REPORT OF COMMITTEE ON STRUCTURAL DESIGN OF ROADS[1]

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The present report of the Committee on Structural Design of Roads, as in the past, is composed of individual reports by various members of the Committee and other contributors These reports have been reviewed and agreed to by the majority of the members of the Committee They appear in the following order

- I Fill Settlement in Peat Marshes, reported by V R Burton
- II Subgrade Studies of the U S Bureau of Public Roads, reported by C A Hogentogler, I B Mullis and A C Benkelman
- III Subgrade Studies, reported by F H Eno
  - A A Comparison of Road Conditions with Atterberg's Limits and the Other Standard Soil Tests
  - B The Slaking Test
  - C A Study of the Moisture Content of Ohio Soils
  - D Pavement Displacement Due to Water and Frost
  - E Sub-base Tests on Route 26, Washington County, Ohio
- IV Impact Forces Exerted by the Motor Truck on the Highway, reported by James A Buchanan
- V Thinner Paving Brick, reported by L W Teller
- VI Some Principles Involved in Bituminous Macadam Construction, reported by George H Henderson
- VII Progress Report on a Field Experiment on Introduction of Planes of Weakness in Concrete Slabs, reported by C N Conner
- VIII Progress Report on the Experimental Curing Slabs at Arlington, Virginia, reported by J T Pauls
- IX Analysis of Stresses in Concrete Pavements Due to Variations of Temperature, reported by H M Westergaard

FILL SETTLEMENT IN PEAT MARSHES

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A very important phase of the soil survey having to do with the settlement of fills in peat deposits has just been completed by the Michigan State Highway Department Settlement over these peat

[1] The report on Experiments on the Extensibility of Concrete, by W K Hatt, was not available in time for publication in these Proceedings It will appear in a future issue of *Public Roads*

marshes has caused serious trouble in many places because not only was it unknown as to how much fill material would be required but even after the fill had been completed no assurance was had whether or not it would maintain the original grade line designed for it It was therefore desired to know first what sort of material this peat was composed of so far as its physical characteristics were concerned, and what information it would be necessary to get in order to enable one to properly locate and estimate the cost of a road over a peat deposit Having been given the location, it was desired to discover whether or not it would be possible to devise a method of construction more economical than that then in use in these peat bogs Finally, what means of maintenance could be used to restore the surface to its proper grade line and prevent further settlement where serious settlement had occurred?

A brief description of peat deposits will be necessary if any adequate idea is to be had of what actually exists under the surface of "sink holes" Peat deposits are classified and mapped stratigraphically in essentially the same way as mineral upland soils Type profiles and boundaries of a peat area are determined by the horizontal and vertical space relations of the different layers exhibited by peat deposits For general peat studies, peat materials have been described by layers in terms of composition, texture, structure and color This gives a fairly good idea of the main differences between separate peat layers and localizes their relative positions

The classification of peat strata in this survey was made in accordance with the system largely developed in this country by Dr Alfred P Dachnowski, of the Bureau of Plant Industry, U S Department of Agriculture In this work of classification we were fortunate in securing Dr Dachnowski's personal supervision on a number of surveys

The following description of peat deposits is taken from an article on the "Stratigraphic Study of Peat Deposits" by Dr Dachnowski published in "Soil Science," Vol XVII, No 2, February, 1924

Distinction should early be made between muck and peat Muck is the thin surface layer of disintegrated peat and is entirely different in appearance and properties from the relatively unaltered peat below it This distinction is made because many engineers use the terms interchangeably with no knowledge that there is a difference

The following table by Dachnowski is from the article previously referred to and gives the classification of characteristic peat layering

Pulpy peat is formed in water basins under conditions of poor drainage from transported organic sediments carried from their origin and redistributed by water currents There are no visible

TABLE I

STRUCTURAL UNITS OF PEAT DEPOSITS AND SOME OF THEIR PHYSICAL CHARACTERISTICS

Group of peat-forming vegetation	Types of peat	Character of peat layers	Color of peat layers	Texture of peat layers	Structure of peat layers
Aquatic	Macerated, colloidal	Pulpy (sedimentary)	Olive green, brown to black	Coarse to very finely divided	Compact, impervious, stiff, plastic or loose, friable
Marsh Bog	Reed Sedge Brown moss Bog moss	Fibrous	Gray, red, or yellow brown to dark brown	Coarse to fine fibered	Dense matter, felty, or porous, spongy
Bog Swamp	Heath shrub Willow-alder shrub Deciduous forest Coniferous forest	Woody	Dark brown to blackish brown	Coarsely fragmental to granular	Compact and granular, or loose wicker-like

bedding planes, although the original sediments were laid down in practically horizontal position under conditions differing by rate of deposition, seasonal changes, etc The plant remains are small in size—in texture the peats vary from coarse to very finely divided particles, while in structure the layer may vary widely in its degree of compaction Fresh from the deposit and while still moist, the colors vary from gray, green and brown to black

As with most peats, on exposure to the air and drying, the material speedily loses its character by oxidation This peat shrinks enormously and becomes a hard water resisting substance when quickly dried out It will not then absorb anything like the original quantity of water Dr Dachnowski states that "it may be accepted as an axiom that undrained deposits of peat contain from about 70 to 95 per cent of water"

The outstanding characteristic of fibrous layers of peat is their matted or felt-like porous nature, which has its origin in the slightly altered remains of roots, rootlets and rhizomes of herbs and from mosses The peat layers differ widely in character Their water content is enormously high, the solid matter commonly composing only from 5 to 15 per cent of the peat mass In texture they vary from coarse to very finely fibered material, usually showing a rather loose porous appearance, with colors ranging from gray through yellow to red brown and dark brown The layer may be interbedded or grade into a layer of woody or pulpy peat admixture or it may occur in overlapping beds of other kinds of fibrous peat

