# Proceedings of the Tenth Muskeg Research Conference, 21 and 22 May 1964

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**Publisher's version / Version de l'éditeur:**
https://doi.org/10.4224/40001144
*Technical Memorandum (National Research Council of Canada. Associate Committee on Soil and Snow Mechanics); no. DBR-TM-85, 1965-05*

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

NATIONAL RESEARCH COUNCIL OF CANADA

ASSOCIATE COMMITTEE ON SOIL AND SNOW MECHANICS

# PROCEEDINGS

# OF THE

# TENTH MUSKEG RESEARCH CONFERENCE

21 AND 22 MAY 1964

PREPARED BY

I. C. MacFarlane

TECHNICAL MEMORANDUM NO. 85

OTTAWA

MAY 1965

# FOREWORD

This is a record of the Tenth Muskeg Research Conference, which was held in the Administration Building of Prince George College, Prince George, B.C., on 21 and 22 May 1964. A list of those in attendance is included as Appendix "A" of these Proceedings. Topics considered covered a wide range and included a symposium on an appraisal of muskeg research and development. Other topics discussed included: vehicles and trafficability, peat bog exploitation, aspects of muskeg in exploration and construction, peat sampling techniques, measurement of the surface roughness of muskeg and fundamental engineering properties of peat. Three technical sessions were held, during which a total of 21 papers and research reports were presented; Mr. C. T. Enright was chairman of the symposium session, Dean R. M. Hardy and Mr. R. A. Hemstock chaired the other two sessions. The final half-day of the conference was devoted to a field trip.

A one-day regional seminar on organic terrain problems was held in Prince Rupert, B.C. in conjunction with the Tenth Conference. A record of this seminar is included herein as Appendix "B" of these Proceedings. A list of those who attended the Prince Rupert seminar will be found in Appendix "C".

The Conference and Seminar were sponsored by the Associate Committee on Soil and Snow Mechanics of the National Research Council.

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Le Comité Associé de la Mécanique des Sols et de la Neige se fera un plaisir de faire parvenir sur demande la traduction française des communications présentées dans ces comptes rendus

## TABLE OF CONTENTS

## INTRODUCTORY REMARKS

Dr. N.W. Radforth introduced Father W. Sweeney, who welcomed delegates to the Conference on behalf of Bishop F. O'Grady, President of Prince George College. He reviewed the history of the College, described its present status and outlined its plans for the future.

Dr. Radforth welcomed delegates to the Conference on behalf of the National Research Council. In explaining the function of the N.R.C. in promoting research, he paid tribute to the Associate Committee on Soil and Snow Mechanics, and particularly to its Chairman, Dr. R. F. Legget.
Dr. Radforth conveyed Dr. Legget's greetings to the assembly and, on his behalf, expressed appreciation for those participating in the Conference. He explained the reasons for coming to Prince George for the Tenth Muskeg Conference; the principal reason being its proximity to an extensive area of confined muskegs, the presence of which will infringe upon the present economic expansion of northern British Columbia. Dr. Radforth referred also to the Seminar to be held in Prince Rupert and drew attention to the types of muskeg which exist on the coast.

# LE SOUS-COMITE DU MUSKEG – LES DIX PREMIERES ANNEES

I. C. MacFarlane

Résumé:

Ce rapport résume l'histoire du Sous-Comité du Muskeg, affilié au Conseil National des Recherches, des débuts au temps présent. Le Sous-Comité du Muskeg se compose de dix membres venant de différentes parties du pays, choisis en tant qu'individus et non en tant que représentants de quelque groupement que ce soit, et qui s'intéressent à différents aspects du problème muskeg. Au début, le Sous-Comité avait comme attribution "de fournir une interprétation du muskeg pouvant servir dans les recherches entreprises sur les terrains organiques par les autorités civiles et militaires." Les attributions initiales ont pris une certaine ampleur et elles comprennent l'organisation des conférences annuelles sur le muskeg. Le Sous-Comité fait la liaison entre divers bureaux et organisations qui s'intéressent aux études sur le muskeg. Il a aussi la responsabilité de recueillir et de distribuer les informations sur le muskeg. Sous ce rapport, il a publié, sous les auspices du Comité Central, plusieurs rapports ainsi que les papiers des conférences annuelles.

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# THE MUSKEG SUBCOMMITTEE – THE FIRST DECADE

I. C. MacFarlane

Abstract

This report reviews the history of the Muskeg Subcommittee of the National Research Council from its inception until the present time. It consists of 10 members from various parts of the country, chosen as individuals not as representatives, who have interests in different aspects of the muskeg problem. Initially, the terms of reference of the Subcommittee were "to provide a useful interpretation of muskeg to assist military and civilian investigations concerning organic terrain". The terms of reference has since widened somewhat and include the sponsorship of the annual muskeg research conferences. The Subcommittee acts as a liaison between various agencies and organizations involved in muskeg studies. It also has the responsibility of collecting and disseminating muskeg information and in this connection, through its parent Committee, has published several reports as well as the proceedings of the annual conferences.

## THE MUSKEG SUBCOMMITTEE - THE FIRST DECADE

I. C. MacFarlane, Secretary

At this Tenth Annual Muskeg Conference it was deemed advisable to review the history, purpose and functions of the sponsoring organization: the Muskeg Subcommittee of the National Research Council.

The Associate Committee on Soil and Snow Mechanics (the parent Committee) was formed in 1945. It is one of about 30 technical committees set up to assist the National Research Council in the discharge of its responsibilities for scientific and industrial research in Canada. The Associate Committee on Soil and Snow Mechanics was set up initially to deal with the 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. It is interesting to note, however, that as a result of a resurgent interest in terrain-vehicle relationships, the Associate Committee is once again making the question of vehicle mobility and trafficability an item of concern. The chairman of this Committee since its inception has been Dr. R. F. Legget, who is also Director, Division of Building Research, National Research Council.

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. In those early days, the Committee could only agree on the fact that muskeg existed; what it was, its location and its extent were matters of conjecture. After preliminary study and discussion, it was decided that the problem could best be solved by a basic approach from the point of view of palaeobotany. Accordingly, the Committee approached Dr. N. W. Radforth of McMaster University, a palaeobotanist, and interested him in the problem of interpretation and classification of muskeg as it relates to engineering problems. They subsidized the start of his work, which has continued until the present time. The Defence Research Board later became associated with this investigation and provided material assistance for aerial interpretation studies.

In 1947 the Muskeg Subcommittee was formed with Dr. Radforth as its Chairman, and held its first exploratory meeting in December of that year. Consequently, the Subcommittee actually is older than 10 years, but it met only 3 times between 1947 and 1955, after which time regular annual meetings were instituted. The Subcommittee is composed of 10 members, chosen as individuals, not as representatives, with interests in various aspects of the muskeg problem. Appointment is on a two-year rotating basis, although - by virtue of their longstanding and continuing interest in muskeg - several members of the Subcommittee have been reappointed for several terms. The present membership is as follows:

Dr. N. W. Radforth, McMaster University, Chairman.*
Mr. C. O. Brawner, Consulting Engineer, Vancouver.
Mr. C. T. Enright, Ontario Hydro-Electric Power Commission.
Dean R. M. Hardy, University of Alberta.*
Mr. T. Harwood, Defence Research Board, Ottawa.*
Mr. J. V. Healy, Bogland Development Supervisor, Newfoundland.
Mr. R. A. Hemstock, Imperial Oil Limited, Calgary.
Mr. J. M. Robinson, Canada Department of Forestry, Ottawa.
Dr. J. Terasmae, Geological Survey of Canada, Ottawa.
Mr. G. Tessier, Quebec Department of Roads.
Mr. I. C. MacFarlane, National Research Council, Secretary.

Asterisk (*) denotes those who have been members of the Subcommittee for more than 10 years.

The terms of reference of the Subcommittee as laid down at its first meeting were "to provide a useful interpretation of muskeg to assist military and civilian investigations concerning organic terrain". Within these terms of reference the Subcommittee is concerned not only with investigations into the terrain as such, but also with the study of the fundamental physical and mechanical properties of the material (peat) relevant to practical engineering problems. The Subcommittee gathers necessary information on the state of knowledge in the field of muskeg research and practice, and particularly on research work in progress in Canada, and through the parent Committee advises the Council on the collection and dissemination of research information. The Subcommittee also attempts to stimulate research in its assigned field and serves as a liaison between the National Research Council and educational, governmental, and other organizations or agencies engaged in or concerned with research on muskeg.

A primary function of the Subcommittee has been to organize the annual Muskeg Conferences. These began in 1955 as a half-day technical session, but very soon this developed into a full day, and eventually into a two-day conference. In addition, the Subcommittee has held regional seminars to acquaint people in the more isolated regions of the country with the current state of knowledge in the field of muskeg. Conferences which have been held thus far are as follows (attendance in brackets):

1. March, 1955. University of Alberta, Edmonton. (55)
2. Feb., 1956. Laval University, Quebec. (70)
3. Feb., 1957. University of British Columbia, Vancouver. (58)
4. March, 1958. National Research Council, Ottawa. (59)
5. March, 1959. University of Manitoba, Winnipeg. (112)
6. April, 1960. Palliser Hotel, Calgary. Beginning of two-day conferences. (160)
7. April, 1961. McMaster University, Hamilton. (121)
8. May, 1962. University of Saskatchewan, Saskatoon. (123)

   Sept. 1962 (University of N.B., Fredericton (91); N.S. Technical College, Halifax (40); Memorial University, St. John's (27)) Atlantic Regional Seminars.
9. May, 1963. Laval University, Quebec. (84)

The Proceedings of these Conferences have provided a useful record of, and the major source of information for, the development of muskeg research in Canada. Altogether, over 6000 copies of the Proceedings of the various conferences have been distributed.

Another function of the Subcommittee - through its parent Committee - has been the publication and distribution of muskeg research papers and, in particular, the early papers of Dr. Radforth. This includes his original paper on "A Suggested Classification of Muskeg for the Engineer," published in 1952, and subsequent papers adding to and enlarging upon the classification system. This practice substantially assisted in making the classification system as well known and as well used as it is today. Subsequently, this information was all drawn together, greatly condensed, and issued in the form of a small booklet entitled "Guide to the Field Description of Muskeg," (Technical Memorandum 44) which is a companion to similar N. R. C. booklet guides to soils and permafrost.

The Subcommittee has maintained close personal and official contacts with many workers in other countries involved with problems of peat and muskeg. Although it has not been a regular feature, this has resulted, from time to time, in papers of international interest being included in the Conference agenda and Proceedings. Papers from Scotland, the United States, Japan and Norway have been included.

At various times the Subcommittee has been faced with muskeg problems which assume a particular significance and this is reflected in the Proceedings of the Conferences. From the very earliest days the question of access has been a concern and it still is. Design of off-road vehicles for use in muskeg, and design of roads of various standards for muskeg conditions, are matters which have been given considerable attention and which will be referred to in greater detail later in these Proceedings.

More recently, concern is being expressed with increasing frequency on the question of muskeg reclamation and development, with the many attendant problems. How muskeg impinges on the economy of Canada, particularly with reference to development in the North, is a continuing item of discussion within the Subcommittee and it is expected that future conferences will reflect this as more information becomes available.

It is anticipated that this 10th Conference, in its consideration of muskeg research and implementation over the past ten years, will provide some indication of the outstanding problems which yet remain to be solved and thereby assist the Subcommittee in plotting its course of action for the next few years.

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# I. AN APPRAISAL OF MUSKEG RESEARCH AND DEVELOPMENT: A SYMPOSIUM

## I.1 INTRODUCTION – DIX ANNEES D'ETUDES, DE RECHERCHES ET DE DEVELOPPEMENTS

C. T. Enright

Résumé:

Cette présentation fait une revue générale de la recherche sur le muskeg et des développements obtenus pendant les dix dernières années. On y fait une évaluation du système de classification Radforth qui sert dans les études sur le muskeg. Le problème de l'accès est considéré dans les items suivants: véhicules "tout-terrain", routes et chemins de fer. Les organisations qui ont été au premier plan dans la recherche et le développement du muskeg au Canada sont mentionnées en relation avec leur contribution approfondie au sujet du muskeg.

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## I.1. INTRODUCTION – A DECADE OF STUDY, RESEARCH AND DEVELOPMENT

C. T. Enright

Abstract

A review is presented of the general course of muskeg research and development over the past ten years. The value of the Radforth classification system in muskeg studies is discussed. Access is considered under the headings: off-road vehicles, road, and rail. Organizations which have been in the forefront of muskeg research and development in Canada are referred to, relative to their contribution to the overall knowledge on the subject.

## I.1. INTRODUCTION - A DECADE OF STUDY, RESEARCH AND DEVELOPMENT

C. T. Enright

Although research and study had been conducted prior to 1955, that year marked the first conference held by the Muskeg Subcommittee of the Associate Committee on Soil and Snow Mechanics of the National Research Council. Organized meetings to integrate and to record research and development of features pertinent to muskeg date from that time.

In attempting to give a history of development and research on muskeg as related to the proceedings of the last 10 years this summary must necessarily be brief, merely touching on the features that will be covered more fully by following authors in their papers, of which this account serves as an introduction.

### Classification

The most complete work on classification was done by Dr. N. W. Radforth, Professor of Botany at McMaster University. Beginning in 1945 at the request of National Research Council, Professor Radforth carried out exhaustive studies to develop an integrated nomenclature for identification. This classification has enabled a naming of the various types of muskeg interpreted from their own environmental characteristics. Tree cover and vegetation is consistent with certain types of muskeg. Patterns evolved by classification nomenclature are associated with particular properties of organic terrain. In other words - the peat under FI cover is always amorphous-granular; under EH cover it is fibrous, with some woody fine fibrous and is much stronger than the amorphous-granular. This consistency and similarity of property is true with regard to observation on the ground as well as from the air. Observation from varying heights above the ground reveal particular pictorial patterns. An example of this is the marbloid pattern evident from the air above 10,000 feet where we find definite muskeg properties associated with a particular terrain pattern.

Classification has simplified and co-ordinated the research and furthered the study of organic terrain, particularly from the point of view of providing a common language in which the symbols and words have a definite understanding and set of values. Dr. Radforth refers more fully to this subject in his paper.

A subject emanating directly from classification is the engineering properties of muskeg which will be further dealt with in this Symposium by Mr. I. C. MacFarlane.

## Access

Generally speaking this relates to three particular features:

(a) Off-road vehicles
(b) Roads
(c) Rail

### (a) Off-road Vehicles

At one time one could not travel over muskeg or organic terrain, or one could traverse it only with the greatest difficulty. At the present time, however, it is comparatively simple to negotiate travel over this terrain - moreover, improvement is going on continuously. While a great deal of study and development is still necessary, it may be said that great strides have taken place. First came the "Water Buffalo", then other vehicles followed. Scarcely a year goes by without some new development taking place in this field. A great many of the advances in vehicle design and construction have been accomplished here in Canada, and the Muskeg Subcommittee, in collaboration with the Organic and Associated Terrain Research Unit of McMaster University, has spearheaded the work. It is interesting to note that practically all the developments related to vehicles have occurred during the last nine years. Articulation, wheels on muskeg, ground effect machines and light personnel vehicles; the construction of all of these have been orientated to classification. Mr. Hemstock's paper details the civilian aspect of off-road transportation whereas Mr. Harwood's contribution covers the features of military concern.

### (b) Roads

Understanding of organic terrain coupled with experimentation has advanced the knowledge of design and methods of road construction. One of the features which has improved to the greatest degree is documentation. Formerly, little was left of the written word to guide the newcomer in this field. With awareness of the problems and the increasing need to move further and further north, however, documentation has increased and a great fund of information has been built up. It is interesting to know that upwards of 500,000 square miles of this country is covered by organic terrain. This area has scarcely been infringed upon. Many projects throughout the country, in British Columbia, the Prairie Provinces, Manitoba, Ontario – in effect all of Canada – have contributed to this store of knowledge. Correlation of field instrumentation with laboratory research studies has produced a practical and accurate method of assessment of various problems. This was carried out on a project well known to the author on an Ontario Hydro service road in the Mattagami River area. Interpretation of the comparison of field and laboratory observations has supplied us with data from which we have been able to design a standard that will be implemented this year in another project. Further documentation of this work will supply proof of our assumptions. Mr. Brawner's paper to this Symposium provides more detailed references to other features in road transportation.

(c) Rail

Although the problem of rail construction over muskeg is not quite as serious as road construction due to the bridging properties inherent in the steel, rail construction over muskeg does present some difficult problems. These have been brought to the attention of the various conferences and documentation is proceeding particularly on new construction. The Subcommittee has been particularly indebted to Mr. Charles of the C.N.R. and Mr. Monaghan of the Quebec North Shore and Labrador Railway. The latter project in particular is an interesting study since it was constructed through virtually inaccessible country to open up a vast area to development. Mr. Charles provided cost analyses that shed considerable light on the problem. This Symposium does not include a paper on railways as such but it will be a topical subject in a later session of this conference.

## Development

As exploration and development of this country expands, extends and proceeds, we go further and further afield. This often means pushing into muskeg country. A striking example of this is the development which has occurred within the petroleum industry, particularly in the exploration of new fields. The initial need is for off-road transportation for survey, followed by access roads for year-round travel for development. This is particularly important in the economy of expansion. A great deal has been done in this regard and records are building up that will serve as guidance to those who come after.

The extension of both major and secondary highways is posing this same problem. Generally speaking, highway entities have attempted if at all possible to bypass critical organic terrain in the past.

This is no longer possible in many cases. More and more areas are being built up, access is required further and further into the north lands and it is no longer possible to avoid these "danger spots". The result is that new methods have to be evolved to construct the required access. In some cases old methods have been adapted to present needs. Documentation and continuous improvement of these methods are tending to change the attitude of the location engineer - he is no longer as apprehensive of this type of terrain as he once was. As a small example of this mention might be made of the comparatively recent development in the use of styrofoam sheets laid on the muskeg to insulate the base from the pavement. A number of years ago the thought of using such a method would have been unheard of. Now the use of new methods and materials is accepted in a matter-of-fact manner.

The final feature is related to the military defence of our country. We will never be able to defend unless we know what we have to contend with. Once we know, we may take steps to determine "how".

Instrumentation has not been touched because it opens up a wide field entirely of its own. One may say, however, that with the increasing awareness of the need for documentation has come the improvement of tools for instrumentation.

The development theme will be a thread running through all the contributions of this Symposium and as such will, it is hoped, provoke questions and discussion.

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## I.2. DEVELOPPEMENT DU SYSTEME DE CLASSIFICATION DU MUSKEG

N. W. Radforth

Résumé:

L'étendue du muskeg au Canada et les limitations qu'il impose à l'usage et à l'accès du terrain qui le contient ont causé l'intérêt du début pour la recherche sur le muskeg, dans les années d'après-guerre. L'organisation, première nécessité de la classification, semblait manquer. Une investigation paléobotanique a révélé, cependant, que les pollens et les spores fossilisés dans la terre noire peuvent servir d'agent de référence à l'organisation. En conséquence, une classification fut élaborée qui utilise certaines caractéristiques du terrain facilement reconnaissables telles que la forme de la végétation et les particularités topographiques. Une deuxième étape importante dans l'interprétation du muskeg fut le développement de l'interprétation des photos aériennes pour des altitudes allant jusqu'à 30,000 pieds. L'identification des groupes sur les photos aériennes, avec la connaissance de ce qu'ils représentent sur le terrain, permet de prévoir les conditions à la surface et sous la surface du sol.

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## I.2. DEVELOPMENT OF THE MUSKEG CLASSIFICATION SYSTEM

N. W. Radforth

Abstract

The extent of muskeg in Canada and its limitation on land use and access sparked the initial interest in muskeg research in the early post-war years. Organization, the prerequisite to classification, seemed to be lacking. A palaeobotanical investigation revealed, however, that fossilized pollens and spores in the peat could be used as a reference agent to organization. Accordingly, a classification system was devised which utilizes certain easily recognizable features of the terrain such as the structure of the vegetation and topographic features. A second important stage of the muskeg interpretive process was the development of aerial interpretation for altitudes up to 30,000 feet. Identification of airform pattern, together with a knowledge of what it represents in terms of ground form, permits a prediction of ground surface and subsurface conditions.

## I.2. DEVELOPMENT OF THE MUSKEG CLASSIFICATION SYSTEM

N. W. Radforth

Canada has an enormous area of muskeg - an estimated 500,000 square miles. This great organic mantle creates a limitation on both accessibility and land use; it presents a serious obstacle to agriculture and forestry and obstructs potential mineral resource development. Foundation engineering in this terrain is also extremely difficult. In the past, the construction of roads and other embankments on muskeg has been expensive and difficult and once built have not always given satisfactory performance. Summer access by off-road vehicles until a few years ago, has been a hazardous undertaking due to the low bearing capacity of the terrain which does not readily permit transportation of heavy equipment.

Until about a decade ago, the casual observer, whether in the air or on the ground, saw little apparent evidence of cosmic arrangement in organic terrain, and where no order reigns, classification is impossible. Without the aid of categorization, sound prediction is not possible, and the ability to predict terrain conditions is essential to the avoidance of many types of difficulties inherent in exploratory and exploitation endeavour in organic terrain. Consequently, research was urgently required. This was commenced by the writer in 1946 - at the instigation of the National Research Council - with the immediate objective of developing a reference system for muskeg. The immediate application was one of off-road access which was becoming more and more critical as exploration for oil and other natural resources accelerated in the immediate post-war period.

Despite the complexity of muskeg, an analytical study revealed organization, thus satisfying the prerequisite to classification. Cosmic relations have been shown to be expressed in organic terrain inasmuch as contemporary terrain has an ordered arrangement.

Initially, samples of peat were obtained from various locations and counts made of the fossilized spores and pollen which had been preserved as the peat accumulated. Histogram patterns were derived and correlated with macro-structure. This microscopic analysis is the direct reference agent to organization and, therefore, to classification of the terrain. On the basis of this paleobotanical investigation, a classification system has been developed which utilizes certain easily recognizable characteristics of the terrain such as the structure of the vegetation and topographic features.

Details of the classification system are to be found in the literature (Radforth 1952). Nine vegetal classes of cover are used in order to characterize the vegetation on the muskeg. These classes of cover are combined to form formulae, which account for admixtures of classes. These admixtures are characteristic and recur frequently.

In the appraisal of organic terrain, expediency rules that attention be given to terrain unevenness. Topographic difference in organic overburden is sometimes caused by irregularities in the mineral substrata, but much of the unevenness of the surface is due to topographic change within the organic material itself. The classification system accounts for sixteen different topographic characteristics of the terrain.

Further reference to the literature will indicate that, in addition to surface features, sixteen categories of peat are recognized on a qualitative basis. These vary in accordance with the organic terrain and also recur across the country.

Fortunately the organization in muskeg can be better appreciated by inspection from a plane or from air photographs. A means had to be developed, therefore, whereby independent investigations could determine the organic terrain character by aerial inspection. This need led to the work reported in Handbooks No. 1 and 2 (Radforth 1955 and 1958) published by the Defence Research Board and which deal with the fundamentals of aerial interpretation of organic terrain for altitudes up to 5000 feet.

There are three chief difficulties, however, in aerial inspection: only the surface of the terrain can be seen from the air or from aerial photographs; therefore the procurement of subsurface details is, in the first instance, interpretive rather than visual. Ground conditions form visual patterns which, when viewed from the air, are not readily discernible in that they merge to form new patterns of another order of significance requiring re-interpretation. Finally, air photos taken at low altitudes are rare and usually the only photographic records available relate to altitudes of the order of 17,000 to 30,000 feet.

In the account of aerial interpretation dealing with altitudes up to 1000 feet (Handbook No. 1), ground form pattern (i.e. form seen at ground level) was correlated with air form patterns. It is between the altitudes of 1000 and 5000 feet that experience with the lower altitude air form changes. Fortunately, the new order of definition can also be appreciated for 30,000 foot records. At this latter altitude, however, new experiences arise which become useful for large-scale mapping. For problems of access (e.g. route selection for roads, off-road vehicles, power transmission lines, etc.) the patterns coming into prominence at 5,000 feet are the practical ones for reference and also obtain for the higher altitude situations. There are five of these patterns: dermatoid, stipploid, terrazoid, reticuloid, and marbloid, descriptions of which are outlined elsewhere (Radforth 1956).

Muskeg is so complex and variable despite its organization that identification, classification and interpretation should be made in the knowledge of the operation or application ultimately intended. Thus, following identification of airform pattern and subsequent groundform features, terrain constitutional factors should be referred to in terms of the need. This might relate to photo interpretation for drainage, or classification or physiography of peat, or chemistry of peat or some aspect of biological assay. On the other hand, the implication might be resources development, in which case interpretation might be required in terms of access, agricultural reclamation, optimization for productivity as an aspect of crop management, economics, or elucidation of terrain characteristics relative to foundation engineering.

The development of the muskeg classification system - and the associated interpretive process - over the past 15 years has been of benefit to the agricultural and forestry industries together with engineering development in one aspect or another. Prediction procedures based on cover and air form pattern have been tested on a circumpolar basis and the results have been very encouraging. In Canada, access is still a most important requirement - whether it is development roads or vehicular access - for northern development. At the present time, not only can access routes across organic terrain be selected for a particular vehicle, but also the operational costs can be estimated (Thomson 1961).

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## I.3. UNE ESTIMATION DES RECHERCHES POUR LA CONSTRUCTION DES GRANDES ROUTES SUR LES MUSKEGS

C. O Brawner

Résumé:

Cette présentation donne un résumé des développements qui ont influencé les projets de route et les méthodes de construction dans les muskegs, depuis les dix dernières années. Les articles des conférences sur le muskeg qui ont trait directement aux routes sont examinés. La méthode de préconsolidation ou de surcharge et l'emploi du bran de scie comme matériel moins pesant dans les remblais sont décrits comme étant deux importants développements dans la technologie du muskeg. On prévoit que les développements futurs dans les techniques consisteront en des améliorations ou des modifications des procédés actuels.

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## I.3. AN APPRAISAL OF RESEARCH FOR HIGHWAY CONSTRUCTION IN MUSKEG AREAS

C. O. Brawner

Abstract

A summary is presented of the developments over the past 10 years which have influenced road design and construction methods in muskeg areas. Contributions to muskeg conferences which directly relate to roads are reviewed. Preconsolidation or surcharging and the use of sawdust as a weightless spacer in road embankments are described as two important developments in muskeg technology. It is predicted that future developments in construction techniques will probably be improvements or modifications to existing procedures.

# I. 3. AN APPRAISAL OF RESEARCH FOR HIGHWAY CONSTRUCTION IN MUSKEG AREAS

C. O. Brawner

The theme of this first session of the Tenth Muskeg Conference provides an appraisal of muskeg research and implementation covering varied fields, one of which is road construction.

This paper briefly summarizes development over the past ten years which has influenced road design and construction methods. Based on this review, some predictions of possible future advances are presented. In addition, several specific avenues of research are suggested, which include advancement of our knowledge of the basic properties of peat necessary for sound design programs and extension of data collection and presentation on actual construction projects.

The effectiveness and efficiency of muskeg research programs carried out on a nation-wide basis is discussed. It is suggested that attempts for greater national co-ordination might be instituted.

## A Review of Technical Contributions

The past ten years has seen a great increase in our knowledge of constructing roads in muskeg areas. Much of the credit is due to the efforts of the Muskeg Subcommittee of the Associate Committee on Soil and Snow Mechanics, National Research Council of Canada.

This Subcommittee, through the media of annual research conferences and committee meetings, has developed a comprehensive program of gathering, reviewing and evaluating past and current work, encouraging research in many fields pertinent to the muskeg problem, preparing and circulating bibliographies, technical guides, reviews, translations, etc., and providing a means for presentation and discussion of worthwhile technical and scientific contributions.

Noteworthy among these contributions have been the following:

(a) "A Suggested Classification of Muskeg for the Engineer". (Radforth, 1952).

(b) "A Preliminary Annotated Bibliography on Muskeg". (MacFarlane, 1955).

(c) "A Guide to the Field Description of Muskeg". (MacFarlane, 1957).

(d) "A Review of the Techniques of Road Construction over Muskeg". (MacFarlane, 1956)

(e) "A Review of Published Material on Engineering Tests on Peat". (MacFarlane, 1958)

(f) "Organic Terrain Organization from the Air" (altitude less than 1000 feet) (altitude 1000 to 5000 feet) (Radforth, 1955, 1958) - (Defence Research Board Publications)

(g) "Review of Corrosion of Concrete Structures by Muskeg Waters". (MacFarlane, 1961)

(h) "Prerequisites for the Design of Engineering Works in Organic Terrain". (Lea, Brawner, Radforth and MacFarlane, 1963).

All of these publications have general application in the highway field. In addition, 25 technical papers have been presented at the annual muskeg research conferences, which have dealt specifically with road construction in muskeg. These may be grouped as follows:

| Number of Papers | General Subject |
|---|---|
| 13 | Case histories of major highway construction. |
| 4 | Service road construction for mining, hydro, oil, gas and forestry access. |
| 3 | Road construction in permanently frozen muskeg. |
| 2 | Construction of winter roads. |
| 2 | Road performance. |
| 1 | Culvert selection. |

In order to effectively design roads and highways in muskeg, it is necessary that we acquire knowledge of the properties of the peat. Sixteen papers have been given which have described research relating to the physical and engineering characteristics. These have dealt with consolidation, shear strength, mechanical analysis, index tests, permeability, ash content, moisture content, density, etc. In addition, numerous efforts have been made to establish correlations between various properties, with some success.

The international aspect has not been overlooked. Papers have been presented from the United States, England, Scotland, Japan and Norway. A summary of research in Russia has also been given.

Road Construction over the Past Ten Years

Road construction in muskeg over the past ten years has been a combination of perfecting and improving existing methods and developing new techniques which do not require muskeg removal.

For low cost roads, relocation, corduroy construction, or "floating" the road over the muskeg, are still accepted procedures. On major construction, complete or partial removal of the peat by overloading, jetting, blasting, etc., has remained in wide use. Better knowledge of blasting techniques and the development of more effective explosives have reduced the possibility of incomplete peat displacement. No major developments, however, have occurred that have reduced the cost of this technique.

Drainage, once suggested as a major requirement for successful road construction in muskeg, is no longer regarded as being so important. Also vertical sand drains in muskeg have lost much of their early appeal as a result of many unsuccessful installations.

Recent developments in road construction techniques have essentially been modifications of the "floating" method. Preconsolidation or surcharging, used so successfully in inorganic soils, has been applied to peat (Brawner, 1959, 1960) (Lea and Brawner, 1959). Projects in British Columbia, Alberta (Anderson and Haas, 1962), Saskatchewan (Mickleborough, 1961), Quebec (Brochu and Paré, 1964), and New York (Goodman and Lee, 1962) have been completed. Early results have generally been encouraging; however, since long-term evaluation has not yet been possible, this technique should only be used with caution and only after detailed engineering studies have been made, preferably supplemented by full-scale field testing.

A further recent modification of the preconsolidation technique incorporates a sawdust layer, which acts as a "weightless spacer". The technique has greatest application where excessive settlements occur (Lea, 1962) (Lea and Brawner, 1963). On the Burnaby Freeway in Vancouver, up to 13 feet of sawdust was placed directly on the peat, followed by the roadway fill material. This highway has recently been opened to traffic and, within a year or two, indications of the success of this procedure will become apparent.

A third technique has been used in Norway in the reconstruction of roads floated over muskeg, which incorporates corduroy, sawdust and road fill (Flaate and Rygg, 1964). The original grade is excavated several feet, corduroy is placed, followed by about 4-1/2 feet of sawdust with 5 mm reinforcing mesh placed over the sawdust and covered by 4 inches of sand and 12 inches of gravel. This has been reported as being very successful on secondary roads. It has not been used on primary roads.

## Construction in Muskeg Areas in the Future

New ideas in many fields develop as a result of practical and economic pressures. When this pressure becomes great enough, attention becomes directed to special studies, investigations and research. It appears doubtful that this approach will alter for some years in the future, possibly not until major expansion into Canada's Northland commences, where muskeg will be such a dominant development factor.

It is extremely difficult to suggest the avenues that new research and road construction might take. Many future techniques will obviously be improvements and modifications of existing methods. However, as scientific endeavor expands in so many other fields, some quite new approaches will undoubtedly develop. Just as "Buck Rogers" ideas have developed in the space program, there is no need to feel that past dreams of fantasy will not also develop into practical and economical techniques in road construction programs.

Techniques or procedures that may ultimately become practical might include some of the following:

(a) The development of large mobile wood chippers that could process brush and trees into sawdust for use as road grade material on access roads over muskeg. Sawdust has shown many indications of providing better stability and trafficability characteristics than gravel.

(b) Chemical stabilization or fusion of the upper 2 to 5 feet of the peat, to provide a stable mat.

(c) Major drainage by massive vacuum or electrical drainage techniques.

(d) Rapid and large-scale burning or disintegration of the peat by such means as extra high voltage electricity or the Laser Beam.

(e) Construction of thin prestressed concrete sections tied together by post-tensioning and placed and levelled on top of the muskeg with the road grade placed on top.

Immediate Research Needs

Before major advances are made in any field, it is usually necessary for detailed knowledge to be available regarding the factors which influence the problem. This is also valid for problems relating to road construction in muskeg. While our knowledge of muskeg and peat has been greatly increased during the past 10 years, much basic information is still lacking. Probably most important is the need for more fundamental knowledge of the chemical and physical properties of peat.

There are still many unanswered questions concerning the consolidation process, shear strength, permeability, the effect of gas content and other properties, and it is suggested that extensive efforts to extend this basic knowledge must be maintained. This should include development of special testing equipment that may be required to determine these basic characteristics, both in the laboratory and in the field. Attention toward correlation of different peat properties should be continued. Also efforts to compare peat characteristics from various areas should be extended. We are still not certain to what extent experience and procedures employed in some areas can be utilized effectively in other areas.

In the construction field, the continued need for description of actual construction details can not be over-emphasized. These case histories should provide detailed data on the physical characteristics (emphasizing test results) of the peat and its environment, a discussion of field procedures and field testing with supporting technical data and a discussion of the effectiveness or success of the project. Two phases which have been overlooked to some extent in the past are continuing long-term evaluation of construction and inclusion of cost data. Both of these are exceedingly important and should not be overlooked.

Failures as well as successes should be reported. The former often provide the most useful data. In some fields, failures are extremely serious and, as a result, cause professional embarrassment and hesitancy to publish pertinent information. In the highway field, however, a limit design approach is strived for. Essentially, this means that if no failures occur, the road or highway is overdesigned.

Major development of Canada's Northland, largely covered with muskeg, is not far off. Therefore, early attention should be directed toward a prediction of problems to be expected and the development of a research program to study means of dealing with them. One might go so far as to suggest that major early research and development of improved methods of construction, equipment, etc., could actually increase the rate of Northern development. When the economic potential of this area is considered, it would appear that millions of dollars spent on research can be justified in the immediate future.

What is the most effective way of instituting further research? This is a difficult and delicate question. Difficult, because there are many courses that might be followed and delicate, because practically every other field of endeavor can show cause for increased research funds.

An existing problem is that research at the present time is, to some extent, haphazard, occasionally duplicated and often uncoordinated across the country. A possible first stage to developing a more effective nation-wide program might be to evaluate past research, with a view to establishing a list of research problems of prime importance. Ranges of apparent priority might also be presented. In some instances, the approach to specific research projects might even be suggested. Such a review could be done most effectively at the government level. Financing such an endeavor might possibly be obtained by contributions from governments, agencies, companies, etc., intimately affected by muskeg.

An effectively co-ordinated program should reduce the cost of specific projects and should provide more efficient and a greater abundance of intellectual thinking.

Essentially, it is suggested the problem might be summed up by stating that the ability and facilities now exist. What is needed is the co-ordination and the money.

Summary

Considerable advances have been made in the highway construction field in muskeg areas during the past ten years. These have included an increase in our knowledge of the fundamental properties of the peat, improvement of existing construction methods, and development of techniques employing preconsolidation, sawdust fill and light-weight construction.

Future developments in construction techniques will probably continue largely by improvement or modification of existing procedures. In the not too distant future, it is expected the techniques of "space age" thinking will greatly modify construction methods.

Continual emphasis on research is very desirable, particularly from the standpoint of assisting in the development of Canada's Northland. Much effective research is now being carried out in Canada. However, greater nation-wide co-ordination and the availability of increased funds could result in a major advancement of our knowledge.

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## I.4. RECHERCHES SUR L'EFFORT DE CISAILLEMENT DU MUSKEG ET SON APPLICATION

R. M. Hardy

Résumé:

Des recherches sur l'effort de cisaillement de la terre noire sont en cours depuis plus de dix ans. Cette présentation donne les conclusions de ces recherches et quelques exemples d'application. L'effort de cisaillement de la matière organique a été calculé à partir d'analyses des cercles de glissement, mais la plupart des informations disponibles ont été obtenues au moyen d'essais "in situ" effectués au scissomètre "Vane". Les valeurs de l'effort de cisaillement ainsi obtenues varient de 100 à 1700 livres par pied carré. Les résultats ont démontré d'une façon concluante que l'effort de cisaillement de la terre noire peut atteindre des valeurs étonnamment fortes, mais elles correspondent à de grandes déformations qui sont anormales. Ce bagage d'informations allié à l'expérience fut utilisé durant la construction du barrage Brazeau dans le centre de l'Alberta. Dans ce projet, les digues furent érigées directement sur le muskeg, en employant la méthode de construction par étapes, pour prendre avantage de l'accroissement de la résistance au cisaillement de la terre noire sous l'effet d'une charge.

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## I.4. RESEARCH ON SHEARING STRENGTH OF MUSKEG AND ITS APPLICATION

R. M. Hardy

Abstract

Research on the shearing strength of peat has been underway for more than ten years and this paper reports on the conclusions of that research, together with some examples of its application. Shearing strength of the organic material has been calculated from analyses of embankment failures, but most of the available information has been obtained from in situ tests with the shear vane. Shearing strengths of peat have been measured over a range of 100 to 1700 pounds per square foot. Results have conclusively shown that surprisingly high shear strengths can be mobilized in peat but these are accompanied by abnormally high deformations. This background of information and experience was utilized during the construction of the Brazeau Dam in Central Alberta. In this project, the dykes were built directly on the muskeg, utilizing stage construction techniques to take advantage of the increase in strength of peat under load.

## I.4. RESEARCH ON SHEARING STRENGTH OF MUSKEG AND ITS APPLICATIONS

R. M. Hardy

These comments are confined to research concerning the shearing strength of muskeg with which the University of Alberta has been associated over the past ten years, and examples of its applications from the author's own experience.

The shearing strength of any potential material of construction is a basic engineering property, and its determination is of major interest in the area of strength of materials in the fields of civil and mechanical engineering. Soils have not lent themselves to the traditional methods for the determination of the strength of materials such as steel, concrete or timber, and the determination of the strength characteristics of soils has, therefore, become a matter of major concern in the field of soil mechanics.

One of the most difficult problems, and one that is still to a considerable degree controversial in the field of soil mechanics, is the determination of the shearing strength of soil complexes. The reason for this is that they may consist of two, three or even four phase systems, and for fine-grained soils such as clays the physical chemical properties of the water wet soil particles may have a marked effect on their strength characteristics. Obviously, organic materials such as muskeg have the characteristics of soil systems in that they are at least two phase systems, solid material segments saturated with water; or they may be three phase systems, solids, water and gas.

Basically, there are two independent methods of determining the shearing strength of a soil. The first is by means of laboratory tests on samples of the soil, and the second is by means of in situ tests. In each case there are a variety of procedures available. Laboratory test methods vary from the simple compression type of tests to the highly sophisticated methods of triaxial testing now available, but, of course, the meaning and reliability of any of these methods are conditioned by the effect on the soil of the sampling operations. There are also a wide variety of in situ methods of strength measurement, including shear vane, plate bearing, and cone penetrometer tests as well as the procedure of arriving at the shearing strength from a mathematical analysis of full-scale failure conditions in nature.

The first attempts, at the University of Alberta, to determine the shearing strength of muskeg were made over ten years ago, and involved a mathematical analysis of a well-defined failure of a highway embankment. This indicated an average shearing strength on the probable failure surface of only 85 lbs. per sq. ft. Subsequent experience has shown that some muskeg soils at depths of up to three or four feet in the soil profile do, in fact, have shearing strengths this low. However, in hindsight it is now clear that in this original analysis the major part of the soil failure was in essentially inorganic soil underlying the muskeg. This by no means indicates that the results are not significant. It is very pertinent from the engineering point of view to appreciate that, in many deposits of organic soil, the inorganic material immediately underlying it may have shearing strength characteristics inferior to the organic cover.

Over the years we have never been able to devise a method of securing satisfactory samples of all types of muskeg for the purposes of laboratory shearing strength tests. In our experience, reasonably good samples of well decomposed organic soil at depths exceeding several feet can be secured by conventional sampling techniques using shelby tubes or core barrels; and for muskeg within the depth of frost penetration satisfactory samples can be cut out when the soil is frozen. However, these methods still leave blanks as far as sampling of all types of muskeg under all physical conditions are concerned. Not the least difficult problem is that of access to the site to be investigated with sampling equipment under any conditions except when the muskeg is solidly frozen. For these reasons our work has been largely confined to in situ testing.

The first comprehensive project undertaken at the University of Alberta concerning the shear strength of muskeg was undertaken by Capt. S. Thomson (1955) as part of an M.Sc. program. This was followed by a second project by Capt. R. C. Wyld (1956), also as part of an M.Sc. program. These involved the development of shear vane equipment suitable for use in muskeg, both in respect to portability (by men on foot), and in ability to measure low shearing strengths. They proved the feasibility of using a specially designed shear vane to measure the in situ shearing strength of muskeg at any depth in the soil profile providing the soil was unfrozen.

The field work of Capt. Thomson was done at a site at Mile 253 on the Northwest Highway System (Alaska Highway), while Capt. Wyld's field work was done in the Pembina Oil Field located about 100 miles west of Edmonton. Capt. Wyld attempted a correlation of the measured shearing strengths with the Radforth (1952) classification of muskeg. The field measurements showed a wide range of in situ shearing strengths for muskeg, with a general increase in strength with depth, except for a frequent anomaly at depths of three to five feet below the surface; and with a general decrease in strength with increasing moisture content and decreasing ash content of the muskeg. In situ shearing strengths were measured within the range of 100 to 1,700 lbs. per sq. ft. with residual strengths, as measured by the vane, varying within the range of about 25% to 75% of the maximum strengths recorded. They also indicated a lower strength, in some cases, for the inorganic soil immediately underlying the organic material as compared to the muskeg just above the discontinuity in the profile. A marked increase in strength was also recorded with consolidation of the muskeg under applied loads such as the weight of an overlying fill. In general, the results showed conclusively that surprisingly high shear strengths can be mobilized in muskeg, but that these are accompanied by very much larger deformations in the muskeg mass than normally occur with inorganic soils.

A third project was undertaken by Mr. K. O. Anderson (1959) as part of his M.Sc. program. This was done in co-operation with Mr. R. A. Hemstock of the Production Research and Technical Service Department of Imperial Oil Limited, and financial assistance was provided by this Company. This project was directed specifically to the engineering problems arising in the construction of roads on muskeg.

The project involved the construction of several low test fills (less than 10 ft. high) in the Pembina Oil Field during the summer of 1958, one of which was increased in height until failure occurred. The test fills were extensively instrumented for settlement, horizontal movements, shear failure surface location, and pore pressures, but difficulties were encountered in protecting the instrumentation in the field. The details of the results of this program are beyond the scope of this symposium. In general, however, the results from the failed section showed that the average shearing strength of the muskeg at failure was in close agreement with the shearing strengths measured in situ with the shear vane. The muskeg exhibited both primary and secondary consolidation. High pore pressures were developed immediately following application of load, but these dissipated at a comparatively rapid rate. The muskeg in its natural state had a void ratio of the order of 14, and the compressive index for primary consolidation was of the order of 5, which was in surprisingly close agreement with the corresponding values from laboratory consolidation tests (5.0 and 5.4). Secondary consolidation under a load of 500 lb. per sq. ft. occurred at the rate of the order of 10% of the logarithm of the time in days from the application of the load.

The properties of muskeg, as indicated by these research programs, greatly influenced the design and construction of some ten miles of dykes on the Brazeau power project of Calgary Power Company Limited located 125 miles west of Edmonton on the Brazeau River. The engineering on this project was done by Montreal Engineering Company Limited with the author collaborating on the dyke problems.

The project required the construction of some eleven miles of dykes varying in height to a maximum of 25 feet (excepting ravine sections), with a large percentage of the mileage being over muskeg terrain. The total yardage in the dykes exceeded a million cubic yards. Problems therefore involved access of hauling equipment over the muskeg and adequate foundations for the dykes. Conventional practice would dictate that the muskeg should be totally removed below the dykes, and possibly also for access roads. Obviously, these procedures would have greatly increased the yardage of embankment material and would have involved the expensive excavation and disposal of some two hundred thousand cubic yards of organic soil.

The haulage roads were built, in the first instance, in the winter, with a pad of till two to four feet thick being laid directly on the frozen muskeg after the brush and trees were cleared off. The road was built so that it would ultimately be a berm on the downstream side of the dyke. The materials for the dykes were successfully hauled on these roads, both summer and winter, using 15 cu.yd. scrapers. During the summer, continual maintenance was required to keep a surface that would permit the hauling units to keep moving at maximum speed. This required almost continual blading, both summer and winter, plus the thickening of the mat as consolidation of the underlying muskeg occurred after thawing.

The dykes were built with homogeneous cross-sections using over-consolidated clay and clay till. Side slopes, as initially designed, were 2-1/2:1 and 3:1 (upstream), and the material was compacted in lifts using heavy sheepsfoot rollers, but with no control of the moisture content at time of compaction.

The characteristics of the muskeg along the line of the dykes were determined in situ using a shear vane, and the thickness of the muskeg was determined from the bore holes. In addition, three test sections were built on the muskeg. The thickness of the muskeg varied from about one to ten feet, but in some areas it was underlaid by soft clay. The muskeg was predominantly "AI" type in the Radforth classification, but a few areas approaching "BI" type were encountered. The

"AI" type has fairly heavy tree growth on it, while the "BI" type has only scrub tree growth.

These investigations confirmed that the muskeg along the dyke route had similar strength and settlement characteristics to that encountered in the University research projects. It therefore appeared feasible to build the dykes on the muskeg. There were, however, three special problems inherent in building on the muskeg. The first of these was the fact that the in situ muskeg did not have sufficient shearing strength to permit a height of more than ten to twelve feet of the embankment to be placed quickly without causing shearing failures. Additional height of fill could not be placed until increased shearing strength developed in the muskeg as the result of consolidation under the first load increment. This dictated stage construction for the dykes, and the maximum height of lift placed at one time was limited to ten feet, with the minimum time between lifts being specified at three months. In point of fact, however, the second lift generally was not placed until the following construction season.

The relatively high permeability of the muskeg as well as its unfavourable creep characteristics created a second special problem. To compensate for these factors, the dykes were designed with a central core section of clay which extended through the muskeg soil. The core section constituted a plug along the center line of the dyke which was considerably less compressible than the muskeg on each side. The performance of one test section showed that the differential settlement between the core and the muskeg could crack the dyke embankment. However, these cracks would be parallel to the crest of the dyke, and therefore would not feed water through the dyke.

The poor trafficability of the muskeg, except when frozen, placed a premium on building the access road along the dyke during the winter. If it is imagined that in the Spring of the year the frozen muskeg below the road should thaw instantaneously, then a highly unstable condition would exist in the thawed muskeg. However, if the muskeg thaws slowly enough, primary consolidation and build-up of shearing strength can occur, such that on completion of thawing the muskeg is more stable than it was prior to freezing. Settlement would, of course, take place during thawing. In view of the comparatively rapid rate of consolidation observed in the research test sections, it was concluded that thawing under the access roads would be so slow that instability would not develop, and the performance of the access roads confirmed this.

The project is not yet in operation and therefore all elements in the design of the dykes have not yet been proven by performance. However, in general the muskeg has performed as predicted. Toe movements occurred at two or three locations in "BI" type muskeg. These were stabilized by local berms placed around the weak muskeg zone. Longitudinal cracks occurred on both slopes in the dyke at several locations over relatively deep muskeg. However, surface run-off has sealed these off, and no additional work has been required on them. Differential settlements have not been of sufficient magnitudes to produce transverse cracks through the dyke. In general, the dykes have given satisfactory performance to date.

The somewhat unconventional construction procedures followed on this project in handling the muskeg problems are particularly pertinent to this Symposium because they are considered to be possible in the first instance because of the research results available on the characteristics of muskeg. The use of the research data on this one project has resulted in savings far exceeding the cost of the research projects. The Muskeg Subcommittee of the Associate Committee on Soil and Snow Mechanics of N.R.C. can indeed feel gratified that their efforts to a large extent provided the incentive for the research projects.

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Discussion

Mr. Thurber asked if any of the data Dean Hardy referred to was published, in particular on the equipment used for field testing. Dean Hardy referred the question to Professor Anderson, who said that some of this information is contained in graduate theses which have been submitted over the years and which are available in the University library. With reference to shear vanes, he said that a portable vane with a torque wrench can be used such as the commercially available Acker vane. Professor Anderson stated that improvements are still being made on their own equipment, as it has been shown that the largest sized vane possible should be used, consistent with portability and ease of operation.

Mr. Zirul commented on having once met a trapper who used snowshoes to successfully traverse difficult muskeg areas and wondered if this is not one solution to muskeg access. He asked if there is any information available as yet on the Brazeau Dam muskeg project. Dean Hardy replied in the negative, stating that information will not be complete until there is water behind the dykes.

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## I.5. LA TRAFICABILITE DU MUSKEG: LES DIX DERNIERES ANNEES

R. A. Hemstock

Résumé:

On fait une revue de la recherche sur la traficabilité du muskeg en répondant aux questions suivantes: pourquoi, quand, où et comment. Le besoin d'accès résume la réponse au pourquoi. La majorité du travail sur la traficabilité a été accompli depuis 1952, par diverses organisations, en particulier, par les industries pétrolières et forestières. Ce travail a été rendu possible grâce au développement d'un système de référence pour le muskeg. Au fur et à mesure que la connaissance des caractéristiques du terrain s'enrichissait, il était possible de faire le projet des véhicules qui tiendraient compte de ces caractéristiques. Cette présentation se termine en considérant les exigences de transport pour tout projet d'ensemble, et non parcellaire. Avec un programme approprié, une soigneuse sélection de routes et un choix judicieux de véhicules pour le terrain et le travail à faire, des résultats optimum peuvent être attendus.

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## I.5. MUSKEG TRAFFICABILITY--THE PAST TEN YEARS

R. A. Hemstock

Abstract

Muskeg trafficability research is reviewed by answering the questions: why? when? where? and how? The need for access is given as the answer to why? Much of the work on trafficability has been carried out since 1952, and has been conducted by various organizations, particularly the petroleum and forestry industries. This work was made possible by the development of a reference system for muskeg. As knowledge of the terrain characteristics increased, it was possible to design vehicles which would take into account these characteristics. The paper concludes with an appeal for the consideration of transportation requirements for any project to be made on an overall basis, not in segments. With proper planning, careful route selection and proper choice of vehicle for the terrain and the job to be done, optimum results can be expected.

## I.5. MUSKEG TRAFFICABILITY--THE PAST TEN YEARS

R. A. Hemstock

This milestone in years presents an opportunity to stop and to assess progress in the field of Muskeg Research. Research on Muskeg--Why?--and if there is a good reason--When, Where and How? Perhaps if these questions can be answered well, we can better plan for the future: not only future research but future development of Canada's Northern Resources.

Why: Why is there a need for muskeg research? Why emphasize trafficability?

The land surface of Canada is about one-eighth muskeg; fortunately most of this area lies in the northern sections--but as this country's growth pushes us farther away from the 49th parallel and as land values rise, the problem of organic terrain increases. Canadians must learn how to build engineering structures on muskeg - how to drain it, how to utilize it and perhaps most of all, how to travel over it. Why emphasize trafficability? Each year it is necessary to go farther afield for natural resources--for timber, mineral ores and oil. Trafficability, or access, is the keynote in exploration, and in exploitation. In Canada's highly developed neighbour, the United States, about 30% of the gross national product is spent on transportation. The exploration for and exploitation of natural resources in the more remote areas of Canada will certainly face a proportionately larger transportation burden without the added problems of muskeg. In one of the most recent areas of interest to the petroleum industry, 70% of the terrain is muskeg - not trifling muskeg either--its 8 to 15 feet deep. Development costs here will be extremely high and the economic implication is important to all of Canada.

