METHODS AND COSTS OF PEAT DISPLACEMENT IN HIGHWAY CONSTRUCTION

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SYNOPSIS

During the last three years, methods used for peat displacement in Michigan have become more or less standardized The tendency is to avoid excessive use of explosives and to depend on methods which are positive and easily controlled Supplementary or complete excavation is used with special emphasis placed on the kind of fill material and on the proper timing of steps in the construction of the embankment Clay is avoided for fill material and sandy or gravelly soil is used whenever available The basic methods described in the report are (1) Deep grubbing for shallow timbered swamps, (2) Partial peat excavation for secondary roads, (3) Total excavation in swamps up to eight feet in depth where rigid or semi-rigid pavement is to be used; (4) Side excavation along old road fills, (5) Construction procedure over marl, (6) Partial excavation and temporary surcharge for peat from 6 to 20 feet deep, (7) Rebuilding old fill through deep swamp, and (8) Jetting process Photographs and drawings illustrate the various methods

During the last eight years several different methods of swamp fill construction have been developed by various states in the North Central and Coastal areas These methods have given, in most cases, satisfactory results depending upon local conditions It is the purpose of this report to present the development and classification of these methods, analyze the costs and draw general conclusions relative to the selection of methods, as determined primarily by their use in Michigan

In the early stages of the solution of the problem presented by peat deposits, it was assumed that treatment for all swamps would consist simply of building the embankment to grade and accepting what subsequent settlement would occur

Such settlements proved to be objectionable especially when occurring in a road paved with concrete They were a hazard to traffic, increased maintenance cost and often necessitated the complete reconstruction of the highway through the swamp Studies were consequently inaugurated to ascertain some of the fundamental principles underlying swamp fill behavior

The Michigan State Highway Department began a careful study of the behavior of highway embankments constructed over peat marshes in the summer of 1925. The results of this study were presented to the Highway Research Board in December, 1926, by V. R. Burton (1).[1] The report contains an excellent discussion dealing with the character and classification of swamp materials and is based on a study of several locations in company with Doctor Dochnowski-Stokes.

Important conclusions of the study considered the fallacy, in the case of hard surfaced roads, of trying to float highway embankments over peat swamps. It was recommended that fill settlement in peat should be accelerated, and considered the use of surcharges and dynamite for this purpose. Five standard methods of building highway embankments through peat swamps were described and illustrated. The most unusual of these consisted of forcing two narrow wedges of fill to the

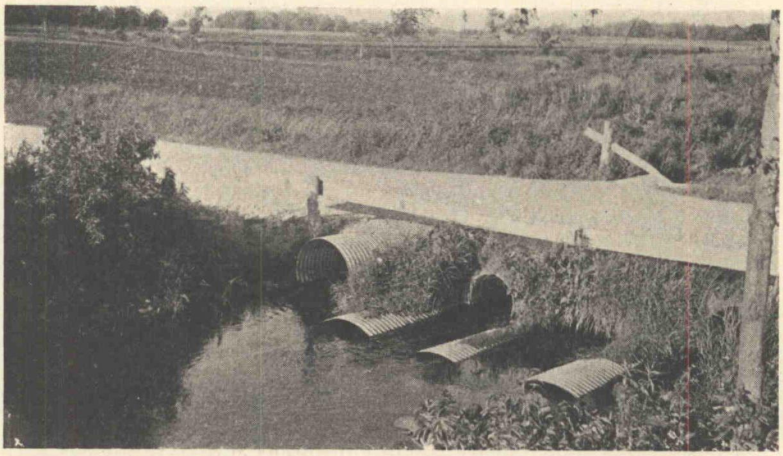

Figure 1. A Floating Road Slowly Sinking into the Underlying Peat

bottom of the swamp, thus compacting the trapped peat between the wedges. It was assumed that this compacted peat would properly support the surface. Subsequent experiences, however, proved the fallacy of this assumption. The trapped peat continued to settle, causing a depression along the highway center line.

Further studies of the Michigan State Highway Department included investigation of the lateral flow of clay fills in some of the deeper swamps. These studies showed that structural defects in concrete pavements are not related to fill settlement in swamp areas, and that the amount of settlement is generally a function of the thickness of peat below the fill, provided that granular filling material is used.

Michigan has not been alone in the study of swamp engineering problems; a glance at the bibliography will indicate that both public

[1] Numbers in parentheses refer to literature cited in the Bibliography.

and private institutions have given much thought to the subject. The resultant literature has dealt principally with the use of dynamite for accelerating subsidence.

Part of an editorial in the April 23, 1931, issue of the Engineering News-Record follows:

"Blasting as a method of sinking highway fills through swamp muck is becoming a well-formulated process. A few years ago when explosives were used at all it was in a haphazard way, with only the general purpose of breaking up the surface mat so that the fill would penetrate and not float on the swamp. The Michigan highway engineers were perhaps the first to undertake blasting as a definite process of forming a subsurface embankment. Later the Minnesota Highway Department even more completely systematized the procedure. Increased experience will make the control of the fill more certain" (9).

Figure 2. A Badly Settled Section of Concrete Surface Being Buried under a Temporary Surface of Gravel.

Rhode Island (18) and New Jersey (23) developed methods which were novel and effective, particularly in the placing of dynamite.

The Minnesota State Highway Department has had considerable experience with highway construction over swamps. In their construction methods subsidence has been forced by means of mechanical excavation, explosives, and by a combination of the two methods.

The results of early studies of the swamp problem were expressed in rather complicated standards or methods. These methods usually involved the use of dynamite (1) and were a great improvement over older practices. Failures in the form of settlement (rapid and slow), however, continued to characterize our highways over peat swamps. To overcome this weakness, methods were changed so fast that it became impossible to agree upon a standard procedure that could stay in effect and satisfactorily meet all situations.

For the past few years, in the State of Michigan, each swamp has been a subject for special study in order to work out methods of construction which seemed best able to satisfy its requirements As a result, certain methods have been used with such consistent success that they have become standardized practice These methods are simpler than the earlier ones and indicate a more thorough knowledge of factors involved in the displacement of peat by a mineral soil fill

METHODS

These basic methods have been developed to handle various types of swamps and are varied when necessary to meet any abnormal swamp conditions encountered For convenience in this study we have grouped the various methods in the following classification

Basic Methods of Swamp Fill Construction

To be used on new location and on reconstruction except where special methods apply.

