical field operators of the petroleum exploration firms and those who have a scientific interest in the soil action involved.

Discussion

The Chairman thanked Dean Hardy for his illuminating talk and opened the discussion by asking if Dean Hardy did not think there were Canadian muskegs on which engineering tests could be performed, as was the case in Ireland. Dean Hardy replied that the Irish peat could be handled as a soil and soil mechanics tests carried out on it, but it is in a much more decomposed state than are our muskegs.

In answer to other queries, Dean Hardy emphasized the importance of drainage in construction over muskeg. He also suggested that the railways might have some information on construction over muskeg. With regard to the sand drain method, Dean Hardy mentioned that it involved some controversy. A bulletin from the Highway Research Board suggests that the method is not too effective. However, from information available from the construction of the New Jersey Turnpike, the A.S.C.E. recommends the system. It is possible, though, for bands of clay and layers of fine sand to cut off drainage through the sand in the drains.

Section 6

Muskeg Problems in Quebec Highway Construction

by

J. O. Martineau

Assistant Chief Engineer

Department of Roads

Province of Quebec

(Read by Dr. Radforth in the unavoidable absence of Mr. Martineau)

Road building through muskeg has never offered great difficulties in Quebec, except in some very particular cases. In the southern part of the Province, in which is to be found the greatest mileage of the highway network, terrain of this nature is rare and generally is of small extent. For this reason, it can often be avoided without much inconvenience, or worked through without much difficulty.

For many years, until about 1930, the technique of building roads through muskeg consisted chiefly of the laying of a mat made of logs and brush, covered with earth to a depth of a few feet. This proved to be adequate for the light vehicles in use at the time and also as a foundation for the gravel surface built up by the addition of granular material as required.

Even in those days, however, notable failures occurred, particularly at culverts and bridge approaches. This was due to the practice of some municipalities of building, on such terrain, embankments consisting of heavy material such as field stone, or gravel containing large stones and small boulders. Gradual subsidence occurred, even under light traffic. The repeated addition of such material, making the embankment still heavier, resulted in further and faster subsidence. In one particular instance, on the Lost River road near Lachute, a bridge and its approaches, which were about three feet above ground on one day, were found to be six feet under water the next day.

However, the development of heavier traffic brought some changes in the manner of dealing with organic terrain. For example, one of the factors needing greater and greater consideration in the planning of adequate transportation facilities was directness of route to reduce mileage, curvature and cost of transportation, and to increase safety and comfort. More than ever it became preferable to go through such terrain rather than around it.

Furthermore with the advent of very heavy vehicles and heavier and faster traffic, it became necessary to build hard road surfaces. The use of mats then proved to be inadequate, particularly due to the variation occurring in the degree of subsidence over the length and even over the width of the road-bed. For instance, if the loads carried in one traffic lane were greater than those in the other, then the subsidence of the road varied accordingly. Consequently, other methods of securing a more stable base had to be considered.

In the shallow organic terrain, it was found practical to remove all of the objectionable soil and to replace it with good material. Thus, a very stable base was obtained. This practice is still being followed in all such cases on important roads.

Such a method, however, was found to be too costly where the organic soil reached a certain depth. So it was that, in 1931, a new method (already used in the United States) of sinking good material by blasting sideways the objectionable material, was resorted to in the reconstruction of the Montreal to Sherbrooke highway, east of Lake Orford. In the previous ten years two culverts had been lost completely over a stretch of this road.

First, a fill of stone, gravel and sand was built to a depth two feet greater than that of the soil to be blasted, as revealed from previous soundings. Then, two rows of blasting holes were dug extending along the whole length of the fill, about five feet from the centre line. They penetrated the whole depth of the fill and one-half the depth of the organic soil to be removed. These were blasted simultaneously. Next, a similar series of holes were dug along the outer part of the fill and again blasted simultaneously. It was then found that the fill had completely subsided and had displaced the underlying organic material. About 2,400 cubic yards of fill were used over a stretch of about 200 feet long, reaching a depth of some 35 feet at a certain point.

By far the most difficult case ever encountered in the Province was that of the Sherrington swamp, some twenty miles south of Montreal. For the purpose of directness of route, and to reduce the cost of the right-of-way needed for the construction of the new four-lane divided highway between Montreal and Champlain, New York, it was decided to go through this swamp for a length of 8,900 feet. Soundings revealed that over a great part of this swamp the organic soil reached a depth varying from twenty to fifty-five feet.

