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16. ABSTRACT

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STATE OF CALIFORNIA
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By

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Supervising Materials and Research Engineer

Presented at the Annual Meeting
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The American Society of Agricultural Engineers
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CONTROL OF SLIDES BY UNDERDRAINAGE

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A. W. Root*

Subdrainage of some type is one of the most commonly used methods of controlling landslides and probably one of the most effective. Ground water is generally believed to be the most important single factor causing land movement. R. F. Baker(1) has stated "Water is a contributing factor in practically all landslides, particularly those involving unconsolidated materials. Aside from the force of gravity, no factor is more generally present as a contributing factor." In his discussion of landslide correction, Terzaghi(2) states that "It is hardly an exaggeration to say that most slides are due to an abnormal increase of the pore-water pressure in the slope-forming material or in a part of its base. In such instances radical drainage is indicated."

Effect of Ground Water on Slope Stability

Since ground water is such an important causative factor in landslides, and subdrainage an accepted method of landslide control, the effects of subsurface water on slope stability should be considered. Water can affect the stability of a slope by a number of different physical actions, of which only a few will be mentioned. Increased weight of the soil due to

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saturation or wetting results in greater activating force tending to produce slide movement; the force of gravity is the one element common to all types of landslide. Aside from this weight factor all of the adverse effects of water are basically the result of reduction in shearing strength of the soil. Water may act in a variety of different ways to weaken the soil; for example, water may accelerate chemical weathering of rock, produce new or wider joints in rock by frost action, or alter the permeability of clay soils through volume change from wetting and drying.

However, the most common and major manifestations of strength reduction are: (1) decrease of cohesion resulting from excessive wetting of cohesive soils; and (2) decrease of frictional resistance due to increased pore-water pressure. Subdrainage for controlling landslides is used primarily for restoring the shearing strength lost by these two processes, that is, increasing the cohesion by lowering the moisture content, and improving the internal friction by reducing pore pressure. The increase in frictional resistance occurs as soon as the hydrostatic pressure is reduced and, therefore, effects an immediate improvement in stability; on the other hand, the increase in cohesion is likely to occur slowly and only when relatively complete subdrainage is accomplished.

The effect of ground water on slope stability is illustrated by the analysis of a landslide which occurred in a roadway cut on U.S. 99 north of Dunsmuir, California. Figure 1 is a typical cross-section through the slide, showing the water table at the time the sliding occurred, and also the lowered water table after subdrainage was accomplished by means of horizontal drains. The water levels were determined by borings which were cased to permit observation during and after the installation of the drains.

In analyzing this slide it was assumed that the factor of safety was unity at the time of failure, when the ground water level was high. The lowering of the water table by subdrainage, as indicated on the sketch, increased the factor of safety to 1.25. In this analysis no allowance was made for any increase in cohesion; only the effect of reduced hydrostatic pressure was considered.

Figure 2 shows a plan of the horizontal drains installed in this landslide. There has been no slide movement since the subdrainage was accomplished, and even during the current winter with unprecedented rainfall, the slopes have remained stable.

The effect of ground water on the stability of an embankment is illustrated by Figure 3, a cross-section of a roadway fill which failed suddenly before any subdrainage treatment could be undertaken. The ground water levels after failure occurred were determined by borings. The original ground water table was assumed. If the factor of safety were 1.20 with the water table at the lower level, the rise in ground water table to the level found after failure would have reduced the factor of safety to less than unity. This reduction in stability is due solely to the effect of excess hydrostatic pressure, without considering any loss in cohesion. The actual decrease in stability was probably much greater, due to the reduction in cohesive strength resulting from saturation of the soil when the ground water level raised. However, the effect of hydrostatic pressure alone would readily account for the slipout of this embankment.

Types of Landslide

Since all types of landslide are not equally amenable to control by subdrainage methods, it is necessary to consider briefly the numerous varieties of slope movement. The term "landslide" has been defined as "downward and outward movement of slope-forming materials -- natural rock, soils, artificial fills, or combinations of these materials."(3) Numerous landslide classification systems have been proposed; the nomenclature used in this paper refers to the landslide classification system described in "Landslides and Engineering Practice" by the Highway Research Board Committee on Landslide Investigation(4). Drainage is seldom used for controlling rock falls, soil falls or dry sand flows or debris flows. Control of wet earthflows, on the other hand, almost always involves some type of drainage treatment. Subdrainage as a control method is most frequently applied to those slides in which "movement is caused by finite shear failure along one or several surfaces which are visible or whose presence may reasonably be inferred." This class of slides includes the common "Slump" type in which the movement is rotational, and the "Block Glide" type in which the movement is planar.

Subdrainage Methods

Numerous methods of subdrainage have been used for controlling landslides, all with varying degrees of success. The design of the drainage system may be influenced by the nature of the slide control, that is whether preventive or corrective. In selecting the subdrainage method a great many factors must be considered, including: topography; permeability of the soils; depths and locations of the sources of ground water; and location of the zone of rupture, either potential or active. Control of landslides by any method is likely to be uneconomical or ineffective unless a thorough preliminary investigation and analysis are made.

