Long-Term Performance of Horizontal Drains

DUANE D. SMITH

A history is given of the 40 years of development of horizontal drain installation techniques and equipment in California. The long-term performance of three drain installations—Cloverdale, 1941; Nojoqui Grade, 1940; and Pacific House, 1969—is evaluated. Major factors that influence the long-term performance of horizontal drains are discussed, such as location and installation methods, the frequency and quality of inspections, cleaning and maintenance programs, the types of casing used, the lithologic characteristics of the site, the pH and mineral contents of the groundwater, and the protective measures necessary to preserve external features such as outlets and collector systems.

Construction and maintenance of highways in hilly and mountainous terrain are often complicated by the reactivation of old landslides and by the development of new ground-mass movements in unstable material during and following construction.

The presence of groundwater is the most important factor that influences the development of slides and embankment slipouts. Subsurface water reduces the stability of cut slopes and embankment foundation soils through reduction of the shearing resistance of the soil, increase in the weight of the ground mass, and seepage forces that add to the driving force.

For the past 40 years, horizontal drains have been used effectively in California as an economical method of draining unstable areas. This paper, in addition to providing a brief history of the development of horizontal drains in California, discusses their long-term performance and the more-important factors that affect their performance.

HISTORY OF HORIZONTAL DRILLING IN CALIFORNIA

Hydrauger

As the need for more-economical methods of draining and stabilizing landslides was recognized, the California Division of Highways (CDH) in 1939 developed a method of installing perforated metal pipe drains in horizontal or slightly inclined holes drilled by a machine called the Hydrauger. The original equipment, purchased from the Hydra Auger Corporation of San Francisco, was designed for placing pipes under sidewalks and streets without disturbing the surface.

It consisted of an air-driven rotary drill mounted on a racked frame in such a manner that a revolving auger-type bit could be advanced into the earth by means of a hand-operated ratchet lever while water was pumped through the drill rod to cool the bit and wash cuttings from the borings (Figure 1).

The first horizontal drains were drilled by a 6.35-cm (2.5-in) pilot bit followed by a 15.0-cm (6-in) reamer. In 1947, rock-type auger bits with seven carbaloy inserts set in the lead and cutting surfaces of the bit were used for drilling in shale, sandstone, and partially decomposed granite. At Camp Tejon, in Kern County, three holes were drilled with this new bit in partially decomposed granite to an average depth of 37 m (122 ft). Several years earlier, when the same slide had been drilled by using the older auger bit, the greatest depth attained had been 24.5 m (80 ft).

A better bit was found in 1949 when the tri-cone roller rock bits commonly used in the oil fields became available in small sizes (Figure 2). These bits were tried and proved superior in all formations except possibly stiff plastic clays. They have been used almost exclusively from that time to the present.

With experience and progress in horizontal drilling techniques, it was recognized that more-powerful drilling equipment was needed to supplement or replace the lighter equipment then in use.

McCarthy Rock-Boring Machine

In June 1951, a more-powerful machine (initially designed for drilling blast holes in eastern coal mines) was purchased. This drill was a self-propelled unit capable of moving about within limits of a job on its three-wheeled undercarriage. Continuous 15.2-cm and 20.3-cm (8-in) flight augers, which required no water for drilling, were used (Figure 3). The drill engine transmission and drill head were mounted on a track that could be moved back and forth during the drilling operation for adding flights or advancing the boring (1).

This machine proved to be an effective, rugged piece of equipment, although the continuous flight augers were limited to drilling in soil or soft rock formations. The practical drilling depth due to lack of directional control caused by the necessary flight-coupling arrangement, inability to drill hard rock, and excessive torque on the flight augers proved to be only about 46 m (150 ft) in most formations.

In 1953, accessory equipment was fabricated so that regular rotary drilling with drill fluid could be accomplished by using diamond N-rod and 11.4-cm (4.5-in) tri-cone roller rock bits. The degree of success on converting the machine to a rotary drill led almost immediately to the present phase of equipment development.

California Horizontal Drill Rig

The CDH Materials and Research Department had for several years realized the need for an improved horizontal drill. Since no completely suitable machine was commercially available, the decision was made in early 1954 to design and build a drill unit specifically for horizontal drilling. The drill rig that evolved was field tested in June 1954 (Figure 4). It was, for the most part, made up of standard or proven parts of subassemblies similar to those used in manufactured drills.

