Proceedings of the Twelfth Muskeg Research Conference

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PROCEEDINGS

of the

TWELFTH MUSKEG RESEARCH CONFERENCE

19 and 20 May 1966

Prepared by

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FOREWORD

This is the record of the Twelfth Muskeg Research Conference, which was held in the Science Complex of the University of Calgary, Calgary, Alberta, on 19 and 20 May 1966. The Conference was sponsored by the Associate Committee on Geotechnical Research of the National Research Council. A list of those in attendance is included in Appendix "A" of these Proceedings.

Three technical sessions were held, during which eleven papers were presented. Chairmen of the sessions were Messrs. R. A. Hemstock, C. O. Brawner and I. C. MacFarlane. A wide variety of topics was considered, including environmental analysis, access and terradynamics, and exploitation.

The Conference concluded with an afternoon field trip to a muskeg area to demonstrate terrain features used for prediction purposes for access.

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TABLE OF CONTENTS

INTRODUCTORY REMARKS

Dr. N. W. Radforth introduced Dr. J. Hine, Dean of Graduate Studies at the University of Calgary. Dean Hine cordially welcomed Conference delegates to the University, on behalf of President H. S. Armstrong who, unfortunately, was ill. He pointed out that there is great interest in Calgary in terrain problems and in the development of the North. He believes that the term "underdeveloped country" also applies to Canada, and stated that only through such groups as this Conference can the full potential of the North be developed.

Dr. Radforth, on behalf of the Conference delegates, thanked Dean Hine for his words of welcome. He also extended the sympathy of the group to President Armstrong, and hoped for a speedy recovery.

Delegates to the Conference were asked to stand and introduce themselves. Dr. Radforth commented on the wide number of interests represented and on the interdisciplinary nature of this meeting. He reviewed the objectives of the National Research Council and explained the organization and function of the Associate Committee on Geotechnical Research and its Subcommittees, in particular the Muskeg Subcommittee.

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SESSION I: ENVIRONMENTAL ANALYSIS

I:1. THE BASIS OF PREDICTABILITY OF MUSKEG STATES

N. W. Radforth*

Abstract:

The basis of predictability in muskeg must ultimately refer to biological principles. Organization within the biological environment is dependent upon heredity and recurrence. There are four controlling factors in environment: the mineral sublayer, ice, the organic material, and water. Predictability of muskeg states also refers to homogeneity and user requirements.

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I:1. CRITÈRES DE PRÉVISION DE LA FORMATION DE MOSKEG+

N. W. Radforth

Résumé:

Les critères servant à la prévision de la formation du moskeg se fondent en définitive sur des phénomènes biologiques.

La structure du milieu biologique dépend de l'hérédité et de la réapparition des espèces. Quatre facteurs principaux déterminent les caractéristiques du milieu biologique: la nature minérale du sous-sol et la présence de glace, de matériaux organiques et d'eau sous forme liquide. La possibilité de formation de moskeg déterminera les exigences de l'utilisateur du terrain et l'homogeneité de ce dernier.

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* See Appendix "A" for affiliation.
+ Orthographe française de "muskeg" (N. du T.).

(SUMMARY)

It is necessary, first of all, to delineate some of the background whereby one can discuss environment. The term "predictability" is a term in more use in realms other than muskeg - in the realm of science as well as engineering. It involves the question of national economics. The expression "predictability" is an important element in planning of muskeg studies; in the last analysis we have to predict environment.

There are questions being raised, such as how are we to handle the water resources problem in Northern Ontario. Whatever we do will be affected by muskeg - kinds of muskeg, etc. Therefore, in fundamental and applied ways, environment in terms of understanding is very important. For example, it is important to be able to predict, in ways that are acceptable, all sorts of properties and all sorts of aspects of behaviour which this kind of terrain will exercise in different circumstances. We have been interested in the question of access in terms of environment. Some time ago we virtually threw up our hands when discussing muskeg access in terms of off-road access. Now we are being quite sophisticated - we also are beginning to jump ahead and say that we can predict ahead before the roads are put down.

We want to be able to compare muskeg areas in one part of the world with those in another. This is the subject of another paper (by Mr. Korpijaakko) at this Conference. Then we have the question of the chemical aspects of muskeg. If we can talk about chemical aspects, there must be some kind of organization in muskeg. It is reasonable, therefore, in order to investigate muskeg, to reveal what organization there may be.

If there is any organization at all, and if this organization is to be utilized, we must refer to the material of which muskeg is constituted: peat, which is comprised of plant remains; therefore we must ultimately refer to biological principles. Predictions, therefore, must ultimately refer to biological organization. We speak of biological organization in terms of plant remains: organs, parts of organs, etc., in terms of plants still living or in terms of chemistry of the remains of plants.

Two questions are entertained with regard to this matter of organization:

(1) Heredity - refers to what part in the design (organization) of plants is governed by hereditary factors. It expresses a means of control of biological activity, and is determined by the cells.

One order of organization is related by individuality. A level of understanding may be on level of the cell or on the level of the whole organism. It is not too difficult to imagine that this is acceptable at the realm of what we call society or community; that is, if we have this orderliness in terms of individuals, we can expect it in terms of multiple effect or in terms of mass. It is not surprising, therefore, that we find this organization reflected in the second question.

(2) Recurrence - We should expect to find types of cover and of peat to recur in close and in extended geographical relationship. It has already been published how we interpret this organization; in this we have suggested but one way. There may be other ways. Regardless of the method or key you use, the important thing is, does it work? Usage will determine whether a reference system will work.

Predictability also refers to:

a) Homogeneity. Continuity in a bog is repetition of similar circumstances with secondary differences. In terms of depth, one finds kinds of peat which express values in structural types with some sort of sameness. Secondary effects do not affect basic structure.

We have confined and unconfined muskegs. In a confined muskeg, we get heterogeneity, but over a very short axis.

b) User requirements. How can something be predicted unless we know the terms whereby it is to be predicted? What is the basis of prediction? Predictability must give some attention to this matter. If the problem is access, there will be one set of terms; if it is utilization there will be another set of requirements. If the problem is in terms of increase in productivity of forests, it will be another aspect again.

The question of water is very important in the matter of control of biological organization. Control can be in terms of edaphic aspects or local aspects. Water may be present in solid form, that is, ice. The constitution of the organic material (peat) itself is an important question.

In summary, there are four controlling factors in environment:-

(1) The mineral sublayer;
(2) Ice;
(3) Organic material;
(4) Water.

These four factors can signify local differences or homogeneity.

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I.2. ANALOGY EXPRESSED BETWEEN FINNISH AND CANADIAN MUSKEG, EMPHASIZING EXPLOITATION

Erkki Korpijaakko*

Abstract:

A short review is presented of some of the main factors and phenomena contributing to paludification and showing analogy between Finnish and Canadian muskegs in this respect. Recognition of analogies between Finnish and Canadian muskeg as to genesis and structure permits some possibilities to be presented by using the analogies in peat utilization mainly with reference to aerial photographic interpretation and its possible application. Aspects of utilization considered include agriculture, forestry, peat moss, peat fuel, peat chemical prospecting and selection of dam sites.

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I. 2. COMPARAISON ENTRE LES TERRAINS À MOSKEG+ DE FINLANDE ET DU CANADA, PARTICULIÈREMENT EN VUE DE LEUR UTILISATION

Erkki Korpijaakko

Résumé:

L'auteur passe en revue quelques-uns des principaux facteurs et phénomènes contribuant à l'emmarécagement, et souligne les analogies pertinentes entre les moskegs finlandais et canadien. L'établissement de l'analogie d'origine et de structure entre les deux types de moskeg et de leur utilisation permet de tirer certaines conclusions au sujet de l'interprétation des photos aériennes et de ses applications possibles dans les domaines de l'agriculture, de l'exploitation forestière, de la production de tourbe horticole et de tourbe combustible, de la prospection géochimique dans les tourbières et du choix des emplacements de barrages.

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* See Appendix "A" for affiliation.

\+ Orthographe française de "muskeg" (N. du T.).

The map of the world-wide distribution of muskeg (Figure 1) shows that it is concentrated in the temperate zones and that the largest areas are in the Northern Hemisphere where the land area of the temperate zone is larger than that of the Southern Hemisphere (von Bülov, 1925). This fairly homogeneous distribution of muskeg in the north implies similarities in the conditions favourable to the paludification in that area, thus rationalizing analogy studies in this respect between various regions.

It has been agreed that the climatic factors form one of the main factor groups prerequisite for paludification. The most important factors in this group are precipitation, temperature, and evaporation, from which can be derived a number of combined concepts useful in the studies on the probable climatic cause of paludification. The map of the distribution of muskeg in Finland (Ilvessalo, 1960) shows that the heaviest concentrations are located around the northern tip of the Gulf of Bothnia, on the Suomenselkä watershed, in parts of Lapland, in eastern Finland (Kuusamo) and in northern Karelia (Figure 2). Because of the lack of space, maps giving more detailed information of the climatic factors contributing to this cannot be included in this paper. Such climatic factors include the sum of effective temperature of the growing season (the sum of the temperatures above +5°C of the season during which the temperature stays above +5°C (Keränen, 1942)), the monthly means of the daily minimum temperatures (Kolkki, 1959), mean annual precipitation (Ruuhijärvi, 1960), potential evapotranspiration (Hare, 1955), hydrothermal quotient ($\frac{\text{precipitation x 10}}{\text{sum of temperatures}}$) (Ruuhijärvi, 1960). But if some of these special data were superimposed on the same map, it could be noticed that the muskeg is not always concentrated in areas with heavy rainfall, but in the areas where the precipitation, temperature, evapotranspiration, etc., values often show a tendency towards a fairly cool and humid condition created by combinations of these factors. A preliminary examination of the soil map of Canada (Atlas of Canada, 1957) shows that the areas where muskeg (peatlands) in Canada appears exhibit similarities in the climatic factors to those of Finland in large areas, as one could expect. The muskeg (peatlands) in Canada is situated in the northern areas such as Newfoundland, Quebec-Labrador, around Hudson Bay to the west in northern Manitoba, Saskatchewan, Alberta, British Columbia, Yukon, and North West Territories. The climatic factors in some of these areas contribute to cool and quite humid climate which favours paludification in the same way as in Finland.

Another similar factor in Finland and in Canada contributing to paludification is the emergence of land from the sea after the last glaciation. This takes place on the coast of the Gulf of Bothnia as well as on the coast of Hudson Bay (the Lowlands). This emerged land is quite flat and the transgressions and regressions of water level keep newly emerged areas wet and paludification ensues.

Both these above-mentioned factors contribute to vast more or less unconfined muskeg, the most appropriate term for which in Scandinavian and also in German terminology is "aapamoor". More confined muskegs (peat bogs) are to be encountered in large pre-cambrian shield areas in Finland as well as in Canada. These have been formed mostly in depressions, lakes, ponds, etc., offered by the topography. In Finland, however, studies have shown that, in certain areas, only 5-10% of the area paludified is a result of filling up of ponds and lakes (Backman, 1919) and the rest has paludified as a result of some other cause.

In analogy studies there is one more phenomenon which can be mentioned here because it can be used in air photo interpretation studies as related to exploitation as will be later explained. This is ombrotrophy-minerotrophy. A muskeg, or to use a better term, a confined muskeg (peat bog), is ombrotrophic if its plant life gets most of the water needed for its growth directly from the atmospheric moisture. This kind of muskeg is quite common in southwestern Finland as well as, for instance, in the Maritimes. They are referred to as "raised bogs" forming more or less centrally raised peat "cakes". They will be dealt with later in this paper and one should keep in mind their similar appearance and distribution in these two countries in their most maritime climate regions. Minerotrophic muskeg, on the other hand, is a muskeg in which the plant life gets most of its water from the ground (Ruuhijärvi, 1960). This type can be joined to the aapamoors and is unconfined muskeg in many cases.

This short review of some of the main factors and phenomena contributing to the paludification and showing analogy between Finnish and Canadian muskeg should justify analogy studies. This kind of analogy study could implement some applications in peat utilization through different means, such as aerial photographic interpretation of organic terrain carried out in one area and applied to another as based on analogy between various regions. Some possibilities based on the realization that there are analogies between Finnish and Canadian muskeg as to the genesis and structure will be presented by using the analogies in peat utilization mainly with reference to aerial photographic interpretation and its possible application. This will be brief and the intention is to limit this to some main aspects of peat utilization.

Agriculture

Nowadays, when different branches of science offer highly sophisticated techniques in peat utilization, peat is used and exploited in a great number of different ways in addition to older, more direct conventional ways and, in this connection, it is no use discussing very many different possibilities. Peatlands and peat have been in older times often a constant menace to farmers threatening their means of survival. At the same time they have been used by farmers in different ways and even cultivated for a few hundred years, for instance, in Finland. Nowadays highly developed techniques and other branches of science have reversed the attitude and often peatlands offer an excellent ground for cultivation. In Finland more than 1 million hectares (approximately 2.5 million acres) of muskeg have been put under cultivation. Reclamation has been mostly based on experence but nowadays science has helped establish more accurate criteria on which it can be based. Figure 3 is an example of muskeg areas from both Finland and Canada. This is a high altitude aerial photo (30000 ft) and it shows clearly the similarities between Finnish and Canadian muskeg. The Finnish area is about one hundred miles north of the arctic circle (Kittilä, Finnish Lapland). The Canadian side is from The Pas region in Manitoba. This Figure shows a good example of one of the high altitude airform patterns, dermatoid (Radforth, 1956), and if one investigates the Figure more closely one can see some low altitude (1000 to 5000 ft) airform patterns, vermiculoid-3 and planoid (Radforth, 1958). The most extended cover classes in these areas would be according to high altitude airform pattern, FI, EFI, and EI (Radforth, 1956, 1962) and it conforms nicely with the low altitude airform patterns and their respective prominent cover classes (Radforth, 1958). In the Finnish side, however, one can, by studying stereo pairs, find small dwarfed trees (pines and probably Betula) on the ridges but their portion is too small ($<25\%$) to be of any significance (Radforth, 1952). This Figure shows clearly the similarities between Finnish and Canadian muskeg as to cover. It would be even better if the Finnish counterpart was from the west of the Gulf of Bothnia because there the FI - EFI cover would correspond more exactly to The Pas area, which on the ground corresponds to the common FI area of coastal regions of Finland, namely so-called "large sedge aapamoors". This area in the north is in some respects better for agriculture than the coastal region. In the north these FI muskegs often are so-called "brownmoors" which means that the F is composed mostly of sedges while I is mostly Bryales (Hypnum) mosses implying quite neutral pH-reaction of the peat. The peat in this area consists mostly of Carex-Bryales peat (non-woody fine-fibrous (Radforth, 1955)) which is better for agriculture (Kivinen, 1948) than Carex-Sphagnum peat of the coastal plains which is a little more acid.

On the other hand, the climate in Ostrobothnia is more favourable to agriculture and there one can see large areas cultivated on muskegs. These two types, however, one with Sphagnum as I, and the other one with Bryales as I, are designed for the assessment of suitability of different kinds of muskeg for agriculture. According to Lukkala-Kotilainen (1945) the best botanical muskeg classes for agriculture are so-called birch brownmoors and Warnstorfii brownmoors (Bryales predominant as I) and of the whitemoors (Sphagnum as I) the best are flood whitemoors, and grassy large sedge whitemoors. These differences observed by ground studies are of a secondary significance and their existence in this case could be forgotten and left to those who determine the final steps in reclamation. This example thus shows the possibilities of the analogy studies and their probable applications to agriculture, especially by using aerial photographic interpretation based on these analogies.

Forestry

Generally speaking, it can be said that in most cases muskeg that is good for cultivation is also good for forestry. Thus the analogies applied to agriculture can also partly be applied to forestry. In Finland more than 1 million hectares (2.5 million acres) of muskeg have been reclaimed to forestry. In most cases, shallow peat layers with boulders and stones in mineral soil are better for forestry than for agriculture. The best cover classes most suitable for forestry purposes are woody classes like A and B connected with FI where F often is grass and ferns and I often Bryales. The situation is thus if Lukkala's (1945) botanical cover classes are converted into Radforth's system (Radforth, 1952). In many cases, areas where peat has been mined for some industrial or other purposes are very good for forestry if the drainage is favourable. All this should apply to Canadian muskegs too, and help reclamation of peatlands as based on analogies.

Peat Moss

Peat, as such, has been used for a long time in different ways. Probably the earliest ones have been as stable litter and fuel. Nowadays, peat moss production is increasing rapidly for other purposes; mostly for use in greenhouses and in various soil improvement procedures. The statistics of the tonnage of peat used in different ways in Finland show a clear tendency from its use as fuel towards its use in agriculture. In 1958, 162 tons were used as fuel and 2 tons in agriculture. On the other hand in 1962, 116 short tons were used as fuel and 6 tons in agriculture. The statistics show that in Canada in 1958 and 1962, 150 and 233 short tons respectively were used in agriculture (Green and Wren, 1964). These statistics do not give any data on its use as fuel in Canada although it has been used for this purpose also (Chalmers, 1904).

The peat moss industry has given new value to earlier despised raw slightly humified sphagnum peat because it has turned out to be the most suitable source of peat moss due to its good absorption capabilities and favourable cation uptake characteristics, etc. (Puustjärvi, 1959). Earlier it was recommended to use this type of peat as fuel, if possible, although it is not very suitable for this purpose. Mostly it was stripped off from the surface as useless and disturbing litter, but at present it seems to be almost the most valuable part of the peat layers. The best sources of this kind of raw sphagnum peat are the central parts of the so-called "raised bogs" which are encountered in the areas of maritime climate (Kivinen, 1948). In the search for peat moss in this case, the aerial photographs are really helpful and also quite easy to use because of the conspicuous characteristic airform patterns the raised bogs possess. Figure 4 is a low altitude aerial photo from southern Finland of a raised bog which has been partly used for peat mining (upper part of Figure). This Figure shows clearly the more or less concentric ridges and their intermediary spaces. The cover class of the ridges is predominantly EI with scarce dwarfed Pinus silvestris, while the cover of the rimpi-like spaces between the ridges is FI. The peat in this case is quite non-woody because the ridges are of less significance than the rimpi spaces. Predominantly peat is composed mostly of Sphagnum and is not well humified being quite suitable for peat moss industry. Figure 5 is a high altitude photograph of a raised bog in Chicoutimi area showing configurations similar to those of its Finnish counterpart suggesting analogous conditions. Figure 6 is from a small raised bog 20 miles west of Helsinki owned and exploited by one family. The peat is used in the greenhouses nearby and this modest enterprise gives a good income for the family operating it. The cover is secondarily invaded strongly by E because of the influence of draining. Figure 7 represents two peat profiles. One is of a raised bog in the Maritimes (Auer, 1927) showing thick layers of quite raw sphagnum peat very good for peat moss industry and the other from central Finland (Korpijaakko, 1966) from the transition zone between southwestern raised bog region and northern and western aapamoor region (Ruuhijärvi, 1960). This latter profile reveals that there are different kinds of peat in layers and that the topmost layer in this case would be good for peat moss industry. This profile will be dealt with later. All these Figures reveal the similarities between Finnish and Canadian muskegs, once more giving justification to analogy studies also with respect to the peat moss industry.

Peat as Fuel

The use of peat as fuel is a long-established practice and perhaps it first was used in this way in simple fireplaces to heat houses. Later its use became quite important in thermal electric plants as fuel and the first plant of this type was built in 1907 in West Germany in Wiesmoor (Salmi, 1953). Since then the use of peat as fuel in different kinds of industrial installation has been quite common. Nowadays its meaning as fuel is steadily decreasing. In Finland it had been used earlier in locomotives but at present its use is mainly confined to some private industries as fuel source (Salmi, 1961). Recently in Finland, also, hydro companies have directed their attention away from peat as fuel in electric plants to nuclear energy which is becoming the most economical way to generate power. Muskeg, however, is still being studied to search peat for fuel and even in Ontario about 10,500 acres have been studied for this purpose (Green and Wren, 1964). One of the earliest attempts to manufacture fuel peat in Canada was made in 1864 by Mr. James Hodges, an English engineer. The bog on which he operated was situated in Quebec's Athabasca county (Chalmers, 1904). In small countries like Finland, peat as fuel could have meaning during hard times (war, etc.) when the import of oil and coal is blocked. In Canada, on the other hand, it could be feasible in the north in private households if the transportation of other fuels is too expensive.

If peat is to be used as fuel, it must fill some requirements. According to studies carried out by Salmi (1961) the ash content should be quite low, less than 5 per cent of dry weight. In Finland it is 2-5 per cent on the average (Salmi, 1961). The humifications using L. V. Post's system should be over 5. The more humified (decomposed) peat is, the higher is carbon content per unit of volume, partly due to decaying and partly to compression of peat layers. The peat type is of significance. Sphagnum peat has the lowest values and the order in heat values is the following from low to high: Sphagnum peat, Bryales-Carex peat, Eriophorum-Sphagnum and Carex-Sphagnum peat, all of which are under the average. Sphagnum-Carex peat, Carex-peat and woody (L-peat = Liqnidi-peat) peat are above the average (Salmi, 1961). The practice in Finland is to mark the most significant factor in mixture of peats last; thus in Bryales-Carex peat, for example, Carex is more prominent than Bryales (Hypnum). Salmi (1961) has calculated that, on the average, the effective heat value of peat containing 30 per cent of water is about 3342 cal. or better than that of wood (3000 cal.).

When one recalls what has been said of peat classes in relation to cover classes and airform patterns earlier, one can realize that Figure 4 is a good example of airform patterns which indicate possible existence of fuel peat. But the Finnish muskeg in this case is not good for fuel as ground studies have revealed that peat in this area is mostly Bryales peat which is not well humified and not good for fuel. In other cases from southern and central Finland, corresponding covers, however, will imply the existence of fuel peat and correspond better to the Canadian counterpart of this figure. Once again it can be noticed that analogies in many cases could be used but that the interpreter should know something about the local conditions to be able to apply obtained data more exactly.

In this connection we should refer again to Figure 7 representing a profile of a Finnish muskeg in central Finland. This profile shows that the same muskeg can be used in different purposes. In this case, for example, the surficial layer could be used as peat moss (some sphagnum peat). The layers under it might be used in agriculture or as fuel depending on the demand and on other factors (remoteness, drainage, etc.). The bottommost layers with higher ash content could offer a good ground for forestry or for agriculture depending on the same factors of remoteness and drainage as mentioned above. Thus if one wishes to interpret and use aerial photographic interpretation and observed analogies, one should also be aware of different possibilities and variations of muskeg in order to obtain feasible results.

Peat Chemical Prospecting

Peat and muskeg can be used also indirectly in many ways. One way with some economical implications is to use peat and muskeg plants as indicators of ores by means of the amount of the trace elements they contain and also by the pH values of peat affected by the underlying bedrock (Marmo, 1958; Salmi, 1950, 1955, 1956a, 1956b, 1958). Salmi has started this kind of work in Finland by comparing a great number of peat samples with each other taken from different areas and comparing their trace element amounts with those of the samples which were known to be underlain by ore deposits. This work has proven the possibilities of using peat in this respect as an indicator of ore deposits and to use it as an aid in determining drilling sites in conjunction with other methods. The pH values of peat are affected by the underlying bedrock quite distinctly and clearly (Salmi, 1958) and can be used in geological studies in areas where bedrock is covered by muskeg. In this case, however, one should be careful because of the influence of other factors like plant life, etc. Because of environmental analogies between Finnish and Canadian precambrian areas, these methods should be applicable in Canada and perhaps have been applied already.

Dam Sites

Of all other innumerable muskeg studies and possible effects, only one more will be dealt with. It is an interesting damming procedure carried out in Lapland. Some hydro companies have built a large dam in order to create a few hundred square mile reservoir for controlling water levels for hydro-electric plants. Large portions of this artificial lake will be lying on muskeg and The Geological Survey of Finland, among others, has carried out thorough peat studies there. Later results of the flooding will show how different kinds of (peat) muskeg behave in this case and how to predict their behaviour. These experiences should give good material for flood control and prediction and could be applicable in Canadian environments because of the analogic conditions.

Conclusions

All the above points should reveal that muskeg is not a badly disorganized, misunderstood tangle of dead and living plants, but that it is in a certain way quite well organized and often similar in different parts of the world. This organization is more apparent if one does not indulge too much in small insignificant details thus failing to understand large entities. This depends, of course, on the end goals of the studies but if we think, for instance, of cover classes and their meaning in aerial photographic interpretation, it is easy to understand that such details as plant species forming a certain class are insignificant to a certain extent especially in analogy studies directed towards peat utilization, trafficability, etc. Let us take an example. Cover class E in Canada may be formed by blueberry or Ledum groenlandicum; in England by heather (Calluna) and in Finland by Ledum palustre, Betula nana, etc. In every case, the significance of this botanical species definition in interpretation studies and, in some cases, even in the goal is negligible. In some cases, however, they may have a high importance, e.g. in forestry, but in these fields experts can readily assess the end results while in trafficability studies for instance the assessment often has to be left in the hands of persons who are not necessarily biologists or botanists. In high altitude aerial photographic interpretation and its applications as based on analogies, the small details have to be omitted partly because their resolution from the photographs is often impossible even by indirect means. In application and analogy studies, of course, some room has to be given to variations in the nature without trying to enforce quite theoretical knowledge too strictly. We have only to recall what has been said about differences in subsurface and surface conditions which can be included into the same high altitude airform pattern; differences between northern and southern Finnish dermatoid airform patterns, for instance. Also it should be borne in mind, as already mentioned, that in certain areas airform analogies are analogies only on the surface as it is in the case of some raised bogs in the peat layers where there are large variations enabling the use of the same bog for different purposes (Figure 7). All this, however, should show that these analogies could be utilized in many cases and especially in exploitation of muskeg. If based on aerial photographic interpretation, this should be carried out carefully and interpreters and those applying analogy studies should be aware of the deviations and variations often caused by local differences in other conditions contributing to the paludification. It is hoped that these examples bring out some possibilities for further analogy studies between two different muskeg areas on the earth without going further in a great many possibilities and opportunities or problems encountered in the muskeg environment.

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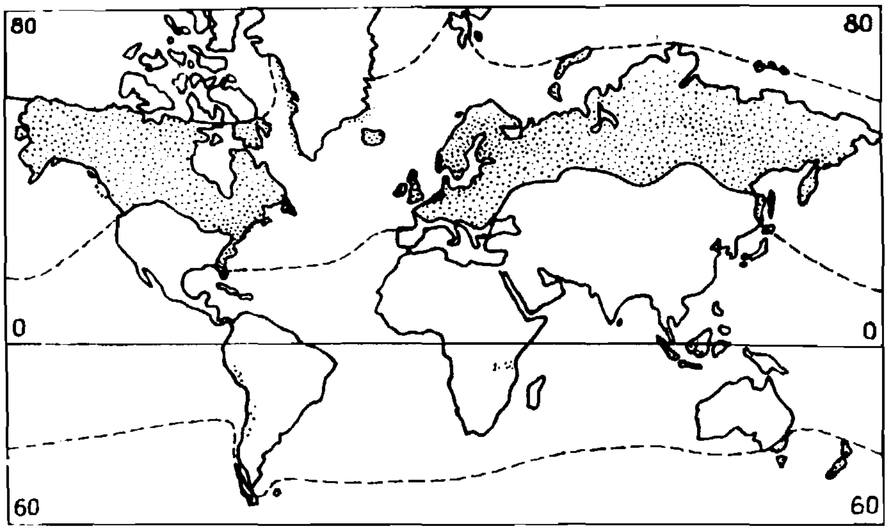

Fig.1. Distribution of muskeg on the earth (Bülev).

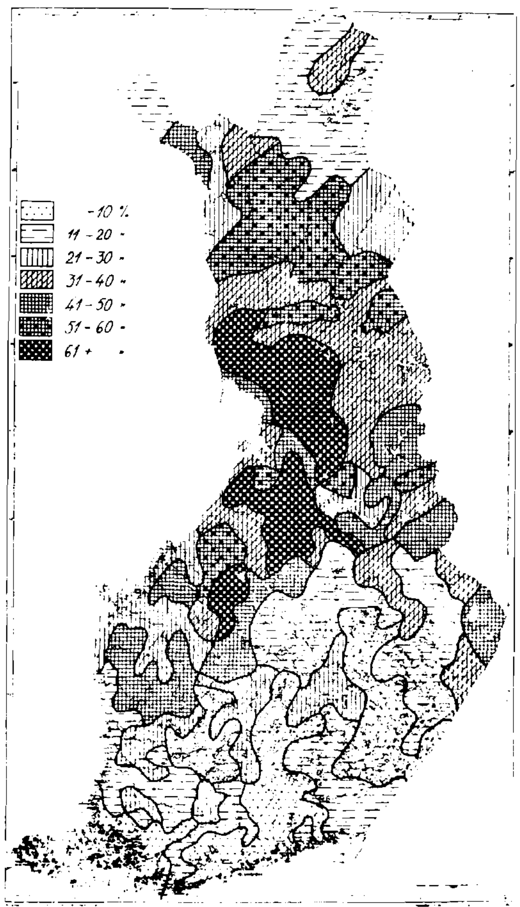

Fig.2. Distribution of muskeg in Finland (Ilvessalo).

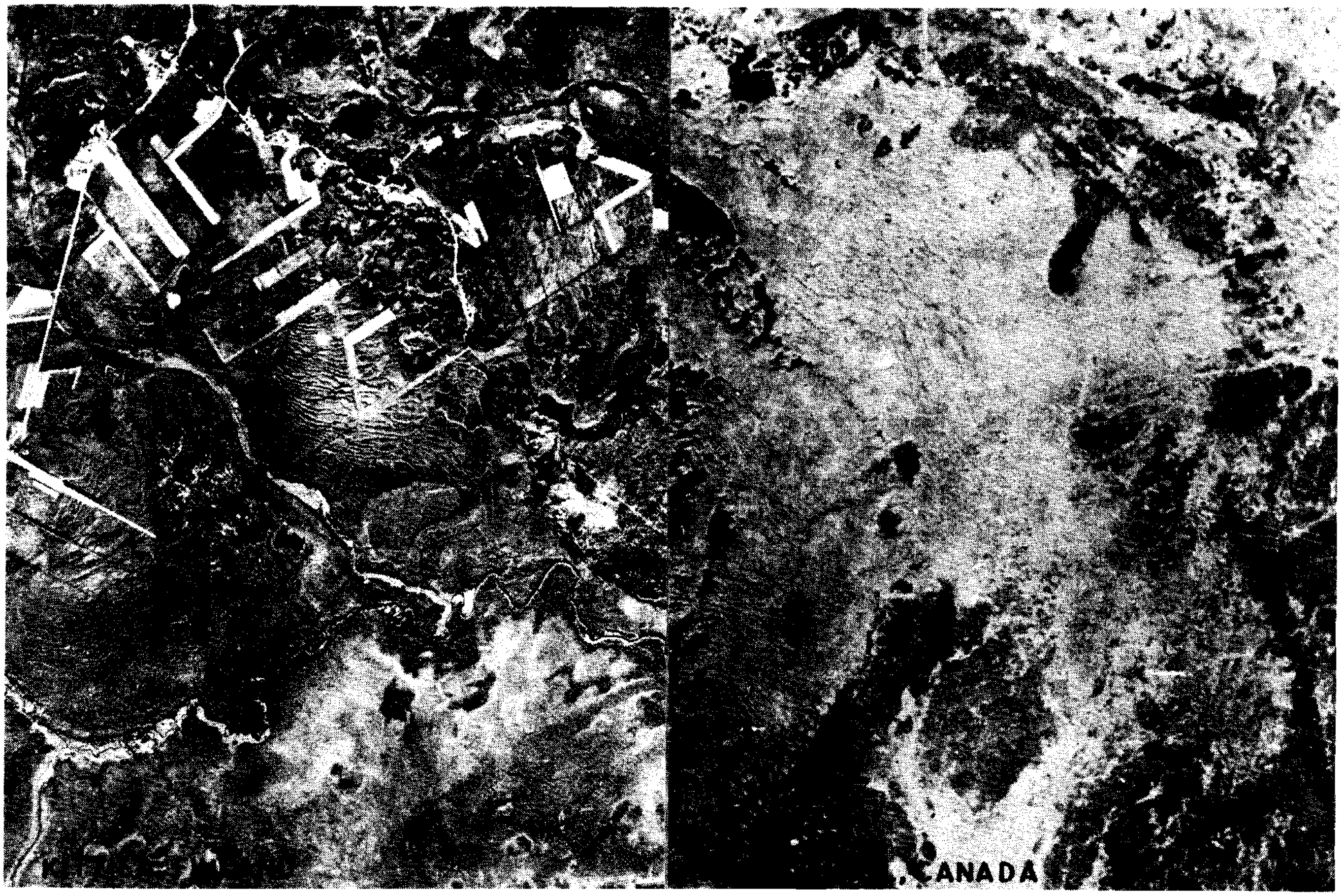

Fig. 3. High altitude aerial photograph; Finland-Canada. (Published with permission of Topographic Commission of Finnish Army, permit n:o 746/5.9.64. and with permission of RCAF).

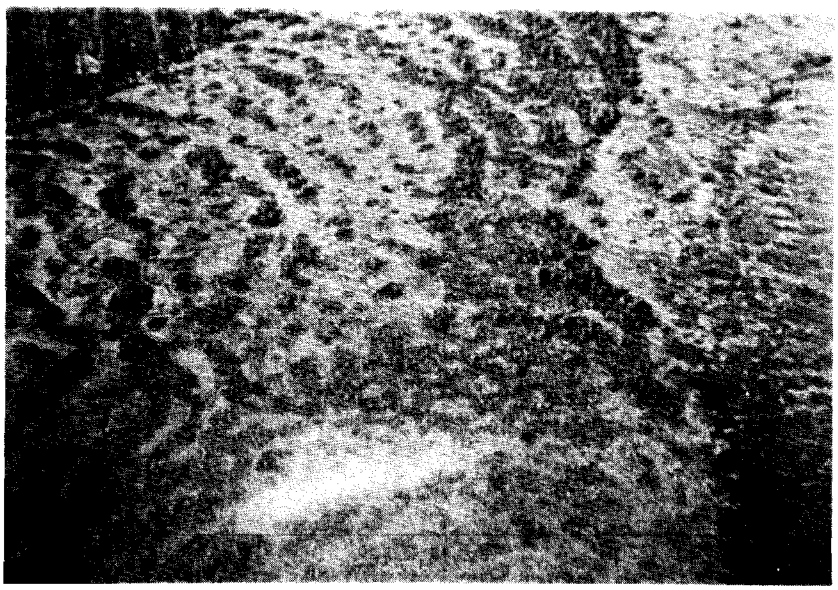

Fig.4. Low altitude aerial photograph from southern Finland. (Published with permission of Finnish Army).

Fig.5. High altitude aerial photograph of a raised bog in Chicoutimi, Quebec. (Published with permission of RCAF).

Fig.6. Peat mining in a small raised bog in southern Finland.

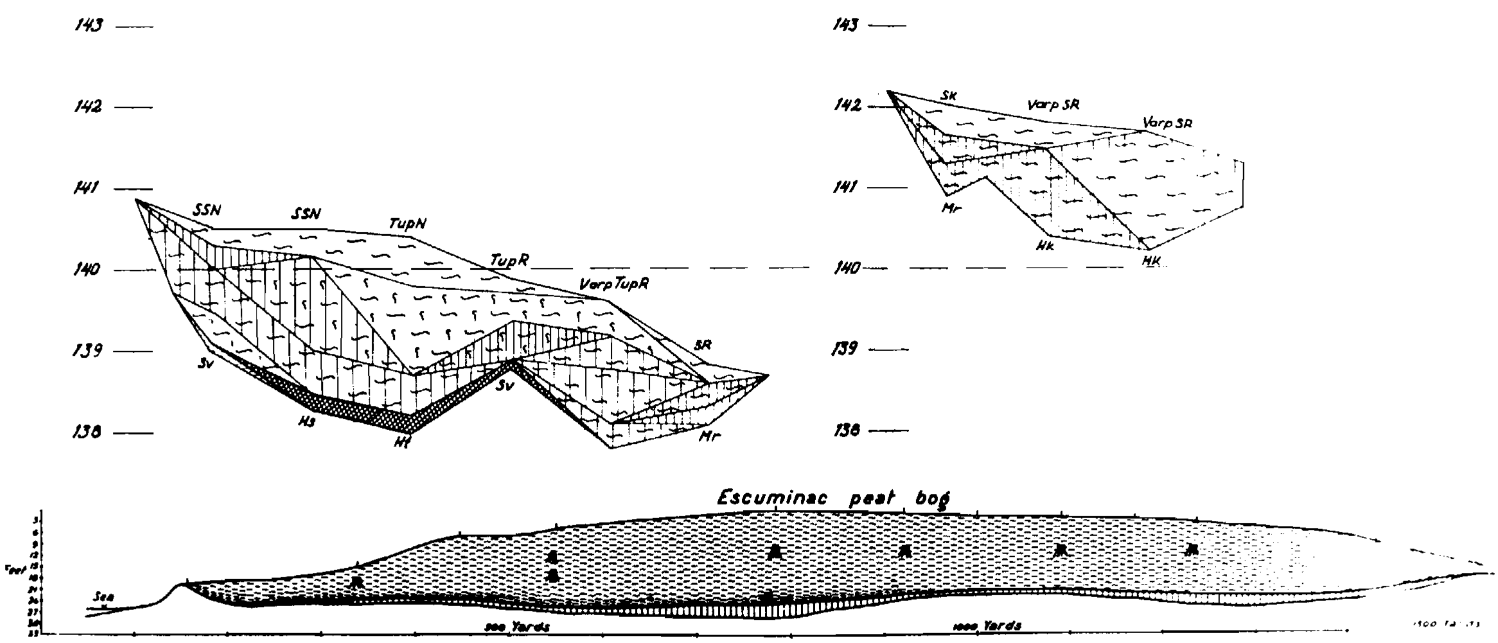

Fig.7. Peat profiles. Upper two from a muskeg in the transition zone between southern raised bog area and northern aapameer area in central Finland. Lower one from the Maritimes, Canada.

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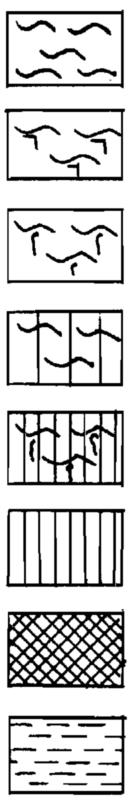

Sphagnum peat

Wood-Sphagnum peat

Eriophorum-Sphagnum peat

Carex-Sphagnum peat

Eriophorum-Sphagnum-Carex peat

Carex peat (sedge peat)

fine detritus

clay

I.3. SOME CHEMICAL ASPECTS OF WETLAND ECOLOGY

E. Gorham

Abstract:

The chemical properties of fen and bog soils are examined in relation to ion supply from the mineral soil and from the atmosphere. As the influence of the mineral soil wanes through accumulation of organic materials, exchangeable hydrogen ions replace exchangeable metallic cations upon the adsorptive complexes of peat deposits, the level of dissolved calcium in peat pools declines to less than 2 mg./l., and acidity rises very sharply -- with pH often falling below 4. The source of this acidity may be oxidation of organic sulphur compounds in the peat, air pollution by sulphuric acid, or displacement of adsorbed hydrogen ions by metallic cations supplied through atmospheric precipitation. Weather conditions and geographical location are shown to have a considerable effect upon the chemistry of rain and bog waters.

The productivity of the plant cover of fens and bogs is shown to be related in some degree to the balance between silt and atmospheric precipitation as sources of nutrients.

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I.3. ÉTUDES CHIMIQUES RELATIVES A L'ÉCOLOGIE DES PALUS

E. Gorham

Résumé:

L'auteur étudie les propriétés chimiques des sols de fagne (fen) et de fondrière (bog) par rapport à la quantité d'ions fournie par le sol minéral et par l'atmosphère. Au fur et à mesure que l'action du sol minéral décroît par suite de l'accumulation de matériaux organiques, les ions d'hydrogène échangeables remplacent les cations métalliques échangeables fixés par les complexes adsorbants des tourbières, la quantité de calcium dissoute présente dans les marais tourbeux diminue jusqu'à moins de 2 mg./l., et l'acidité augmente très rapidement, le pH descendant souvent au-dessous de 4. Cette acidité peut provenir de l'oxydation des composés organiques sulfureux présents dans la tourbe, de l'acide sulfurique polluant l'air ou du déplacement des ions d'hydrogène adsorbés par des cations métalliques provenant des précipitations atmosphériques. L'auteur montre que les conditions

atmosphériques et l'emplacement géographique ont un effet considérable sur les propriétés chimiques de la pluie et des eaux de fondrière.

Il établit un rapport entre l'abondance de la couverture végétale des fagnes et des fondrières, et l'équilibre des apports nutritifs du limon et des précipitations atmosphériques.

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A major characteristic of wetlands is the accumulation, under waterlogged and anaerobic conditions, of muck and peat deposits built up of silt and the remains of plants such as reeds, sedges, grasses, mosses and a variety of shrubs and trees. Often peat deposits originate with the filling in of a lake, which in northern regions may be followed by a swamping of extensive areas of surrounding mineral soil (Sjörs, 1961). As the deposits increase in area and depth, they commonly become more organic, through a decline in the inwash of silt from surrounding mineral soils. Peat surfaces which are subject to some degree of silting or drainage from mineral soils are said to be minerotrophic, but when the peat surface no longer receives any inflow of water from the mineral soil, and depends for its mineral supply wholly upon atmospheric precipitation, it is said to be ombrotrophic (DuRietz, 1949, 1954; Sjörs, 1961). Current Swedish usage, which is accepted here, designates minerotrophic sites as fens and ombrotrophic sites as bogs. The differentiation, therefore, rests upon the nature of mineral supply and not upon vegetation, although fens are commonly dominated by reeds, sedges, grasses and hypnoid mosses, while bogs are usually dominated by Sphagnum mosses, cottongrasses, deersedge and heaths.

The present review deals mainly with the chemical properties of peat and water which differentiate minerotrophic fens from ombrotrophic bogs in the British Isles. For a more general coverage of wetland ecology, broader reviews may be consulted (Gorham, 1953, 1957).