1 Partial excavation[2] (and gravity subsidence)
   (a) Deep grubbing
   (b) Excavation of surface mat
2 Partial excavation[2] and further treatment (forcing subsidence)
   (a) Partial excavation with surcharge (gravity subsidence)
   (b) Partial excavation with jetting or deep shooting
3. Gravity fill (gravity subsidence)
4 Gravity fill and further treatment (gravity and forcing subsidence
   (a) Relief trenching[2] and dynamiting or jetting
5 Total excavation[2]
   (a) Total excavation of peat
   (b) Total excavation of peat and compaction of underlying marl with surcharge (special case)

Special Methods of Swamp Fill Construction

To be used in reconstruction with old fill in place

S-1 Side excavation[2] (partial or total) on high fill in shallow swamps
S-1 Rebuilding through deep swamps
   (a) Gravity fill and dynamiting or jetting (gravity and forcing subsidence)
   (b) Gravity fill with relief trenching and dynamiting or jetting (gravity and forcing subsidence)

These basic and special methods have all been used by the Michigan State Highway Department The following diagrams and discussions of these methods illustrate procedures which the Department has used with satisfactory results during the past two years

[2] Excavation with dynamite or mechanical means

DEEP GRUBBING

Method 1(a)

This method has been used to a limited extent in the shallow timbered swamps occurring principally in the northern part of the state The chief disadvantage is the difficulty encountered when the ground is frozen Deep grubbing consequently does not lend itself to winter work This method requires a fill at least three feet thick in order that the highway will not break through in the spring It is recommended only when the highway is to be surfaced with gravel or related materials (Figure 3.)

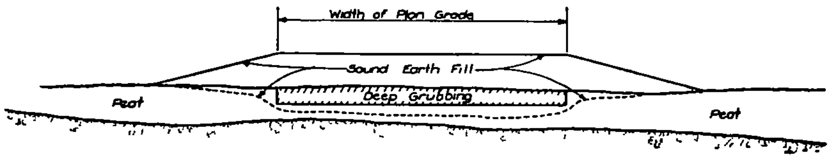

Figure 3. Deep Grubbing Through Swamps for Secondary Roads. Deep grubbing consists of removing all stumps, roots and logs over 3″ in diameter to a depth of 2 feet and to a width equal to the width of plan grade. Estimate one foot loss to grubbing operations and from 50 to 75 per cent compaction of remaining peat.

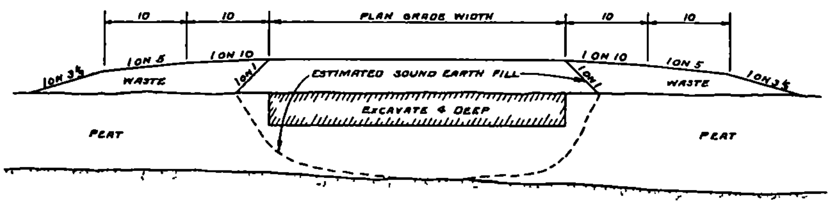

Figure 4. Partial Peat Excavation for Secondary Roads. Backfill shall be placed as the excavation progresses leaving a minimum of open trench.

PARTIAL PEAT EXCAVATION FOR SECONDARY ROADS

Method 1(b)

This method is recommended for projects on which the type of construction does not warrant the cost of complete excavation of peat Dynamite may be used for excavation, especially if the swamp is soft and wet Experience to date indicates that the fill settles practically to the bottom of the swamp at the time of construction. To prevent moving peat from piling up in front of the advancing fill it is highly important that the backfill be placed as the excavation progresses When dynamite s used for excavation not more than 50 feet of trench should be shot at one time The embankment should be built of the most sandy, gravelly material available (Figure 4)

PARTIAL EXCAVATION AND TEMPORARY SURCHARGE

Method 2(a)

The procedure illustrated in Figure 5 has proven to be very effective in displacing peat of all depths greater than six feet and is especially

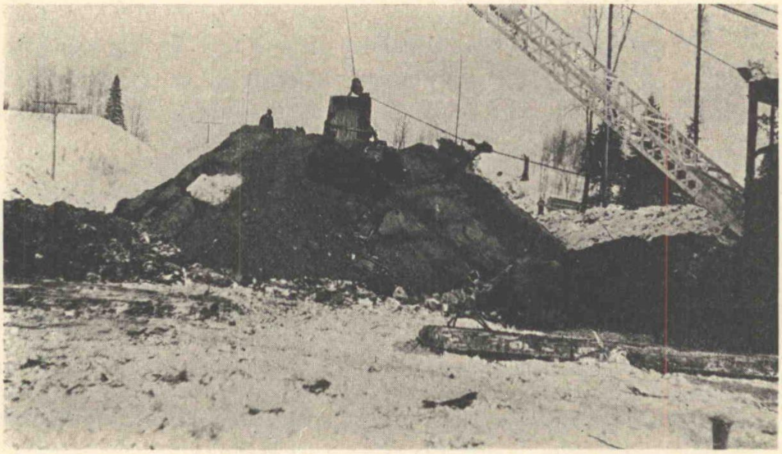

Figure 5

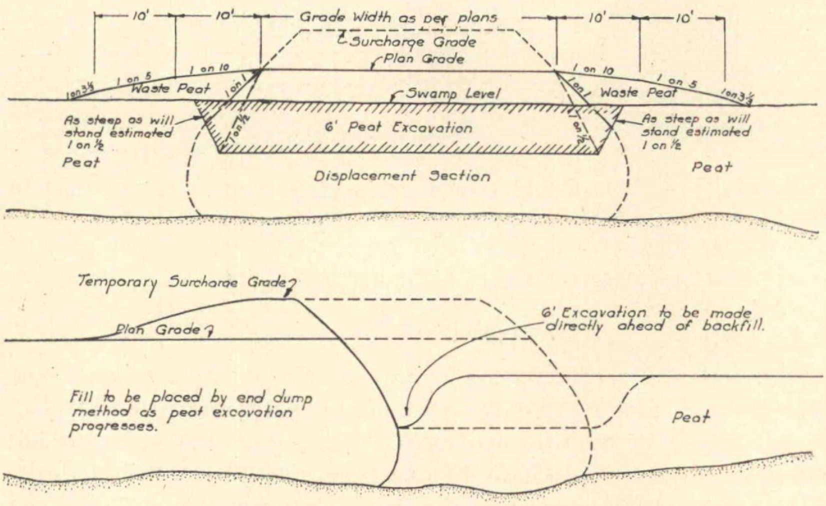

Figure 6. Partial Excavation and Surcharge for Peat Displacement

effective for that critical depth range between 6 and 20 ft.. Peat displacement in this critical range gave considerable trouble under older methods of construction. The secret of the success of this method lies in relieving the pressure at the advancing toe of the embankment, which can be accomplished both by dynamite and by machine excavating to a depth of approximately six feet. The surcharge is usually brought forward with a bulldozer as construction proceeds, because its only purpose is to add weight at the point of loading. It is highly important again that sandy, gravelly filling materials be used.