Woody peat may occur either as the dominant component or as a prominent admixture in other types The woody plant remains are broken down partly into granular debris and partly into irregularly shaped woody fragments which are almost unaltered by decomposition The woody peats differ widely in composition and character They may be as finely divided as sawdust or as coarse as a tangle of waterlogged brush heaps and logs Several layers may be found, as, like the fibrous peats, they are developed on moist flat land under conditions of a rising or fluctuating water table Land may grow up to forest, be submerged to form a marsh, and then emerge again to become forest In one peat deposit examined on this survey three distinct forest layers were plainly visible

Marly phases of peat are formed from calcareous plant remains and shells of mollusks and are usually found admixed in the macerated types of peat materials Extensive deposits of marl occur mainly in regions underlain by limestone rock or where the soil adjacent to and underneath a peat area is derived from limestone drift It varies in color from gray to brown and is usually a soft plastic mass with particles from fine to comparatively coarse, depending on the amount and character of plant or shell remains present

The lake clay found in the bottom of most deep peat deposits is structureless, mainly siliceous material from plant remains consisting of diatomaceous shells and drift debris It is gray to gray blue in color, fairly compact, but with a high percentage of water in it and is quite plastic and sticky It is, however, a much more compact and weighty material than any of the peats or marls

In carrying out the study of fill settlement it was decided to cross-section the marsh accurately by borings which should show the various peat layerings and the exact position of the filled material with reference to them Samples of the various classes of peat were to be collected and sent to the laboratory for physical tests in an effort to discover some relationship between their bearing power and the known settlement for various water contents If a large number of existing fills were thus examined it seemed logical to us that general conclusions might be drawn to serve as a guide in future work

Fills over eight different peat deposits were cross-sectioned at eighty-three different points where the depth of the peat deposits ranged from one to sixty-six feet The shape of the fill material in the peat was accurately determined by a field party with a two-inch

Empire drill The peat around and underneath the fill was cored with the Davis peat sampler where the peat had not been too heavily compacted If the Davis sampler could not be used in the compacted peat the Empire drill and jet were used Enough test holes were put down on the cross-section chosen to show the fill shape fairly accurately and an effort was made to extend the cross-section in both directions from the fill sufficiently far to get out of the zone where the layers were disturbed by filling In a few cases it was evident that the test holes at the extremities of the cross-section were not placed far enough from center line

Samples of the different peat layers were collected at various depths and sent to the laboratory for physical tests Results were very disappointing in this regard, first, because it is impossible to maintain the peat in its original condition on exposure to the air and after drying Peat as it comes from the ground is only partially oxidized and at the greater depths there is actually some reducing action Consequently, immediately it is handled in air, oxidation begins and if it is attempted to dry it, a totally different material results Next, it is certain that the amount of compression under loading in a vessel such as is used in the standard bearing value test which does not permit of a free displacement in all directions, will not give results at all indicative of the behavior of the same material in its natural place It must be remembered that peat is from 70 per cent to 95 per cent water in its natural state and that consequently resistance to flow is very small

The only way, then, to secure the solution of the various problems involved in this investigation was by a careful study of the cross-sections showing the fill shape and the peat layerings in the disturbed position after filling It was attempted to reconstruct the position of the layering as it originally existed from the position of the layers outside of the distorted area on the cross-section A study of the fill cross-section and the distortion later produced on the original layers as reconstructed led to the conclusions drawn from these effects

The various factors which it was thought should determine the amount of settlement are depth and character of peat layering, height of the water table, slope of the mineral subsoil beneath the peat, height of fill and width of fill The weight and character of the fill material would also be a factor, but the difference in weight of the materials studied was so small as to be neglected All fills in this investigation were earth and varied from a clay to sand No rock fills were studied

So far as could be determined, there is very little difference in fill settlement dependent on the character of the peat layering There is, to be sure, a decided difference between the top foot or two of the peat where the material is fairly well decomposed, but this is more due to a smaller water content than in the actual character of the material itself The lake clay which occurs in the bottom of most of our deeper peat deposits is enough different in character so that its effect must be considered separately It is also probable that if any considerable thickness of pure marl with a heavy texture were encountered it should be grouped with the clay or given separate treatment As it happened in this investigation no very great amounts of marl were found except as they occurred as a peat admixture A soft soupy marl should probably be classed as peat in considering its effect on fill settlement The preliminary work of sounding a peat bog preparatory to estimating fill settlement is thus considerably simplified for the engineer, as, where a uniform marl is absent only two layers, the peat and lake clay need be considered No differentiation of peat layering is necessary for estimating fill settlement

If there were any great variation in the height of the water table compared to the depth of the deposit, this factor should certainly show its effect on our problem It so happened that the road ditches through the shallow depths of peat were not greatly different in their depths, and in the greater depths the depth of the ditch was very small in comparison to the total depth of the peat The water table in most cases varied from one to three feet below the fill surface The varying height of water table, which would be to a certain extent dependent on the time of year, as well as on the particular situation of the cross-section, was not taken into account Some inconsistencies in the shallower depths are probably due to the neglect of this factor

The height of the fill above marsh surface is, of course, a factor, although not so great a one in the case of loading over a wide area as one would expect The effect is most marked in medium depths from 10 to 25 feet In depths of less than 10 feet of peat the settlement is small and the effect of other factors so great that the results are very inconsistent In depths above 25 feet the total depth of fill is so great in proportion to the height above marsh surface that the amount of this additional loading is not important This refers to those fills which were made prior to the time of this investigation and refers to the amount of fill height after the fill has been made The height of fill that is placed in the early stages of filling is extremely important, but in most of the earlier work this was kept to a minimum until settlement was nearly complete

The slope of the mineral subsoil produces a marked effect on settlement and the bottom of the fill nearly always takes the same direction of slope as the marsh bottom This is due to two reasons, first, the flow of the peat beneath the fill is aided by gravity, and, second, the greater depth of peat down slope induces greater settlement Most of the inconsistencies in amount of settlement from the determined normal occur above sharp slopes in the mineral subsoil The amounts varied so much, however, that no general law could be observed It is safe to say that in general if the mineral subsoil does slope quite sharply the normal amount of settlement will be increased

One very important factor met in special cases is the effect of the peat compression by neighboring fills on fill settlement This compressed peat is much more resistant to flow than is the uncompressed peat, and hence flow on the side adjacent to an old fill is very much smaller than on the free side