The California horizontal drill rig incorporated the desirable features of various machines into a lightweight, compact drill rig especially suited for the type of drilling required for installation of horizontal drains. These light portable units had the advantage of greater mobility when access and setup room were problems. In addition, they greatly reduced time required for casing a boring because of the longer lengths of casing that could be used. The California drill had an optimum range of up to 107 m (350 ft) and a maximum of approximately 152 m (500 ft). Beyond this depth, drilling was usually very slow because of lack of power and water pressure. Although these rigs are no longer operated by the state, they remain in use by private drilling contractors.

Modern Horizontal Drilling Equipment

As attention to the effect of highway construction

Figure 1. Hydrauger, first used in 1939 to install horizontal drains by CDH.

Figure 2. Progressive development of drill bits (left to right): folding bit, fishtail bit, and tri-cone roller rock bit.

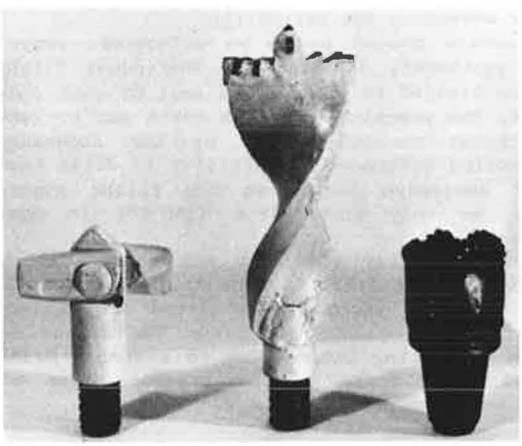
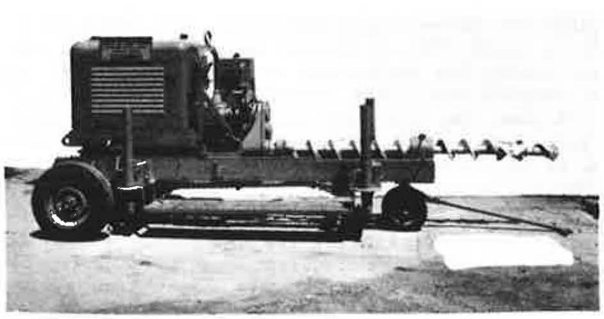


Figure 3. McCarthy rock-boring machine, June 1951.



on the environment increased in the mid-1960s, there was a great deal of concern over the disturbance of the natural landscape by newly pioneered drill roads and drill pads. Location of drill sites in areas that would greatly reduce or eliminate drill access roads often resulted in longer drains in order to intercept the target areas of saturated soil and rock. Longer holes therefore produced the need for more-powerful equipment and heavier drill rod that would not twist off under large torques. The lack of access roads called for a drill rig that could

Figure 4. California horizontal drill rig, June 1954.

traverse fairly rough terrain and carry sufficient drill rod and accessory equipment to do the job. These requirements gave birth to our present drill equipment, which is track-mounted and powered by a diesel engine.

In place of using the conventional drill chuck, the Jensen drill was purchased in 1970; it has a power swivel or drill head that travels a distance of approximately 3.4 m (11 ft) on a side-mounted carriage (Figure 5). Drill rods 3 m (10 ft) long are used. The rig can be adapted to drill with NW, NX, or NX-wire-line drill rod or NX and BX casing, if desired. The power swivel has a 7.6-cm (3-in) opening, which makes it possible to run 5.1-cm (2-in) standard steel pipe through it.

A second problem that had been present since the first horizontal installation is casing a boring that has caved in or is in broken rock. In October 1969 (according to A. D. Hirsch, formerly of the California Division of Highways), an installation at Pacific House in the Sierra Nevada Mountains was completed by using NX-wire-line drill rod. A modified bit adaptor was designed that had a J-shaped slot that received a modified 11.4-cm (4.5-in) roller rock bit that had a 0.95-cm (0.4-in) pin that extruded from the sides of the bit shank (Figure 6). After the required depth of drain had been reached, the drill rod was rotated one-quarter turn counterclockwise, so that the bit was dropped at the end of the hole. Schedule 80 slotted polyvinyl chloride (PVC) casing that had an inside diameter of 3.8 cm (1.5 in) was then inserted inside the drill rod, and the rod was retracted from around the casing without the bit, which left the boring cased to its full length. By using this scheme, drilling can progress as rapidly as possible without the need to maintain an open hole. This process, with various modifications, has been widely adapted by the drilling industry.