Influence of Organic Accumulation Upon the Chemistry of Waterlogged Soils

The increase in soil organic matter ensuing upon the succession from lake through fen to bog has profound consequences for the chemical properties of the soil, as may be seen by an examination of the average ion-exchange characteristics of a series of soils from lakes, fens and bogs in the English Lake District (Gorham, 1953). Figure 1 shows that as organic content (per unit dry weight) rises, the capacity of the soil to adsorb and exchange cations is greatly increased, up to a level of about 1 milliequivalent per gram dry weight as soils become almost wholly organic. In the less organic soils, most of the exchange capacity is saturated by metallic cations (Ca, Mg, Na, K) from soil minerals, but as organic content rises both the amount and percentage of exchangeable hydrogen ions increases slowly. As fens give way to bogs and the influence of soil minerals declines, concentrations of exchangeable metallic cations fall steeply; at the same time the concentration of exchangeable hydrogen rises equally steeply and it comes to predominate strongly among the adsorbed cations. The transition from fen to bog occurs at about 80-90 per cent organic matter, although a few fen peats exceed 90 per cent. The picture given by exchangeable cations is reflected by soil pH, as measured by direct insertion of a glass electrode (see Gorham, 1960). A slow decline from pH values above 6 to values of about 5 occurs as organic matter accumulates to about 85 per cent dry weight. Then as the cation balance shifts sharply toward hydrogen ions, pH drops to almost 3 in the highly organic bog peat.

Plant composition is strongly influenced by, and in turn influences, soil properties. While the mineral ash content of underwater plants averages about 18 per cent dry weight, the fen plants average 5.9 per cent and the bog plants only 2.5 per cent. Presumably these differences reflect differences in the availability of mineral nutrients in the substratum, although the exceptionally high levels of mineral ash in underwater plants are probably partly due to low contents of carbonaceous supporting tissue.

Changes in other important soil properties are also evident. For example Figure 2 indicates that the total nitrogen content of soil organic matter is about 4 per cent dry weight in the least organic soils, and declines rather sharply to less than 2 per cent as fens give way to bogs. This general trend reflects the levels of nitrogen in contributing vegetation, which are above 4 per cent in underwater plants and below 1 per cent in Sphagnum mosses.

The changes which are demonstrated here by a comparison of surface soils in several different stages of evolution can also be seen in examining peat profiles. Figure 3 illustrates the characteristic decline in soil pH which occurs as bog peats accumulate over fen peats in the southern part of the English Lake District (Gorham, 1949). It is accompanied, as expected, by a decline in the proportion of metallic cations to hydrogen ions adsorbed on the soil exchange complex (percentage neutralization). It is of some interest that the acidity of the topmost sample is considerably greater than that of the next beneath, despite similar values for percentage neutralization. This suggests the presence of stronger acids in the surface peats, and, as will be seen later, surface peats tend to be high in sulphuric acid either from oxidation of organic sulphur compounds or from air pollution.

Both calcium and iron exhibit a similar upward decline, as shown in Figure 4, and bear further witness to the insulating effect of a blanket of peat upon the chemical influence of the mineral soil.

Water Chemistry in Fens and Bogs

Owing to their dependence upon atmospheric mineral supply, bogs in the English Lake District exhibit very low levels of calcium in their waters, the concentrations always being less than 2 mg./l. Fen sites transitional to bog, in which carpets of Sphagnum papillosum and S. recurvum often grow luxuriantly (the lacustrine bogs of Pearsall (1938)), usually range between 1 and 4 mg./l. Normal fens range from 3 to 23 mg./l. in non-calcareous sites. Calcium levels are shown in relation to pH in Figure 5 (data from Gorham and Pearsall, 1956). It is evident that calcium concentration rises slowly between pH 4 to 6, and rapidly above pH 6 as the influence of the mineral soil becomes pronounced. In fen sites the calcium ions are balanced by bicarbonate ions from the weathering of mineral soils (Gorham, 1956). The pH range of bog waters is from 3.8 to 4.4, while transitional sites range from 4.1 to 6.0, and normal non-calcareous fens from 4.8 to 6.9.

An extreme example of the effect of a peat blanket upon the chemistry of surface waters can be seen at Malham Tarn in Yorkshire, where the main inflowing stream contains 80 mg./l. of calcium, the lake itself 47 mg./l., and pools on deep bog peat beside the lake only 0.5 mg./l. (Gorham, 1961).

It should be remarked here that most of the ions in peat are strongly adsorbed in the soil exchange complex. Table 1, which presents data from Irish bog peats (Sjörs and Gorham, unpublished), shows that

TABLE 1

Ions Dissolved in the Interstitial Water as a Percentage of Total (Dissolved + Adsorbed) Ions in Surface Peats from Irish Bogs

Na	K	Ca	Mg	H
30	8	1.4	0.9	0.03
		SO_4	Cl	
		11	ca. 70	

this is especially true of hydrogen ions, with only traces present in the free state, and of the divalent metallic cations magnesium and calcium, which are about 99 per cent adsorbed. Even about nine-tenths of the divalent sulphate anion appears to be present in the adsorbed state. The monovalent ions sodium and chloride, relatively abundant because of sea spray in these maritime peats, exhibit the lowest degree of adsorption.

Acidity of Bogs

Much of the free acid in British bogs appears to be sulphuric acid (Gorham, 1958), either from air pollution (Gorham, 1958a) or from oxidation of organic sulphur compounds in the peat (Gorham, 1956). Figure 6 shows the relationship between hydrogen and sulphate ions in waters from five inland bogs with a living Sphagnum cover in northern England, Scotland and Wales; and it may be noted that the two highest acidities are observed in the sites closest to the great industrial areas of Britain. The cross represents rain in the English Lake District, which is subject to considerable air pollution. An extreme example of the influence of air pollution is the case of Ringinglow Bog on the outskirts of Sheffield, where sulphate ions reach a level of 0.96 milliequivalents per litre and hydrogen ions 0.58 milliequivalents (pH 3.24).

Another source of acidity may also have considerable importance, namely, the exchange of metallic cations brought down in rain for hydrogen ions adsorbed by bog plants and peats. The hydrogen ions are produced metabolically either by the living bog plants or in the course of their decomposition. Gorham and Cragg (1960) have suggested such a mechanism to account for part of the acidity of peat pools in the Falkland Islands, and Clymo (1964) has calculated from growth rates of Sphagnum that such a source of hydrogen ions may also be a very significant factor in British bogs.

Atmospheric Ion Supply to Bogs

The atmospheric nature of ion supply to bog surfaces can be illustrated by a comparison of ionic concentrations in rain from the English Lake District (Gorham, 1955) and bog waters from Moor House in the Pennine mountains nearby (Gorham, 1956b). This comparison is given in Table 2, from which it is clear that in wet weather bog pools approximate rainwater in composition. During dry weather ionic levels in the bog pools rise considerably owing to evaporation, as in the case of chloride which nearly doubles its concentration. Other ions may exhibit further rises in concentration owing to other causes. For example, sulphate increases nearly fourfold, and shows the greatest increases in the smallest pools most subject to drying out (Gorham, 1956b). It seems

TABLE 2

Ionic Composition of Rain and Bog Waters from Northern England

	Na	K	Ca	Mg	Cl	SO_4	pH
	(milligrams per litre)						
Rain, Lake District	1.9	0.2	0.3	0.2	3.3	3.2	4.45
Bog pools, Moor House							
Wet weather	1.7	0.17	0.30	0.20	3.2	4.0	4.21
Dry weather	4.3	0.33	1.17	0.82	5.9	15.2	3.85
Ratio $\frac{dry}{wet}$	2.5	1.9	3.9	4.1	1.8	3.8	2.4

reasonable to ascribe much of the increase in sulphate to the oxidation of reduced sulphur compounds in the peat to sulphuric acid. Some of the hydrogen ions so produced may then exchange with metal cations adsorbed on the peat, thus raising concentrations of these metal cations above the levels which might be ascribed to evaporation. Calcium and magnesium are much more affected by such an exchange than are sodium and potassium, because the divalent metal cations are much more abundant than the monovalent cations on the adsorptive complexes of the peat. This greater abundance of adsorbed divalent cations is shown in Table 3, which presents data for natural bog peats at Moor House (Gore and Allen, 1956).

TABLE 3

Exchangeable Cations in Natural Bog Peats from Northern England

Na	K	Ca	Mg	H
(milliequivalents per 100 grams dry weight)				
0.68	1.13	4.29	4.79	150

The location of a bog exerts a marked effect upon the type of atmospheric mineral supply to which it is exposed. The influence of air pollution upon water chemistry has already been mentioned in the discussion of acidity in peat bogs. The influence of sea spray also depends very much on geographical location, as may be seen in Table 4, which presents data on the water chemistry of ombrotrophic bogs from different parts of the world (Gorham and Cragg, 1960). The sites in the Falkland Islands, Western Ireland and Northern Scotland are distinctly

TABLE 4

A Comparison of Bog Waters from the Falkland Islands and Various European Areas

	pH	Total cations (m.equiv./l.)	Cations Na	K	Ca	Mg	Anions Cl	SO_4
			(milligrams per l.)					
Falkland Islands	4.10	2.35	38.6	1.6	2.1	5.4	72.0	13.4
Gowlan East, W. Ireland	4.40	0.783	12.5	0.5	0.8	1.8	20.6	7.7
Sutherland, N. Scotland	4.51	0.760	13.9	0.6	0.5	1.1	23.6	5.3
Coom Rigg, N. England	3.90	0.508	5.3	0.5	1.0	1.1	9.3	10.9
Moor House, N. England	3.91	0.371	3.4	0.3	0.9	0.6	5.0	11.4
Rannoch Moor, W. Scotland	4.50	0.169	2.2	0.1	0.3	0.3	4.3	2.7
Eastern Sudeten Mts., Poland	3.92	0.169*	0.2	0.2	0.5	0.3**	0.3	7.7

* Anion sum, Mg not done on all samples
** Single sample

maritime and exhibit very high levels of sodium and chloride. The last site, in Poland, is the most continental, and is extremely low in both these ions.

Even within one site the direction of rain-bearing winds may have a profound influence upon atmospheric ion supply. Figure 7 (modified from Gorham, 1958a) shows the effect of wind direction upon the amount of ion supply per unit area of ground at a site in the English Lake District. The site is nearest the sea in a southwesterly direction, while the nearest centres of population and industry lie to the south and east. As expected, the largest amounts of chloride come from the southwest and the largest amounts of sulphate (and nitrate) from the southeast. An increase in wind speed also has an effect in raising the level of ion supply by atmospheric precipitation, especially in the case of chloride where the difference between calm periods and gales may be more than tenfold. This is not only because the transport of sea spray inland is increased by high winds, but also because the actual entrainment of spray droplets into the air is favoured by stormy weather.

Some Effects of Disturbance Upon the Chemistry of Bog Peats

The changes in bog vegetation which are brought about by human interference have been discussed at length by Pearsall (1950). When bogs are drained and burned repeatedly, so that their Sphagnum cover is replaced by heather (Calluna vulgaris) and cottongrass (Eriophorum vaginatum), or in extreme cases by pine (Pinus silvestris), the chemical properties of their peats are greatly affected. For example, in the English Lake District (Gorham, 1961) peat pH averages only 3.0 under pinewood on bog peat, while under regenerating Sphagnum the pH averages 3.6, much the same as in the more acid of undisturbed ombrotrophic bogs. Also, concentrations of both mineral ash and nitrogen in the peat are about 40 per cent higher in the damaged Lake District bog surfaces than in the average intact Sphagnum-covered surface. Presumably a greater degree of oxidative decomposition has been induced by the draining and burning, with much organic matter having disappeared as carbon dioxide while nitrogen and mineral material have been conserved.

Productivity of Wetlands

Presently available data are insufficient to provide accurate comparisons of annual plant productivity in fen and bog communities of diverse types. Some indication of differences can be derived, however, from terminal harvest of above-ground standing crops (Pearsall and Gorham, 1956), as shown in Table 5. The range is from 4,000 to 11,000 kg dry weight per hectare. In a general way, the table proceeds from

TABLE 5

Above-ground Standing Crop in British Wetlands

		Terminal Harvest (kg dry wt./ha)
REEDSWAMP	Typha latifolia	11,000
	Phragmites communis	7,600
GRASS FEN	Deschampsia caespitosa	10,000
	Calamagrostis lanceolata	8,800
	Phalaris arundinacea	8,700
	Molinia caerulea	4,000
SEDGE FEN	Carex acutiformis	6,300
	Carex lasiocarpa	5,100
	Carex rostrata	4,200
DEERSEDGE FEN AND BOG	Trichophorum caespitosum	4,500
SPHAGNUM FEN AND BOG	Sphagnum spp.	~ 6,500

productive stands to unproductive ones, and from circumneutral silted sites to acid peaty habitats. For example, the reedswamps represent a fen type of vegetation most characteristic of rich silted habitats along lake shores. Grass fens of the Deschampsia, Calamagrostis and Phalaris types generally occur in drier silted sites. Grass fens of the Molinia type are an exception, however, and occur frequently on quite highly acid peats similar to those inhabited by Trichophorum fen and bog.

The estimate for Sphagnum, based on data from two sources (Clymo, 1964; Pearsall and Gorham, 1956), is rather high in comparison to the Molinia and Trichophorum values, and cannot be regarded as definitive. It may be noted, however, that in this case above-ground is equivalent to total productivity, whereas in the other cases it is not. Moreover, Sphagnum appears to have an exceptionally low demand for nutrients such as phosphorus and nitrogen (Malmer, 1958, 1962; Malmer and Sjörs, 1955). If either of these nutrients limits growth in bog habitats, and there is evidence that both can do so (Tamm, 1965), then Sphagnum may be able to produce more dry matter per unit of nutrient uptake than other bog plants with a greater nutrient demand. The autecology of Sphagnum species is urgently in need of study, with particular reference to the factors controlling growth and productivity.

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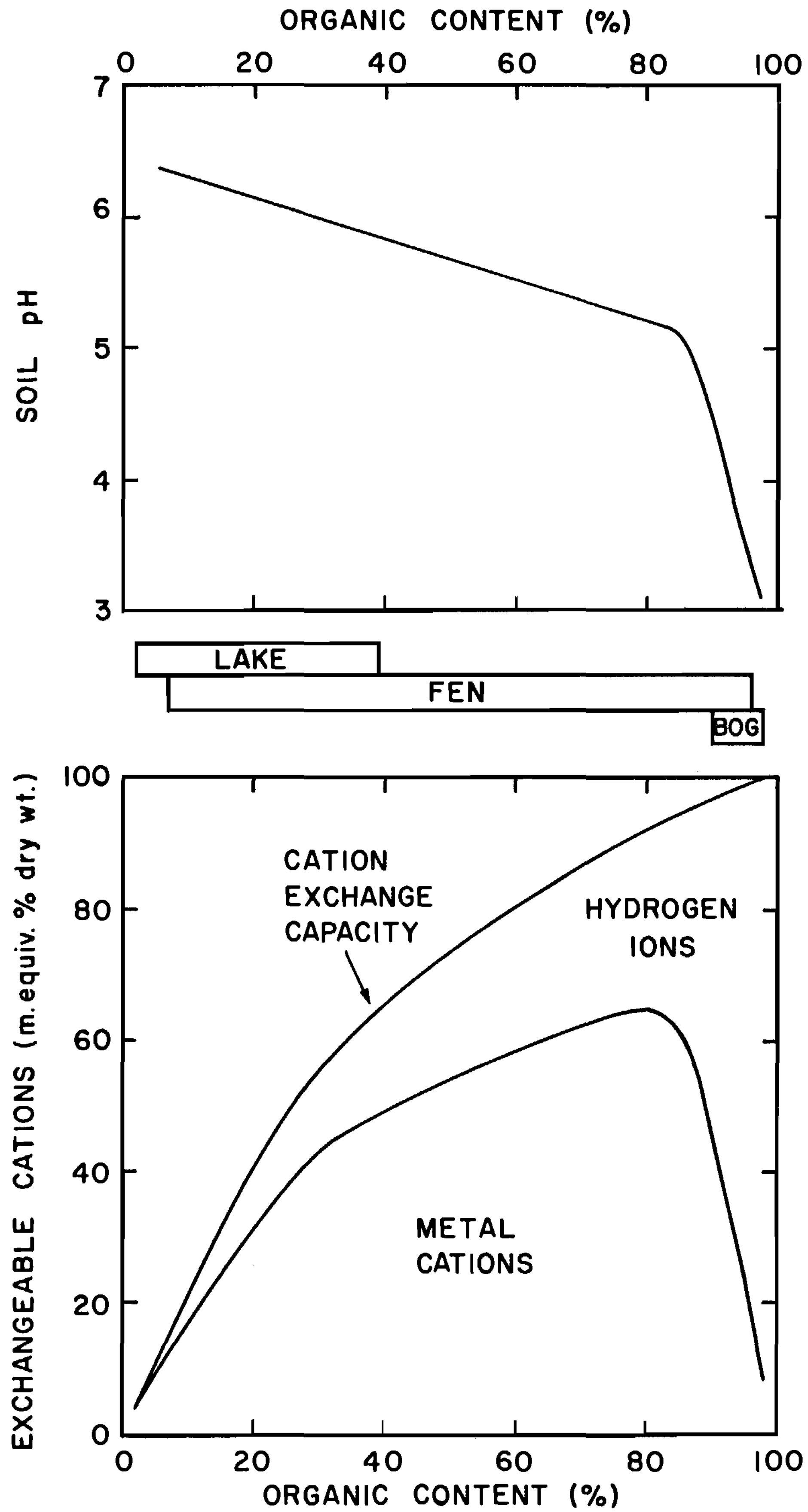

FIGURE I. pH AND EXCHANGEABLE CATIONS IN RELATION TO ORGANIC CONTENT OF LAKE, FEN AND BOG SOILS

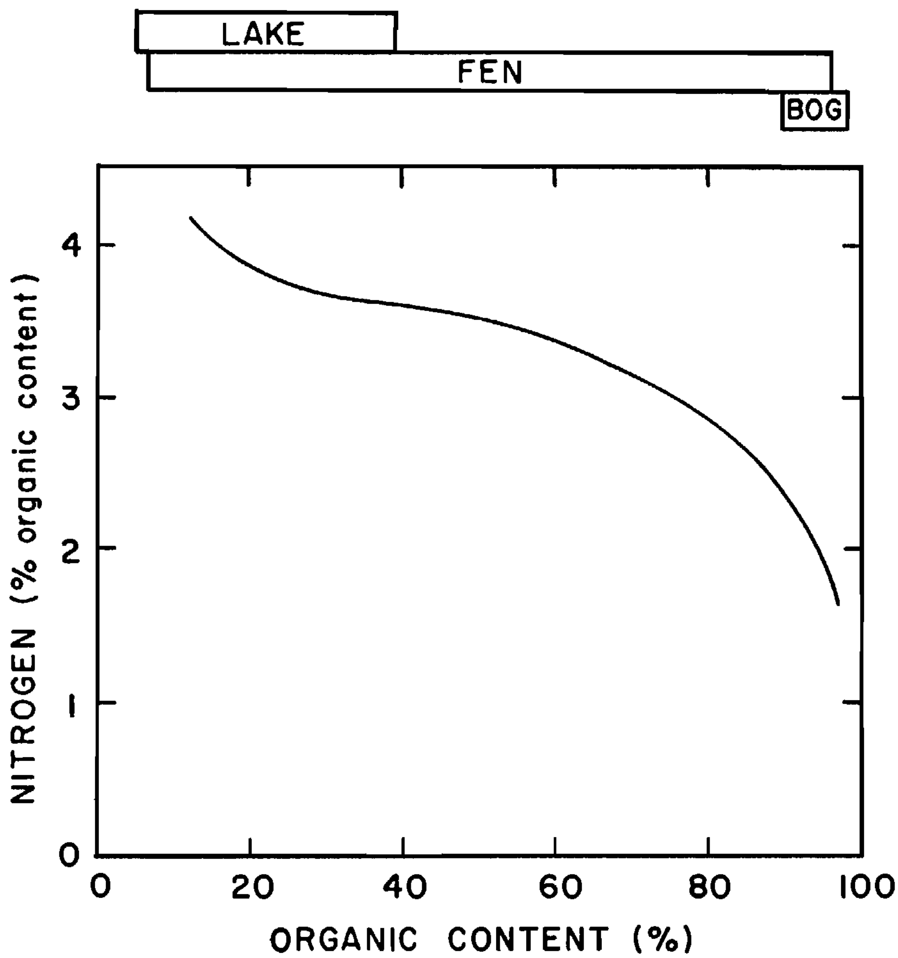

FIGURE 2. NITROGEN IN THE ORGANIC MATTER OF LAKE, FEN AND BOG SOILS WITH DIFFERING ORGANIC CONTENTS

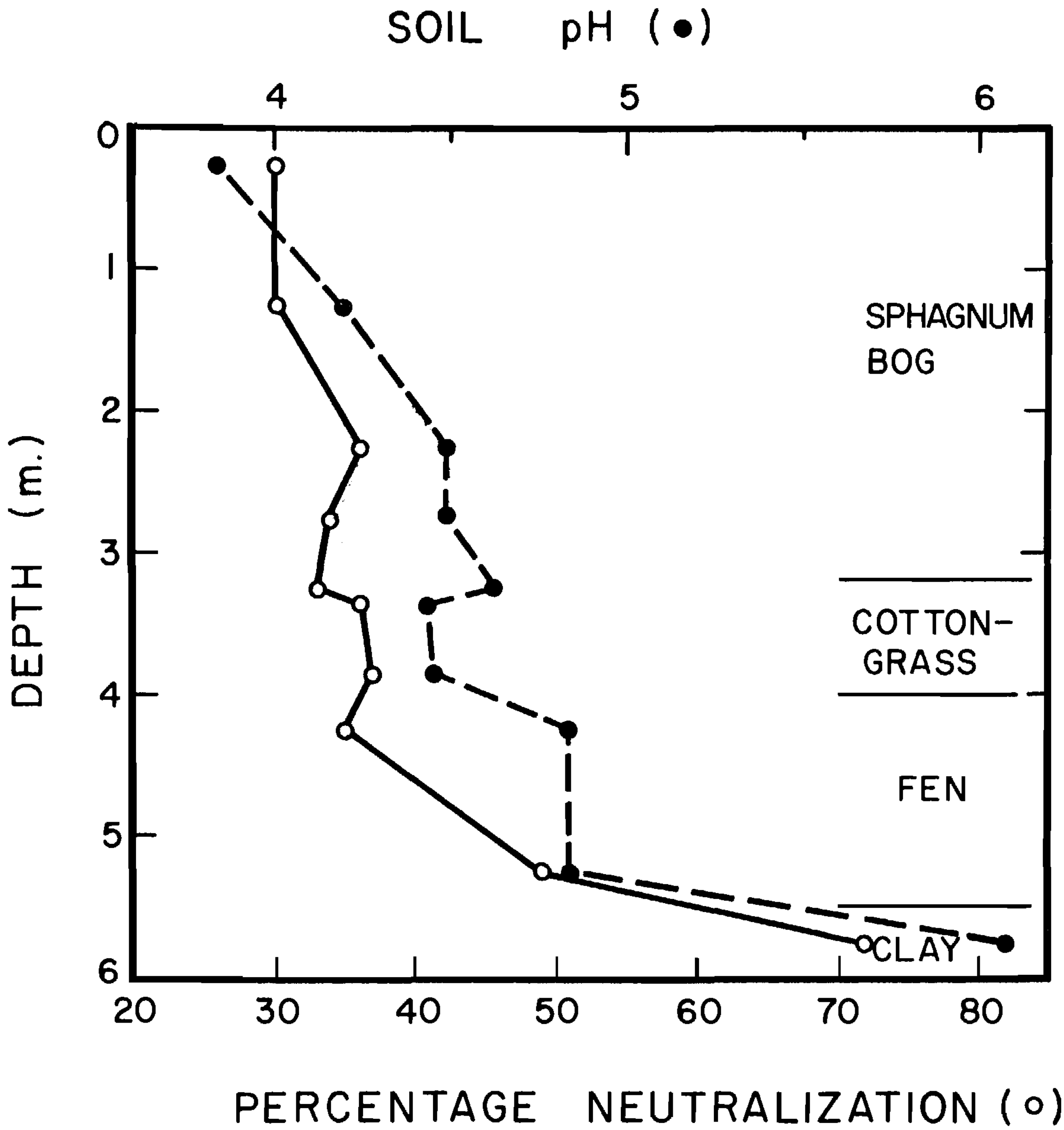

FIGURE 3. pH AND % NEUTRALIZATION IN A BOG PEAT PROFILE

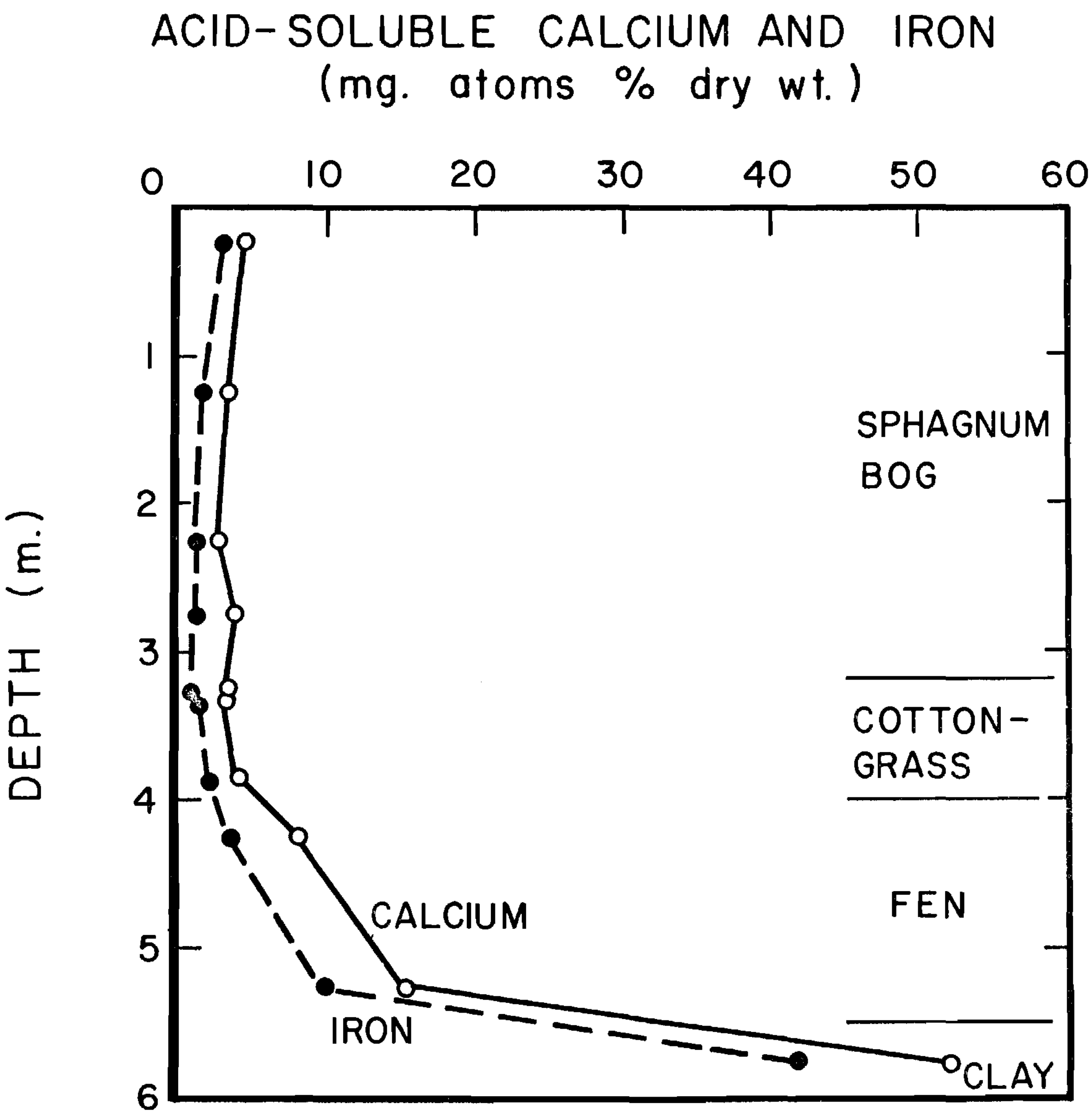

FIGURE 4. CALCIUM AND IRON IN A BOG PEAT PROFILE

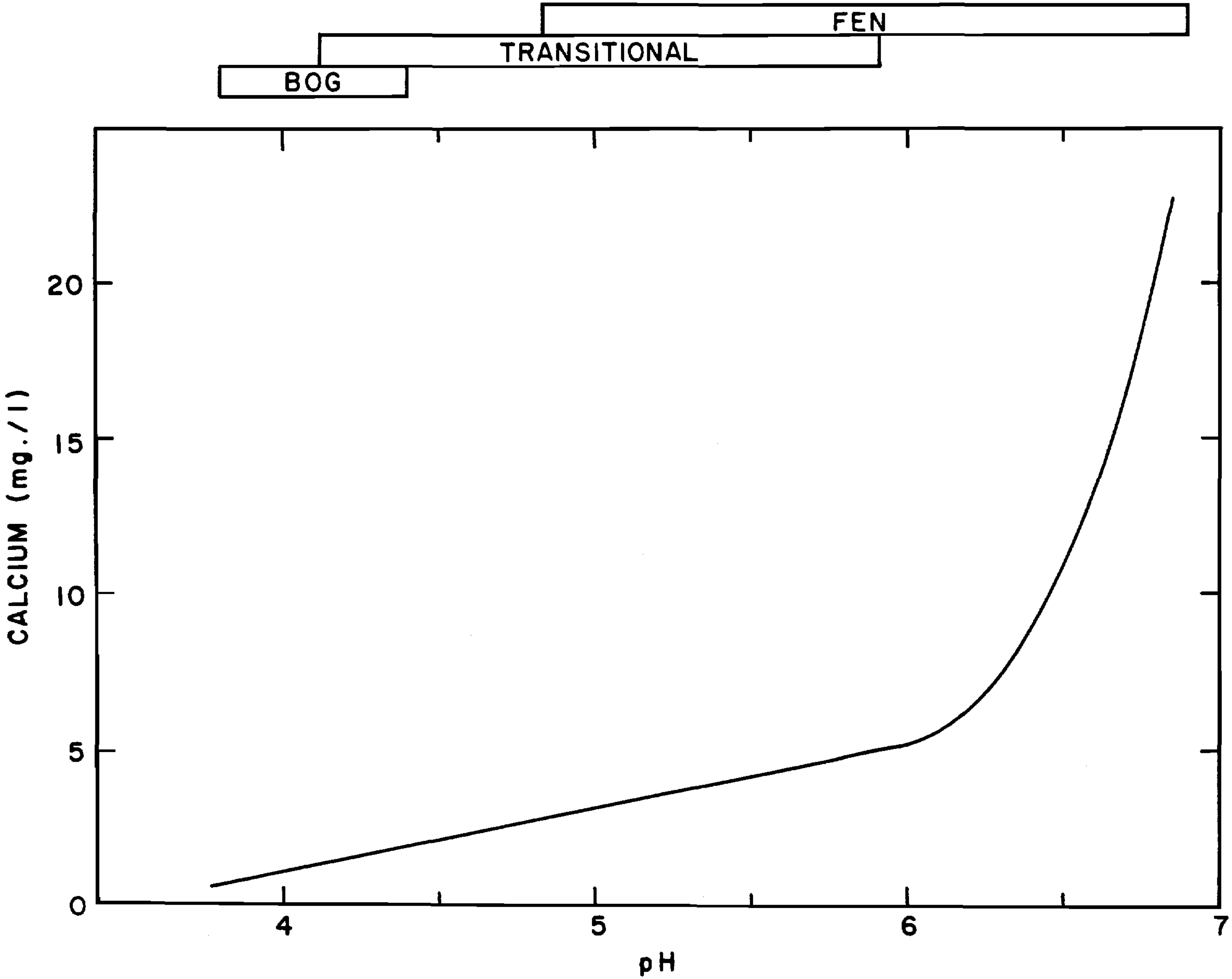

FIGURE 5. THE RELATION BETWEEN CALCIUM AND pH IN FEN AND BOG WATERS

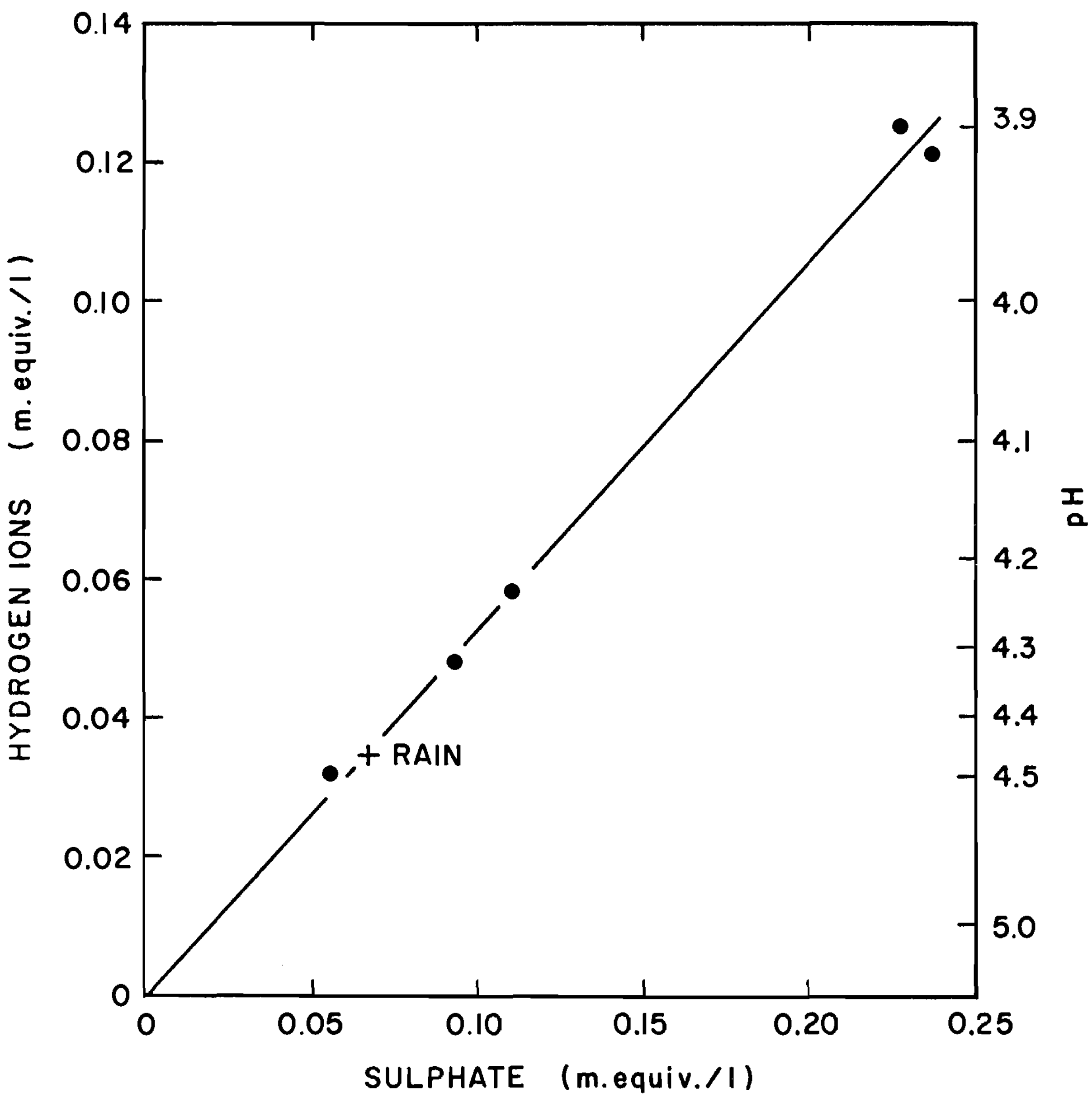

FIGURE 6. THE RELATION BETWEEN HYDROGEN AND SULPHATE IONS IN FIVE INLAND BRITISH BOGS

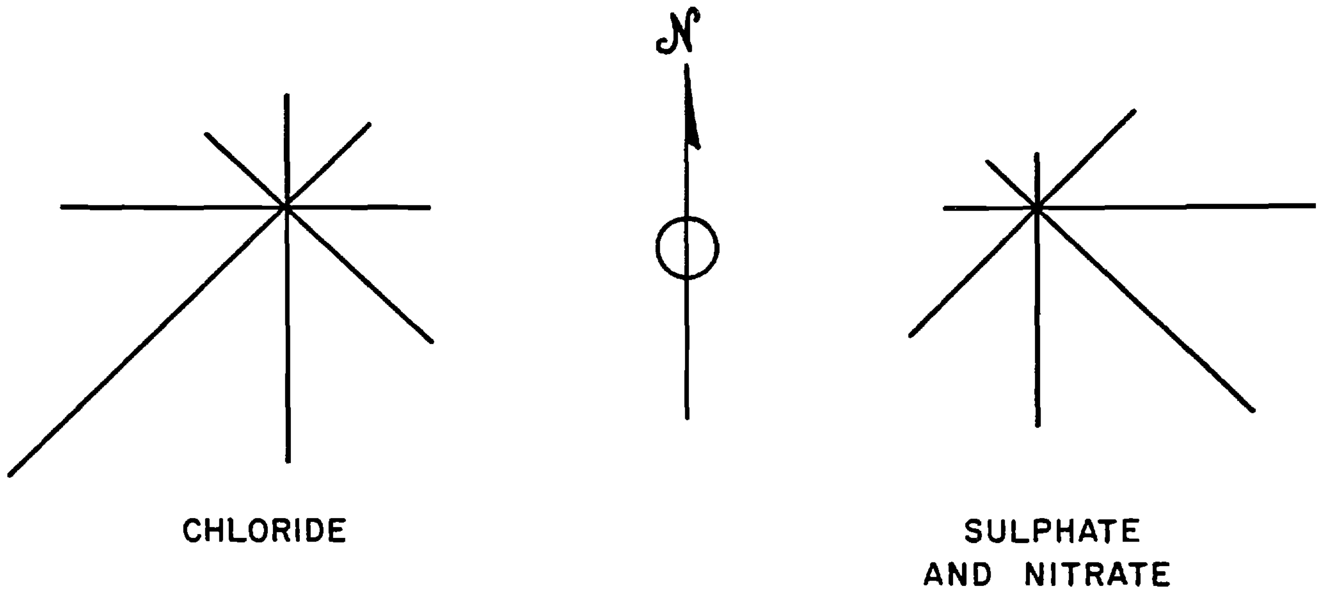

FIGURE 7. THE INFLUENCE OF WIND DIRECTION UPON ATMOSPHERIC ION SUPPLY TO A SITE IN THE ENGLISH LAKE DISTRICT (LENGTH OF LINE PROPORTIONAL TO ION SUPPLY)

Discussion

Dr. Cragg pointed out that scientists are land users and water users and it is important that some areas, preferably large areas, are left in an untouched condition for fundamental investigations on methods. Their claims for certain areas of wetland can be supported by the work of Pearsall and others, and areas should be set aside now for future scientific research. Dr. Cragg commended Dr. Radforth for his paper, stating that, with regard to organic matter problems, it is essential to know more about microbiological processes in peats. He said that we do not yet know much about the micro-elements in peat and this is a whole field of study in itself.

Dr. Radforth congratulated Dr. Gorham on his paper, pointing out that it is timely in that it gives an appreciation of organization on other levels. The matter of conservation is of very great concern, although he doubted that we need to worry too much at this time due to the immense areas of muskeg in Canada. The divergence of water, however, would greatly affect environment and would be unwise conservation without serious planning.

Mr. Hemstock wondered if the pipeline people are aware of the work being done on the chemistry of peat areas, and if any correlation of this work with corrosion is being made. A pipeline company representative agreed that any work along this line is of vital importance due to the economic importance of corrosion. Pipeline companies are aware of the need for such information. He remarked that, in the past, when constructing pipelines through muskeg, it was done in summer at great cost. Now, they are developing methods of utilizing winter construction.

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SESSION II: ACCESS AND TERRADYNAMICS

II. 1. "A HYPOTHETICAL APPLICATION OF AN AERIAL ROPEWAY SYSTEM FOR TRANSPORTATION OVER MUSKEG"

J. N. Siddall*

Abstract:

This paper is a report on a fourth-year Mechanical Engineering design project at McMaster University in which an aerial ropeway system is designed to transport semi-refined ore from a hypothetical uranium mine in northeastern British Columbia to the Alaska Highway - a distance of 100 miles. Twenty miles of the route is over muskeg. The design included a preliminary cost estimate. The system designed is an interesting example of the concept of continuous bridging over muskeg. Conclusions indicate that this could be a promising transport system over muskeg for certain applications.

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II. 1. "UTILISATION ÉVENTUELLE D'UNE TÉLÉBENNE AU-DESSUS DU MOSKEG†"

J. N. Siddall

Résumé:

L'auteur expose dans cet article un projet élaboré à l'Université McMaster par des étudiants de quatrième année de la Section de construction mécanique: il s'agit d'une télébenne (téléphérique) destinée à transporter sur une distance de 100 milles, jusqu'à la route de l'Alaska, du minerai semi-concentré tiré d'une mine hypothétique d'uranium située dans le nord-est de la Colombie-Britannique. Vingt milles de ce parcours traversent une région de moskeg. Le projet comprend une évaluation preliminaire du coût. Cette liaison par télébenne représente une application intéressante du concept d'une voie continue au-dessus du moskeg. Les études permettent de conclure que ce moyen de transport pourrait dans certains cas être employé avantageusement au-dessus du moskeg.

† Orthographe française de "muskeg" (N. du T.).

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* See Appendix "A" for affiliation.

A substantial amount of successful development work has been done in Canada on over-muskeg vehicles. It would seem true to say that very little work has been done in the field of medium to high capacity fixed transportation systems over muskeg. It is true, of course, that permanent roads and railroads have been successfully built over muskeg. They are expensive, however, and an investigation of alternate schemes is highly desirable.

In the Fall of 1965, the fourth-year Mechanical Engineering class at McMaster University were given such an alternate transportation system as their major design project. Specifically, the problem was to do a preliminary design of a system to transport semi-refined uranium ore from a hypothetical mine in northeastern British Columbia to the Alaska Highway, a distance of 100 miles. The location is shown in Figure 1. No further information was given except a predicted capacity curve for the uranium ore out of the mine, shown in Figure 2. This output is substantially larger than any existing uranium mine in Canada; but in view of the rapid increase in nuclear power stations, it is perhaps not too far-fetched.

A study of the terrain from topographical maps and aerial photographs showed that twenty miles of the route is muskeg, mostly FI; the remaining eighty miles is mineral terrain, including one mountain range. The design concentrated on the muskeg portion of the route.

The students examined several alternate systems before selecting the most promising. These included truck trains using a roadbed of plastic foam, a monorail system, and an aerial ropeway or tramway system. The most promising appeared to be the ropeway system.

An investigation by the students of uranium mining disclosed that a substantial amount of sulphur is required at the mine processing plant to make sulphuric acid for treating the raw ore. The predicted requirements for sulphur going into the mine site are also shown in Figure 2.

