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An effort is made to avoid serious slides; but the variable nature of most earth and weathered rock formations often leads to slim margins of safety in cut slope design. As a consequence, failures sometimes do occur. The present report describes several important cuts that have been required in the past few years for the construction of California highways. They represent a wide range in conditions and performance, and point up the gigantic problems that must be faced by highway designers and builders.

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SOME CASE HISTORIES

By

T. W. Smith and H. R. Cedergren

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A.S.T.M. Meeting
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T. W. Smith* and H. R. Cedergren**

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INTRODUCTION

Broad Features of Cut Slope Design

Whenever a change is made in the shape of a portion of the earth's crust, a new pattern of stresses is set up. If the strengths of the masses are not equal to the new demands failure takes place. Whenever a highway cut is made in a hillside or mountain slope, there is a possibility that a potential slide condition may be created. The designer must satisfy himself that the strengths of the earth masses involved are adequate to prevent a serious slide. In broad terms, the new slope must be designed to have a factor of safety of at least unity for the worst combination of conditions that may occur during the life of the project.

The first step in a cut slope design is to get the broad picture. This involves soils and geological examinations of surface conditions, searches for evidences of stability or instability, and studies of the performance of any existing natural slopes and cuts in the area. It also includes a look at broad features that can change the stability of a slope, such as natural changes in ground water conditions, earthquakes, etc., and man-made changes such as aggravated ground water caused by infiltration from adjacent lawns, broken water mains, leaky sewer lines, etc. The broad look also involves a general appraisal of the probable change in the overall stability that will be produced by the proposed cut. Under some circumstances a cut may produce an overall flattening of an existing slope, and an overall increase in stability. Generally this is not the case. After the general overall picture has been obtained the investigation is planned in an effort to answer the questions produced by a specific project.

Investigation

The information needed for the economical design of cut slopes includes: the nature and strengths of the materials that will be excavated, ground water conditions, the attitude in beds of sedimentary rocks, the degree of weathering, the extent of joints, bedding planes, fractures, and other surfaces of potential weakness, and the presence of landslides, active or ancient. To obtain this information several of the following methods commonly are utilized: visual inspection on the ground, study of topographic maps and airphotos (also required for the broad picture), geological surveys, geophysical explorations, explorations by borings, either vertical or horizontal, evaluation of boring data, ground water observations, and testing of undisturbed soil samples or rock cores.

The methods to be employed in an individual cut slope design will vary with the scope of the problem, with the sources that are available, and with the physical conditions at an individual location. Very often the most suitable type of exploration or investigation and the best methods to use will not be known in the beginning, and can be determined only during the progress of the exploration and studies.

If the material to be excavated is a fairly uniform fine-grained soil, shear tests can be made on undisturbed samples, and the stability of various slopes can be calculated by stability analyses. However, the cut more often contains more or less rock and is heterogeneous, making it virtually impossible to determine by laboratory tests the average or effective shear strength of the slope forming material. In such cases the stability analysis by theoretical soil mechanics methods is not possible, and the cut slope design must be determined by application of judgment and experience, after evaluating and taking into consideration all of the factors mentioned above which might affect slope stability.

In summary, the usual procedure for investigating a proposed cut is to evaluate all available data, study surface conditions, and develop a working hypothesis. On the basis of this hypothesis an exploration program is laid out and started. As the explorations add to the fund of knowledge about the properties of the earth masses involved, the methods are altered as required to get the needed answers. If it were always known in advance just what kind of methods were most appropriate, where all explorations should be located, and how deep they should be made, one would already have many of the answers that are being sought by the explorations.

Correction or Prevention

In the Division of Highways an effort is made to avoid cut slope failures, but it would be necessary to be very conservative to avoid all failures. When any of importance occur they are studied very carefully to try to determine the causes. Sometimes the causes are obvious; other times they are very obscure.

The stability of cut slopes usually can be improved by one or more of the following methods:

1. Changing highway alignment or grade.
2. Flattening slope or unloading upper part of cut slope.
3. Adding support at the toe in the form of buttresses.
4. Drainage.

