Ground Water Control for Highways

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Two recently completed highway contracts are used as a background for the discussion of subsurface drainage procedures in use in the design and construction of highways in California.

Investigations to determine the needs for subsurface drainage are described and can be grouped under field reviews, geologic studies, borings, tests, and analyses.

Methods of subsurface water controls most commonly used are stripping and blanketing with permeable material, stabilization trenches, horizontal drains, and other somewhat specialized measures. The application, construction, and effectiveness of these methods are discussed.

Particular consideration is given to the characteristics of the permeable material that is used as a part of most of the subsurface water control measures.

•CONSTRUCTION OF FREEWAYS covered by two contracts will be used as a background for discussing subsurface drainage practices in the construction of highways in California. Under these two contracts, approximately 7.8 mi of freeway were constructed along I-5 in the northern part of California. The construction started in the latter part of 1958 and was completed early in 1961.

The magnitude of the subsurface drainage that is involved on major highway construction in the fairly mountainous terrain (Fig. 1) can best be illustrated by comparing the costs of construction of these two projects and the costs of the subsurface drainage facilities.

The first contract awarded in 1958 was for \$4,140,000 of which \$434,000 or approximately 10 percent was for subsurface drainage facilities. Contract Change Orders in the amount of \$860,000 were approved, and \$86,000 or 10 percent of this amount was for subsurface drainage facilities. Thus, the total contract for \$5,000,000 included \$520,000 or approximately 10 percent for subsurface drainage facilities.

The other contract was started in 1959 and was for approximately \$5,095,000 and the subsurface drainage facilities represented \$965,000 or approximately 19 percent of the total cost. Contract Change Orders in the amount of \$944,000 were approved and of this amount \$82,000 or 9 percent was for subsurface drainage facilities. Of the original drainage facilities, \$200,000 was deleted. Thus, on the total contract for \$6,038,000 the subsurface drainage facilities represented \$847,000 or approximately 14 percent. Certainly these expenditures totaling some \$1,367,000 out of a total of a little more than \$11,000,000 indicate that a substantial portion of the expenditures for highway construction in this type of terrain is for subsurface drainage. The actual breakdown of items for ground water control and costs is given in Table 1.

Ground water is a major factor in instability of embankment foundations and cut slopes. By far the majority of landslides on California's highway system are the results of instability caused by subsurface water. The most common means of improving stability is removal of the ground water. If the ground water is not removed or adequately controlled, landslides often result and these may be very serious in regard to disruption of traffic as well as cost. Figure 2 shows destruction of a portion of highway caused by

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Figure 1. Typical mountainous terrain.

Figure 2. Landslide—fill foundation failure.

TABLE 1

COMBINED COSTS OF CONTRACT ITEMS FOR GROUND WATER CONTROL[1]

Item	Cost ($) Unit	Total
Stabilization trench excavation	1.30 cu yd	512,962
Permeable material:		
Stabilization trenches and blankets	1.65 ton	286,844
Underdrains	7.00 cu yd	93,792
Drainwells	5.75 lin ft	98,270
PMP underdrains	2.00 lin ft	139,008
Horizontal drains	2.75 lin ft	224,443
Collector pipes	2.00 lin ft	11,300
Ground water control items		1,366,619
Other contract items		9,672,658
Total		11,039,277

[1] Contract Nos. 59-2TC18 & 60-2TC2.

failure of a fill foundation. Traffic was detoured for several weeks over a rather inadequate detour and the cost of correction and reconstruction was in excess of $100,000.

IMPORTANCE OF SUBDRAINAGE

Subdrainage has become increasingly important as a means of stabilization of cut slopes and foundations for embankments in highway construction in California in recent years. The mountainous terrain and the high annual rainfall of northern California have combined to create a situation conducive to foundation problems (1).

Three factors have contributed to the increased importance of subdrainage. First, the necessity for more favorable alignment and grade in highway construction has resulted in much larger cuts and fills in the mountainous terrain that is prevalent throughout much of California. Second, traffic volume has, on much of the highway system, made the older two-lane road obsolete, and it has been necessary to replace it with modern freeways with four or more lanes. This has also resulted in cuts and fills of far greater magnitude than were necessary a few years ago. Third, much of the mountainous terrain, particularly in northern California, is located in areas of moderately high rainfall and somewhat poor foundation conditions.

If subsurface water exists and stability of fill foundation or cut is somewhat doubtful, removal or alleviation of the adverse subsurface water conditions is usually a must. To ignore the subsurface water in the construction of cuts or fills in these areas, in the hopes that construction or natural conditions will improve the subsurface drainage, can be a disastrous and costly process. Almost without exception it is more economical and more practical to correct adverse subsurface drainage conditions before construction rather than to attempt to handle this situation as a maintenance operation.

METHODS OF ANALYSIS AND DESIGN

Exploration

In the design and construction of the subsurface drainage facilities for highways, exploration plays an important part. The various stages of the exploration usually consist of one or more of the following parts: field review, geologic studies, borings, tests, and analysis of data.

Field Review

In the early stages of any project, usually as early as the planning stage and certainly during early phases of design, a field review is made to determine to some degree the foundation problems that may be encountered and to obtain some impression of the magnitude of corrective measures that may be necessary to construct a stable road. This field review will usually include representatives of several departments such as planning, materials, design, and construction and will serve as a basis for making the further studies that will be necessary for design of foundation treatments.

As the design nears completion, a more detailed field review should be made to study the relationship of the planned subsurface drainage features to the project as a whole to make certain all anticipated problems have been provided with a satisfactory solution. This review will usually include representatives from some or all of the units involved on the earlier field review.

The following is a quotation from a letter prepared as a result of a field review made in connection with one of these projects:

> At all locations where embankments are to be constructed the borings show foundations of questionable stability. The soil is predominantly wet soft clay containing numerous cobbles and boulders. Free water was encountered in most of the borings, apparently in large quantities. The depth of the wet material was indeterminate; in several of the borings no firm material was found at depth of about 70 feet, the maximum depth penetrated.
>
> Although the transverse slope of the natural ground is relatively flat, it is our opinion that the risk of embankment slipouts will be excessive unless extensive sub-drainage treatment is provided. Fill failures would not only cause interruption to movement of traffic on the freeway, but would also jeopardize or destroy streets and buildings adjacent to the right-of-way.

