Construction and Performance of Pavement over Muskegs

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ABSTRACT

The long-term performance of embankment and pavement over muskegs along the James Bay access road is described. The road was built in 1973 in a discontinuous permafrost region. The embankments were designed by a preloading method based on the Von Post classification. Twenty-four embankment sections over deep muskegs were selected from a total of 54 for detailed performance studies. They have been characterized by their distribution along the road; their geometry; the type and quality of their underlying soil; the Von Post classification; the shear strength and depth of their peat materials; and the height, type, and typical cross section of their embankment. The performance of pavement built over deep muskegs has been defined in terms of long-term settlement, change in pavement roughness, structural behavior, and deterioration of the surface. On the whole, 8 years after construction, the performance of pavement built over deep muskeg is satisfactory: Long-term settlement generally varies between 25 and 50 percent of the thickness of the peat deposit except where ice is present under the peat; the riding quality, which still has a good rating, is 50 percent rougher over peat deposits than elsewhere; there is a loose relationship between the height of embankment and the maximum deflection; the dynamic modulus of peat under the embankment is on the order of 50 mPa under Dynaflect loading conditions; and longitudinal cracking is two to four times greater over peat deposits than in other areas.

The techniques of design and construction of highways over muskeg are well documented in the literature (1,2) and generally fall within four categories:

- Complete or partial removal of peat material underneath the roadway,
- Stabilization of material by draining and preloading,
- Building of pile-supported roadway through peat deposits, and
- Building the embankment using bridging techniques and delaying pavement construction to allow postconstruction settlements.

In northern regions, where muskeg occurrence is great and where it is not always possible to relocate a road to avoid muskegs, complete or partial excavation of peat material is recommended (3) only if the depth of peat is less than a meter, drainage can be improved, and the underlying material has a good bearing capacity. In all other cases, it is preferable to build the embankment over the muskeg after limited removal of vegetation, using bridging techniques where necessary, and to accept some postconstruction settlements.

Although the technique of building embankments over muskeg is important and will eventually gain more importance with the rapid development of the north, very little is known about its reliability; indeed, a literature survey revealed that very few papers dealing with the performance of roads over muskegs (3,4) place great emphasis on the relation between the properties of the peat and the long-term performance of the embankment.

An attempt will be made to describe the long-term performance of embankment and pavement over muskegs along the James Bay penetration road. The design of the road was based on simple relations established by Lefebvre et al. (5) between the Von Post classification of peat (6) and its short-term physical and mechanical behavior.

THE ROAD

The principal access road to the James Bay hydroelectric complex in northern Quebec was built during the summers of 1972 and 1973 in an almost virgin territory. The access road is 620 km long and runs from Matagami (North 49.8 degrees) to LG-2 (North 53.8 degrees). It was paved between 1974 and 1976, and since then its general performance had been periodically monitored according to a pavement maintenance management system (7).

The territory where the road is situated is a discontinuous permafrost area (8) that can be divided in two geomorphologically different zones as shown in Figure 1:

1. From kilometers 0 to 275, approximately, the road crosscuts the James Bay lowlands (9); principal soil types are classified A-5 to A-7, mostly silty clay or clayey silt, sometimes varved, with low shear strength and consolidation. The southern part of the region is heavily wooded with spruce and birch.
2. From kilometers 275 to 600, the undulated terrain exhibits rock outcrops aligned in the east-west direction and is crosscut by low valleys and moraine plateaus (9); principal soil types are classified A-1 to A-4; in the low areas and depressions the soils are classified A-6 or A-7. Between kilometers 400 and 530 and kilometers 550 and 600, the sandy soils found almost everywhere along the road have jack pine vegetation and almost no organic soil. In the low area, spruce swamps or string bogs are common along slow-draining creeks.

DISTRIBUTION OF MUSKEG

Mean distribution of principal soil types is given in Table 1 for each geomorphologic region. Although the whole area is considered a territory with a moderate (north) to a high (south) probability of

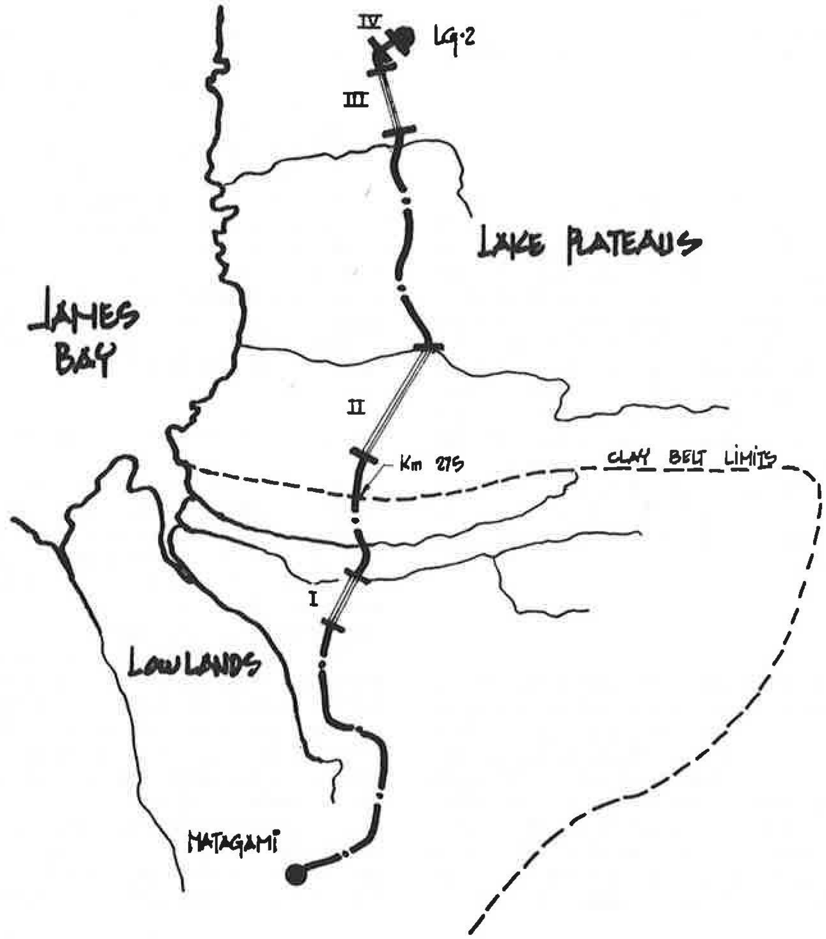

FIGURE 1 High muskeg occurrence zones (I, II, III, & IV), James Bay access road.

