CUSHION TIRES (FIGURES 11, 12, 15, AND 16)

Again the section under greatest load is the one directly under the center line of the axle, and the load decreases in both directions from this point

The load in pounds per square inch increases proportionately on each of the sections as the wheel load is increased

This was the first type used in the test, but as the other tests were run on single tires, a single tire of this type was also procured and tested with the results noted above It might be stated however, that the results obtained on the dual type paralleled those obtained on the single tire

PNEUMATIC TIRE (FIGURES 13 AND 14)

Here again the section under the greatest load is the one directly under the center line of the axle, and the load decreases in both directions from this point

The load in pounds per square inch increases proportionately on each of the sections as the wheel load is increased

CONCLUSIONS

The greatest stress in the contact area of all the tire types is at the point where the plane of the center line of the axle is normal to the pavement, and decreases in intensity in both directions from this point

The uneven distribution of the load on the sections to the right and left of the center line section is attributed to the eccentric setting of the lugs in the periphery As the load is increased this difference is decreased

FURTHER STUDY OF FILL SETTLEMENT IN PEAT MARSHES

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The State of Michigan has experienced unusual trouble in the construction and maintenance of roads over peat marshes Not only are the construction costs and subsequent maintenance expenditures invariably much greater than those of roads built upon upland soils but the long delays consequent to construction are a source of great

concern in themselves. An idea of the magnitude of the peat problem in Michigan is had from the fact that over 3 per cent, or about fifty miles, of the present paved mileage in the State traverses peat marshes

A report on fill settlement in peat marshes by V R Burton was published in the Sixth Proceedings of the Highway Research Board. This paper discussed the methods of classifying and mapping peat deposits and described in detail the origin, formation and character of the various structural units to be found in a peat profile The report proper presented the results of a field study on fill settlement of eight different peat deposits These deposits were cross sectioned at various points where the depth of the peat ranged from 1 to 66 feet

This study demonstrated that the depth of the peat was consistently the most marked factor affecting fill settlement. In some instances it was evident that the character of the peat profile was slightly responsible for differences in settlement Layers of compact marl, for example, seemed to appreciably stabilize some deposits and to reduce settlement Marl-peat admixtures and soft, soupy marls, however, did not appear to effect the degree of settlement In the case of one deposit a neighboring railroad fill was effective in reducing normal settlement, especially on the side adjacent to the old fill. The effect of the slope of the mineral subsoil beneath the peat was particularly evident in that the bottom of the fill invariably assumed the same direction of slope as the marsh bottom

From the series of cross sections studied a diagram was prepared giving the amount of settlement of the fill for the respective depths of the peat as measured from the original marsh surface The diagram indicated that the amount of fill settlement increased uniformly but was not great up to marsh depths of 20 feet As the marsh depth increased from 20 feet to 26 5 feet, the settlement increased rapidly and when the depth exceeded 26 5 feet the fill penetrated through the peat in practically every instance This analysis was purely empirical in nature and represented merely the average behavior of a considerable number of fills composed of different mineral soils and made in different manners Extreme variations of actual from expected settlements as determined from the relation were found to be 100 per cent for an indicated settlement of 5 feet, 60 per cent for 10 feet, 30 per cent for 20 feet, 20 per cent for 25 feet, 10 per cent for 30 feet and somewhat less for greater amounts

LATERAL DISPLACEMENT OF FILLS AN UNEXPECTED DEVELOPMENT

All of the cross sections examined in the previous study showed that in no case did the fill material extend beyond a vertical line drawn through the toe of the slope at the marsh surface, and in most cases the fill was less in width at the base than it was at the marsh surface. Early in 1928 heavy overruns of earth work above the estimates were re-

ported in certain peat deposits which could not be explained except on the basis that some fill shapes must have gone beyond this vertical line It was therefore decided to pay particular attention to these deeper deposits and during the past year eleven different deposits have been carefully cross sectioned at a total of 60 different locations Much to our surprise, it was found that in a number of cases the fills had spread out to a large extent near the bottom of the deposit and in one case this spreading started almost at the surface Some doubt was then expressed as to the accuracy of the earlier cross sectional observations and several of the deposits which had been studied before were reexamined In two cases it was discovered that this spreading had not been detected because of the particular locations of the cross sectional observations

In this year's study information was obtained concerning the position and character of the peat layering, the depth of penetration of the fill and the shape of the fill Samples of the fill material were collected and sent to the laboratory for testing in order to verify the identification of the soil that was made in the field All salient facts concerning the manner in which the fill had been constructed were also obtained from those familiar with the project