At the present time the contractor is paid full excavation price for the 6-ft. trench and full excavation price for half of the remaining area of submerged fill.

This construction procedure lends itself to good work because it is to the contractor's advantage to conduct his operations in such a manner as to place the maximum amount of fill and thus incidentally obtain good peat displacement. The cross sectional area of the final embankment is determined by borings.

THE JETTING PROCESS

Methods 2(b), 4(a), S-2(a), S-2(b)

The jetting process may in itself be a complete method for displacing peat, or it may be used in connection with three or four of the other basic methods. For instance partial excavation and jetting may be combined in order to overcome the peat's resistance to displacement.

Displacing peat by means of jetting consists principally in pumping water into the peat being displaced and into the fill which is doing the displacing. The process is continued until a satisfactory fill cross section is obtained. The method has been used with varying success on nine projects in Michigan, varying in depth from 10 to 45 feet. The degree of success seems to have varied with the kind of fill material, age of the fill before jetting was started, location of the jets, type of pumping equipment, composition of the peat materials and depth of the swamp. The best results have been obtained in the deeper swamps.

Such experience as we have had with the jetting procedure seems to warrant a few statements regarding the method to be considered in future work in order to obtain the best results.

1. The filling should be of a sandy gravelly nature. Soils high in clay content have a tendency to "set up" after being placed and therefore respond more slowly to movements in peat resulting from jetting operations. Clay fills also have a tendency to flow laterally in the deeper swamps. This action might be exaggerated through the use of the jetting method under some conditions.

2. The jetting operation should be carried on at the same time as the fill is being placed so as to keep the peat as fluid as possible while it is being displaced. Experience indicates that making the peat fluid enough to flow is a slow and difficult process after it has been compacted and partially dried out by the weight of the overlying fill. It is consequently suggested that water be pumped into the peat before the fill is

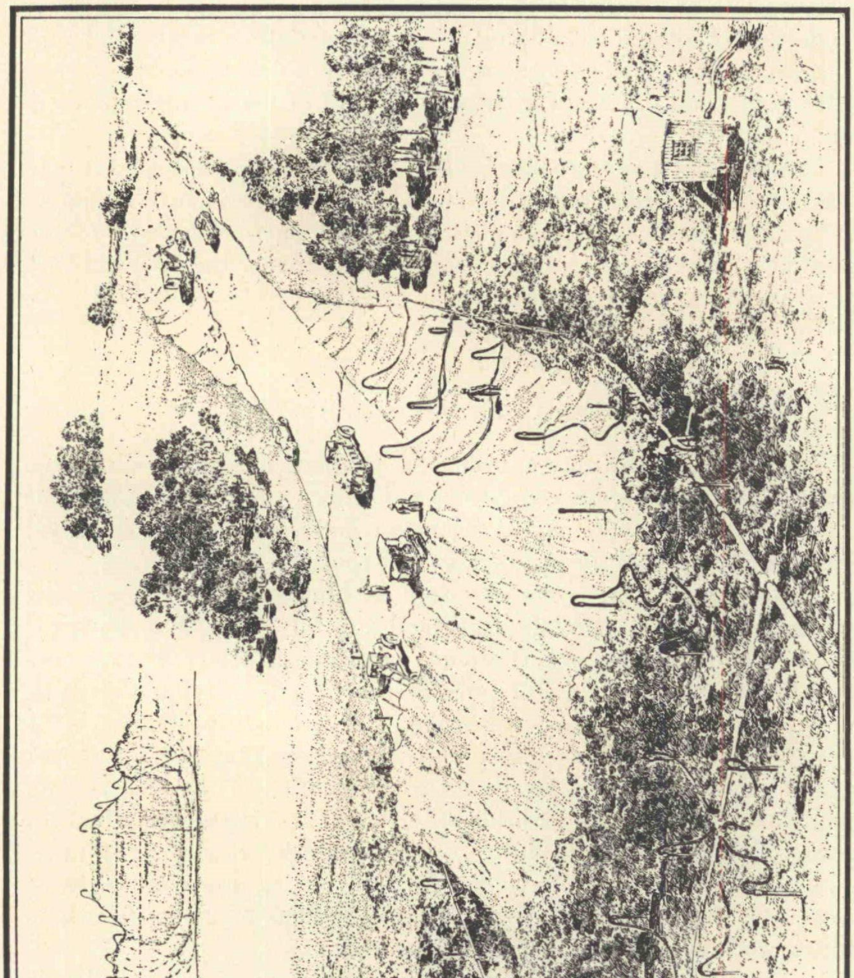

Figure 7. The Jetting Process

being placed and as long thereafter as the fill continues to settle. Borings will indicate where extra jetting is necessary.

3. It should be remembered when locating the jets that the peat to be displaced is the peat which should be kept soft and wet, and also that

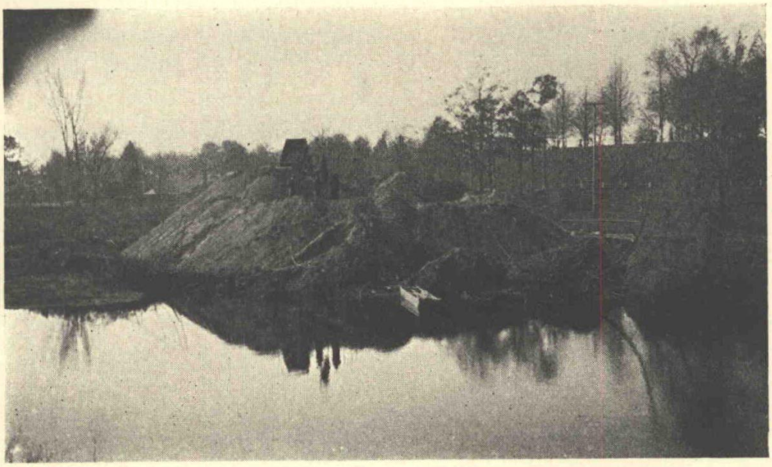

Figure 8. The Jetting Procedure Being Used as an Aid in Forcing the New Fill to Firm Bottom.

