exceeded 1° from the planned alignment, the hole was whipstocked to the correct bearing and plunge by the use of a wedge. The wedge (Figure 6) is a carefully machined bar of steel. An NX wedge is 7.30 cm in diameter and 2.44 m long. The face of the wedge is machined to form a curved face with an angle of 1.5°. The nose of the wedge is a chisel point. The position of the wedge is fixed in the hole by a fast-swelling wooden plug that is split by the chisel point of the wedge.

The wedge is positioned in the hole by using the Eastman R Single Shot surveying instrument so that the face is in the required direction to deflect the hole. As in taking oriented core, the fiducial line of the instrument is aligned by using an orientation sleeve and a slimlong dropper bar. The slimlong dropper bar is aligned with the face of the wedge by shear pins. The wooden nose plug and the wedge and instrument assembly are inserted in the hole at the end of the drilling rods and the orientation of the face is determined by taking a survey. The face of the wedge is then rotated to the desired position and a check survey is made. When the correct position of the face of the wedge is obtained, hydraulic pressure is applied to the drill rods, the chisel point on the wedge splits the wooden plug, and the pins that hold the wedge to the slimlong dropper bar are sheared. The entire orientation assembly is then withdrawn from the hole.

The new hole direction is obtained from the face of the wedge by drilling with limber hookup. A bullet-nosed bit smaller than the desired diameter of the hole is put on the front of a small-diameter steel rod. A reamer bit the size of the desired hole and a short length of solid rod are attached behind the bullet-nosed bit and rod (Figure 6). The entire limber hookup is attached to the standard drill string.

RESULTS

Figure 7 is a portion of the geologic map (plan view) of drill hole 1 at Wheeler Junction prepared from the oriented core. Geotechnical data recorded included the bearing of the hole; footage; bit size, casing, and location of wedges; percentage of core recovery; and the range and average size of pieces of core recovered. The geologic data recorded included rock type and the attitude of the foliation, joints, faults, and veins.

CONCLUSIONS

Oriented-core horizontal diamond-drilled holes can be used to determine the geological and geotechnical data for the design and construction of tunnels in rock. Technology is available to drill and control the bearing of core holes and to obtain oriented core from which geologic data can be recorded. The cost of drilling oriented diamond-core holes is considerably less and requires less time than the construction of a pilot tunnel to obtain the same data. The apparent limit on the use of oriented diamond-core holes is length. Present drilling equipment is capable of drilling holes to about 1750 m.

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Mississippi's Experience with Horizontally Drilled Drains and Conduits in Soil

WENDEL T. RUFF

This paper relates the experience of the Mississippi Highway Department (MHD) with horizontally drilled drains and conduits in soil. MHD has used horizontally drilled drains that had an inside diameter of 3.8 cm (1.5 in) and conduits that had an inside diameter of 12.7 cm (5 in) with interconnecting vertically drilled drains to effectively achieve subsurface drainage. The advantages of drilled drains and conduits over trench excavations (to eliminate the risk associated with the latter) are discussed. Two case histories are described. The first describes the use of large-diameter interconnecting vertically drilled shafts to create a drainable reservoir in a deep irregular formation. The second describes the use of long horizontally drilled perforated drains to reduce the water table in an active landslide.

The primary cause of landslides in Mississippi can usually be traced to inadequate subsurface drainage. Likewise, the correction of all stability problems generally includes some method of relieving subsurface hydrostatic pressures or controlling seepage. This paper describes the experience of the Mississippi Highway Department (MHD) in accomplishing subsurface drainage by using horizontally drilled drains and conduits.

Simply defined, horizontally drilled drains are small-diameter wells drilled nearly horizontally into a hill or embankment for the purpose of removing groundwater and controlling seepage (1). Their purpose and benefit is to lower the water table rather than to serve as a seepage cutoff wall, as would be the case in trench-excavated interceptor drains. The most common horizontally drilled drainage pipe is Schedule 80, type II polyvinyl chloride that has an inside diameter of 3.8 cm (1.5 in), which conforms to ASTM D-1785. The pipe has two rows of slots cut around the circumference of the pipe on two of the one-third points (120° apart).

