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EARTH ROADWAY FILLS ACROSS
PEAT MARSHES

THESIS FOR THE DEGREE OF C. E.

C. H. Cash

1931

THESIS

Roads-Muligan
Title

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EARTH ROADWAY FILLS ACROSS PEAT MARSHES

A Thesis Submitted to the Faculty
of
Michigan State College
of
Agriculture and Applied Science

by

C. H. Cash

Candidate for Degree

of

Civil Engineer

June, 1931

THESIS

INTRODUCTION

The problem of crossing peat marshes with roads is a particularly important one in Michigan. The location of many of our highways has been influenced by swamps. In many cases the present trunklines, which wind in and out to evade marshes, will soon have to be straightened and their sharper curves eliminated to keep pace with the trend toward high speed traffic. The cost of crossing marshes, once considered prohibitive, has decreased in the last few years as modern equipment has lowered the cost of moving earth. Mr. G. C. Dillman (1)* has pointed out that, "Since 1920 the unit prices for doing work have been decreasing steadily. On grading today the average cost is only one-third of what it was ten years ago." The trend toward higher speed, greater volume of traffic, and lower grading costs has made avoiding marshes and heavy grading secondary in importance to directness of route in the location of trunklines. The Research and Statistics division of the State Highway Department have computed the portion of our paved trunklines traversing peat marshes to be over 3%, or about 50 miles, before 1930 construction season.(2)

The Michigan State Highway Department has spent much time and money investigating peat marshes and several papers have been presented on the subject (2,3). These papers were of course, of a general nature but resulted in standard

*Numbers in parentheses refer to bibliograph on page 51.

plans which are being used in the field. Progress in this study is indicated by the frequent revision of these plans.

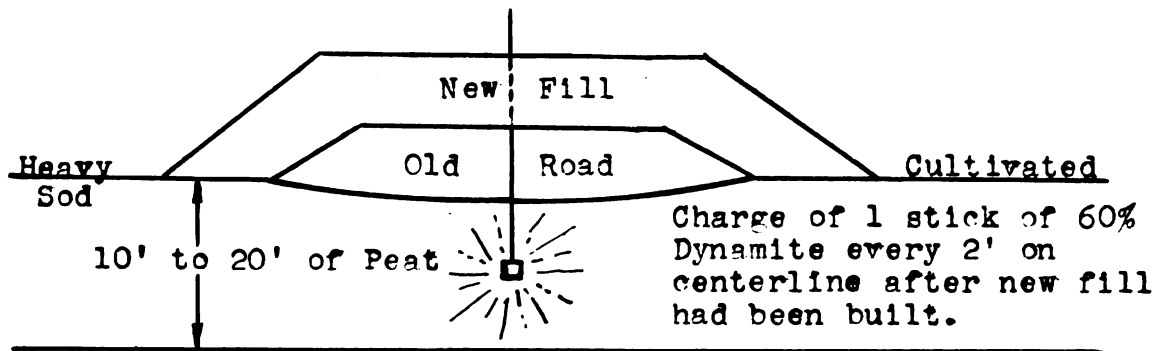
DEVELOPMENT OF METHODS OF FILLING ACROSS SWAMPS

The following are some of the methods used by the Michigan State Highway Department in the development of standards for the displacement of peat. This is not intended as a list of all of the blasting methods tried, but only those that have been observed by the writer. When the methods first tried were not successful, field engineers often tried other methods. In fact so many field changes were made that the research engineers, who designed the methods, were often at a loss to know the actual results obtained.

#1. Floating Across Shallow Swamps.

Before hard surfaced roads were generally used, stability was not important. Settlement could gradually go on year after year and when the dip became very bad it could be refilled to grade and resurfaced at small expense. The method used was simply to fill over the peat and place the surfacing. The surface mat was not broken and was depended upon to support the fill. As drainage was particularly important the first standard called for a ditch extending to the bottom of the swamp, when this method was used. It is still being used on secondary roads and is fairly satisfactory although these fills are very hard to maintain during the spring breakup.

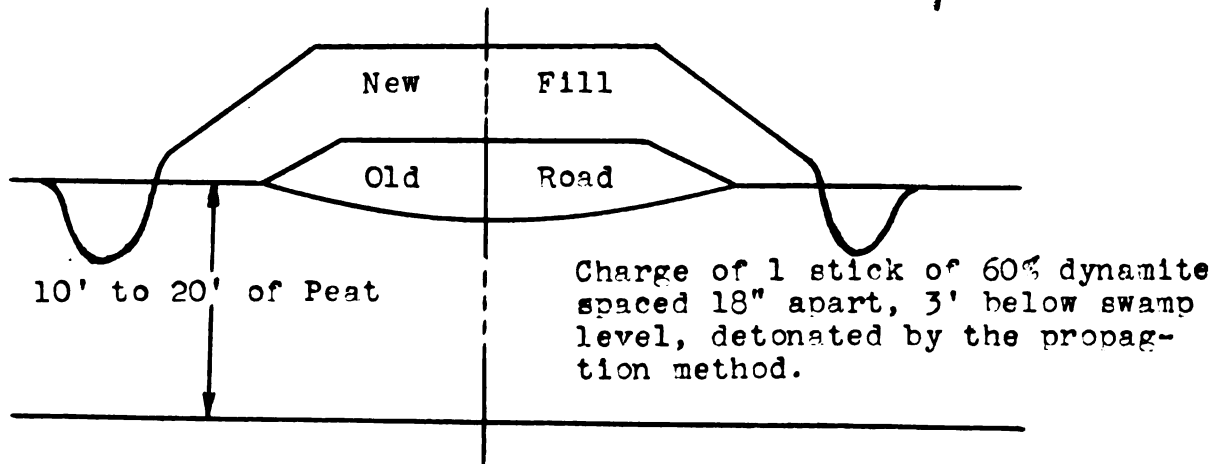
#2. Single Blasting On Centerline After Fill Had Been Placed. U.S. 16, Ionia County, 1925.



About 50' was shot as shown above. It was expected that the explosion would push the peat out and form a cavity and that the fill would settle to hard bottom. When 1 stick every 2' failed to show any effect, the quantity of dynamite was increased to 3 and then 5 sticks in a hole. In the latter case the fill was cracked up somewhat but very little settlement occurred.

The experiment failed because the mat was strong enough to hold the fill in place. The cracks in the fill were formed radially from the location of the charge and indicated that continued increasing of the size of the charge would tend to blow up the fill rather than displace the muck.

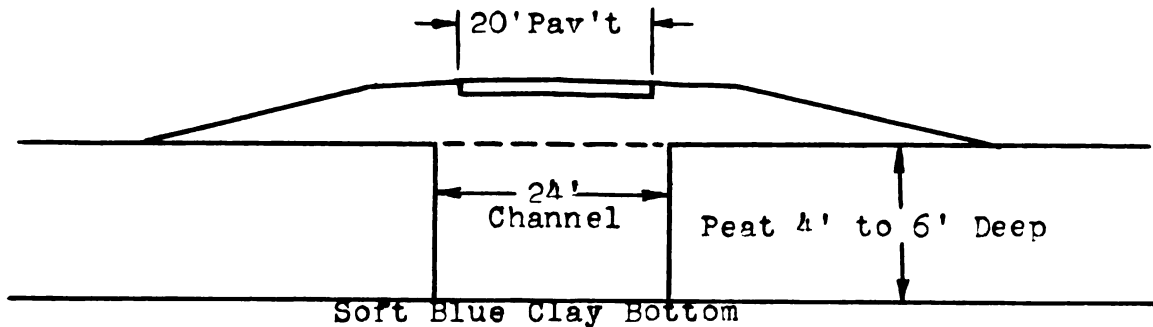
#3. Single Blasting To Form Trench At The Toe Of Slope On Each Side Of New Fill. U.S. 16, Ionia County, 1925.



After the new fill had been built to an elevation about 4' above the swamp level, the trenches on each side were made by blasting as shown. The propagation method of blasting consisted of placing single sticks of dynamite 18" apart in rows and detonating the first stick by use of a fuse. The explosion of the first stick detonated the stick next to it and so on down the line. Only 50 or 60% straight nitroglycerine dynamite is unstable enough to be used successfully in this manner.

The fill was left this way for several months to give it a chance to settle. When settlement ceased the trenches were filled with the excess earth in the fill. This method was effective in breaking up the surface mat but the fill was not heavy enough to displace the peat. This method was effective as a float across the shallower portion of the swamp but the deeper section, having soundings of about 20', has continued to settle every year. This demonstrated that breaking up the surface mat alone was not sufficient to cause appreciable settlement.

#4. Excavating Peat To Clay Bottom. M 14, Lenawee County, 1927.

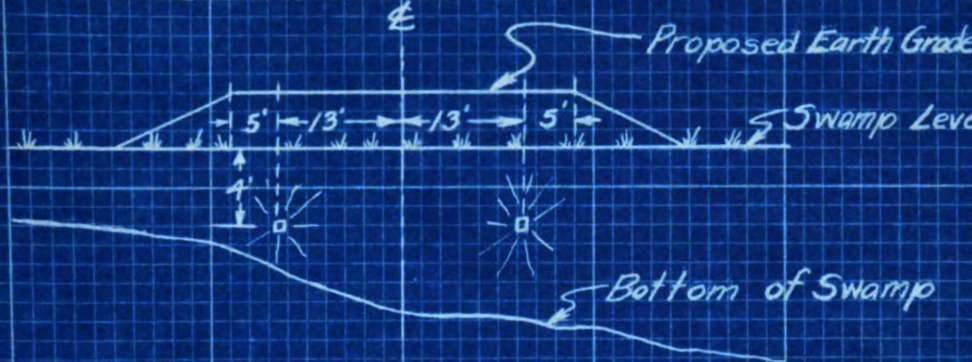


The peat was excavated and the trench was backfilled with earth. Precautions were taken to follow up with the backfilling very closely behind the excavating as the critical height at which the peat would stand vertically was not known and caveins were anticipated.

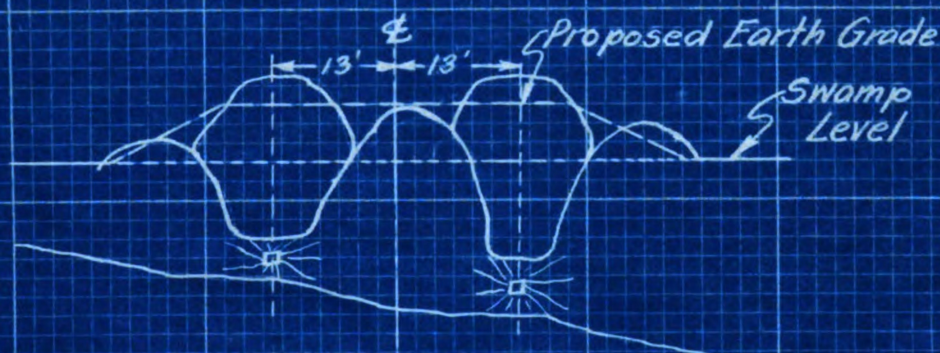
The method was successful and no noticeable settlement or pavement cracks have developed.

The depth of peat excavated has gradually been increased until swamps up to 12' deep are now being handled in this way. Peat less than 12' deep has not been successfully displaced by dynamiting and loading, especially in well drained swamps.