Obviously, for reasons of economy, cut slopes should be as steep as possible, consistent with stability. Typical slopes for various materials might be somewhat as follows: in cohesionless sands the slope should be no steeper than 1½:1, since this is about the angle of repose for such soil; in cohesive soils, containing silt and clay along with sand, slopes of 1½:1 or flatter are usually in order; in cemented sediments, such as sandstone, shale, and conglomerate, steeper slopes may be used, depending on the degree of cementation, bedding, jointing and ground water conditions; in weathered rock, slopes may vary from 3/4:1 to 2:1, again depending on degree of weathering, ground water, etc.; and in hard fresh rock slopes as steep as ½:1 or 3/4:1 are sometimes possible.

Frequently highway alignments cross landslides, many of which are more or less active. When it is necessary to cross known landslides the design is developed with a view to improving stability rather than lowering it. In some cases material is removed from the head of the slide and in others fill is placed at the toe. Improved drainage often is provided.

One of the aims of the design and construction of highways in cut areas is to keep slides to a reasonable minimum.

Probably the most important single factor in the prevention of slides is selection of the proper cut slope to prevent the development of stresses beyond the strengths of the formations. If ground water is present, some type of subsurface drainage usually improves stability and lowers the probability of failures.

The California Division of Highways pioneered the use of horizontal drains for stabilizing highway cut and fill slopes, and has used them extensively over a period of nearly 25 years.(1) When these drains are able to intercept and remove appreciable amounts of ground water, they are an effective means of increasing slope stability. Often they are installed as a construction item as a planned means of preventing slides when conditions are favorable to their use.

In recent years vertical wells have also been used to a limited extent as a means for intercepting seepage, and wells with drainage galleries have been used in a few cases where difficult ground water problems existed.

In spite of all the efforts that are made to prevent slides, major slides sometimes occur - often during the construction. After a slide has started, the correction usually involves more extensive treatment than would have been required for its prevention, since the strength of the formations usually is lowered, and natural drainage impeded.

After a slide has begun to move, a field examination is made to determine its general aerial extent and decide if an investigation should be made. In many cases, a boring and testing program is an essential means of establishing the kind and extent of corrective treatment to be applied. In others, a field survey provides sufficient information to determine how to procede in correcting the slide.

The correction of slides involves the same basic methods that are used for their prevention, namely: unloading the head of the slide, reinforcing the toe, and improved drainage. The methods to be used for a particular project are selected after a careful study of all available information.

It should be pointed out that even though the shear strength of most cut materials cannot be measured by laboratory tests, it is still possible to compare the relative stability of various slope designs by assuming or estimating reasonable values of cohesion (c) and angle of internal friction (Ø). Stability analyses can also be made, using the ground contours that exist after slides have developed. Assuming a factor of safety of unity, the soil strength can be calculated. Various corrective treatments can then be compared on the basis of these strengths. In this way it is possible to select a corrective treatment that is the most economical consistent with the required stability. Judgment, experience, geology and soil mechanics all play a part in the prevention and correction of slides in highway construction.

Four California Highway Projects

The current highway construction program in the State of California is producing some major construction problems. Four recent cut designs in the California Highway construction program are described in this report. The general features of these projects are as follows:

1. Dyerville Cut

    This is a high side-hill cut in rather stable formations. A benched cut design with horizontal drains was employed here. The cut has passed through four winters without trouble.

2. Carquinez "Big Cut"

    This is a large through cut involving about 9,000,000 cubic yards of shale and soft sandstone excavation. Considerable ground water was present. Fairly flat slopes and a considerable number of horizontal drains were used here. Some localized sloughing has occurred, and one slide involving about 125,000 cubic yards of material.

3. Mulholland Cut

    Construction for the San Diego Freeway included a large cut a few miles to the northwest of Beverly Hills. At its deepest point the planned depth was to be 320 feet below original ground. When partially completed, a very serious slide developed in some slightly tilted beds of shale and soft sandstone. The cut has been redesigned, and completed with flattened slopes, buttress fills, and a raise in grade. Traffic was scheduled to be using this section of freeway in the fall of 1962.