TABLE 1 Mean Soil Distribution Along the James Bay Access Road[a]

Southern section (0-275 km)		
Soil types	Mean %	Range %
Till	8	4-15
Sand or gravel	5	0- 7
Silt	22	5-40
Clay	55	50-60
Peat:		
- all deposits	-	6-37
- deposits of more than one meter deep	9	2- 8
Rock	5	0-10

Northern section (275-620 km)		
Soil types	Mean %	Range %
Till	20	8-32
Sand or gravel	37	20-57
Silt	13	6-10
Clay	7	0-20
Peat:		
- all deposits	-	10-30
- deposits of more than one meter deep	9	2-12
Rock	16	3-33

[a]According to the original geotechnical investigation before construction; the actual road has less than 5% of peat section having more than one meter on depth: 3% have more than 150 m long.

occurrence of muskeg areas (2), most of the muskeg areas crossed by the road are less than a meter in depth and are concentrated in four well-defined zones.

Zone 1

Zone 1 is between kilometers 150 and 230; it is situated south of the Broadback River in a clay belt that is typical of the James Bay lowlands. Peat sections are typically spruce swamps on clay deposit and are generally heavily wooded and concentrated in low areas. Thin peat deposits are very frequent; however, only 10 to 15 deposits are more than 1.5 m in depth. The Von Post classification index (6) of peat material varies between H-2 and H-10, often with an index from H-2 to H-4 at the surface (0-0.5 m) and from H-6 to H-10 toward the bottom of the deposit. Some deposits show only one category of peat material. The H-10 material is therefore rare; most of the peat material is H-7 or H-8 at most. The underlying material is silty clay and often very hard at the contact zone.

Zone 2

Zone 2 is between kilometers 315 and 400; it is located in the southern part of the plateau region where thin sheets of muskeg are found in the depressions between low-lying outcrops. Peat sections are typically spruce swamps or areas of low vegetation over clayey silt deposits. Peat deposits are often more than 300 m long with 1.2 to 2.5 m of peat material. The Von Post classification indices vary from H-4 to H-8 and the underlying clayey silt is often very soft with low consolidation or shear strength.

Zone 3

Zone 3 is between kilometers 535 and 570; it is located in an area similar to zone 2 but at the edge of a vast sandy deposit with frequent sandy or silty sand underlying material. Palsas [discontinuous permafrost characteristic features (10)] are common in this zone that is in the dryest part of a muskeg area, under low peat cover (1-1.5 m maximum), at the edge of the muskeg area, and in close contact with inorganic highly freezing silty material. In this zone, at least five palsa fields were crosscut by the road (11).

Peat deposits in the zone vary between 100 and 400 m in length and are 0.5 to 2.5 m in depth. The Von Post classification index is typically H-7 to H-10, and in at least one area (km 549.7) there is a deposit of organic brown clay of high shearing resistance (Su > 90 kPa). Underlying soil is typically a low resistance clayey silt, dense sandy silt, or silty sand.

Zone 4

Zone 4 is located between kilometers 604 and 618 where the road runs along the La Grande River valley. Muskegs are common in a low-lying area between outcrops where spruce or bush vegetation is scarce. More than 25 percent of the total road length in this section is muskeg.

Other Sections

Other peat sections along the road are typically bog areas adjacent to lakes or along creeks meandering between cliffs. Most of those areas are unvegetated short stretches with deep (2-5.5 m) low bearing capacity materials overlying rock or sandy-silty deposits. The thickest rockfill was used over many of these sections.

Careful selection of the road alignment before construction and relocation of alignment during construction avoided many important muskegs that can be seen from the roadway. In fact, the road crosses 54 deep (> 1.0 m deep and > 150 m long) muskegs that together represent 16 km of road, 60 percent of which are located north of kilometer 275. Figure 2 shows typical longitudinal profiles of the muskegs. A summary of the general characteristics of each muskeg is given in Table 2.

DESIGN OF EMBANKMENT OVER MUSKEG

To minimize long-term settlement the design of embankment over muskeg was based on the concept of consolidation before paving. The embankment and the subbase of the pavement were built during the summer of 1973, and the road was opened to heavy traffic and maintained during the 3 years before paving in the summers of 1975 and 1976.

On deep muskegs, the duration and magnitude of loadings were based on the Von Post classification index (Table 3) using a relationship established between the Von Post scale (VPS) and the following properties: specific gravity, natural void ratio, virgin compression index, rebound index, and deformation modulus (5).

As indicated by the authors (5), this approach, based on simple tests and classifications, has proven to be very practical when a good estimate of the order of magnitude is desired and when

- There are a good number of muskegs coupled with a difficult field access;
- The properties of peat vary considerably from one location to another within and between muskegs;
- It is almost impossible and very costly to perform a comprehensive analysis of each muskeg; and
- Based on field settlement measurements, the calculated settlement tends to overestimate (VPS > 5) or underestimate (VPS < 5) the true settlement.

PERFORMANCE OF PAVEMENT BUILT OVER MUSKEGS

The entire 620 km of road have been subjected to periodic evaluation since the road was paved:

- Dynaflect deflection measurements were made once in the summer of 1978 at a rate of four measurements per kilometer;
- Road roughness was evaluated eight times during the summer, and twice in the winter to measure the effects of winter; and
- Degradation of the surface was identified and quantified in terms of extent and severity in 1978, 1980, and 1982.

Generally, until now, the pavement has performed satisfactorily over peat deposits except for the several settlement zones where palsas were encountered and where leveling and reloading were periodically required.