A quote here of an example of the effect of modern transportation is in order. It was recently pointed out that the Geological Survey of Canada will be able to compress 300 years of work into 30 years by the simple expedient of using helicopters to move their geologists around. Costs per square mile mapped will be about the same but progress will be 10 times as fast. The helicopter is a valuable part of the transportation system in the north and in this instance is being utilized for work that suits it ideally.

When: Muskeg research is comparatively new. References to peat and its fuel properties can be found dating back for many years but the study of muskeg as a terrain factor began with Dr. Radforth's work, first reported in 1952. Ten years ago at the first muskeg conference everyone talked in general terms in describing muskeg. So general, in fact, it is certain that many of the participants did not know what the other fellow really meant. Classification and definition as outlined by Dr. Radforth's research enabled a common language to be used and put numbers in place of generalities. This is strikingly evident if one goes back over the proceedings of these meetings for the past ten years of muskeg work.

At the first research meeting, tracked vehicles were just making an appearance, no one know their capabilities nor those factors which limited capabilities. There has been a remarkable change in ten years, for in those ten years several thousand vehicles have been built for muskeg and used in a great variety of applications. With this usage there has been growth in both research knowledge and empirical result.

Where: Research has been done at several centres in Canada, although the effort in terms of manpower has not been great. Radforth's work at McMaster under the sponsorship of the various Government agencies, the work of the National Research Council, and finally, projects of the various highway departments, the pulp and paper industry and the mining and petroleum industries. Much of this work has been reported through the medium of proceedings of these meetings and forms a solid base for application to field problems. We speak of the centres of muskeg research implying buildings and laboratories; the most authentic research is done in the field when new methods and concepts are applied in practice. Fortunately, the great search for, and exploitation of, natural resources has been an active proving ground for fundamental research in Canada.

How: As has been seen, the real proof of the success of research is its application. There have been many papers presented outlining muskeg research work and there have also been others telling of field results. It doubtless would be quite correct to say that over the past ten years these papers in general have been success stories.

Consolidation and strength characteristics have been determined and engineers now know the broad limits that apply for highway or airport construction, as well as having a good idea of the drainage properties of muskeg. Extensive vehicle tests have been run at several locations and data are available on bearing strength, stability, effect of number of passes, track configurations and so on. It has been found, for example, that most muskeg is much tougher than was first thought and with large tracks it will support three or more pounds per square inch. There has been some note of the importance of the mineral soil in the total system and in some cases it has been found that mineral soil is the limiting feature, not muskeg. This data has been applied to vehicle design (although never to the extent the researcher would like) until now there is a wide range of tracked vehicles available. In many cases, thousands of hours of working time have been put on these vehicles under widely varying field conditions. This work, particularly in Canada and Alaska, has resulted in a growing confidence in tracked vehicles and a far better understanding of the advantages and disadvantages of this type of vehicle.

What are some of the points that have come from this work?

(1) Tracked vehicles will have higher operating costs per hour than conventional wheeled vehicles. However, the ability of a tracked vehicle to operate for 12 months of a year has resulted in some cases in lower year-round costs.

(2) Tracked vehicles are a compromise. They are called upon to traverse mineral terrain, snow, mud and muskeg. No one vehicle has the optimum characteristics for all conditions.

(3) Open water may be crossed with amphibians but this added ability will come at some penalty in weight, manoeuverability, etc.

(4) A round number for freight costs is likely about $1.00 per ton mile for tracked vehicles.

(5) Tracked vehicles have demonstrated their ability to get most exploration crews wherever they want to be at any time of year at some premium in cost.

(6) Present tracked vehicles have best cross-country speeds of about 6 miles per hour. Maximum length of haul should therefore be probably not over 100 miles.

(7) Tracked vehicles have hauled loads of up to 28 tons over muskeg and have moved complete drilling rigs weighing 500 to 700 tons to keep oil drilling going on a year-round basis. From various reports, the author understands that equally fine contributions have been made in the pulp and paper industry, in power and pipe line work, and in reclamation.

(8) Tracked vehicles have demonstrated their worth in cross country work in Canada and their abilities have resulted in applications far afield. They are reclaiming land in Carolina, at work on the Llanos of Columbia, the snow of Antarctica, on the deserts of Australia, and in several European countries.

What are the features we should look to for further improvement?

(1) The problem of transportation must be given far more importance by management. It has been considered as a necessary evil but it is always with us, however, and it will account for 1/3 to 1/2 the costs of many exploration plays. Transportation should be carefully studied and planned as an integral part of any program--not as only a troublesome sideline.

(2) Careful study should be given to logistics of any development. Emphasis should be placed on proper packaging, ease of handling, weight saving, etc. The best vehicle will not perform well if it is overloaded, or the load is not properly placed.

(3) The development of tracked vehicles has been very gratifying. Capabilities are now proven to 20-ton capacity. This should be the limit on size for the present. Progress can be made by unitizing equipment, use of light metals, etc. to keep maximum loads at about 20 tons.

(4) Route selection has become almost a science. The use of aerial photographs, interpretive techniques, ground reconnaissance, and so on, have given us the ability to accurately predict the terrain conditions on any given route. However, proper use of this ability can only be made if the route is selected with full understanding of the strengths and limitations of the vehicle. Many times routes have been selected for muskeg vehicles that were properly selected for a highway grade, or a heavy tractor--but certainly not for a light tracked transporter.

These remarks may be summarized by reiterating a few points.

(1) Excellent progress has been made in muskeg research in the past ten years; the work should continue. Emphasis should be placed on a study of the overall muskeg-mineral-soil system in trafficability.

(2) For optimum results from a practical standpoint the strong and weak features of cross-country vehicles must be fully understood. They have limitations in size, in range, gradeability, water-crossing ability, and so on.

(3) Transportation requirements for any project should be considered on an overall basis, not in segments. It may involve trucks on improved roads, helicopters, fixed-wing aircraft or tracked vehicles. Each has a place in the transportation picture, each has its strong points and each its limitations.

(4) Management should be aware of the importance of transportation and the overall improvement that can be made by proper planning.

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## I.6. RECHERCHE SUR LA MOBILITE DES VEHICULES

T. A. Harwood

Résumé:

Les facteurs qui influencent le plus la mobilité des véhicules sont la topographie, les conditions du sol et les caractéristiques mécaniques des véhicules. Sur le terrain, les facteurs qui empêchent la mobilité comprennent les côtes, les cours d'eau, les forêts et les tourbières. Dans le muskeg lui-même, les facteurs micro-topographiques peuvent limiter la mobilité du véhicule. Les tourbières ont joué un important rôle stratégique dans les tactiques militaires aussi récemment que lors de la seconde guerre mondiale. Les conditions du sol dans les muskegs impliquent généralement des problèmes comprenant l'effort de cisaillement de la terre noire, la capacité portante et les caractéristiques du tassement. Dans le développement des véhicules pour les terrains mous au Canada - pour fins civils et militaires - le principe de direction "articulée" a été employé plutôt que celui de la direction "glissante". L'évolution des véhicules pour les terrains mous a généralement abouti à un véhicule long et mince qui a permis l'exploitation de la configuration dite "sans-ventre". On conclut qu'il n'y a pas de réponse toute prête à la mobilité dans les muskegs. Les véhicules doivent être projetés pour des besoins spécifiques et pour l'application militaire; chacun de ces usages spécifiques devrait inclure, pour l'appareil, la capacité d'être amphibie.

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## I. 6. VEHICLE MOBILITY RESEARCH

T. A. Harwood

Abstract

Major factors influencing vehicle mobility are topography, soil conditions and mechanical features of the vehicle. Terrain factors inhibiting mobility include hills, water courses, forests and bogs; in the muskeg itself, micro-topographic factors can be limiting to vehicle mobility. Bogs have played an important strategic role in military tactics as recently as the Second World War. Soil conditions in muskeg generally involve problems of the shear strength of peat, bearing capacity and settlement characteristics. In the development of soft terrain vehicles in Canada - for both civilian and military purposes - the articulated principle of steering has been used rather than skid steering. The evolution of soft terrain vehicles has generally resulted in a long narrow vehicle which permits the exploitation of the so-called bellyless configuration. It is concluded that there is no ready answer for mobility in muskeg areas. Vehicles must be designed for specific purposes and for the military application, each of these specific uses should include the ability to be amphibious.

## I. 6. VEHICLE MOBILITY RESEARCH

T. A. Harwood

Summary - (This paper was an abbreviated version of a paper given at the Prince Rupert Seminar. For a complete text, see Appendix "B" of these Proceedings: "Trafficability and Mobility in Muskeg", by T. A. Harwood.)

Major factors influencing vehicle mobility are topography, soil conditions and mechanical features of the vehicle. Terrain factors inhibiting mobility include hills, forests and water courses as well as bog. Bogs have played an important strategic role in military tactics as recently as the Second World War. In the muskeg itself, micro-topographic factors can be limiting to vehicle mobility; these include mounds and ridges, gravel bars and boulders, peat plateaus and raised polygons, open and closed ponds, and lake margins. The problem of soil conditions in muskeg can be subdivided into shear strengths of the peat, bearing capacity, and settlement characteristics. With only a fragmentary knowledge of muskeg and peat characteristics, vehicle development was undertaken by two major Canadian oil companies (Imperial Oil and Shell) inspired by the necessity for all-year exploration. From this come the Imperial Oil Musk-Ox and the Nodwell Transporter both of which utilized the concept of articulated rather than skid steering. Development of military vehicles for muskeg stemmed from the design of vehicles for snow, such as the Tucker Sno-Cat and the Canadian Army Rat, both vehicles having incorporated the articulated steering principle. From the latter has developed the Dyna-Trak, a highly successful articulated vehicle. The evolution of soft terrain vehicles has generally resulted in a long narrow vehicle which permits the exploitation of the so-called bellyless configuration. In the purchase of a tracked vehicle, whether articulated or a single hull, the cost is generally between 95 cents and $1. 15 per pound.

The Ground Effects Machine is also under consideration for muskeg travel. This operates on a cushion of air, free of the surface. It has a negligible ground pressure but, at the present stage of development, it has several disadvantages such as its inability to operate in treed areas, to negotiate grades and to decelerate quickly as well as its high initial cost.

It is concluded that there is no ready answer for mobility in muskeg areas. With the wide variations in terrain, and the varying need for an optimum bearing pressure, there will be wide variations in the configuration and tracks of the vehicle. Vehicles must be designed for specific purposes and for the military application each of these specific uses should include the ability of the vehicle to be amphibious.

From the engineering standpoint, good progress has been made in dealing with muskeg over the past ten years. A classification system for muskeg has been devised and found satisfactory. Methods are available to allow interpretation from aerial photographs. Engineering studies have been started and have been continued. A muskeg vehicle has been shown to be a feasible proposition. The most important thing is that muskeg is no longer considered psychologically by both civilian and military as a complete barrier to summer activity.

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## I.7. DIX ANNEES DE RECHERCHES SUR LES PROPRIETES DE LA TERRE NOIRE

I. C. MacFarlane

Résumé:

La grande partie des premières recherches sur les propriétés de la terre noire concerna les caractéristiques chimiques et botaniques de ce matériel. Les efforts sérieux pour déterminer les caractéristiques mécaniques des terres noires n'ont débuté vraiment que dans les premières années de 1950. Ces recherches furent inspirées par un besoin universel croissant d'utiliser les terres marginales dont une grande partie comprend les tourbières, les savanes et les marécages. Les données empiriques obtenues par plusieurs investigateurs tombent dans deux principaux groupes: les propriétés déterminées en laboratoire et les caractéristiques de force et de déformation. En dépit des recherches importantes qui ont été faites sur le terrain et en laboratoire, il reste encore beaucoup de travail à faire. Le développement d'un système de classification quantitatif de la terre noire est de première importance.

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## I. 7. A DECADE OF RESEARCH INTO THE ENGINEERING PROPERTIES OF PEAT

I. C. MacFarlane

Abstract

Much of the early research on peat properties was related to the chemical and botanical characteristics of the material. Serious efforts at determining engineering characteristics of peats did not gain any impetus until the early 1950's. This research was inspired by an increasing world-wide need to utilize marginal land, much of which is peat bogs, swamps or marshes. The empirical data obtained from many investigators fall into two main groups: index properties, and strength and deformation characteristics. Despite the extensive field and laboratory research which has been carried out, much work still remains to be done. Of primary importance is the development of a quantitative classification system for peat.

## I. 7. A DECADE OF RESEARCH INTO THE ENGINEERING PROPERTIES OF PEAT

I. C. MacFarlane

Prior to the 1940's much of the research into peat properties was concerned with the chemical and botanical characteristics of the material, usually relative to its possible use as a resource such as fuel, peat moss, etc. Serious efforts at determining the physical and mechanical characteristics of peats, with the view to better design of roads and other structures sited on this complex soil, really did not gain any impetus until the early 1950's. Therefore much of the information that is available on this particular aspect of peat has been determined within the past decade.

During this interval, the high interest in Canada in engineering properties of peat has come from a wide variety of organizations which have been brought face-to-face with the muskeg problem in one way or another. These include provincial highway departments - especially in Ontario and British Columbia - Ontario Hydro, McMaster University, the University of Alberta and the Alberta Research Council, the National Research Council, the Oil Companies - particularly Shell and Imperial Oil - and several consulting engineering firms, particularly on the West Coast.

Interest in the engineering problems involving muskeg and peat has not been confined to Canada by any means but active studies have been underway in the United Kingdom, Eire, the USA, Japan, Scandinavia and the USSR. A considerable number of laboratory and field tests have been carried out on a wide variety of peats in an effort to determine some of the unknown parameters. In most cases, however, correlation of results with those of other workers has been next to impossible since the various investigators have used their own descriptions for the terrain and for the material tested. The empirical data, however, can be broadly divided into two main groups:

1. Index Properties.
    a. Water content
    b. Organic and inorganic content
    c. Specific gravity
    d. Acidity
    e. Void ratio
    f. Permeability
2. Strength and Deformation Characteristics.
    a. Shear strength
    b. Bearing capacity
    c. Settlement properties

These various characteristics are briefly discussed in a paper to the Prince Rupert Seminar (MacFarlane, I. C. - The Engineering Characteristics of Peat) which appears in Appendix "B" of these Proceedings. This brief discussion shows the general range of values which have been found in the various investigations for several fundamental peat properties, and also gives some indication of whether further research is required.

It is clearly evident that a large amount of information is now available on the engineering characteristics of peat. Nevertheless, many gaps still do exist and in certain facets of the muskeg problem, specific detail is virtually non-existent. Certain recommendations can be made, therefore, with regard to future research needs:

(1) The available classification systems for peat are qualitative and visual. Until some qualitative description of peat is devised which can describe composition, structure, permeability, etc., adequate correlation of engineering properties can not be made.

(2) Very little information is available on thermal properties and other physical properties of peat which may have a geophysical application.

(3) Peat hydrology is one aspect of the study of peat which has been largely neglected.

(4) The shear strength of various peat types warrants a considerable amount of further study. Development of the field vane, the cone penetrometer and other instruments needs to be continued. Documentation of actual shear failures in peat should be extended.

(5) A large part of the work done on the engineering aspect of peat has been carried out on settlement characteristics. In general, laboratory tests agree with field observations in the general behaviour pattern, but many questions concerning various aspects of the settlement process can not yet be answered. Consequently, there is still opportunity for fundamental research on this aspect of peat.

(6) The shearing strength and the bearing capacity of the muskeg mat has undergone relatively little investigation. The dynamic aspect of this problem is a primary concern in the McMaster O.A.T.R.U. vehicle testing program, but the static aspect also needs to be investigated.

Since the answers to many of the practical problems concerning muskeg (access, construction, etc.) are contingent upon a knowledge of the engineering properties of the material, it is evident that increased research into these fundamental characteristics of peat is of the utmost importance.

## II.1. LES RECHERCHES SUR LE MUSKEG APPLIQUEES A CERTAINS PROJETS D'INDUSTRIE PETROLIERE

T. G. Watmore

Résumé:

Les problèmes d'exploration et de production pétrolière en terrain marécageux sont énoncés en regard de l'aide obtenue par les recherches sur le muskeg, en particulier le développement du système de classification. Le transport "tout-terrain" est grandement facilité par un choix de tracé fait au préalable à l'aide de photos aériennes. Une interprétation détaillée pour 160 milles peut être effectuée en trois ou quatre jours. Des méthodes de construction de chemins d'accès sont décrites ainsi qu'un schéma des coûts en rapport avec divers types de routes.

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## II. 1. MUSKEG RESEARCH APPLIED TO CERTAIN OIL INDUSTRY PROJECTS

T. G. Watmore

Abstract

Problems in oil exploration and production in muskeg country are recounted, with reference to the assistance which has been gained through muskeg research, particularly the development of a classification system. Off-road transport is substantially aided by prior route selection from aerial photographs. A detailed interpretation of 160 miles can be accomplished in 3 to 4 days. Procedures in constructing access roads are described and indication given of the costs involved in various types of road.

## II. 1. MUSKEG RESEARCH APPLIED TO CERTAIN OIL INDUSTRY PROJECTS

T. G. Watmore

The application of muskeg research has provided a number of interesting projects for the Exploration and Production Departments of the Peace River Division of Imperial Oil Limited. Exploration still favors the frozen winter trails but has also increased considerably its summer operations using track vehicles. Production fields have made significant construction advances over localized muskegs.

The Division area encompasses the plains of northeastern British Columbia, part of northern Alberta and on through the Northwest Territories and Yukon to the Arctic Ocean (Figure 1). This comprises 440 thousand square miles where ground conditions are largely muskeg. Exploration seismic crews are currently working year-round from the permafrost regions south of Inuvik to the farmlands of the southern limits. Two highways, the Alaska and MacKenzie, provide the only arterial access into this virtually uninhabited wilderness now laced and criss-crossed by networks of bulldozed cutlines. Tugboats and barges of the Mackenzie waterways systems provide summer surface transportation from the end of the roads.

Production fields, except for Norman Wells, are located along the southern confines (Figure 2). These fields mingle largely with the outer fringes of farmlands and have a high rate of mineral terrain. Smaller muskegs on which projects have been completed are present. These serve as test plots for future continuous muskeg on which development will have to take place throughout the summer and winter.

### Exploration

Because of the frozen terrain, winter is the only period when bulldozers can alternately cut and clear lines through dense timber stands and over muskegs with relative ease. Consequently, freeze-up has become the time of intense seismograph activity. Trailer camps and supply lines can be quickly established in the wilds. Crews with truck-mounted equipment quickly follow the dozers over frozen lines with their shot hole drills, shooting crew recording units and surveyors to obtain miles of subsurface contour records.

These "seismic cutlines" become both the routes of future winter access and the trails on which seismic crews working on track vehicles carry out summer operations.

The lines are not cut with a view to summer use, but are more economical than employing labor crews to brush new trail to provide an undisturbed mat for track units in the frost free seasons.

Experience has proven travel over bulldozed lines, just after spring breakup, to be impractical for all but amphibious vehicles. From late May to mid-June, when surface water remains trapped by surface ice in muskeg, the deterioration of peat on the travelled surface occurs rapidly as the ice recedes. Detours of sections and corduroy stretches become all too common. Excessive wear is induced on equipment. Field production is often consumed by hours of winching and corduroying.

The period from mid-July until freeze-up affords the most ideal conditions for travel over all types of muskeg in the southern part of the region. This is when subsurface ice has disappeared and free surface water has drained away. Problems of note are encountered where a bulldozed trail enters the transition section from mineral to organic terrain (Figure 3). The predominant cover is BFI. Deterioration is most severe at the clay-peat interface, decreasing to almost nil where the depth of peat exceeds one foot. As detour paths become necessary, they should be cleared by hand labor; but often the trees are knocked down by the brush guard and tracks of the vehicle and inflict eventual damage to tracks, drive assembly and body.

Deterioration also occurs in heavily wooded, shallow AFI and AEI muskeg. Detouring in these is extremely difficult without excessive vehicle damage. It is more desirable to detour these features at their start, sending only necessary traffic along the line.

The seismograph crew operates at minimum with 12 field units and 5 camp units. Bombardiers and Nodwells are the vehicles used. The camp is all self-propelled and is a relatively recent and very welcome divergence from tenting on the ground.

Route investigation using air photos can be a vital asset to overall field operations (Keeling, 1961). Low altitude photography serves to accurately assess terrain conditions and plot trail locations. Muskeg types and extent are identified; points where access difficulties will be experienced are marked on the photos and this interpretation is transferred to a map. Copies of the final map are provided for vehicle operators.

Photo interpretation time will depend on the terrain cover and skill of the interpreter. It has been found that a chart of 160 miles of line will take from 3 to 4 days to complete. Photography, with favourable weather, would involve two days flying time and two days processing.

The project cost will vary from $500 to $1000 depending on flying distances, which must then be weighed against a saving in field operating time and extremes of vehicle abuse.

Another activity in exploration is wildcat well drilling. Locations are often picked 50 to 100 and at times 200 to 300 miles beyond all-weather roads. The networks of seismograph lines trace out an easy route to follow and are most often used, but occasionally lengthy trails must be cut through unexplored sections.

Long access roads following existing lines must start as soon after freeze-up as possible if rigs are to get to their location, drill and move out before breakup, while short access roads may well await construction until the intense freezing of late December or January. With two or three inches of frozen ground and three or four inches of snow, normally arriving in later November, many of our long roads have been started using Bombardiers, other track units or smaller bulldozers. These units compact the snow through which frost penetration becomes more rapid. Upon reaching 5 inches of frozen ground with the bonded snow cover, the large bulldozers can move in to prepare creek crossings, make cuts and fills, and widen and repair as necessary.

Our winter road opening costs have averaged $100 per mile to open, $50 per mile for motor patrol and drag operation, and $50 per mile for maintenance throughout a winter season of four months. This is a total of $200 per mile for a winter's operation. Speeds on these trails start from 5 to 15 miles per hour, but as the packed snow surface thickens and fills, sustained rates increase between 15 to 40 and higher. Access roads vanish with spring breakup.

New winter roads to be cut to rig sites are studied on air photos and outlined on a map. A confirmation flight is made at medium altitude for final revisions. From this, the ground observer can set off courses for his bulldozers.

The road ends at a drilling location selected according to three surface conditions: one on mineral terrain for summer drilling with an airstrip nearby for summer use; one on mineral terrain which is moved before breakup; and one on muskeg over which an earth mat has been placed suited to winter drilling and removal before breakup. The latter will be discussed in the production section.

## Production

Our methods of construction over muskeg have been obtained from the many publications by the Associate Committee on Soil and Snow Mechanics of the National Research Council. Muskeg classification is by the Radforth System (Radforth, 1952).

Once a field development well is decided on, its location is set within a definite pattern called the target area. This will be 660 feet square for oil or 1980 feet square for gas. Those target areas now to be described are wholly on muskeg and their access roads are mixed sections of mineral soil and muskeg.

An air photo study is first made to determine the type of muskeg at a given site and to select the best route of access. Sources of fill material are located and cost and construction time estimated for the road and site. Ground inspections, usually synonymous with the location surveys, are made. Changes are undertaken if necessary. A new location may often depend upon the productivity of a well just drilled, resulting in a concentrated effort of surface preparation at a time when the rig is about ready to move.

## Roads

Road selection is done with a view to economy. The life of a field is generally estimated at 25 years, for which a road must give continuous service and enter as much as possible an integrated network for daily operating travels. Crude tankers and rig moves with some loads from 40 to 50 tons must be supported by the road in its initial stages.

Cost gathering shows a mile of road on mineral terrain with a 24 foot road top, culverts and a 66 foot right-of-way cleaned of stripping and all bush, to cost $5,000. The same length of road on muskeg is found to be $10,000. Gravel is not included. These costs, as well as muskeg types, help in the decision of whether to "head into the swamp" or detour.

## Road Preparation Over Muskeg

The selected road centreline is surveyed and axe cut. Crews with chainsaws and axes clear a 66 foot right-of-way. All trees over 3 feet high are cut and placed in a 34 foot wide band along centreline. Since forestry regulations require slash disposal, this is a money saving means of getting rid of it under the road bed. No special effort is made to corduroy unless the type of muskeg has a low shear strength and poor mat structure such as FI featuring tussocks.

Every effort is made to prevent damage to the natural mat. All equipment is kept from the right-of-way until the fill material is in place. A damaged mat will take a great deal of careful corduroying to prevent loss of fill and ensure the peat will not work up through the road bed.

Fill material from selected borrow pits is pushed onto the muskeg directly following the brushing crew. The predominant grey woodland clay of our present area has been found most suitable in its binding and compaction qualities. A red sandy clay, also frequently found, does not provide the same qualities of stability.

Self-propelled earth movers dump loads onto the centreline close to the end of fill (Figure 4). A bulldozer pushes and spills the load over the end of fill, carefully raising the blade to let the earth slide freely onto the mat. At least four feet of fill is kept under the units to guard against mat damage. The grade width is maintained by a line of stakes set at the toe of the side slopes 17 feet from centreline. Compaction is obtained from weight of the bulldozers and repeated trips of the loaded scrapers.

After unloading, the scrapers back up to a prepared turn around, and away for the next load. Turn arounds are made at 600 foot intervals by pushing a pad 20 feet wide and 40 feet long out from the road shoulders. Two self-propelled scrapers and one bulldozer construct the grade and a motor patrol is brought in to slope and trim the final grade (Figure 5).

Gravel is spread, on completion, at 500 yards to the mile.

## Lease Preparation

An area of 400 feet square, centred on the well, is hand cleared. All bush is placed as corduroy under the earth fill mat. For some muskegs this may only serve as a means of disposing of bush; for others with low cohesive strength, additional corduroy may have to be brought in.

The earth mat for the wellsite is an extension of the road to the well centre. At the centre, the fill is spread uniformly in 4 feet thickness in all directions. The loaded scrapers purposely circle and unload around the wellhead. This simulates the surcharge method of preconsolidation in an area where strength is needed most (Brawner, 1959).

The basic mat area (Figure 6) is 110 x 200 feet positioned about the well and additions are made to accommodate pipe rack and buildings.

This fill pad 4 feet thick is ample support for a rig capable of drilling to 8,000 foot depths, as the combined weight of rig and pad will remain below a loading of 1,000 pounds per square foot.

Campsites, which add an extra light plant to the operation, are located along the access road on suitable mineral terrain. The sump for rig waste is dyked over the muskeg adjacent to the mat as opposed to the usual pit in the ground.

Winter mats follow similar construction, with the advantage of hauling on frozen muskeg. The disadvantage is the additional heavy ripping equipment required to break open and maintain a borrow pit, as well as handling moist earth at freezing temperatures.

## Conclusion

Our varied experience in problems of access and construction on muskeg, in winter and summer, has been guided by the conferences and publications of the National Research Council. Summer projects are small as yet. When the gates swing wide for far northern production to fill market demands, we should be able to meet the vast organic terrain challenge with proven theories.

## Acknowledgements

The author extends his appreciation to Mr. George Schlosser, of Imperial Oil Limited, who helped in the preparation of this paper.

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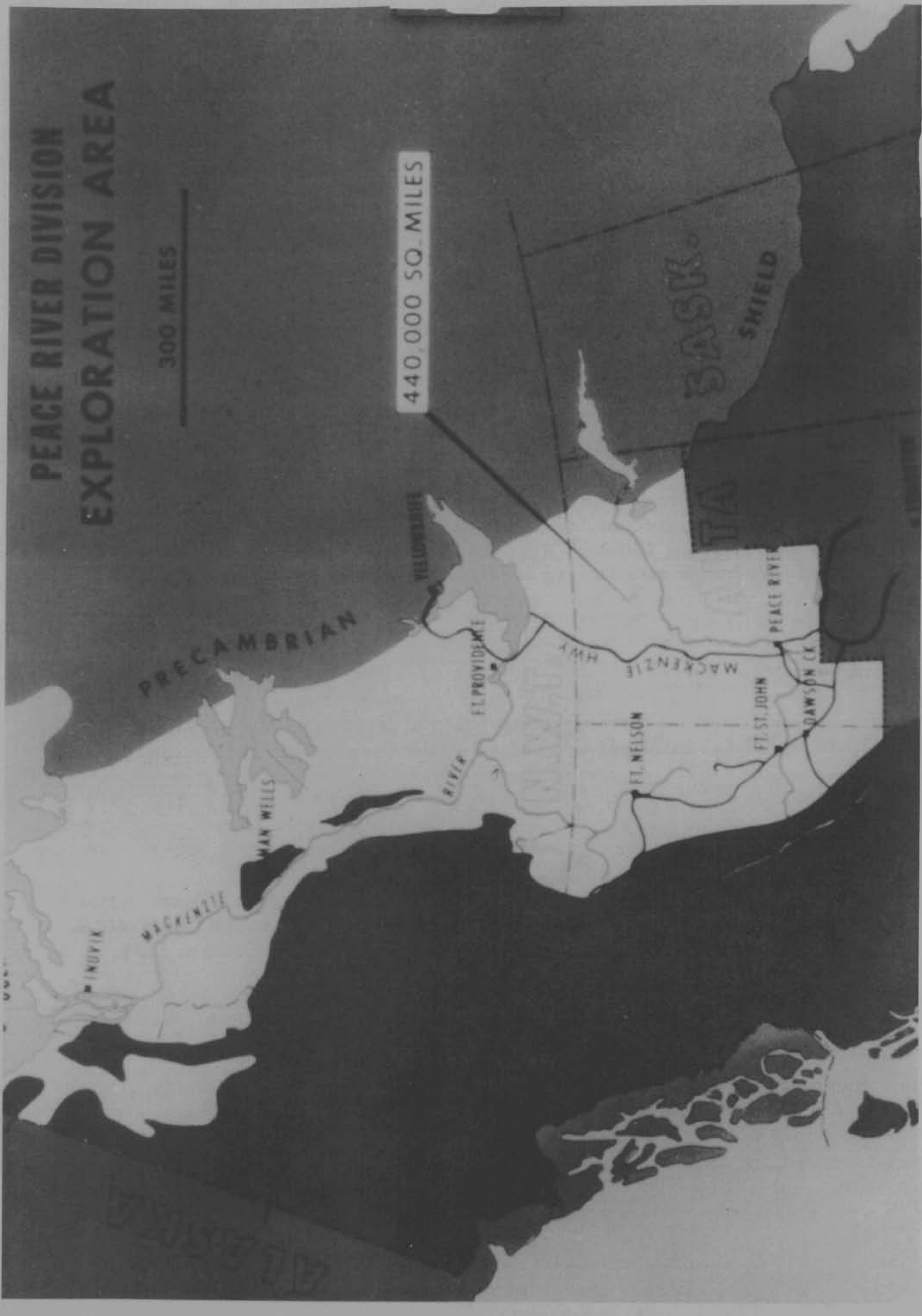
PEACE RIVER DIVISION
EXPLORATION AREA
300 MILES
440,000 SQ. MILES
PRECAMBRIAN
SHIELD
SASK.
YELLOWKNIFE
FT. PROVIDENCE
MACKENZIE
HWY
PEACE RIVER
FT. ST. JOHN
DAWSON CK.
FT. NELSON
RIVER
MACKENZIE
INUVIK

FIG. I

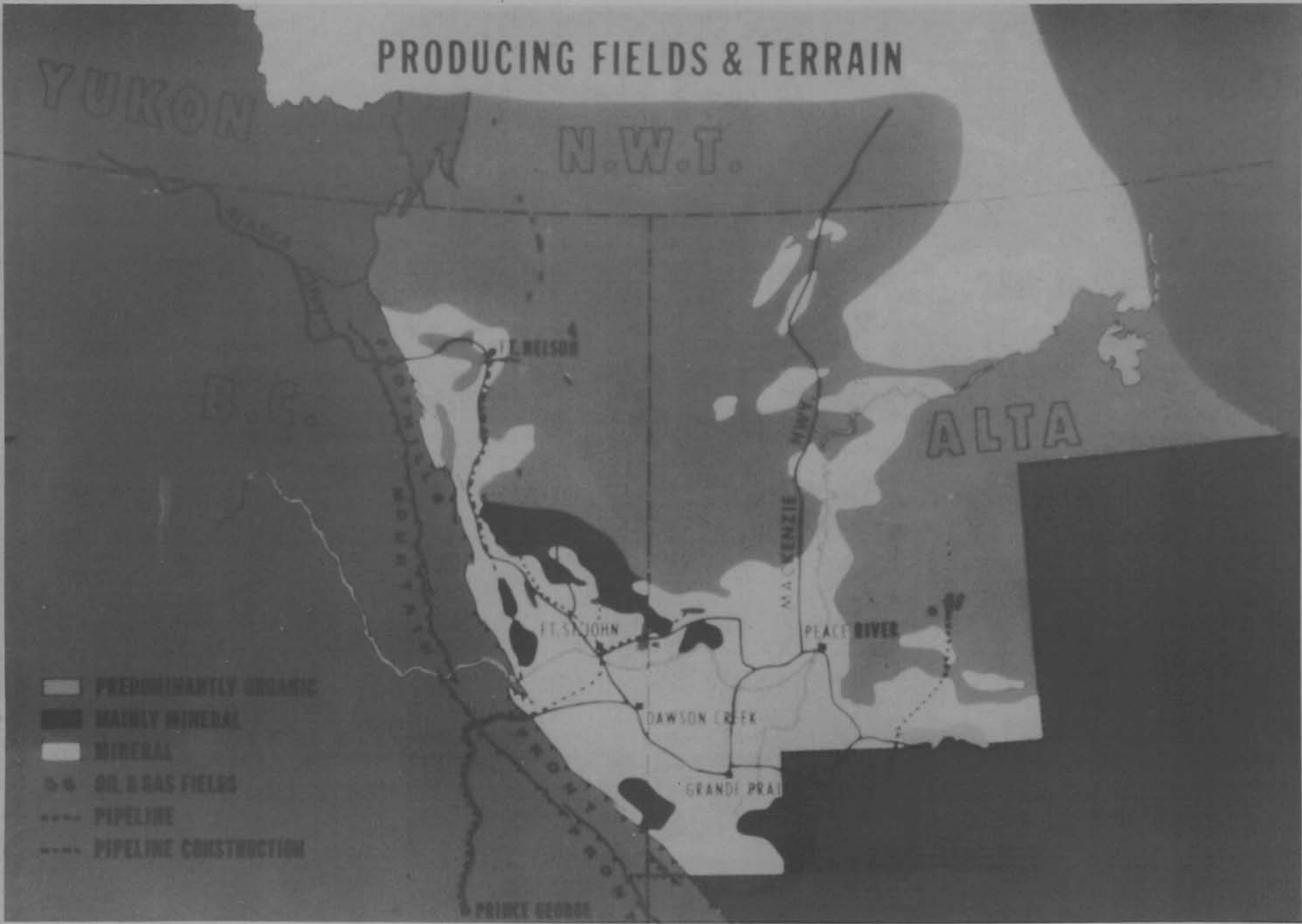
PRODUCING FIELDS & TERRAIN
YUKON
N.W.T.
B.C.
ALTA
FT. NELSON
FT. ST. JOHN
DAWSON CREEK
GRANDE PRAI
PEACE RIVER
MACKENZIE HWY.
PRINCE GEORGE
PREDOMINANTLY ORGANIC
MAINLY MINERAL
MINERAL
OIL & GAS FIELDS
PIPELINE
PIPELINE CONSTRUCTION

FIG. 2


FIG. 3

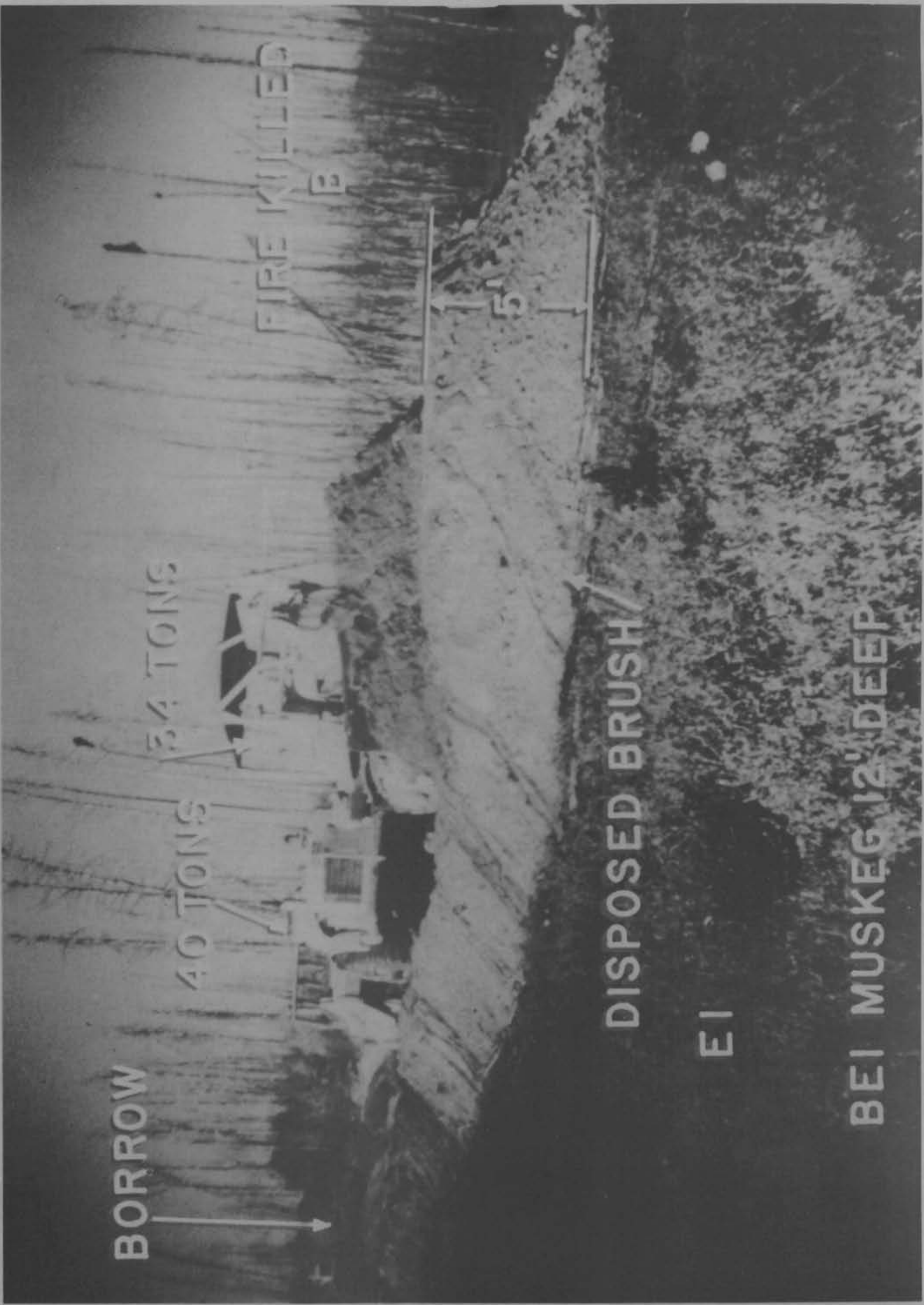
BORROW
40 TONS
34 TONS
FIRE KILLED
B
5'
DISPOSED BRUSH
EI
BEI MUSKEG 12' DEEP

FIG. 4

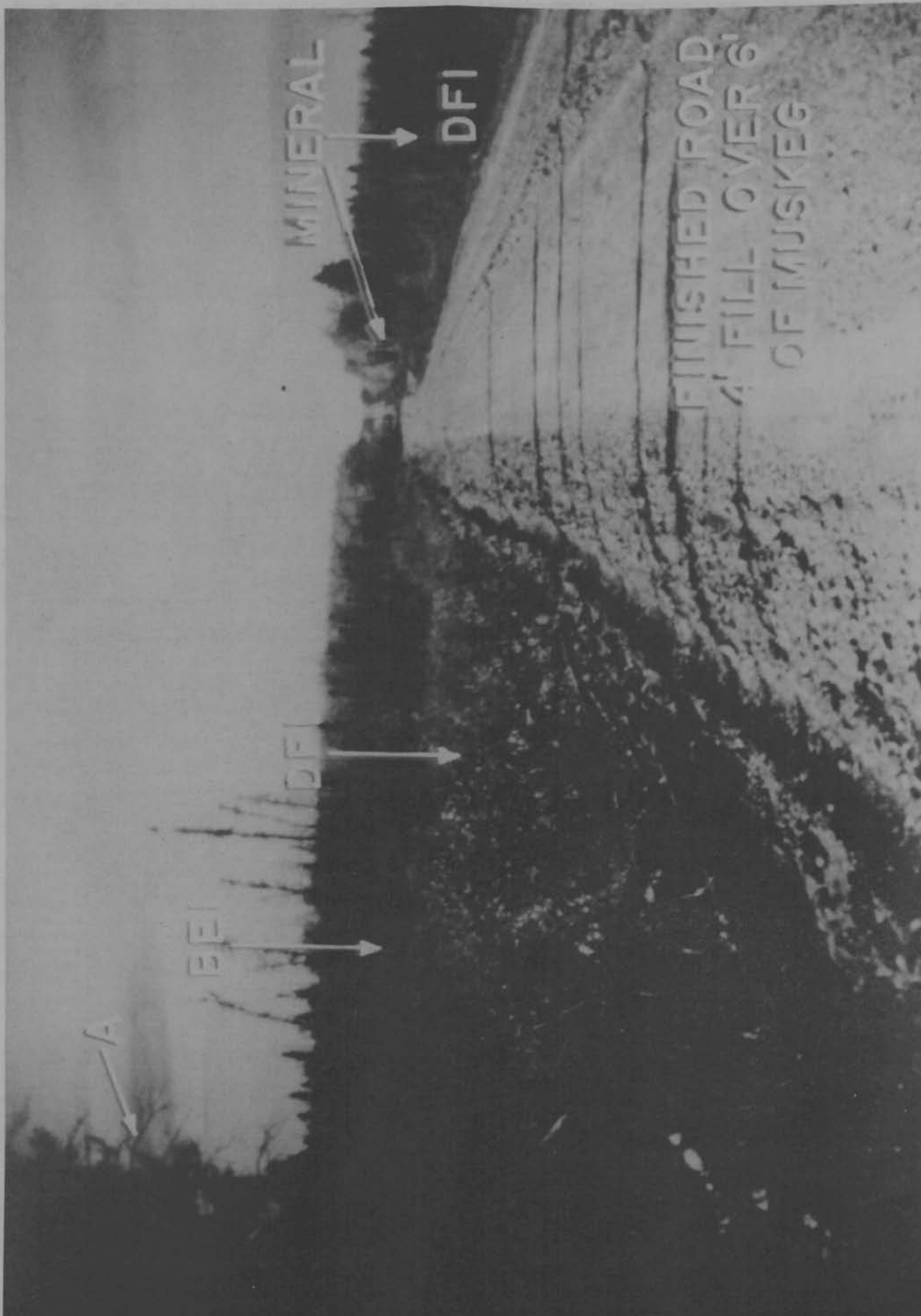


FIG.5

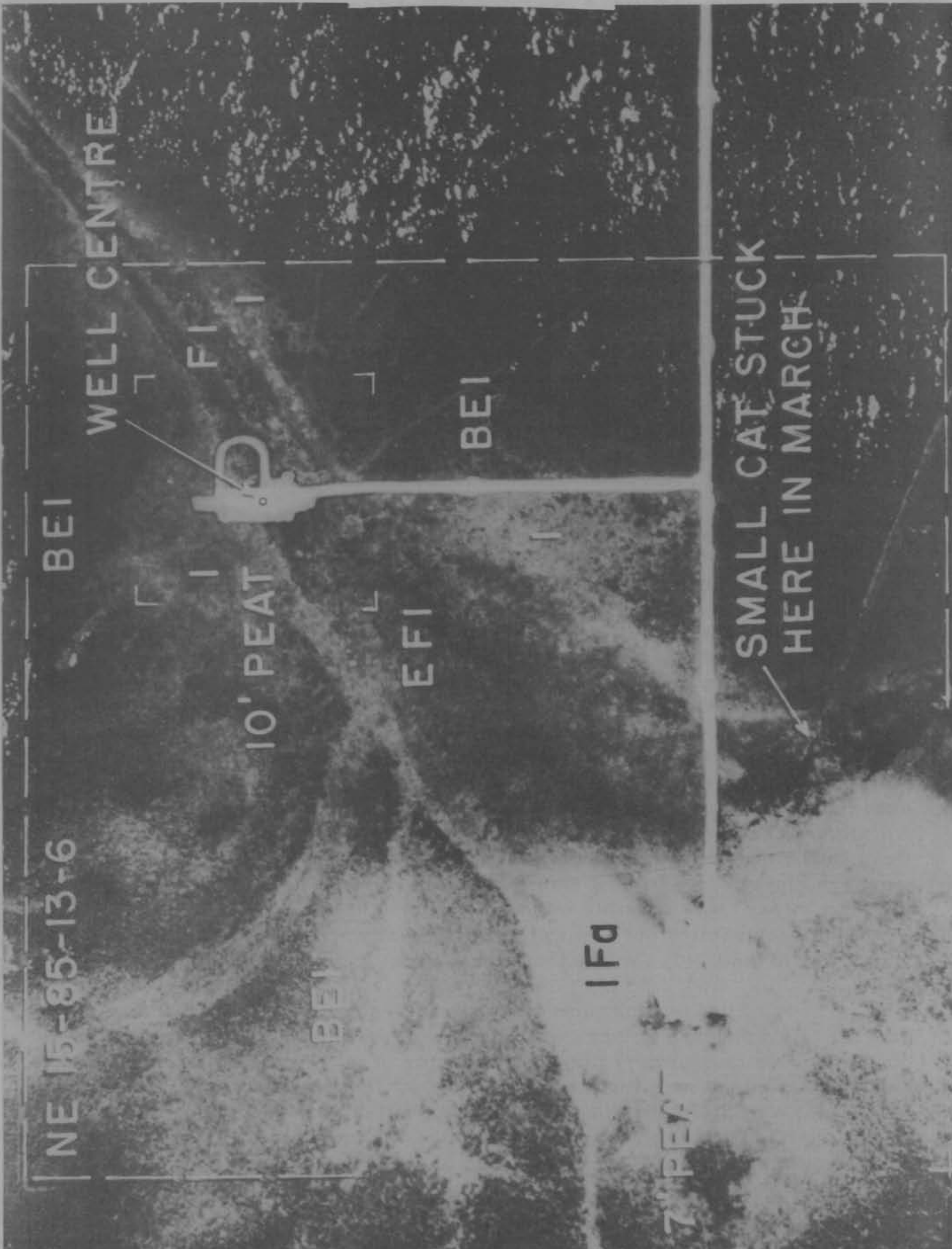
NE 15-85-13-6
WELL CENTRE
BEI
FI
BEI
10' PEAT
EFI
SMALL CAT STUCK
HERE IN MARCH
BEI
IFa
7' PEAT

FIG.6

Discussion

Mr. Enright asked about the fill quantity of 500 cu. yd. per mile quoted in the paper. Mr. Schlosser replied that this is a greater volume of gravel than is usually placed. Due to the existing conditions in muskeg, which includes a greater than normal amount of water seeping up into the roadbed in Spring, the heavier the gravel placed, then the greater the likelihood of the embankment remaining intact for 10 years. Mr. Schlosser said that it has not been possible to study a road section for this length of time, however, as the oldest roads with which they are concerned have been built for only 4-5 years.

Mr. Hemstock commented on some of the magnitudes involved. He and Mr. J. Thomson of Imperial Oil had once calculated that there are some 180,000 miles of seismic lines in muskeg. In muskeg, road construction costs about $5,000 per mile more than on non-organic terrain. Consequently, a field of 1000 wells - and 1/2 to 1 mile of road is required for every well - in muskeg will cost several million dollars extra.

Dr. Radforth pointed out that the EI muskeg (shown in one of the slides and on which end dumping was taking place) can also support a wheeled vehicle (of a certain type) for 4 to 5 passes.

Dean Hardy asked if there was any difficulty in obtaining fill material and wondered what was considered to be a reasonable length of haul. Mr. Watmore replied that a reasonable length of haul was about 2000 feet. The area under discussion is on the fringes of farmland, with localized muskeg, so hauls were not very long. The tendency was to site roads to cut down on haul lengths. Initially, the roads are located from from aerial photos (2" to 1 mile scale). Originally only RCAF photos were used but now these are supplemented by photos taken for the Company. All mineral and organic terrain is isolated, then the road is located. Dean Hardy enquired if this haul length applied both to gravel and to the northern clay. Mr. Watmore said that it did, more or less. Working from the air photos it was possible to keep the length of haul generally low. Mr. Schlosser pointed out that in the Fort Nelson area, however, it was necessary to haul 2-1/2 miles from the nearest source of fill material.

Professor Anderson enquired about the wellsite pads during drilling. He wondered if there was any undue settlement (tilting of the rig, etc.). Mr. Watmore replied that no problems of this type have been encountered as yet with their experience of 10-15 rigs on muskeg. Mr. Schlosser said that in this regard every effort was made to keep the water used in drilling out of contact with the fill material and thereby avoid softening the top of the fill.

## II.2. QUELQUES METHODES DE CONSTRUCTION DANS LES TOURBIERES ET LES SAVANES DE LA COLOMBIE BRITANNIQUE

R. C. Thurber

Résumé:

Cette présentation démontre, par quelques exemples, comment les compagnies de chemin de fer de la Colombie Britannique, en raison des wagons plus pesants et de la demande pour des trains plus rapides, sont consentantes à dépenser une plus grande somme d'argent afin de réduire la spongiosité des rampes de chemins de fer sur les savanes. Après la construction d'une rampe de chemin de fer traversant plusieurs savanes au nord de Prince-Georges, on a constaté, à certaines périodes durant l'année, qu'une instabilité existait et qu'un léger glissement additionnel prenait place. Cela indiquait que la rampe avait un facteur de sécurité très minime ou nul contre le mouvement. Un gain dans le facteur de sécurité fut obtenu en plaçant des bermes composées de matériaux locaux. Une méthode économique d'installation de conduites d'égoût en ciment asbestos dans la terre noire est aussi commentée.

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## II.2. SOME METHODS OF CONSTRUCTION IN PEAT BOGS AND SWAMPS IN BRITISH COLUMBIA

R. C. Thurber

Abstract

Examples are given in this paper of how the railways in British Columbia, due to heavier cars and the demand for faster trains, are now willing to spend a larger amount of money to reduce the sponginess of railway grades over swamps. Where railway grade has been constructed to cross several swamps north of Prince George, it was found that at certain times of the year instability would develop and a small amount of additional sliding would take place. This indicated that the grade had little or no safety factor against movement. Additional safety factor was gained by placing berms of local material. An economical method of placing asbestos cement sewer lines in a peat area is also discussed.

## II. 2. SOME METHODS OF CONSTRUCTION IN PEAT BOGS AND SWAMPS IN BRITISH COLUMBIA

R. C. Thurber

The author deals with peat bogs and muskeg quite frequently; however, in most cases there is little or no time and often very little money available for carrying out any research and often as much testing as would ordinarily be required. Nevertheless, more from the practical point of view new things are being learned about swamps every year. A change in thinking or higher requirements of railways can be reported with regard to grades over swamps in the last few years in B.C. Also cases of instability of swamps and control by berms are discussed as well as the placing of asbestos cement sewer pipe over peat areas.

At the Sixth Muskeg Research Conference (Thurber, 1961), mention was made of the problems the railways were having with swamps in B.C. It is interesting to note that since that time there has been a change in the thinking of railway engineers as to the treatment of peat bogs and swamps. It has now been found that sponginess or unevenness in railway grades, that in the past was considered acceptable, can no longer be tolerated. This change in thinking has been due to a new look at slow orders that delay traffic and result in added costs. Basically, the problem arises from the fact that there are much heavier railway cars, much longer trains and a demand for the much faster movement of trains, all due to the increased activity in western Canada. These new requirements for railway traffic in turn demand that a railway track be uniform with a narrower tolerance of unevenness and sponginess. As a result, the railways are now taking another look at locations where the grade has been economically floated over swamps and soft areas.