The width of the slots can be specified depending on the gradation of the material in the aquifer. The lengths of stock pipe vary from 1.53 to 6.1 m (5-20 ft) and are simply glued together in the field. The drainpipe is inserted into the ground through the center of the drill rod as the rod is retracted.

Horizontally drilled conduits provide an alternative method to the installation of jointed pipe in an open-trench excavation. The same type of horizontal drilling equipment is used for installing both drains and conduits.

Figure 1. Approximate angle of repose for sloping sides of excavations.

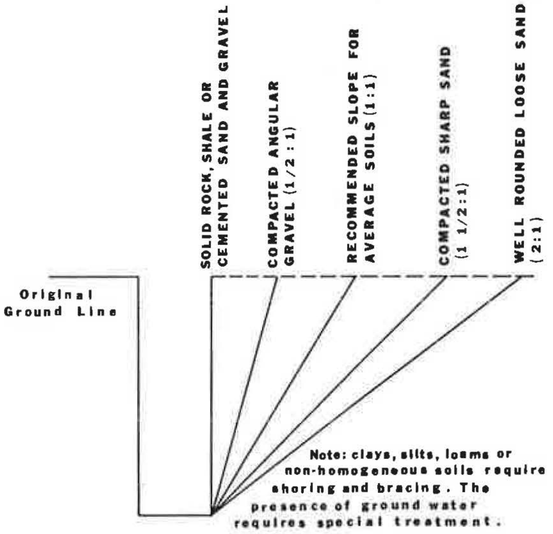
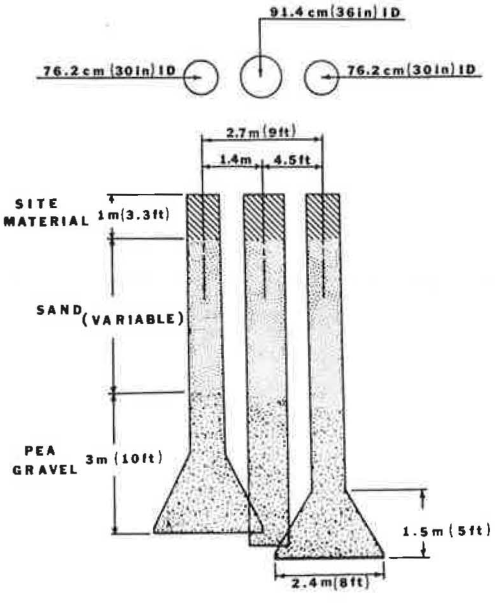


Figure 2. Connecting vertical drains.



OPEN EXCAVATION VERSUS DRILLED DRAINS

The practicing engineer has to evaluate the risk and cost-benefit ratio of each type of drainage system before the final selection is made. The type of system chosen to effect subsurface drainage depends on the subsurface and site conditions. The depth of the aquifer below the surface of the ground is usually the primary determining factor. If the depth of the aquifer is as great as 6 m (20 ft), the method of excavation to install a drainage system is, in reality, usually something other than that commonly referred to as a trench. Excavation depths greater than 6 m for no other purpose than to install a subsurface drain should be carefully evaluated.

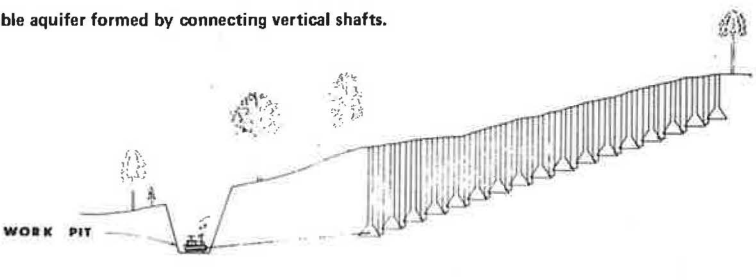
Since passage of the Occupational Safety and Health Administration (OSHA) Act of 1970, which specified trenching requirements, the cost of trenching has increased significantly. OSHA regulations require that banks higher than 1.5 m (5 ft) be shored or laid back to a stable slope or that some other equivalent means of protection be provided when employees may be exposed to moving ground or cave-ins (2). The recommended guide for sloping banks is presented in Figure 1.

