Proceedings of the Third 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, which consists of about fifteen Canadians appointed as individuals and not as representatives, each for a 3-year term, has funds available to it for making research grants for work in its fields of interest. Inquiries will be welcomed and should be addressed to: The Secretary, Associate Committee on Soil and Snow Mechanics, c/o The Division of Building Research, National Research Council, Ottawa, Canada.

NATIONAL RESEARCH COUNCIL OF CANADA

ASSOCIATE COMMITTEE ON SOIL AND SNOW MECHANICS

PROCEEDINGS

OF THE

THIRD MUSKEG RESEARCH CONFERENCE

FEBRUARY 20 AND 21, 1957

Technical Memorandum 47

Ottawa

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FOREWORD

This is the record of the Third Annual Muskeg Research Conference, the technical sessions of which were held in the library building of the University of British Columbia, Vancouver, B.C., on February 20, 1957. A list of those in attendance is included as Appendix A of these proceedings. This Conference was the first to be held in British Columbia, and was sponsored by the Associate Committee on Soil and Snow Mechanics of the National Research Council.

The Conference took the form of a symposium on problems of access over organic terrain. The morning session of February 20th was under the chairmanship of Mr. R.A. Hemstock. Progress reports were read from the various centres of muskeg research in Canada and three papers were presented and discussed. The afternoon session was chaired by Mr. C.F. Ripley. Five papers were presented, followed by a general discussion.

On the second day of the Conference, February 21, a field trip was made to several local points of interest, with regard to muskeg problems and peat development. Acting as guides on various parts of this field trip were: Dr. J.E. Armstrong, Mr. R.C. Thurber, Mr. C. Leonoff and Mr. E.E. Carncross.

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Morning Session, February 20

Section 1

INTRODUCTORY NOTES

After registration, the Chairman, Mr. R.A. Hemstock, opened the technical sessions by calling upon everyone present to introduce himself. He then introduced Dr. N.W. Radforth, Chairman of the Muskeg Subcommittee. Dr. Radforth expressed his pleasure at seeing such a large representation from industry and government at the Conference, as he thought that such meetings are an excellent way of exchanging muskeg information and experiences. Dr. Radforth read a telegram from Mr. R.F. Legget, Chairman of the Associate Committee on Soil and Snow Mechanics, in which he regretted his inability to be present due to other commitments.

In introducing the host for the day, Dr. Radforth said that the National Research Council, and in particular the Associate Committee on Soil and Snow Mechanics, was in a very favourable position because of its splendid working relations with the University of British Columbia. He said that he was most pleased to have Dean G.C. Andrews, Assistant to the President, present to open the technical sessions.

Dean Andrews cordially welcomed those present and hoped that they would feel at home on the U.B.C. campus. It was the desire of the University to be of every possible assistance to the Muskeg Conference, Dean Andrews said, and to make available any facilities that were required.

Mr. Hemstock thanked Dean Andrews for his remarks, then introduced Mr. MacFarlane, Secretary of the Muskeg Subcommittee. Mr. MacFarlane outlined the arrangements which had been made for luncheon and for the field trip of February 21.

Section 2

Progress Reports

A. Muskeg Research Laboratory, McMaster University

by

Miss J. Evel

During the past year, muskeg research at the Muskeg Laboratory, McMaster University has progressed primarily with the aid of grants from the National Research Council and the Defence Research Board.

As you may know, Handbook No. 1, entitled "Organic Terrain Organization from the Air (Altitudes less than 1,000 feet)", has been the first step in the interpretation of ground patterns from the air. This handbook has interpreted topographic and coverage features (observed at ground level) from altitudes of 150 to 1,000 feet. By knowing the coverage classification of a certain area and its associated features, (e.g., one with ridges or mounds), one can interpret conditions from the air.

Related procedures have been developed and applied for altitudes proposed in Handbook No. 2 - 1,000 to 5,000 feet, because it has been observed that certain ground features (e.g., hidden boulders and hummocks) can not be resolved at this altitude, while others, such as gravel bars and peat plateaus, have become the marked characters and take prominent roles in appreciation of pattern. Thus, new orders of pattern had to be agreed upon and explained.

It has already been announced at the technical sessions of the Muskeg Subcommittee held last year, that investigations at the laboratory attempt to prescribe for conditions experienced at altitudes as high as 30,000 feet. The mechanics involved in reconciling lower altitude patterns with high, have proved to be more difficult. Small and yet significant interpretive values must be accounted for before correlation of 30,000 and 5,000 foot experiences can be achieved. Therefore, for high altitude work, new terms for air form patterns had to be designated. These new terms are:

Cumuloid - This term, applied to a billowy, cloud-like pattern, is used to designate those areas composed of groups of peat plateaus. These plateaus produce a light tone in aerial photos, the coverage being EH or HE (1).

Apiculoid - The pattern suggested by this term is used for areas that appear to be strippled. This effect is produced by trees or shrubs, (AE or BE) on a background of light tone (H).

Planoid - Studies in connection with this term have led to the addition of a new term in the topographic features' table - that of "flats". These are extensive areas, apparently featureless, dark in tone, usually composed of FI or E coverage and may have a high water table.

Vermiculoid - This term has been divided into three parts to classify three distinct air form patterns. The first pattern is composed of long ridges with EF or EH coverage in a flat area with FI coverage. The second is made up of mounds having an EH coverage in a flat area with FI coverage. The third pattern is comprised of short ridges and mounds in a flat area with FI coverage. These areas usually contain more open ponds than the preceding two types of vermiculoid.

Intrusoid - In a flat area, there may be numerous small plateaus and closed and open ponds, as well as other topographic features. These areas, often extensive and flat, may be confused with planoid areas, but are characterized by the intrusion of these various topographic features.

Polygoid - As this term implies, there are certain areas where polygons are frequent. However, polygons are just barely visible at 5,000 feet and probably merge into the cumuloid pattern at this altitude, or into the marbloid pattern at 30,000 feet (2).

An attempt has been made to map air form patterns at 5,000 feet, as well as to define them. In this way an area may be assessed at 5,000 feet and the ground conditions predicted. Much consideration was given to the size of areas to be mapped. The mapping symbols agreed upon at the laboratory can be used for quite small areas. It was felt that any area showing a pattern characteristic of one of the previously mentioned terms should be mapped, so that all terrain components in a given large map are accounted for.

A new approach to the study of muskeg has been attempted, that of examining sections of peat *in situ*. To facilitate this study, a modified paraffin infiltration technique was found to be the most acceptable. This method was appropriate for sectioning the peat with relative ease, and the procedure was not excessively long. By this method, quantitative readings of the density of the peat can be made. The peaty elements were classified morphologically into woody stems, non-woody stems and leaves, leaves of woody plants and lichenaceous material, and amorphous organic micronodules which were not classified because of their extremely small size and lack of detail.

Until this study was made, knowledge of peat structure was based on visual and, therefore, qualitative observations. With this new approach, the relative abundance of elements in the peat can be studied. It was observed that the surface vegetation described as HE, or low woody shrubs and lichen, was not entirely reflected in the structure of the peat, because the lichenaceous material apparently played almost no part in the structure of the peat. This contrasts with the FI sample (grasses and mosses) where non-woody materials were the only elements observed in the peat. The stems found in the woody peat apparently lie parallel to the surface and form layers. This fact might explain slippage in some peats when pressure is applied. The future results of this work should explain more fully the correlation between surface vegetation and sub-surface structure, and thus be readily applicable by any concerned with access over muskeg.

A new set of borings has been analysed for microfossils (index units). These, on the whole, are deeper than those examined previously. Correlation between these units and surface vegetation has been achieved and a broader contribution has been made to our knowledge of aerial to sub-surface interpretation than was formerly possible.

Mention must also be made in this report of the scientific papers written during the past year and published in various journals. These are:

"Muskeg Access with Special Reference to Problems of the Petroleum Industry". This paper was presented at the seventh technical meeting, petroleum and natural gas division, Canadian Institute of Mining and Metallurgy, in Calgary, 1956. It has been published in the Canadian Mining and Metallurgical Bulletin, Volume 49, Number 531, July 1956, and in Oil in Canada, August 6, 1956. It has also been published as Technical Memorandum No. 43 of the A.C.S.S.M., National Research Council.

"Peat in Canada and Britain - Economic Implications". This paper was presented at the meeting of the Royal Society of Arts, London, in July, 1956, and was published in the Journal of the Royal Society of Arts, No. 4990, Volume CIV, November 1956.

Handbook No. 2 entitled "Organic Terrain Organization from the Air (Altitudes 1,000 to 5,000 feet)" was presented for approval in December, 1956 to the Defence Research Board.

"Correlation of Palaeobotanical and Engineering Studies of Muskeg (Peat) in Canada" by N.W. Radforth and I.C. MacFarlane is to be presented at the 1957 International Soil Mechanics Conference in London.

References

1. Suggested Classification of Muskeg for the Engineer. The Engineering Journal, pp. 1199-1210, November 1952.

2. The Application of Aerial Survey over Organic Terrain. This paper was presented to the Muskeg Subcommittee Meeting in February 1956, and was published in Roads and Engineering Magazine, Auguet 1956. It has also been published as Technical Memorandum No. 42, National Research Council, Associate Committee on Soil and Snow Mechanics.

B. Muskeg Committee of the Canadian Petroleum Association

by

J.P. Walsh

The Muskeg Committee of the Canadian Petroleum Association has now been functioning for two years.

During the past year we have continued to work with other groups interested in muskeg problems. It was not difficult to choose an area when we learned that there were parties ready to undertake research and field studies. We were very pleased to be hosts to Mr. MacFarlane of the National Research Council and Captain Wyld of the Army Engineers. This work took place last summer in the area of the Pembina Oil Field about 100 miles west of Edmonton.

I think that Mr. MacFarlane and Captain Wyld will agree that such studies must be continued from year to year and in several different areas. Such study, both theoretical and applied, is at the same stage as was soil mechanics twenty-five years ago. It took fifteen to twenty years for soil mechanics to be accepted as an important field of engineering. In Western Canada and the oil industry especially, it is important that no unnecessary delay occur in bringing the realization of problems and the technological answers to the attention of all concerned with muskeg.

It is surprising that so many in the industry do not fully realize the difficulty when faced with it. There are between 300 and 400 active oil companies in Western Canada employing about 80,000 employees. In the Pembina field alone there will be a greater dollar investment than in the St. Lawrence Seaway, excluding the power development. Yet it would be difficult to find half a dozen foundation engineers in this area.

Our muskeg committee is attempting to get some answers and give them to the industry. Up to now the classic interpretation of oil exploration would be to leave all the problems in the hands of the geologist and geophysicist; and of oil production to leave all problems with the driller and petroleum engineer.

Construction foremen have been substituting for engineers and tractor operators for route surveyors. Consequently there is little record of trial or what has or has not been successful.

Our committee has two general problems:

1. The lack of information.
2. To educate the industry with whatever information we do have.

And we have two aims:

1. To obtain information on muskeg.
2. To give this information away.

C. Muskeg Subcommittee, National Research Council

by

I.C. MacFarlane

It was thought that it might be useful to trace again the history of the interest of the N.R.C. in muskeg research and to explain how this research has developed up to the present time.

The Associate Committee on Soil and Snow Mechanics was organized in 1945. It is one of about 30 technical committees which assist the N.R.C. in the discharge of its responsibilities for scientific and industrial research in Canada. The Associate Committee was set up initially to deal with trafficability problems of Canadian terrain, and at the time of its inception consisted of an equal number of civilian and military members. Its main concern was track studies, snow and ice research, soil mechanics, permafrost, and muskeg research. The work on track studies was later dropped.

Shortly after its inception the Committee looked into the problem of muskeg and encountered a great diversity of opinion about what really constituted this unusual type of terrain. After much preliminary study, it was decided that the problem could best be solved by a basic approach from the point of view of palaeobotany. Therefore, the Committee subsidized the start of the work in this field, which was carried out by Dr. N.W. Radforth of McMaster University, and has continued to support his work until the present time. The Defence Research Board later became associated with the work and provided material assistance for field studies of muskeg in the Churchill district.

Muskeg Subcommittee

In 1947 a Muskeg Subcommittee was formed with Dr. Radforth as Chairman, and the first meeting was held on December 2, 1947. The terms of reference as laid down at that meeting are "to provide a useful interpretation of muskeg to assist military and civilian investigations concerned with organic terrain." At present it goes somewhat beyond these terms since the Subcommittee attempts to co-ordinate muskeg research in Canada and to collect, correlate and disseminate information on actual field experiences and problems with this type of terrain. It also has the responsibility of organizing these research conferences. The Muskeg Subcommittee has had six formal meetings to date, and this is the third research meeting to be held. The first was held in March, 1955, at the University of Alberta and the second at Laval University, Quebec City, in February, 1956.

A number of papers pertaining to muskeg have been issued by the A.C.S.S.M. in the form of Technical Memoranda Most of them have been authored by Dr. Radforth and indicate the tremendous amount of effort he has put into this field of endeavour. These publications are on display here today and may be obtained free of charge. Any or all of the papers also may be ordered.

Special attention might be drawn to A.C.S.S.M. T.M.44: "Guide to a Field Description of Muskeg", which is available today for the first time. It contains the essentials of the Radforth Classification System for muskeg as culled from his many papers on the subject, and is designed for use in the field. Since this may be a somewhat imperfect document, comments and criticism are earnestly solicited. Then, after it has been put to the test for a year or two, it may be revised if valid suggestions are received.

Division of Building Research

In 1947 the Division of Building Research was set up by the National Research Council to provide a research service for the construction industry of Canada. The Building Research Centre was completed in 1953. From the outset the Division has had a keen interest in muskeg research, particularly in its engineering aspects. The responsibility for this project rested with the Soil Mechanics and Permafrost Sections of the Division, but pressure of other and more urgent projects prevented, for some time, the carrying out of any large amount of specialized research into muskeg. In October, 1954, the author joined the staff of the N.R.C. as a member of the Soil Mechanics Section of D.B.R. and was given the specific task of pursuing investigations into the field of muskeg research, from an engineering point of view. Initially, a literature survey was carried out, and subsequently a preliminary annotated bibliography was issued as Bibliography No. 11 of the Divisional series. This aspect of the work is continuing and it is hoped that in the near future a complete and comprehensive bibliography on muskeg will be available.

In the summers, field investigations are usually carried out and samples are obtained for laboratory study. The author spent the summer of 1956 in the Pembina Oilfield district of Alberta as a guest of member companies of the Canadian Petroleum

Association, in particular of Mobil Oil and Mr. Walsh. Studies were carried out in co-operation with a graduate of the University of Alberta who is also a member of the Canadian Army, into the development of a field vane tester for determining the shear strength of peat. The ultimate aim of the field investigations is to make use of the Radforth Classification System for muskeg, to check its ease of application under various conditions, and to determine the correlation, if any, between the various muskeg types and the corresponding shear strength of the peaty material.

As yet, not much work has been carried out in the laboratory. A number of tests have been made on peat samples in order to establish accurate and consistent procedures for determining such physical properties as water content, specific gravity, and carbon content for correlation purposes. No significant results have yet been established. It is proposed to attempt to determine strength characteristics of the peaty material on the basis of accepted soil mechanics principles, although some modifications of the standard testing equipment may be necessary for the testing of organic material. There is some controversy, however, about the usefulness of such laboratory tests on peat due to the extreme difficulty of obtaining reasonably undisturbed samples. A piston-type sampler has been developed which will obtain 2.8-in. dia. samples but it is questionable just how representative the samples are. Triaxial shear and consolidation tests have been carried out on some Irish peats at the University College, Dublin, so there is reason to believe that similar tests can be made on comparable Canadian peat types.

