Field Observations on Sand Drain Construction on Two Highway Projects in Illinois

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● IN the past few years the use of sand drains for fill construction over marsh areas has assumed increasing prominence. Numerous articles following O. J. Porter's in 1936 (*1*) have appeared describing the successful employment of this procedure in the construction of fills over soft and compressible subsoils. The studies of Kyle and Kapp (*2*) indicated a reduction in the water content of the subsoil after stabilization with sand drains.

The principal basis of this method of construction is that the drains accelerate the process of consolidation in the subsoil under the weight of the fill. Furthermore, the resulting reduction in water content of the subsoil leads to an increase in the shear strength. The function of the sand drain is therefore twofold. It shortens the time interval required for consolidation and settlement and thus permits early installation of the permanent structures. Secondly, it increases the strength of the subsoil as a result of the consolidation.

From 1952 to 1954, in connection with two highway projects involving sand drain construction in Illinois, the opportunity arose to make fairly complete field and laboratory investigations. The primary objective was to evaluate the effectiveness of this method of construction. In the subsequent paragraphs the description of the projects and the analysis of the observed data are presented.

RELOCATION OF HIGHWAY U. S. 51, LASALLE, ILLINOIS

The relocation of the highway at LaSalle involved the construction of an embankment 25 to 30 feet high over the flood plain of the Illinois River. The relocation began near the embankment of the Burlington Railroad at the north and joined the existing highway at the south end. The total length of the section was about 3 miles. Figure 1 shows the profile of the section and locations of the borings and field installations.

Subsoil Conditions

Subsoil conditions were investigated by five borings; the results of laboratory tests on 2-inch diameter thin-walled tube samples are presented in Figures 2 to 6. In general the subsoil consisted of soft silty clay containing thin seams of sand. The clay had a strength of around 0.5 ton per square foot. Apparently the subsoil represented the alluvium laid down by the Illinois River. Dense sand and gravel were encountered at a depth of 40 feet.

History of Construction

During the design of the embankment, it appeared uncertain whether the subsoil would be capable of supporting the weight of the fill. Stability computations indicated a factor of safety with respect to base failure of only 1.1 for the softest part of the deposit. In order to minimize the possibility of slides, vertical sand drains were adopted. The sand drains were 1 foot in diameter and were spaced at 12.5 feet. The average length was about 45 feet.

Construction began in the winter of 1952 with the removal of all dumped materials and muck near the ground surface. Excavation was carried to an average depth of 5 feet. Following this, 5 feet of sand were placed to form the working platform. The sand drains were installed in the usual manner during the spring of 1953. As the material for the fill was a clean coarse sand capable of providing excellent drainage, no separate drainage blanket was used. The fill was placed hydraulically in

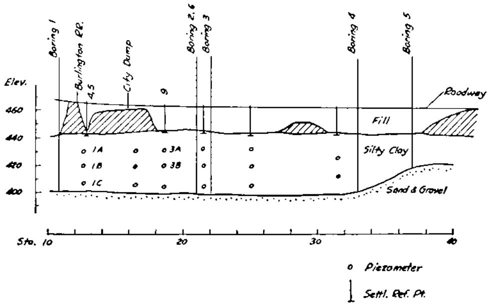

Figure 1. Profile, US 51, LaSalle.

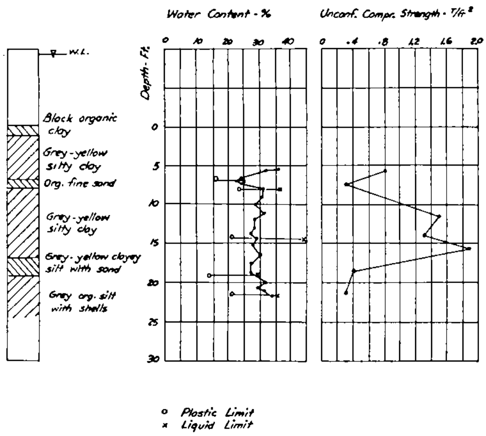

Figure 2. Boring 1, station 10 + 83.