4. Towle Slide

Improvement of highway U.S. 40 to freeway standards on the west slope of the Sierras involved the construction of the highway across several old landslides. The "Towle" slide was one of the more troublesome. Although the road was to be in a very shallow cut, extensive stabilization measures were used, including four large stabilization trenches, horizontal drains, and a drainage gallery. The new road has withstood two winters without distress; however, the effectiveness of the installation probably has not been fully proven, since the seasons have been drier than normal.

DYERVILLE

The highest single cut in the history of road building in California was in the first unit of the Redwood Freeway, on U.S. 101. The contract for this unit was awarded on April 10, 1957. This cut, located on the southerly end of the project about 2½ miles north of Weott, removed the northerly end of a high, steep watershed ridge, as shown by the photograph in Fig. 1. The top of the cut stands 480 feet above the grade of the finished road, and the toe extends a quarter of a mile along the new alignment.(2)

Though this cut represented only one-twentieth of the total project mileage, it furnished half, or 1,400,000 cubic yards, of the roadway excavation needed for the 4.4-mile project.

The major geological formations in the area are the Franciscan undifferentiated sediments of Cretaceous-Jurassic Age of the Coast Range. At the site of the cut the materials are principally thick bedded interbedded sandstone and shale, and some conglomerate. The sediments have been subjected to considerable deformation and fracturing. Many of the fracture systems contained heavy accumulations of ground water. Seepage was evident at the old roadway near the toe of the new cut.

Investigations at the site included a geological and soils reconnaissance, two vertical borings in the upper part of the cut and two horizontal borings, one 80 feet and one 150 feet above the old roadway.

The investigations confirmed the general aereal geology at the site, showing interbedded sandstone and shale, with beds of conglomerate. The upper 50 feet was highly weathered. All materials drilled were fractured and jointed. Ground water was encountered in the vertical borings. A large initial flow was produced by the horizontal boring 80 feet above the old road, but no flow was produced by the horizontal boring at the 150-foot level. In general, the dip and strike of the sediments were normal to the direction of roadway, although there was considerable variability due to the regional movements to which the area had been subjected.

A plan of the cut area is given in Fig. 2 and a typical cross-section in Fig. 3. The locations of the borings are shown on the plan. Their logs, in simplified form, are given in the cross-section sheet. The horizontal boring (H-1) furnished useful information; however, it penetrated the hill nearly parallel to the dip and gives a distorted picture of the thickness of the beds penetrated.

On the basis of field study and an examination of the cores, it was concluded that the slope had a good degree of stability. The presence of large redwood trees on the slope with an age of at least 2000 years confirmed this conclusion as they were living proof that no important slide movement had occurred for many centuries. It was concluded that a slight over-all steepening of this slope would not involve serious risk of failures.

In view of the great height of this cut the recommended design called for 1:1 slopes with 20-ft. benches at 60-ft. vertical intervals. This design produced a slope roughly parallel to the slope that existed before this cut was excavated. The cut is "side-hill" and involved the slicing off of a 60- to 80-foot thick prism of earth from the face of the slope. To insure a reasonable margin of safety during periods of high ground water, more than 3000 linear feet of horizontal drains were installed in this cut. A pervious blanket, and underdrains with perforated metal pipes were installed below the roadbed for the protection of the structural section from excess ground water.

This cut was constructed according to plans and the job was accepted as complete on November 12, 1958. It has passed through four winter seasons without any signs of instability. Considering the great height of this cut, this project has been very satisfactory. The exploratory borings indicated that there would be no significant changes in material except for the top soil and degree of weathering for the depth that was to be removed, and that the new slope would be in the same kind of material revealed by occasional exposures in the original hill-side. This was borne out by the construction.

One cannot always be sure from surface indications alone of the quality of the formations that will be exposed by highway excavations. There have been numerous instances in the California highway construction program of cuts being made into apparently stable rock formations, in which a hard knob formed a shallow cap over much weaker formations. In such cases, the hard rock exposure gives a false picture of the true condition, and the stability of a proposed cut may be much less than is apparent from surface indications. It is standard practice in the California Division of Highways to explore important cuts with borings. The exploratory work and testing that was done for the Dyerville cut removed much of the guess-work regarding the character of the materials that would have to be excavated by the contractor and may have been reflected by more favorable bid prices than otherwise would have been offered. They also removed much of the uncertainty regarding changes in quality of materials as they might effect the stability of the new cut slope. The performance of this cut has been most satisfactory.

