Hydraulic Fill Compaction

OLAF STOKSTAD and KENT ALLEMEIER, Michigan State Highway Department

The subject of fill compaction has rightly received special emphasis in connection with the improvement of pavement smoothness. The problem of building fills over deep peat marshes presents conditions which defeat conventional compaction efforts.

This paper deals with the use of flowing water as a compacting and stabilizing agent. The technique described involves introducing water into the "end dump" fill by means of jets to develop a temporary condition of flotation (quicksand) progressively along the length of the marsh fill.

The procedure described obtains embankment movement and settlement during jetting operations, which would otherwise take place over a period of years.

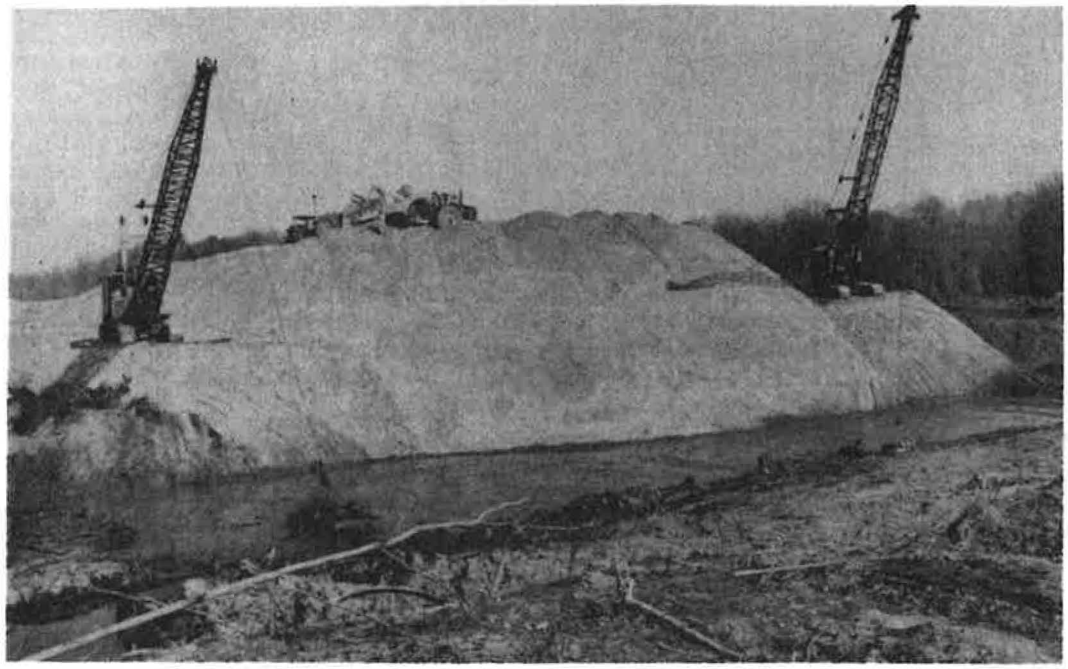
THE LAST 25 years have seen great progress in the development of techniques for embankment compaction. This development includes both equipment for compacting work and the yardstick necessary for measuring the degree of compaction. As a result of the evolution in compaction testing, it has become possible to specify results to be obtained rather than methods to be used in embankment construction.

Nevertheless, some problems remain. One of these stems from conditions which surround the building of embankments across deep deposits of peat and other marsh materials. Deep peats (more than 10 or 15 ft) never compact within reasonable time limits to the point where overlying embankments will stop settling. If such movement cannot be tolerated, it becomes necessary to improve the situation by sinking the fill to the marsh bottom. This operation is greatly facilitated by loading the peat to the point of failure, which is generally accomplished by end-dumping the embankment material to some surcharge grade as the filling progresses across the marsh (Fig. 1).

This technique of fill construction does not permit the proper mechanical compaction of the fill as it is being placed. Thus, road settlement may be experienced in the deep marsh crossings even though complete peat displacement has been obtained. The slow and continuing fill compaction with associated volume change, which takes place over the years following construction becomes a threat to traffic safety and the source of an expensive maintenance nuisance.