An important factor has been to establish liaison with other research workers and organizations involved with muskeg research in some aspect both in Canada and abroad. The Division in its muskeg research program works very closely with Dr. Radforth and the Muskeg Research Laboratory at McMaster. Through the Muskeg Subcommittee, personal contact is maintained with the Special Committee on Muskeg of the Canadian Petroleum Association as well as with the work carried out each year by graduate students at the University of Alberta under Dean Hardy, who has been interested in and involved with muskeg problems and research for some years. We have liaison with Professor Hanrahan of University College, Dublin, who has been carrying out engineering tests on Irish peats, and also with the Bord na Mona (Peat Board) of Eire which is interested in the reclamation of peat lands for fuel and agricultural purposes. The Board na Mona translates many foreign papers pertaining to various aspects of peat. In the U.S.A. contact has recently been made with the Project Committee No. 9 of the Highway Research Board (for the Survey and Treatment of Marsh Deposits).

This report has been necessarily brief, but it is hoped that it has imparted some idea of the scope of the Muskeg Research program as supported by the Muskeg Subcommittee and carried out by the Division of Building Research.

Discussion

Mr. Hemstock pointed out that the Canadian Petroleum Association is one of the first organizations of its kind to recognize the problems presented by muskeg. Their special committee on muskeg provides a means of gathering pertinent information and passing it on. Dr. Radforth commented that he agreed with the point of view expressed by Mr. Walsh in his report. Mr. Hemstock asked Mr. MacFarlane, on the basis of his field work of the previous summer, if there was any correlation established between shear strength of peat and access problems. Mr. MacFarlane replied that it is difficult to say definitely on the basis of only 2 1/2 months of field work, although he felt there probably would be some correlation. More information is needed along with more intensive field work than can be carried out by one person.

Capt. Thomson asked if there has been any work done on the amount of consolidation associated with shear in the peaty material. He wondered if it is possible to solve the problem of high deformations and subsequently high shear values in the vane test. Mr. MacFarlane said that no special study has been made of this problem as yet. Mr. Walsh said that the University of Alberta and the Canadian Petroleum Association working in conjunction hope to find some correlation between the shear strengths as determined from the analysis of active failures of fills built on muskeg, and strengths as determined from the vane tester. He believed that this is the only way to evaluate the vane test results.

Section 3

Some Operating Problems on Peat Moss Bogs

by

E.E. Carncross

Before we agree that a peat bog presents a cantankerous and frustrating surface on which to work it is only fair to take a quick look at some of its interesting features.

From a geological point of view a peat bog makes an attractive study and on closer acquaintance, develops a charm and personality all its own. Its surface flora is selective to its peculiar environmental conditions and the bog itself is comparatively easy to profile. This profile usually reveals how it has been built up in horizons each made up of distinctive plant remains that tell not only the story of its formation, but also much of the contemporary history of the surrounding territory.

Formed under very wet and soft conditions and generally acid in reaction, a bog is able to entrap and preserve specimens of plant and animal life, identifiable pollen grains of conifers, evidences of fires and climatic changes, and in older countries the tools, pottery, ornaments, buildings and clothing of ancient civilizations going back to the Niolithic age. We have an example here where, in bogs ranging from Vancouver to Seattle and at depths ranging from 16 to 29 feet, we find a sharply defined layer of volcanic ash about one inch thick. Thousands of years ago, when these bogs were young they entrapped this wind-born ash from some heavy volcanic eruption in the area. This layer of ash has been used as a common datum point from which to study the later geology of the district.

Simply put, the problem which a peat moss plant faces in its bog operations is to take from the bog peat moss containing about 92 per cent water, air-dry it on the surface of the bog during favourable summer weather and move this air-dried material into stacks or other storage before the start of fall rains or winter conditions set in. This storage represents an inventory sufficient to last the market for a year and is processed through the plant as required. Thus, the production and harvesting of our inventory of dried moss is similar to the production of farm crops in that it revolves once a year and is subject to the hazards of weather.

The surface layer of a commercial peat moss bog consists of undecomposed sphagnum moss - the only true peat moss. It generally varies from 2 to 6 feet in depth over the bog surface. Drainage is essential and this is greatly helped by the fact that the surface of a sphagnum bog is convex, roughly like an inverted saucer, and the top working layer can be readily drained.

After drainage, which takes off the free water, there is considerable settling but the raw moss lies like a giant sponge still retaining about 92 per cent water and the surface remains soft and resilient under any type of pressure. The problem of traversing the surface is not so severe as on muskeg, where very watery conditions even to open water are met, but traction slippage and limited load carrying capacity are an ever present problem. Usually we traverse the surface on padded caterpillar tracks but have done no work on some of the newer ideas now evolving, such as the Cuthbertson "Slipe-Haul" method. His Power Slipe is completely amphibious and, equipped with a capstan winch, can travel on a pre-laid cable through even open-water muskeg. Neither have we had any experience with the "Rolligon" equipment as developed by the Four Wheel Drive Truck Co. and others, but the principle looks very promising.

It should be noted that to obtain 100 lbs. of "dried" peat moss containing say 28 per cent moisture, from raw moss taken out of the bog at 92 per cent moisture, 900 lbs. of this raw moss must be lifted from the bog, and to reduce its water content by 64 per cent, the difference between 92 per cent and 28 per cent, 800 lbs. of water must be removed by drying. Hence, in a large production the weight of water to be eliminated by drying compared to the "dried" moss produced, runs into astronomical figures. This great difference between percentages and weights is often too little and even incorrectly appreciated by so-called experts.

The layout for production on the bog consists of grids of parallel working trenches from 60 to 80 ft. apart. The raw peat moss is cut by hand from the sides of the trenches in rectangular blocks about 6 by 12 by 16 in. long and spread on the surface of the bog along the trench lines. This digging is done by hand and is heavy and expensive. One might well ask why a digging machine is not used for this purpose.

A peat moss bog remains permanently waterlogged, even after "free" water is drained off, and is soft and resilient under any kind of surface pressures. A digging machine not only must have mobility along the trench but since the moss must be cut in blocks for drying, the cutting mechanisms - blades, knives, or chain saws, must also operate along a combination of horizontal and vertical planes that are reasonably true. Deviation from either of the planes involves immediate grief. Forward movement on padded caterpillar tracks is not difficult to attain but on a resilient surface forward movement combined with the maintenance of horizontal and vertical cutting planes presents an extremely involved engineering problem.

The answer lies somewhere in a "Rube Goldberg" machine with universal mountings, hydraulic motors, flexible driving shafts, gyroscopic or other types of automatic levelling devices and an unanswered number of problems that must be solved by trial and error, if they can be solved at all. Machines can and have been built, only to be proved uneconomical. The problem of maintaining operating planes along with movement on a peat bog is still awaiting a genius for its solution.

Once the air-drying process has progressed to the harvesting stage, our next major problem is the collecting of the moss into suitable stacks or storage sheds where it can be protected from the weather and give us our working inventory. When the drying stage is finished the moss is still located along its working trenches which, in large operations, means that it is spread over several hundred acres. Traction is poor on the bog surface and load-carrying capacities are small. Often the tractor is lucky to carry its own weight and both tractors and tractor-drawn vehicles have plenty of ability to strain and stall and bog down under the skimpiest of loads. The harvesting of this moss presented a major problem.

We solved this problem by evolving a belt conveyor made up of five-sixteenths steel cable, iron cross slats, and hexagonal wire netting 24 by 1-1/2 in. mesh by 15 gauge. Mounted to a portable head-end elevator, a portable tail end, and supported in between by portable "horses" with top and bottom rolls, we found that this belt could be operated up to lengths of 1,500 ft. It was easily portable into the dried moss on the bog, and travelling at right angles across the grid of trenches with the belt running at a speed of 250 ft. per minute, it could carry in, elevate, and stack the blocks of dried moss as fast as a working crew of 30 to 40 men could feed it. It is usually late summer when the air-drying of our moss is completed; the hazard of the fall rains is then present and these belts have been very effective in giving a safe, fast and efficient harvest.

In general our operations on the bog involve an excessive amount of manual labour. To a production engineer this often appears outmoded, expensive and elementary. At first glance he is seized with an insatiable desire to mechanize what appears to be a backward operation only to find that even his brightest ideas soon land him in deep trouble. The logical rapidly turns out to be highly illogical and that which at first appears to be a simple problem can only be solved the hard way. In spite of this, progress is being made in mechanization, both in working bogs and movement over their surface, but its evolution is slow and painful.

Time will not permit an examination of other methods of peat moss production, i.e., air-drying by surface scratching and the production by hydraulic methods, extraction of water by mechanical pressure and drying by artificial means. Both have their merits, their problems, and their limitations.

In closing I would like to make some observations on the utilization of time in building roads across a peat bog. Let us take a hypothetical case of the construction of a main paved highway across a bog a mile wide and varying in depth from 6 to 20 feet. Such highways are usually built with pressure put on the engineer and the contractor to complete the job. Let us also assume that the road-bed across the bog can be drained to a depth of 5 feet, that a brush mat is laid on the surface of the bog and a fill 45 ft. wide and 6 ft. in depth is made to take a 24 ft. pavement. Immediate settlement takes place when the fill is put on and compaction and levelling of the road-bed is carried on for several weeks after which the pavement is laid on what appears to be a firmly compacted and level bed. Three years later this stretch of road is a wavy, undulating, and somewhat dangerous surface where safety demands a reduction of speed.

Let us now examine what has taken place in the bog underneath the road-bed proper. The original deposit of peat was of varying density and water content. Its water table could only be lowered to a depth of 5 feet. Peat deposits are colloidal by nature, with great affinity for water, so that the road bed sat on more or less a colloidal mass of peat.

Colloidal water cannot be expelled by pressure and a colloidal condition acts as a barrier for the expulsion of any free water. As this free water is not compressible, so long as it remains rapid settling of the peaty material cannot take place but is geared to the time required for the downward pressure of the road-bed to expel the water. If this downward pressure is too great or applied too rapidly, the peat is often expelled along with the water causing sumps to appear. Expulsion is further hindered because it has to work against the water table below the drainage level.

Thus, there exists in the peat underlying the road-bed a sort of vicious circle to retard the compaction and settling of the peat itself except by slow, limited, and steady pressures from the road-bed above over a long period of time.

This settling problem exists in varying degrees from bog to bog and the time required to take advantage of it can only be estimated after a profile study of the deposit itself. The one sure thing is that during this settling period the element of time is unbeatable and may extend up to two, three and four years. Too often road builders ignore it and the longer the engineer can utilize this time factor for settling and re-levelling the road-bed, the more he will mitigate against the chances of winding up with an undulating pavement.

Section 4

British Approach to Organic Terrain Problems

by

Dr. R.W. Radforth

(For the sake of brevity, the text of Dr. Radforth's paper is not included herein. For a resumé of the main points discussed, Dr. Radforth suggests that the attention of the reader might be directed to his recent paper entitled: "Peat in Canada and Britain-Economic Implications", which has been issued by the Associate Committee on Soil and Snow Méchanics as Technical Memorandum No. 45).

Discussion

Referring to one of the slides which accompanied the talk, Mr. Powell asked if the water table had gone down as there was very little water evident in the ditch. Dr. Radforth replied that when the ditch was dug originally it was full of water. The water level goes down in the course of the summer, but the peat never becomes completely dry. Even so, vehicles can be fairly freely operated on the surface of the bog. Dr. Radforth explained that these ditches were dug by machine, in preparation for planting trees or for cable laying. In reply to a question about the slope of the organic terrain areas observed in the slides, Dr. Radforth said that there was no more gradient in organic terrain of Scotland than in such terrain in northern Manitoba.

Section 5

Winter Roads Over Muskeg

by

J.G. Thomson

It is generally accepted that a winter road over muskeg represents a financial outlay which is fully depleted as soon as the spring weather breaks up the road. This is true in the majority of cases and the cost of haulage over such roads is consequently high. Extreme cases, for example, during construction of some sections of the Quebec North Shore and Labrador Railway, have shown surface haulage charges over winter roads as high as those for charter airlifts or 20 to 25 cents per ton mile. Charges for any private airstrips which may have to be constructed in connection with the operation will be in addition to these figures and will vary widely. By contrast, the pulp and paper industry in northern Ontario, through the re-use of each route for periods often extending up to 10 years and the application of high traffic densities shows an average road charge of only 0.7 cents per ton mile for pulpwood on hauls of 10 to 80 miles. The remaining charges per ton mile will be the same as for highway semi-trailer transport.

These two examples show that before the decision is made to build a winter road, care should be taken to assure that the cost of the road is recoverable and that an economic gain will be made through reduced transportation costs. Further, the class of surface to be applied to the road must also be matched to the type of service on the basis of economic considerations.

The value of a winter road is twofold:

(1) increased ease of cross-country operations resulting in lower equipment maintenance costs and the opportunity of substituting cheap, fast, wheeled vehicles for slow, expensive, tracked equipment;

(2) a longer working season for winter operations; normally, at latitudes above the 52nd parallel it should be possible to enter the field and begin effective operations not later than the first of December and to continue these operations until the snow in open fields beside the road is almost all melted in the spring. This represents an increase of about six weeks in time available for field operations over present common practice in many industries.

The two main components of a road are: (Fig. 1)

(a) The subgrade which is the load-carrying element of the road. In the case of an all-weather road this is usually granular fill to some substantial depth. Frozen native soil replaces granular fill as the subgrade for a winter road.

(b) The pavement which is the wear surface which protects the subgrade from direct disturbance from traffic imposed forces such as the normal contact pressures of wheel and track loads and from the scuffing action of tire treads and track grousers.

There are two main methods of preparation:

(a) Compaction of a deep snow pack over unfrozen or slightly frozen subgrade. This method is not recommended since it usually produces a rough surfaced, weak road.

(b) Compaction of the snow in layers as the first few snowfalls occur and clearance of subsequent snowfalls from the iced surface, thus creating or maintaining a firmly (and probably deeply) frozen subgrade early in the frost season and preserving it for the duration of winter. This method of preparation also permits the early use of bulldozers for smoothing the route prior to completion of the snow pavement.

The strength of the compacted snow, commonly called "compact", results from the close proximity of the individual snow grains and the ice boundaries joining them. When deep snow is compacted without extensive mechanical agitation the density will usually decrease quite markedly with depth and this results in a mass which has varying thermal properties through its vertical profile. Thus a condition is set up which will permit rapid metamorphosis of the lower reaches of the pack. The snow near the bottom of the compact will, over a period of time, turn into depth hoar which is friable and a good thermal insulator when compared to ice or fine-grained compact. Subgrade strength is lost due to reduced heat transfer through depth hoar and the brittle compact or ice pavement surface collapses into the friable depth hoar when loaded.

It is recommended on the basis of the foregoing that compaction be started before the snow depth exceeds one foot and that subsequent layers be rolled when the snow depth reaches 2 to 4 inches. If it is necessary to compact deep snow, precautions must be taken to ensure that compaction does extend uniformly through the snow pack to the ground surface.

A. Methods of Preparation

1. Route Selection

When possible the route for a winter road should be selected to avoid topographical obstacles such as hummocks and depressions to minimize the traction demanded of the road surface. Thus the route should normally be chosen to traverse muskeg whenever possible without too great an increase in route length.

Since, after completion of the road to the stage of icing, the surface maintenance for the remainder of the winter will be by normal snow removal procedures, some care should be exercised in the choice of route to avoid the topographic features which will cause drifts to form across the road and to take advantage of topographic features which will induce snow clearance by wind action.

Specifically, the roads should not be built close to the prevailing lee side of trees or land elevations where an alternative exists. If possible, the road should be offset a distance of 10 to 15 times the height of any up-wind obstacle. In barren areas it is often essential to use snow fences to control drifting and these should be offset as above. Snow discharged from removal equipment should be thrown downwind (based on the prevailing wind) and should not be allowed to form a tall windrow, which will act like a drift fence, close to the road.