The Aerial Tramway System

The system designed consists of two aerial tramways mounted side by side on the same tower. The system can handle the expected capacity with only one side in operation for the first three years. The design is a bi-cable ropeway consisting of a fixed track rope to support the wheeled carriers, and a driven traction rope to haul them. A schematic diagram of a single system is shown in Figure 3. Note the counterweight on the traction rope-pulley system to provide driving friction between rope and sheave; and the counterweight on the track rope to maintain proper sag with temperature changes.

Such a system cannot be continuous for the whole one hundred miles. The tension in the traction rope would be extremely high; the drive equipment would be very large; the traction rope counterweight would be very large; and travel of the counterweights would be awkwardly long. The optimum station spacing was estimated to be 12,000 ft, yielding a traction rope diameter of 1-1/8 ins. These breaks in the system require a means of transferring carriers from one system to the next at each station. The system travels at a speed of 5.7 M.P.H., close to the upper limit currently used in aerial tramways.

Let us begin our closer examination of the design with the ore carrier. The ore cannot be carried as loose bulk; it is packaged in sealed cylindrical containers 2 ft in diameter by 4 ft long each carrying 3,000 lbs of ore. Sulphur for the sulphuric acid plant is returned in the same containers on the return side of the system. The carriers are spaced at intervals of 225 ft. The carriers are simple open framed cradles, pivoted on a four-wheeled carriage which rides the track rope, and incorporating a gravity operated clamp for attachment to the traction rope. The carrier and ore container are shown in Figure 4. The carrier must be unclamped from the traction rope at the transfer stations and this is done by transferring the weight to the unclamping wheels which are picked up on special tracks at the stations. This opens the clamps.

A primary set of interrelated design decisions was spacing of the intermediate towers, height of the towers and track rope size. This presented a complex optimization problem. A tower height of 70 ft was selected and a computer programme set up which determined the optimum cable size of 1-3/8 ins. and tower spacing of 1,000 ft. These calculations were based on a rope sag of 45 ft, which was determined by snow clearance.

The intermediate tower design is shown in Figure 5. Its structural elements are a truss carrying the track and traction ropes, a superstructure on the truss carrying electrical power cables, two V-orientated lattice columns carrying the truss, four guy ropes, and the foundation. This appears to be an efficient structural configuration and particularly well adapted to the support of four track ropes.

The tower design also has a simple foundation, making it particularly suitable for muskeg. It consists of four wooden piles capped by steel beams and pivots for the columns. It is shown in Figure 6. The single pin-jointed support point eliminates any moment on the foundation, minimizes muskeg contact, and minimizes the horizontal reaction at the foundation. The vertical foundation force is 185,000 lbs, carried substantially by support of the subsoil on the piles. From the small amount of geological and soil data available, it was estimated that the peat is rarely greater than 20 ft in depth, and the subsoil is a saturated clay-like soil having a shear resistance of 1,000 lbs/sq.ft. Using a standard pile formula, the indicated depth of the piles in the subsoil was 15 ft. The horizontal reaction at the foundation due to wind loading on the columns is 2,500 lbs, carried substantially by the peat.

The guy rope loading is 28,600 lbs. The anchor for the guy, shown in Figure 6, is a 10 WF49 pile, driven parallel to the rope to a depth of 15 ft in the subsoil.

The track rope is supported at the intermediate tower by a saddle, free to rock and let the rope slide over it. The traction rope is carried by five sheaves just below the saddle.

The transfer stations were located at the mid-point of a span so that the ropes enter horizontally at their lowest point. Figure 7 shows a schematic diagram of the transfer station arrangement. It contains the anchor for one track rope and the counterweight for the adjacent one. The ends are bridged by a fixed rigid track. Included in the arrangement are an anchored idler sheave for the traction rope; closely adjacent to it is the dual-drive sheave system attached to the counterweighted take-up sheave.

The carrier must be unclamped from the traction rope while crossing between adjacent drive systems. Momentum, and a 9-in. drop between sections, is relied on to carry the carriers from one system to the adjacent one.

The mechanical drive is shown in Figure 8. The dual-drive sheaves are driven by pinions and bull gears from a differential transmission, in turn driven by a 230 hp, 900 r.p.m., wound rotor, 2,300 volt AC motor. The speed of these motors will not vary more than 5 per cent over the whole system; thus carrier spacing error can never exceed 10 per cent.

Required start-up tension in the traction ropes is substantially greater than required operating tension. To use the same tension for both would greatly reduce rope life. An ingenious automatic winch arrangement is used to increase rope tension temporarily during start-up.

The steel structure, and supporting steel pile foundation is designed to carry an unbalanced load on the assumption that a cable on one side has failed. The transfer station is protected by a building, with minimum openings for the carriers.

Control of the system is all done remotely, using high frequency carrier signals carried by the transmission cables. The whole system is shut down automatically if failure occurs in any section.

An important and difficult element of the design is the loading and unloading terminals. The design used at the mine end is shown in Figures 9, 10 and 11. Unloading is done by tilting the carriers so that the containers roll onto conveyor rollers which carry the sulphur-laden containers into the processing plant. The ore-laden containers are carried out of the plant on individual rail cars. These cars, moving at ropeway speed, pick up and tow the released empty carriers by an extended arm, so that they move together. The carrier is tipped by rollers and, at the same time, the tipping table of the car is raised by rollers, so that the container rolls by gravity from the car to the carrier, which then disengage and the carrier clamps onto the traction rope. The rather critical problem of timing is solved by stacking the loaded cars on a ramp. An incoming empty carrier trips a car release, the car attains ropeway speed by gravity down the ramp, the two engage, and the transfer of load is made. The towing chain for the cars has lugs spaced exactly at the proper carrier spacing of 225 ft. One of these picks up the car as the load transfer is occurring; thus presenting the carrier to the ropeway system at exactly the correct speed and spacing.

Comparative Cost of the System

The cost estimate was an important aspect of the design, and was done as thoroughly as possible. The result was encouraging but not conclusive. The ropeway cost estimate was $263,000 per mile. This may be compared with a cost of $238,000 per mile for the Wabash Lake Railway, including rolling stock.

Discussion

This design exemplifies an important approach to the design of high capacity fixed transport systems over muskeg in which the continuous bridging principle is used. Other possibilities using this principle are belt conveyors, conventional vehicle roadbeds, monorails, and air cushion vehicle roadbeds. To minimize structural loadings and costs on these systems, it is essential that vehicles be as spread out or continuous as possible, in analogy to the continuous and equally spaced sequence of carriers on the aerial tramway. The continuous bridging approach minimizes the foundation problem – a major difficulty in muskeg. The choice of bridge span will be a problem in optimum cost design, as was the case for tower spacing in aerial tramway design.

This study suggests a promising and fertile field of investigation for transport systems over muskeg. Particularly useful would be the study of localized foundations in muskeg.

DESIGN SUMMARY

Dual bi-cable system
Maximum capacity - 7,800 tons per day
Ore container size - 2 ft dia. by 4 ft long
Ore container weight - 3,000 lbs
Carrier spacing - 225 ft
System speed - 5.7 m.p.h. or one carrier every 27 seconds
System length - 100 miles, 20 miles on muskeg
Track rope size - 1-3/8 in outgoing side
Traction rope size - 1-1/8 in
Transfer station spacing - 12,000 ft
Tower spacing - 1,000 ft
Tower height - 70 ft
Rope sag - 45 ft
Tower foundation - 4 wooden piles
Station foundation - steel piles
Peat depth - about 20 ft
Subsoil - saturated clay
Motor - 230 h.p., 900 r.p.m., 2,300 volt AC, wound rotor
Cost per mile - $263,000.

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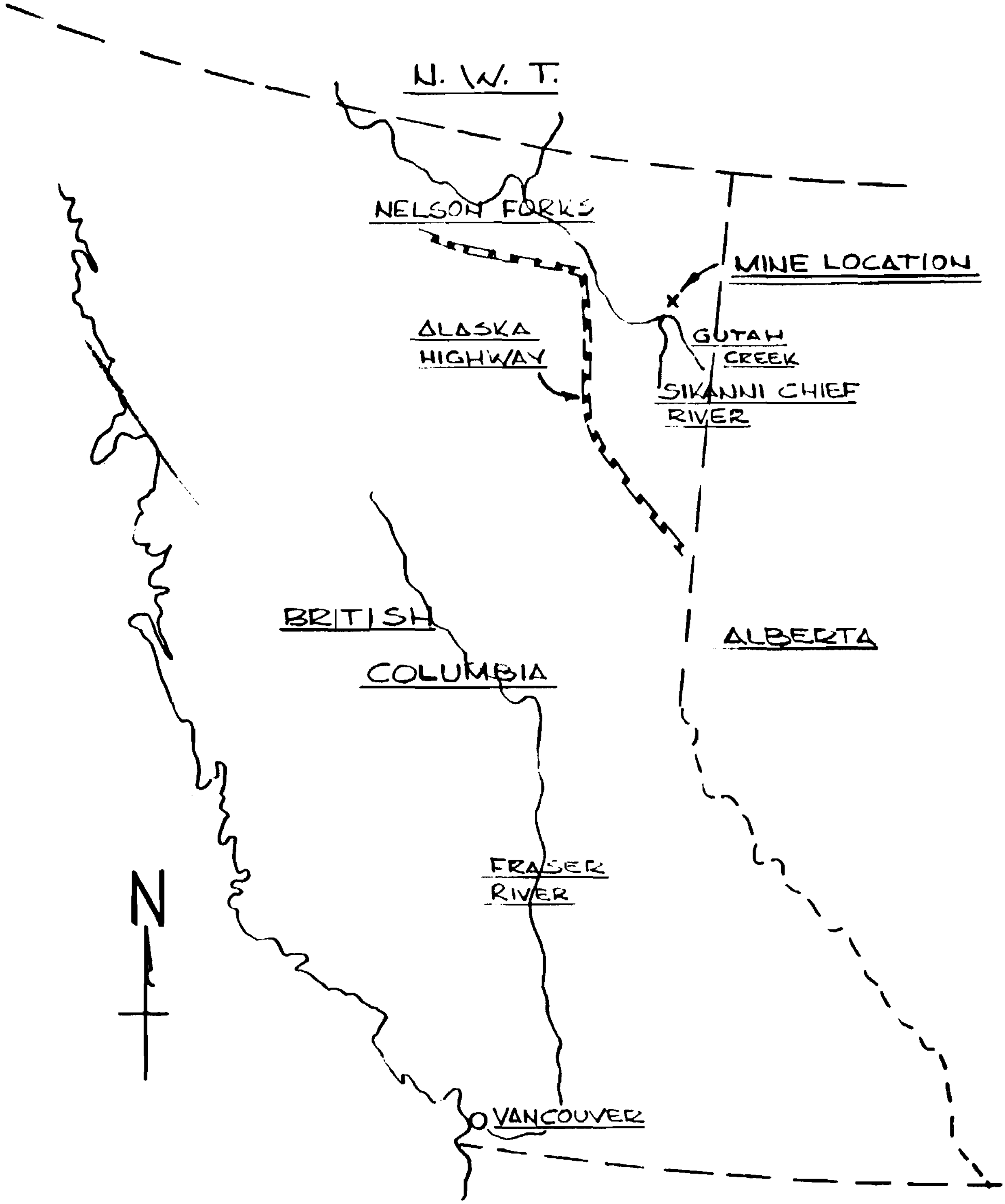


FIG. I URANIUM MINE LOCATION

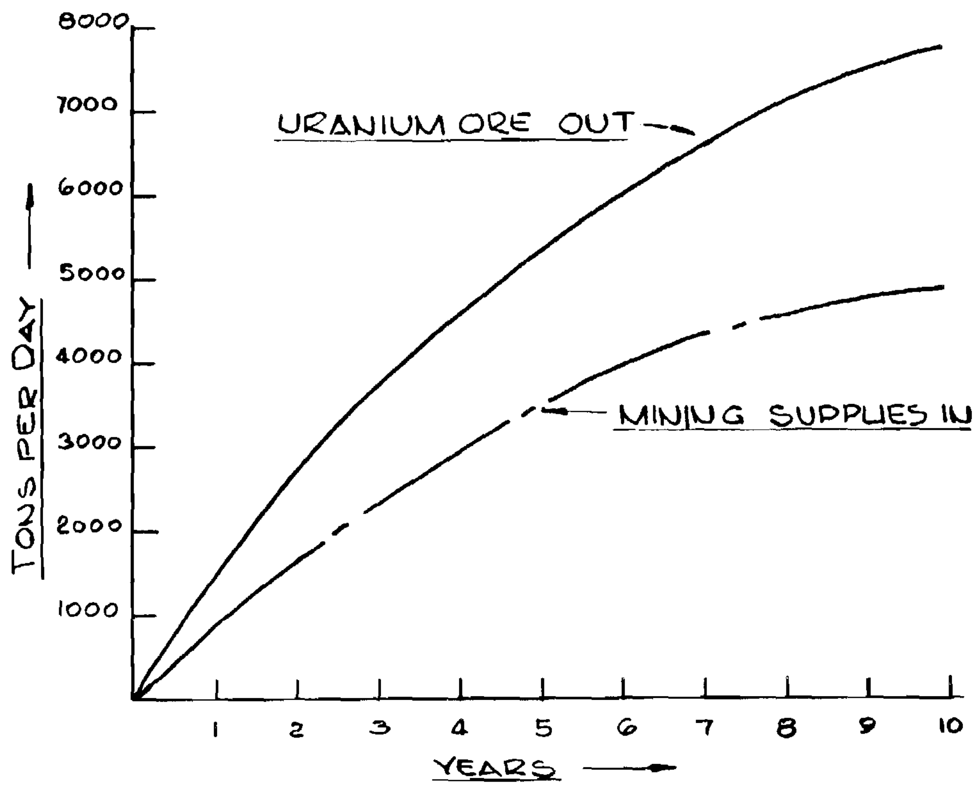


FIG. 2. CAPACITY CURVE FOR TRANSPORTATION SYSTEM

B.H. KAMUTZKI APRIL 7/66

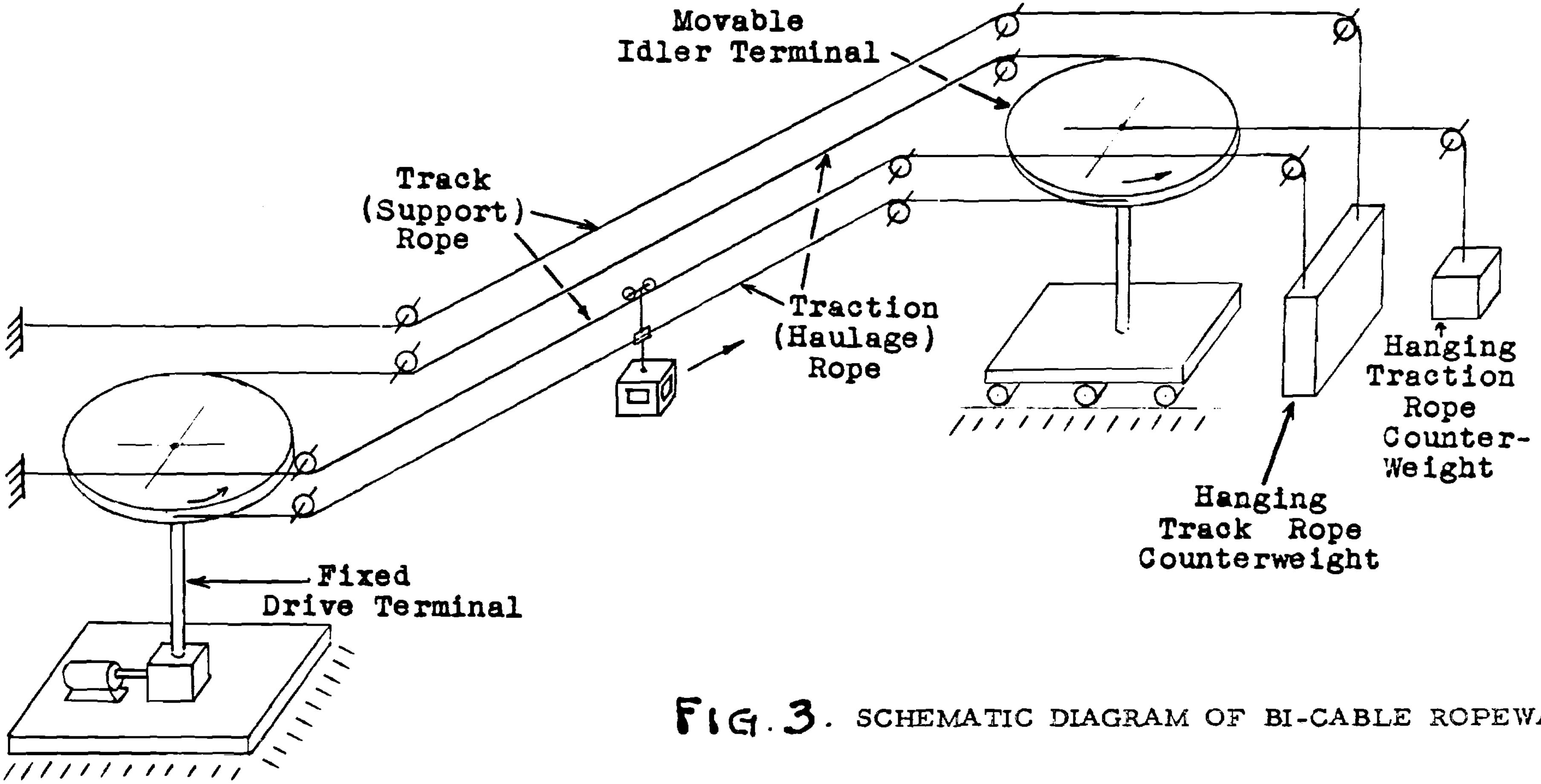
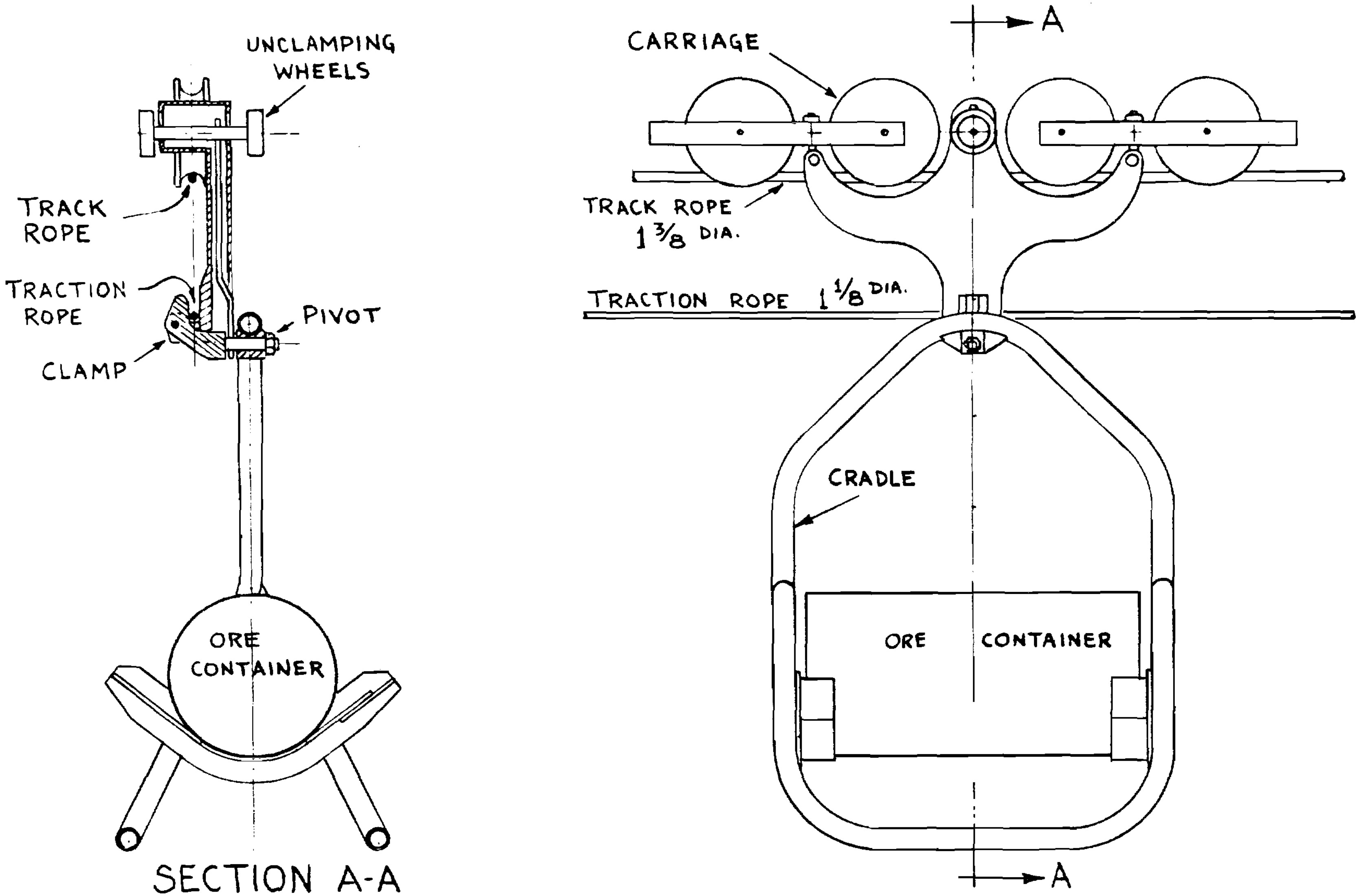
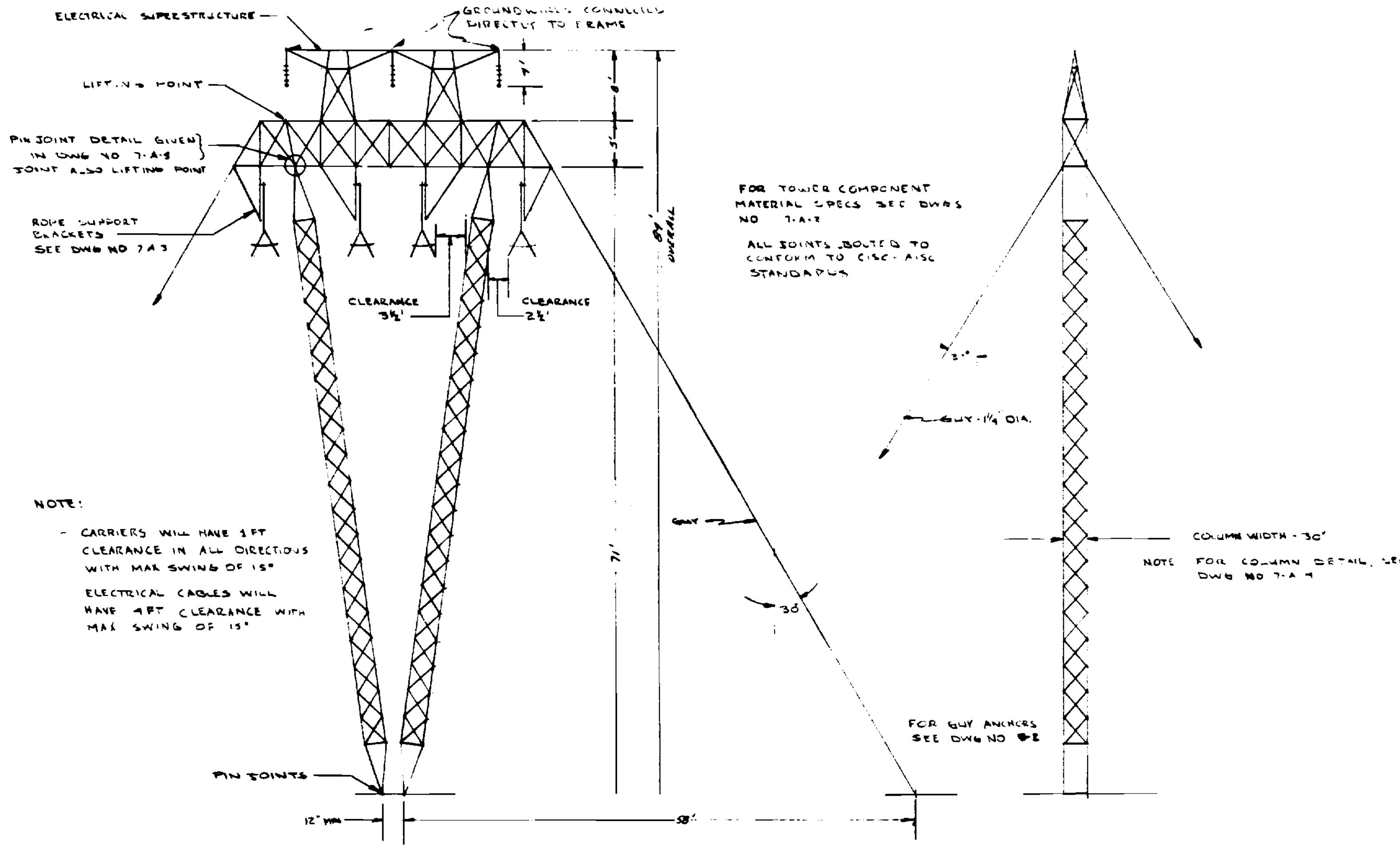


FIG. 3. SCHEMATIC DIAGRAM OF BI-CABLE ROPEWAY



ORE CARRIER

FIG. 4



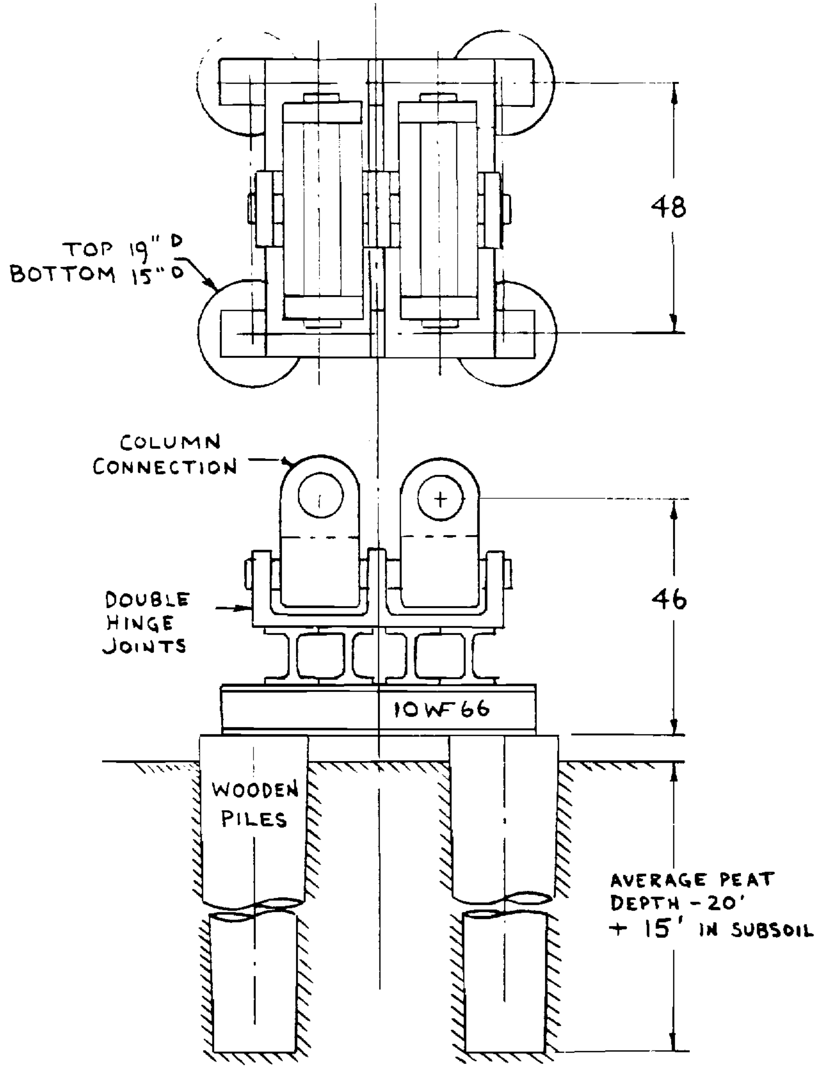
CONSTRUCTION NOTES - TOWER TO BE ALL BOLTED STRUCTURE
- USE ASTM A 325 HIGH STRENGTH BOLTS

MATERIAL - USE ASTM A242 LOW ALLOY HIGH STRENGTH CORROSION RESISTANT STEEL
DURING ERECTION LIFT ONLY AT POINTS SO MARKED

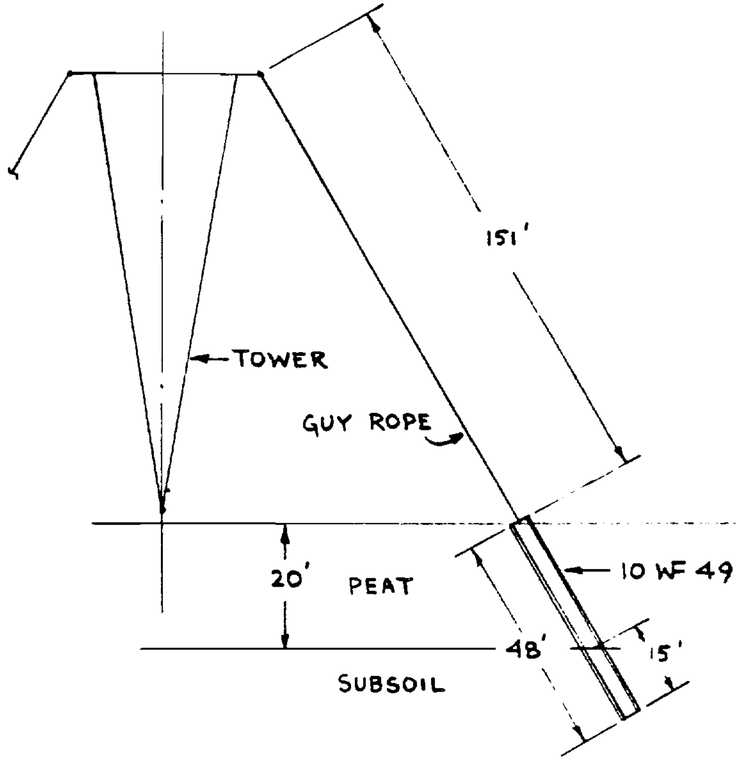
FIG. 5

McMASTER UNIVERSITY HAMILTON, ONT	DWN: HILL DATE SCALE 1/8" = 1' APP'D
GENERAL LAYOUT GUYED-V TYPE TRAMWAY TOWER	DWG NO 7-A-1

THE INTERMEDIATE TOWER



INTERMEDIATE TOWER FOUNDATION



GUY ROPE FOUNDATION

FIG. 6

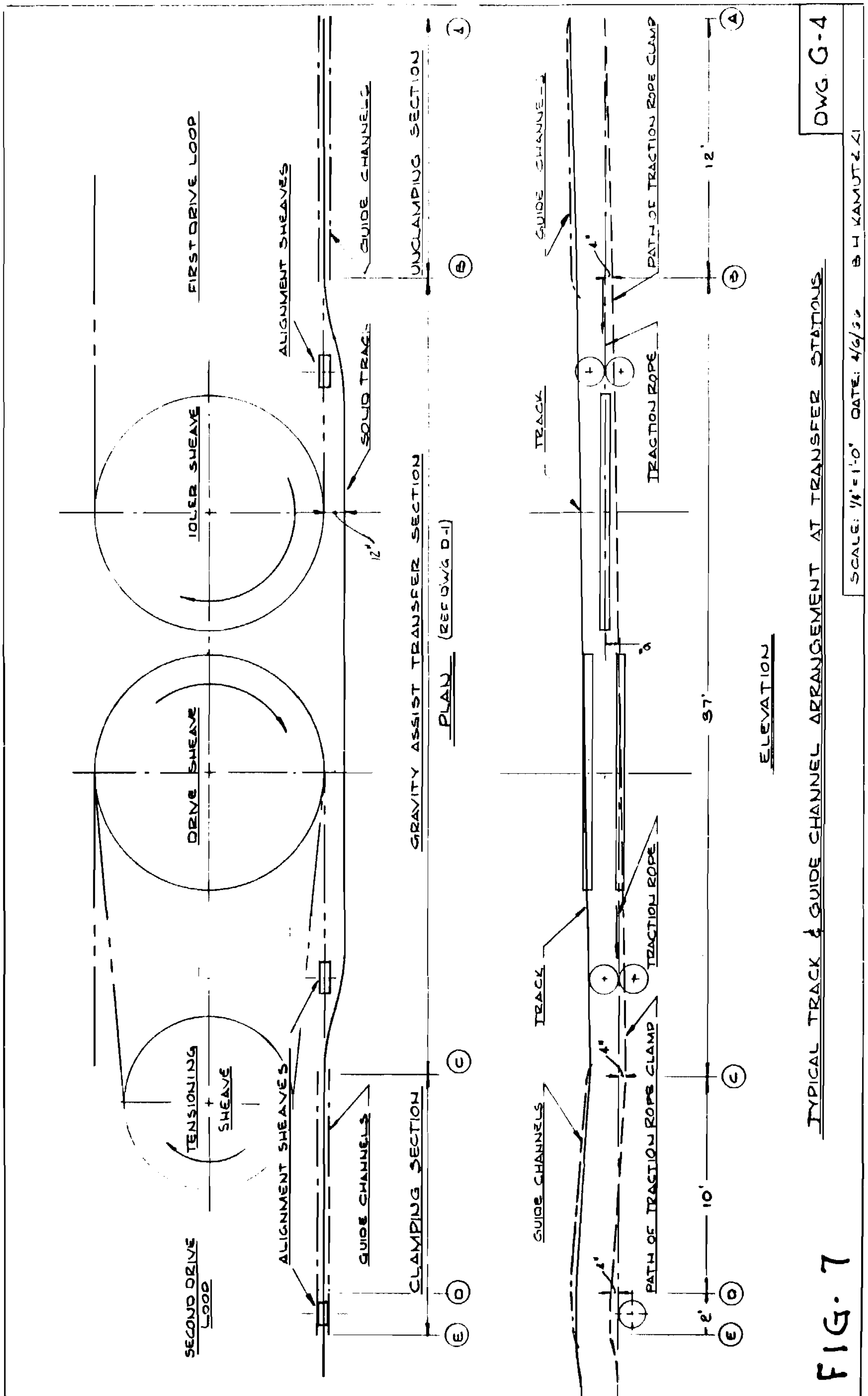

FIRST DRIVE LOOP
SECOND DRIVE LOOP
IDLER SHEAVE
DRIVE SHEAVE
TENSIONING SHEAVE
ALIGNMENT SHEAVES
ALIGNMENT SHEAVES
GUIDE CHANNELS
GUIDE CHANNELS
SOLID TRACK
12"
UNCLAMPING SECTION
GRAVITY ASSIST TRANSFER SECTION
CLAMPING SECTION
PLAN
(REF DWG D-1)
A
B
C
D
E
GUIDE CHANNELS
GUIDE CHANNELS
TRACK
TRACK
TRACK
TRACTION ROPE
TRACTION ROPE
PATH OF TRACTION ROPE CLAMP
PATH OF TRACTION ROPE CLAMP
PATH OF TRACTION ROPE CLAMP
4"
4"
4"
12'
37'
10'
2'
ELEVATION
TYPICAL TRACK & GUIDE CHANNEL ARRANGEMENT AT TRANSFER STATIONS
SCALE: 1/8"=1'-0"
DWG G-4

FIG. 7

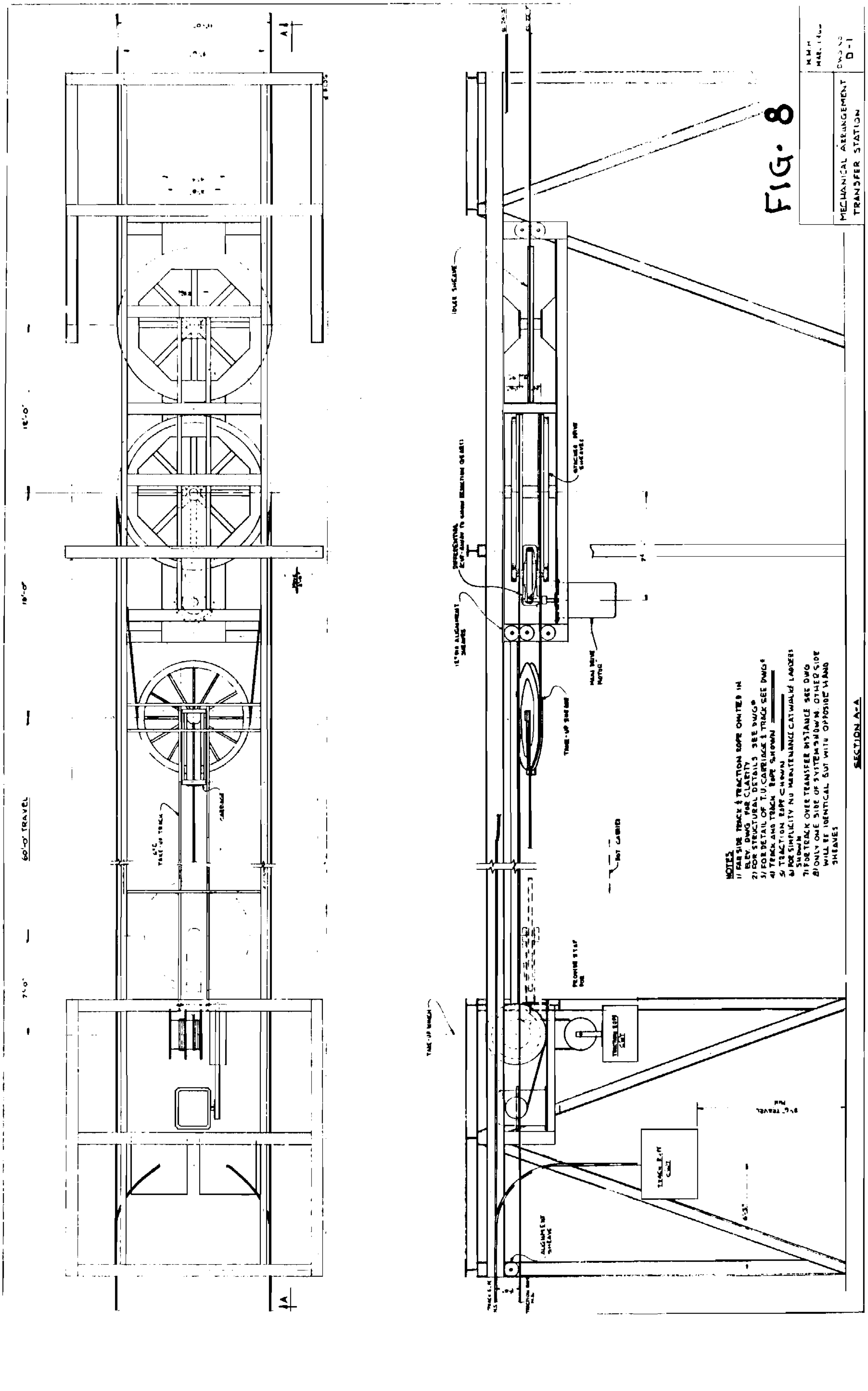


FIG. 8
MECHANICAL ARRANGEMENT
TRANSFER STATION
D-1
60'-0" TRAVEL
SECTION A-A
NOTES
IDLER SHEAVE
TAKE-UP SHEAVE
CARRIAGE
MAIN DRIVE MOTOR
ALIGNMENT SHEAVE
TRACK ROPE CWT
TRACTION ROPE CWT