A small shallow stream, the Montreal River, crossed the swamp. The Provincial Department of Agriculture had decided to dig out this stream, making it ten to twelve feet deep, for the purpose of draining the surrounding land. It had been thought that this work would result in the consolidation of a sufficiently deep layer of organic soil to permit the building of the highway over at least some parts of it. However, drainage did not prove to be a very great advantage because of the great depth of the organic soil in general. The construction method which was tried in this location consisted of building a very heavy stone fill, the toe of which was overloaded with fill material for forced subsidence, pushing the organic soil sideways. The fact that as much as 5,000 yards of stone per 100 feet was sunk in this manner proved that some degree of success had been achieved.

Unfortunately, this method was not entirely successful since the underlying inorganic soil was not sufficiently consistent. What was really obtained by this method was, so to speak, a floating fill with possible and even certain subsidence under vibration by traffic as was later revealed.

The four-lane highway, of cement concrete construction elsewhere, was built over the swamp with only three lanes with a bituminous pavement, in order that it could be repaired more easily. It will probably be many years before this section of the Montreal to New York highway can be rebuilt as originally planned.

Of late, one of the most important muskeg areas to be dealt with in the Province is that of Havre St. Pierre on the north shore of the lower St. Lawrence River, where a new secondary type gravel road is to be built between Havre St. Pierre and Mingan. Havre St. Pierre is surrounded by a large expanse of organic terrain and the only possible location for the new road is through this terrain. A railroad had been built by the company operating the Allard Mine, located about thirty miles from Havre St. Pierre, and untold difficulties had been met with during and after the construction of the railroad.

This muskeg extends some four miles between Havre St. Pierre and Mingan. From the air, the terrain looks like a leopard skin, being dotted with numerous little lakes. The muskeg skirts the St. Lawrence River and is crossed by two important streams, the Ainsly and Romaine rivers. It is about ten feet deep and lies on a sand bottom.

Since the road was of secondary importance, it did not seem justifiable to excavate or to blast the organic soil. Numerous gullies existed so it was decided first to dig ditches on both sides of the proposed road. A year later, the ground-level was found to be two feet lower than it originally had been. The dried organic surface layer had gained important supporting power. It is hoped that before long this muskeg will have dried deep enough so that the projected secondary type gravel road may be built over it.

On the Talbot Boulevard, between Quebec and Chicoutimi, numerous muskeg areas were encountered, none of which were of great importance. All of the organic soil was excavated or blasted. However it appears that in one particular location, near Lake Sept Iles, the contractor, for some reason, had failed to remove all of the organic soil and trouble soon developed. The weight of the fill was pushing the remaining organic soil sideways causing important subsidence of the road-bed and pavement. As this occurrence was being observed, a tour of this highway was made by Dean R. M. Hardy, of the University of Alberta, accompanied by engineers of the Department of Roads. At his suggestion, a counterweight fill was built on each side of that small section of the highway, and no further trouble has been experienced.

In the Abitibi region, numerous muskeg areas exist, varying from three to ten feet in depth and lying on a very soft, silty clay bottom. Several road sections have been built over a log and brush mat, and additional gravel has to be spread now and then where subsidence occurs. At Macamic, soundings have revealed a layer of three feet of organic soil overlying a layer of approximately thirty-five feet of this kind of clay. The problem here, as often met with elsewhere, is not that of dealing with the organic soil but, indeed, with the inconsistent underlying soil. Until a more advanced technique of road building in muskeg areas is developed, the Department will continue to deal with them as follows, according to conditions and requirements:

1. Avoiding organic terrain;
2. Drainage to the greatest possible depth;
3. Building supporting mats of logs and brush;
4. Building a wide sand mat by stages and grading;
5. Excavating the organic soil;
6. Blasting the organic soil;
7. Forced subsidence by overloading;
8. Vertical sand drains to hasten consolidation.

Section 7

Limitations in Assessing Subsurface Organic Terrain Characteristics in Pre-construction Survey

by

Dr. N. W. Radforth

(Abstract of Dr. Radforth's paper)

Perhaps if I present some background information the answers to some of the difficulties which have arisen in discussion prior to this paper will be more obvious. The important approach to the muskeg problem is to find a method of reference for muskeg that can be utilized in reports. It must be found what can be accepted in the term "muskeg" and what cannot.