A detailed survey of road sections built over major muskeg was done in June 1983. The survey consisted of

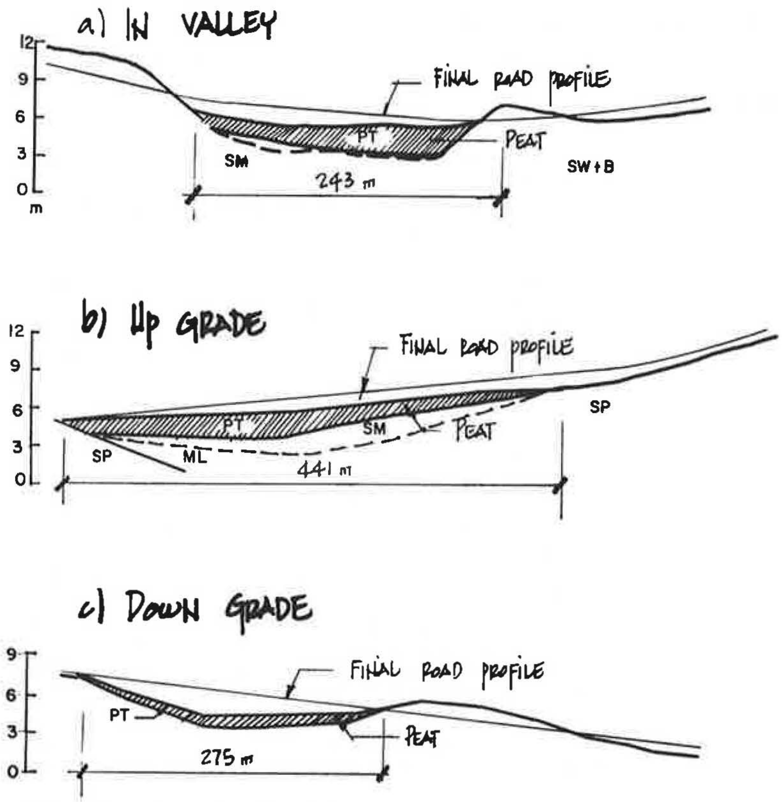

FIGURE 2 Typical profiles of peat deposits.

TABLE 2 Characteristics of 54 Deep Muskegs[a] Crossed by the James Bay Access Road (16.81 km or 2.7 percent of road)

Regional Distribution		km	Number	Length/km
James Bay Lowlands		0-150	4	1.66
		150-275	13	4.6
Lake Plateaus		279-450	18	6.2
		490-620	16	3.35
		600-620	3	1.00
Initial[b] Peat Thickness (m)		km	%	
<1.5		3.75	22.3	
1.5-2.5		11.00	69.4	
2.5-3.5		1.60	9.5	
>3.5		0.7	4.1	
Soils Type underneath Peat		km	%	
CL	A-7	6.55	39	
ML, CL, ML thin	A-5, A-6	6.00	35	
SM-SP	A-2, A-3, A-4	3.60	21	
SP	A-1	0.41	2.4	
Rock		0.46	2.5	
Topography		km	%	
Up grade		5.2	31.5	
Down grade		3.2	17	
Crossing of valley		6.0	35.5	
Plateau		3.0	17	
Maximum thickness of embankment (m)		km	%	
<1.5		2.7	16.1	
1.5-2.5		11.5	68.4	
2.5-3.5		2.0	11.9	
>3.5		1.0	6	

[a] Peat deposits having more than 150 m in length and more than 1.0 m in depth.
[b] Before construction of embankment.

TABLE 3 Degree of Decomposition After Von Post (5)

DEGREE OF DECOMPOSITION VON POST'S SCALE	INFORMATION FOR IDENTIFICATION
H_1	Completely unconverted and mud-free peat which, when pressed in the hand, only gives off clear water.
H_2	Practically completely unconverted and mud-free peat which, when pressed in the hand, gives off almost clear colourless water.
H_3	Little converted or very slightly muddy peat which, when pressed in the hand, gives off marked muddy water. The pressed residue is somewhat thick.
H_4	Badly converted or somewhat muddy peat which, when pressed in the hand, gives off marked muddy water. The pressed residue is somewhat thick.
H_5	Fairly converted or rather muddy peat. Growth structure quite evident but somewhat obliterated. Some peat substance passes through the fingers when pressed but mostly muddy water. The pressed residue is very thick.
H_6	Fairly converted or rather muddy peat with indistinct growth structure. When pressed at most 1/3 of the peat substance passes through the fingers. The remainder extremely thick but with more obvious growth structure than in the case of unpressed peat.
H_7	Fairly well converted or marked muddy peat but the growth structure can still be seen. When pressed, about half the peat substance passes through the fingers. If water is also given off, this has the nature of porridge.
H_8	Well converted or very muddy peat with very indistinct growth structure. When pressed, about 2/3 of the peat substance passes through the fingers and at times a somewhat porridgy liquid. The remainder consists mainly of more resistant fibres and roots
H_9	Practically completely converted or almost mudlike peat in which almost no growth structure is evident. Almost all the peat substance passes through the fingers as a homogeneous porridge when pressed.
H_{10}	Completely converted or absolutely muddy peat where no growth structure can be seen. The entire peat substance passes through the fingers when pressed.

- Boring, sampling, and measuring the static and dynamic shear strength using the Corps of Engineers type of penetrometers on the virgin peat outside the road, in the ditches, or through the embankment;
- Topographic surveys and determination of the profile of embankment resting on deep peat deposits; and
- Mays ride meter pavement roughness measurements in the most heavily used lane, along the muskeg and 2 km on either side of the muskeg.

CHARACTERISTICS OF 24 DEEP MUSKEGS

Twenty-four road sections crossing muskegs deeper than 1.5 m and more than 150 m long were selected for detailed performance studies using pavement evaluation data obtained since 1978 and results from detailed surveys made in 1982 and 1983. Table 4 gives the characteristics of the 24 most important peat deposits:

- Location and length of muskeg;
- Depth, Von Post classification, and shear strength of peat material;
- Type, quality, and estimate of shear strength of underlying material;
- Height, type, and typical profile of the embankment actually observed in the field; and
- Evaluation of embankment settlement 10 years after construction (June 1983); the settlement was estimated by boring through the fill material and by topographic surveys of embankments compared with the natural surrounding peat and embankment level.