A number of cross sections illustrating unusual shapes taken by fills under different conditions are shown in Figures 1 to 3 Figure 1 shows a fill made in a deposit over 30 feet in depth The fill material was a fairly heavy plastic clay which during the course of filling was displaced laterally on one side for a distance of 130 feet The effect of this displacement was manifested by heaving and distortion of the peat for a distance of 180 feet from the center of the fill A 20-inch maple tree on this side was raised a matter of 5 feet without apparent damage The marsh bottom had an appreciable slope to the left, the direction in which the displacement occurred The fill was constructed with industrial railway equipment

Figure 2 shows another clay fill made with industrial railway equipment which was laterally displaced to both sides of the center line The shape of the displaced portion of the fill on the left indicated that the peat became highly compacted near the vertical upper portion of the fill As the clay flowed outward near the bottom of the deposit the vertical resistance of the peat was less and the fill assumed the shape indicated Obviously this fill material was highy plastic The displacement to the right was, without doubt, reduced by the upward slope of the marsh bottom on this side

Figure 3 shows a fill in another deposit where the depth of peat was almost 60 feet This fill was made with trucks over an old corduroy road The fill material was a fairly coarse sand It was impossible to drill through this fill, hence the depth of penetration was not determined,

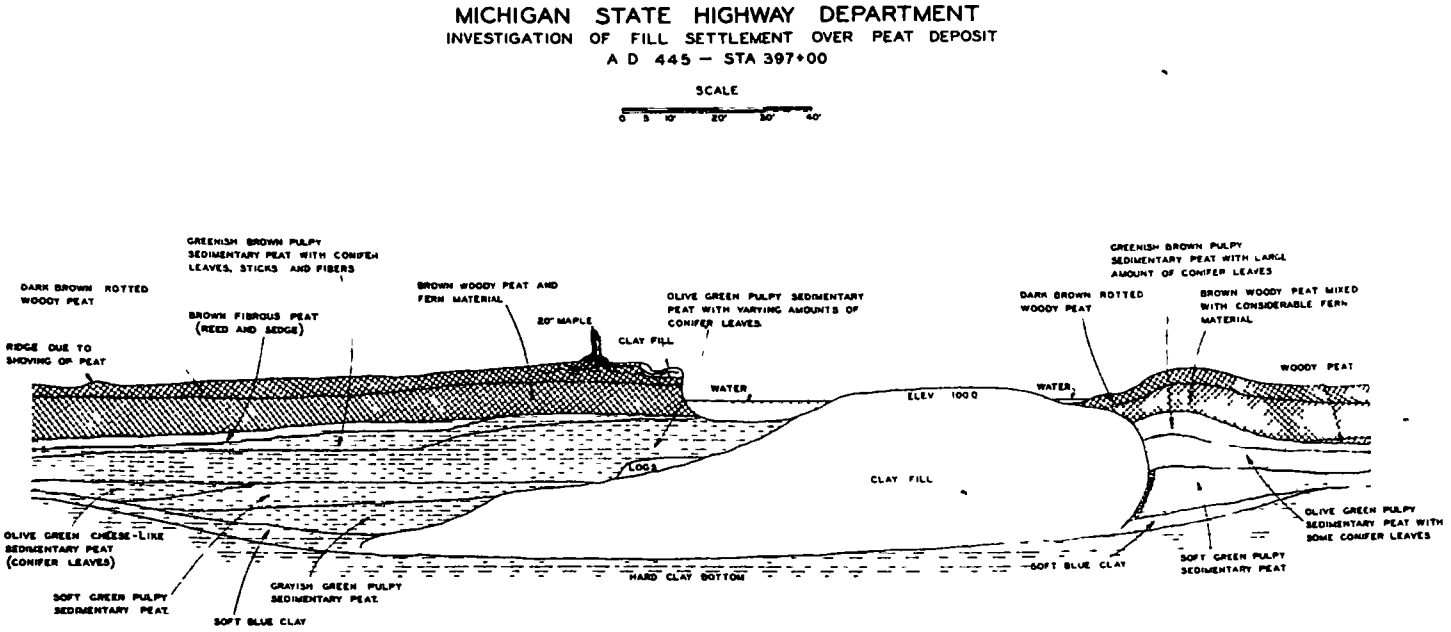
MICHIGAN STATE HIGHWAY DEPARTMENT
INVESTIGATION OF FILL SETTLEMENT OVER PEAT DEPOSIT
A D 445 — STA 397+00
SCALE
0 5 10 20 30 40
GREENISH BROWN PULPY SEDIMENTARY PEAT WITH CONIFER LEAVES, STICKS AND FIBERS
DARK BROWN ROTTED WOODY PEAT
BROWN FIBROUS PEAT (REED AND SEDGE)
BROWN WOODY PEAT AND FERN MATERIAL
20" MAPLE
CLAY FILL
OLIVE GREEN PULPY SEDIMENTARY PEAT WITH VARYING AMOUNTS OF CONIFER LEAVES
RIDGE DUE TO SHOVING OF PEAT
WATER
ELEV 1000
LOGS
CLAY FILL
WATER
DARK BROWN ROTTED WOODY PEAT
GREENISH BROWN PULPY SEDIMENTARY PEAT WITH LARGE AMOUNT OF CONIFER LEAVES
BROWN WOODY PEAT MIXED WITH CONSIDERABLE FERN MATERIAL
WOODY PEAT
OLIVE GREEN CHEESE-LIKE SEDIMENTARY PEAT (CONIFER LEAVES)
SOFT GREEN PULPY SEDIMENTARY PEAT
SOFT BLUE CLAY
GRAYISH GREEN PULPY SEDIMENTARY PEAT
HARD CLAY BOTTOM
SOFT BLUE CLAY
SOFT GREEN PULPY SEDIMENTARY PEAT
OLIVE GREEN PULPY SEDIMENTARY PEAT WITH SOME CONIFER LEAVES