Figure 9. The Jetting Procedure Being Used as an Aid in Sinking an Existing Fill to Firm Bottom.

the more fluid this peat becomes the more easily it is displaced. A single line of jets along each side of the embankment has been found to be sufficient. Jets are usually placed from 10 to 25 feet apart and about two-thirds of the way through the peat. The area jetted extends from the front part of the fill to as far as 75 feet in advance of the fill depending on the number of jets and volume of water available. Relief trenching on the sides is often resorted to in order to facilitate peat displacement

4 Equipment which has been operated effectively in Michigan consists of a five-inch, three-stage centrifugal pump powered by a six-cylinder, 90 HP engine This unit has a capacity of 500 gallons of water per minute at a 250-foot head when operating at 1450 RPM and is guaranteed to operate successfully 15 jets, each having five openings of $\frac{7}{32}$ inch diameter Twenty jets can be operated successfully with a motor speed of 1700 RPM

5 The presence of sand or marl in a swamp deposit has a very marked influence on the displacement that can be obtained through the use of the jetting method

6 The jetting method requires an adequate supply of water located near the swamp, such as a stream, pond or drain

7 Continuous operation seems to be more effective than interrupted operation

TOTAL EXCAVATION THROUGH SHALLOW PEAT SWAMP

Method 5(a)

This method involves complete excavation of peat in swamps up to approximately eight feet in depth for all highways on which a rigid or semi-rigid surface is to be placed The unique part of the method represented by this cross section is that the width of excavation varies with the distance from plan grade to swamp bottom As this distance increases the width of excavation also increases by an equal amount Such varying of the width of excavation is resorted to in order to overcome the tendency toward side settlement in fills through the deeper swamps excavated It is important that the embankment be built of sandy gravelly soils, especially in the deeper excavations. (Fig 10)

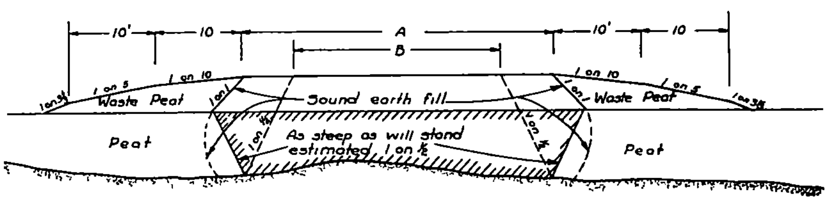

Figure 10 Method Used for Total Excavation through Shallow Peat Swamps. Backfill shall be placed as the excavation progresses, leaving a minimum of open trench. A = width of plan grade B = 4 ft wider than metal

CONSTRUCTION PROCEDURE OVER MARL

Method 5(b)

Deposits of marl will support highway embankments if they are first properly compacted (20) The amount of compaction depends on the height of the grade above swamp level and the amount of water and organic matter contained by the marl The average deposit of marl compacts to about two-thirds of its original depth

The surface mat of peat should be excavated by mechanical means or dynamite and the trench filled as the excavation progresses in order to prevent the accumulation of disturbed peat in front of the backfill The backfill need not, and probably should not, be built to surcharge grade or even to plan grade as the excavation progresses. Rather the fill above the swamp level may be built in layers or lifts until a stable surcharge grade is obtained (20) (Fig 11)

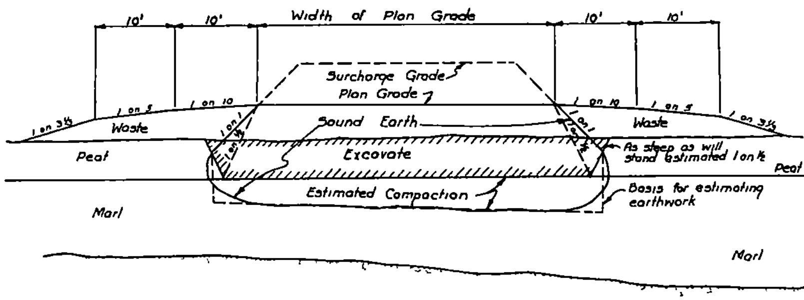

Figure 11. Highway Construction over Marl Deposits Estimate that average marl will compact to about two-thirds of its original depth

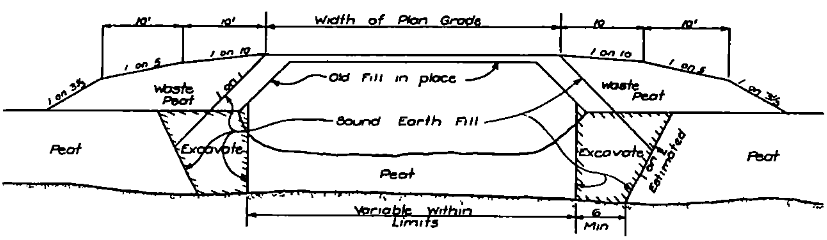

Figure 12. Side Excavation on Old Road Locations. This method is used in shallow peat swamps when the old narrow fill in place is stable and of sufficient thickness to make total excavation impracticable On secondary projects side trenches may be excavated to a depth of from 4 to 6 feet

SIDE EXCAVATION ON OLD ROAD LOCATIONS

Method S-1

In rebuilding a highway, swamp fills are often encountered which are of such stability and size that they may be left without being disturbed The new fill, however, is usually wider than the old, and side excavation is resorted to in order that the sides of the new embankment may be as stable as the center This method is used in shallow swamps and the side trenches may or may not be excavated to bottom, depending upon the importance of the highway Here again the trenches should be filled as the excavation progresses, partly as a safety measure and partly to prevent sliding and caving The distance between the trenches must vary with the width of the old fill, but outside limits need not extend beyond the area indicated as sound earth fill in the diagram. (Fig 12)

REBUILDING THROUGH A DEEP SWAMP

Method S-2

The force of gravity is the greatest aid in securing a proper cross section in a swamp as deep as the one illustrated by the accompanying cross section The great weight of so large a fill is usually enough to displace most of the peat Often, however, other means must be used in order to obtain adequate bottom width in the embankment This is especially true where there is an old fill in place to be settled and widened

