Muskeg Research: A Canadian Approach

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Muskeg comprises approximately 12 percent of the terrain of Canada, most of it in the northern regions, thereby presenting an engineering problem of considerable proportions. Research into this type of terrain, in progress since 1945, is largely government sponsored. The initial approach was from a palaeobotanical point of view and from this has developed a muskeg classification system, which is subsequently being used by many engineers involved with problems related to this type of terrain.

Current research is almost entirely of an engineering nature and is being pursued in various phases. It involves studies of aerial photographic interpretation of muskeg to permit route plotting of this terrain for off-the-road vehicles; field and laboratory studies to determine certain engineering characteristics of the material, by applying soil mechanics theory and techniques or modifications thereof; and the development of vehicles for off-the-road access over muskeg areas.

• MUSKEG, a word distinctive to the northern United States and Canada, is derived from the Chippewa Indian word "maskeg," meaning "grassy bog." Although the word has many modern connotations, for engineering purposes muskeg (or "organic terrain" as it is now widely known) may be defined as *terrain composed of a living organic mat of mosses, sedges and/or grasses, with or without tree growth, and underlain by a usually highly compressible mixture of partially decomposed and disintegrated organic material, commonly known as "peat" or "muck"* (*10*). Muskeg is characterized by its high water content and its low bearing capacity. The depth of organic deposits varies widely from a few inches (presenting a not too serious engineering problem) to many feet (which may present a serious engineering problem).

A large part of the total area of Canada is made up of muskeg, much of it occurring in the subarctic regions well north of the main centers of population. There is estimated to be more than 500,000 square miles of muskeg in Canada; this great organic mantle is rivalled in prominence only by water or permanent snow and ice cover (*22*). It is present to a greater or lesser degree in every province, as well as in the Yukon and Northwest Territories.

The existence of muskeg limits the use of land. It is not conducive to agricultural or forestry activity and it is a serious obstacle to the development of mineral resources. For example, it is a very real problem in oil exploration, as the operating costs of drilling for oil in muskeg territory are more than double those in mineral soil terrain (*7, 27*). This is because of the difficulty of achieving access either by off-the-road vehicles or by roads. The low bearing capacity of the terrain does not readily permit transportation of heavy equipment, as there are large areas of muskeg which conventional tracked or wheeled vehicles cannot negotiate. Vehicles have been known to break through the surface mat and disappear entirely from sight.

In normal road construction it is often possible to avoid areas of muskeg. This was done in the construction of the famous Alaska Highway, which skirts many large muskeg areas. As national development spreads farther north into regions where muskeg blankets great expanses of the terrain, detours are not always easily available, or even expedient. Also, present standards of road building require more rigid maximum grade and curvature restrictions and increased minimum-sight visibility. This means crossing terrain where adverse conditions will be encountered. The difficulties of road construction over organic terrain are well known and present a constant challenge to the highway engineer.

HISTORY OF MUSKEG RESEARCH IN CANADA

Interest in the engineering aspect of the muskeg problem was stimulated by military requirements in Northern Canada during the latter part of World War II. Access over large areas of this complex terrain became both a necessity and a concern. Some work on vehicle trafficability was carried out, but because of the military implications any reports were classified. Immediately after the war a program of research was initiated by the Associate Committee on Soil and Snow Mechanics of the National Research Council (Canada) into the various types of terrain of Canada, including soils, snow, and ice, as well as muskeg.

The initial approach to the muskeg problem was a fundamental one which considered the nature and manner of formation of the material. This pioneer work was carried out by N. W. Radforth, a palaeobotanist from McMaster University. Under the auspices of the National Research Council and the Defence Research Board, investigations were carried out for several years in the region of Churchill, Manitoba. More recently, similar investigations have been made in most of the provinces of Canada to confirm the original results.

The research program covered three phases: ground studies, laboratory investigations, and aerial photographic interpretation. The primary purpose was to establish the nature of muskeg in terms useful to engineers and to formulate a classification system for it. Muskeg was found to be a problematical but not a disorderly medium; on this basis, a classification system for engineering use was developed and first presented in 1952 (*13*). Subsequent investigations have been discussed in a number of papers by Radforth (*14* to *23*) outlining extensions to the classification system and explanations of its use. Considerable attention has been given to route plotting for vehicles through interpretation of aerial photographs.