When it is necessary to install a subsurface drainage system across or within an active landslide or inactive failed mass, the excavation is very hazardous. The existence of cracks within the mass makes it mandatory that stringent requirements be placed on the method of excavation. Alterations of the mass are usually accompanied by some additional movement, since the factor of safety is usually close to 1.0 against a sliding failure. Sliding forces must be taken into consideration in the design of a bracing system for such excavations. Excavations must be conducted in small sections that have a sequence of operations that call for the backfilling to proceed along with the excavation. Contractors usually dislike such restrictive work plans and tend to reflect this in their bid price. Another factor that affects the design and selection of a drainage system is the existence of buildings and other structures adjacent to an area in which an excavation is being considered. It is often desirable to avoid deep excavations in which the risk to an adjacent structure is high.

HORIZONTALLY DRILLED DRAINS AND CONDUITS REDUCE RISKS

The installation of horizontally drilled drains and conduits eliminates the risk associated with trench excavations. A drilling plan is much more flexible than an excavation plan. Regardless of the time and expense spent on a subsurface investigation of a project, changed conditions still occur. When these conditions occur on a trenching job, the plans are

Figure 3. Drainable aquifer formed by connecting vertical shafts.



usually altered to include deeper excavations and greater project costs. Alterations in a drilling plan can be made without affecting the completed portions of the drain.

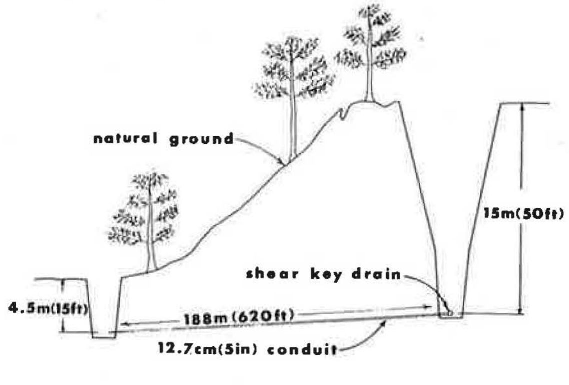
The following case histories describe the use of horizontally drilled drains and conduits to achieve subsurface drainage. In both cases, the installation of drains and conduits by horizontal drilling was considered to be more economical and safer than the installation of drainpipe in an open-trench excavation.

Case History 1

In 1975, a landslide occurred in a side-hill fill of US-61 in Warren County, Mississippi. The maximum fill height of the four-lane corridor was approximately 18 m (60 ft) from the toe of the slope to the roadway crown. The subsurface investigation revealed approximately 9 m (30 ft) beneath the surface a stratum 1-2 m (3-6 ft) thick of silty sand that had clay layers and that channeled water into the slide area. The sandy stratum, approximately 122 m (400 ft) wide, varied considerably in depth and thickness. Due to the depth of the deposit, a trench-excavated interceptor drain was not considered practical. Likewise, due to its irregular cross section, it was not felt that sufficient intersection could be achieved with horizontally drilled drains. Therefore, it was decided to drill a series of vertical connecting shafts, which could be backfilled with pea gravel to create a drainable artificial aquifer or reservoir. The bottoms of the shafts were stairstepped in such a manner as to provide a sump or low point in the series. A typical section of the interconnecting shafts is presented in Figures 2 and 3.

The system, which contained 37 belled shafts and 36 straight shafts, was completed in approximately one month. Construction was accomplished by drilling the belled shafts first and then making the connection by means of straight shafts. At the low point in the system, a well casing was inserted so that dewatering could temporarily be accomplished by using a submersible pump. A similar casing was also installed at the high point in the system to permit the injection of dye into the aquifer to determine whether continuity had been achieved between the connecting shafts. The tests indicated that continuity had been achieved. At a later time in the construction sequence, a plastic discharge conduit that had an inside diameter of 12.7 cm (5 in) was installed from a point at which gravity flow could be obtained to the low point in the artificial aquifer. Installation was achieved through an oversized shaft by placing the drill stem inside the conduit and pushing against a plug affixed to the end of the conduit. Since plans for a conventional trench-excavated interceptor drain alternative had not been fully developed, an exact cost comparison could not be made. However, it was estimated that the vertical shafts and the horizontally drilled conduit were installed for approximately 40 percent of what a braced excavation would have cost.

