HORIZONTAL DRAINS ON CALIFORNIA HIGHWAYS

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SYNOPSIS

With the knowledge gained through the experience and study of the pioneers in this field, and the dissemination of this knowledge among the engineers, many agencies both public and privately owned have adopted horizontal drains. Since their use has become so widely accepted it seems timely to discuss the changes in methods of installation, development of equipment, engineering aspects, and the merits of horizontal drains as a means of slide or slipout correction or prevention in the light of these sixteen years of elapsed time and thousands of feet of drains installed.

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INTRODUCTION

The California Division of Highways installed what is believed to have been the first horizontal drains for slope stabilization in 1939. Basically horizontal drains are holes or borings that are drilled into an embankment or cut face. They are on a slight plus grade and are usually cased with perforated or porous liners.

Since that first job in 1939 approximately 235,000 lineal feet of horizontal drain has been installed by State forces and several installations have been made on certain roads by contract during construction.

Horizontal drains have served a useful purpose in the construction and maintenance of highways in California. They have far more than paid their own way in the saving of construction and maintenance dollars. This word of caution, however: they are not the answer to all problems relating to slides and slipouts, nor should they be considered a substitute for good planning, design and construction.

Experience has shown that horizontal drains are effective under a wide variety of soils and geologic, topographic, climatic, and ground water conditions. Some drainage installations have been made that were completely effective, a few have been made that were not effective, and the remainder have been effective in various degrees. The majority of installations made by the Division of Highways falls in this latter category. Horizontal drains are frequently used in combination with other

measures to prevent or correct slides and slipouts.

The use of horizontal drains for prevention or correction of conditions that produce slides can be discussed best in several rather broad phases. These phases are purpose, investigation, planning and installation, equipment, maintenance and effectiveness. The phases naturally overlap and in actual practice cannot be completely segregated.

Purpose

The principal function of horizontal drains is to remove subsurface water from hillsides, cut slopes and fills. They are used in an effort to prevent slides by correcting the conditions that cause slides in cut slopes or embankments in certain types of soil or rock formations. They perform this function by removing the subsurface water either from the mass of sliding soil or from its source in the adjacent area.

The removal of the subsurface water tends to produce a more stable condition in several ways. The seepage forces are reduced. These seepage forces are not necessarily in the direction of sliding, but in general they would be far more detrimental than beneficial. Removal of the subsurface water tends to increase the shear strength of the soil. Cohesive soils that have a very high shear strength in a relatively dry state may have almost negligible shear strength in a saturated condition. This is especially true of plastic soils in fissures or in planes that have been weakened by previous movement. Removal of the subsurface water reduces any excess hydrostatic

pressures that develop. Associated with excess hydrostatic pressures there is a loss in normal forces and hence a loss in frictional shear strength. Thus, a reduction in excess hydrostatic pressure causes a restoration or an increase in the frictional shear strength.

Investigation

The earliest phase of the necessary investigation that should precede the installation of horizontal drains should usually consist of a field review of the site to evaluate the conditions that are causing or tending to cause a slide or slipout. During this phase various methods of correction or treatment are considered. These methods may include horizontal drains. The people making the field review should be competent engineers or geologists who are familiar both with the causes of slides and slipouts, and the various methods of evaluating these causes. They should also have knowledge of various means which might be used to correct or improve the conditions.

The second step in the investigation frequently consists of geologic investigations, and/or exploratory borings, either vertical or horizontal. Generally, it is advantageous to have vertical boring data prior to the installation of horizontal drains. However, there are many instances where horizontal drains can be used for exploration purposes. In these instances the necessary soil and geologic data may be obtained and, at the same time, the holes may serve the more practical purpose of drainage.

The exploration should provide information on soils and geologic conditions as well as information on ground water conditions. In the installation of horizontal drains, it is important to know the location of the ground water and also the character of the material in which this water might be intercepted.

In vertical borings, once water is encountered, it is frequently very difficult to determine whether the entire soil stratum beneath is saturated or if there are layers of "perched" water. This information is important in installing horizontal drains and frequently it can be obtained by drilling exploratory horizontal holes.

Planning and Installation

The first step in planning a horizontal drain installation is a careful analysis of the information available from field reviews, geologic investigation, borings, ground water studies, maps - including contours and sections, and all available data on construction and previous soil movement in the immediate vicinity. It should be emphasized that this phase of the work requires experience, sound judgment, and ingenuity.

The location and depth of the ground water, together with the topography will determine the locations from which the drains will be started. Since the drains will remove the water from the area by gravity, the starting point for a drain must be below the elevation of the point where water is to be intercepted. An exception to this idea would be the relief of excess hydrostatic pressure by a combination of vertical wells and horizontal drains. (Figs. 1, 2 & 3).

The spacing of the drains should be dependent upon the drainage characteristics of the soil, the quantity of water intercepted, and the character and magnitude of the slide involved. In drilling from any one elevation, usually drains are planned at intervals of 25 to 100 feet. Drains spaced with intervals of 100 feet would seldom provide adequate drainage, but would determine whether water could be intercepted. If large quantities of water exist it is frequently necessary to space the drains at intervals of less than 25 feet. Drains are often installed from more than one level if the terrain permits and the distances are such that the subsurface water can be reached from various levels.

The depths to which the drains are made are controlled by several factors. Perhaps the primary factor is the depth to which the drains must extend to contact the water bearing strata and properly drain the area and produce a stable condition in the slide. Other factors that may actually control the depths are difficulty of drilling, quantity of water drained, the economy and effectiveness of a greater number of shorter drains compared with fewer, but longer drains, and occasionally some other factors. The California Division of Highways have installed drains of various depths from 50 to in excess of 300 feet. Most of the drains have been between 100 and 200 feet long.

The grades on which the holes are drilled are largely determined by the topography and the ground water conditions.