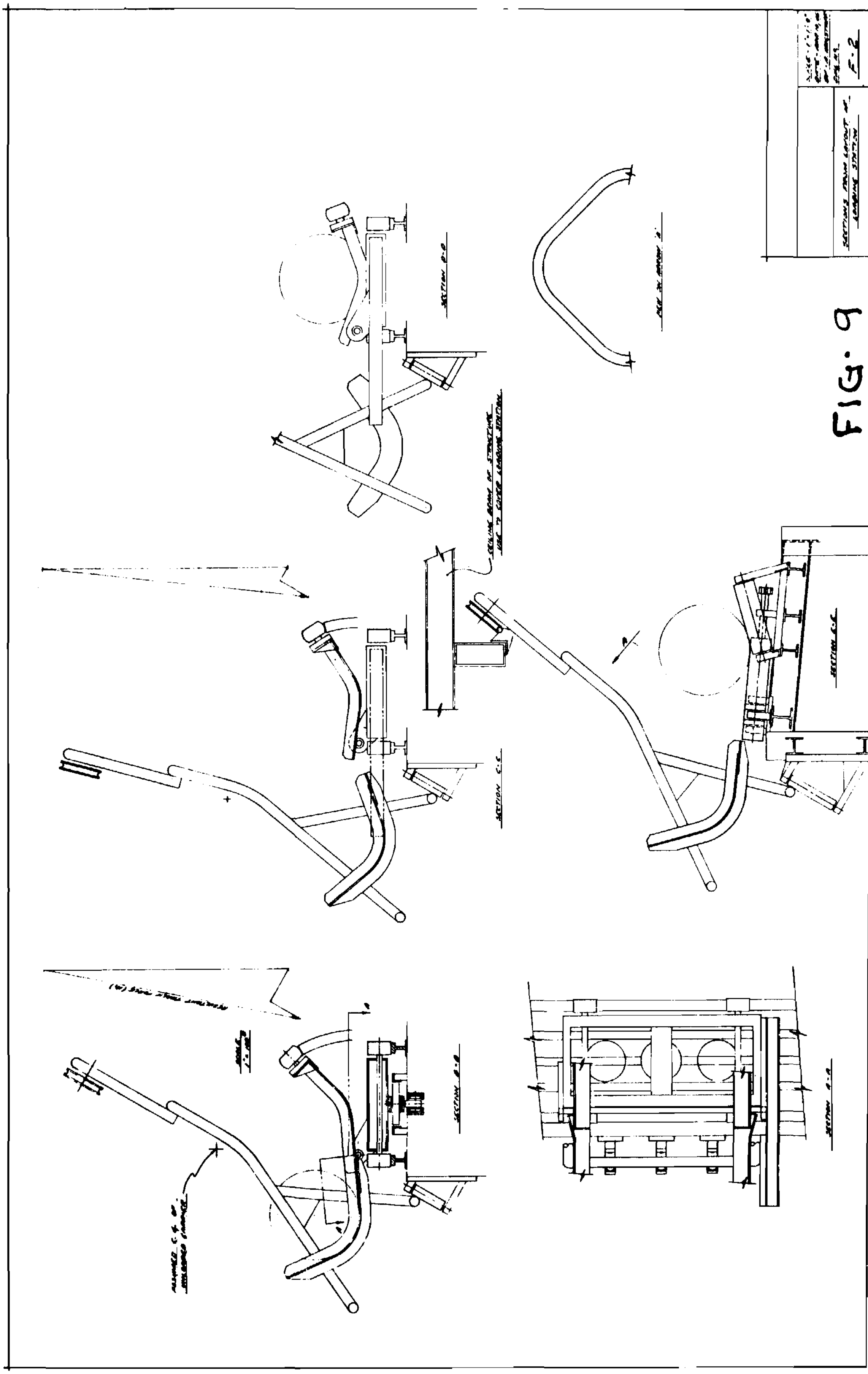


FIG. 9

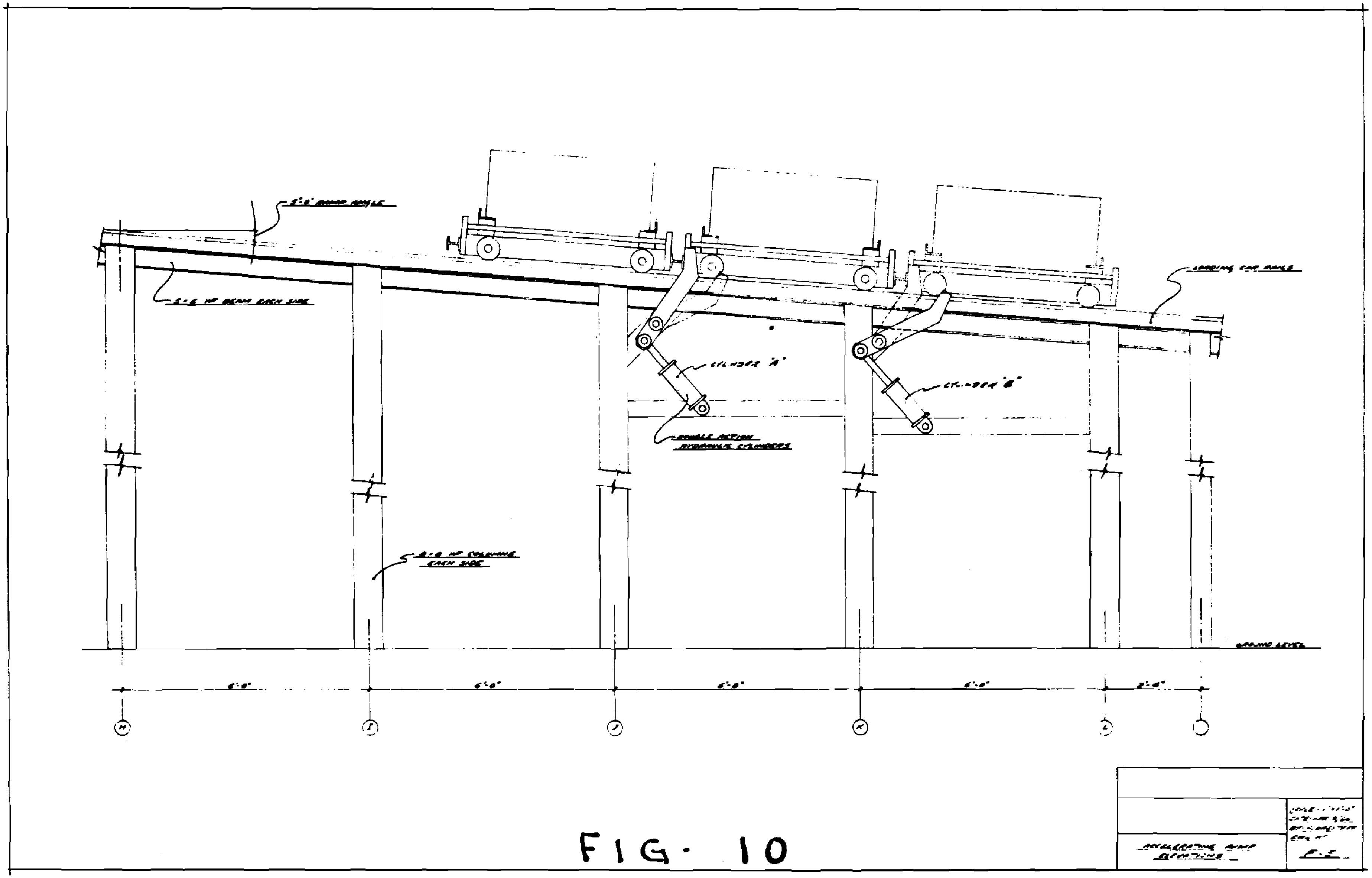


FIG. 10

LOADING RAMP STANDBY

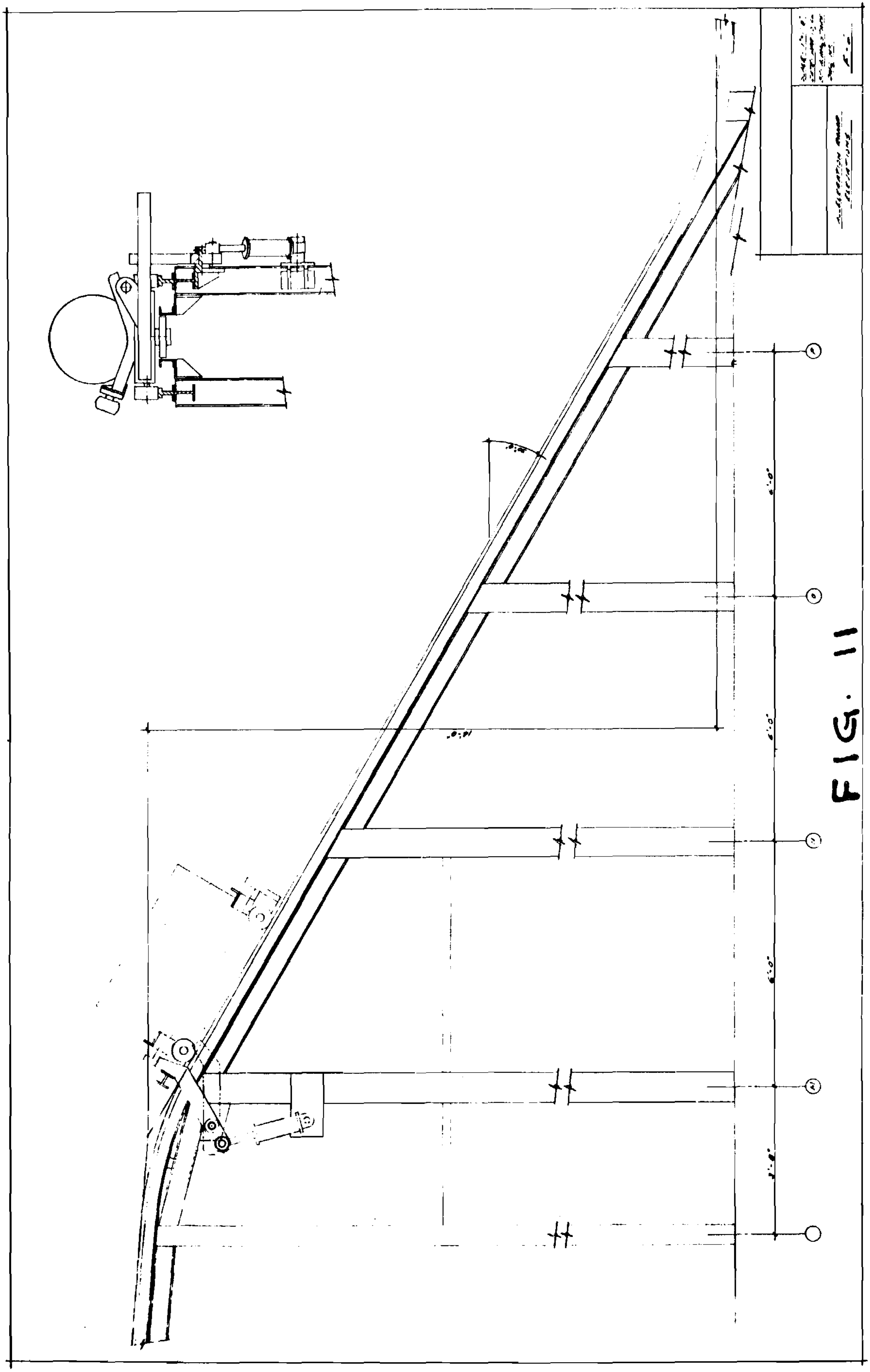


FIG. 11

LOADING RAMP RELEASE

Discussion

Mr. Brawner expressed his great interest in hearing of new developments such as that outlined in Professor Siddall's paper. Mr. Wiskel asked Prof. Siddall if he had been able to calculate the cost of ore per ton-mile, to which Prof. Siddall answered in the negative.

Mr. Dawson asked if the cost of replacing the cable periodically was considered, to which Prof. Siddall replied that it was; the estimated cable life was ten years.

Mr. Brawner wondered if a solids pipeline was considered. Prof. Siddall said that it had been considered, but not enough water was available for a pipeline. Mr. Dawson suggested using individual motors on each carrier, instead of one large one - applying the streetcar principle. Prof. Siddall said that this had not been considered; there would be some problem in getting the power to each unit.

Prof. Siddall was asked about the kind of piles used. He replied that friction piles were used, with a friction value of 1000 lb/sq. ft. in the subsoil. There was no reliance at all on the peat. The question was asked if the cost per mile was based on the total 100 miles or on the 20 miles of muskeg. Prof. Siddall answered that it was based on the 20 miles of muskeg.

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II. 2. THE SIGNIFICANCE OF TRACK DESIGN APPROACH ANGLE TO CRITICAL BEARING CONDITIONS OF MUSKEG

J. E. Rymes*

Abstract:

Four basic muskeg categories are described which recur all across Canada and which represent the types of terrain problems for vehicular access. Problems of vehicle design relative to terrain characteristics are discussed and include the following: (a) type of track design and ramp angles; (b) the weight distribution; (c) the L/C ratio – steering; (d) the terrain on which the vehicle would operate; (e) the maximum operational speed requirement; and (f) the vehicle suspension. A track design is being utilized with a front ramp angle of 26°.

- *** -

II. 2. L'IMPORTANCE DE L'ANGLE D'ATTAQUE DES CHENILLES DES VÉHICULES SE DÉPLAÇANT SUR UN MOSKEG INSTABLE

J. E. Rymes

Résumé:

L'auteur décrit quatre types fondamentaux de moskeg répandus au Canada, qui présentent chacun des difficultés particulières pour le déplacement des véhicules. Il étudie la conception des véhicules en fonction de la nature du terrain, particulièrement sous les aspects suivants: a) types de chenilles et inclinaison de leur rampe d'attaque, b) répartition des charges, c) rapport L/C : braquage, d) nature du terrain devant supporter le véhicule, e) vitesse maximale de fonctionnement, et f) suspension du véhicule. On utilise des chenilles dont l'angle d'attaque est de 26°.

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* See Appendix "A" for affiliation.

This paper presents some basic considerations regarding the design of a track vehicle and, in particular, its track design and its relationship with the muskeg terrain. Before delving into these considerations, however, it would be well to paraphrase very briefly the Radforth Classification System for Terrain Descriptions and, in particular, the significance of the terrain itself. Muskeg is, of course, a broad or general name given to an organic terrain which many people classify into two categories: namely, bad and terrible. For those who have had the opportunity of being stuck in a typical muskeg carpet failure, the description of that particular type of terrain is generally referred to by different but well-known adjectives. For the purpose of describing some of our thoughts, and indeed some of the test programs which our company have conducted, we are fundamentally only concerned with four typical combinations or categories of muskeg that recur not only all across Canada but in other countries similarly located to Canada in both the northern and southern temperate zones. These four categories are FI, EI, DI or DFI, and BFI.

FI is predominantly a short or grass-like terrain, is usually quite flat, is almost always wet and, in many areas, extends as a floating mat over water or fluid peat. This type of muskeg offers very little support initially, is soon rutted, and most vehicles have considerable difficulty in negotiating this type of terrain.

EI is where the predominant cover is low brush with mosses underneath. It is generally flat but where the brush has growth, mounds occur and there is considerable growth at these points. In the northern regions, it is possible that ice can exist in these mounds well into the summer and conceivably on a year-round basis. Travel over this type of EI terrain is easier than in the FI but since it presents these mounds as well as moss undergrowth, high-speed travel can be a problem.

DI or DFI is generally much heavier in bushes with a low bearing capacity of peat between the bushes. In this type of terrain, bush spacing will vary up to 8 ft and there can be upwards of 6 ft of vertical branches which cause a great deal of difficulty in the forward motion of vehicles. With the high relative heights of the bushes coupled with the fluid peat spacing, it is sometimes extremely difficult to steer a course through this type of terrain successfully and in many areas immobility can occur and generally quite suddenly.

In the BFI characteristic, trees which are usually stunted exist in the FI area. Due to the remains of previous trees this type of terrain indicates a somewhat drier condition than the normal FI. Hence it presents an easier terrain for vehicle mobility, providing of course the tree density does not impede the vehicle motion as in the case of the DFI.

These four basic categories of muskeg contain most of the terrain conditions which should be recognized and understood if successful and repeated travel by a vehicle is to be obtained.

In our earlier vehicles, the track design did not include a front ramped track but rather the whole vehicle was designed to produce a slight nose-up attitude when negotiating an FI muskeg. This particular design approach worked very well and recognized one of the vehicle design parameters, i.e.: weight distribution. There were many limitations but, generally speaking, the relationship of weight distribution and the terrain was a step in the right direction.

Our first attempts in providing a vehicle with a ramped front track were related only to the problem of mounting and negotiating relatively high and abrupt terrain conditions, i.e., those found in the woodland industry. In this design, research was conducted into the average heights of cut stumps, types of dead fall, etc., and the ramp angle was set so as to provide for this climbing ability. With the actual installation made, we found certain other features that were desirable in a front-ramped track and a prototype of a large muskeg vehicle was built and sent out to various areas for tests. The improved mobility was effective immediately, particularly in the EI and DFI terrain, and this, coupled with the relief of the stresses imposed on the previously unprotected front load wheels, indicated that a) a kit should be made available to convert existing vehicles, if desired; and b) all new vehicle designs should incorporate as standard a ramped track feature.

With the limited success of the adoption of the front idler, we then began to consider the whole question of new vehicle design in relation to the following:-

a) The type of track design and ramp angles;
b) The weight distribution;
c) The L/C ratio : steering;
d) The terrain on which the vehicle would operate;
e) The maximum operational speed requirement; and
f) The vehicle suspension.

With the requirement for the development of a new vehicle, which we now call the RN-35, these 6 factors were for the first time considered relative one to the other instead of separate entities. Among these factors was, as noted, the track design and, in particular, the front-ramped angle. In our previous designs, front climbing ability was the basic consideration. Now we were to design a vehicle with more speed and to have greater manoeuverability. We considered the front track ramp angle to be fundamental in the ultimate success of the vehicle and, as a few examples, the following were considered:-

a) If the angle was too large, and the suspension stiff, we would create an abrupt pitch followed by a sudden roll on a one-track abutment approach.

b) If the angle was too large and the suspension too soft, we would create an almost instantaneous pitch and roll motion, sufficient to put the vehicle out of control if the approach speed were large.

c) If, under any condition, the ramp angle was too large, there would be a larger power loss and a larger load imposed on the front load carrying wheels.

d) If the angle was too small, we would create a butting action similar to having no front ramped track and create a severe loading on the non-load bearing front idler assembly.

In our deliberations, the size of load wheels, frame height, suspension and ground clearance were examined and related to the location and position for a front idler. As an optimum, the ramp angle was set at 30° but was modified due to other factors to 26°; the tangent of 26° being approximately equal to the sine of 30°. We therefore obtained a ramp angle that had a projected track area on the ground equal to twice the rise. We concluded that, from a mobility and power point of view, we would obtain optimum performance with the least power requirement. By this means, we also obtained a good front climb ability and, with the suspension matched, we were able to reduce to the lowest degree any excited pitch and roll characteristics. The 26° ramp angle also provided a length of ramped track that would absorb any abrupt force and not materially transmit this force to the front load wheel. With the front ramped track angle at 26°, a more gradual stress build-up was obtained in FI and EI muskeg which in turn reduced the maximum soil stress enabling the vehicle to complete a greater number of passes over the same area. It is our belief that the 26° ramp angle designed specifically for the now designated model RN-35 was a good step forward in vehicle design as it relates to terrain conditions, particularly muskeg. This design figure of 26° and, in general, the entire track, load wheel and suspension characteristics were based on a theoretical evaluation coupled with a good deal of previous experience. To learn more about our theories, last summer and again this year actual field tests have been, and will be, conducted to relate more closely the vehicle and terrain conditions. Some conclusions have already been obtained which are briefly paraphrased as follows:-

1) Maximum effectiveness is gained when the approach idler is unobstructed by over-hanging or forward-protruding vehicle structures which would prevent effective contact for the frontal apex.

2) Although the 26° ramp angle has proven to be very effective from the test results, more quantitative analysis is desirable to ensure the optimum angle.

3) The front ramped track tends to relieve the front load carrying wheel and thereby provides for less soil stress under the actual load bearing points. In effect, a greater track area is brought to bear on the yielding terrain conditions. A greater degree of analysis by electronic equipment would confirm these conclusions.

4) Under forward motion, and particularly noticeable at higher speeds, a dynamic wave is produced. This particular wave phenomenon is thought to produce momentary increased density which tends to offset the higher pressure loadings which increases with each oncoming load bearing wheel.

5) The optimum width of tracks, the degree of flexibility, etc., are other items which are yet to be examined but from the empirical results prove to be quite effective.

These are but a few of the tentative results obtained and we are looking forward to further tests and studies. So important is the relationship between the vehicle and its environmental terrain that vehicles of different sizes and mobility objectives do not necessarily need to have a 26° ramped track as has our RN-35 but rather a separate study should be made to effectively arrive at the optimum conclusion. It needs only to be mentioned at this time that the angle of the front ramped track is only one of many considerations.

In the area of optimum track design, which relate to such items as minimum power losses, mobility and speed, suspension and steering, etc., we have only scratched the surface in our knowledge and understanding of these design parameters, particularly when related to terrain conditions, be they muskeg, sand or snow. It will be in such conferences as this that our knowledge will be increased. This increased knowledge will in turn be reflected in the advancement and sophistication of vehicle designs and their field operations.

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Discussion

Mr. Young asked Mr. Rymes if he could see any other environmental factors to suggest a change in the 26° angle. Mr. Rymes replied that probably density, shear effect, etc., may cause some change. Mr. Brawner wondered if there is any possibility of building machines with a variable angle. Mr. Rymes said that this is a possibility.

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II. 3. HYBRID COMPUTER SIMULATION OF TERRAIN-VEHICLE SYSTEMS

J. R. Radforth*

Abstract:

This report describes a design project initiated at the University of Waterloo in which it is planned to employ a hybrid (digital-analogue) computer to simulate the vertical motion of tracked vehicles travelling over rough muskeg. It is argued that simulation by hybrid computer offers a fast and relatively inexpensive method of checking experimental vehicle designs.

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II. 3. SIMULATION DES MOUVEMENTS D'UN VÉHICULE TERRESTRE À L'AIDE D'UN ORDINATEUR HYBRIDE

J. R. Radforth

Résumé:

L'auteur expose dans ce rapport une méthode élaboree à l'Université de Waterloo, selon laquelle on utiliserait un ordinateur hybride (numérique et analogique) pour simuler les mouvements verticaux de véhicules à chenilles se déplaçant sur le moskeg† raboteux. Il démontre que la simulation par ordinateur fournit un moyen rapide et relativement peu coûteux de vérifier les caractéristiques des modèles de véhicules.

† Orthographe française de "muskeg" (N. du T.)

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* See Appendix "A" for affiliation.

Twenty years ago the problem of traversing muskeg with any type of ground vehicle was poorly defined. Few people had had experience with the operation of vehicles in the Canadian North, where the problem is prevalent, and a simple muskeg classification system was not available for common use. As a result, the characteristics of muskeg and whether all muskeg could be crossed with a vehicle were unknown.

Since then, vehicle manufacturing companies, logging and pulp and paper companies, and oil exploration companies have gained some insight into the problem and have made some progress in solving it. It is now known that some types of muskeg can be crossed by some types of vehicles, even during the summer. With this level of confidence established, another problem has appeared. If two different vehicles with the same payload can cross an area of muskeg, it sometimes happens that one vehicle can do so more easily, or efficiently, or faster than the other. This difference arises from differences in vehicle design which allow one vehicle to accommodate to terrain features better than the other.

The fact that one vehicle is more efficient than another for a given job has important economic implications. Therefore any study that could find some means for improving vehicle efficiency would be worthy of pursuit.

One organic terrain feature which represents an obstacle to vehicle performance is roughness. Muskeg with EFI cover commonly presents a mounding condition on the ground surface (Figure 1). The size of these mounds is quite characteristic, and they can cover a considerable area. When vehicles are confronted with this condition, and are required to travel over it at speeds above approximately 5 mph, it appears that the size, weight, running gear, and suspension characteristics of the vehicle have important effects on the behaviour of the vehicle. Some vehicles are subject to violent pitching motion which, if sustained, can be damaging to the vehicle, its driver, and in some cases, its cargo. On the other hand, other vehicles can cross the same terrain at equal and higher speeds with much less pitching and apparently much less effort.

Another common muskeg surface condition is represented by grass-covered hummocks (Figure 2). These hummocks have almost vertical sides about 12-18 ins. high, have rounded tops, are spaced about 6 to 12 ins. apart and are often firm and unyielding when a load is applied to them. This condition results in a very rough surface for a vehicle to traverse.

The fact that these conditions exist, that some vehicles can accommodate to them better than others, and the assumption that improvement of vehicle operating efficiency is worthwhile, provide sufficient justification for attempting to:

(1) Learn more about vehicle performance on rough ground; and

(2) Use this knowledge to improve the design and rough ground performance efficiency of off-road vehicles.

In an attempt to work towards these objectives, a design project has been initiated at the University of Waterloo in which it is hoped to employ a hybrid (digital-analogue) computer to simulate the vertical motion of tracked vehicles travelling over rough muskeg. The simulation model (Figure 3) to be used will consist of the vehicle mass, dimensions, road wheels, and spring and shock absorber characteristics set up on an analogue computer. A modified terrain profile will then be used as a driving function fed into the vehicle model. The response of the vehicle, representative of the vertical motion and the pitch angle amplitude will be plotted by a chart recorder. The effect of changing vehicle design parameters, such as length, spring constant, number of road wheels, etc., can then be observed and comparison of vehicle designs on an impartial basis will be possible.

It was mentioned earlier that the terrain-vehicle system model would incorporate a modified terrain profile. The data used to obtain the original profile consists of height measurements in inches taken at horizontal intervals of four inches. When a vehicle with a flexible track rests on a rough ground surface, the track does not conform exactly to the original ground profile but tends to bridge small gaps and depress any abrupt mounds if they are the least bit soft.

If one considers the ground surface profile as a random collection of periodic waveforms of various frequencies and amplitudes, then this "smoothing" action of the track has the effect of removing the higher frequency components from the profile.

In the vehicle model under consideration, it is intended to make the simplifying assumption that the road wheels form point contacts on the track which in turn comprises the modified terrain profile. In other words, if one thinks of the vehicle crossing the terrain in terms of the terrain profile moving under a stationary vehicle, then the terrain profile becomes a driving function for each of the point contacts under the vehicle. Moreover, for small amplitudes of this driving function, each point contact experiences the same displacements only at different times. That is, a small bump is transmitted to the first road wheel, a short interval of time passes, and then the same bump is transmitted to the next road wheel, and so on.

The road wheels are linked to the vehicle mass through springs and shock absorbers which will have limited travel. For large amplitudes of the terrain profile, the driving function will be dependent on the speed and moment of inertia of the vehicle. This means that, on large bumps, one end of the track, and therefore one or two road wheels lose contact with the ground. This is undesirable behaviour since the track often regains contact with the ground with considerable force.

This is the type of vehicle behaviour which can easily be observed in the field. It is undesirable behaviour for reasons already discussed. As a result of observing this behaviour, one is inclined to think that, if only some of the vehicle design characteristics could be changed, the vehicle would ride much more smoothly over the rough ground. The problem of what design features should be altered, and how much they should be altered, then arises. To attempt this only with pencil, paper, and intuition might provide a partial solution. A problem, however, with so many parameters and an inadequate theoretical foundation is a most unwieldy one. One tends, therefore, to look for a quick, easy and, if possible, cheap method of educated trial and error. One trial and error approach would be to build vehicle prototypes and test them on actual selected terrain. However, this is expensive and time-consuming on an experimental basis. Also, design characteristics of the vehicle are not amenable to quick change.

Simulation by hybrid computer offers, if it works, a fast and relatively inexpensive method of checking experimental vehicle designs. Changes in design parameters are easy to make,and the resulting effects on vehicle behaviour can be quickly observed and analyzed. Changing a design parameter on the simulation model does not involve replacement or adjustment of a mechanical part as it would on an actual vehicle prototype. There is, therefore, a minimum loss of time, money, and material involved in making a design change. For example, adding an extra road wheel to the vehicle is similar to adding more cards to a deck of computer cards.

It is felt that these reasons provide more than enough justification for investigating the feasibility of simulation models as a tool for vehicle design. Construction of the computer model itself requires design, however, and for this reason, is being undertaken by the author as a design project in the Department of Design at the University of Waterloo. The old proverb that "the proof of the pudding is in the eating" holds true in this case. It will be fascinating to see how much progress can be made in this direction.

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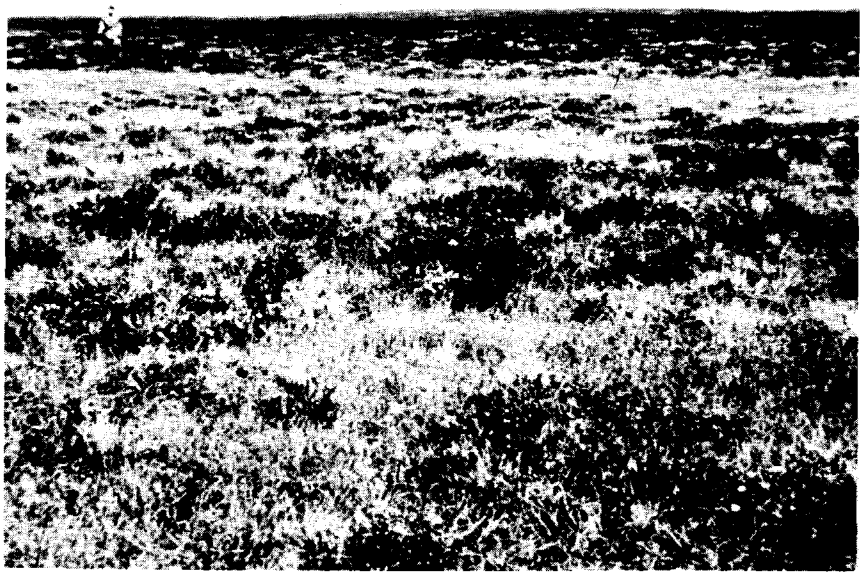

Figure 1. Muskeg with EFI Cover

Figure 2. Grass-covered Hummocks

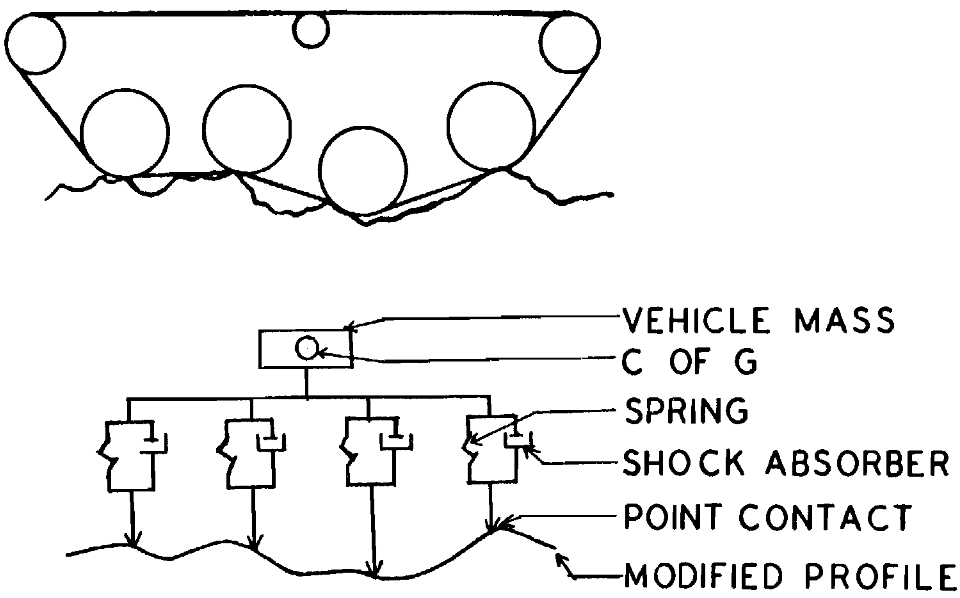

FIGURE 3. SIMULATION MODEL OF VEHICLE

Discussion

Mr. Brawner commented that the application of computer techniques has been adopted in many fields and it is interesting to see this particular application. Mr. Rymes asked if there was any consideration in the computer analysis of differentiation between suspended and unsuspended weight. Mr. Radforth replied that there wasn't as yet. They are starting as simply as possible and will be building complexities such as unsuspended weight into the computer model.

Mr. Schlosser wondered how the terrain model was developed. Mr. Radforth pointed out that the model actually was not fully developed as yet. His report only described an approach, which was purely hypothetical. He was asked if another alternative would not be to build a laboratory model and measure the stresses and strains in the underlying soil. Mr. Radforth agreed that this is one alternative, and in fact this is the approach being applied both in Europe and North America. He feels, however, that the possibility of a computer approach gives more flexibility, allows the vehicle response to be observed, requires less time for parameter changes, and costs less.

Prof. Siddall asked if the ground contour input would be a reproduction of an actual contour, or would it be theoretical. Mr. Radforth stated that it was a reproduction of an actual ground roughness. This gives considerable scope for analyzing measured data and examining them for random characteristics and sinusoidal characteristics. Prof. Siddall asked further if the ground roughness is represented mathematically, to which Mr. Radforth replied that it was.

The question was asked if Mr. Radforth proposed to instrument an actual vehicle and check the response. He answered that this would be the next logical step after attempting to analyze the computer model. This is still well in the future, however, as far as the scope of this particular project is concerned.

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II.4. SOME RESULTS OF SURFACE ROUGHNESS MEASUREMENTS ON MUSKEG

W. R. Newcombe*

Abstract:

The progress on an investigation of the surface roughness of muskeg is reviewed. Profile data has been obtained on several typical types of muskeg as classified by the Radforth classification system. This data was obtained by using a simple datum bar device called a profile height gauge rather than by developing an expensive, automatic measuring system.

A computer analysis of the data was made to determine if specific types of muskeg have repeatable and typical roughness values. The proposed method of expressing roughness as the arithmetical average absolute deviation of the profile from the mean is discussed. Design parameters for a measuring system such as the interval between profile height measurements and sampling lengths are investigated.

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II.4. QUELQUES RÉSULTATS DE MESURES DE LA RUGOSITÉ DU MOSKEG +

W. R. Newcombe

Résumé:

L'auteur passe en revue les progrès qui ont été enregistrés jusqu'ici au cours d'une étude de la rugosite superficielle du moskeg. On a obtenu des données quant au profil de plusieurs types de moskeg mentionnés dans la classification de Radforth. Ces données ont été obtenues à l'aide d'une simple règle de mesurage appelée indicateur de hauteur de profil, et non par l'élaboration d'un dispositif coûteux de mesurage automatique.

On a analysé les données à l'aide d'un ordinateur afin de déterminer si certains types de moskeg ont des valeurs spécifiques réitératives de rugosité. L'auteur expose la méthode qu'il propose pour exprimer la rugosité en tant que valeur absolue de l'écart du profil avec la moyenne arithmétique. Il étudie des paramètres de calcul servant de base à une méthode de mesurage, tel l'intervalle existant entre les mesures de hauteur de profil et les longueurs d'échantillonnage.

+Orthographe française de "muskeg".

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* See Appendix "A" for affiliation.

As well as such mechanical properties as the elasticity and strength of the mat, surface roughness is a property that affects mobility, especially the mobility of small light vehicles. To determine how surface roughness affects mobility, we must be able to measure it and to express it as a number. Although many types of muskeg appear relatively flat, there is a superimposed rather regular roughness, and in some types of muskeg hummocks occur which have a peak to valley height of about 2 ft. These hummocks have a distinct effect on the mobility of most vehicles, and when frozen they are dangerous obstacles to all vehicles.

It is postulated that each type of muskeg as classified by the Radforth System has a characteristic roughness value, and one of the aims of this project is to prove or disprove this assumption.

Several projects have been concerned with the measurement of roughness of inorganic terrain This is sometimes called "stable ground roughness". Generally, muskeg can be considered as unstable ground. Bogdanoff, Cote and Kozin (1963, 1965) and Bogdanoff and Kozin (1964) have measured ground roughness over several stable ground profiles. They have expressed this roughness in terms of ground spectral density, and investigated its effect on the mathematical model of a linear vehicle. Sattinger and Sternick (no date) have developed an instrumentation system for the measurement of terrain profile using wheels in tandem on a trailing arm. Brown (1960) developed an automatic system which measures runway roughness, and automatic systems have been developed for the measurement of roughness of paved highways. These automatic systems are all very expensive, and are not practical for use on ground covered with dense vegetation. No references have been found on the measurement of the surface roughness of muskeg.

Purpose

The purpose of this project is to determine a practical means of measurement of the surface roughness of muskeg, and to determine some of the important design parameters for a measurement system such as sampling length and profile height measurement interval. We also wish to determine if different types of muskeg have characteristic roughness values, and, if possible, to determine an optimum method of expressing this roughness.

Method of Approach

Since the surface finish of metals can be measured directly with a surface roughness meter, it is considered desirable to be able to obtain a direct reading of the surface roughness of muskeg on some type of automatic instrument. As a starting point, we decided that the basic principles of operation of a muskeg roughness meter should be analogous to those of the meter used for metal surfaces. This meter gives a reading in microinches which represents the arithmetical average, or root mean square average, deviation above and below a mean datum line. The roughness of muskeg is about a million times greater, and a muskeg roughness meter would display a roughness reading in inch units. The metallic surface roughness meter uses a stylus which makes a continuous measurement of profile height as it is drawn over a surface. A finite number of profile height measurements will be satisfactory, however, if the profile height measurement interval is small enough. A further discussion of the principles of operation and definition of terms is given in a paper by Newcombe and Radforth (1964).

Our preliminary plans for this project involved the design and manufacture of an automatic meter which would sample some length of a muskeg profile (this length is called the roughness width cut-off), compute a roughness value on a portable analogue type instrument and display this as a direct dial reading. Since such design parameters as sampling length, profile height measurement interval and measurement pressure were unknown, we decided to carry out a preliminary project in an attempt to determine some of these parameters. Furthermore, we wished to determine if this method of measuring and expressing the surface roughness of muskeg gave consistent results for given types of muskeg before building expensive equipment.

A simple yet versatile data collecting device which shall be called a profile height gauge is shown in Figure 1. This device was used to measure roughness height in straight line profiles. Although the length of this device is only about 11 ft, the sampling length can be varied by rotating the horizontal bar about one end stake which is kept fixed in the muskeg, and proceeding to any length of profile in step fashion. Also, the profile height measurement interval and measurement pressure are easily varied.

A programme for obtaining data for a statistical determination of roughness values of the various types of muskeg was designed, and a sample size of 24 variables was selected. A variable consists of an 11-ft length of profile height measurements, and using a 4-in. measurement interval each variable required about 34 profile height measurements. A 4-in. interval between measurements of profile heights was selected as a standard with the aim that results obtained using this 4-in. interval could be compared with roughness figures calculated from the same data, but using an 8-in. or other length of interval.

The 24 variables for a sample were obtained by taking, at random, 8 33-ft lengths of profile measurements (3 11-ft lengths end-to-end in a straight line by stepping the height gauge datum bar) in each area of muskeg that was typical of a certain classification. This procedure will enable various sampling lengths (roughness width cut-off lengths) in a 33-ft range to be compared. For this series of measurements the measurement pressure used was 2 psi. A computer programme has been written which produces the arithmetic average and root mean square average roughness values for each sample.

Results

Tables 1 to 12 show the results of individual roughness calculations for each of the 24 variables in a sample from each of 12 different areas of muskeg. To be rigorous the column called "Sample No." in Tables 1 to 12 should have been called "Variable No."; the sample consisting of these 24 variables. The approximate location of the areas sampled is shown in Figure 2.

The roughness calculation for each variable has been based on about 34 profile height measurements. The actual number of profile height measurements varied between 33 and 35. The arithmetical average roughness is given by the formula:

$$\text{Avg. Roughness} = \frac{y_1 + y_2 + y_3 + \cdots + y_n}{n}$$

The root mean square average roughness is given by:

$$\text{RMS Roughness} = \frac{y_1^2 + y_2^2 + y_3^2 + \cdots + y_n^2}{n}$$

where y = profile height measurement
n = number of measurements

The arithmetic average roughness and root mean square average roughness was calculated for each variable using a measurement interval of 4 in., and also by using every second measurement to give a measurement interval of 8 in. The results of these calculations are compared in Table 13. In general, the percentage variation is so small we can conclude that an 8 in. interval between profile height measurements is quite adequate. Although the percentage variation in the two calculations is nearly 6 per cent in one case, the actual difference in the roughness figure is less than 0.1 in., and this is within the range of probable error in each individual measurement. This same data, however, will probably be used in spectral density analysis, and it may be necessary to maintain a 4 in. interval between profile height measurements.

A typical distribution diagram for the 24 variables used in one roughness calculation is shown in Figure 3.

Figure 4 is a bar diagram showing the results of all roughness calculations based on a 4 in. interval between profile height measurements. Two samples of each of the first four types of muskeg were obtained from different test areas, and these are shown together. A fairly wide range between samples from similar types of muskeg is apparent. The difference between the root mean square average roughness and the arithmetical average varies between 20 per cent and 30 per cent.

Figure 5 shows the arithmetical average roughness of the 8 different muskeg types measured, arranged in ascending order. Where two samples from the same muskeg type were obtained, however, they cover quite a large range on the scale. The difference in roughness values of the first 7 types of muskeg is not great, and it is not possible to confirm the original hypothesis that each different type of muskeg has its own characteristic roughness value. A more definite trend may be evident when more samples from the same type of muskeg are obtained.

A typical profile approximately 11 ft in length of the roughest muskeg sampled is shown in Figure 6. The horizontal and vertical scales are the same. Figure 7 shows a typical profile of the smoothest muskeg sampled drawn to the same scale.

When the design of an automatic measuring system was under consideration, it was thought that a sampling length of 20 ft might give an approximation of the roughness value in one measurement. With the data obtained it has been possible to investigate the effect of sampling length on the roughness value obtained.

The roughest and smoothest types of muskeg measured were selected and the 10, 20 and 30 ft sampling lengths that had the greatest variation from the mean were compared with the result obtained by averaging 24 10-ft sampling lengths. The variation from the mean is expressed in per cent for each sampling length in Table 14.

Conclusions

The average roughness for all types of muskeg appears to be quite variable and, considering the data obtained, it appears that each type of muskeg does not have a typical roughness value. Because of this variability, statistical methods are definitely necessary if representative roughness values are to be obtained.

An 8 in. interval between profile height measurements is equally as suitable as a 4 in. interval for obtaining average roughness values.

If an accuracy of better than 20 per cent is required, then the sampling length for a single measurement made to obtain an average roughness value must be in excess of 30 ft.

The arithmetical average or root mean square average is a practical and descriptive term for expressing roughness, and it is an expression that is easily understood. If, however, the roughness property is to be included in vehicle suspension design, it will probably be necessary to express roughness in terms of spectral density which accounts for the frequencies of the non-periodic roughness function and the extent to which each frequency contributes to the roughness function. The same data can be used to calculate spectral density.

Practical applications of the quantitative values of the roughness property are few at present, but as our design methods become more sophisticated because of the use of the computer, it will be useful to have quantitative values for terrain roughness. In the meantime, the measurement of this property will add to our overall understanding of the nature of muskeg.