It should be recognized that subdrainage is not a cure-all and should not be adopted indiscriminately as a control method for every landslide. Very small landslides can frequently be corrected more economically by other means. Impervious clay soils are not amenable to drainage unless there are pervious zones which allow more rapid movement of ground water.

Some of the drainage methods which have been used successfully are: interception drainage trenches, drainage tunnels, horizontal drains, and vertical sand drains. Frequently a combination of two or more types of drainage may be found most effective, and subdrainage is often used in combination with other treatment, such as restraining structures or slope flattening. Following is a brief description of some of the subdrainage treatments which have been used for controlling landslides in California.

Intercepting Trench Drains

Drainage trenches are often installed near the head of a landslide for the purpose of intercepting ground water before it enters the slide mass or unstable area. Such trenches are commonly excavated with back-hoes or draglines, and after placing an underdrain conduit the trench is backfilled with filter material. Such drains are usually effective only if the following conditions obtain: (1) the trench is carried down into an impervious layer so that no water flows below the bottom of the drain; (2) the underdrain will not be destroyed or damaged by slide movement; and (3) there are no aquifers at elevations below the bottom of the trench which can supply water to the slide area. Figure 4 illustrates the use of an intercepting drain.

Conformance to the first two requirements can generally be determined by thorough preliminary exploration, but the presence of other and deeper aquifers is not always revealed by borings. Although these intercepting trenches have in some cases effectively controlled landslide movement, the percentage of failures has been high. It is the author's opinion that this type of drainage treatment should be used with caution, and only after a comprehensive exploration has been made.

The depth to which the interception trench can be excavated economically is limited, and cave-ins or slides into the open trench may constitute a problem. Where the depth of the aquifer exceeds the practical depth limit for trench excavation, a variation of the trench principle has been used. This consists of a row or two rows of closely spaced wells 36" to 48" in diameter bored to the required depth with power augers; the bottoms of the wells are interconnected by a conduit installed in a short tunnel excavated manually between adjacent wells. A suitable outlet must, of course, be provided to drain such a drainage gallery. The wells are backfilled with pervious material. These drainage galleries serve the same purpose as an interception drain, but can be excavated much deeper than an open trench. In other respects this system is subject to the same deficiencies and limitations which apply to the trench system.

Stabilization Trenches

A drainage method which has been used extensively by the California Division of Highways for preventing embankment failures consists of construction of stabilization trenches in the unstable foundation area before constructing the embankment. These trenches, which are excavated by scrapers or other power equipment, are carried down into firm material below any aquifers; the side slopes are designed with the steepest slope which will be stable during the time required for excavation and backfill, usually 1:1 or 1½:1 (1½ horizontal to 1 vertical) slopes. An underdrain pipe is placed in the bottom of the trench and the bottom and side slopes of the trench are blanketed with a layer of filter material about three feet in thickness. The remainder of the trench is backfilled with material from roadway excavation, thoroughly compacted.

The location and number of such stabilization trenches depend on the terrain, size of embankment, character of the soil formation and the location of water bearing layers and weak zones. In a confined fill area one trench normal to centerline may be sufficient; for larger areas a trench more or less parallel to centerline may be located under the fill, often between the shoulder line and the lower slope line; under some conditions a Wye, Tee or herringbone configuration may be required.

Although these stabilization trenches are primarily drainage trenches, they are listed as a distinct type of treatment because they differ from the usual interception trenches in two respects. In addition to the drainage function these wide trenches with compacted backfill act in some degree as earth buttresses, and provide an appreciable increase in restraining force, as compared to a conventional underdrain. Also, the dimensions and construction methods are different, as the excavation is made with usual earthmoving equipment and no shoring is required. The depth limitations of the intercepting trench do not apply to the stabilization trenches; depths of 25 ft. to 30 ft. are common and some have been excavated to depth of fifty feet or more.

Figure 5 shows a plan and Figure 6 a typical cross-section of a stabilization trench designed to prevent sliding of an embankment on a project now under construction on a portion of the Redwood Freeway, U.S. 101. The magnitude of the slide control treatment on this contract is indicated by some of the contract quantities:

153,000 Cu. yds. of trench excavation,
98,000 Tons of filter material, and
10,000 Lineal feet of horizontal drains

Drainage Tunnels

Where trenches of any kind would be impractical because of the depth of the water bearing zone, drainage tunnels have been used to control landslides. Only a few drainage tunnels have been used by the California Division of Highways, but some of the other States and the railroads have installed a considerable number of drainage tunnels in the past. The use of tunnels has greatly diminished in recent years because of the current high costs, and also due to the fact that other methods have been developed.

A unique and interesting variation of the drainage tunnel used for controlling a landslide in the Palisades near Santa Monica in Southern California has been described by R. A. Hill[5]. This installation, in addition to providing outlets for drainage of gravitational water, incorporated a hot-air furnace for circulating heated air to dry out the soil.