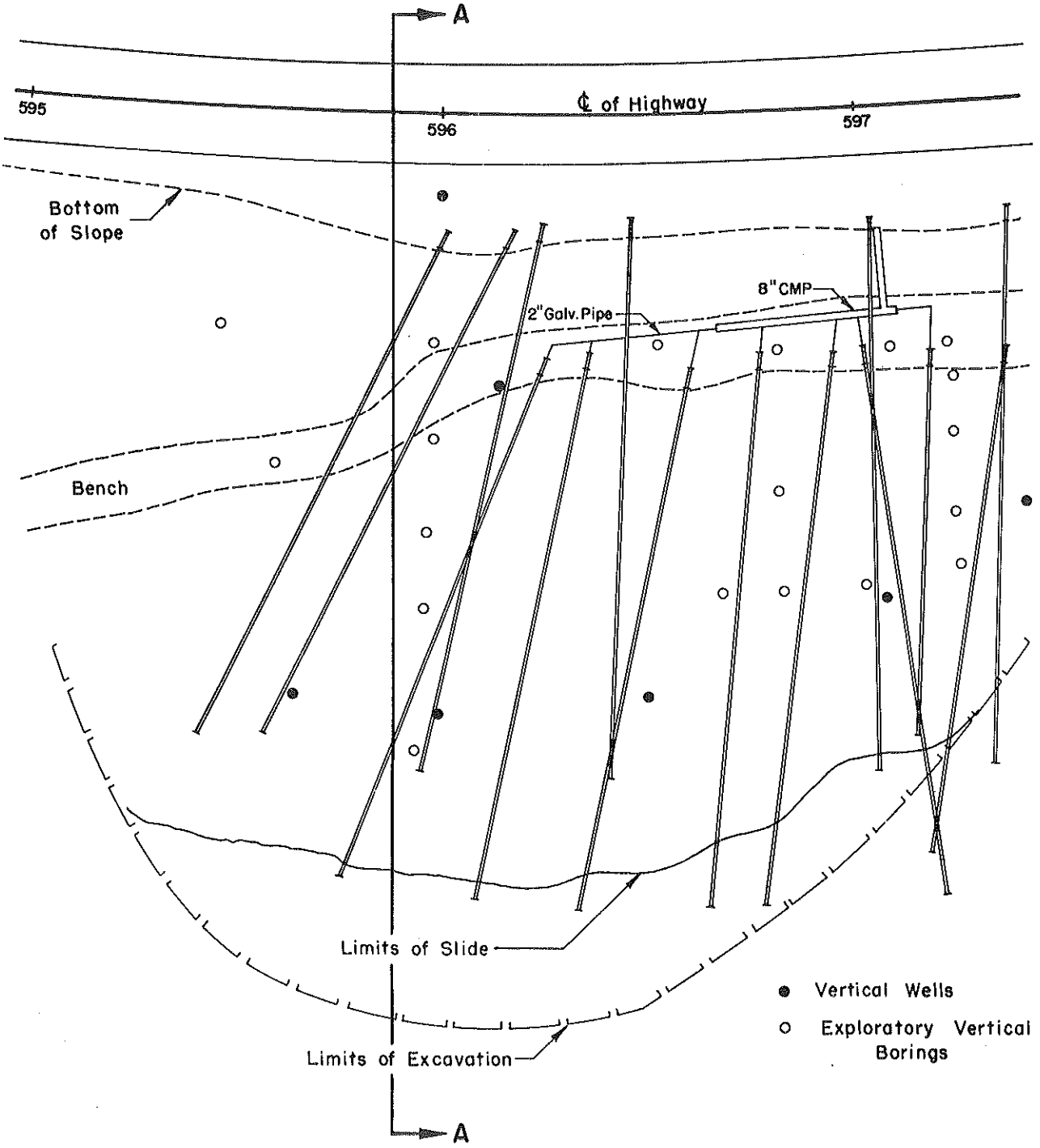
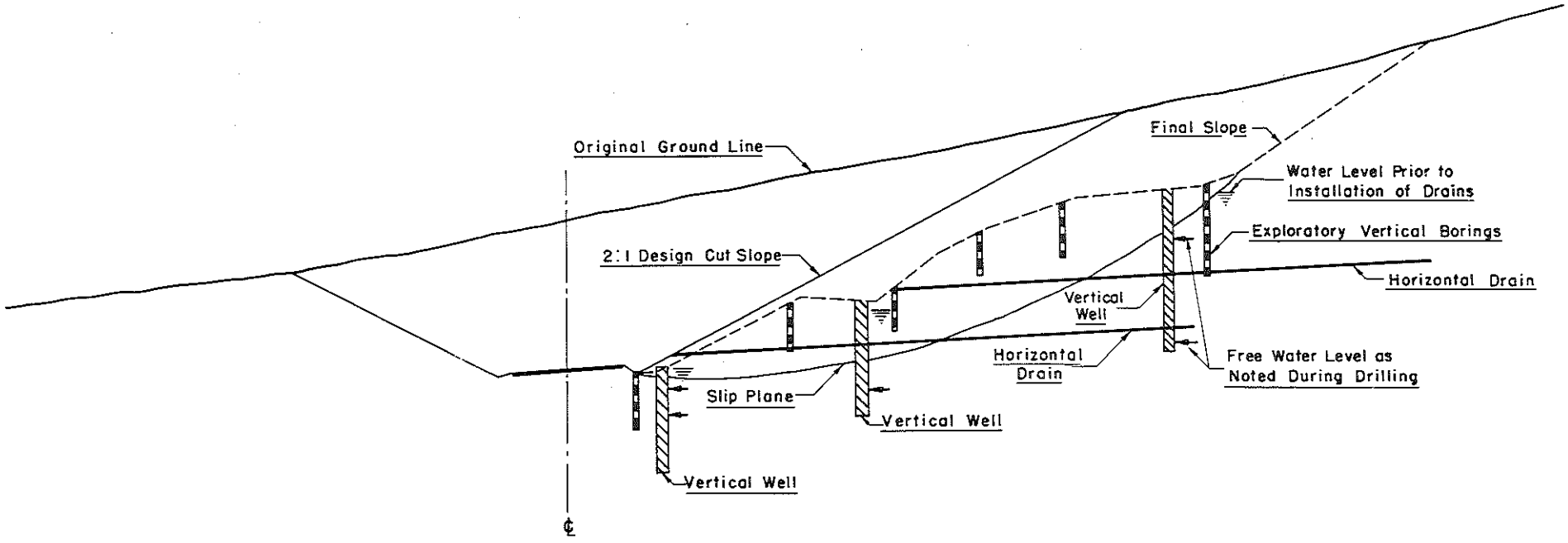


FIG. 1 SLIDE CORRECTION

HORIZONTAL DRAINS IN COMBINATION
WITH VERTICAL DRAIN WELLS



SECTION A-A

FIG. 2 SLIDE CORRECTION

HORIZONTAL DRAINS IN COMBINATION WITH VERTICAL DRAIN WELLS

Fig. 3. Slide condition corrected by vertical wells and horizontal drains (see Fig. 1 & 2).

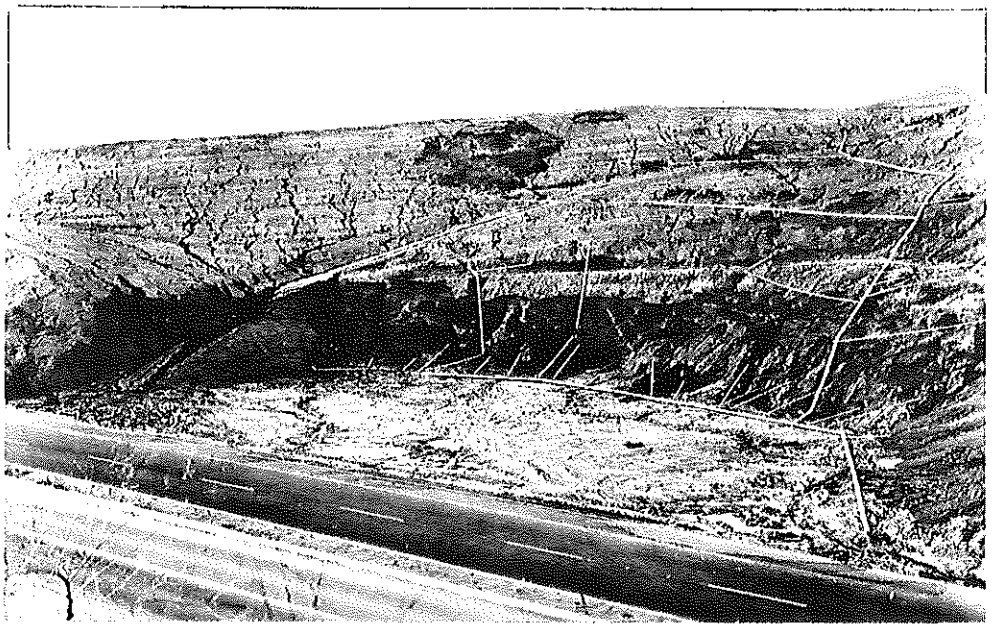


Fig. 4. Completed drain installation and collector pipe system.