As an example of the above, the author's firm has been engaged this year to investigate a section of line where the railway was floated over the peat. As the grade was not very high, it has been maintained comparatively trouble-free for many years. Recently, however, the heavier and longer trains have had to reduce their speed limit over such areas, principally due to somewhat of a plunging action which is developed by loaded freight cars. A slow order is necessary to prevent derailments. The terms of reference are to gather the data and soils profile, and to work out a satisfactory method of eliminating sponginess of the railway grade. It is an extremely busy line which means that restriction of the rail traffic must be kept to a minimum. The results of this investigation will no doubt provide interesting material for a future conference.

At another location, a railway has a grade constructed over two swamp areas where the peat is approximately 13 feet deep and underlain by a soft silty clay for an additional 10 to 12 feet. The grade was originally built directly over the peat; however, due to the above-mentioned reasons, it is considered to be unsatisfactory. A programme is now underway of placing dynamite charges in the underlying peat to displace the soft material and obtain a more stable grade. The procedure in this case (where the grade is in place) will be to drill holes to place the charges directly under the grade and to also place toe charges by means of the Ashley core punch bar. It was hoped that this work would have been carried out before this conference and more details of the results could have been presented. However the area has been inaccessible and at the present time it is still not accessible. Here again records will be kept to present at a future time and the case is mentioned mainly to illustrate the change in engineering thinking of the railways in the last few years.

In a talk given to the Soils Mechanics Group in Vancouver in 1956 (Thurber, 1956), a criteria was mentioned which was developed while the author was working with Dr. R. M. Hardy on some road research work in Alberta in 1947. Basically it was as follows:

1) For a muskeg less than 15 feet deep, the maximum permissible height of fill to avoid shear failure is 12 feet.
2) For a muskeg over 15 feet deep, the maximum height of fill to avoid shear failure is 8 feet.

It is pointed out that the depth of muskeg as discussed above was that depth of material which could be comparatively easily penetrated with a 5/8" penetration rod and would include any soft clays underlying the peat. This rule of thumb was a result of an analysis carried out on a section of road which failed in Alberta, and utilizing the data applicable to that location. Since that time, the author has analysed several failures of a similar nature in British Columbia and found the criteria was satisfied in every case. In addition, a large number of cases have been checked where fills have been built over peat bogs, where failures have occurred, and also where no failures have occurred. In each case, the above criteria was satisfied.

It is pointed out here again, however, that this rule of thumb is strictly a case of detecting an approximate height of fill where an actual shear failure would take place. Where fills have been placed over peat bogs and have carried the load without shear failure, in most cases varying degrees of unsatisfactory performance have been detected due to settlement, sponginess and deflection under loads.

To illustrate what was done to improve a grade floated over a swamp and which was causing continued trouble, it will be useful to report on conditions found at a few sites north of Prince George. The author's firm had the opportunity to investigate several locations in the past 5 to 6 years where the railway grade had been built over peat areas. At the time of construction, failure had occurred and a large amount of additional material was placed causing peat upheaval on both sides. Equilibrium was reached eventually and the railway was put in use for 3 or 4 years. It was found that continued sponginess and erratic small amounts of settlement were of real annoyance to the railway traffic and an investigation was carried out to find why this should continue even though shear failure had appeared to stop. The investigation at these locations showed that a similarity was typical in each case. Figure 1 illustrates this point, where a fill is built over peat and soft clay and settlement had taken place, but no shear failure has occurred as yet. In Figure 2 a shear failure has occurred. Figure 3 illustrates where additional material, often in the form of expensive gravel, has been placed to try and maintain the grade in a passable condition. Shear failure has occurred on both sides and the upheaval in some cases is very large in an effort to counterbalance the heavy fill or gravel material being placed. In each case, the same conclusion was reached:

1. It is not satisfactory to continue filling a failure of this kind in a swampy area with heavy clay or gravel. It takes a tremendous upheaval of the low density peat to counterbalance the fill or grade and create equilibrium. Also, after equilibrium has been obtained, it takes very little change to cause further shear failure and disruption at a later date.
2. In spite of the large yardage of material placed in failures of this kind, it was found that there was still a large amount of peat directly under the grade.

Generally the best solution would be to remove the peat directly under the grade and also one must increase the factor of safety against shear failure so that future changes in conditions will not cause additional movement. In most cases where the railway is in use, it is not economically feasible to remove the peat directly under the fill, particularly where large quantities of soil have slipped to each side of the peat.

Figure 4 illustrates what has been done in several cases to increase the factor of safety against sliding. Toe loading berms, somewhat of the shape as shown, were constructed in the areas where shear failure had taken place. The advantages of this are as follows:

i) It takes a smaller yardage to create a sufficient safety factor against shear failure, as against continued filling on the grade with the general idea of counterbalancing the grade with the upheaved peat.

ii) A definite factor of safety is developed against shear failure which would guard against further movement as conditions (such as water table, load, etc.) change.

iii) Local soil is satisfactory for berms and no special compaction is usually necessary.

It is pointed out that the above practical application of toe loading berms assists in relieving sudden movement by shear failure only and does not necessarily improve conditions in connection with sponginess of the grade or consolidation of the peat.

Another example of a problem encountered in peat areas and the last one to be covered here, was a sewer line in Victoria. The Saanich Municipality, near Victoria, presented the author's firm with a problem wherein they had to place sanitary sewer lines in a low lying, marshy area in Cadboro Bay below the water table and quite near the ocean. The problem was described and conditions were found by a preliminary investigation to be as follows: An area covering about 4 city blocks was found to have from 0 to 17 feet of a soft, fibrous peat overlying a silty sand and clay-silt. It was found from penetration tests that piles would have reasonable bearing if they penetrated the underlying sand about four feet.

The water table during dry part of the year was found to be from 1 to 5 ft. below the surface and was known to fluctuate considerably and during a good part of the year the water table was at the ground level. Parts of the area were presently covered with road fill, sawdust and miscellaneous clay-fill to depths varying from a few inches to 6 feet or more at various locations. The project was to lay 6 inch and 8 inch asbestos-cement sewer pipe at a grade of 0.3% and a depth from 3-1/2 to 6-1/2 feet. Economics of the project ruled out expensive construction, such as well-points, to lower the groundwater table.

<u>The problem was as follows:</u>

a) To prevent damaging settlement of the sewer pipe which could either disjoint it or could reverse the gradients and cause difficulty;

b) To simplify the problem of installation in peat and below the water table economically;

c) To eliminate damage by vehicles, roadways, and by the placing of additional fill over the pipes at various locations in the future.

A solution was devised utilizing a structure as shown in Figure 5. This plan utilized a single pile with a prefabricated 6 x 12 creosoted timber with drift pins into the pile. 2" x 8" fir planking was well spiked to each side of the timber to form a trough for the sand and pipe. The sand bedding was then placed in the trough and the pipe laid in the sand. Steel trapping was placed around the pipe to prevent pipe floating as the water level came up. The trench was then backfilled with a pitrun gravel to ground level.

This procedure was adopted over other possibilities as it suited the requirements of:

(a) Economy
(b) Construction possible with locally available equipment.
(c) Providing sufficient support for locally expected traffic.

A contract was let for this work and the additional cost over normal sewer installation was $5.55 per foot extra. The supply and driving of cedar piles was $1.30 lineal foot of piling and box and installation $2.60/lin. foot. In most cases machines were able to work over the area prior to excavation and alongside the trenches. The piles were driven in the water in the open trenches and the timber trough, sand and pipe were all prepared. Utilizing pumps, the water level was lowered temporarily to the pile cut-off elevation. The piles were cut off, the timber trough installed, sand placed, and then the pipes were laid. The whole operation took very little time and in many cases the men found they could carry out the installation partially under water when dewatering of the trench proved to be extremely difficult. For parts of the line, the installed sewer line became a temporary outlet for the ground water. The entire operation proceeded quite smoothly and was installed in a reasonable length of time. A recent check showed that in spite of considerable development of the area, there have been no reported problems in connection with these lines.

It was generally found that where the peat was less than 6 feet deep, it was satisfactory to excavate the peat completely and backfill with pitrun gravel to form a bed for the pipe. Where the peat was over 6 feet deep and up to 10 feet deep, it was proposed to use the single pile support as in Figure 5. Where the peat was over 10 feet deep it was felt lateral support should be greater and it was proposed to use a double pile with a similar arrangement to Figure 5. By actual field checking and inspection of the single pile structure placed in peat up to 21 feet in depth, it was found that the lateral stability was quite satisfactory and the double piling method was decided not to be necessary. This installation has been in satisfactory service for four years and has not been disrupted in spite of machines and local development over the area.

To conclude, the above points have been discussed to illustrate some of the encounters with peat bogs which the author's company has had recently and the comparatively successful practical application of stabilizing measures and just what satisfaction a person can expect from such work. Also, it is interesting that railways and highways are interested in spending comparatively larger sums of money to obtain a higher standard of grade in the swamp areas in B.C.

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REFERENCES

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Thurber, R. C. "Construction Experiences in Peat Bogs and Muskeg in B.C." Proceedings, Sixth Muskeg Research Conference, NRC, ACSSM. Tech. Memo. No. 67, p. 1-6, Ottawa, 1961.

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Discussion

Dr. Radforth pointed out that this was the first time at any muskeg conference that a paper on railway construction in muskeg had dealt with this philosophy and approach. It has been known what happens and also something of the cost, with reference to railways over muskeg, but this paper has given a better idea of what to look at and what to measure. He asked Mr. Thurber if he had any information at all about the vegetal cover of the muskeg in Figure 3. Mr. Thurber said that, in this particular area, they generally tried to avoid peat bogs but when they were encountered they were localized confined bogs. The whole range of classification was encountered, from those with woody growth at the centre, to those with a confined pond at the centre of the deposit.

Dr. Radforth referred to the mass of peat in the grade which was not removed by blasting, and suggested that it must have been mainly EI cover, perhaps EFI. He drew attention to the failure some years ago of a road over muskeg at Moonbeam, Ontario, where there was no failure of the mineral soil sub-layer.

Dean Hardy mentioned that some of the shearing strengths of peat measured by Capt. S. Thomson were over 1000 p.s.f. and were comparable to clay, although the strains were very much greater. It is unlikely that material of shearing strength equal to or greater than 1000 p.s.f. will be displaced, which is possibly the case for the situation in Figure 3. He said also that the geological conditions must be taken into account. If the organic and inorganic are recent geological depositions, the inorganic is normally consolidated only under its own submerged weight and the very light submerged weight of peat (5 pounds/cu.ft. approximately).

Dr. Radforth pointed out that often under AEI cover a dirty gravel is found.

Mr. Brawner, in commenting on the references to sewer installation in muskeg, said that it can be assumed that the sewer pipe is a rigid structure. He wondered if they had to use flexible couplings from the houses to the main sewer. Mr. Thurber said that they expected some settlement, but support for the pipe was considered to be rigid. In the particular area discussed in the paper, there were no house connections. A question was raised regarding the construction of manholes and whether these had flexible connections to the sewer. Mr. Thurber referred the question to Mr. Nasmith who replied that the area in question was designated as parkland. Consequently it had neither manholes nor house connections. A pumping station has been built in this muskeg area, but the construction technique was to take the foundation through the peat and onto firm material. Mr. Hemstock asked if any trouble had been experienced in shooting out the peat from beneath the grade after the peat had become consolidated. Mr. Thurber replied in the affirmative and estimated that three times as much blasting power is required for this situation as for the normal circumstances. He said that he hopes to have movies and more specific data for the next conference. Mr. Zirul wondered if the blasting charges were arranged in a line or as a group. Mr. Thurber said that propagating powder was used; the cap in one charge would propagate 8 or 9 feet.

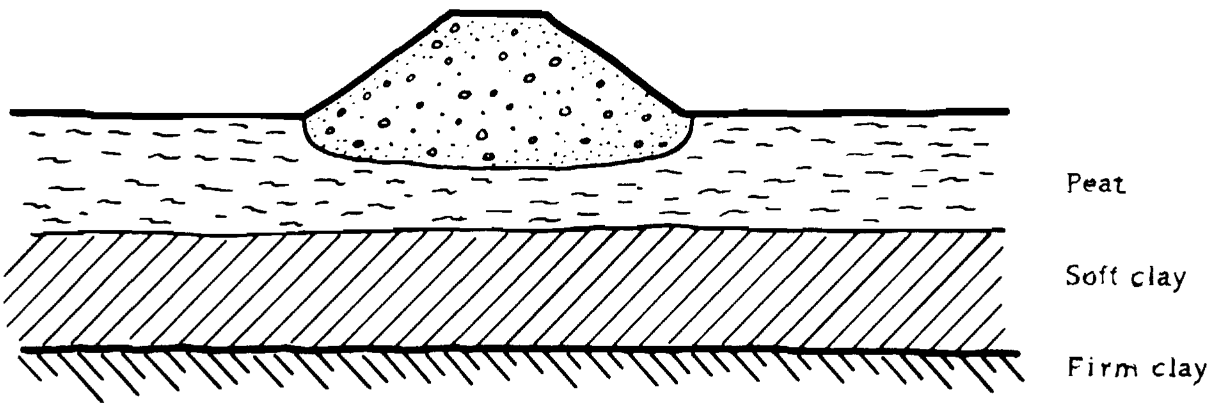


FIGURE 1

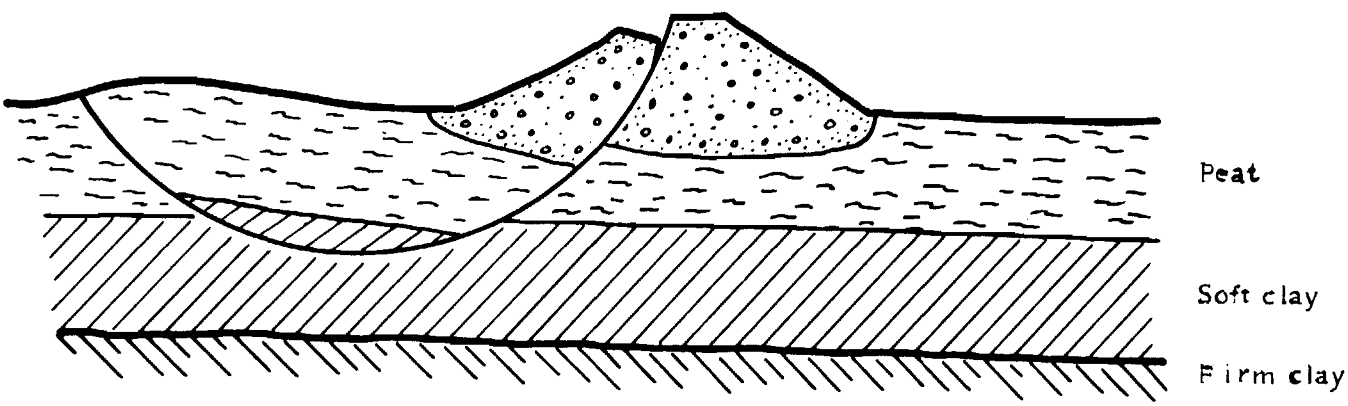


FIGURE 2

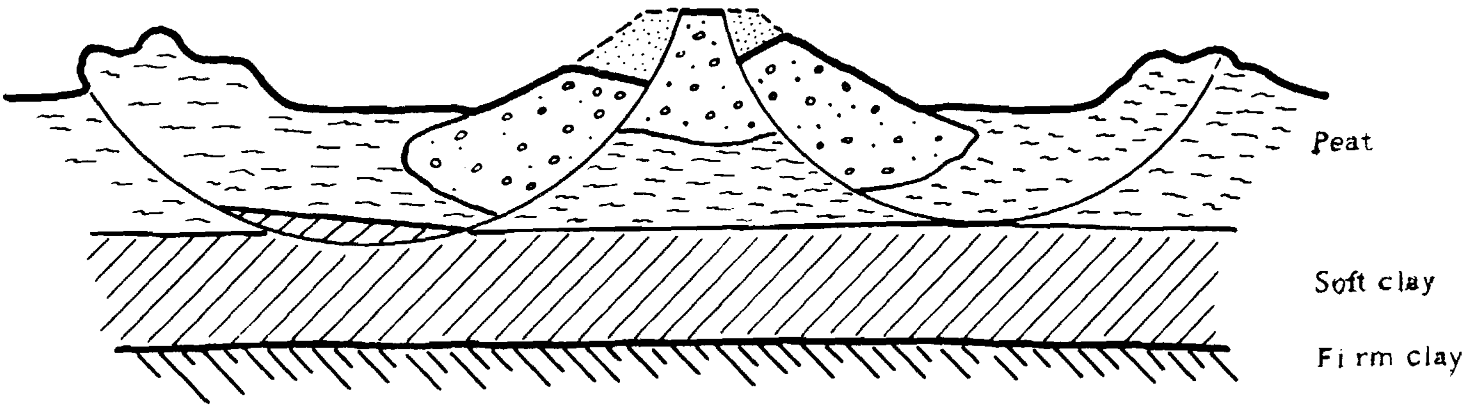


FIGURE 3

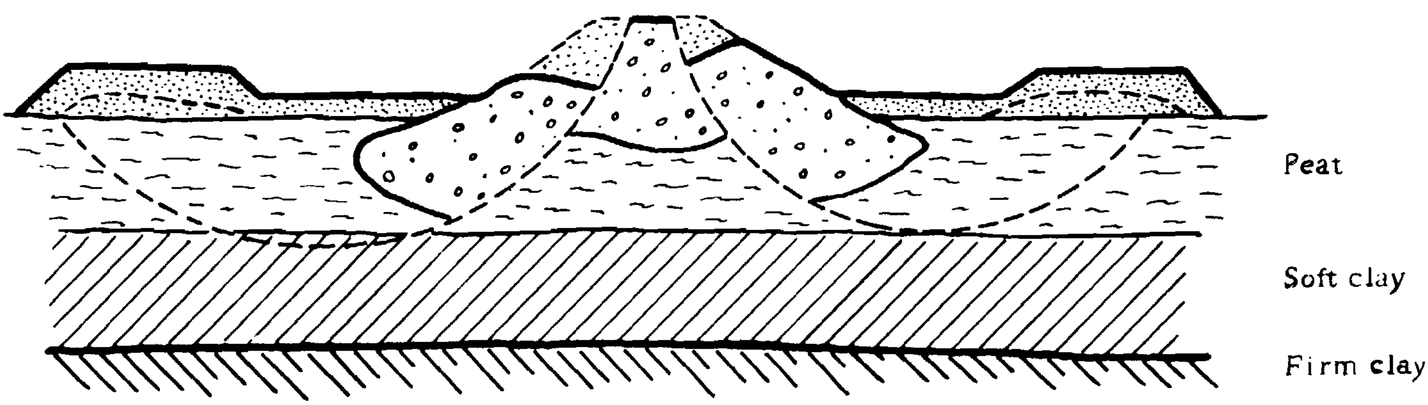


FIGURE 4

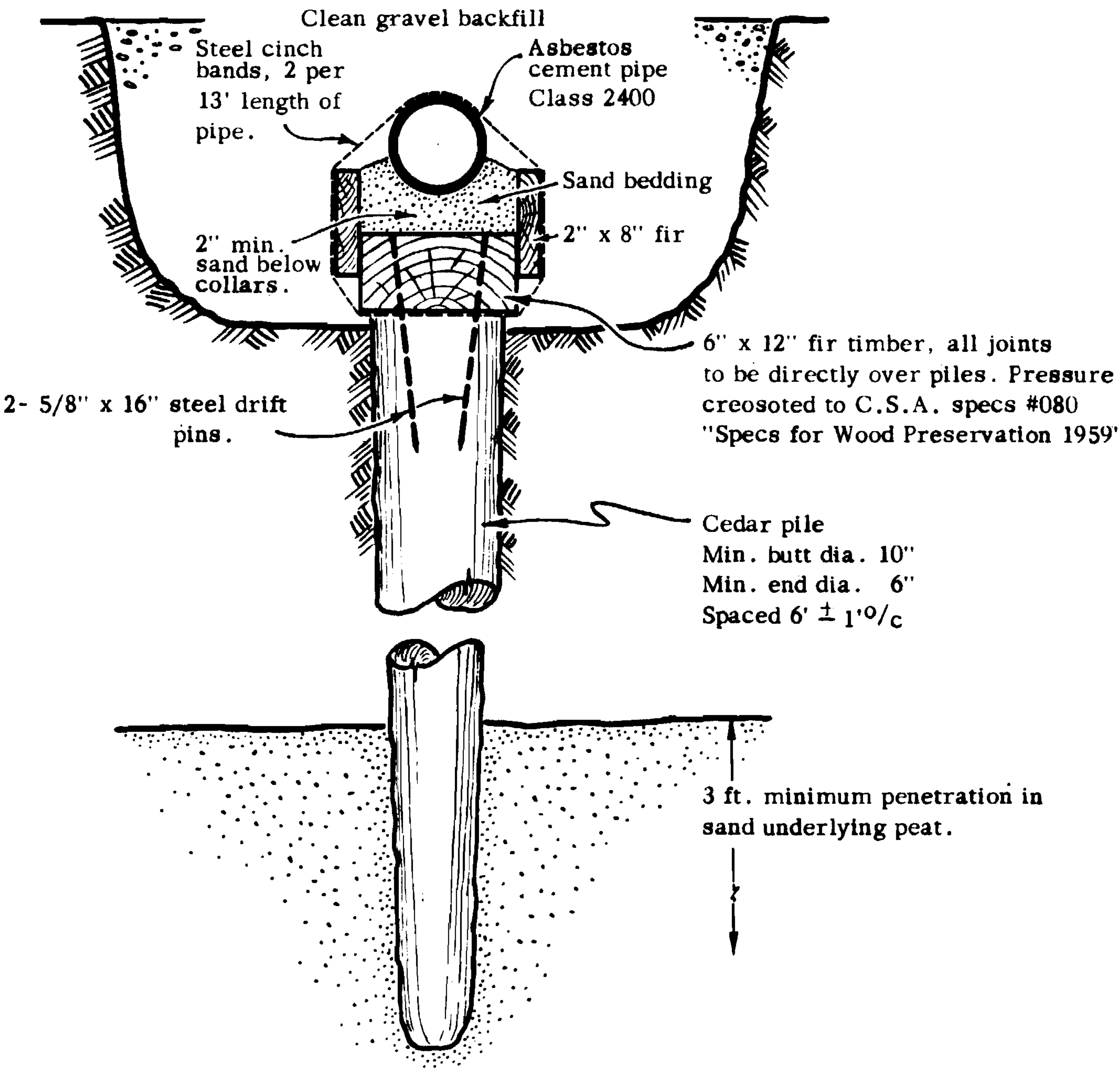
Clean gravel backfill
Steel cinch bands, 2 per 13' length of pipe.
Asbestos cement pipe Class 2400
Sand bedding
2" x 8" fir
2" min. sand below collars.
6" x 12" fir timber, all joints to be directly over piles. Pressure creosoted to C.S.A. specs #080 "Specs for Wood Preservation 1959"
2- 5/8" x 16" steel drift pins.
Cedar pile
Min. butt dia. 10"
Min. end dia. 6"
Spaced 6' ± 1'o/c
3 ft. minimum penetration in sand underlying peat.

FIGURE 5

## II. 3. THE EFFECTIVENESS OF VEHICLES IN MUSKEG

D. Campbell

(Manuscript not available for publication)

Discussion

Dean Hardy observed that the contact pressure was said to be 16 psi and asked over what area was this effective. Mr. Campbell said that 6 inches of tire penetration gives 4 psi. He pointed out that the tires are not of a special type, and are resistant to any obstruction. If they give too much, the walls will be destroyed.

Mr. Hemstock stated that the developmental problems on wheeled vehicles in muskeg are similar to the developments for vehicles in the desert. A Mr. Kerr, now with the USA Government, wrote a book on tires for desert use which is considered to be the "Bible" for tire users. Many of the same problems he covered are now being discussed. Mr. Kerr found that the tire pressure should be as high as possible to get through the area under consideration. The idea is to reduce the tire pressure in a difficult situation, then pump it up again later.

Mr. Schlosser wondered if the operations are in only one type of muskeg, to which Mr. Campbell replied that they are in all types. Mr. Schlosser asked if all these could be negotiated with the machine described. Mr. Campbell pointed out that these vehicles have not actually been used as yet in the spraying programme; the information given in his paper refers only to the trials at Parry Sound, Ontario. Mr. Schlosser wondered further if any tests were performed while the frost was still in the ground, so that advantage could be taken of the ice. Mr. Campbell said that at the time of the tests in Parry Sound last November, there was some frost in the ground but it was more of a deterrent than an advantage. Dr. Radforth commented that in November two or three sites had frozen up and there was some strengthening of the mat. In later tests there was ice in the knolls, so there has been some limited experience with the ice factor and this vehicle. The FI area was particularly difficult and the loaded vehicle could complete only one pass.

Mr. Stoneman noted that Mr. Campbell's experience with tracked vehicles had included high maintenance costs. He wondered just where these costs were concentrated. Mr. Campbell replied that 50% of the cost was in the undercarriage in both makes of machine used. Mr. Schlosser asked if they were single or articulated vehicles. Mr. Campbell said that apart from one articulated machine, they were all single vehicles. Mr. Schlosser enquired further if Mr. Campbell did not achieve better experience with the articulated machine. Mr. Campbell did not believe that there was any difference at all in machine experience - any improvement in experience he felt to be strictly an operator factor. Mr. Schlosser questioned Mr. Campbell on the use of the smaller articulated vehicles but he said that he was really not too familiar with these vehicles.

## II.4. RECHERCHE SUR LA MOBILITE DE VEHICULES A GRANDE MOBILITE

J. S. Watson

Résumé:

Une équipe de l'Université McMaster connu sous le nom de "Organic and Associated Terrain Research Unit of McMaster University" a effectué sur Muskeg et terrain de même genre, près de Parry Sound en Ontario, une évaluation comparative de deux véhicules à petites roues. Le véhicule "A" pèse 240 livres et peut transporté un poids utile de 300 livres dans de très mauvais endroits. Il est actionné par six roues motrices ou par chenilles superposées sur ses roues. Le véhicule "B" pèse 700 livres et transporté un poids utile maximum de 520 livres. Huit roues de chaque coté forment à dessein une voie roulante; de toutes façons 3 roues de chaque coté sont constamment par terre. Cette communication est un résumé du rapport de rendement sur ces deux véhicules et inclus des données sur la vitesse, l'accélération, le rayon de braquage et essaies de vitesse a travers champs. Les deux véhicules furent étonnement efficaces sur plusieurs genres de Muskeg.

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## II.4. MOBILITY RESEARCH ON SMALL, HIGH-MOBILITY VEHICLES

J. S. Watson

Abstract

The Organic and Associated Terrain Research Unit of McMaster University carried out a comparative evaluation of two small-wheeled vehicles in muskeg and associated terrain near Parry Sound, Ontario. Vehicle "A" is a 240-lb. vehicle which can carry a 300-lb. payload over poorest terrain conditions. It operates on six powered wheels or on tracks superimposed over the wheels. Vehicle "B" is a 700-lb. vehicle which carries a maximum 520-lb. payload. Eight wheels designed as a rolling track are located on each side of the body; three wheels per side are always in contact with the ground. A resume of the performance of these two vehicles is given in this report, and includes their speed, acceleration and turning radius on land and water as well as a cross-country speed test. Both vehicles were amazingly effective in many types of muskeg.

## II.4. MOBILITY RESEARCH ON SMALL, HIGH-MOBILITY VEHICLES

J. S. Watson

(Paper presented by Mr. T. A. Harwood)

Under contract to DND/DRB, the Organic and Associated Terrain Research Unit of McMaster University carried out a comparative evaluation of two Canadian vehicles in muskeg and associated terrain during August 1963. The vehicles are designated in this report as Vehicle "A" and Vehicle "B".

Vehicle "A" is a 240-lb. vehicle that will carry a 300-lb. maximum payload over poorest terrain conditions. It runs on six powered wheels (Figure 1) or on tracks superimposed over the wheels (Figure 2) on land or water. The vehicle has been tested under several different types of terrain and climatic conditions (e.g. tropical environment in Panama in May 1963, and in snow environment) and presumably it is in its final stage of development. The features of the vehicle are, in fact, an improved version of the models that have been purchased by OSD/ARPA for testing in Thailand.

Vehicle "B" is a 700-lb. vehicle that carries a maximum 520-lb. payload. Vehicle "B" uses basically the same concept of locomotion as the Airoll. It differs from the Airoll, however, in having a much smaller net weight, i.e., 700 lb. versus 19,100 lb. Eight wheels designed as a "rolling track" are located on each side of the fiberglas body; three wheels per side are always in contact with the ground (Figures 3 and 4). Vehicle "B", like Vehicle "A", is amphibious. Vehicle "B" was an early prototype and had not been pre-tested as rigorously as Vehicle "A" and consequently was plagued with mechanical difficulties. In switching the transmission system from another prototype of Vehicle "B", the gear system was reversed and the forward, low-high gear could be used only in reverse-drive position and the low gear in forward-drive position. Tests of the vehicle in high gear, therefore, were conducted with the vehicle going in reverse. The tires on Vehicle "B" were in very poor condition and gave considerable trouble. The development and promotion of this vehicle has been taken over by Canadair and current prototypes would not show these shortcomings.

This work was carried out in the area of Dinner Lake, north of Parry Sound, Ontario, near Highway 69. The purpose of the tests was to measure and to compare the mobility performance of Vehicles "A" and "B" in muskeg terrain. The vehicle tests consisted of: (a) evaluation of a

50-pass performance and determination of maximum speed, minimum turning radius, and acceleration in several types of muskeg; (b) checks on floatability, steerability, manoeuverability, and maximum speed in water; (c) determination of speed and check on manoeuverability over short trails in inorganic terrain; and (d) determination of speed and check on manoeuverability along a 1-1/2 mile cross-country course selected to cover a practical range of water, soil, rock, and vegetal obstacles typical of the terrain. Results of these various tests are summarized in Tables I to VIII.

Prior to initiation of testing, two drivers spent a few hours driving each of the vehicles in order to familiarize himself with its operation. Vehicle "A" performed exceptionally well on rocky terrain. Manoeuverability was excellent. In the marsh (Figure 5) between the muskeg mat and rock-land surface, Vehicle "A", without tracks, manoeuvered well but occasionally hung up on obstructions (tree stumps). When the vehicle became immobilized, the driver easily lifted it off or away from the obstruction and continued. A few minutes were required for two men to install tracks on Vehicle "A". While manoeuvering in the marsh area, the vehicle ran over a tree stump in about 2 ft. of water and flipped over, landing on its topside and submerging the driver. Although several men quickly righted the vehicle, the driver stated that he could have gotten out easily and righted the vehicle himself. No damage occurred to the vehicle or to the driver. The engine, which had been completely submerged, was dried out and running again in about 15 minutes. Vehicle "B" had some difficulty in the steering mechanism and required some adjustments (Figure 6).

TABLE I

FIFTY PASS TEST

| Vehicle | Payload Lbs. | Muskeg Type | No. of Passes Completed | Cone Penetrometer | | | |
|---|---|---|---|---|---|---|---|
| | | | | Before Test | | After Test | |
| | | | | 0-12" | 0-72" | 0-12" | 0-72" |
| A, with tracks | 370 | FI | 38 | 34 | 29 | 25 | 23 |
| B | 530 | FI | 20 | 30 | 28 | 28 | 33 |
| A, with wheels | 300 | FI & FIE | 50 | 28 | 25 | 30 | 23 |
| B | NO TEST | | | | | | |

## TABLE II

### SPEED, ACCELERATION AND TURNING RADIUS IN FEI MUSKEG

| Vehicle | Acceleration Sec/15 ft. | Acceleration Sec/50 ft. | Max. Speed Sec/100 ft. | Max. Speed MPH | Turning RAD. Feet |
|---|---|---|---|---|---|
| A, with wheels | 3.0 | 6.1 | 9.2 | 7.4 | 1 |
| B | 6.8 | 11.6 | 21.0 | 3.15 | 4 |

## TABLE III

### SPEED AND PERFORMANCE TESTS IN G MUSKEG

| Vehicle | Payload Lb. | Maximum Speed Sec/100 ft. Avg. | Maximum Speed MPH Avg. |
|---|---|---|---|
| A, with wheels | 300 | 45 | 1.52 |
| B | 530 | 70 | 0.97 |

## TABLE IV

### SPEED AND PERFORMANCE ON BFI AND FEI MUSKEG
(See Figures 7 and 8)

| Vehicle | Payload Lb. | Maximum Speed Sec/100 ft. | (Avg.) MPH |
|---|---|---|---|
| A, with wheels | 365 | 12.6 | 5.41 |
| B | 440 | 12.35 | 5.51 |

## TABLE V

### SPEED AND PERFORMANCE ON FEI AND EFI MUSKEG

| Vehicle | Payload Lb. | Maximum Speed Sec/100 ft. | (Avg.) MPH |
|---|---|---|---|
| A, with wheels | 365 | 8.1 | 8.42 |
| B | 440 | 13.6 | 5.05 |

## TABLE VI

### PERFORMANCE AND SPEED TESTS IN WATER
(See Figures 9 and 10)

| Vehicle | Payload Lb. | Maximum Speed Sec/100 ft. | (Avg.) MPH |
|---|---|---|---|
| A, with jets | 300 | 38.3 | 1.78 |
| A, without jets | 300 | 39.8 | 1.71 |
| B, high gear | 530 | 36.0 | 1.89 |
| B, low gear | 530 | 48.0 | 1.42 |

## TABLE VII

### SPEED TESTS OVER SHORT TRIALS IN INORGANIC TERRAIN

| Vehicle | Payload Lb. | Distance Ft. | Time Sec. | MPH |
|---|---|---|---|---|
| A | 300 | 600 | 48.0 | 8.88 |
| B | 530 | 600 | 56.6 | 7.23 |

REMARKS: Course selected to test vehicles over rock pavement, rock outcrops, boulders, low vertical ledges, and stretch of vegetation consisting of grass and relatively dense cover of 10 ft. high trees with trunks less than 1 inch thick.

## TABLE VIII

### CROSS-COUNTRY SPEED TEST

| Vehicle | Run | Distance Miles | Time Min. | Speed MPH | Fuel Consumption ML. | Gal. | Mile/Gal. |
|---|---|---|---|---|---|---|---|
| A | 1 | 1.5 | 35 | 2.57 | 2720 | 0.72 | 2.09 |
| | 2 | 1.5 | 41 | 2.20 | - | - | - |
| B | 1 | 1.5 | 41 | 2.2 | - | - | - |
| | 2 | 1.5 | 27 | 3.3 | - | - | - |

REMARKS: Course laid out to cross several types of muskeg, rock steps, rock slopes with maximum gradients up to 100%, boulder fields, shrub and tree areas, in water and on land, and beaver channels. Course meandered from water to land consisting of soft muskeg, bare rock, or heavy vegetation and then back to water.

Comments and Conclusions

Vehicle "A" had no difficulty crossing an area in FIE-type muskeg whereas two M29C tracked vehicles (Weasels, used as support vehicles) dropped into a hole in the mat and were immobilized. The Weasels were also immobilized in a few other localities during testing. Vehicle "B", had it been operative at that time, probably also could have crossed the area.

Pressure cells were installed at depths of 3, 6, 12, 18, and 24 in. in the FI-type muskeg test lanes, and measurements were taken during the first few passes of the vehicles. The gauge indicated disturbance to depths of at least 24 in. Negative pressures were recorded in front of the approaching vehicle and after the vehicle passed the cell.

The driver of Vehicle "A" had to constantly shift his weight in rugged terrain in order to negotiate a given obstacle properly. Occasionally, he had to jump out of the vehicle and steer it from outside the cab when negotiating a particularly steep grade or when, in a given difficult situation, the vehicle could possibly have overturned and threatened his safety. The driver was jostled about the vehicle in negotiating rugged terrain; however, the vibration and impact on sudden stops, in large part, were absorbed by the tires (no suspension system) and affected him less noticeably than those for many other vehicles tested in this terrain. Vehicle "B" was not tested sufficiently to provide reliable information on driver safety and comfort. Preliminary tests indicate vehicle vibration and driver jostling were comparable to or of slightly less magnitude than those of Vehicle "A".

Vehicle "A" was observed to be very manoeuverable and comfortable riding on highways. It has a maximum speed of 16 mph. The owner intends increasing its maximum speed to 27 mph.

In non-scheduled tests, Vehicle "A", with the driver in most cases manoeuvering the vehicle from outside the cab, (a) bulldozed a path through a dense cover of small trees (with trunks less than 1 ft. thick and about 10 ft. high), vines, and shrubs, and (b) descended and ascended a road embankment rock talus slope of about 100 percent.

Throughout the testing, the accelerator on Vehicle "A" was oversensitive. The slightest touch caused the vehicle to break away and occasionally to get out of control. The owner intends to reduce the sensitivity.

Metal flanges and hubs were used to provide high density payloads, but neither vehicle could accommodate its specified full load.

Neither had adequant provision for stowing or securing loads and, because of the need in each to distribute the load to maintain stability, the drivers' foot-space was encroached upon. Concern with shifting loads and possible injury may therefore have militated against full exploitation of the vehicles' performance capabilities.

While both owners were helpful in indicating handling methods, it was apparent that they had not previously exposed their vehicles to some of the difficulties presented by organic and associated terrain and driving techniques had to be developed as the tests proceeded. This need and control problems such as the sensitive throttle of Vehicle "A" or the occasionally maladjusted steering system of Vehicle "B" also may have limited performance.

To surmount an obstacle such as a moderately steep rock ledge, the operator of Vehicle "A" would bring it to the foot of the ledge, turn the throttle twist-grip fully forward and allow the vehicle to surge forward unaccompanied. The spring-loaded throttle then would cut the engine back to idling, bringing the vehicle to a halt a short way beyond the obstacle, and so allow the driver to negotiate the obstacle alone and resume control.

Vehicle "B", on the other hand, would be accompanied over the obstacle by the driver who was required to reach over the moving upper wheels to retain throttle control and be prepared to leap clear should the machine topple or should he not be able to keep pace with it.

The difference in success in obstacle climbing would seem to lie not in ultimate capability, but in methods of control. If each vehicle were equipped with a 10 ft. cable control to the throttle, probably their ability to surmount obstacles would be about equal.

One important conclusion from these tests is that both vehicles are able to remain mobile and move effectively in any kind of muskeg so far as bearing capacity of the terrain is concerned. In this, these vehicles are unique. For instance, both vehicles can maintain mobility on the terrain in which the M29C tracked vehicle bogged down. The Water Buffalo vehicle, which can negotiate all categories of muskeg, must do so in the last analysis with the aid of power applied to an anchored cable. Vehicles built on the principles employed in the ones tested will be useful therefore anywhere in Canada where muskeg occurs, provided other aspects of organic terrain such as surface obstruction or microtopography, or inherent mechanical design characteristics of the vehicles do not limit the operation. It is worth emphasizing that these two vehicles are the first to give this kind of result, and show great promise with respect to off-road activities using an operator and light payload.

Their performance on mineral terrain is equally successful, there being virtually no trafficability problems so far as practical mobility is concerned. Limitations to forward travel are similar to those applying for organic terrain.

Performance on still water including the activity of entering and leaving water is satisfactory but the low speeds attained may limit the usefulness of these vehicles in even moderate currents.

- * -

Discussion

Professor Naemi wondered how well Vehicle "B" worked in snow. Mr. Ashdown observed that the designer says it works very well in snow. Professor Naemi expressed surprise at this, for the principle of locomotion is similar to the Airoll vehicle which does not work at all well in snow. Dr. Radforth suggested that the fact that the drive mechanism is different might have some significance. Mr. Ashdown said that films he had seen of Vehicle "B" operating in snow were impressive.

Professor Naemi asked whether the "marsh screw" vehicle had been tried in muskeg. He mentioned that it also gets bogged down in snow. Dr. Radforth said that the "marsh screw" vehicle may be included in the O.A.T.R.U. field programme this summer (1964).

Figure 1

Figure 2

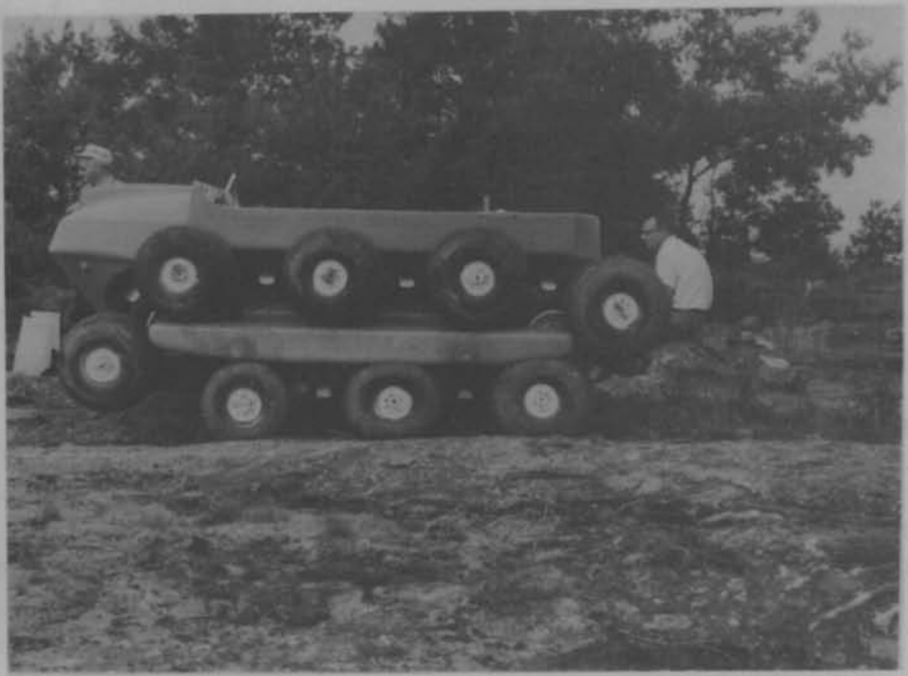

Figure 3

Figure 4

Figure 5

Figure 6

Figure 7

Figure 8

Figure 9

Figure 10

## II.5.a. EVALUATION DES TOURBIERES POUR LA PRODUCTION DE LA TOURBE

T. E. Tibbetts

Résumé:

Le Canada est un des premiers pays au monde pour l'étendue des tourbières, qui couvrent une superficie de plus de 37,000 milles carrés. Il n'est dépassé que par l'U.R.S.S. et la Finlande. L'abondance d'autres combustibles au Canada empêche l'usage du combustible provenant de la terre noire, du moins pour le moment. Cette présentation décrit comment le Département des Mines du Ministère des Mines et des Relevés Techniques tente d'évaluer le potentiel nécessaire au développement commercial des dépôts de terre noire connus en termes de la production de la tourbe, un produit qui est utilisé considérablement en Amérique du Nord pour fins d'agriculture et d'horticulture. Dans cette évaluation, l'étude des cartes et des photos aériennes,les essais sur le terrain et les analyses en laboratoire sont menés en considérant les importants facteurs comprenant la qualité et la nature de la tourbe telles que déterminées par les méthodes analytiques, l'accès, l'emplacement, la topographie, le drainage, la superficie, le type de couverture et l'épaisseur de la tourbière.

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## II.5.a. EVALUATION OF PEAT BOGS FOR PEAT MOSS PRODUCTION

T. E. Tibbetts

Abstract

Canada is one of the leading countries of the world in reserves of peat lands which are estimated to cover more than 37,000 square miles, this being exceeded only by the U. S. S. R. and Finland. The abundance of other fuels in Canada precludes the use of peat fuel, at least at present. This paper describes how the Mines Branch of the Department of Mines and Technical Surveys attempts to assess the potential for commercial development of known peat deposits in terms of production of peat moss, a product which is extensively used in North America for agricultural and horticultural purposes. In this evaluation, study of maps and aerial photographs, field investigations and laboratory analyses are conducted to consider the most important factors including quality and nature of moss as determined by analytical methods, accessibility, location, topography, drainage, area, type of overgrowth, and depth of bog.

## II.5.a. EVALUATION OF PEAT BOGS FOR PEAT MOSS PRODUCTION

T. E. Tibbetts

It has been estimated that peatbogs cover in excess of 37,000 square miles (100,000 square kilometers) of Canada with a large proportion of that area in Central Canada. Peat represents the only major hydrocarbon fuel resource of Ontario and Quebec; these provinces, being far removed from the Canadian coalfields, were once largely dependent upon foreign sources, mainly the United States, for their fuel supply. Lack of precise knowledge of the coal reserves of the United States and the natural desire to render the central provinces "less dependent on a foreign source for a fuel supply" prompted the Mines Branch, some fifty years ago, to undertake investigations to determine the feasibility of developing some of the peat deposits in Central Canada as a source of fuel. Following "the serious fuel shortage with which Canada was confronted in 1917", interest in this project became keen and a Joint Peat Committee was appointed by the Federal and Ontario Governments to further the investigations (Haanel 1924, 1926).

The proving of large coal reserves in the United States close to the industrial heart of Central Canada, and the development of other fuel resources in Canada, combined to spell economic failure for the immediate exploitation of our peat fuel deposits. The finding of new uses for peat has reawakened industry and resource evaluation agencies of governments to a new realization of the potential economic value of peat lands.

In Canada and other countries over the years uses of peat other than for fuel has been developed, such as (1) a source of chemicals, (2) special use in refining of metals (magnesium), (3) in the building industry (board and insulation), (4) for packing purposes, (5) for medicinal purposes, and (6) for horticultural and agricultural purposes. It is the growing awareness of the benefits derived from the use of the relatively unhumified material from peat lands - peat moss - for agricultural and horticultural purposes, which has brought about economically successful exploitation of peat bogs in Canada.

Peat moss is a nonreplaceable resource, as distinguished from perennial plant crops, and therefore falls within the areas of investigation encompassed by the Mines Branch; these investigations are made through the Fuels and Mining Practice Division because of its association with the earlier studies of peat fuels.

The objectives of the division with respect to peat are (1) to evaluate the peat deposits in Canada with reference to peat moss, (2) to aid industry technically in determining the best means of exploiting the peat resources, (3) to assist industry in solving problems associated with marketing, and (4) to investigate additional uses of peat moss and other peat materials.

A method used by the division to realize the first objective is the main subject of this paper and is described following a brief outline of the expansion of our peat moss industry in the past two decades.

## Growth and Evaluation of the Peat Moss Industry

The tonnage of peat moss produced in Canada has multiplied more than fifteen times in the past twenty years with a corresponding rise in value. Production has tripled in the past decade and the gross value of products, including containers, is now more than 10 million dollars annually. More than 80 per cent of the production is exported, mainly to the United States. About 98 per cent of the production is for horticultural purposes.

Figure 1 illustrates the growth of production and trade of peat moss during the period 1952-62. The pie diagrams of Figure 2 show the uses for which peat moss has been produced from 1945-62.

## Method of Selecting Peat Bogs for Examination

Air photos, obtained from the National Air Photographic Library and from provincial governments, and topographical maps, obtained from the Surveys and Mapping Branch, Department of Mines and Technical Surveys, of recorded bogs, are examined.

Areas of organic terrain exhibit features on air photographs which permit of easy identification, namely:

(1) They usually occur in local depressions.
(2) They are usually characterized by dense forest growth with local open areas.
(3) Open bog areas which could contain peat are usually rimmed by a thick shrub growth and alder and poplar stands succeeded towards the open area by spruce trees.
(4) If no spruce trees are present, either thick, low bush grows between the deciduous trees and the open area, or a mixture of all three growth types, is present.
(5) Organic terrain is distinguished from mineral soil, on the air photograph, by the type of cover, texture or grain.
(6) If a bog is too shallow to be of interest for peat moss production, this fact can sometimes be distinguished on air photographs by the gradual merging of shading and textural contrast

between the organic and mineral soils. Cultivation seldom enters the area of heavy growth rimming a deep bog.

In this way, and with the help of the stereoscope and topographical maps the size, accessibility, density of growth, topography, and drainage pattern can be determined. In some instances it is possible to distinguish bogs that are too shallow to be of interest. The selection of bogs for field examination is made from the above information on the basis of surface growth, drainage and area. Below are some of the considerations:

Surface Growth: Other things being equal, the fewer the trees that grow in a bog the lower will be the cost of preparation. Particular attention is paid to those bogs that are essentially free of trees.

Drainage: The cost of drainage is an important factor in bog development. Topographic maps are examined to determine the feasibility of drainage. Bogs adjacent to lakes and rivers represent a prohibitive development cost if they are at the same elevation as the adjacent water.

Area: The bog area required depends on the depth of the moss and on the scale of production anticipated. To be commercially attractive on other than a part-time basis, a supply to support a production in the order of 150,000 six cu ft bales per year should be considered. Assuming a minimum depth of five feet (1.52 meters) and a settling of two feet (0.61 meters) due to drainage, one acre contains 130,680 cu ft (3700 cu meters). Assuming a volume of 150 cu ft (4.2 cu meters) per ton for air-dried peat, there are present 871 tons per acre. This is equivalent to 21,780 bales, or sufficient to supply production for 0.14 years. Based on the above estimates, 75 to 100 acres of open bog are taken as minimum prerequisite area.

## Field and Laboratory Evaluation

If, from the examination of air photos and topographical maps, it appears that a peat bog may meet the requirements of area, cover, drainage, depth, etc., for feasible development, field and laboratory investigations are made. This consists of a preliminary survey to gain familiarity with the area and to verify information gained from air photos and maps, followed by sampling and analysis.

## Sampling

The general procedure that is followed in establishing sampling areas of a bog is to select three locations forming the apices of a triangle; the distances between them being 1000 to 1500 feet (305 to 457 meters). The pace-and-compass method is used for locating the points, and these are connected by reference to topography on aerial photographs. If the results warrant, additional sample areas are selected. The sample areas are then plotted on aerial photographs at the scales indicated.

A thick-walled, piston-type sampling instrument (see sketch, Figure 3) is used to collect samples at the selected sampling areas. This instrument consists of a sample chamber, about 3/4 inch (1.91 cm) in diameter and 15 inches (38.1 cm) long, and a piston, one end of which is tapered to allow easy movement through the bog material. The overall length, including the detachable rod handle, is five feet (1.52 meters). In sampling, when the desired depth is reached, the piston is drawn into the sample chamber by pulling upward on the handle. This upward motion is arrested automatically by a locking device. The open sample chamber is then pushed downward, forcing material from the bog into the chamber and thereby allowing recovery of a sample core. Extension rods are attached to the handle of the instrument to recover samples beyond a depth of 5 feet (1.52 meters). These rods can be marked off at one-foot intervals in order to measure intermediate depths. Many deposits yield strata of well-humified peat underlying a heavy growth of sphagnum moss; it is therefore important to sample at regular intervals in depth in order to obtain a true conception of the structure of a bog and the quality of its different strata and their thicknesses.

Green or only slightly humified moss does not core in the sampler; hence lack of core recovery is an indication of little or no humification. However, in locations where the sampler can not be used, the bog is sampled with a shovel or some other convenient device to a depth of 2-1/2 feet (0.76 meters). In other areas, a post-hole auger can be used to obtain samples to a depth of 5 feet (1.52 meters) or more.

In the field, the samples collected are examined and certain physical characteristics are briefly noted. Particular attention is given to the colour and texture to give an indication of the degree of humification. The latter is, within wide limits, further indicated by a simple test described by Rigg (1959). In this test a quantity of peat material is pressed in the hand and observation is made of what comes out between the fingers and what remains in the hand. If nothing but clear water comes out, humification has not begun. If all of the material comes out and nothing is left in the hand, humification is almost complete. There are stages between the extremes, indicated by such words as slightly, somewhat or moderately humified. The fibrous unhumified stage is termed peat moss, and the final stage is noted as peat fuel.

Consecutive samples of similar material are grouped as one. Each sample is identified in regard to location and depth.

Loss of moisture in samples between the field and laboratory is minimized by using readily sealable plastic bags.

A sample of about 500 grams of raw peat is desirable for testing purposes.

Analysis

Our qualitative evaluation of peat moss is carried out with the use of the material in mind - for agricultural and horticultural purposes.

Benefits from the use of peat moss in agriculture - for litter purposes generally - are derived mainly from the absorptive capacity. The ability of peat moss to absorb moisture is also of prime importance in evaluating the material for use in horticulture. It is unfortunate that no standardized method presently exists for measuring this most important property of peat moss as such a method could eliminate much confusion in the trade and enable comparison of the product internationally.

Colour, density and texture of peat moss are considered in view of the relationship of these physical characteristics to the degree of humification - a very important factor in evaluating peat moss for use as a soil conditioner. A reliable test to directly measure the degree of humification is being sought by the Mines Branch in order to better chracterize peat moss in this regard.