TYPICAL CROSS SECTION OF SETTLED EMBANKMENT OVER PEAT DEPOSIT

Two typical cross sections of embankment were noted over peat deposits along the road (Figure 3):

- Where embankment height is less than 1.5 m, as it is in a spruce swamp muskeg, ditches 0.5 to 1.0 m deep are along both sides of the embankment and the actual level of the pavement surface has more or less reached the level of the muskeg due to settlement of the embankment. Fill material is typically uniform sand or sandy gravel, and the actual slope of embankment is small (i.e., 3 to 5 horizontal for 1 vertical).
- Where embankment height is more than 1.5 m and peat deposits are deep, with or without trees, and have open water, ditches are nonexistent and the slope of the embankment is less than 1.5 to 2.0 horizontal for 1 vertical. Most of the time, the rockfill has been placed over a bed of trees bridging the fill. Penetration of the fill into the peat deposit can be as much as 1.5 m, and the actual road level is 1.5 to 4 m above the surrounding muskeg.

TABLE 4 Description of Deep Peat Deposits (>1.5 m) Along the James Bay Road[a]

Station km	Unit of peat deposit	Nature of peat deposit: Depth m	Von Post	Su[a]	Underlying material: Type	Su[a]	Embankment: Height	Type[b]	Class (fig.3)	Settlement After 10 years: Meter	% peat depth
152.8	0.29	1.4	H-8	12-30	ML	100-200	1.4	SG	1	0.8	57
183.7	0.415	4.6	H-5		CL		1.3	SG	1	0.6	13
193.7	0.365	2.28	H-5	0-25	CL	40-90	1.7	SP-SG	1	1.3	57
202.7	0.14	2.2	H-6	45	IP=10 CL	40-60	1.51	Rock fill	1	0.7	32
206.5	0.21	1.5	H-4	0-15	ML sabl.		2.15	SG Rock fill	2	0.8	53
226.4	0.152	2.74	H-3	0-15	IP=10 ML	60-100	1.95	SG	1	0.9	32
230.5	0.46	3.66	H-2	0-25	IP=5 ML	30-150	1.23	SG	1	1.7	46
316.3	0.20	2.5	H-5	0-20	ML	45-70	2.33	SG	.2		
318.5	0.27	2.35	H-8	0-25	ML-Cl	70-80	1.65	SG	2	0.90	38
319.0	0.31	2.30	H-8	0-17	ML-CL	70-80	1.65	SG	2	0.75	33
336.4	0.50	2.5	H-7	0-15	ML-SM		1.0	SP	1	0.75	28
337-6	0.19	2.1	H-7	0-27	ML-SM	75-80	2.1	SG	1	0.75	36
388.9	0.75	3.0	H-8	6-48	ML	80-105	2.7	SG Rock fill	1	1.0	33
518	0.23	2.5	H-10	0-12	SM-SP	N=25	4.2	SG Rock fill	2	0.90	36
548.1	0.21	2.5	H-6	0-20	ML		2.28	SG	1 Berm	0.70	28
549.7	0.285	2.0	H-10	93+	SM-ML	N=20	2.2	SG	1	0.75	37.5
550-4	0.14	2.0	H-7	12-30	ML	66	2.7	SG	1	0.6	30
550.6	0.40	2.1	H-4	3-18	ML	6.6-1.2	2.7	SG	2		
552.5	0.28	2.0	H-6	18-39	IP=3 ML		1.3	SG	1		
558.4	0.21	1.6	H-7	5-27		87+	2.6	SG	2	0.5-0.9	31-22
559.3	0.213	1.8	H-7	0-12	ML		2.57	SG	2		
604.1	.411	1.95	H-6	30-40	ML	120	2.35	SG-SP	2	0.6	31
609.9	.305	2.6	H-4 H-5	12-50	ML	110	1.65	SG	2	0.51	25
613.2	0.274	2.1	H-4	50-60	ML	140	2.30	SG	2	0.8	38

[a]Su, undrained shear strength resistance, KPa.
[b]According to unified soil system classification.

GEOTECHNICAL BEHAVIOR OF PEAT

Shear Strength of Peat

Shear strength of peat is always low. It is normally less than 40 kPa and less than 20 kPa for peat in the virgin state for most deposits outside the road. Under the embankment, the peat was consolidated and a notable increase in shear strength was observed; as shown in Figure 4, this is true even under low embankment heights.

Von Post Index and Long-Term Settlement of Embankment over Peat

Although a certain relationship exists between the Von Post index and settlement of peat after a week (5), this analysis did not confirm any clear relationship between settlement after 10 years and the Von Post index. This is shown in Figure 5. Long-term settlement of peat has been measured and varies between 13 and 57 percent of the thickness of peat deposits. The great variation can be attributed to different initial water contents and compressibility of the peat material, and to the type of material used as fill and occasional bridging with logs.

RIDING QUALITY OF PAVEMENT OVER PEAT DEPOSITS

A Mays ride meter was used to determine the riding quality of a pavement built over fill resting on peat deposits in each of the four muskeg zones. The riding quality was measured in the most heavily traveled lane. In most cases the riding quality was measured 2 km before the muskeg, over the muskeg,