Drainage tunnels have been used successfully for controlling large slump type landslides in natural slopes and for stabilizing embankments founded on wet unstable soil. Subsequent to the development and wide spread adoption of the horizontal drain method, drainage tunnels have been used infrequently; however, in spite of the high cost of tunnels, there are certain conditions where they may be the only feasible means of providing subdrainage.

Horizontal Drains

Horizontal drains, which consist of perforated casing installed in a hole bored into a slope at a slight angle to the horizontal, have been used by the California Division of

Highways since 1939. In recent years many other agencies have made numerous installations of such drains. One of the most extensive systems of horizontal drains was installed in a large landslide area in the oil fields near Ventura, California, where the aggregate length of drains exceeded forty miles. The method of installing horizontal drains and examples of their usage have been described by Smith and Stafford, 1955[6].

Horizontal drains have been used effectively both for correcting and for preventing landslides; they have been installed in many natural slopes and cut faces, and are used both for controlling landslides in cuts above roadway grade and for embankment slipouts. The majority have been effective in controlling landslide movement, but there have been a few failures. No one type of corrective treatment will be effective or economical for all landslides, and horizontal drains should not be considered a panacea. Slides may occur in clay soils with such low permeability that drainage will be too slow to permit control of the movement. Any increase in cohesion occurs very slowly, and increased frictional resistance accounts for the principal increase in shear strength dervied from reduction in hydrostatic pressure; hence, the initial increase in shearing strength of clays with uniformly low permeability and very small angle of internal friction is likely to be relatively small.

Horizontal drains are currently being installed under several highway fills where the high ground water level has caused incipient failure. In all cases where the subdrainage has been effective in lowering the water table and reducing hydrostatic pressure, the fills have been stabilized and slide movement has ceased.

A number of horizontal drain treatments have been described in published reports. Figure 7 shows a cross-section of a large landslide which was controlled by subdrainage with horizontal drains.

Vertical Sand Drains

Vertical sand drains are extensively used for stabilizing saturated soil under fills or other structures; this type of drain consists of vertical wells, usually 12" to 24" diameter, backfilled with clean sand or other pervious material, together with a blanket of filter material over the treated area for draining the water laterally. The drains normally extend to the bottom of the layer of weak compressible soil; in plan, the drains are generally installed in a grid pattern, with spacing varying from 8 ft. to 20 ft. or more.

Such drains serve a dual purpose: consolidation of the compressible soil is accelerated, thus reducing a post-construction settlement; by reducing pore pressure the drains improve the shearing strength of the soil and thereby serve as a slide preventative. Vertical sand drains have been installed almost exclusively as a preventive measure rather than for correction of a landslide. However, a novel application of sand drains for controlling an active landslide has recently been reported by Dick Braun(7). On this project, near Minneapolis, Minnesota, a slipout 700 ft. long occurred in an embankment under construction at a time when the proposed 75 ft. fill had been built to a height of about fifty feet.

Vertical sand drains are now being installed as remedial treatment of the slide.

Vertical sand drains have proved very successful under certain conditions, but should never be used until a careful analysis has been made to evaluate the need for and effect of sand drains. If the soil has sufficient strength to support the proposed loading and is so pervious that virtually all settlement will take place during the construction period, a surcharge may be just as effective as sand drains. If, on the other hand, the soil is extremely impervious, the consolidation and concomitant increase in shearing strength may be so slow that vertical sand drains would be ineffectual for any reasonable construction period. In such cases the embankment may fail during the loading operation or settlement may continue long after completion of the structure. Failures of both types are not uncommon, but can be avoided by proper testing and analysis during design stages.

Surface Drainage

Although the subject of discussion is subdrainage, mention should be made of the importance of surface drainage in slide control work. Obviously, it is better to intercept and remove surface water at the source, rather than to allow it to percolate into the slide mass and attempt to remove it by subdrainage. Proper surface drainage should be the first step in any drainage work for controlling landslides. All necessary measures should be taken to prevent surface runoff water from entering the slide; methods for improving surface drainage include: sealing of cracks; reshaping the slopes to prevent ponding; construction of paved surface ditches; treating the slopes with bituminous or other material.

Summary

In the majority of landslides, especially the slump type, ground water is a major factor causing the slide movement. Several different types of subdrainage have been used successfully for correcting and preventing landslides. Frequently subdrainage of some type is used in conjunction with other control treatments. It is emphasized that subdrainage is not always the most economical or most effective method of controlling a landslide. The most appropriate method of treatment can be designed only after a careful exploration, analysis and evaluation. By judicious application of the principles of soil mechanics the probable effectiveness of alternate control methods can be compared; the best type of control treatment can then be selected by making economic analyses.