The drains must of necessity start from some point that can be reached with the drilling equipment or to which access can be provided. To be serviceable the upper portion of the drain must intercept the subsurface water that is contributing to the unstable soil condition. The drains are usually installed on grades of 3 to 20 per cent with 10% being the best working grade. Occasionally steeper or flatter grades are used, but generally they are not practical. There is a tendency to lose or gain grade in the drilling operation. If soil conditions, through which the drilling is done are uniform, the tendency is to lose grade due to weight of the drill rods and bit. Non uniform character of the formation through which the holes are drilled has a great effect on maintenance of grades. The bit will tend to follow the path of least resistance, i.e. to follow fissures, soft layers, or along the contact between layers of material having different drilling characteristics.

Caving has proven to be the greatest single difficulty encountered in the installation of horizontal drains. Slide areas are usually composed largely of loose and broken material and the walls of the hole are unsupported while drilling is in progress. Much footage is lost due to the hole collapsing either during drilling or after drilling has been completed, but before the casing can be installed. With modern rock bits it is possible to drill very hard formations, but no satisfactory method of drilling and casing in one operation has yet been devised.

One other important consideration in planning a drain installation is a collection pipe or system to carry the intercepted water out of the critical area. (Fig. 4). If the outlet of the drains discharge into an existing gutter, usually no other steps are taken. If this is not the case, some other means is used. Access is provided at the lower ends of the drains for future inspection and cleaning.

The most satisfactory installation has been the use of 6" to 8" galvanized CMP. The drain outlets are connected to the larger CMP which in turn collects the water from the drains and carries it to any desired location outside the slide area, such as a natural surface channel.

At least two important things should be kept in mind during layout and installation of the collecting pipes:

1. Easy accessibility of the individual drain for future inspection and maintenance is important.

2. Collecting pipe should be anchored in such a way (preferably to drain outlets themselves) that slight slide movement or local sloughing will not cause the collector pipe to move away from the drain outlet and become disconnected.

Where freezing may occur during the winter season it may be necessary to bury the collecting systems.

Open flumes and paved ditches have been used for collecting and carrying the intercepted water, but because these two types of collectors require constant inspection and cleaning they have not proven too satisfactory.

Equipment

The first equipment used by the Division of Highways in 1939 for horizontal drilling was relatively light (Fig. 5). It was originally designed and developed for utility construction work where insertion of pipes under side walks, streets, highways and property was necessary without disturbing the surface.

This equipment consists of a rotary drill mounted on a racked frame in such a way that a revolving drill bit may be advanced into the earth with a hand operated ratchet lever while water is pumped through the drill rod to cool the bit and wash the cuttings from the borings. (Fig. 6). Five-foot lenths of drill rod are added as the drilling proceeds. Compressed air engines which are quite compact and portable are utilized for pumping water and operating the drills. The compressor and water pump are placed at convenient locations with suitable pipe or hose lines leading to the drilling units. With this arrangement of equipment it is not necessary to move the heavier compressor and pump when moving from the location of one boring to another.

The first horizontal drain holes were drilled by a 2" pilot bit and then reamed to 6" in diameter before casing with 4" PMP. It was soon found that it would be more practical to perform the drilling in one operation. This resulted in the adoption of a 4" modified fishtail bit to do the drilling in one operation.

The 4" modified fishtail bit was progressively improved, beginning with construction out of a good steel followed by

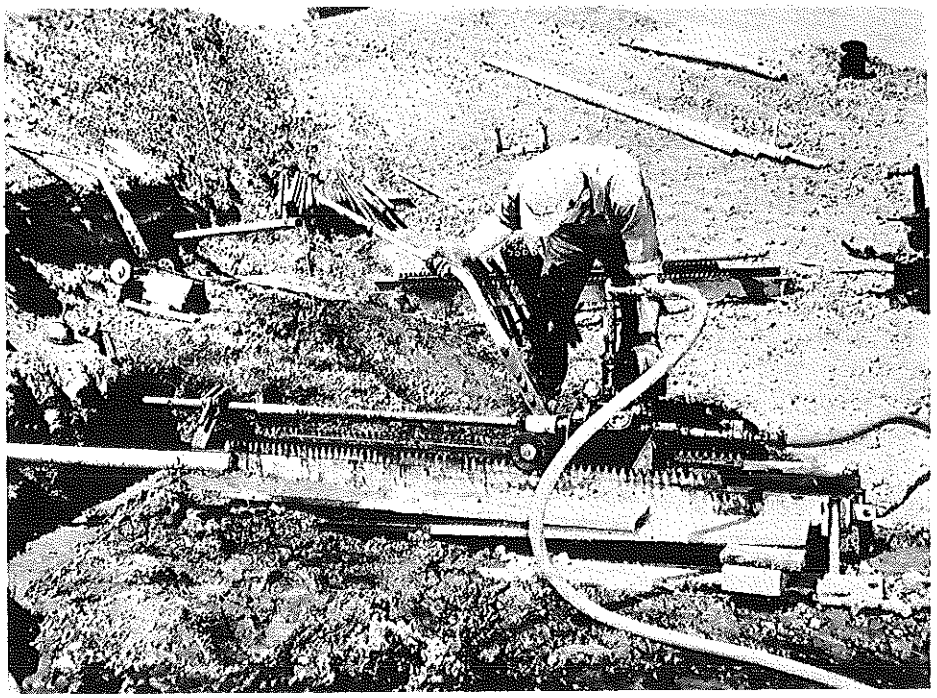
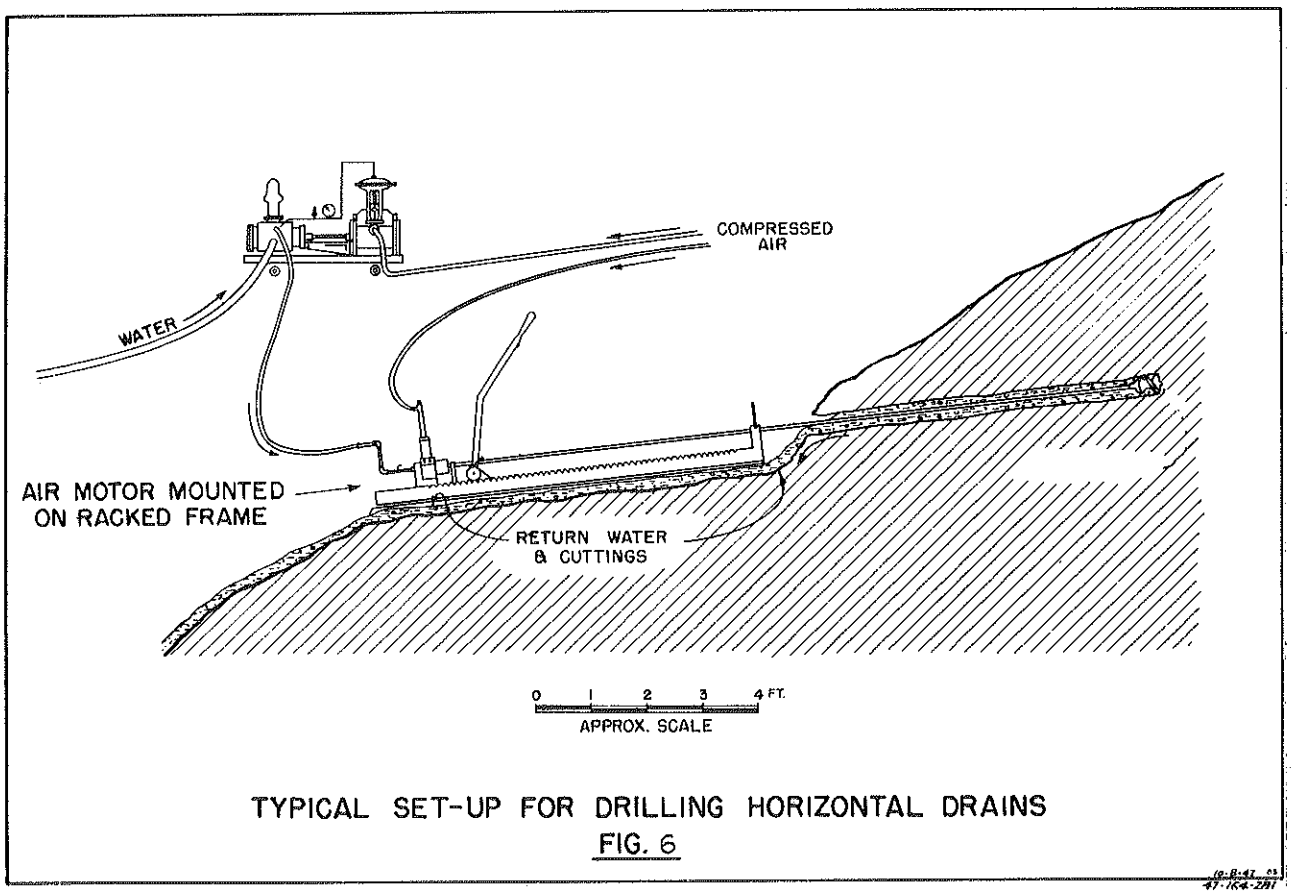