Figure 1

MICHIGAN STATE HIGHWAY DEPARTMENT
INVESTIGATION OF FILL SETTLEMENT OVER PEAT DEPOSIT
F 041-10C — STA 89+00

SCALE
0 5 10 20 30 40

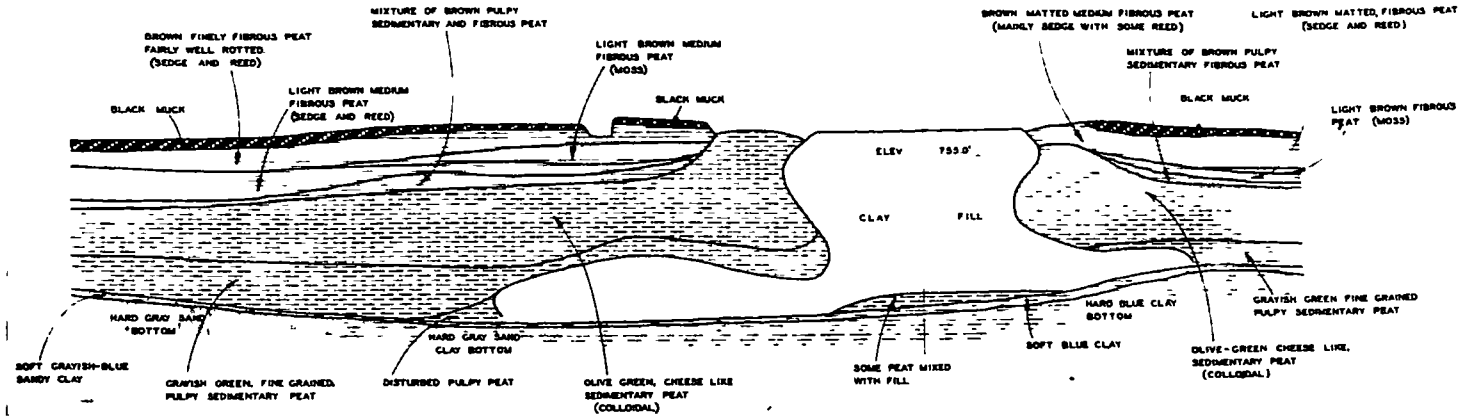

Figure 2

MICHIGAN STATE HIGHWAY DEPARTMENT

INVESTIGATION OF FILL SETTLEMENT OVER PEAT DEPOSIT

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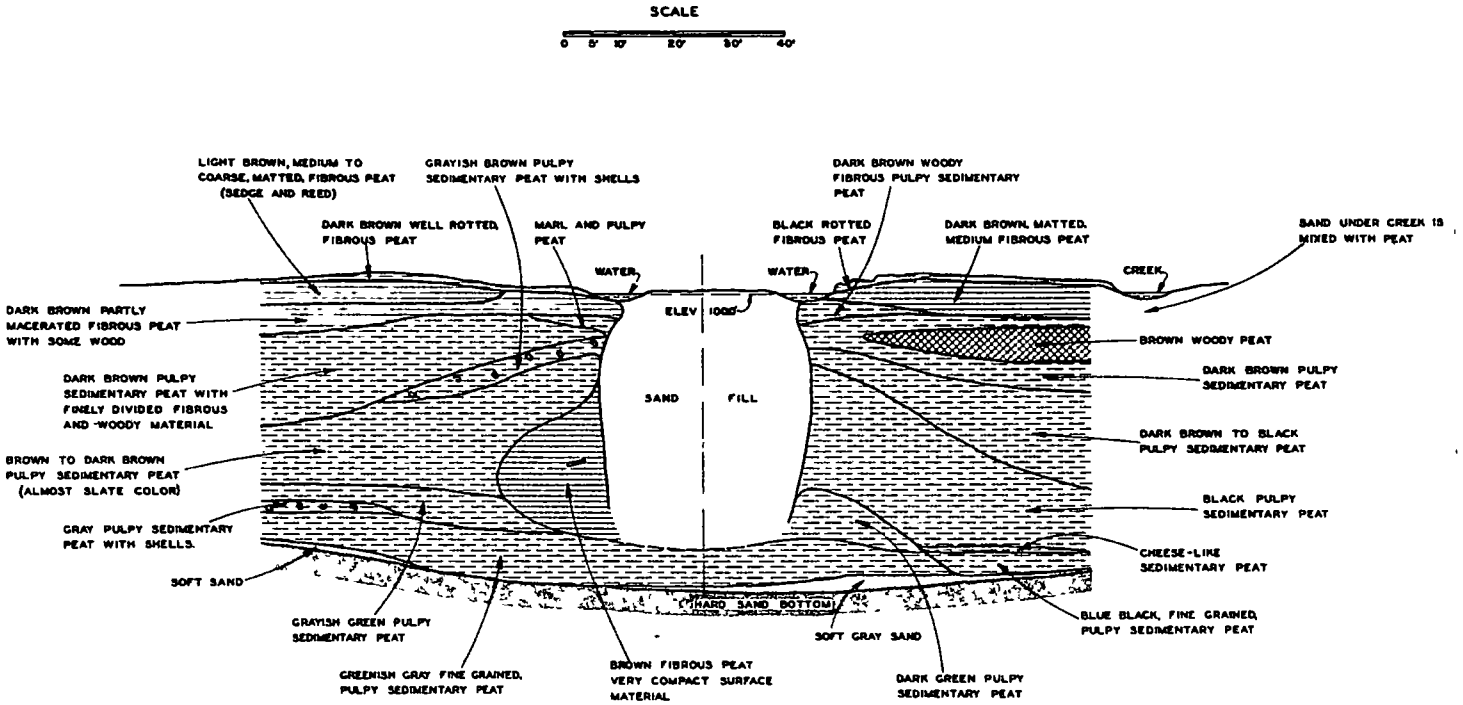

Figure 3

although, judging from the distortion of the peat layers near the fill line it is evident that penetration had occurred to the 45-foot level This fill had not reached a static condition when the soundings were made In all probability it will eventually penetrate to the extreme bottom of the deposit

PENETRATION AND LATERAL DISPLACEMENT OF FILLS NOT INFLUENCED BY CHARACTER OF PEAT

The various factors which were considered as having a possible effect upon the depth of penetration and lateral displacement of fills were character and depth of the peat layerings, character of the fill material and method which was used in construction of the fill In the evaluation of the effect of these variables the data were first assembled in tabular form For each cross section there were listed the average dimensions, in feet, of (1), the depth of the deposit, (2), the depth of the fill, (3), the width of the fill, and (4), the penetration of the fill There were also listed, in square yards, the total cross sectional area of the fill and the respective portions of the fill that were laterally displaced Information was also recorded concerning the method used in filling and the character of the deposit and fill material Such miscellaneous information as the nature of the preexisting roads and fills, if any, was also listed for each cross section

In order to analyze the effect of the character of the deposit, the various structural units of the profile were classified as follows (1) woody peat, (2) fibrous peat, (3) sedimentary (both colloidal and pulpy layerings), (4) marl, (5) marl-peat admixtures, (6) lake clay The thickness of these variations in the profile was then expressed as a percentage of the total depth of the deposit The character of the fill material was classed in the table as being clay, loam, very fine sand or sand