CARQUINEZ "BIG CUT"

One of the main highways giving the population of the San Francisco Bay area access to inland areas is U.S. Highway 40 which skirts the northeast shores of San Francisco Bay, crosses over the Carquinez Straits, progresses northerly a few miles and then heads easterly across the State. When the original Carquinez Bridge was completed in 1927 it was one of the nation's outstanding steel bridges, and the highway was very adequate for the traffic of the times. As the years passed, this highway became more and more congested because of insufficient lanes and innumerable bottlenecks in the numerous cities through which the road passed. A bold solution to this traffic bottleneck was the construction of a second bridge parallel to the 1927 structure, and the rerouting of the highway across Tormey Valley east of the original highway.(3)(4) The chief obstacle in the way of the new routing was a large rolling hill just south of the Straits. The projected line penetrated this hill to a maximum depth of nearly 350 feet. The natural terrain was standing on slopes approximating 3:1 or flatter, and many slide scarps were visible, indicating surface sloughing. The north end of the area encroached on a populated area known as Valona and several dwellings were located dangerously close to the proposed cut. The area was known to contain two active faults; the Franklin Thrust and the Mare Island Fault, and the region is subject to seismic activity. The earthquake record of the region since 1854 shows four shocks with intensities of X on the Rossi-Forel scale and 58 of lesser intensity. Studies were made of the relative cost of tunnel construction vs. open cut. The high cost and uncertainties of future permanence eliminated tunnel construction as a practical alternate. An investigation was then made in a study of construction by open cut methods, and subsequently the construction was made in this manner (See Figs. 4 and 5).

In the fall of 1953 and the spring of 1954 several deep exploratory core holes were made in the cut area. In general the deposits were soft interbedded shales and sandstones of the

Paleocene-Cretaceous Age, but the sediments ranged from hard sandstone to soft friable sand, from firm silty shale to soft clay-shale. Interbeds varied from microscopic to visual. Substantial evidence of ground water was disclosed by the borings. When deposited, the sediments that form this region were uniform and competent, but intensive folding and faulting has greatly weakened the masses. The locations of borings are shown on the plan of the cut (Fig. 6) and on the typical cross-section (Fig. 7). All of the borings were bailed to within a few feet of the bottom of the casing, and the rising water level recorded for a period of time after the bailing to obtain an indication of the general permeability of the formations.

The character of the formations as determined by the explorations may be summarized by the following excerpts from the report of this foundation investigation:

> "In summary, it is believed that it is feasible to construct the proposed road...without serious risks. It should be recognized that the cuts would be high and the soil far from ideal. Even with proper slope design, some surface sloughing and minor slides can probably be expected. The possibilities of a major slide, one that would close all or even two or three lanes of the road, are very remote. It is believed that the risks involved ...are not seriously greater than they are on numerous major roads where foundation design problems are complex."

To aid in visualizing the variations in conditions within this cut a scale geological model was constructed, and the deduced and actual geological conditions shown on various surfaces of the model. Photographs of this model are reproduced in Figs. 8 and 9.

On the basis of all available information about the soils and geological conditions in the area, it was determined that this road could be designed on the basis of an open cut through the hill south of the Straits. The typical cross-section reproduced in Fig. 7 shows approximately the maximum section through the cut. The cut was designed with slopes of 2:1 and 30-foot wide benches at 60-foot vertical intervals. This cut was widened about 30 feet on each side at roadway grade to provide protection against the blocking of traffic lanes in the event large slides should take place after the road was opened to traffic. A substantial number of horizontal drains(5) were to be installed at various levels in the cut.

As designed the "big cut" had a length of about 3000 feet, a top width at the crest of 1370 feet and a maximum depth of 350 feet (See Figs. 4 and 5). The total volume was calculated to be more than 9,000,000 cubic yards.

A contract for construction of this highway between 0.6 mile N. of Hercules to Crockett, a distance of 2.9 miles, was awarded on December 7, 1955. The completion date was November 6, 1958.