During muskeg studies in the Churchill area, it was found that there were changes in the subsurface fossilized material. Size and arrangement of particles provided different physical relationships in different areas. Through examination of peat samples from various sites it was discovered that there were only sixteen kinds of organic material; many more had been expected. Thus, the problem of muskeg has been made simpler rather than more difficult.

The problem is now one of interpretation rather than classification. In order to interpret, it may be necessary to know what is under the living layer for certain cases. Depth of the muskeg can be estimated in a fairly reasonable manner.

Where peat is mined in Scotland, a solid mineral soil foundation in the form of a cherty material is found. In our North one may find clays, silt, sand or gravel beneath the peat. It is commonly assumed that silt is the only type of base in the sublayer for peat. I hope my remarks will discourage this view.

Also, in many cases, the line of demarcation between the organic layer is not very sharp, giving rise to an indifferent * see below layer (or mixed mineral and organic layer). This layer does not present too great a problem because the classification system so far in use helps in the location of these sublayers. However, this layer has not yet been dealt with directly in the classification system.

Finally, assessment of limitations cannot be achieved unless it is done with the fundamental definition of muskeg before us. This was given in "A Suggested Classification of Muskeg for the Engineer".[1]

p.23 line 24 read "Also, in many cases, the line of demarcation between the organic and the mineral layers is not very sharp, giving rise to an indifferent layer (or mixed mineral and organic layer)."

" 'Muskeg' has become the term designating organic terrain, the physical condition of which is governed by the structure of the peat it contains, and its related mineral sub-layer, considered in relation to topographic features and the surface vegetation with which the peat co-exists."

Now one may proceed more precisely to an assessment of the limitations involved in a pre-construction survey.

In most cases, limitations are associated with a precise problem and that problem must be defined. In a given area, the muskeg characteristics may be mapped and relationships between the organic coverage and underlying mineral layer discovered. Upon learning these relationships, problems of vehicle manoeuvrability or performance may be solved by the route selection method. In the same manner, road or building construction may be undertaken with some assurance and a knowledge of future maintenance problems.

In assessing limitations it is helpful to classify the surface coverage. This is not necessarily a job for a botanist and indeed may become involved if tackled from a botanical standpoint. For the engineer, coverage may be classified in terms of stature and texture, or in other words, by form and consistency. These classes arranged in groups will lead to an overall picture of an area that in turn can give the key to subsurface characteristics. Eighteen of these coverage classes have been portrayed in Handbook No. 1[2], but representation of many more is possible by rearrangement of the constituents.

Topography may also be used as a key in defining organic terrain. By much research it was discovered that there were sixteen major topographic characters and many of these occurred faithfully with a certain coverage designation. Descriptive information is now available as to how these may be referred to.

Colour, in assessing limitations, is of least importance in adequately interpreting organic terrain. It has been found that it is possible to use colour chips from the Munsell Book of Color[3]. It may be thought that colour would be infinite, but it has been found that there are ranges.

In the interpretation of the limiting factors, the documents already available are useful. From the point of view of seeing coverage one must interpret by shape, size, density, tone, texture and pattern used together. These can be grouped to give the answer with respect to the construction of organic terrain.

Naturally, such a system of classification is not foolproof; there are parts of Canada that are unexplored. But with regard to the areas that have been worked over, they will work. Deviations are to be expected but it is not expected that any will disturb the basic principles established for interpretation.

Subsurface ice must also be dealt with as a limiting factor in pre-construction survey. Eight ice patterns have been defined that are associated with coverage and topographic limitations[4].

Thus, for pre-construction survey, though structure of organic terrain can now be ascertained by interpretive methods, depth of peat and nature of the sublayer can be interpreted with only partial certainty. Best use of Handbook No. 1 will be made when the type of problem for which interpretation is to be made, is kept before the observer. For all problems, best interpretive results are obtained when topography, ground-cover and colour are utilized in deriving interpretive data. For greatest clarity and maximum certainty, laboratory analyses of cover on a microfossil basis are advised. This will assist materially in interpreting the distribution of the various types of peaty construction and terrain conditions derived through the application of the Handbook.

References

1. Radforth, N.W. A Suggested Classification of Muskeg for the Engineer. Journal, Engineering Institute of Canada, 35:11:1-12, November, 1952.

2. Radforth, N.W. Handbook No. 1 - Organic Terrain Organization From the Air (Altitudes Less Than 1,000 feet). To be published by the Defence Research Board.