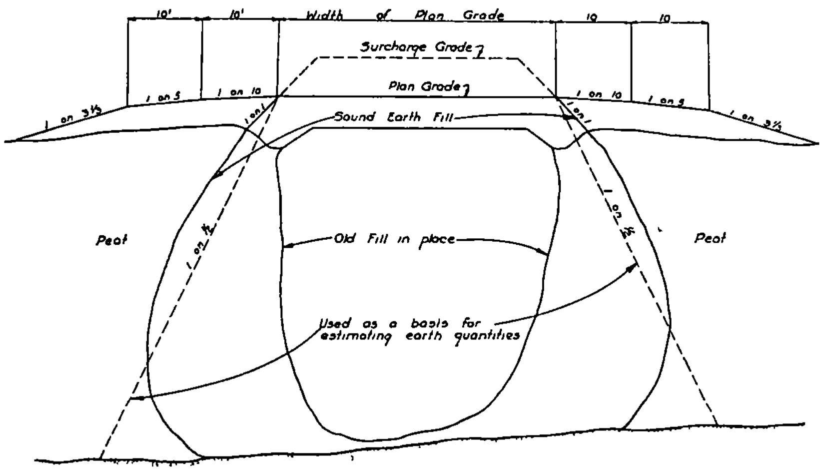

Figure 13. Rebuilding through a Deep Swamp The condition represented by this diagram illustrates a situation where the jetting method or dynamite may be used to advantage

Widening may be accomplished by partial excavation and surcharge, dynamiting, or jetting

In order to hold the embankment within the reasonable limits shown by Figure 13 it is necessary that a sandy gravelly filling material be used Clay fills in deep swamps have a tendency to spread to unusual widths at the bottom Swamp ditches should be omitted except when needed as farm drains, because of their disturbing influence on the newly established equilibrium between the fill and surrounding peat

Cost Analysis

The previous reports dealing with accelerating fill settlement in peat marshes contain considerable information on methods used in different states, but very little information on the costs involved.

During the fall of 1933 the Minnesota State Highway Department was kind enough to make the results of their cost studies available to the Michigan State Highway Department. These costs were subsequently sorted, reduced and tabulated. At the same time similar, though less extensive, Michigan cost studies were compiled. The results of these studies are presented in the tables which follow.

The Minnesota State Highway Department has done more to develop costs of highway construction over peat marshes than any other state. In their studies they have separated the costs which are peculiar to the work of forcing subsidence from the costs of ordinary earth moving operations. The costs of forcing subsidence include such items as labor, materials, excavation, soundings and miscellaneous expense, such as damages. The Michigan costs do not include the cost of making soundings. Soundings are a part of some of the Minnesota methods

Figure 14

and, consequently, their costs are included in the Minnesota cost studies. Michigan also makes soundings both before and after construction, but they are not considered essential to any particular method. Their cost, consequently, is no more a part of the method than the cost of hauling filling material.

In order to have a fair basis for comparison the cost of forcing subsidence is spread over the cubic yards of submerged fill (subfill), the portion of the embankment which rests below the original swamp level. In this way the cost of peat displacement is distributed over the actual amount of peat displaced.

JETTING COSTS

Method S-2(a)

Rebuilding Through Deep Swamps Using Gravity Fill and Jetting

Four of the five locations considered in this summary had old or new fills in place before the jetting was started. No special excavating was done to facilitate peat displacement The unit cost is obtained by dividing the total cost of jetting by the yards of submerged fill measured after the jetting is completed

Number of projects	5
Total length	3,301 ft
Maximum depths	23 to 40 ft
Cubic yards of subfill	102,755
Cubic yards of subfill jetted	93,735
Total cost of jetting	$6,459 03
Unit cost of jetting	
Maximum	$0 1383
Average	$0 0689
Minimum	$0 0370

STABILIZING OLD FILL IN PLACE WITH RELIEF TRENCHING AND DEEP SHOOTING (MINN)

Method S-2(b)

Relief trenching consists in mechanically excavating trenches in the peat along each side of the old embankment before placing the new fill This work is listed as special peat excavation and is added to the cost of blasting in order to arrive at the unit cost

Considering the fact that an old fill is in place, these costs are fairly uniform and $ 1263 should be a representative average

Number of projects	13
Total length	12,030 ft
Maximum depths	10 to 30 ft
Cubic yards subfill	168,684
Cost special peat excavation	$5,717 22
Blasting costs	$15,579 64
Total costs	$21,296 86
Cost of peat displacement per cubic yard of subfill	
Maximum	$0 2997
Average	$0 1263
Minimum	$0 0618

ACCELERATING FILL SETTLEMENT WITH DYNAMITE (MICHIGAN)

Method 4(a)

This method consists in building the embankment to surcharge grade and completing the displacement of peat by deep shooting

The cost per cubic yard of subfill is slightly low because in some cases the shallow ends of the swamp were mechanically excavated The records contain no information as to the amount and cost of this excavation

Labor charges when not available are figured at 3 6 cents per pound of dynamite

This method has not been used during the last two years

Number of swamps studied	13
Total length	9,469 ft
Maximum depths	13 to 37 ft
Sub-fill dynamited	157,038 cu yd
Dynamite used	32,740 pounds
Cost of dynamite	$14,531 03
Cost of peat displacement per cubic yard of subfill	
Maximum	$0 1940
Average	$0 0925
Minimum	$0 0606

PARTIAL EXCAVATION WITH TEMPORARY SURCHARGE (MICHIGAN)

Method 2(a)

The actual cost per cubic yard of subfill was obtained by dividing the total cost of excavation by the total number of yards of subfill The theoretical cost per cubic yard of subfill is based on paying the contract unit price for excavating a six-foot trench plus the contract unit price for one-half of the remaining area of submerged fill There is a possibility that on future projects the quantities involved in peat excavation and peat displacement will be listed separately and paid for as separate items of work The actual amount of peat displacement will be determined by borings through the completed embankment

Number of projects studied	4	
Total length	3,120 ft	
Maximum depths	19 to 37 ft	
Total subfill	117,955 cu yd	
Mechanical peat excavation	81,250 cu yd	
Total cost of peat excavation	$12,444 88	
Unit Cost of peat displacement per cu yd subfill	Maximum	$0 1500
	Average	$0 1055
	Minimum	$0 0622
Unit cost based on more recent methods for computing pay quantities	Maximum	$0 1258
	Average	$0 0974
	Minimum	$0 0880