In comparing the depth of penetration of the fills with the various character classifications of the peat, there appeared to be no consistent or well defined influence of this factor for deposits of similar depth However, it was apparent in case of most of the deposits studied that as the depth increased the percentage of sedimentary peat increased correspondingly Sedimentary peat is characterized by its pulpy or colloidal cheese-like properties, and no doubt its presence at the lower levels is responsible in a large measure for complete fill penetration and for lateral displacement in deposits over 25 feet in depth

In general, the average of the results obtained in the 1928 study with regard to the amount of fill penetration and corresponding depth of peat were in close agreement with the relation developed from the 1925 data The variable character of the fill materials, as classified, did not seem to influence the degree of penetration, although, as shown later,

plastic materials were found to be associated with the phenomena of lateral displacement

In Figure 4 the amount of lateral displacement expressed as a percentage of the central portion of the fill is platted against the respective depth of the deposit Two types of fill material and two methods of filling are represented in the values shown Although the number of values are limited and are quite divergent, the trend suggests an increasing degree of displacement, (0 to 180 per cent) for a range in the depth of deposit of 26 to 38 feet With one exception, the depth of the peat was over 25 feet where lateral displacement was observed

In ten out of twelve cases where lateral flow occurred the fills were constructed with industrial railway equipment Usually in filling marshes, where the deposits are deep, after only a comparatively light

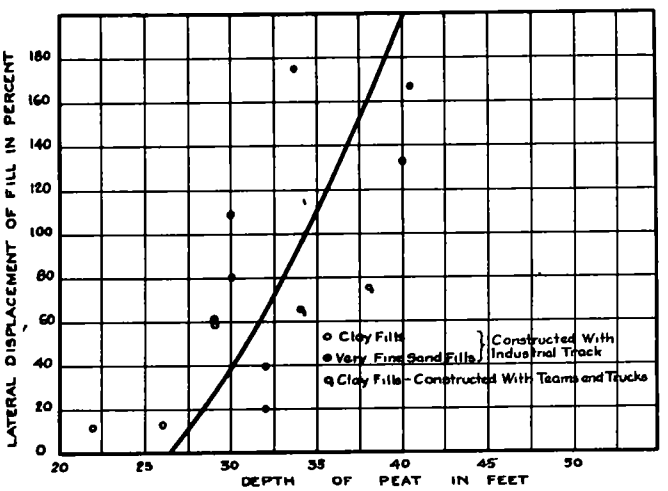

Figure 4

loading the entire crust breaks and fill and crust disappear beneath the water Filling thereafter, until a large amount of material is deposited, is done directly into the water It is quite evident then, especially where the fill grade is some distance above the marsh level, that the dumping of a clay material into the water from a considerable height of trestle will not produce any initial compaction of the material whatsoever When a fill is constructed with trucks and teams it is usually accomplished by pushing the fill ahead from one side or the other until a runway is established The use of teams or trucks then insure considerable compaction while the fill is being deposited In the case of industrial railway filling no compaction is possible and the fill is constructed of entirely loose material, leaving the compaction to be later accomplished by the weight of the material itself and what little may be obtained by traffic over the finished fill.

Lateral flow of the fill material has been to a large extent associated with the finer grain materials, which become plastic when the material carries a high moisture content The lateral flow of these fills is a phenomenon which occurs during the actual course of fill construction The peat is forced outward laterally and upward vertically as the fill material flows along the marsh bottom under the superimposed load This flow continues until the material both within the fill and the peat adjacent to it becomes compacted so that equilibrium is established and no further movement develops It is probable that this flow takes place in a series of slips, much in the fashion of some landslides rather than by any continuous process This has been indicated a number of times by the manner in which the fill disappears The embankments appear fairly stable until a certain critical loading has been placed and then within a comparatively short time a very large amount of settlement will take place The fill is again built up above the marsh surface without noticeable settlement until the load again becomes too great for the support afforded and another slip takes place The fill material in contact with the wet peat usually contained a very much higher percentage of water than that far in the interior of the fill This has been noticed in moisture examinations of a number of fills

Although it is certain that lateral adjustment of fills in peat marshes occurs over a long period of time, the dimensional changes in the mass are probably small in comparison to those which occur by virtue of plastic flow Settlements occuring where the fills had reached the bottom and lateral flow had taken place during construction are probably due, to a certain extent, to the compaction of the fill material itself and the normal settlement common to earth fills of large size

Inasmuch as this analysis has shown that clay soils are very much more subject to a lateral flow, where the depth of deposit exceeds 25 feet, it is quite evident that the use of this character of fill material should be avoided if possible If, however, it is necessary to use such soils, care should be taken to compact them as they are placed The effect of this construction feature has been so noticeable in this study that future specifications will prohibit the use of filling by means of industrial track except in those cases, of course, where such a method is absolutely necessary.