In geographic areas characterized by numerous marsh deposits, the problem of marsh fill compaction has received much thought. Acceleration of the compaction process has been accomplished by procedures involving vibration or the use of water. Michigan's experience with vibration has been limited to a technique employing explosives as a source of energy. Generally, the use of water in a fill jetting operation has proved to be faster, more flexible, and more effective. This discussion, therefore, is limited to a description of jetting procedures (hydraulic fill compaction) which are serving greatly to reduce a serious design, construction, and maintenance problem in Michigan—a problem which has become especially acute with greater earth moving capacity and the exploitation of this capacity in connection with an accelerated building program.

Historically, the jetting of marsh fills is an outgrowth of an attempt to soften peat trapped below an embankment and thus facilitate peat displacement. In this procedure, an unreasonable time lag was experienced between the beginning of pumping operations and the beginning of accelerated fill settlement. A study of this phenomenon revealed that settlement action did not begin until the condition of saturation had extended into the fill above the peat. With jets placed in the peat, the water tended to cut channels through the peat and escape before saturating either the peat or fill. Lifting the jets out of the underlying peat so as to pump water directly into the embankment brought



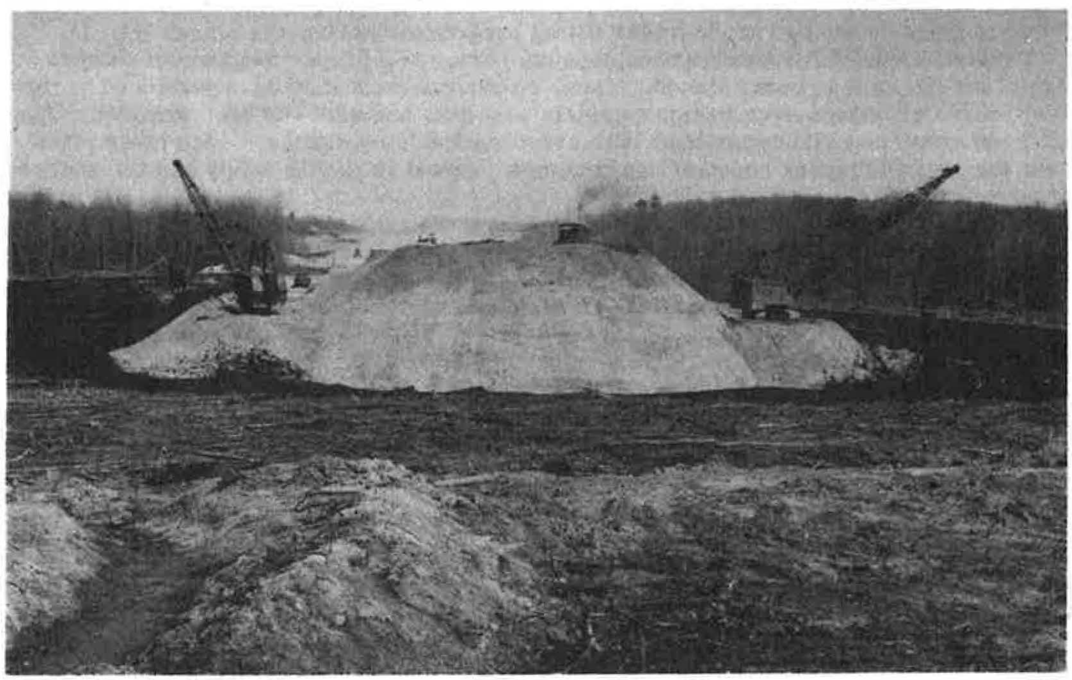


Figure 1. Peat displacement and embankment construction to surcharge grade by end dump method before treatment by hydraulic fill compaction (marsh 45-ft deep).

Figure 2. Extensive settlement cracking.