3. Munsell Book of Color. Munsell Color Company, Inc., Baltimore, Md., 1929-42, Pocket Ed.

4. Radforth, N.W. Palaeobotanical Method in the Prediction of Sub-surface Summer Ice Conditions in Northern Organic Terrain. Transactions, Royal Society of Canada, Series 3, Section 5, Vol. 48, 1954.

Discussion

When questioned about the possibilities of determining glacial features (e.g. eskers) from the surface, Dr. Radforth replied that the possibilities are quite good. We can get an idea of those things which cannot be seen from what is visible on the surface. To the question of whether there was a liaison between the Geological Survey and the Muskeg Research Laboratories, Dr. Radforth answered that unfortunately there was none. He hoped, however, that there will be in the future, through the medium of the Subcommittee.

The Chairman noted that nothing had yet been mentioned about the problem of the petroleum industries, that of temporary access to certain areas. As has been pointed out, muskeg is not always frozen in the winter, and a tracked vehicle (preferably amphibious) should be devised to cross this material. He suggested that a flexible track be designed to take advantage of the basket or membrane effect of the organic mat. He asked for comments from representatives of the petroleum interests.

Mr. R. A. Hemstock thanked the Subcommittee on behalf of the petroleum industry for what he had learned at the meeting. He said that he had no idea that classification of muskeg had gone so far. He did not know if it would help men very much or not to know what they were working in. He said that the basic problem of the petroleum industry is one of access, and that they are looking for a method whereby they could get in and out of an area quickly, cheaply and efficiently. This is the most costly problem right now. If the oil exploration is successful, then the next problem is to get temporary roads built which would last as long as possible, or until supplies and personnel could be moved in on a permanent basis. Few facilities were available to the industry for practical research but information could be collected by the companies and analyzed by research workers to help bring fundamental research and practical field work together in co-operation. A small laboratory set-up is available for fundamental research, but the need is felt for direction as to what to tackle first and suggestions would be welcome. Mr. Hemstock thought that in the case of vehicle research and trafficability studies, the fundamental properties of muskeg should be studied.

Dean Hardy explained that the interest of the petroleum industry was great, as shown by the large number of representatives at the meeting, although the companies had not been informed of it until just two days previous. He thought that the type of information which would be of use to the petroleum or forestry industries was important. As to liaison with the petroleum industry, Dean Hardy mentioned that a representative from the Petroleum Association is present. It might be recommended that they appoint a representative to the Muskeg Subcommittee, and in that way channel back to the industry any useful information.

Dr. Radforth thought that this was an excellent suggestion, and stated that this need for liaison between research and industry would be brought to the attention of the Associate Committee on Soil and Snow Mechanics.

With regard to access, Dr. Radforth thought that now that the fundamental work had been done, the next step would be to get aerial photographs of the area in question and make them available to the research people. They could help in interpreting the subsurface conditions of the terrain and advise companies as to route selection, maintenance, etc. He advocated the use of Handbook No. 1 which was like a key in that it must be applied in order to assess its value.

On the subject of vehicle design, Dr. Radforth said that co-operation here was very important too. He considered that the designers of vehicles knew nothing of the fundamental characteristics of muskeg. He had been associated with vehicle testing and had been able to observe performance over different types of organic terrain. With a knowledge of the fundamental characteristics, the design of vehicles can be looked at anew. At the present time, however, route selection seems to be the logical approach to the problem.

Dean hardy suggested that liaison with the Army and Airforce would be valuable and would provide information for the design of vehicles. They had done considerable research on vehicles, many reports of which are now unclassified.

Dr. Radforth then thanked Dean Hardy for providing facilities for the meeting in the Engineering Building of the University, and for gathering so many interested people together for it. He said that it was gratifying to see such a response to the meeting since muskeg is of great interest to him.

Dean Hardy replied that the success of the meeting had been due largely to Dr. Radforth's efforts.

The session was then adjourned.

APPENDIX A

LIST OF THOSE PRESENT AT THE WESTERN MUSKEG RESEARCH MEETING

Aitken, C.T., Special Contracts Dept., Bell Telephone Co., 1050 Beaver Hall Hill, Montreal 1, Quebec.

Anderson, K.O., Dept. of Highways, Edmonton, Alberta.

Birt, H., Shell Oil Co., Calgary, Alberta.

Blanchet, P.H., Blanchet, Trorey and Associates Ltd., 718 - 8th Ave. W., Calgary, Alberta.

Bowser, W. Earl, University of Alberta, Edmonton, Alberta.