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TABLE 1

TEST AREA	COVER TYPE	SAMPLE NO	AVG ROUGHNESS		RMS ROUGHNESS	
			4	8	4	8
1(A)	FI SOME F	1	3.46	3.36	4.17	4.30
		2	2.56	2.54	3.21	3.13
		3	2.55	2.58	2.92	2.99
		4	2.49	2.42	2.71	2.62
		5	2.68	2.65	2.33	2.39
		6	3.70	3.61	4.16	4.33
		7	3.06	3.15	3.74	3.44
		8	2.47	2.76	3.12	3.19
		9	3.19	2.93	3.56	3.39
		10	3.17	3.21	3.74	3.76
		11	2.92	3.18	3.43	3.78
		12	3.16	3.20	3.76	3.79
		13	3.66	3.81	4.49	4.51
		14	4.10	4.10	4.61	4.59
		15	3.33	3.50	3.94	4.08
		16	3.43	2.77	4.15	3.49
		17	3.40	3.49	3.97	3.79
		18	1.92	1.72	2.29	2.05
		19	4.28	4.37	4.88	4.84
		20	3.41	3.38	3.99	4.02
		21	2.87	2.84	3.79	3.67
		22	4.00	3.85	4.55	4.41
		23	3.12	3.27	3.61	3.70
		24	3.28	3.12	4.11	3.82
AVERAGE OF COLUMN			3.176	3.159	3.771	3.729
STANDARD DEVIATION			0.563	0.585	0.631	0.653
PROBABLE ERROR IN MEAN			0.078	0.081	0.087	0.090

TABLE 2

TEST AREA	COVER TYPE	SAMPLE NO	AVG ROUGHNESS		RMS ROUGHNESS	
			4	8	4	8
1(B)	FI SOME E	1	1.84	1.81	2.15	2.13
		2	1.11	1.08	1.36	1.28
		3	3.52	3.47	4.25	4.29
		4	0.83	0.88	0.96	0.98
		5	1.48	1.32	2.08	1.98
		6	3.62	3.71	4.13	4.22
		7	1.10	0.95	1.44	1.28
		8	1.42	1.17	1.71	1.43
		9	1.39	1.32	1.62	1.50
		10	1.08	1.31	1.46	1.70
		11	0.76	0.83	1.08	1.21
		12	1.03	0.92	1.30	1.25
		13	0.98	0.79	1.18	0.97
		14	0.93	0.97	1.04	1.17
		15	0.84	0.81	1.03	1.10
		16	0.39	0.36	0.53	0.51
		17	1.56	1.59	1.74	1.75
		18	0.87	0.82	0.78	0.95
		19	1.75	2.02	2.07	2.26
		20	1.87	1.98	2.16	2.24
		21	1.21	1.24	1.55	1.61
		22	2.43	2.35	1.03	2.04
		23	1.52	1.53	1.87	1.89
		24	1.49	1.33	2.07	1.76
AVERAGE OF COLUMN			1.459	1.441	1.735	1.763
STANDARD DEVIATION			0.785	0.809	0.915	0.931
PROBABLE ERROR IN MEAN			0.108	0.111	0.126	0.126

TABLE 3

TEST AREA	COVER TYPE	SAMPLE NO	AVG ROUGHNESS		RMS ROUGHNESS	
			4	8	4	8
2	FF1	1	1.10	1.07	1.30	1.16
		2	1.47	1.43	1.79	1.73
		3	0.64	0.56	0.89	0.75
		4	0.73	0.69	0.92	0.92
		5	1.05	1.06	1.28	1.21
		6	1.71	1.73	2.25	2.33
		7	0.93	0.84	1.13	1.03
		8	1.81	1.36	2.24	1.69
		9	1.63	1.31	1.95	1.60
		10	0.69	0.84	1.11	1.07
		11	1.15	1.04	1.41	1.30
		12	3.08	2.94	4.15	4.05
		13	2.20	2.49	2.75	2.89
		14	2.49	2.40	2.88	2.90
		15	2.13	2.28	2.65	2.68
		16	2.54	2.43	3.03	2.95
		17	2.25	2.07	2.63	2.51
		18	2.15	2.23	2.44	2.48
		19	1.35	1.38	1.75	1.75
		20	1.47	1.44	1.71	1.70
		21	1.42	1.36	1.74	1.63
		22	2.79	2.84	3.23	3.28
		23	1.71	1.69	2.10	2.19
		24	1.02	0.95	1.25	1.19
AVERAGE OF COLUMN			1.655	1.601	2.024	1.958
STANDARD DEVIATION			0.676	0.699	0.828	0.861
PROBABLE ERROR IN MEAN			0.093	0.096	0.114	0.118

TABLE 4

TEST AREA	COVER TYPE	SAMPLE NO	AVG ROUGHNESS		RMS ROUGHNESS	
			4	8	4	8
9(A)	FE1	1	1.12	1.06	1.47	1.31
		2	1.35	1.33	2.12	2.05
		3	2.18	2.23	2.65	2.74
		4	0.83	1.03	1.04	1.26
		5	0.93	0.76	1.26	1.09
		6	0.78	0.75	0.96	0.96
		7	1.15	1.32	1.40	1.60
		8	1.51	1.43	2.14	2.13
		9	0.63	0.51	0.78	0.69
		10	0.93	0.73	1.21	1.01
		11	0.89	0.90	1.03	1.02
		12	1.36	1.31	1.76	1.68
		13	1.15	1.37	1.38	1.59
		14	0.96	1.09	1.29	1.37
		15	0.96	0.92	1.29	1.27
		16	2.43	2.33	3.00	2.91
		17	2.12	1.62	2.96	2.49
		18	0.74	0.78	0.88	0.89
		19	1.50	1.51	1.93	1.97
		20	1.88	1.92	2.54	2.62
		21	1.33	1.44	1.57	1.70
		22	1.11	1.05	1.47	1.31
		23	1.18	1.38	1.78	2.19
		24	2.14	2.23	2.59	2.74
AVERAGE OF COLUMN			1.297	1.292	1.687	1.692
STANDARD DEVIATION			0.507	0.499	0.663	0.662
PROBABLE ERROR IN MEAN			0.070	0.069	0.091	0.091

TABLE 5

TEST AREA	COVER TYPE	SAMPLE NO	AVG ROUGHNESS 4	AVG ROUGHNESS 8	RMS ROUGHNESS 4	RMS ROUGHNESS 8
VIHI	DEI	1	1.00	0.97	1.23	1.25
		2	1.10	1.18	1.28	1.37
		3	1.56	1.77	2.03	2.23
		4	2.24	2.31	2.81	2.91
		5	1.62	1.60	2.19	1.96
		6	1.75	1.89	2.41	2.10
		7	1.13	1.41	1.46	1.78
		8	2.07	2.66	3.15	3.34
		9	2.27	2.51	2.76	2.99
		10	1.43	1.45	1.87	1.90
		11	2.58	2.83	3.24	3.54
		12	2.30	2.29	2.51	2.53
		13	1.27	1.17	1.68	1.89
		14	2.24	2.09	2.54	2.36
		15	1.28	1.24	1.59	1.47
		16	1.94	1.94	2.45	2.38
		17	1.32	1.53	1.59	1.81
		18	0.99	0.99	1.18	1.15
		19	1.06	1.21	1.44	1.59
		20	1.54	1.45	1.89	1.84
		21	1.04	0.89	1.25	1.14
		22	0.72	0.77	0.86	0.94
		23	1.27	1.17	1.49	1.40
		24	0.80	0.75	0.93	0.89
AVERAGE OF COLUMN			1.562	1.595	1.918	1.951
STANDARD DEVIATION			0.580	0.603	0.707	0.710
PROBABLE ERROR IN MEAN			0.080	0.083	0.097	0.101

TABLE 6

TEST AREA	COVER TYPE	SAMPLE NO	AVG ROUGHNESS 4	AVG ROUGHNESS 8	RMS ROUGHNESS 4	RMS ROUGHNESS 8
VICI	OI	1	1.53	1.41	1.78	1.74
		2	1.70	1.71	2.10	2.13
		3	1.23	1.17	1.70	1.91
		4	0.91	0.92	1.07	1.05
		5	1.27	1.18	1.47	1.36
		6	0.99	1.12	1.30	1.48
		7	1.92	1.96	2.35	2.35
		8	2.14	2.16	2.70	2.84
		9	2.10	1.79	2.62	2.10
		10	1.42	1.45	1.66	1.70
		11	2.26	2.20	2.65	2.62
		12	1.24	1.23	1.67	1.75
		13	0.90	0.78	1.18	1.06
		14	1.27	1.48	2.00	2.17
		15	1.59	1.36	2.29	1.84
		16	1.47	1.67	1.93	2.16
		17	1.96	2.00	2.51	2.73
		18	1.91	1.78	2.38	2.20
		19	1.47	1.74	1.91	2.01
		20	2.87	2.75	3.31	3.28
		21	1.24	1.34	1.52	1.55
		22	0.87	0.79	1.07	0.95
		23	0.81	0.95	1.16	1.25
		24	1.55	1.93	2.04	2.28
AVERAGE OF COLUMN			1.533	1.546	1.936	1.938
STANDARD DEVIATION			0.502	0.487	0.602	0.593
PROBABLE ERROR IN MEAN			0.069	0.067	0.083	0.082

TABLE 7

TEST AREA	CØVER TYPE	SAMPLE NØ	AVG RØUGHNESS		RMS RØUGHNESS	
			4	8	4	8
9(D)	BEI					
		1	1.81	1.78	2.58	2.58
		2	1.83	1.94	2.28	2.45
		3	1.87	1.87	2.31	2.23
		4	1.19	1.27	1.32	1.41
		5	1.69	1.53	2.19	2.18
		6	1.99	1.85	2.55	2.28
		7	1.04	1.16	1.30	1.42
		8	1.15	1.38	1.39	1.59
		9	1.67	1.69	2.34	2.25
		10	0.52	0.57	0.69	0.72
		11	0.99	0.98	1.12	1.12
		12	1.24	1.18	1.55	1.51
		13	1.99	2.11	2.57	2.66
		14	2.07	2.23	2.31	2.42
		15	1.42	1.32	1.79	1.72
		16	1.15	1.04	1.54	1.35
		17	0.85	0.71	1.07	1.00
		18	0.89	0.89	1.10	1.14
		19	0.83	0.96	0.96	1.06
		20	0.79	0.85	0.98	1.04
		21	1.40	1.38	1.72	1.66
		22	1.31	1.33	1.68	1.65
		23	2.03	2.05	2.42	2.37
		24	1.02	1.00	1.36	1.39
AVERAGE ØF CØLUMN			1.364	1.378	1.714	1.717
STANDARD DEVIATIØN			0.462	0.470	0.599	0.581
PRØBABLE ERRØR IN MEAN			0.064	0.065	0.082	0.080

TABLE 8

TEST AREA	CØVER TYPE	SAMPLE NØ	AVG RØUGHNESS		RMS RØUGHNESS	
			4	8	4	8
9(C)	FI SØME E					
		1	0.73	0.84	0.98	1.09
		2	1.09	1.11	1.51	1.60
		3	0.59	0.59	0.72	0.70
		4	0.68	0.70	0.77	0.79
		5	0.66	0.72	0.86	0.95
		6	1.17	1.14	1.45	1.49
		7	0.89	0.93	1.18	1.22
		8	0.83	0.87	1.00	1.07
		9	1.46	1.64	1.71	1.89
		10	0.75	0.75	1.07	1.04
		11	0.60	0.63	0.80	0.82
		12	1.15	1.09	1.50	1.50
		13	0.77	0.88	0.97	1.10
		14	1.16	1.16	1.39	1.45
		15	0.94	0.93	1.08	1.10
		16	0.52	0.63	0.74	0.85
		17	1.15	1.29	1.57	1.68
		18	0.90	0.93	1.07	1.08
		19	0.97	1.01	1.11	1.16
		20	0.73	0.80	0.89	0.93
		21	0.71	0.61	0.90	0.83
		22	1.22	1.31	1.43	1.53
		23	0.76	0.73	0.96	1.04
		24	1.14	1.37	1.37	1.63
AVERAGE ØF CØLUMN			0.899	0.944	1.127	1.191
STANDARD DEVIATIØN			0.244	0.275	0.294	0.327
PRØBABLE ERRØR IN MEAN			0.034	0.038	0.041	0.045

TABLE 9

TEST AREA	COVER TYPE	SAMPLE NO	AVG ROUGHNESS		RMS ROUGHNESS	
			4	8	4	8
65-1A	EF1	1	1.00	0.87	1.23	1.08
		2	0.89	0.95	1.27	1.38
		3	0.85	0.95	1.04	1.15
		4	1.36	1.13	1.74	1.34
		5	0.89	0.95	1.09	1.13
		6	1.50	1.35	1.86	1.58
		7	1.06	1.25	1.31	1.50
		8	0.88	0.75	1.12	0.99
		9	1.15	1.09	1.38	1.29
		10	1.20	1.25	1.44	1.50
		11	0.83	1.03	1.06	1.26
		12	0.86	1.11	1.13	1.39
		13	0.82	0.91	1.11	1.30
		14	1.17	1.26	1.39	1.40
		15	0.92	0.97	1.27	1.40
		16	1.29	1.20	1.65	1.46
		17	1.10	0.92	1.46	1.27
		18	1.22	0.99	1.59	1.29
		19	0.94	0.92	1.20	1.12
		20	0.93	1.00	1.19	1.30
		21	0.71	0.60	0.89	0.70
		22	2.07	1.93	2.58	2.32
		23	0.98	1.08	1.23	1.37
		24	1.36	1.34	1.70	1.74
AVERAGE OF COLUMN			1.082	1.075	1.372	1.344
STANDARD DEVIATION			0.293	0.257	0.357	0.295
PROBABLE ERROR IN MEAN			0.040	0.035	0.049	0.041

TABLE 10

TEST AREA	COVER TYPE	SAMPLE NO	AVG ROUGHNESS		RMS ROUGHNESS	
			4	8	4	8
65-1B	D1	1	2.58	2.59	3.07	3.05
		2	1.88	1.89	2.08	2.10
		3	1.14	0.93	1.45	1.15
		4	1.04	1.00	1.36	1.34
		5	1.37	1.53	1.92	2.17
		6	1.68	1.54	2.29	2.20
		7	2.54	2.46	3.05	2.91
		8	1.64	1.92	1.91	2.14
		9	2.71	3.00	3.21	3.47
		10	0.95	1.00	1.15	1.17
		11	1.29	1.26	1.51	1.53
		12	3.21	3.21	3.69	3.73
		13	2.35	2.42	2.85	2.90
		14	2.31	2.12	2.96	2.81
		15	1.94	2.08	2.52	2.55
		16	1.02	0.97	1.23	1.22
		17	0.94	0.85	1.35	1.32
		18	1.88	1.67	2.31	1.94
		19	1.39	1.56	1.81	1.87
		20	2.19	1.98	3.08	2.73
		21	1.29	1.12	1.54	1.38
		22	1.52	1.35	1.62	1.71
		23	0.92	1.10	1.24	1.52
		24	2.14	2.18	2.49	2.48
AVERAGE OF COLUMN			1.747	1.739	2.163	2.141
STANDARD DEVIATION			0.645	0.672	0.752	0.754
PROBABLE ERROR IN MEAN			0.089	0.093	0.104	0.104

TABLE 11

TEST AREA	COVER TYPE	SAMPLE NO	AVG. ROUGHNESS		RMS ROUGHNESS	
			4	8	4	8
65-2(A)	F1					
		1	1.12	1.10	1.44	1.51
		2	0.76	0.69	0.72	0.86
		3	0.44	0.75	1.32	1.17
		4	0.48	0.95	1.22	1.29
		5	0.75	0.96	1.17	1.13
		6	0.44	0.89	0.76	1.06
		7	1.21	1.49	1.48	1.78
		8	1.20	1.24	1.58	1.63
		9	1.50	1.34	1.82	1.74
		10	1.19	1.60	1.46	1.26
		11	1.01	1.02	1.27	1.30
		12	0.89	0.90	1.09	1.17
		13	1.01	1.04	1.27	1.28
		14	1.11	2.08	2.41	2.68
		15	0.70	0.92	0.94	1.13
		16	0.79	1.02	1.18	1.25
		17	0.90	0.94	1.17	1.18
		18	1.28	1.12	1.52	1.28
		19	1.10	0.98	1.28	1.11
		20	1.24	1.33	1.47	1.56
		21	1.37	1.22	1.90	1.59
		22	0.90	0.68	1.09	1.08
		23	1.15	1.03	1.46	1.29
		24	0.74	0.61	0.93	0.67
AVERAGE OF COLUMN			1.073	1.067	1.349	1.332
STANDARD DEVIATION			0.268	0.233	0.346	0.387
PROBABLE ERROR IN MEAN			0.037	0.040	0.048	0.053

TABLE 12

TEST AREA	COVER TYPE	SAMPLE NO	AVG. ROUGHNESS		RMS ROUGHNESS	
			4	6	4	6
65-2(B)	F1					
		1	0.57	0.52	0.76	0.70
		2	0.71	0.70	0.83	0.81
		3	0.68	0.80	0.88	0.98
		4	1.53	1.53	1.77	1.74
		5	0.95	0.97	1.27	1.41
		6	1.00	1.01	1.24	1.12
		7	2.25	2.13	2.50	2.41
		8	1.39	1.43	1.74	1.70
		9	1.51	1.55	1.94	1.82
		10	1.94	1.73	2.24	2.04
		11	1.57	1.60	1.98	1.99
		12	1.68	1.81	2.17	2.38
		13	0.99	1.02	1.31	1.34
		14	1.45	1.60	1.77	1.92
		15	1.50	1.52	1.89	1.73
		16	0.74	0.79	0.84	0.88
		17	1.30	1.27	1.54	1.48
		18	1.01	1.10	1.26	1.39
		19	1.38	1.32	1.57	1.58
		20	1.56	1.36	2.19	1.86
		21	0.72	1.08	1.16	1.30
		22	1.47	1.41	1.71	1.86
		23	1.61	1.76	2.02	2.23
		24	1.55	1.01	1.73	1.34
AVERAGE OF COLUMN			1.333	1.292	1.614	1.593
STANDARD DEVIATION			0.420	0.378	0.499	0.481
PROBABLE ERROR IN MEAN			0.058	0.055	0.069	0.066

TABLE 13

SAMPLE TEST AREA	ARITHMETICAL AVERAGE ROUGHNESS		% VARIATION	ROOT MEAN SQUARE AVERAGE ROUGHNESS		% VARIATION
	4" INT.	8" INT.		4" INT.	8" INT.	
1A	3.176	3.159	0.5	3.771	3.729	1.1
1B	1.459	1.441	1.2	1.795	1.783	0.7
2	1.655	1.601	3.4	2.024	1.958	3.4
9A	1.297	1.292	0.4	1.687	1.692	0.3
9B	1.562	1.595	2.1	1.918	1.951	1.7
9C	1.533	1.546	0.8	1.936	1.938	0.1
9D	1.364	1.378	1.0	1.714	1.717	0.2
9E	0.899	0.944	5.0	1.127	1.191	5.7
65-1A	1.082	1.075	0.7	1.372	1.344	2.1
65-1B	1.747	1.739	0.5	2.163	2.141	1.0
65-2A	1.073	1.067	0.6	1.349	1.332	1.3
65-2B	1.303	1.292	0.9	1.614	1.593	1.3

TABLE 14

EFFECT OF SAMPLING LENGTH
ON ROUGHNESS VALUE OBTAINED
BY A SINGLE MEASUREMENT

SAMPLING LENGTH	VARIATION FROM CALCULATED AVERAGE	
	SMOOTHEST MUSKEG MEASURED	ROUGHEST MUSKEG MEASURED
10'	62%	40%
20'	34%	22%
30'	18%	16%

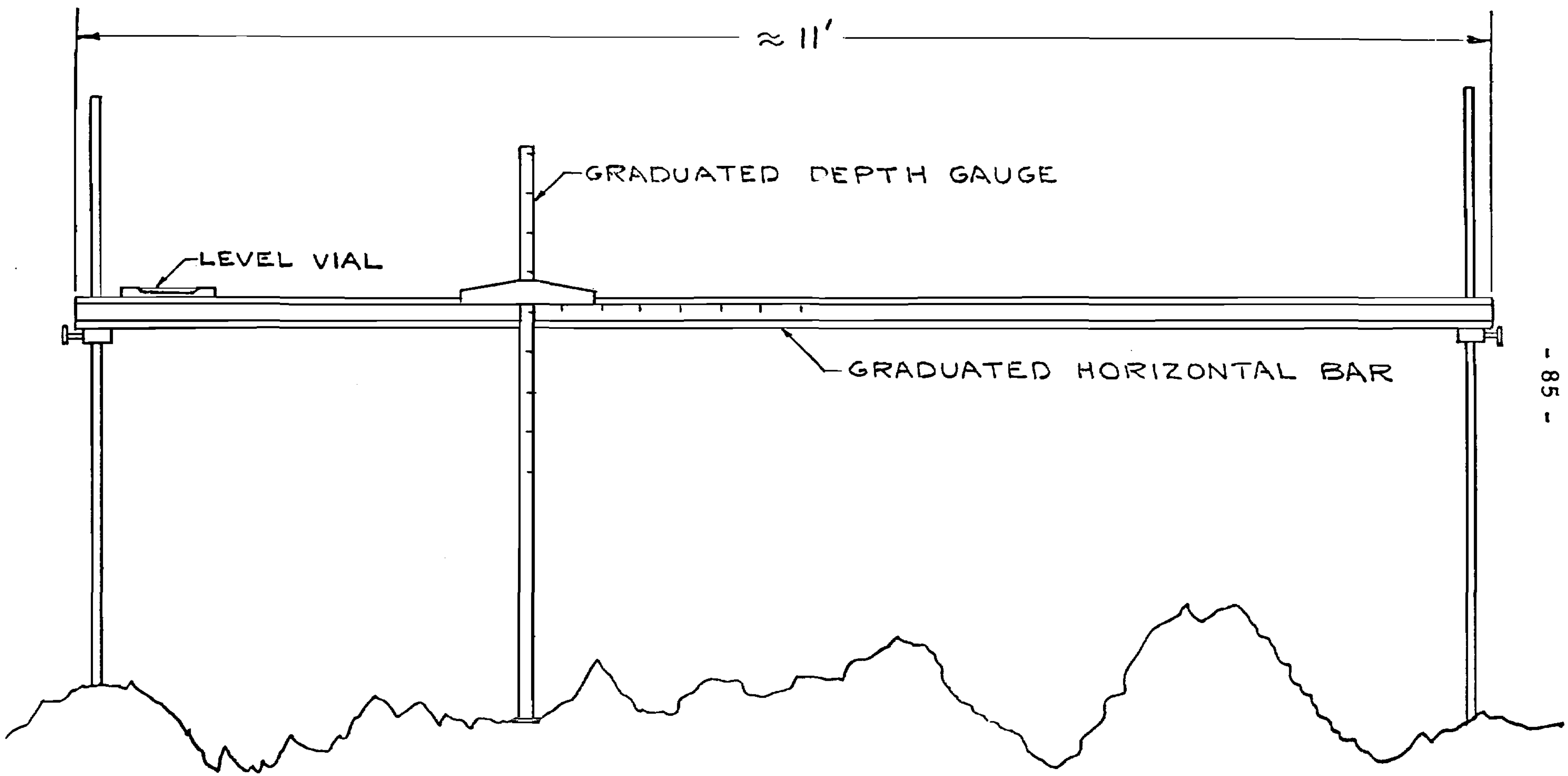
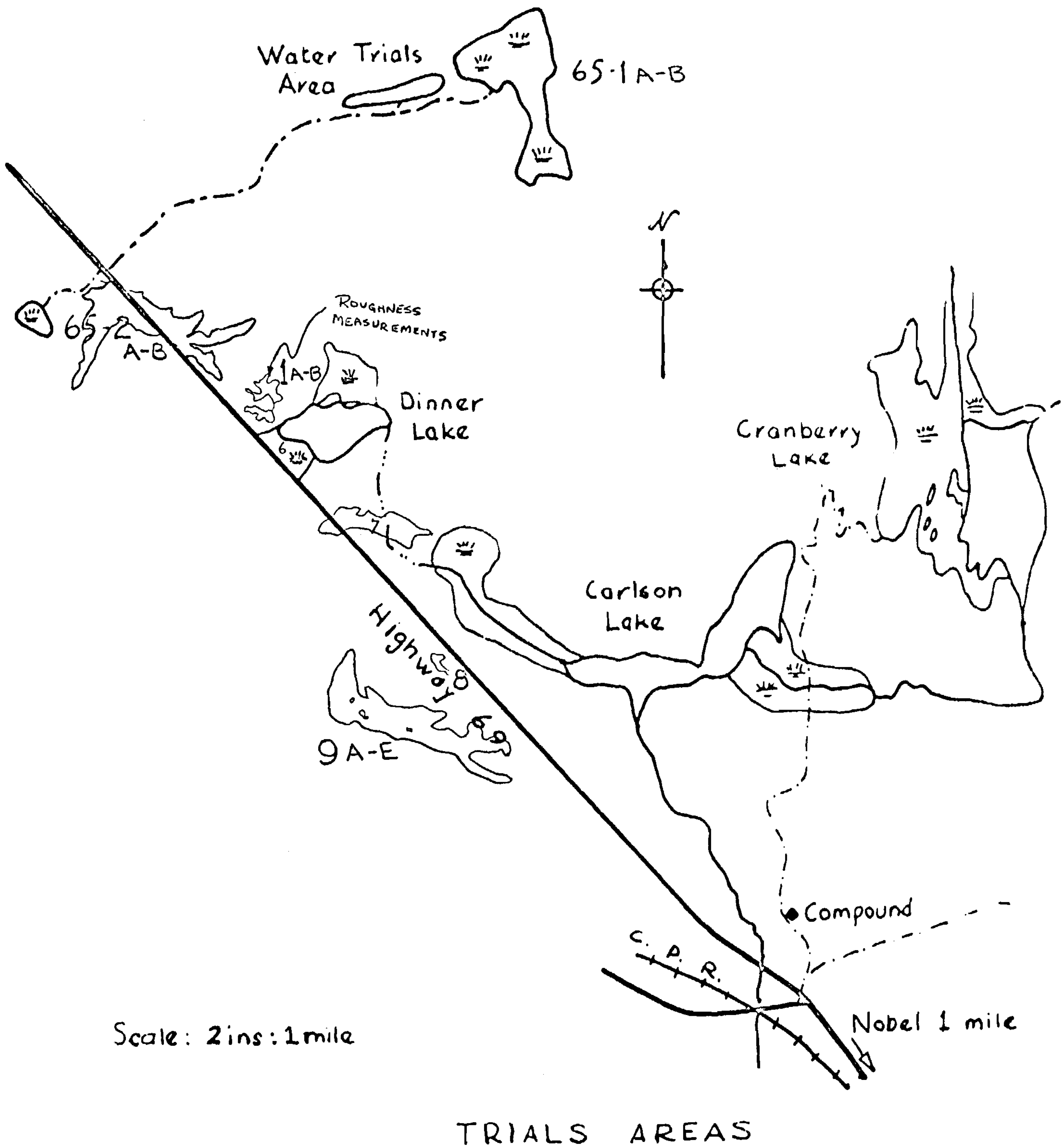
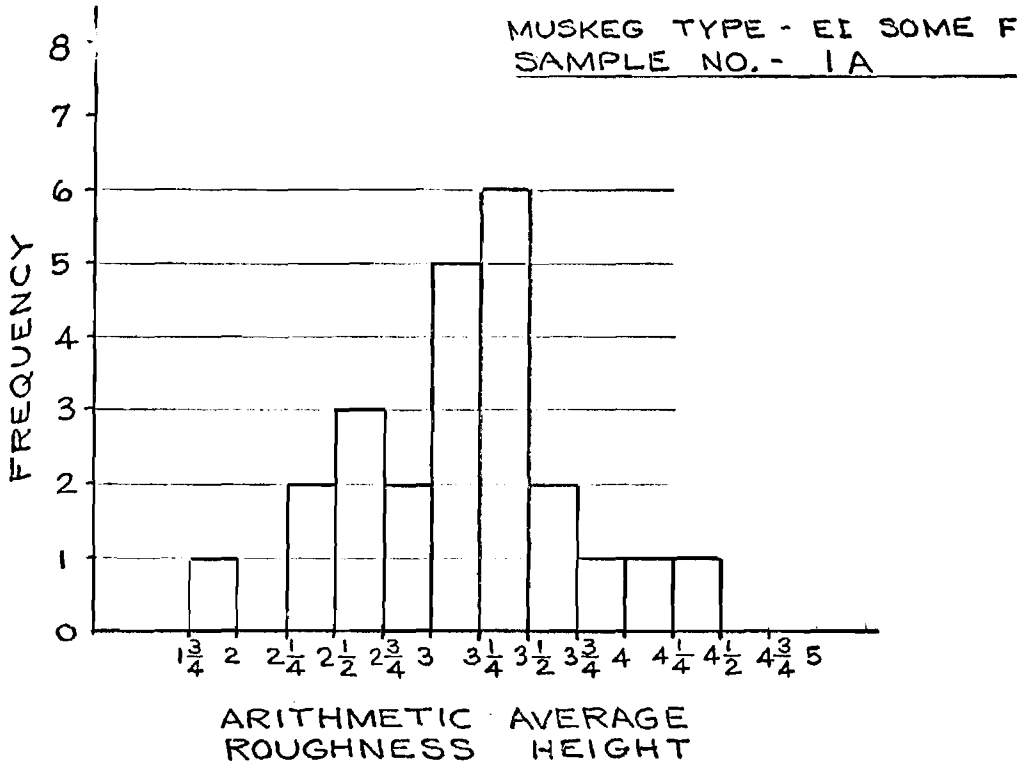


FIG. 1. PRELIMINARY DEVICE FOR OBTAINING SURFACE ROUGHNESS DATA ON MUSKEG



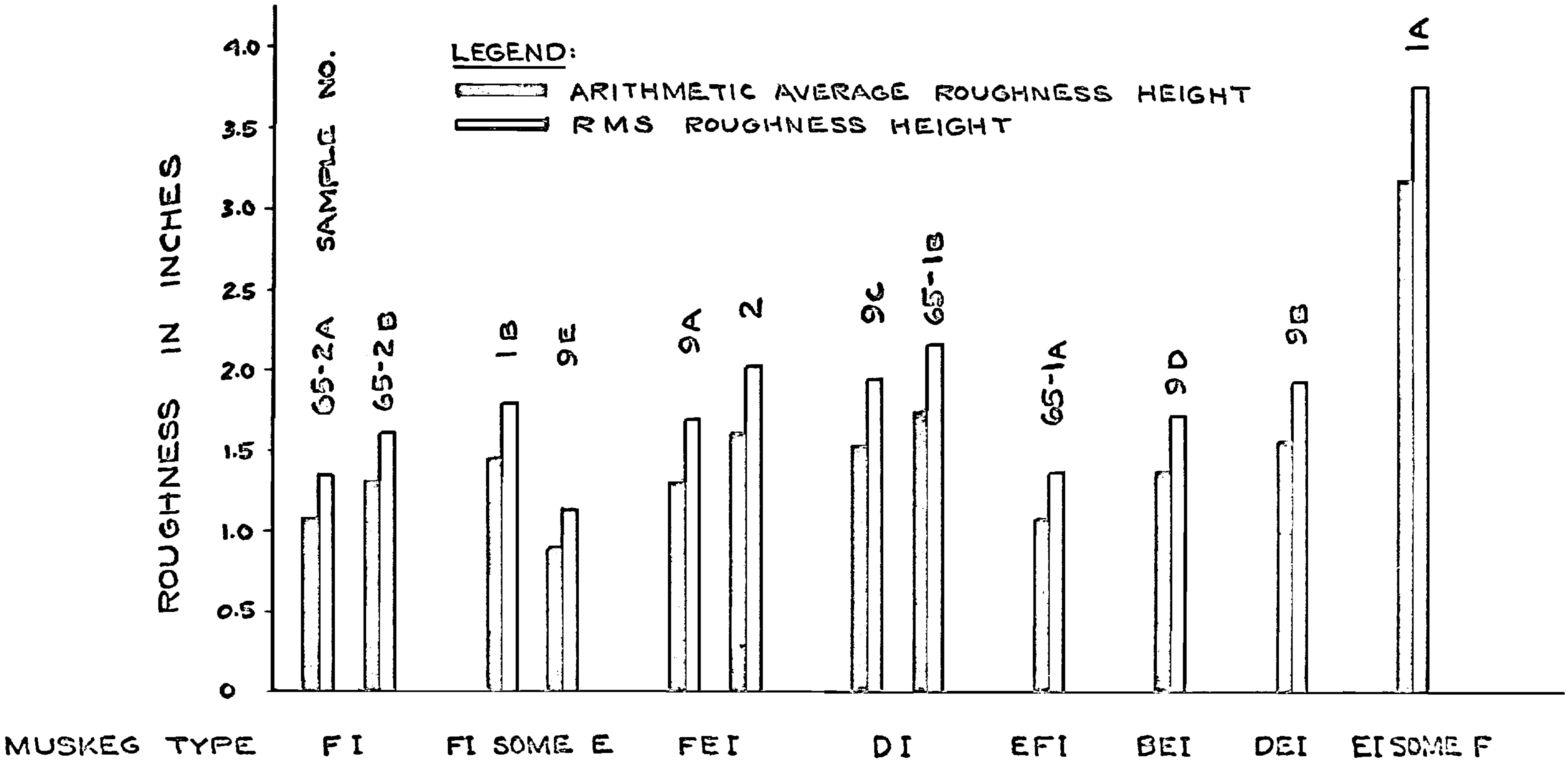
TRIALS AREAS

FIGURE 2



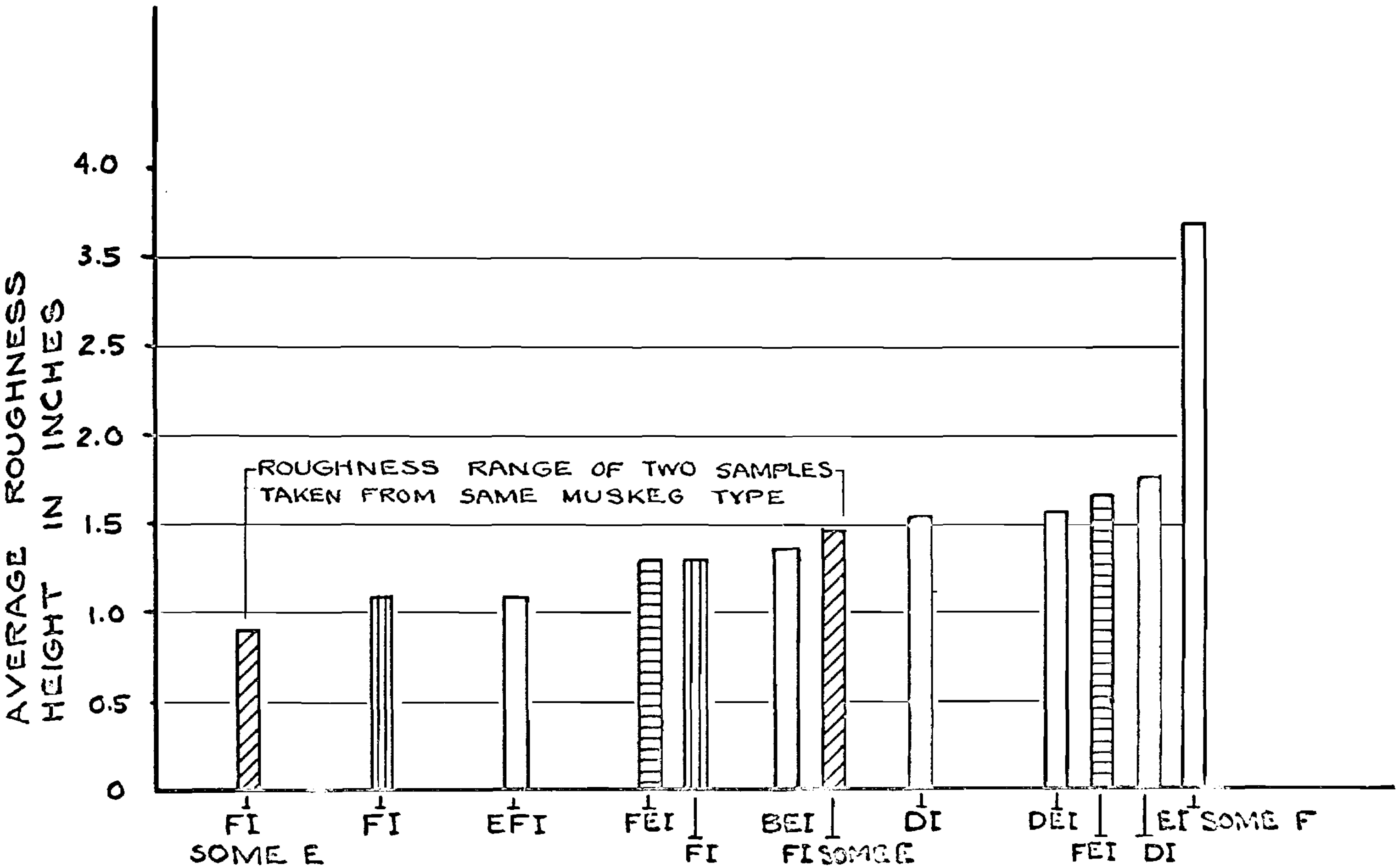
TYPICAL DISTRIBUTION DIAGRAM

FIGURE 3



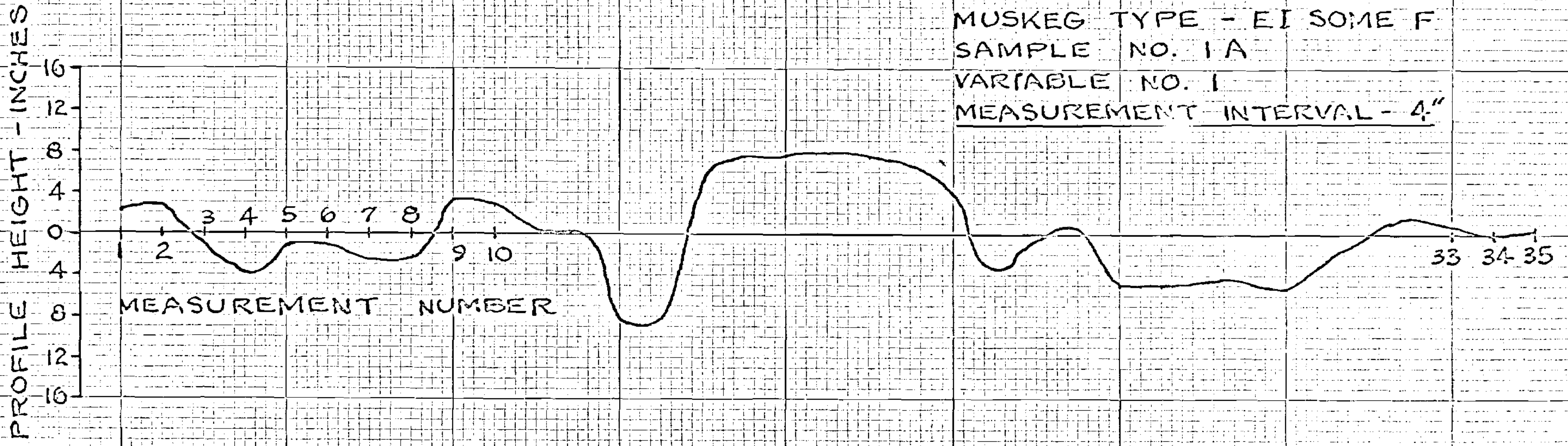
ARITHMETIC AVERAGE AND ROOT MEAN SQUARE ROUGHNESS HEIGHT OF SAMPLES FROM VARIOUS MUSKEG TYPES.

FIGURE 4



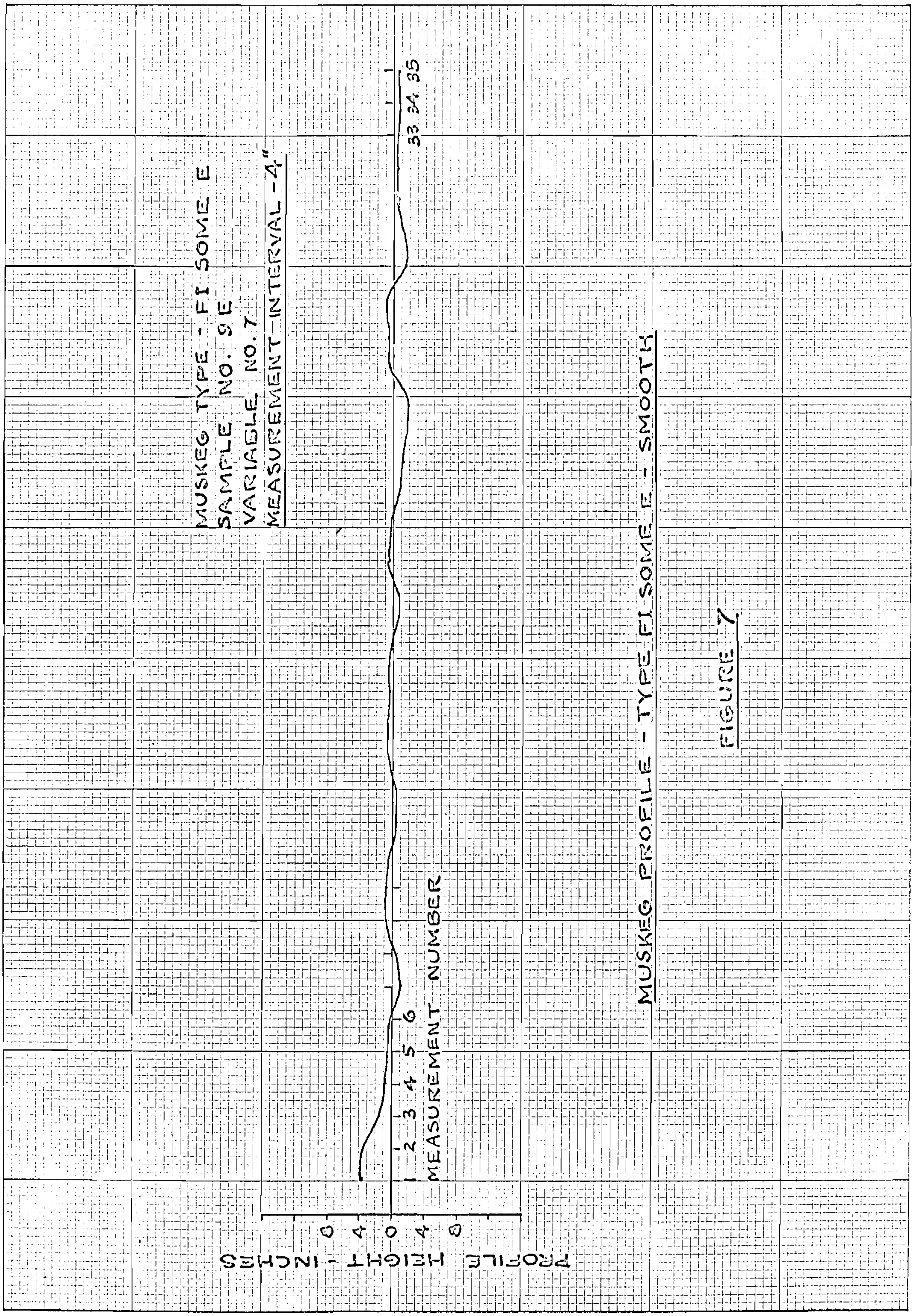
ROUGHNESS OF VARIOUS TYPES OF MUSKEG ARRANGED IN ASCENDING ORDER

FIGURE 5



MUSKEG PROFILE - TYPE EI SOME F
ROUGH

FIGURE 6



MUSKEG PROFILE - TYPE FI SOME E - SMOOTH

FIGURE 7

Discussion

Mr. Tessier wondered how the mean line was selected. Prof. Newcombe replied that the average of all the heights gave the mean line. The question was raised of the effect of the slope of the ground over a long distance, using a level rod. Prof. Newcombe admitted that there would be a slope effect, but so far his measurements have been carried out in level muskeg areas with no inclination or slope whatever.

Dr. Radforth noted that the maximum roughness was in EI type muskeg, containing some F. He wondered to what extent Prof. Newcombe could predict that one would always find the maximum roughness in this type of muskeg. This roughness is characteristic for this type of muskeg, which occurs with high frequency in some areas of Canada. Consequently, the question is of considerable significance. Prof. Newcombe replied that, from the limited number of samples, it would be difficult to predict and to say that this type of muskeg will always have the maximum roughness. Prof. Siddall commented that if a consistent histogram can be given for all the EI everywhere, then one can only give a probability as a prediction. Prof. Newcombe agreed, stating that at the present time there is no such consistency. It will be necessary for him to go on to the next step of examining many areas of EI and to work up a new analysis. The question was asked as to whether there was any consistency within the area investigated. Prof. Newcombe replied that there wasn't, as he had not really done sufficient work yet for this to be indicated. He has only taken 12 samples, 8 of which are from different muskeg types.