UNUSUAL CASE OF PAVEMENT SETTLEMENT INVESTIGATED

In 1923 a concrete pavement was constructed over a large marsh just north of Lansing on Road No U S. 27, at a location where it was 6,500 feet in length The fill was completed in 1921 and up to the time the pavement was laid in 1923 very little settlement had occurred. This pavement had a uniform thickness of 8 inches, was 18 feet in width, with a tongue and groove steel center joint and 5-foot dowel

spacing The slabs were reinforced with steel bar mats, the effective weight of which were 78 pounds per 100 square feet. The average length of slab between expansion joints was 250 feet

The increase of traffic on this route has necessitated serious consideration toward widening the pavement to 40 feet and since the original fill was only 26 feet in width, it would be necessary to widen this to 52 feet, which is standard for a 40-foot pavement

Settlement of the present pavement has occurred gradually since the road was open to traffic, several serious settlements occurring during the first year, but since that time the general subsidence has proceeded

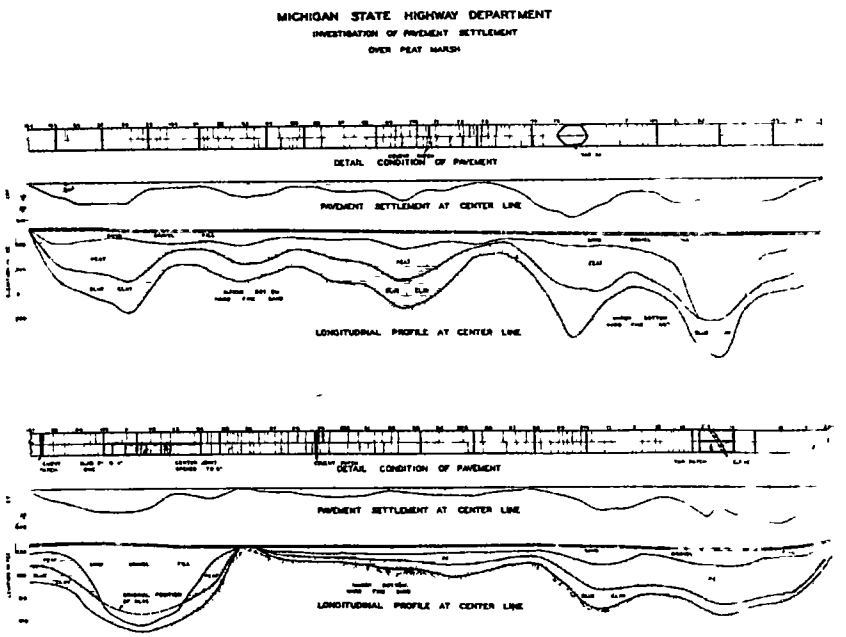

Figure 5

to such a degree that even though widening were not contemplated, measures would have to be taken within a very few years to bring this pavement back up to grade.

At the time this pavement was built, no investigations had been made to determine suitable methods for filling over peat deposits and the seriousness of settlement likely to occur was not appreciated In order to determine just what course should be followed in the widening of this pavement, whether, for instance, it would be better to widen along the present roadway, or to abandon the location completely, a careful study was made of this deposit, and an attempt was made to

determine what factors had caused the various degrees of settlement at different points crossing the marsh

The thickness and character of the fill, peat and clay beneath the pavement, were determined by soundings at forty locations along the roadway These soundings were made at the edge of the slab and at intermediate points out to a distance of 100 feet from the center line A condition-survey of the pavement was also made and elevations of the slab were taken along the center line

Cross sectional diagrams were prepared from these sounding data, from which, in turn, by interpolation for intermediate values, a longitudinal profile was developed that indicated the thickness of the fill, peat and clay at the center line of the pavement This is shown in Figure 5, together with a detailed sketch of the pavement condition and a plat to an exaggerated scale of the degree of the pavement settlement

The thickness of the fill, which consisted of a uniform gravelly sand, did not vary appreciably except at two locations (stations 181 to 184 and 190 to 194) where the depth of the peat exceeded 25 feet At these locations the fill had penetrated entirely through the peat profile and to some extent into the clay layers beneath the peat The average thickness of the fill, excluding the above locations, was about 5 feet, of the peat about 9 feet and of the clay about 6 feet