Fig. 5. Operating Hydrauger equipment.



TYPICAL SET-UP FOR DRILLING HORIZONTAL DRAINS

FIG. 6

facing on the cutting edges with tube borium. The ultimate was reached with this type of bit by using a combination of tungsten carbide inserts and tube borium on the cutting and wearing surfaces for drilling in hard formations.

Various other types of commercially available bits were tried. No better bit was found until 1949 when the rock roller bit commonly used in the oil fields became available in small sizes. (Fig. 7) These bits were tried, proved superior in all formations except possibly stiff plastic clays, and have been used almost exclusively since.

Standard perforated 2" iron pipe with the following specifications is used for casing:

> "Standard 2" black steel pipe perforated with 3/8" diameter holes on 3" spacing drilled in 3 rows at the quarter points, to be furnished in random lengths of 16 to 24 feet without threads or couplings. Pipe to be vertically dipped in a standard pipe dipping asphalt subsequent to drilling."

This casing is butt welded with oxy-acetylene equipment as it is jacked into the hole. The principal purpose of welding the joints together rather than using screw joint couplings is to hold the perforation rows in alignment. The perforations are normally placed up so the intercepted water will be carried out of the critical area to discharge into the collector drain.

The borings are cased by the use of an extra carriage which replaces the drill on the racked frame after the drilling is completed. The casing was originally held in the carriage

saddle and kept from slipping by the use of 36" pipe wrenches. This arrangement was later revised and improved by constructing a grip similar to a standard chain pipe vise as an integral part of the carriage.

During the first few years of drain installation work a sharpened wooden plug was driven into the leading portion of casing to serve as a guide with the idea in mind that a retractable folding bit could be used through the casing to drill out an occasional large obstruction caused by caving during the casing operation. Experience indicated that in most cases the wooden plug was merely driven back into the casing and only served the purpose of plugging the end. This did keep soil and rocks from entering the casing but drilling out cave-ins did not prove too satisfactory. This procedure was abandoned in favor of pointing the perforated metal pipe itself and rotating, occasionally, to push obstructions out of the way.

With the experience and progress in horizontal drilling technique it was recognized that more powerful drilling equipment should be obtained to supplement the lighter equipment in use. Consequently a more powerful machine with a 60 horsepower gasoline engine was purchased early in 1951.

This drill is a self-propelled unit, capable of moving about within limits of a job, having a hydraulic feed, using continuous flight augers and requiring no water for drilling. (Fig. 8). It proved to be a very good rugged piece of equipment, but the continuous flight augers were limited to drilling in soil or soft rock formations. The practical drilling depth,

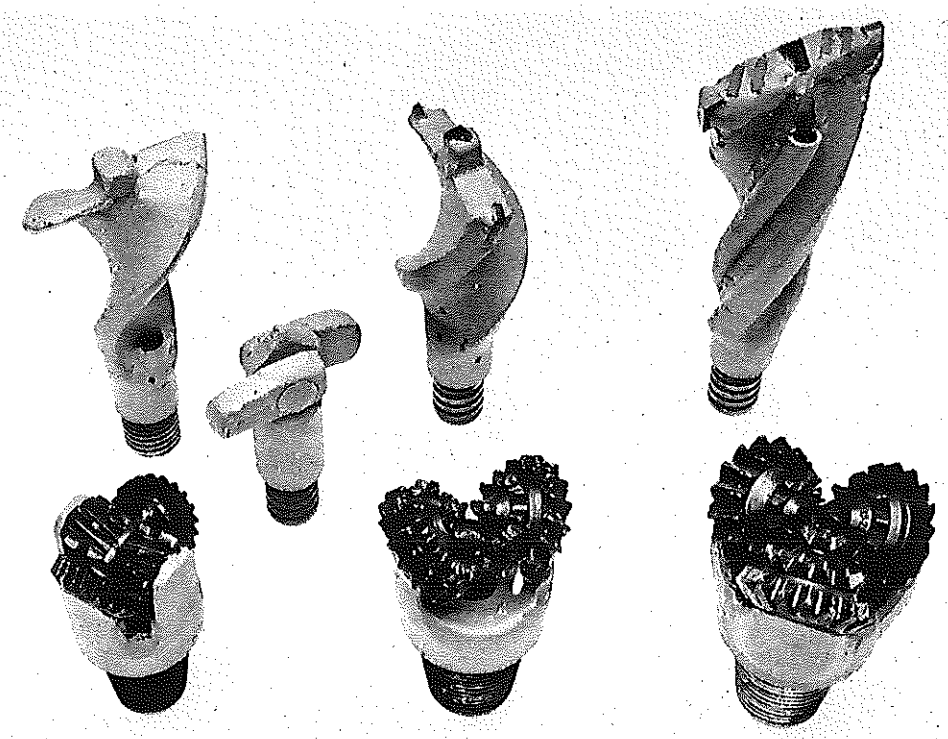


Fig. 7. Bit types past and present used for drilling horizontal drains.