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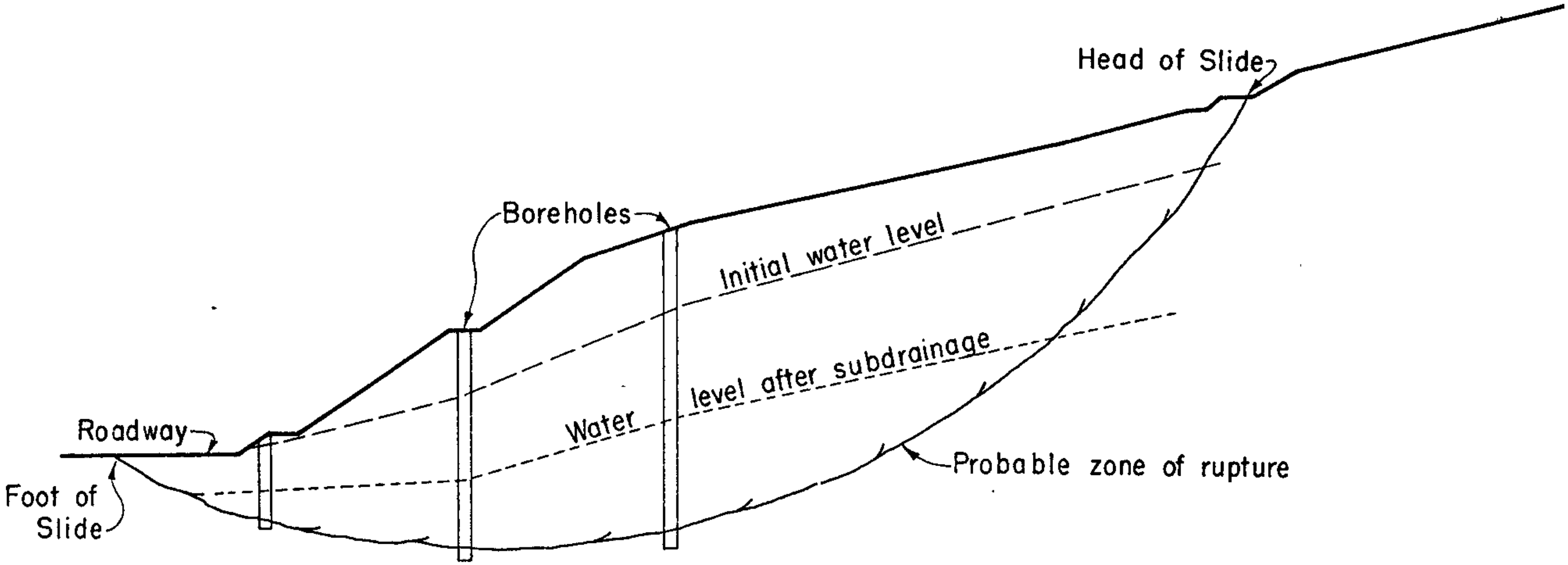


