Draining in a New Direction

Wick drains are not new, but in an innovative horizontal application they are proving effective for stabilizing slopes and remediating landslide effects. The horizontal wick drains have several advantages over conventional drains, including lower costs.

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Drains can stabilize slopes and landslides by lowering water levels and water pressures. Conventional drilled drains, driven vertically into the ground, tend to clog with fines and need periodic cleaning. Additionally, because they are made of inflexible polyvinyl chloride (PVC), they can be ruptured by landslide movement. Horizontal wick drains alleviate some of these drawbacks.

Horizontal wick drains are encased in a geotextile fabric of fine mesh that reduces clogging, and they may be deformed by as much as 60 to 100 percent before rupturing. The drains are currently being monitored at three test sites in Missouri, four in Colorado, and one in Indiana. So far, the horizontal drains have cost less to install than the drilled types. Following one or two days of training, a crew consisting of an equipment operator and three laborers can install 12 to 21 m of wick drains in as little as one hour.
Installation is fairly easy. The horizontal wick drains are 4 by 100 mm in cross section and come in 300 m lengths. Installation can be carried out with bulldozers or trackhoe excavators that push a small-diameter steel pipe into the landslide mass. The pipe sections are preloaded with 3 m lengths of wick drain, rolled into long, tight cylinders, and tied at 0.3 m intervals with electrical cable ties. The first pipe has a drive plate attached to the front end of the wick. Next, a drive head is slid over the back end of the first pipe and the wick is folded out of the way. The first pipe is then aligned—usually horizontal or at an angle of less than 5 degrees upward—and pushed into the slope.

Installers drive additional pipes by using a plier/stapler to splice the wick end protruding from the previously placed pipe to the end of the wick in the next pipe. The spliced portion is rolled and tied, the drive pipes are threaded together, and the new piece of pipe is pushed in the same manner as the first. Sections may be added until the drain length is reached or until refusal. Next, workers use a pulling head and a chain to ease each section smoothly out of the ground. The wick remains in the ground because the drive plate anchors the wick in place and resists withdrawal.

The equipment can be purchased from drill pipe vendors or can be readily constructed in a machine shop. The drive plate is modeled after the type used in vertical wick drain installation. The plate is 76 mm² and is cut from 12 to 18 gauge (1.3 to 2.7 mm) sheet steel. A piece of #4 reinforcing bar is welded to the steel, and a washer is welded to the other end of the rebar, which holds the plate in place and forms an attachment point for the wick during withdrawal.

The drive pipe should have a minimum inner diameter of 32 mm to accommodate the rolled wick. The outer diameter is limited only by the pushing force available from the driving machinery. The pipe used for the test sites was able to drive drains 30 m long through materials with stiffnesses—as determined by the standard penetration test (SPT)—requiring up to 28 blows per 0.3 m. Drill pipe of larger diameter can withstand higher driving pressures, but it is significantly more expensive.

A drive head receives and transmits the pushing load induced by the driving equipment while protecting the female threads of the drive pipe and reducing the tendency of the pipe to slide off the equipment or buckle. A pulling head constructed from a short piece of drill pipe to which hooks have been welded simplifies the attachment and removal process. Bulldozers or trackhoe excavators in the 11,000 to 20,000 kg range seem to be best suited for this task, since larger equipment may not provide the fine control needed during driving.

The most common problem encountered during drain installation was flexure of the pipe under driving pressure. The problem was most serious when a new pipe was first being driven and was not yet confined by the hillside soils. The flexure generally subsided once workers drove 1 m of the pipe. However, the pipe would also buckle when hard materials, such as sloping bedrock surfaces or boulders, were encountered. Drill pipe with a larger diameter and a thicker wall than that used in these tests will offer more resistance to buckling. For the tests, buckling was reduced by using a larger pipe as a sleeve. The sleeve may be pushed into the hillside along with the pipe and then pulled out to be reused with the next pipe section. Finally, workers can minimize buckling by supporting the drive pipe from below with timbers and then forcing the flexure downward by controlling the attack angle on the bull- dozer blade or trackhoe bucket (see figure 3).

As with drilled drains, the final layout pattern for horizontal wick drains depends on the slope and bedrock geometry.
and the location of water-bearing zones. The initial design should address drain length, angle, spacing, and filter size, with the understanding that these parameters may need to be altered in the field.

In general, longer drains produce more water because there is a greater inlet length along the drain and because a longer drain is more likely to intersect water-producing zones. Researchers recommend that drilled drains extend no more than 3 to 5 m beyond the shear zone, as they may convey water into the landslide mass. Wick drains have been successfully pushed 30 m through materials with stiffness requiring 20 to 28 blows per 0.3 m at the test sites. This length would be suitable for a landslide with a sliding plane that is 25 to 27 m back in the hillside. With more robust equipment, drains with lengths of 45 to 60 m could be driven through similar soils.