As a matter of fact, the factors of the greatest importance and the ones least difficult of determination are simply the depth of the peat layer and the depth of the lake clay beneath it Other factors undoubtedly have their influence, but the depths alone, so far as could be determined from the information available, directly determine the amount of settlement which will occur No other factors operated with the consistency or effect of these

Let us consider what happens when a fill of heavier material is placed over a peat deposit The top crust is first subjected to compression beneath the interior of the fill and to shear and tension at its edge The communication of this compression to the interior of the peat is resisted by the resistance to flow of the peat or its internal friction Due to the inertia of the peat particles to movement, water is squeezed out of the material nearest the fill and the material compacted, and this process goes on in continually decreasing amounts farther away from the fill until at some distance the peat is practically undisturbed

The peat is a semi-solid substance largely composed of water, but with an appreciable amount of internal friction causing a resistance to flow If the resistance of the peat to compaction is less than the applied pressure, then both vertical and horizontal deformation of the plastic mass results The very low cohesive forces in the mass cause an actual displacement of material from these deformations and flow follows

Particles of peat near the center are from the first subjected to greater pressure than those near the outside When bending of the elastic crust takes place, compression is greater near the center and lateral flow quickly begins This flow is a result of the transformation of the vertical to lateral pressure due to the increasing resistance below, to the horizontal component of pressure due to the internal friction of the material, and also to the horizontal component of pressure due to the inclined position of the settling load These center particles in their flow laterally are subjected to pressure for a considerable time in their flow to the edge and hence further compaction with an increase of internal resistance results Those particles nearer the edge are not subjected to this pressure for long and communicate their pressure to the undisturbed peat on the outside In the course of time the peat beyond the fill becomes compacted and finally the compressive stresses are completely absorbed in further resistance to lateral displacement

It is easily understood, then, that the width of fill is a function of the amount of settlement which takes place The fills in this investigation do not vary greatly in width, viz , from 24 to 30 feet, and so no account is taken of this factor It is important, however, in considering the cause for the greater settlement in deeper deposits

When deposits are relatively deeper in proportion to their width, considerable vertical movement can take place before any marked reaction is experienced from the mineral subsoil below Flow laterally, then, is comparatively small at first, a large amount of settlement is possible before any great amount of compaction can take place, the elastic crust ruptures in tension and shear and the whole weight of the fill is suddenly thrown on the soft material below This sudden application of weight very quickly compacts the peat below to a degree at which lateral flow begins in a considerable amount and we have a "sink hole" The peat flowing from beneath the load of earth expands on the release of pressure and the peat is heaved up on the sides Due to the lighter weight of the peat as compared to the fill material, a correspondingly larger amount of peat must be raised to balance the heavier fill Subsequent loading increases this heaving until the weight of the heaved peat becomes sufficient to compact the material beneath enough to prevent further flow

In the latter stages of fill settlement the rate of settlement is very slow, but even a rate of a foot a year is decidedly objectionable This rate is progressively decreasing until finally, after a long time, equilibrium is established The length of time before a stable condition is reached is known in some cases to be more than five years We have arbitrarily set the rate of settlement of five hundredths of a foot in thirty days as being the rate at which filling may be stopped Since the rate will progressively decrease, usually this should give a settlement of less than 6 inches per year

Unfortunately, at times, if the early settlement was not rapid, some later cause may accelerate the rate of settlement Fills completed in the fall under earlier methods were quite apt to settle rapidly the following spring The vibration of traffic also tends to increase the rate of settlement after a road is first opened Large ditches cut along an old road are quite apt to start considerable settlement As a matter of fact, unless settlement during filling has been accelerated in every way possible in order to insure its completeness, some subsidence is almost sure to take place later

A number of cross-sections illustrating the various shapes taken by fill under different conditions are shown Figure 1 shows a fill of

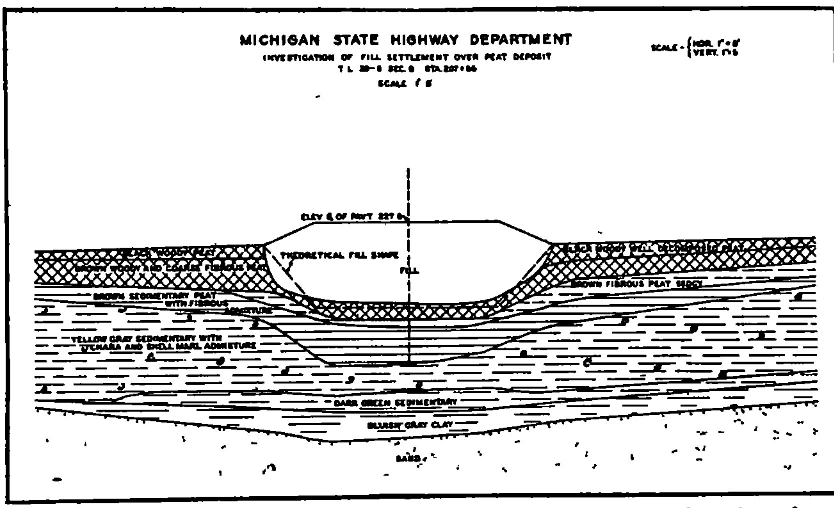

Figure 1—Fill of normal cross-section in peat marsh about 22 feet deep from surface to clay

normal cross-section in a peat marsh about 22 feet deep from surface to clay The theoretical shape of fill is shown by the dashed line and is obtained by a method described later This deposit is of nearly equal depth on both sides of the fill and therefore the shape of fill is quite regular

Figure 2 shows a fill which is partly on upland soil and partly over peat marsh It will be noticed that the mineral subsoil slopes sharply toward the peat deposit, and for this reason the proportion of the fill beneath the surface of the peat is considerably increased above that shown on the normal cross-section It will also be noticed that due to the flow of the material only a very small amount of the peat which is originally under the fill remains, and that the thickness of the layers to the right of the fill are considerably thickened due to their flow from beneath the fill and subsequent expansion due to decrease of pressure