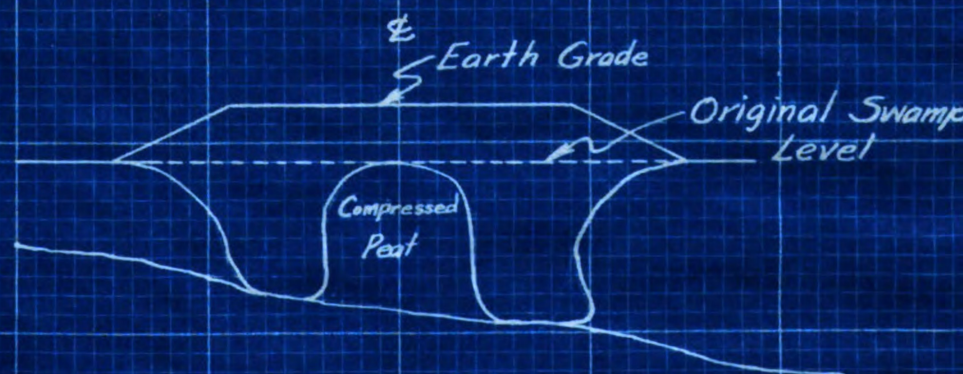
DETAILS FOR LOADING AND BLASTING ADDISON SWAMP



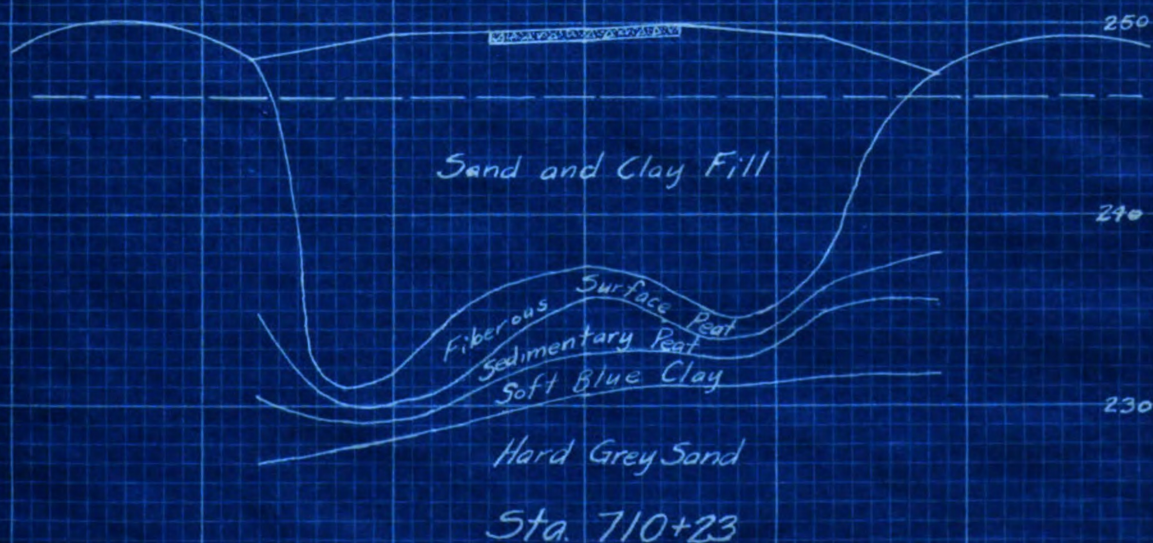
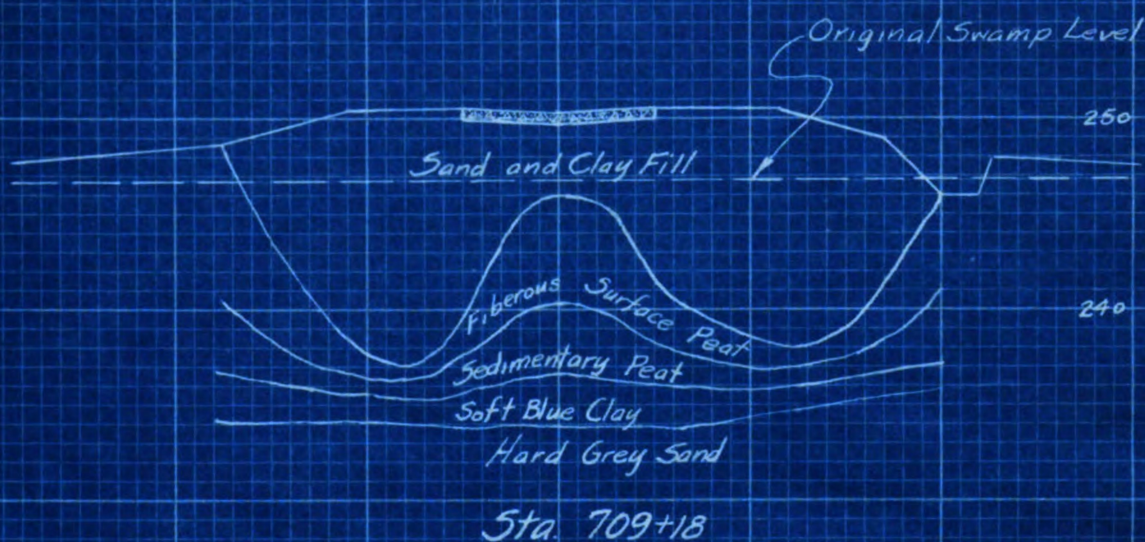
Detail of preliminary blasting, consisting of charges of 3 sticks of 50% straight nitro glycerine dynamite placed 4' deep and 4' apart in rows 13' each side of centerline



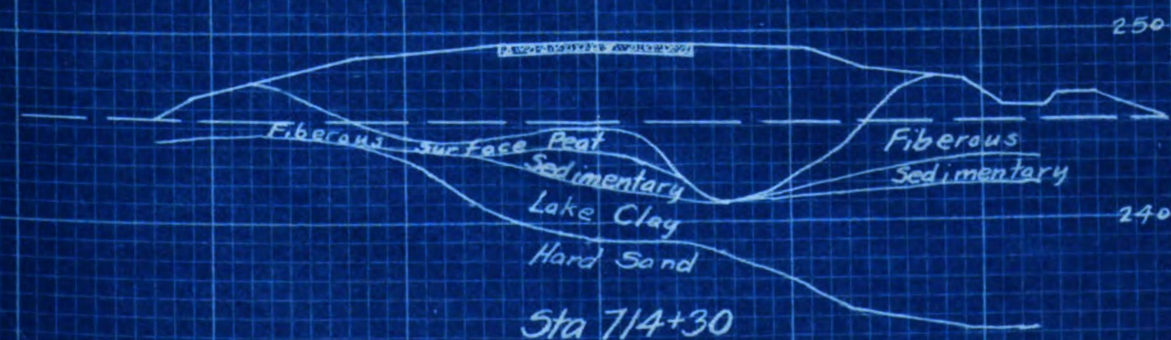
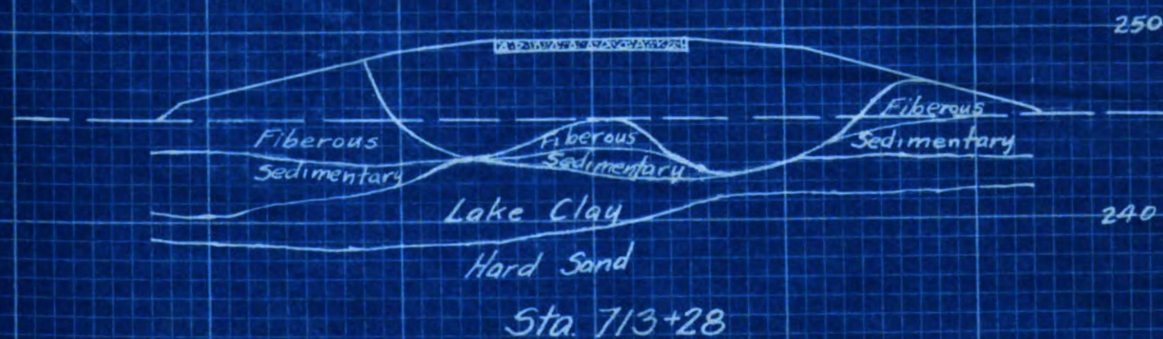
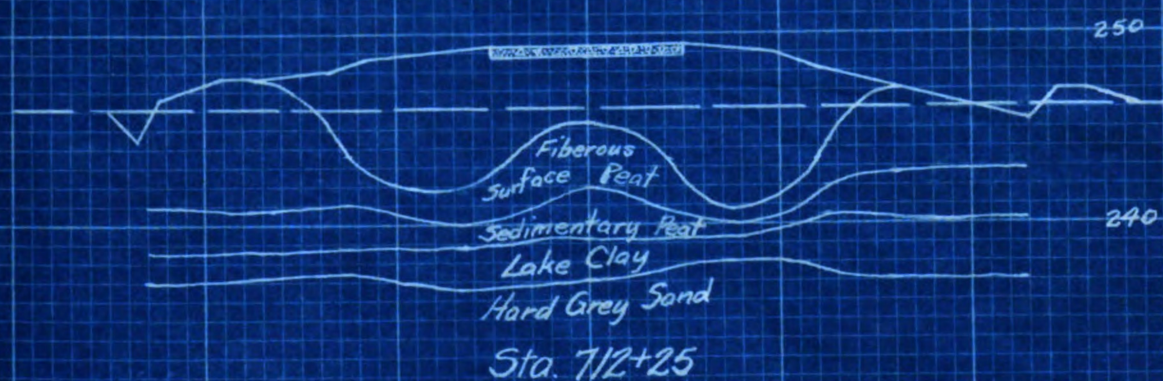
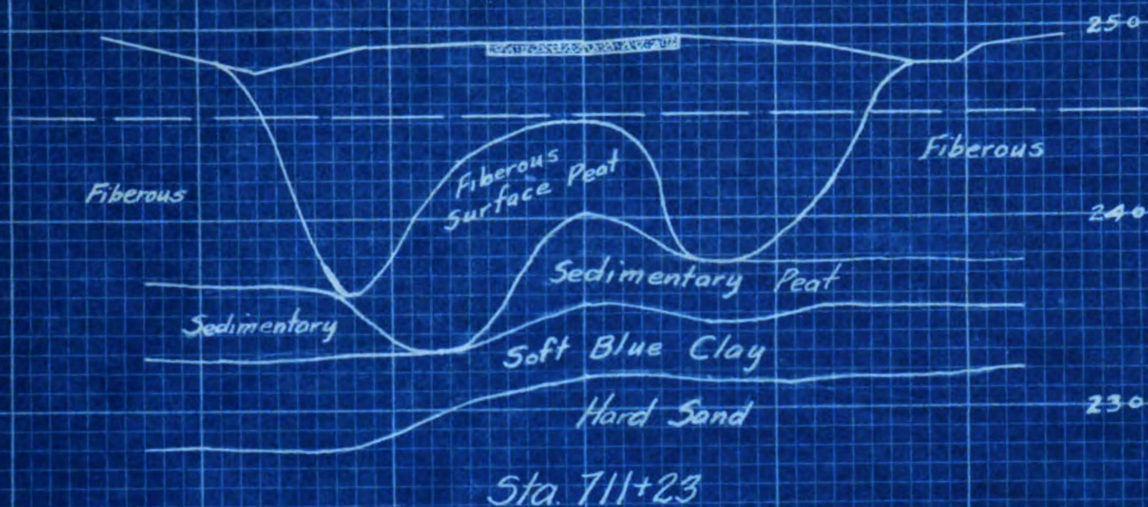
Detail showing loading after preliminary blasting and location of charges for final blasting, consisting of 3 sticks of 50% dynamite spaced 4' apart in rows 13' each side of centerline



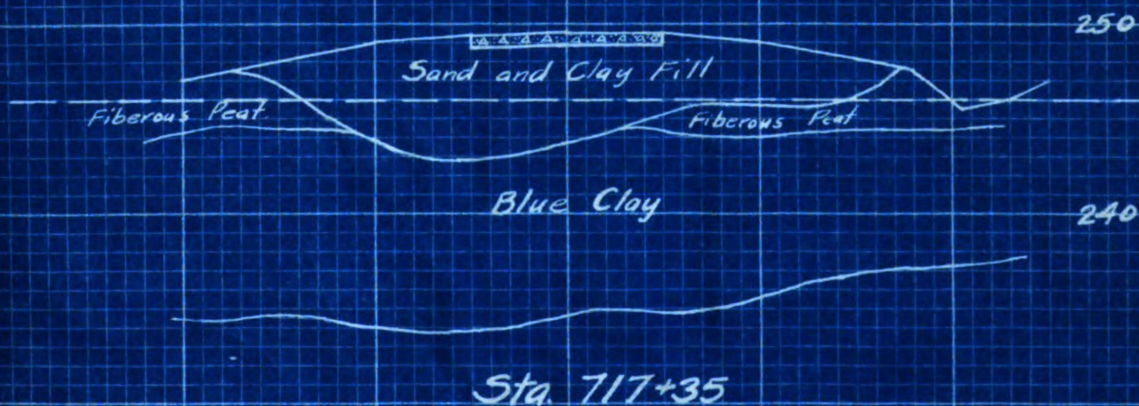
Detail showing final embankment and approximate displacement of peat.