Cross-section through Dunsmuir landslide

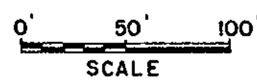
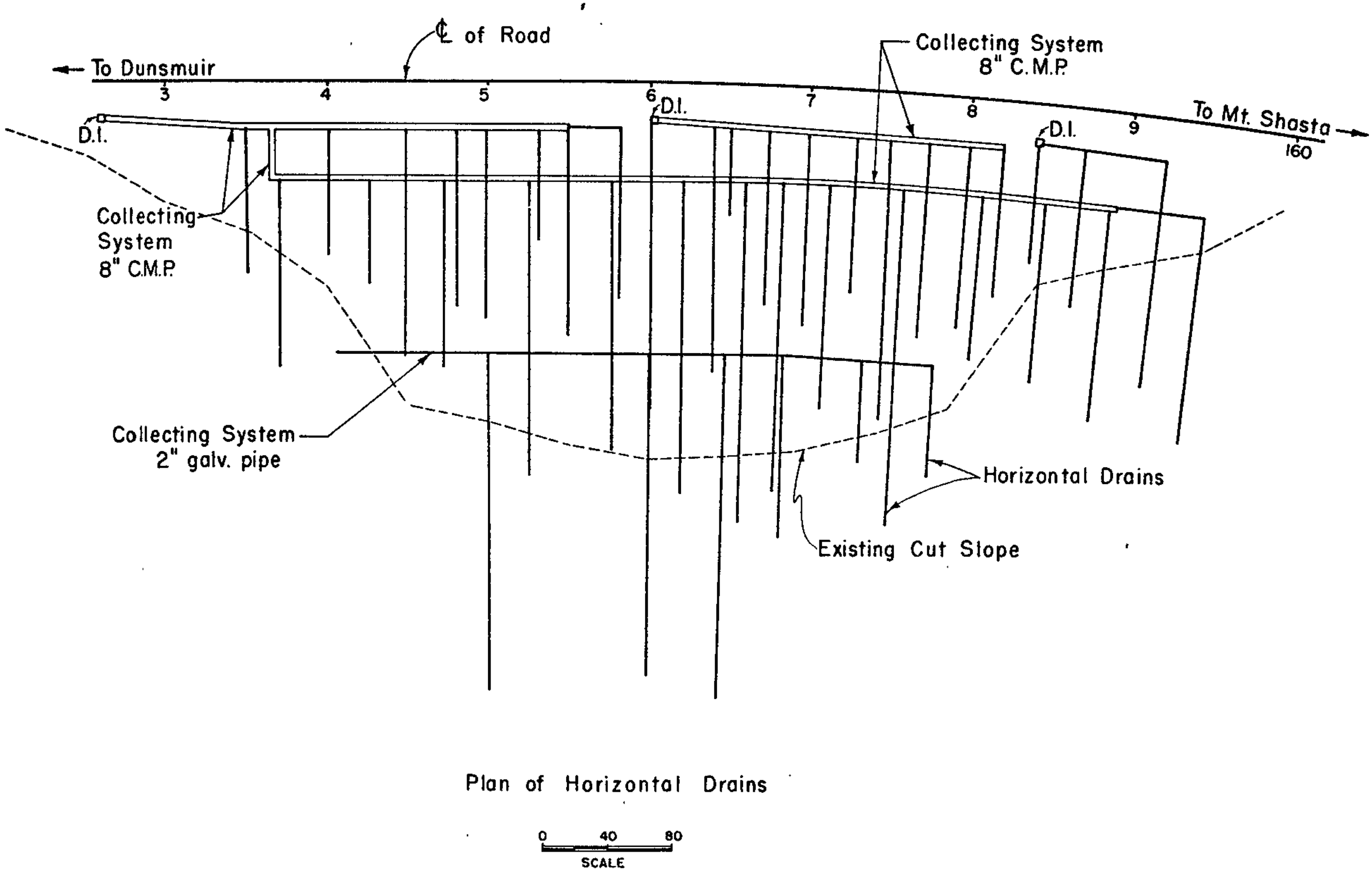
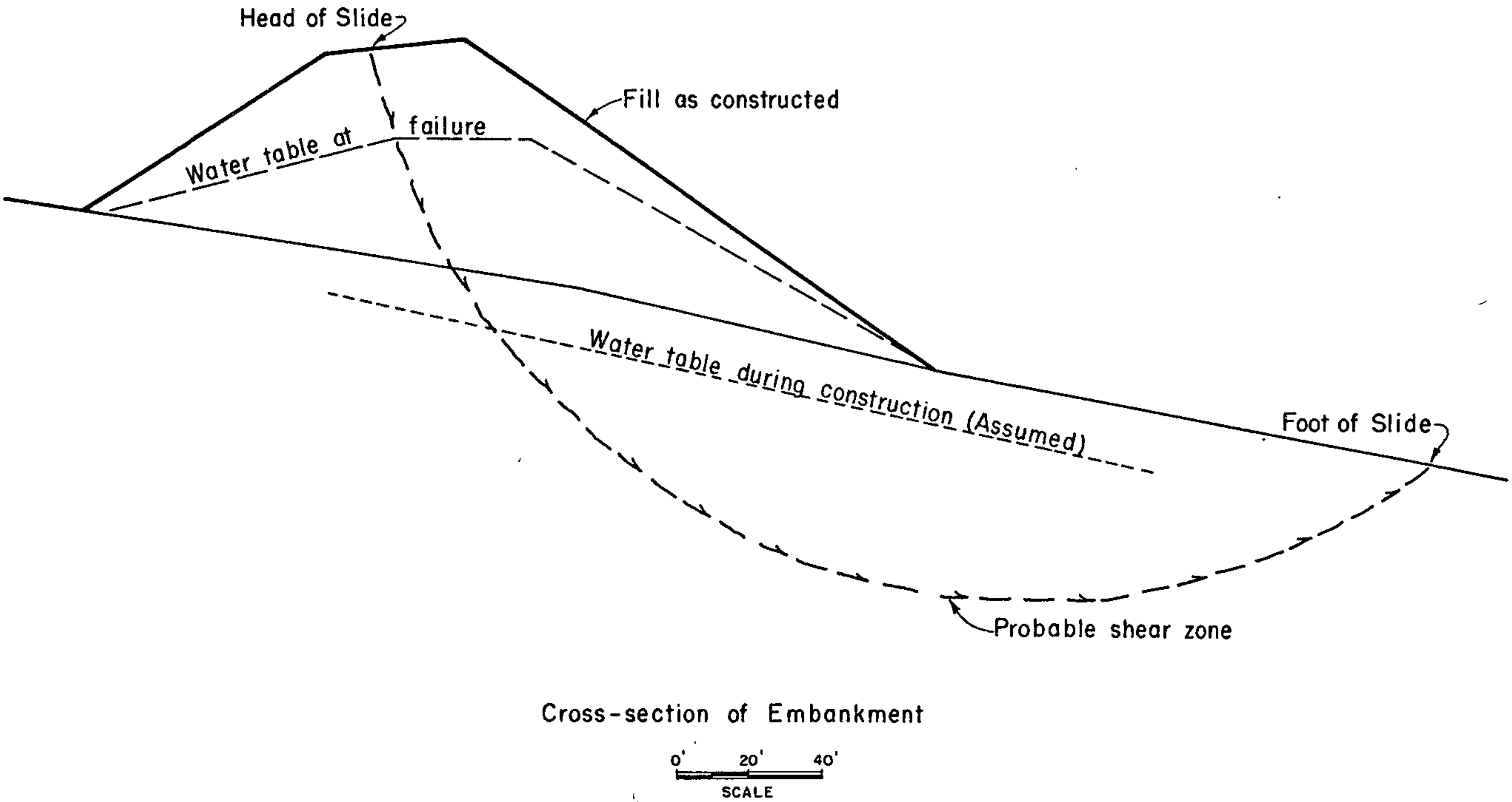