Figure 4. Horizontally drilled conduit.



Another part of the restoration plan called for the construction of a sand shear key along and adjacent to the toe of the embankment. The shear key was installed by excavating a trench to specific widths and depths and then backfilling it with sand. A perforated interceptor drain was installed along the base of the key to keep seepage water from building up in the shear key. At the low point in the shear key drain, a discharge conduit was required. A conventionally constructed open-trench discharge conduit would have required an excavation 4.5-15 m (15-50 ft) deep for a distance of 189 m (620 ft). In lieu of an open-trench excavation, a plastic conduit pipe that had an inside diameter of 12.7 cm (5 in) was installed through a horizontally drilled shaft (Figure 4).

Installation was achieved by removing the slightly oversized bit from the stem at the point at which it emerged and replacing it with an adaptor that permitted the attachment of the conduit to the drill stem. The conduit was then pulled toward the drilling rig as the stem was retracted. The grade of the 12.7-cm (5-in) conduit was checked by connecting a vertical section of pipe to the upper end of the conduit and discharging water into it until the outflow at the lower end was equal to the inflow. The inflow was then stopped and the head in the vertical section was allowed to equalize. The test indicated that at some point in the line the conduit actually rose 0.46 m (18 in) above the inlet flowline elevation. Since the discharge end was about 1.2 m (4 ft) below the inlet flowline, the grade of the horizontally drilled conduit fluctuated considerably over the 198 m (620 ft). The results were considered acceptable in view of other circumstances and the fact that the shear key was designed to function under a larger head. It was

Figure 5. Generalized soil profile.

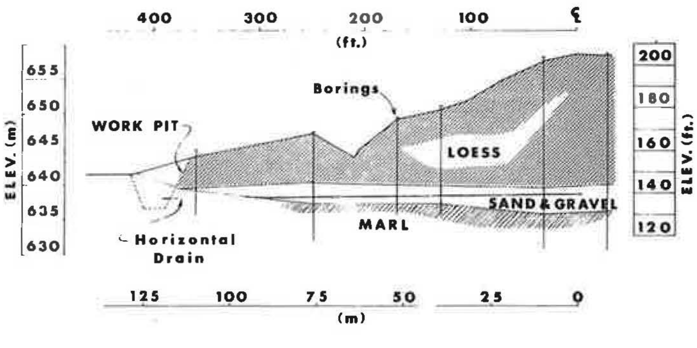
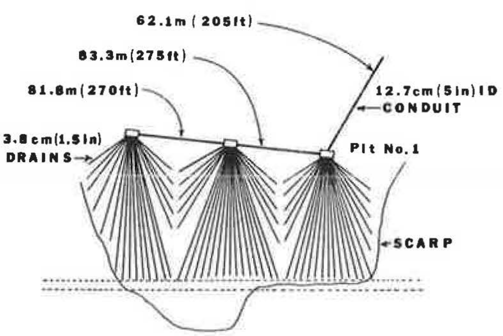


Figure 6. Horizontally drilled drains and conduits.



estimated that the discharge conduit line was installed in approximately 25 percent of the time that would have been required for an open-trench installation and at a substantial cost savings.

Case History 2

The telltale signs of a major stability problem were noted in 1974 along a section of MI-3 approximately five miles north of Redwood, Mississippi, in Warren County. In this vicinity, MI-3 meanders in and out of the loess hills that separate the Mississippi delta from the upland region. The field investigation revealed that the failure was occurring in a wet stratum of medium-dense sand that had gravel and clay seams between the upper loess formation and the lower impervious hard marl and rock (Figure 5).