Figure 3 shows a fill in a peat marsh which is still settling at a rapid rate The slope of the bottom of the fill is quite noticeably

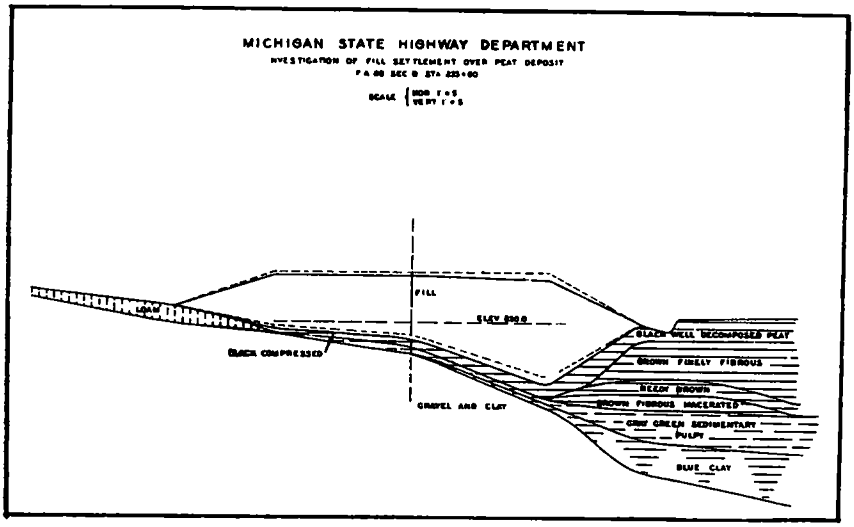

Figure 2—Fill partly on upland soil and partly on peat marsh

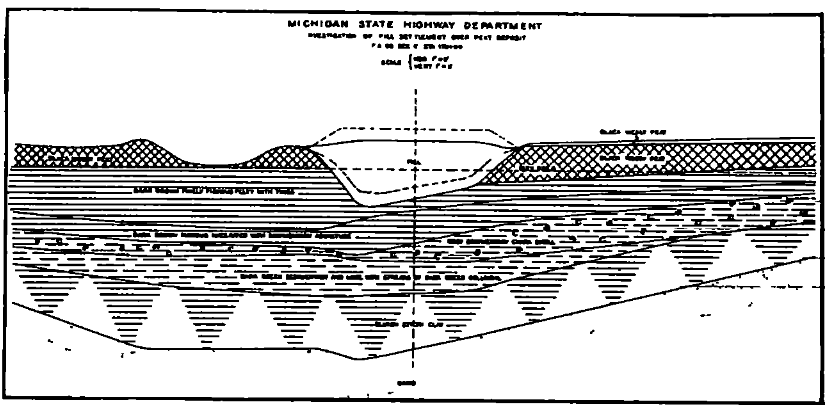

Figure 3—Shape of fill in peat considerably affected by slope of mineral soil at bottom of peat bed

parallel to the slope of the mineral subsoil beneath the light clay and the most of the distortion of the peat layers has occurred on the low side of this mineral subsoil It is quite evident that even with this considerable depth of peat beneath the fill, pressure is communicated throughout the entire mass

A still more exaggerated case of the direction of pressure induced by the slope of the mineral subsoil is shown in Figure 4, on which it will be noticed that except immediately adjacent to the fill practically all of the disturbance of the peat has taken place to the left of the center line, indicating that flow has largely occurred in this direction

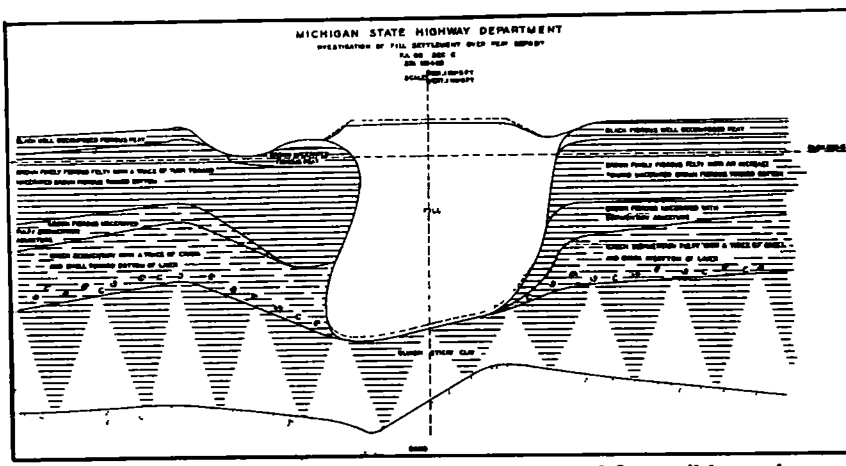

Figure 4—Distortion of peat fill to left due to slope of firm soil beneath peat bed

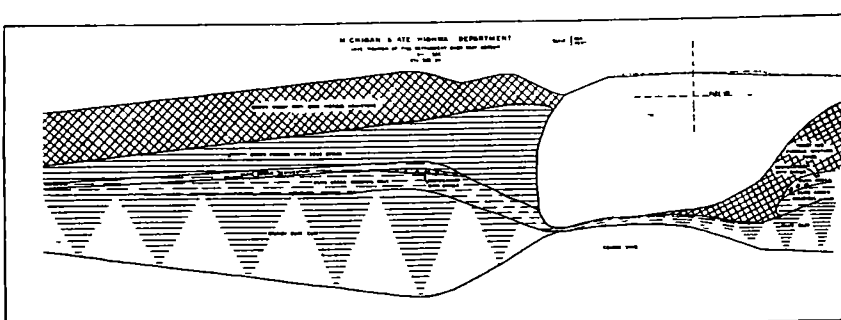

Figure 5—Fill adjacent to a railroad fill at right but not shown

Figure 5 shows a fill which was placed adjacent to a railroad fill, at the right of the figure In this instance it will be noted that the compacted peat to the right of the center line reduced the amount of fill necessary in a material manner It will also be noticed that a very considerable amount of distortion of the layers is shown on the left of the figure In this instance the peat is heaved above the normal level of the marsh some 10 or 12 feet, and this slopes away from the creast of the heaved material in a fairly uniform manner