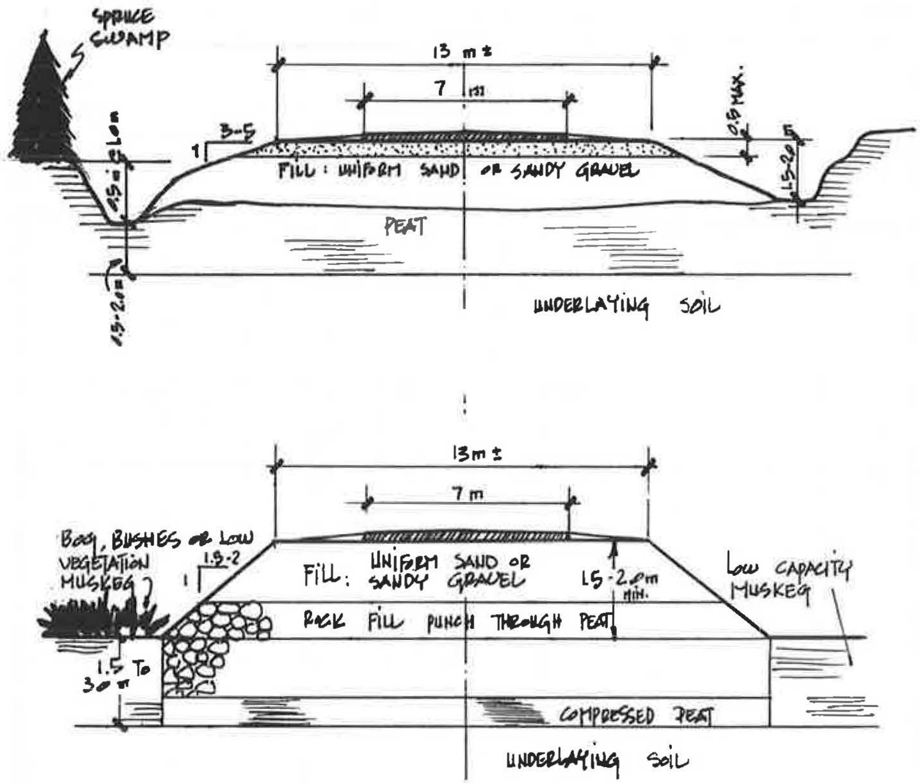

FIGURE 3 Typical transverse profile of embankment over peat sections.

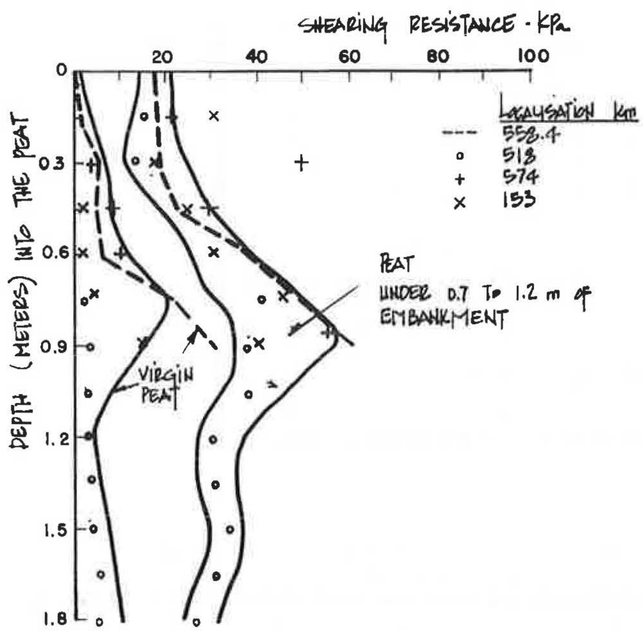

FIGURE 4 Increased shear resistance of peat material under low fill.

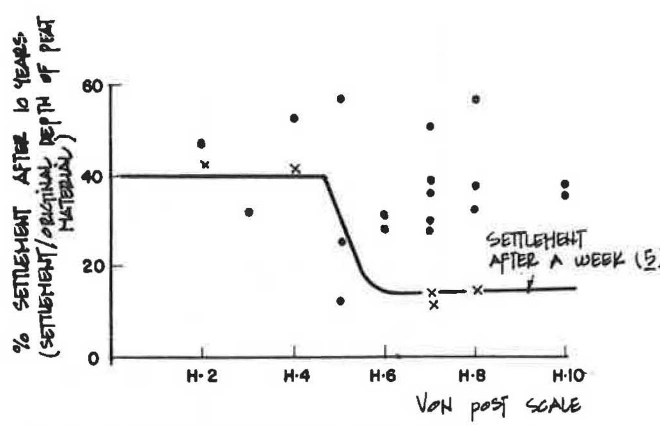

FIGURE 5 Relationship between long-term settlement of peat under 1.0 to 2.2 m of fill and Von Post classification *(5,6)*.

between peat deposits, and 2 km after the last peat deposit. The riding quality of minor peat deposits of less than 1.0 m in depth or less than 0.15 km in length was also evaluated.

Table 5 gives a summary of test results of the evaluation conducted in June 1983. As indicated, the pavement is about 50 percent rougher over peat deposits than over sections with no peat (Mays RCI 131 versus 87 in./mile). A particularly important point in the data observed is the transition zone between peat and no-peat sections. As the data given in Table 6 indicate, the riding quality of the pavement in the transition zone is about 40 percent rougher than the riding quality of the pavement outside transition zones (Mays RCI 109 versus 81 in./mile).

CRACKING OF ASPHALT PAVEMENT OVER PEAT DEPOSITS

The extent and severity of cracking have been evaluated every 2 years since the paving of the access road in 1976. The amount of longitudinal or transverse cracking was measured, and the extent of longitudinal cracking, which includes centerline, lane, or edge cracks (Figure 6a), is expressed in meters per kilometer of length of the road.

Transverse cracking is classified in four types and is expressed in the number of cracks per kilometer of road as shown in Figure 6b:

TABLE 5 Riding Quality of Pavement Over Deep Peat Deposits (>1.5 m) Along the James Bay Road Compared with Adjacent Pavement

Pavement over peat deposit					Pavement outside peat deposits (in relation to peat deposit)					
			Riding confort index		Before		Between		After	
Localization	Nb of 1/20 m sections	Total length	Nb	Mean in/mile	Nb	Mean in/mile	Nb	Mean in/mile	Nb	Mean in/mile
150-156	3	0.88	12	100	37	116	22	93	13	96
182-186	2	0.88	12	125	32	108	17	134	5	174
196-200	2	0.65	8	195	22	122	7	113	13	104
202-208	2	0.49	6	193	9	145	54	120	21	106
225-232	4	0.81	10	168	21	100	14	131	41	110
315-322	5	1.85	23	102	20	57	16	58	28	69
332-340	2	0.81	10	58	33	70	7	62	31	51
386-394	2	1.45	18	82	36	50	21	46	20	52
534-536	2	0.56	7	106	6	46	13	45	18	41
546-553	10	2.58	32	177			54	114		
553-562	9	2.41	30	126	18	119	39	100	24	84
561-565	1	0.25	3	84	17	63			23	71
572-580	5	0.88	12	111	21	59	25	74	48	62
602-606	4	1.61	20	141	17	53			14	66
608-616	9	2.49	31	200	8	65	48	96	8	73
TOTAL	62	18.6	231	1968	391	1173	283	1186	307	1159
AVERAGE				131		84		91		83

TABLE 6 Riding Quality at Transition Zones and Outside Transition Zones

Localisation km	At transition zones		Outside transition zones		
	Number	Riding quality	Number	Riding quality	Ratio
150-156	7	99	65	106	0.93
182-186	7	160	47	117	1.37
196-200	4	123	38	114	1.08
200-208	4	116	80	93	1.25
225-232	9	128	67	109	1.17
315-322	16	119	48	61	1.95
332-340	4	77	67	60	1.28
386-394	7	83	70	44	1.89
534-536	2	51	37	43	1.19
546-565	37	96	138	97	0.99
602-606	5	119	26	47	2.53
608-618	12	133	52	79	1.68
TOTAL	114	109	817	81	1.44

<u>Note</u>: The length of transition zone is 160 m: 80 m before the peat deposit and 80 m on the peat deposit.