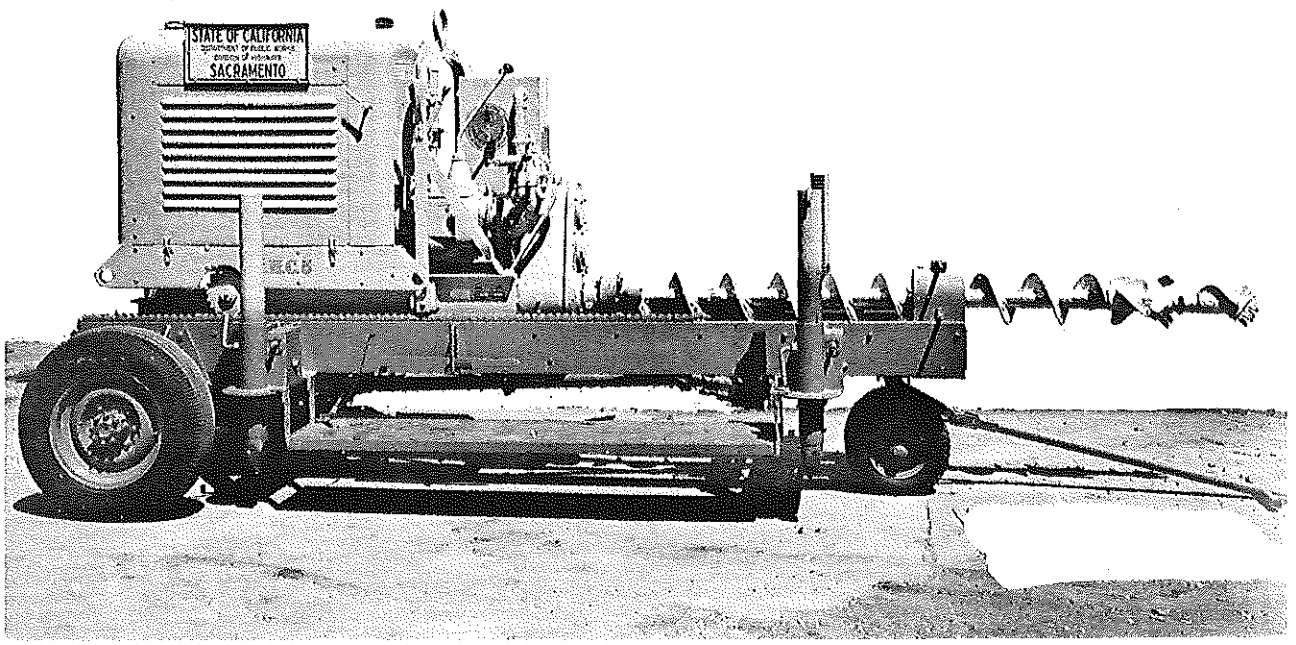


Fig. 8. McCarthy Rock Boring Machine with continuous flight augers.

due to lack of directional control caused by the necessary flight coupling arrangement, limitations on power, and strain on the equipment proved to be only about 150 ft. in the formations found in slide areas.

In 1953, two years after obtaining this more powerful machine, accessory equipment was fabricated so that regular rotary drilling could be accomplished using diamond N-rod and 4½ in. rock roller bits. (Fig. 9). The degree of success upon converting the machine to a rotary type drill led almost immediately to the existing phase of equipment development.

The converted machine operated very satisfactorily, and it was found that the use of heavier drill rod, the hydraulic feed and superior power all were advantageous. This machine, however, had one serious drawback: when using the machine for forcing the casing into the drilled hole, the casing must be in front of the drill carriage, as the design of the machine prevents working through a chuck; this necessitates using lengths of casing which can be inserted between the carriage and outlet end of the drain at the ground surface. In restricted working areas it is necessary to use 5 ft. lengths of casing, with a correspondingly large number of field welds. Also this machine was somewhat larger and more powerful than necessary for the rotary drilling work on drain installations, which results in some sacrifice in mobility.

Development of Improved Machine

No drill rig on the market designed specifically for drilling holes for horizontal drains could be found and none

Fig. 9. McCarthy Rock Boring Machine modified to drill with circulating fluid.

which satisfied California's requirements. A drill rig was desired incorporating the following features: the drill unit should be complete with a gasoline engine of adequate power; a suitable transmission to permit control of speed of rotation over a wide range; a hydraulic feed with a minimum stroke of six feet, capable of exerting a 4000-lb. thrust; provision for slowly rotating the casing concurrently with the jacking operation when necessary; a chuck readily interchangeable for A-rod, N-rod or casing and so designed that long lengths of rod or casing can be operated through the chuck; rugged, but easily operated spuds for maintaining alignment and grade of the drill; rubber-tired wheels and three-point suspension to permit sharp turns; and, finally the overall length not to exceed twelve feet and the weight of the complete drill to be not more than 3000 lbs.

The California Division of Highways Materials and Research Department had for several years realized the need for such an improved horizontal drill, and as no completely suitable machine could be purchased, it was decided to design and build a drill unit specifically for horizontal drilling. The new drill rig, (Fig. 10) for the most part, is comprised of standard or proven parts of sub-assemblies similar to those used in manufactured drills. The machine is unique because it incorporates the desirable features of various machines into a light-weight, compact drill rig especially suitable for the type of drilling required for installation of horizontal drains. The power unit is a 20 horsepower, 4-cylinder, air-cooled engine, connected