Drilled drains have typically been installed at a large range of angles above horizontal, from as little as a 2 to 3 percent grade to as much as a 20 percent grade. Wick drains driven at a low angles or no angle appear to be the most effective. The gravitational force pushing the water out of the slope is the same, and low-angle drains will lower the water table and pore-water pressures to a greater degree farther back in the slope. Wick drains with higher angles may be necessary in, for example, a sloping bedrock surface.

There are two general approaches to drain layout: a fan pattern radiating from a single installation point and a parallel layout from a line of evenly spaced installation points. Some research indicates that there is no difference between fan and parallel drain layouts. Based on research presented at the Canadian Geotechnical Conference in 1992, the Canadian National Railways prefers a fan pattern, because installing a

Guidelines to Follow

Based on the tests being conducted in Missouri, Colorado, and Indiana, as well as on the technical literature, the following design guidelines are suggested for the use of horizontal wick drains:

1) Drains should not extend more than 3 to 5 m beyond the potential failure surface.
2) Drains should be installed horizontally or at as low an angle as possible.
3) Drains should be installed in clusters that fan outward, aiming for a typical average drain spacing of 8 m in zones that produce water.
4) For soils with a significant sand component, #70 wick filter fabric is suitable. Finer filter mesh (#100 to #200) should be used for soils that are predominantly silt or clay.
5) The reduction in flow caused by soil smear can be minimized by pushing the pipes containing the drains, rather than pounding or vibrating them into place. The cross-sectional area of the pipes should be kept to a minimum.
6) Finished drains should be protected from root growth by sheathing the drains at the surface with PVC pipes. Drains should be protected from ice in extreme climates by burying the drain outlets in sand or some other highly permeable medium. Drain outlets should be joined through manifolds so that flow can be conveyed to a practical discharge point.
number of drains from a single pad is faster and easier and causes less slope disruption.

The U.S. research so far also suggests that fan patterns are more efficient and just as effective as evenly spaced drains. Drains should be fanned at angles with average spacing of approximately 8 m, measured at approximately half the drain length. Both drain spacing design and slope stability analysis of stabilized landslides require an estimation of new groundwater levels after installation. The groundwater table will coincide with drain elevations near the drains, but it will be higher between them. The calculation depends on drain flow rate, drain length and spacing, and soil permeability. For example, a series of drains 30.5 m long spaced at 7.6 m in sandy soil will have an average water table height that can be up to 0.6 m above the drain height.

Several researchers have investigated soil compaction and smear during vertical wick installation. Pushing or pounding drains displaces soil and creates a zone of disturbance around the wick, in contrast to such nondisplacement methods as drilling. This disturbed zone typically has reduced horizontal permeability. To reduce soil smear during installation, pipes and drive plates should have a small cross-sectional area and should be pushed smoothly into the slope. Clogging can also result from soil pressure compressing the wick filter into the drain channels, constricting water flow along the channels.

The best approach at this point is to set the filter permeability and drain discharge capacity higher than expected to counter clogging from the migration of fine particles or the creep of filter fabric.

Drain clogging from fine soil particles can be reduced if the drain filter fabric is properly matched to the soil type. Wick drain types correspond to the size of pore openings and range from #70 to #200 (0.21 to 0.05 mm) sieve mesh sizes. In general, the #70 mesh filter is effective for silt and clay soils with a significant sand component in which 85 percent of the soil is coarser than 0.15 mm. The #100 and #200 mesh filters are more effective for nearly pure silt and clay soils.

The effects of soil smear, fine particle migration, and filter fabric creep can be combined to gauge the long-term performance of wick drains. Previous technical research by others measured the effects of various causes of clogging of vertical wick drains. That research shows that drainage from horizontal wick drains should improve during the first few months of operation as the effects of soil disruption during installation wane and that clogging will occur slowly as a consequence of the fine soil migration and filter fabric compaction over the next several decades.

Horizontal wick drains can be clogged by root growth or ice, as can drilled PVC drains. Root intrusion may be reduced by sheathing the 3 to 5 m of wick closest to the surface in
galvanized steel or PVC pipe. The sheath pipe will also work as part of the water collection and conveyance system. Ice buildup may be reduced by burying collection systems and drain outlet points, but according to some research drains tend to thaw out before pore pressures increase to a critical value and the effects of ice on slope drainage are minimal.

Because most landslide masses are heterogeneous, groundwater flow is unpredictable and seems to concentrate in zones. Furthermore, infiltration is strongly influenced by tension cracks caused by slide movement and fissures caused by soil development. Research suggests that landslide groundwater may concentrate in water lenses, which are frequently created as voids caused by dilation of the landslide during slope movement. Water lenses, however, may simply be part of a preferred flow network within the soil. For instance, a horizontal wick drain installed at the Meeker, Colorado, site produced water at a rate of up to 20 L/min for several days before reducing to a trickle. An adjacent drain fanned out from the same drive pad was dry. Both were in a homogeneous silty clay fill. Substantial flow has been observed at the test sites even in clay materials of low permeability. For example, a drain in silty, clayey soil at the Jasper, Indiana, landslide produced over 4 L/min immediately after installation.