Excavation of the "big cut" was started in late March, 1956, and completed in June, 1958. As the excavation was deepened, ground water levels were recorded in numerous sounding wells and horizontal drains were drilled into areas where the water level did not drop rapidly with the deepening of the cut. On the whole the designed and constructed slopes have been stable. From time to time small slides have occurred at various points on the faces of the cuts. One slide of rather major proportions took place at the north end of the cut in an area known locally as Valona. The extent of this slide in relation to the magnitude of the cut may be seen in the photographs reproduced in Figs. 4 and 5.

In February, 1958, some cracking was observed above the cut in the area on the west side of the cut, noted above. Subsequently, a retaining wall was badly cracked and noticeable cracks showed up in the basements of two of the houses at the top of the slope. The condition got progressively worse, and several houses had to be removed and the slide mass removed. After this treatment this area showed no further evidence of instability.

In relation to the total volume of this cut, the slide was of rather nominal size. Nevertheless approximately 125,000 cubic yards of earth was removed in correcting this slide. Had this cut been designed initially on a slope sufficiently flat to guarantee 100% security against slides, a rather enormous additional quantity of roadway excavation would have been required (several million cubic yards).

This large cut is another example of a highway project in which soils and geological explorations and test borings provided very essential design information. The knowledge (information from the borings) furnished to prospective contractors, placed all bidders on a relatively even basis in judging the rippability of the formations and in estimating the costs involved in handling the excavation materials. Knowledge of the character of the formation was essential to determining the "safe" slope on which the cut was to be excavated. The ground water information gave a means of locating initial horizontal drains and in estimating the approximate cost of a horizontal drain system that would be needed to safeguard the stability of the slopes.

On the whole this excavation has been exceedingly successful. It is a tribute to the combined experience and judgment of the engineers and geologists who developed and executed its design.

MULHOLLAND

Construction of the San Diego Freeway required an unusually deep and large cut in the vicinity of Sepulveda Boulevard and Mulholland Drive, a few miles to the northwest of Beverly Hills, California. At its deepest point, the proposed highway grade was to be 320 feet below the original ground line.

Geological and soils reconnaissance of the area indicated that the formations in the cut probably were largely laminated sandstones and shales. In view of the great depth of the cut and its proximity to urban developments, it was decided that a number of deep borings should be made.

In 1955, starting August 11, five borings were made in this cut area. The locations of the borings are shown on Fig. 10. A simplified log is given on Fig. 11. Supplementing the data obtained in the actual drilling operations were electric logs of all of the borings. The foundation conditions are illustrated by an abbreviated summary of hole C-1. The upper 100 feet consisted of beds of firm shale of variable thickness and loosely to moderately cemented sandstone. The next 100 feet was made up of loosely to moderately cemented sandstone with an occasional thin bed of firm shale. From 200 feet to the bottom of the boring (333 ft.) the materials consisted of laminated firm shale and loosely cemented sandstone. The dip of the formations generally was 15° to 20°, and the strike was generally normal to the roadway. The water table was recorded 120 feet above the proposed grade in this boring. In general the sandstones were softer than had been anticipated from preliminary investigations, but appeared to be relatively stable. Slight variations in the strike resulted in a slight dip, less than 3°, into the roadway prism in the vicinity of Station 501 to 502.

After a review of the boring logs and the geological history of the area, it was recommended that this cut be constructed with 1½:1 slopes with 30-foot benches at 60-foot vertical intervals. Subsequently a large excavation was made in this area to obtain borrow for another highway project. This excavation stood on a 1:1 slope without any serious failures. It was then decided that the Mulholland cut could be designed on 1:1 cut slopes benched at 60-foot vertical intervals.

On July 25, 1960, a contract was let for the construction of a portion of the San Diego Freeway which included this cut. Of the 7,900,000 cubic yards of roadway excavation in the contract, the major part was in this single large cut.

Excavation of this cut was started from the north end and taken nearly to grade. The plan was to progressively push the excavation further south into the hill. It so happened that the slight dip of the formations previously noted was toward the excavation that was being made. The major slide which is described here involved the mass to the west of the excavation, which slipped toward the excavation with a rotary motion, most of the movement being longitudinal.