Boyrock, L.A., Research Council of Alberta (Pleistocene) Edmonton, Alberta.

Boytzer, B.E., Texaco Exploration Co., 8221 - 109th St., Edmonton, Alberta.

Campbell, J.A.B., Geophysical Associates, Edmonton, Alberta.

Campbell, J.W., Research Council of Alberta, Edmonton, Alberta.

Carlyle, R.H., Canadian Gulf Oil Co., Calgary, Alberta.

Cronkhite, R.H., Dept. of Highways, Edmonton, Alberta.

Curtis, W.E., University of Alberta, Edmonton, Alberta.

Dickson, H., Canadian Army Headquarters, Edmonton, Alberta.

Dubas, W.S., Superintendent of Buildings Office, University of Alberta, Edmonton, Alberta.

Eggen, N., Texaco Exploration Co., 8221 - 109th St., Edmonton, Alberta.

Ells, D.R., Arthur A. Voice Construction Co. Ltd., Edmonton, Alberta.

Evel, M.J., Dept. of Biology, McMaster University, Hamilton, Ontario.

Fish, A.W., Canadian Pacific Railways, Edmonton, Alberta.

Flanders, R.E., Imperial Oil Co., Edmonton, Alberta.

Freeborn, W.D., Texaco Exploration Co., 8221 - 109th St., Edmonton, Alberta.

Grace, N.H., Research Council of Alberta, Edmonton, Alberta.

Halasa, L.L., Northern Alberta Railways, Edmonton, Alberta.

Hardy, R.M., Dean of Engineering, University of Alberta, Edmonton, Alberta.

Harrison, W.C., Manitoba Paper Co. Ltd., Pine Falls, Manitoba.

Heglin, C.M., Stanolind Oil and Gas Co., 5807 - 104th St., Edmonton, Alberta.

Hemstock, R.A., Imperial Oil Co., Edmonton, Alberta.

Hess, H.R., Parker Drilling Co., P.O. Box 4460, South Edmonton, Alberta.

Hill, N.H., California Standard Oil, Calgary, Alberta.

Hollingshead, R.J., Dept. of Highways, Edmonton, Alberta.

Horne, G.S., Texaco Exploration Co., 8221 - 109th St., Edmonton, Alberta.

Jubien, W.E., University of Alberta, Edmonton, Alberta.

Kerby, I.B., Canadian National Railways, Edmonton, Alberta.

Lessard, J.I., Northern Alberta Railways, Edmonton, Alberta.

Linke, G.W., Canadian National Railways, Edmonton, Alberta.

Longley, Richmond W., Dept. of Transport, Suffield Experimental Station, Ralston, Alberta.

McCubbin, T.J., Canadian Petroleum Association, Calgary, Alberta.

MacFarlane, Ivan C., Division of Building Research, National Research Council, Ottawa, Ontario.

Mathieu, A.L., Research Council of Alberta, Edmonton, Alberta.

Millions, K.A., Dept. of Highways, Edmonton, Alberta.

Morison, A.G., Oilwell Operators Ltd., Edmonton, Alberta.

Nowlan, B.C., (Special Contracts Dept.) Bell Telephone Co., 1050 Beaver Hall Hill, Montreal 1, Quebec.

Paull, A.M., Dept. of Highways, Edmonton, Alberta.

Perry, B.R., Consulting Engineer, 1168 St. Catharine St. W., Montreal 2, Quebec.

Pollock, Donald H., Dept. of Civil Engineering, University of Alberta, Edmonton, Alberta.

Punshon, O.H.G., Industrial Engineering, 9711 - 111 St., Edmonton, Alberta.

Radforth, N.W., Dept. of Biology, McMaster University, Hamilton, Ontario.

Risdon, R.W., Seismic Service Supply Ltd., Calgary, Alberta.

Robertson, H.F., Imperial Oil Co., Edmonton, Alberta.

Roblin, N.L., Canadian National Railways, Edmonton, Alberta.

Shields, B.P., University of Alberta, Edmonton, Alberta.

Simmonds, Sidney H., Building and Maintenance Office, University of Alberta, Edmonton, Alberta.

Sinclair, S.R., Civil Engineering Dept., University of Alberta, Edmonton, Alberta.

Smith, P.N., Seismic Service Supply Ltd., Calgary, Alberta.

Stoneman, D.C., Shell Oil Co., Calgary, Alberta.

Yurkiw, P., R.M. Hardy and Associates, Edmonton, Alberta.