Horizontal drains more than 305 m (1000 ft) long have been drilled by using this equipment. Grades of 0-20 percent can be obtained by a simple adjustment of the drill carriage. Horizontal drains 107 m (350 ft) long are commonly drilled and cased during an 8-h shift, and 137-m (450-ft) drains can be installed within the same time frame under ideal conditions.

CASE HISTORIES

Horizontal drains have been used successfully in California since 1939. The following case histories are typical of the earlier installations and should serve to illustrate the long-term performance of horizontal drains.

Figure 5. Jensen drill, January 1980.

Figure 6. J-slot bit adaptor (top) and dropoff bit (bottom).

Cloverdale, 1941

During extremely heavy rainstorms in February 1941, a large landslide occurred on CA-101 near Cloverdale, about 145 km (90 miles) north of San Francisco. Portions of a high cut slope and side-hill embankment in poorly bedded, sheared shale with minor lenses and beds of sandstone slid into the Russian River and severed approximately 335 m (1100 ft) of the roadway (Figure 7). Large quantities of water in the form of springs and saturated slide debris were associated with the failure.

Corrective measures included a benched 1.5:1 cut slope and a reconstructed 2:1 embankment slope. Between March and June 1941, 97 horizontal drains were installed by using the Hydrauger equipment and 5.1-cm (2-in) perforated steel casing placed in 10.2-cm (4-in) drilled holes. The loose broken shale caused a great deal of difficulty during the installation. The average drain length was only 16.7 m (55 ft). Several holes were abandoned because of caving and the lack of a workable method to case the holes under these conditions. A complete record of initial flows is missing from the original report, although some of the individual drains were known to have produced between 568 m^3/day (150 000 gal/day) and 757 m^3/day (200 000 gal/day).

Drain outlets and downpipes were connected to corrugated metal pipe that was buried below the shoulder, which thus prevented periodic inspection of the drains. Heavy rains during the winter of 1955-1956 produced appreciable quantities of water, which appeared in various places along the toe of the cut slope. Investigation of the 15-year-old installation showed that this water was coming from around the horizontal drains, which had ceased to function properly because of heavy deposits of rust, gypsum, and root growth (Figure 8).

As a result of the inspection, a drain-cleaning and restoration program was recommended and completed in the summer of 1956. A total of 49 drains was located. Prior to cleaning, the drains produced a combined total flow of 697 m^3/day (184 250 gal/day); one drain produced 541 m^3/day (143 000 gal/day) of this total. Immediately after being cleaned, they produced a cumulative total flow of 1077 m^3/day (284 440 gal/day). This flow increase clearly illustrates the value of the work performed (Table 1).

In addition to the cleaning and reconditioning of the collector system that had easily accessible cleanouts, three new drains were installed in the most critical areas. A fourth drain was attempted but was abandoned without casing. Although considerable difficulty was still encountered during the installation of the three new drains, by using the McCarthy rock-boring machine and N-rod and rock roller bits, an average length of 35 m (114 ft) was obtained. These three drains produced initial flows that totaled approximately 106 m^3/day (28 000 gal/day).

During October 1956, 11 additional horizontal drains that had an average length of 38 m (125 ft) were installed in a slipout immediately south of the original failure. Initial flows totaled 992 m^3/day (261 989 gal/day). More drains were recommended at that time to stabilize the large area. In 1959 these drains were installed. Unfortunately, there is no record of the number of drains in this installation or of their performance.

In 1974 the installation was again evaluated. Of the 147 drains examined, approximately 40 percent had flows. Many of the original drains installed 38 years before were still functioning; one of these had a flow of 136 m^3/day (36 000 gal/day). Most of the steel casings were severely rusted. Root growth from willows and other native plants had clogged many of the drains and the 20.3-cm (8-in) collector system. Sloughing of the weathered slopes had buried many of the drain outlets both on the bench and at grade.

Nojoqui Grade, 1940

In December 1940 approximately 61 m (200 ft) of the northbound lanes of CA-101 was lost or endangered by the slipout of a portion of a side-hill embankment. Vertical borings in the foundation area indicated the presence of a high water table in soft, poorly bedded claystone and siltstone. A smaller slipout of a similar nature occurred about 244 m (800 ft) north of this site at approximately the same time.