In 1954 the Division of Building Research of the National Research Council began a program of muskeg research in view of the increasing number of engineering problems with muskeg in northern Canada. The terms of reference of the program are to determine the physical and mechanical properties of muskeg and to develop a scientific method of application of these properties in actual field problems. An attempt to accomplish this by applying soil mechanics theories and techniques or modifications was proposed. The assembling and correlating of data in the form of a literature review have resulted in the compilation of an annotated bibliography (*9*), a review of road construction techniques over muskeg (*10*), and a recent review of published material on engineering tests on peat (*11*). An adequate engineering classification system for muskeg was necessary to permit easy comparison of various features of the terrain and the material at different locations. Now the Radforth Classification System is in use and field records are being obtained in an attempt to correlate the various muskeg types and the corresponding shearing strengths of the peaty material (*12*). Close liaison exists between the work at the Division and at the Muskeg Research Laboratory of McMaster University under Dr. Radforth (*24*).

Within the past three or four years, with the accelerated pace of northern development, interest in muskeg has increased proportionately with regard to construction. Organizations other than the National Research Council, the Defence Research Board, and McMaster University, have become interested in the muskeg problem and are conducting research into its various aspects. Some are government agencies (including the Departments of Highways of British Columbia and Ontario, and the University of Alberta); others are private organizations (such as Imperial Oil, Ltd.)

A Muskeg Subcommittee, under the auspices of the Associate Committee on Soil and Snow Mechanics of the National Research Council, is concerned with the study of physical, chemical and mechanical properties of muskeg soil (or, more properly, "peat") with reference to practical engineering problems. The Subcommittee gathers necessary information on the state of knowledge in this field as defined, particularly on research work on muskeg in progress in Canada, and advises the Council through the parent Committee (the Associate Committee on Soil and Snow Mechanics) on the collection and dissemination of research information generally. The Subcommittee investigates and stimulates muskeg research work in Canada and serves as liaison between the National Research Council and governmental, educational and other organizations and agencies engaged in or concerned with research on muskeg. One of the major tasks of the Subcommittee has been to organize annual conferences at which muskeg problems are presented and discussed and progress reports on research are given.

RADFORTH CLASSIFICATION SYSTEM FOR MUSKEG

Despite the apparent complexity of muskeg, an analytical study revealed organization as a prime prerequisite to classification. On the basis of the palaeobotanical investigation, Radforth (*13*) developed a classification system consisting of three subsidiary systems utilizing surface, subsurface, and topographic features of the terrain. When considered together, these present a fairly complete picture of existing conditions for a given area.

Surface vegetation, the first factor observed, is the easiest to assess. Vegetation has been grouped into nine classes, designated "A" to "I," inclusive. These classes are not delineated by species of plants, but by qualities of vegetation, such as stature, woodiness, external texture, and certain easily recognized growth habits. Classes A, B, D and E are woody and range in height from less than 2 ft to over 15 ft. Classes C, F, G, H and I are non-woody and include tall and short grass-like forms (C and F), herbaceous plants (G), and low creeping plant forms (H and I). Class H is leathery to crisp, class I is moss-like. Pure classes seldom exist by themselves, but are in combination with other classes. A particular muskeg area is thereby designated by a coverage formula, consisting of two or three letters, never of four. If a particular coverage class property is not present in 25 percent of the terrain, it is not included in the formula. In the combination of letters, the one which represents the most prominent set of properties is placed first and other letters follow in order of prominence. Although there would seem to be many combinations of the coverage classes, the number of combinations which commonly occur in Canada are limited to about 18. A summary of the properties designating the 9 pure coverage classes is given in Table 1. Figures 1 to 9 illustrate examples of these classes.

A second subsidiary system was developed for the subsurface material, or peat. The peat categories are classed according to woodiness and fibrousness. Some of the peat types consist mainly of an amorphous-granular base; others are predominantly fine-fibrous, the fibers being either woody or non-woody. A third group is predominantly woody and coarse-fibrous. Again, although large numbers of combinations of these three basic types seem possible there are only 16 main categories. These are listed in Table 2. The peat types vary according to variations in the organic terrain.