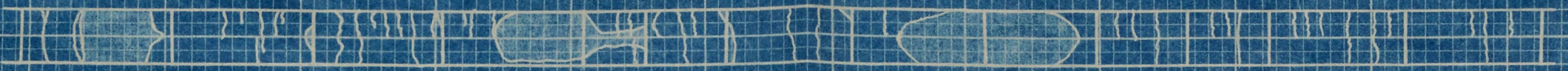
50 40 30 20 10 0 10 20 30 40 50



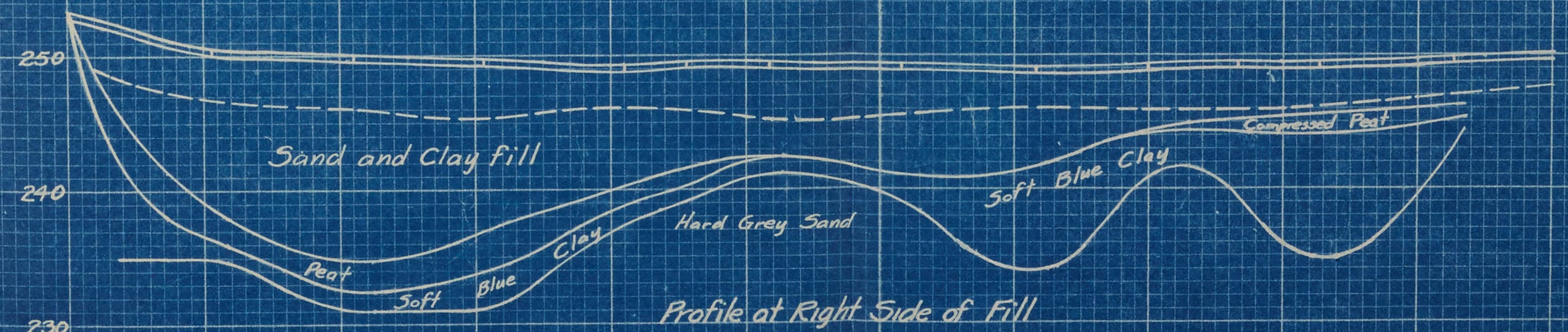
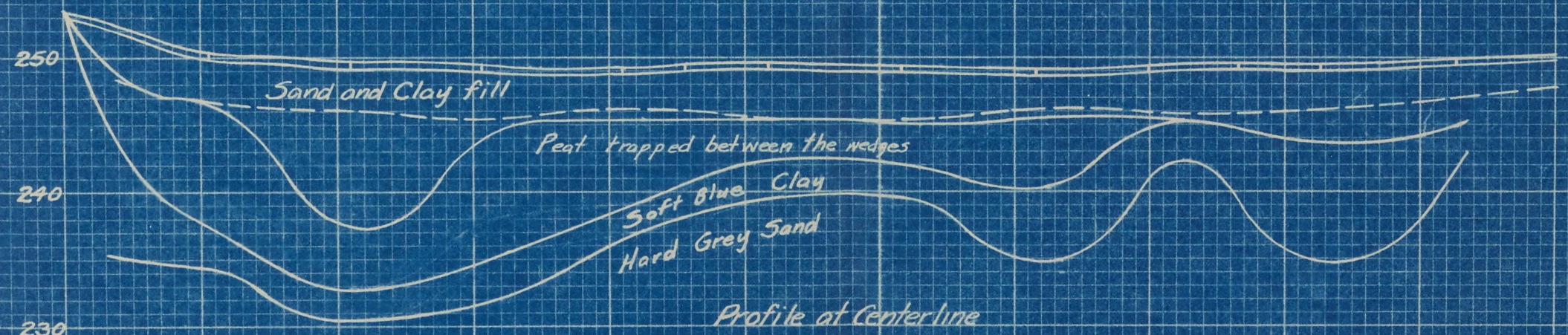
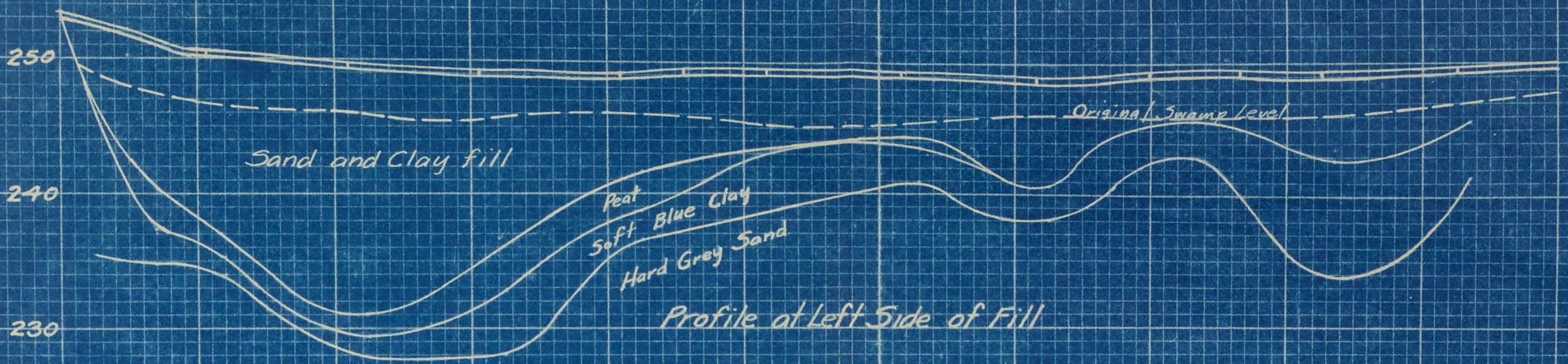
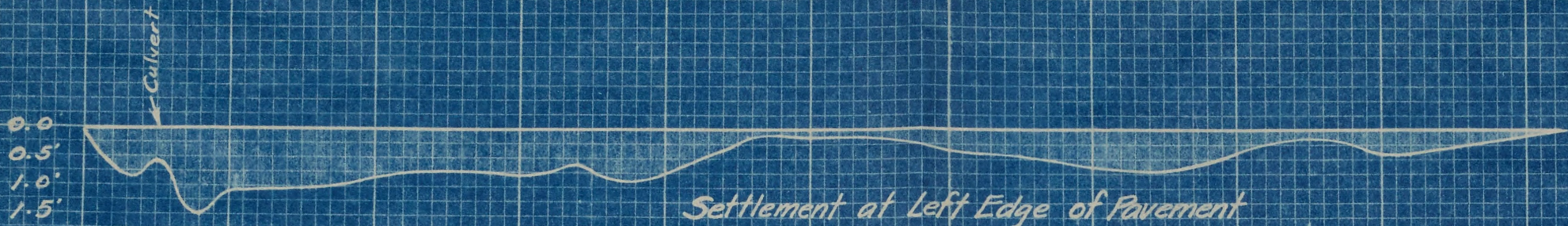
50' 40' 30' 20' 10' 0' 10' 20' 30' 40' 50'



108 109 110 111 112 113 114 115 116 117 118 119



Detail Showing Pavement Cracks, Joints and Patches



108 109 110 111 112 113 114 115 116 117 118 119

#5. Two Parallel Wedges 26' Apart, 2 Blastings.

U.S. 127, 2 $\frac{1}{2}$ Miles North Of Addison, 1927.

The loading and blasting in this swamp was done as shown by the details on sheet #7. The preliminary blasting and loading was done in the fall of 1926 and the final blasting and grading was done in the spring of 1927. 20' concrete pavement with mesh reinforcement was placed in July, 1927, after a series of levels indicated that settlement of the fill had ceased.

The peat, displaced by the fill, caused heaving on both sides of the road from Stat. 703+50 to 712. After the pavement was in place, swamp ditches were dug 45' each side of the centerline throughout, except from 708-711 L where heaved peat made it necessary to place the ditch 70' out. When these ditches were dug, further heaving of peat kept fillin them up. This indicated that cutting the ditches through the surface mat on each side had disturbed the equilibrium.

Settlement, especially on the centerline, began to appear soon after the pavement was opened to traffic. The cross sections, profiles and pavement condition sketches shown on sheets 8 to 11, inclusive, show developments after the road had been used by traffic for less than three years, in the spring of 1930. As this swamp is still unstable, plans have been made to excavate the peat, refill and repave in 1931.

Analysis of the cross sections shown on sheets 8 to 10, inclusive, indicate that the following results were obtained.

1. As the wedges settled the peat trapped between them, tended to spread them apart. The section at Sta. 708/72 shows wedges that had penetrated about 7' and were still 26' apart. At Sta. 709/18 there was a penetration of 10' and the wedges had spread to 41' apart. At Sta. 710/23 there was an average penetration of 13.5' and the wedges had spread to 41' apart. The quantity of peat trapped between the wedges was smaller than at Sta. 709/18.

2. In most cases the wedges had penetrated at least three-fourths of the way through the peat.

3. The sections were approximately the shapes anticipated by the designer.

4. At Sta. 711/23 the trapped fibrous peat was sufficiently compacted so that it acted as part of the left wedge and entirely displaced the sedimentary peat under it.

5. Displacement of some of the soft blue clay under the points of the wedges indicate that the peat under the fill has been compacted.

Examination of the profiles and pavement sketches shows the following.

1. Pavement settlement was greater on centerline than at either edge for the entire length of the swamp.

2. Although some lake clay was displaced under the wedges, the depth of this material did not greatly affect the stability of the fill.

3. The soundings, as they were shown on the plans, indicated the bottom of the lake clay instead of the bottom of the peat. They were probably taken with an ordinary $\frac{1}{2}$ " pipe, which was pushed down until hard sand bottom was struck. Unless some provision is made for taking samples at various depths, it is often difficult to tell when the rod strikes the clay. If the soundings had been correct, the plan would have been to excavate the peat through the portion of the swamp where the depth was 6' or less, and it could have been to excavate for the entire length.

4. The worst failures occurred: (a) where the original depth of peat was 6' to 10'; (b) where the depth of peat was changing, that is, where the marsh bottom was on a grade; (c) where the largest quantity of peat was trapped between the wedges.