During the summer of 1941, 42 horizontal drains were installed after the embankments had been reconstructed. They were placed into the hillside from locations immediately below the toe of the slope in the saturated foundation area. These drains

Figure 7. Cloverdale landslide and slipout, December 1941.

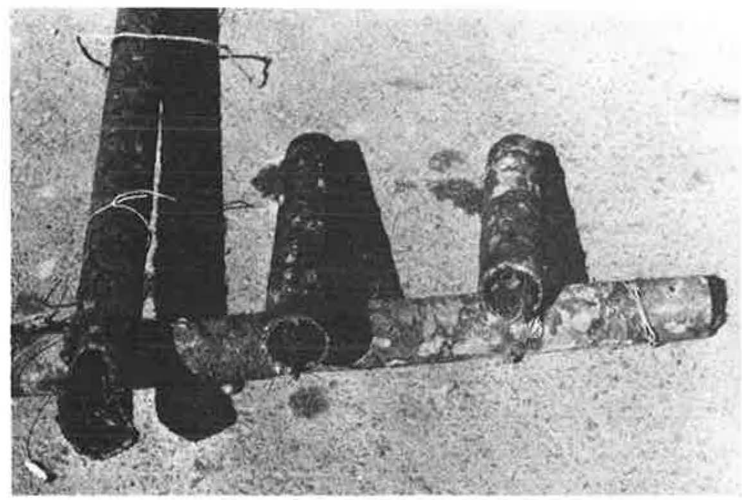


Figure 8. Rusted and rootbound 5.1-cm (2-in) casing from Cloverdale.

Table 1. Effect of drain cleaning on flow at Cloverdale, 1956.

Drain No.	Hole Length (m)	Length Cleaned (m)	Flow Before Cleaning (m^3/day)	Flow After Cleaning (m^3/day)	Remarks
3	19.8	19.8	3.1	4.1	Heavy root growth and rust
6	18.3	18.3	541	541	Gypsum and heavy rust
9	15.2	15.2	9.3	16.4	Gypsum and heavy rust
11	22.9	22.9	1.1	162.8	Very heavy root growth
13	24.4	24.4	5.5	27.3	Heavy rust
18	13.7	13.7	0.38	40.8	Heavy root growth and silt
19	9.1	3.4	10.9	27.3	Heavy root growth and rust
21	7.9	7.9	0.38	16.4	Heavy root growth
22	10.7	1.8	1.4	4.1	Heavy root growth
23	10.7	2.4	25.1	40.8	Heavy root growth and rust
24	11.3	11.3	0.76	46.7	Heavy root growth and rust
27	17.4	17.4	2.7	5.8	Heavy rust
29	13.7	13.7	1.1	65.4	Root growth first 6 m; sand and rust

Note: 1 m = 3.2 ft; 1 m^3/day = 264 gal/day.

were drilled by the Hydrauger; they ranged in length from 22 to 58 m (72-191 ft)--a record at that time. Perforated 5.1-cm (2-in) steel casing was used in 10.2-cm (4-in) holes that used auger bits and diamond A-rod. Grades ranged from 2 to 10 percent. Records that show initial flows are not available and may not have been made.

Although the drains may have been cleaned from time to time, the first record of cleaning was in December 1962, about 21 years after they had been installed. Only 27 of the original 42 drains were found. The others had been buried by end-dumping of slide material from a cut slope immediately south of the embankment. A heavy accumulation of roots, rust, and silt was evident in most of the drains cleaned. No appreciable increase in flow was noted after cleaning (Table 2), although cleaning was done at the end of a hot, dry summer. Thus flows undoubtedly increased considerably during the wet season.

In late 1974 a contract was entered into to widen the embankment and construct two additional lanes for traffic. Shortly after commencement of the project, it became evident to the resident engineer that additional subdrainage facilities would be necessary to assure construction and maintenance of a stable roadway. Boggy conditions, especially along the toe of the existing embankments in the area of buried drains, caused very slow and difficult operation of the contractor's excavation equipment.

Table 2. Effect of drain cleaning on flow at Nojoqui Grade, 1962.