The acidity of our peat moss varies from about pH 3.5 to pH 6 and this factor to a considerable extent governs its use as an additive to the soil. An accurate determination of the degree of acidity is therefore considered very important in a qualitative evaluation of peat moss.

It is a well known fact that peat contains a large percentage of organic matter. The presence of large quantities of mineral matter in peat moss, in addition to reducing the proportion of desired organic matter, increases the weight of the product out of proportion to the accepted weight/volume ratio thus unfavourably affecting transportation costs.

Although in general a determination of the nitrogen content is part of our analysis, it is not considered of the same importance as other values mentioned as it is realized that the nitrogen contained is largely in a form not available to plants.

Testing actually begins in the field, during sampling, with the Rigg humification test outlined earlier. Other methods of analyses conducted by the Fuels and Mining Practice Division at Ottawa are outlined below:

Moisture Content

Five to ten grams of sample (as received) are weighed to the nearest milligram in a tared, porcelain crucible and placed in a drying oven and dried at a temperature of 105°C to 110°C until constant weight is obtained; this normally requires about three hours. Before each weighing, the crucible and contents are cooled to room temperature in a desiccator. The percentage of moisture is computed based on the oven-dry weight.

Mineral Matter (Ash) and Organic Matter

In determining the mineral matter in peat, the dried sample and the crucible from the moisture determination are used. The weighed crucible and the peat material are placed in a standard muffle furnace, which is at room temperature. The furnace is then heated to a temperature of 750°C and this temperature is maintained until a constant weight of the residue is obtained. The crucible and residue are cooled in a desiccator and weighed. The weight of the residue is recorded and calculated as the percentage of dried peat. Organic matter is determined by difference (100 per cent minus mineral matter).

Absorptive Value

For this determination peat in the raw state should not be subjected to partial preliminary drying, because dried or partly dried peat or muck may not re-absorb water to its original absorbing capacity. In the analysis 30 grams of as received peat material are placed in a beaker of 2 litre capacity and 1 litre of boiling water is poured over it. The mixture is then stirred several times until it is noted that all material will sink to the bottom of the beaker when stirring ceases. The peat is allowed to soak for at least 6 hours, then the water is decanted off and the material remaining in the beaker is transferred to a mortar and mashed with a pestle. The decanted water is then added to the mash and stirred to dissipate any lumps. The contents of the mortar are then poured into a tared, cube-shaped, copper-wire basket having a mesh of from 2 to 1 millimetre, and a content of 1 litre. If it is obvious that peat substance has passed through the basket mesh with the water, screening is repeated. No notice is taken if the filtrate is muddied and still contains some small particles of peat. The basket is then inclined at an angle of 45 degrees with one corner turned downward and is kept in this position until less than one drop of water a minute passes from the basket. The basket with contents is then rotated 180° and again allowed to drain until less than one drop of water a minute passes from the basket. The basket and contents are then weighed, standing in an evaporating basin. The basket, peat and basin are dried at 105°C until a constant weight is obtained. When the weight of the empty basket and basin are known, the absorptive value is computed for absolutely dry peat and for peat of 25 per cent moisture.

Acidity

In preparing the solution for this determination, distilled water and the sample are mixed in a ratio of 4:1, respectively, by weight. The peat material is permitted to soak for a minimum of 30 minutes at room temperature (20°C to 30°C). The hydrogen ion concentration of the solution is then determined by use of a pH meter.

Nitrogen

This determination is made by the Kjeldahl-Gunning method. One gram of sample is boiled with 30 ml of 1.84 specific gravity sulphuric acid, 7 to 10 grams of potassium sulphate and 0. 6 to 0. 8 grams of metallic mercury in a 500-ml Kjeldahl flask until all particles are oxidized and the solution is nearly colourless. Boiling is continued for two hours after the colourless stage is reached.

The solution is then cooled and diluted with 200 ml of cold water and the following reagents are added: 25 ml of potassium sulphide (40 grams of potassium sulphide per litre), to precipitate the mercury; 1 to 2 grams of granular zinc, to prevent bumping; and, finally, sufficient strong sodium hydroxide solution to make the whole solution distinctly alkaline (usually 80 to 100 ml). The flask is inclined and the sodium hydroxide is slowly added. The flask is immediately attached to a condensing apparatus and the solution is agitated by gently shaking the flask. The ammonia is distilled over into 10 ml of standard sulphuric acid solution. The solution is distilled slowly until 150 to 200 ml of distillate have passed over. The distillate is then titrated, using methyl orange indicator, with standard sodium hydroxide solution. The percentage of nitrogen in the sample is then calculated using a standard formula.

## Demonstration of Methods of Evaluation

A recent study was made of fourteen peat bogs in the southern part of the province of Ontario (Graham and Tibbetts, 1961) using the methods outlined above. A map (Plate I) and an air photo (Plate II) of one of these bogs are given in this paper to demonstrate how these aids are used in evaluation work of this nature. The significant information gained from examination of air photos with the aid of a stereoscope, topographical maps and field and laboratory studies is demonstrated by duplication of the actual report data on one of the peat bogs studied during the survey mentioned above.

The main area of the bog is outlined on the accompanying topographical map which shows the location of the bog in relation to such important factors as access highways, railways, potential labour, elevation and possible means of drainage, source of electric power and modern communications.

The air photo provides information within wide limits on the depth of the bog at various locations and the height of overgrowth, and also enables outlining of the open area of the bog. Sampling locations are based on information gained from the examination of the air photo with particular attention being given to shading and textural contrast.

## Newington Bog

### Location

The Newington Bog is mainly in Concession 1, Roxborough township, Stormont County. It extends east from the west boundary of the township for 5.4 miles (8.7 kilometers) and west into Osnabruck township for 0.4 mile (0.6 kilometer). It has an average width of 1/2 mile (0.8 kilometer). A lobe at the east end extends a short distance into Cornwall township.

### Access

The bog is easily accessible by roads along the north side, across the central part, and along the south side at the east and west extremities.

Avonmore, on the Canadian Pacific Railway, lies 2 miles (3.2 kilometers) by road to the north.

### Area

The Newington Bog encompasses an area of some 4,400 acres. Guided by Nystrom and Anrep's (1909) description, the open western portion of 283 acres was examined. This portion was described as containing the least humified material.

### Topography and Drainage

The Newington Bog lies along the height of land separating drainage to the south into the St. Lawrence and to the north into the Ottawa River.

With reference to the portion of the bog investigated, the gradient is steepest to the north. Ditching is most feasible from the north-west end and would require a length of approximately 1-1/4 miles (2.0 kilometers). Most of this would be deepening a pre-existing ditch, and drainage could be attained to a depth of 20 feet (6.6 meters).

Approximately 3,500 feet (1067 meters) of ditching would be required to drain the swamp south into a creek flowing into Palen Creek. This would provide drainage to a depth of perhaps 5 feet (1.52 meters) and would facilitate early development. Since the Newington Bog is wet, considerable drainage would be required.

Cover

The bog is rimmed by a heavy growth of deciduous trees, succeeded by spruce adjacent to the open area proper. Extending east from the open area, the central portion supports a thick growth of small spruce.

That part of the bog examined is covered by a high proportion of sphagnum moss supporting a heavy growth of labrador tea with a few pitcher plants and some eriophorum.

Depth of Bog

The bog was not tested below a depth of 22 feet* (6.71 meters). Nystrom and Anrep's results indicate the depth in this area to be 20 to 26 feet (6.10 to 7.92 meters).

Nature of Peat

Nine areas were sampled, along a length of 4,500 feet (1372 meters) and across a width of 1,500 feet (457 meters).

Unhumified to slightly humified material is present in these areas to the bottom of the sampled section, which varied from 12 to 22 feet (3.66 to 6.71 meters). The top 10 to 14 feet (3.05 to 4.27 meters) consist of unhumified moss. In the case of Areas 1, 6 and 9, the top 6 to 12 feet (1.83 to 3.66 meters) of moss would not core in the sampler, a sign of unhumified material. The remaining material is slightly humified. Water squeezed from the wet moss came out clear and the hands were left clean.

The moss is mainly sphagnum, with minor eriophorum and carex.

A 5-foot (1.52 meters) sample was taken in the vicinity of Sample Area 1, with a post-hole auger, to determine whether there were any important variations in this upper portion.

Water absorption was high and ash content low for each 0.5-foot (0.15 meter) sample. The moss dried to a tough elastic matt of medium brown colour. Some layers up to 3 to 4 inches containing some carex and/or eriophorum are present in the top 2 to 3 feet (0.61 to 0.91 meter) but in insufficient quantities to adversely affect the quality of the moss.

Sample columns for the different areas tested are as follows:

Sample from Post-Hole Auger

| Depth | |
|---|---|
| 0 to 2 feet (0 to 0.61 meter) | Light brown, unhumified sphagnum with minor reeds and fine root-filaments, the latter concentrated between 0.3 and 0.5 feet (9.1 and 15.2 centimeters). |

* The depth of Area 2 where bottom was not reached.

| | |
|---|---|
| 2 to 4.5 feet (0.61 to 1.37 meters) | A little darker in colour, slightly humified, fewer reeds and sparse fine roots. |
| 4.5 to 5 feet (1.37 to 1.52 meters) | Light brown sphagnum, some reeds. |

Samples Collected by Sampler

| Sample Area 1 Depth | | Sample Area 2 Depth | | Sample Area 3 Depth | |
|---|---|---|---|---|---|
| 0 to 10 feet (0 to 3.05 meters) | No recovery | 0 to 12 feet (0 to 3.66 meters) | Relatively unhumified sphagnum moss | 0 to 12 feet (0 to 3.66 meters) | Relatively unhumified sphagnum |
| 10 to 12 feet (3.05 to 3.66 meters) | Slightly humified sphagnum moss | 12 to 22 feet (3.66 to 6.71 meters) | Slightly humified sphagnum moss in a divided oozy state, some larger remnants | 12 to 14 feet (3.66 to 4.27 meters) | Slightly more humified |

| Sample Area 4 Depth | | Sample Area 5 Depth | | Sample Area 6 Depth | |
|---|---|---|---|---|---|
| 0 to 9 feet (0 to 2.74 meters) | Relatively unhumified sphagnum | 0 to 10 feet (0 to 3.05 meters) | Relatively unhumified sphagnum | 0 to 6 feet (0 to 1.83 meters) | No recovery |
| 9 to 12 feet (2.74 to 3.66 meters) | Slightly more humified, slimy | 10 to 14 feet (3.05 to 4.27 meters) | Slightly more humified | 6 to 14 feet (1.83 to 4.27 meters) | Relatively unhumified sphagnum |
| | | | | 14 to 18 feet (4.27 to 5.49 meters) | Oozy material |

| Sample Area 7 Depth | | Sample Area 8 Depth | | Sample Area 9 Depth | |
|---|---|---|---|---|---|
| 0 to 14 feet (0 to 4.27 meters) | Relatively unhumified sphagnum | 0 to 14 feet (0 to 4.27 meters) | Relatively unhumified sphagnum | 0 to 12 feet (0 to 3.66 meters) | No recovery |

The results of laboratory tests are as follows:

| Sample Area | Depth Feet | Depth Meters | Absorptive Value at 25% Moisture (Times own weight) | Ash % Dry | Nitrogen % | pH |
|---|---|---|---|---|---|---|
| 1 (shovel sample) | 0.5 to 2 | 0.15 to 0.61 | 25.6 | 2.0 | 0 | 5-6 |
| 2 | 0.3 to 0.8 | 0.09 to 0.24 | 24.5 | 2.5 | 0.6 | 5-6 |
| | 0.8 to 2 | 0.24 to 0.61 | 27.4 | 2.5 | 1.1 | 5-6 |
| 3* | 12 to 14 | 3.66 to 4.27 | 21.4 | 3.1 | 1.2 | 5-6 |
| 4 | 0 to 9 | 0 to 2.74 | | | | |
| 5 | 0 to 10 | 0 to 3.05 | 16.2 | 3.1 | 1.1 | 5-6 |
| 6 | 6 to 14 | 1.83 to 4.27 | | | | |

* Sample air-dried before analysis.

The results of tests on the 5-foot sample taken with the post-hole digger are as follows:

| Depth Feet | Depth Meters | Absorptive Value at 25% Moisture (Times own weight) | Ash % Dry | Nitrogen % | pH |
|---|---|---|---|---|---|
| 0.5 to 1 | 0.15 to 0.30 | 31.0 | 1.5 | | |
| 1 to 1.5 | 0.30 to 0.46 | 32.3 | 1.9 | | |
| 1.5 to 2 | 0.46 to 0.61 | 39.0 | 2.0 | Average | Average |
| 2 to 2.5 | 0.61 to 0.76 | 24.8 | 1.9 | 2.0 | 5-6 |
| 2.5 to 3 | 0.76 to 0.91 | 30.6 | 1.2 | | |
| 3 to 3.5 | 0.91 to 1.07 | 31.5 | 1.0 | | |
| 3.5 to 4 | 1.07 to 1.22 | 22.7 | 1.2 | | |
| 4 to 4.5 | 1.22 to 1.37 | 23.9 | 1.0 | | |
| 4.5 to 5 | 1.37 to 1.52 | 27.2 | 1.4 | | |

## Importance of Market Analysis

Evaluation of the potential of a peat bog for commercial development is not complete without a study of the various factors of marketing and distribution. Among the important considerations in a market analysis are the following: (1) price to consumer, (2) production costs, (3) freight costs, (4) demand, (5) dealers' requirements.

The demand for horticultural peat moss is growing as reviewed earlier in this paper and this trend is expected to continue judging from the many enquiries for sources of supply received from distributors, particularly in the United States. The main market is home gardening; this is served through garden supply companies, department stores and various other retail outlets. Up-to-date knowledge of the demand in specific areas is a necessity in view of the possible saturation of market areas favourably located to the peat bog being evaluated.

The price obtainable for peat moss is, to a degree, governed by the principles of supply and demand and is a reasonable barometer of the stability and competition present in the market area.

With the possible exception of production costs, the transportation cost for peat moss from the factory to the market area is considered the most important factor in a market analysis. It is certainly the most fluctuating factor in reference to one area from another and can well be the deciding factor in assessing the potential of a peat bog that has otherwise met all requirements for successful development. In general, in Canada peat moss is sold f.o.b. the point of delivery and the producer bears the cost of freight.

Factors bearing heavily on production costs are: capital investment for equipment, degree of mechanization, labour, and power costs. Not to be overlooked in any evaluation of a peat bog for peat moss production is the climate - a factor which has a considerable influence on production and drying methods; artificial drying of peat moss is a high cost operation.

Market requirements in terms of physical characteristics of peat moss such as colour, texture, weight, degree of humification, mineral matter, absorptive capacity, acidity, etc., enter into the problem of evaluation in that the quality demands should be correlated with the material present in the peat bog.

- * -

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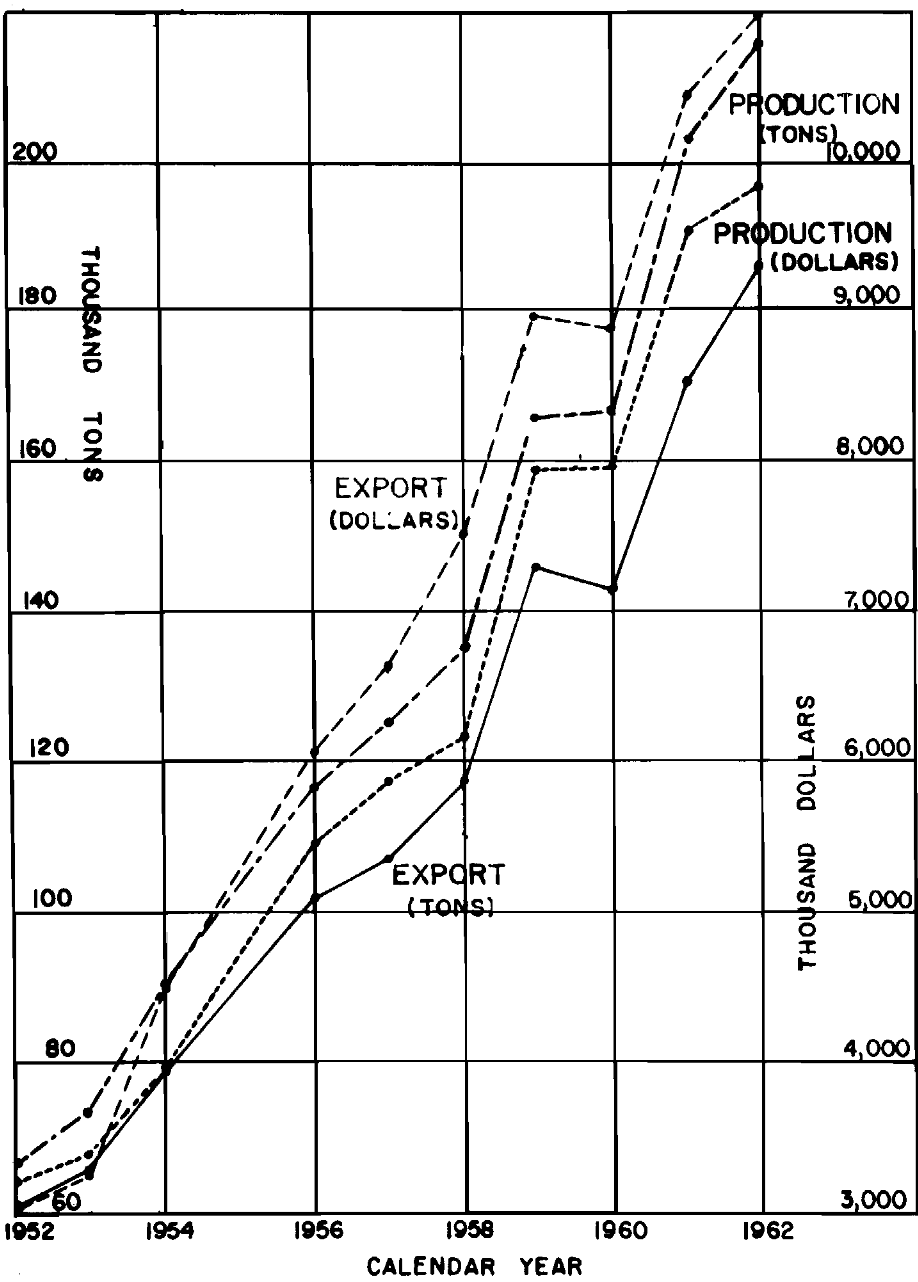
Rigg, George B. Peat Resources of Washington; Bull. No. 44, Div. Mines and Geol., Dept. Conservation, State of Washington, U.S.A. 1959.

# FIGURE 1 - GROWTH OF PEAT INDUSTRY IN CANADA, 1952-62.

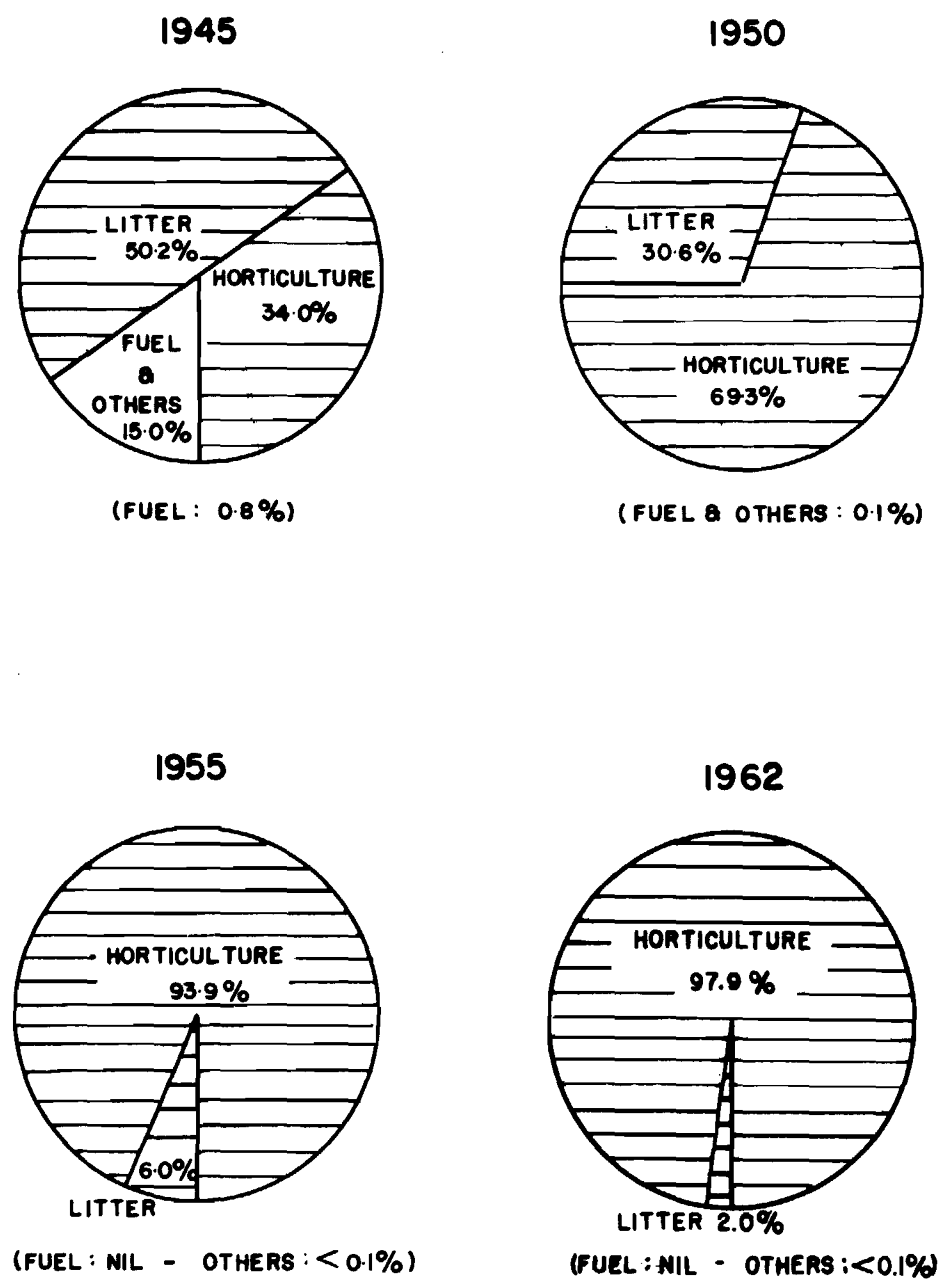



| YEAR | THOUSAND TONS* | GROSS VALUE THOUSAND DOLLARS |
|---|---|---|
| | PRODUCTION | |
| 1952 | 67.9 | 3257 |
| 1953 | 74.1 | 3432 |
| 1954 | 90.4[x] | 3966 |
| 1956 | 116.2 | 5451 |
| 1957 | 124.9 | 5899 |
| 1958 | 135.5 | 6185 |
| 1959 | 166.9 | 7909 |
| 1960 | 167.6 | 7937 |
| 1961 | 203.2 | 9551 |
| 1962 | 215.9 | 9818 |
| | EXPORTS | |
| 1952 | 61.9 | 3128 |
| 1953 | 66.7 | 3290 |
| 1954 | 79.2 | 4500 |
| 1956 | 102.8 | 6069 |
| 1957 | 106.9 | 6669 |
| 1958 | 117.1 | 7507 |
| 1959 | 146.2 | 8976 |
| 1960 | 142.9 | 8826 |
| 1961 | 170.2 | 10415 |
| 1962 | 186.1 | 10992 |

[x] Includes 584 tons of peat fuel.

* Metric Tons (2205 lbs)

FIGURE 2 - CANADIAN PRODUCTION OF PEAT AND PEAT MOSS BY USES, 1945-62



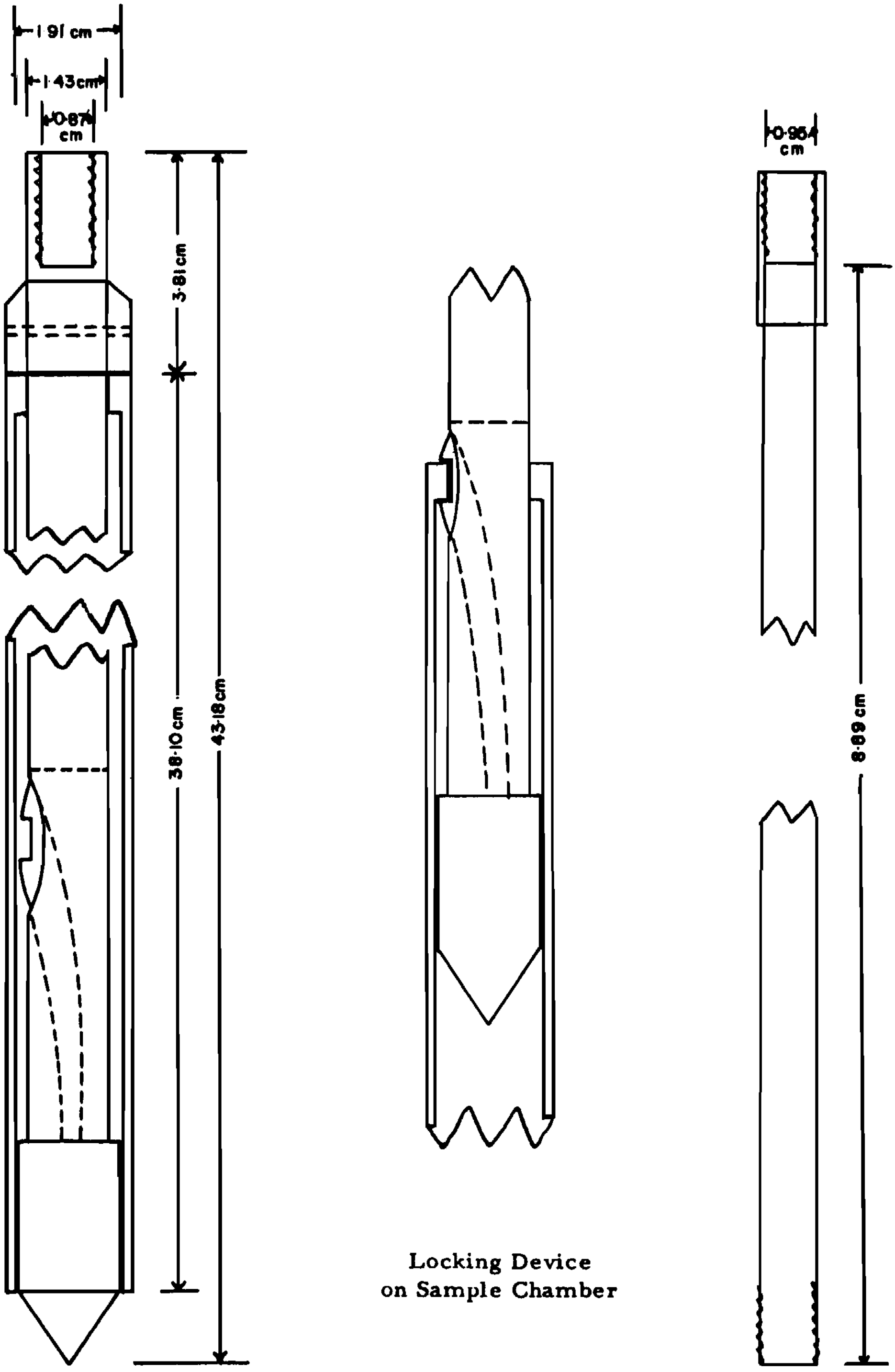
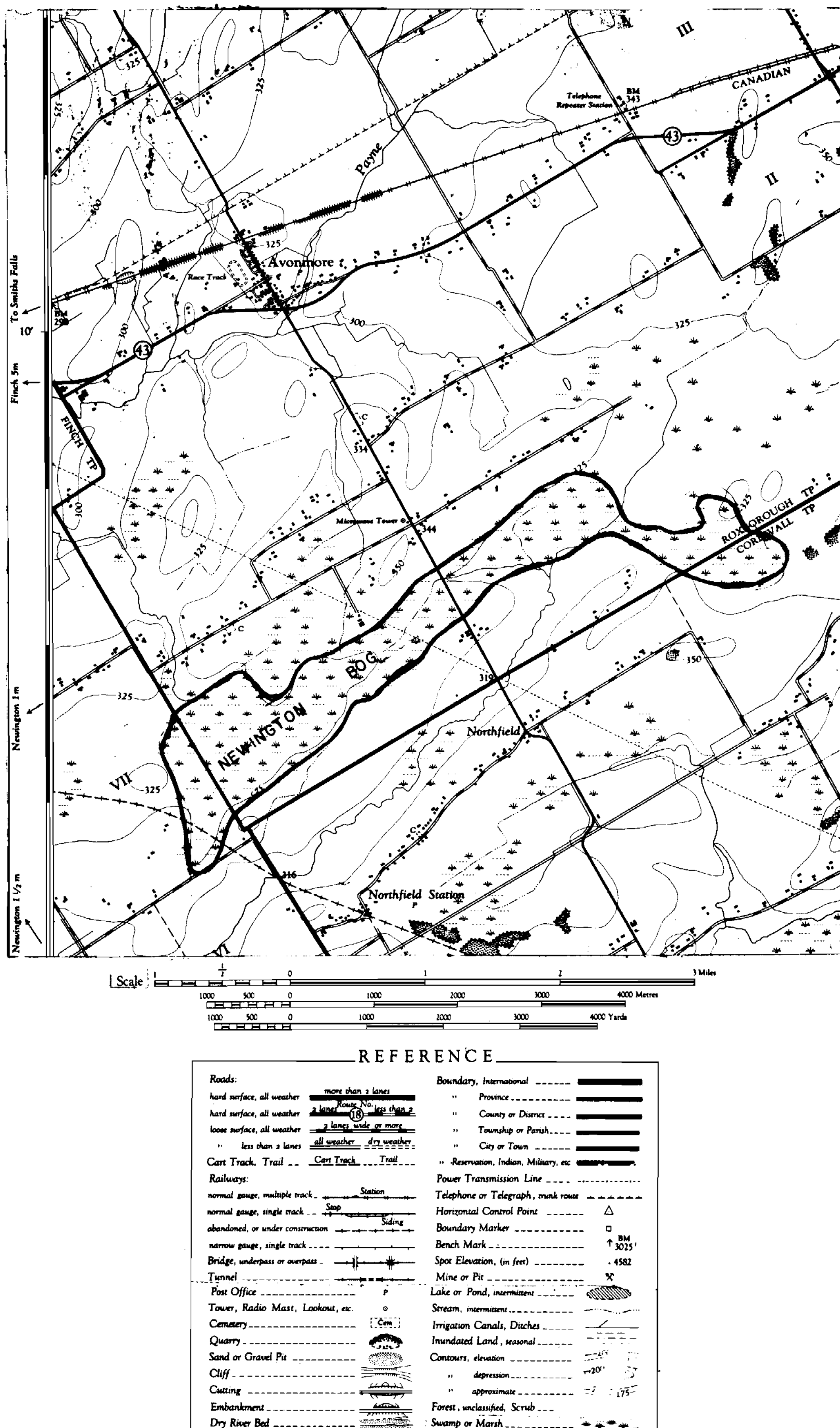



FIGURE 3 - PEAT SAMPLER, FUELS AND MINING PRACTICE DIVISION

PLATE I




TOPOGRAPHICAL MAP OF NEWINGTON BOG

PLATE II


AIR-PHOTOGRAPH OF NEWINGTON BOG

## II.5.b. EXPLOITATION D'UNE PETITE TOURBIERE

T. E. Tibbetts et R. E. Kirkpatrick

Résumé:

Ce mémoire décrit les méthodes élaborées par une compagnie canadienne pour la production et le traitement de la tourbe d'une petite tourbière. On y donne une description des diverses phases de la préparation de la tourbière, telles que le drainage, l'éclaircissement et la découverte. Les sujets de production traités sont l'aménagement de la tourbière, l'utilisation de pistes pour véhicules, l'extraction, la mise en longs tas, le chargement, le défibrage et la mise en tas. On a aussi inclus dans la description du traitement de la tourbe les techniques suivies pour le séchage et l'emballage. On fait aussi allusion aux essais d'utilisation commerciale de toutes les matières se trouvant à la surface, à l'intérieur et au-dessous de la tourbière, telles que la mousse florale, les matières à composte et la chaux de tourbière.

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## II.5.b. EXPLOITATION OF A SMALL PEAT BOG

T. E. Tibbetts and R. E. Kirkpatrick *

Abstract

Descriptions of the methods devised by a Canadian company to produce and process peat occurring in a small peat bog are outlined in this paper. The steps in bog preparation such as drainage, clearing and stripping are described. Production topics covered are bog layout, use of vehicle runways, cultivating, windrowing, loading, shredding and piling. Included in the description of the processing of the peat are the techniques followed for drying and packaging. Mention is made of the attempts to make commercial use of all materials occurring on, in, and under the bog such as floral moss, compost materials, and bog lime.

## II.5.b. EXPLOITATION OF A SMALL PEAT BOG

T. E. Tibbetts and R. E. Kirkpatrick

This paper is an attempt to outline the methods devised by R. E. Kirkpatrick, Production Manager, Grand Falls Peat Co. Ltd., Grand Falls, New Brunswick, for the commercial exploitation of a small peat bog.

The methods described for the operation have been tried and, for the most part, adopted by that company. As development of the bog progresses and larger markets are established for the production, it is anticipated that some of the present manual operations will be mechanized.

The primary purpose of the company was to devise a simple, fast and cheap method of producing peat material from a small bog. Experiments were made over a period of four years with various methods and suggested techniques that led to the methods outlined in this report. The minimum production capacity aimed for is one hundred railway carloads annually at a rate of one carload per day.

Some time was spent on the site by T. E. Tibbetts and, from the study made of the operation and from consultations with Mr. Kirkpatrick, a detailed report was prepared incorporating many suggested operational techniques. The limitations of the proceedings of this conference restrict this presentation to a summary of that report. Publication of the full report by the Mines Branch at a later date is planned.

### Location and Type of Bog

The peat bog consists mainly of humified peat moss and covers an area of about forty-five acres contained within the boundaries of two forty-acre mining claims. It is located near California Settlement, a small community about twelve miles south of the town of Grand Falls in the province of New Brunswick. A lake formerly covered about fifteen acres of the property before it was drained by a ditch that was excavated during the early stages of developing the property for the purpose of producing peat.

Figure 1(E) represents a typical section through the bog and illustrates the layers of the various types of peat material of which the bog is comprised. The average depth of peat material in the bog is about 9 feet.

### Preparation of the Bog

#### Drainage

Figure 1(A) is a sketch of the bog in section and in plan. The plan illustrates how the bog is all but divided into two separate areas (indicated by A and B) by the bed of the former lake, which, as mentioned above, was drained by an outlet ditch. This ditch was excavated initially to a depth of 20 feet at the south end of the bog tapping the lake at the bottom. It is approximately 3,000 feet to its lower discharge end. As development and working of the peat operation continues, this ditch will follow the course of the small brook that presently passes through the approximate centre of the bog and drains the upper bog area. As illustrated in Figure 1, a supplementary ditch drains the lower bog area carrying water to the main outlet ditch. This supplementary ditch, which was excavated manually, is two feet wide and six feet in depth. Where the occurrence of springs or small brooks necessitates supplementary drainage of the upper bog area, other lateral ditches will be made.

Prior to the excavation of main and supplementary lateral ditches, an area of the bog 12 to 15 feet wide was stripped of vegetation on either side of, and parallel to, the proposed ditch. This allowed piling of the peat material from the excavation on the bog without danger of contamination by surface vegetation.

It was found necessary to excavate the main or centre ditch only a short distance ahead of the working area of the bog.

The manner of working the bog, as will be shown below, supplements the drainage of the established ditches.

Clearing

After the bog was drained sufficiently for travel, areas scheduled for early production were cleared of vegetation such as trees, shrubs, alders, blueberry plants and other small bushes. Except for the small bushes that were surrounded by clumps of sphagnum moss, all of this vegetation was cut close to the bog surface. Small pulp saws and ordinary chopping axes were used to cut the trees. Small axes were used to remove the shrubs and alders and bush hooks or scythes were used to cut smaller vegetation such as blueberry bushes. The bog was raked clean of twigs, leaves, boughs, etc. after clearing to prevent these from interfering with the stripping.

Stripping

This operation pertains to the removal of the top 6 inches of the bog and includes trash, sod and sphagnum or floral moss suitable for floral use.

Trash consists of materials such as embedded wood, leaves, twigs, etc. which were not removed during the clearing operation. This is gathered and hauled off the bog and burned.

Sod consists of grass patches and partially rotted moss which is not suitable for floral purposes. It is cut to a depth of 2 to 6 inches, down to the humified peat or layer of peat moss, in 10 to 12 inch squares by means of a broad-bladed axe. This material is used to make up a compost pile.

Sphagnum or floral moss is removed by pulling upwards on the clumps of bushes which are generally found among the moss and then cutting the root systems. This allows the moss to be pulled clear of the bog in strips about 4 feet long and 12 inches wide. The strips are then extended on the surface of the bog and cut into three sections with the final cut being made near the bushes.

In the process of stripping the bog, the workers clean carefully around all stumps and finally rake the whole area clean. Removal of stumps follows the stripping of the three products described. Using a double-bit axe, the roots of the stumps are cut and usually the stumps can then be pulled clear of the bog by hand. Larger stumps can usually be removed with the aid of a peavey and prying bar, although occasionally a tractor and a chain have been required.

## Runways and Bog Lay-Out

### Runways

The runways are the means of travelling on the bog with trucks which are used to remove the stripped materials and the humified peat moss as prepared on the bog. They are constructed as illustrated in in Figure 2(C) from 1 in. x 4 in. and 1 in. x 8 in. boards, rough. They are from 8 to 16 feet long and 2 feet wide. The type of construction overcomes the problem of warping since the runways can be turned over periodically; travel is equally easy on either surface.

Figure 2(A) illustrates the manner in which the runways, designed to support a carrying load of up to 2 tons, are placed on the bog; they are parallel to one another and all are kept parallel within the various working sections of the production area.

### Lay-out of the Bog

Figures 2(A) and 2(D) illustrate the manner in which the bog is planned for production. The area to be worked is laid out in units of 100 feet frontage, each unit is divided into two sections 50 feet wide and each section is divided into four working strips, A, B, C and D, each of which is

12-1/2 feet wide. All of these strips are parallel to one another and as near as possible to 90 degrees to the perimeter of the bog and the centre-line ditch. Present working sections on this bog are 150 feet long and four sections are being worked. The peat is gathered from two sections and prepared simultaneously on two adjacent sections thus allowing a full day or more for careful preparation of the peat. Two sections of this length are sufficient to provide the desired production of one carload of peat per day.

## Production

### Handling Runways and Working the Sections

Following lay-out of the working area, referring to Figure 2(D), the wooden runways are placed and the sections worked as follows:

1. The runways are placed on B strips and peat is produced on A and C strips to a depth of 1-1/2 feet keeping the base of the last cut as regular as possible. Foreign materials such as sticks and rotten wood are piled on D strips.
2. The runways are moved to the C strips, the foreign material is loaded and hauled away and production is proceeded with on the B and D strips. Production is continued to a depth of 3 feet which, as will be shown below, is six complete working cycles of cultivating and windrowing.
3. The runways are moved back to the B strips and the production continues as in 1 and 2 above.

In working the sections the working base is kept level or slightly sloped towards the centre ditch as this aids in the drainage of the area.

### Cultivating

This term pertains to the breaking up of the peat in the bog and is accomplished by means of a small commercially available walking-type tractor with a roto-tiller attachment at the rear. The roto-tiller is 30 inches wide and breaks up the peat to a depth of 6 inches at one time. The complete cultivating unit costs about $550.00.

Thorough cultivating, which can be done by passing the cultivator through the peat about six times, results in easier loading, hauling, unloading and shredding in addition to greatly increasing the rate at which the peat dries.

Referring again to Figure 2(D), strip A is cultivated followed by cultivating on strip C. While trucks are hauling off materials from strips A and C of one section, corresponding strips in the next section are cultivated.

## Windrowing

This operation, which pertains to pushing the cultivated peat into windrows for loading, follows the cultivating and drying of peat on the bog. It is accomplished by means of a bulldozer-type blade attached to the front of the walking-type tractor as used for cultivating. The blade is attached at the required angle to push the peat to the desired position for loading. At present loading is by hand using shovels; therefore, the peat is windrowed towards the runways. When a loading conveyor is used, the windrows will be away from the runways.

Two strips can be windrowed simultaneously by moving in one direction on one strip and in the opposite direction on the second strip on either side of the runways.

## Loading, Hauling and Unloading

Forks and shovels are used to load the peat from the windrows into trucks positioned on the runways. Currently 1/2-ton pick-up trucks are being used to haul the peat from the bog to the shredder. The trucks are backed-up to either side of the shredder and, when two trucks are being unloaded simultaneously, care is taken to shovel or fork the material alternately to prevent overloading of the shredder. As the shredder ejects stones and solid pieces of roots from the rear, for safety reasons the trucks must not be positioned at the rear of the shredder.

## Shredding or Beating

Shredding or beating of the peat is performed by the working unit, consisting of the concave and beating wheel, of the old-type threshing machine formerly used on farms and still available on many farms throughout this country. It is illustrated in Figure 3. It is powered by a tractor take-off but can be equipped with a separate 8 to 10 horsepower gasoline motor.

In addition to shredding the peat, the beater separates the peat and foreign material quite efficiently by centrifugal force. Peat is thrown up to 8 feet from the front of the machine, whereas dense wood is thrown 15 to 20 feet where it is stopped by a framed canvas back-stop erected to prevent contamination of adjacent peat piles. Some dense peat and light weight wood are sometimes thrown from 7 to 10 feet from the machine and this "middlings" product is returned to the beater.

A galvanized steel sheet, 8 to 9 feet long and 3 feet wide, with a sloped wall is placed against the front of the machine to serve as a shoveling surface.

From the beater the peat is piled by hand into stockpiles in the open or in drying sheds.

## Stockpiling, Drying and Bagging

### Stockpiles

Stockpiles, in the open or in specially constructed drying sheds, are built up running east and west lengthwise in order to take advantage of the maximum sun heat for further drying the peat. These stockpiles are 21 feet wide at the base, 8 feet high and any convenient length. Each lineal foot of such piles contains approximately 5 cubic yards of peat.

### Drying

Some of the peat is hauled from the bog, shredded and stockpiled in special drying sheds that are positioned in an east-west direction lengthwise and constructed to take advantage of the maximum sun from the south side. The stockpiles in the sheds are built up similarly to those outside.

The drying shed is illustrated by Figures 4A and 4B. The most unique feature of its construction are the placing of 2 in. x 4 in. rafters flat side down rather than on edge and the wire-mesh plastic used for the south-side roof and part of the wall to permit greater drying by the sun. Creosote treated posts driven into the ground form the foundation of this building. The floors consist of 4 to 6 inches of gravel taken from the excavated material of the main outlet ditch. The north wall is left open at the top to one foot below the eave. The shed is large enough to conveniently accommodate dump-trucks.

The overall cost of construction of such a shed is about $1,200 per one hundred feet of length.

As the peat dries on the southern faces of stockpiles both in the open and in sheds it is raked or scraped down on this side to the base of the pile in layers about one inch deep. It is estimated that on an average drying day 3 inches of material can be sufficiently dried to allow it to be bagged. Drying at this rate on such piles yields 100 cubic yards, or one carload, of peat per day from a total length of 1,200 feet of stockpile. One worker can rake down one 100-cubic yard carload of peat per day, at a cost of 10 cents per cubic yard.

The degree of drying is checked by measuring the weight per cubic foot; about 20 pounds per cubic foot is considered the weight satisfactory for all markets with slightly greater weights for local delivery and for small bags.

## Bagging

With the exception of some local deliveries where the customer prefers a jute bag for the peat, all bags used are plain plastic with the only identification being provided by a tag which is placed on the bag after filling together with an instruction sheet on the use of humified peat moss.

The largest bag used has a capacity of 3 cubic feet and some distributors have advised that this size is preferable to the more or less standard 6 cubic feet size if the price per unit volume is comparable. Other bag sizes used range from 1-1/2 cubic feet capacity to 3 quarts.

The bags are filled by measuring the peat in special containers and shaking down, giving a weight and appearance similar to bales and packages of compressed peat moss.

Copper wire ties are used to secure the larger bags and plastic-covered wire ties are used for the 3 to 8 quart capacity sizes.

The large bags of peat can be piled and stored outside even over the winter months but it is advisable to store those of less than 1-1/2 cubic feet capacity inside.

It is anticipated that shipping large quantities of the small bags of peat by large van or carloads will require that the bags be packed in cartons.

All bags of peat are presently loaded by hand but the advantage of a small loading conveyor is realized.

## Preparation of By-Products

As was mentioned in the introduction of this paper, the company is endeavouring to eliminate waste as much as possible and to profitably exploit all materials removed from the bog. Use has been made of gravel from the excavation of the main outlet drainage ditch for floors for the drying sheds. Trees removed from the bog have been used for building purposes and for fuel while some have been marketed as Christmas trees. The most important by-products of the production of humified peat moss that have been prepared are floral moss, compost and mixed peat. Their preparation is illustrated in Figure 5.

### Floral Moss

The unhumified sphagnum moss from the surface of the bog is taken to a special drying shed, similar to that described above, where it is cleaned and dried for two to three days on a raised deck of 1-inch-mesh chicken wire. It is packed in cartons and sold to florists for about 16 cents a pound.

Compost

This is prepared from the sod (which consists of grass patches, leaf-mould and partially decomposed sphagnum moss unsuitable for floral purposes) and removed from the bog during the stripping operation. A pile is built up using layers of these materials and lime from the bog deposit. The compost is shredded and sold locally for use in gardens and on lawns.

Mixed Peat

The mixed peat pile consists of very wet and woody peat, highly humified peat and unhumified peat moss, which are removed from the bog during regular production but which occur in concentrations too large to permit blending with the current marketed product, humified peat moss. These materials are put down in layers on the pile in a similar manner to that used in building the compost pile. The product is sold locally after shredding.

## Costs, Selling Prices and Profits

The cost of producing and loading the humified peat moss in bulk from the bog is $1.50 per cubic yard. This includes the following individual costs: drainage ditches, $0.05; clearing, $0.05; stripping, $0.10; roads and runways, $0.05; buildings, $0.15; equipment, $0.15; salaries and overhead, $0.25; royalty, $0.20; cultivate and row, $0.25; loading, $0.25.

Additional costs for the shredded and dried product are as follows: hauling to the shredder, $0.25; piling from the shredder, $0.25; raking down the piles, $0.10; and loading, $0.40. Total cost for this product is $2.50 per cubic yard, by bulk.

The costs of sacks, bags and tags range from $2.20 to $4.00 per cubic yard depending upon the capacity of the bags. The costs of bagging range from $0.90 to $5.00. Costs of loading the bags to shipping facilities range from $0.30 to $0.90. Total costs then range from $2.50 per cubic yard by bulk to $12.00 per cubic yard for the peat in 3-quart capacity plastic bags.

Costs, selling prices, and profits from the sale of completely prepared humified peat moss in bulk and in plastic bags are tabulated below (all values are in dollars).

| Unit Size | Cost Allowed | Selling Price* to A | B | C | Per Unit | Per Cu. Yd. |
|---|---|---|---|---|---|---|
| Cubic Yard | 2.50 | 6.00 | - | - | - | 3.50 |
| 3 cu. ft. | 0.60 | 1.20 | 1.00 | 0.90 | 0.30 | 2.70 |
| 1 1/2 cu. ft. | 0.30 | 0.75 | 0.60 | 0.50 | 0.20 | 3.60 |
| 8 qt. | 0.10 | 0.40 | 0.25 | 0.20 | 0.10 | 8.00 |
| 5 qt. | 0.08 | 0.30 | 0.20 | 0.16 | 0.08 | 9.60 |
| 3 qt. | 0.06 | 0.25 | 0.16 | 0.13 | 0.07 | 14.00 |

*A refers to local sales, B to local dealers, and C to distributors.

The selling prices to distributors are lower than to dealers and to local customers; therefore, the profits indicated are minimum.

Peat moss loaded to the buyer from the bog costs $1.50 to produce and is sold for as much as $4.50 per cubic yard.

Cost of compost is given as $2.00 per cubic yard and is sold for as much as $5.00 per cubic yard.

Cost of mixed peat is $2.50 and sold to the customer for as much as $5.50 per cubic yard.

## Acknowledgments

R. E. Kirkpatrick wishes to express great appreciation for the work and helpful suggestions provided by Sandford Radgate and Harry Hamilton, both of Grand Falls, during the four years of experiments and to Dr. Edgar Chiasson, President of Grand Falls Peat Co. Ltd. for his encouragement and financial assistance. T. E. Tibbetts, who spent several days in the field studying the operation and in consultation with Mr. Kirkpatrick, wishes to gratefully acknowledge the unique cooperation of Mr. Kirkpatrick in supplying the details of the operations of the Grand Falls Peat Co. Ltd. Without this superb effort on the part of Mr. Kirkpatrick, this report would not be possible.

Acknowledgment is also due William Goodwin, a retired mining engineer and presently residing in Manotick, Ontario, who encouraged this project.