Figure I



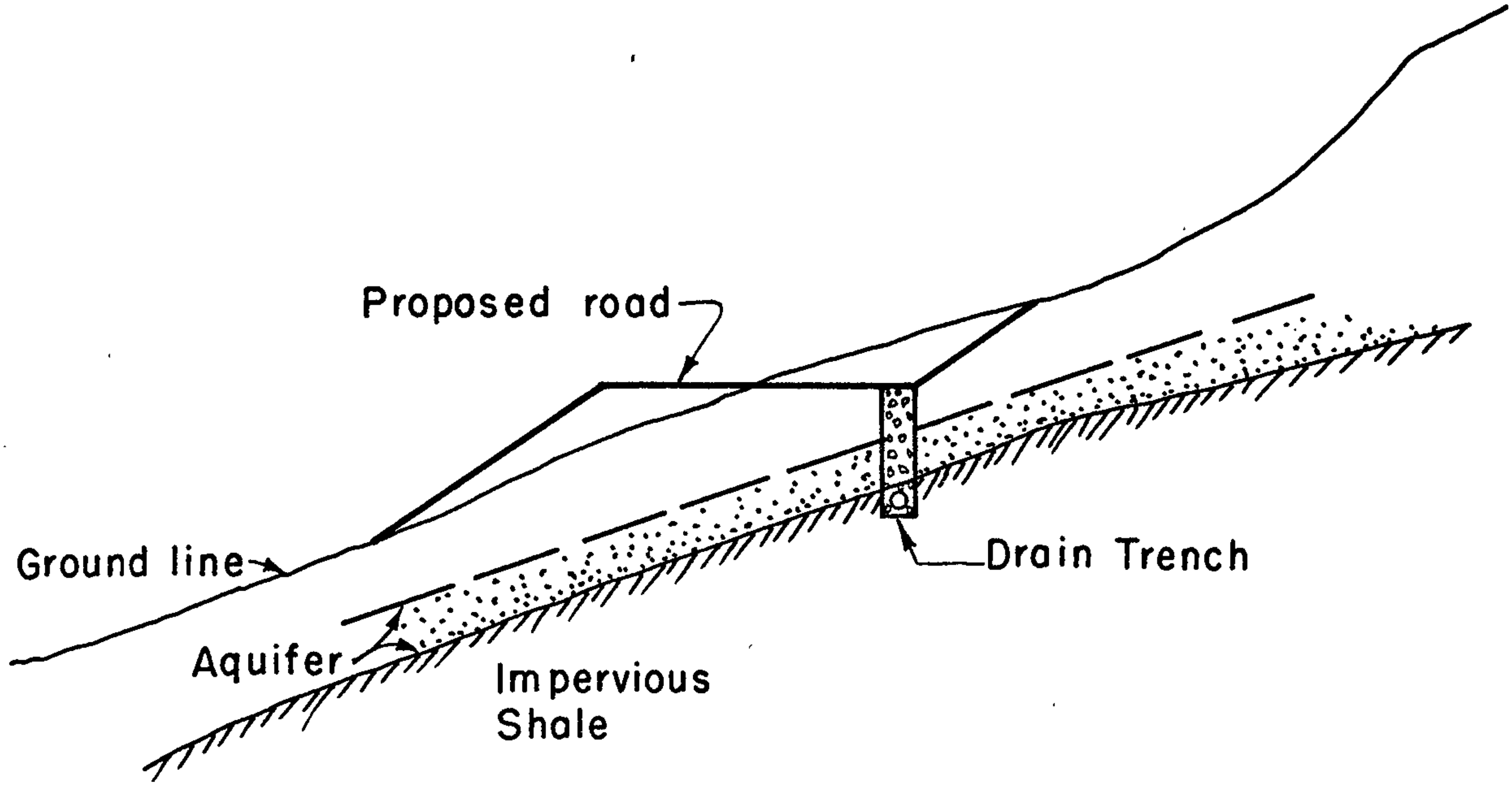
Plan of Horizontal Drains

Figure 2



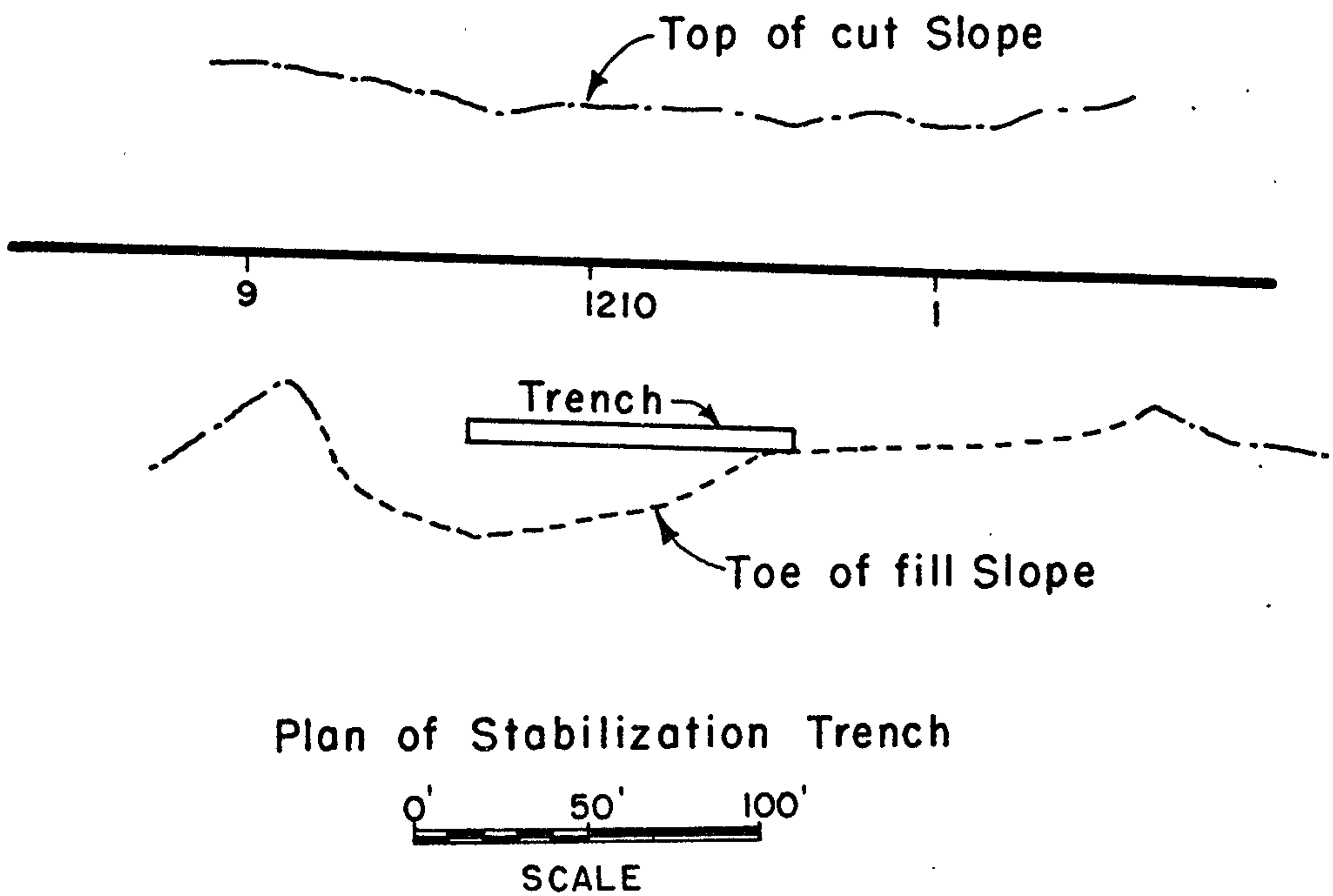
Cross-section of Embankment