The contract unit price for excavation ranged from $0 14 to $0 165 per cu yd

TRENCH BLASTING AND DEEP SHOOTING (MINNESOTA)

Method 2(b)

This method consists in blasting a wide trench in the swamp surface before placing the embankment and completing the process by deep shooting after the filling is complete

The cost summary of this system has separated the swamps into groups based on the number of cubic yards subfill per station Note that the unit cost of blasting decreases as the cubic yards per station increase. These costs indicate that swamps containing less than 500 cu. yd. of peat displacement per station can be more economically excavated by machine methods than by dynamite. In other words,

Figure 15. Deep Blasting Used as an Aid to Force an Embankment to Firm Bottom (Michigan).

mechanical excavating of peat costs less than displacing the peat by surcharge and dynamiting in swamps less than six feet in depth.

Number of swamps studied 43
Total length .... 42,666 ft.
Maximum depths .... 2 to 66 ft.

Class Cu. Yd. Subfill Per Sta.	Cu. Yd. of Subfill	Total Cost of Blasting	Unit Cost
0 to 500	32,427	$9,037.60	$0.2786
500 1000	79,509	9,062.35	0.1136
1000 1500	86,587	11,970.64	0.1382
1500 2000	143,887	14,289.11	0.0993
2000 3000	24,505	1,297.16	0.529
3000 up	261,359	18,209.30	0.2697
Total	$628,274	$63,866.16	$0.1017

COMBINED MECHANICAL EXCAVATION AND DYNAMITING (MINN.)

Method 2(b)

This method consists in first excavating the surface mat of peat by mechanical means. The fill is next placed and finally the proper displacement of peat is accomplished by deep shooting.

Note that in general the cost of displacing peat by this method when spread over the cubic yards of peat displaced is greater for the shallower swamps than for the deeper swamps.

Number of swamps studied	24
Total length	30,223 ft
Maximum depths	3 to 32 ft
Total sub-fill	394,407 cu yd
Mechanical peat excavation	
Cubic yards	121,388
Total cost	$17,977 36
Unit cost—Maximum	$0 2000
Average	$0 1492
Minimum	$0 1100
Peat displacement by dynamiting	
Cubic yards	273,019
Total cost	$31,275 71
Unit cost—Maximum	$0 4412
Average	$0 1145
Minimum	$0 0341
Average unit cost for method	$0 1249

TRENCH BLASTING AND GRAVITY FILL (MINN)

Method 1(b)

This construction procedure consists in blasting a wide trench in the peat after which the embankment is built in the trench and left to settle The cost of blasting this trench should remain fairly constant for all depths of peat and vary only with the width of the trench and character of the peat The average cost of blasting per cubic yard of subfill consequently becomes less as the depth of the swamp increases or, in other words, as the cubic yards of submerged fill per station increase.

Number of swamps studied			17
Total length			7,541 ft
Maximum depths			2 to 30 ft
Class Yds Subfill per Sta	Cu Yd Subfill	Total Cost of Blasting	Unit Cost
0 to 500	4,229	$358 20	$0 0771
500 1000	23,959	1,633 35	0 0641
1000 1500	21,921	955 71	0 0414
3000 up	41,760	187 92	0 0045
Total	91,869	$3,135 18	$0 0341

JETTING COSTS

Method S-2(b)

Rebuilding Through Deep Swamps Using Gravity Fill, Relief Trenching and Jetting

The relief trenching used on these swamps consisted of mechanically excavating trenches 4 to 6 ft deep and 10 to 20 ft wide along each side of the embankment The purpose of the trenches is to break the surface mat and relieve pressure in the peat along the sides of the fill in order to facilitate settlement The cost of this special excavation was added

TABLE I

AVERAGE—COST SUMMARY OF METHODS USED IN SWAMP FILL CONSTRUCTION

		Method	No Swamps Studied	Total Yds Subfill	Cost of Fill Not Included		Remarks
					Total Cost	Unit Cost	
1		Partial excavation (and gravity subsidence)					
	a	Deep grubbing				$1 to $2 per sq rod	Contract unit price
	b	Partial excavation (Surface mat)	17	91,869	3,135 18	034 per cu yd of subfill (Minn)	1933 Mich average Contract unit price for peat excavation 20¢–27¢ per cu yd
2		Partial excavation and further treatment					
	a	Partial excavation with surcharge (gravity subsidence)	4	117,955	12,444 88	1055 per cu yd of subfill	Michigan Costs
	b	Partial Excavation (Mech) and Deep Shooting	25	394,407	49,253 07	1249 per cu yd of subfill	Actual Cost Minnesota
	b	Trench blasting and deep shooting	44	628,513	63,865 66	1016 per cu yd of subfill	Actual Cost Minnesota
3		Gravity Fill (Gravity Sudsidence)					No additional cost for displacement of peat

4	Gravity Fill and Further Treatment						
	a	Gravity Fill Accelerating with Dynamite	13	157,083	14,531 03	0925 per cu yd of sub-fill	Removal cost of surcharge not included
	a	Relief trenching and jetting				16 per cu yd mech ex 13 per cu yd jetting	1934 Contract unit price Inc 05 per cu yd Royalty
5	Total Excavation						
	a	Total excavation of peat				16¢–20¢ per cu yd of actual excavation	Contract unit price
	b	Total excavation of peat and compaction of underlying marl				16¢–20¢ per cu yd of actual excavation	In addition there is the cost of placing and removing the surcharge
S-1	Side Excavation Shallow Swamps					16¢–17¢ per cu yd	Contract unit price Costs vary according to amount of peat
S-2	Rebuilding through deep swamps						
	a	Gravity fill and dynamiting					Cost approx same as 4A
	a	Gravity fill and Jetting	5	93,735	6,459 03	0689 per cu yd of sub-fill	Actual Cost
	b	Gravity fill, relief trenching and deep shooting	13	168,684	21,296 86	1263 per cu yd of sub-fill	Actual Cost
	b	Gravity fill, relief trenching and jetting	4	265,724	21,823.90	0821 per cu yd of sub-fill	Actual Cost

to the cost of jetting and the sum divided by the cubic yards of submerged fill to obtain unit costs for this method