In the appraisal of organic terrain some attention must be given to terrain unevenness. Although topographic differences in the organic overburden are sometimes caused by irregularities in the mineral substrata, much of the uneven-

TABLE 1
PROPERTIES DESIGNATING NINE PURE COVERAGE CLASSES
(from Radforth Muskeg Classification)

Coverage Type (class)	Woodiness vs Non-Woodiness	Stature[1] (ft)	Texture	Growth Habit	Example
A	Woody	15 or over	—	Tree form	Spruce, larch
B	Woody	5 to 15	—	Young or dwarfed tree or bush	Spruce, larch, willow, birch
C	Non-woody	2 to 5	—	Tall, grass-like	Grasses
D	Woody	2 to 5	—	Tall shrub or very dwarfed tree	Willow, birch, Labrador tea
E	Woody	up to 2	—	Low shrub	Blueberry, laurel
F	Non-woody	up to 2	—	Mats, clumps, or patches, sometimes touching	Sedges, grasses
G	Non-woody	up to 2	—	Singly or loose association	Orchid, pitcher plant
H	Non-woody	up to $\frac{1}{3}$	Leathery to crisp	Mostly continuous mats	Lichens
I	Non-woody	up to $\frac{1}{3}$	Soft or velvety	Often continuous mats, sometimes in hummocks	Mosses

[1] Approximate height.

ness of the surface is due to topographic change within the material itself. These topographic features are especially important when assessing the terrain for access by off-the-road vehicles. Table 3 lists the most usual topographic features encountered, together with the associated vegetal coverage and peat type.

The classification system in its final form involves an integration of these subsidiary systems. When the surface, subsurface and topographic features are known, other conditions may often be inferred — that is, the relative bearing capacity and the vegetal hindrance to vehicles. A definite relationship exists

Figure 1. Class A; woody, 15 ft or over.

Figure 2. Class B; woody, 5 to 15 ft.

Figure 3. Class C; non-woody, 2 to 5 ft.

Figure 4. Class D; woody, 2 to 5 ft.

Figure 5. Class E; woody, up to 2 ft.

Figure 6. Class F; non-woody, up to 2 ft.

Figure 7. Class G; non-woody, up to 2 ft.

Figure 8. Class H; non-woody, up to 4 in.

Figure 9. Class I; non-woody, up to 4 in.

TABLE 2
SUBSURFACE CONSTITUTION

Predominant Characteristic	Category	Name
Amorphous-granular	1.	Amorphous-granular peat.
	2.	Non-woody, fine-fibrous peat.
	3.	Amorphous-granular peat containing non-woody fine fibers.
	4.	Amorphous-granular peat containing woody fine fibers.
	5.	Peat, predominantly amorphous-granular, containing non-woody fine fibers, held in a woody, fine-fibrous framework.
	6.	Peat, predominantly amorphous-granular containing woody fine fibers, held in a woody, coarse-fibrous framework.
	7.	Alternate layering of non-woody, fine-fibrous peat and amorphous-granular peat containing non-woody fine fibers.
Fine-fibrous	8.	Non-woody, fine-fibrous peat containing a mound of coarse fibers.
	9.	Woody, fine-fibrous peat held in a woody, coarse-fibrous framework.
	10.	Woody particles held in non-woody, fine-fibrous peat.
	11.	Woody and non-woody particles held in fine-fibrous peat.
Coarse-fibrous	12.	Woody, coarse-fibrous peat.
	13.	Coarse fibers criss-crossing fine-fibrous peat.
	14.	Non-woody and woody fine-fibrous peat held in a coarse-fibrous framework.
	15.	Woody mesh of fibers and particles enclosing amorphous-granular peat containing fine fibers.
	16.	Woody, coarse-fibrous peat containing scattered woody chunks.

between the structure and character of the subsurface material and the vegetative cover (*16*). It is also possible to make certain generalizations regarding the properties of the terrain from a knowledge of merely the surface vegetation and the topographic features. In exceptional cases, however, this will not be possible, such as where a fire has destroyed the original vegetation (which would have indicated subsurface conditions) and where existing vegetal cover is of a "secondary" nature.

One of the more common coverage classes is type BEI muskeg, representing dwarfed trees 5 to 15 ft high, low woody shrubs up to 2 ft high, and a soft velvety non-woody mat up to 4 in. high (moss). Normally, the subsurface material (peat) will be a woody, fine-fibrous peat held in a woody, coarse-fibrous framework (category 9). Associated topographic features are mounds and peat plateaus (b and i, Table 3). These conditions represent a favorable combination for road construction, as the bearing capacity of BEI is relatively high and material for corduroying is readily available should that method of construction be used. If excavation is to be carried out the fibrosity of the peat holds together well enough to prevent a cave-in of the trench (at least for fairly shallow depths), thus making it one of the easiest types to excavate.