Figure 6 shows the deepest cross-section which was encountered in this investigation, and is about 66 feet from the elevation of the surface of the highway to the bottom of the mineral subsoil This marsh, over which the fill was made, lies between two fairly large lakes which are at present connected by a small stream It is quite evident that the location of the highway in this particular instance was very unfortunate in that the center line of the highway at the cross-section shown is practically on the center line of the old glacial drainage channel between the lakes in the early stage of their formation A location of center line 30 feet to the right of its present location, which in this instance would have been possible, would have eliminated about 25 feet of fill It will also be noticed that the entire amount of the lake clay, which probably nearly filled the

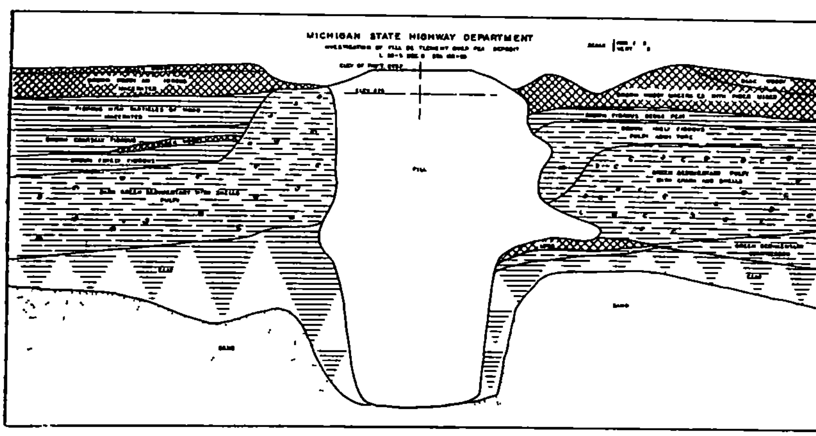

Figure 6—An unusually deep fill

old channel, has been forced to one side by the load of fill above it The iregular shape of the cross-section on the right is probably due to filling at the time that the peat heaved 8 or 10 feet on the side, leaving about 8 feet of water to fill in This peat later broke off and fell back into the hole It will be noticed that surface peat on both sides has been carried through considerable depths by the placing of this fill

From the whole series of cross-sections of the character of those just shown, most of which, however, are considerably more regular, diagrams giving the amount of settlement and shape of fill of marsh fills have been prepared Depths of peat and marl on center line of fill were platted against the total depth to which the fill penetrated the peat and marl measured from the original marsh surface These points were collected into three groups, one of fills from 1 to

3 feet, one from 3 to 4 feet, and one from 4 to 5 feet, and curves drawn through them to give the average amount of fill penetration for the various depths. The depth to which the fill penetrated the lake clay was also platted, setting the amount of penetration against the total depth of marsh deposit, and a curve drawn to fit. The other less important factors in fill settlement were neglected.

No claim is made that there is any scientific reason for the shape of these curves. They are purely empirical and simply represent the average behavior of a considerable number of fills. So little is known about the method of loading that any other means of handling the problem would be impossible. We have devised a standard method of loading to be later described, which should yield more consistent data in the future.

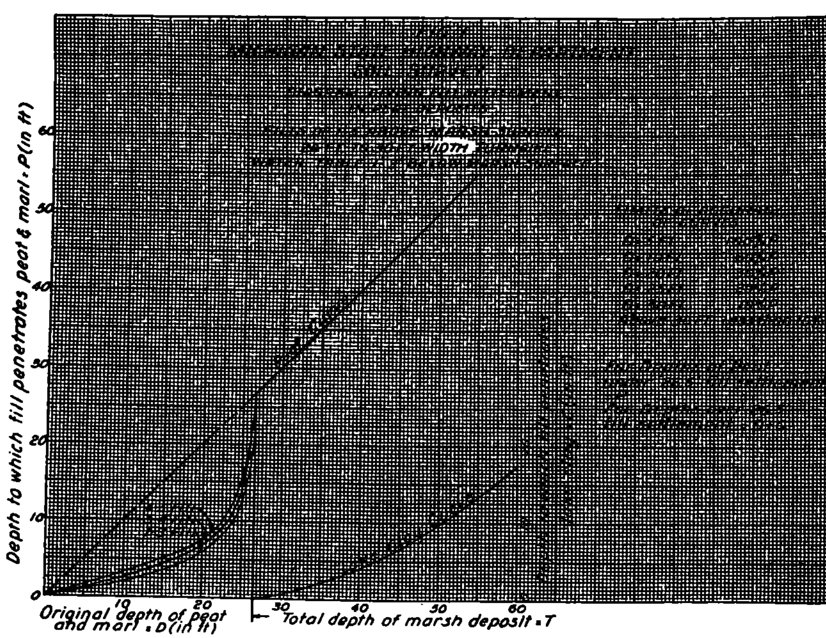

Figure 7—Diagram giving fill settlement in peat marshes

The peat curve on the diagram, Figure 7, giving the fill settlement, shows that the settlement increases fairly uniformly and quite slowly up to depths of about 20 feet. From 20 to 26.5 feet the rate of settlement increases very rapidly with depth, and in peat marshes above 26.5 feet deep the fill goes completely through the peat in every instance, so that the penetration equals the depth and the curve becomes a 45-degree line.

Addition to this amount of settlement must be made in the case of a deposit underlain by lake clay where the peat is completely penetrated. In this case we add to the peat penetration the amount of clay penetration, using the total depth of marsh deposit as the argument. If the amount of the clay penetration exceeds the depth of deposit shown by the boring, then the fill will displace all the clay beneath it and the total depth of deposit is the fill penetration. That is, the fill will not stop settling until it reaches the mineral subsoil beneath the marsh deposit.