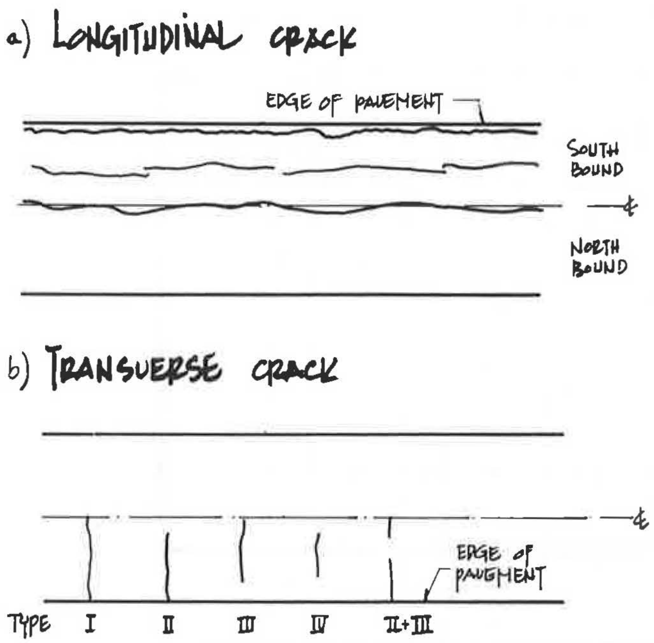

FIGURE 6 Typical crack patterns.

- Type I cracks extend from the centerline to the edge of the pavement;
- Type II cracks extend from the edge of the pavement toward the centerline;
- Type III cracks extend from the centerline toward the edge but do not cross the complete lane; and
- Type IV cracks are typically lane cracking without crossing the edge and the centerline.

A summary of the extent of cracking (measured in June 1983) of the 24 sections of pavement built over peat deposits is given in Table 7.

Longitudinal cracking is common in both directions in pavements built over peat deposits. As the data given in Table 8 indicate, the length of longitudinal cracks in pavement built over peat deposits is generally 2 to 4 times greater than in other areas. An attempt to correlate length of cracking with either height of fill or depth of peat deposits was not successful even where longitudinal cracking is a visual sign of embankment instability.

Types II, III, and IV transverse cracks are common over peat deposits. Type I cracks usually occur at the beginning and the end of the peat deposits or directly above a culvert. Sometimes frost cracks, which extend beyond the pavement into the shoulders, are also found.

TABLE 7 Cracking of Pavement Built Over Deep Peat Deposits (>1.5 m) Along the James Bay Road

Station km	Length of peat deposits	Longitudinal cracking[a]					Transverse cracking[a]				
		Center line	Lane cracking		Edge cracking						
			N	S	N	S	I[b]	II	II et III	III	IV
152.8	0.29	3	3.6				3	9		16	10
183.7	0.415	28	9.1	104	40.3	20.4	19	4		24	4
197.7	0.365	82.3	11.6	65.5	36.6		4			9	4
203.6	0.14	31.4	10.6	30.5			$4^{(2)}$			2	4
226.4	0.152	15.2			38.1			4		3	6
230.5	0.46	198.1	74.7	74.7			12	3	6	34	22
206.5	0.21		45.7	22.9	152.4			1		2	1
316.3	0.20	9.1	30.5	45.7	45.8		$5^{(4)}$			2	
318.5	0.27		6.1	25.9		265	$8^{(6)}$	13	5	39	15
319.0	0.31				79.3		$4^{(2)}$			1	1
336.4	0.50	21.3	4.6	10.7	30.7	131	23	2	3	24	
337.6	0.19	6.1	9.1	27.4	31.1		2			40	
388.9	0.75	39.6	38.1	33.6	369		$11^{(2)}$	1		3	1
518	0.23	97.5	28.9	6.1	3.1		14	2	1	16	16
548.1	0.21	9.1	82.3	82.3			64	14	3	19	17
549.7	.285	48.8	16.8		88.4		6		3	3	2
550.4	0.14		12.2	9.2	12.2		7			4	10
550.8	0.40	26.5	6.1	67	45.7	60.9	49	10	4	16	6
552.9	0.28	76.2		44.1		15.2	28		4	16	0
558.4	0.21	26.5					10			8	3
559.3	0.213	25.9	30.4	4.6			4			4	
604.1	.411	241.7	356.6	201.1	33.5		115	41	20	60	25
609.8	.305	35.0	42.7	17.3		7.6	14	26	32	.27	8
613.2	.274	100.5	13.7	128.3	9.1		28	8	6	25	3

[a]See Figure 6 for description of cracks.

[b]$4(2)$ = 2 out of 4 transverse cracks are crossing the shoulders on both sides.

TABLE 8 Cracks in Pavement on Peat Deposits Compared with Cracks in Pavement on Ordinary Soil

Localization	Longitudinal cracks m/km			Type 1 transverse cracks nb/km		
	On peat deposits	On ordinary soils	Ratio	On peat deposit	On ordinary soils	Ratio
km 180-240	664	18	37.0	19	12	1.6
km 330-370	787	173	4.5	22	32	0.7
km 370-390	635	79	8.0	15	19	0.8
km 540-560	407	70	5.8	95	69	1.4
km 600-620	1160	40	29.0	143	69	2.1
TOTAL	3653	380	9.6	294	201	1.5

Types II and III cracks often occur together and could represent developing type I cracks. As the data in Table 8 indicate, there are generally fewer type I cracks over peat sections than over other sections, except between kilometers 600 and 620 where the traffic is heavy.