On the other hand, the worst type of terrain for normal activity is represented by class FI muskeg, denoting a non-woody structure up to 2 ft high (grasses, etc.) and a mossy mat. This type usually is associated with a high water content and often with ponds (topographic feature 1). The peat type will be fine-fibrous and non-woody (category 2). Although the depth of this muskeg type may not be great, its presence usually represents a particularly treacherous condition, which will present serious construction problems. The bearing capacity of the terrain is very low and often it cannot be crossed safely on foot. Vehicles traversing this type of terrain must be amphibious because of the associated high water table. Except for dredging, excavation is very difficult or impossible.

CURRENT MUSKEG RESEARCH IN CANADA

A proposed 4-lane divided highway from Vancouver, B.C., to the U.S. border at Blaine crosses 2 mi of muskeg on Lulu Island (*1*). The vegetal cover is DEI and the peat is basically amorphous granular. The depth varies from 6 to 11 ft. Two construction possibilities were considered: excavation and backfill with granular material, or preconsolidation by surcharge. In 1957 the British Columbia Department of Highways installed a test section at the center of the organic deposit to determine whether preconsolidation would provide a stable grade. A detailed soil survey, laboratory testing, and a field instrumentation program were carried out. Samples of the peat were obtained with a thin-walled

TABLE 3
TOPOGRAPHIC FEATURES

Topographic Feature	Symbol	Location by Coverage	Occurrence Distribution	Peat Category	
Hummock	a	FI background hummock coverage, F	In groups, commonest near peat plateaus or ponds	Non-woody, fine-fibrous	(2)
Mound	b	FI background mound coverage, EH	Random, common where ill-drained	Non-woody, fine-fibrous; mound itself, coarse-fibrous	(8)
Ridge	c	FI background ridge coverage, HE	Regularly associated common or ill-drained plains	Coarse-fibrous, traversing fine-fibrous	(13)
Rock gravel plain	d	HEB where covered	Infrequent, interruptions	Amorphous-granular, with woody, fine-fibrous held in coarse-fibrous	(6)
Gravel bar	e	HEB	Coastal plain		
Rock enclosure	f	EHB	Uncommon, on elevated rock ridge or plateau, often near ponds	Coarse-fibrous woody	(12)
Exposed boulder	g	EHB	Random, common in EHB background of FI		
Hidden boulder	h	EH	Random, common under EHB background of FI	Woody, fine-fibrous, held in coarse-fibrous	(9)
Peat plateau, even	i	HE	Spreading, usually equidimensional, common interrupting FI	Amorphous-granular in fine-fibrous	(3)
Peat plateau, irregular	j	HFE	Spreading, usually linear, common traversing mixed background	Amorphous-granular fine-fibrous non-woody in woody, fine-fibrous	(5)
Closed pond	k		Random in HE, occasionally FI; common, usually associated with ridge margin	Amorphous granular	(1)
Open pond	l		In FI, common		
Pond or lake margin, abrupt	m	EH	Often part of drainage route in F, common, often with marginal ridge of EA	Non-woody and woody, fine-fibrous, held in coarse-fibrous	(14)
Pond or lake margin, sloped	n	F	Random, in flooded plains; common, in F	Non-woody, fine-fibrous	(2)
Free polygon	o	EH	Random, uncommon in EH or FI background	Woody, fine-fibrous held in coarse-fibrous	(9)
Joined polygon	p	HE, FI	Random areas, common on peat plateaus or confined FI	Non-woody, fine-fibrous covering amorphous-granular in fine fibrous	(7)

6-in. diameter sampling tube 12 in. long. The samples were quick-frozen in the laboratory and test specimens were prepared in the frozen state. Samples were then placed in the consolidation apparatus and allowed to thaw for 24 hr before testing. Field instrumentation included settlement plates, piezometers, and lateral movement gauges. Readings were taken daily during the construction period and every two weeks thereafter. Test results and field measurements were not expected to be complete until late in 1958 and were not yet available when this paper was written.

The Department of Highways of Ontario is carrying out a study of the bearing value of muskeg for highway purposes, including a correlation of the Radforth classification with engineering properties of muskeg (*3*).