Mr. Schlosser wondered at what time of year the measurements were taken, to which Prof. Newcombe replied that they were taken in the Spring. Mr. Schlosser asked further if there was any appreciable difference in the measurements in June and July as compared to August and September. In the former period one might encounter ice; in the latter period there would be no ice. Prof. Newcombe said that he did not think there was any difference. Dr. Radforth remarked that this was a very good question and thought that there would be some difference. As the ice knolls freeze in the mounds, we get a greater amplitude. It is more useful, however, to find out if EI always designates the maximum degree of roughness. Then, if we do get ice knolls on top of this, we can be assured that in certain seasons we have a very rugged terrain indeed.

Mr. Hemstock congratulated both Prof. Newcombe and John Radforth on their very basic and fundamental research. He said that it makes him optimistic of the future. These approaches will eventually assist in the design of the undercarriage of vehicles. The techniques which have been described will eventually enable us to go out and measure the roughness of an unprepared landing field, for instance, and come up with numbers for the pilot. Also, it has application even in the case of winter roads and the design of suspension systems for wheeled vehicles using these roads.

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SESSION III: ACCESS; EXPLOITATION

III. 1. HIGHWAY CONSTRUCTION THROUGH MUSKEG AREAS IN NORTHERN ALBERTA

R. H. Cronkhite*

Abstract:

This paper is in the form of case histories indicating the construction practices and considerations employed in muskeg areas. Muskeg still remains an obstacle to avoid if practical alternatives are available. It is suggested that extensive investigation of muskeg be carried out before adopting a road alignment over it or carrying out a highway design. The greater the depth of muskeg, the greater the possibility of failure. Designers and estimators must anticipate failure to the extent that reasonable provision is made for alternatives to the original design and construction methods. As the muskeg depth increases, the rate of loading must be decreased and stage scheduling has proved advantageous in many instances.

Major highway construction can economically take advantage of the well known support value of muskeg during the frozen period. Modern construction equipment, which can economically rip out the frozen overburden, haul, compact, and slope grade embankment rapidly, is available and, when operated in controlled spreads, can produce stable grades through muskeg areas.

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III. 1. CONSTRUCTION DE ROUTES DANS LE NORD DE L'ALBERTA À TRAVERS DES RÉGIONS DE MOSKEG†

R. H. Cronkhite

Résumé:

L'auteur expose dans cet article divers cas de construction de routes dans des régions de moskeg, et il décrit les méthodes auxquelles on a recouru et les considérations qui ont guidé les travaux. Le moskeg demeure toujours un obstacle qu'il est preférable de contourner lors-

†Orthographe francaise de "muskeg" (N. du T.)

* See Appendix "A" for affiliation.

qu'il existe d'autres solutions pratiques. L'auteur est d'avis que l'on devrait réaliser une étude poussée des aires de moskeg en cause avant d'établir un tracé de route y passant ou avant de procéder à la réalisation d'une route. Les risques de difficultés ultérieures augmentent en fonction de l'épaisseur de la couche de moskeg. Le bureau d'études doit tenir compte de ces risques l'affaissement en prévoyant le recours éventuel à d'autres tracés ou à d'autres méthodes de construction. Il faut réduire la vitesse de chargement d'autant plus que la couche de moskeg devient plus épaisse, et la division en étapes du programme de travaux s'est révélée avantageuse dans nombre de cas.

Les grands travaux de construction routière peuvent souvent être réalises de façon plus économique si l'on tire profit des qualités bien connues de résistance du moskeg gelé. Il existe maintenant un équipement moderne de construction qui peut éventrer les terrains de couverture gelés, transporter, compacter et taluter les matériaux de remblayage de la chaussée d'une façon rapide et économique, et qui permet d'établir des chaussées stables au-dessus du moskeg, si l'on procède par sections régulières.

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The Province of Alberta, while known as a Prairie Province, is blessed with a great variety of geological, topographical and environmental conditions and while these add to the economy and beauty of the area, they pose many problems in the development of highways and roads.

The southeastern portion of the province, largely a prairie zone, presents few construction problems other than the stabilizing of road beds where dune-type sand areas are crossed. Most construction people in this area keep a sharp eye to water supplies to facilitate compaction to standards required. This situation is in sharp contrast to the central western and northern areas where the extraction of excess moisture becomes a very definite problem in the highway construction industry.

The north and northwestern portions of the province tend to a greater variety of land forms ranging from tracts of farmland to parkland and large areas of near wasteland as far as surface productivity is concerned. In this area we encounter muskeg terrain of considerable magnitude and the highway construction operation is presented with many more difficulties. Construction through muskeg areas has always been a problem but, as would be expected, with the advance into paving of the majority of the highway system including the northwestern areas, less tolerance or movement of grades can be accepted with the placing of pavements.

General

Some years ago, the major program of constructing Highway 16 between Edmonton and Jasper Park through areas containing extensive and deep muskeg basins made it quite clear that design considerations were more essential than previously recognized or considered. A program was introduced in the preliminary engineering stage of probing muskegs for depth and an estimate of bearing capacity, approaching the problem strictly from a ground review. This process, at best, was most tedious and time-consuming from a location point of view and, like most other highway agencies, the development of aerial photo-analysis techniques was adopted to outline the muskeg areas before attempting to develop the most suitable band for attempting a highway location or relocation.

During this period, many embankments across deep muskegs were successfully constructed based on design criterion which estimated the safe embankment depths which could be supported and on which a pavement could be constructed without excessive deflection. There are, however, many cases where the muskegs failed or the consolidation was so great that the profiles required alteration before and after the initial paving operation. There appears to be plenty of scope yet for investigations into the effect of embankment loads on muskeg areas years after the initial load was constructed as many of the settlements have not occurred in the first five years of life.

The construction practices used in the Province normally follow a stage development process with the embankment and other grading being done not less than a year in advance of base paving and in muskeg areas, 3 to 5 years before paving. By observation, it was evident that in the majority of cases, most of the differential consolidation in these areas occurred in the first 2 or 3 years allowing corrective work to the grade profile prior to pavement construction. From our experience, it is most evident that stage construction is most essential when dealing with the variable terrain involving muskegs, particularly if these muskegs are of sufficient depth where excavation cannot be considered economically justified.

On projects where muskegs have been isolated and where the bearing capacity is extremely low, we have, in the construction process, introduced some short duration loading schedules in an attempt to reduce the possibility of shearing which is evidenced on occasions due to too rapid application of embankment load. This practice is included in construction projects where the base paving is to follow immediately behind the embankment finishing stages. This practice involves the partial construction of embankment based on an estimate of the bearing capacity without load and delaying the subsequent layers of embankment until it is estimated that sufficient consolidation has taken place so that the possibility of shearing would be minimized. These operations have been successful in most instances; however, some failures have also occurred.

Figure 1 shows an example of an isolated muskeg which commenced to fail with minimum embankment load sufficient only to carry the construction equipment.

With this type of failure occurring, it was considered that there was little possibility of "floating" the embankment or achieving any early strength gain through consolidation. A decision was made, therefore, to advance loading in stages employing a widened base embankment in an attempt to force displacement uniformly while keeping the embankment intact. This operation advanced and, while an effective depth of embankment of some fifteen feet was placed, the profile was raised less than one foot indicating indeed that displacement was being forced.

Unfortunately, severe lateral shearing and displacement of the muskeg followed on one side. This action released the support gained through the previous more uniform displacement and a portion of the embankment material sheared off. Work was halted to permit further drilling to determine the depth of embankment penetration in relation to the stronger zone at the bottom of the muskeg. While nearly full displacement had occurred, it was obvious that the lateral movement of the muskeg must be counteracted to stabilize the embankment.

A berm counterload was delayed until just prior to winter shutdown and was applied over the displaced muskeg following the shape of the concentric rings which show up in Figure 1. This Spring, very limited change has been noted and further loading of both berm and embankment section has been undertaken.

It is too early, at this stage, to say whether acceptable stability of this embankment has been achieved. From the drill test penetrations, however, indications are that close to full depth displacement has occurred, and observations over the last few months indicate little change in the settlement picture.

, The brief description of the embankment construction through this muskeg has been presented to indicate the type of muskeg encountered in the province which has presented the greatest problem to main highway construction. Figure 2 shows a cross-section illustrating the depth of displacement, the muskeg upheaval, and the slope of the compressed layer below the embankment. In this case, the lateral movement of the embankment was to the left.

In general, our practice in the construction of main trunk highways has been to displace muskeg encountered with the embankment until equilibrium has been reached. Excavation is rarely done and is generally limited to profile points where the depth of embankment cannot be increased to provide a stable roadbed. Economy generally dictates the choice of method.

It is considered absolutely essential to have sufficient detailed information on the muskegs prior to construction. Our planning and locating engineers now provide airphoto mosaics delineating the areas which are probed for depth and estimated bearing during the preliminary survey stages. This information is used by the designer, and estimates of displacement, surcharge are included in the contract quantities. The theoretical approach to design must be conditional to the practical methods of embankment construction. Where a muskeg commences to fail with only sufficient embankment to carry the construction equipment, then there is little hope that a roadway stable enough on which to place a permanent pavement will result without further and extensive displacement. In such instances, the alternatives must be reasonably known and anticipated in the contract terms.

The Construction Engineer must exercise caution with the deep muskeg deposits and the embankment must always be placed slowly if equilibrium is to be reached with the least quantity of material. The construction schedule should require a stage loading process to permit as much consolidation as possible A testing operation, to follow the penetration of the embankment load in relation to the firmer bottom of the muskeg, is important and should include an attempt to determine the direction of possible lateral movement of the embankment core. While much has been learned from investigation, muskegs in general should be avoided where topography will permit this possibility. For deep muskegs, in particular, detailed investigation is essential and construction contract conditions must anticipate and make provision for the substantial displacement or failure of this low support material.

Winter Construction

In 1963, construction was commenced to provide the first road link to the Fort McMurray townsite and tar sands area (Figure 3). The final location of this 156-mile project was chosen by airphoto analysis with the necessary refinement through ground surveys. While the alignment took advantage of high ground consistent with the shortest practical route, substantial muskeg areas were crossed. The soil types varied from silty sands to medium plastic clays. Clearing operations for a 200 ft wide right-of-way were advanced in the winter of 1963 through the interior portion of the project, taking advantage of frozen ground support.

The first three construction projects (70 miles) were seriously delayed by weather conditions. The parallel drainage channels, which were projected well in advance of embankment construction, flowed heavily but were unable to accelerate the muskeg drainage fast enough to significantly aid the initial construction operations. Many of the muskeg areas were of such expanse that all embankment material had to be hauled in from one direction. Costs began to soar, progress was delayed, and serious mixing of fibrous material and select borrow soil occurred.

A decision was made in the winter commencing in December of 1964 to advance base embankments through the muskegs remaining on the current projects and to award a further contract of 27 miles applying the same principle. The procedures adopted in this first major winter grading operation involved the following:-

(1) To advance the drainage ditching through all muskeg areas;
(2) To remove snow from roadbed areas when sufficient frost had penetrated to support the equipment;
(3) To construct the embankments over the muskeg areas keeping the elevation approximately one foot below final grade;
(4) To construct the embankment in sections of such length that fill would be placed in the normal layers, compacted, and covered before serious freezing took place;
(5) To apply compaction in the normal manner excepting moisture adjustment; and
(6) Shape the base grade for quick surface drainage.

This procedure permitted the completion of base embankment through the majority of all muskegs encountered in some 45 miles of the project. Overhaul was sharply reduced as it was possible to get over the expansive muskegs to haul fill in from both sides. Concern as to the amount and expense of conditioning and correction work required the following Spring made the contractors cautious or a greater volume of work could have been completed.

The results of this initial winter operation exceeded our hopeful expectations. Drainage was accelerated through the advance drainage system. The settlements which occurred were uniform and gradual, having advanced slowly during the winter through the partially frozen fibrous material. Ready access was available to borrow pits for completing the grades. Equipment could be organized and advanced ahead to complete work between the muskeg areas where normal cut-fill could not previously be reached nor equipment serviced.

With the return of Spring and Summer of 1965, weather conditions again returned to its normal obnoxious pattern and, once the construction had advanced beyond the winter construction zones, construction came to a virtual halt until late Fall. Fair weather in November permitted good progress and at December 1st, the 156-mile road link was complete except for approximately 30 miles in the centre; therefore, no roadway. Arrangements were completed for a full-scale winter operation to close the gap. The findings from the previous winter operations in this same area led us to the decision that the embankments could be constructed to finished grade and that embankment surcharge could additionally be placed in the normal manner through muskeg areas. It had also been found during the conditioning operations in the Spring that it was much simpler and more economical to dry and recompact the material in the grade on the drained right-of-way than to re-enter a large number of borrow pits.

In addition to the Fort McMurray project, a 28-mile section of the Hondo - Slave Lake portion of new Highway No. 2 through similar terrain (Figure 4) was advanced employing the same procedures.

Both grading projects were completed to passable standards before Spring break-up with the Fort McMurray highway open to continuous use since March 10th. Softening of a 5-mile section, partially constructed before and after the Christmas break, has experienced some severe rutting under loaded trucks, confirming the need to complete sections quickly. The highway has been kept open and serviceable for normal traffic, and conditioning is now underway.

<u>Summary</u>

The preparation of this paper has been in the form of case histories indicating the construction practices and considerations employed.

Muskeg terrain still remains an obstacle to avoid if practical alternatives are available. It is suggested that extensive investigation of muskeg terrain, which must be traversed, be carried out prior to adopting an alignment or carrying out a highway design. The greater the depth of muskeg, the greater the possibility of failure. Designers and estimators must anticipate failure to the extent that reasonable provision is made for alternatives to the original design and construction methods. As the muskeg depth increases, the rate of loading must be decreased and stage scheduling has proved advantageous in many instances.

The support value of muskeg during the frozen period, which provides mobility to the industries developing our resources, is well known. Major highway construction can take advantage of this same feature economically. Modern construction equipment, which can economically rip out the frozen overburden, haul, compact, and shape grade embankment rapidly on an around-the-clock basis, is available and, when operated in controlled spreads, can produce stable grades through muskeg areas. Again, the importance of extensive engineering information of the area and the establishment of practical work conditions is emphasized.

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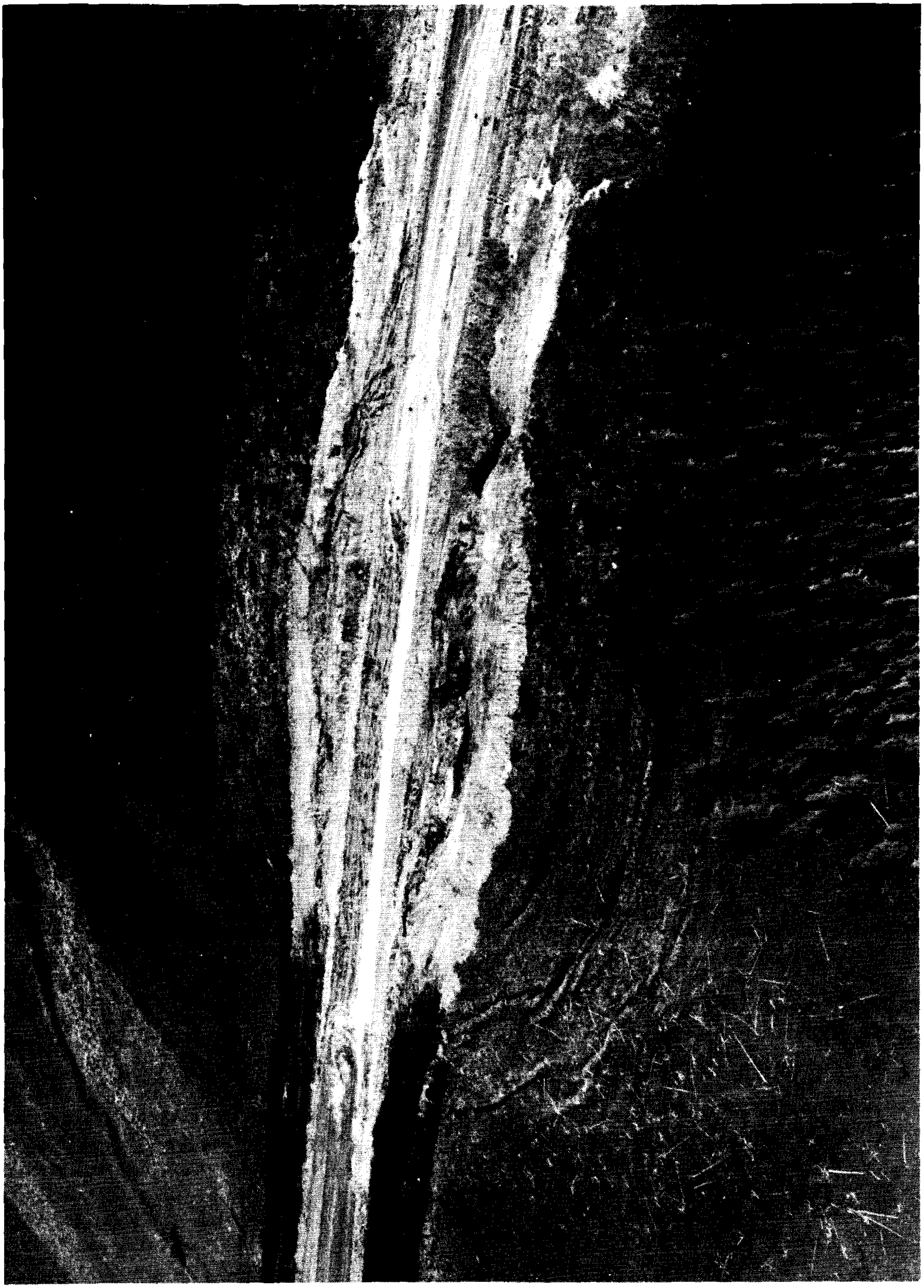
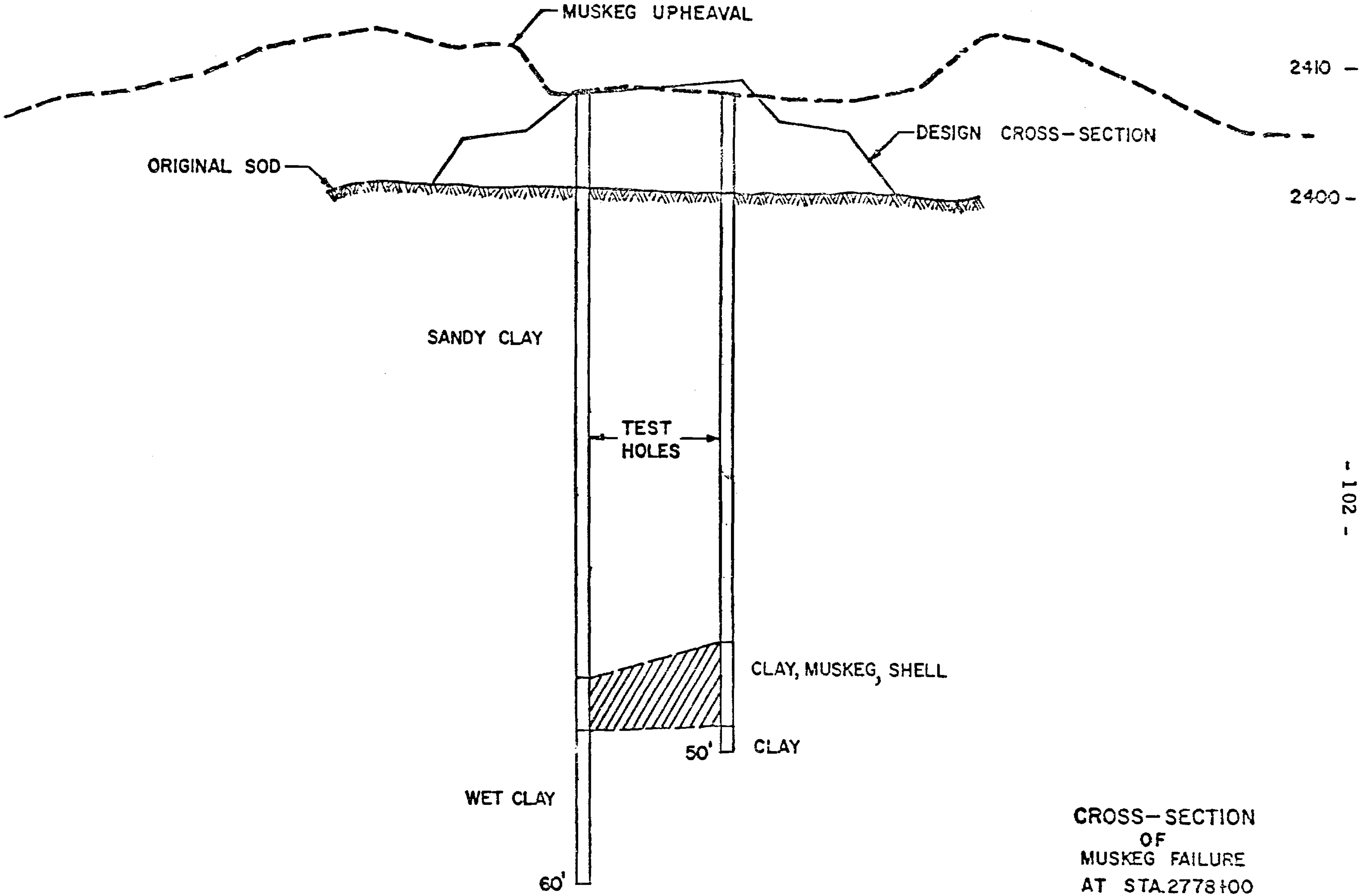


FIG. 1
ROAD FAILURE OVER MUSKEG



CROSS-SECTION
OF
MUSKEG FAILURE
AT STA. 2778+00
HWY. 16-C-2, W. OF GAINFORD
SCALES:
HORIZ. 1" = 20'
VERT. 1" = 10'

FIGURE 2

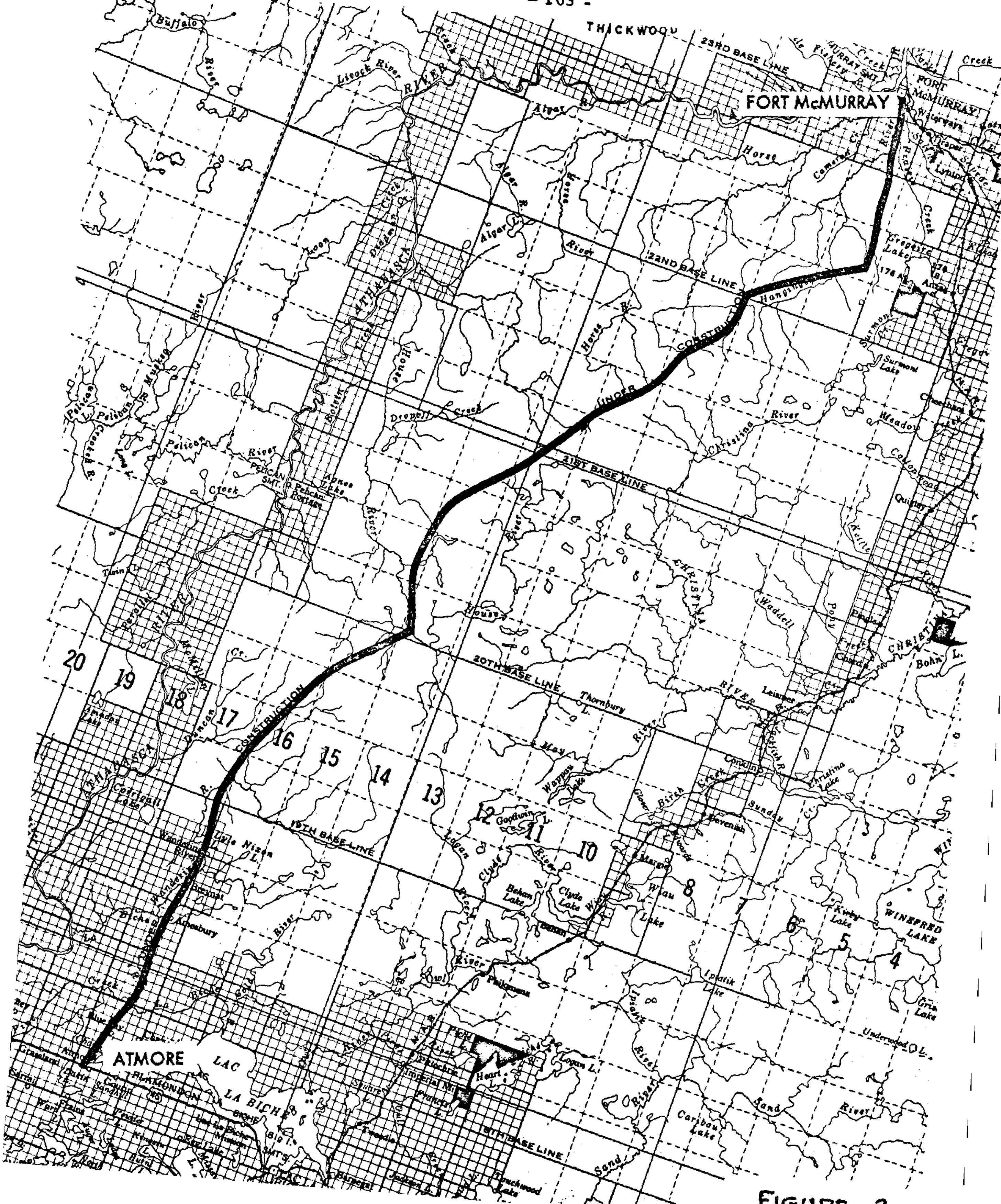

FORT McMURRAY
ATMORE
THICKWOOD
23RD BASE LINE
22ND BASE LINE
21ST BASE LINE
20TH BASE LINE
19TH BASE LINE
18TH BASE LINE
UNDER CONSTRUCTION
CONSTRUCTION
ATHABASCA
RIVER
CHRISTINA
WINEFRED LAKE
LAC LA BICHE
Algar R.
Horse R.
House
Pelican
Wandering River
Conklin
Philomena
Heart L.
Thornbury L.
Goodwin L.
Winefred Lake
20
19
18
17
16
15
14
13
12
11
10
8
7
6
5
4

FIGURE 3.

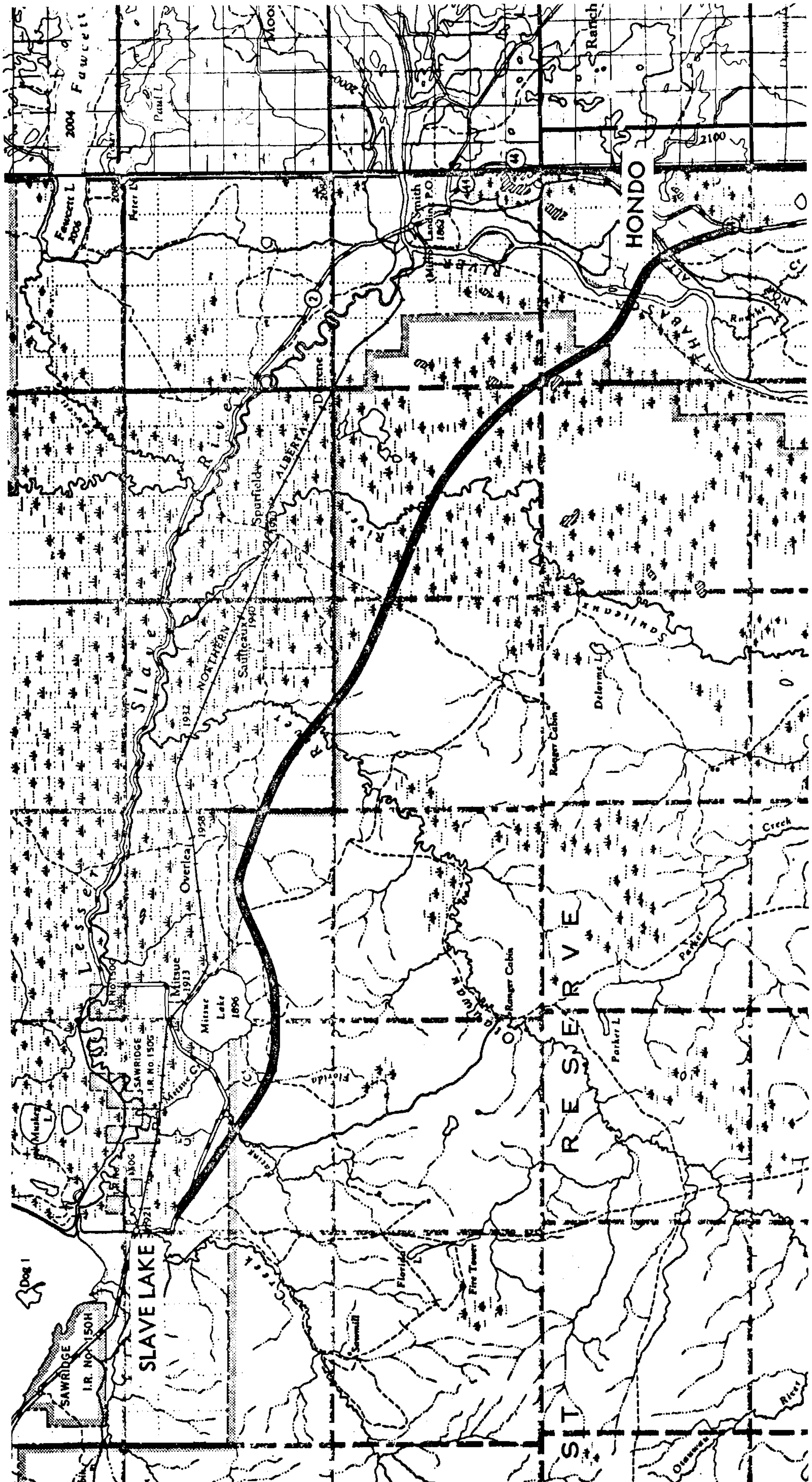

SLAVE LAKE
HONDO
SAWRIDGE I.R. No. 150H
SAWRIDGE I.R. No. 150G
Mitsue Lake
Lesser Slave River
NORTHERN ALBERTA
Smith
Fawcett L
RESERVE
Ranger Cabin
Fire Tower
Sawmill
Parker L
Delorme L
Creek
River

FIGURE 4

Discussion

Question - What is the difference in cost between winter and summer operations?

Mr. Cronkhite - The cost to the Department for the 1964 winter operation was the same per unit as the summer as the original contract prices were enforced. Considerable money was saved due to the reduction of overhaul and in the displacement of the soft underlying materials.

Mr. Schlosser - How much frost was in the muskeg when the fill was placed?

Mr. Cronkhite - Frost penetration was only a foot or two and generally confined to the fibrous material.

Mr. Schlosser - Was fracturing experienced?

Mr. Cronkhite - Some fracturing was experienced; however, this was less noticeable in the winter construction.

Mr. Brawner - What was the maximum thickness of the grade soil?

Mr. Cronkhite - The thickness was not less than 4 to 5 feet for constructed embankments over muskegs.

Mr. Bergan - Were the heights of fill varied with the type of material?

Mr. Cronkhite - Not much difference was made in the design for the type of grading material except that it would be accounted for in the follow-up pavement design.

Mr. Bergan - Was drainage a costly item?

Mr. Cronkhite - The drainage was more easily introduced in the winter period due to the partially frozen fibrous material which was easier to excavate and which also provided better support for equipment.

Question - Is it preferable to clear the right-of-way ahead of time?

Mr. Cronkhite - It is not advantageous generally to clear the right-of-way ahead of time if winter grading is to be introduced. Frost seems to penetrate less with the snow cover and tree cover left intact until actual construction is put underway. Through muskegs, however, it is desirable to have sufficient frost penetration where the fill will be placed, therefore clearing if necessary is desirable through the muskeg areas themselves.

Mr. Dawson - What steps are taken to avoid frozen lumps?

Mr. Cronkhite - Some lumps are encountered, however these are limited by stripping the borrow pits only as the fill is required, and placing the material rapidly in short work zones on the highway. The key would be to keep ahead of the freezing action.

Mr. Dawson - What steps are taken for wintertime compaction?

Mr. Cronkhite - Compaction is carried out in the regular manner except that no attempt is made to adjust moisture content.

Mr. Dawson - Are muskeg profiles obtained?

Mr. Cronkhite - Muskeg profiles are run on each muskeg by a probing procedure which establishes both depth and a general measure of the strength. This muskeg profile information is plotted for design and construction information.

Question - Would more horizontal shear failures result from winter operations?

Mr. Cronkhite - It was observed that far less horizontal shear occurred during and following the winter construction operation. More uniform settlements with the embankment remaining intact occurred.

Mr. Schlosser - How was the design depth of grade obtained?

Mr. Cronkhite - This was established from the muskeg profile, and strength estimates, on which information, a decision is necessary as to whether full or partial displacement is likely to occur. The profile grade should be 4 to 5 feet above water level.

Question - What controls were set up for compaction and what specification was set on moisture content?

Mr. Cronkhite - Winter compaction was carried out using the regular compaction equipment generally of the heavier impact pressures. It is recommended that nothing less than 500 p.s.i. pressures on tamping rollers is suitable. With regard to moisture content, no adjustment of moisture content was attempted during freezing temperatures and it is definite that an adjustment in moisture and recompaction is necessary in the following season.

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III. 2. ÉTUDE COMPLÉMENTAIRE SUR LES SURCHARGES DANS LES SAVANES DE NAPIERVILLE

G. Tessier*

Resume:

Des essais supplémentaires au scissomètre vane ont été effectués à Napierville et à Orsainville. Des palettes de différentes dimensions et deux sortes d'appareil vane ont ete utilises. De plus, à Napierville, les profils stratigraphiques ont permis de compiler les tassements qui ont eu lieu sous la vieille route construite en 1941. Les resultats sous forme de figures et de tableau sont analyses dans cette presentation. D'une façon générale on peut conclure que dans les terres noires libres de racines et dans les argiles molles, le torquemètre (sans tuyau-enveloppe) se compare à l'appareil vane Suédois (avec tuyau-enveloppe) si on utilise les palettes de dimensions moyennes (65 mm x 130 mm) et si la force de cisaillement est inférieure à 500 lb/pi.car. Les tassements excessifs dans les savanes de Napierville sous la vieille route s'expliquent en partie par le fait que les conditions du sol étaient différentes en 1941 et aussi par le fait que dans ces savanes la croûte de surface avait probablement été défoncée par les matériaux lourds du remblai.

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III. 2. A SEQUEL TO THE NAPIERVILLE CASE

G. Tessier

Abstract:

Additional vane tests and borings were performed at Napierville and at Orsainville using different-sized vanes and two different apparatus to register the shear strength. Soil profiles were also plotted and settlements which occurred under the old road built in 1941 at Napierville were determined. This paper analyzes the results which are given in Figure and Table form. In general, we may conclude that in peats free of roots and in soft clays, the torque-wrench (without casing) gives results equivalent to those given by the Swedish vane apparatus (with casing) if the medium vane (65 mm x 130 mm) is used and if the shear strength is less than 500 lb/sq ft. In the Napierville peat bogs, excessive settlements under the old roadway can be explained by the fact that the soil conditions were different in 1941 and also because the surface of the peat bogs had been damaged by the fill.

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* See Appendix "A" for affiliation.

Comme suite à notre papier sur la construction de routes sur savanes au Québec présenté en 1965 au onzième congrès annuel sur le muskeg (Tessier, 1965) nous avons effectué des essais supplémentaires dont voici les résultats sous forme de figures et de tableau. Ces essais furent effectués à Napierville et à Orsainville. On peut en répartir les résultats en deux groupes:

A) Essais au scissomètre vane.

B) Compilation des tassements et des pressions.

Le présent rapport comprend des commentaires sur chacune des figures qui groupent les résultats de ces essais.

Essais au scissomètre vane

Nous avons effectué deux séries d'essais au scissomètre vane

I) En utilisant des palettes de différentes dimensions pour un même appareil.

II) En utilisant deux appareils différents, soient l'appareil Suédois (avec tuyau-enveloppe) et un simple torquemètre (sans tuyau-enveloppe).

Les différentes palettes employées sont les suivantes:

1) Petites palettes: 55 mm x 110 mm soit une aire de 6050 mm^2.

2) Palettes moyennes: 65 mm x 130 mm soit une aire de 8450 mm^2 équivalente à 139% de l'aire des petites palettes.

3) Grosses palettes: 75 mm x 150 mm soit une aire de 11250 mm^2 équivalente à 186% de l'aire des petites et 133% de l'aire des palettes moyennes.

Avec l'appareil Suédois, nous n'avons pas utilisé les grosses palettes étant donné l'ouverture restreinte pour libérer les palettes du tuyau-enveloppe. Avec le torquemètre, nous avons utilisé les trois sortes de palettes.

I) Palettes différentes:

Les figures 1 à 5 donnent les résultats des essais faits avec les palettes de grosseurs différentes. Les figures 1 et 2 montrent les résultats obtenus avec l'appareil Suédois en utilisant les petites et les moyennes palettes, dans les savanes 1 et 3 à Napierville. On constate que l'écart entre les deux courbes n'est pas constant, et que les palettes moyennes produisent les plus petites forces de cisaillement. Les figures 3 et 4 donnent les résultats des essais faits dans les mêmes savanes avec les 3 sortes de palettes disponibles en employant le torquemètre. Dans la figure 3, les résultats concordent avec ceux de MacFarlane (1960). Plus les palettes sont grandes, plus la force de cisaillement est petite. Cependant, ceci est le seul cas où les conclusions concordent aussi parfaitement avec ceux de MacFarlane. Dans la figure 4, les résultats sont différents et les courbes se croisent. Nous ne pouvons dans ce cas appliquer la même conclusion que précédemment, de même que pour la figure 5 qui produit les résultats des essais faits à Orsainville avec les mêmes palettes en utilisant le torquemètre. D'autre part, on constate que l'écart entre les courbes provenant des essais avec les différentes palettes est plus grand quand on utilise le torquemètre que quand on utilise le vane Suédois. En examinant des graphiques, nous pouvons nous demander trois choses:

a) Est-ce que la différence entre les dimensions des palettes est assez marquée pour influencer les résultats ou bien ceux-ci sont-ils indépendants de cette différence?

b) Est-ce que les résultats sont les mêmes dans différentes catégories de terre noire (amorphe, fibreuse, ligneuse ou non ligneuse) ou bien quelle est l'influence des fibres de différentes grosseurs sur les palettes?

c) Quelles dimensions les palettes doivent-elles avoir pour obtenir les résultats les plus représentatifs?

II) Appareils différents:

Les figures 6 à 8 donnent les résultats des essais faits avec l'appareil vane Suédois et avec le torquemètre, pour des palettes données. Les figures 6 et 7 montrent les résultats pour les palettes moyennes (65 mm x 130 mm). La différence entre les deux courbes produites par le vane Suédois et le torquemètre est faible (de l'ordre de 10%). La figure 8 donne les résultats pour les petites palettes (55 mm x 110 mm). L'écart entre les deux courbes produites par les deux appareils est alors plus grand. Par ailleurs, nous avons constaté que pour des forces de cisaillement supérieures à 500 lb/pi. car., l'écart s'accentue. On peut dire en général que pour les terres noires libres de racines et pour les argiles molles, le résultat est revelateur: l'appareil vane sans tuyau-enveloppe (torquemètre) se compare à l'appareil vane avec tuyau-enveloppe (Suédois), en utilisant les palettes moyennes. Il reste à faire plusieurs essais du même genre dans toutes les catégories de terre noire.

III) Essais vane sous la vieille route:

Nous avons effectué des essais au scissomètre vane à Napierville, sous la première chaussée construite en 1941 et nous avons compilé les résultats avec ceux obtenus au centre de la deuxième chaussée avant la pose du remblai. Les deux figures suivantes illustrent cette comparaison pour des essais faits avec l'appareil vane Suédois (figure 9) et avec le torquemètre (figure 10). Par ailleurs, nous ne pouvons faire la comparaison entre l'écart obtenu par l'appareil Suédois et celui obtenu par le torquemètre étant donné que les essais ont été effectués dans deux savanes différentes, soient S-1 et S-4.

Tassements et pressions

Les figures 11 et 12 montrent les profils stratigraphiques sous la vieille chaussée dans S-1 et dans S-4. Nous constatons la présence de 4 à 5 pieds de gravier (GW-GM) comme matériel de remblai. La terre noire a été comprimée sous ce remblai pendant 24 ans. Le tableau de la figure 13 donne les pourcentages de tassement après 24 ans sous la vieille chaussée. Ces valeurs ont été compilées pour un remblai d'une hauteur de 5 pieds. On y montre aussi les pourcentages de tassement sous la nouvelle chaussée pour un remblai d'une hauteur de 9 pieds et après 400 jours. Ces pourcentages de tassement ont été compilés pour des hauteurs de remblai uniformes sur toutes les savanes. On peut se demander pourquoi il s'est produit un si grand tassement dans les savanes 1, 2 et 4 depuis 24 ans.

a) Les conditions du sol étaient différentes à l'époque. Le drainage a amélioré la croûte de surface depuis 24 ans. Les essais au scissomètre vane effectués en 1941 auraient donné des valeurs inférieures à celles qui ont été trouvées au centre de la nouvelle chaussée en 1962, du moins dans la région près de la surface.

b) Dans les savanes 1, 2 et 4 la croûte de surface a probablement été défoncée par les matériaux lourds du remblai, ce qui expliquerait les tassements excessifs, surtout dans S-2.

c) La couche d'argile posée en 1941 dans l'emplacement de la future voie dans S-3x (de 0 + 00 à 40 + 00) a contribué à préserver la croûte de surface. Rappelons que dans la savane 3, de 48 + 00 à 120 + 00, la terre noire a été défoncée en profondeur par le remblai de chargement.

Les figures 14 et 15 donnent le rapport entre la pression effective (P.E.), le pourcentage de tassement (% T) et l'indice des vides (e) pour Saint-Élie d'Orford et Napierville. Deux remarques s'imposent:

1) Il serait intéressant de connaître le rapport entre l'accroissement de l'indice des vides (Δe) et l'augmentation du pourcentage de tassement (Δ% T) pour une catégorie de terre noire déterminée. Ce rapport est-il constant pour toutes les catégories de terre noire?

2) Quelle relation existe-t-il entre "e" calculé suivant l'essai de

consolidation en laboratoire et "e" existant dans le sol en place, si nous prélevons des échantillons à différentes étapes de la construction?