Figure 3. Settlement cracking and jet spacing.

almost immediate action. Thus, hydraulic fill compaction may be described as a procedure to compact and stabilize deep marsh fills through the action of flowing water introduced into the fill under pressure by means of a system of jets. The objective is accomplished mainly by developing a temporary condition of flotation (quicksand) in the granular fill progressively along the length of the entire marsh embankment. The procedure appears to produce improved embankment stability through a twofold influence: first, the flowing water seems to rearrange soil grains into a somewhat more compact arrangement, and second, the temporary "quick" condition greatly reduces the tendency of a granular fill to bridge or arch over areas of deficient embankment

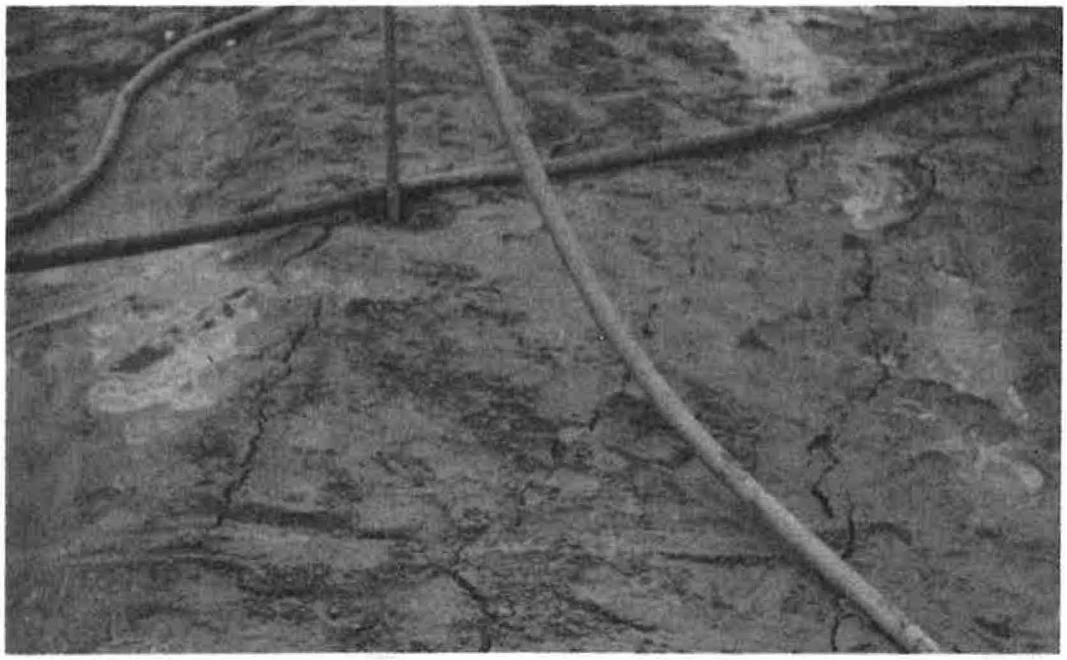


Figure 4. Crack pattern showing readjustment of embankment.

Figure 5. Jet pattern and distribution setup.