Because of the danger of sun damage, southward facing slopes should be strictly avoided even at the expense of increasing the route length.

2. Construction of the Road

(a) Subgrade

Given sufficient time and sufficiently low temperatures, a subgrade will form as a natural occurrence. However, this dependence on natural conditions leads to time delays and weak subgrades, neither of which are tolerable in any operation which depends for its success on available field time and certainly of cross-country transport.

Suitable subgrade strengths can be attained earlier in the winter season and will reach greater numerical magnitudes by means of any procedure which will permit an increase in the rate of heat loss from the subgrade materials (native soil and water). To promote heat loss, the efficiency of the overlying snow as an insulating material must be reduced either by total removal of the snow or by reduction of the air voids between the snow grains. The latter is the more reasonable procedure since the void reduction is accomplished by simple compaction and the resulting product is then a suitable material for the pavement.

The compaction of the snow should be begun immediately after the end of the first snow storm in order to prevent heat transfer from deep soil layers from thawing or warming the natural beginning of the subgrade. This compaction may best be carried out by a fairly low ground pressure tracked vehicle (about 2 to 4 psi) which should be almost capable of traversing the area in question in the unfrozen state.

After allowing time for further heat loss from the subgrade (one or two days at temperatures from -10°F. to + 10°F.) and for age hardening of the compacted snow the trail should be further compacted by passes of high ground pressure vehicles (6 to 10 psi). Dragging and rolling should follow within eight hours of the high ground pressure compaction in order that preliminary smoothing of the route will be accomplished before full-age hardening of the snow occurs. In this condition the trail will usually be suitable for efficient tractor train operations and may even be suitable for selected wheeled-vehicle operations.

Completion of the road must await further light snow falls. When new snow is available it may be used either as fill material for smoothing hollows and ruts in the road preparatory to icing, or, if sufficient pavement depth (4 to 8 in.) was not produced from the first fall, it may be compacted where it fell and later dragged and rolled as in the case of the initial fall. Either procedure must be carried out immediately upon cessation of the snow fall in order to prevent heat damage to the first layer of the pavement and the subgrade.

The development of subgrade strength is entirely due to natural forces and can only be assisted by the provision of suitable surface conditions. Therefore, if there is a subsurface condition, such as a warm water boil, which prevents the natural development of a strong, frozen subgrade then an alternate subgrade must be used. The most successful and easiest alternative for most localized subgrade failures is a corduroy patch with a plank or pole decking and snow pavement. Such a patch should be 1 1/2 times as wide as the road and should extend at least 10 feet onto the satisfactory portion of the subgrade at each end of the failure. If possible, drainage of the warm water from beneath the road should also be provided.

If use of the road is required almost immediately after the first snowstorm of the season, or if the fall was of sufficient depth (8 to 12 in.) to provide sufficient snow for the pavement course, the 'breaking' passes following the first snow fall may be followed immediately (preferably within eight hours) by a combined dragging and rolling pass which in turn is followed about 12 hours later by a watering pass. This short procedure does not produce the best finished road and is wasteful of water.

(b) Pavement

The degree to which the pavement is completed will depend on the envisaged road usage. If traffic is to be infrequent, tractor use permitted, or if only a few heavily laden trucks (say 20-ton payload) will use the road throughout its life, it is probably reasonable to omit the expensive watering procedure detailed below. However, for the sake of completeness the various steps in production of the best pavement follow.

In providing the proper conditions for subgrade development most of the pavement material has been placed and roughly finished. It remains now to smooth and harden the pavement so that it will successfully resist the traffic and snow clearing loads to be imposed throughout the winter.

Final smoothing of the road is accomplished by dragging and rolling thin layers of snow which fall, blow, or are mechanically dragged onto the surface. Either a motor grader or a tractor-hauled drag and roller may be used for this purpose. Greater flexibility is available with the motor grader (which may also be used in future snow removal), but the availability of equipment will probably govern the choice of method.

Hardness is imparted to the road by the addition of water to the pavement layer. Great care must be exercised during the watering procedure to ensure that water is not added in such quantity that it erodes the grain boundaries of the cemented snow causing a spongy, weak pavement which will crumble under vehicle loadings.

Water may best be applied as a fine spray from nozzles which pass very close to the snow surface (to prevent prefreezing of the water) or as drips from an uncaulked wooden tank. Several passes of the watering equipment will be required in order to permit the deposition of sufficient water without damage to the snow structure.

If a greater thickness of ice is required (as on heavily travelled roads) than can be produced by the above procedure this may be provided by rolling another thin layer of snow and wetting it or by thoroughly, repetitively soaking the initial ice surface. These latter procedures are permissible only after the initial icing has sealed off the compacted pavement snow.

It is essential that all traffic be barred from the road during, and for 4 to 12 hours following, any watering procedure.

The chemical content of the water used for icing is not of too great importance provided it does not contain large quantities of salts which strongly depress the freezing point. The water used must be clear if at all possible since coloured waters (particularly the brown water from muskeg) increase insolation and consequently the rate of deterioration of the surface.

B. Maintenance

Winter-long efficient transport services over the road are the only justification for the financial expenditures involved in the preparation of a temporary winter road. It then follows that good maintenance of the road, which will promote efficiency in the primary operation by ensuring the availability of supplies and the longest possible working time in the field, is essential.

The number of maintenance tasks is small although they must be carried out frequently and promptly. The following are the major tasks:

(a) Snow Removal

When possible traffic should be halted during a snow storm and clearing carried out before it is resumed. This eliminates the build-up of tire tracks which roughen the road and subsequently cause fairly severe vibrational loadings on the brittle pavement structure. Local but progressive failure of the surface can be caused by these loadings. If traffic cannot be halted during a snow storm, ploughing should be started when the snow on the road (not the snow fall) reaches two inches in depth and continued until the storm is over.

As soon as the road is re-opened after a snow storm or simultaneously with the clearing operation, the snow banks should be cut down and well back from the right-of-way by means of a wing plough. If this is not done the soil under the snow bank is liable to thaw leaving no side support for the subgrade, and failure may occur due to mud being squeezed from under the subgrade into the unfrozen "shoulders".

(b) Potholes and Other Surface Failures

It is unlikely that an absolutely uniform pavement will be produced and small localized failures must therefore be expected. These failures should be repaired immediately or they will act as a nucleus for further failure along the traffic lane.

Most surface failures can be repaired by tramping snow into the failed section of the surface and then adding water. This is best done on a cold day when the time interval, until full strength is attained in the patch, will be short and the possibility of water damage to adjacent pavement will be slight.

(c) Grades

Sand or other such material should not be used on the snow or ice pavement to improve traction on grades since it will increase insolation and thus severely damage the surface. Traction on grades can be slightly improved by pebbling the surface by the addition of a coarse water spray to a very cold, iced surface. This procedure is not generally considered to be worthwhile since it is difficult to produce sharp pebbling and even when produced it quickly wears smooth. A thin layer of compacted snow over the ice surface will also improve traction. This layer will require frequent renewal since traffic action will quickly turn it into ice.

Except when the temperature is high (above +25°F.) an expert driver with a properly loaded vehicle will be able to negotiate a 20 to 25 per cent iced grade. For grades in excess of 25 per cent which cannot be avoided by relocation of the route or a diagonal routing across the side slope it may be necessary to clear the snow to bare ground or accept the early deterioration of the road occasioned by the use of sand. Where bare ground or sand is to be used the road should be located to take advantage of natural shade from trees to protect it against the sun.

It should be noted that cleared or sanded slopes will not usually be the initial points of subgrade failure in the springtime since they will not usually be muskeg covered. However, a few days of warm weather will result in a mud slurry developing downward from the surface under traffic action.

Restricting traffic to night use of the road in the late winter season will prolong the serviceability of the road.

C. Miscellaneous Procedures

1. Route Clearing and Improvement

Small trees and brush which can be bent over or broken off by light-tracked vehicles need not be pre-cut. The bulldozer used for the second or third stage of the compaction will be able to shear these off with the blade after their roots are firmly frozen in.

Trees too large to be run over by light tracklayers must be cut off close to the ground before commencing snow compaction if they cannot be avoided by using previously cut routes such as seismic and forestry trails. It will usually be found more economical to detour the route through an existing cut than to resort to hand cutting of a direct route. If hand cutting cannot be avoided the operation is best carried out after the ground surface is frozen but before the arrival of snow. The logs so obtained should be piled so as to be obtainable for use in corduroy patches along the route after the snow has arrived.

Rough or hummocked ground can be smoothed by bulldozing after sufficient subgrade depth has been developed. This is often carried out by blading off the hummocks (usually organic) along with the compacted snow rather than by filling the hollows with snow. On any road which will be used for a number of years such as a main access road it will be found of value to level the subgrade in this manner since re-preparing the road in subsequent years will be more expeditiously and cheaply accomplished.

2. Vehicle Loading

In areas where continuous cold weather may be expected, this type of winter road will usually carry safely axle loads of 16,000 pounds on single or dual wheels at inflation pressures of 85 psi. For good traction the vehicle should be loaded so that about 60 per cent of the gross vehicle weight will be borne by the powered wheels if all-wheel drive is not provided. This means that a truck should be loaded tail heavy and the trailer of a semi-trailer tractor combination loaded nose heavy.

Traction can be further improved by increasing the percentage of the gross vehicle weight carried on the powered wheels. This will ultimately lead, however, to a loss of steering control and general instability on side slopes or tilted sections of the road. If the grades along the route are such that maximum traction must be obtained, then all wheel-drive trucks should be employed.

3. Tires

The use of snow or other cross-country tires on heavy equipment is not recommended for operations over winter roads. Many, if not all, of these tires induce local areas of very high stress within the contact pattern which result in road surface spalling and high maintenance costs.

D. Conversion to All-Weather Road

It has often been demonstrated in the building of all-weather roads over muskeg that the local construction loads on the muskeg itself are usually greater than the traffic loads that are later transferred to the muskeg through a granular or clay fill. The cost of such roads has been substantially reduced in some Alberta operations by use of small load capacity construction equipment, thereby reducing the depth of fill pushed down into the muskeg during construction.

At least one Ontario all-weather granular subgrade roadway, suitable for continuous heavy hauling, has been prepared by dumping gravel over a winter road and dressing it to a uniform 6-foot depth. In the spring when the winter road thawed, the fill sank and displaced muskeg into the ditches from where it was removed by dragline. Re-levelling of the road was accomplished primarily by further removal of muskeg alongside high spots in the road bed. Muskeg from under the roadbed then flowed to the edges and the bed settled approximately to the desired level.

For medium to light service roads it may be possible to attain even greater economy in the amount of fill placed if the clay is placed over a winter road or trail. This procedure would permit the economies and speed obtainable through the use of large machines, without increasing the required quantity of fill through excessive construction loads on the native soil.

Discussion

Mr. Walsh asked to what depth the muskeg was frozen to enable the mentioned loads to be carried. Mr. Thomson replied that 2 ft. of frozen muskeg is possible when the snow is kept packed down. He has seen payloads of 15 tons carried on 14 in. of frozen muskeg. In reply to a question about his statement advising against the use of coloured water on winter roads, Mr. Thomson said that the "black body" effect of muskeg waters has a high insolation value, since the surface is darkened. Dr. Radforth asked if the statement had been made that rubber-tired vehicles are not desirable for prepared roads over muskeg in winter. Mr. Thomson explained that the use of snow or other cross-country tires is not recommended. The roads break up much faster than for heavier loads on highway type tires. Mr. Powell asked how late in the spring the road can be used. Mr. Thomson said that he has observed a road in use 2 weeks with bare ground and water beside the road.

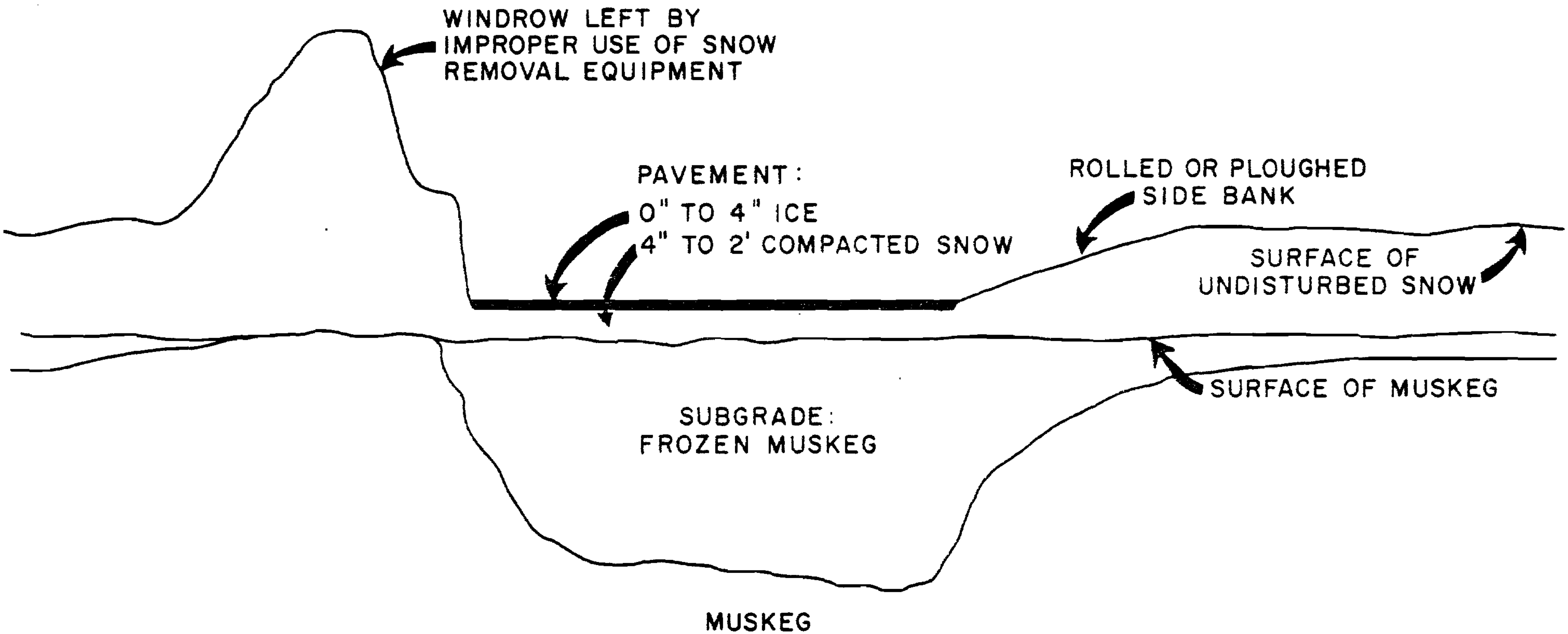

FIGURE I.

DIAGRAMATIC SECTION THROUGH WINTER ROAD OVER MUSKEG

(VERTICAL SCALE = TWICE HORIZONTAL SCALE)

Afternoon Session, February 20

Mr. C.F. Ripley was introduced as the Chairman for the afternoon session. He said that muskeg was of considerable interest to British Columbia engineers and complimented the Muskeg Subcommittee on their program. He said that the ever increasing expansion of development in B.C. has brought engineers face to face with muskeg and the problems of travel over it.

Section 6

Route Establishment Over Muskeg in Winter

by

B.C. Nolan

Mr. Nolan's talk was followed by a 40-minute film entitled "Sky Watch on 55" produced.by the Trans-Canada Telephone System and which pertained to the construction of the Mid-Canada Radar Line.

Establishing a route across muskeg areas in winter has peculiar complications due to the vagaries of weather in addition to those of the terrain itself. While the experience from which I speak is not unique, it does have some interesting features and may be of some use to others.