The settlement of the pavement ranged from 0 02 to 3 02 feet, the former amount at a point where the slab rested directly upon an outcropping of mineral soil and the latter at a point where the fill was 5 feet in thickness, the peat 17 feet, and the clay 15 feet At the two locations where the fill had penetrated through the peat profile, the settlement was 1 5 feet

STRUCTURAL DEFECTS NOT RELATED TO DEGREE OF PAVEMENT SETTLEMENT

One interesting fact brought out by the pavement condition survey was the apparent lack of correlation of the visible defects of the slabs with the degree of settlement Generally more transverse cracking had developed, or was visible at locations where the pavement was concave downward than where it was concave upward No longitudinal cracks were visible and very few corner breaks were noted In general the condition of the slabs laid over the marsh, as far as structural defects were concerned, was comparable to portions of the same pavement laid on upland soils This comparison has little significance, however, inasmuch as the pavement existing on upland soils was not reinforced

PAVEMENT SETTLEMENT A FUNCTION OF THE THICKNESS OF PEAT ON WHICH THE FILL RESTS

In the analysis of the data the degree of pavement settlement was first platted against the corresponding thickness of the peat below the

mineral soil fill The developed relation (Figure 6) shows for peat depths less than 25 feet, and for fill penetrations less than 75 per cent,

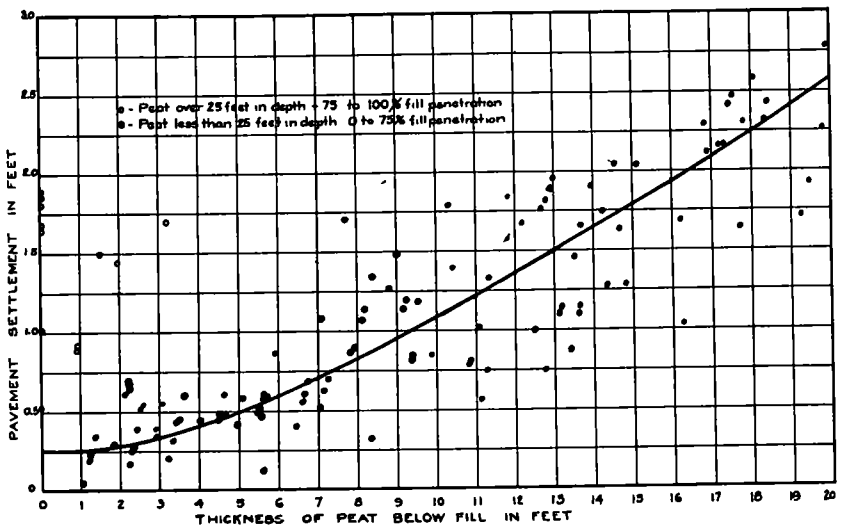

Figure 6

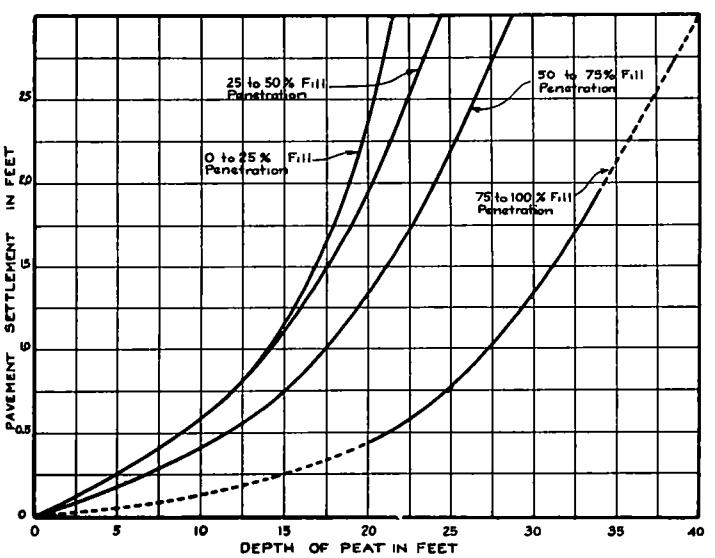

Figure 7

that the settlement increased almost uniformly as the peat thickness increased The average settlement, for a peat thickness of 5 feet, was 0 5 feet, and for 20 feet it was 2 5 feet For depths greater than 25

feet, where the peat was practically displaced by the fill, the average settlement was about 1 5 feet This later degree of settlement is believed to be excessive under the circumstances, although in these particular instances it is probable that the lake clay beneath the peat was compressed, or laterally displaced by the superimposed load.