As with drilled drains, horizontal wick drains will show varying rates of water production, even within the short horizontal distances between adjacent drains. This is especially true during dry periods. A number of case studies confirm that a significant number—6 to 55 percent—of conventional drilled PVC and steel pipe drains are initially dry. Some turn out to be permanently dry.

**When to Think Twice**

Horizontal wick drains may not be appropriate in all cases. The tests being conducted around the country show the following potential limitations of horizontal wick drain installation:

1. Wick drains may be driven into material with an SPT value of 30 or less; the ideal material has a value of 20 or less.
2. The maximum drain length is expected to be 30 m for harder soils and 45 to 60 m for soft soils.
3. Drains can be driven through some hard or rocky zones, but bedrock, large rocks, or dense sand or gravel will cause refusal.
4. A significant number of dry drains can be expected on a project (just as for drilled drains), but these drains often become active during wet periods.
The data from these reports match observations so far regarding horizontal wick drains. Many of the drains will be dry at installation; indeed, a higher percentage have been dry at the test sites because most of the drains have been shorter and shallower than those typically installed by drilling. Nevertheless, dry drains will still serve as water outlet points during the wet season. At the Jasper site, 36 percent of the drains were wet or dripping following installation, but all produced water after a rainstorm two weeks later. Drains should be installed in areas of suspected water accumulation, such as draws or zones where bedrock is deeper, even if the first drains in the area are dry.

One should not judge the success of a drainage program by the water produced. Although large flow volumes are impressive, relatively minor flow tapped from a critical soil unit may be more important for the overall slope stabilization. One researcher concludes that the most successful drains for slope stabilization are those that show decreasing flow rates over time and those that show drainage only after rainfall events. Drains with relatively constant flow rates may be tapping groundwater that has nothing to do with landslide movement.

The first installations of horizontal wick drains in Missouri, in 1998, and Colorado, in 1999, focused on proving the feasibility of the wick drain driving method and on refining the installation technique. The latest installation, which took place last year near Jasper, is a complete landslide remediation project, with drain length and layout sufficient to have an effect on the entire slide mass (see figure 5).

The first site tested, a constructed embankment in Missouri, was approximately 45 m in volume and had a 1:1 front slope face. Instrumentation includes six piezometers, 16 nested soil moisture meters, and 20 survey markers. Half the slope was stabilized with six wick drains, each 6 m long. The other half, which was not stabilized, was used as a control point. Researchers tested the influence of the wick drains by inducing groundwater infiltration through a trench at the back of the slope and then simulating a 100-year, 24-hour rainfall event using sprinklers.

The testing showed that the drains removed a substantial volume of water from the slope (almost 40 L/h apiece), lowering groundwater levels by over 0.3 m. Survey stakes showed substantially less movement within the drained half of the slope.

After installing wick drains at the test embankment, the researchers placed drains at locations with varying geology using various types of driving equipment. They drove the drains through natural and fill materials with spt values as high as 28 blows per 0.3 m, although 20 blows per 0.3 m appears to be the realistic limit for longer drains. Drains were driven through rocky or hard zones over 1 m in width, although these zones sometimes deflected the drain pipe toward the ground surface or completely halted the driving progress. Wick drains have visibly
reduced water levels at the south Meeker and Jasper landslides, and water drainage has been observed at the Boonville and St. Joseph sites in Missouri, the north and south Meeker sites, and the Jasper site. Flow rates from a single drain have been as high as 20 L/min at the north Meeker site and 4 L/min at Jasper. Drains at the Río Blanco landslide, in Colorado, were installed too high to intercept groundwater because of limited access points to the landslide. Drains at the Rye landslide, also in Colorado, were too short to intercept groundwater, and later installation of an uphill cutoff trench lowered the groundwater table below wick levels. The length of the Rye drains was limited to 12 m because a standard wick drain driving crane was used to push the drains horizontally into the hillside.

The drains installed in 1998 and 1999 show no evidence of clogging by dirt or algae, except where the drains lie directly on the ground surface and had been trampled. At locations where a short PVC pipe was used to encase the drain and was inserted a few feet into the soil, the drains were in excellent condition. Continued monitoring of the drains will include periodic observations of drain conditions, water levels, and slope conditions for the Missouri and Colorado sites. The Jasper site will be more closely monitored through eight piezometers and two inclinometers.

Costs for horizontal wick drains are less than for conventional drains. At the Indiana site, a crew with no prior experience installed almost 800 m of wick drains in less than nine working days, for an average cost of approximately $11.50 per meter. These costs will decrease with experienced crews. Conventional drilled drains cost on average from $20 to $36 per meter. Start-up costs to purchase wick driving equipment vary, depending on the size and type of driving rod used. For example, 45 m of drill rod of type A0—as defined by the Diamond Core Drill Manufacturers Association—and the construction of drive and pulling heads, plus 100 drive plates, would cost between $1,500 and $2,000.

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