Our requirement was to deliver large quantities of material overland to a site on the south shore of Hudson Bay, 400 miles from the nearest railhead. The most direct means would have been by sea but the depth of water was too shallow for ships to be effective. The next choice would have been by air but we were confronted by the frequent dilemma of needing an airstrip while being unable to get onto the ground in order to built it. A winter tractor train operation was attempted for two purposes: to deliver equipment to build the airstrip serving our marshalling area; and to test the feasibility of establishing a route which might also eventually serve as a feeder for a chain of stations.

It was fortunate that air photos were available covering most of the route, as well as topographical maps. Photo interpretations supplied us with the most likely route. Summer routes tend to avoid muskeg, and seek ridges, river banks, and wooded stretches. Winter conditions would suggest following open stretches even over muskeg, assuming them to be frozen and, therefore, to provide easier going. Our actual experience fell between the two.

The operation occupied 68 days, from early February to mid April. Aerial observations were used for navigational assistance. The importance of such assistance can be recognized when contrasted with the experience of anyone who has travelled by car over roads new to him without the aid of road maps, sign posts or local inhabitants to answer questions. However in winter, aircraft cannot always fly, while the tractors have to advance before the season runs out. This sometimes necessitates making difficult decisions.

The difficulties, of course, vary with geography and in 400 miles we met with many different situations.

Where snow is light and the surface is hard, the trail can be made while hauling loaded sleighs at the same time. In wet, deep snow it can become necessary to make more than one pass with a tractor alone to clear a path for the train. Sometimes this snow will not slide off the blade and may pack in the track gear which may be broken if not cleared.

Making repairs in the field is difficult at the best of times but it is extremely painful at temperatures well below zero. Batteries are also weaker and fresh water is harder to obtain readily. Batteries can be warmed in an oven and snow can be melted but these are extra steps and take up time.

The route which appears most suitable from a photo is not always the best on the ground. Photos show the summer situation and assumptions can be made to convert them to winter conditions. But nature does not always behave as expected. The weather may leave wet muskeg under a layer of ice too thin to support equipment. This occurs frequently as a transition from a frozen muskeg area to higher land. It is most annoying to have travelled such a stretch to good advantage of time and effort only to find that you cannot get off, forcing a back-haul over the same route to try again over more difficult country.

A flat country can still have contours enough to complicate travel. When a trail bears east-west and ridges generally run north and south, the intervening muskegs may not all be easy going and the ridges are usually treed so that route selection includes much trial and error. The muskegs sometimes have air pockets and the equipment drops through and bogs down.

Ravines can usually be bulldozed full of trees, snow or debris which, when packed, make an effective bridge. Steep down-grades can be negotiated by assistance from a second tractor holding back on the load, but river banks may be too abrupt and may have to be cut down or a log ramp built. These are time-consuming tasks.

Rivers are not all frozen even under severe temperatures and a sudden rise in temperature to a balmy 50° may hearten the spirits but it does weaken the ice. Slush over thin ice, however can sometimes be compacted by a light vehicle moving to and fro until the thickness is built up to take the heavier loads -- such loads would be winched across one unit at a time instead of as a train.

Before traversing a deep valley it may be wise to scout for a beaver dam. Above the dam where the valley has flooded and frozen an easier crossing may be provided by reducing the height of the banks.

The accompanying selected extracts from the diary of the operation relate this experience in greater detail.

<u>Exercise Feasibility - February to April, 1955</u>

Feb. 12 - Received instructions to follow 22nd Base Line to Brooks Creek and Angling River. Broke road to Little River.

Feb. 13 - Crossed Kettle River safely. Making new road as we go.

Feb. 14 - Moved on to locate Base Line. Very rough and slow going.

Feb. 15 - Pushed road to Wilson Creek. Contacted the Pas. Brought map up to date.

Feb. 22 - Made route check by plane. Made good time through open country to Pennycuttaway River. Very high banks and rough crossing. Position 93° 00' 56° 27'

Feb. 23 - Make road 3/4 mile further south. Crossed large creek and large open muskeg and broke road through burnt over bush. Position 92° 50' 56° 28'

Feb. 27 - Waiting at lake at 92° 25' 56° 23' for Norseman to bring in fuel.

Mar. 1 - Making good time through fairly open patches between bush. We are now at 91° 48' 56° 23'.

Mar. 2 - Copter arrived at 4:20 p.m. with spare crossarms and mechanic. Temperature is 36° below.

Mar. 3 - 7:30 a.m., 48° below zero. Made good distance today with copter pointing the way over best route. Dozer falls through ice.

Mar. 4 - Contact the Pas and arrangements are made to bring wire rope and blocks. Position 91° 22' - 56° 19'.

Mar. 5 - Tractor recovered from river at noon. Running again at 5 p.m. Copter having valve trouble.

Mar. 6 - Norseman picks up gas at Ilford for helicopter.

Mar. 7 - Scouted new river crossing with helicopter. Proceeded due east over ridges and fairly open muskeg for 7 miles to head water of Kaskattama River.
Position 91° 14' 56° 19' at noon.

Mar. 8 - Crossed Kaskattama head water and climbed ridge.
Position 91° 08' 56° 18'.

Mar. 9 - Radio signals dead again today at 9 a.m.
Position 91° 05' 56° 17'.

Mar. 10 - With helicopter pointing the way, we crossed three creeks. Progress is very good today; we covered 11 miles. Radio signals still poor but clear at short intervals. Position 90° 54' 56° 22'.

Mar. 11 - Helicopter exploded and crashed, killing pilot and foreman. Unable to get message through. R.C.M.P. finally notified.
Position 90° 25' 56° 19'.

Mar. 13 - Filed progress report, time sheets and helicopter bills. Moved bodies in Bombardier to Long Lake further east and dozed out bush at end to give Norseman B.H.S. better take-off. He picked up R.C.M.P. Coroner and helicopter Flight Engr. at lake further east.

Mar. 15 - Blizzard conditions. Radio signals poor. Requested replacement of aerial maps lost with helicopter. Progress is very slow now due to a series of steep ridges.
Position 90° 11' 56° 15'.

Mar. 16 - Temperature -5° wind N.W. 25 mph. Heavy ground drift. We cannot make a start this a.m. Fuel line on dozer, frozen and broken. Spent night installing fuel line and heating tractor dozer.

Mar. 18 - Crossed one of the worst obstacles, a deep ravine crossing. We are now one mile from the Ontario border at 90° 00' 56° 14'.

Mar. 23-24 - Mild, and snowing very hard. Flying washed out. We are trying to find an access to Black Duck River.

Mar. 26-28 - We break a road toward the Black Duck River, and cross despite deep snow and thick trees. Track breaks on D6 dozer.

Apr. 1 - Today we crossed the Miskibi River with the train. We continue down open muskeg strips between the bush and reach position 89° 10' 56° 02'. Radio signals have been dead for the last two days.

Apr. 3 - Fort Severn is in sight from the plane also Hudson Bay ice. Today we progressed to 88° 50' 55° 58'.

Section 7

Some Economic Aspects of Construction in Muskeg Areas, with Particular Reference to Oilfield Roads

by

J.P. Walsh

With the formation of the Canadian Petroleum Association Muskeg Committee, a study was made of all available pertinent literature; nothing was found pertaining to the construction of secondary roads in muskeg areas.

All jobs studies referred to first class highways or the like, where removal of the muskeg, or total displacement with fill, were justifiable, although costly.

Some Standards for Secondary Roads

A railroad or highway is a capital investment, whereas an oilfield road is an expense item, which appears on a financial statement only as a lower net profit per barrel of oil.

In text books, "peat" as foundation material is classed as unsuitable. Specifications are written to control the choice of materials of construction, but for secondary roads over muskeg, we must accept this foundation and use only available materials.

Only early in the life of an oilfield road, is it required to take a few applications of loads up to 70 tons, distributed on five axles, thereafter, it has only the lighter service traffic to contend with. It is economical, therefore, to carry out for a short period, extra maintenance or even some rebuilding, rather than construct initially, a much higher standard of road.

Muskeg itself may be greatly increased in strength by surface loading it with fill. As a result of the construction of a 3-foot grade the shear strength in the upper foot of the muskeg may be increased by 100 per cent. This increase in strength decreases with depth but there will still be about a 40 per cent increase at 6 to 8 feet. The analysis of pressure distribution and load effect will show that the muskeg has been increased in strength in some proportion to the bearing demand placed upon it.

The method of placing fill will have major bearing both on the quality of construction and the cost of the finished grade.

An Argument for Adequate Drainage (Figs. 1(a) and 1(b))

Except for surface water, muskeg will not readily drain. Water loss from the body of the muskeg, however, may be brought about by the construction of well defined deep ditches, adjacent and parallel to the grade. The consolidating effect of placing the fill, the dead weight of the fill in place, and the traffic over it, all tend to force water toward the ditches. A hydrostatic pressure created by a 6-foot deep ditch will also cause some drainage from the muskeg below the grade.

In most cases muskegs are saturated and the volume of water is from 7 to 12 times the volume of solids. The more water that is eliminated, (even though the material remains saturated), the higher is the shear strength. If it is not saturated, this strength is higher still. We may conclude that, although the consolidating effect of grade construction and the weight of fill will increase the strength of the muskeg beneath, unless there are ditches to receive the displaced water, the muskeg will remain saturated and there can be no further increase in strength. It might be reasoned also, that the buoyant force of the water on the fill will reduce the consolidating effect.

The fill-muskeg interface may be maintained relatively dry where drainage ditches were built at the time, or previous to grade construction. Otherwise this interface is saturated and the clay fill will be muddy and will have little strength through its lower 6 inches to 1 foot, at least.

The construction of ditches will not eliminate entirely the basket effect of the surface mat. This basket effect is as yet an unknown quantity. However, even though it be considerable, if berms of 10 to 25 feet are left between the toe of the slope and the inside edge of the ditch and since the strength of the fibrous surface mat must increase with reduction in moisture content, I would suggest that such construction for drainage, has no negative results. When the escape of water is provided for, and the surface mat has increased in strength with drying, the construction operations necessary for placing the fill are less likely to puncture the mat. Therefore, the basket effect may be better preserved by a previous provision for drainage.

The following points summarize the argument for drainage:

1. To allow for run-off of surface water.
2. To permit consolidation of the muskeg beneath the grade with provision for the escape of soil (muskeg) water.
3. To permit consolidation without the buoyant effect of a surface water table.
4. To allow the muskeg under the fill to become somewhat less than saturated, which will in turn provide for a dryer interface.

5. To preserve as well as possible the natural surface mat.

Some Misconceptions Resulting in Poor Practice

The earliest construction in muskeg included what we call corduroying. In fact, many trails were made passable for light loads without further effort.

Today in the construction of secondary roads it is not economically practical to corduroy. There are some advantages, but they are not balanced by the cost. The main recommendations for this method are the spreading of the load and preserving of the surface mat.

The extent of corduroying should be limited to placement of all tree growth on the right of way beneath the fill. This provides for bush disposal at the same time. When the ground is not frozen, such work has to be performed by labour, and even when it is frozen it should be done the same way. Some will try to build a mat with a bulldozer. However this practice should not be permitted. The corduroy should be placed at right angles to the centre line to form a close, even cover, and the mat should have constant width. Usually, in muskeg areas the tree growth can be handled manually.

There is a practice becoming more common with industrial urgency and the advent of those associated with such development, who come from a more temperate climate than that of Canada. This is grade construction over muskeg during the winter season.

The advantages are obvious. Any size of machine may be used when there is support from the frozen surface. Fill can be placed without any submergence and machines may move at the speeds of which they are capable. An examination of these points will show that they all favour the building contractor, and not the owner who must use this road in all seasons, through the years following. This method is most common where the contractor lacks conscience or is ignorant of good practice, and where the owner is short of, or without qualified supervising engineers.

Two important qualities of grade construction are almost impossible when temperatures are below freezing. These are moisture loss and compaction. The grade that freezes as it is built, will be very high in voids. Any further precipitation during the rest of the winter and spring will tend to fill these voids. Therefore not only is moisture loss impossible, but a condition is set up by which the moisture content of the soil in the grade can increase to a point greater than that encountered in the borrow pit.

There are conditions when this method can and should be used if owner planning permits it. In the spring, and after freezing temperatures, many muskegs are still frozen to a depth that will permit the free movement of construction equipment over them. At such time a quality grade may be built and yet maintain high economic use of equipment.

Building the Grade over Muskeg for the Secondary Road

There are three methods of placing the fill:

1. By self-propelled scrapers loading from borrow pits.
2. By crawler-drawn scrapers loading from borrow pits.
3. By crane machine - usually drag lines obtaining fill material from below the muskeg in the ditches alongside the grade. In this method the construction of the grade and the drainage is one operation.

Trucks have been used to construct muskeg fills; however where there is economical use for them, the method could be grouped with number 1.

The economics of earth moving in road construction outside the muskeg areas do not apply in the construction of secondary roads over muskeg.

Self-Propelled Rubber-Tired Scrapers: (Fig. 2)

In ordinary terrain it is usually advisable to use crawler-drawn scrapers up to a 500- or 600-foot haul, and when the distance is greater than this, a switch to self-propelled rubber-tired scrapers is in order.

The very use of self-propelled rubber-tired scrapers for grade construction of secondary roads requires the fill to be deeper than necessary. The larger the unit used the greater will be this increase in depth of fill. We must bear in mind that we are not now concerned with a main highway but with an access or service road. If a 2 1/2-foot fill, well gravelled, will satisfy the requirements then that is what should be built. However, on deep muskeg, using an 18-yard self-propelled scraper it will require substantially more than 2-1/2 feet, in fact 3-1/2 to 4-1/2 feet will be necessary to support this machine in the construction operation. Therefore this factor alone can account for a 70 per cent increase in the cost of the grade.

A road of 16- to 24-feet in width is sufficient for traffic requirements on secondary roads. A crawler-drawn scraper can efficiently work on grades as narrow as 14 feet. As long as the power unit has some footing, the crawler-drawn unit can work close to the toe of fill.

The large self-propelled scrapers require turning radii in excess of 40 feet. They must have good footing at all times and this requirement is more pronounced as the capacity is increased.

Therefore, though an 18-foot top grade may be all that is required it is impossible to built it with some types of equipment. This factor of operating radius will increase width and consequently yardage, and therefore increase cost by perhaps 60 or 70 per cent. This increase will be in proportion to the size of the machine used.

Wherever they are used, one of the main arguments for self-propelled rubber-tired scrapers is their speed. For wide, high-standard highways, I suppose the faster the machine the cheaper is the cost of placing the fill. Here again, there is a difference when building small grades over muskeg. A machine of this type begins to bounce at 6 to 10 miles per hour, and this action increases with speed. The grade that will carry such equipment at 8 miles per hour may be completely flattened out and punched full of ruts when the speed is increased to 15 or 20 miles per hour.

Those of you who have had experience in construction in muskeg will appreciate the difficulties when a machine gets bogged down. The loss in productive time, and the extra machines necessary to extricate a piece of equipment are important factors for consideration. This of course is argument against the use of large heavy machines.

The use of the self-propelled scrapers is not ruled out for construction of secondary roads over muskeg. However, for this work they must be re-evaluated:

1. The shorter the turning radius the more pactical is the unit.
2. Capacity is not as significant as in the construction of highways.
3. Speed of the unit does not pay off as it would on grades outside of the muskeg.
4. A high horse power yardage ratio is advantageous.
5. Low pressure tires are important.
6. As much clearance as possible especially under the power wheels is preferable.

Crawler-Drawn Scrapers

Where the grade is built using crawler-drawn scrapers, it is almost always economical to use sheep's-foot packers in conjunction with them. The resulting reduction in moisture and the compaction are good and sufficient reasons for their use. A grade built in this manner although only 2-1/2 feet thick will provide considerable support for traffic.