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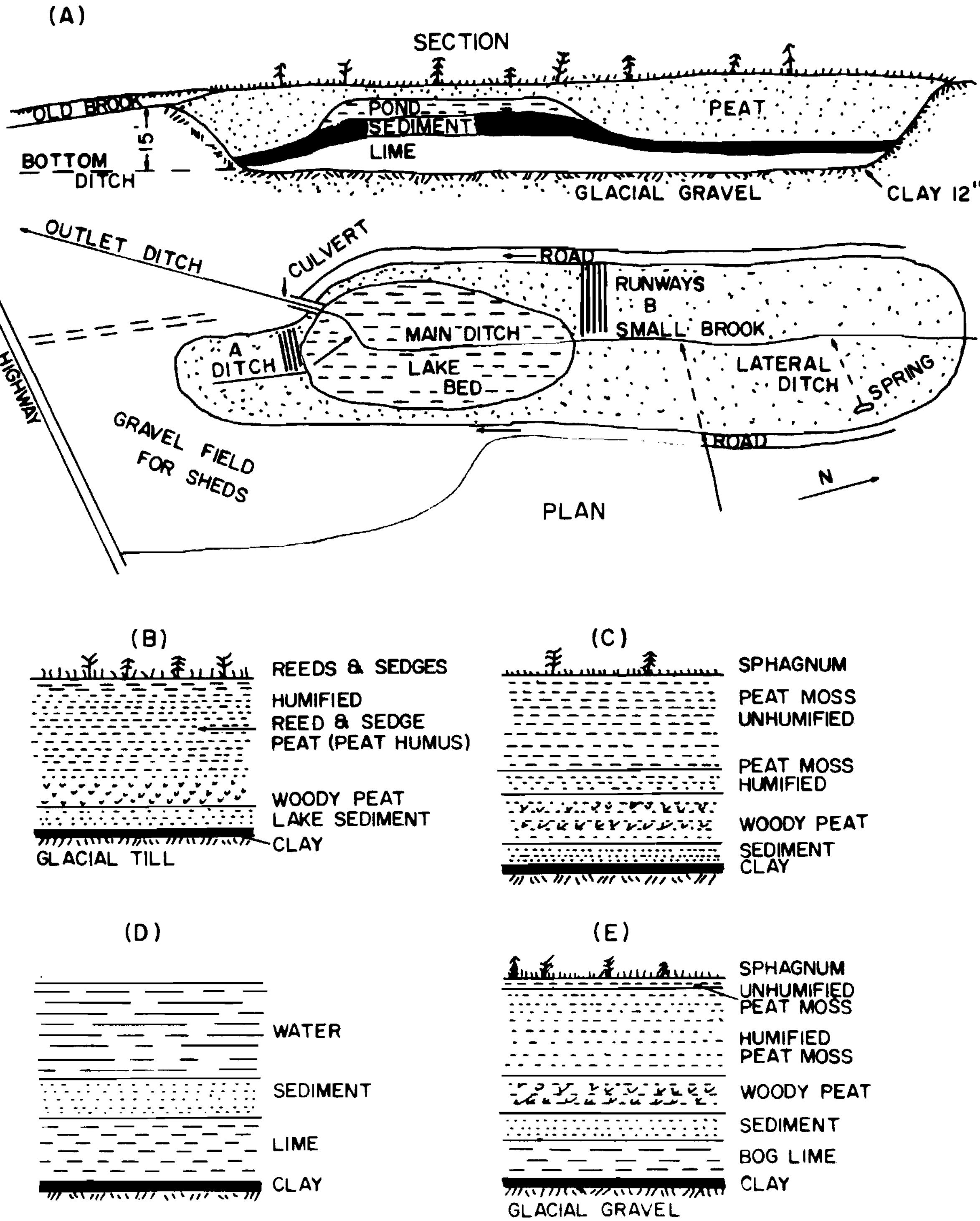


FIGURE I - PEAT AND LIME BOGS

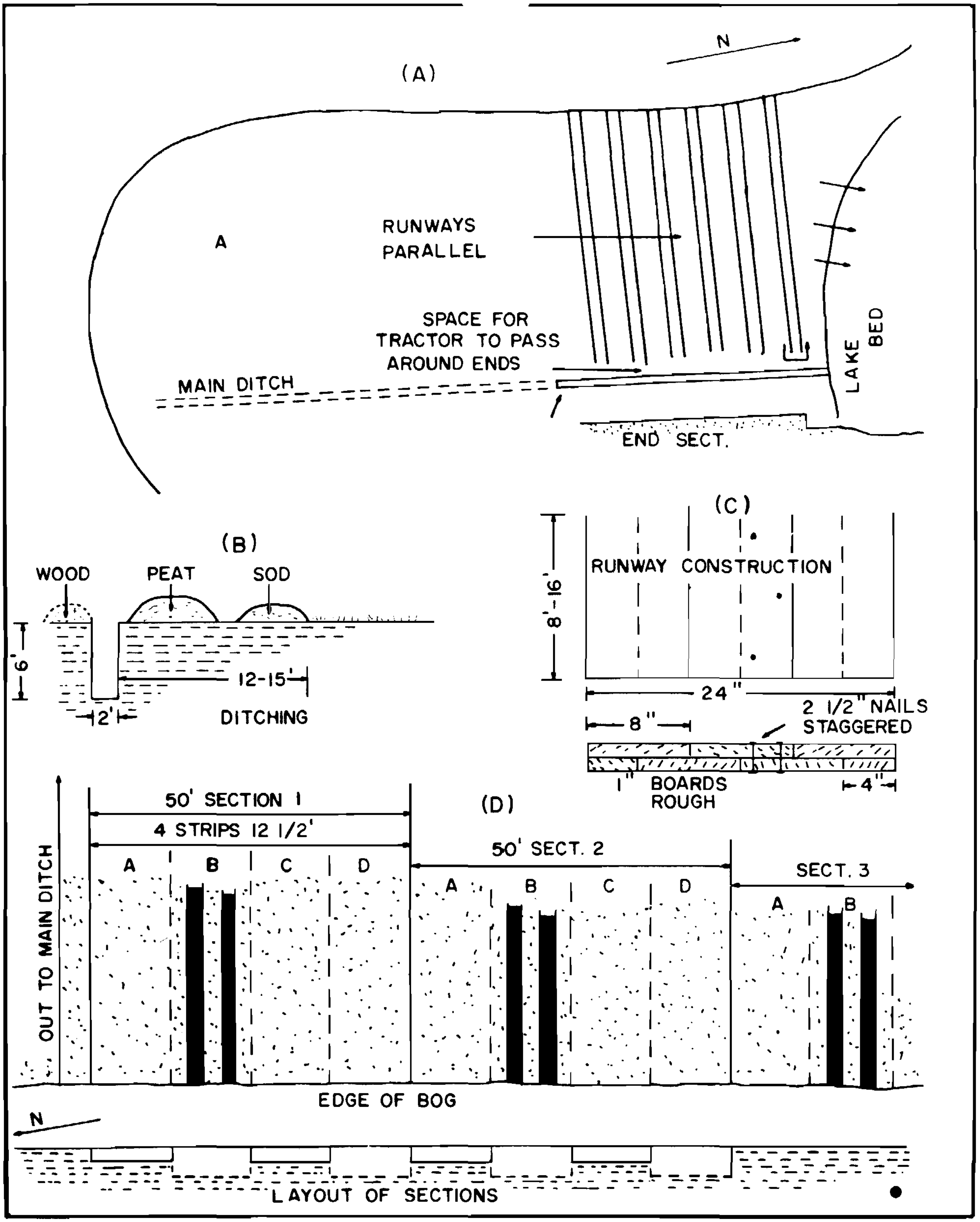


FIGURE 2 - LAYOUT OF BOG AND RUNWAYS

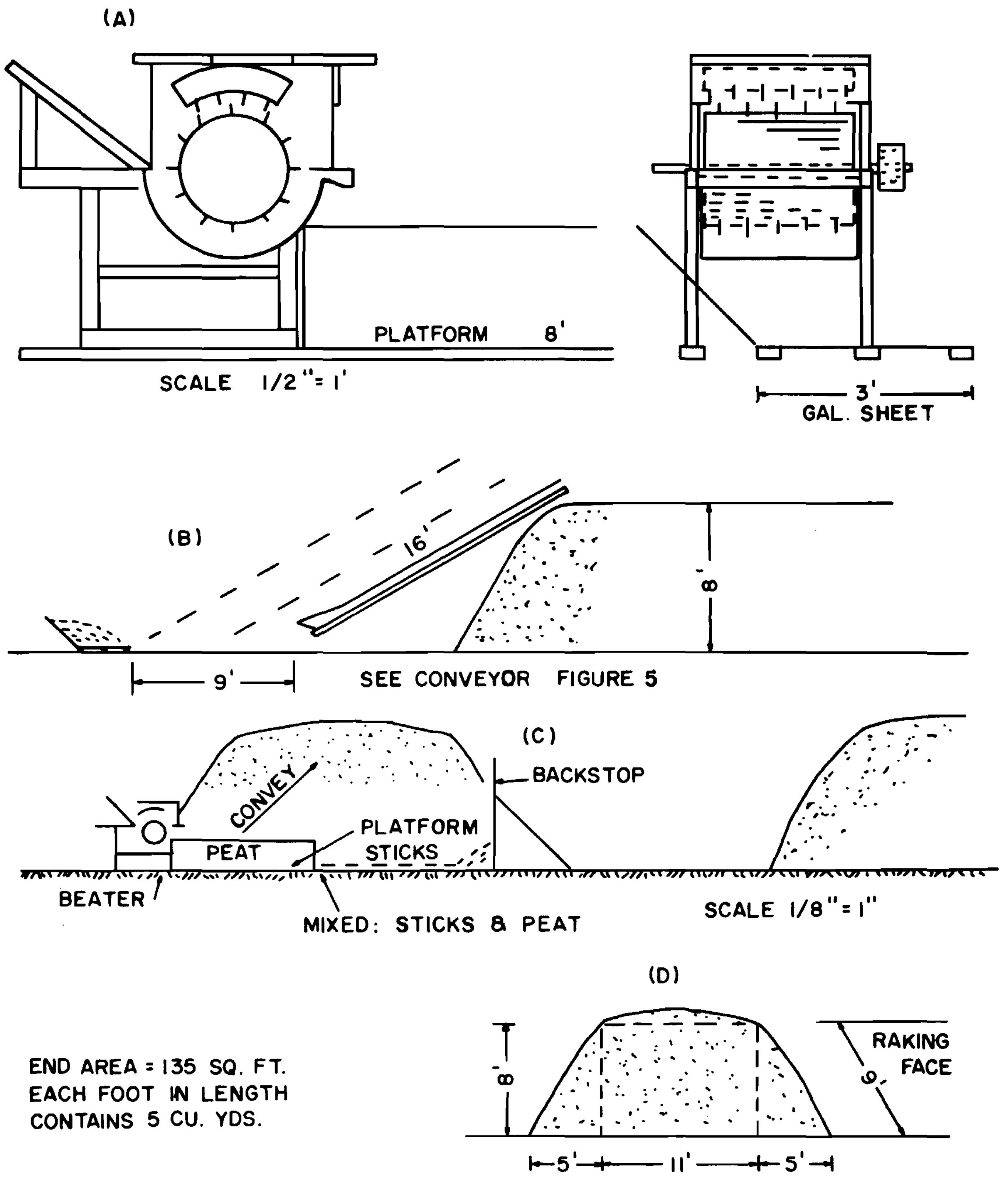


FIGURE 3 - BEATER (SHREDDER)

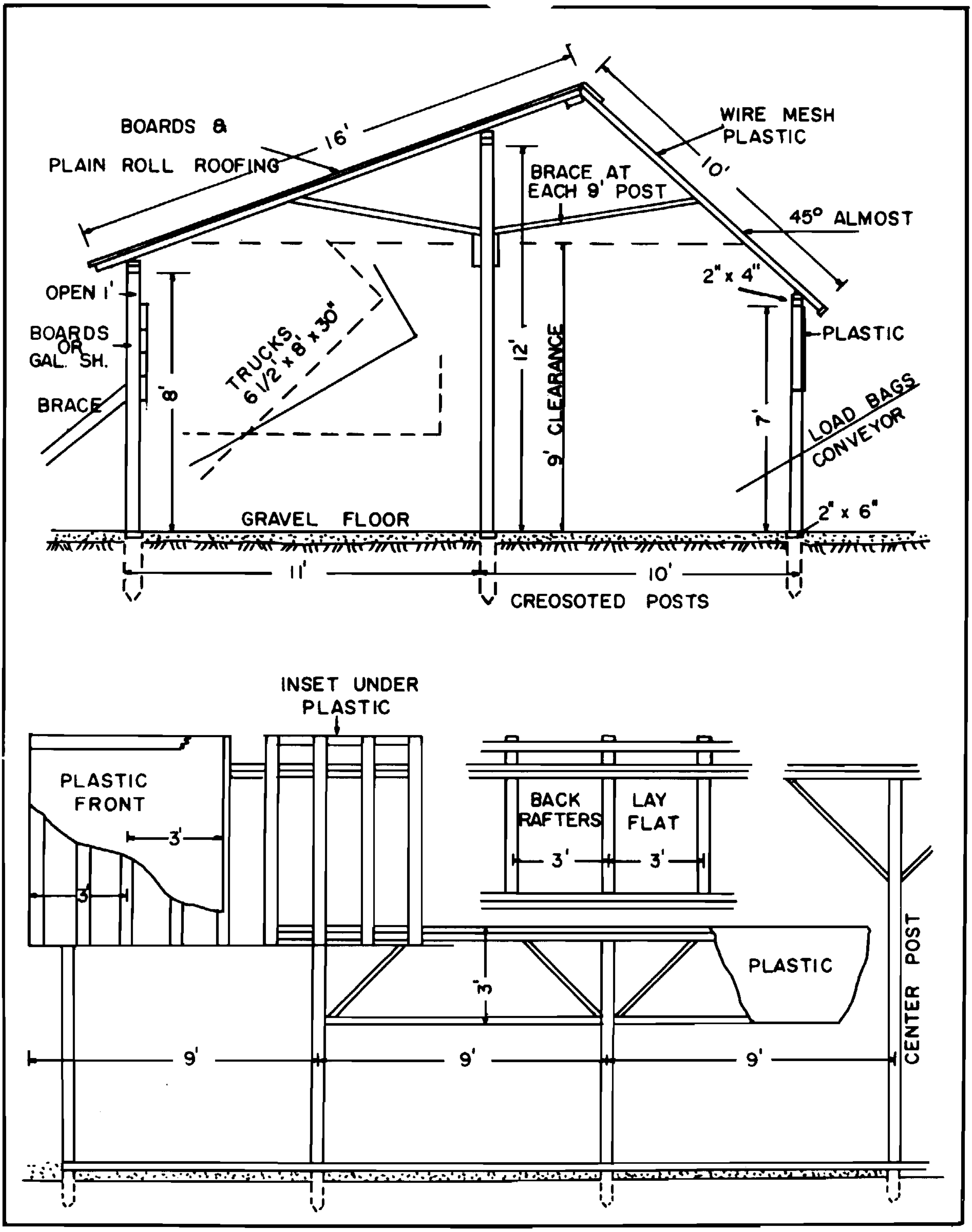


FIGURE 4A - DRYING SHED

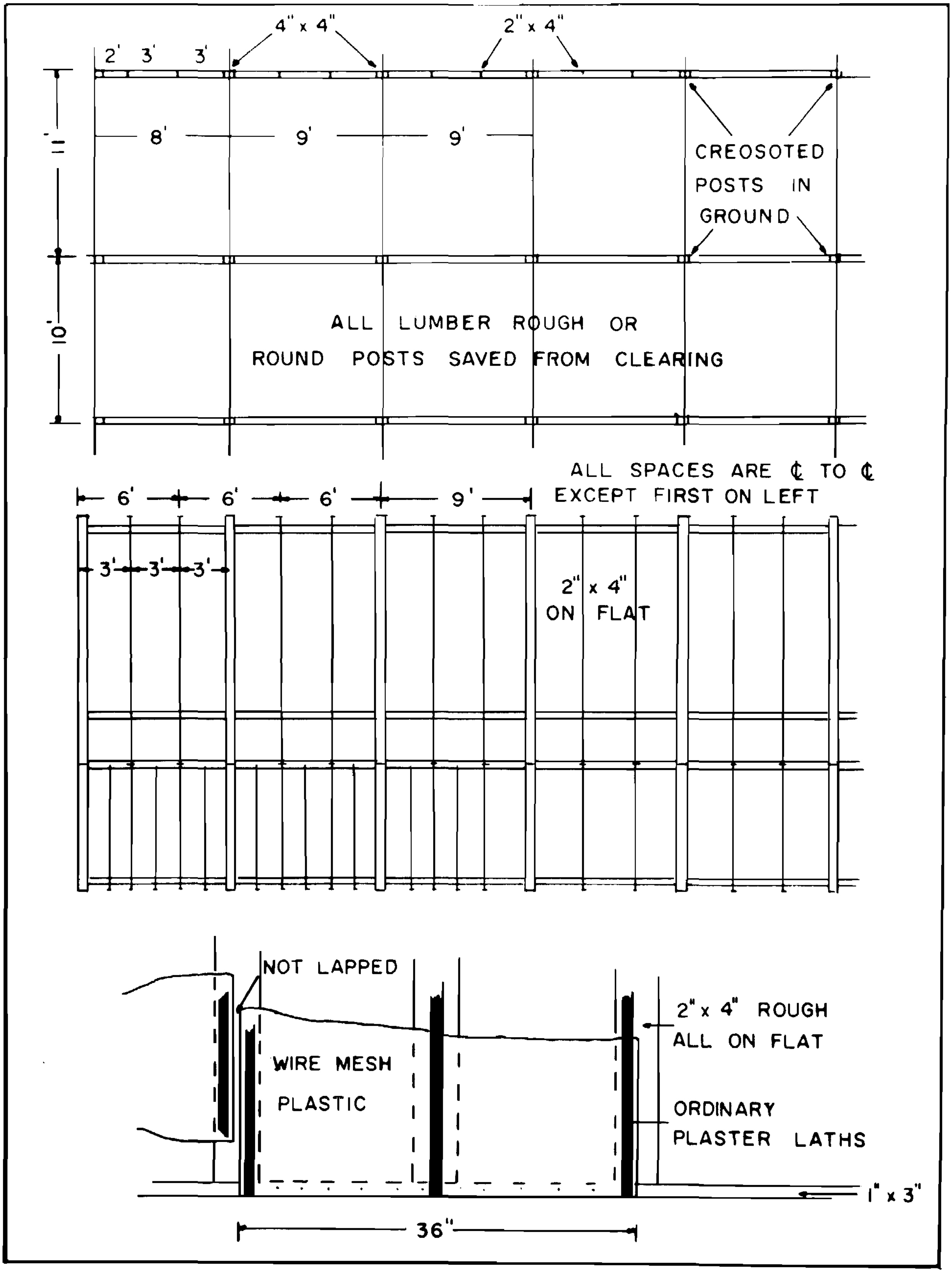


FIGURE 4B - DRYING SHED - LAYOUT OF POSTS AND FRAME

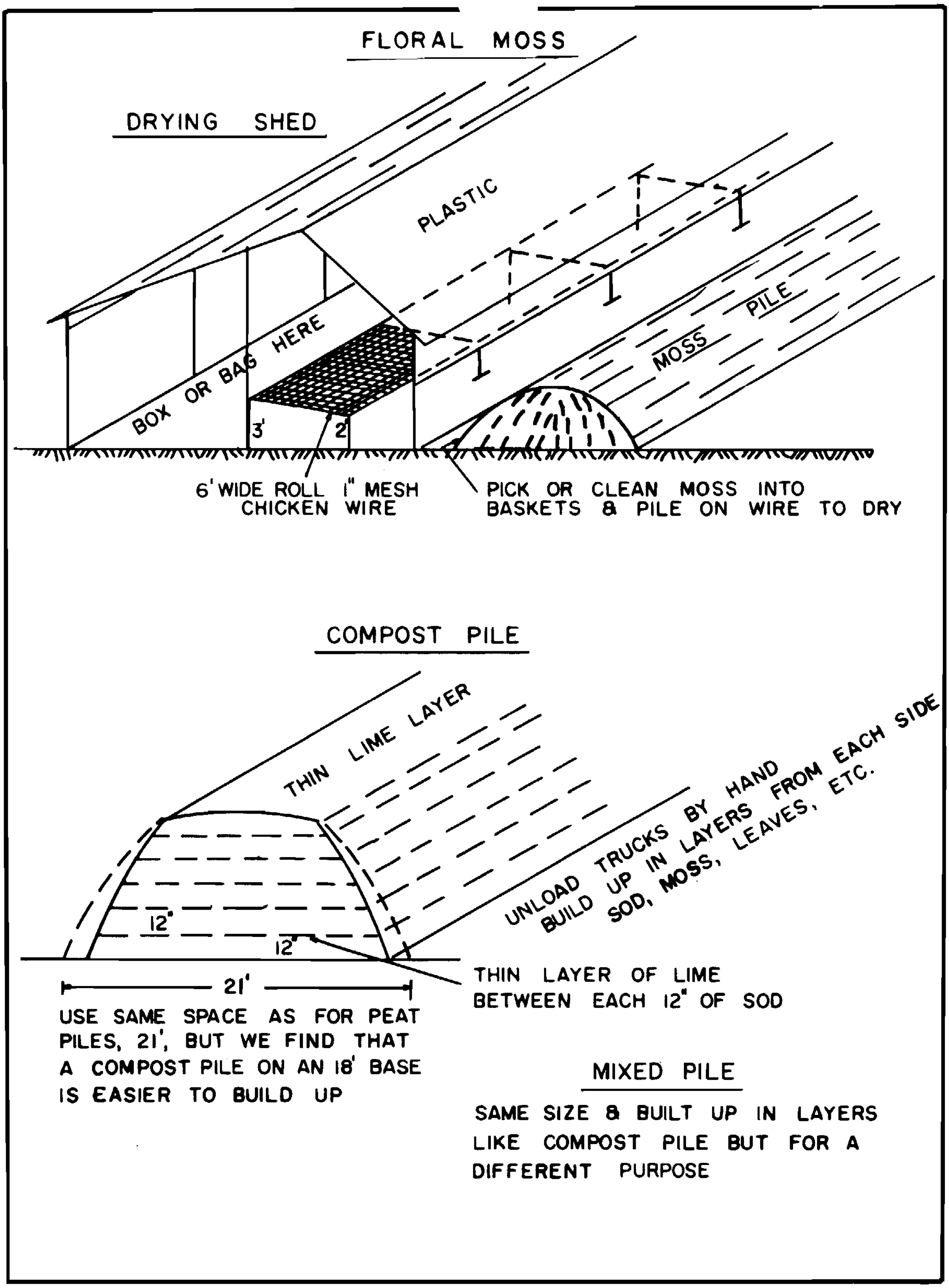


FIGURE 5 - PREPARATION OF BY-PRODUCTS

## III.1. MESURES DE VISCOSITE POUR DETERMINER LA FORCE DE CISAILLEMENT DE LA TERRE NOIRE

H. R. Krzywicki et N. E. Wilson

Résumé:

Des mesures de viscosité furent faites afin d'établir un essai qui donnerait la relation entre les propriétés mécaniques de la terre noire et les contraintes de cisaillement, la vitesse de déformation et la teneur en eau. De plus, des considérations sur la mobilité des véhicules suscita un intérêt dans la mesure des propriétés d'écoulement de la terre noire. Un viscosimètre Brookfield fut utilisé pour des études de viscosité sur une terre noire amorphe-granulaire. Ces recherches ont montré que la terre noire est un matériel thixotropique qui reprend de la force pendant une période d'inactivité appelée temps d'arrêt.

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## III.1. VISCOSITY MEASUREMENTS TO DETERMINE THE SHEAR STRENGTH OF PEAT

H. R. Krzywicki and N. E. Wilson

Abstract

Viscosity measurements were made to establish a test which would relate the engineering properties of peat with shear stress, speed of shear and water content. Also, vehicle mobility considerations inspired an interest in measuring the flow properties of peat. A Brookfield viscometer was used for viscosity studies on an amorphous-granular peat. This investigation showed that peat is a thixotropic material and also showed that peat regains strength during a period of inactivity, called the "setting-up" time.

# III. 1. VISCOSITY MEASUREMENTS TO DETERMINE THE SHEAR STRENGTH OF PEAT

H. R. Krzywicki and N. E. Wilson

The shear strength of a soil is one of the basic factors which determine the behaviour of a soil under load. As an example, the ultimate bearing capacity of a soil, whether it is used for structural foundations, piling, or subgrade, depends on its shear strength. Of great interest to those concerned with the problems of construction on organic terrain is the shear strength of peat from the viewpoint of vehicle mobility.

Those persons concerned with the problem of construction and mobility on organic terrain are aware of the difficulties associated with the determination of the engineering properties of peat. The standard tests in soil mechanics are often of little use when attempted on peat. At the present time, the field vane and the penetrometer cone (Anderson, 1962) (MacFarlane and Rutka, 1962) are common methods for determining shear strength, but the validity of the results can be questioned when the fibrous nature of peat is considered. In the vane test, the effective diameter of the shearing surface, the speed of rotation and the voids produced by the rotation of the vane are not considered (Figure 1).

It appears that what is required is a fundamental approach to the shear strength problem; a study based on the rheological properties of the material appears to be logical. Accordingly an attempt was made to measure the viscosity of remoulded amorphous-granular peat, using a Brookfield viscometer.

## Purpose:

The purpose of measuring the viscosity of peat is two-fold. Firstly, it may be possible, by using a viscometer, to establish a test which would correlate the engineering properties of peat with shear stress, speed of shear and water content. This type of relationship may be compared to the Atterberg Limits of a soil. Secondly, the interest in measuring the flow properties of peat with a Brookfield Viscometer is from the standpoint of vehicle mobility. As the shear mechanism is basically the same for both a rotating bob and a rotating wheel in peat, trends observed with the viscometer may be applicable to operating machinery.

Apparatus:

A Brookfield Synchro-Lectric Viscometer, Model HBT, was used for the viscosity studies on amorphous-granular peat. This instrument has been used in the pulp and paper industry as a control device and is frequently used in industries relating to food (Hand et al., 1955), asphalt (Lyttleton and Traxler, 1948), printing (Prew, no date), paint (Ronai and Weisburg, 1954) and plastics. The HBT model can operate at various speeds from 0.5 to 100 rpm. The instrument is equipped with two types of spindles, the disc shaped bobs and the "T" spindles (Figure 2).

The function of the viscometer is simple. The drag force which is exerted by the fluid on the rotating spindle is resisted by a calibrated torque spring; the torque is indicated by a reading on a rotating dial. The torque reading can be converted into a viscosity measurement by applying a calibration factor which is unique for a given spindle and speed.

While it has been stated that the spindles can be used to measure the viscosity of pastes and slurries (Brookfield Laboratories, no date), consistent measurements on peat could not be obtained because of the influence of fibres in the material.

The sample of amorphous-granular peat under test was contained in a 2000 ml. beaker and no flow took place at the walls of the container.

The Thixotropic Nature of Amorphous-granular Peat

When a material behaves as a thixotropic fluid, there is difficulty in obtaining consistent torque measurements with a viscometer; amorphous-granular peat exhibits this property. In thixotropic fluids, if the shear rate is kept constant, the torque reading decreases with time. The problem is to decide when the torque readings should be taken. If the maximum value of torque is required, the factors which govern this are:

1. Mixing - The method of mixing the sample and the mixing time affect the maximum torque reading by altering the relative density of the material.
2. Curing Time - The curing time, which is defined as the period between mixing and testing, has a definite influence on the maximum torque reading. As the curing time increases, the maximum torque increases (Figure 3). This is due either to consolidation of peat under its own weight or to "setting-up" process.
3. Speed of Rotation of the Bob - The speed of rotation is important because at the higher shear rates, it was noticed that the maximum torque readings were affected by the momentum of the spindle on the calibrated spring.

There are advantages in using the minimum value of torque for viscosity calculations on thixotropic fluids. This method has been used previously in a study of the viscosity of clays (Eden and Kubota, 1962). The importance of maximum torque measurements is greatly reduced when minimum torque measurements are obtained. The speed of rotation of the spindle is not a consideration, as the momentum effect of the spindle on the calibrated spring is dampened after the first revolution of the spindle. The method and time of mixing is still important, but the effects of these factors on the minimum torque reading are reduced. The main objection to using the minimum torque value is the period of time required to perform the test. It may be several hours or even days before a minimum reading can be obtained. During this period, evaporation and consolidation takes place.

## Influence of Curing Time on Values of Maximum Torque

One series of tests was performed to determine the influence of curing time on the value of maximum torque. It was found that the torque increased with the curing time (Figure 3). This could be attributed to a combination of the consolidation of peat under its own weight and some "setting-up" process which occurs within the structure of the peat.

One application of this test, with respect to vehicle mobility would be to determine the significance of a delay between vehicle passes over organic terrain. By controlling the interval between vehicle passes, the optimum mobility for a vehicle convoy could be obtained.

## Influence of Elapsed Time and Rotational Speed on Torque

As amorphous-granular peat is thixotropic in nature, the torque reading at a given speed decreases with time (Figure 4). It is expected that the mechanism for this phenomenon is (a) reduction of effective shearing radius due to the alignment of the fibres in the peat and (b) lubrication of the spindle caused by the migration of water to the shearing zone (Figure 5).

These results indicate that it is advantageous to operate a vehicle under full power to get out of the peat as soon as possible. The shear strength, however, decreases rapidly at high speeds and this effect should be considered.

## Conclusions

This fundamental investigation has shown that peat is a thixotropic material and it can be expected that peat behaves as other thixotropic materials.

It has been shown that peat regains strength during a period of inactivity, called the "setting-up" time. This is significant in vehicle mobility as the peat has a greater shearing resistance if a time interval is available between vehicle passes.

The breakdown of the peat structure when continuously stirred also has an application to vehicle mobility. The shear resistance has a maximum value at the initial stages of shear and, consequently, the maximum tractive effort can be obtained by a vehicle under full power. However, the structural breakdown at high speeds is rapid and the spinning wheels can readily cause a reduction in shearing resistance.

Acknowledgements

The research for this paper was supported by the Defence Research Board, Grant Number 9768-04.

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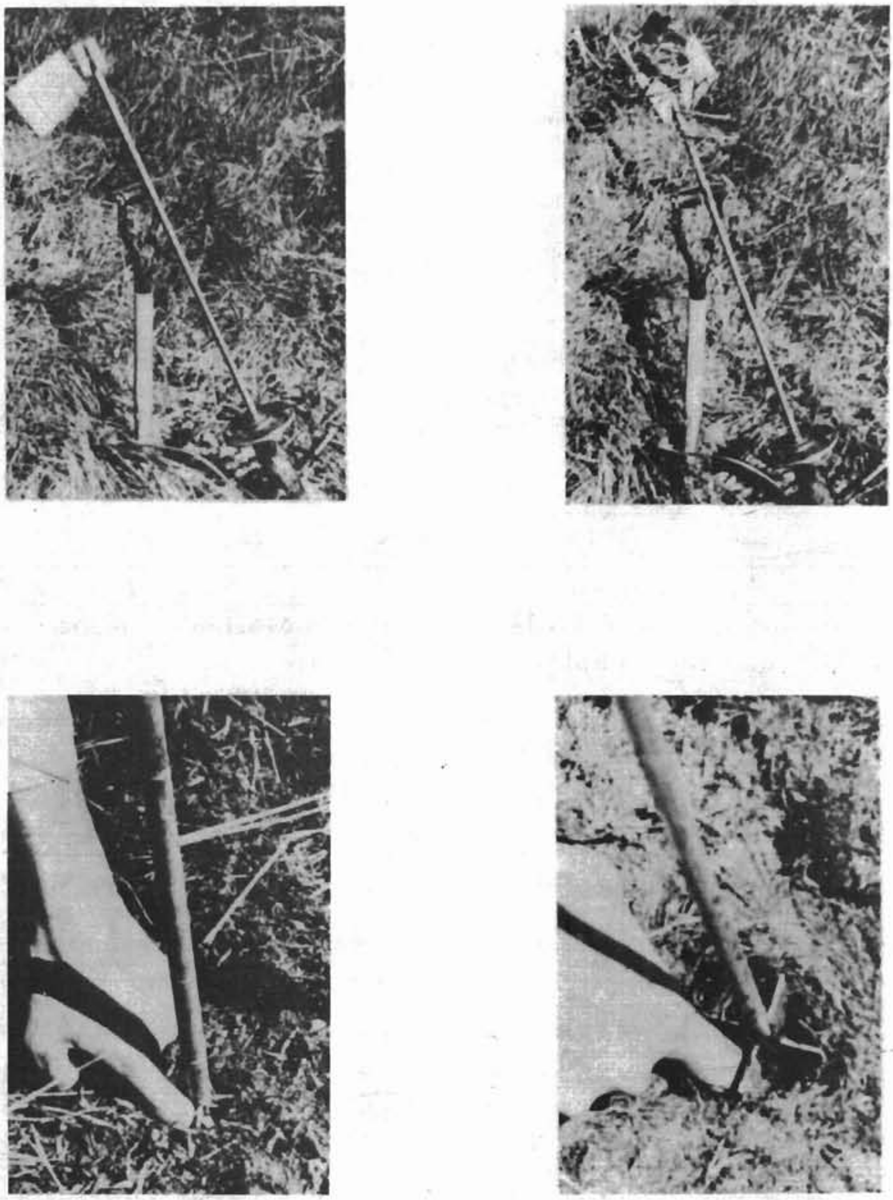

FIELD VANE IN FIBROUS PEAT

FIGURE 1

FIGURE 2: BROOKFIELD VISCOMETER

## TYPICAL CURVES SHOWING BREAKDOWN WITH TIME AT VARIOUS SPEEDS

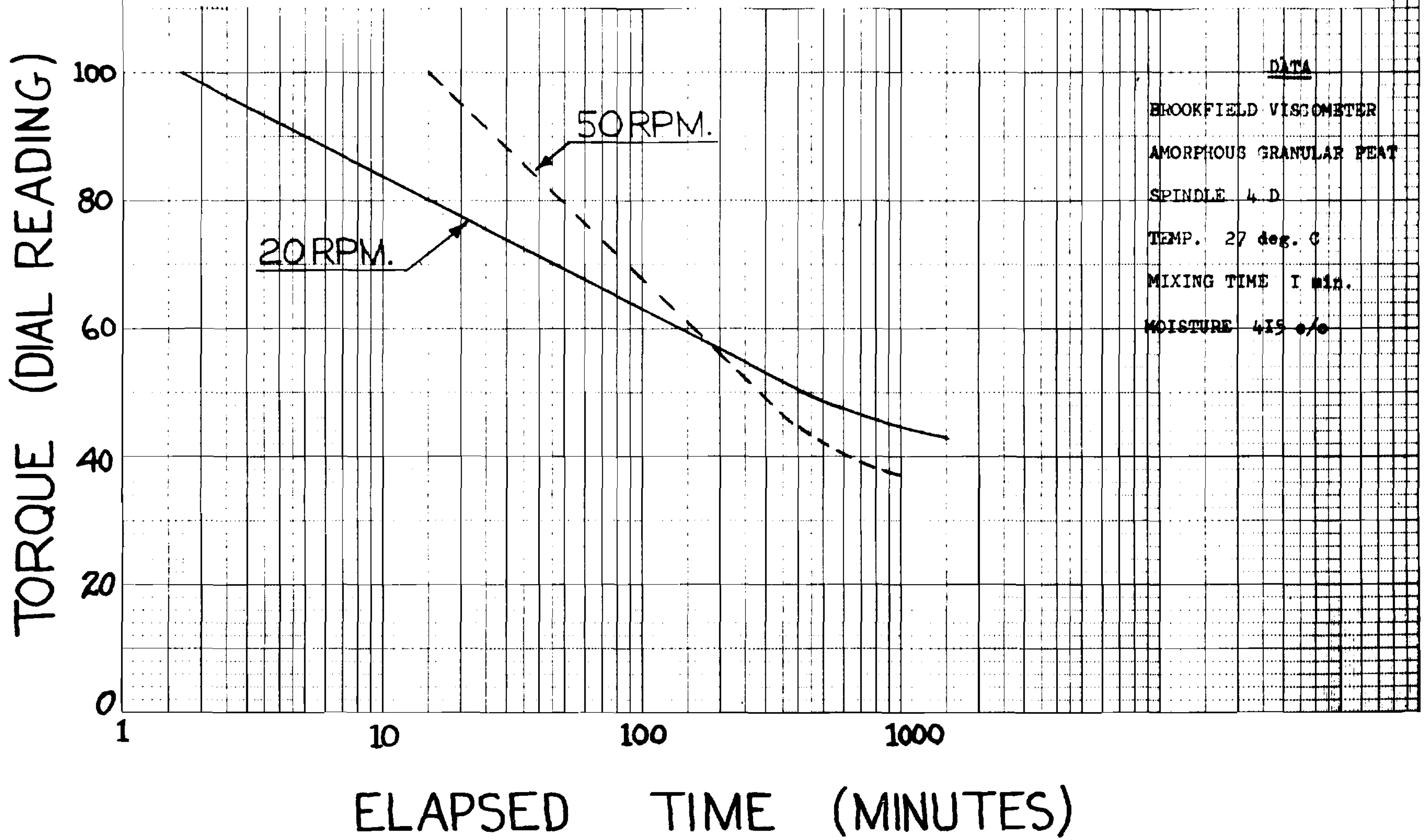


FIGURE 4: INFLUENCE OF CONTINUOUS STIRRING

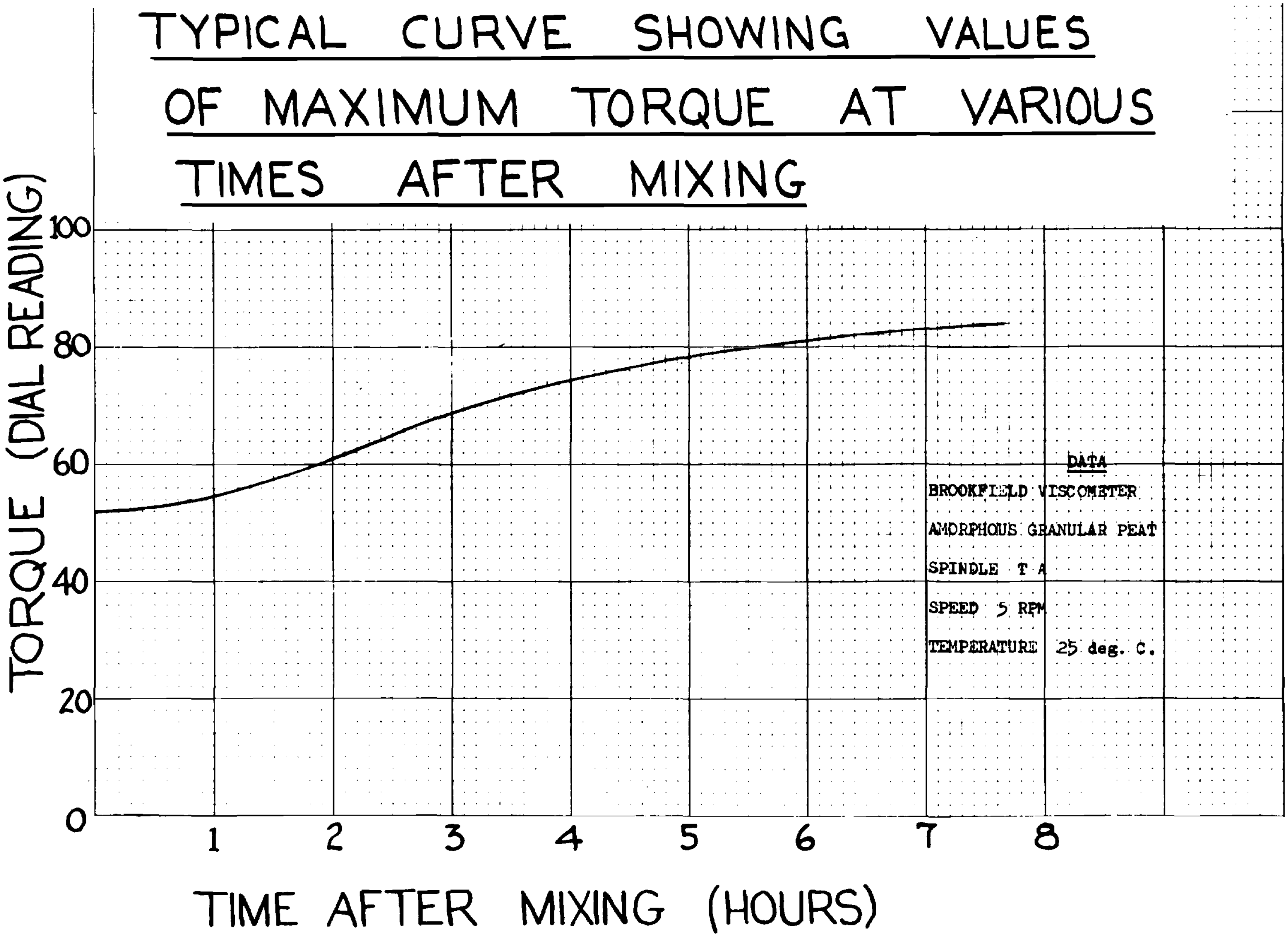


FIGURE 3: INFLUENCE OF CURING TIME

FIGURE 5: CLOSE-UP OF ROTATING SPINDLE

Discussion

Mr. Schlosser wondered if the resistance to torque would be less in the fluid layer of peat under the mat. Prof. Wilson expected this to be the case but emphasized that he was treating a laboratory sample in an attempt to determine fundamental characteristics of the material. Dr. Radforth commended Prof. Wilson's approach. He thought it was a useful approach from the point of view of soil mechanics; it is also convenient to think about what happens to the material in relation to field conditions.

Professor Anderson mentioned that the viscometer measured shearing resistance at high speeds and referred to the fact that it was not able to record the initial torque. He wondered if Prof. Wilson anticipated using a miniature vane in the peat slurry. Prof. Wilson said that he did plan to do so eventually; this is a matter of instrumentation. It will be necessary to have this information, so perhaps a small vane could be used with various speeds. He thought that it would be interesting to see if the initial torque at 50 rpm would be 2-1/2 times that at 20 rpm.

Mr. Ashdown asked if there were any families of curves with different spindles in identical material; any curves to show the dependence of contact area. Prof. Wilson replied that shear is not a function of the radius of the spindle, since the shear plane occurs at some distance "X" from the circumference.

Prof. Naemi referred to the time-loading effect and to Prof. Wilson's comments on giving a vehicle "the gun" to get through a difficult area. He asked Prof. Wilson if by this he meant maintaining the engine speed. Prof. Wilson said that he referred, rather, to keeping up the wheel speed and not giving it a chance to drop off permitting the vehicle to bog down. Mr. Campbell concurred with this view.

The question was asked if anyone had ever used a hydromatic transmission in muskeg vehicles. Prof. Naemi said that his group had tried one in a tracked vehicle used in heavy wet snow. It produced a jerky action in the vehicle and it eventually bogged itself down. He suggested that it may react the same way in muskeg.

Referring to Prof. Wilson's remark about the torque at 50 rpm possibly being 2-1/2 times the torque at 20 rpm, Mr. Hemstock suggested that it would be the power input and not the torque which would increase 2 1/2 times. He thought that the torque would remain constant, but the power input would go up. Mr. Ashdown mentioned that the units should be considered in this, power is in ft-lb/sec whereas torque is in ft-lb. Prof. Naemi doubted that the torque would remain the same. He thought that it should vary with speed. Fluid friction is obtained along the plane of shear.

Mr. Schlosser referred to the variation in the radius of the cylinders used in the viscosity measurements. He wondered if the length of the cylinders immersed in the sample were also changed. Prof. Wilson explained that the spindles were very long in relation to their diameter (e.g. 0.5" diam. and 3" long) to eliminate end effects. In any case, one end is exposed as the spindle is not completely immersed. Mr. Schlosser asked if this could be related to tire width rather than to wheel diameter. Prof. Wilson suggested that it might be, and reiterated that the purpose of the research project is to determine the thickness of the boundary layer "X" and to get a family of curves. Prof. Anderson commented that, in using the field vane, it is wise to go to as large a diameter vane as is possible, for if the layer "X" is 0.10 inch thick, then this is proportionally very high to a small diameter vane. For a large vane, it is not that important, since it is only a small percentage of the vane diameter. Prof. Wilson pointed out that one problem in increasing the diameter of the vane is that it also increased the shear rate at the shearing face. Although the angular rotation is the same, regardless of vane diameter, it is not angular deformation with which we are concerned.

Mr. Hemstock commented on the effect of wheel diameter and tire contact area. In the desert work, mobility was found to go up directly as the width of the tire. On the other hand, mobility increased as the square of the wheel diameter. Therefore, it pays to have large diameter wheels.

## III.2. TRANSFERT D'EAU INTERSTICIELLE PENDANT LA CONSOLIDATION DE LA TERRE NOIRE

M. B. Lo et N. E. Wilson

Résumé:

On présente une analyse graphique de la consolidation de la terre noire au moyen de la distribution de la teneur en eau. Les distributions ont été mesurées sur des échantillons consolidés à différents intervalles de temps. Après un certain temps, la courbe de distribution approche une relation linéaire avec la profondeur et devient finalement une verticale au moment de la consolidation ultime. En prolongeant la courbe de distribution de la teneur en eau au sommet de l'échantillon, on obtient la teneur en eau à la surface supérieure. Il est démontré que la teneur en eau, qui est fonction de la perméabilité, varie avec le temps. Quand les courbes de distribution de la teneur en eau sont prolongées au-delà de l'épaisseur du sol, elles s'interceptent en un point près de la teneur en eau à la consolidation ultime. On s'est servi de ce point pour prédire la consolidation ultime d'après l'hypothèse que la teneur en eau atteint une valeur ultime. Le temps de la consolidation ultime peut être prédit par rapport au changement de la teneur en eau à la surface supérieure. On suggère que si cette méthode est valable pour la consolidation sur place, elle peut être prédite par une méthode graphique semblable en n'utilisant que deux séries de mesures de la teneur en eau.

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## III.2. MIGRATION OF PORE WATER DURING THE CONSOLIDATION OF PEAT

M. B. Lo and N. E. Wilson

Abstract

A graphical analysis of peat consolidation by means of water content distribution is presented. Water content distributions were measured when samples were consolidated for various time intervals. After some time has elapsed, the water content distribution curve approaches a linear relationship with depth and finally becomes vertical at ultimate consolidation. By extending the water content distribution curve to the top of the sample, the water content at the upper surface is obtained. It is shown that the water content, which is related to permeability, varies with time. When the water content distribution curves are extended beyond the soil depth, they intersect at a point close to the water content at ultimate consolidation. This point was used to predict the ultimate consolidation according to the hypothesis that the water content reaches an ultimate value. The time to the ultimate consolidation can be predicted by relating it to the change in water content of the upper surface. It is suggested that if this method is valid for field consolidation, it can be predicted by a similar graphical method using only two sets of water content measurements.

## III. 2. MIGRATION OF PORE WATER DURING THE CONSOLIDATION OF PEAT

M. B. Lo and N. E. Wilson

Consolidation, as defined by Terzaghi, is "Every process involving a decrease in the water content of a saturated soil without replacement of the water by air" (Terzaghi, 1943). In other words, the process of consolidation is migration of water in a saturated soil stratum. In Terzaghi's one-dimensional consolidation theory some assumptions, such as the negligible compressibility of soil grain and the constant values for certain soil properties, are not applicable to peat.

In the model Terzaghi designed for the demonstration of consolidation, the velocity of water flow out of the vessel depends upon the constant size or area of the perforations in the piston. In consolidation of peat, the permeability of the top layer controls the rate of water flow. Whether or not the permeability, which is related to the perforations in the piston in Terzaghi's model, remains constant during the consolidation process remains to be proved.

The classical definition of the degree of consolidation is the ratio of the average void-ratio along the depth of sample before and after consolidation under a given loading. This definition holds valid for a very thin layer of highly permeable soils. In the case of a thick layer of soils of low permeability, the bottom layer remains unconsolidated while the top layer reaches a certain degree of consolidation during the early stage of the process. In practical application the consolidation of a thick layer of peat is more relevant than a thin layer.

Owing to the complexity of the structure and composition of peat, the assumptions and analysis method developed by Terzaghi do not appear entirely applicable. A general theory of peat consolidation including composition factors is required (Lo, 1964); in this paper a practical analysis method of peat consolidation is described.

### Apparatus

A one-dimensional consolidometer was designed to facilitate the retrieval of the samples. A section of lucite cylinder, 6 inches high with an I.D. of 4-15/32 inches, was glued to an aluminum base. This consolidometer was cut into three vertical sections as shown in Figure 1; rubber strips were glued on the saw cuts to prevent the leakage of pore water. When assembling the consolidometer these three sections were tightened with two hose clamps.

A piston attached to a porous stone (4-7/16" Dia. Norton, #P260), was connected with a loading plate by means of an aluminum shaft.

Consolidation Tests

The material used in this investigation was obtained two feet below the water surface near Parry Sound, Ontario, and is classified as an "amorphous-granular" peat (Radforth, 1952). The sample, obtained from the field, had the consistency of a thick slurry. The water content ranged from 600 to 700 per cent of dry weight. The specific gravity of the sample was 1.95 to 2.05. The ignition loss was 25.5 per cent of oven dry weight. Additional physical properties of this sample of amorphous-granular peat are available (Lo, 1964).

To achieve reproducibility of results, the peat was remoulded by mixing. The initial water content was checked and controlled by adding or removing water before the test was performed; the initial water content in these tests varied from 623 to 636 per cent. All the samples, with an initial height of 4 inches, were loaded under 3.14 $lbs/in.^2$. The settlements which were recorded with a dial gauge, were plotted versus log. time as the test progressed (Figure 2). When retrieving the sample, the consolidometer was split into three sections, and a segment was cut from the undisturbed sample. Water contents at six different depths in this segment were measured.

Water Content Distribution

A hypothesis was proposed that, for a sample loaded under a constant stress, the ultimate consolidation was reached when the water content reached equilibrium throughout the depth of the sample. At this stage, the change of water content throughout the depth was zero and the water content distribution curve became vertical. This hypothesis was confirmed by a long-term one-dimensional consolidation test conducted in the laboratory. The sample for this test was 8" in diameter, 17-3/4" high and loaded under 4 $lb/in.^2$. After 266 days consolidation, the sample was 5-1/4" high and the water content distribution is shown below:

| Layers | Top 1 | 2 | 3 | 4 | 5 | Bottom 6 |
|---|---|---|---|---|---|---|
| Water content Percentage of Dry Weight | 364 | 364 | 364 | 364 | 365 | 366 |

The water content at ultimate consolidation is a function of applied stress.

It has been proposed (Schmid, 1957) that the coefficient of permeability is linearly related to the porosity. For a saturated soil, the water content is a function of porosity and thus a function of permeability.

As the permeability of the top layer of the soil sample controls the rate of drainage, the water content of the top layer shows the extent of consolidation.

In Figure 3 the water content distribution curves for samples consolidated for various elapsed times were plotted. For samples consolidated for a short time (i.e. less than 100 minutes), the upper part of the soil was linearly consolidated while the lower part was unchanged. As time elapsed, the permeability of the top layer was reduced as shown by the decreased water content; this reduced the rate of consolidation. After a longer elapsed time (i.e. more than 500 minutes) the consolidation in the lower part was faster than in the upper part of the sample. The consolidation reached the ultimate value as the water content distribution curve became vertical.

The water content of the extreme upper surface of the sample for any elapsed time, which is a function of permeability, was obtained by extending the water content distribution curve to the top of the sample. The curves for various elapsed times intersected at a point above the upper surface. The logarithm of the water content of the upper surface was plotted versus the logarithm of time in Figure 5. It is shown that the permeability of the upper surface, which controls the consolidation process, is not constant.

Figure 4 shows the profile of samples consolidated for various time intervals; the extent of consolidation can be seen by the water content in the samples.

## Prediction of Consolidation

Water content distribution curves for various elapsed times intersect at a point above the upper surface; the intersection moves closer to the ultimate water content distribution curve as time progresses (Figure 3). Accordingly, the ultimate water content at the end of consolidation can be predicted by two consolidation tests conducted with different time intervals; the accuracy of prediction depends on the consolidation intervals. From Figure 5, the time to reach ultimate consolidation can be obtained.

## Field Application

If the straight line relationship of Figure 5 exists in the field consolidation, the ultimate consolidation can be predicted by the method proposed. For an embankment, two sets of water content measurements along the depth of the peat at different time intervals are required for the prediction of ultimate consolidation. The water content distribution curves are first plotted as in Figure 3. The intersection of the extensions of these two curves gives the approximate water content at ultimate consolidation. By the straight line relationship, the time to the ultimate consolidation can be obtained (Figure 6).

## Conclusions

Consolidation is a process of migration of pore water from the soil stratum. As Terzaghi's theory, and some attendant assumptions, are not applicable to peat consolidation, a graphical analysis of peat consolidation by means of water content distribution has been presented.

In this investigation where samples were consolidated for various time intervals, water content distributions were measured. As the extent of consolidation is a function of water migration, it can be shown by the water content distribution curves. When some time has elapsed, the water content distribution curve approaches a linear relationship with depth and finally becomes vertical at ultimate consolidation. By extending the water content distribution curve to the top of the sample, the water content at the upper surface is obtained. It is shown that the water content, which is related to permeability, varies with time.

When the water content distribution curves were extended beyond the soil depth, they intersected at a point close to the water content at ultimate consolidation. This point was used to predict the ultimate consolidation according to the hypothesis that the water content reaches an ultimate value. The time to the ultimate consolidation can be predicted by relating it to the change in water content of the upper surface. If this relationship is valid for field consolidation, then it can be predicted by a similar graphical method using only two sets of water content measurements.