Local slides of a minor nature developed during early progress of this contract, getting progressively worse as the excavations progressed. By October, 1961, cracking developed on the east side of the Mulholland cut which forced the owner of an adjacent home to leave his home on Scadlock Lane. Additional cracking in the street and adjacent properties on the west side of the cut indicated a slide potential of major proportions. Accordingly, the contractor suspended operations in this portion of the cut and moved his equipment to higher ground.

Minor cracking had occurred in the east side of the cut as early as July 1961, but this was not considered serious until early in October when cracks began to develop in the floor slabs of the private dwellings on Scadlock Lane, as noted above, and more definite cracking occurred through the contractor's yard and in the pavement of old Mulholland Drive. The extent of the slide may be seen in the photograph in Fig. 12. To aid in analyzing the geological conditions and the slide movement, a geological model was constructed (See Figs. 13 and 14).

A series of investigations by the District Office, Headquarters Materials and Research Department, and consulting engineering geologist, Dr. Arthur Cleaves, was conducted late in October, 1961. These investigations indicated that the slide movement was in the form of a block glide, the slippage occurring on the gently dipping siltstone bedding planes that sloped toward the excavation. A study of this slide indicates that it probably was caused by a combination of factors, of which the following are believed most important: (a) a slight dipping of the formations into the roadway excavation, (b) the relief of stresses within the earth masses caused by the unloading, and (c) the breakdown of shale into clay by the slide movement, producing very slippery planes. There was nothing observed in the original explorations to indicate that a serious slide potential existed. The stresses set up by the tremendous earth mass evidently exceeded the strength, which caused the movement to start, setting off the cycle described above. Following these investigations a number of alternate corrective treatments were considered including slope flattening, use of buttress fills, raising the grade, shifting the line to the west in conjunction with slope flattening and buttress fills, tunnel construction, and split roadways with steepened grades. Estimated costs of the corrective treatments varied from $2,500,000 to $38,000,000 (the highest being for bored tunnels).

The alternate selected made the following changes (See Fig. 11):

a. Grade raised 50 to 60 feet through the main cut area.

b. Grade rate steepened from 4½% (design rate) to 5½% for a distance of about one mile.

c. Slope in slide area flattened to 3:1.

d. Buttresses constructed at base of slopes to a height of approximately 80 feet and a face slope of 3:1. The base width of the west buttress 75 feet and the east buttress 50 feet.

It is evident from the experience during construction that the cut slopes, as designed, were not stable. As the project nears completion it appears that the revised design has produced a stable cut.

TOWLE

Anyone who has driven along U.S. 40 from San Francisco, California, to Reno, Nevada, undoubtedly has been impressed by the amount of solid granite exposed in the Sierras. The general impression one gets is that this must be an excellent place to construct stable highways and surely there can be no foundation problems in this area. And yet, some very serious foundation problems do exist and some very serious slides have occurred. The conditions at a point near the town of Towle have been especially troublesome.

During the winter of 1957-58, a large slide occurred in the area between U.S. 40 and the Southern Pacific Railroad just below the town of Towle.(6) The slide extended for approximately 1,000 feet along U.S. 40 and the railroad. The head of the slide was at the railroad tracks. Actually some fill moved from beneath the tracks leaving the tracks in one direction suspended. The disruption in the vicinity of the tracks can be seen on Fig. 15. The piles visible in the picture were driven in an effort to provide support for the tracks after the slide occurred, but were not effective. The toe of the slide was near U.S. 40 and spilled onto the highway. This condition is shown on the photograph on Fig. 16 looking westward along the existing highway. There was some evidence of an ancient landslide in the area but no recent movement or construction operation had occurred for several years.