The size of crawler-drawn scrapers requires consideration when building these small roads. Short turning radius, high horse power yardage ratio, and maximum clearance are important specifications. From personal experience I would suggest that the 9-yard scraper with 100 h.p. tractor is the most practical. Certainly it is not advisable to use units larger than the 13-yard size.

The Use of Draglines

There is a third method of grade construction. This is by the use of draglines. It should be noted that the contractor who is properly equipped for muskeg work must have draglines to build the drainage.

To illustrate the economical use of draglines suppose the muskeg cover is shallow, about three feet; this depth is fairly constant; the muskeg area is large, extending about five miles, and there is an absence of borrow pits in this expanse. This set of conditions is not uncommon. Ditches parallel to the centre line, and at a distance that provides for an adequate berm are excavated. The muskeg cover is wasted on the outside, and the clay or other soil subgrade is cast in, to form the grade. By this method fill is moved 50 feet as an alternative to several miles. The work should proceed up-grade so the water will run away from the dragline. Almost always there is some slope to a muskeg surface.

As soon as the loose fill provides support, a small dozer works it to increase density and to reduce the moisture content. Later, a sheep's-foot packer is added and at this stage a larger dozer should replace the first one. The grade is finished off by a crawler-drawn scraper which shapes the grade and, if necessary, moves some fill longitudinally to obtain a good grade line. When this method is used, drainage is provided for, as a part of grade construction.

Liberal Use of Gravel

The relative cost of gravel to fill is much lower for muskeg roads than for roads outside these areas. There are two reasons for this:

1. On a highway, an inch of base course may equal 2 or 3 inches of grade depth in strength. This ratio will be much higher for the muskeg fill.

2. The cost of gravel is approximately equal for any road. The relative cost of gravel, to cost of fill, on yardage basis is much lower for the muskeg road.

A cover of 1000 to 1500 yards may be quite suitable for a 20-foot top road. Since the standard of fill is not high, that of the gravel need not be either. Many dollars can be saved if a source of pit-run is available near by. It is not economical to crush for this type of road. Pit-run up to four inches, will readily pound into the grade under the action of gravel trucks. After a year or two a light application of crushed gravel may be applied as a surface course.

Conclusion

At this time industry is suffering the frustration of not being able to cope with the muskeg problems, and in many cases where development is progressing in these difficult areas, there are very high costs due to poor practice and the use of wrong construction methods.

Where both the foundation and materials of construction are so poor, the discerning engineer and the experienced and conscientious contractor are needed.

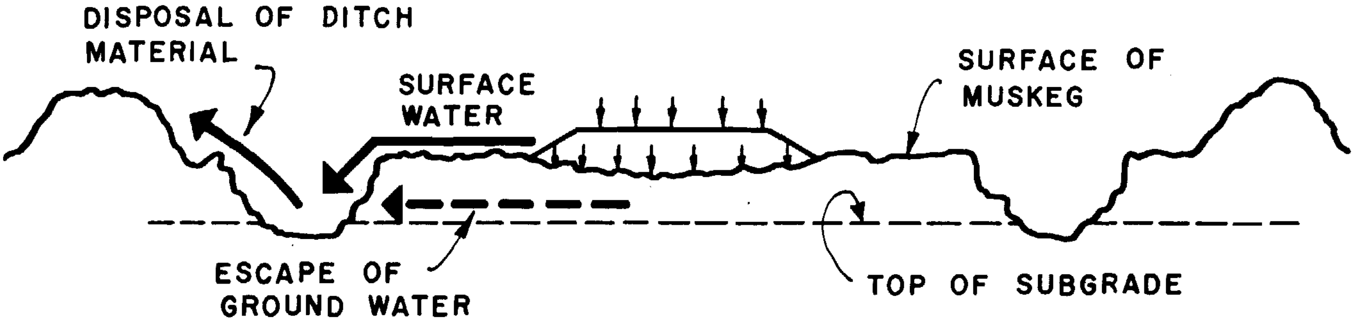

FIGURE I(A)

EXAMPLE OF METHOD REQUIRING MINIMUM YARDAGE AND PROVISION FOR ADEQUATE DRAINAGE.

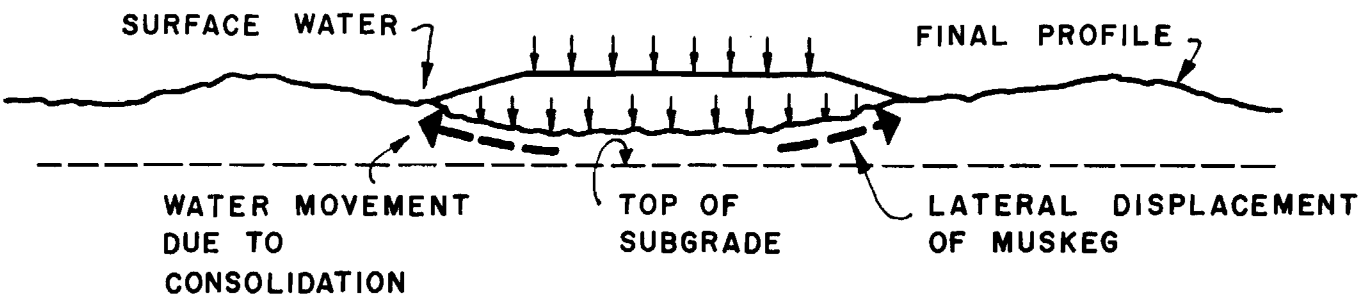

FIGURE I(B)

EXAMPLE OF COMMON METHOD EXEMPLIFYING LACK OF ECOMONY AND NO PROVISION FOR DRAINAGE.

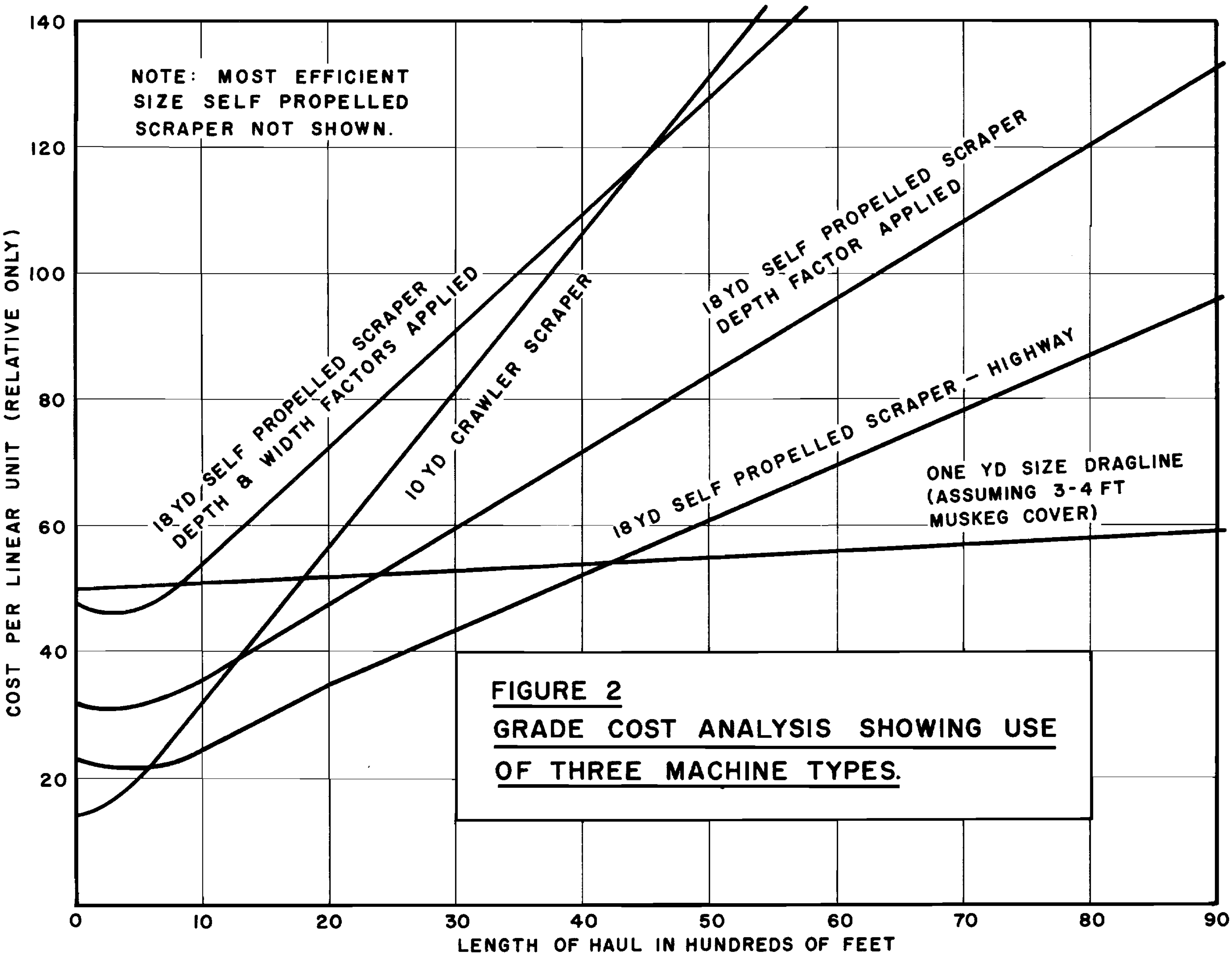

FIGURE 2

GRADE COST ANALYSIS SHOWING USE OF THREE MACHINE TYPES.

Section 8

Some Aspects of Muskeg as it Affects the Northwest Highway System

by

Capt. S. Thomson

The problems posed by muskegs to the Northwest Highway System have been considered in this paper under three general headings:

1. New Construction over Organic Terrain,
2. Maintenance of Roads through Muskeg Country, and
3. The Effect of Muskegs on Costs.

The last two of these headings are influenced by the presence of organic terrain; the highway need not necessarily cross it.

One point requiring clarification is the type of highway construction envisaged. The Alaska Highway is a gravel-surfaced road and the remarks and conclusions of this paper pertain to this type of surface. Obviously, if a pavement is to be placed on the fill immediately or shortly after construction, then the problem assumes a totally different character. Hence, consideration is given only to a fill that will not receive a high type surface until satisfactory stability has been achieved.

Before discussing any of the chosen headings, it is necessary to describe briefly the muskegs encountered on the Alaska Highway. Using Dr. N.W. Radforth's classification (1), they would be described as BEI muskeg. Geologically, they are young, probably forming during the Quatenary Period. At depths of about 20 feet, the fibrous nature of the soil is still clearly visible. The organic material varies in colour from that of living vegetation, such as stunted spruce trees, sedge grasses and mosses at the surface, to a light brown just beneath the surface to a darker brown at the bottom. On exposure to air, the subsurface material rapidly turns a very dark brown to black. Generally, the muskegs are very soft and the water table is practically at the surface. One consolidation test indicates that a settlement of 50 per cent of the depth may be expected under a load of one ton per square foot. They are tedious to walk on and the black flies and mosquitoes harboured by them are extremely annoying.

1. New Construction over Organic Terrain

In a paper presented at the Eastern Muskeg Research Conference early in 1956, Mr. MacFarlane outlined the various techniques of road construction over organic terrain (2). Generally, these have been used as a basis for discussion for this part. Many of the remarks made by Mr. MacFarlane must, of course, be considered applicable to the Alaska Highway. I am referring to such points as using gravel as a fill material as opposed to clay, the depth to which a muskeg can be excavated economically, and the definitions that he presented in his paper.

Relocation is, of course, the most desirable solution to the problem of road construction over organic terrain. If crossing it is unavoidable, then there are three general possibilities to be considered for construction. These are:

(a) Displacement of a muskeg as exemplified by underfill blasting or by inducing the muskeg to flow from under the fill by deep side trenches,

(b) Excavation of the muskeg prior to filling either by machinery or high explosives,

(c) Flotation of the road either on or partially within the muskeg.

The displacement of muskeg in Northern Canada, in many cases, is difficult for two main reasons. The first is the time element. It is about the end of June before the frost is out of the ground and in September or October you can expect to have freezing temperatures again. About three or four months are available, therefore, when the muskeg could be effectively displaced. The second reason is the cost. Large quantities of explosives may be involved as well as a trained crew to use them. Complete displacement, that is, ensuring that the fill goes to the bottom of the muskeg, is more expensive in fill material than flotation, as the following example illustrates. Suppose the muskeg is 20 feet deep and the fill is to be 5 feet above the surface, then the total depth to be placed is 25 feet. On the other hand, if a settlement of 50 per cent is allowed for consolidation of the muskeg, then the fill height will amount to about 15 feet. This represents a difference in fill material of about 80,000 cubic yards per mile. The use of a surcharge to hasten settlement or displacement also has the disadvantage of using more material. The maintenance imposed by the settlement over the next few years is dealt with under the next heading.

Excavation of the muskeg is recommended for depths of about 10 feet. Again this is difficult due to the water present and also the possible presence of seasonal frost or permafrost. To wait for a frost-free condition may mean having to lose up to two months of construction time. In one particular case, however, the muskeg was only 4 feet deep and about 200 yards long. This was removed by following the frost down, i.e., by dozing off layers 6 to 8 inches in thickness as they thawed. A little experience in blasting indicates that the use of high explosives is not too reliable when the ground is frozen. The large part of the explosive energy comes back up the hole through which it was loaded. The ground which is broken remains in large unwieldy chunks.

The last of the general possibilities is flotation of the fill in or on the muskeg. Included under this heading is the settling of the fill into the muskeg as well as pure flotation. That is, the fill can settle into the muskeg say 50 per cent of its depth and for the purposes of this paper still be considered as floating.

The original construction of the tote road illustrates a procedure that may be defined as pure flotation. Apparently, every effort was made to avoid large cuts and fills, judging from the numerous curves and steep grades now so much in evidence. When a muskeg was encountered, the tote road tortuously wandered from high spot to high spot to find the most stable route across. Sometimes, a considerable amount of corduroy was laid successfully, in terms of tote road requirements. The use of corduroy does not appear to affect materially either the rate or amount of settlement due to consolidation, except that the loading due to construction is considerably lighter. There does not appear to be any lasting buoyancy or flotation effect. Regrading in the last few years, i.e., about 10 years after construction, has uncovered pieces of the corduroy which have apparently worked their way to the surface. Corduroy does, however, have the advantage of making the settlement more uniform in that long sags rather than distinct holes occur.

In the summer of 1950, a 2-mile relocation was constructed, portions of which traversed a muskeg with a depth of up to 15 feet. The relocation to a new alignment was necessitated by severe sliding conditions on the old road. With a small crew and the urgent need for the new alignment, it was necessary to start construction as early in the season as possible. The flotation technique was therefore adopted. This project employed the principle of extending the road fill by end dumping. The fill was all fairly clean pit-run gravel that had to be hauled about 5 miles from a poorly located pit. Other than vehicle compaction and vibration from tractors dozing out the fill, no attempt was made to obtain any stabilization during construction. The following 3 or 5 years saw a very heavy maintenance commitment. Something in the order of 3,000 to 5,000 cubic yards of gravel per mile per year was hauled to bring the road back up to grade. During this period the road was rough since it would not have been worthwhile to place surfacing material. From both economical and practical standpoints, surfacing must wait until stability of the fill is reached.

One other factor which will influence the method chosen to construct over organic terrain is the presence of permafrost. Recent work in Alaska indicates that permafrost cannot be maintained under normal road construction. That is, unless an excessively high and wide fill is used, thawing and subsequent settling of the road will inevitably occur. There is little doubt that, when permafrost is encountered, the construction of a stable fill is more time consuming and costly. For reasons mentioned previously, excavation and displacement are hardly feasible. Filling across the frozen muskeg is the easiest solution, but the price paid is the necessity for repeated bringing up to grade over a great period of time before equilibrium is reached.