Supposing we had a peat marsh consisting of 30 feet of peat and marl and 5 feet of lake clay. The peat curve gives us complete penetration of the full 30 feet of peat, and from the 35 feet total depth of the marsh deposit we read off from the clay curve 2 feet for clay penetration. There will then be a distance from bottom of fill to marsh surface of 32 feet. Again, if we had a peat deposit consisting of 38 feet of peat and 2 feet of lake clay we should get 38 feet peat penetration plus 4 feet of clay penetration. The total 42 feet exceeds our total depth of deposit and the fill therefore stops at the marsh bottom with a 40-foot penetration. This last case is not common except in the very deep deposits of 50 feet or more. It will usually be found that in depths of marsh of over 50 feet with the ordinary proportions of peat to lake clay the fill goes entirely to the bottom.

The limit of accuracy of the curves is shown with the diagram, in percentages of penetration, and represents the extreme limits of variation of the observed points from the curves. It is, of course, perfectly obvious that the percentage of error should be considerably smaller for the greater depths. Average amounts of penetration are usually well within the limits given.

The method of estimating fill quantities is shown by diagram in Figure 8. The shape of the fill and formulæ for computing the cross-sectional area of this fill are given. This typical shape was arrived at by drawing on cross-section paper all of the cross-sections of equal depth superimposed on each other with the marsh level as a base line, and then fitting an average figure to them. It will be noted that the side slope of the embankment above marsh level is a 1 on 3 slope. This slope was used because of the fact that most of the fills studied had approximately this slope. The fills quite generally slope in to a point directly beneath the shoulder line from the outermost edge of the embankment. From shoulder to shoulder only comparatively slight variations from center depth were noted although, as we should expect, the center is somewhat lower. The depth of penetration has been set to take account of these variations and give the average depth from shoulder to shoulder.

It may be surprising to some to note that the slope of the fill sides beneath the surface of the peat is towards the center of the road, but, with a little consideration, the reason for this is quite apparent. In the first place, the fill load as placed varies from zero at the toe of slope to its maximum at the shoulder line, and hence should pro-

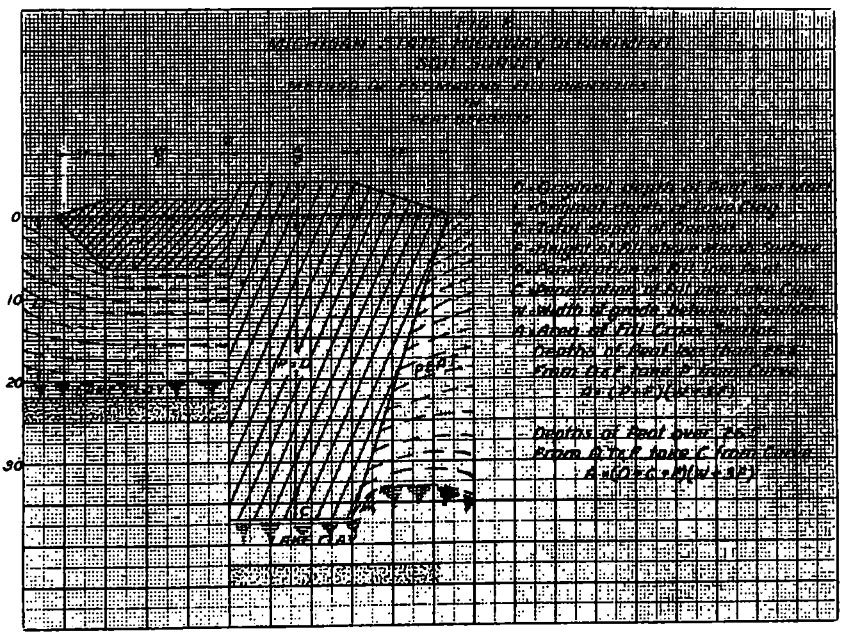

Figure 8—Diagram giving method of estimating fill quantities in peat deposits

duce a fill shape corresponding to this loading. Next, in a good many instances the fill has been carried across the marsh at less than full width after heavy settlement has taken place and this sinking produces a narrower fill. Undoubtedly the drag of the compacted peat at the side also tends to narrow the fill width as it sinks. This is indicated in the fact that the center is quite generally lower than the rest of the cross-section.

One of the striking features of this investigation was the irregularity shown in the topography of the marsh bottom. In a number of instances a slight shift in line would have saved thousands of yards of earth in filling. It is therefore necessary, when the location of the road requires the crossing of a peat marsh, to map the topographical features of the marsh bottom quite accurately. This is more important than on upland soil because visual inspection of the proper location cannot be made but must be determined by the topographical information secured from sounding.

In places where there is any considerable depth of peat it is highly necessary that settlement during filling be encouraged in every way possible This settlement is bound to take place sooner or later and it is vitally important that it be practically complete before any rigid surfacing be placed The construction of brush mats in order to float the fill is not advisable in the case of highway work where hard-surface pavement is to be placed These mats only delay settlement and do not stop it This is contrary to the practice of some railroads, but in railroad work it is a simple matter to add ballast and bring the track back to grade as settlement progresses, without interrupting traffic In the case of settlement in any considerable amount on a hard-surfaced highway, the subgrade must be refilled and a new surface placed This always involves more or less interruption to traffic besides the greater expense of placing this new surface with the maintenance forces

The length of the bog should influence us somewhat in our choice of methods of filling Settlement over short bogs, even in small amounts, is much more objectionable than on longer stretches because of the sharper deflection of the settled surface, and the liability to offsetting of the pavement slabs A long gradual settlement of considerably greater amounts is not so noticeable either to the eye or in the riding qualities of the pavement Of course, settlement over either long or short bogs is objectionable if the amount is great enough to interfere with the drainage Settlement enough to cause trouble from this score is not liable to occur in marshes of less than 6 feet in depth

In Figure 9, which gives the "Methods of Filling Over Peat Bogs," now standard with the Michigan State Highway Department, these methods are varied with both the length and depth of the bog to be crossed Method No 1 simply consists of placing the fill on the peat surface and is used for depths up to 6 feet where the bog is longer than 300 feet If settlement should take place the bog is long enough so that it should be rather gradual, and the 24-inch clearance above the original marsh surface will usually absorb this settlement without bringing the top of fill too close to the marsh surface