Table 9 and Figure 7 present data on cracks over peat deposits from 1980, 1982, and 1983 surveys. Cracking increases rapidly with time: Longitudinal cracks and particularly edge cracks almost doubled between 1982 and 1983. However, type I transverse cracks did not increase substantially during the same period.

STRUCTURAL BEHAVIOR OF PAVEMENT OVER PEAT DEPOSITS

Analysis of structural behavior of pavement over selected peat sections has been done using Dynaflect deflection data, measured every 0.25 km along the road, collected in 1978 and check data collected in 1979. Maximum deflection of pavement over peat deposits is generally higher than deflections measured over other soil types, whatever the height of embankment. Studies (3,4,12) suggest that a minimum acceptable height of embankment over peat deposit is necessary to assure acceptable performance; 1.0 to 1.3 m of embankment is generally suggested.

TABLE 9 Cracking of Pavement on Peat Deposits—Comparison of 1980, 1982, and 1983 Surveys

Type of crack	Unit	Cracking - Average		
		1980	1982	1983
Transversal, Type 1	Nb/km	38	47	50
Longitudinal, All types	M/km	180	298	615
Lane cracking		-	210	287

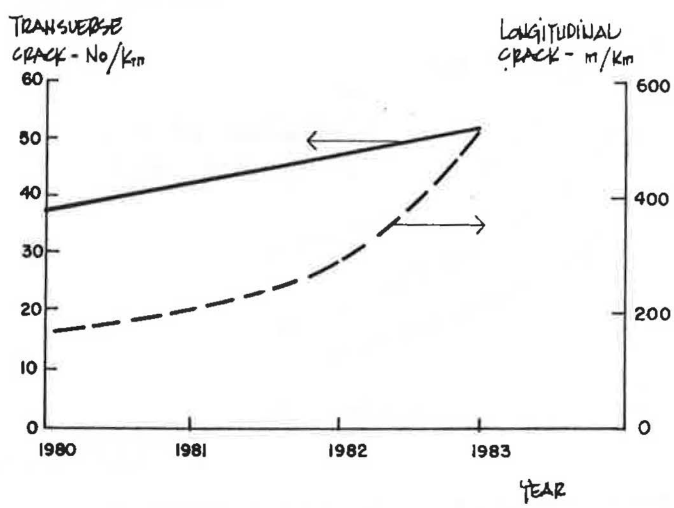

FIGURE 7 Progression of cracking of pavements built over peat deposits, James Bay access road.

The relationship between measured maximum Dynaflect deflection (S_1), deflection at 1.2 m (4 ft) from the loading point (S_5), height of embankment over peat deposit above ditch level (type I embankment), and height above level of surrounding muskeg (type II embankment) is shown in Figures 8a nd 8b. Using statistically derived data it is possible to determine the required height of embankment to limit the deflection to a certain design value. As an example, an embankment height of 3 m or more will always result in a maximum deflection of less than 1.0 E-3 in., and (at a height of 1.2 m) a deflection of less than 0.3 E-3 in.

Summary results of an evaluation of the dynamic modulus of compressed peat 10 years after construction are given in Table 10. The modulus was calculated with the FHA program OAF for Dynaflect loading condition and for 40 kN wheel load. The following constants were used in the calculation:

	Density (kN/m³)	Thickness (m)	Poisson's Ratio
Bituminous surface	22.76	6.4	0.40
Base course	21.90	45.7	0.37
Embankment	19.15	See Table 10	0.45
Compressed peat	10.98		0.50

Examination of all test results indicates that the dynamic modulus of compressed or consolidated peat is quite constant with a mean value of 7 ksi under Dynaflect loading and 12 ksi under 40 kN wheel loads. Eighty-five percent of the values are equal to or greater than 6 and 2, respectively, for the two loading conditions.

SEVERE SETTLEMENT OF PAVEMENT ON PEAT DEPOSITS

A detailed survey of severe settlement zones where pavement was badly deteriorated revealed that settlement is due to the presence of palsa (or its ice core) buried under muskegs covered with black spruce and tamarack. Indeed, these settlement zones are characterized by the fact that their settlement far exceeds that which is predictable by geotechnical calculation; the level of soil-embankment contact generally varied from 1.5 to 2.5 m below natural ground level, whereas 20 to 30 cm could have been anticipated from soil consolidation.

Settlement generally appears either in late fall or in early summer and is highly differential. Settlement is rapid at first and slower during each following thaw season. As shown in Figure 9, total settlement of pavement over palsa varies between 1.0 and 1.3 m and the maximum annual rate of settlement varies between 20 and 30 cm. The problem of design and maintenance of pavement over palsa is discussed by Keyer and Laforte in another paper in this Record.