The two wedge method of displacing and confining peat was designed to keep the quantity of filling material as low as possible. It was based on the assumption that settlement of a fill over peat was mostly due to displacement or flowing of the peat from under the embankment. When the peat was confined so that flowing could no longer take place, it was thought that the fill would be stable. Quick sand and other unstable soils have been successfully confined by similar methods.

Peat is unlike other soils in that it contains a much higher percentage of voids. Dr. Dachnowski (4) says that, "it may be accepted as an axiom that undrained deposits of

peat contain from about 70 to 95 percent of water." Compaction of peat is a squeezing out of some of the water. This kind of a compaction would go on at a gradually decreasing rate almost indefinitely. Even if the wedges had penetrated to hard bottom, compaction of the trapped peat would still continue and the water would soak into the fill or seep through it. As the center of the pavement is subjected to greater pressure than either edge, it is probable that settlement would continue to take place along the centerline for years to come. The proposed plan to excavate the peat before repaving this swamp is unquestionably the best way out.

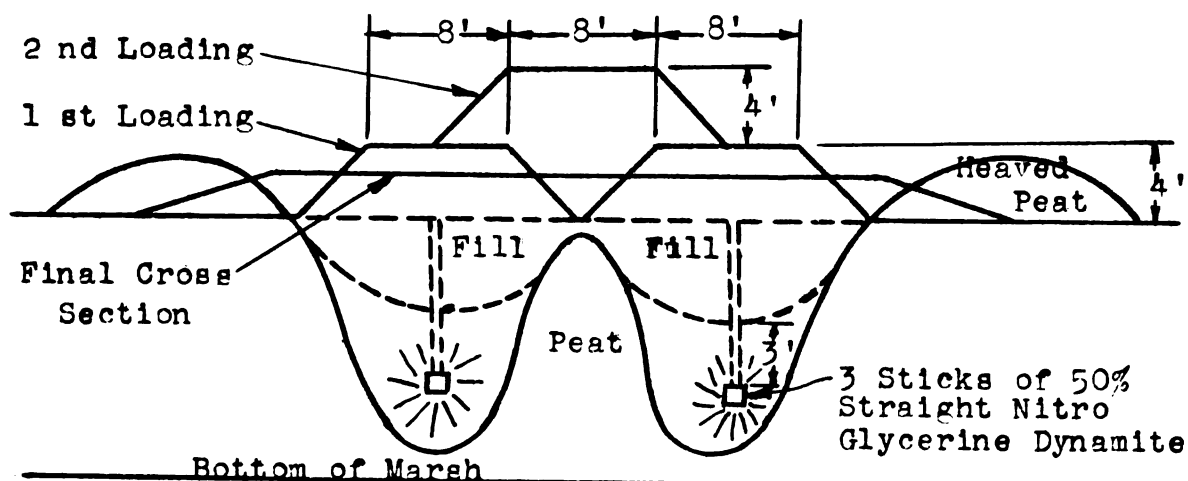
#6. Two Parallel Wedges 16' Apart And Surcharge. U.S.
223 At Devils Lake, 1928.

The method used is shown on sheets 17 and 18. It was similar to the method used for the Addison swamp except that the wedges were closer together, a surcharge was used, and complete penetration to the marsh bottom was not expected.

Part of the preliminary blasting and filling was done in the late fall and early winter of 1927 and the remainder in the spring of 1928. The preliminary blasting did not make ditches 8' each side of the centerline as was anticipated but made a series of holes separated by pieces of unbroken surface mat. The filling earth was mostly sand and sandy gravel although there was some loam and clay. The swamp was poorly drained as a county drain would have been necessary for proper drainage. However, the ground water level could be kept at least a foot below the surface of the peat.

In July, 1928, after settlement had apparently stopped, the borrow was found to be about 6000 cyds. in excess of the estimated quantity even though the final blasting had not been done. It was thought that the settlement must be nearly complete, so borings were taken at Sta. 821/50, 823, 824, and 825/50. The borings indicated that the fill had penetrated nearly to hard bottom at Sta. 823 and 824 but that very little peat had been displaced at the ends of the swamp where there were shallower soundings. Final blasting was therefore carried out at Sta. 819-822 and 825-827 and a surcharge was maintained until settlement was less than .05' in 30 days. The pavement was placed in September, 1928. The cross sections, profiles and pavement condition sketches shown on sheets 19 to 22, inclusive, were plotted from levels and borings taken the spring of 1930 after the pavement had been in use one and one-half years.

PLAN FOR LOADING AND BLASTING DEVILS LAKE SWAMP (6).



FIRST SHOOTING

Holes 2' to 4' deep shall be bored in the peat, spaced 4' apart in rows 8' each side of the centerline. "2 sticks of 50% straight dynamite shall be placed in each hole and unless the explosive is completely covered with water, the hole shall be tamped with earth. A minimum number of 30 holes shall be shot at one time by means of a blasting machine. Each line of holes may be shot separately.

SECOND BLASTING

"After the first loading is complete holes spaced the same as at first shall be bored to 3' below the bottom of the settled fill provided that in no case shall holes extend to within 1' of marsh bottom. 2 sticks of 50% straight dynamite for depths of peat under 10' or 3 sticks for depths of 10 to 20' shall be placed in each hole and unless the explosive is completely covered with water the hole shall be tamped with earth. A minimum of 30 holes shall be shot at one time by means of a blasting machine. Both lines of holes must be shot at once.