Geologic Studies

Some of the districts in the Division of Highways have engineering geologists on the staff of their Materials Departments. The Materials and Research Department, a headquarters unit of the Division of Highways, also has several engineering geologists on the staff. Typically, Materials Reports include a geologic description of the area involved in construction. The nature and magnitude of the geologic mapping and study that is done will depend to a large degree on the nature of the topography, type of terrain and magnitude of the problems encountered. The following is a quotation from the geologic phase of the Materials Report on one of the projects:

> The project is located on the west side of the Sacramento River Canyon and traverses rugged mountainous terrain. Rock types found within the limits of the project consist of ultramafic rocks of various types, some with a schistose structure. The rocks have a general northeast-southwest strike and dip steeply to the southeast. Recent flows of pyroxene andesite are found along both sides of the canyon and occupy earlier channels of the river. The present channel of the river follows the trend of the weaker rock structure in the ultramafic rocks and is in part responsible for the many slides that occur in the canyon. The soil mantle in general is silty clay, sandy gravelly clay, tuffaceous clay, silty sandy gravel and residual boulders of various types.

Borings

The drilling that is done in exploring projects of this nature is determined largely from field reviews, available geologic information and information obtained as drilling progresses. On the two projects under consideration, a total of 150 borings were made. These borings varied in depth from a few feet to in excess of 100 ft. These borings included considerable exploration in connection with cut slope design, as well as the borings necessary for fill foundation stabilization which consists primarily of subsurface drainage. Most of the borings were made with power equipment and continuous flight augers. A limited amount of exploration was done with power equipment and 2-in. diameter samplers that are pushed or driven to obtain undisturbed soil samples for visual inspection and testing. Some sampling was done with 1-in. diameter hand-driven samplers to secure samples primarily for visual inspection. The exploration was concentrated in the areas where field review and geologic mapping indicated that questionable foundation conditions might exist. Most of the exploration was done during design stage after the actual line and grade had been adopted. In areas where this exploration revealed extremely unfavorable foundation conditions, line or grade changes were frequently made to improve stability. An appreciable portion of the exploration was done in the early stages of construction after clearing and pioneering had been completed. This exploration was aimed primarily at more completely delineating the extent of foundation treatment required and exploring areas where foundation problems were encountered during construction that had not been evident during design.

Testing

The testing on these two projects was rather limited, due primarily to the nature of the problems encountered and to the type of soils and rock that were present. Much of the foundation soils for the embankments consisted of layered or heterogeneous combinations of fairly firm soil mixed with rock; and soft saturated clays, silty clays or clayey silts intermixed with soft to hard rock. Most of these softer formations or zones were water bearing. Figure 3 shows a typical boring profile. Securing representative samples of these softer materials was difficult although some testing was done to get a comprehensive picture of the strength characteristics of this material. The testing consisted primarily of unconfined compression tests and a limited quantity of consolidation and triaxial compression tests. To supplement these tests, numerous unit weight, moisture content, grading, and Atterberg limits tests were made.

Ground Water Observations

A careful survey was made of evidences of ground water and seepage in the area where the two projects being described were to be constructed. As the borings were made, signs of excess moisture or seepage were carefully noted. Soil samples were examined to determine moisture conditions, and the borings were sounded frequently during drilling operations to determine if there was free water in the borings. Measurements were made of the rise of water in the borings subsequent to completion of the borings.

During construction, observations were made to determine the effectiveness of the ground water control measures that had been or were being incorporated in the construction. Ground water conditions were observed in the various excavations as they were made. Observations were also made of flows of water from the various ground water installations that were a part of the construction.

During construction of the projects, pumping tests and drawdown observations were made in vertical relief wells that are described later. These tests were made to determine the effectiveness of the combined installation of vertical relief wells and horizontal drains. Figure 4 shows typical pumping test data depicting the drawdown.

Analysis of Data

Information available from the field review, geologic studies, borings, tests and analyses was used in an effort to determine the nature and magnitude of any corrective measures that were necessary to construct a stable road. Subsurface drainage facilities were incorporated in the design when it was believed that data from the aforementioned sources of information indicated that cuts or fill foundations would be unstable or borderline for stability. The most common situation that indicated the necessity