In order for the railroad to relocate the tracks and get them back in operation, it was necessary that they do considerable excavation above the tracks in what appeared to be fairly stable terrain. In order to expedite this operation, the excavated material was cast across the tracks into the head of the landslide. It developed that the slope above the tracks was somewhat unstable, and considerable ground water was encountered. Hence, considerably more excavation was necessary than had originally been anticipated. This excavation, when relatively completed, can be seen in Fig. 17. The slide continued to move; and it was necessary that the toe of the slide, as it spilled onto the highway, be excavated as rapidly as possible in order to carry traffic through the area. Traffic was disrupted on the highway for periods of a few hours to several days, and the railroad's operation was seriously curtailed. It should be evident that the operations of wasting excavation into the upper part of the slide and removing debris on the roadway at the toe were certainly not conducive to stabilization of the slide. However, with more favorable weather and completion of the excavation at the upper part of the slide, movement ceased or diminished. Considerable slide removal was done by contract the following summer. This resulted in a further reduction in movement.

The new freeway, with plans relatively complete when the slide occurred, was to be between the existing highway and the railroad in a fairly shallow cut. It was evident from reviews of the slide conditions, boring data obtained from many borings, operation had occurred for several years.

In order for the railroad to relocate the tracks and get them back in operation, it was necessary that they do considerable excavation above the tracks in what appeared to be fairly stable terrain. In order to expedite this operation, the excavated material was cast across the tracks into the head of the landslide. It developed that the slope above the tracks was somewhat unstable, and considerable ground water was encountered. Hence, considerably more excavation was necessary than had originally been anticipated. This excavation, when relatively completed, can be seen in Fig. 17. The slide continued to move; and it was necessary that the toe of the slide, as it spilled onto the highway, be excavated as rapidly as possible in order to carry traffic through the area. Traffic was disrupted on the highway for periods of a few hours to several days, and the railroad's operation was seriously curtailed. It should be evident that the operations of wasting excavation into the upper part of the slide and removing debris on the roadway at the toe were certainly not conducive to stabilization of the slide. However, with more favorable weather and completion of the excavation at the upper part of the slide, movement ceased or diminished. Considerable slide removal was done by contract the following summer. This resulted in a further reduction in movement.

The new freeway, with plans relatively complete when the slide occurred, was to be between the existing highway and the railroad in a fairly shallow cut. It was evident from reviews of the slide conditions, boring data obtained from many borings, and geologic investigation, of the area that rather drastic corrective measures would be necessary in order to construct the new freeway in this area. The upper 30 to 40 feet of the slide mass was saturated light-weight volcanic ash and shale and had a strength so low that the entire mass constituted a mud flow.

It would have been desirable to construct a longitudinal stabilization trench between the existing highway and railroad, but it was evident that the upper side of the stabilization trench would not be stable, and the railroad would be endangered during construction of the trench. It was finally decided to construct a series of transverse stabilization trenches extending from the existing road toward the railroad, recognizing that even the upper ends of these trenches would have to be kept some distance from the railroad during construction. These trenches were constructed as the first order of work on the new freeway. Several wells were drilled through the slide mass and pumped prior to and during construction of the trenches. The location of these trenches is shown on the plan sheet, Fig. 18. The trenches were in the order of 30 feet deep, 12 feet wide at the bottom, and with side slopes of $1\frac{1}{2}$:1. The geometrics of these trenches can be visualized from the above plan and the section shown on Fig. 19. The slide mass was so weak that numerous small slides occurred on the side and end slopes of the trenches. It is desirable, in fact nearly imperative, that the bottoms of stabilization trenches be in stable material if they are to effectively stabilize a slide. Although it is believed that the bottoms of all of the trenches were below the bottom of the slide, the bottoms of some portions of the trenches were not in material that was as stable as might have been desirable. A partially completed stabilization trench can be seen in the photograph on Fig. 20. Horizontal drains were fanned from the upper ends of these trenches to depths of 100 to 150 feet. The upper ends, bottoms, and lower portion of the sides of the trenches were blanketed with a layer of pervious material as shown on Fig. 19.[7] A perforated pipe was placed in the lower part of the trench to carry the water flowing into the trench. These stabilization trenches were spaced on two hundred-foot centers. The Southern Pacific installed a large quantity of horizontal drains above and below the railroad during this period.