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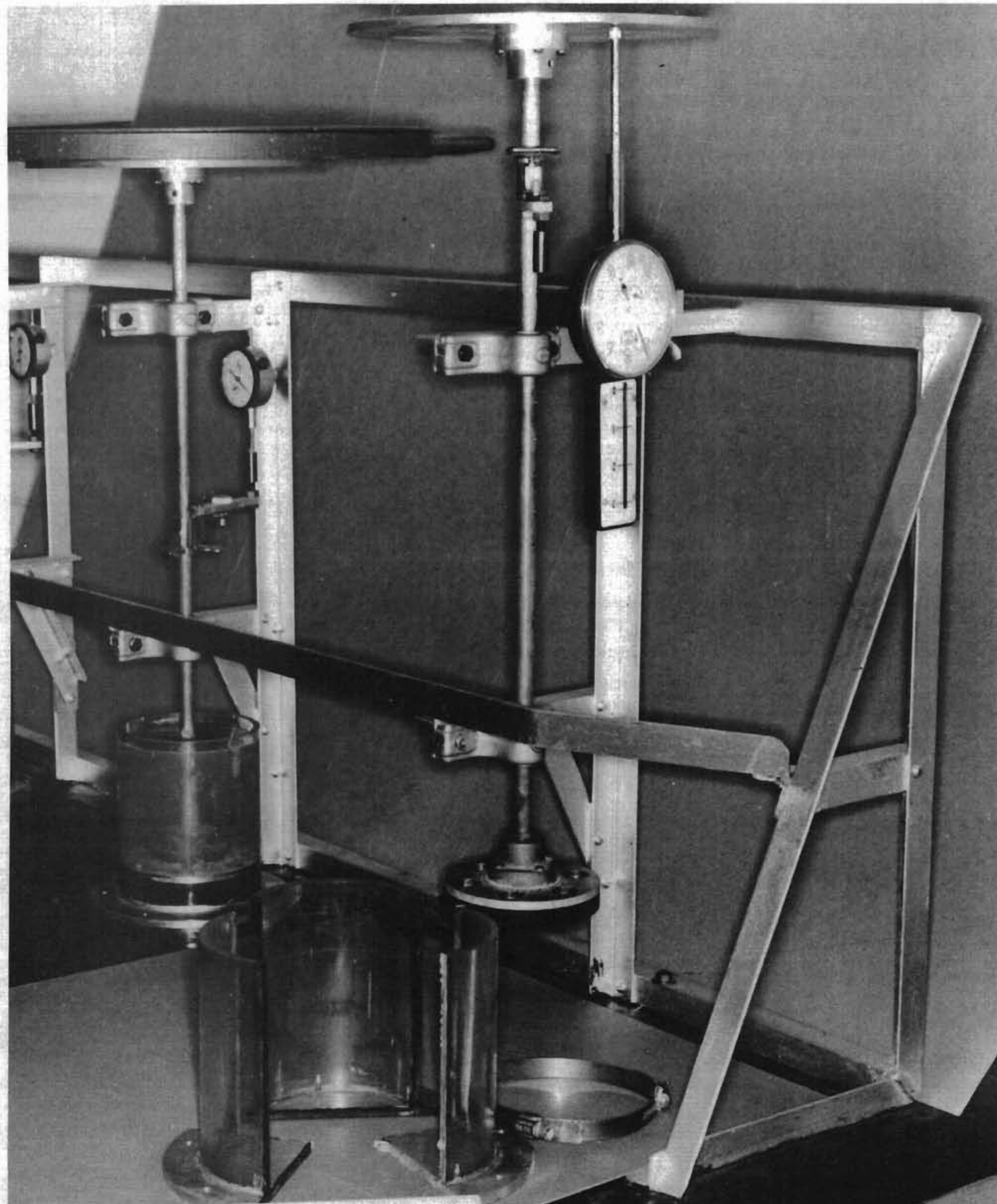


FIG. 1. CONSOLIDOMETER.

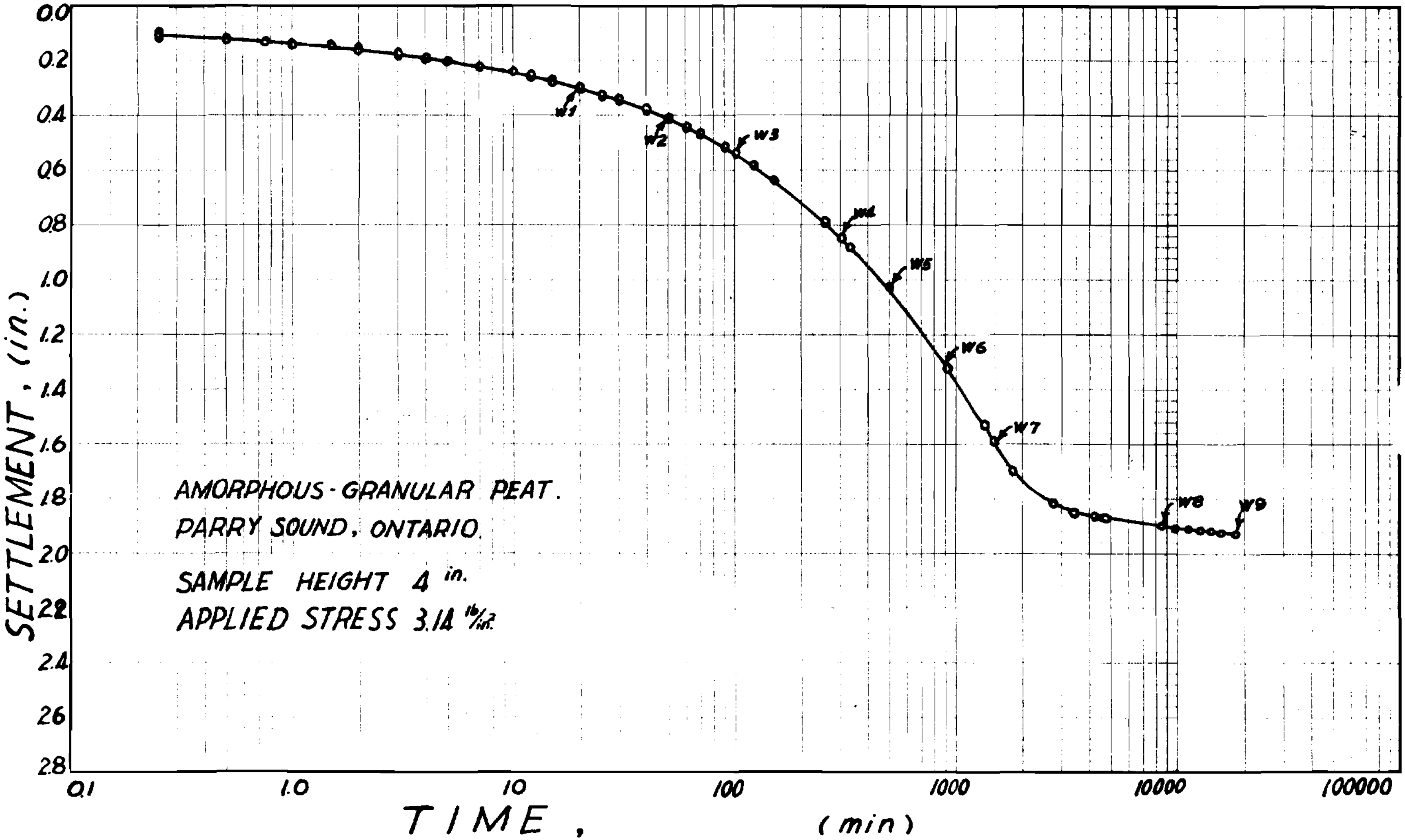



FIG. 2. SETTLEMENT - TIME CURVE

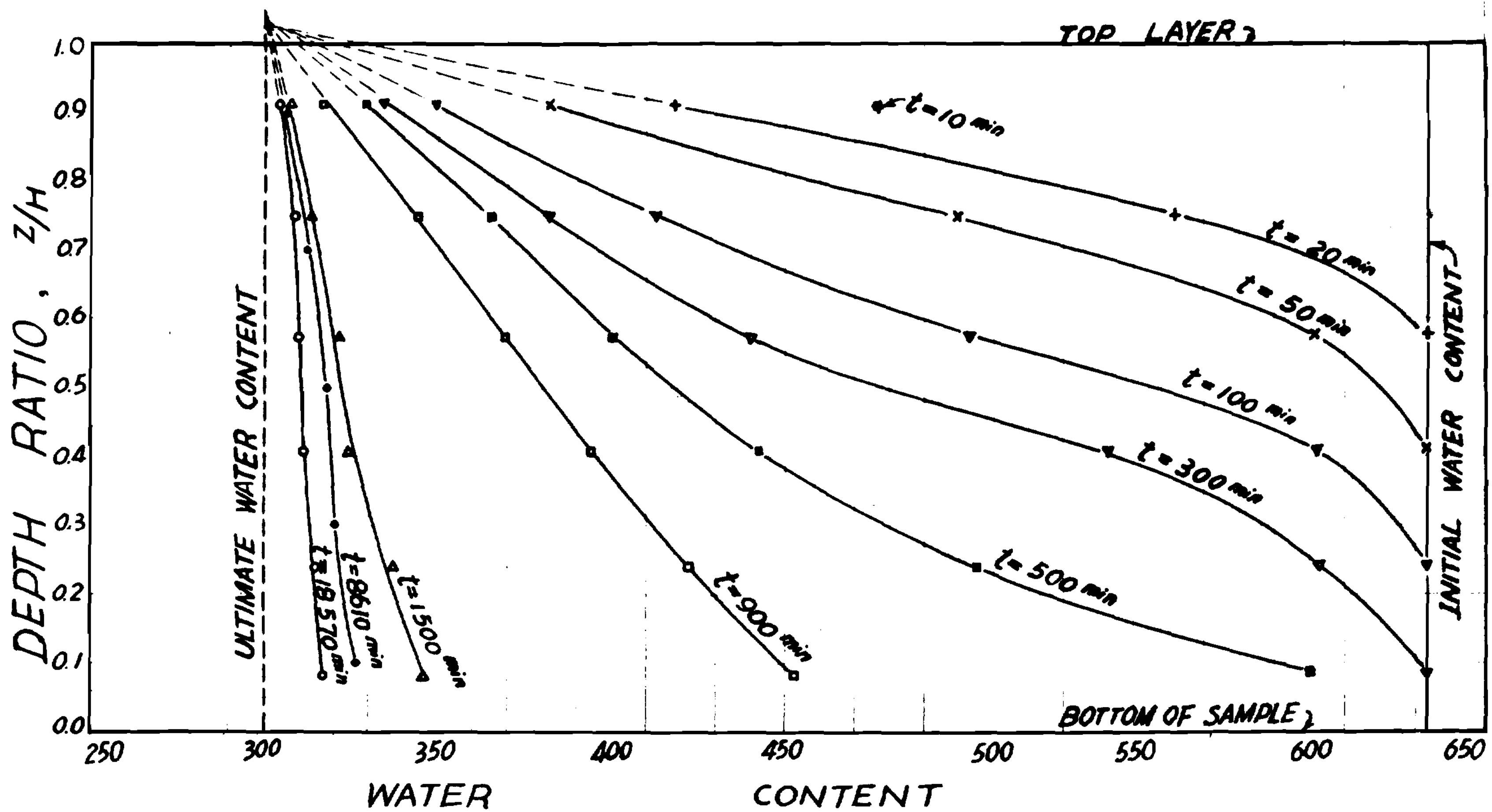
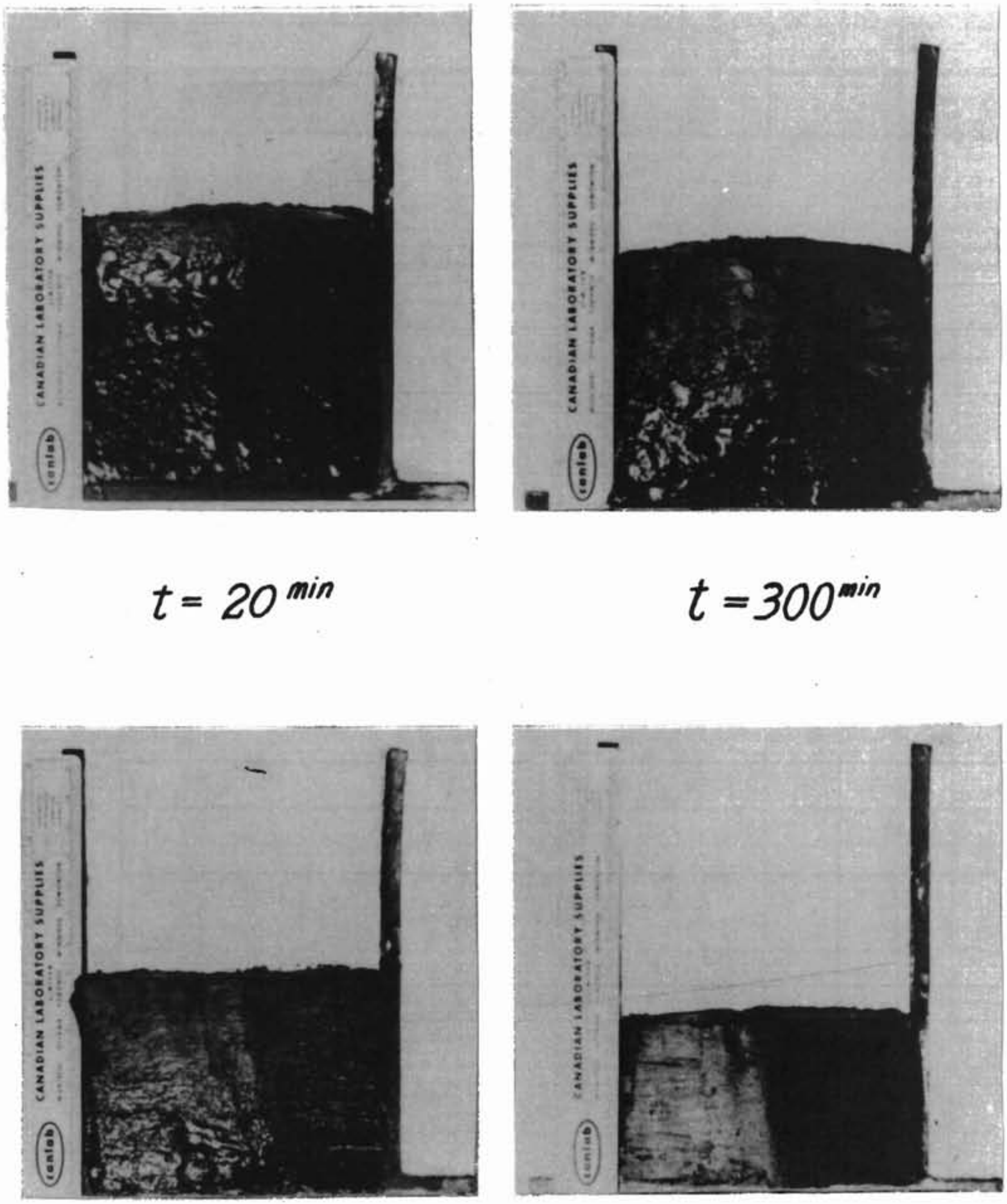



FIG. 3. WATER CONTENT DISTRIBUTION




t = 20 min

t = 300 min

t = 500 min

t = 1500 min

FIG. 4. SAMPLES AT VARIOUS STAGES OF CONSOLIDATION

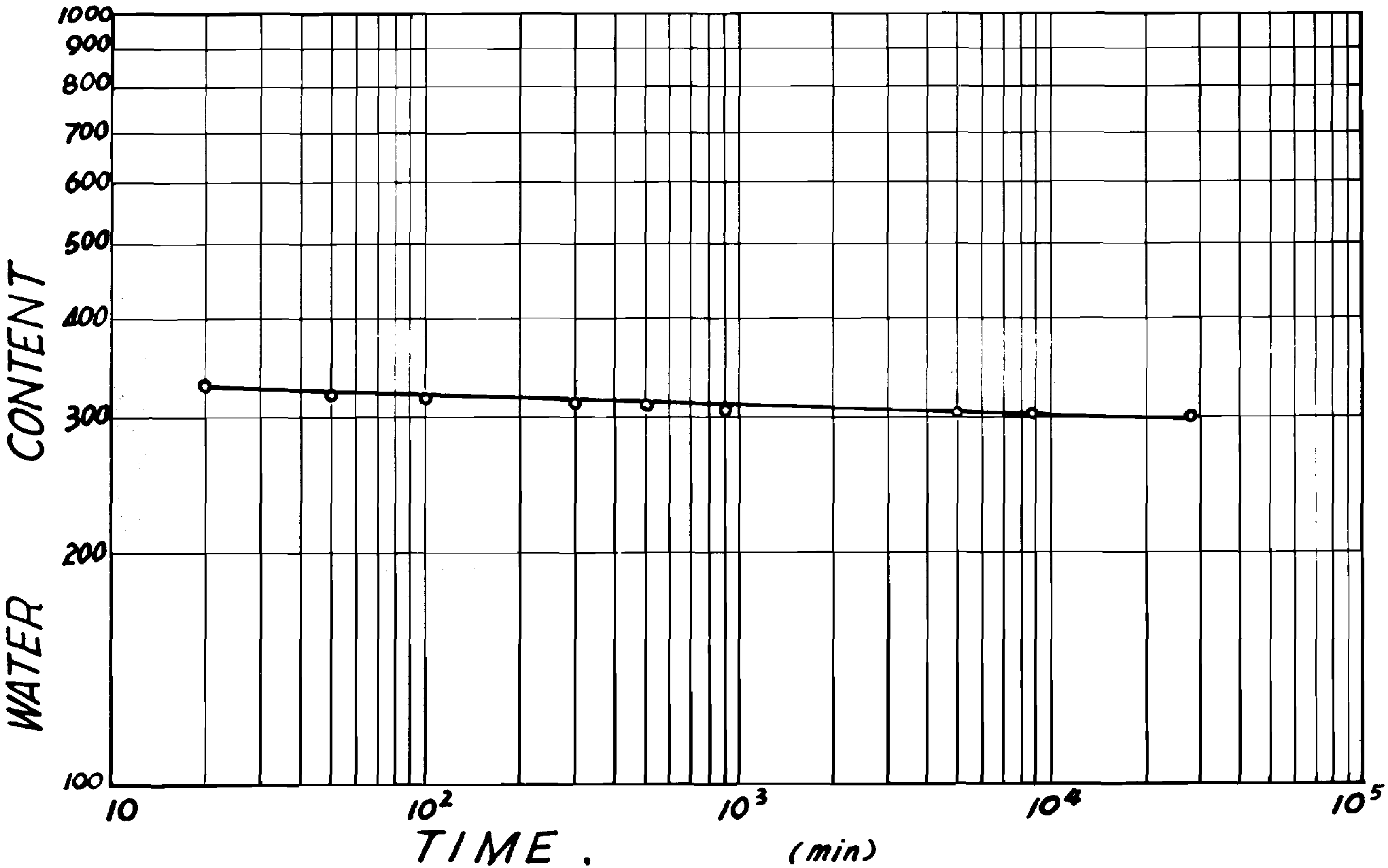



FIG. 5. CHANGE IN WATER CONTENT OF TOP LAYER.

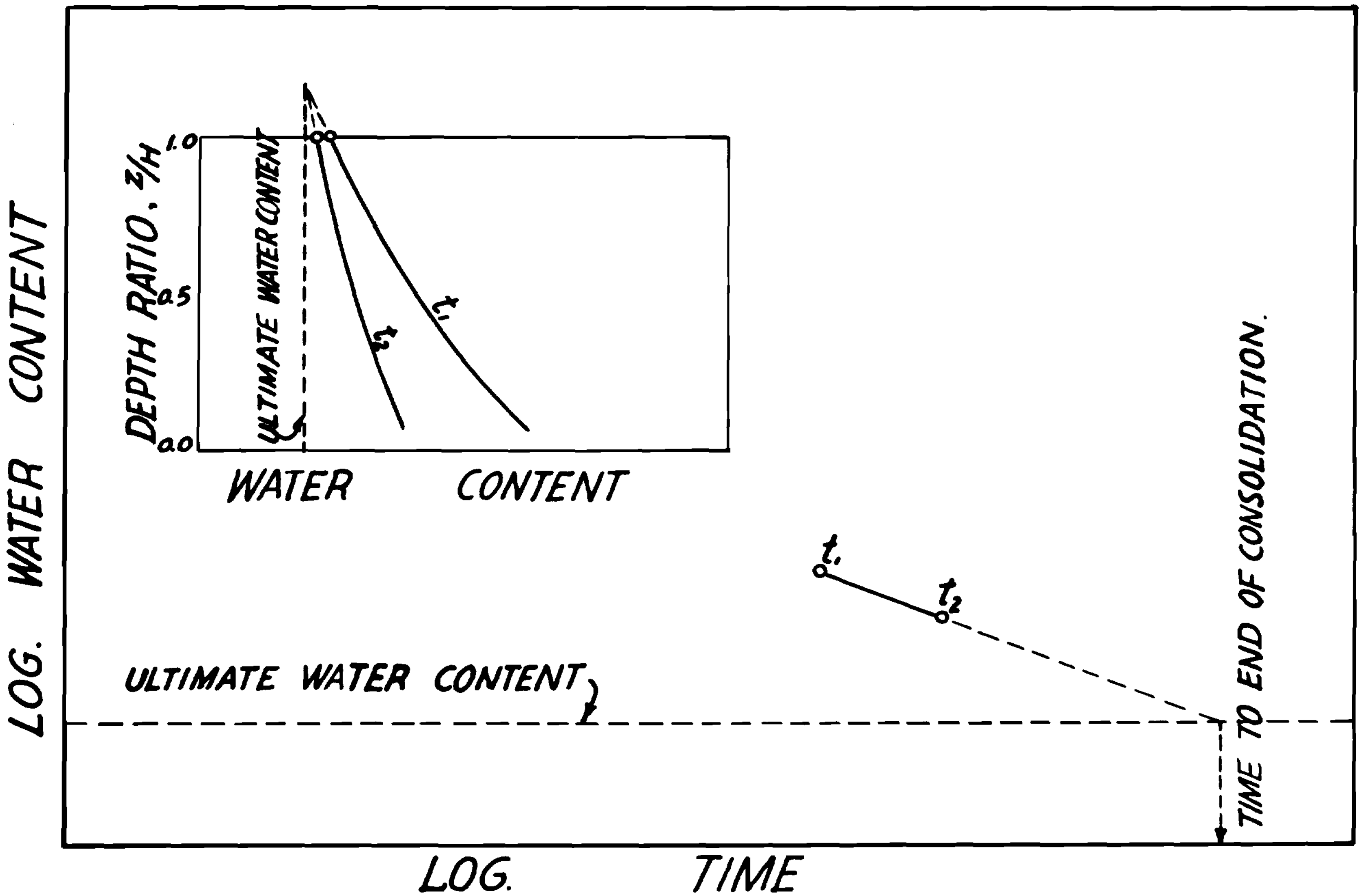



FIG. 6. APPLICATION TO FIELD CONSOLIDATION

Discussion

Mr. Hemstock asked about hysteresis when the load was removed from the sample. Prof. Wilson said that the curve was very flat; practically no rebound was observed. He explained that most of the tests were stopped, however, and not allowed to rebound since it was desired to obtain the water content in various parts of the sample immediately after the load had been removed.

Mr. Schlosser asked Prof. Wilson at what depth he would correlate his testing - near the surface or deep down in the peat layer. Prof. Wilson replied that they would be correlated to deep in the peat layer, the values would then be projected upwards through the profile.

## III. 3. SAMPLING IN MUSKEG FOR ENGINEERING PURPOSES

K. O. Anderson

(Manuscript not available for publication)

Discussion

Mr. Zirul suggested that Prof. Anderson is probably familiar with snow samplers and mentioned the possibility of dynamic sampling of peat with a very high rate of penetration. Prof. Anderson said that Hvorslev in his book also mentions this approach.
Dr. Radforth raised the question of frozen samples and pointed out that great difficulty has been experienced by his group in obtaining samples at depth in the frozen state. The technique was to insert a tube into the peat, then to pour in liquid air. The sample is brought up frozen onto the outside of the tube. He wondered, however, if it is really an undisturbed sample. Certainly, it is not a perfect sample in terms of dimensions, as it is pear-shaped. Mr. Harwood stated that it is almost impossible to get a sample out of its natural environment without losing some of its moisture. He stressed that it was necessary to determine first of all why the sample was needed, then to develop a method to give the desired information. He suggested that acoustical or resistivity methods might be used.

## III.4. DESCRIPTION D'UN RUGOSIMETRE DE SURFACE POUR LE MUSKEG

W. R. Newcombe et J. R. Radforth

Résumé:

Ce papier décrit un instrument qui donne facilement et rapidement une lecture représentant les caractéristiques de rugosité d'un certain type de muskeg. Les principes de base d'opération du rugosimètre de muskeg sont semblables et analogues à ceux du rugosimètre de surface du type métallique. L'appareil servant à recueillir les données consiste simplement en une barre montée, au niveau ou en pente, sur deux supports verticaux. Une sonde semblable à une jauge mécanique de profondeur glisse le long de la barre. La sonde glisse aussi suivant la verticale. La hauteur relative de rugosité, mesurée le long d'un profil à n'importe quel intervalle, est transmise à une calculatrice qui fournit rapidement une valeur de rugosité. La calculatrice vient de subir une période d'essais au laboratoire et n'a pas encore été expérimentée sur le terrain. On suggère d'utiliser les valeurs de rugosité en corrélation avec les facteurs de rendement connus des véhicules et en prévision du rendement des véhicules projetés.

- * * * -

## III.4. A PROPOSED SURFACE ROUGHNESS METER FOR MUSKEG

W. R. Newcombe and J. R. Radforth

Abstract

This paper describes the development of an instrument that will give a reading representative of the roughness characteristics of a certain type of muskeg easily and quickly. The basic principles of operation of the muskeg roughness meter are similar and analogous to those of the stylus type metallic surface roughness meter. The prototype data collecting device will consist simply of a bar which will be set up on two vertical supports and levelled or aligned to a slope. A probe similar to a mechanic's depth gauge will slide along the bar; the probe will also slide in a vertical direction. Relative roughness height measured along any profile at any interval is fed into a computing component which quickly displays a roughness value. The computer component has just passed through the laboratory development stage and has not yet been tested in the field. It is suggested that surface roughness values can be used in correlation with known vehicle performance ratings and in the prediction of vehicle performance.

## III. 4. A PROPOSED SURFACE ROUGHNESS METER FOR MUSKEG

W. R. Newcombe and J. R. Radforth

The need to travel "cross-country" in Canada's Northland and thus the need to travel over muskeg is rapidly becoming very great. Not only will it be necessary to know the performance of many types of vehicles on many types of muskeg, but one will need to be able to predict the performance of vehicles.

To know the performance, it is necessary to be able to measure it. The following often-quoted statement of Lord Kelvin emphasizes the need for measurements: "I often say that when you can measure what you are speaking about and express it in numbers you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind."

One of the characteristics of muskeg which affects the performance of vehicles, especially the performance of small, light vehicles is surface roughness, and the aim of the project described herein is to develop an instrument that will give a reading representing the roughness characteristic of a certain type of muskeg easily and quickly.

Since the measurement of the surface roughness of machined metallic surfaces is already a well-developed art, it was decided that, as a starting point, the basic principles of operation of the muskeg roughness meter should be similar and analogous to those of the stylus type metallic surface roughness meter. This meter gives a reading in microinches (40 microinches approximately equals 1 micron) which represents the arithmetical average or root mean square average of the height and depth of surface irregularities above and below a mean datum. A typical roughness reading for a finely ground surface is about 10 and for a roughly machined surface is about 250. Typical readings which would be expected from a muskeg roughness meter would be a million times greater, and thus, the reading would be in inch units. For instance, a reading of 20 will mean that the mean deviation of the surface irregularities will be 20 inches.

Although it would be possible to take measurements of surface deviations from some datum by ordinary surveying methods and process the data by long hand or by digital computer, it is felt that a portable instrument which will give a direct reading of the roughness in the field is desirable. This device will be described in the following paragraphs.

## Definitions

Surfaces in general are very complex in character, and before one attempts to measure the roughness characteristic of muskeg one must define what is being measured. It is also necessary to make some simplifications, set up a mathematical model of a typical surface and select a datum from which measurements are to be made.

The surface roughness of muskeg can be defined by direct analogy to the definitions of surface roughness of machined metallic surfaces.

## Waviness

Surface irregularities of considerable wavelength of a periodic character.

## Roughness

Relatively finely spaced surface irregularities, the height, width, and direction of which establish the predominant surface pattern. Roughness is superimposed on the waviness of the surface.

## Roughness Height

In the measurement of metallic surface roughness the roughness height is rated in microinches arithmetical average deviation from the mean line. The curve shown in Figure 1 represents a roughness profile of a short portion of a surface. To obtain an average height measurement of this curve it is necessary to establish a datum from which to measure and the mean line or centreline is used for this purpose. This is a line drawn through the centre of the curve so that the area above the line is equal to the area below the line.

The equally spaced vertical lines $y_1$, $y_2$, $y_3$, etc. show the deviations of the surface from the centreline. Two types of average deviation have been used to evaluate surface roughness height as described in the following paragraphs. In arriving at an average, the parts of the curve below the line are considered to be inverted or positive in sense.

## Arithmetical Average Height

The arithmetical average height of the profile in Figure 1 can be expressed as follows:

$$\frac{y_1 + y_2 + y_3 + y_4 \cdots\cdot + y_n}{n}$$

n = total number of vertical measurements.

Taking an infinite number of vertical measurements the arithmetical average height is:

$$\frac{1}{\ell}\int_{x=0}^{x=\ell} y\,dx$$

x - distance along line
$\ell$ - length over which average is taken

## Root Mean Square Average Height

This type of average gives greater weight to the larger deviations from the centreline. It gives values about 11% higher than the arithmetic average, and this difference will be negligible in most circumstances.

The R.M.S. average height of the profile shown in Figure 1 is:

$$\sqrt{\frac{y_1^2 + y_2^2 + y_3^2 + \cdots + y_n^2}{n}}$$

n - total number of vertical measurements.

Taking an infinite number of vertical measurements the R.M.S. average height is

$$\sqrt{\frac{1}{\ell}\int_{x=0}^{x=\ell} y^2\,dx}$$

x - distance along centreline
$\ell$ - length over which the average is taken

## Roughness Width

The roughness width is the maximum spacing between repetitive units of surface pattern. The roughness width is used to establish the roughness width cutoff value or sampling length which should always be greater than the roughness width.

## Roughness Width Cutoff or Sampling Length

Many methods have been used to evaluate surface roughness depending on the aspects of roughness which seem to have the most important influence on the problem which is involved. It is felt that an instrument which will measure and display the arithmetic average roughness height of a muskeg surface will give a satisfactory and consistent representation of the roughness characteristic. However, difficulties arise when a sampling length and measurement interval must be selected. Although it is possible to take an arbitrary length of the surface and consider everything within the selected length, the result may not be a good value of the roughness.

Referring to Figure 2, it is clear that different values would be obtained for the surface roughness if determined separately for lengths

$L_1$ and $L_2$, since the waviness affects each reading to a varying extent, and the question arises as to what extent the waviness should be allowed to influence the assessment of the roughness. Another problem arises when surfaces of the type shown in Figure 3 are being assessed. The roughness value will again depend on the sampling length L, but now there is the problem of the position of L on the surface. The sample length could be made sufficiently long to include a significant proportion of both the rougher and the smoother parts of the surface but the value of the result would be of a dubious nature. Fortunately, it is believed that muskeg has a more regular surface roughness.

Since it is difficult to assess which frequencies are important and which are not, the best that can be done is to select and standardize a reasonable sampling length. The roughness values obtained must be accompanied by a statement or understanding of the value of the sampling length, and, if the sampling length is compatible with the character of the surface roughness, consistent and meaningful results may be expected. A suitable sampling length cannot be fixed until some experimentation with different sampling lengths has been done. However, the largest waves in muskeg have an estimated half-wave length of 4 feet and a sampling length of 12 feet will be selected for the first trials.

## Proposed Meter

### Data Collecting Device

The prototype data collecting device will consist simply of a bar which will be set up on two vertical supports and levelled or aligned to a slope. A probe similar in nature to a mechanic's depth gauge will slide along the bar, and the probe will also slide in a vertical direction. The bar will be graduated in appropriate intervals and the probe will be graduated in inches. A diagram of this device is shown in Figure 4. Relative roughness heights can be measured along a profile at any desired interval. This data will then be fed into the computing component which will quickly display the roughness value. After sufficient experimentation has been completed so that a suitable sampling length and measurement interval can be fixed, it is envisaged that a data collecting boom can be attached directly to a vehicle. This boom would be fitted with a probe, or more likely a probe at each measurement interval, which would automatically transmit data to the computing component.

### Computing Component

A device has been designed and partially constructed that will analyse a finite number of ground profile height measurements and from these measurements compute the arithmetic average or the root mean square roughness of the ground profile. This device consists of two main parts, a profile simulator and the computing component itself. This instrument has just passed through the laboratory development stage and therefore has not yet been constructed in a form suitable for use in the field. However, its construction has proceeded far enough to enable it to be calibrated and to test the principles of operation.

The purpose of the profile simulator is to translate ground profile measurements into a corresponding electrical signal which can then be processed by the computing component.

The profile simulator consists of two main parts, a bank of 16 potentiometers and an 18-position motor-driven switch. The profile data measured from an arbitrary reference datum is manually set on the potentiometers. The motor-driven switch is operated and it selects each potentiometer output for a finite period of time, so that over one switching cycle the 16 outputs are selected in a sequence which is then the electrical signal corresponding to the original profile. This signal does not represent the true profile but a stepped approximation, as shown in Figure 5. The height of each step corresponds to the height of the measuring point on the true profile, and the width of the step is proportional to the length of time that the switch contacts dwell on each potentiometer output.

For the preliminary development of the instrument, a Donner desk-type analogue computer was used as the computing component.

The circuitry was designed to perform the operations involved in the calculation of arithmetic average roughness and mean square roughness height. These operations are shown in block diagram form in Figure 6.

Firstly, all 16 potentiometer outputs are simultaneously fed into block one which automatically computes their average and attaches a minus sign to this average. This negative average is fed to block two along with the sample input, which has already been described as the output from the motor-driven switch. Block two adds the negative average to the sample input, thus establishing a mean line through the electrical signal representing the ground profile.

Block three takes this signal and inverts the portion below the mean line so that the input to block four consists of the absolute value of the steps which made up the input signal to block three.

Block four is an integrator which adds up the heights of all 16 steps as they are fed in. The output from block 4 is a finite voltage which is supplied to a voltmeter. This voltmeter, which forms the readout stage, can be calibrated to read arithmetic average roughness height in inches.

For the calculation of mean square roughness, block 3 is a squaring circuit which puts out the absolute value of the square of each step in the profile. The readout stage can then be calibrated to read either mean square or root mean square roughness height in inches squared or inches respectively.

It has already been mentioned that a data collecting device is envisioned that will consist of a number of probes spaced at equal intervals along a vehicle-mounted boom. Each probe could be fitted to its own potentiometer so that the function of the present profile simulator would be duplicated. In this way, profile measurement and roughness calculation would be accomplished in one relatively convenient operation.

Further development of the instrument, if carried out, will mainly involve design considerations in order that a fully portable instrument capable of being used under field conditions can be constructed. The basic principles of operation have been fully tested and proven in the laboratory, and it is expected that they will be incorporated in the final instrument.

## Measurement Interval

Since this meter has been designed to give a roughness value from a finite number of measurements of ground profile height it will be necessary to specify a standard measurement interval that will give a satisfactory value representing the surface roughness. The prototype measuring device will allow measurements to be taken at any interval and a satisfactory interval will be selected after experimentation. It is believed that a four-inch interval will produce sufficiently accurate and consistent results.

## Measurement Pressure

The basic reason why roughness values for muskeg surfaces are required is that it is hoped that this information can be used in correlation with known vehicle performance ratings and in the prediction of vehicle performance. Therefore, there should be a direct relation between measuring pressure and vehicle ground pressure. A typical value of vehicle ground pressure is in the range 2-4 psi and it would not be difficult to apply this pressure with a measuring probe. However ground pressure on the hummocks will be much higher due to impact from a vehicle in motion and this creates a problem which will need to be investigated. It is possible that a roughness value obtained by a higher measuring pressure might provide better correlation with vehicle performance ratings because of the variability in the compressibility of the muskeg surface.

## The Bearing Area Curve and Form Factor

Another method of evaluating surface roughness is by constructing a bearing area curve. In Figure 7 a bearing area curve has been constructed by adding the lengths a, b, c, etc. at depths x, y, z, etc. below the reference line. The bearing curve indicates the percentage bearing area which becomes available as the crests are removed or pushed down. A measure of this kind might have a closer relationship to vehicle performance as it refers to the condition after the muskeg surface has been compressed by the vehicle.

The load carrying area of surfaces can also be expressed by a form factor obtained by measuring the area of material above an arbitrarily chosen baseline in the section and the area of the enveloping rectangle. Then the degree of fullness is:

$$\text{Degree of fullness} = \frac{\text{area of profile section}}{\text{area of enveloping rectangle}}$$

These two measures of surface roughness can be obtained from the same data that will be used to calculate the arithmetic average roughness height, and the relative value of all three measures of surface roughness could be investigated for their usefulness in describing muskeg.

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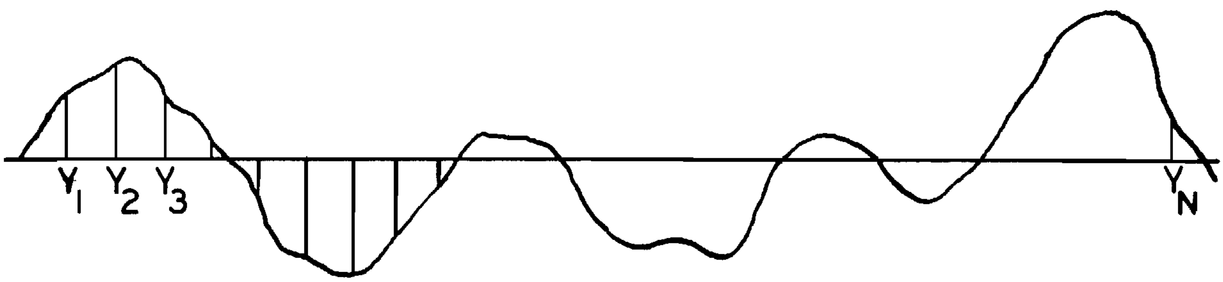


ROUGHNESS HEIGHT MEASURES

$$\text{ARITHMETICAL AVERAGE} = \frac{Y_1 + Y_2 + Y_3 + \ldots\ldots + Y_N}{N}$$

N = TOTAL NUMBER OF MEASUREMENTS

FOR AN INFINITE NO. OF MEASUREMENTS,

$$AA = \frac{1}{\ell}\int_{X=0}^{X=\ell} Y\,dX$$

X = DISTANCE ALONG LINE

$\ell$ = LENGTH OVER WHICH AVERAGE IS TAKEN

$$\text{ROOT MEAN SQUARE} = \sqrt{\frac{Y_1^2 + Y_2^2 + Y_3^2 + \ldots\ldots + Y_N^2}{N}}$$

FOR AN INFINITE NO. OF MEASUREMENTS,

$$RMS = \sqrt{\frac{1}{\ell}\int_{X=0}^{X=\ell} Y^2\,dX}$$

X = DISTANCE ALONG LINE

$\ell$ = LENGTH OVER WHICH AVERAGE IS TAKEN

FIG. 1. ROUGHNESS PROFILE AND ROUGHNESS HEIGHT MEASURES.

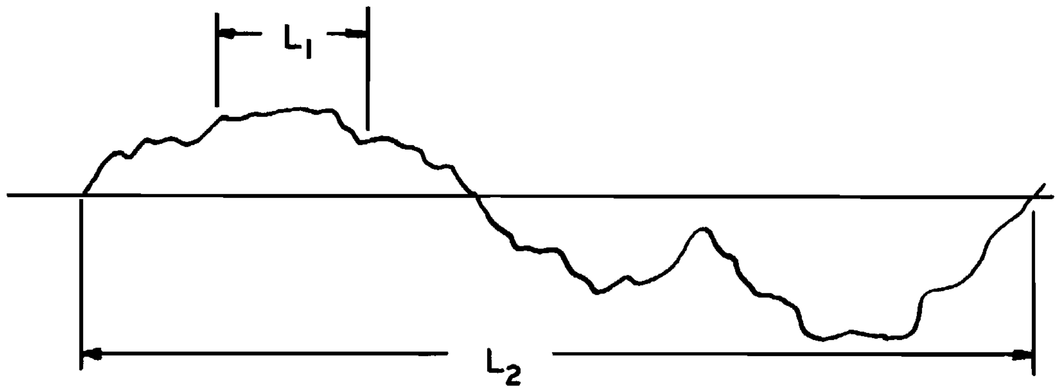


FIG. 2 EFFECT OF DIFFERENT SAMPLING LENGTHS ON MEASURED VALUE OF SURFACE ROUGHNESS

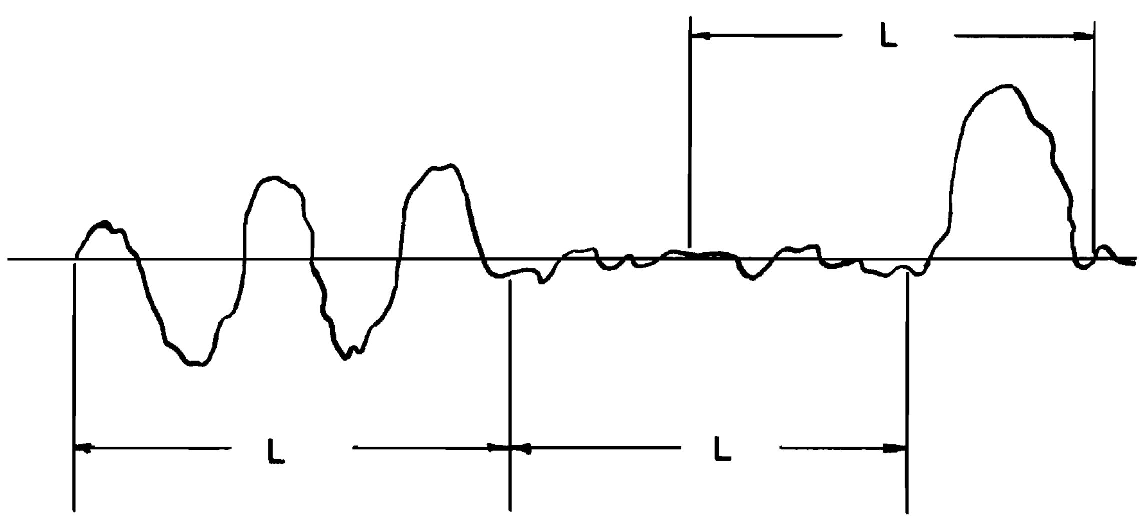


FIG. 3 EFFECT OF POSITION OF SAMPLING LENGTH ON MEASURED VALUE OF SURFACE ROUGHNESS

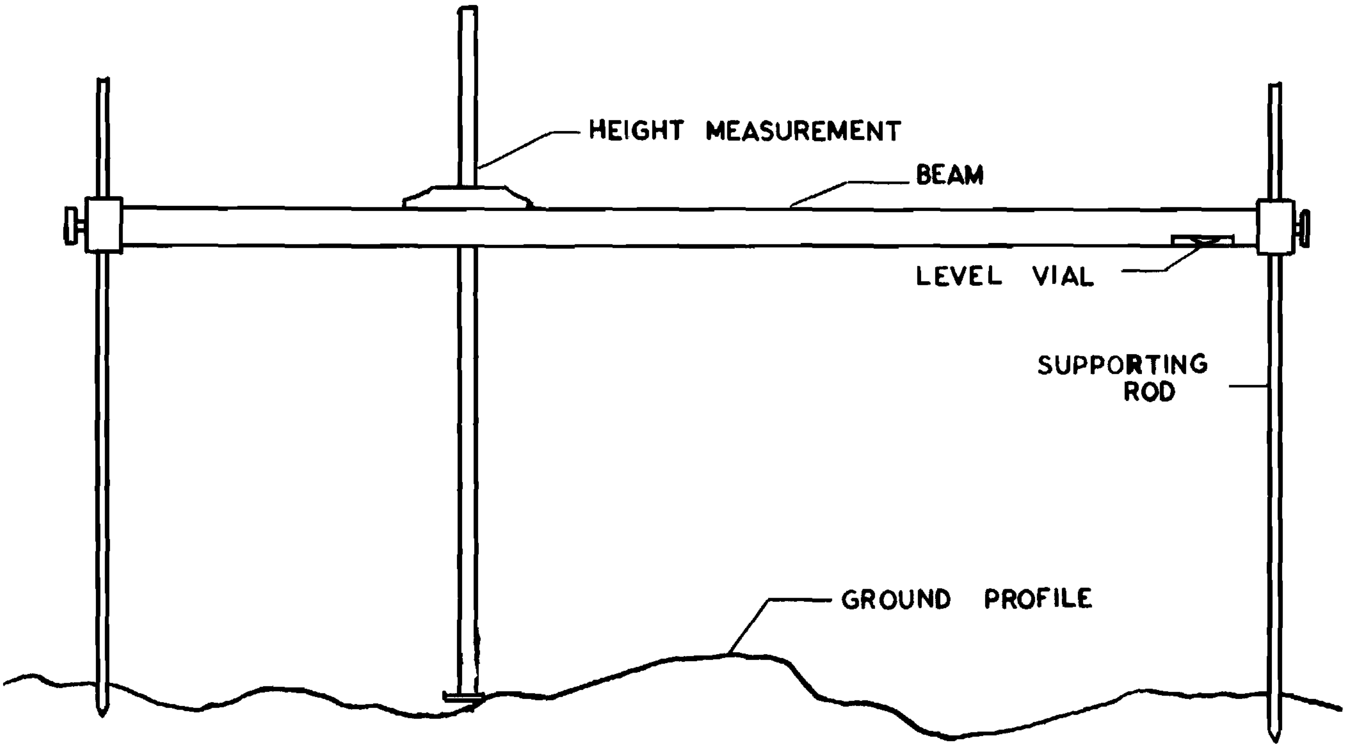


FIG. 4 DATA COLLECTING DEVICE

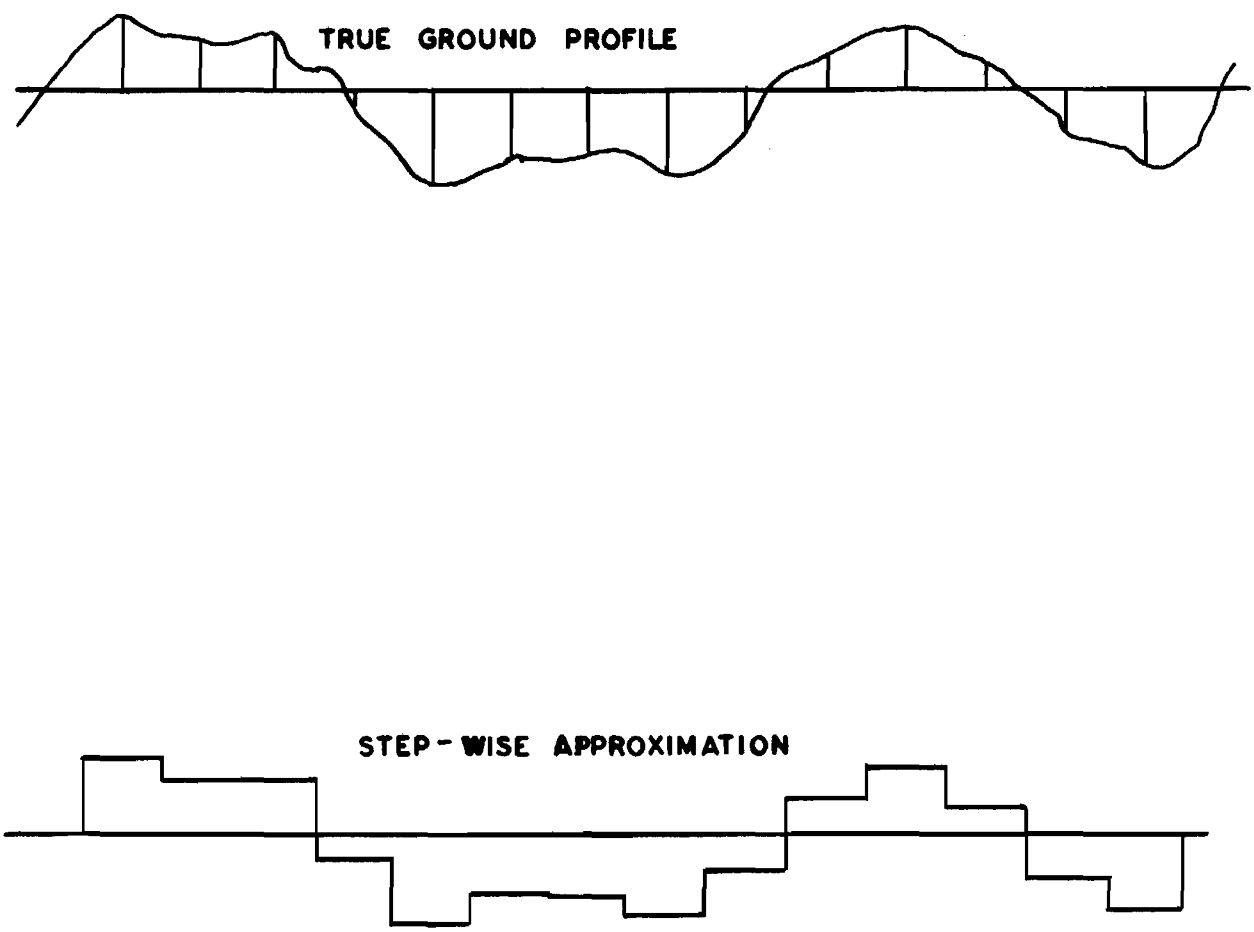


FIG. 5

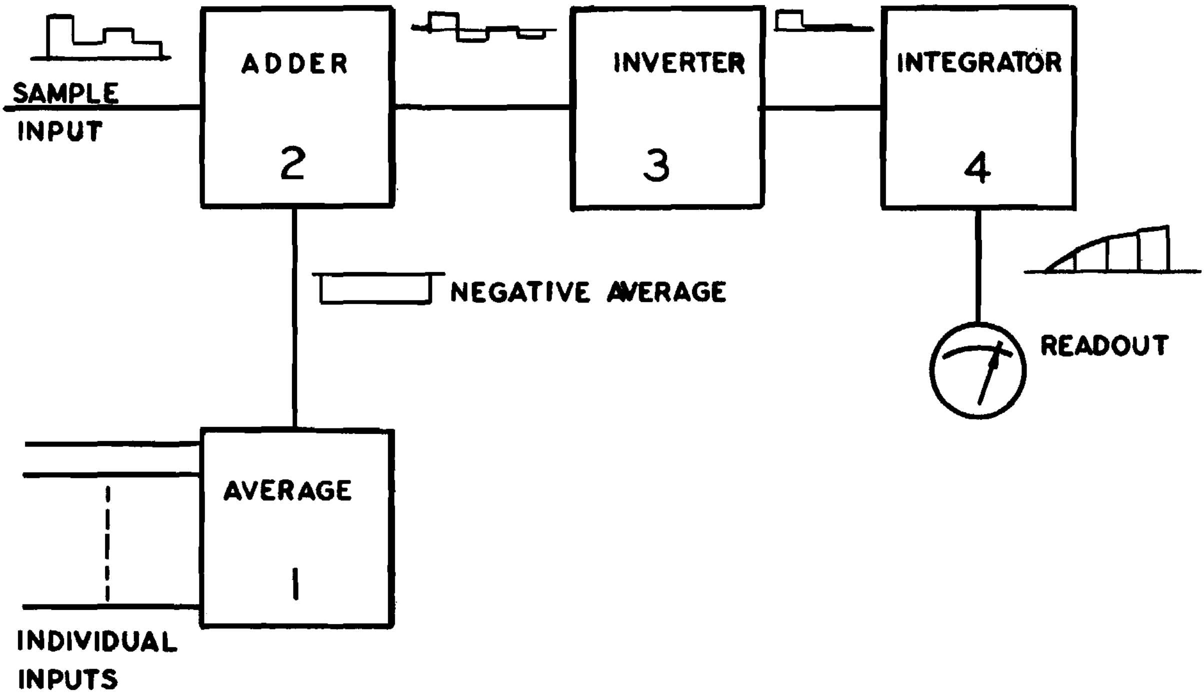


FIG. 6 BLOCK DIAGRAM - ARITHMETIC AVERAGE ROUGHNESS COMPUTER

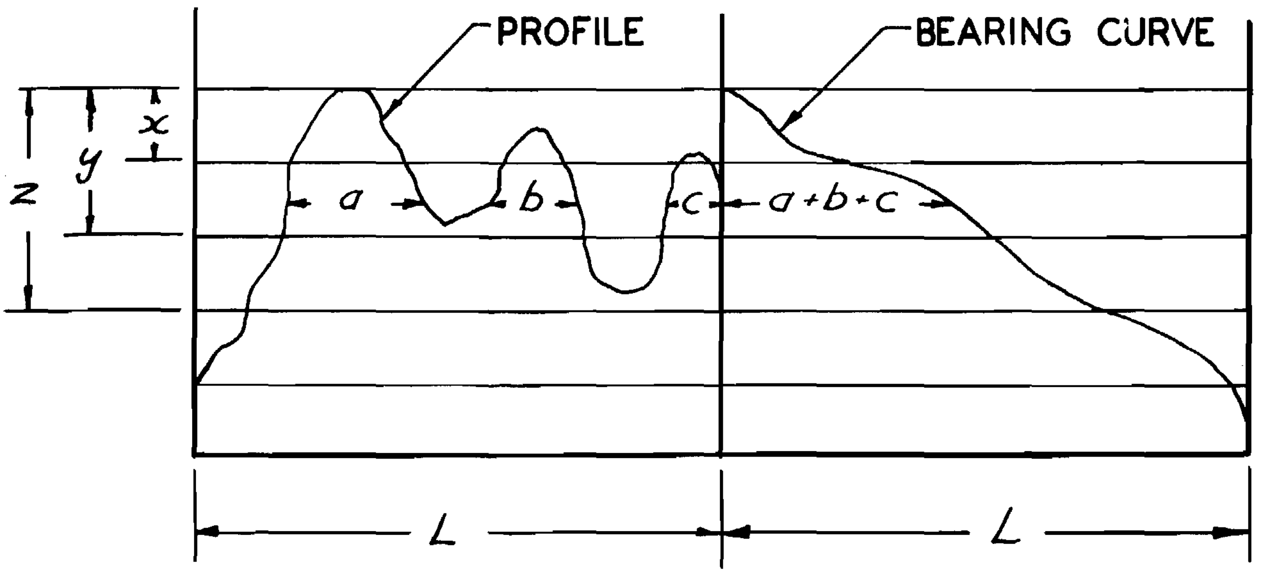


FIG. 7 BEARING AREA CURVE

Discussion

Prof. Wilson wondered how the instrument accounted for the pitch of the vehicle Mr. Ashdown pointed out that the measurements are taken when the vehicle is stationary. Dr. Radforth observed that the matter of field measurements presents quite a problem. The presence of a measuring device - a vehicle, or whatever the device may be - affects the measurement. In measuring the pitch and roll of a vehicle, the conformation of the terrain is affected by the approach of the vehicle. The surface recovers, however, to a very large degree. Measurements of elasticity, among other things, are involved. It is necessary, therefore, to get down to basic principles which this approach attempts to do.