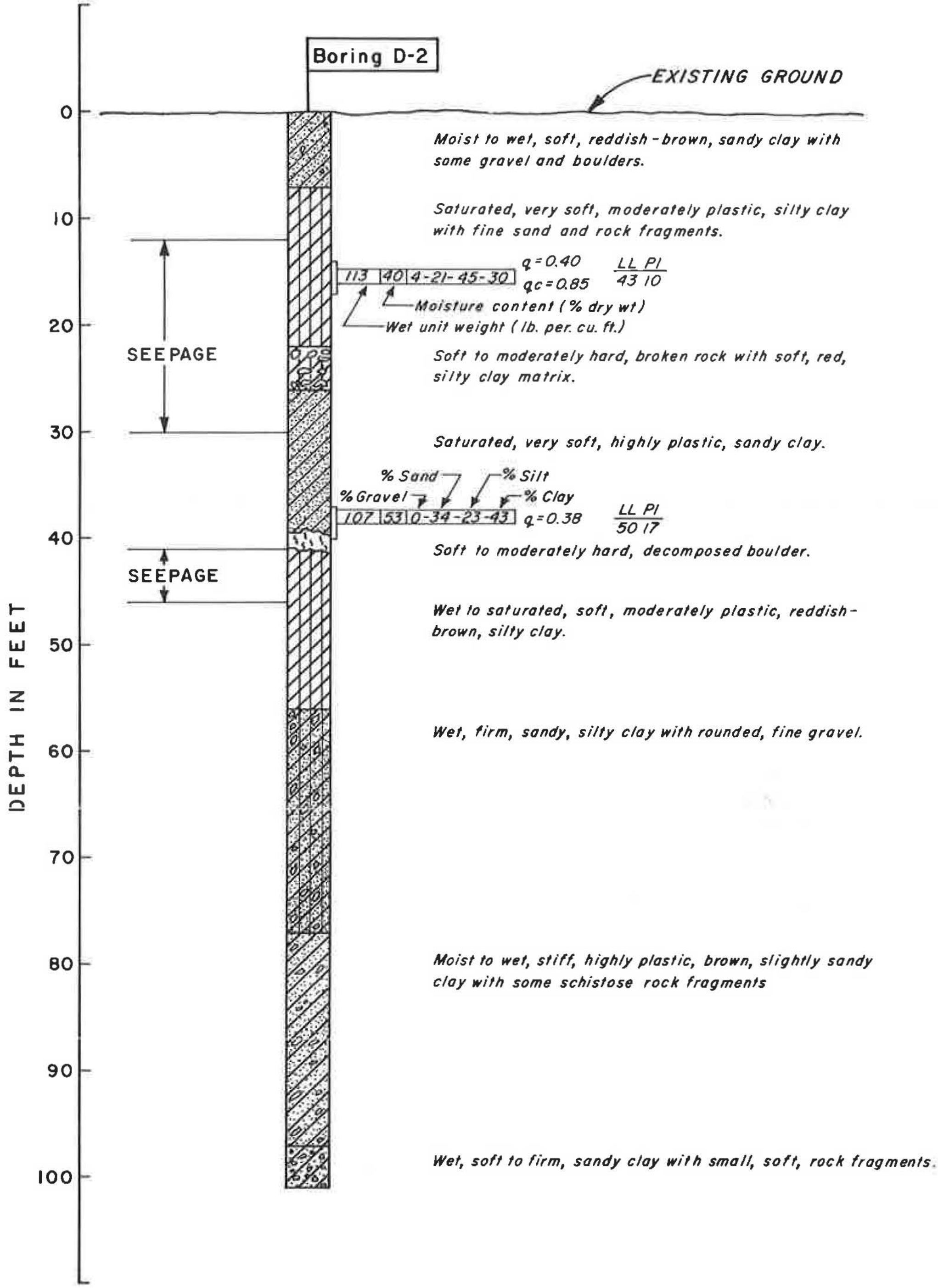


Figure 3. Typical boring profile.

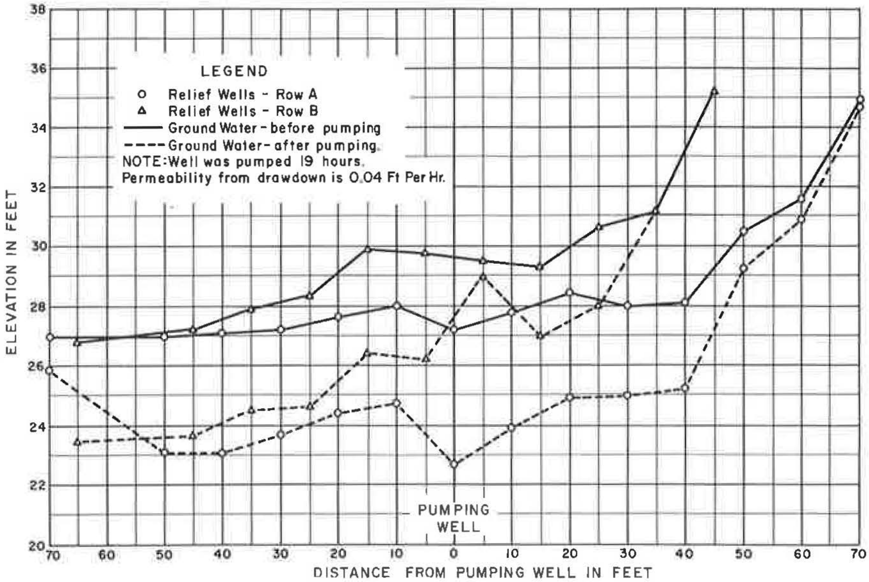


Figure 4. Typical graph of drawdown in vertical relief wells.

for subsurface drainage on the fill foundations was layers of water-bearing soft material interspersed with drier, firmer layers of soil containing more rock. Strength testing was concentrated in the soft zones. If embankments are placed over these areas, there is usually a tendency to compress the water-bearing strata and to reduce the ability of these strata to provide drainage. Thus, hydrostatic pressures are increased, especially during wet seasons and the stability of the foundations is endangered. Experience in the California Division of Highways indicates that most of the problems in subsurface drainage occur in soils of grain sizes that normally would be classified as relatively impervious. Most of the water appears to be moving in strata that are relatively fine grained and that may contain relatively high percentages of clay. The water is moving along fissures, fractures, joints, or bedding planes that are somewhat more capable of carrying water than the main soil mass.

It is apparent that the soil conditions and types of formations described previously do not lend themselves readily to rigorous solutions by the usually accepted soil mechanics procedures. Rather, the design of subsurface drainage facilities under these conditions is largely a matter of using the information available from all sources such as field review, geology, borings, tests, and analyses, as an aid to experience and judgment in the design of these facilities. More rigorous soil mechanics procedures are used assuming certain parameters in checking the designs that are indicated by the rational methods previously described.

METHOD OF DRAINAGE

Several methods of drainage or treatment are used depending on soil conditions and ground water conditions that prevail. The subsurface drainage methods that are most commonly used to stabilize fill foundations are (a) strip and provide a drainage blanket, (b) construct stabilization trenches, (c) install horizontal drains, and (d) occasionally use relief wells. The most commonly used methods of subsurface drainage in cuts are underdrains and drainage blankets or horizontal drains. The methods used are discussed separately, although in actual practice subsurface drainage at any single location frequently entails a combination of two or more of these procedures.

Stripping and Blankets

If the zone of water-bearing material is fairly shallow, less than 10 to 20 ft, and is