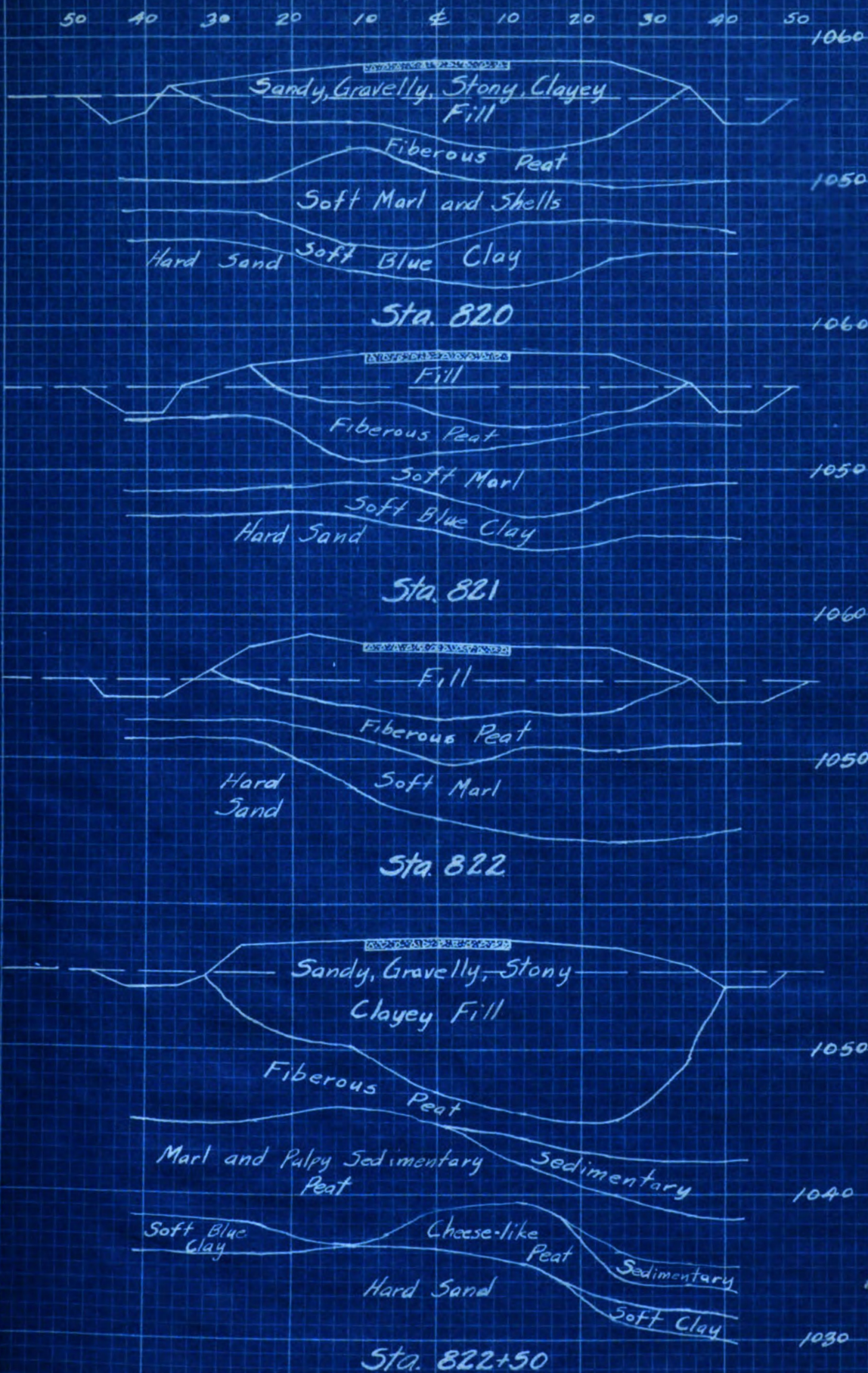
LOADING

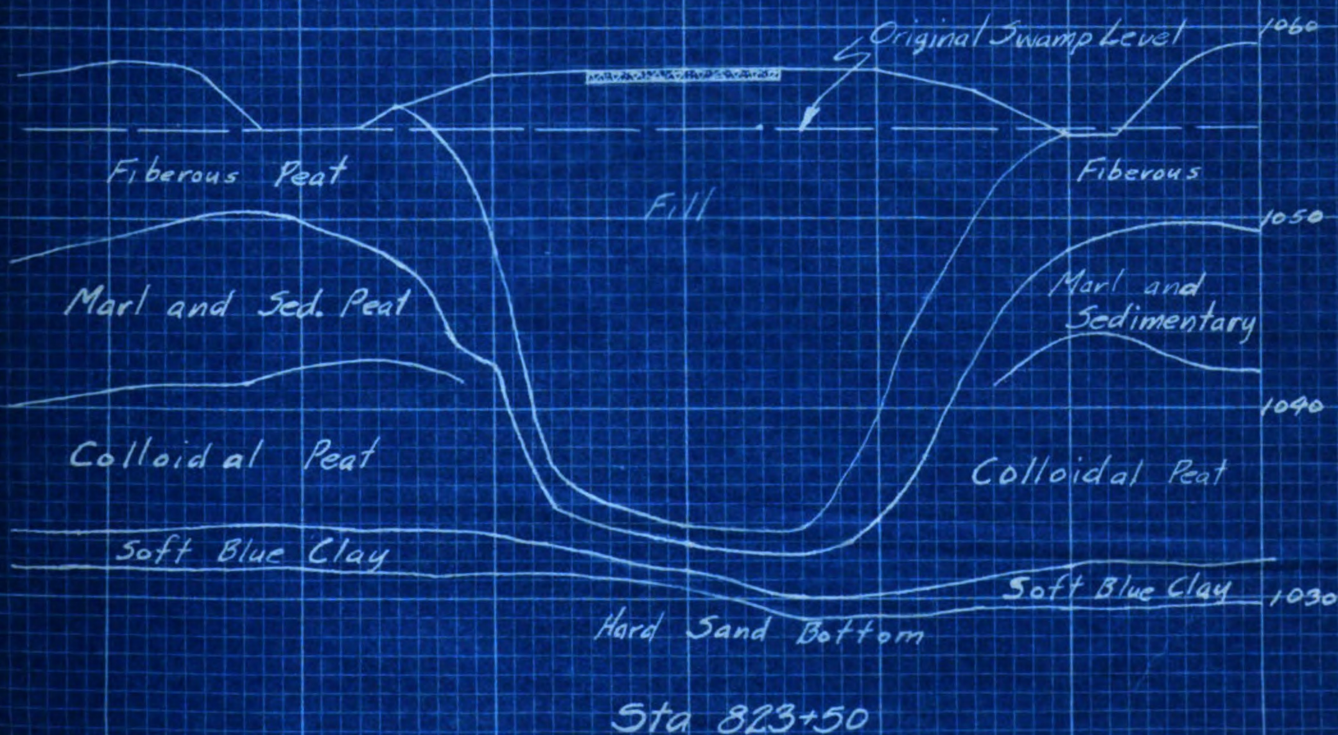
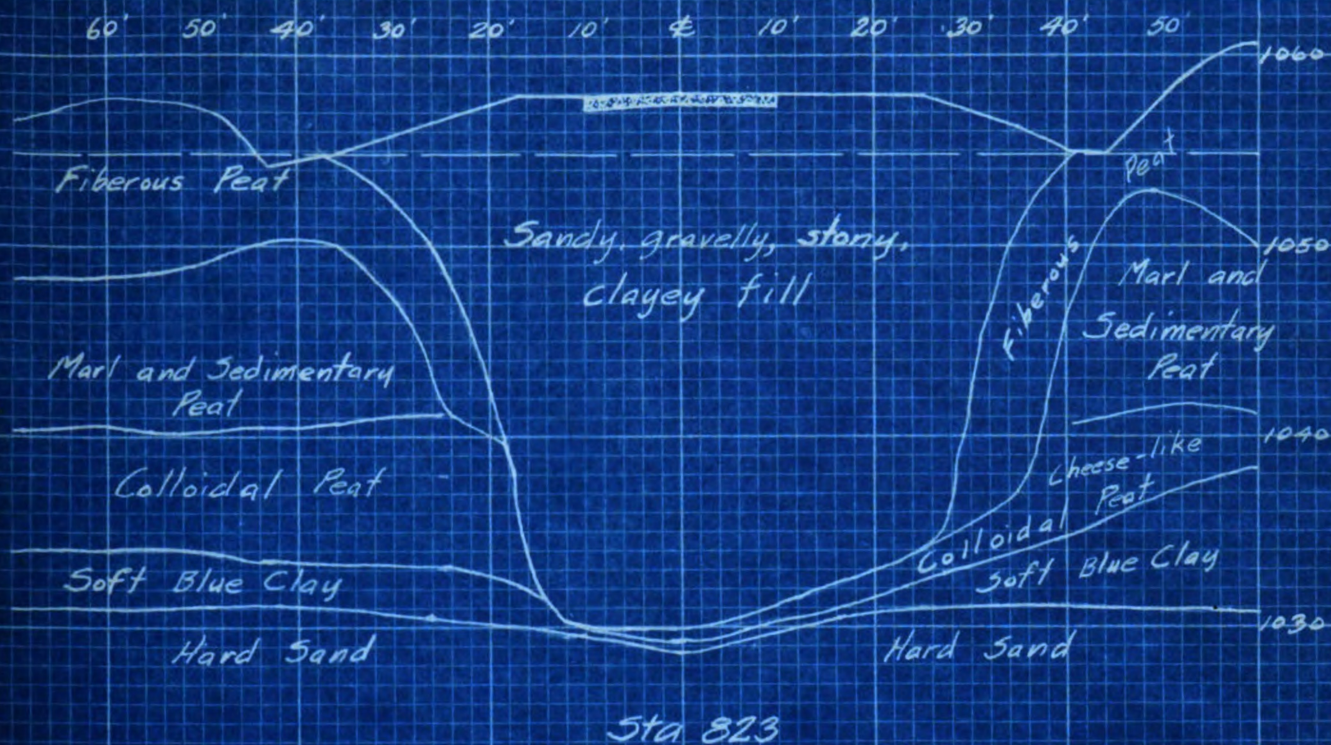
"After the 2 trenches have been blasted across the marsh, the first loading shall be started from one end in these trenches and both sides advanced equally from the end. The loading shall be carried full height and width as shown on the above cross section and any other loading than that shown will not be permitted. The two fills must be carried across by end dumping.

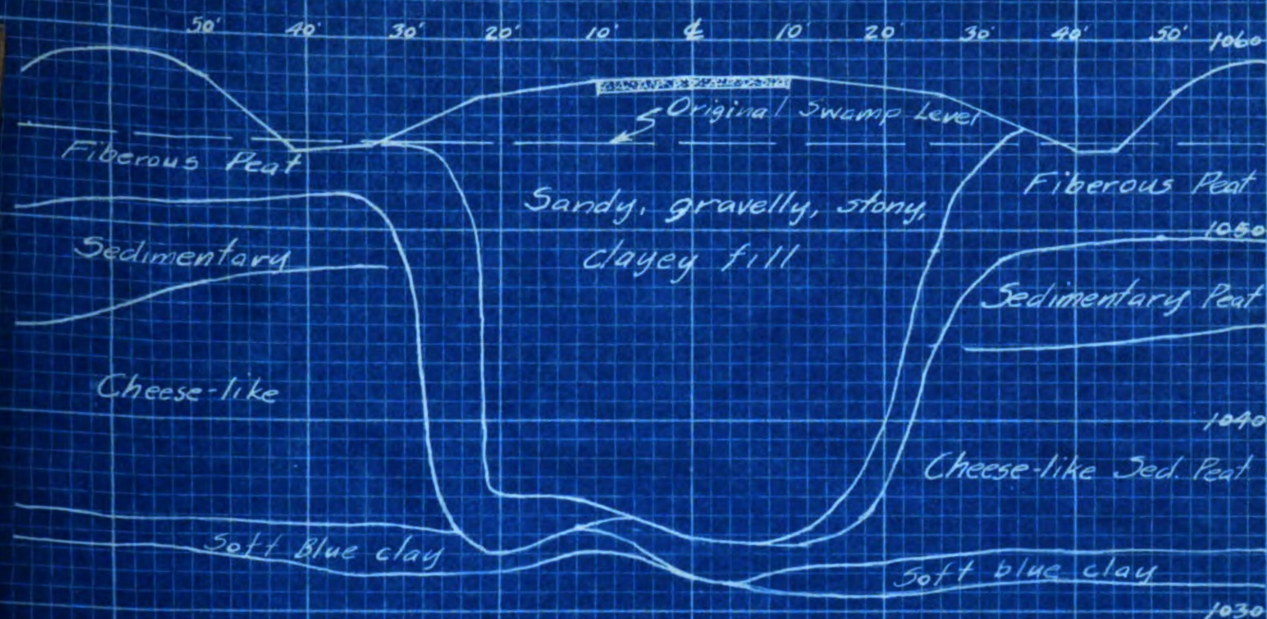
"As soon as the fills of the first loading have been completed to the stage at which settlement is less than at the rate of two-tenths of a foot per day, the second shooting may be done. At the time of this second shooting, both fills must be within five-tenths of a foot of grade. Should the distances to be filled by this method exceed 200', after the first 150' is completed the second shooting of the first 50' may be done, but at no time shall the distance of shooting be less than 100' from the end of the uncompleted fill. After the second shooting, the first loading shall be immediately brought to grade and the second loading applied.

"Each loading shall be carried full height and width as shown on this plan. If at any time during the application of the second loading the preceding load shall have settled more than 1' from its original grade it shall be immediately refilled to the grade shown before proceeding with the additional loading."

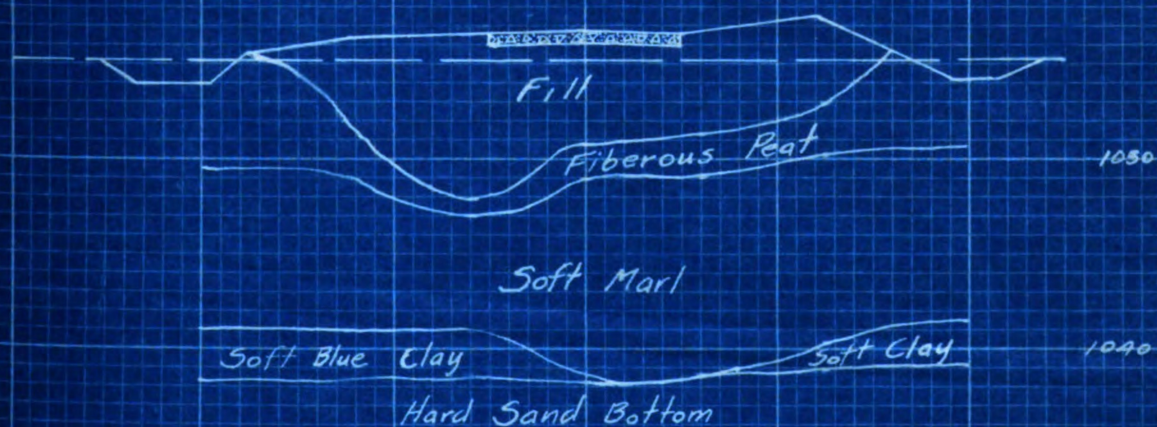
Examination of the cross sections profile and pavement condition sketches of the Devils Lake marsh shown on sheets 19 to 22, inclusive, shows the following results.







Sta. 824



Sta. 825



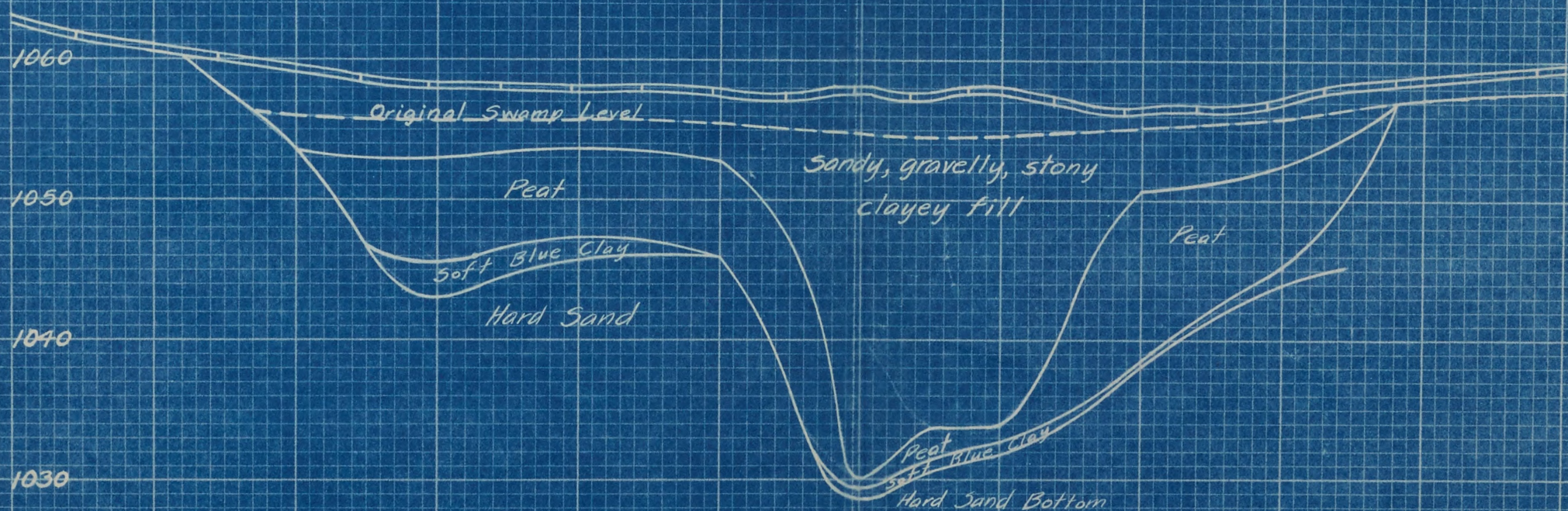
Sta. 826



Detail Showing Pavement Cracks, Joints and Patches

0.0
0.5'
1.0'
1.5'
2.0'

Pavement Settlement at Centerline



Profile at Centerline

818

819

820

821

822

823

824

825

826

827

828

1. Fill penetration into the peat was $1\frac{1}{4}$ to $1\frac{1}{3}$ the depth of the peat for a depth of 16' and less.