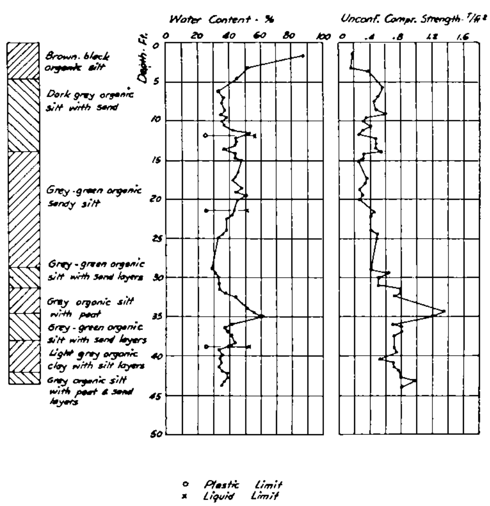

Figure 3. Boring 2, station 21 + 00.

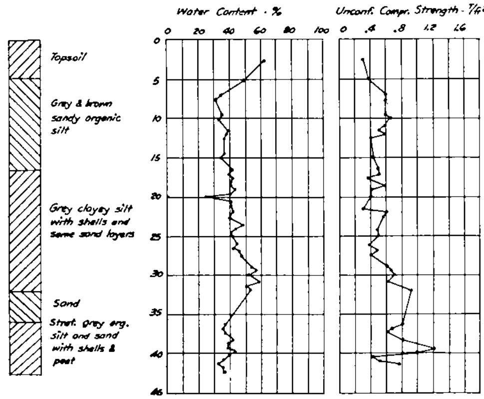

Figure 4. Boring 3, station 22 + 00.

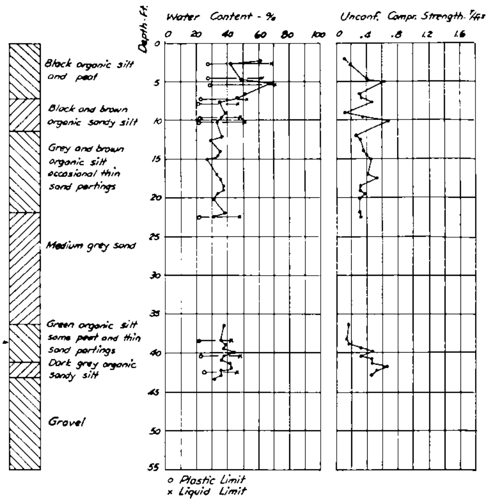

Figure 5. Boring 4, station 33 + 00.

four lifts of 5 to 10 feet and sufficient time was allowed to elapse between each lift to insure consolidation of the subsoil. After each lift no additional fill was placed until the rate of settlement had dropped off to a negligible value. In this manner the entire fill was completed near the end of 1953.

Field Observation

The program of field observation consisted of measurements of pore-water pressure and settlement. The pore-water pressure was measured by piezometers similar in construction to that developed by A. Casagrande (*3*) with the exception that a well point was used

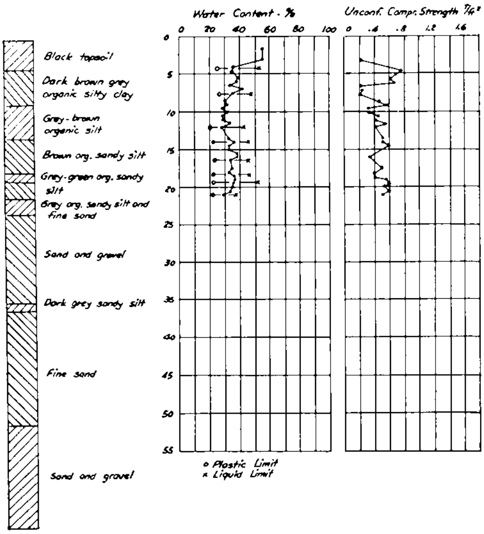

Figure 6. Boring 5, station 37 + 00.