Figure 3



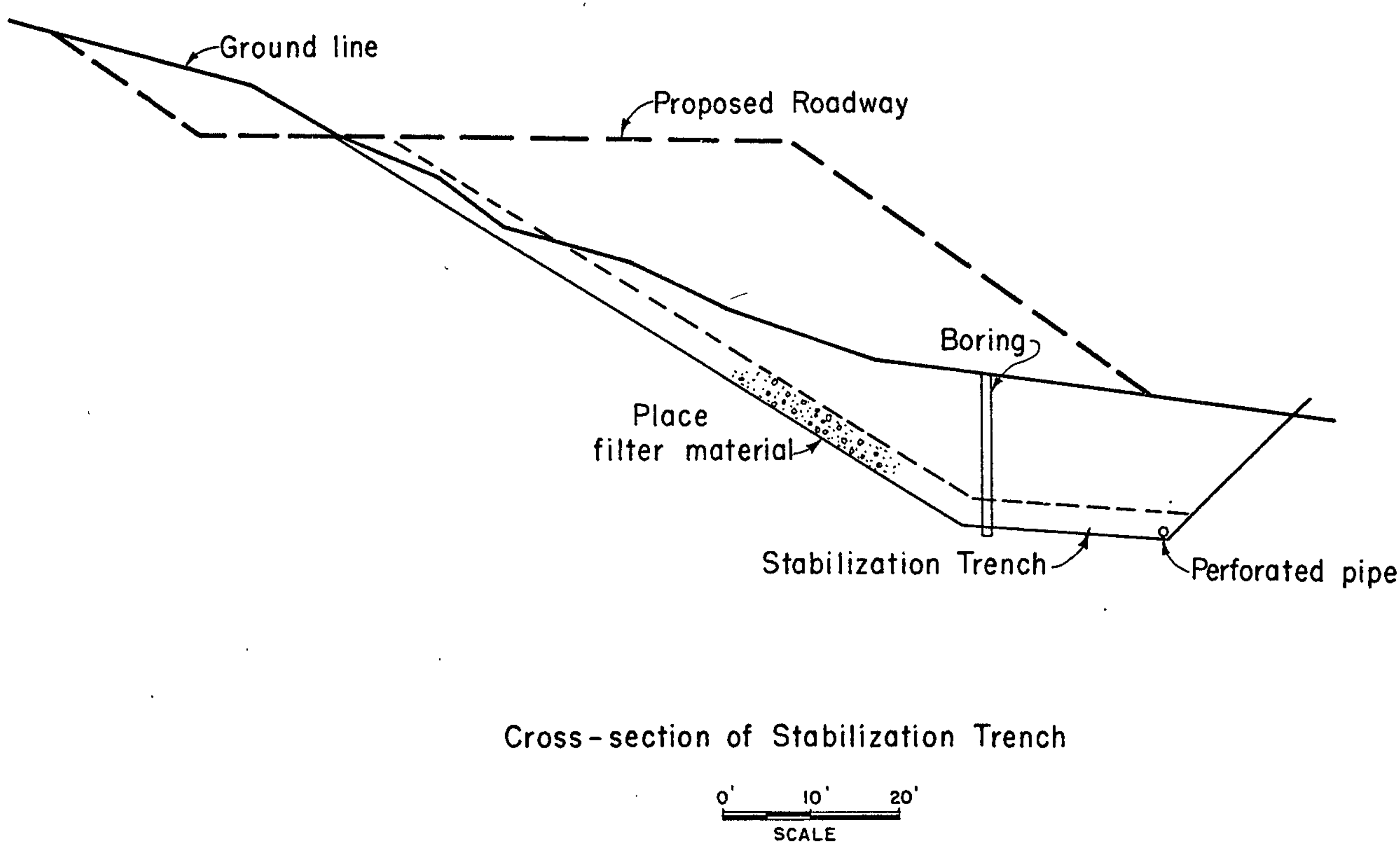
Intercepting drain: Schematic cross-section

Figure 4



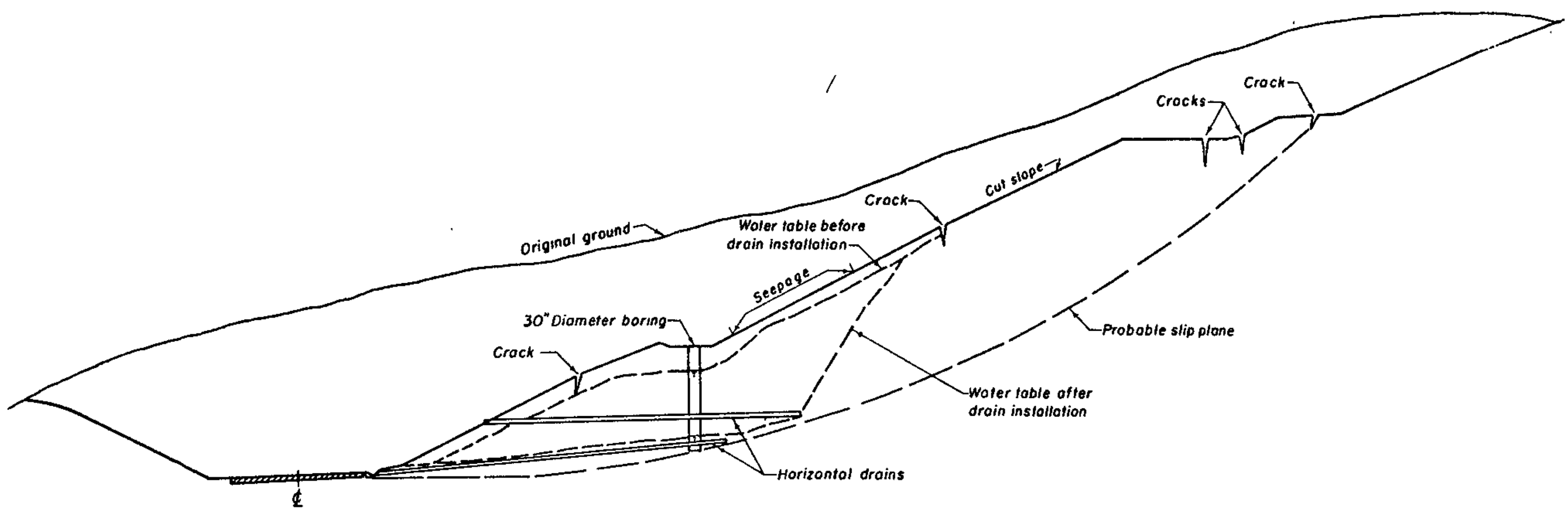
Plan of Stabilization Trench

Figure 5



Cross-section of Stabilization Trench

Figure 6



Typical cross section of slide
with horizontal drains

Scale~ 0 10

Figure 7