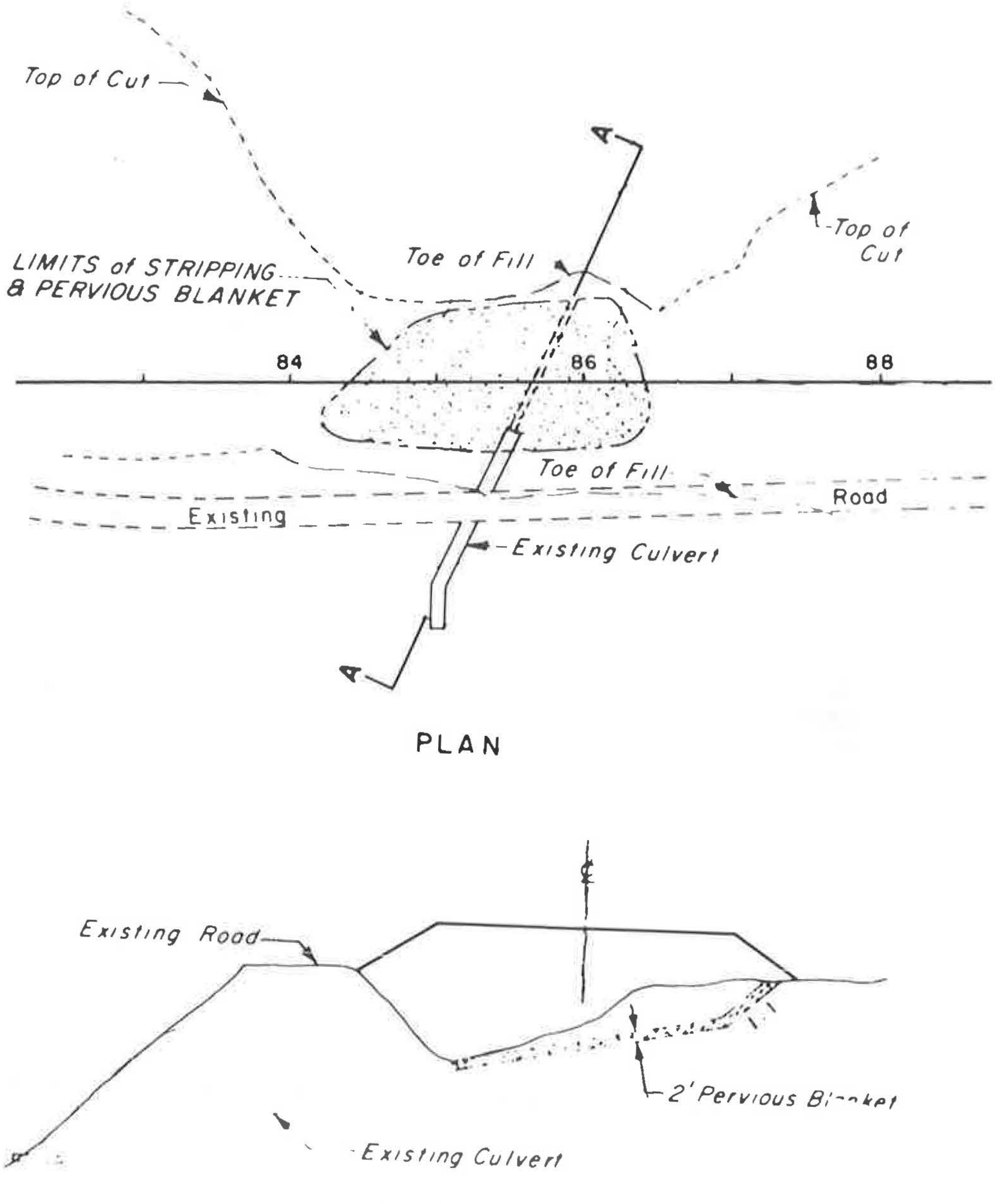


Figure 5. Stripping and blanketing.

underlain by firmer material, a common method of treatment is to strip the soft material and to provide a pervious blanket to remove the ground water. This procedure is illustrated in Figure 5 which shows a plan and cross-section through an area where stripping and blanketing were accomplished. This procedure serves a dual purpose of removing the wet, weak material and replacing it with material that is compacted and of appreciably higher strength. It also provides a layer of permeable material which serves as a means of egress for the ground water, the primary cause of the trouble. Limiting conditions for the use of this type of treatment would be the depths of the soft, water bearing material, and slopes of the surrounding area which would determine the feasibility of providing outlets for the drainage layer. If this procedure is adaptable to the conditions that exist, it is a relatively positive method of correction. One precaution in its use is to determine by exploration that all of the water-bearing material is actually being removed, and that the stripping does not merely extend to a zone of stronger material that in turn is underlain by weaker, water-bearing material that is the basic source of the ground water.

The nature of the permeable material that is used for the blankets is discussed later. Experience has indicated that it is inadvisable to provide a pervious blanket without also providing a perforated pipe to remove the water from the pervious blanket.

Stabilization Trenches

Stabilization trenches to remove the subsurface water were used extensively on the two contracts under consideration. The method of exploration where stabilization trenches are used would be identical with the exploration that would be necessary if stripping and pervious blankets are used. In fact, stabilization trenches might be considered a special type of stripping operation. Much of the credit for the development and early use of stabilization trenches should be given to A. W. Root who was for many years head of the Foundation Section of the Materials and Research Department (2). He retired from service with the California Division of Highways in April 1962. A plan of a longitudinal stabilization trench is shown in Figure 6 and a cross-section of a similar trench is shown in Figure 7. Trenches may be either longitudinal or transverse, depending on the terrain and the relationship of the topography to the roadway. Stabilization trenches have been used most extensively where subsurface water is encountered in the exploration at depths between 10 and 30 to 40 ft below the existing ground. Trenches have been generally constructed with a bottom width of 12 ft or more and with side slopes as steep as they will stand during construction. The bottom width of 12 ft or more is largely predicated on the use of usual dirt-moving equipment for excavation. The side slope can generally be constructed somewhat steeper than it is anticipated would be possible for permanent construction, because in the normal construction operations trenches will be constructed and backfilled within a few days to a few weeks. Typically, on the two contracts under discussion, side slopes on the trenches were in the order of 1:1 to 1½:1. Figure 8 shows the completed excavation of a longitudinal stabilization trench. This same stabilization trench is shown in Figure 9 during placement and compaction of backfill material. Some slides within the trenches occurred when side slopes of 1:1 were used especially in cuts of 20 ft or more in height. Almost no difficulty with slides was encountered where 1½:1 side slopes were used even though the slopes were high (50 to 100 ft or more). Maximum depth at centerline of the trenches on these two contracts was in the order of 25 to 35 ft. Thus, slopes on the low side of the trench were in the order of 10 to 25 ft, and on the high side, slopes in the order of 50 ft or more were not uncommon. Generally the bottom, high side and ends of the trenches were blanketed with a layer of 3-ft thick permeable material. One or more perforated pipes were placed in the bottom of all of the trenches to remove the water from the stabilization trench. An outlet was provided to remove the water from the lower end of the trench. These outlets in reality usually constitute a short transverse stabilization trench. A diagrammatic sketch of a stabilization trench is shown in Figure 10.