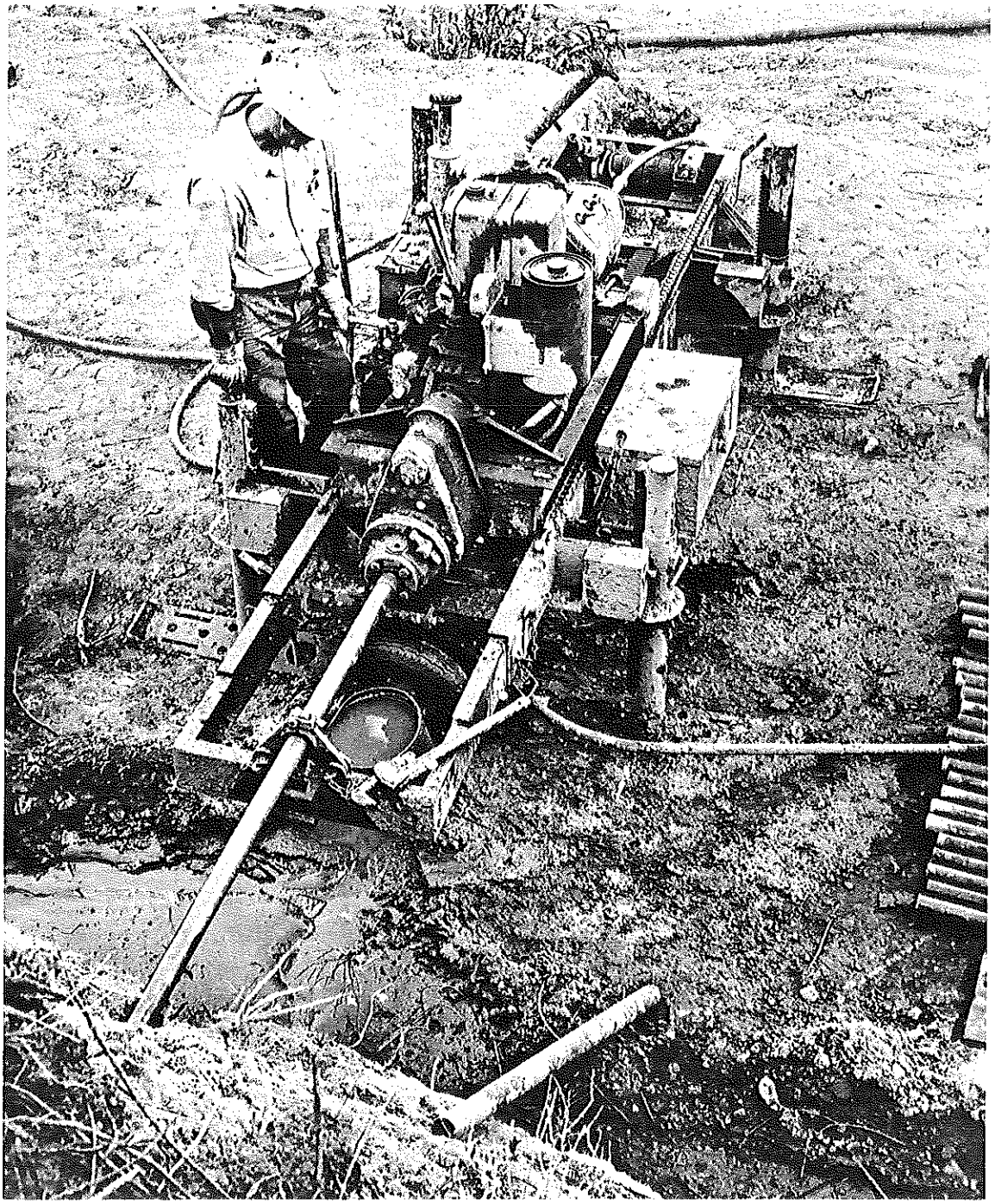


Fig. 10. California horizontal drill rig in operation.

through a fluid drive to a 4-speed transmission. Rotation of the chuck is accomplished by a gear train from the transmission enclosed in an oil-tight housing. The entire drive assembly is mounted on a hydraulically operated carriage with a travel of six feet. A ten-gallon-per-minute oil pump, also driven by the 20-horsepower air cooled engine, supplies oil to two hydraulic cylinders, by means of which the thrust can be controlled at any desired feed pressure up to 4000 lbs.

A specially designed chuck assembly was required to permit the use of long lengths of drill rod or casing, and to provide for interchanging chucks for different size rods. Standard A-rod and N-rod chuck heads are used, with a shop-designed chuck holder which permits quick change of chuck heads. A special chuck for gripping the two-inch casing is used in the same chuck holder.

While the horizontal drilling equipment has gone through several stages of development, the development has usually resulted from particular needs dictated by drilling conditions encountered. This is borne out by the fact that while the new California Horizontal Drill just recently built to particular specifications, which make it definitely superior in many respects to other available equipment, several of the original units are still being used essentially as they were modified in 1939 for the first horizontal drilling. These light, portable units still have the advantage of greater mobility where access and set-up room is a problem.

Maintenance

Some maintenance of horizontal drain installations is necessary if they are to continue to be effective for long periods of time. The maintenance required is dependent upon local soil conditions, vegetation, rainfall, road conditions, and other factors.

Considerable maintenance has been eliminated by the use of approximately 20 lineal feet of non-perforated galvanized pipe for the last length of casing placed in the boring. This, in most cases, minimizes trouble from root growth in the casing and retards corrosion at the outlets. (Fig. 11). Aside from regular inspection and repair of visible damage and obstructions the major maintenance consists of cleaning at intervals of three to ten years to remove root growth, corrosion, and soil from drains.

It is important that the drains be cleaned thoroughly when their efficiency has been impaired. This, in the great majority of cases, restores them to their original effectiveness.

While limited cleaning may be done with hand tools the only satisfactory method has been with the use of power equipment. This is usually accomplished with the original installation equipment modified for this purpose or with a relatively light hand-held air motor similar in operation to the original horizontal drain machine. Diamond drill E-rod with an auger type bit small enough to rotate freely in the casing is used for the drilling tools. Some of the water

Fig. 11. Extreme case of root growth in horizontal drain.

jets of the cleaning bits are so directed that the casing is thoroughly washed and flushed as the bit progresses through the casing. Water delivered to the air motor at 150 psi to 200 psi has proven adequate. Standard practice has been to clean the drains to a 50 ft. minimum depth or 10 ft. beyond the point where the flushing water becomes clear when greater cleaning depths are necessary.

The chief advantages of machine cleaning operations are:

1. Drains may be cleaned to much greater depths than by hand.

2. Cutting out the root growth entering the casing perforations is more complete.

3. Vibration as a result of machine operation of cleaning tools combined with adequate pressure and volume of the flushing water tend to loosen and wash out rust, scale, soil and any other deleterious material which may be in the casing or its perforations.

4. Vibration also tends to agitate soil adjacent to the casing, allowing larger flow of subsurface water into casing.

It has sometimes been necessary to replace the outlet ends of the casing where rusting and corrosion have caused excessive damage to the "stickout." Galvanized pipe is always used for this replacement. No replacement to date of this portion of the drain has been necessary where a length of galvanized pipe was used for the outlet end in the original installation.

Effectiveness

Drain installations that have been preceded by adequate investigation and that are properly planned have usually been effective in removing subsurface water and this in turn has corrected or improved the unstable condition.

Drain installations have been most effective in areas where the subsurface water could be intercepted in well defined aquifers or layers, where the soil was sufficiently permeable to permit ready removal of the water, and where the water could be reached with holes not more than 300 feet long on 5 to 15 per cent grades through formations that can be drilled successfully and where the borings do not cave.

Some installations made with as few as eight to ten drains, all less than 100 feet in length, have been effective in correcting a slide. Other installations have required in excess of one hundred drains, some of which were drilled to the maximum practical depth.

Perhaps the two types of foundations in which it is most difficult to make installations are (1) silty fine sands that tend to erode or wash badly during the drilling operation and cave to the extent that casing the holes is difficult; and (2) hard broken formations that are difficult to drill. In this type of material loss of circulating fluid is a problem, as well as the caving during drilling and casing operations. Competent drilling personnel are a must in the installation of drains and this is certainly emphasized when drilling or casing operations are difficult.

The quantity of water that is produced or drained at the time of installation may not be a good measure of the flow that will occur later or of the effectiveness of the installation. Some drains may produce large flows during the rainy season or during and after actual periods of rainfall, and be dry or produce very little water at other times. Other drains may produce flows that vary somewhat with the seasons yet are relatively constant. It is also true that in some instances the removal of a relatively small quantity of subsurface water will produce a stable soil condition, whereas other instances may require the removal of very large quantities of water to produce the desired results.