La figure 16 donne le rapport entre la pression effective et le pourcentage de tassement en fonction du temps. P.T. représente la pression totale exercée par le remblai. La figure 17 donne le rapport entre le tassement, la pression totale et la pression interstitielle en fonction du temps. En dessinant sur le graphique la cote 30% de la pression totale, nous aidons le technicien et le guidons dans les étapes de la construction car il voit à un moment donné quelle est la position de la pression interstitielle par rapport à la cote critique.

Conclusion

Plusieurs constructions de routes sur muskeg ont été réalisées avec succès au Canada depuis quelques années; ce qui a constitué une étape importante dans les études et les travaux sur la terre noire. Il reste d'autres tâches à accomplir, celles de compiler les données de tous les cas rencontrés, de les étudier attentivement, d'apprécier les similitudes, de déduire une méthode générale et approfondie d'étude des savanes (sur le terrain et en laboratoire) et de construction de routes sur ces savanes. De la sorte, nous pourrons écrire non pas une suite à un cas particulier comme Napierville, mais une suite à plusieurs cas sinon à la majorité des cas.

Remerciements

Je remercie les autorités du ministère de la Voirie du Québec qui m'ont permis de présenter cette communication au douzième congrès annuel sur le muskeg. Je remercie en outre M. G. Robert Tessier, Chef du Service des Sols et Matériaux, qui m'a permis de faire les études nécessaires pour compléter cette publication et qui m'a fortement encouragé, ainsi que les équipes qui ont effectué les sondages et les essais sur le terrain.

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MacFarlane, I. C.: "Evaluation of Road Performance over Muskeg in Northern Ontario", Proceedings, Sixth Muskeg Research Conference, Calgary, April 1960.

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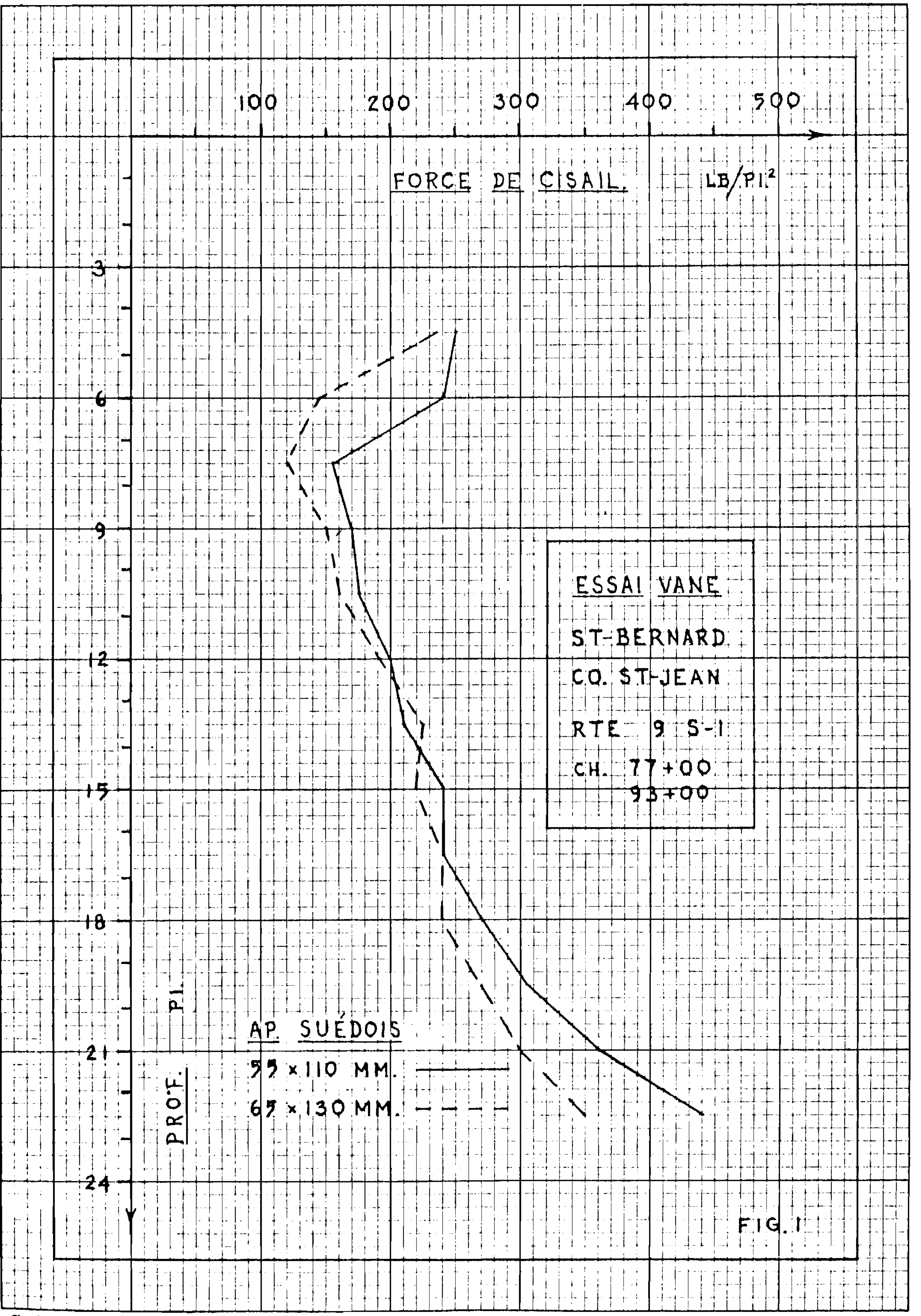
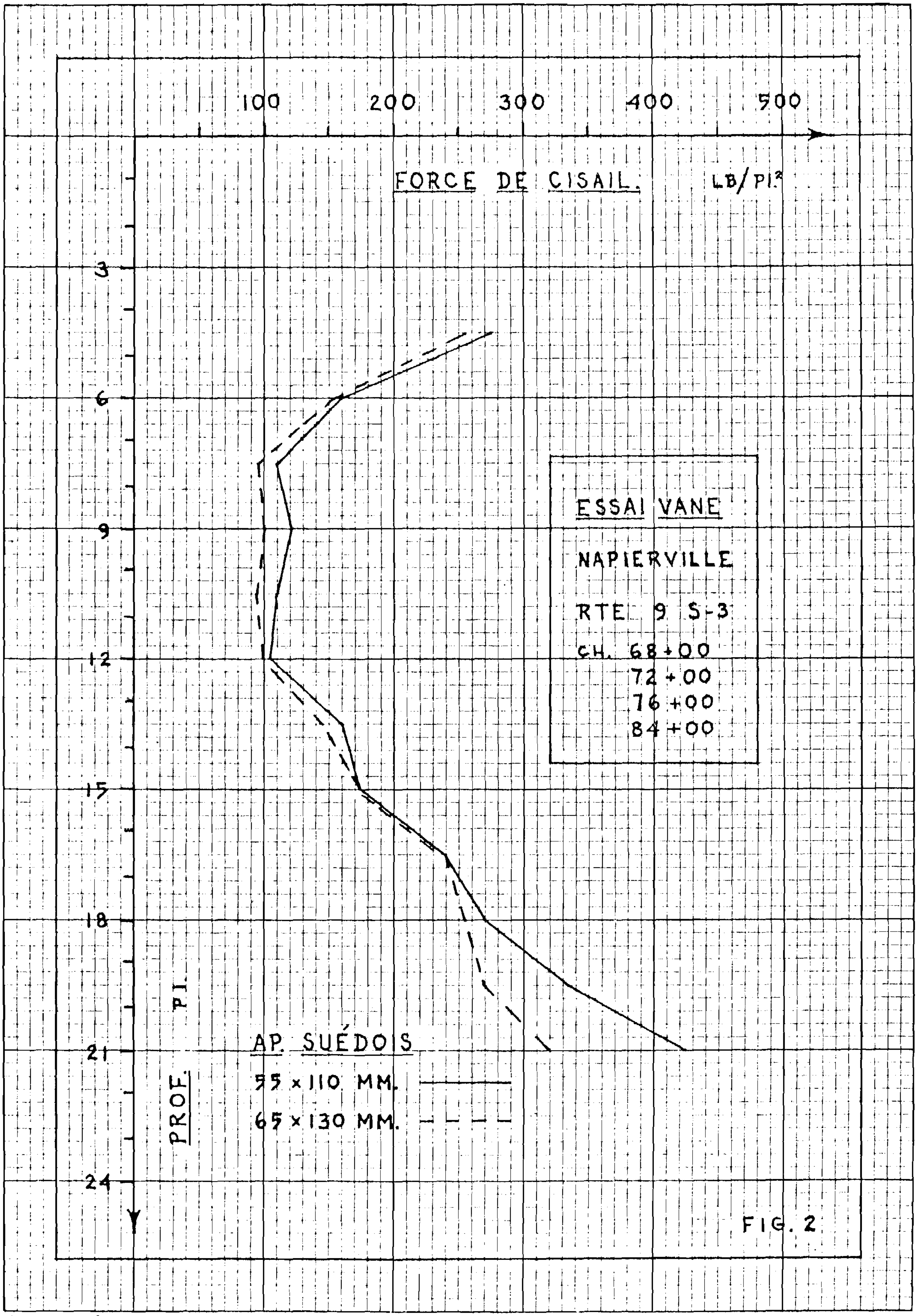
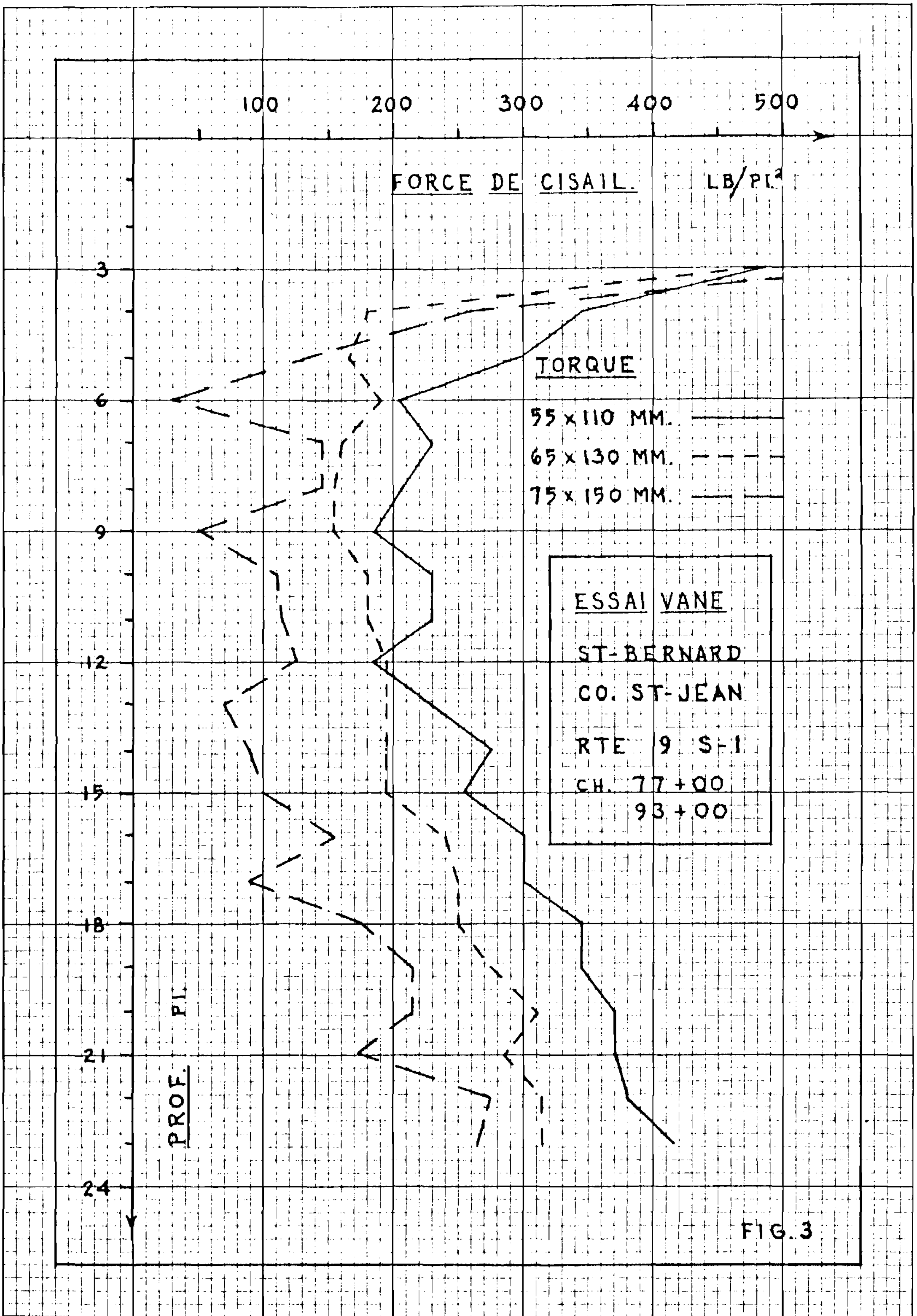


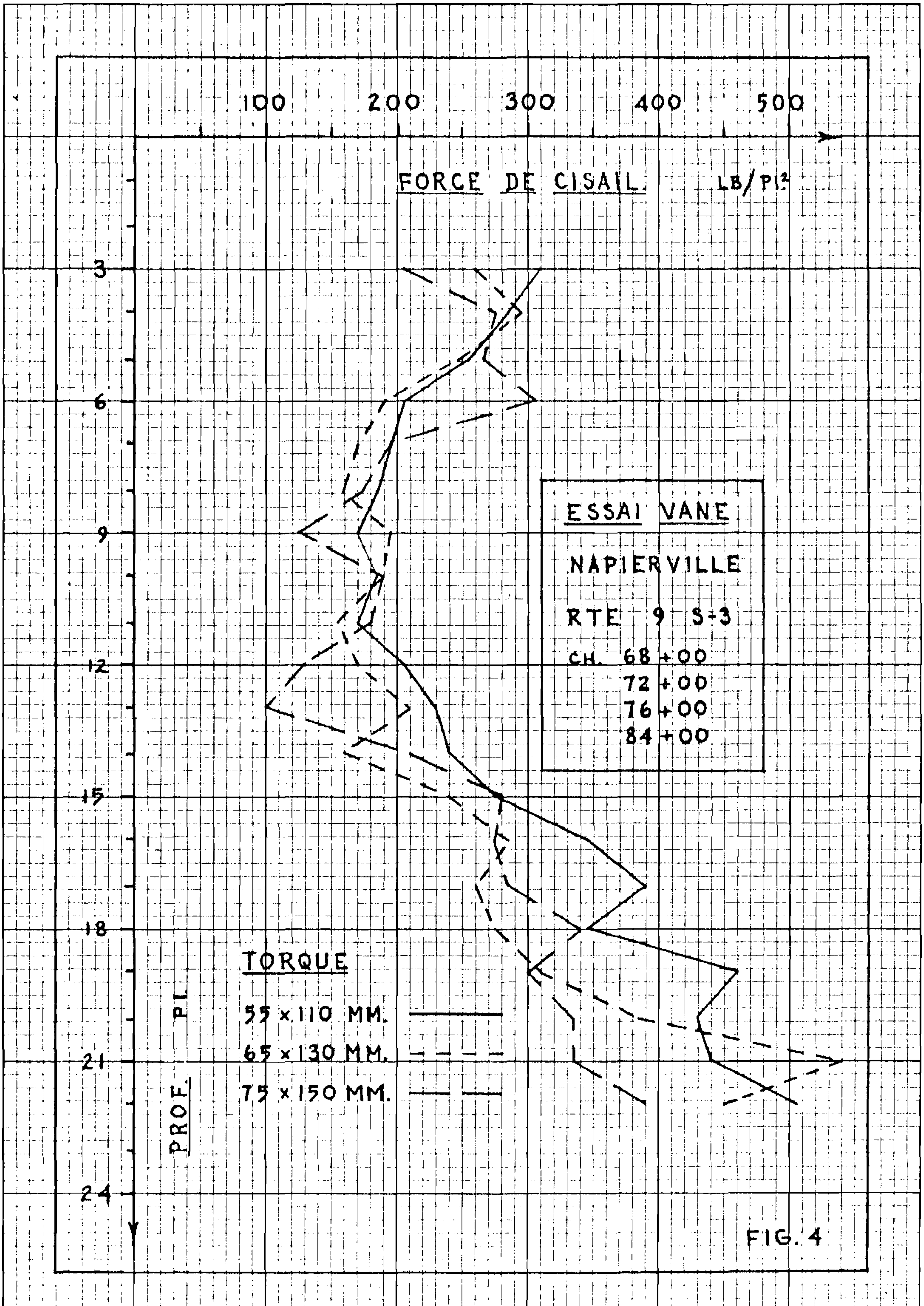
Scissomètre vane: petites et moyennes palettes, appareil Suédois. Saint-Bernard de Lacolle, S-1.



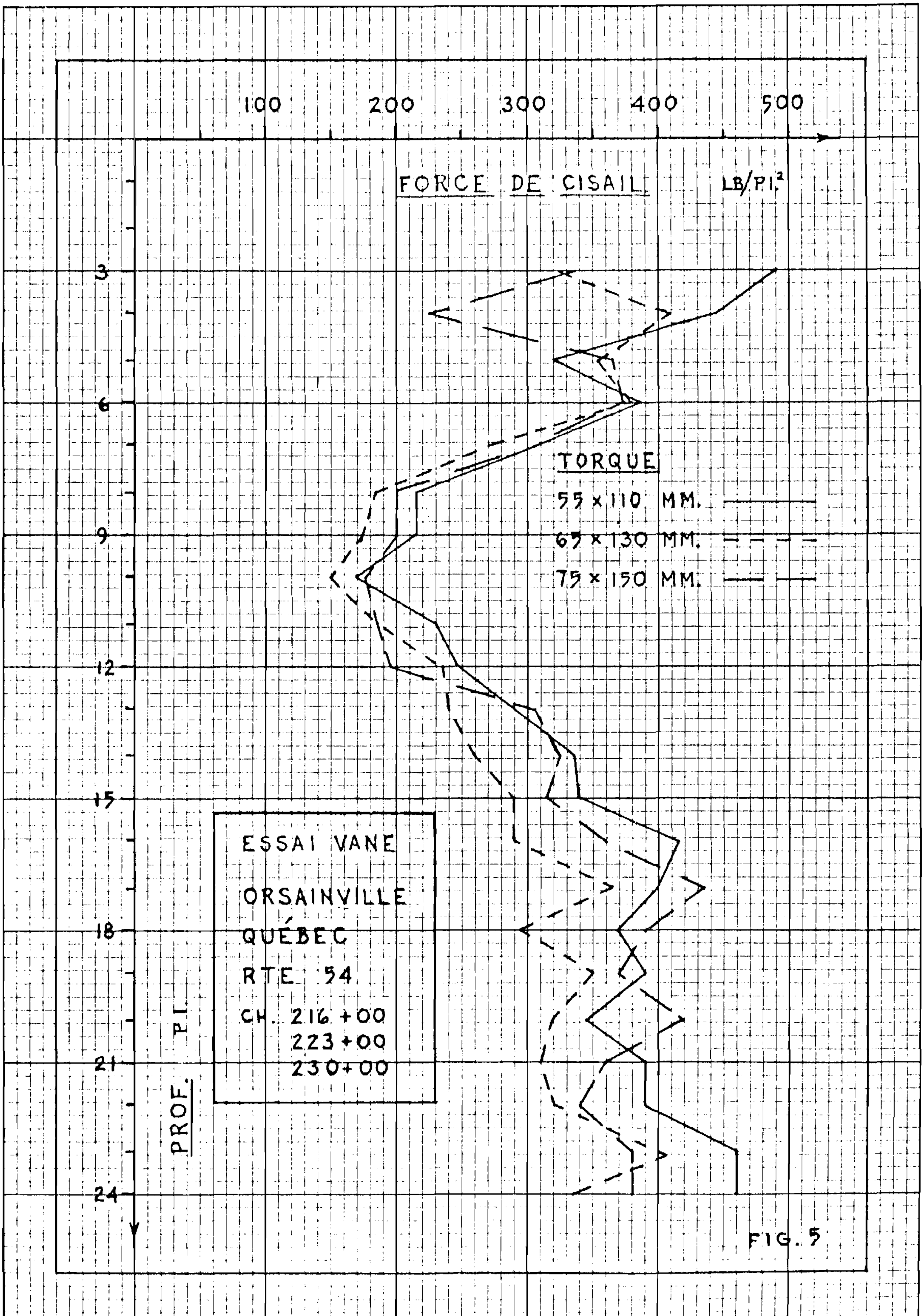
Scissomètre vane: petites et moyennes palettes, appareil Suédois. Napierville, S-3.



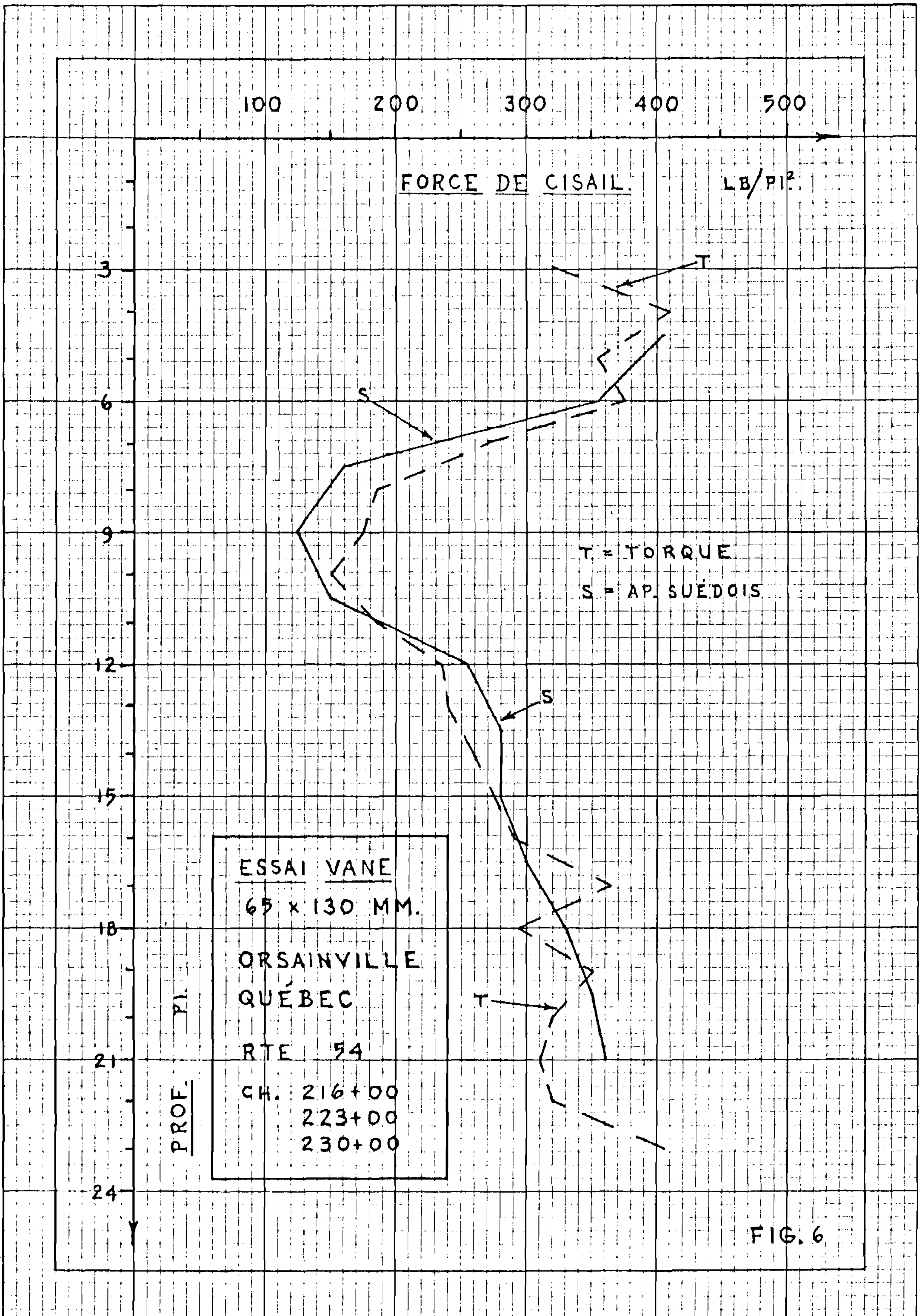
Scissomètre vane: petites, moyennes et grosses palettes, torquemètre. Saint-Bernard de Lacolle, S-1.



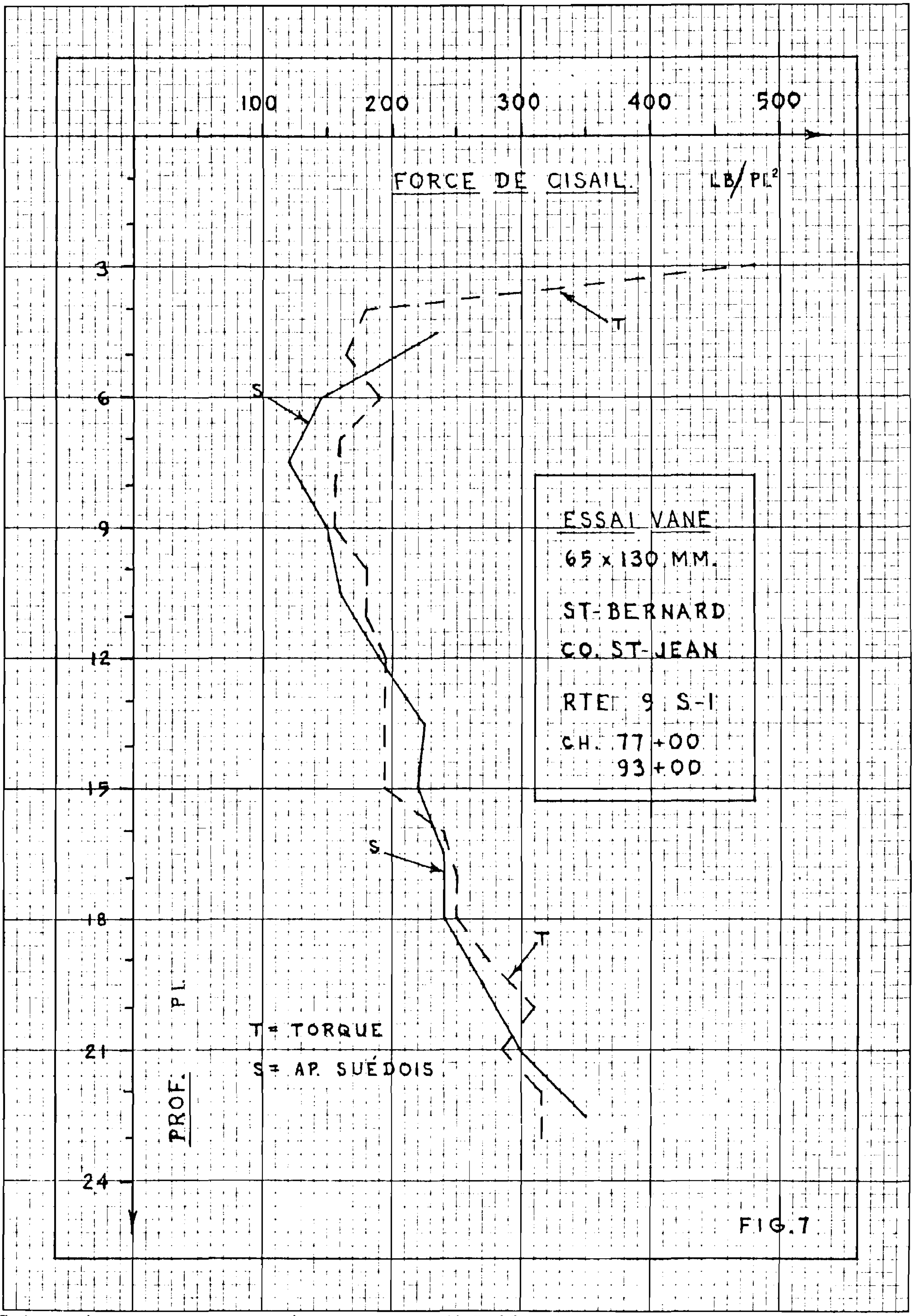
Scissomètre vane: petites, moyennes et grosses palettes, torquemètre. Napierville, S-3.



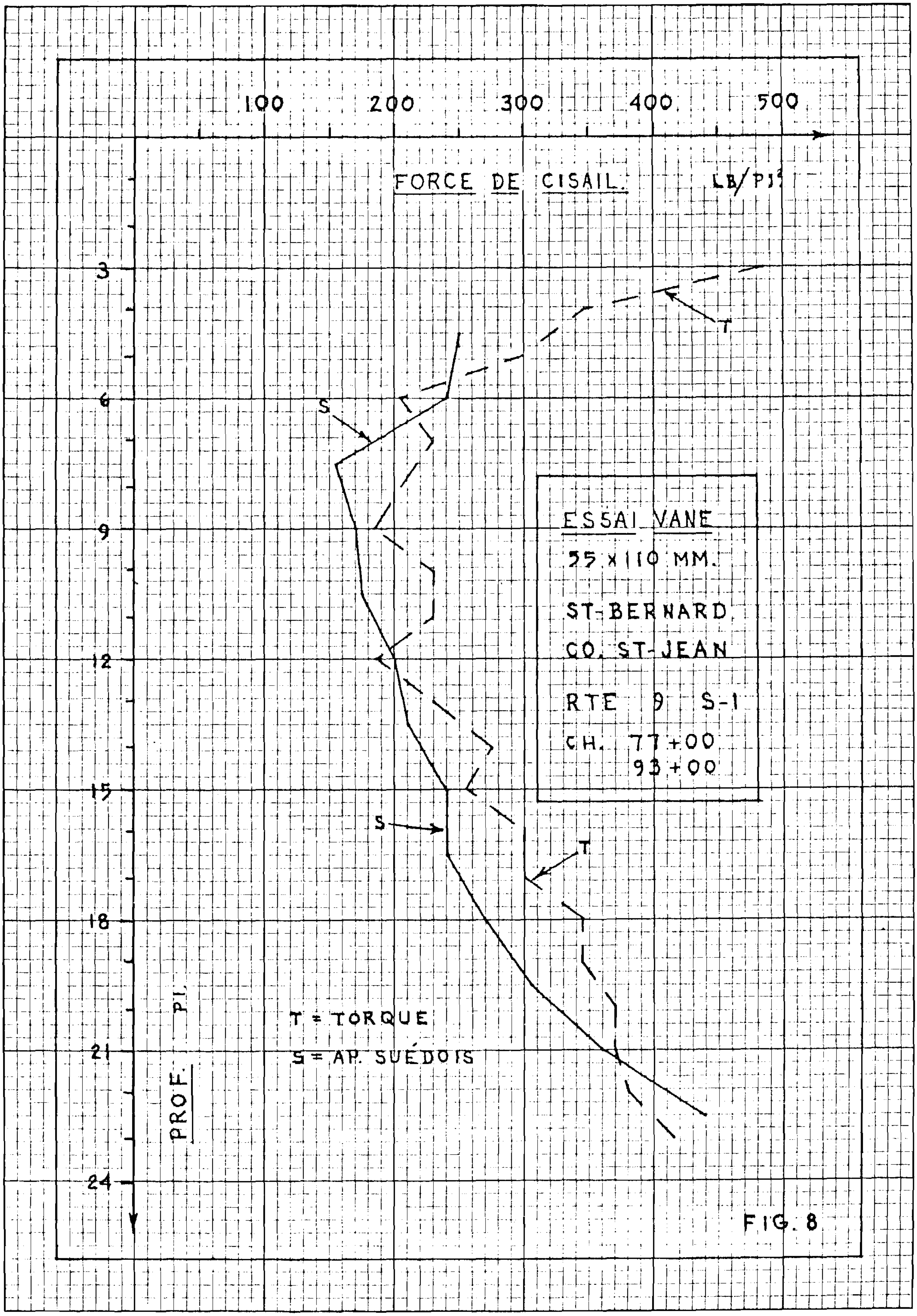
Scissomètre vane: petites, moyennes et grosses palettes, torquemètre. Orsainville.



Scissomètre vane: torquemètre et appareil Suédois, palettes moyennes. Orsainville.



Scissomètre vane: torquemètre et appareil Suédois, palettes moyennes. Saint-Bernard de Lacolle, S-1.



Scissomètre vane: torquemètre et appareil Suédois, petites palettes. Saint-Bernard de Lacolle, S-1.

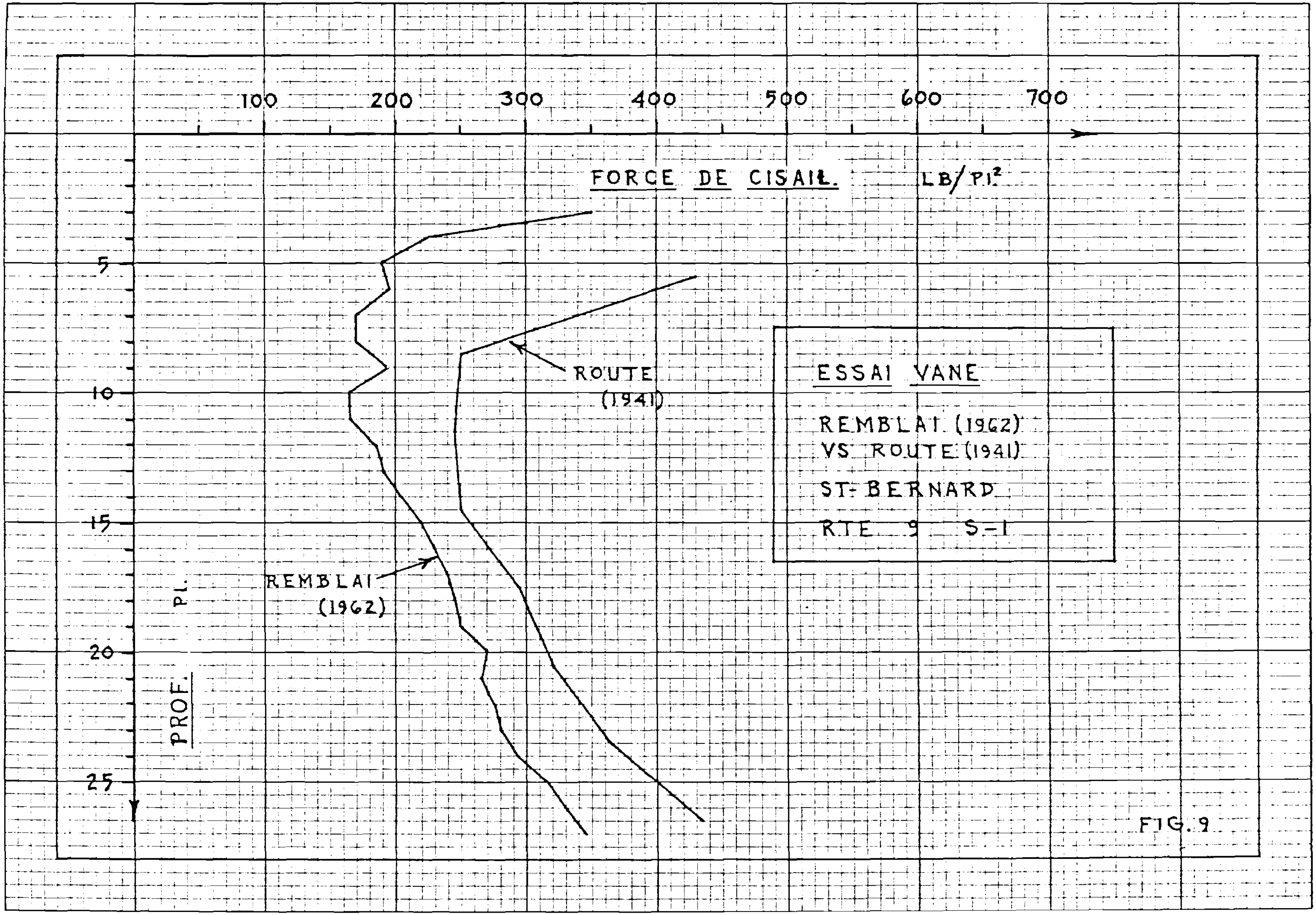


FIG. 9

Force de cisaillement sous la vieille route et sous la nouvelle chaussée. Saint-Bernard de Lacolle, S-1.

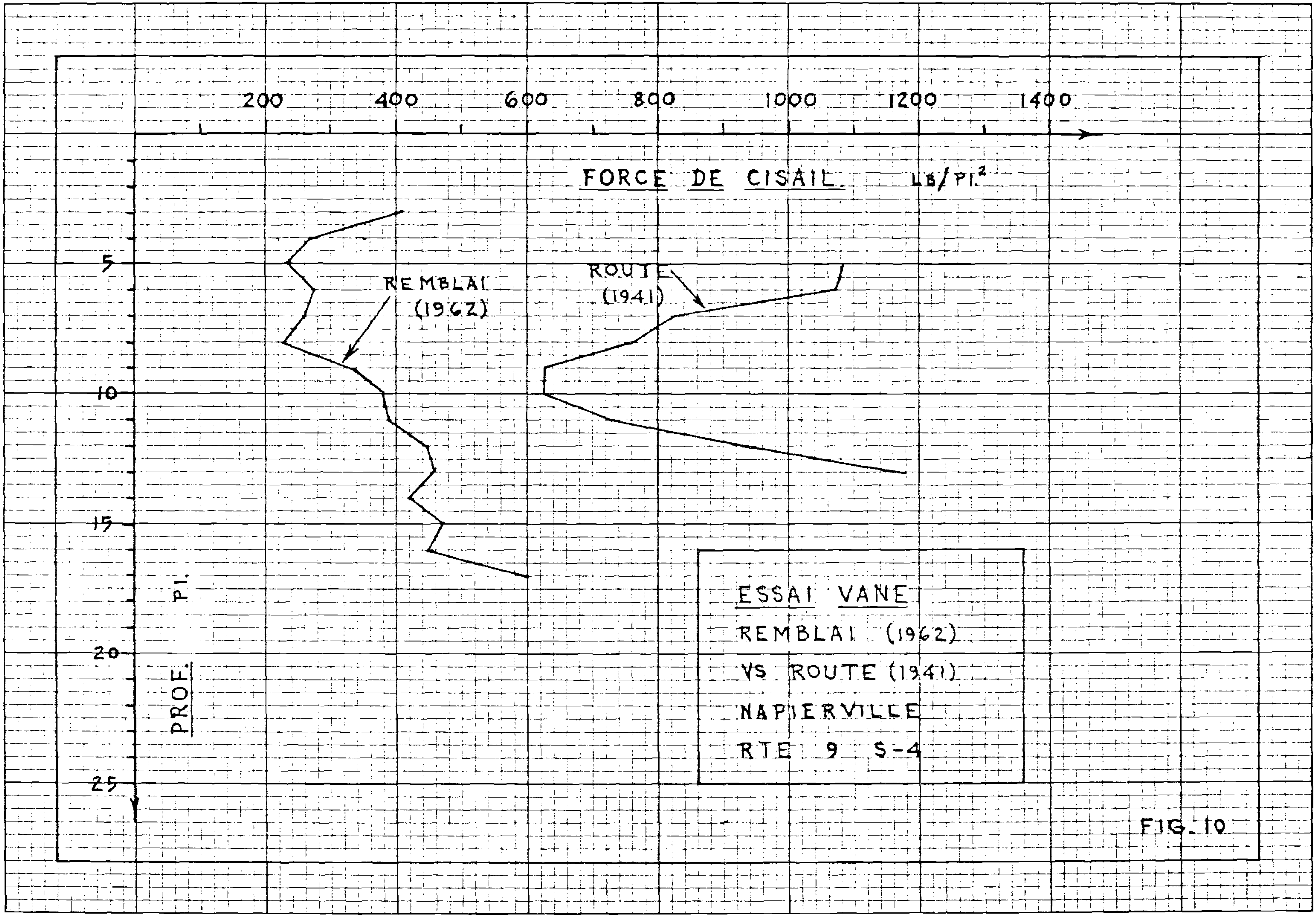


FIG. 10

Force de cisaillement sous la vieille route et sous la nouvelle chaussée. Napierville, S-4.