2. The fill was the least stable:

a. Depth of peat 12' to 20'.

b. Where marsh bottom was on a 7% grade or greater.

3. The cross sections indicate that the two wedges 8' each side did not settle together into peat less than 20' deep and that they combined to form a wedge which penetrated nearly to the bottom where the depth was greater than 20'. In the shallower peat the wedge which started first usually displaced peat or marl in the direction of the other wedge and tended to retard its settlement. This is indicated by cross sections for Sta. 820, 821, 822/50, and 825.

4. The shape of the fill was not as anticipated because the wedges did not continue to settle separately but joined to form either one wedge or a mat which acted as a float.

5. The swamp depth was about the same at Sta. 826 as at Sta. 820 to 822 and about the same penetration was obtained when the swamp was originally filled but pavement settlement was greater at Sta. 826 apparently because the marsh bottom was on a grade.

6. The peat could have been excavated for the first 300' and the last 100' of the swamp. Plans have usually called for using the same method of dynamiting and loading throughout the entire length. Where there are several hundred feet

of shallow peat, it could be excavated even though the remainder of the swamp requires loading and blasting.

7. In this case use of the two wedges apparently retarded settlement instead of promoting it.

8. Pavement settlement was approximately proportional to the depth of the remaining peat under the fill.

SUMMARY

About the only results common to these two swamps were (a) pavement settlement was proportional to the depth of the remaining peat under the fill and (b) the worst failure occurred where the swamp bottom was on a grade but the depths at which these failures occurred was variable. Both are examples of failure of a method which proposed to trap peat under the fill to reduce the quantity of filling earth necessary.

It is apparent that fills over swamps less than 25' deep will be unstable unless they have penetrated to the bottom of the peat. If merely an equilibrium is reached it is too easily upset. Some of the factors which tend to disturb the equilibrium are (a) drainage of the heaved peat, (b) slow compaction of the peat under the fill, (c) freezing and thawing, and (d) flooding.

One of the factors preventing the displacement of peat is the weight of the heaved peat. After it has stood above the ground water level for some time, most of the water drains out or is evaporated. This leaves the heaved peat only a fraction

of its original weight. Much of the water usually drains out before the surcharge is removed but this alone may not sufficiently decrease its weight to start a flowing of peat from under the fill after it has once stopped. Later standards which called for placing a heavy surcharge before the final blasting was done, gained a point here. Most of the heaving took place before the final blasting and the peat had time to lose much of its water while the contractor was getting ready to do the deep shooting.

Compaction of the peat under a fill was discussed on page 15.

This type of fill is more apt to settle immediately after the frost leaves the ground in the spring than at any other time. This is rather conclusive proof that considerable lateral support is derived from the surface mat. Frost action in soils has been described by Prof. Steven Tabor (5). Certain soils, including muck, heave when frozen due to "segregation of ice in layers or lenses." Swamps seldom freeze to a depth of more than 2 or 3'. When these layers or lenses of ice melt, the surface is left in a frictionless and cohesionless condition and its lateral support is practically released and the equilibrium is upset.

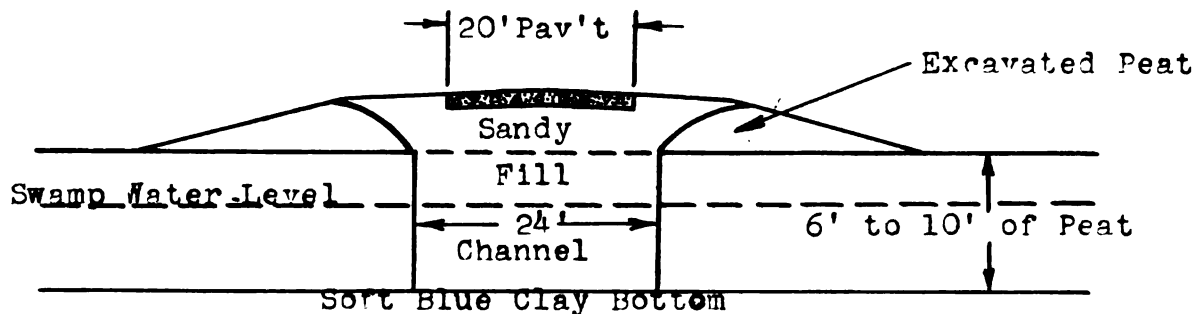
The finished grade is practically always wider at the top where the earth from the surcharge has been disturbed over the peat. This layer of earth is most easily sheared when it is saturated with water when the internal friction and cohesion are at a minimum.

It can be seen that the factor of safety of the above type of fill is small. The weight of a 5' surcharge is more than twice the normal loading of a highway, but it is a static load. When the vibration, due to traffic, is combined with the several destructive factors mentioned above, the factor of safety obtained by removal of the surcharge is overcome.

LAKE CLAY

Some of the cross sections shown indicate that the plastic blue clay known as "lake clay" has been displaced by the fill or even by the compacted peat under the fill. This clay does not have the same characteristics as peat. It is saturated with water which does not readily give up under pressure as does peat. It has been found to satisfactorily hold up fills where the peat has been excavated. In the swamps just studied the clay was displaced at the points of the wedges only where the bearing was small. It is not subject to compaction but to flow only. The study made by the Research Division of the State Highway Department indicated that it is very rarely displaced in swamps less than 25' deep. For deeper swamps average penetration has been found to be 4' for swamps 40' deep, 10' for swamps 50' deep and all the way to hard bottom for deeper swamps.

#7. Excavating Peat Below Ground Water Level. U.S.27,
South Of Marshall, 1928.



This method was used on several swamps ranging from 300 to 600' long. The trench was first excavated all the way across the swamp by a power shovel with a clam bucket. The suitable filling earth from the old road embankment was cast to one side so that it could be recovered, and the peat was cast to the other side of the road. The trench soon filled to swamp water level with water which held a considerable quantity of peat in suspension. This soupy liquid was forced ahead in the trench as the new fill was placed. The pavement was placed early in the summer of 1929.

The pavement started warping out of shape shortly after it was opened to traffic. By the next spring there were several dips where settlement of 6" to 1.0' had taken place. Several theories were advanced to explain this. First, that the buoyancy of the ground water had been sufficient to keep the fill from compacting until it was offset by traffic on the pavement; second, that there had been lateral displacement

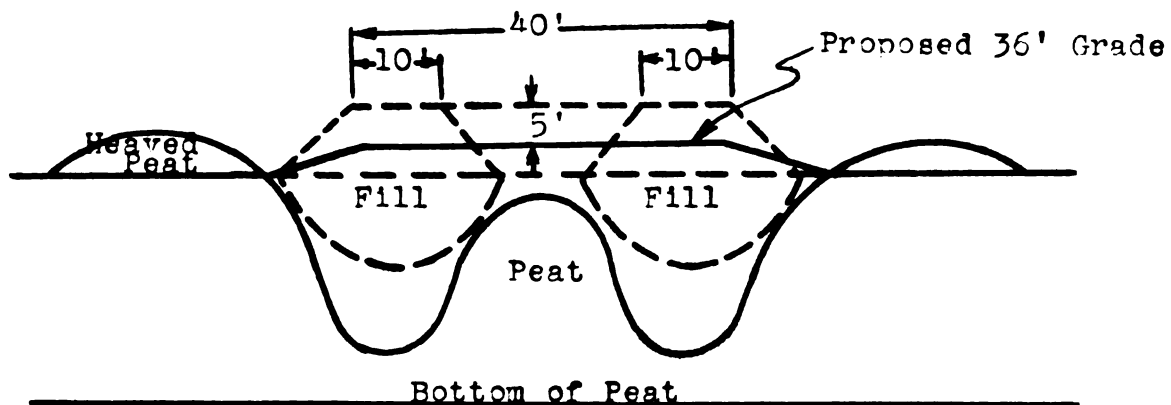
causing the fill to widen out at the bottom; third, that the fill had settled into the plastic lake clay.

Borings indicated that none of these theories were correct but that soupy liquid in the trench had caused the trouble. The worst dips were at the ends of the swamps where the trench was filled last. Most of the water and suspended peat had been pushed ahead until it reached the end of the trench where it was trapped under the fill. A slight heaving adjacent to these places was due to displacement of some of this material by traffic and not to a lateral movement of the fill.

A new standard, being considered, calls for placing a surcharge to help displace this soupy peat and to hasten compaction of the fill itself. It is necessary to fill the trench by end dumping to keep the liquid pushed ahead. In doing this an important specification requirement of placing fills in 12" layer is dispensed with. If the filling material is clay, compaction of the fill itself may require a couple of years if it is not hastened in some manner.

Another suggestion has been to widen the trench 6' to 10' on each side at the end to be filled last, and at places where the soupy material is most apt to be trapped. The fill would then be placed the regular width only, leaving a space on each side for the liquid. This would make its displacement more certain and, where the filling material was sand or sandy loam, would seem to make the surcharge requirement unnecessary.

#3. 1929 Standard Plan For Marshes 3-20' Deep.(6)



PRELIMINARY BLASTING

Before any filling is done the surface of the peat shall be blasted by the propagation method in 2 rows, 10' or 15' each side of the centerline, using one stick of 50% straight nitroglycerine dynamite in each hole, 18" deep and spaced 18" apart in the rows.

FIRST LOADING

The marsh shall be loaded in 2 runways centered 15' from the centerline to an elevation 5' above plan grade and to a top width of 10', with 1 on 1 slopes to a maximum height above the surface of the peat equal to $\frac{1}{2}$ the depth of peat or until rapid settlement takes place, after which the loading shall be kept to an elevation 5' above plan grade by additional filling until the rate of settlement is not more than 0.1' per day. After this stage of settlement has been obtained the "Final Blasting" shall be done.

FINAL BLASTING

2" pipes, plugged at the bottom end, shall be driven 10' apart in rows 10' apart each side of the road centerline, to a depth approximately halfway between the bottom of the first loading and the bottom of the peat. The pipes may be driven in a vertical position or on an angle at the base of the fill. After the pipes are placed, the plugs shall be removed and 1 stick of dynamite shall be shot in each hole to form a chamber after which 20 to 30 sticks of 50% straight nitro-glycerine or gelatine dynamite shall be placed in each hole. The number of sticks per charge shall be varied in proportion to the depth of the peat. A minimum of 20 charges shall be shot at one time by means of a blasting machine and both rows shall be shot together. After this blasting the final loading shall be made.

FINAL LOADING

The loading shall be brought to an elevation 5' above plan grade and a top width of 40' with 1 on 1 slopes and shall be maintained at this elevation by additional filling until the rate of settlement is not more than .05' in 30 days, after which the load is spread and thoroughly compacted to form the cross section and grade shown on the plans; provided however, that excess earth shall be used to uniformly widen the grade and flatten the slopes on each side.