Two projects have recently been placed under contract on which this method is being used On one the unit price for peat excavation is 17 cents per cu yd and the unit price for jetting is 13 cents per cu yd of peat displaced On the other project the unit price for peat excavation is 14 9 cents per cu yd and the unit price for jetting is 15 cents per cu yd of peat displaced The jetting prices include a royalty of 5 cents per cu yd of peat displaced

Number of swamps studied	4	
Total length	9,590 ft	
Maximum depths	25 to 43 ft	
Total subfill	376,322 cu yds	
Total cost of relief trenching	$4,872 19	
Total subfill jetted	265,724 cu yds	
Combined cost of relief trenching and jetting	$21,823 90	
Cost of peat displacement per cu yd of subfill		
Maximum		$0 2004
Average		$0 0821
Minimum		$0 0703

COST SUMMARY

The cost summary tabulation contains the total costs and average unit costs of each individual method on which we have made a detailed cost study in this report In addition it contains recent contract unit prices for methods on which we have not made a detailed cost study

The order in which the methods are arranged in this summary is the same as in the classification of methods

The cost of excavating the peat in methods calling for partial or total peat excavation has varied from 14 to 27 cents per cubic yard When the yardage of peat excavation is large enough to warrant listing it separately, the bid price for excavating peat is very much less than when all earth excavation is included in one classification

The cost of deep grubbing on projects on which this method has been used has varied from $1 to $2 per square rod of swamp area grubbed

The Minnesota State Highway Department report, Acceleration of Subsidence in Swamp Fill Construction, Data for 1932, contains the following information on the comparative costs of dynamiting and mechanical excavation

In shallow peat formations, from 4 to 5 ft deep, blasting clean wide trenches is difficult This is particularly true if the ground water has receded and left the peat in a dry condition In contemplating mechanical excavation, however, the swamp should be firm enough to support a dragline on mats, the grade line must be high enough to provide storage space for the peat and conditions should be such as to permit casting to the side A trench approximately 28 ft wide and 4 ft deep would involve about 400 cu yd excavation per station. At a unit price of 10 cents per cu yd the cost per station would be $40. Five hundred pounds of dynamite costing 17 cents per lb, including labor in placing, will amount to $85 per station Two hundred thirty pounds of dynamite will cost $39 per station In a general way, the shallow peat formation, if dry enough to support a dragline on mats, can be more economically and satisfactorily trenched by mechanical excavation

Choice of Method

In selecting a method to use for a particular swamp it is necessary to consider numerous factors, the more important of which are

1 Importance of highway
2 Type of surfacing to be used
3 Classification of the swamp material
4 Depth of swamp
5 Presence of buildings, bridges, railroads, drains or pipe lines in the immediate neighborhood
6 Presence of an old embankment
7 Condition of the swamp surface as to whether it is better drained and timbered or covered with water
8 Availability of water in case the jetting method is to be used

The outline in Table II represents an attempt to show as briefly as possible what factors or combinations of factors are important for each of the methods described

Conclusions

The present tendency in Michigan is to avoid the excessive use of explosives and to depend more on methods which seem to be very positive and easily controlled The emphasis now is placed on such factors as (21) the kind of fill material to be used and the proper timing of steps in the construction of the embankment The latter factor is important in that it permits obtaining the maximum advantage which may result from the fluid character of peat and the greater weight of the fill To avoid the necessity of dealing with comparatively dry and compact peat, such as forms below a heavy embankment, special attention is given the point of filling The high pressure in the peat at this point is being continuously relieved by mechanical excavation Maximum fill weight is applied here by building the fill to surcharge grade or more by the end dump method This surcharge is moved forward with the bulldozer as the filling progresses Even when the peat is completely excavated there is a proper time for placing the backfill This is true especially when the excavation is deeper than three or four feet The fill should be placed by end dump methods to plan grade as the peat is being excavated so as to prevent the sides of the excavation from sliding into the trench and to prevent the accumulation of disturbed peat in front of the backfill This peat if allowed to accumulate, will become partly buried from time to time and cause weak spots in the embankment

The necessity of choosing proper material for filling purposes cannot be over-emphasized Many of the more recent failures over peat

TABLE II

CHOICE OF METHODS

Method	Dominant Factors Influencing Choice of Methods	Remarks
1 Partial Excavation		
(a) Deep Grubbing	Type of surfacing	Method only used on gravel and related surfacings
	Depth of swamp	Used on long, comparatively shallow swamps
	Condition and character of swamp surface	Used if roots, stumps and logs are present
(b) Excavation of surface mat	Type of surfacing	Method only used on gravel and related surfacings
	Depth of swamp	Used in comparatively shallow swamps
	Condition and character of swamp surface	
2 Partial Excavation and Further Treatment		
(a) Partial excavation and temporary surcharge	Presence of buildings, bridge structures, etc	Causes less damage to adjoining property than the more violent methods
	Comparative cost	
	Depth of swamp	Very effective for depths between 8 and 25 ft
(b) Partial excavation with dynamiting or jetting	Depth of swamp	Most important—Use in swamps of over 8 to 10 ft depth
	Character of swamp material	Presence of marl would eliminate method—use 5b
	Availability of water	If jetting is considered
	Comparative cost	Other methods (2a, 3 or 4)
3 Gravity Fill	Depth of swamp	Use in swamps 25 ft or more in depth
	Character of swamp material	Lacustrine clay under peat facilitates peat displacement

TABLE II—*Concluded*

Method	Dominant Factors Influencing Choice of Methods	Remarks
4 Gravity Fill and Further Treatment		
(a) Relief trenching, dynamiting or jetting	Depth of swamp	Used in swamps of 15′ and over
	Comparative cost	2a or 2b
	Behavior on construction	
	Character of swamp material	If material is dry, well rotted and compact relief trenching may be used
	Cost of trenching	
	Availability of water	If jetting is considered
5 Total Excavation		
(a) Total excavation of peat	Depth of swamp	Not over 8′
	Compaction of swamp surface	
	Importance of road-type of surfacing	
(b) Total excavation of peat to marl underneath	Quality of marl	
S-1 Side Excavation		
On high fill in shallow swamps	Presence of old embankment	Depth of fill in place greater than that of underlying peat
	Depth of swamp	Shallow swamp—6′ to 8′ in depth
S-2 Rebuilding in Deep Swamp		
(a) Gravity fill, dynamiting or jetting	Presence of old embankment	If bottom width is wide use S-2b
	Position of old embankment	
	Availability of water	If jetting is considered
	Comparative cost	S-2b
(b) Gravity fill, relief trenching, dynamiting or jetting	Condition and character of swamp surface	
	Availability of water	If jetting is considered

swamps in Michigan are due to the warping or shifting of clay embankments rather than to movement in the underlying peat Sandy gravelly soils should be used when they are available On some heavily traveled roads where detours and temporary surfacings are a serious consideration, it is felt that a three-mile haul may be justifiable in order to avoid a clay backfill