Discussion of Representative Installations

Lookout Point

This is a side hill cut adjacent to the Pacific Ocean on U.S. Highway 101 approximately 1 mile south of Orick constructed in 1949. The toe of the cut is approximately 1000 ft. long at roadway level tapering to about 100 feet in length at the top of the cut some 225 ft. above the road. Traffic during construction was carried by the existing road at the top of cut and this road would have been endangered by a major slide. An echelon faulting with many slip planes and old landslides were in evidence particularly in the northern portion of the area. The cut was constructed on a 1:1 slope with benches 60 feet apart in elevation. The material encountered consisted chiefly of a graphitic schist interbedded with seams of fractured quartz.

During the early stages of the excavation of the cut active springs were exposed on the cut face. It was decided during this phase of construction that a few exploratory horizontal borings should be made to locate the water bearing formations and to determine the feasibility of effectively subdraining the entire cut area by this method. An initial flow rate of 10,000 gallons per day was developed by the first 4 exploratory drains. From this and the excavation data it was soon apparent that the bulk of the subsurface water was located in the lower two-thirds of the cut slope and that a comparatively large volume of this seepage could easily be intercepted and controlled by means of horizontal drains.

The horizontal drain installation was continued, covering the cut slope area from the two lower benches and roadway level with a total of 30 drains approximately normal to the highway centerline. These drains averaged 127 feet in depth. The horizontal holes ranged in grades from 6 to 22 percent. The total maximum flow rate from all the drains amounted to over 140,000 gallons per day which decreased to 5,000 gallons per day after the perched or impounded water was drained out.

The installation continues to produce around 5000 gallons per day during the wet season of the year decreasing to only a few hundred gallons per day during the summer months.

At this location the horizontal drains were installed as a preventive measure in an unstable area where the slide potential was definitely aggravated by the presence of a considerable amount of ground water. The conceivable magnitude

of a slide in such a large cut warranted any reasonable stability insurance that appeared practical.

Six years have elapsed since construction. Several million gallons of water have been drained out of this potentially unstable cut during this period. Only minor sloughing and local slides have occurred since construction, and it appears that the horizontal drain installation has been effective.

Willits Slide

This slide occurred in the right side of a thorough cut which was constructed in 1947. This cut is 2½ miles south of Willits on U.S. Highway 101. Seepage was noted in the cut slope during construction, but was not alarming in view of the planned slopes of 2:1. However, in the winter of 1948 three small slides developed and were smoothed up by maintenance forces. During the winter of 1950 the slide again became active, probably because of the exceptionally heavy rainfall that year. The amount of seepage water was much greater than previously observed and the sliding was more extensive. A break joining the three previous slides developed much higher on the slope and a plastic movement of the entire mass created a traffic hazard by encroaching on the traveled way every winter until the installation of 17 horizontal drains in 1953. See Figs. 1, 2 and 3.

When the horizontal drains were installed the upper limit of the semicircular slide scarp extended about 220 feet from the highway centerline and the slide was about 300 feet wide

at the toe of the slope. A stratum of stiff blue clay composed the first 20 feet of the cut slope and had remained fairly stable through the years. This blue clay was overlain by alternate layers of brown silty clay and terrace gravel, which were sliding over the blue clay and onto the traveled way.

One unique feature of this installation was the placing of several vertical borings near the outer periphery of the slide scarp to connect the pervious gravel strata separated by the impervious clay.

Ten of the 17 horizontal drains were installed along the contact of the blue clay and overlying material, while the remaining seven drains were installed from roadway grade. In general the drains were installed from the northern two-thirds of the slide and all are angled slightly toward the south. The upper drains were spaced 10 to 20 feet apart while the roadway drains vary from 10 to 50 feet. The horizontal drains averaged 130 feet in length and produced a maximum initial total flow of 13,265 gallons per day. Of this total, one drain located near the south extremity of the slide produced a flow of 10,000 gallons per day. These initial flows decreased as the various water forces in the sliding mass were relieved.

The sustained flow from this installation has never been very high, ranging from a relatively small amount during the summer to something in the order of 1500 gallons per day during the winter. However, this relatively small daily flow does amount to an appreciable quantity of water when added up over a period of several months. At least the sub-surface drainage

of the slide area has been sufficient to stabilize the slide, for only local surface sloughing has occurred during the three winters since the horizontal drains were installed, while sliding has taken place in adjacent areas not stabilized by horizontal drains.

Sears Point Slide

This slide is located on the Black Point Cutoff road north of San Francisco Bay between Vallejo and highway 101. Several major earth movements occurred at this one location during construction and at least two of these repetitive slides reached the median of the newly graded four-lane roadway. After about 80,000 cubic yards of slide material had been excavated from the area 10 horizontal drains, totaling 2000 lineal feet, were installed from one level in the approximate center of the slide. Immediately after the installation of these drains another major slide occurred which destroyed one drain and damaged several of the others. After the loose material had been excavated and the area again resloped, additional horizontal drains were installed from various levels through the slide area. This is illustrated by Figure 4. Forty-nine drains were installed in this area to an average depth of 157 feet. The 7397 lineal feet of horizontal drain installed in this area makes this the second largest installation ever constructed by this department.

The slide material was composed largely of a soil of a clayey nature which was very unstable in the presence of water and yet was impervious enough to prevent adequate movement of

ground water to allow easy subdrainage. This impervious nature of the soil accounts for the high footage of horizontal drains which were required to properly control the subsurface water. Vertical observation wells drilled in the area prove the horizontal drains have effectively lowered the water table in the slide area.

The slide extended about 300 feet along the roadway while the upper limits of the excavation was normal to and about 400 feet from centerline. The final slope of the excavated area was about 3:1 indicating the flatness of the plane upon which this material was sliding. Exceptionally high initial flows were not developed by any of these drains although the combined total was approximately 50,000 gallons per day. Since the water table has equalized at its lower elevation this installation has produced some 4000 to 5000 gallons per day during the summer and up to 20,000 gallons per day during the winter.

Horizontal drains alone could not have been relied upon to control this slide. However, the drains coupled with the unloading and slope flattening have proven to be a successful stabilization treatment. Sliding in adjacent areas continues on very flat slopes. It is believed that the horizontal drains have been an aid in preventing movement in this old slide crater where no sliding has occurred since 1951.

Half Moon Bay Slipout

Failure of this highway embankment took place during the 1951-52 wet season. The highway affected is a 5 mile connecting road in the San Francisco penninsula area connecting State Sign Route No. 5 with State Sign Route No. 1 at the little town of Half Moon Bay.

During the early part of the winter settlement of approximately 200 feet of roadway took place at a point about 4 miles east of Half Moon Bay where a side hill fill existed. This was followed by major movement in the latter part of the winter involving the entire width of the traveled way. A vertical displacement of some 10 to 12 feet with a maximum horizontal movement of slightly less had occurred at roadway level and on the upper part of the embankment. Some movement was indicated about 100 feet down the fill slope.

Exploratory borings showed a large quantity of water in a sand and gravel blanket which had been placed under the embankment about 20 to 25 feet below the outside shoulder. The presence of this water was considered proof of ineffective drainage. Considerable spring water from the original ground slope above the embankment was also indicative of inadequate subsurface drainage.

After analysis of the data horizontal drains appeared to be the only practical means of subdraining the slipout area.