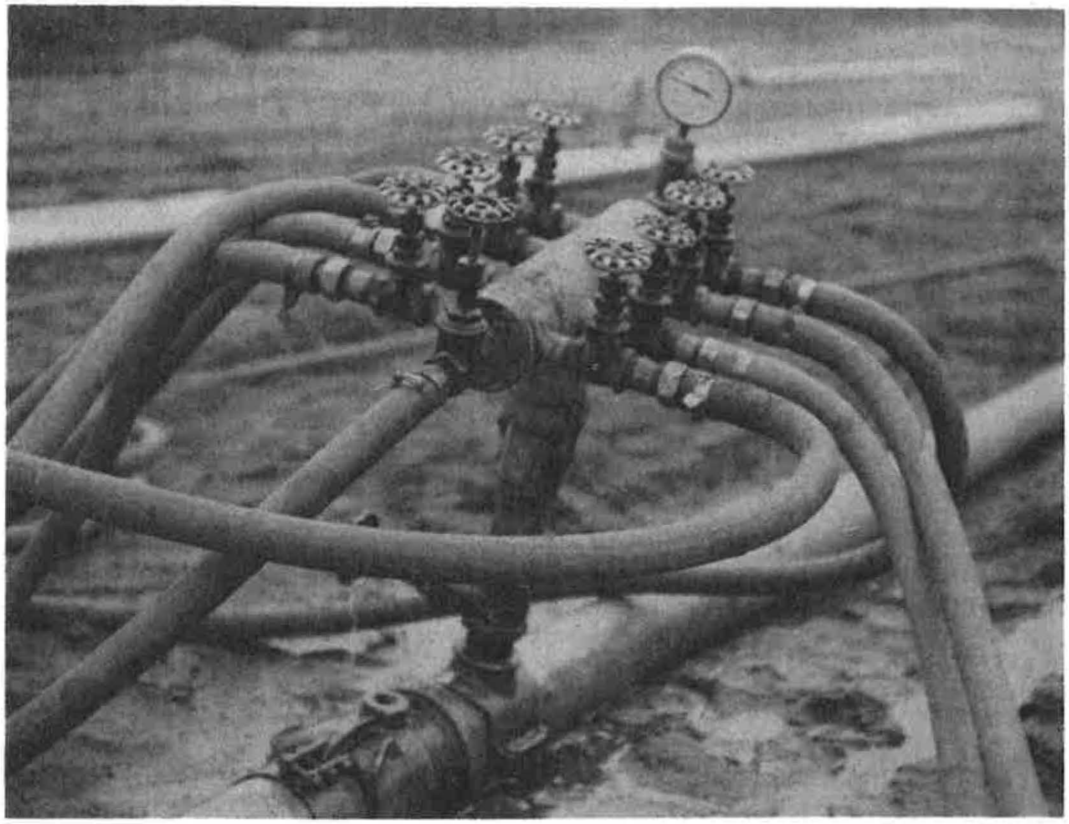


Figure 6. Typical tee with pressure gage.

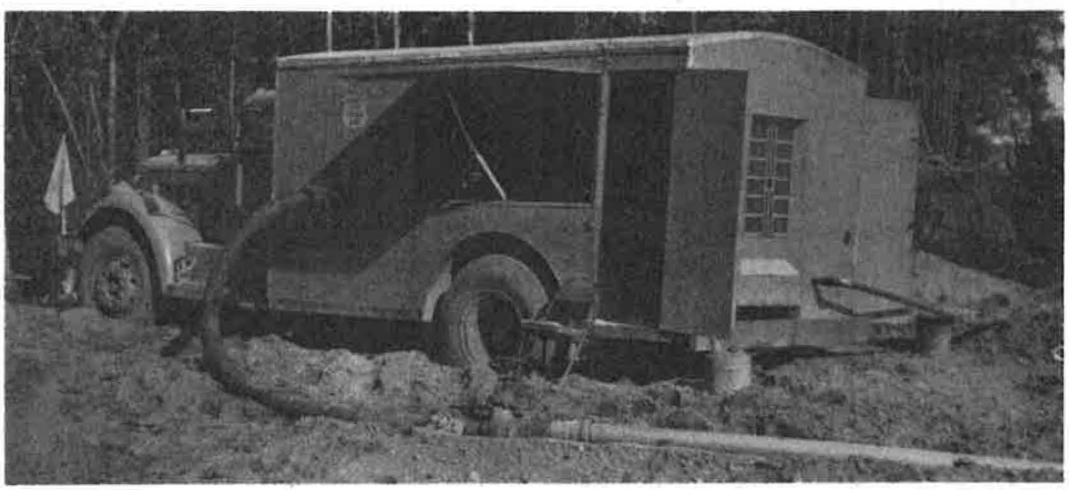


Figure 7. Truck-mounted 1,000-gpm pump.

support. The first action results in added compaction; the second results in additional peat displacement and a more stable fill cross-section.

The jetting procedure has three serious limitations:

1. It demands that a substantial supply of water be conveniently available. A well which might be completely ample for a farmstead will not provide the rate of flow needed for a marsh fill stabilizing project. Likewise, a small pond is quickly pumped dry. A small stream capable of supplying at least 1,000 gal per minute will serve. This dependence on an adequate source of water would be a serious handicap except for a recent development in pipelines designed for irrigation purposes. A lightweight aluminum pipe with a very effective snap-on coupling arrangement used in this field permits tapping of water sources as much as two miles distant.