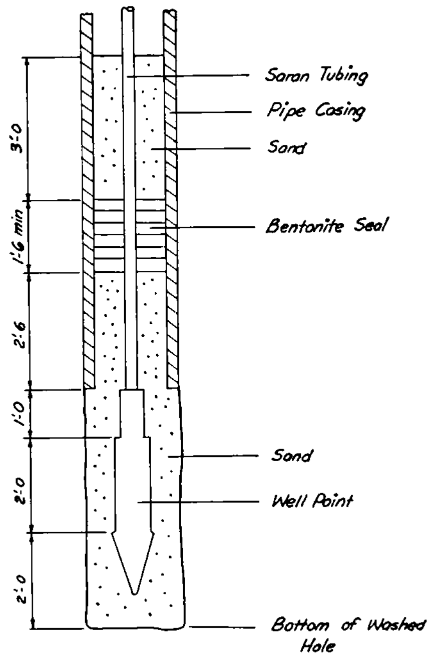

Figure 7. Piezometer.

for the porous tip. Figure 7 is a simplified diagram of the piezometer assembly. The reference points for settlement measurement consisted of iron pipes fastened to wooden platforms. The platforms were placed at the base of the fill and level readings were taken on the top of the pipes.

The results of the field measurements are presented in Figures 8 and 9. The data in Figure 8 are typical for the section of the fill between stations 10 and 18. This is the area where about 25 feet of dump existed before construction. It is evident that the subsoil had consolidated under the weight of the dump. The observed settlement due to the weight of the embankment consequently was small and little pore-water pressure was measured. The behavior of the subsoil between stations 18 to 27 is represented by Figure 9.

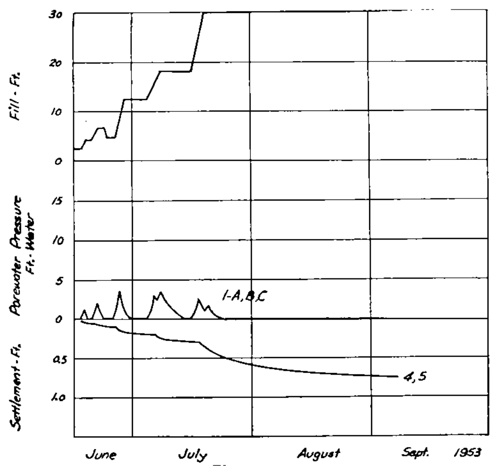

Figure 8. Settlement and pore-water pressure, LaSalle.

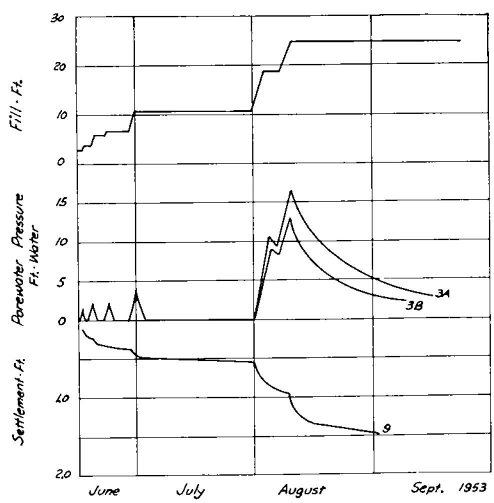

Figure 9. Settlement and pore-water pressure, LaSalle

It is seen that the addition of any fill produced an instantaneous rise in the pore-water pressure and a rapid rate of settlement. The process of consolidation was accurately reflected in the reduction of the rate of settlement and the corresponding dissipation of pore-water pressure.

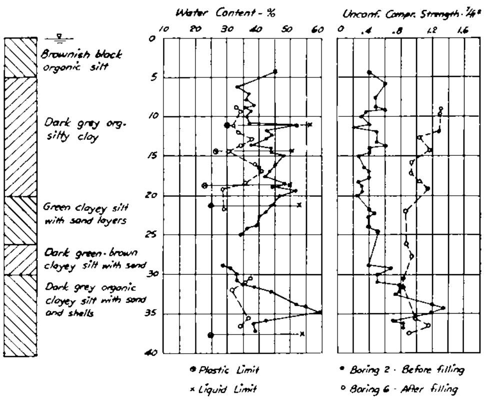

Figure 10. Boring 6, station 21 + 00.

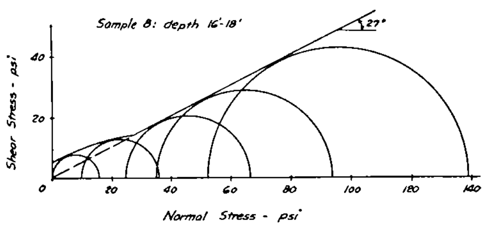

Figure 11. Mohr's circles of stress.