Method No 2 is similar to method No 1 except that in this case the marsh drainage ditch goes through the peat deposit entirely This should give a much drier subgrade and the lowered water table should help to prevent considerable settlement This scheme should be used where conditions of the marsh drainage system require the use of ditches of considerable size

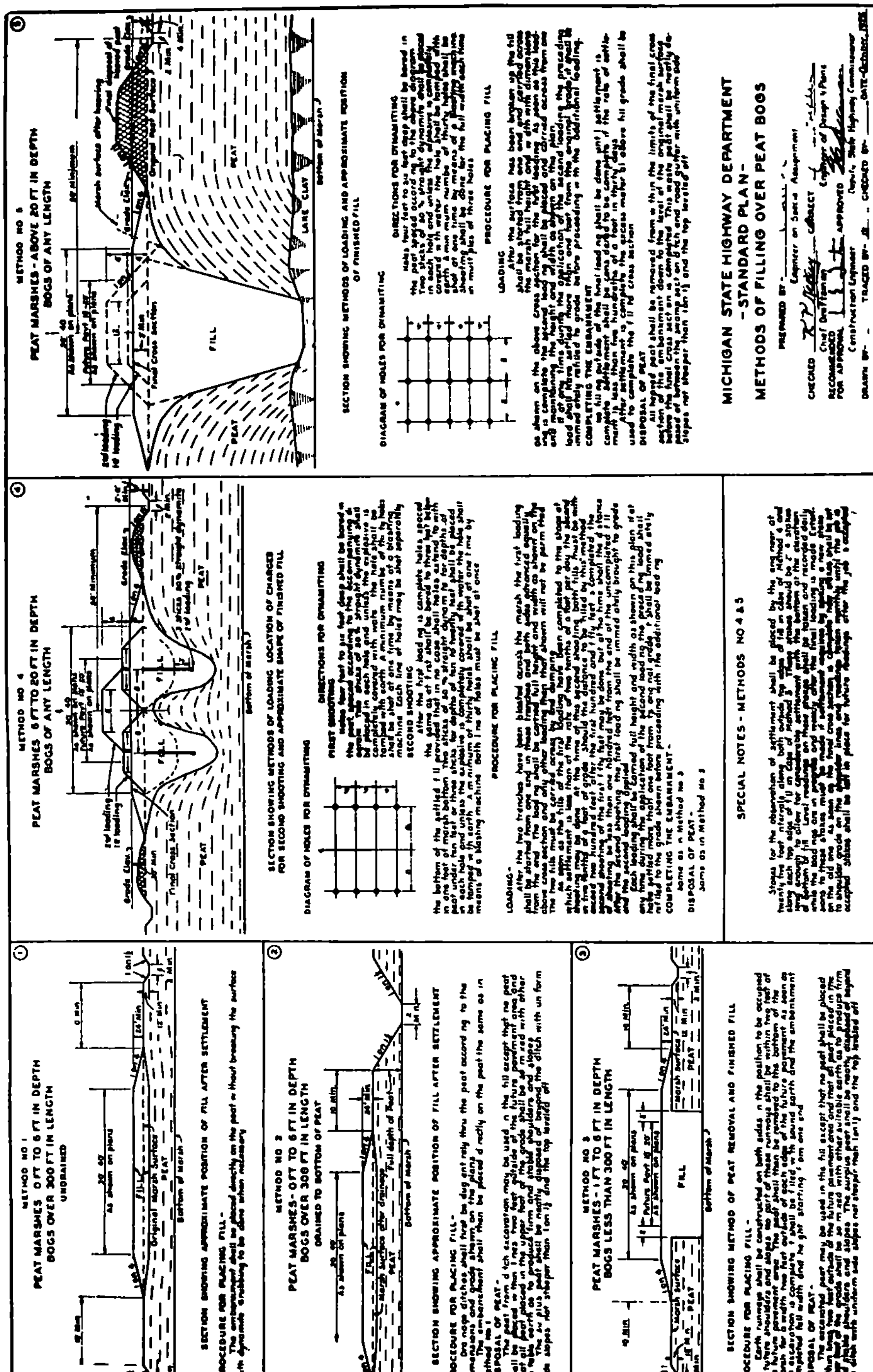

Figure 9—Method of filling over peat bogs

Where bogs are comparatively short, say less than 300 feet, and even small settlements would be undesirable, method No 3 is used This method requires that all the peat to a width of 2 feet wider on each edge than the proposed pavement slab be excavated to marsh bottom, and the excavation be filled with sound earth This method is not so expensive as it would seem because the peat is very easy to move and can usually be disposed of with a very short haul Peat excavation of this type is not practical for over a six to eight foot depth on account of the large amounts of peat which slide into the hole from the sides

In the deeper deposits settlement is sure to take place and the sound policy therefore, is to see that this settlement is aided in every way possible The original fills are placed on a peat surface which has been broken up to destroy any crust effect from the edges The fills are made as narrow as possible so as to increase the unit loading and insure deep penetration The compaction of the peat adjacent to these narrow fills will permit of loading it after the original fills are made, without serious danger of settlement in any amount The proper technique, then, of marsh filling consists of driving a narrow fill into the peat as deep as possible and then spreading the remainder of the fill over the compacted peat

In accordance with the policy of accelerating early settlement and taking advantage of the compaction of the peat between and outside the two fills, method No 4 is proposed for peat marshes of a depth of less than 20 feet and more than 6 feet The supporting power of the peat crust is destroyed by blasting in two trenches parallel with the center line These trenches are back filled with earth in four-foot lifts and carried simultaneously across the marsh, trapping a certain amount of peat between the two fills When the first two lines of embankment are complete and settlement has become slowed up to a considerable extent, charges of dynamite are placed from two to three feet below the bottom of the fill in the peat, spaced 4 feet center to center and on the center line of the two embankments, and exploded This second blasting drives the peat from beneath the wedges of earth and induces further rapid settlement After refilling the settlement, due to the shooting, the second loading of earth is added in a four-foot lift on the center line of the road This second loading helps drive the wedges of earth still further into the peat and insures a maximum compaction in the center so as to eliminate the possibility of center settlement due to the method used in the first loading This loading is maintained and settlement refilled until the rate of settlement is less than five hundredths of a foot in 30 days The excess earth is then spread to form the complete embankment