2. Hydraulic fill compaction requires the use of soil materials which permits a fairly free movement of water through the embankment. Free draining sands are the most suitable. Clay soils are definitely not suitable. Fill compaction by water, therefore, cannot be used except in locations where sand or sand and gravel are available for embankment construction.

3. Hydraulic compaction of fills cannot be considered equivalent to methods where layer construction permits proper compaction as filling progresses. Working with marsh fills often involves sand bodies more than 100 ft wide and 75 ft deep, as compared to the units of 6- or 8-in. layers tested in conventional compaction control operations. As yet, no attempt has been made to check the amount of compaction actually obtained by pumping water into a large embankment of sand. The evidence of fill compaction is visual and consists of simple subsidence or of shear failures as illustrated in Figures 2, 3, and 4. Thus, embankment stability and compaction can be roughly determined by observing fill behavior and can be controlled by varying the position of jet points, by timing of jet operations, and by varying the volume of water pumped.

Experience has shown that no two embankments react exactly the same. For that reason, the operation requires the good judgment of an experienced supervisor to obtain satisfactory results without costly and sometimes dangerous slides.

A properly planned hydraulic compaction project infers proper preliminary studies of the marsh, beginning with a classification of marsh materials. After fill materials have been placed and before hydraulic compaction operations begin, it is essential to obtain cross-sections of the embankment to determine its position with respect to the marsh bottom. Such sections are needed at 100-ft intervals and sometimes at 50-ft intervals if the marsh is short or has an irregular bottom. These sections are determined by wash borings.

NORMAL OPERATING PROCEDURES

Jets are spaced at 10-ft intervals, both parallel and perpendicular to the centerline (Figs. 2, 3, and 5). The embankment is jetted from shoulder line to shoulder line with occasional jets placed in the slope if original borings indicate that this is desirable. The jets consist of $\frac{3}{4}$-in. extra-strength pipe cut into 10-ft lengths, and connected to the water line by 1-in. high-pressure rubber hose. A gage valve is incorporated in each hose connection to permit absolute control of each individual jet.

The jets, operating at a pressure of from 50 to 75 lb per sq in., are forced to within 5 ft of the bottom of the fill material. They are left at this elevation only for the period of time required to inject a volume of water previously calculated to be sufficient to saturate the fill material. The volume may be controlled by a water meter. At the end of this time, they are lifted 5 ft and left at this elevation as before. The operation is repeated until the jets are at the surface and the fill is completely saturated. The normal pumping time per 5 ft of fill depth averages approximately 30 minutes. This time varies depending on the texture of the fill material and the number of jets operating. Medium to fine sands require more pumping time than more coarse textured materials. Where a stony fill material has been used, penetration of the jets is often facilitated by preboring with a truck-mounted power auger.

Marsh areas having inclined clay bottoms may be subject to serious embankment slides if the jetting process is used. Consequently, this type of marsh requires that jetting operations be given special study and be conducted so as to keep the fill under control at all times.

An average jetting crew consists of approximately 15 laborers, hired locally by the road contractor, in addition to the pump operator and the supervisor. A crew of this size will operate from 35 to 40 jets simultaneously.

Cost records show that jetting costs for a modern dual-lane embankment (94 ft from center to center) ranges between \$500 to \$1,000 per station (100 ft), depending upon the depth of marsh, height of fill, and texture of the back fill material. From 35 to 100 ft of dual embankment can be jetted in a 9-hr day.

CONCLUSIONS

Experience with hydraulic fill compaction demonstrates that pumping water into a peat marsh fill under controlled conditions has an immediate stabilizing effect on the embankment. The adjustments and movements obtained would otherwise take place slowly over a period of years and result in detrimental pavement settlement. Because of the success of the operation and because of an expanded road program, the Michigan State Highway Department has added a second set of jetting equipment. The additional equipment will permit the treatment of all end-dump marsh fills of 10 ft or more in depth.