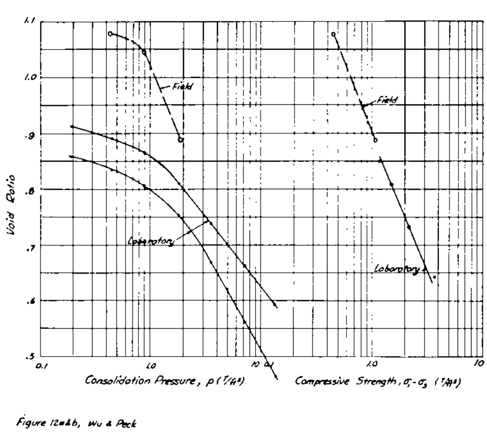

Figure 12. *a.* Pressure-void ratio relationship; *b.* strength-void ratio relationship.

Laboratory Investigation

In the summer of 1954 a sixth boring was made at the location of Boring No. 2 to study the change in the subsoil produced by the weight of the fill. The unconfined compressive strengths and natural water contents of 2-inch diameter thin-walled tube samples are plotted in Figure 10. Comparison with the values obtained from Boring No. 2 showed a reduction in water content accompanied by a significant increase in strength from about 0.5 to almost 1.1 tons per square foot.

Several triaxial and consolidation tests were also performed. Figure 11 contains the Mohr's circles of stress obtained from consolidated-quick tests. The strength versus void ratio relationship of the tests are plotted in Figure 12*b*. The field relationship in the figure represents the average water contents and average unconfined compressive strengths of the subsoil between depths of 9 and 27 feet before and after the construction of the fill. The pressure versus void ratio curves for consolidation are shown in Figure 12*a*. The field values were computed from the observed settlements and average water contents of the subsoil.

The data presented in Figure 12 indicate that the laboratory consolidation tests and shear tests gave results that agree closely with the observed behavior of the subsoil in the field. Furthermore, the strength versus void ratio curve is parallel to the pressure versus void ratio curve of consolidation.

The foregoing data indicate that the consolidation of the subsoil agrees with that predicted by the theory of consolidation. The evidence also demonstrates that the relationship between the water content and the strength of the subsoil is in agreement with the observed behavior of laboratory specimens (*4*).

HIGHWAY ILL. 11, BARRINGTON, ILL.

Route 11 is a dual lane, divided highway northwest of Chicago. Near Barrington the route is located over several peat deposits. The highway consists of two parallel embankments for the two directions of traffic, and although the fill nowhere exceeded 15 feet in height, the softness of the peat presented serious problems during construction.

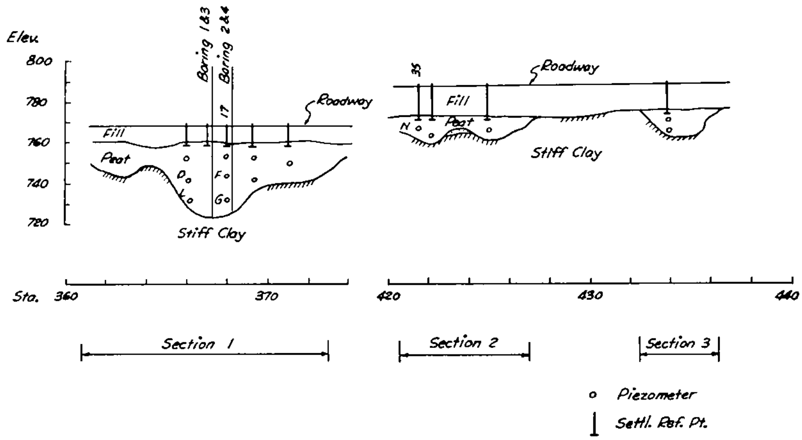

Figure 13. Profile, Ill. 11, Barrington.

Subsoil Conditions

As indicated in Figure 13, three peat deposits were encountered near Barrington. The one between stations 363 and 373 was the deepest. These deposits were explored by numerous auger borings and by two wash borings from which undisturbed 2-inch samples were taken. Figures 14 and 15 contain the results of laboratory tests on the undisturbed samples. The material was predominantly peat and organic silt. Its water content was as high as 400 percent. The average unconfined compressive strength was around 0.27 ton per square foot.