It would appear, then, that the most feasible method of road construction over organic terrain in Northern Canada is to place a fill as conveniently as possible and to accept the heavy maintenance requirement imposed for the next 3 to 5 years. Briefly, the reasons are summed up as follows: Excavation and displacement are difficult due to the nature of the muskeg, the time element and possible presence of frost. In effect, you are left with only one choice, that of flotation. If permafrost is encountered, a distinct advantage of the flotation method is that the fill may be placed when the ground is frozen and is passable to trucks. Another slight advantage to flotation is that the cost is spread out over several years. However, before any final decision is made as to which technique is most suitable, a thorough soils investigation program should be carried out and all alternatives explored.

Based roughly on the ideas just outlined, a relocation was planned across a muskeg having a depth of about 20 feet. This relocation was to replace about 1 1/2 miles of winding road. The plan proposed was to construct a rock fill 15 feet high with side berms about 20 feet wide and 5 feet thick. All this material was to be placed on the muskeg during the winter. The advantage sought here was the mobility provided by the frozen muskeg. The fill material was to be quarried rock that could only be obtained during the winter since it was situated on the far side of the muskeg. Also, because it could be done during the winter the amount of work increased that could be accomplished during a fiscal year. Unfortunately, this project was never started, but it does indicate one line of thought as a solution to crossing a muskeg.

2. Maintenance of Roads through Muskeg Country

Turning now to the maintenance of roads in muskeg country, perhaps the first thing to note is the extra maintenance effort required when the fill is not placed at the bottom of the muskeg. Besides the direct cost of the gravel necessary to bring the road up to grade each year, there is a necessity for more constant grading throughout the summer to keep the road relatively smooth. It is estimated that such a portion requires about three times as much grading as a road over inorganic terrain.

One of the most serious ramifications of this type of construction is that a surface crew is committed to a definite task for these 3 or 5 years. This means that other work must be postponed. For example, during this period of commitment the length of road normally surfaced by the crew will be reduced. There is a hidden cost which is extremely difficult to assess, i.e., how much money are you losing when the other jobs you should be doing have to be delayed another year? I am referring here to another section of the road that requires resurfacing. If the base course is showing, then the road is generally rougher and tends to washboard more readily, hence it requires more grading. Indirectly, therefore, the muskeg is responsible for the increased maintenance of this section.

The maintenance of a finished and fairly stable road over muskeg presents problems also. The surface material which is pushed or blown off the road cannot be reclaimed by pulling the shoulders or cleaning the ditches. This material is just lost and, therefore, the road must be resurfaced every two to four years, instead of every three to five years. That is, about one year of life of the surface material is lost.

Where a road traverses a muskeg, the drainage is poor. Unless the fill is of sufficient height, say, more than the capillary rise of the soil comprising the fill, the subgrade is soft and may shift laterally during the summer. In the winter, it is subject to frost heaving. It is, therefore, a year-round maintenance problem and, except for a grade raise, little can be done. Good fill material always seems to be at a premium in a muskeg area and on the highway, it never seems to be within good hauling distance of a muskeg.

One winter problem, often attributable to the presence of a muskeg, is the formation of masses of ice that build up and spill out over the road. These distinct driving hazards, which are peculiar to the north country, are referred to in Russian literature as "nalyeds". Locally, our people call them "glaciers". They are formed by the freezing of successive sheets of water and can build ice to almost unbelievable dimensions, both vertical and horizontal. In some cases, ice up to 10 feet thick and a quarter- to a half-mile long will form. The high insulating value of muskeg and snow limits the frost penetration to relatively shallow depths. Water will keep seeping all winter, therefore, despite temperatures well below zero. The frost penetration under the bared road is deep enough to seal off the flow with the result that the seeping water is forced up to the surface at the roadside where it freezes. Gradually, this ice encroaches on the road and must be bladed off. It must be admitted that the road need not necessarily cross the muskeg but must interfere with the general drainage pattern no matter how ill-defined it may have been. The significant point here is that the muskeg provides a year-round water supply.

Another situation in which muskeg occasionally plays an important role is in providing water to a soil that is susceptible to sliding. One particular case is at Mile 228 on the Alaska Highway. A muskeg about 3 to 4 feet deep is situated on top of a hill and the road is about one-quarter of the way down the slope. Considerable sliding has occurred which necessitated continuous work on the road. Last summer, trenches were cut in the muskeg and a drainage system installed. Unfortunately, insufficient time has elapsed to assess the adequacy of the drainage scheme, but it is hoped that the slide situation will improve.

Any work that must be done in a muskeg, such as the installation of a drainage system, can only be done at certain times of the year. If bulldozers are considered, they can only work in the spring for about a month when they must follow the frost down. That is, they doze off a thawed layer 6 inches or so in thickness and rely on the frozen muskeg beneath them for support. In this way, they work their way down to either the depth required or to inorganic soil. If the muskeg contains permafrost, this is probably the only way to move it. The frost must be out of the ground if the efficient use of high explosives is contemplated.

3. The Effect of Muskegs on Costs

In discussing the extra costs to the Northwest Highway System attributable to muskegs, I must be very general. Such factors as depth of muskeg and length of haul of the fill material, as well as other like factors will have a decided effect. Another very real reason I cannot be more explicit in the line of costs is that our cost accounting system is set up to handle sections of the road and not specific locations. We, therefore, do not have any specific figures relating the maintenance costs of roads over muskeg to roads over inorganic material. With these factors in mind, I will attempt to assess some costs.

The extra initial construction costs imposed by muskeg terrain are fairly obvious. Removal in any manner is a cost not associated with inorganic terrain. Any pure flotation method is expensive. Corduroy, for example, using native timber has a high demand for labour. The cheapest appears to be placing fill on the muskeg and accepting subsequent settlement. It will cost in the order of $15,000 per mile for a 5-year period to bring the road up to grade and keep it fairly smooth. This must be compared to the cost of putting the road to the bottom of the muskeg during construction.

The figures for straight grading operations on the highway indicate that those sections having a high proportion of the road over organic terrain cost about 60 per cent more to grade than those sections over inorganic soil. This is an average figure only and varies from section to section. One section of road over inorganic terrain may not get as much grading as it should due to the weather or pressure of other work. Another more trouble-free section will be able to do more grading. There is no doubt, however, that roads over muskeg do cost more to maintain. I would estimate about $100 to $150 per mile per year more than roads over good soil.

The cost of bringing the road up to grade after placing a fill on a muskeg will run about $1,500 to $2,000 per mile per year, but it may be more depending on the gravel haul and the amount of material necessary. During the 3- to 5-year period of settling of the road, the surface requires grading about three times as often. Thus the grading costs are three times normal, something like $900 per mile instead of $300 per mile per year.

For a stable road across organic terrain, the life of the surface is shorter. Generally, this is made up by patch surfacing which costs from $800 to $1,000 per mile. If a grade raise of three feet is contemplated, then about $8,000 per mile is necessary if gravel is nearby.

The nalyeds that were mentioned earlier cost more than $50,000 in maintenance effort during the winter of 1955-56. It must be pointed out that not all nalyeds can be traced back to muskegs, but in 60 to 70 per cent of the cases organic terrain is a vital factor. This high maintenance cost cannot be eliminated, but it can certainly be reduced. Individually, nalyeds cost from one to two hundred to several thousand dollars per year, depending on their size, location and distance from the maintenance camp.

Summary

In summary, when considering a gravel surfaced road, it appears that the advantages offered by filling across a muskeg outweigh the disadvantage of having a heavy maintenance for the ensuing 3 to 5 years. Some of the advantages are: the maximum working time, the mobility of frozen muskeg, and the ultimate saving in fill material.

Muskegs increase the maintenance effort whether or not the highway traverses them. Roads over organic terrain require more grading and resurfacing. Frost heaves, soft subgrades and nalyeds are associated in the majority of cases with the proximity of a muskeg.

An over-all picture of costs indicates roads over organic terrain are more expensive to build and to maintain. Just how much more expensive will depend on the individual section, but a figure of two to three times seems to be the case.

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Section 9

Access Over Muskeg

by

R.A. Hemstock

The development of Northern Canada is being hampered in many cases by the difficulty of access. Not only are distances great but terrain conditions are such that normal means of overland travel are inoperable. Of course, the chief difficulty is muskeg, that spongy covering of organic material so common in the North which has been an almost insurmountable barrier except when frozen. This is the reason that most of the development in these new areas is carried on in winter. It is simply the only time that men and machines can work, the sub-zero temperatures are the lesser of two evils.

The petroleum industry has been searching for the answer to this problem for several years. Of course, in order to explore and develop petroleum resources reliable access is most important. The industry faces two main problems. First, the quick and cheap access required for geophysical prospecting in which large areas must be covered with a fairly close grid but with loads that are relatively light (4 tons or less). Second, wildcat drilling rigs and other heavy machines weighing up to 28 tons must be moved into areas. This phase usually results in a fairly complete road network with power lines, pipelines, and towns. These areas are developed or civilized on a fairly long-term basis.

Progress with respect to the first problem will be reviewed here. Many types of machines have been tried, generally featuring very large wheels or tracks. Looking back at them now, some seem to be definitely of the Rube Goldberg variety but each probably added something to our knowledge of muskeg problems. They taught us, if not what to do, what not to do. The most promising of the first machines was the Weasel (Fig. 1). Mechanical problems were the chief difficulty although performance was good enough to point the way to development of other machines. The Weasel did, however, travel over soft ground that had not been possible to cross before. Several of these machines were used in geophysical exploration for a limited time. Their chief drawbacks were insufficient load capacity and frequent mechanical failures.

Based on the approach which the Weasel indicated, Imperial Oil Limited built a test machine for muskeg work (Fig. 2). It featured rubber belt tracks, and was fitted with a waterproof hull to make it amphibious. Hydraulic power was used to drive the tracks; unfortunately this feature proved most difficult and a satisfactory light-weight drive mechanism was not achieved. The development was dropped after limited field testing.

Several machines of various types followed but the most satisfactory one was, for a time, the Muskeg Tractor, an all-track vehicle, built by Bombardier (Fig. 3). These machines have been used quite extensively in exploration work and generally their performance has been good. The Muskeg Tractor does not have the capacity required for carrying heavy drills but has been used for carrying all other sections of a seismic exploration party. Since certain areas cannot be worked properly without heavy, high power drill units, it was essential to have a vehicle with greater load carrying ability.

It was decided that an articulated vehicle would be the best approach. The front or steering segment was to be the Scout Car, a small track vehicle manufactured by Bruce Nodwell Ltd, in Calgary. The Scout Car weighs 4,150 pounds, has a ground pressure of 1.25 lb/sq.in. and is powered by a six-cylinder Ford engine (Fig. 4). Tracks are nylon belt with steel cross links. The track is driven by a specially designed rubber sprocket which exerts its driving force close to the belt. This allows much deeper recess of the cross links and makes it possible to hold tracks on the vehicle under very adverse conditions. The trailer portion features similar construction but is much larger. It rides on 40-in. wide nylon belt tracks which allow it to carry a 4-ton net load with less than 2 lb./sq. in. ground pressure. It is driven by a Ford-six engine which supplies power to the tracks through a conventional torque converter. The trailer is fastened to the front vehicle through a patented drawbar which allows for ample movement between the machines (Fig. 5).

These two vehicles were first tested as a unit in July 1956, they have been in continuous service since then (Fig. 6). The first task was to haul fuel into an area inaccessible by any other means of travel except by air. After performing well on these tests it was equipped with a heavy seismic drill and put to work in muskeg areas, and also in the foothills of Alberta. It has been used continuously in that service since.

The success of these machines encouraged the construction of a third vehicle which is called the Scout Truck. This is much larger than the Scout Car. It is equipped with 40-in. tracks with a total bearing area of 7200 sq. in., which will allow payloads of up to 3 tons with less than 2 lb/sq. in. bearing pressure. The suspension is similar to that used in the trailer. Steering is accomplished with a cross-drive similar to that used in the Scout Car. Preliminary tests of this machine are most encouraging.

It is hoped that this family of vehicles when used separately or in various combinations will provide a satisfactory answer to Industry's search for means of light access in muskeg areas.

This talk was accompanied by a short film.

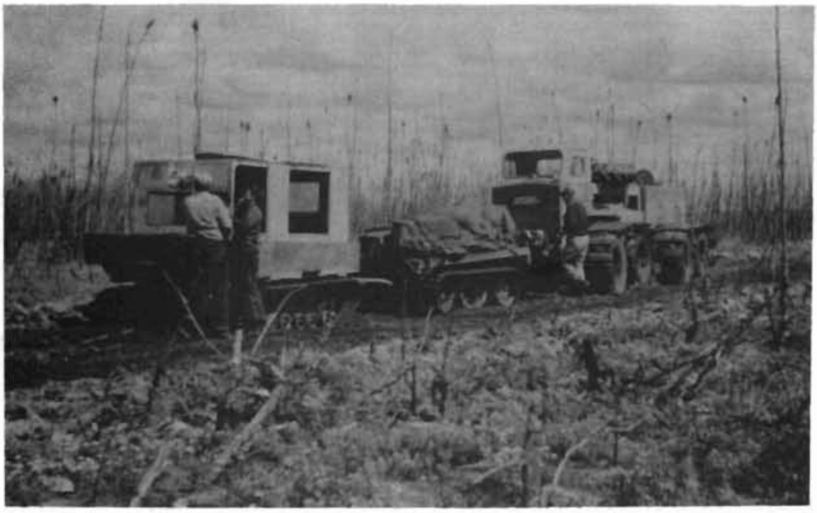


Figure 1 From left to right, a Weasel with a track trailer and a North King fitted with tracks. The North King proved to be too heavy for muskeg.

Figure 2 A hydraulic drive track vehicle built by Imperial Oil Limited. Its success was defeated by mechanical troubles.

Figure 3 A Bombardier Muskeg Tractor fitted with seismic instruments for year-round work.

Figure 4 The Nodwell Scout Car which has shown well during its first year of operation.

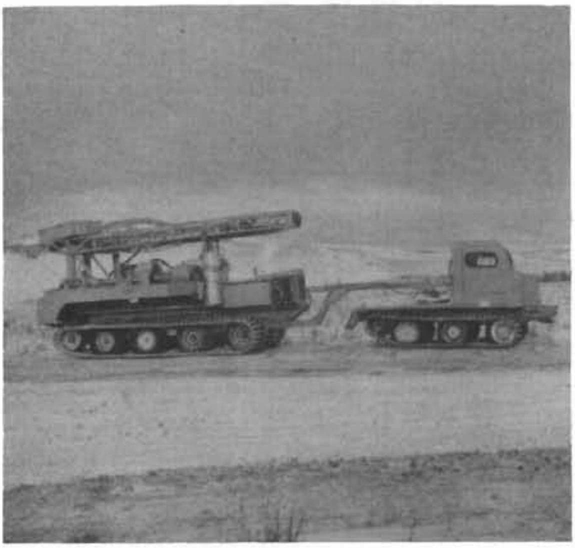


Figure 5 Scout Car with Scout Trailer carrying a heavy seismic drill. This equipment is performing well.

Figure 6 Scout Car with trailer successfully negotiatimg difficult muskeg conditions loaded with 4 tons of fuel.

Section 10

Problems of Access as Pertaining to Off-the-Road Vehicles

by

Dr. N.W. Radforth

There are different viewpoints on the subject of vehicular access to muskeg country. Some people emphasize transport as the fundamental function to be satisfied, others favour construction or preparation for construction, and doubtless there are those who visualize the achievement of a special function, dependent upon ability to lift and deposit loads of varying shapes and material. In this account it will be possible, especially by reference, to touch upon each of these aspects, but chief consideration will be given to transport, which can claim to be of primary importance because it is more likely to provide the most characteristic problems which differ widely in type.