Trenches will effectively remove the subsurface water from an area if they can be constructed deep enough to intercept the water-bearing strata. They do not have the

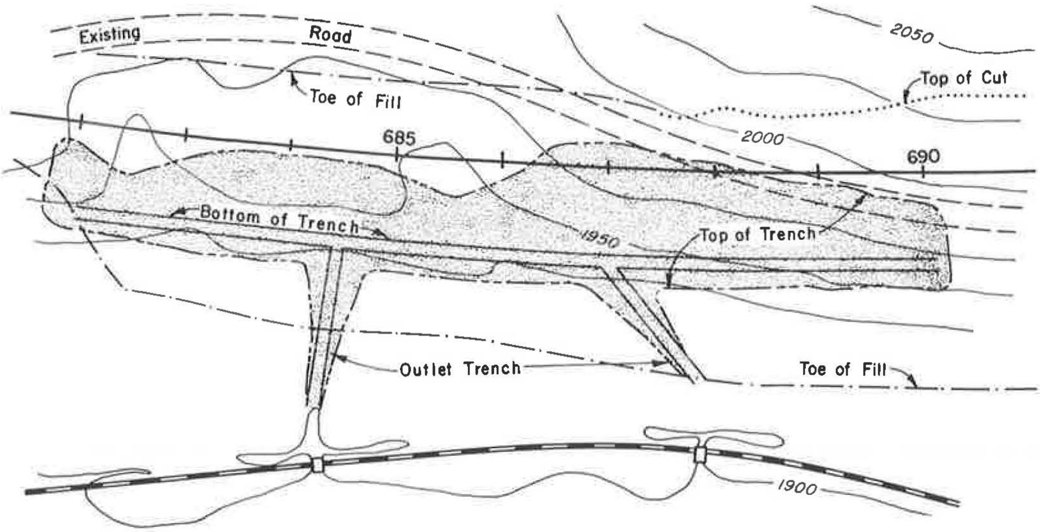


Figure 6. Plan of longitudinal stabilization trench.

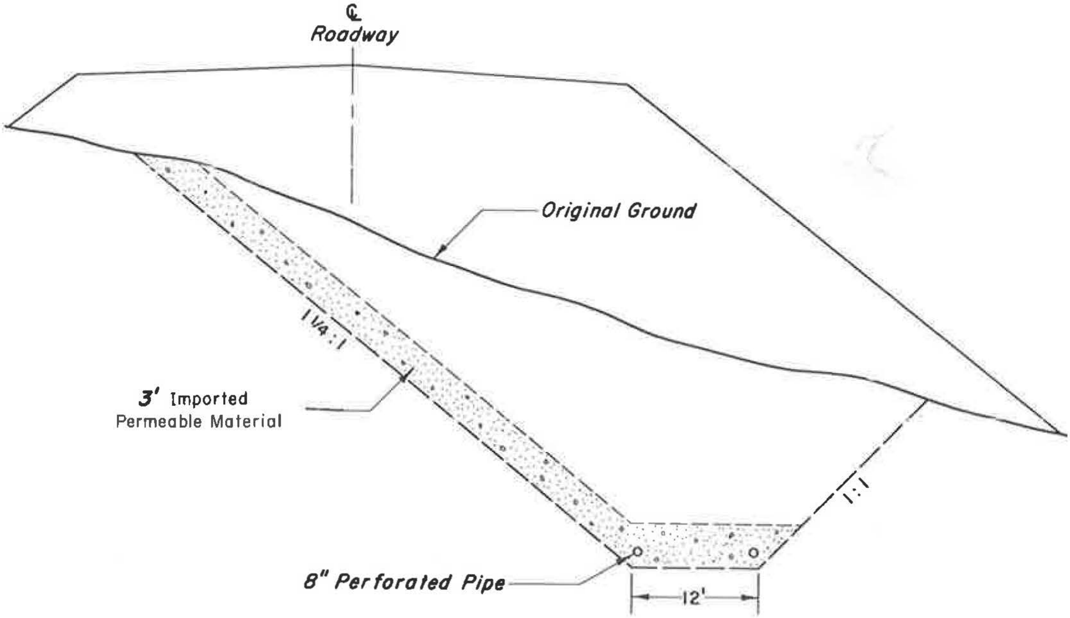
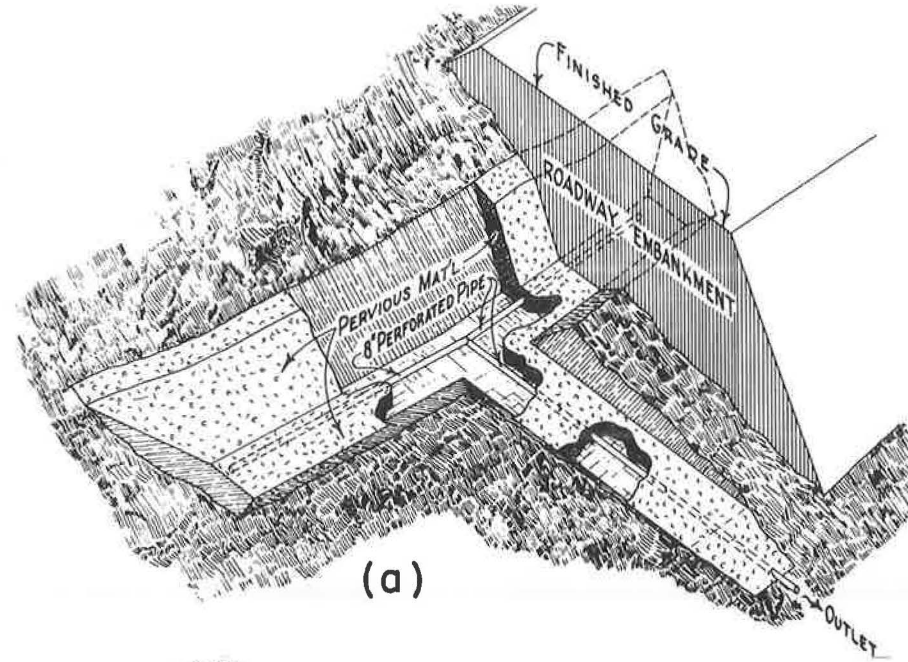


Figure 7. Cross-section of longitudinal stabilization trench.

Figure 8. Excavated longitudinal stabilization trench.

Figure 9. Partially filled longitudinal stabilization trench.