It is desirable that the portion of the fill which will support the future slab be exposed to the elements of weathering and that it reach a uniform compaction before the surface is placed The embankment, consequently should have the advantage of at least one winter's freezing and thawing before the final surfacing is placed

Peat that has been highly compressed and dewatered by the weight of a heavy fill is very difficult to displace For this reason it seems logical to conclude that any method which results in complete peat displacement as the filling process progresses should be economical of both time and material This should be particularly true in case of dynamiting or water jetting

A careful study should be made of each swamp with respect to the character of the peat and condition of the existing embankment in order that economical and effective construction procedure may be planned

Except in the case of partial excavation and gravity fill the Michigan Highway Department attempts to obtain complete displacement of the peat over an adequate width It is believed that this is necessary in order to obviate future settlement Some states have, however, contended that underlying peat can be compacted so that satisfactory stability is established

At the present time it seems that swamps up to eight feet in depth should be excavated to bottom ahead of placing the backfill, that swamps ranging in depth from 8 to 25 ft should be treated as indicated by the method labeled "Partial excavation and surface," and that swamps of greater depth than 25 ft should be jetted provided that an adequate supply of water is available There will be some overlapping in the use of the last two methods depending on conditions encountered on each particular project

The wide range in unit costs seems to be characteristic of methods employing the use of dynamite

It is not practicable to attempt to draw diagrams to represent every condition encountered under actual construction An attempt has been made, however, to illustrate basic methods, variations of which will provide for the common swamp problems There are certainly opportunities for further improvement In other words, the stage has not been reached in this study when standard procedure can be substituted for imagination, experience and a knowledge of fundamentals

BIBLIOGRAPHY

1 Fill Settlement in Peat Marshes—V R Burton, *Public Roads*, Vol 7, No 12, Feb 1927
2 Further Study of Fill Settlement in Peat Marshes—V R Burton and A C Benkelman, *Good Roads* 72, 142–5, 155–6, Mar 1929

3 Blasting Muskeg for Road Construction—T H Mitchell, *Roads and Streets*, 68 132, Mar 1928
4 Swamp Road Construction—J J Mundinger, *Roads and Streets*, 68, 503–4 Oct 1928
5 Blasting a Trench in Swamp Mat for Highway Fill—J A Johnston, *Engineering News Record* 102, 417–18, Mar 14, 1929
6 Blasting Settles Road Fills in Minnesota Muskeg—P W Riedesel, *Engineering News Record* 102, 788–91, May 16, 1929
7 Accelerating Fill Settlement With Explosives—P W Reidesel, *Explosives Eng* 8, 329–34, Sept 1930
8 Road Crosses Swamp on Timber-Pile Foundation, *Engineering and Contracting* 70, Jan 1931
9 Fill Settlement With the Use of Explosives—J A Williams, *Roads and Streets* 71, 139–44, April 1931, *Engineering News-Record* 106, 687–9 April 23, 1931
10 Blasting Roads to Settle Them—*Scientific American* 145, 114–15, Aug 1931
11 Settling Highway Fill in a California Marsh—*Public Works* 63, 38, Jan 1932
12 Blasting to Settle Swamp Fills Approaches Rational Practice—*Engineering News-Record* 108, 354–5, Mar 10, 1932
13 Accelerating Fill Settlement by the Trench Method—W J Keese, *Explosives Eng* 10, 111–14, April, 1932
14 Settling Fills with Explosives—L F Livingston, *Engineering and Contracting* 71, 149–50, June 1932
15 Blasting vs Excavation Through Swamps—*Public Works* 63, 22, Aug 1932
16 Settling a Road Embankment by Underfill Blasting—C G Wahl, *Public Works* 64, 15–16, Mar 1933
17 Explosives for Settling Highway Fills—E Godfrey, *Canadian Engineer* 64, 11–13, May 2, 1933
18 New Method of Blasting Swamp for Highway Fill—C L Wooley, *Engineering News-Record* 110, 715–17, June 1, 1933
19 New Methods in Highway Fill Settlement Work in Rhode Island, *Roads and Streets* 76, 249–52, July, 1933
20 The Supporting Value of Marl for Highway Embankments—O L Stokstad, Mich State College—1933
21 Latest Developments in the Testing of Subgrades—A C Benkelman, *Proceedings of the Eighteenth Annual Conference on Highway Engineering* University of Michigan Official Publication Vol 34, No 3, July 9, 1932
22 Use of Explosives for Settling Highway Fills, (Bulletin) E I DuPont De Nemours & Co , Inc
23 Accelerating Swamp Fill Settlement with Explosives (Bulletin) Hercules Powder Company
24 Application of Soil Science to Highway Engineering—V R Burton, *Roads and Streets* 71, 163–65, May, 1931
25 Dynamite Preserves Highways—J A Williams, *Ag—Ex News* Vol II, No 1, March, 1931

DISCUSSION—METHODS AND COSTS OF PEAT DISPLACEMENT

Mr A G Livingston, *Delaware State Highway Department* Delaware has made three large fills in swamps somewhat in the nature of a peat The methods given by Mr Kushing are useful as a guide to any future work of that nature It was interesting to note his formula for the estimate of the quantity of material necessary to make the fill.

Several years ago our Mr Mack developed a formula with one unknown for developing the quantity of earth necessary for a fill This formula and that of the Michigan State Highway Department were compared about a year ago and were found to check very closely It was noted in the talk that in some cases lateral displacements occurred in the fill This was very noticeable at our location in Barker's Landing where the fill travelled as much as one hundred and fifty feet away from the centerline This was at a location occupied by the main ditch before the cutting through of the navigation stream The fill at Barker's Landing was dynamited until it was very evident that it had settled on the hard stratum below the swamp mud and very complete records were obtained by borings This should afford a very interesting study sometime later when all the data are completely assembled