LIMITS OF OPERATION

Where feasible, all material for fill shall be sandy or

gravelly soil. If the fill material is clay, the fills shall be built up in compacted layers, the first layer not more than 3' above the surface of the peat and succeeding layers not more than 1' in thickness.

Use of this method of loading and blasting was observed by the writer in 3 marshes, viz.; a swamp about 900' long, 12' to 20' deep on U.S. 27, north of Tekonsha; another swamp about 200' long with the marsh bottom tilted, located in the same vicinity; and a marsh about 500' long, 8' to 16' deep on M 78, southwest of Bellevue. All three were loaded and blasted during the late fall of 1929 and early spring of 1930, and were paved during the summer of 1930. As borings have not been taken, the results obtained can only be anticipated by the apparent stability of the fill and the quantity of borrow earth required. In this standard as well as others just studied the designer has not anticipated that the wedge would penetrate to the marsh bottom.

The longer marsh at Tekonsha, above mentioned, required about 5000cyds. of borrow earth more than estimated on the plans. This would be an average settlement of 4' more than expected, so it is probable that the wedges penetrated to the marsh bottom. The preliminary load was in place during the spring breakup, at which time considerable settlement occurred. Peat was heaved on both sides for nearly the entire length of the marsh. The pipes used for the final blasting were jettied through the fill by a stream of water under pressure. Heaving of peat between the new fill, which was on relocation, and the

old road embankment, which was about 100' away, had blocked the drainage. The jetting process left the water standing on both sides of the fill and in the trench between the two rows forming the surcharge above the wedges. As the filling material was mostly clay this flooding undoubtedly aided settlement materially. The final blasting was much more effective than for the other methods described, as the charge, being over 4 times as great as those previously used, was sufficient to raise the entire fill with surcharge several feet into the air. For about 150' where the marsh depth was the greatest, peat, which had been trapped between the wedges, was forced up through the center of the fill to a height of about 4'. This peat was excavated to about swamp level and replaced with borrow earth previous to the final loading. The final loading was placed and left about 2 months until settlement was less than .05' in 30 days. The heaved peat was leveled off and the surplus earth in the surcharge was used to widen the grade and flatten the fill slope for the entire length of the marsh. The fill had been so completely saturated by the jetting, two months previous, that, after the surcharge had been removed, it was necessary to allow the grade to dry for one week during the dry summer of 1930, before the pavement slab could be placed. Drainage was considered poor, as water had several times risen above the old road, but dry seasons have prevailed since the new road has been built and water has always been kept at least 2' below swamp level or about 5' below the pavement grade.

To date, no noticeable settlement has taken place, In as

much as the fill, while loaded with a surcharge, (a) was subjected to freezing, and thawing, (b) was flooded, (c) the heaved peat given ample time to drain before the final blasting, and (d) the factor of safety increased by widening the grade with the surcharge material, therefore, this fill should be as stable as possible for the two wedge method. It would not be surprising if some settlement took place along the centerline due to compaction of the peat between the wedges. In this particular case, most of the marsh is on a super-elevated curve where the crown was left in the pavement. A small settlement would merely remove the crown and the super-elevation would still provide drainage for the slab.

The other marsh at Tekonsha was handled in the same manner and at about the same time as the one just described. In this case the marsh was only about 200' long and the old road was at the same location. The marsh bottom sloped toward the middle of the fill longitudinally and was also tilted laterally. The old road fill was nearly to hard bottom on the shallow side. As the old gravel road was a trunk line which carried fairly heavy traffic, the peat under the old fill was probably compacted to the extent that it was not readily displaced. Drainage was much better at this location. The filling material was partly sand and partly clay. The fill settled quite rapidly on the low side and heaved peat on that side only. Since it has been paved some settlement has taken place at the point where the marsh was the deepest. The steep tilt to one side was probably the cause.

The marsh, on M 78 southwest of Bellevue, was about 500' long and from 8' to 16' deep. Following preliminary blasting and loading the quantity of peat trapped between the wedges was unusually large. As the wedges settled the peat heaved up between them along the centerline of the road. At this point the loading and dynamiting plan was abandoned and the peat was excavated and replaced with borrow earth. This was expensive but the heaving of an abundance of peat along the centerline indicated beyond doubt that the two wedge method of displacement would be a failure so excavating the peat and backfilling with earth was the best and surest way out.

Comparison Of The 1926 And 1929 Standards.

The 1929 standard plan used on the Tekonsha marshes was unquestionably an improvement over the 1926 standard plan used for the Devils Lake swamp. The principal changes were substitution of the propagation method of preliminary blasting, increasing the size of the charge of dynamite, and increasing the size of the surcharge. The propagation method of preliminary blasting required $1/3$ more dynamite but fewer caps than the old method. It was easier to execute and more successful in cutting the mat. The first standard required a very small surcharge before the final blasting and therefore did not cause much heaving until after the final blasting. By displacing as much peat as possible by the first load better results are obtained by the final blasting for the heaved peat has had a chance to dry out and become much lighter. The charge for the final blasting was increased to three times that required by the 1926 standard and

made large enough to raise the fill and surcharge into the air so that the wedges struck the peat with an impact. The final load for the 1929 standard was almost 4 times as heavy as that required by the earlier plan.

The Two Wedge Method Being Replaced.

Although the 1929 standard plan is still in use the two wedge method is gradually being discarded and is being replaced by the method recommended for deeper swamps on the 1929 standard plan. This method calls for the same preliminary blasting but for starting the load in the center and building it to a height of 5' above grade with a top width of 20' with 1 on 1 slopes. This is in the form of one wedge instead of two and is designed to penetrate all the way through the peat. The final blasting is the same as for the two wedge method. The final surcharge is only 20' wide on top for the width of grade and pavement being considered.

A Proposed Standard.

A new standard plan which is being considered but which has not yet been adopted is practically the same as the last method mentioned above except for the final blasting which is as follows: (6) "2" pipes plugged at the bottom end shall be driven 10' apart in 3 rows spaced 7' apart for future 20' pavement, or spaced 14' apart for future 40' pavement. The center row to be driven along the road centerline, and all rows to be driven to a depth approximately half way between the bottom of the first loading and the bottom of the peat. The pipes may

be driven in a vertical position or an angle at the base of the fill.

"After the pipes are placed, the plugs shall be removed and one stick ofdynamite shall be shot in each hole to form a chamber, after which 20 to 30 sticks of 50% straight nitro-glycerine or 60% gelatine dynamite shall be placed in each hole. The number of sticks per charge shall be varied in proportion to the depth of peat except that in all cases the number of sticks in the center blasting row are to exceed those of the other two rows by five sticks; and the center blasting row charges are to be fitted with Delay Detonating Caps. A minimum of 20 charges shall be shot at one time by means of a blasting machine and all three rows shall be shot together.In lieu of the above method of placing charge, contractor may use the jet method."

This method is proposed for all depths but is aimed particularly at depths of 12' to 25' where complete penetration has been most difficult to obtain. The charges for the outside rows have been demonstrated to be sufficiently large to raise the fill. While the load is in the air the charges along the centerline, which were equipped with delay electric caps, explode and start displacement of the peat and the impact of the fill, as it falls, continues the action.

The manufacturer recommends the old type waterproof delay electric blasting cap for this kind of work as the new type caps are designed for use with ammonia dynamites only (7).

These delay caps are made in five different sizes for different periods of time. First delay would probably be sufficient in this case.

THE MINNESOTA METHOD

A method of displacing peat is being used in Minnesota which has been described by Mr. P.W. Riedesel, former resident engineer of the Minnesota State Highway Department (12). It is being briefly outlined here and compared with the Michigan standard.

PRELIMINARY BLASTING AND LOADING

Step #1. Place charges of one stick of 60% dynamite 1' apart and 5' or 6' deep in 3 rows, one on the centerline of the road and one 8' each side of the centerline; and shoot by the propagation method.

Step #2. Build a fill the width of the trench at the toe of the slope and to a height 5' above the swamp level.

Step #3. Place charges, consisting of 1 stick of 60% dynamite, 1' apart and 5' to 6' deep, along the toe of the fill and shoot by the propagation method.

Step #4. Fill the resulting trench to a height 10' above swamp level.

FINAL BLASTING

Place charges of 150 lbs. of 40% dynamite 20' to 30' apart on the centerline at points three-fourths the distance from the

bottom of the fill to the bottom of the peat, and shoot 6 holes at a time. Maintain a surcharge 10' above swamp level and repeat blasting until the fill penetrates to hard bottom. For wider fills, use charge of 100 lbs. of 40% dynamite 20' apart in rows 10' each side of the centerline.

The above method was said to be successful but rather expensive. It will be noted that the preliminary blasting is very complete. It requires 250# of 60% dynamite per station as compared with 67# of 50% dynamite per station called for by the latest Michigan standard. Mr. Riedesel gives 4 reasons for requiring a very complete preliminary blasting; First, it opens the way to immediate natural settlement; second, it makes settlement from the final blasting more certain; third, it saves dynamite; and fourth, it lessens the danger of side slipping.

Shearing of the surface mat is very important especially in shallower marshes and it is possible that the Michigan standard does not place enough emphasis on the first blasting. The Minnesota method is designed to remove a large portion of the mat while the Michigan plan is to merely shear it. The quantity of dynamite required to break up the mat depends upon the denseness of the mat. In some cases where the mat is tightly woven together by roots it might be advisable to excavate to a depth of 3' or 4'. In other instances where the surface is very soft no preliminary blasting at all is necessary. The stiffness of the mat depends on the water content of the peat as well as the quantity of vegetation. The Minnesota method calls for 60% gelatine dynamite while the Michigan requires

50% straight nitro-glycerine dynamite. The latter is less stable and therefore more easily detonated by the propagation method.

There is less difference in the final blasting. Minnesota uses 750# of 40% gelatine dynamite per station while Michigan requires 415# of 60% gelatine dynamite or 50% straight nitro-glycerine dynamite. 60% dynamite has only 1.23 times as much energy as 40% dynamite but it explodes with a more shattering blow. It appears that the Minnesota method was designed to actually displace the peat with the dynamite while the Michigan standard depends on a sudden impact to start the flow of peat and the weight of the fill to continue action.

MARSHES OVER 25' DEEP

An entirely different problem has arisen in the settlement of fill over marshes more than 25' deep than that encountered in the shallower marshes. The first Michigan State Highway Department investigation of marshes that had been filled without the use of dynamite, indicated that in nearly every case where the depth of peat was over 25', the fill had settled to the marsh bottom. The first standard plan developed, did not call for a second blasting of these swamps. The surface mat was broken and the sinkhole was filled until settlement stopped. Excessive overruns in the quantity of borrow earth required for some of these marshes led to an investigation which showed that lateral displacement was causing the loss.

None of the deeper marshes are being studied from borings in this paper as was done with the shallower marshes. Some results that were obtained in the Highway Department investigations are being used together with some facts and theories of earth pressures to determine the probable causes of lateral displacement and precautions that might be taken to prevent or decrease it.

INTERNAL FRICTION AND COHESION

As George Paaswell, C.E., has said (11), "The correct interpretation of the character, distribution and amount of pressure throughout an earth typical of ordinary engineering construction, cannot be expressed by exact mathematical analysis. The usual earth mass retained by a wall contains so many uncer-

tain elements that can neither be anticipated nor determined by typical tests, that it becomes very hard to assemble sufficient data for a premise upon which to found any satisfactory conclusion."