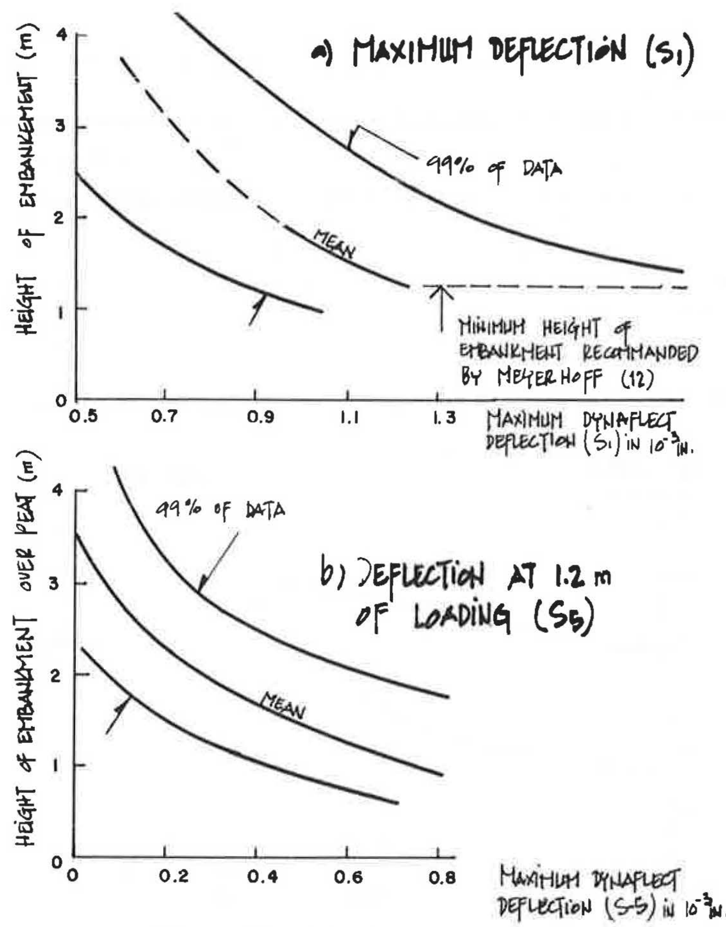

FIGURE 8 Influence of the height of embankment on maximum Dynaflect deflection and deflection at 1.2 m when the thickness of peat is at least 1.5 m.

TABLE 10 Dynamic Modulus of Peat Subjected to 10 Years of Consolidation

Peat Von Post Scale	Heigth of embankment cm	Under Dynaflect loading ksi	Under Dynaflect loading mPa	Under 40 kN (9 000 lb) wheel load ksi	Under 40 kN (9 000 lb) wheel load mPa
H2	124	9	59	17	121
H4	39	8	57	12	81
H5	69	7	51	12	81
	78	6	43	11	77
	160	2	15	5	33
H7	78	10	72	18	127
H8	35	7	48	10	70
Mean	83	7	49	12	84
Range	35-66	2-10	15-72	5-17	33-127
85%	Value above	6	43	10	70

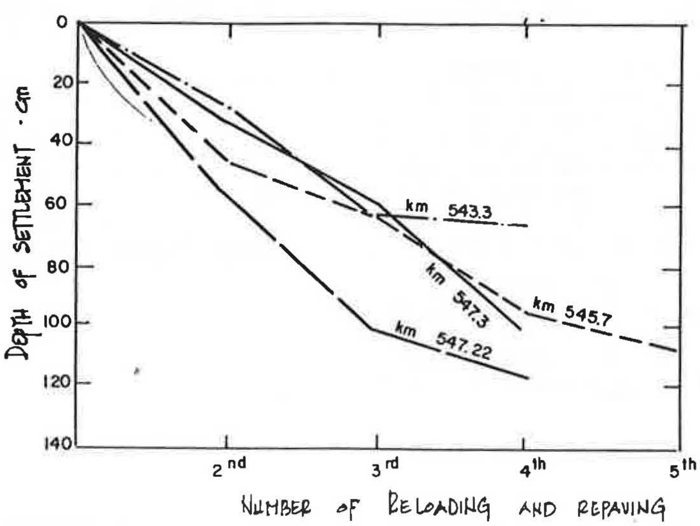

FIGURE 9 Progressive subsidence of five settlement areas over palsa field.

CONCLUSIONS

The following conclusions refer to the performance of pavement and embankment built over muskegs in northern Quebec. The design of embankment is based on relations established by Lefebvre et al. between the Von Post classification of peat and its physical and mechanical behavior under loading.

Along the 620 km of the James Bay penetration road, which run straight north from parallel 49.8° N to 53.8° N, the length of peat deposits along different sections covers a range that varies between a minimum of 6 percent and a maximum of 37 percent of the length of each section. One-third of all peat deposits are more than a meter deep. Most of the muskeg areas along the road are concentrated in four well-defined zones 80 km, 85 km, 35 km, and 14 km in length. The 620 km of road cross 54 deep muskegs that together represent about 16 km of road. The characteristics of each muskeg have been defined in terms of regional distribution, initial peat thickness, type of soil underneath the peat, topography, and maximum thickness of embankment.

The design of embankment over muskeg was based on the concept of preconsolidation; the order of magnitude of the duration of load was evaluated using the Von Post classification of peat. Design approach based on simple classification was found to be practical for northern roads in view of the great number of muskegs, the difficulty of field access, the variability of peat deposits, and the difficulty of predicting settlement with precision.

The performance of pavement and embankment built over muskegs has been evaluated periodically by Dynaflect deflection measurements, Mays road roughness measurements, and condition surveys. On the whole the performance of pavement 8 years after construction is satisfactory.

Two typical cross sections of settled embankment over peat deposits were noted: embankment made of sand or sandy gravel, which has settled to the level of the surrounding muskeg, and embankment made of rockfill constructed over a bed of trees, which is 1.5 to 5 m above the surrounding muskeg. For peat deposits thicker than 1.4 m the long-term settlement generally varies between 0.5 and 1.0 m or between 25 and 50 percent of the depth of the peat deposit. No clear relationships can be found between long-term settlement and the following properties: depth of peat deposit, Von Post classification of peat, shear strength of peat, material underlying peat deposit, embankment height, and type of embankment.

Shear strength of peat is always low; it is normally less than 20 kPa in the virgin state and 40 kPa under embankments.

Although the riding quality of pavement on peat deposit is still rated good, the pavement surface is 50 percent rougher over peat deposits than over no-peat sections. The riding quality of pavements in transition zones between peat and no-peat sections is about 40 percent rougher than that of the no-peat sections.

Transverse cracking is not influenced by the presence of peat deposits; however, longitudinal cracks in pavement built over peat deposits are generally 2 to 4 times larger than cracks in other areas and are increasing rapidly. It has not been possible to correlate the length of longitudinal cracking with either the height of fill or the depth of peat deposits.

Maximum Dynaflect deflection of pavement over peat deposits is generally higher than deflections measured over other soil types whatever the height of embankment. There is a loose relationship between the height of embankment and the maximum deflection.

The dynamic modulus of peat under embankment is quite constant; it is around 50 mPa (7 ksi) under Dynaflect loading and 80 mPa (12 ksi) under 80 kN (18 kips) axle loads.

Severe settlement of fill on peat deposit encountered along the road is due to the presence of ice under the peat. Total settlement of pavement over palsa varies between 1.0 and 1.3 m and the maximum annual rate of settlement varies between 20 and 30 cm.

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