Studies were conducted to determine the groundwater levels, and slope inclinometer tubes were installed to determine the location of the shear plane. The permeability characteristics of the sand stratum were determined by rate-of-flow tests and draw-down data obtained from two test wells. The laboratory investigation was confined to determining the permeability and grain-size distribution of the sand stratum. By using the data obtained by both the field and laboratory tests, the permeability was found to range between 1×10^{-3} and 1×10^{-4} cm/s. The tests also indicated that the permeability of the sand stratum decreased toward the toe of the bluff.

The major contributing factor to the failure was the buildup of hydrostatic pressure in the sand stratum during periods of high rainfall. The permeability of the loess allowed water to be absorbed during rainfall periods. Since the aquifer did not have a natural outcrop in the vicinity, large hydrostatic forces developed. Stability analyses indicated that a factor of safety of 1.3 against a sliding-block failure could be achieved by reducing the hydrostatic head 3.1 m (10 ft) in the vicinity of the centerline.

Drainage was achieved by installing horizontally drilled perforated drains that had an inside diameter of 3.8 cm (1.5 in). Plans were developed that called for the drains to be fanned out from three work pits. The work pits were necessary in order to obtain gravity flow. The drains were installed from the lowest pit first, which then served as a collector for the other two pits. After the drains in the first pit had been completed, a discharge conduit that had an inside diameter of 12.7 cm (5 in) was horizontally drilled to a point at which gravity flow could be achieved. The second pit was then opened and a connector pipe that had an inside diameter of 12.7 cm was drilled between the first and second pits. Drilling then proceeded in the second pit as the drains in the first pit were connected to a cast-in-place junction box. A plan view of the design is presented in Figure 6. The junction boxes were designed to provide surface access so that the rate of flow from each drain could be monitored in the future. Care was taken to place a sand blanket around each drain hole so that the seepage that occurred along the outside of the drainpipe could eventually find its way into the junction box through weep holes.

The average length of the 68 drains installed was 94.5 m (310 ft). The maximum length was 128 m (420 ft). The percentage of grade varied between +0.7 and +3.3 percent. Installation of the 6718 m (22 026 ft) of drilled drains was completed in June 1977 at the contract price of $21.33/m ($6.50/ft). The drilling was achieved at an average rate of penetration of 0.46 m/min (1.5 ft/min). The combined flow rate one month after completion was 232 m^3/day (61 272 gal/day). After three months, the flow rate had dropped to 191 m^3/day (50 472 gal/day). An analysis of the piezometric data indicated that the water table had declined 3.3 m (10.8 ft) on completion of the installation. Approval was then given to proceed with the restoration of the roadway, which had been closed to traffic for approximately one year. The restoration work consisted of remolding the surface area to close all cracks and reconstructing the embankment.

CONCLUSION

It has been the experience of MHD that horizontally drilled drains can be effective. There are, however, areas in which this technique needs to be improved. One of the major deficiencies is the horizontal and vertical control. The desired slope of the horizontal drain is set by adjusting the 4.6-m (15-ft) long drill carriage. Maintenance of the desired slope is difficult and depends on the type of soil encountered and the drain length. Measurements of the slope after the drill stem enters the ground are not very accurate. The elevation of the bit is determined by filling the stem with water and measuring the height to which the water rises in a manometer attached to the daylight end. The results are affected by the pump-induced pressure and a vacuum caused by the foot valve located in the bit. Deflections obviously occur in every drilled hole. A better method of determining horizontal and vertical location is needed.

Care should be exercised to keep the drain slots clean when the drainpipe is stored on the site and when it is being installed. The use of some additives such as drilling mud may reduce the efficiency of the drain. The torque capacity of the drilling rig can be exceeded by drilling long drains through collapsible soils. It can therefore be necessary to use something to reduce the shaft friction. The use of drilling soap is recommended rather than commercial drilling mud. Preventing the slots from becoming clogged is of primary importance due to the difficulty of cleaning the drains after they have been installed.

One of the major benefits of horizontally drilled drains is the ability to effectively reduce hydrostatic pressures with little or no alteration to the site. This benefit saves money and reduces construction risk.

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