Mr. Harwood suggested that it might be possible to get the vehicle itself to indicate something about terrain roughness, and "digitalize" that. Mr. Hemstock disagreed, pointing out that the roughness coefficient of a large vehicle is entirely different from that of a small vehicle. He said that a roughness factor for the terrain has to be related to a particular vehicle.

Prof. Naemi asked if the objective of the study was operator comfort. Mr. Ashdown replied in the negative, and explained that it had to do with vehicle capability. He said that Prof. J. N. Siddall of O.A.T.R.U. is interested in the fundamental properties of the terrain to permit better design of vehicles to accommodate to the terrain. Prof. Naemi pointed out that amplitude and frequency do have an effect on driver comfort. Mr. Schlosser mentioned that they also affect the undercarriage of the vehicle.

Dr. Radforth remarked that 10 years ago muskeg was thought of as something beautifully flat. Winter roads are built in muskeg on this premise, since this terrain is flatter than other terrain. As soon as winter goes, however, the flatness disappears. He pointed out that muskeg can actually present a very difficult face, i.e. it is anything but flat. Vehicle features (tracks, load carrying capacity, driver comfort, etc.)have to be designed relative to the terrain features. Mr. Ashdown suggested that everyone present probably knows the range of amplitude and frequency of mounds in EI, for instance kinesthetically, but this information is not quantified. Dr. Radforth stated that in the area of Kenora, Ontario, the mounds in EI muskeg can be in the order of 3-4 ft. high. In southern Ontario (as in northern central B.C.) the mounds are in the order of 2 ft. high. Therefore, this factor is variable and depends on environmental characteristics.

Mr. Harwood considered that this paper presented a very interesting approach. No statistical information is available on ice surface conditions, but once it can be sampled, perhaps by the method outlined here, then there are some data to go on.

# III.5. UNE ETUDE DU COMPORTEMENT PHYSIQUE DES COMPOSANTS DE LA TERRE NOIRE SOUS L'EFFET DE LA COMPRESSION: UN EXPOSE EN COURS

I. C. MacFarlane et N. W. Radforth

Résumé:

Cet exposé en cours présente quelques commentaires sur l'arrangement structural des terres noires et le processus physique prenant place pendant le chargement. Il décrit aussi le développement d'un appareil qui utilise un microscope et les techniques de photomicrographie pour observer les phénomènes physiques de la terre noire soumise à la compression. L'exposé indique aussi la direction à prendre dans les recherches futures.

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# III.5. A STUDY OF THE PHYSICAL BEHAVIOUR OF PEAT DERIVATIVES UNDER COMPRESSION - A PROGRESS REPORT

I. C. MacFarlane and N. W. Radforth

Abstract

This progress report presents some comments on the structural arrangement of peats and the physical process taking place during loading; describes the development of an apparatus utilizing a microscope and photomicrographic techniques to assist in observing the physical phenomena in peat subjected to compression; and indicates the direction to be taken in continuing research.

## III. 5. A STUDY OF THE PHYSICAL BEHAVIOUR OF PEAT DERIVATIVES UNDER COMPRESSION - A PROGRESS REPORT

I. C. MacFarlane and N. W. Radforth

Investigations into the compression characteristics of peats have been underway for at least 25 years although - as mentioned in a paper presented earlier at this conference - most of the work has been done in the past 10 years. From the outset it has been evident that peats exhibit characteristics which militate against a precise settlement analysis based on the Terzaghi consolidation theory. In general, however, the approach to the settlement process in peats has been similar to that for mineral soils exhibiting exceptionally large secondary compression effects. Most investigators have been preoccupied with the need to obtain immediate results; consequently (and understandably) they have relied on the concepts and techniques readily at hand.

In the study of the settlement process in peats, some phenomena do show a striking resemblance to clay (and particularly to organic clay) compression characteristics. Although these similarities are recognized and provide guidance for research, it is considered that in many ways the physical process of compression of a peat is substantially different from that of a clay or silt, due to the complex biological nature and structure of the peat.

Recent investigators are beginning to treat peat as a unique material and to recognize its botanical (or biological) distinctiveness as compared to mineral soils. This is exemplified by the work of Adams (1964) in his hypothesizing as to water movement in peat during compression and by Schroeder and Wilson (1962) with their rheological approach to peat under load. It is now generally appreciated that the concept of compression as comprised of two separate and distinct phases, one terminating at a clearly defined point and the other continuing for a long period of time, is not at all accurate for peats. Primary consolidation and secondary compression are considered to be purely empirical divisions of a continuous compression process, both occurring simultaneously during part of the process.

What happens to peat is very largely a function of the structure of the material. By "structure" is meant the arrangement of the constituent peat elements, both in the macro- and in the microscopic aspects. It is this structure or arrangement that affects the retention and expulsion of water in the system, gives it its strength, and which differentiates one peat type from another. The question immediately arises: how does one refer to peat structure in precise mathematical terms? The investigation described rather briefly herein was undertaken at McMaster University to study the structure of a particular peat type, in its macro and micro aspects, and the effect on this structure of the application of compressional loads. A more complete account will be published in due course. The investigation is based on the hypothesis that certain peats that are pure as to a single genetic plant constituent, and certain other peats that are consistent admixtures of two or three generic plant constituents, control the quality of physical change in that peat when it is subjected to compressional loading. Although only one particular peat is presently under investigation, it is hoped that the research program will establish principles that can be applied equally well to other types.

The peat used in this investigation is termed a "non-woody, fine fibrous" peat and was obtained from a site near Moonbeam, Ontario, at the location of a failure of a highway built on that peat. The peat sample is in an excellent state of preservation and shows little evidence of disintegration or decomposition. The chief generic constituent of this peat is hypnum, although there are occasional intrusions of a sedge (carex). The characteristic macrostructural feature of the peat is its homogeneity, not only in its generic constitution, but also in the arrangement of the peat elements. Axes of the fossilized plant material are generally oriented horizontally and parallel to one another, presenting an appearance of remarkable consistency. This, of course, is a function of the growth habit of the chief generic constituent of the peat and, subsequently, of its deposition.

The peat elements (i.e. the discrete particles) consist of a central stem, sometimes with branches, and with a spiral system of leaf appendages, the latter curled about the stem or branch and thereby providing many minute capillary spaces. The stems are actually hollow tubes with an average outside diameter of 0.25 mm when wet and 0.15 mm when dry. The wall of this tube is four or five cells thick. The individual elements vary considerably in length from 3 to 32 mm (in a random sampling). The cell structure within the leaves and stem is very uniform in appearance.

The peat has a water carrying capacity of close to 1500%, a specific gravity of 1.3 and a loss on ignition of 96%.

In any treatment of the structure of peat, the matter of designation is most important. In the peat under investigation, the discrete elements are often called "fibres". In fact, they are much more than just fibres (which are defined as "very elongated cells with tapering ends, occurring singly or variously grouped into strands"). They may - and probably do - contain fibres, but these elements also include leafy appendages, as has already been indicated. Sometimes such elements are referred to as "axes" (i.e. as woody or non-woody axes) but they do not really fall within the definition of an axis.

Such elements are common components of many peats. It is true that they vary in size, orientation, and even in gross morphology, but they obviously do have a family resemblance, which is why they are grouped together and called "fibres" or "fibrous peat". Considerable thought is now being given to the development of a mathematical expression for this sort of discrete peat element (based on dimensional analysis), to incorporate both the macro- and the microstructure, then to assign a name to it. If successful, a similar approach can be made to other peat constituents such as the woody elements (lignified tissues) and amorphous elements.

A primary characteristic of peats and directly related to the question of structure is their associated water content. Water is a component part of a biological system and even in this fossilized condition of the plant matter it plays an important rôle. The physics and chemistry of water retention in peats are significant in any consideration of permeability characteristics, shear characteristics, and the expulsion of water from a system under load. One of the earliest examinations of the methods whereby water is held in peats was that carried out by Ostwald (1921) and later modified somewhat by Dumansky and Stabnikosf (Dalton, 1954). The various types of held water are:

1. Free water in large cavities of the peat.
2. Capillary water in the narrower concave and convex cavities.
3. Physically bound or adsorbed water.
4. Chemically bound water or water of hydration.
5. Colloidally bound water.
6. Osmotically bound water.

The two extremes of the peat structure spectrum may be represented on the one hand by an open-structured course fibrous peat with the interstices filled with a secondary structural arrangement of non-woody fine fibrous elements, and on the other hand by an amorphous granular peat with its high proportion of microscopic particles and its large colloidal fraction. In the former peat type, which represents fossilized elements in an excellent state of preservation, most of the held water will be free water and capillary water. Under normal circumstances the initial void ratio is very high and consequently this peat will have a large primary consolidation phase. Dissipation of excess pore water pressures will be very rapid and the load is transferred to the organic structure at a very early stage in the test. It is doubtful that there is much "collapse" or "rupture" as such of the discrete peat elements, either during this or later stages. Rather they will gradually creep, rearrange themselves relative to each other, and slowly assume a more densely packed arrangement. The microscopic study of the peat elements showed that the cell walls appear to be quite freely permeable to water. This would imply that all water molecules within the peat mass are in contact and thereby eliminating the possibility of any "trapped" water. However, this aspect will be more carefully studied in a later stage of the present investigation.

In the amorphous granular peat there is proportionally less free water and capillary water and much more physically bound and colloidally bound water. Initial void ratios again can be quite high but upon application of load the pores and channels quite rapidly become clogged with flocculating colloidal matter and the permeability of the peat is significantly reduced. Consequently, for this peat type the primary consolidation phase may stretch out for a long period of time and will not represent as high a proportion of the total settlement as for the other peat type considered. Amorphous granular peats have been shown by Schroeder and Wilson (1962) and colleagues to be a quasi-plastic material and after pore water pressure dissipation settlement will continue over a long period as plastic flow.

Between these two extreme peat types, all gradations exist and will exhibit the combined features of both the amorphous granular and fibrous peats. There is little doubt that the contradictions and confusion in published results of laboratory consolidation tests arise, in part, from the use of diverse types of peat in the tests.

The primary consolidation phase of the settlement process in peats is relatively straightforward; ultimately however, we are much more interested in the secondary effects and what causes them since they represent such a large proportion of the overall settlement.

In a consideration of the reaction to compressional load of the peat type under study, certain questions arose relative to the actual physical process taking place within the peat structure:

1. What structural deformation of the discrete particles, macroscopic or microscopic, takes place during the excess pore water pressure phase of compression? Do the peat elements change their shape?
2. What sort of structural rearrangement (plastic or viscous flow) takes place following the excess pore water pressure phase? To what extent do the peat elements change their position relative to one another?

To assist in answering these questions, a microconsolidometer is being devised whereby a small peat sample under load can be observed under a microscope. It is designed to utilize small cube samples of peat 2 cm on a side. The microconsolidometer chamber is constructed of lucite and incorporates "windows" to permit viewing of the peat sample with a microscope while the sample is undergoing compression. Considerable time has been spent in the development and setting up of the apparatus so that very little actual testing has been carried out to date. Since the purpose at this stage is simply to observe deformations of the peat elements, usual consolidation test procedures are not being rigidly followed.

A saturated sample was loaded up to 19 psi and during loading the sample was observed under a microscope at a magnification of 28X and occasionally at 70X. In general, the discrete elements under observation simply moved with the surrounding mass as the load was applied. Over a period of several days, with the load left on the sample, there was only a slight densification of the mass and no observable deformation of the peat elements. These tests are continuing, both for the wet and dry state.

As part of this research program, it is planned to examine and test at least one other peat with another characteristic generic constituent (e.g. sphagnum) and ultimately to apply this procedure to a wide variety of peat types. It is hoped that this sort of approach, together with a rheological study of peats under compression, will assist in the clearer understanding of the true forces at work within a peat under compressional load.

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## III. 6. SOME CONSIDERATIONS OF MUSKEG IN BRITISH COLUMBIA

A. C. Kinnear

(Summary)

In a brief lecture, Mr. Kinnear showed a series of slides of various muskeg areas in British Columbia and described these slides. He pointed out the need to get into the bush to fight forest fires, such as that shown in Figure 2 (B.C. 1192:81) which would involve vehicles capable of negotiating all types of terrain. Many fires are left to burn themselves out since they are so inaccessible. A selected group of the photographs are included herein with the descriptions as follows:

| Figure No. | Photo Number | Geographical Location | Photo Date |
|---|---|---|---|
| 1 | BC 1753:33 | Area of the B.C.-Alberta Boundary line crossing the Petitot River | 2 August 1953 |
| 2 | BC 1192:81 | Forest fires burning in muskeg. General area of northeast B.C. | 26 August 1950 |
| 3 | BC 762:109 | Rocky Mountain Trench looking northwest down the Fraser River from 18,000' above sea level | 26 Sept. 1948 |
| 4 | BC 516:92 | Looking north from area near Tatla Lake over the Chilcotin country | 21 Sept. 1947 |
| 5 | BC 5094:10 | Vertical view of muskeg on the northeast coast of Graham Island, Queen Charlotte Islands | 27 May 1964 |
| 6 | BC 570:7 | Oblique view looking south over the South Arm of Fraser River. Richmond Peat Bog on the left side at middle ground distance | 31 May 1948 |
| 7 | BC 5064:162 | Vertical view of the peat processing plant at Richmond, B.C. alongside the bog | 4 May 1963 |

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### Discussion

Dr. Radforth said that in asking Mr. Kinnear to give a talk on muskeg in British Columbia he was really asking him to do something that would take years of study. He commended Mr. Kinnear for his illustrated talk, which gave a good idea of the distribution of muskeg in this Province.


FIGURE 1.


FIGURE 2


FIGURE 3


FIGURE 4

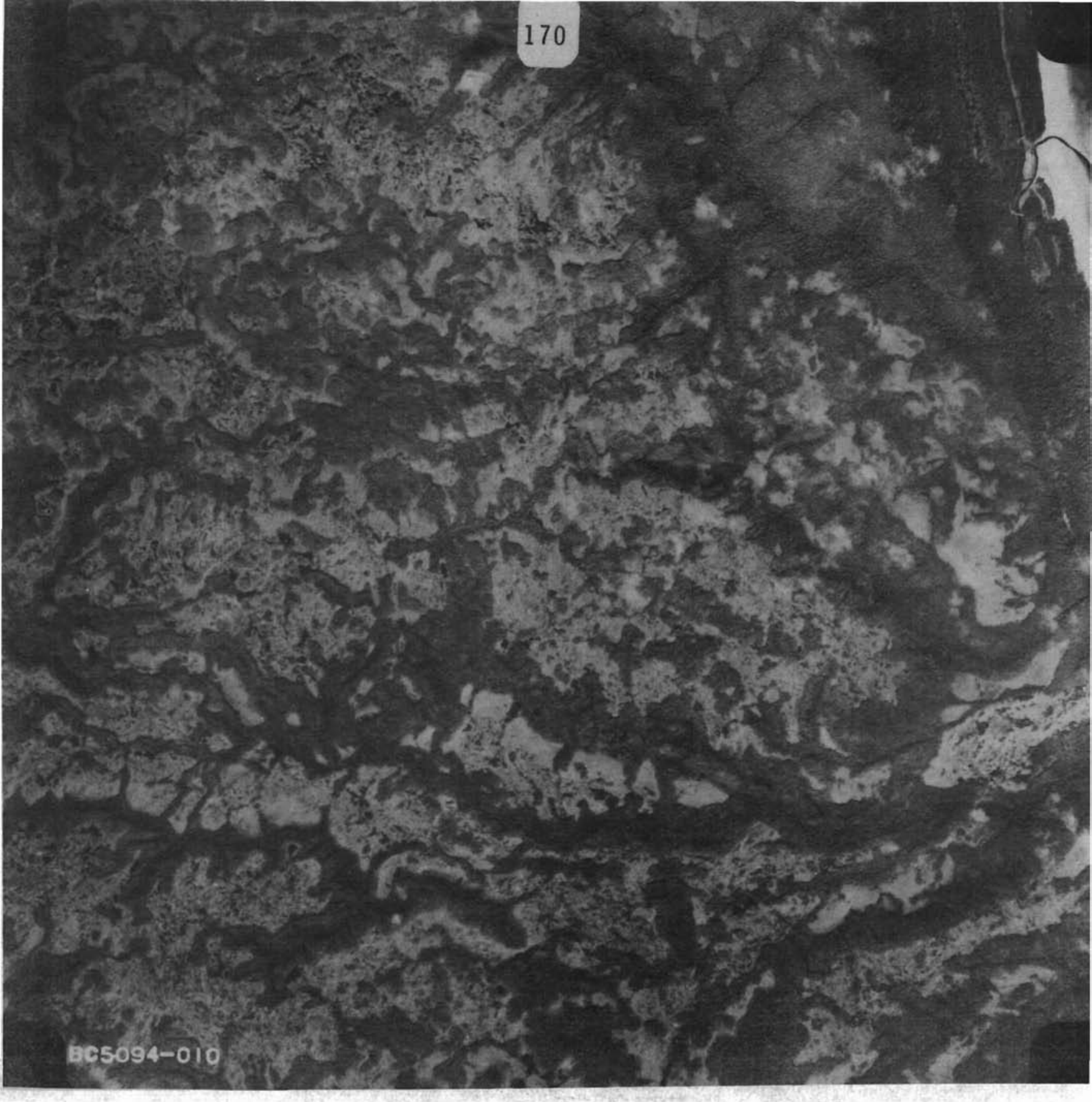


FIGURE 5

FIGURE 6


FIGURE 7

# III.7. L'ORIENTATION DE LA RECHERCHE ET DU DEVELOPPEMENT DU MUSKEG AU CANADA - UNE PREDICTION -

N. W. Radforth

Résumé:

Bien que beaucoup de choses aient été accomplies dans la recherche sur le muskeg pendant les dix dernières années, il reste encore beaucoup à faire. En quelques endroits, cependant, la recherche a le pas sur l'application. Il y a eu très peu d'études dans le domaine du muskeg en rapport avec le développement du nord du pays. Quand les problèmes spécifiques surviennent, des solutions ad hoc sont envisagées, en regard seulement de ces situations bien particulières. Dans la recherche future, l'instrumentation devra recevoir au préalable une attention spéciale. L'emploi des photos aériennes devra être accru dans le travail de reconnaissance sur le muskeg. L'atterrissage des avions sur le muskeg et l'expédition par pipe-lines de la terre noire liquéfiée ne sont que deux développements probables pour l'avenir.

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# III.7. THE TREND OF MUSKEG RESEARCH AND DEVELOPMENT IN CANADA: A PREDICTION

N. W. Radforth

Abstract

Although much has been accomplished in muskeg research over the past decade, much has been left undone. In some areas, however, research is ahead of application. There has been very little planning to accommodate for muskeg in northern development. When specific problems arise, an ad hoc approach is taken, to accommodate for these situations only. In future research, instrumentation should receive primary consideration. Use of airphoto libraries should be extended for reconnaissance work on muskeg. Landing of planes on muskeg and shipping peat slurry by pipeline are only two developments which are probabilities for the future.

## III. 7. THE TREND OF MUSKEG RESEARCH AND DEVELOPMENT IN CANADA: A PREDICTION

N. W. Radforth

The time has come to discuss what we have not done. We have passed a few milestones and have made some progress, but there are still aspects of the problem which have not been investigated properly, if at all.

In many fields, research gets miles ahead of application. This happens not only in molecular research, but can happen also in muskeg research. This is really what we can be blamed for in the whole muskeg approach. We have been somewhat careless in that we have not planned naturally. We have not anticipated that the work that has been described during this conference could be done. We need people who are aware of the needs, right now. How will a community be developed? One thinks of Inuvik and Moak Lake. In these, and other developments, are the two aspects of permafrost and muskeg. We have not planned to accommodate for the problems. We have not dealt with water resources, power development and use, communications and so on. Everything is ad hoc. Specific situations arise and we only accommodate to these. In agriculture and forestry, there is a planning with regard to muskeg resources. No caretaker element is present to look after this planning factor.

With regard to future research, one might mention first of all instrumentation. This is just beginning, and before quantitative values can be placed on muskeg parameters, instrumentation must be developed to measure them.

Identification and interpretation of muskeg areas are most important, as is the use of airphoto libraries. Canada is extremely fortunate in the extent of its airphoto coverage and the use of airphoto libraries will increase in preliminary surveys and planning as time goes on.

Landing of planes on muskeg will eventually be a possibility with improved design of undercarriages and an improved knowledge of terrain characteristics. Shipping peat slurry by pipelines for the peat moss industry is a real possibility for the future.

The design of services in muskeg for northern communities will doubtless receive increased attention as will the economic implications of muskeg generally. Research into the commercial area of peat doubtless will also receive considerable attention in the future.

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## CONCLUDING REMARKS

Dr. Radforth expressed the appreciation of the Muskeg Subcommittee on behalf of the ACSSM to Prince George College for their hospitality and co-operation. He stated his conviction that the discussions at these sessions would be of assistance in planning for muskeg research in the years ahead.

### Session IV

Field Trip. A field trip was made approximately 50 miles north of Prince George on Highway No. 97; some 32 people participated. Different types of muskeg were described from aerial photos prior to the trip, then were observed at ground level.

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APPENDIX "B"

# PROCEEDINGS

# OF THE

# REGIONAL SEMINAR ON ORGANIC TERRAIN PROBLEMS

# PRINCE RUPERT, BRITISH COLUMBIA

25 MAY 1964

# FOREWORD

A Regional Seminar on Organic Terrain Problems was held in the Prince Rupert Senior Secondary School on Monday, 25 May 1964. Two sessions were held, during which seven papers were given. In the morning session, three local papers were presented, together with two papers pertaining to muskeg classification and to trafficability and mobility problems. There was no afternoon session. During the evening session, two papers were given, one on engineering properties of peat and one on horticultural problems in peat, and a film was shown on the work of the Organic and Associated Terrain Research Unit of McMaster University. Mr. A. Brokenshire was Chairman for part of the morning session; Mr. C. T. Enright chaired the remainder of the morning session and the evening session.

# TABLE OF CONTENTS

## INTRODUCTORY REMARKS

Mr. A. Brokenshire of CELGAR Pulp and Paper Co. welcomed delegates to the Seminar on behalf of the local planning committee. He outlined details of the program which was to be followed during the day which included sessions in the morning and evening, with the afternoon free. He expressed appreciation for the use of the High School facilities for the seminar. He introduced Dr. Radforth to the assembly, who expressed the pleasure of the Muskeg Subcommittee, and other out-of-town guests, at being able to participate in the seminar. He paid tribute to the local committee, and particularly to its Chairman, Mr. W. Hankinson of the CBC, for their efforts in arranging the seminar. He referred to the interesting and useful trip around the city, on which the Subcommittee members were taken following their arrival the previous afternoon, and stated that it gave a preview of some of the problems which would be discussed during these sessions. Mr. Brokenshire also introduced Mr. C. T. Enright, who was to act as Chairman during the last part of the sessions.

## B.1. LA CONSTRUCTION SUR LE MUSKEG

J. Martin

Résumé:

Les coûts du logement à Prince-Rupert sont approximativement de 20% supérieurs à ceux de Prince-Georges et des environs de Vancouver. Les trois-quarts de cette augmentation du coût sont dus au problème du muskeg. Les muskegs peu profonds sont excavés jusqu'au roc solide; dans les plus profonds, on utilise des pieux avec une construction sur tubes et piliers. L'expérience a démontré que cette technique est très efficace. Tant que les pieux sont au-dessous de la table d'eau, aucune détérioration ne se produit.

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## B.1. BUILDING IN MUSKEG

J. Martin

Abstract

Housing costs in Prince Rupert are approximately 20% more than in the Prince George and Vancouver areas; three-quarters of this increased cost is due to the muskeg problem. Shallow muskegs are excavated to solid rock, in deeper muskegs, piles are utilized, with ringwall and pier construction. Experience has proven that this technique is very effective. As long as the piles are kept below the water table, no deterioration problem arises.

## B.1. BUILDING IN MUSKEG

A Summary of the paper by

J. Martin

To those who are involved in construction in southern areas or in hardpan, mineral soil construction involves relatively few problems – at least they know where they are going. Here in Prince Rupert is mountainous terrain and widely varying depths of muskeg, which overlies rock, clays, or gravel. Housing costs are approximately 20% more in Prince Rupert than in the Terrace, Prince George and Vancouver areas and 15% of this is due to the muskeg problem.

It is obvious that one cannot drive a tandem truck off the street and to the edge of an excavation. One of the principal problems therefore is access. Once at the site, however, the muskeg has to be removed. New methods of excavation are being developed, but there is as yet no perfect method. Equipment big enough and heavy enough to work in other areas economically, cannot negotiate successfully on bog. Small vehicles which can negotiate are inadequate to fulfil the task.

In muskeg, the problems are tackled on the basis of experience which has been gained over the years. For shallow muskeg, i.e. up to 8 feet deep, it is possible to completely excavate it to solid bottom (always rock) and to use ringwall or pier foundations. For muskeg deeper than 8 feet, the contractor has to resort to piling, which is very expensive. Also the piling is invariably wood and has to be forever protected. The only way to do it is through the natural water system. The piling is put well below the water table, capped with concrete, and the foundation put on. It is then hoped that no one will alter the water table. If the water table is lowered, then in time the piling will rot, whether it is treated or untreated.

Building in muskeg has played an important part in the development of Prince Rupert. It has made the local people careful in their selection of lots. Consequently, the areas of deep muskeg and of sharp rock outcrops have been left until last.

The foundations for light buildings on deep muskeg are built as follows. None of these are entirely acceptable to the National Building Code, which is accepted almost in toto in Prince Rupert. For less than 125 p.s.f. floor load (private home, small warehouse, etc.):

1) Excavate to below water table.
2) Drive pin piling, 2 feet on centre, battered.

3) Reinforce and cap.
4) Ringwall construction. Develop for piers, etc.

The author has observed over a ten-year period that with 48 in. ringwall and 72 in. by 72 in. pier footings, settlements have been less than one-eighth of an inch. The reason for this is that the pin piles have developed a certain amount of friction value. Also, they have tied in a large "ball" of peat which gives stability.

This method, used without heavy equipment, is suitable for old or new buildings. The piling is driven with an air jack, but can be done with a hydraulic jack or an air hammer.

The water level is often inadvertently lowered by adjacent roads settling and bringing the water table down. This must be carefully watched due to the detrimental effect on the piling, mentioned above.

The author is of the opinion that it would be useful for representatives of the CMHC to come out to Prince Rupert to observe the local conditions. Because of the abnormal foundation cost, local residents have to pay larger down payments for their mortgages than anywhere else in the country. The CMHC makes no allowance whatever for the higher foundation costs. The muskeg condition in Prince Rupert is an inescapable fact which has to be faced.

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Discussion

Mr. Tessier asked about the length of piling used. Mr. Martin replied that they are 5 to 8 feet long. He suggested as a rule-of-thumb that they should be twice as long as the difference in elevation between the ground surface and the water table. In some areas heavy stumps will be encountered suitable for end bearing, in other areas longer piling will be required to develop the necessary friction.

A question was raised as to the possibility of drilling and using concrete piling. Mr. Martin said that this technique has not been used in Prince Rupert. One problem is that static water pressures exist at depth and this will affect concrete piles.

Dr. Radforth congratulated Mr. Martin on his succinct presentation of a set of conditions which are fundamentally important, locally and nationally; also for bringing distinct problems clearly to the fore. A few years ago it was very difficult to get an answer to the question: "What are your problems?" Dr. Radforth referred to Mr. Martin's rules-of-thumb and to his comments on the National Building Code and said that these were most significant and pertinent. He drew attention to the point which had been made regarding the importance of maintaining the water level, i.e. the piles must be in the same environment as the peaty material. Here failure of the pile results when the water table is lowered— so apparently the water table can be lowered. Dr. Radforth asked for Mr. Martin's view on whether or not you can drain muskeg, and also on the matter of protection of concrete in muskeg. Mr. Martin explained that his views are based on personal observations only. With regard to concrete, a good dense concrete is generally considered to be resistant to damage from most peat waters. He was referring in his earlier remarks, mainly to the effect of peat waters on the "green" concrete. Once the concrete has set, there is little to worry about. Concerning drainage of muskeg, Mr. Martin said that it is certainly possible. The coarser the texture of the organic material, then the better it will drain. Fine textured peats, however, are self sealing. He referred to a feature of the local terrain where ponds are perched on quite pronounced slopes. He stated that certain muskegs will not drain naturally except when excess water is added to them.

## B.2. L'INSTALLATION DES EGOUTS DANS LE MUSKEG

C. J. Gustafson

Résumé:

Dans le cas des conduites principales d'eau et d'égoût dans les muskegs profonds, en pratique, on creuse la tranchée à une profondeur suffisante, on utilise des pieux avec bouchon servant d'assise pour la structure, puis on remplit avec du matériel granulaire approprié. Les dépôts peu profonds sont excavés jusqu'au fond ou presque. Les conduites reliant les égoûts collecteurs aux maisons sont souvent placées sur des plate-formes de planches pour empêcher les bris. Les routes sont généralement construites flottantes sur le muskeg en utilisant la technique de l'excavation partielle.

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## B.2. INSTALLING UTILITIES IN MUSKEG

C. J. Gustafson

Abstract

For water and sewer mains in deep muskegs, the practice is to trench to an adequate depth, utilize piling with capping as a saddle for the structure to sit on, then backfilling with appropriate granular material. Shallow deposits are excavated to, or close to, the solid bottom. Sewer lines from the mains to houses are often placed on plank platforms to prevent breakage. Roads are generally floated on the muskeg, usually utilizing the partial excavation technique.

## B.2. INSTALLING UTILITIES IN MUSKEG

A Summary of the paper by

C. J. Gustafson

Water Mains and Sewer Lines in Deep Muskeg Formations:

For depths of 15 feet and over, the practice is to trench, then piling to bedrock, with capping as a saddle for the structure to sit on. The trench is backfilled with aggregate to protect the pipe. In outlying districts, where there is no road, the trench is backfilled with peat. It is essential at any depth that piles be driven.

In 1912, a cast-iron pipe was installed, 350 lb test (normally 250 lb test pipe is used), and the main constructed in the manner described above. The piling was untreated cedar driven at 8-ft intervals along the trench in dual formation, and was capped. The piles are as good now as the day they were driven. The main thing in this construction method is that the surrounding muskeg must remain undisturbed. If the muskeg is removed or the water table lowered, rot immediately commences and failure will eventually occur. If the piling is below the water table - and kept there - the wood need not be treated. If creosoted timber is used, it is not necessary to worry as much about the water table.

Water Mains and Sewer Lines in Shallow Muskeg

In shallow muskeg, say 6 ft to 10 ft or so, the trench is excavated and backfilled to the appropriate level with coarse rock. To this is added a layer of fine aggregate or crushed gravel. On this is laid a plank saddle and then a decking (2" x 12" cedar planks) constructed on this. The pile is laid on the decking, and the trench backfilled with select granular.

At other places where it is not too far to go down to bedrock, then the practice is to excavate right down to it and the trench backfilled with select granular.

In no case should the above procedure be followed if adjacent to the installation there is to be an excavation and the peat permitted to dry out.

Roads

The principal roads are on muskeg. In the early days the common method was to use retaining walls of rock. On 3rd Avenue it is up to 30 feet down to bedrock. The road was built in this manner and is still settling after 30 years. At one spot it has gone down 8-7/8 inches in 13 years. To compensate for this it is the practice to add to the blacktop.

In rural areas, under certain conditions, a trench is excavated to 5 feet, backfilled with rock and topped up with select aggregate. This will produce some settlement. Certain areas - depending upon the muskeg type - will settle quite fast.

The present method of rebuilding a road is to excavate the present fill down to the old corduroy. The planking (decking) is placed on the corduroy and over this is placed a layer of 4 in. (or less) of granular. On this is put a layer of finer aggregate, 3/4" or less and the wearing surface on that. Roads such as this are used in muskeg areas in all residential districts of Prince Rupert. Where differential settlement occurs, dishing, etc. results and is filled in with blacktop.

House Utilities from Mains to Residence

Most of the sewer blocking problems are with the house mains. If a driveway is built over a sewer line, and if the sewer bridges over roots or a stump, then the pipe will break when the driveway settles. It is now common practice to use a plank platform from houses to the main sewer line to avoid damage to the sewer lines. Water lines from the mains to houses are laid in wavy rather than straight lines as this seems to resist settlement better. Soldered connections are not used, rather "switched" couplings are utilized.

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Discussion

Mr. Enright asked if the settlements have been gradual and diminishing - i.e. no abrupt settlement. Mr. Gustafson said that at the beginning it is quite fast, but it diminishes as time goes on. Mr. Enright noted that partial excavation was referred to and wondered why it was necessary to excavate at all. He suggested that this technique would destroy any advantage of the surface mat. Mr. Gustafson replied that in some instances partial excavation was carried out to give better stability to a road subjected to heavy traffic. In other cases, construction is right on the surface of the muskeg - a rock fill and then granular fill overlying that. The required height of grade has a lot to do with it.

Mr. Gustafson pointed out that the location of the school in which this seminar is taking place was once a deep muskeg with a growth of spruce 8 ft in diameter. Eventually these trees disappeared as people cut them down for fuel. The area was then used as a garbage dump, which was covered by an earth fill before construction of the school.

Dr. Radforth congratulated Mr. Gustafson on his paper, which contained a great deal of useful information. He mentioned that Mr. Gustafson had emphasized differential settlement for different peat types. If this is so, he wondered if it is not possible to make a mistake with regard to a building site and even get differential settlement in a house. Mr. Gustafson replied that if a slab foundation is used, then one would certainly get differential settlement; that is why piles or concrete piers are recommended. He stressed that under no circumstances would he advise house construction on any other foundation than piles, certainly not slabs. Dr. Radforth wondered if differential settlements would not be probable in such areas as the one covered with ponds seen on the previous day's trip around the city. Mr. Gustafson reiterated that differential settlement would be unlikely, as the piles would go down to bedrock. In the 1940's some wartime housing was put on pads and these structures did experience differential settlement.

Professor Wilson remarked that sometimes lowering of the water table would be unavoidable and enquired if this had caused any legal problems. Mr. Gustafson replied that this has not been a problem, although of course such a thing is possible. Nothing is written into the law in this regard, but contractors normally take measures to safeguard the water table level so that protection is accorded structures adjacent to the new construction.

## B.3. QUELQUES PROBLEMES RENCONTRES DANS LA CONSTRUCTION D'UNE ROUTE SUR LE MUSKEG

N. J. Martinusen

Résumé:

On commente la construction d'une voie d'accès longue de 1-3/4 mille, reliant la route No. 16 de la Colombie Britannique à un barrage-réservoir proposé pour la Columbia Cellulose Ltd. Environ la moitié de la route fut construite sur le muskeg. Pour la construction des parties de routes sur le muskeg, on utilisa le procédé "corduroy". Les fossés ont été creusés au bas des pentes de la chaussée de chaque côte. Des ponceaux ont été installés aux endroits nécessaires. Les difficultés dues à la température ont retardé le contracteur et ont augmenté le coût de la route de 25%. La route terminée donna un bon rendement, mais le passage des lourds camions provoqua sur la surface de la route des ondulations ayant une amplitude de un pied environ.

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## B.3. SOME PROBLEMS ENCOUNTERED IN ROAD CONSTRUCTION ON MUSKEG

N. J. Martinusen

Abstract

The construction is reviewed of a 1-3/4 mile access road from B.C. Highway 16 to the location of a proposed storage dam for Columbia Cellulose Ltd. About one-half of the route of the road was over muskeg. Corduroy construction was utilized over the muskeg sections. Ditches were dug along the edge of the road, on both sides, with culverts installed as necessary. Weather difficulties delayed the contractor and increased the cost of the road by 25%. The completed road gave good service, but the passage of heavy trucks was observed to cause a wave-like motion in the road surface with a vertical amplitude of approximately one foot.

## B.3. SOME PROBLEMS ENCOUNTERED IN ROAD CONSTRUCTION IN MUSKEG

N. J. Martinusen

In 1960, Columbia Cellulose Company Ltd. undertook to build a one and three-quarter mile long access road from Highway 16 to the outlet of Diana Lake near Prince Rupert where a concrete gravity type storage dam was to be built. Contractors were told to select a route and to quote on the basis of a 16 ft working width roadbed to carry a 25 ton load. An additional stipulation was that no gravel or borrow material was to be taken from Diana Creek so as to avoid interference with the salmon-spawning beds. Bids were compared, routes reviewed, and a contract awarded.

The contractor's plan was to locate the road on the side hills, where less muskeg would be encountered, and where experience on former projects had shown him that gravel and sand were likely to be situated, if any at all were to be found. In areas where muskeg would be encountered, he planned to lay trees with limbs removed ("punching") on undisturbed overburden. Ditches would then be dug along the ends of the punching, and culverts installed as necessary, to provide maximum drainage. Strong emphasis would be placed on minimum disturbance to overburden and on adequate drainage. The former would assist in load transmission, and would act as a membrane to prevent muskeg from infiltrating the punching. No effort was made to remove stumps or roots as they formed part of the membrane. The provision of ditches would assure the best bearing values possible with the available material.

This plan in general was followed. Trees were felled and limbed and a one and one-half yard tracked shovel, weighing approximately 40 tons, and operating from punching and moveable pads, moved the punching into place on as close spacing as feasible; the punching axis was, of course, perpendicular to the road centreline. The shovel was then used to dig the ditches which drained to low points, i.e., which drained away from the road. Culverts, both of pipe and of timber, were installed as required. Grading material was in the first instance shot rock obtained from a borrow pit near the highway, transported by tandem trucks, and placed by bulldozer. Suitable turnouts were provided.

As the distance from the borrow pit to the work increased, the search along the road bed intensified for suitable surfacing material. This was found, not along the side hills as was first expected, but in low ground approximately 200 feet from Diana Creek. The area was probably an old stream bed.

This construction proved entirely satisfactory. The heavy shovel was able to move over the finished road without pads. Trucks carrying gravel, cement, and other material to the dam-site also encountered no problems. As a point of interest, vertical wave-like motion in the road bed of approximately one-foot amplitude were observed as loaded trucks passed the observer standing on overburden beside the road. Oscillations could be felt during the vehicle's approach, and after it had passed. This motion is to be expected in the rather fluid material upon which the road was built, and created no problem. If the road were to have been black-topped, this motion could of course have presented problems.

The road is still passable today, although it is but little-used and requires "patch-repair".

The basic principles underlying this type of construction were:-

(a) Avoidance of the problem by locating the road away from muskeg areas wherever possible.
(b) Good drainage to preserve or enhance muskeg's poor load carrying ability.
(c) Minimum disturbance to overburden and tree roots to preserve the membrane, and its load-distributing qualities.
(d) Provision of good punching closely spaced perpendicular to the road centreline to distribute wheel loads before they contact the muskeg, and to provide flotation.

Had any severe problems been encountered, it is the writer's opinion that "tie-logs" could have been placed above the punching, at each edge and parallel to the road centreline, and cabled to the punching. These members would assure load transmission over a much larger area than just one or two punching logs, and thus would increase the changes of success. Road cost would have been much greater, possibly 50 per cent greater, for the areas which might have required this treatment. Longer punching could also have been used.

The contract price for the road was $44,000. However, the start of the work was delayed, through no fault of the contractor, until October, rather than August as was originally contemplated. A severe weather problem, 23 inches of rain in October, hampered the contractor unduly and resulted in 25 per cent higher cost to the owner. Elapsed construction time was 2-1/2 months approximately.

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<u>Discussion</u>

Mr. MacFarlane enquired about the distance of the ditches from the road centreline. Mr. Martinusen replied that the punchings were 20 ft long and the ditches were dug along the edges parallel to the road. Culverts were located at the low points and natural drainage was used to get rid of the water.

Mr. Enright asked the depth of the muskeg, to which Mr. Martinusen replied that the depth actually had not been determined. Mr. Enright enquired further about the cost of the road. Mr. Martinusen said that it was a $44,000 contract, but the cost was $55,000 by the time it was finished.

Dr. Radforth commented on an apparent contradiction. In other instances it has been advised that there be no ditching, whereas in this case ditching is obviously practised. There is quite sharp disagreement in some quarters whether to ditch or not to ditch. He referred to the problem of cutting the mat adjacent to the road with possible consequent dishing of the edge of the road as the shoulder fails and sloughs into the ditch. Mr. Martinusen said that he had very little previous experience to draw from, so decided to follow the procedure outlined in his paper.

Mr. Harwood asked how much of the road was over muskeg and Mr. Martinusen indicated that 3/4 mile of the 1-3/4 mile road was over this type of terrain. Mr. Harwood wanted to know how many tons of fill material went into the construction of the dam. Mr. Martinusen informed him that it was about 1000 tons. Mr. Harwood observed that the cost was therefore about $25 per ton-mile, which is quite high. Mr. Martinusen pointed out, however, that the road will be of use to the company again. Although its primary purpose was as an access road to permit the construction of a dam, it will have fairly constant use in increasing the size of the dam, should a proposed Kraft mill be installed.

## B.4. UN SYSTEME DE CLASSIFICATION DU MUSKEG ET SES APPLICATIONS

N. W. Radforth

Résumé:

L'organisation du muskeg est reflétée dans la formule de la couverture végétale qui est périodique comme on peut le constater en traversant le Canada. Cette formule provient d'une combinaison de neuf classes simples de couverture qui caractérise la végétation du muskeg. En outre, sur une base qualitative, seize catégories de terre noire sont reconnaissables. L'indice le plus utile de l'organisation est les microfossiles (pollens et spores) qui se sont déposés dans la terre noire depuis son origine et en sont devenus des composants microscopiques. Les groupements de ces microfossiles expliquent la couverture de surface et la macrostructure de la terre noire. Les caractéristiques géomorphiques des terrains organiques proviennent de quatre différents facteurs naturels: le dépôt minéral sous-jacent, la glace, le matériel organique lui-même et l'eau. L'organisation du muskeg est décelée des airs. Les contours de couverture forment des groupes qui se renouvellent et qui permettent de faire une interprétation de la structure de la terre noire aussi bien que des particularités du dépôt minéral sous-jacent. La documentation complète sur les photos aériennes à haute altitude qui est disponible au Canada permet une interprétation du muskeg tant pour l'exploitation que pour l'exploration.

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## B.4. A CLASSIFICATION SYSTEM FOR MUSKEG AND ITS APPLICATION

N. W. Radforth

Abstract

Organization in muskeg is reflected in the vegetal coverage formulae which are recurrent as one travels across Canada. These formulae arise from a combination of nine pure coverage classes of cover which characterize the vegetation on muskeg. Furthermore, on a qualitative basis, 16 categories of peat are recognizable. The most useful index of organization is microfossils (pollens and spores) which have been deposited as microscopic components of peat from the time of its origin. Assemblages of these microfossils explain both the surface cover and the macrostructure of the peat. Geomorphic characteristics of organic terrain arise from four different natural factors; the mineral sublayer, the ice factor, the organic material itself and the water factor. The organization in muskeg is seen from the air. Delineations of cover formulae make up patterns which recur and which enable an interpretation to be made of the structure of peat as well as of features of the mineral sublayer. The complete library of high altitude photographs which is available in Canada permits an aerial interpretation of the muskeg factor for both exploration and exploitation.

# B.4. A CLASSIFICATION SYSTEM FOR MUSKEG AND ITS APPLICATION

N. W. Radforth

## Introduction

When the writer commenced work on organic terrain in 1946, there was great confusion as to meaning of "muskeg". This expression has been interpreted from the Indian as meaning "grassy bog", but this turned out to be unsatisfactory as an expression of the intended meaning. Some claimed that muskeg was treeless; others that it was tree-covered. In almost all cases, the areas of land in question were very wet, but it transpired that some recognized that muskeg could be dry. There was disagreement as to whether muskeg was swamp or marsh. It finally proved possible to say in broad terms what was in the mind of everyone whenever the expression "muskeg" was used. In this respect the expression "organic terrain" is now in wide use, for everyone agrees that, whatever muskeg may be, it is fundamentally an expanse of land with special physiographic characteristics. Also, it is organic in the sense that it consists of living material - at the surface - and dead remains of past plant material beneath, the latter have become fossilized to form peat. The organic terrain thus constituted of this material usually bears special relationship to the mineral terrain beneath it, and therefore, just as its existence bears on climate, it also originates as a function of kind and conformation of mineral terrain.

Muskeg is circumpolar in occurrence and is indeed present not only in the northern but also in the southern hemisphere. It has been noted that Canada possesses probably more than 500,000 square miles of it and there is some in each province of the Dominion. Its importance as a terrain feature has been emphasized over the past several years because of engineering and military development on a national and international basis. This is partly because of the need for access to lands where natural resources have heretofore been regarded as remote. The National Research Council and the Defence Research Board which have supported the writer in his research have recognized the need for an interpretive program as applied to muskeg and are aware of the significance of the terrain in relation to national requirements.

## Kinds of Muskeg

One of the reasons for the difficulty in finding agreement as to what was intended by the expression "muskeg" is that there are many variables involved, and it is difficult to say which combination should constitute a type. It is easy to eliminate swamp and marsh, for experience suggests that each of these kinds of terrain lack peat, an essential ingredient of muskeg. Probably the reason that no peat exists in a true swamp or marsh is that the water table or some other physical means of maintaining high concentration of water at the surface are inappropriate with respect to peat formation. It can also arise that when the water table is high, wave action can be such as to oxygenate the dead vegetation and so discourage its fossilization. The writer finds that it is acceptable to differentiate between a swamp and a marsh on the basis of the swamp possessing significant areas of open water.

One can readily appreciate how different kinds of muskeg arise when some attention is given to the subject of muskeg origin at the edge of the prevailing icecap. On Ellesmere Island, which the writer visited during the summer of 1962, one can see examples of confined muskeg (bogs) close to the edge of the icecap. The majority of these have a vegetal cover which is non-woody and grass-like as to its constitution. The peat beneath this kind of cover is largely granular (aggregates of colloidal flocculence), but in many cases this kind of structure associates with a non-woody fibrous component. Where the muskeg is more inclined to spread (unconfined), a woody constituent is important in the cover and presence of the same kind of material shows up as a woody fibre in the peat beneath. Usually this kind of peat occurs on slightly higher ground than the former kinds. One has to travel south of the tree-line to discover the coarser kinds of peat.

Mr. MacFarlane has produced a Handbook (MacFarlane, 1958) in which he records the nine classes of vegetal cover that are used in order to characterize the vegetation on the muskeg, whether the latter be confined or unconfined. It is indicated in the Handbook how these classes of cover are combined to form formulae which account for admixtures of classes. It should be indicated here that these admixtures are characteristic and they recur frequently, hence it will not be surprising that the accompanying map (Figure 1) produced by the Defence Research Board will show areas where certain cover formulae predominate across the country.

This recurrent phenomenon is the first indication of organization in muskeg. It is fortunate that it arises, because otherwise it would be virtually impossible to classify muskeg or to refer to the different kinds of peat in the organic sublayer.

Further reference to MacFarlane's Handbook will indicate that, on a qualitative basis, 16 categories of peat are recognizable. These are also found to recur across the country.

The most useful index of organization exists in the form of microfossils (pollen and spores) which have been deposited as microscopic components of the peat from the time of its origin. An examination of the composition of peat with respect to these microfossils shows characteristic assemblages of them for given depths in the peat. It is now known that certain assemblages are not only characteristic for a given depth, but also characterize the peat as a whole in total depth. These assemblages explain the presence and association of macro-components which constitute the bulk of the peat. They also suggest that one could predict the present nature of the cover which is, in fact, the vegetal composition that is going to supply the last component to the assemblage of microfossils which characterizes the peat. In some cases, the succession of microfossils does not characterize the peat in depth. In these cases there is a shift in the composition of the assemblage as one proceeds from the base to the top of the peat. Even in these cases, the contemporary cover is predictable in the laboratory once the evolution of the microfossil assemblage is known. Also, these evolutionary shifts are characteristic and therefore it is understandable that they too recur along with the vegetal cover that characterizes them.

If one were to attempt to work out organization on the basis of macro- rather than microstructure, a difficulty would arise in characterizing the peat in depth and over area. Because the components may be as large as tree trunks or as small as moss leaves, one can not comprehend the extent or delineation of organization in reliable or adequate perspective even though the macro-components are in plain view. The microfossils on the other hand - the microscopic components that have been distributed more or less homogeneously relative to the macro-components from which they arose - display the organization readily. This may, in fact, be read from samples no bigger than a cubic centimetre in size for any given depth.

Classification in the ultimate sense thus relies upon the microfossil assemblages. Since these explain both the macrostructure and the surface cover, characteristic compositions of surface cover as reflected by cover formulae can be used conveniently in direct reference to the macrostructure making up the fossilized sublayer of the organic terrain. This can be done on a predictable basis.

Physiographic Relationships

It has been indicated elsewhere (Radforth, 1962) that geomorphic characteristics of organic terrain arise as the result of the application of four different natural factors.

The first of these is the mineral sublayer. It is known that organic terrain can exist on a great variety of mineral sublayers. It was once thought that clay or silt formed the mineral base for the development of peat. It is now known that igneous rock, coarse mineral aggregate, pure sand, silt or clay, all of differing chemical and physical constitution, may occur beneath peat. It usually arises that rock or coarse aggregate support slow accumulation of peat, whereas clay or silt, usually in depressions, afford rapid accumulation. Whatever the rate of deposition, it will arise that the conformation of the mineral terrain will influence time of initiation of peat. In continuous muskeg, it is most frequently the case that there are numbers of points of origin which have contributed to the ultimate single expanse. In confined muskeg which may arise in a kettlehole or in a depression of similar conformation, origin of peat is at the circumference and it is significant to note that, contrary to common understanding, it is not always the same kind of peat that is initiated.

Whether the muskeg be continuous or confined, variation is in part a direct result of the influence of the mineral terrain.

Another factor is ice. Topographic differentials that one finds in muskeg are often functions of the ice factor. There is a relationship between polygons and the depositional relationship of ice as it occurs in areas where climafrost (Radforth, 1954) is effective. Mounds characteristically occur in muskeg with EI cover, and these contain ice knolls which, well into the summer, conserve the form of the mound. The work supported by the Defence Research Board has recently resulted in the disclosure that H, as a cover class, designates the southern limit of permafrost across the country (Newfoundland excepted).

The dynamics of muskeg formation are such that the ultimate total contour of the terrain is dome-shaped. This is undoubtedly due to factors inherent in the organic material itself and therefore, geomorphologically, the organic state is intrinsically contributory.

Finally, it has been observed that the water factor, in that it contributes to erosion and change in rate of deposition of peat, is an effective agent in encouraging geomorphic change in muskeg. Imponding and migrations of ponds delineate geomorphic circumstances in muskeg of some kinds. In other kinds, dendritic drainage of a highly dissected character is frequent.