Twenty-six horizontal drains were placed in two general locations. Twelve were placed near the toe of the fill some 40 feet below the road. The other 14 drains were installed

from roadway level to intercept the subsurface water before it reached the critical fill area.

Grades ranging from 8 to 25 percent were used for the borings below roadway level. These grades were determined for each succeeding drain as the work progressed by analysis of the boring records of all previous drilling. Those installed from roadway level were drilled as flat as practical. Grades of 2 to 11 percent were used. These grades were largely predicated on data obtained as the drilling progressed. In other words as the various formations were encountered the grades on the next holes were adjusted accordingly.

An attempt was made to install the drains below the road to a depth of 200 feet and those above the road to 150 feet. It was possible to case only about 85 percent of the 4000 feet of drilled hole due to the loose rocky nature of the soil in the area. Caving also made the drilling operations quite difficult.

Maximum initial flows from all the drains aggregated some 13,000 gallons per day. Flow readings taken since the installation was completed show a range from a few hundred gallons per day in the dry summer months to about 8000 gallons per day during the wet season.

The roadway was reconstructed and brought up to grade after the horizontal drains were completed. During the reconstruction an underdrain was installed along the upper side of the roadway for the entire length of the slipout area. This was to intercept subsurface water entering the roadway section near grade.

Four years have elapsed since this work was done. To date no distress or movement has taken place in the area, indicating that the stabilizing treatment, which was primarily installation of horizontal drains, has been successful.

Nevada City Slide

In realigning State Sign Route 20 in the vicinity of Nevada City it was necessary to construct a new intersection with a county road known locally as the Bloomfield connection.

It was necessary to make a side hill cut about 200 feet in length with a maximum height of approximately 35 feet. This excavation was completed during the summer of 1953. The soil encountered was principally a silty sand with varying amount of clay binder. During the winter of 1953-54 severe erosion and gullying of the cut slope occurred, together with some minor sloughing and local sliding.

In May and June a bench about 20 feet wide was excavated approximately 10 feet below the original top of cut, the excavation from this bench was pushed over the cut slope to fill up the erosion gullies and restore a uniform slope.

Upon completion of this resloping, seepage developed in the cut slope below the bench with local sliding reoccurring at the same location as previously. This sliding was of somewhat larger magnitude, with wet slide material moving onto the roadway. Cracking and bulging was in evidence on the cut slope for a distance of about 150 feet along centerline of the road connection. Considerable seepage was evident throughout the broken area. Only about two or three thousand yards

were involved at this time. It appeared that the slide would grow progressively worse and ultimately move beyond the slope line. This would create right-of-way problems and would jeopardize a water main just outside of the right-of-way.

Three methods of control were considered, as follows:

1. Removal of the loose slide material, construction of benches, and flattening of the slope; however, with the original slope being 1½:1, this indicated that a very flat slope might be required to stabilize the cut. With this method aquisition of additional right-of-way would be needed and the water main would have to be replaced. This appeared to be too costly.

2. Removal of the displaced slide material and covering the exposed wet slope with a heavy blanket of freedraining rock or gravel. This treatment would have been quite costly due to the necessity of using either a clamshell or dragline rig for placing the pervious material. No suitable pervious material was available with the project limits or in close proximity thereto. Importation of such material would be costly.

3. Subdraining the area by the installation of horizontal drains. Estimates indicated that such treatment would cost about $2000. To stay within the right-of-way the drains could not exceed 100 feet in length.

This latter method of subdraining the area with the installation of horizontal drains was chosen as treatment by the engineers reviewing the problem. It was believed that, although not a positive corrective measure, it would offer

reasonable assurance of controlling the slide at a minimum cost.

Twelve drains were placed from roadway grade to depths averaging about 80 feet. Grades varied from plus 15 to 20 percent. The average maximum initial flow rate for the twelve drains was 890 gallons per day.

Drying up of the spring areas on the face of the slide area occurred as the impounded ground water was intercepted by the progressive installation of the drains. By the time the work was completed the flow rate from the completed installation was only 2000 gallons per day. This rate has been typical of the flow during the wet seasons.

Total cost of the treatment amounted to $2350.00 which gave a unit cost figure of less than $2.50 per foot of installed drain.

As of this date no furthur slide movement of any consequence has taken place in the area, indicating that the treatment has been effective and was well chosen.

Santa Rosa Slide

During construction of the Santa Rosa by-pass in 1947 on U.S. Sign Route 101 it was necessary to make a small cut at the junction with the old highway at the north end of the city. This realignment involved cutting back the point of a ridge composed of a very silty sandy material. The maximum height of the cut was only approximately 20 feet and about 200 feet in length.

During the wet season immediately after construction minor sliding developed in the cut area. During the succeeding winters the sliding continued making it necessary to remove small amounts of material which slide onto the roadway. Since the slide was growing progressively worse during each wet season and was affecting property outside the right-of-way, it was decided that some steps to correct the condition should be undertaken.

Vertical borings were made in the slide area. Data from these borings together with seepage on the surface of the slide indicated that a considerable quantity of ground water was present.

Horizontal drains appeared to be the most logical and economical means of draining the critical area.

Thirteen horizontal drains were installed from two general locations. Five drains were fanned into the slide area from the north edge of the active slide. The remaining 8 drains were fanned into the area from the south edge of the slide.

Far more difficulty was encountered in installing these drains than had been anticipated. Quantities of sandy material which continually sloughed and caved, blocked the holes so the casing could not be advanced in many cases, resulting in the loss of nearly one-quarter of the hole drilled.

A total of 1645 feet of horizontal drain was installed with 1575 feet of casing being placed in 2078 feet of drilled hole. The drains developed a combined maximum initial flow of about 5000 gallons per day.

The flows produced by these drains were not as large as had been anticipated and the water levels in the vertical borings were not greatly lowered. Some parts of the slide area where it was desirable to place drains could not be reached due to the sandy material mentioned above. The drains installed did not produce any flows which continued in large enough volume to lower the water table in the area.

The advisability of placing the drain perforations down instead of in their normally upward position was considered, due to the possibility of the sandy material plugging the drain. However, two drains were flushed and no appreciable amount of silt was found and the flows did not increase. Consequently the perforations were placed up, so the intercepted water would be carried out of the slide area.

Movement in this area has continued. The interception of the ground water was not considered great enough for the installation to be considered a successful one.

This installation is used to illustrate that horizontal drains are not always successful, even though preliminary investigation and study indicates that their installation would be an effective and economical means of slide control.

SUMMARY

It is the opinion of the writers, based on their experience and the experience of other personnel in the Materials and Research Department of the California Division of Highways that:

1. Installation of drains should be preceded by investigation and planning by competent engineers with thorough knowledge of soils and geology.

2. The actual installation should be made by trained personnel who are proficient in this type of work.

3. The field work should be under the supervision of personnel with sufficient engineering and geologic background and with the authority to make changes in the installation as the need arises based on available information.

4. Much progress has been made in the development and utilization of available equipment, but there is still a large field for development in this direction.

5. Systematic inspection and maintenance is a vital part of the overall program of an effective horizontal drain installation.

6. Horizontal drains have a definite place in the correction and prevention of slides in the design, construction and maintenance of embankments and cuts, and when properly planned, installed and maintained they are effective.

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