Drain No.	Length Cleaned (m)	Flow Before Cleaning	Flow After Cleaning	Remarks
2	35.1	Dry	Dry	Rust and silt
3	16.8	Dry	Dry	Rust and silt; pipe broken
8	36.6	Damp	Drip	Bit went through pipe at 34 m
9	6.7	Damp	Damp	Rust, roots, silt; pipe broken at 7 m
11	1.8	Slow drip	Drip	Pipe bent at 2 m
12	9.8	Damp	Damp	Roots, rust, silt; pipe bent or broken at 10 m
13	54.9	Damp	Damp	Roots, rust, and silt
14	47.2	Dry	Dry	Heavy rust, roots, and silt
16	57.9	Dry	Dry	Roots, rust, and silt
17	53.3	Drip	Fast drip	Roots, rust, and silt
19	57.9	Drip	Drip	Roots, rust, and silt
21	53.3	Dry	Dry	Roots, rust, and silt

Note: 1 m = 3.2 ft.

Figure 9. Iron oxide and algae build-up, Nojoqui Grade, 1978: distant view of two drains (top) and close-up of drain at right (bottom).

Several of the buried drains were uncovered by the contractor's equipment and were still functioning. The casings were mostly rusted through. Those drains that had exposed outlets had large accumulations of rust and algae on the ground below the casing (Figure 9).

A total of 32 new drains was installed in the spring of 1975, all of which showed some flow at the time of installation. The combined maximum initial flow was approximately 596 m^3/day (157 480 gal/day). The combined flow at the completion of the job was approximately 43 m^3/day (11 350 gal/day). The drains ranged in length from 46 to 137 m (150-450 ft); 25 are 91 m (300 ft) long.

A very successful horizontal drain installation in terms of drilling progress and quantities of water produced was completed at Nojoqui Grade. An average of 84 m (275 ft) of drilled and cased drain was placed per 8-h shift. There were several days when the length was of the order of 107 m (350 ft) per 8-h shift by using modern equipment.

In March 1978, the installation was again inspected. Of the original 42 drains, all but 8 were destroyed or replaced during the widening project of 1974. Of the eight remaining drains, two were dry, one had a drip, two displayed a trickle, two produced 0.3 m^3/day (90 gal/day), and one had a flow of 2.7 m^3/day (720 gal/day). The steel casings of the 38-year-old drains were severely rusted and would probably be totally destroyed if disturbed by a cleaning operation.

Pacific House, 1969

A field review of an unstable cut slope at Pacific House, located on CA-50, was made in August 1969. Saturated clayey soil and decomposed coarse-grained granitic debris were encroaching on the eastbound lanes from a 0.75:1 slope 90 m (30 ft) high, which caused a traffic hazard. The slide mass was fed by a spring, which may have been partly sustained through irrigation of a large apple orchard upslope from the top of the cut.

Ten horizontal drains were installed in late October and early November 1969. A total of 549 m (1800 ft) of drain was installed, which ranged in length from 47.5 to 64.9 m (156-213 ft). Grades varied from 2 to 4 percent. Schedule 80 PVC casing that had an inside diameter of 3.8 cm (1.5 in) was used in 4 of the 10 drains, and conventional 5.1-cm (2-in) perforated steel casing was used in the remaining 6 drains. The combined initial flow was 99.4 m^3/day (26 285 gal/day). On completion of the project, the flows totaled 58.4 m^3/day (15 438 gal/day).

On November 1, 1978, the site was again inspected. Although the cut slope has remained stable for the past 10 years, wet spots are common around the drains and two of the drains show more water coming from around the casings than through them. Heavy root growth from a dense stand of willows has plugged most of the drains. Approximately 11.4 m^3/day (3000 gal/day) was measured during the review.

This was the first project where PVC was used as casing by the California Department of Transportation. Both steel and PVC were used on the same job so that a meaningful comparison of performance could be made. The 10-year-old PVC casing was in excellent condition and should perform well for many years. The steel casing, although somewhat rusted, was in good condition and should last an additional 20-30 years in this environment.

FACTORS THAT AFFECT LONG-TERM PERFORMANCE

By means of the three case histories, the long-term performance of horizontal drain installations in California has been demonstrated. Some drains that are nearly 40 years old are still producing large quantities of water, although their steel casings have largely deteriorated to thin shells of rust. In most cases, an attempt to clean them at this stage would result in severe damage or total loss of their structural integrity.