## The Photo-interpretation Approach

Fortunately the organization in muskeg which has already been referred to can be better appreciated from inspection from a plane or from air photographs. Largely this is because aerial inspection affords better persepctive of ground conditions for the observer. Were the situation otherwise, the interpretation of muskeg conditions would be most difficult for areas of large size because, as the accompanying photographs have shown, it is most difficult to traverse muskeg.

The practice of photo-interpretation usually results in identification of ground features. This is not enough for muskeg interpretation.

Determination of the characteristic features of muskeg merely supplies the basis for interpretation. If application is to be considered, interpretive procedure must go further than mere identification.

In the first place, as one proceeds from low to high altitude, the delineations of cover formulae which lead directly to structure of the subsurface peat, and which provide leads to features of the mineral layer beneath, merge into a grander pattern. At altitudes of 30,000 feet, one recognizes the characteristic patterns which recur and which have already been named as Dermatoid, Stipploid, Terrazzoid, Marbloid and Reticuloid (Radforth, 1958). To identify these makes the question - is interpretive advice as expected? Secondly, muskeg is so complex and variable despite its organization that identification should be done in the knowledge of the operation or application ultimately intended. Thus, following identification of airform pattern and subsequently groundform features, terrain constitutional factors should be referred to in the terms of the need which might be, say, teaching and research, and which might relate to photo-interpretation for drainage, or classification or physiography of peat, or chemistry of peat, or some aspect of biological assay. On the other hand, the implication might be resources development. In this case, interpretation might be required in the terms of access, agricultural reclamation, optimization for productivity as an aspect of crop management, economics or elucidation of terrain characteristics in relation to foundation engineering.

In this kind of interpretation, one may expect a common system of reference to arise through which one can assess and correlate aspects of national development which will inevitably involve the muskeg factor. It is perhaps worth emphasizing that our top primary industries, forestry and agriculture, as these are contemplated in relation to our undeveloped lands, could best be correlated for purposes of exploitation and study via this reference medium which can now be established with the aid of our very complete library of high altitude air photographs. The mining of peat for chemical resources as well as for soil improvement can now be planned on a national scale, but it will be done most effectively on the basis of a common denominator of reference similar or equivalent to that which has now been devised.

Acknowledgements

The writer wishes to acknowledge the assistance of the National Research Council which has sponsored ground studies in muskeg; and of the Defence Research Board which, through its Geophysical Section, has supported the work on aerial interpretation.

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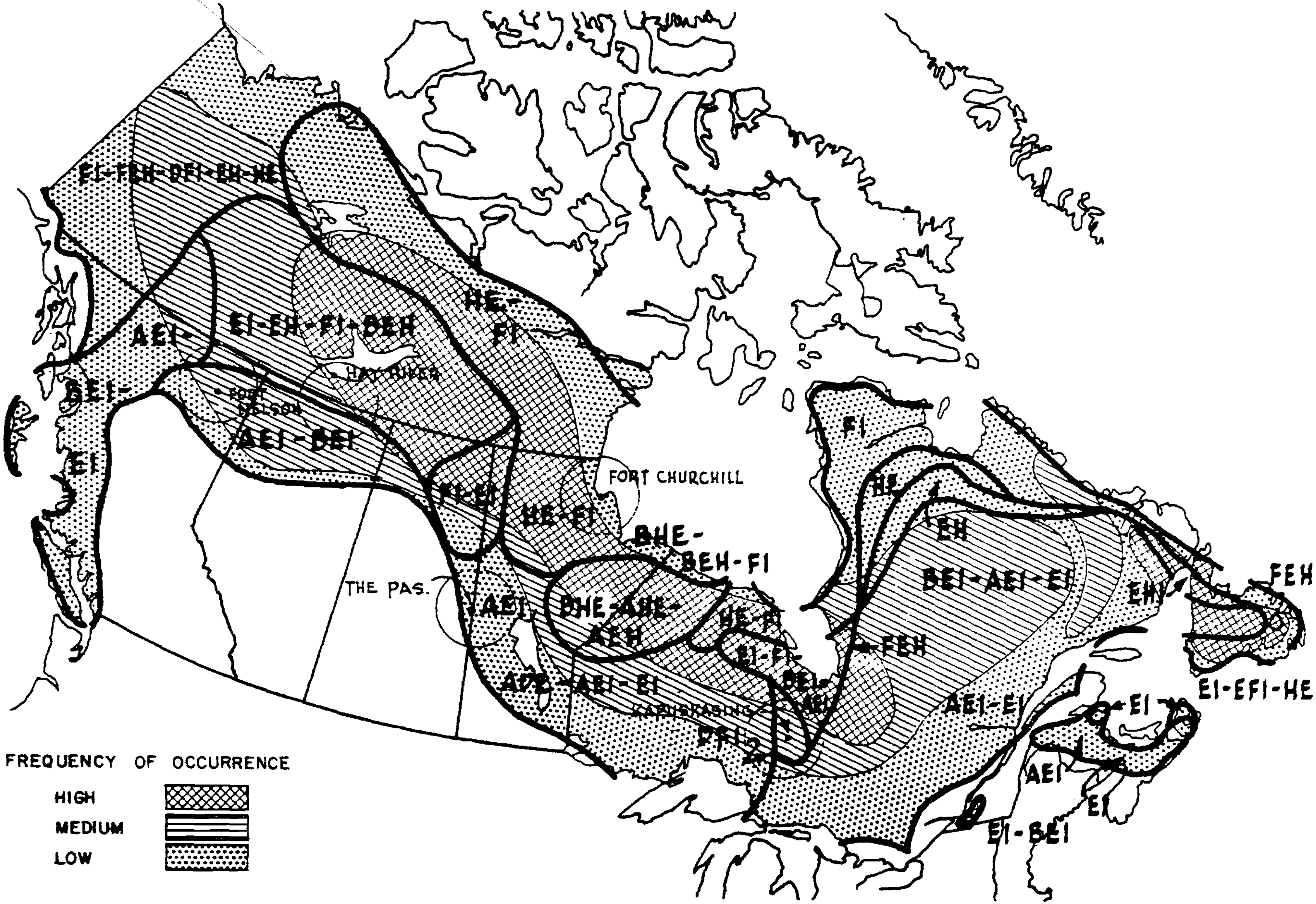
## Discussion

Mr. Scholten enquired whether the classification of muskeg is based on past growth and wondered if past growth is the same as present growth. Dr. Radforth said that this aspect was the first thing he looked into when he commenced his work on a classification system. He referred to the study of pollen and spores of plants which grew up with the peat. It was found that whereas there is usually considered to be peat succession, in muskeg when one thing got started – relative to structure – it continued through the depth of peat. This is true of the large muskeg areas in the northern plains. However, in confined muskeg such as here in northwestern B.C. there is a sequence in the structure. Once one knows what sort of growth the deposit started with and what it is now, then it is possible to extrapolate back. Dr. Radforth emphasized that generally it is found that for a given cover type, a specific peat category will be obtained beneath it, for another cover type a different peat category will be obtained. The peat categories are assigned to a profile in general.




MUSKEG AREAS

BR 2515-3

ORIGINAL

## B.5. TRAFICABILITE ET MOBILITE SUR MUSKEG

T. A. Harwood

Résumé:

Les facteurs qui influencent le plus la mobilité des véhicules sont la topographie, les conditions du sol et les caractéristiques mécaniques des véhicules. Sur le terrain, les facteurs qui empêchent la mobilité comprennent les côtes, les cours d'eau, les forêts et les tourbières. Dans le muskeg lui-même, les facteurs micro-topographiques peuvent limiter la mobilité du véhicule. Les tourbières ont joué un important rôle stratégique dans les tactiques militaires aussi récemment que lors de la seconde guerre mondiale. Les conditions du sol dans les muskegs impliquent généralement des problèmes comprenant l'effort de cisaillement de la terre noire, la capacité portante et les caractéristiques du tassement. Dans le développement des véhicules pour les terrains mous au Canada, - pour fins civils et militaires - le principe de direction "articulée" a été employé plutôt que celui de la direction "glissante". L'évolution des véhicules pour les terrains mous a généralement abouti à un véhicule long et mince qui a permis l'exploitation de la configuration dite "sans-ventre". On conclut qu'il n'y a pas de réponse toute prête à la mobilité dans les muskegs. Les véhicules doivent être projetés pour des besoins spécifiques et pour l'application militaire; chacun de ces usages spécifiques devrait inclure, pour l'appareil, la capacité d'être amphibie.

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## B.5. TRAFFICABILITY AND MOBILITY IN MUSKEG

T. A. Harwood

Abstract

Major factors influencing vehicle mobility are topography, soil conditions and mechanical features of the vehicle. Terrain factors inhibiting mobility include hills, water courses, forests and bogs; in the muskeg itself, microtopographic factors can be limiting to vehicle mobility. Bogs have played an important strategic role in military tactics as recently as the Second World War. Soil conditions in muskeg generally involve problems of the shear strength of peat, bearing capacity and settlement characteristics. In the development of soft terrain vehicles in Canada - for both civilian and military purposes - the articulated principle of steering has been used rather than skid steering. The evoluation of soft terrain vehicles has generally resulted in a long narrow vehicle which permits the exploitation of the so-called bellyless configuration. It is concluded that there is no ready answer for mobility in muskeg areas. Vehicles must be designed for specific purposes and, for the military application, each of these specific uses should include the ability to be amphibious.

# B.5. TRAFFICABILITY AND MOBILITY IN MUSKEG

T. A. Harwood*

## Introduction

The Armed Forces, possibly because they have been involved in mobility for so long, have evolved some of the best definitions for mobility, one of which is "ground mobility" or the "quality which bestows upon an organization freedom and speed of movement so as to attain any required destination". Necessarily the speed factor must be qualitative. The Armed Forces further break down "ground mobility" into "vehicle mobility" and "vehicle tactical mobility". It is the former with which this discussion is most concerned.

"Vehicle mobility" (mechanical) is "the extent to which the vehicle can operate under field conditions without loss of functional efficiency". The major influencing factors are:

(a) Topography, which includes all natural and cultural surface features;
(b) Soil conditions, such as shear strength, adhesion, surface friction, vehicle configuration;
(c) Mechanical features, reliability, power/weight ratio, internal rolling resistance.

Finally, "tactical mobility", is considered to be influenced by the logistic support required for the vehicle or vehicles, bridge limitations, and navigation and driving aids.

In civilian sense, all the above is applicable except for a matter of costs. It is not to be supposed, however, that the consideration of cost does not come into the design of a military vehicle. It does, and in exactly the same manner as a civil vehicle; one gets exactly what one pays or asks for. In the case of a military vehicle, a higher payment may be made for a vehicle with stream-crossing ability (assuming that bridges will not be available) than for a civil vehicle where it can be assumed that in most cases bridges will be available from other capital development costs.

Naturally, in the military sense, ultimate mobility is desirable, but unfortunately not really achievable. Compromises all along the line have to be accepted, but in one important factor a compromise is seldom sacrificed and that is "reliability". It is usually this that really differentiates between a civil and military vehicle as to cost.

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Considering the problem of mobility in underdeveloped areas, obviously the civil and military requirement is identical. Looking at the civil requirements in some detail, it is found that a requirement for mobility (off-road) is confined basically to three areas. Taking Canada as an example, these are:

(a) the logging industries;
(b) the oil and mineral industries;
(c) civil governments' operations such as in wildlife management and (northern) surveys and exploration.

The logging (pulp and paper) industry is stabilizing very rapidly due mainly to union demands for year-round employment. This in turn has led to the development of all-weather roads and consequently to the development of a great deal of capital assets in the woodlands, with a tendency towards preponderance in the use of wheeled vehicles over tracked vehicles. Nonetheless, in summer the employment of tracked vehicles for the support of cruising parties and skidding on the whole has increased.

On the other hand, the oil industry in Canada (Hemstock, 1956) has moved to a great extent off the great plains into the bush and, as a result, tracked vehicles have markedly increased for exploration, well drilling and well maintenance and in fact have started a new industry in Western Canada.

Use of tracked vehicles, other than bulldozers, in the mineral industry has been rather less dynamic. This is due mainly to the fact that mineral exploration requires surface exploration over wide areas as well as to a natural desire for aerial methods, which in effect increases the sweep rates and thus the area covered in a shorter period. Another reason is the natural disinclination to hazard relatively costly vehicles of any sort on the topography of the Pre-Cambrian Shield. Nonetheless in the north beyond the treeline where access is difficult and airstrip sites are rare, use has been made of tracked vehicles to a considerable extent.

In the last ten years governmental activity in the North, and particularly in the Northwest Territories, has increased manyfold. All such activity has been involved mainly in exploration and surveying. Consequently, in underdeveloped areas, considerable use of tracked vehicles has been made. Many examples can be given which, on the whole, have been employed mainlv for personnel transport and for logistics.

In the military sense, as in the pulp and paper industry, the majority of vehicles used for mobility are in reality logistics vehicles. The term logistics is simply defined as "the art of moving troops or materiel to an operational point", the aim being to do this at the minimum cost consistent with vehicle mobility capability with regard to terrain conditions.

All this leads to a consideration of terrain obstacles, which, in the final analysis, limit mobility and influence to a great extent the design of vehicles.

Terrain Factors and Some Military Consideration

The most obvious of terrain factors in the inhibition of mobility are hills, forests and watercourses. Depending on the degree of mobility desired, bogs also become vitally important, for while it may be possible to clear forest and climb hills, in the past it has been extremely difficult to cross boggy areas.

The influence that boggy ground has played in determining the course of history is remarkable, for boggy ground has, in military tactics, been considered the ultimate in obstacles, and always to be circumvented. In Roman and medieval times, it was a normal tactic to cover a flank with boggy terrain and where opponents were so incautious to get involved in an attack across such terrain, they were almost inevitably decimated. Agricola in 79 A.D. describes, through Tacitus, such an incident, in the conquest of Scotland.

The Battle of Bannockburn between Bruce and Edward the Second in 1314 where the English Army was hemmed all around by the bog is another such example. Also of interest was the defeat of Sir John Cope by Bonnie Prince Charlie at Prestonpans, where Sir John was so confident that the Scots could not cross the bog that he allowed the camp to sleep without adequate sentries during the night. In recent history, of course, the various battles throughout Poland and Russia around the Pripet marshes east of Warsaw are the best example of these terrain conditions inhibiting movement.

When the Germans started to fall back in the summer and winter of 1943 and 1944, they attempted to stabilize a front north of the Pripet marshes by a series of fortified bunkers sited along a "forest-marsh" line where the heavy armour was generally impeded, and to fight a war of movement south of the Pripet marshes where the terrain factors were to their advantage. Unfortunately to the north of the marshes and south of the marsh forest line in northern Poland and Latvia, a gap in this line of bogs proved to be the nemesis to the German Army. A wide sand plain lies between Minsk and Baranovici extending to and across the Polish border. It was through Baranovici, by-passing the bog country to the north and to the south along the axis of this plain, that one arm of the Russian forces north of the Pripet marshes broke through the German Army group centre and reached the Bug River in late 1944, and so to Berlin in the Spring of 1945.

These are classic examples of the importance to strategic and tactical mobility of terrain obstacles formed by muskeg and marshy areas in Europe.

## Microtopography

One of the problems of trafficability in muskeg areas is the fact that the muskeg is not always level and smooth, and just as in the surface description classification types have been found useful in simply and quickly defining topographic conditions. A classification has been suggested by Radforth (Radforth, 1952) and has been used in describing types of topography normally found with organic terrain. The sixteen separate classes, however, present detail which is not normally required by the engineer or the vehicle operator. The classification can possibly be simplified by grouping the features into four main categories:

(1) mounds and ridges;
(2) gravel bars, boulders, and hidden boulders;
(3) peat plateau and raised polygons;
(4) closed ponds, open ponds, and lake margins.

It will be noted that those features which affect vehicle mobility all appear in the same major grouping. Hummocks, mounds and ridges, regardless of the origin of these features, cause vehicle pitching and all present obstacles to vehicle travel. Rock plains, gravel bars, rock enclosures, and boulders all indicate rocky terrain and thus probably track maintenance problems, whereas peat plateau and irregular peat plateau together with joined polygons, if frozen, will indicate extreme pitching and, like rocky terrain, probable maintenance problems. Closed ponds, open ponds, and lake margins are quite obviously barriers to vehicles without an amphibious capability and thus impose certain considerations on vehicle design.

## Vehicle Design Related to Muskeg and Microtopography

A vehicle travelling over a muskeg area can be considered as posing a continuous engineering problem which involves the strength of the muskeg mat and the shear strength and compressive strength of the peat below the mat. Thus, to understand trafficability in muskeg some assessment of the strength and deformation characters of the peat and living mat has to be evolved. The problem can be subdivided for consideration into:

(1) shear strength of the peat;
(2) bearing capacity;
(3) settlement characteristics.

In the case of trafficability, settlement characteristics of the peat can be disregarded since these are considered to take place over long periods. The scarcity of published observations and the lack of a consistent system for correlating various results in actuality severely restricts this approach.

One of the most important single characteristics is, of course, shear strength of the peat. A common form of *in situ* measure of shearing strength is accomplished with the vane tester (MacFarlane, 1959). What little work has been done shows that:

(1) mineral material, if present in the peat and greater than 20%, materially increases the strength of peat;
(2) the effect of mineral contamination and drying out can result in an increased strength of the surface layers;
(3) the moisture content of the peat gives little guide to its strength unless the degree of humification and degree of mineral contamination are known.

A quick reference to the Radforth muskeg map of Canada (Radforth, 1960) shows that the broad belt of muskeg extends in a northwesterly direction across the country. This belt, in the West, is on the northern fringe of the present-day access routes and railroads, into the more northerly part of the western sedimentary basin (White, 1960). The particular muskeg here includes trees up to 15 centimetres in diameter and non-woody materials such as mosses and lichen (AEI or BEI), the whole of course overlying various types of peat.

Thus, with only a fragmentary knowledge of the bearing strength of muskeg and peat, a great deal of which was qualitative, the designers of the vehicles which were to operate in Northern Alberta and Southern Yukon were faced with a dilemma, for the vehicle had to be rugged enough to handle the treed muskeg but with a track flotation low enough to handle the water-filled and lichen muskeg. Inevitably such an approach had to lead to a heavy vehicle with low ground pressure, requirements which generally are incompatible.

Thomson (1958) also pointed out another dilemma for the designer, stating that "tests could not be run on vehicles which did not exist and vehicles could not be built because desirable design data was not available", i.e., no soil or muskeg strength parameters were available.

As a result, Thomson conducted a series of tests on some vehicles which were readily available and found that in muskeg:

(1) the drawbar performance of a vehicle decreased as the muskeg (as a whole) shear strength was reduced by the vehicle operation over the muskeg mat (i.e., the destruction of the mat);
(2) shear vane tests produced a shear vane profile which was found to be compatible with vehicle test results (for a unique area);
(3) muskeg of specific classification did not have an exclusive shear strength. Moisture content and the thickness of the formation appeared to influence the strength;
(4) motion resistance of a vehicle was found to be one-fifth of the total powered external motion resistance;

(5) an increase of the track pitch of certain vehicles resulted in a 10% increase in drawbar performance;
(6) as long as bearing capacity was available to prevent ultimate sinkage of the vehicle, the net traction of the vehicle can probably be predicted from the shear strength of the muskeg mat;
(7) the shear strength stress values of peat are in all probability strain rate dependent.

At the time Thomson undertook these tests, there was great interest in the problems of well drilling in muskeg areas (Hemstock, 1956), both by Imperial Oil and Shell Oil. The two companies, however, were in effect separated in their ideas of the types and design of vehicles required. Imperial Oil, in conjunction with Wilson, Nuttall and Raimond, undertook the development of a very large "broken back" fully articulated vehicle called the "Musk-ox" and employed some of the results of the tests described above. The Shell Oil Company (Stoneman, 1961), in conjunction with the Nodwell Company of Calgary, also designed and built a somewhat different vehicle, the Nodwell Transporter. This vehicle was based on the design of a highway tractor-trailer combination, with both the tractor and the trailer portions being powered. The platform was connected to the tractor by the fifth wheel method. The steering is, like the concept in the Imperial Oil Musk-ox, "broken back". This vehicle is now in quantity production at the Nodwell plant at Calgary and therefore must be considered to be successful for its purpose.

<u>Articulated Vehicles</u>

In the development of off-road vehicles for muskeg, one of the major concepts, which dates from the turn of the century, was that of steering tracked vehicles by articulation rather than by skid steering.

Almost without exception the tracked vehicles of today and those of the past fifty years are controlled directionally by some form of skid steering. In this system the moment necessary to change the heading of the vehicle against the resistance of frictional and/or soil shear force is generated in its contact area with the ground. It is supplied by reducing the longitudinal thrust of one track and, if possible, increasing the thrust of the other. Where the vehicle soil contact is already stressed close to failure, the increase in stress from one track is not possible and steering is accomplished by a net reduction in total thrust. Thus, in cases where operation is marginal as a result of ground weakness and usually accompanied by sinkage, attempting to steer by this means usually leads to complete immobilization.

An alternative is to so construct the vehicle that the direction of thrust of its running gear may, by means of internal forces, be controllably disposed in the steering plane to make the vehicle follow the curved path after the general fashion of ordinary motor cars (Nuttall, 1951). This general method of steering tracked vehicles will be referred to as steering by articulation or simply articulated steering.

The concept of steering tracked vehicles by articulation was first proposed in 1908 by Diplock (The Engineer, 1917). Later the British tanks of World War 1 were steered in part at least by a large tracking wheel which was a form of articulation. In later models, track speed was controlled to affect steering, thus full-skid steering was used. However, towards the end of World War 1, the British conducted some brief tests with two tanks connected in tandem by means of a flexible joint and steered by control of their relative position around this joint. This appears to be the first experimental study of fully articulated steering. The matter was dropped, however, at the end of that war. The thread of this particular method of steering vehicles was picked up by Lt. Col. Bekker of the Canadian Army in 1952 (Bekker, 1956) when he called attention to the limitations inherent in skid steering.

The first practical tracked vehicle incorporating articulated steering was the four-tracked Tucker "Sno-Cat". The second modern example of articulated steering was the Canadian Army "Rat" developed by the Directorate of Vehicle Development, Ottawa, during 1955 and 1956. This particular vehicle was bellyless and steered by articulation of two train units about a common ball joint (Stypinski, 1959). The next development was the introduction by Wilson, Nuttall and Raimond of the "Polecat" which was the conversion of two World War II "Weasels". This vehicle was powered by a single engine mounted in the rearmost of two train units. Power for the front tracks was transmitted on a standard universal jointed shaft through the steering joint and the joint design permitted full roll and pitch between the two units, but motion in the steering plane was at all times under full hydraulic servo control.

Concurrently with all these developments Robin-Nodwell began to supply to the Canadian oil industry a low ground pressure tractor, the "Scout", and a companion, separately powered, tractor trailer. This combination was capable of moving two to four-ton loads in summer muskeg operations. While not fully capitalizing on the principles of either articulated steering or train operations, the combination derived advantages from each. For example, the skid-steered tractor applied tongue forces to steer the trailer, thus the trailer continued to work with full effect during the turn even though the tractor did not. Nodwell later introduced a wagon-steered articulated 10-ton carrier, the "Nodwell Transporter". This entered muskeg service with a major oil company during the summer of 1958 and, following a usual season of mechanical teething, this two-engine vehicle has since given excellent service, and is now very widely employed.

The largest and technically successful fully articulated vehicle built to date is the Imperial Oil "Musk-ox", designed and built for Imperial Oil as a result of the performance demonstrated by a smaller carrier, the "Centipede", built a few years earlier. The "Musk-ox" is a 20-ton payload carrier grossing 45 tons. It is bellyless, nearly 50 feet long and 10 feet wide, and 10 feet over the cab. Its four tracks are powered at all times by a single 375 horsepower diesel mounted in the front unit.

It is worthwhile to make some comparison of the advantages gained by articulated vehicles. A long, narrow vehicle encounters much less external motion resistance in soft soil or snow than does a short wide vehicle with the same track area underneath it. Straight ahead drawbar pull tests in snow on a "Polecat" have shown that its drawbar pull is 240% of that of the parent "Weasel". The increase of over 200% can be traced to reduced external motion resistance. It is also interesting to note that when articulated vehicles sink into the snow evenly from front to rear as slip and drawbar load is increased, they do not assume the characteristic tail-down attitude of conventional track machines when undergoing such tests.

It is also evident that a long narrow vehicle form also reduces the resistance arising from obstacles - trees and boulders, etc., and makes over-the-road transport, whether on a trailer or a rail car under its own power, much easier. Finally, such a form permits the exploitation of the so-called bellyless configuration without resort to extremely wide tracks with attendant track and suspension, structure and weight problems.

There are a number of additional advantages that train-joint articulated vehicles have which are not easily understood. Experience with these vehicles has shown that:

(1) their ride is significantly better than that of comparable skid-steered machines, their greater length being the overall reason;
(2) generally the structure of the individual units and the track suspension component need be proportional to the gross weight of one unit rather than that of the entire machine. (This general easement of structural requirement makes possible the development of vehicles having high mobility, adequate ruggedness, and acceptable payload gross weight configuration. For example, the Musk-ox which counts 45% of its gross weight as useful payload compares favourably with much simpler vehicles, such as the U.S. Army 6 by 6 truck whose off-road payload to gross weight ratio is only 35%.)
(3) Their performance at all speeds up to relatively high speeds is excellent in all respects insofar as steering and control are concerned.

There are one or two disadvantages, however. The most obvious is that the articulated track vehicle cannot make a pivot turn, rather important if they are to be used as armoured vehicles. However, the turning radius of most of these vehicles and their rapid steering response make these machines extremely agile. Other disadvantages relate principally to first cost which, particularly in the smaller-sized vehicles, is somewhat increased by the necessary replication of suspension systems, etc.

Summarizing, the articulated vehicle, whether fully articulated or the Nodwell type, has improved the mobility of tracked vehicles through the elimination of constant braking and by making practicable a near bellyless configuration capable of carrying large loads at unusually low nominal unit ground pressure (3 psi).

Although the emphasis has been on the apparent virtues of articulated vehicles, nothing of the above should preclude the value of single hull vehicles. These vehicles, properly designed and with low ground pressure, may also be used over muskeg. The main drawback of the single hull vehicle, however, is that without broken back steering the tracks, as has been mentioned earlier, on the turn destroy the mat in the first pass. For this reason, where cost is not a consideration, they appear to offer marginal solutions to the problem of vehicular trafficability over muskeg.

In the matter of cost, it is interesting to note that in purchasing tracked vehicles one can generally lay down a price of approximately 95 cents to $1.15 a pound. This simply means to say that in the purchase of an articulated vehicle, which is in effect two vehicles, one pays twice the first cost over a similar vehicle which is not articulated. And it is this apparent first cost which inhibits the purchaser in making the first purchase of an articulated vehicle. Thus, it is only where "absolute trafficability" is required, such as in the oil fields, that this first cost will be paid. This of course leaves the field wide open for single hull vehicles, even though they may have limited trafficability. Normally what happens is that with this limited trafficability most of the muskeg areas are circumvented by semi-prepared tote roads. Some mention should therefore be made of the fact that Nodwell also builds a variety of single hull tracked vehicles in Calgary; Bombardier builds a series of similar vehicles in Valcourt, Quebec; and another small company in Owen Sound will undertake to provide vehicles on a custom basis.

## Road and Route Location

One of the aspects which has not yet been discussed in this problem of mobility in muskeg is the use of a road. The term "road" here is used in the sense of any improved or stabilized track that is utilized for travel, and the degree of improvement involving road standards suggests a subdivision into:

(1) "tote" roads;
(2) secondary roads;
(3) primary roads.

There is, in fact, a considerable amount of overlapping between each subdivision to accommodate cost and construction methods.

The choice of a particular construction method depends on the type of road required and the funds available. Low cost roads can be designed for winter operations (Thomson, 1957) or with minimum location improvements for tracked vehicles in the summer (Stoneman, 1961). Secondary roads are often "floated" on muskeg. Such roads have a greater summer and winter capability than the tote road. With primary roads the common construction method involves the removal of muskeg and/or the techniques of preconsolidation.

In relatively unmapped areas of Canada, air photographs have been utilized for ground locations of routes (Mollard, 1960). The procedure consists of first determining the origin and destination of the road. A tentative route is plotted from the aerial photographs. A ground survey crew is then moved into the area, the road plotted on foot to the first contact point, and any slight adjustments are made in accordance with the actual ground conditions.

There is always an initial temptation to utilize the snow or ice as a bearing surface over sub-grade such as muskeg. Winter roads of such a nature over muskeg usually will safely carry axle loads of over 12,000 lbs on single or dual wheels, and it is quite possible to induce two feet of frozen muskeg in a well-packed winter road. In summer, corduroy or fascine construction (consisting of logs or planks to provide a certain amount of buoyancy to spread the weight of the road evenly over the muskeg and to prevent the fill material from penetrating the surface of the mat of the muskeg) has been used extensively. When such roads must sustain heavy traffic loads and they are literally floated on the muskeg, it may be necessary to provide lateral support to prevent lateral slow failure of the subsurface material. This is accomplished by building counterweights or fills, sometimes called berms, on either side of the roadway to stabilize the unstabilized organic material beneath the embankment.

Costs

Access in muskeg areas must involve cost (Hemstock, 1956). Unfortunately the lack of information and the difficulties of correlating individual reports make cost estimates extremely difficult. For convenience, individual published estimates of access costs have been subdivided into two categories:

(1) Access costs (off-the-road vehicles).
(2) Road costs.

In the case of off-the-road vehicles, the technical and operational success of special muskeg vehicles, while they demonstrate the feasibility of satisfactory transport in even the worst muskeg areas, do not mean that they are a cure-all for transportation. Both major oil companies estimate that the initial cost of special muskeg vehicles capable of carrying the unit loads required for their purposes is in the order of $4,000 to $6,000 per ton of capacity. This cost is high and there appears to be little that can be done to reduce it. Another difficulty of determining the economics of tracked vehicles is that the development of these vehicles has been carried on while the bulk of the vehicles are in field service. Thus it is difficult to separate the operating and development costs. However, Thomson has estimated that tracked transportation machines can be operated for $1 to $2 per ton/mile. This high cost can be justified only when road construction costs of any route preparation can be avoided or when access to remote locations at a particular time is worth a premium. For comparison, rail rates average 5¢ per ton/mile and trucks vary from 5¢ to 20¢ per ton/mile on highways and 20¢ to 50¢ per ton/mile (exclusive of road costs) on winter roads.

It has been reported that a summer road over muskeg to a wildcat well in the Alberta area costs approximately $2,000 to $12,000 per mile and will usually be abandoned after 1200 tons have been moved over it. The road charge is then $1.60 to $10 per ton/mile and the total freight cost is $1.80 to $10.50 per ton/mile.

At the same time, despite claims to the contrary, some trail preparation is always necessary, particularly for the larger sized, specially designed muskeg vehicles. Thus, it turns out that winter trail preparations in muskeg areas average something in the order of $700 per ton/mile. Stoneman (1961) notes further that summer road costs to carry conventional tracked units are estimated at a minimum of $2,000 per ton/mile. These must be added to the costs mentioned above. It is assumed in the oil industry that the cost of an oilfield access road in Alberta will cost at least 1.45 times a similar road built in the forested area but outside an area in which muskeg is not necessarily predominant but is persistent.

## Ground Effect Machines

In this problem of mobility over muskeg, one other vehicle has yet to be considered and will be dealt with briefly. This is the ground effect machine sometimes known as the GEM. The GEM operates on a cushion of air free of the surface. But more than this, because of the augmented lift attainable when very close to the ground, the GEM can carry payloads comparable to present wheeled vehicles, and at potentially much greater speed. However, while GEMs are feasible aerodynamically and can operate with equal facility over land, water, mud, muskeg, and fairly level swamp surfaces, and are capable of high speeds, at present they are limited to an operating height of 3 feet over land and probably 2 feet over water, and only capable of a continuous climb up a 12% slope.

In defining muskeg it is assumed that in the upper end of the category much of the area will be treed, and certainly in the far north some of the boulders or hummocks may well be over 2-1/2 feet in height. GEMs of course cannot cross wooded areas and they probably will not have the ability to batter them down so that it will be necessary to choose routes and terrain very carefully. Although it will be advantageous to have a vehicle which has, in effect, no bearing pressure whatsoever, the GEM has a number of disadvantages besides the fact it can not work its way through treed areas. One thing will be that the GEM will have much larger dimensions than present-day vehicles. A GEM, like an aircraft, will have higher maintenance times and costs than trucks or other tracked vehicles. It cannot negotiate grades, as was mentioned before, and the GEM, among other things, presents a very difficult deceleration problem and - like tracked vehicles - for military purposes leaves an operational signature. It would seem, therefore, that the major problem of operating a GEM of any size in muskeg areas where trees may predominate would again involve the building of a tote road. This will mean that there will have to be some maintenance costs and first costs for the cleared track. Coupled with the high first cost of the GEM vehicle, this will probably take it out of the field, certainly at the present time, where ordinary civilian operators will care to use it.

## Conclusions

One major conclusion is that there is no ready answer for mobility in muskeg areas. However, this is true for any area, both for the land and the sea where vehicles are used. It can be seen, however, that with the wide variations in terrain and consequently the varying need for an optimum bearing pressure, there will be wide variations in the configuration and the tracks of the vehicle. It follows that vehicles must be designed for specific uses and in the case of the military application each of these specific uses should include the ability for the vehicle to be amphibious. It is not difficult to design a vehicle for any specific purposes. What is more difficult is the ability of the operator to define what that specific purpose is. It is in this field that the greatest advance is yet to be made. For example, one of the things that is required to be known in the design of the muskeg vehicle is the degree of pitching which must be damped out in these vehicles. This degree of pitching can be both a function of latitude and of climate. Another matter in dealing with muskeg vehicles is the degree and ability that this vehicle should have in order to work in treed areas.

One may say that, from an engineering standpoint, it would appear that rather good progress has been made in dealing with muskeg over the past ten years. A classification system for muskeg and peat has been devised and found satisfactory. Methods are now available to allow interpretation from aerial photographs. Engineering studies have been started and have been continued sporadically by a variety of organizations in the United States and Canada and some evidence points to the probability that the soil mechanics approach to muskeg problems is valid. In the field of vehicle design it has been shown that a muskeg vehicle is a feasible proposition, and it is possible that a satisfactory vehicle in all sizes up to 20 ton ranges will be readily available on the commercial market.

It must be stated, however, that operations in muskeg areas are still costly despite the progress and this condition is expected to remain even though further improvements may take place. Vehicles are bound to be more costly to run and roads more costly to build and the economics of any operation must allow for this. However, the most important thing is the fact that muskeg is no longer considered psychologically by both civilian and military as a complete barrier in the summer and there is now an increasing realization that methods and machines are available that will allow work in such areas throughout the year. This is a very definite step forward.

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## B.6. LES CARACTERISTIQUES MECANIQUES DE LA TERRE NOIRE

I. C. MacFarlane

Résumé:

Les problèmes de l'existence du muskeg tombent dans deux principales catégories: les problèmes économiques et ceux de l'ingénieur. Quelques uns des problèmes propres à l'ingénieur sont: l'accès sur le terrain, la construction des routes et des chemins de fer, le drainage et les caractéristiques mécaniques. Le manque d'un système de classification rationnel et quantitatif de la terre noire est un des principaux obstacles à l'établissement d'une comparaison adéquate des résultats obtenus par divers investigateurs. Les propriétés mécaniques de la terre noire considérées dans ce rapport comprennent les propriétés déterminées en laboratoire telles que la teneur en eau, le pourcentage de matières organiques, le poids spécifique, la réaction à l'acide, le pourcentage des vides et la perméabilité, et aussi les caractéristiques de force et de déformation telles que l'effort de cisaillement, la capacité de support et les caractéristiques du tassement.

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## B.6. THE ENGINEERING CHARACTERISTICS OF PEAT

I. C. MacFarlane

Abstract

Problems presented by the existence of muskeg fall into two main divisions: economics and engineering. Some of the specific engineering problems are: off-road access, road and railway construction, drainage, and engineering characteristics. One of the main obstacles to adequate comparison of test results of various investigators is the lack of a rational, quantitative classification system for peat. Engineering properties of peat considered in this paper include index properties, such as water content, organic content, specific gravity, acidity reaction, void ratio and permeability, as well as strength and deformation characteristics such as shear strength, bearing capacity and settlement characteristics.

## B.6. THE ENGINEERING CHARACTERISTICS OF PEAT

I. C. MacFarlane

The problems presented by the existence of muskeg are basically twofold:

1. Economic

The main question is one of land use: can muskeg be economically reclaimed and put to good use for forestry, agriculture, or as a mineral resource (e.g. as fuel)?

2. Engineering

Problems arise from characteristics of the terrain and of the material:

(a) Their unpredictability;
(b) The high water table;
(c) The low shearing resistance;
(d) The low bearing capacity;
(e) The extremely compressible nature of the material.

Specifically, some of the engineering problems are:-

(1) Off-road access over muskeg, which involves route location, trafficability of the terrain, and mobility characteristics of proposed vehicles.

(2) Road and Railway Construction over muskeg, which is related to the particular muskeg type and involves route location as well as embankment stability considerations, settlement characteristics of the peat, etc.

(3) Drainage in muskeg, which involves problems of route location, ditching techniques, and cut-slope stability. This is of concern not only in agricultural reclamation of muskeg and in road construction, but also in water supply and sewage disposal systems of towns adjacent to muskeg areas.

(4) Engineering characteristics of the peat, relative to the solution of some of the above-mentioned problems.

At the present time there is considerable interest in these problems and their solution, not only in Canada but also in Britain, the U.S.A., Japan, Eire, and to some extent in the U.S.S.R., although information from the latter country is not readily available. A considerable number of laboratory and field tests have been carried out on peat in an effort to determine some of the unknown parameters. A review of much or the resulting information has been published in an earlier paper (MacFarlane, 1959) and will be only briefly summarized here.

1. Classification

The need of a rational, quantitative classification system for peat is evident, if results of various investigations are to be adequately compared. In the past, the peat type has rarely been described. Certain routine index tests are now becoming common, however, as a means of describing the peat under investigation: water content, organic (or ash) content, specific gravity, acidity, permeability and void ratio.

2. Water Content (per cent dry weight at 105°C)

Peat has a great capacity for taking up and holding water and this affinity for water is one of the most important characteristics of the material. For pure peats, when saturated, the water content is more than 600% of dry weight, generally ranging between 750% and 1500%, although it has been observed to be as high as 3200% of the dry weight. The fibrous peats will hold more water than the decomposed peats. A small percentage of inorganic material in the peat will seriously affect the water content, and the water content will drop sharply as mineral soil contamination increases.

3. Organic and Inorganic (ash) Content (basedon loss-on-ignition test)

Peat which is mainly free of extraneous mineral matter has up to 95% organic content, based on dry weight. From this maximum, every gradation done to a mineral soil is found. The organic content of peat has a considerable effect on its physical and mechanical properties.

4. Bulk Density and Specific Gravity

Bulk densities have been observed to range from 25.0 lb/cu. ft for a moss peat to 75.0 lb/cu. ft for an amorphous peat. Dry unit weight ranged from 5 to 20 lb/cu. ft, the latter representing considerable mineral soil contamination. Reported values of true specific gravity range from 1.1 to 2.0 with the average about 1.5 or 1.6. Values over 2.0 indicate a considerable degree of mineral soil contamination.

5. Acidity Reaction (measured by pH-negative logarithm of hydrogen ion concentration in an aqueous suspension of the soil)

Usually peat has an acid reaction, the "moss peats" being the most acidic with pH values as low as 2.0. The usual range is from 4.0 to 6.0, however, although values as high as 8.0 have been reported.

6. Void Ratio (volume of voids/volume of soil solids)

Fibrous peats have a very high natural void ratio, whereas amorphous peats exhibit low void ratios. An extreme void ratio range of 3 to

25 has been reported, the latter being for a fibrous peat and gives some indication of the settlement which might be expected. A range of 5 to 15 is more usual.

7. Permeability (the property of a substance which permits passage of fluids through the pores of a material)

Permeability of peat varies widely, depending upon: (1) the amount of mineral matter in the soil, (2) the degree of consolidation, (3) the extent of decomposition. A report from the United States gives the average value of permeability of peat in the vertical direction as $1.06 \times 10^{-3}$ cm/sec and in the horizontal direction as $7.06 \times 10^{-4}$ to $4.6 \times 10^{-3}$ cm/sec. A report on Japanese investigations indicates that the peat type studied had permeability coefficients of 2 to $13 \times 10^{-3}$ cm/sec in the horizontal direction and 2 to $7 \times 10^{-3}$ cm/sec in the vertical direction, with an anisotropy ratio of 3 to 6. An Irish study showed that a sample of partly humified peat had a natural void ratio of 13 and a permeability of $4 \times 10^{-4}$ cm/sec. Under a load of 0.56 kgm/cm$^2$, after 2 days, the void ratio was reduced to 6.75, the permeability to $2 \times 10^{-6}$ cm/sec, and after seven months the void ratio was reduced to 4.5 and the permeability to $8 \times 10^{-9}$ cm/sec or 1/50,000 of the initial permeability. A similar study of a peat sample from Northern Ontario showed a significant reduction in permeability with load, changing from $5.1 \times 10^{-2}$ cm/sec to $5.1 \times 10^{-7}$ cm/sec (or 1/10,000 of initial value) with load increments up to 2.89 kg/cm$^2$.

8. Strength and Deformation Characteristics

Most of the engineering problems with muskeg fall into three general categories:

(1) Shear strength of the peat.
(2) Bearing capacity.
(3) Settlement characteristics.

(1) Shear Strength. The principal factors influencing the shearing strength of peat are: (a) texture (b) moisture content and (3) inorganic soil content. Three main methods of assessing shear strength have been utilized: in situ measurements, stability analysis, and laboratory shear tests. A summary of reported results from in situ tests on peat using the vane apparatus are shown in Table I. The only recorded cases of the stability analysis being used to determine shear strengths for peat have been in Alberta and British Columbia. In the Alberta study, the following results were obtained:

| | |
|---|---|
| Circular arc analysis: | 160 p.s.f. |
| Sliding block analysis: | 180-234 p.s.f. |
| Elastic theory: | 150 p.s.f. |
| Vane apparatus: | 125-225 p.s.f. |

This indicates good agreement between results from stability analysis and in situ tests. On the other hand, analyses of two shear failures which occurred during embankment construction over muskeg in British Columbia indicated that the computed average shear stresses at failure were close to the remoulded vane shear strength, which is about one-half to one-third of the undisturbed vane shear strength. The difficulty of obtaining good undisturbed samples of peat has militated against the carrying out of extensive laboratory strength tests. However, average values for a drained Irish peat were 290 to 575 p.s.f. An English peat had an average laboratory shear strength of 250 p.s.f., and a very wet peat from Florida indicated a shear strength of 200 p.s.f. from triaxial tests.

(2) Bearing Capacity. This has its most direct application to vehicles and mobility, and it is generally agreed that for successful operation in muskeg a vehicle should not have a ground pressure in excess of 3 p.s.i. (430 p.s.f.).

(3) Settlement Characteristics. The most obvious characteristic of peat is its exceptionally high compressibility under load. This facet of peat behaviour has received a great deal of attention and extensive literature is now available on the subject. However, there is still considerable controversy about the mechanism of consolidation in peat and the relative contributions to the total settlement of the primary consolidation phase and of the secondary compression phase. Some success has been achieved in predicting the amount of settlement to be expected, but a prediction of the rate of settlement has been much more difficult. Conclusions of the various investigators on which there is general agreement may be briefly summarized as follows:-

(a) In the laboratory, "primary" consolidation occurs very rapidly, generally in a few minutes, and may constitute as little as 50% of the total settlement.

(b) Complete consolidation is reached only after a long period of time - several months even for small specimens.

(c) "Secondary" compression is considered to be of a viscous or plastic nature, its magnitude affected by temperature, the nature of the peat and the state of stress. It is independent of drainage conditions. "Secondary" compression is unusually high for peats and may account for up to one-half of the total settlement.

(d) In the secondary stage of compression the plotted relationship between settlement and log time approximates a straight line, both for laboratory and field observations.

(e) If the load is fully removed during or following the "secondary" compression phase, rebound may be quite significant.

The use of consoldiation tests to predict the amount and rate of settlement in peat is much less refined than for clays. It is generally conceded that where major structures are contemplated, it is advisable to carry out large-scale tests to verify consolidation test results.

Conclusion: This brief report has endeavoured to point out the highlights of current available information on the engineering characteristics of peat. It is evident, however, that despite the extensive work which has been done there are still large gaps in the knowledge. Consequently, there is adequate opportunity for further research by industry, by government agencies, and especially by the universities.

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## REFERENCE

MacFarlane, I. C. "A Review of the Engineering Characteristics of Peat". Amer. Soc. Civil Engineering, Proceedings, Vol. 85, SMI, Pt. 1, pp. 21-35. 1959.

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## Discussion

Mr. Berezowski asked if the load distribution in peat under a foundation was 45°. Mr. MacFarlane replied that it was generally considered to be 45°.

A question was raised about the use of peat, considering its large cellulose content. Mr. MacFarlane said that other and more economic sources of cellulose in Canada rendered the possibility of using peat for this purpose rather remote at the present time.

Mr. Tessier asked about the relationship between the settlements of the soft clay underlying the peat and those of the peat itself. Mr. MacFarlane replied that there are two settlements and it is necessary to differentiate between them in the engineering analysis. He declined to suggest any percentage figures for the two settlements, without some information on the many variables involved.

Table I

| Locale of Investigation | Shear Strength | Remarks |
|---|---|---|
| Britain | 360 and 72 p.s.f.<br>504 and 216 p.s.f. | moss peat: 4-in. & 22-in. depths<br>fen peat: 4-in. & 22-in. depths |
| Alaska Highway | 106 and 610 p.s.f. | 21-in. and 12-ft. depths |
| Edmonton area | 100 to 200 p.s.f.<br>210 to 1090 p.s.f.<br>Sensitivity range: 1.5 - 3.7 | FI muskeg<br>BEI muskeg<br>Shear strength inversely proportional to water content |
| Northern Ontario | 450 to 850 p.s.f.<br>Sensitivity range: 1.5 - 10 | mainly BEI muskeg<br>vane size critical<br>No correlation observed with either depth or water content |
| Saskatchewan | 202 to 1295 p.s.f. | BEI muskeg<br>Water content not in excess of 500% |
| British Columbia | 290 to 430 p.s.f.<br>148 to 258 p.s.f.<br>Sensitivity range: 1.12 - 2.45 | ADI avg. water content 1000%<br>DEI range of water content = 1400-1700% |
| Japan | 102 to 510 p.s.f.<br>avg. = 205 p.s.f. | Shear in vertical plane = twice shear in horizontal plane |

## B.7. LE MUSKEG ET L'HORTICULTURE

N. W. Radforth

Résumé:

L'emploi de la terre noire en horticulture n'est pas nouveau. Depuis plusieurs années, elle est utilisée en Ecosse et dans plusieurs autres pays. A un certain moment, la terre noire servit même à faire du papier et du carton. Les parcs sont un très bon usage pour les terrains marécageux. On peut faire pousser de l'herbe avec de bons résultats sur ce genre de terrain. Il est vrai que cela entraîne plusieurs problèmes, mais il est tout de même possible de bien réussir. Glasgow possède un excellent jeu de boules sur gazon qui est effectivement construit sur une tourbière. Les utilisations de la terre noire sont presque illimitées. Pourquoi ne pourrait-on pas délayer la terre noire, au lieu de l'assécher, puis l'expédier sur les marchés par pipe-lines? En Suède, les produits dits "jiffy pots" (pour les plantes) sont faits de terre noire et de pâte de bois, et sont expédiés dans le monde entier. Pourquoi ne peut-on fabriquer un produit similaire à Prince-Rupert?

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## B.7. MUSKEG AND HORTICULTURE

N. W. Radforth

Summary

The use of peat in horticulture is hardly new. For many years it has been used in Scotland, as well as in other countries. At one time peat was even used to make paper and cardboard.

One very good use for muskeg areas is as parkland. Excellent crops of grass can be grown on this type of terrain. It is true that it entails many problems but it can be done. Glasgow has a first class bowling green which is on a peat bog.

Uses of peat are almost unlimited. Why could not peat be wetted, rather than dried, and be shipped to markets by pipeline? So-called "Jiffy pots" (for plants) are made of peat and wood pulp in Sweden and shipped all over the world. They are even used in Prince Rupert. This is like carrying coals to Newcastle. Why could a similar product not be made in Prince Rupert?

Discussion

Dr. Radforth was asked to explain the relationship, if any, between peat type and pH and to advise how much lime to use to correct the pH. Dr. Radforth said that any plant can tolerate a certain range of acidity. The thing to do is to work not with the peat but with the plant. Once you know the range of tolerance of a plant, you can alter the peat accordingly. Dr. Radforth predicted that the time will come when we use peat for a great many things. The variety of chemicals stored in peat is quite startling.

One delegate remarked that ammonium nitrate is used to break up the peat fibre. He wondered how much should be used so as to not destroy the peat's value entirely. Dr. Radforth agreed that some ammonium nitrate should be used to promote decomposition. In raw peat there is a very limited number of bacteria. In fact, it is even thought that there is a limited amount of antibiotics in peat. Dr. Radforth referred to the Leningrad Peat Congress which had a whole session devoted to the medicinal values of peat. Adding ammonium nitrate to peat builds up a growing medium for bacteria and they begin to break down the peat. Once this commences, he said, it is not necessary to add any more ammonium nitrate. If you keep doing this too long, the structure will break down too much. Deliberately adding woody peat will decrease the rate of breakdown. Therefore, the more lignin in the peat, the more ammonium nitrate will be required. Actually the pH factor is really not as important as the structural factor. Dr. Radforth thought that the peat moss producers should indicate what their product can do, what it contains, and so on.

Mr. Martinusen wanted to know if all bacterial action ceases when peat is formed. Dr. Radforth replied that it did not cease entirely. Sometimes there is anaerobic bacterial action in situ, but it is not very great relative to the peat mass.

It was pointed out that it has been found possible to grow almost the entire range of garden vegetables in peat but no success has been achieved in Prince Rupert with green beans. Dr. Radforth was asked why this is so. He replied that between Cochrane and Kapuskasing in Ontario there is a great deal of muskeg and beans are grown very successfully in that area. He could not say what might be the local problem, except that perhaps the water content of the peat may be too high.

A further question was raised concerning the moss growth on lawns, which is quite a local problem. Addition of lime is a temporary cure, but a more permanent remedy is needed. Dr. Radforth suggested that it is possible to attach a special device to the garden hose to enable a chemical preparation to be sprayed on the lawn, thereby changing the acidity of the peat. He recommended that those members of the Prince Rupert Garden Club who have specific problems might usefully contact a member of the Muskeg Subcommittee who has had extensive experience in horticulture: Mr. J. V. Healy of the Newfoundland Department of Agriculture.

## CONCLUDING REMARKS

Following presentation of the papers, Dr. Radforth and Mr. K. Ashdown showed a brief film on the vehicle testing program carried out at Parry Sound, Ontario, by the Organic and Associated Terrain Research Unit of McMaster University. This film illustrated the performance of various vehicles - both tracked and wheeled - in different muskeg types. Following the film a question was raised regarding how long after the first pass (when a vehicle can make only one pass in a specific muskeg area) can the second pass be made. Dr. Radforth replied that the mat will not return to normal for 12-15 years. The time until a second pass can be successfully made will depend, however, upon the damage done to the mat during the first pass. If only one pass is possible, then the damage will be quite critical.

Dr. Radforth was asked how far away from the track of the first pass should the second pass be. He said that the deviation should be about 15 feet.

Another questioner wanted to know the special characteristics of the Timberjack. Dr. Radforth explained that it is an articulated vehicle and therefore flexible.

In concluding the Seminar, Dr. Radforth once again expressed his pleasure - and that of the Muskeg Subcommittee - at the opportunity of being in Prince Rupert and participating in the interchange of ideas and information. He said that the keen interest in muskeg shown by today's sessions is a source of inspiration to the Subcommittee and that their impressions will be passed on to the parent committee - the Associate Committee on Soil and Snow Mechanics.

APPENDIX "C"

## LIST OF THOSE PRESENT AT PRINCE RUPERT SEMINAR 25 MAY 1964

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