Depths of peat from 6 feet to 20 feet usually give more trouble than any other depths due to the fact that it is seldom that any rapid settlement occurs without excess loading and surfaces are laid on fills over deposits of this character long before complete settlement has been attained It is much more difficult to secure complete settlement due to the early resistance of the peat to compaction, and it is for this reason that the two narrow wedges of earth are used in an effort to secure as deep a penetration of these wedges as possible The final loading under this scheme gives a static load which is nearly twice the normal load and it is felt that little danger of further serious settlement need be feared To insure the acceleration of settlement we desire, it is required to maintain the grade to within one foot of the designed elevation at all times In long marshes in order to avoid the necessity for too long backing up by the trucks in end dumping, provision is made for shooting part of the fill at a time It is believed though, that at least a hundred feet of fill should be held for settling at all times before any shooting is done

For depths of peat over 20 feet, the center loading is used at once after the surface of the peat has been broken up by dynamite A fill twelve feet wide at the top and four foot high is carried across on the center line This fill is maintained to grade as nearly as possible until it is entirely across the space over which this method is to be used As soon as this fill can be maintained at this height entirely across the marsh, a second four-foot lift is made without any preliminary shooting It is felt that with a fill width of this amount, dynamite would not displace the peat sufficiently to justify its use In addition to this, the deeper depth of the marsh makes settlement so much easier that the loading alone produces sufficient settlement After the settlement has slowed down to a rate of five hundredths of a foot in thirty days, the fill is unloaded and the excess material spread to form the remainder of the cross section The compressed peat on both sides of the narrow fill will usually support the remainder of the turnpike with little settlement

Any combinations of these methods may be used in crossing peat marshes of considerable length, suiting the method to the depth and length encountered The cardinal principle in all marsh filling where pavement is to be placed is to insure settlement, and not attempt to avoid it Unless the fill has become stabilized, this settlement may occur over long periods and the former practice of attempting to "sneak across" with light loadings has been responsible for a great deal of maintenance expense in locations of this character

The proper time to take care of this settlement is on construction, as it is extremely difficult to maintain in a satisfactory way a surface which is continually settling

If any bridges are to go in over streams thru deep peat deposits, the approaches should always be completed first Filling should continue toward the center of the stream so that excavation for footings should occur in the filled earth In some cases, where streams are small, it will be found advisable to carry this filling completely across the old stream bed The expense of later cleaning out the earth above stream bottom and taking care of the stream flow during filling is money well spent

The above may seem ridiculously obvious to many engineers, but the frequency with which bridge failures have occurred during the past because of ignorance of the troubles which may arise through neglect of this item justifies it When a bridge rests on piling with lengths of over ten feet penetrating soft peat before hard bottom is reached, the bonding stresses induced in the piling during back filling can easily cause failure where sufficient penetration of the mineral subsoil can be had to give a good piling anchorage If penetration of the piling is limited by a hardpan layer below the peat, sliding of the bottom of the piling may take place If the deposit is deep, the piling may be flexible enough so that it acts as a cantilever fixed at the bottom and the whole structure moves in one direction The forces due to the compression and flow of the peat during filling have been the cause of many a bridge failure

In one case in Michigan, in 1916, a 40-foot bridge was put in, supported by 50-foot spliced piling Some time after filling of the approach was started the bridge began to move, slid over towards one end and inside of a week had completely disappeared from sight In another case in a peat deposit about 40 feet deep, a 40-foot bridge rotated about one end about five degrees, and settlement then began in sufficient amount to destroy the bridge Had the approach fills been made first, these failures would not have occurred

The maintenance of a road surface which is settling is a comparatively difficult matter to handle In a number of cases where the amount of settlement is not over a foot or two, the slabs have been jacked back to grade and the space beneath the slab refilled with tamped earth It is for this reason that mesh reinforcement is desirable, as it has been found that reinforced slabs can be jacked back into place with very much less breakage than the plain slab In other cases, where the settlement has been accompanied by considerable slab breakage, it has been necessary to remove the surface, bring the fill back to grade, and replace the surface Where the amount of settlement is considerable it may be possible to remove only a part of the pavement at each end of the settlement in order to be able to join the replaced slab properly to the surface adjacent to the settlement

It is unfortunate that the present methods of filling have been used for so short a time, as it is impossible for us to accurately estimate the amount of filling material necessary in Methods No 4 and No 5 Amounts will in each case be less than that obtained by using the curves derived from an investigation of fills which have been placed full width on the surfaec of the undisturbed peat It is hoped that in the near future, as soon as a sufficient number of these examples are available, to cross section and determine the amount necessary in using the new method We are confident that the methods proposed will to a great extent eliminate a great deal of the settlement formerly encountered, and will involve the use of smaller amounts of material in filling

SUBGRADE STUDIES OF THE U S BUREAU OF PUBLIC ROADS

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The purpose of this report is not to furnish information on how to build highways, but rather to secure assistance in the solution of a problem which has thus far vexed the research engineer, namely, that of designing the pavement to suit the subgrade condition

At present, very little information concerning the influence of subgrade on pavement behavior is assembled in such forms as to be utilized by the highway engineer Until recently, research of this character has been devoted in the main to laboratory tests and gratifying progress has been made Assuming that volumetric change and supporting value were the primary influencing characteristics of subgrade soils, practical field and laboratory tests were developed for measuring these properties In accordance with this assumption, current literature classed as poor subgrade those soils with high moisture equivalents and shrinkage values and as good subgrades those soils having comparatively low values in these tests However, as pointed out by Clifford Older[1] at last year's meeting of the Highway Research Board, our knowledge of pavement condition with respect to available subgrade information is meager

[1] Proceedings of the Fifth Annual Meeting of the Highway Research Board, Dec 3-4, 1925, Part I, pp. 129-130