History of Construction

It was apparent during the initial phases of design that the construction of any fill over the peat deposits would lead to excessive settlements due to a consolidation of the subsoil even if a bearing capacity failure did not occur. Stability analyses indicated a factor of safety of 1.3 with respect to a base failure. The location of the critical circle is shown in Figure 16. Vertical sand drains were employed as a means of accelerating the rate of consolidation and increasing the strength of the subsoil. A temporary surcharge of 7 feet was decided upon.

The sand drains and drainage blanket were constructed in the usual manner. By February 1954, the fills had reached the design height of 7 feet over Swamp 1. However, shortly afterwards, a crack developed in the north fill between stations 367 + 00 and

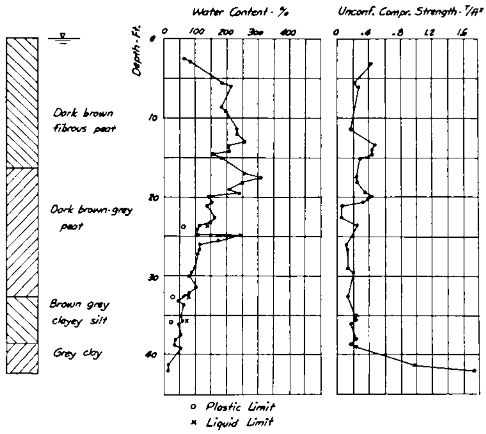

Figure 14. Boring 1, station 367 + 06.

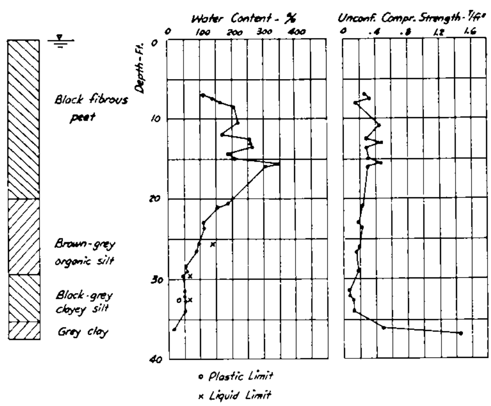

Figure 15. Boring 2, station 368 + 06.

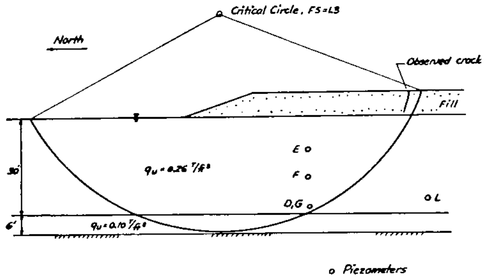

Figure 16. Stability analysis, Barrington.

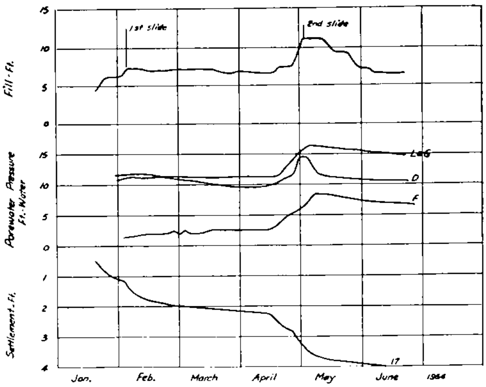

Figure 17. Settlement and pore-water pressure, Barrington.

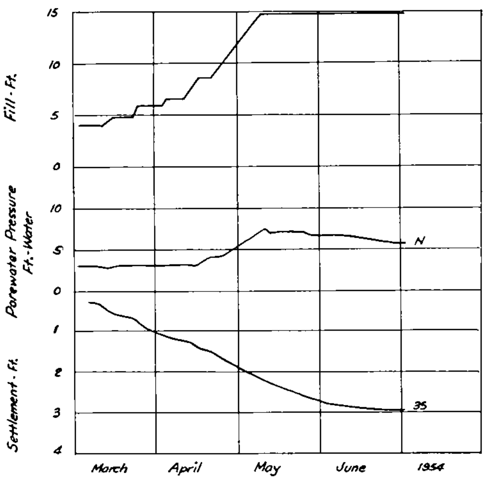

Figure 18. Settlement and pore-water pressure, Barrington.