Experience suggests that attainment and continuity of access are mainly dependent upon two major factors: (1) organic terrain character and (2) mechanical adequacy and excellence of the proposed vehicle in relation to whatever limitations and advantages the terrain offers. More importance is attached to terrain character. Successful design and performance requirements cannot be met as efficiently if attempts for mechanical excellence are approached merely by adaptation of known mechanical devices designed with an indifference to the total experience the terrain is going to afford.

Therefore, in the following section the terrain will be analysed and given preference over vehicle design and performance. Then these last two will be considered. Finally, by way of illustration and example, a type vehicle will be assessed in a third section.

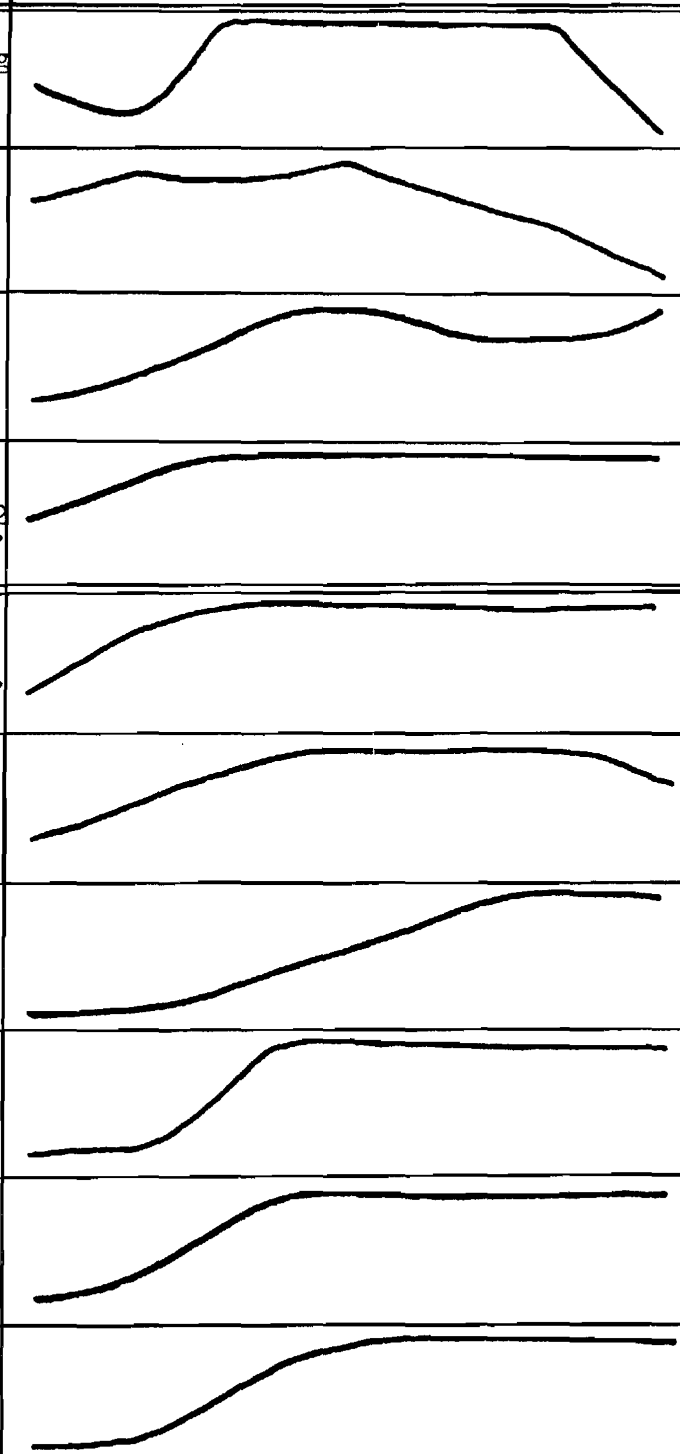
Terrain Character

Muskeg studies dealing with topographic and structural variation (above and below ground), subsurface ice features and surface obstructions have been portrayed in some detail in previous accounts by the author. They are summarized and conveniently related for application in a recent handbook provided by the Associate Committee on Soil and Snow Mechanics (1). For the present purpose there remains the co-ordination of this and other information (2, 3), in order to assess the total effect of terrain properties (whether these will help or hinder) in relation to anticipated vehicle performance. As a suggested analysis, this is expressed in Table I.

TABLE I

PRIMARY ORGANIC TERRAIN CONDITIONS LIMITING VEHICLE DESIGN AND PERFORMANCE (SUMMER)

MECHANICAL FACTOR	TERRAIN REFERENCE TYPES AE AEH BEI DFI EH EI FI	
Track Run Conforming to ground contour		Design Requirement Assessment (Relative Degree of Necessity)
Frontal Drive Sprocket		
Synchronized Winch and Track		
Ground Pressure lower than $1\frac{1}{2}$ lb/in.^{2}		
Possibility for Maximum Speed 6 mph.		Functional Response (Relative)
easy Manoeuvrability difficult		
good Pitch Avoidance poor		
high Load Towing Desirability low		
high Displacement low		
high Displacement re Towed Vehicle with no traction low		



It will be noted here that terrain character is exemplified by "cover formulae" which describe the vegetation (4). Reference to the literature (5, 6, 7) will explain that major factors in organic terrain character can now be tied-in with vegetal cover. Therefore, the use of this cover in Table I is appropriate.

For the sake of simplicity, only seven cover formulae were selected. This represents a small number of the total that might actually occur. The range is reasonably complete, however, although others may be inserted into the scheme by the reader. Each cover type represented is a common one, and one is apt to occur as commonly as another in the "average" type of traverse.

Also it is important to note that the cover types are so arranged that the one on the extreme left (AE) permits maximum traction, and the one on the extreme right permits minimum traction. The others, in succession from left to right, suggest the progressively increasing influence of water in the peats where degrees of displacement are to be expected when vehicles are applied.

The particular characteristics of each terrain type responsible for variability in vehicle performance are best considered when vehicle response is being analysed.

Vehicle Design and Performance

In Table I, in the left-hand column a set of ten mechanical conditions has been selected for examination. Others might have been chosen instead of, or in addition to these, but wherever vehicle performance in muskeg is discussed, the listed conditions are the most frequently mentioned generalized ones in the writer's experience. The first four relate to design and the remainder to function during field operation. Each of these is analysed in tabular form in Table II.

TABLE II

Case 1 - Bottom Track Run Adjusting to Ground Contour

AE to AEH - Requirement for large area application of track to ground contour not essential to achieve buoyancy or fast travel. Total contact with the ground would be difficult to achieve. Supporting mat is very strong with high shear resistance.

BEI to EI - Chance of displacement not great if track-ground contact is high.

EI to FI - Due to low shear values, especially on second and subsequent runs, sustained contact is not achieved.

Case 2 - Frontal Drive Sprocket

Greatest need is in DFI type terrain. Pockets of FI interrupt a shallow mat. Unless there is a slope to the lower front portion of the bottom run of track, progress will be very difficult.

AE to AEH - The feature will assist against long, thick, woody erratics separating less resistant pockets into which the nose of the track might pitch because of sharp, closely applied terrain irregularities.

BEI to EH - In softer terrain where displacement is higher and mat tends to be homogeneous, the feature is not so important.

Case 3 - Synchronized Winch and Track Speed

DFI and FI - The requirement is essential if progress is to be made, unless in DFI, the FI element can be avoided.

BFI and EI - At significant intervals, particularly between peaty plateaux, the need is very great.

Case 4 - Ground Pressure less than 1 1/2 lbs./in.^{2}

Essential for all types where maximum displacement is to be avoided. Much advantage is to be gained in range BEI to EI with lowest ground pressure possible.

Case 5 - Maximum Speed 6 mph.*

If the vehicle is built for maximum displacement, sustained high speed will be experienced in BEI to FI. If the machine is not built for maximum displacement, moderate speeds will be sustained in AE and AEH but low speeds will be experienced in BEI, EH and EI with immobilization imminent in DFI and certain for FI.

Case 6 - Manoeuvrability

Surprisingly, it is perhaps easier to change direction at short range of distance in BEI, EH and EI not because of lack of obstacles, but because the mat is less encumbered by frequent changes in structure. In AE and AEH, it is

---

* The estimated highest speed yet attained by any vehicle (known to the author), travelling with payload under the worst muskeg conditions.

essential to manoeuvre, but often difficult because of close stands of heavy timber and irregular contour. In DFI, good steerability is essential.

Case 7 - Pitch, Fore, Aft and Lateral

AF to BEI - Pitch is maximum amplitude, frequent and in in all directions. It is usually gradual and the operator is forewarned.

DFI - Pitch is normally of moderate amplitude except in isolated cases when it is severe and can be catastrophic. In all cases it is sudden, experienced in the fore-aft axis of the vehicle and comes with little or no warning.

EI to FI - Pitch is low to negligible except where hidden boulders occur if the organic layer is shallow. Here there is danger to tracks.

Case 8 - Towing vs. Carrying Load

AE to AEH - No special advantage to towing. On the contrary, resistance to haul is very high.

BEI to EI (excluding DFI) - Towing is desirable as best procedure for load transport.

DFI - Carrying the load is desirable, but the vehicle must be fully buoyant in open fresh water.

FI - Load towing is advised.

Case 9 - Displacement Possibility for Vehicle

The possibility arises infrequently in AEH but is progressively greater for other types, being essential for EI, DFI and FI.

Case 10 - Displacement Possibility for Towed Vehicle

AE to AEH - No displacement should be encountered in summer conditions.

BEI - Moderate possibility of displacement.

DFI to FI - Full buoyancy in open fresh water should be provided for.

Consideration of a Type Vehicle

From the analyses of terrain-vehicle relations presented, the reader will appreciate the difficulties in development of a vehicle expected to perform well where terrain conditions are at their worst. The Modified Water Buffalo, at present available, is satisfactory already. So, too, is the Powered Slipe used in the Slipe-Haul Method (8). On the other hand, for general needs, the design principles incorporated into the Nodwell Scout Car and Trailer (latest version) give excellent results where the organic terrain conditions are moderately bad, but not at their worst, and these conditions may be typical for selected areas.

It should also be appreciated that vehicle design is not solely a function of terrain, but that it relates to the purpose or range of purpose for which the vehicle is to be applied. Best performance will be achieved, therefore, not by one all-purpose vehicle, but by a range of vehicle types. It must also be claimed, however, that if operations are proposed for areas where the terrain factors are limiting, the design principles incorporated into the vehicles must compensate accordingly, in spite of the nature of the job to be done.

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2. Radforth, N.W., Palaeobotanical method in the prediction of sub-surface summer ice conditions in northern organic terrain. Trans. Royal Society of Canada, Vol. XLVIII, Series III, Section 5, June 1954. National Research Council, Associate Committee on Soil and Snow Mechanics, Tech. Memo 34, March 1955.

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7. Radforth, N.W., Peat in Canada and Britain - economic implications, Journal of the Royal Society of Arts, London, No. 4990, Vol. CIV, November 1956. National Research Council, Associate Committee on Soil and Snow Mechanics, Tech. Memo 45, March 1957.

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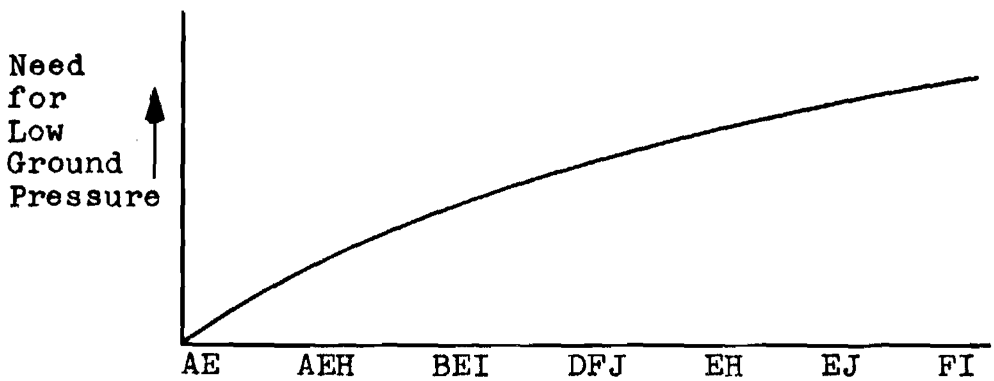
Section 11

General Discussion

The Chairman introduced Mr. J.L. Charles, Chief Engineer, Western Region, C.N.R., who led off the discussion. Mr. Charles said that his experience with muskeg has been of a personal nature, namely walking over and through it, rather than of an academic nature. He had listened with great interest to the papers and had concurred with much that was said. Mr. Charles stated that his original experience with muskeg was during the construction of the Hudson Bay Railway. He said that he could not over emphasize the importance of good drainage of organic terrain and the construction of adequate off-take ditches. Along the Hudson Bay Railway there are drainage ditches 3 miles in length to carry water away from the railway grade. He thoroughly agreed with Mr. Walsh's arguments about building the embankment on the muskeg. He could not see the need for excavation by machine or by blasting. Mr. Charles admitted that there are some difficult spots along the railway which need ballasting from time to time, but in spite of this he is convinced that the flotation method of construction is the cheapest one to use. He warned that eventually it may be necessary to re-excavate the drainage ditches. In his experience, ten years is the limit for the life of a ditch in muskeg.

Mr. Powell asked if Dr. Radforth could relatively correlate the different letters of the classification system with the load bearing capacity of the muskeg type represented by the particular letter. Dr. Radforth said that it will eventually be possible to correlate bearing capacity and classification, dealing, however, with a range of values. He stated that often the governing criterion is a ground pressure of less than 1 1/2 lb./sq. in. A sketch was drawn to illustrate the correlation between the coverage class types and the need for a low-ground pressure in a vehicle.



Mr. Ripley said that Mr. Charles had mentioned the need of re-excavation of ditches. He wondered what was the maximum depth at which it is practical to maintain ditches. Mr. Charles replied that generally 6 feet is the practical depth, although there are some ditches on the railway 8 to 10 feet deep. The deeper the ditch, the wider it will have to be at the base, so that it is not always practical to go too deep. Mr. Ripley explained that he has the problem of building a canal through muskeg with a depth of up to 15 ft. Mr. Charles remarked that for very deep ditches there may be slope failures, but if the width is adequate there is not too much difficulty.

Dr. Radforth mentioned that he has had the opportunity of examining ditches in at least 3 types of peaty material. In one case there was sloughing, in another there was a marked depression at the surface, (i.e., consolidation of the material) and in the third case there was no change. Apparently one can expect some difference in experience, depending upon the peaty material with which he is dealing. This would also relate to the water content. As the structure of peat changes, so would the water content.

Mr. Ripley remarked that Capt. Thomson had mentioned a proposed relocation of a road across muskeg, using rock fill. He was reminded of once seeing a high rock fill across a muskeg. He didn't know the muskeg type but was amazed at the height of fill carried by the bog and couldn't see why there wasn't a failure. He wondered why Capt. Thomson planned to use rock for the fill rather than some other material. Capt. Thomson replied that rock is easier to quarry in winter than other materials also it was more accessible to the particular location in question than was gravel, sand, or some other fill material.

Mr. Stoneman asked Mr. Hemstock if any difficulty had been experienced with the Nodwell Scout Car in crossing bogs and similar obstacles. Mr. Hemstock replied that there has been no difficulty with the vehicle in that way. On the whole, its performance has been very good. In answer to another query, he said that the vehicle is not completely buoyant.