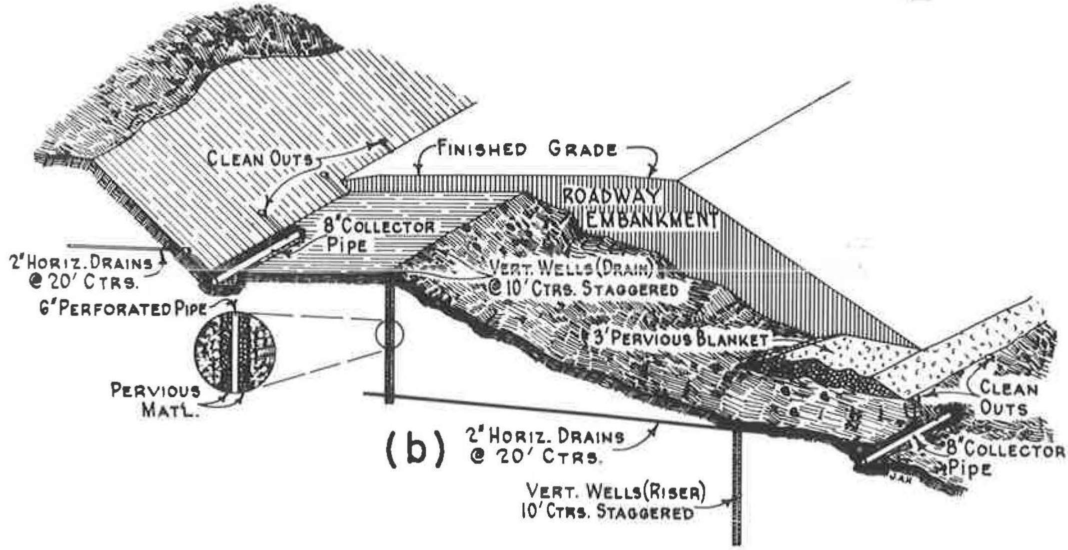


Figure 10. (a) Diagrammetric sketch of stabilization trench, and (b) diagrammetric sketch of embankment stabilization with horizontal drains and vertical relief wells.

feature of removing as great a percentage of the underlying weak material as is usually possible if stripping is used. Reference to the cross-section shown in Figure 7 will indicate that, due to the narrow bottom width of the stabilization trench, considerable weak material is left in place under the roadway prism. These stabilization trenches do have the feature of being able to intercept ground water at a greater depth than is often economically practical with total stripping. They provide a wedge of stable compacted material that is keyed into the stable underlying foundation soil.

Horizontal Drains

Although horizontal drains are most frequently used in connection with stabilization of cut slopes or landslide correction they are occasionally used as a preventative measure on fill foundations where subsurface water is a problem. They are usually installed from the toe of the proposed fill slope or some convenient position at a lower elevation. This will afford access for maintenance. It is sometimes possible to remove subsurface water by this method to depths greater than is economically practical by the use of stripping or trenches. Drains are frequently installed to depths varying from 150 to 300 ft. Thus, is is often possible to reach well beyond the toe of slope on the upper side of the road with drains that have been installed from the lower toe of slope. Drains are sometimes installed from the upper toe of slope to attempt to remove subsurface water before it has an opportunity to reach the foundation of the embankment. Drains for cut stabilization are usually installed from the toe of cut or from benches on the cut slope. Grades for the drains vary from 2 or 3 percent to as steep as 15 to 20 percent. The installation of horizontal drains was pioneered by the California Division of Highways in the later 1930's, and is described in considerable detail in earlier publications (2, 3, 4, 5, 6).

The holes are drilled with 3- to 4-in. diameter roller rock or drag bits with water used as a circulating medium. Casing consists of 2-in. perforated steel pipe that has been asphalt dipped. Casing is butt welded on installation. Collecting systems to remove the water from the outlet of the horizontal drains and to prevent its infiltration into the surrounding soil are generally necessary. Horizontal drains are an effective means of removing subsurface water with proper soil conditions. They increase the strength of the material by removal of the water and reducing hydrostatic pressure.

Relief Wells

Something of an innovation was used for subsurface drainage purposes on the two contracts covered by this paper. Ground water was at such a depth in many of the foundation areas that it was not practical to construct trenches deep enough to intercept the water. Vertical relief wells were installed and horizontal drains were drilled from the lower toe of slope to intercept these relief wells at some elevation between the ground surface and the bottom of the relief wells. These relief wells were in the order of 40 ft deep and were approximately 24 in. in diameter. They were drilled with a bucket-type auger and were not cased. Six-inch diameter perforated transite pipe was placed in the center of these wells and the concentric area between the pipe and the wall of the well was backfilled with permeable material. These relief wells were installed in two rows on 10-ft centers (Fig. 11). The line of wells underneath the main part of the fill did not have a layer of permeable material placed at the ground surface,

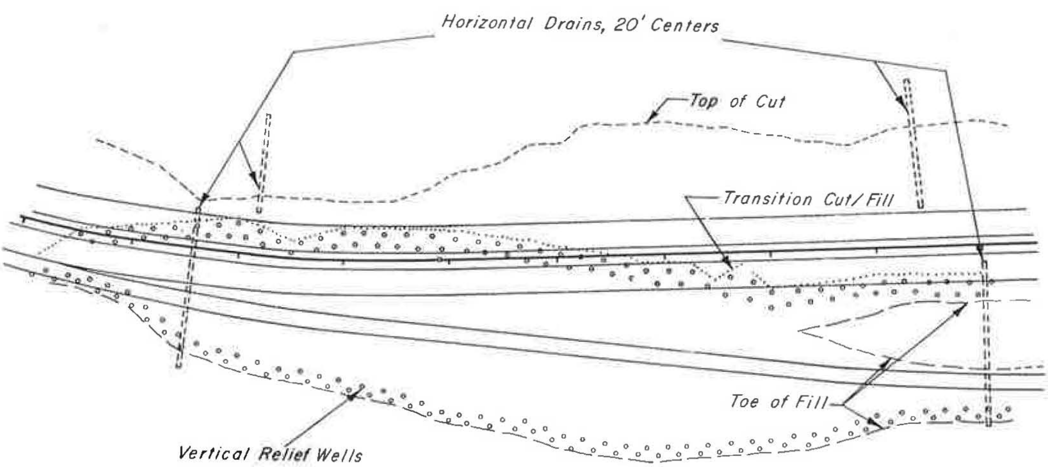


Figure 11. Plan of horizontal drains and vertical relief wells.

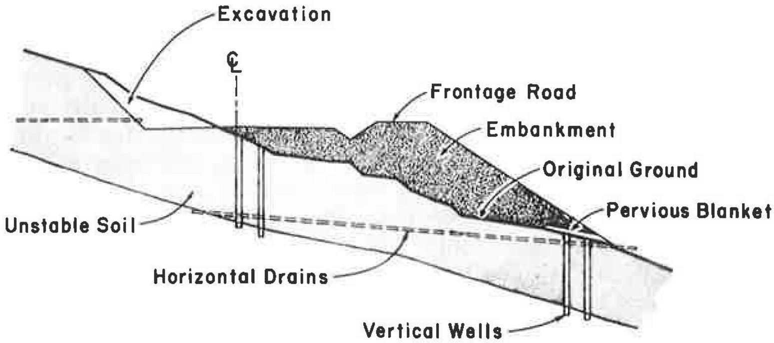


Figure 12. Typical section of horizontal drains, vertical relief wells, and pervious blanket.

but the lower part of the wells was drained by horizontal drains. However, the line of wells near the lower toe of slope had a pervious blanket of permeable material 2-ft thick placed over the original ground, but had no outlets from the bottom of the wells (Fig. 12). The spacing and diameter of the relief wells were such that slightly more than 50 percent of the horizontal drains would intercept relief wells. Apparently it was not necessary to intercept the wells because the subsurface water would flow through the native soil and relieve the pressure within the wells. In some areas these vertical relief wells were installed in the bottom of stabilization trenches. A diagrammatic sketch of vertical relief wells and horizontal drains is shown in Figure 10.