370 + 00 and lateral movements of up to a foot were observed. Construction of the fills was immediately stopped and no additional fill was placed for a period of about two months. During the interval, settlement of the embankment continued and the pore-water pressure did not dissipate to any significant degree. On account of the requirements of the construction schedule, a surcharge was added to the fill in April, 1954. When the surcharge reached 3.5 feet, the north fill developed another crack and underwent further movements. It then became apparent that this fill could not be stabilized in a short period of time and a pile-supported concrete pavement was finally resorted to. On the south fill, 7 feet of surcharge were added without any mishap and the surcharge was

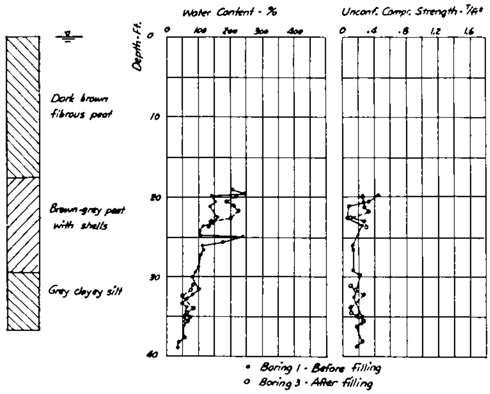

Figure 19. Boring 3, station 367 + 06.

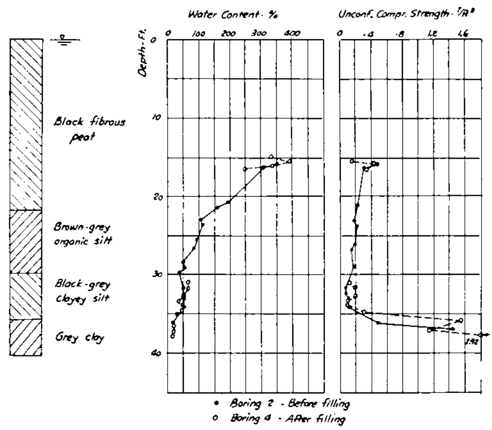

Figure 20. Boring 4, station 368 + 06.

removed in June. The operations over Swamps 2 and 3 proceeded successfully according to the same general pattern.

Field Observations

The system of field observations was the same as that adopted for the project at LaSalle. The locations of the piezometers and settlement reference points are indicated in Figure 13. Typical settlement and pore-water pressure data obtained from section 1 are plotted in Figure 17. After the placement of fill, settlement continued at a high rate and the pore-water pressure remained at a nearly constant value. This is obviously inconsistent with the behavior predicted by the theory of consolidation. In the south fill, progressive settlement ended only after the removal of the surcharge.

The data from sections 2 and 3 are represented in Figure 18 and the performance of the subsoil in this section followed a similar pattern to that described for Swamp 1.

Laboratory Investigation

After the completion of the embankment, two borings were made in 1954 at the location of Borings No. 1 and 2. Boring No. 3 was made 50 feet away from the slide and Boring No. 4 was located inside the slide area. The unconfined compressive strengths and natural water contents of 2-inch undisturbed samples are plotted in Figures 19 and 20. In this case there was no change in the water content of the subsoil, despite the weight of the 7 to 14 feet of fill, and the unconfined compressive strengths were no higher than those obtained from Borings No. 1 and 2.

From the information presented in the foregoing paragraphs it is evident that the weight of the fill produced little or no consolidation in the subsoil. The large settlements, then, probably must be attributed to a plastic flow of the subsoil in the lateral direction.

CONCLUSIONS

It is not the objective of this discussion to arrive at final conclusions regarding the merits or inadequacies of sand drain construction. Rather, the data are presented with the hope that studies of this nature will eventually lead to a better understanding of the subsoil behavior under such conditions. However, the observations at LaSalle leave little doubt as to the fact that the subsoil behavior is in general agreement with the theory of consolidation and that consolidation was accompanied by an increase in strength. On the other hand, the studies indicate that at Barrington the performance of the subsoil represented a departure from what may be expected according to the theory of consolidation.

ACKNOWLEDGMENTS

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