It would appear that a 40-year life span is about the maximum that can be expected for drains that have steel casings and perhaps 30 years is a more-practical guide. Although our oldest installation

Figure 10. Paddle marker used to locate drain.

that used PVC casing is only 10 years old, we anticipate that, by means of an effective maintenance and cleaning program, the 40-year life may be considerably extended, certainly well beyond the design life of the highway.

Several factors influence the long-term performance of horizontal drains, such as frequency and quality of a maintenance program, type of casing, pH and mineral content of the water, lithologic characteristics of the installation, and protective measures taken to preserve external features such as outlets and collector systems.

Maintenance

Perhaps the single most important factor in the long-term performance of horizontal drains is a well-developed and well-executed program of inspection, repair, and cleaning. To start, a drain cannot be maintained if it cannot be located. Lack of good records, which includes plans that show the locations of the drains in relationship to survey monuments or permanent landmarks, is common. These sites can be obscured or lost in time because of transfers, retirements, or promotions of personnel who are aware of them only because of personal experience.

The establishment and maintenance of a central file of all drain installations as well as the placement of paddle markers (Figure 10) or other means of marking each drain in the field (such as well-marked steel posts or signs) is good practice.

Drains located near the toes of embankments are sometimes lost through the practice of end-dumping waste material over the side of the fill, which covers the outlets. This practice, in addition to burying the drains, can reactivate movement in unstable areas, particularly when the load is placed at or near the head of the slide mass.

Dense growth of water-seeking plants, such as willows, around the outlets tends not only to conceal the drains but also to curtail their performance by extensive root growth within the first 3-6 m (10-20 ft) of the drain openings. Selective herbicides have been used successfully around the drain outlets to retard or eliminate undesired vegetation. Solid pipe is used for the outer 6 m (20 ft) of each drain to discourage roots from entering the drains.

Horizontal drains are also lost or damaged because they are not protected against rockfall, particularly in the case of exposed PVC casing, or because they are vulnerable to snowplows, rockplows, or vehicles that stray near the edge of the traveled way. A good practice is to protect the PVC casing at the outlet with a galvanized pipe sleeve that slips over the PVC casing and is inserted into the drilled hole approximately 3 m (10 ft). The exposed end of the metal pipe is then connected to a cleanout plug by an elbow that allows the surface pipe to lie adjacent to and parallel with the slope. The pipe is then connected to a buried collector system located at the base of the slope. Cleanouts should also be provided for the collector system.

Drain cleaning and maintenance records should be kept for each installation. These records should include dates of cleaning and repairs; flows recorded for each drain prior to and after cleaning; depth of cleaning, shearing, or damage of drains due to slide movement or external forces; the general condition of each drain; and the person responsible for the operation.

pH and Mineral Content

The long-term performance of horizontal drains is also a function of the pH and mineral content of groundwater. These factors appear to be more important than the type of environment (coastal, valley, or mountain). High acidity (low pH) or the presence of corrosive elements commonly found in fault zones or highly mineralized areas may significantly shorten the life of the drain, particularly when steel casing has been used.

Groundwater highly charged with calcium sulfate or iron, for example, may also reduce the performance of the drain by plugging the slots or perforations. Mineral compounds are usually precipitated near the outlet at which the ionic solutions undergo changes in temperature and pressure.

Lithologic Characteristics

The lithologic characteristics of the formations in which drains are placed is a definite factor in their long-term performance. An installation located in moderately hard broken rock will usually have a long life because of a minimal amount of silt and clay fractions that can gradually build up around the outside of the drain and block the passage of the groundwater. Conversely, drains placed in fine sands or silts may have a shorter life because of an abundance of fines and may require more-frequent cleaning or replacement.

A 5-mm (0.020-in) slotted PVC casing is used in the majority of installations made in California today. When poorly cemented fine-grained sands are encountered, a mechanical analysis is run to determine the proper slot size. Three of these installations have required the use of 2.5-mm (0.010-in) slotted casing to prevent the fine-grained sand from entering the drains. The oldest of the three is now seven years of age and is still performing well but requires cleaning with a high-pressure water system every second year. Installations in rock or well-cemented sediments may not require cleaning for as long as six or even eight years unless root growth is a problem.

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1. T. W. Smith and G. V. Stafford. Horizontal Drains on California Highways. Presented at ASCE Meeting, New York, Oct. 1955.

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