Within the past few years some research has been carried out by the University of Alberta. The research program has involved the analysis of failures of roads built over muskeg to determine the shearing strengths of the peat, and also the development of a field vane tester for use in muskeg (*4*, *5*). Test results have shown that shearing strength of the peat increases directly with depth, although the maximum shearing strength was only developed after an extraordinarily high degree of deformation. Recently, the University of Alberta has begun a determination of in-place strength of organic terrain by building test fills to failure and comparing with vane-test strength results (*3*). The results of this investigation are not yet available.

Various private individuals have been investigating the physical and mechanical properties of peat in connection with certain engineering projects. Lea (*8*) reported basic research into the engineering properties of peat through a program of consolidation and triaxial strength testing in connection with the Burnaby Lake Freeway near Vancouver. The vegetal cover is ABD to BDE, the subsurface material ranging between categories 2 and 3. It is suggested that, based on the limited records available, there is no reason to treat peat differently from inorganic soils as regards strength except to give adequate attention to the volume change. For consolidation characteristics, preliminary information indicates that primary consolidation is a much more important factor in peat consolidation than has been previously assumed. Because of the physical nature of peat, creep is a significant phenomenon and will receive detailed consideration. The elastic properties of peat are believed to be of great importance, particularly when a road is floated over a muskeg. A full-scale test section of the Burnaby Lake Freeway is planned, the peat being preloaded. After the removal of the surcharge, plate-bearing tests are planned in order to study the elastic properties of the peat. This work has also included studies of peat sampling techniques with special reference to the use of the Swedish Foil Sampler (*3*).

Ripley (*3*) reports that in the course of construction of an 18-ft high embankment over a 30-ft peat deposit, progressive stage construction was controlled by field settlement and shear-strength measurements of the embankment foundation during construction. Cook (*2*) has attempted to correlate mechanical properties of peat obtained from deposits in the Vancouver area. He shows a relationship between the coefficient of compressibility of peat and moisture content. There is also correlation between moisture content and specific gravity, void ratio and submerged weight of peat. He suggests that these simple relationships are sufficient to permit calculation of settlement without lengthy consolidation tests.

Imperial Oil is carrying out research into vehicle mobility performance on the various tracked vehicles used in over-muskeg travel (*6*). The objectives of the vehicle mobility studies (which have been dubbed "terradynamics") are: (a) to determine the applicability of the available information on vehicle mobility to vehicle operations in muskeg, and (b) to determine quantitatively the levels of mobility performance of a few current muskeg vehicles (*26*). In addition to its study of the performance of existing vehicles, Imperial Oil is pioneering in the design of new vehicles for travel over muskeg (*25*).

The aims of the Muskeg Research Laboratory at McMaster University in 1958 have been to determine whether a relationship exists between the quantitative analysis of organic terrain structure and its shear strength, and to assess the relationship of bearing capacity and depth range in organic terrain. Efforts are under way to demonstrate the relationship between the mechanical structure of peat and hydrological conditions, including ice phenomena.

The muskeg research program at the Division of Building Research of the National Research Council is now being directed toward a more fundamental approach to the problem of determining mechanical and physical properties of peat, and a number of exploratory laboratory studies have been undertaken. Tests carried out on a number of tube samples have included consolidation, permeability, and laboratory vane tests, together with such routine tests as water content, density, organic content, acidity, and specific gravity.

In cooperation with the Department of Highways of Ontario, an assessment has begun of existing roads built on muskeg in northern Ontario. There will be attempts to correlate the road performance and condition with the muskeg type, depth, mineral substrata, etc. In connection with this program, vane tests have been carried out and further studies are planned of the effectiveness of the vane apparatus for determining the *in situ* shear strength of peat.

A cooperative program of research has also been undertaken with the McMaster Muskeg Research Laboratory. A series of tests were carried out to determine the strength of the surface mat of various muskeg types. A special test apparatus was used to obtain the tearing strength of the organic mat. These tests are to be continued.

CONCLUSIONS

Although muskeg research is at present an active field of investigation in Canada, there are still many unsolved problems. The Radforth Classification System, however, has received general acceptance by field engineers involved with this type of terrain, so that the large hurdle of standardization of terminology is past. With the rate of northern development expected to increase, the pressure of the problems encountered with muskeg will undoubtedly stimulate others to conduct research into various aspects of the problem. The future can be faced, therefore, with confidence in the knowledge that the engineering problems presented by the many thousands of square miles of organic terrain in Canada are gradually being overcome by the cooperative efforts of research workers and engineers in the design office and in the field.

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