The pavement settlement was also platted against the depth of the peat profile Well defined relations were thus established for different ranges of fill penetration, namely, 0 to 25, 25 to 50, 50 to 75 to 100 per cent These are shown in Figure 7. The curves were established by computing the center of gravity of the settlement values for similiar peat depths

For fill penetration up to 75 per cent, the average pavement settlement increased uniformly, being less than 0 75 feet at a peat depth of 12 5 feet As the peat depths increased from 12 5 feet up to 25 feet, the settlement increased very rapidly, the maximum settlement recorded being 3 02 feet at the latter depth For fill penetrations over 75 per cent, the average pavement settlement likewise increased uniformly, but was only 0 75 feet at a peat depth of 25 feet. An average settlement of 1 5 feet developed at a peat depth of 31 feet for this latter degree of fill penetration In other words, the above analysis indicates that as the extent of fill penetration increased from a minimum to a maximum degree, the amount of pavement settlement was reduced over 75 per cent

Although this study embodied a length of pavement only slightly over a mile in length, the indications are so well defined that the importance of securing full penetration of the fill has been very greatly emphasized and definitely evaluated

It is quite apparent from the foregoing that probably the most economical thing to do in widening this pavement is to completely abandon the old location, since it was found by the topographical map prepared from the soundings that it would be possible to skirt the edge of the marsh along one side and cross it diagonally on a line at which the depth of peat does not exceed 20 feet, at the same time avoiding a number of holes in which the depth of peat is about 45 feet, and on which the marsh length totals only about 800 feet The new location will then skirt the other side of the marsh and will cross one corner where the depth of peat is only 2 to 4 feet deep. Had this study been made seven years ago, we would not now be under the necessity of completely abandoning one mile and a quarter of comparatively new location.

Certain changes have been made during the last two years in the standard methods of peat marsh filling previously adopted by the Michigan State Highway Department In the first place it was discovered that our methods of dynamiting, in order to insure an accelerated settlement, needed considerable revision. Formerly holes were

put down at four foot intervals after the fill had been made and four to six sticks of dynamite were used in each hole, in order to displace the peat and insure further settlement. It has been found much more economical to space the holes at a distance of ten feet and use a very much larger amount of dynamite. These holes are made by driving scrap water pipe, an inch and a half to two inches in diameter, provided with a wooden plug at the lower end, down through the fill material at the shoulder line. The end of this pipe is forced to a point approximately half-way between the bottom of the fill material and the bottom of the marsh, at which point the wooden plug is driven from the pipe and a half stick of dynamite exploded below, in order to create a pocket for the placing of more dynamite From 20 to 30 sticks of 50 per cent straight nitroglycerin dynamite are then placed in this pocket and about 20 or 30 holes shot at the same time This very effectually forces the fill down, and in addition seems to compact the peat to a remarkable degree In the one case where dynamite was used, it was found that the force of the explosion had driven the water out of the peat and compacted it to such an extent that a large open hole was created alongside of the fill This peat was so compact that the hole never refilled, much like a similiar hole would have acted in a very dense clay

As was stated in a former article the most difficult situation is between the range in depth at which peat can be excavated, generally about 7 or 8 feet, and the point at which little difficulty is experienced in obtaining complete fill penetration, which is about 25 feet. Between these limits we have, up to this time, used two separate fills at some distance apart from each other, in order to take advantage of the entrapped peat between the two fills, which, when compacted, was considered would give satisfactory support to the pavement to be laid upon the fill Results obtained on some fills made in this manner would seem to indicate that it may be desirable to abandon this method There has been some settlement near the center after pavements have been laid, and in one case the side fills were displaced laterally by the center loading This phase of our standard methods is to receive considerable study during the next year, in order to determine whether or not it should definitely be abandoned It is, however, very difficult to obtain full penetration on a fill of any width at these shallower depths and in the case of widening an old road, it is, of course, the only method which can be used where the old fill comes within the limits of the new shoulders In this connection it might be stated that even where fills have been apparently stable for a number of years but on which no serious efforts were made to obtain complete fill penetration that, if additional shoulder width is given the road, further serious settlement is amost sure to take place.

Considerable attention is being paid to the settlement of these fills

after placing, by the engineers in the field, and a great deal of interest has been manifested in securing proper results in this type of construction It is felt that this study will result in considerable benefit to ourselves and that further work along this line will enable us to eliminate to a large degree those serious drops in grade which have occurred on many of our pavements, in some instance to such an extent as to make them absolutely dangerous, besides necessitating extensive repairs at frequent intervals