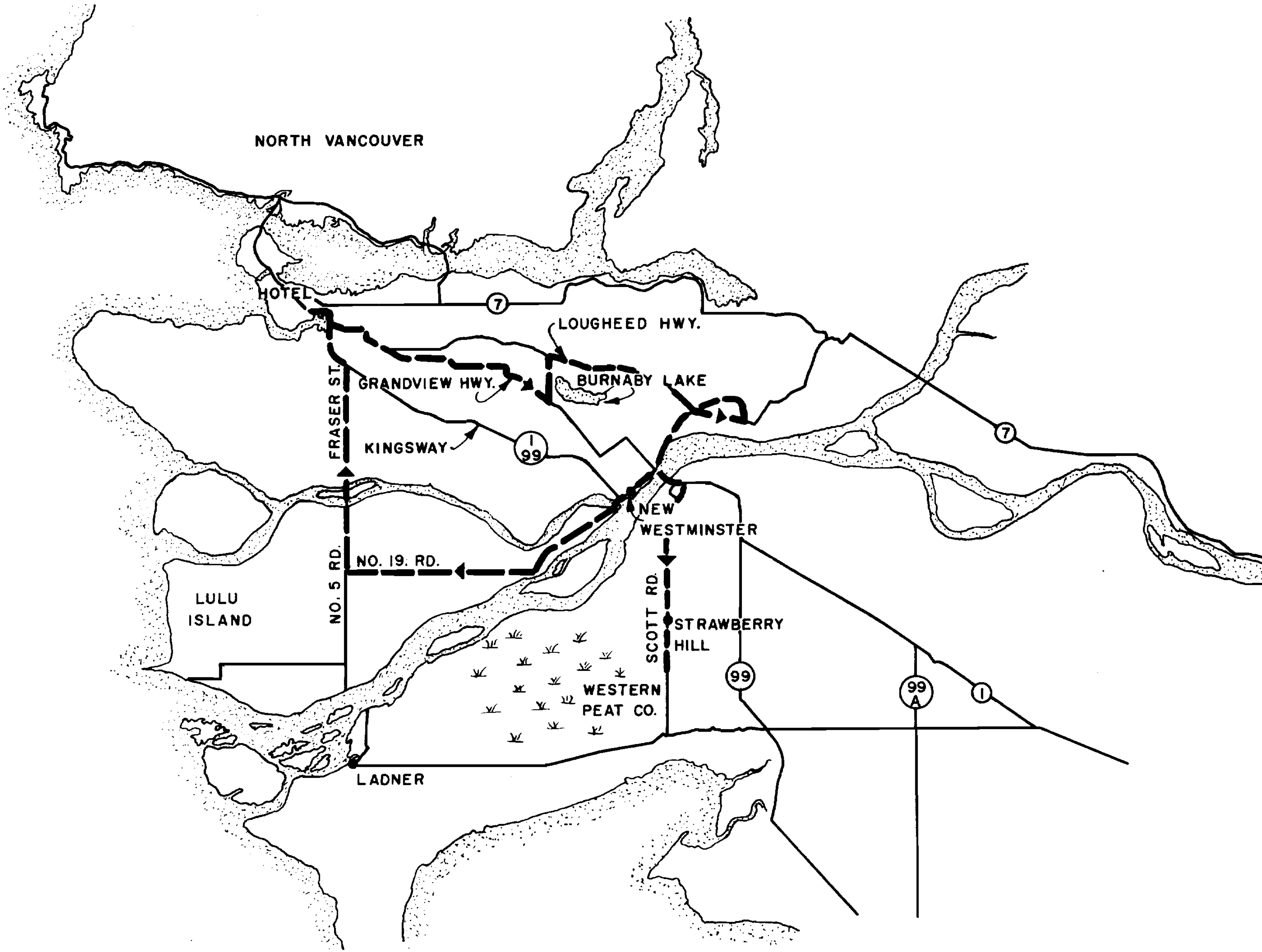
Capt. Thomson asked if Mr. Charles had any formula for preventing beavers from building their dams in ditches almost as fast as they are dug. Mr. Charles replied that it is a rather serious problem, as there have been derailments resulting from the failure of a beaver dam. All anyone can do is to keep in contact with the Natural Resources people and when beavers become objectionable, have them trapped.

Mr. Ripley called upon Dr. Radforth to close the technical sessions. On behalf of the Muskeg Subcommittee, Dr. Radforth expressed his gratitude to all those who had contributed to the conference. He believed that the contributions made collectively towards the understanding of muskeg problems have been considerable.

He said that because it is now possible to get on top of some of the problems, all sorts of projects are anticipated. This type of situation must grow and he looked forward to other such conferences. Dr. Radforth extended an invitation for papers for future technical sessions and urged everyone who had a paper which has evolved as a result of experience or study to let him know about it. The session then adjourned.

Field Trip of February 21

A field trip was arranged in conjunction with the conference to enable those present to obtain a first-hand view of some of the problems caused by muskeg. Twenty-nine people were on the field trip, which lasted most of the day. It included visits to roads constructed over muskeg and buildings built in it, as well as a visit to a large plant which reclaims peat bogs for commercial purposes. A map of the Vancouver area is shown, and the route of the field trip is noted. The field trip to roads built over muskeg was guided by Mr. R. Thurber of the B.C. Dept. of Highways; foundation problems of buildings constructed in muskeg areas were pointed out by Mr. C. Leonoff, of Ripley and Associates; the visit to the plant of the Western Peat Company was under the capable guidance of Mr. E.E. Carncross; a running commentary of relevant geological features of the various bogs was kindly supplied by Dr. J.E. Armstrong of the Geological Survey.



ROUTE OF FIELD TRIP

APPENDIX A

LIST OF THOSE PRESENT AT THE THIRD MUSKEG RESEARCH MEETING, FEBRUARY 20th AND 21st, 1957

Agassiz, G.C.	United Trailer Ltd., 3715 Edmonton Trail, Calgary, Alberta.
Anderson, Lars	Ripley and Associates, 1930 West Broadway, Vancouver, B.C.
Armstrong, Dr. J.E.	Geological Survey of Canada, Room 102, 739 Winch Building, Vancouver, B.C.
Blake, F.P.	B.C. Telephone Co., Vancouver, B.C.
Brown, W.G.E.	Spartan Air Services, 136 Queen Street, Ottawa, Ontario.
Charles, J.L.	Chief Engineer, Western Region, Canadian National Railways, Winnipeg, Manitoba.
Cotsworth, P.F.	Canadian Fina Oil Co., Calgary, Alberta.
Doughty-Davies, J.H.	Water Rights Branch, Parliament Buildings, Victoria, B.C.
Enbanks, E.B.	622-8th Avenue West, Calgary, Alberta.
Evel, Miss Jean	Dept. of Biology, McMaster University, Hamilton, Ontario.
Farrel, R.D.	Dept. of Highways, Victoria, B.C.
Gerry, W.G.	c/o Saguenay-Kitimat Co., Box 361, Kitimat, B.C.
Grimble, L.G.	Stanley, Grimble, Roblin Ltd., 11605 Jasper Ave., Edmonton, Alberta.
Halcrow, A.F.	Hudson's Bay Oil and Gas Co. Ltd., 320-7th Avenue West, Calgary, Alberta.
Hansen, H.K.	Ripley and Associates, 1930 West Broadway, Vancouver, B.C.
Hardy, R.M.	Dean of Engineering, University of Alberta, Edmonton, Alberta.
Henderson(WO)C.D.	R.C.A.F. Lincoln Park, Alberta.
Hemstock, R.A.	Imperial Oil Ltd., 300-9th Avenue West, Calgary. Alberta.

Huggins, R.	Morton Engineering Ltd., 1340 Commercial Drive, Vancouver, B.C.
Hughes, Eric.	Department of Agriculture, 70-8th Street, New Westminster, B.C.
Hyslop, T.W.	Supt. of Lands, Parliament Buildings, Victoria, B.C.
Kirby, A.S.	Editor "Public Works in Canada", Mitchell Press Ltd., P.O. Box 6000, Vancouver, B.C.
Leonoff, Cyril.	Ripley and Associates, 1930 West Broadway, Vancouver, B.C.
MacFarlane, I.C.	Division of Building Research, National Research Council, Ottawa 2, Ontario.
Mackinnon, D.F.	Texaco Exploration Co., 8221-109th Street, Edmonton, Alberta.
Mathews, Dr. W.H.	Division of Geology, University of British Columbia, Vancouver, B.C.
McLean, A.A.	Department of Transport, 739 West Hastings St., Vancouver, B.C.
Monahan(S/L)J.M.	R.C.A.F., Lincoln Park, Alberta.
Moonen, F.H.	B.C. Telephone Co., Vancouver, B.C.
Nodwell, Bruce.	United Trailer Ltd., 3715 Edmonton Trail, Calgary, Alberta.
Nowlan, B.C.	Bell Telephone Co., 1050 Beaverhall Hill, Montreal 1, P.Q.
Olsen, M.	1407 Gray Avenue, S. Burnaby, B.C.
Paget, A.F.	Comptroller of Water Rights, Parliament Buildings, Victoria, B.C.
Peebles, Prof. A.	University of British Columbia, Civil Engineering Dept., Vancouver, B.C.
Powell, G.C.	Imperial Oil Producing Dept., Edmonton, Alberta.
Pullen, N.F.	B.C. Telephone Co., Vancouver, B.C.
Radforth, Dr.N.W.	Dept. of Biology, McMaster University, Hamilton, Ontario.
Rickel, W.K.	Amerada Petroleum Corp., 622-8th Avenue West, Calgary, Alberta.

Ripley, C.F.	1930 West Broadway, Vancouver, B.C.
Roethel, H.L.	Bureau of Economics and Statistics, Dept. of Trade and Industry, Victoria, B.C.
Rouse, Dr. G.	Biology and Botany Dept., University of British Columbia, Vancouver, B.C.
Shields, D.H.	Ripley and Associates, 1930 West Broadway, Vancouver, B.C.
Spence, R.A.	Civil Engineering Dept., University of British Columbia, Vancouver 8, B.C.
Stevenson, H.A.	Dept. of Transport, 739 W. Hastings, Vancouver, B.C.
Stoneman, D.G.	Shell Oil Co., Box 186, Edmonton, Alberta.
Sullivan, J.J.	The British American Oil Co. Ltd., P.O. Box 130, Calgary, Alberta.
Tait, T.W.	Dept. of Transport, 739 W. Hastings, Vancouver, B.C.
Terasmae, Dr. J.	Geological Survey of Canada, Pleistocene Section, Ottawa, Ontario.
Thomson, J.G.	Imperial Oil Producing Dept., 300-9th Avenue West, Calgary, Alberta.
Thomson, Capt. S.	H.Q. Northwest Highway System, Whitehorse, Y.T.
Thurber, R.C.	Materials Engineer, Dept. of Highways, Victoria, B.C.
Tubbesing, Karl.	Racey, MacCallum and Associates Ltd., 3240 Thomson Crescent, West Vancouver, B.C.
Veale, A.C.	National Research Council, c/o B.C. Research Council, Vancouver 8, B.C.
Walsh, J.P.	Mobil Oil of Canada Ltd., Drayton Valley, Alberta.
Webster, A.T.	c/o Materials Testing Branch, Dept. of Highways, Victoria, B.C.
Williams, R.S.	3550 W. 31st Street, Vancouver, B.C.
Wilson, H.P.	Meteorological Service of Canada, Weather Office, Airport Administration Building, Edmonton, Alberta.
Zimmerli, F.	Richfield Oil Corp., 709-8th Avenue W, Calgary, Alberta.

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LIST OF TECHNICAL MEMORANDA

1 Proposed field soil testing device. August 1945 *

2 Report classified "restricted". September 1945

3 Report classified "confidential". November 1945

4 Soil survey of the Vehicle Proving Establishment, Ottawa, Oct. 1945 *

5 Method of measuring the significant characteristics of a snow-cover. G. J. Klein. Nov. 1946 *

6 Report classified "confidential". November 1945

7 Report classified "restricted". March 1947.

8 Report classified "confidential". June 1947

9 Proceedings of the 1947 Civilian Soil Mechanics Conference. Aug. 1947 *

10 Proceedings of the Conference on Snow and Ice, 1947. Oct. 1947 *

11 Proceedings of the 1948 Civilian Soil Mechanics Conference. Oct. 1949 *

12 Index to Proceedings of Rotterdam Soil Mechanics Conference. Soil Mechanics Bulletin No.1. May 1949 *

13 Canadian papers: Rotterdam Soil Mechanics Conference. June 1949 *

14 Canadian papers presented at the Oslo meetings of the International Union of Geodesy and Geophysics. December 1949

15 Canadian survey of physical characteristics of snow-covers. G. J. Klein. April 1950

16 Progress report on organic terrain studies. N.W.Radforth. April 1950

17 Proceedings of the 1949 Civilian Soil Mechanics Conference. Aug. 1950

18 Method of measuring the significant characteristics of a snow-cover. G.J.Klein, D.C.Pearce, L.W.Gold. November 1950

19 Proceedings of the 1950 Soil Mechanics Conference. April 1951

20 Snow studies in Germany. Major M.G.Bekker, Directorate of Vehicle Development, Department of National Defence. May 1951

21 The Canadian snow survey, 1947-1950. D.C.Pearce, L.W.Gold. Aug. 1951

22 Annual report of the Canadian Section of the International Society of Soil Mechanics and Foundation Engineering (June 1950 - June 1951). Soil Mechanics Bulletin No. 2.

23 Proceedings of the Fifth Canadian Soil Mechanics Conference, Jan.10 and 11, 1952. May 1952

* Out of print (Continued on back of cover)

24 A suggested classification of muskeg for the engineer. N.W. Radforth. May 1952

25 Soil mechanics papers presented at the Building Research Congress 1951 November 1952

26 Annual report of the Canadian Section of the International Society of Soil Mechanics and Foundation Engineering (June 1951 to June 1952). Soil Mechanics Bulletin No. 4. December 1952

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28 The use of plant material in the recognition of northern organic terrain characteristics. N.W. Radforth. March 1954

29 Construction and maintenance of roads over peat. F.E. Dryburgh and E.R. McKillop (Reprinted with permission of D.S.I.R., Great Britain.) July 1954

30 Canadian papers presented at the Third International Conference on Soil Mechanics and Foundation Engineering. July 1954

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33 Proceedings of the Seventh Canadian Soil Mechanics Conference, Ottawa, December 10 and 11, 1953. September 1954

34 Palaeobotanical method in the prediction of sub-surface summer ice conditions in northern organic terrain. N.W. Radforth

35 Proceedings of the First Regional Soil Mechanics Conference, Fredericton, April 23 and 24, 1954

36 Proceedings of the Eighth Canadian Soil Mechanics Conference, Ottawa, December 16 and 17, 1954. April 1955

37 Guide to the Field Description of Soils for Engineering purposes. December 1955. Price 10 cents

38 Proceedings of the Western Muskeg Research Meeting March 2, 1955. September 1955

39 Range of Structural Variation in Organic Terrain by Dr. N.W. Radforth, March 1956

40 Annual report of the Canadian Section of the International Society of Soil Mechanics and Foundation Engineering (June 1954 - December 1955). Soil Mechanics Bulletin No. 6. May 1956

41 Proceedings of the Ninth Canadian Soil Mechanics Conference, Vancouver December 15 and 16, 1955. October 1956

42 Proceedings of the Eastern Muskeg Research Meeting, February 22, 1956. October 1956

43 Muskeg Access, with Special Reference to Problems of the Petroleum Industry by Dr. N.W. Radforth, November 1956

44 Guide to a Field Description of Muskeg. Prepared by I.C. MacFarlane. January 1957. Price 10 cents

45 Peat in Canada and Britain, economic implications, N.W. Radforth. (Reprinted from Journal of the Royal Society of Arts, Vol. CIV. November 9, 1956)

46 Proceedings of the Tenth Canadian Soil Mechanics Conference, Ottawa. December 16 and 17, 1956. (in Press)

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