These vertical relief wells are primarily a means of relieving hydrostatic pressure. They do not effectively drain all of the water from the soil mass.

Underdrains and Pervious Blankets

A method commonly used for removal of subsurface water in highway cuts is by installation of underdrains or underdrains in combination with pervious blankets. A typical section of an underdrain is shown in Figure 13. The underdrain consists essentially of a narrow trench, 20 in. wide and 2 to 8 ft deep. A 6-in. layer of permeable material is placed in the bottom of the trench and perforated pipe 8 in. in diameter is then laid. The remainder of the trench is then filled with permeable material. These underdrains are installed primarily to intercept water that is flowing laterally into the roadway through rather well-defined zones. Underdrains are generally installed under one shoulder in cuts. They are occasionally installed at both shoulders and in the median if conditions warrant. Underdrains have been beneficial in areas where the subsurface water is flowing through the entire mass of soil and may be moving into the cut from underneath. However, they are not necessarily completely effective under these conditions and their effectiveness would depend largely on the quantity and source of water involved and the uniformity of the soil mass. Generally, under these conditions a pervious blanket is used in combination with a system of underdrains. In highway practice in California, the minimum thickness of blanket that is used is 1 ft, and this blanket is used in combination with one or more underdrains. Usually no pipe is installed in the blanket proper but the pipe in the underdrains serves as an outlet for the water that is picked up by the blanket as well as the water picked up by the underdrain. Transverse or diagonal underdrains are frequently installed at the transition from cut to fill. This tends to prevent the migration of the subsurface water from the cut areas into the adjacent fill areas. The primary purpose of underdrains as well as the pervious blankets in cuts is to prevent distress of the pavement rather than to improve stability in the cuts.

Permeable Material

No discussion of methods of subsurface drainage would be complete without some

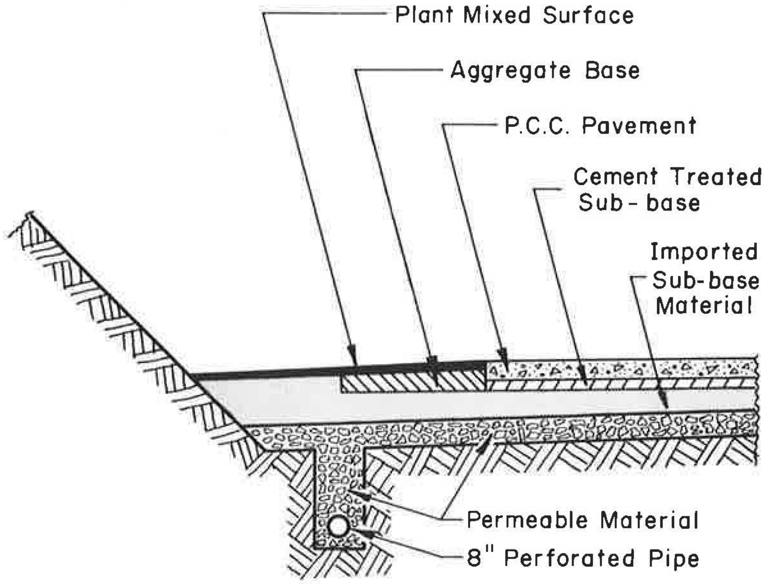


Figure 13. Typical section of underdrain and pervious blanket.

consideration of the characteristics of the permeable material that will be used to drain water from the unstable areas. In the process of stripping and blankets, stabilization trenches, relief wells, and underdrains, permeable material is provided to serve as a means of removing the subsurface water. Perforated pipe of some sort is used along with the permeable material as outlets in these various installations.

Permeable materials for drainage purposes should have two characteristics that are somewhat contradictory. First, the material must be many times as permeable as the surrounding soil from which water is to be drained; hence, the desirability for the material to be very porous and capable of carrying large quantities of water. Second, the permeable material should not contain voids sufficiently large to permit the migration of the soil into the permeable material or to permit the migration of the fine portion of the permeable material through the coarse phases of the permeable material.

The history of the grading of permeable material that has been used for subsurface drainage purposes in California highways shows trends that appear to be characteristic of the thinking both in the Division of Highways and in other agencies that have made similar installations. Two or three decades ago permeable material usually consisted of rock or cobbles with very large voids. Each successive step in the process shows grading specifications that used smaller and smaller sizes. With the California Division of Highways this trend was reversed in 1960 when coarser material or at least cleaner material was required than had been used in 1954 specifications. Table 2 gives grading specifications at various times from 1927 to the present time. Typical specifications are shown on the grading curves in Figure 14.

TABLE 2

GRADING SPECIFICATIONS OF PERMEABLE MATERIAL

Year	Sieve Size (% pass.)														
	6 In.	2½ In.	2 In.	1½ In.	1¼ In.	1 In.	¾ In.	⅜ In.	No. 4	No. 8	No. 16	No. 30	No. 50	No. 100	No. 200
1927-40	100					0									
1940-45	100						0								
1945-54		100					40-100		15-50	5-30		0-5			0-2
1954-60		100		80-100			60-95		35-65	25-50		5-25			0-3
1960:															
Coarse portion			100	90-100			60-80		40-60						
Fine portion									100	65-90	45-70	20-40	8-16	0-4	0-2
Proposed						100	90-100	40-100	25-40	18-33		5-15	0-7		0-3