In the definition and discussion of the resistance to movement of a prism of earth, Charles Terzaghi, Research Consultant, U.S. Bureau of Public Roads, is quoted (8,9). "The resistance to movement is a combination of forces due to the attraction existing between the individual soil grains and is independent of the pressure acting upon the surface under consideration. It is a constant value for any unit area within the embankment if the material is uniform.

"The internal friction is caused by the resistance to soil grains sliding over each other and varies with the pressure upon the sliding plane.

"It should be understood that cohesion and internal friction in every respect correspond to the shearing strength of solid bodies. They represent the combined result of the properties of the soil constituents and of the conditions under which the soil exists. Thus they include friction and true adhesion between the individual particles, skin friction between soil particles due to capillary pressures, etc. When these conditions change, both the cohesion and the internal friction of the same material are apt to change, similar to the change in shearing strength of a solid body due to change in the temperature. Therefore, strictly speaking, the terms cohesion and internal friction refer not only to definite

materials but also to definite states. In general, the finer the soil constituents the more variable both quantities become.for materials with even a trace of cohesion, the "angle of repose" has no relation to the angle, ϕ , and may, for the same material, be very different, depending on the height of fill."

NONUNIFORMITY OF MICHIGAN SOILS

As Michigan soils are glacial deposits they vary greatly. A recent bulletin resulting from several years of soils research along Michigan State Highways, lists 51 different kinds of soils which have been classified into 6 groups. While carrying on this survey to determine the effect on pavements of various types, observations were taken mostly in cuts as the fills consisted of mixtures of different soils. It can be seen that a fill, partly made of earth taken from cuts 1000' or more each side of the swamp and the remainder taken from one or more borrow pits, is by no means a homogeneous mass. Taking this into consideration, it is altogether unlikely that the soils making up the average fill would have constant physical properties.

PHYSICAL PROPERTIES OF PEAT UNKNOWN

An attempt by the Research Division of the State Highway Department to determine the physical qualities of various kinds of peat by laboratory methods failed. The reasons are given by Mr. V.R.Burton (3) as follows: "First, because it is impossible to maintain the peat in its original condition on exposure to

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 is doubtful whether the stability of peat should be expressed as internal friction and cohesion which acts according to Coulomb's hypothesis. Fibrous peat, which usually composes the top five to twelve feet of Michigan marshes, will stand vertically, when a trench is cut through it, to a critical height of 12', more or less depending on the height of the ground water level and the consistency of the peat. Cross sections have proven its horizontal thrust to be sufficient to offset the opposing thrust of a fill up to 25' deep. Yet research engineers for the Bureau of Public Roads (8) state that "Bearing properties depend on the combined effect of cohesion and internal friction" and in the same article describe peat as affording "exceptionally low support".

COHESION AND INTERNAL FRICTION VARY WITH FIELD CONDITIONS

The method used in building a fill can greatly effect the cohesion and internal friction of the mass. Experiments by Jacquinet and Frontard in 1910 on earth taken from a dam which had failed, showed the following results:

"1. f ($= \tan \phi$) varied only 0.14 for the soft, pasty earth to 0.18 for earth nearly dry. Neither the amount of water used for the puddling or ramming caused much variation in f .

"2. On the contrary, the amount of water used effects the cohesion very much, and sufficient ramming can more than double the coefficient of cohesion."

In 10 out of 12 cases studied by the Research Division of the State Highway Department, where lateral displacement of fills had taken place, the fills were built with industrial railway equipment. This material was not compacted and was often dumped from a trestle directly into water. In such a fill the soil would have a minimum coefficient of cohesion due to the high water content and lack of compaction. The method of building a fill of cohesive earth may greatly effect the water content even though the fill later becomes submerged. The interior of these fills usually are found to have a lower water content than the outer portion. If a fill can be built before it is submerged its internal friction will be greater. Charles Terzaghi, Research consultant, U.S. Bureau of Public Roads, (9), says, "The coefficient of internal friction, $\tan \phi$, of a cohesive material is very different depending on whether the water content of the earth has or has not an opportunity to adapt itself to changes in pressure." Clayey soils are some times almost impermeable and when they once become saturated are very loath to give up their water. Lateral displacement apparently takes place in a series of slides. The fill is built

up until the weight is sufficient to shear the weakest place, at which time a portion of the fill slides. The resistance of a fill to shear is entirely dependent on the combined effect of its cohesion and internal friction and these factors are greatly affected by methods of construction.

EFFECT OF BUOYANCY

The buoyancy or hydrostatic uplift of a submerged fill of porous soil has been described by William Cain (10) as follows: "If this filling earth weighs 100# per cu. ft. in air and has 40% voids, then 1 cu. ft. contains 0.6 cu. ft. of solids, and since the buoyant force of the water equals the weight of an equal volume of water or 0.6×62.5 equals 37.5 pounds, the true weight of the filling in fresh water is $100 - 37.5 = 62.5$ pounds per cu. ft.

"This method can be applied to get the approximate weights in water of such materials as rip-rap, cobble-stones or clean gravel. It cannot apply to finer materials, as clean sand, bank sand or loam, because in such earths free circulation of the water is not realized; the water cannot get under the material everywhere and its full buoyancy effect cannot be exerted."

The above quotation was given in connection with the design of tunnels and was intended as a warning against depending on hydrostatic uplift of a submerged fill over a tunnel unless the soil was very porous. Buoyancy has been found to have caused a decrease in bearing capacity of cohesionless

sand by research engineers for the Bureau of Public Roads (3) who are quoted as follows: "If the water rises near to the surface of the ground, the specific gravity of the sand apparently decreases on account of the hydrostatic uplift; and, as a consequence, the bearing capacity also decreases." The bearing capacity of cohesionless sand was found to be decreased 35% due to buoyancy, which was proportional to the loss in weight. As long as water is free to flow under a mass the buoyancy will be equal to the weight of the water displaced. In case of a fill of sand or gravel the buoyancy would probably be about 35% during the time that settlement was taking place and probably slightly less than that after settlement was complete when compaction would slightly decrease the ease with which water could circulate. In case of a more impermeable fill, the water displaced would be nearly the volume of the fill and the buoyancy would appear 50% during the time that settlement was taking place and water could flow under the mass. As soon as complete settlement had taken place, the lake clay at the bottom of the marsh, into which the fill sinks would almost entirely stop circulation and buoyancy would no longer affect the mass. At this time the internal stresses in the fill would be more than doubled.

From the above it appears that lateral flow does not start until the fill has penetrated into the lake clay. If the cohesion and internal friction are sufficient to hold the fill together, the increase in weight will compact the fill and increase its stability; if not, lateral flow will start and a portion of the fill will break away and form an angle of repose

with the marsh bottom. The plane of the shear on the remaining portion of the fill, becomes wet so that when the fill is again built up another slide takes place more readily than the first. Cases have been found where one side of the fill stood nearly vertical while the other formed an angle of repose of as low as 20° with the marsh bottom.

The Coulomb hypothesis is (10), "that the friction on a plane in the interior of a mass of earth, is equal to the normal pressure multiplied by the coefficient of friction, $f = \tan \phi$, and the cohesion is equal to the area of the plane considered multiplied by c , the cohesion per unit of area. In other words, the friction is proportional to the normal pressure on the area considered, whereas cohesion is simply proportional to this area and is independent of the normal pressure."

The following formulas are developed in Cains' text (10).

E = horizontal thrust of earth against a vertical plane.

w = weight of earth per cubic foot.

ϕ = angle of internal friction.

f = coefficient of friction = $\tan \phi$.

c = coefficient of cohesion in pounds per square foot.

h = depth of the fill in feet.

For non-cohesive earth:

$$E = \frac{wh}{2} \tan^2(45^{\circ} - \frac{\phi}{2}) \quad \text{Equation \#1}$$

For earth endowed with both cohesion and friction:

$$E = \frac{wh}{2} \tan^2(45^{\circ} - \frac{\phi}{2}) - 2ch \tan(45^{\circ} - \frac{\phi}{2}) \quad \text{Equation \#2}$$

Most soils weigh about 100# per ft. and it is seldom that there is more than a 10% variation from this figure. Taking buoyancy into consideration values for w will be used as follows: sand 60#, loam 70#, clay 80#.

Coefficient of cohesion, c , will be considered as follows: sand 0, loam 200# 1 sq. ft., clay 400# 1 sq. ft.

The angle of internal friction, ϕ , will be taken as follows: sand 26° , loam 16° , clay 4° .

Substituting the above values into Equation #1 or 2 and solving; the total horizontal thrust, E , for various depths of marshes, h , is found to be as follows;

h	Sand E	Loam E	Clay E
25'	7330#	1080#	3100#
30'	10550#	3030#	8860#
40'	18750#	8430#	25330#
50'	29300#	15800#	49740#

If buoyancy acts on the clay fill while it is submerging so that w becomes 50# per cu. ft. the values of E are -5070, -1340, -4250, and 17100 for the 4 values of h considered. It is evident that the effect of buoyancy is probably the most variable factor. The above partially explains why clay fills do not penetrate the peat as readily as granular soils and why lateral displacement is so apt to take place in fine grained soils. A soil which is endowed with both internal friction and cohesion and yet is porous enough to be affected by buoyancy is the ideal soil.

CONCLUSIONS AND RECOMMENDATIONS

MARSHES 0 - 12' DEEP

Displacement by dynamiting has not been successful but the peat can be readily excavated. If the ground water level is below the bottom of the trench the fill should be built up in layers and compacted. The same specifications used for normal fills of the same height may be used. If the trench contains ground water some provision should be made for the displacement of the resulting soupy liquid in the trench.

MARSHES 12 - 25' DEEP

More emphasis on preliminary blasting is recommended. A solid mass fill which has penetrated to the bottom of the peat is necessary. Even though a fill which has a static load shows no signs of farther settlement it may be suspended in peat and continue to settle when subjected to the impact and vibrations of motor traffic. The quantity of borrow earth used is an indication of the depth of penetration but complete borings are desirable as a check. Where water is available jetting the pipes through the fill is preferred to driving them. A properly built fill is too stiff to permit driving pipes without first making holes with an auger. Having surcharge in place during the spring breakup, or during a time when the fill is flooded, will help to force the fill through the peat or aid compaction of a fill already on hard bottom. Drainage is important but swamp ditches should not be cut through heaved peat as there is danger of disturbing the equilibrium. Particular

attention should be paid to portions of marshes where the bottom is on a steep grade either laterally or to one side. If there are sections several hundred feet long of peat less than 12' deep and the remainder deep enough to require blasting, the shallow portions should be excavated and a method of loading and dynamiting used on the remainder. In case there is an old road fill, the preliminary blasting should include shearing the old embankment near the ends of the swamp and possibly at other points so that the fill will be free to settle.

MARSHES MORE THAN 25' DEEP

In the selection of borrow pits sandy, gravelly or loam soils are most desirable and heavy clay should be avoided as much as possible. Where sand or gravel can be alternated in layers with clay the latter is much less objectionable. Clean sand is less desirable than sand containing some cohesive material. The danger of lateral displacement of the fill increases rapidly with the depth of the marsh. Rigid enforcement of specifications for properly building fills will increase the internal friction and cohesion of the soil and decrease the danger of lateral displacement. The quantity of borrow earth used does not indicate the depth of penetration as much of the earth may be consumed by lateral flow. Heavy overruns in borrow earth over the original estimate indicates that there has been lateral flow. Although the unit weights of different kinds of soils do not vary greatly in air it is probable that the effect of buoyancy makes this variation much greater for soils composing a submerged fill.

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