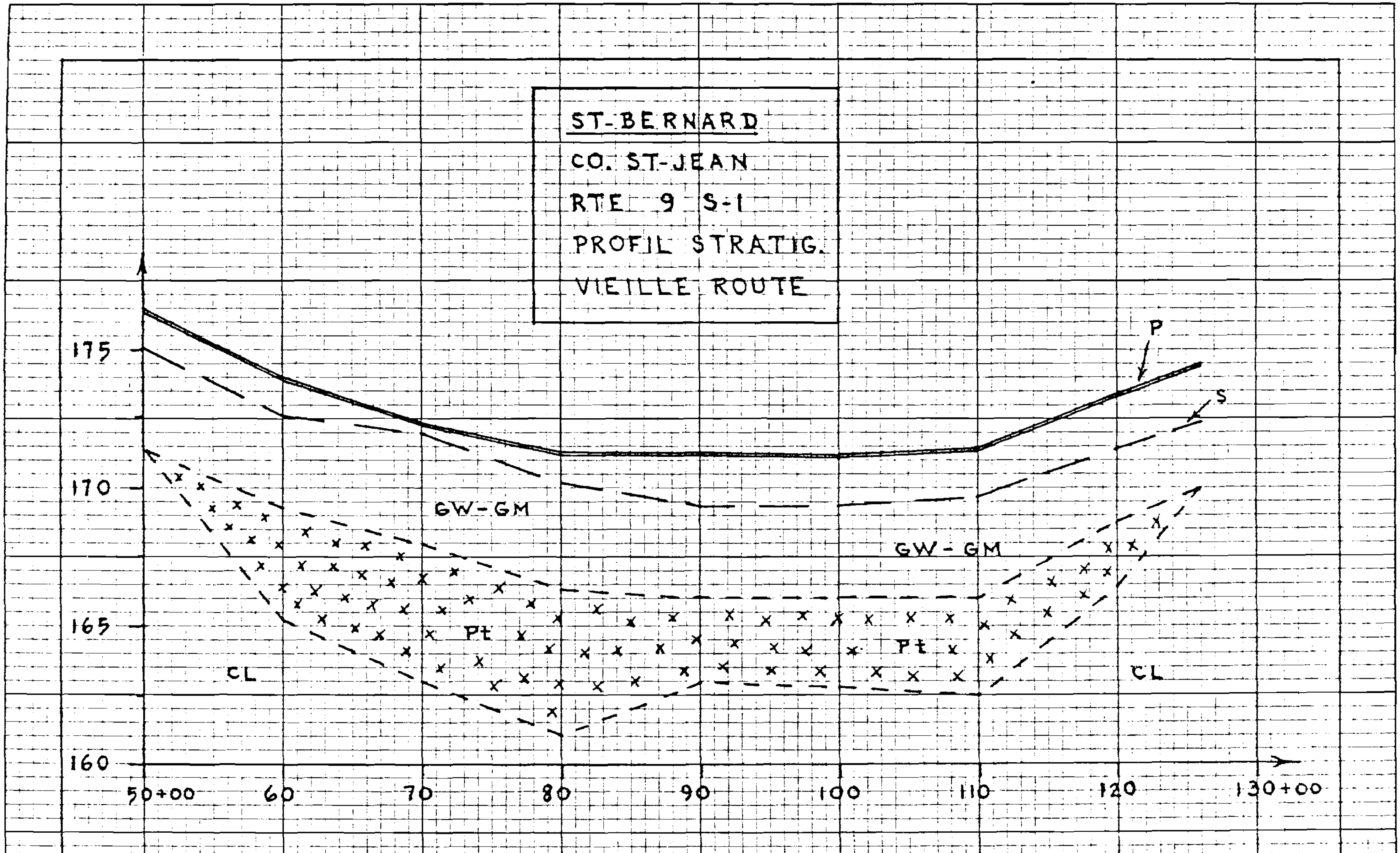
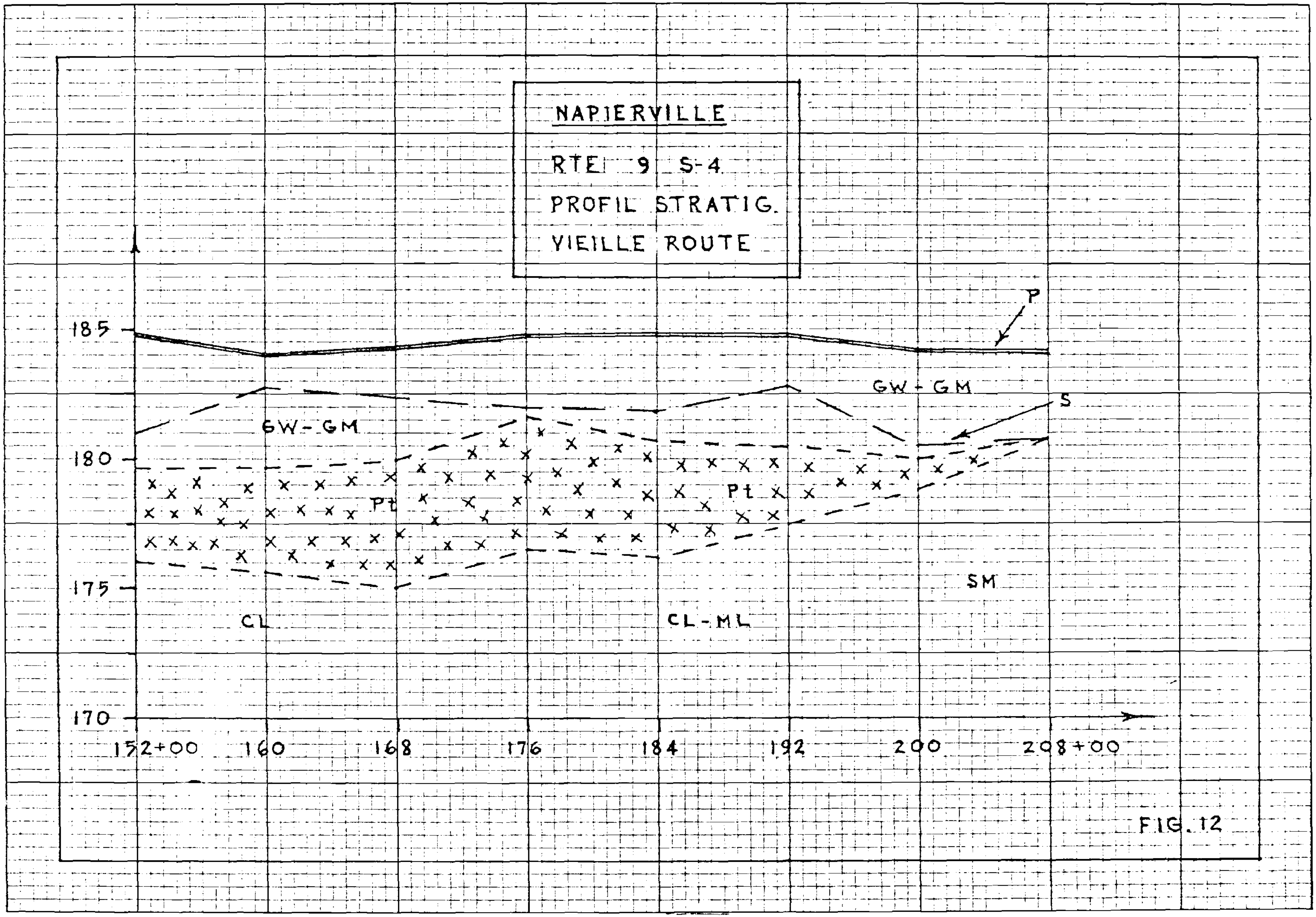


FIG. 11

Profil stratigraphique sous la vieille route. Saint-Bernard de Lacolle, S-1.



Profil stratigraphique sous la vieille route. Napierville, S-4.

SAVANE		TASSEMENT	
		ROUTE	REMBLAI
S-1	55+00 À 115+00	4.0' = 52 %	2.4' = 32 %
S-2	244+00 À 280+00	2.6' = 55 %	1.3' = 32 %
S-3X	0+00 À 40+00	3.8' = 32 %	3.4' = 34 % SOUS 4.5' CL 1.6' = 24 % SOUS REMBLAI 5.0' = 50 % TOTAL
S-3	48+00 À 120+00	DÉFONCÉE	4.3' = 50 %
S-4	152+00 À 196+00	3.8' = 53 %	2.3' = 31 %

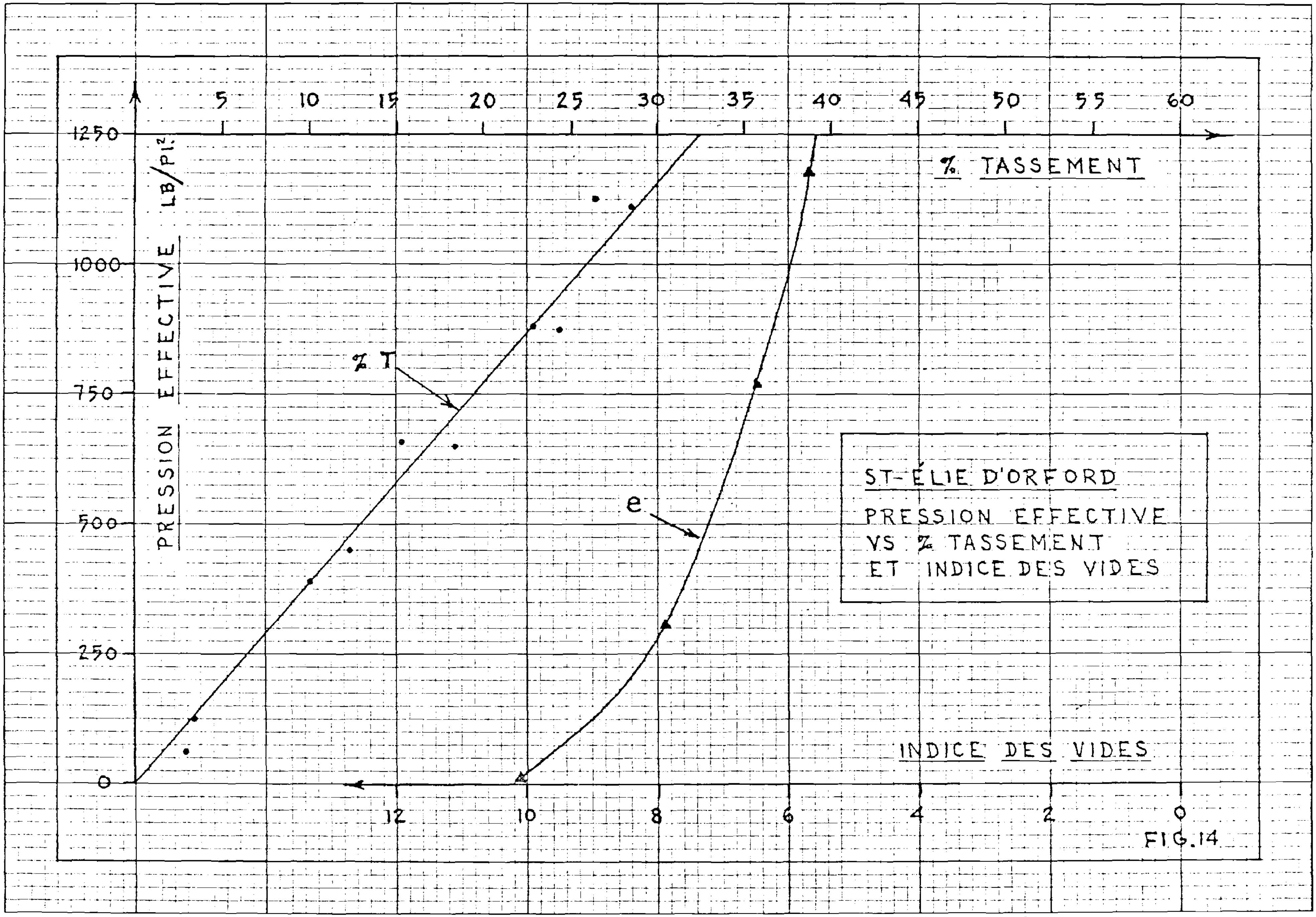
NAPIERVILLE

RTE 9 S-1-2-3-4

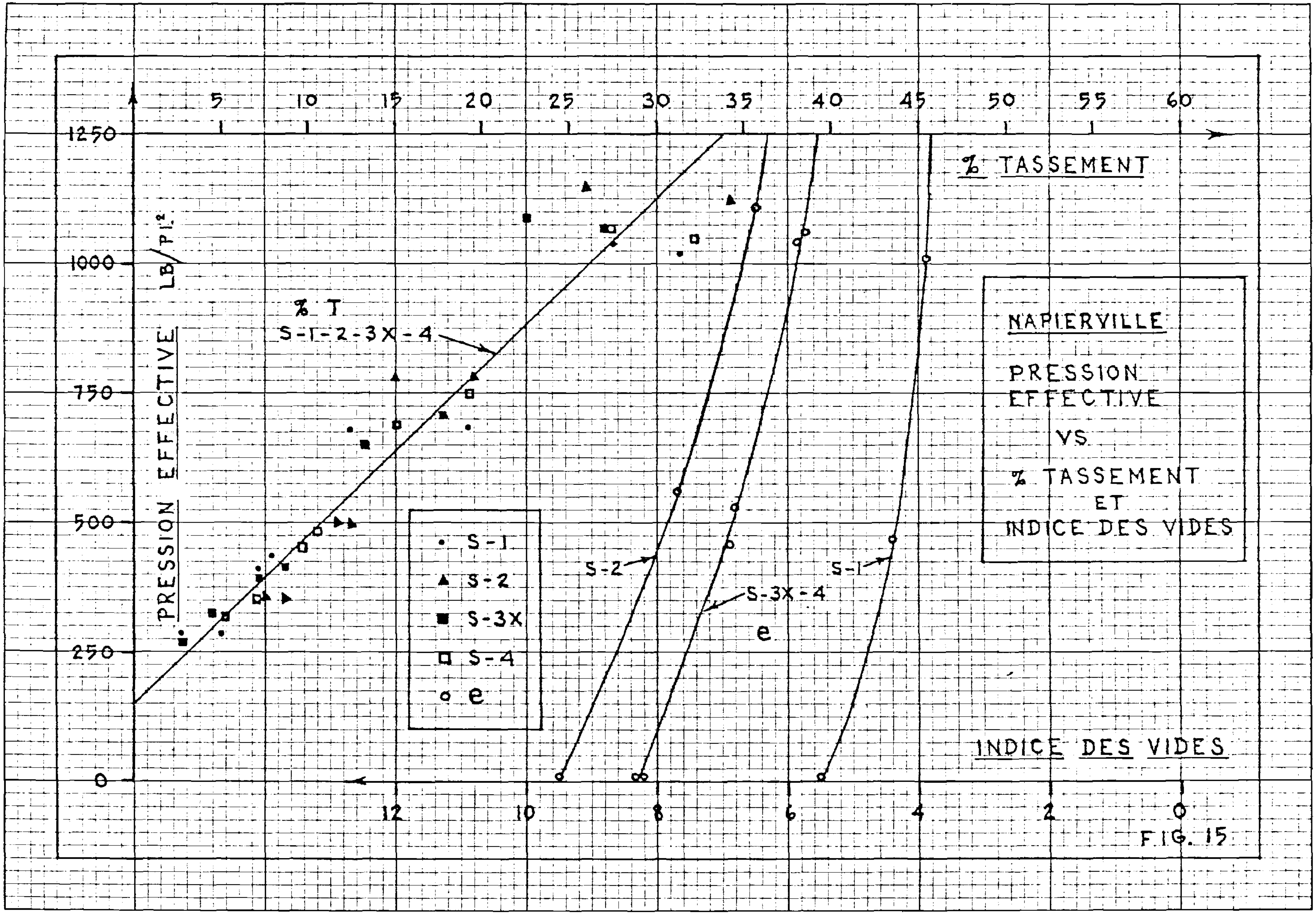
% TASSEMENT

FIG. 13

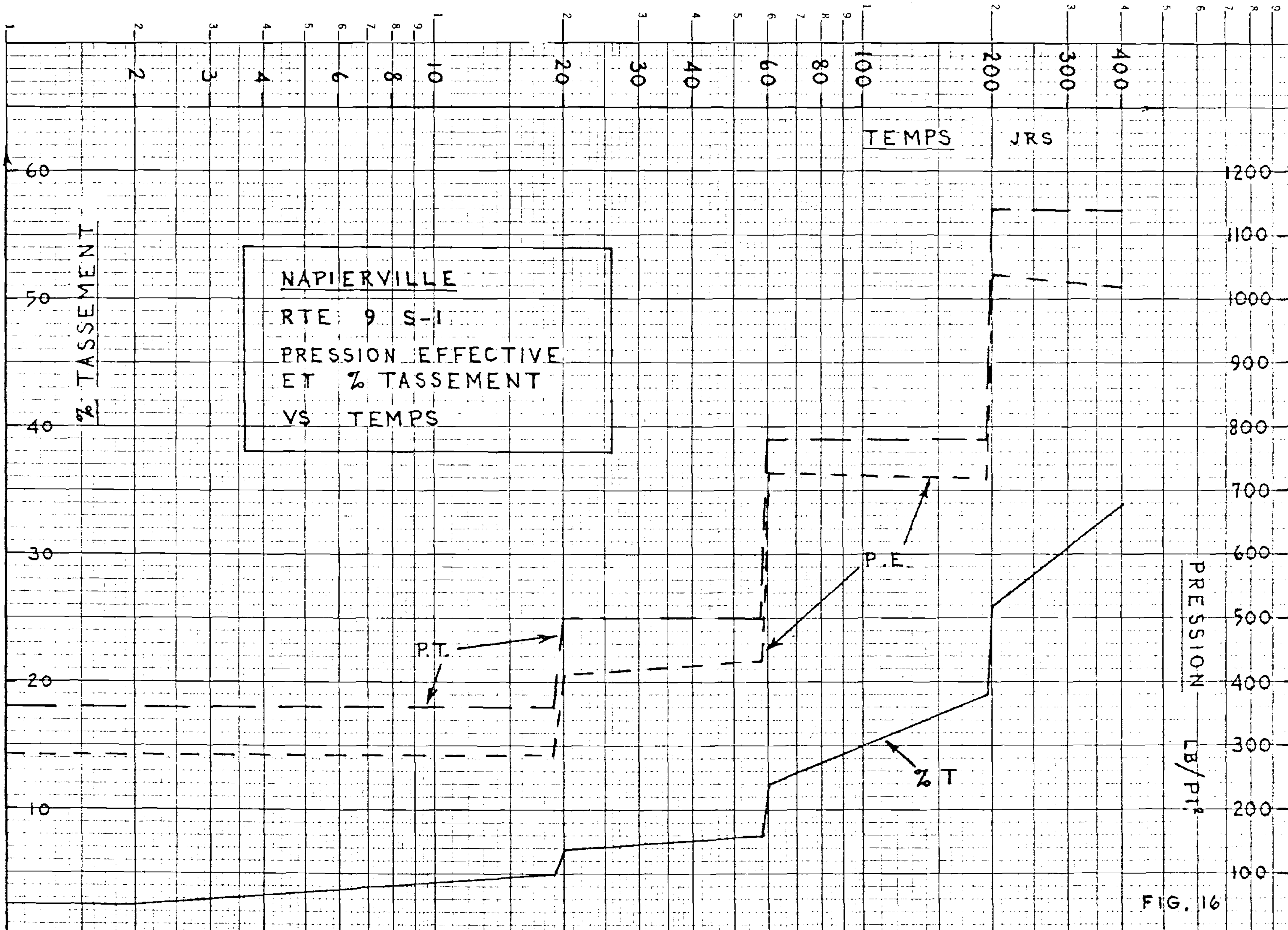
Table des tassements sous la vieille route et sous la nouvelle chaussée dans les savanes de Napierville.



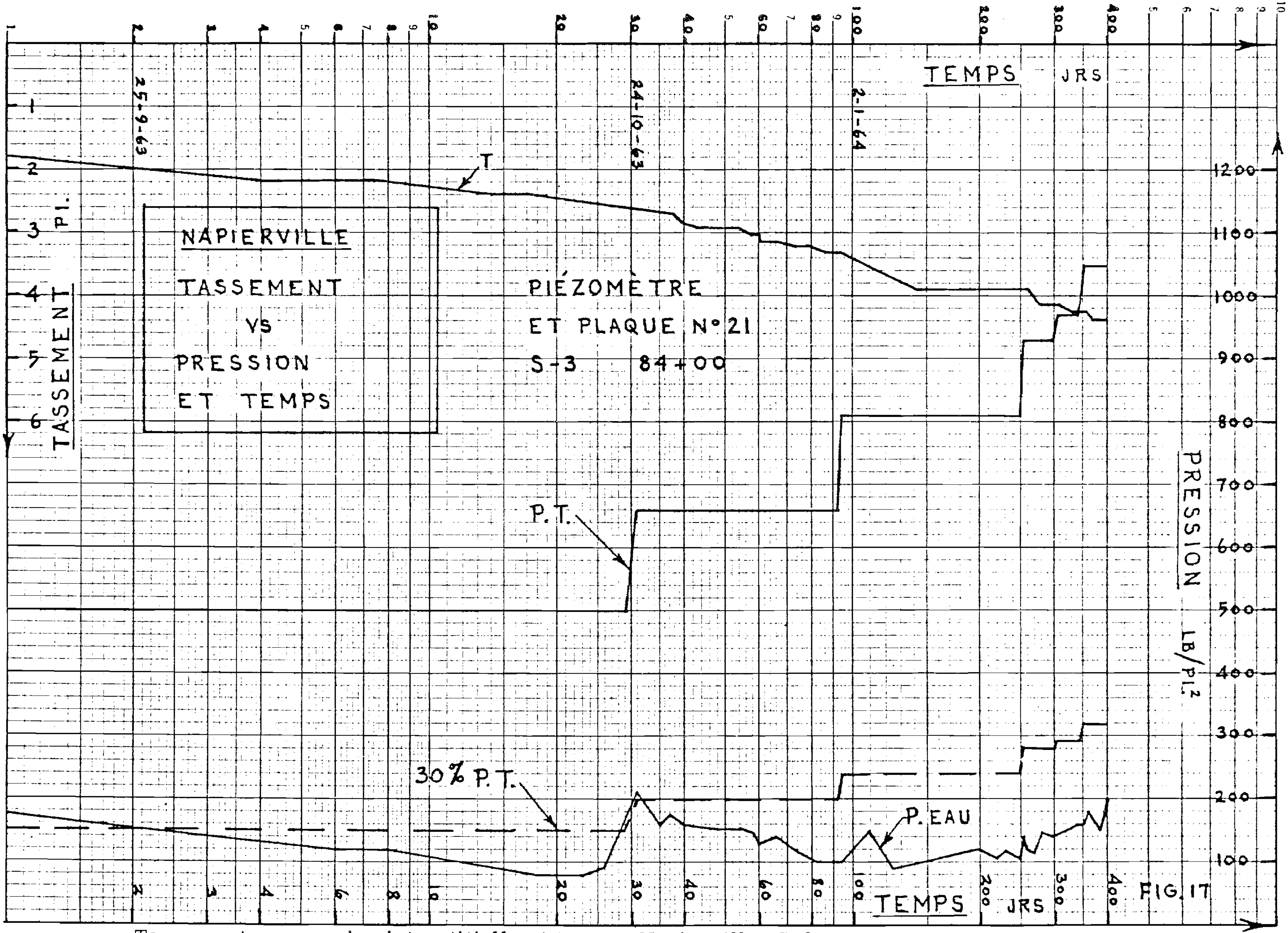
Pression effective vs pourcentage de tassement et indice des vides. Saint-Élie d'Orford.



Pression effective vs pourcentage de tassement et indice des vides. Saint-Bernard de Lacolle et Napierville. S-1-2-3-4.



Pression effective et pourcentage de tassement vs temps. Saint-Bernard de Lacolle, S-1.



Tassement vs pression interstitielle et temps. Napierville, S-3.

Discussion

Mr. Paré asked if the increase in shear strength was obtained with the large-sized vane. Mr. Tessier replied that it was obtained with the small-sized vane. He explained that the smallest vane gives the highest strength. Mr. MacFarlane reiterated that the larger the vane the smaller the shear results. He believed that results obtained with a particular size of vane has a great deal to do with particle-size factor.

Mr. Cronkhite asked Mr. Tessier if there was a time element when he began building on his muskeg, and did the pore pressure drop. Mr. Tessier replied that, for the first layer of about 3 ft, pore pressure goes down but as the depth increases, the pore pressure takes longer to go down.

Dr. Radforth, in commenting on Mr. Cronkhite's question, said that if we attempt to go from cover class and peat category to values such as pore pressure and other mechanical values or properties, we have to indicate what sort of range with respect to the properties we could work to. He felt that within a year we can give some values; we can effect a degree of judgment that is acceptable in construction. This has been done on a localized scale and a good example is recorded in the Proceedings.

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III.3. PEATLAND FORESTRY IN NORTHERN ONTARIO

J. McEwen*

Abstract:

Problems are discussed of the development of the forestry industry in the two major areas of organic terrain in Ontario: the Hudson Bay Lowlands and the Cochrane Clay Belt. Reference is made to a long-term study of the regeneration history of cutovers. After 41 years it is evident that there will be regeneration after logging on a slope of 1 per cent or more. For flatter areas, special treatment of the site is required for another timber crop. Methods of paludifying sphagnum are discussed: (1) establishment of a network of shallow ditches at the time of logging; (2) biological drainage, i.e., utilization of vegetation with high transpiration rates; (3) chemical approach; and (4) test planting to provide heavy shade.

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III.3. EXPLOITATION FORESTIERE DANS LES REGIONS A TOURBIERES DU NORD DE L'ONTARIO

J. McEwen

Résumé:

L'auteur étudie les problèmes que pose le développement de l'industrie forestière dans les deux grandes régions à sol organique de l'Ontario: les Basses Terres de la Baie d'Hudson et la Zone argileuse de Cochrane. L'auteur cite une étude à long terme du phénomène de régénération dans les coupes à blanc-étoc. L'observation d'une coupe blanche après 41 ans révèle que la régénération s'est produite sur les pentes atteignant 1% et plus. Un traitement spécial des zones plus horizontales est nécessaire pour l'obtention d'un nouveau peuplement forestier. L'auteur étudie les méthodes suivantes d'assainissement des terrains tourbeux: 1) établissement d'un réseau de rigoles peu profondes lors des opérations d'abattage des arbres, 2) assèchement biologique par l'utilisation de végéraux possédant un fort taux de transpiration, 3) méthode chimique, et 4) plantations d'essai donnant beaucoup d'ombre.

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* See Appendix "A" for affiliation.

As a preliminary to the main topic, attention must be drawn to a feature unique to forestry. Unlike mining, for instance, forestry deals with a renewable resource. What has been our goal for many years is sustained yield – to harvest as much, but no more, than we can grow – and to grow as much as we can. Unlike agriculture, which also deals with a renewable resource, our crop is not an annual but one which requires many decades to develop. Since pulp logging in our northern coniferous forests is only some 50-60 years old, we lack full knowledge of even one crop rotation to guide us. What we depend on is a series of studies of different ages of forests and certain European practices which have worked with different species of trees. So much for background.

In Ontario we have two major areas of organic terrain. The largest is the Hudson Bay Lowland, which spills over into Manitoba on the one side and into Quebec on the other. It is hard for a visitor to Ontario to realize that almost one-quarter of the province is covered by what Hugo Sjörs of the University of Upsala called a "watery desert".

The marshes and bogs which comprise the Lowland have made access virtually impossible and what knowledge we have comes from aerial investigations from the relatively few scientists who have visited widely separated points. A good feature is that it lies on Paleozoic rock rather than directly on the Precambrian shield. Over half of it is fen rather than bog.

From the standpoint of climate, two things should be noted. Moosonee has an average of 143 days a year with an average temperature of 42°F or more. A similar climate exists north of the Gulf of Bothnia where there is good agriculture. Also it has been reported that white spruce about 100 ft in height and approximately 110 years of age exist at the junction of the Attawapiskat and the Muketei. Climatically, all land south of this point is available for forestry use.

The second large area of organic terrain lies southeast of the Lowland and is separated from it by a form of low escarpment. This Cochrane Clay Belt has relatively low relief, carries balsam fir, white spruce, poplar and birch on the fresh sites and black spruce on the extensive lowlands.

In 1925, the Abitibi Power and Paper Company, concerned about regeneration on their cutovers, established a series of 48 plots in order to follow their histories. About half were in black spruce type and the remainder were on fresh sites where a mixed forest of conifers and hardwoods had grown. These plots were 100 ft square and were sited in 9 out of a block of 14 townships.

In 1947, after twenty-two years, the Department of Lands and Forests took over the study. After weeks of work, 43 of the 48 plots had been located and measured to provide information about the regenerative period. The plots were also remeasured in 1957 and in 1965. It is now over 40 years since the last of these plots were cut over. The rest are older (the oldest dating back 50 years). After the most recent remeasurement, it was felt that we should be able to find significant data in the merchantable sizes and we wished to correlate this with information which could be available at the time of logging. In the report made in 1947, the field party recorded the slope of the surface of the plots. Nearly half the plots were described as flat; the remainder had slopes of 1-5 per cent.

Table I lists on the left the plots which were described as flat in 1947 and, in the right, the plots with their recorded slope in 1947. There is also recorded for each plot the cross-sectional area of the tree stems at breast height - a measurement which in forestry is commonly used to compare the productivity of a site. The flat areas average less than one-third of the basal area found on the minor slopes. Only one flat plot, No. 26, has enough basal area to compare favourably with the slopes. But plot No. 26, back in 1925, was described as having a large amount of white cedar less than one foot in height. Again in 1947 the record of ground vegetation (in 1947) mentions wild sarsaparilla, and shield fern. These three species would not be present unless there was movement of soil water.

On the face of it, it now looks as if we could log on any slope of 1 per cent or more and get regeneration. If we work on flatter areas, special treatment of the site will be necessary to ensure a crop. The critical slope ties in with some foreign experience. In 1961, Boris Meshechuk of the Norwegian Forest Services mentioned 6 ft slope in 1000 as a criterion between soligenous and ombrogenous bogs.

Certain caution is needed here, however, as the critical slope for forest renewal may vary from zone to zone even in Ontario and may also be linked to the permeability of the inorganic soil below and to the presence or absence of paludifying sphagnum. A report on this study has been submitted and, we hope, will be published in due course. Further work on this subject is definitely proposed for the coming year.

Mention has been made above of paludifying sphagnum. A study on this was carried out in 1964 and 1965 and will be published in the June 1966 issue of the Forestry Chronicle. This report is a confirmation or an enlargement upon observations made by Dansereau and Segadas-Vianna (1952) in Canada, by Lebarron (1945) in the U.S.A. and by numerous authorities in Europe. The bare facts of the process are these:-

Sphagnum grows best under conditions of partial shade and plentiful water. When a site is subjected to cataclysmic change, such as wild fire or logging, transpiration from the site is sharply reduced and moisture accumulates. Species which successfully competed with sphagnum in the forest are killed by fire or by the new unfavourable moisture regime and the sphagnum remains. A new tree crop or shrubs provide partial shade and the sphagnum begins to mound. Its peculiar construction makes it most efficient in holding water and the sphagnum cuts off essential air from the tree roots. The accompanying Figure illustrate the results. Figure 1(a) shows the central root system from a spruce on a eutrophic site. It is shallow and all roots lived and functioned. Figure 1(b) is a rooting system from a mesotrophic site. A typical tree was nearly 200 years old but the oldest horizontal root was only 83. What had happened was that the lower roots were inundated and died. The tree grew new roots higher up and the cycle was repeated. This need of replacing roots, coupled with the low available nutrient content of the sodden site, has resulted in the poor growth characteristic of low sites and the formation of the vast areas of stunted muskeg.

The question is - What can be done? There are a number of lines of approach, some of which have never been put to the test. First, on the flat sites at the time of logging, establish a network of shallow ditches using special ploughs such as have been developed in Finland, Sweden or the U.S.S.R. By expediting the run-off we may prevent the initial takeover by sphagnum.

Next is to resort to what might be termed biological drainage. Since movement of moisture in all organic soils is slow and is almost nil in certain types, could we find annuals or perennials which could exist on these wet acid sites and, by transpiration, pump out the moisture? Taking a leaf from agriculture, could we use clover, birdsfoot trefoil, timothy or reed canary grass? If these agricultural standbys fail us, could we collect and utilize the seed from sedge or molinia grass?

The third method is the chemical approach. Russian authorities report that lime in any form will kill sphagnum and polytrichum without harm to other vegetation. Unfortunately it seems that about a ton per acre would be required. Could we spot the cutovers with a pattern of lime concentrations? Would other chemicals do as well in lesser quantities?

Fourthly, where planting is necessary would nest planting to produce localized heavy shade serve to kill sphagnum?

These are some of the lines we could pursue in seeking to prevent the loss of these forest sites which have been highly productive in the past. If we can establish an actively growing vegetation on an area, it will actually cause a drop in the level of organic soil and with this drop we draw nearer to the fertile mineral soil which lies below.

If we can succeed here, then we can look to an expansion northward where so much organic terrain is lying idle.

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Dansereau, Pierre and F. Segadas-Vianna, Ecological studies of the peat bogs of Eastern North America. Canadian Journal of Botany, Vol. 30, 1952.

LeBarron, Russell K., Adjustment of black spruce root systems to increasing depth of peat. Ecol. 26, 1945.

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TABLE I

Flat Sites		Sloping Sites	
Plot No.	Basal Area	Plot No.	Basal Area
1	30	6	100
2	16	7	126
3	35	8	77
4	47	9	142
12	19	10	117
15	54	11	76
17	30	13	109
18	31	14	82
20	49	16	79
25	65	21	89
26	88	24	66
28	54	27	80
29	13	35	97
30	16	36	175
31	18	37	147
32	8	38	103
33	38	42	144
34	6	43	98
39	52	44	146
47	63	46	185

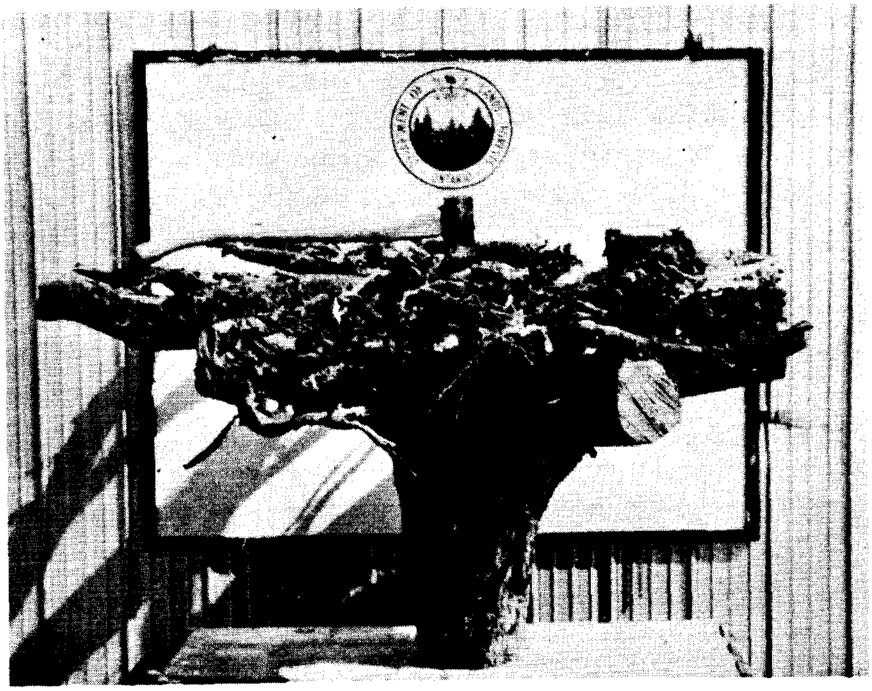

Figure 1(a). Central Root System from a Eutrophic Site.

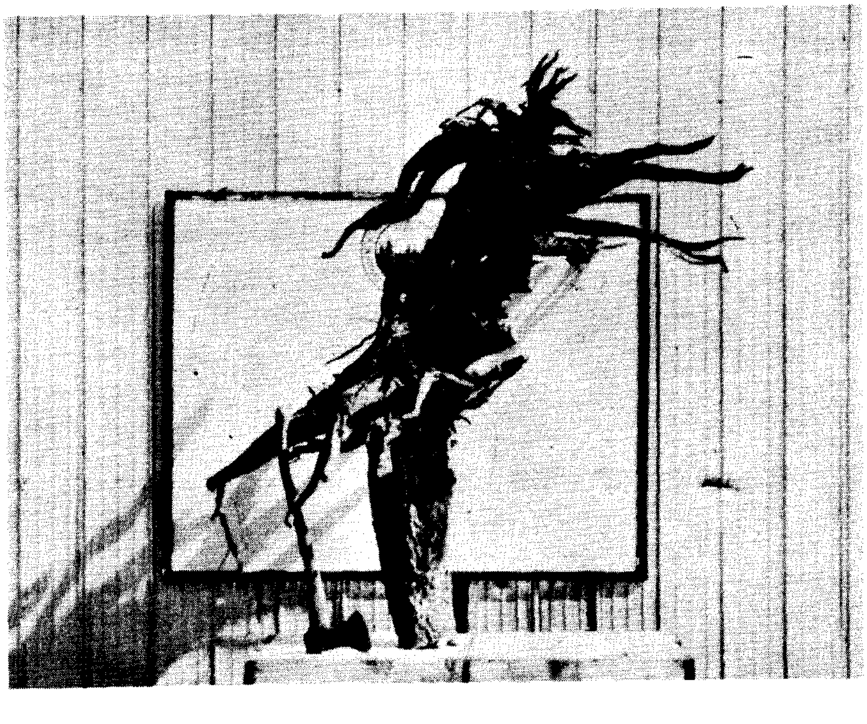

Figure 1(b). Rooting System from a Mesotrophic Site.

Discussion

Dr. Gorham asked if there are any data on transpiration, particularly on sphagnum. Mr. McEwen replied that there was. It was Russian in origin and was reported in 1959 in the Proceedings of their Forestry Institute.

Dr. Gorham thought that sphagnum would transpire. Mr. McEwen agreed, but said that the rate is very low. Dr. Gorham asked Mr. McEwen if he had any idea of the types of sphagnum studied. Mr. McEwen regretted that he did not. He stated that there are possibly 30 species of sphagnum and the Finns are probably the only people capable of identifying these without a microscope.

One delegate said that he was surprised to learn that Mr. McEwen had success with scotch pine. Mr. McEwen replied that he is conditioned by European experience. He noted the spruce in England is equivalent to our white spruce. He advised that last year they found that the initial growth on scotch pine was four or five times as great as that of spruce and he considered that pine may be able to keep ahead of the sphagnum growth. Scotch pine would succeed on fen peats.

Dr. Gorham asked Mr. McEwen if he had any rule of thumb as to what thickness of sphagnum peat is worth draining. Mr. McEwen replied that he had very little practical experience with it. He stated that they still concentrate on areas where peat is not too deep. He advised that in cases like this they might be able to treat with lime, phosphorus and/or potassium.

Dr. Radforth wondered how we are going to improve our method of sampling and measuring amounts of water present in the surficial layers of the organic terrain. Mr. McEwen replied that in the sphagnum the water content is so high that whether the water table is up or not most of the sphagnum areas over much of the year is running 85% water - sometimes 95%.

The question was asked whether lime has strictly a pH effect or what effect would it have on the sphagnum. Mr. McEwen replied that he had studied Russian and United Nations literature and the evidence was that there is more than a pH effect.

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III 4. PROSPECTS IN PEAT UTILIZATION

N. W. Radforth

Abstract:

Exploitation involves the use of land for the wisest possible purpose. This requires co-operation, consultation, and understanding on the part of the three main fields of interest involved: -

(1) those interested in fundamental research;
(2) the engineer who must apply the fundamental principles; and
(3) the layman, or user of the terrain.

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III. 4. UTILISATION FUTURE DE LA TOURBE

N. W. Radforth

Résume:

Il est nécessaire d'exploiter les terrains à moskeg de la façon la plus avantageuse. Cet objectif nécessite la collaboration, les consultations réciproques et la comprehension entre trois groupes de personnes concernées: 1) les scientifiques s'intéressant à la recherche fondamentale, 2) les ingénieurs utilisant les principes fondamentaux, et 3) les utilisateurs du terrain.

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(SUMMARY)

We have been talking a good deal about exploitation and utilization over the years. The program of the Annual Muskeg Conferences has reflected this. The point has always been made that we could get nowhere from the point of view of utilization until we do something about the access problem. The access problem, in the first instance, is a question of off-road vehicles affording reasonable cross-country mobility. A few years ago, we were helpless in this situation, except in winter. Now we have encouragement in the matter of access. On the basis of assuming that we can get into an area and construct roads, then we can look into the matter of exploitation. This will have more widespread application in the future.

Exploitation involves the use of land for the wisest possible purpose. There is a possibility of conflict on the use of organic terrain for agriculture or forestry. This dilemma will be on our doorstep soon, as it is already in Britain and in certain European countries.

Some of us will be involved with highly fundamental research as there is very little information on many basic subjects. We do not yet know how to treat organic terrain to get optimum results. We do not know how to advise agricultural people to treat organic terrain. Therefore, fundamentalists must be aware of these problems, whether in relation to agriculture, engineering, forestry, or manufacturing.

From time to time new propositions, with regard to definition, are introduced among us. Engineers may hear expressions for the first time. Fundamentalists may hear expressions from engineers for the first time. In an interdisciplinary study, this is necessary.

Another level is that of the layman. We have intelligent laymen and must apply an intelligent and sophisticated approach. Therefore, we have principles developed by fundamentalists and utilized by engineers. It is possible to educate laymen, e.g. vehicle operators, to appreciate these principles. It is possible to take a group of people, lecture to them on muskeg organization, take them out in the field to examine organic terrain, take notes, etc., and there will be a similarity in their notes.

We have reached the time when the fundamental approach should be examined and re-examined by all categories of engineers with regard to utilization. We are now at the threshold of intensifying utilization and must not lose touch with the fundamentalists. We must be aware of the responsibility we have to the lay population.

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APPENDIX "A"

LIST OF PERSONS ATTENDING TWELFTH MUSKEG RESEARCH CONFERENCE, CALGARY, 19 AND 20 MAY 1966

K. S. Attrell,
British American Oil Co. Ltd.,
P.O. Box 130,
Calgary, Alberta.

G. Ballivy,
Service Géologie,
Hydro-Quebec,
75 Dorchester Street West,
Montreal, P.Q.

G. E. Baldwin,
Saskatchewan Department of Highways,
300 - 9th Street East,
Prince Albert, Saskatchewan.

J. A. Barr,
Department of Mines and Natural Resources,
Norquay Building,
Winnipeg 1, Manitoba.

A. T. Bergan,
University of Saskatchewan,
Saskatoon, Saskatchewan.

H. Birch,
Chevron Standard Limited,
Medical Arts Building,
Calgary, Alberta.

C. D. Bird,
Department of Biology,
University of Calgary,
Calgary, Alberta.

S. R. Blair,
Alberta Natural Gas Company,
Calgary, Alberta.

O. Botar,
D.O.T. Air Services,
Edmonton, Alberta.

W. W. Boucher,
Sarnia Products Pipe Line Division,
Imperial Oil Ent. Ltd.,
Box 380,
Waterdown, Ontario.

P. M. Brady,
Water Investigations Branch,
Department of Lands, Forests and Water Resources,
Parliament Buildings,
Victoria, B.C.

C. O. Brawner,
Golder, Brawner & Assocs. Ltd.,
1037 West Broadway,
Vancouver, B.C.

Miss J. Butler,
Division of Building Research,
National Research Council,
Ottawa, Ontario.

W. A. Campbell,
Department of Northern Affairs and National Resources,
Ottawa, Ontario.

J. F. Capelle,
Hydro-Quebec,
75 Dorchester Street West,
Montreal, P.Q.

R. B. Christie,
Director of Sales,
Robin-Nodwell Mfg. Ltd.,
P.O. Box 1450,
Calgary, Alberta.

A. W. Clifton,
Department of Civil Engineering,
University of Saskatchewan,
Saskatoon, Saskatchewan.

A. R. Coad,
Department of Northern Affairs & National Resources,
725 - 11 Avenue, S.W.,
Calgary, Alberta.

R. F. Comstock,
Stanley Assoc. Engineering Ltd.,
534 - 8th Avenue S.W.,
Calgary, Alberta.

J. B. Cragg,
University of Calgary,
Calgary, Alberta.

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

D. K. F. Dawson,
Mobil Oil Canada Ltd.,
Edmonton, Alberta.

W. J. Dickson,
Warnock Hersey Soil Investigations,
250 Madison Avenue,
Toronto, Ontario.

R. Dubas,
R. M. Hardy & Assocs. Ltd.,
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