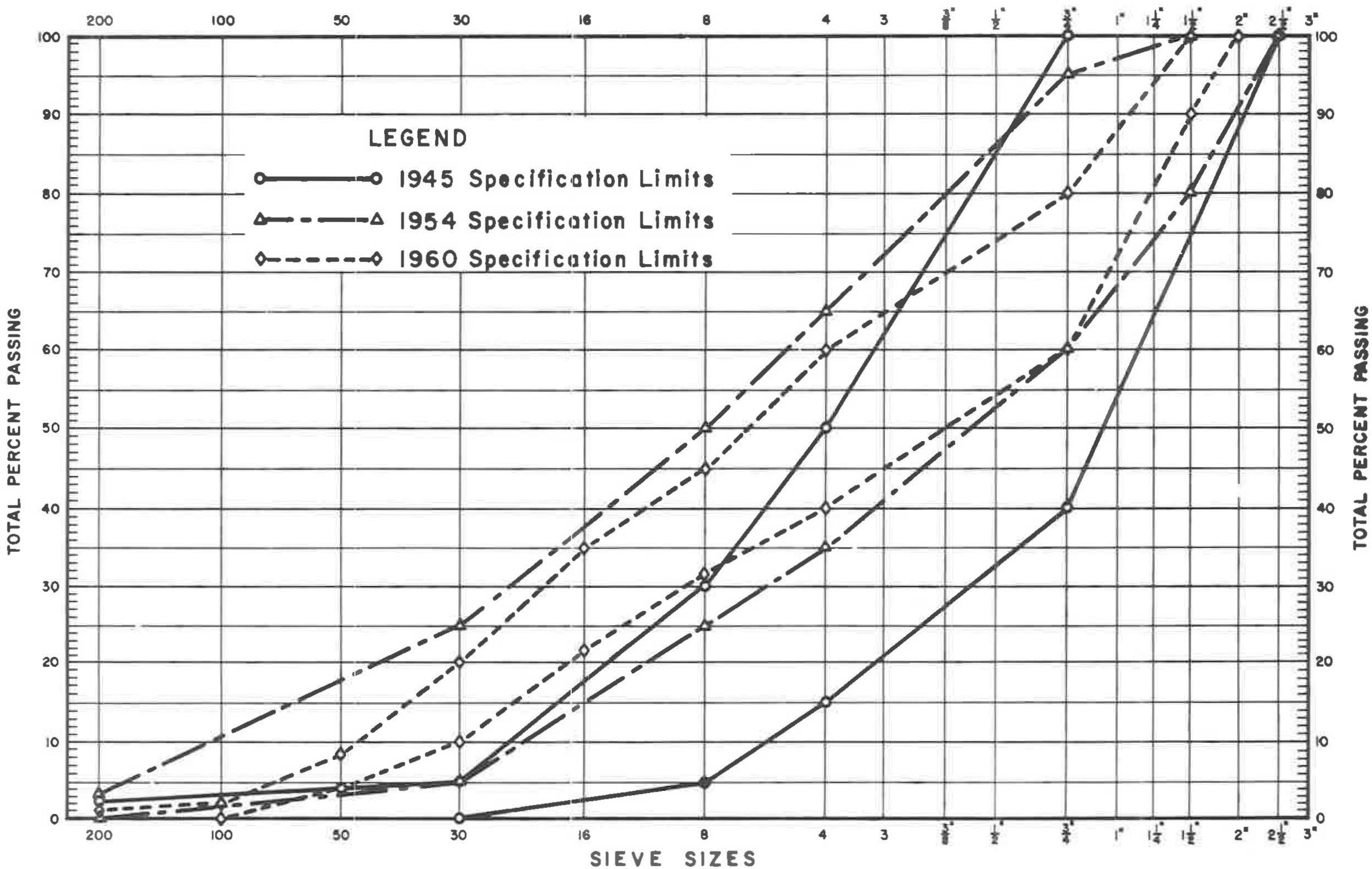


Figure 14. Grading specification limits for permeable material.

It is recognized that permeability rather than grading should probably be the basic criterion for specifying permeable material. Permeability tests are difficult tests to use as a construction control test. Although permeability tests have to a large extent become standardized, they are not highly reproducible except by skilled technicians with considerable experience. Therefore, the procedure has been to use grading and quality tests on the aggregate in the preparation of specifications for permeable material rather than using permeability. It is also recognized that the permeable material should be tailored to fit the soil encountered in the various cuts and stabilization work (7). In highway construction this is usually difficult due to the extreme variation of material encountered in the various cuts and subsurface drainage features. Since 1960, an effort has been made to base the specifications for the permeable material on the character of soil to be drained somewhat in conformity with the general requirements advocated by Barron (8) and Barber (9).

Most of the permeable material used in the construction of California highways has been secured from commercial sources; however, every effort is made to use local deposits where suitable material is available and soil conditions are such that it can be used.

SUMMARY AND CONCLUSIONS

Provision for adequate control of ground water in highway construction is imperative. Experience on California highways in general, and particularly on the two projects described herein, indicates that extensive subsurface drainage was necessary to prevent the expenditure of far larger sums of money for corrective measures.

The need for thorough investigation in connection with subsurface drainage cannot be overemphasized. If thorough investigation is not made, the need for subsurface drainage cannot be ascertained. Similarly, the investigation will point to the type and degree of subsurface drainage that is necessary. The investigation for subsurface drainage may take many forms, and the nature of the problem encountered should dictate the type and nature of the investigation that is warranted.

The two contracts described illustrate the types of subsurface drainage that are commonly or on occasion used in California highway practice. There is every evidence that these subsurface drainage methods are reasonably successful. The fact that considerable additional subsurface drainage was determined necessary, as a result of observations during construction, is evidence that the original subsurface drainage was not overdesigned. On these two contracts no embankment slipouts of major proportions have occurred since construction. Some slides have occurred, but these have for the most part been rather minor slides that have obstructed not more than one or two lanes of the freeway.

If proper subsurface drainage is not provided in areas where it is needed, the results may vary from disastrous to minor inconvenience. There have been cases where major highways have been closed as a result of slides or slipouts that could have been prevented by more extensive subsurface drainage. In other cases minor inconvenience has occurred such as the necessity of the removal of small quantities of slide debris from the traveled way thus reducing highway capacity to some degree. Although it is recognized that the cost of subsurface drainage is an item of major proportions on much of the California highway system, it is strongly believed that the expenditure of these sums of money actually results in savings far beyond their cost and produces highways that are far more serviceable to the traveling public.

It should be emphasized that the subsurface drainage facility is no better than the construction and material that is incorporated in the facility. Proper investigation and adequate design will not insure a workable, satisfactory facility unless the features are incorporated in the finished product. One feature that should be particularly emphasized is the necessity of good-quality permeable material. The permeable material is the device that must ultimately remove the subsurface water from the natural soil; hence, the need for material that is sufficiently permeable to remove the ground water without developing excess hydrostatic pressure and at the same time will not become clogged with fines and cease to function.

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