After completion of these stabilization trenches and a winter shutdown on construction operations, borings were made to determine whether the trenches had been effective in removing the ground water from the entire area. It should be noted that the construction of the trenches removed less than one-third of the slide mass in the area of the trenches. Any increase in stability of the mass remaining in place was dependent upon decreasing moisture contents and hydrostatic pressures by drainage. It was found that the ground water was standing quite high in the area between the trenches, and it was decided that further drainage facilities would be necessary.

Drain wells were installed along a line connecting the upper ends of the stabilization trenches and roughly parallel to the new freeway. These drain wells and other corrective measures are shown on Figs. 18 and 19. These drain wells, 30 inches in diameter, were installed on 8-foot centers and were connected at the bottom by hand excavation. A slotted pipe was placed in this tunnel connecting the bottoms of the drain wells, and the remainder of the tunnel was backfilled with pervious material. Vertical perforated pipes were placed in the drain wells, and the area around the pipes backfilled with pervious material. This in reality provided a pervious drain wall or gallery connecting the upper portions of the stabilization trenches. The freeway was subsequently completed and this installation has gone through two additional winters. The Southern Pacific Railroad has since done considerable filling in the upper part of the slide to provide support for the railroad.

There have been no serious signs of distress or movement in this area after completion of the freeway. There has been some sliding beyond one end of this stabilized area, thus confirming the need for stabilization and indicating that the stabilization should have been extended. However, it should be kept in mind that the two winters since the completion of this installation have not been severe and hence ground water conditions may not have provided a real test of the effectiveness of this installation.

CONCLUSIONS

The case histories of several cuts in the California Highway Construction program have been presented in the above paragraphs. Wide ranges in conditions and performance are represented.

These case histories point up the need for experience and judgment and the use of the best and most modern tools that are available if potentially weak areas are to be detected in advance of construction and serious slides are to be avoided.[8]

Of paramount importance are the orientation, continuity and dip of natural planes of weakness and no matter how carefully all evidence is studied, the overall slide potential of a given earth mass is never truly known until the excavation has been made and the mass has been put to a full-scale test.

The California Division of Highways is making every effort to apply reasonable margins of safety to the design of cut slopes. Toward this end, geological and soils studies, exploratory borings and laboratory tests play an important role.

ACKNOWLEDGEMENTS

Grateful acknowledgement is given to the many Division of Highways employees and others who have given assistance or information for the preparation of this paper, particularly to Mr. D. R. Whetsel and Mr. D. A. Justice for assembly of data and preparation of illustrations and to Mrs. M. Lark for editing and typing the paper. The foundation investigations and design of the special treatment on the projects described were under the supervision of Mr. A. W. Root, Supervising Materials and Research Engineer who retired on May 1, 1962, and under the direction of Mr. F. N. Hveem, Materials and Research Engineer.

REFERENCES

1. T. E. Stanton, "California Experience in Stabilizing Earth Slopes Through the Installation of Horizontal Drains by the Hydrauger Method," Proceedings 2nd International Conference on Soil Mechanics and Foundation Engineering, June, 1948.

2. H. W. Benedict, "Redwood Freeway," California Highways and Public Works, Sept.-Oct. 1957, p. 52.

3. Leonard C. Hollister, "Now Read This," California Highways and Public Works, Jan.-Feb. 1957, p. 37.

4. Leonard C. Hollister, "New Parallel Bridge," California Highways and Public Works, Jan.-Feb. 1959, p. 1.

5. T. W. Smith and G. V. Stafford, "Horizontal Drains in California Highways," Paper 1300, Journal of the Soil Mechanics and Foundations Division, ASCE Vol. 83, No. SM3, July 1957.

6. T. W. Smith, "Major Slides of the Trans-Sierra Highway," a report presented at the Pacific Southwest Council Convention, A.S.C.E., San Diego, California, April 5-7, 1962.

7. H. R. Cedergren, "Seepage Requirements of Filters and Pervious Bases," ASCE Proceedings Paper No. 2623, Journal of Soil Mechanics and Foundations Division, October, 1960.

8. A. W. Root, "Correction of Landslides and Slipouts," Paper No. 2738, ASCE Transactions, Vol. 120, 1955, p. 281.

Fig. 1 - View of Completed Dyerville Cut

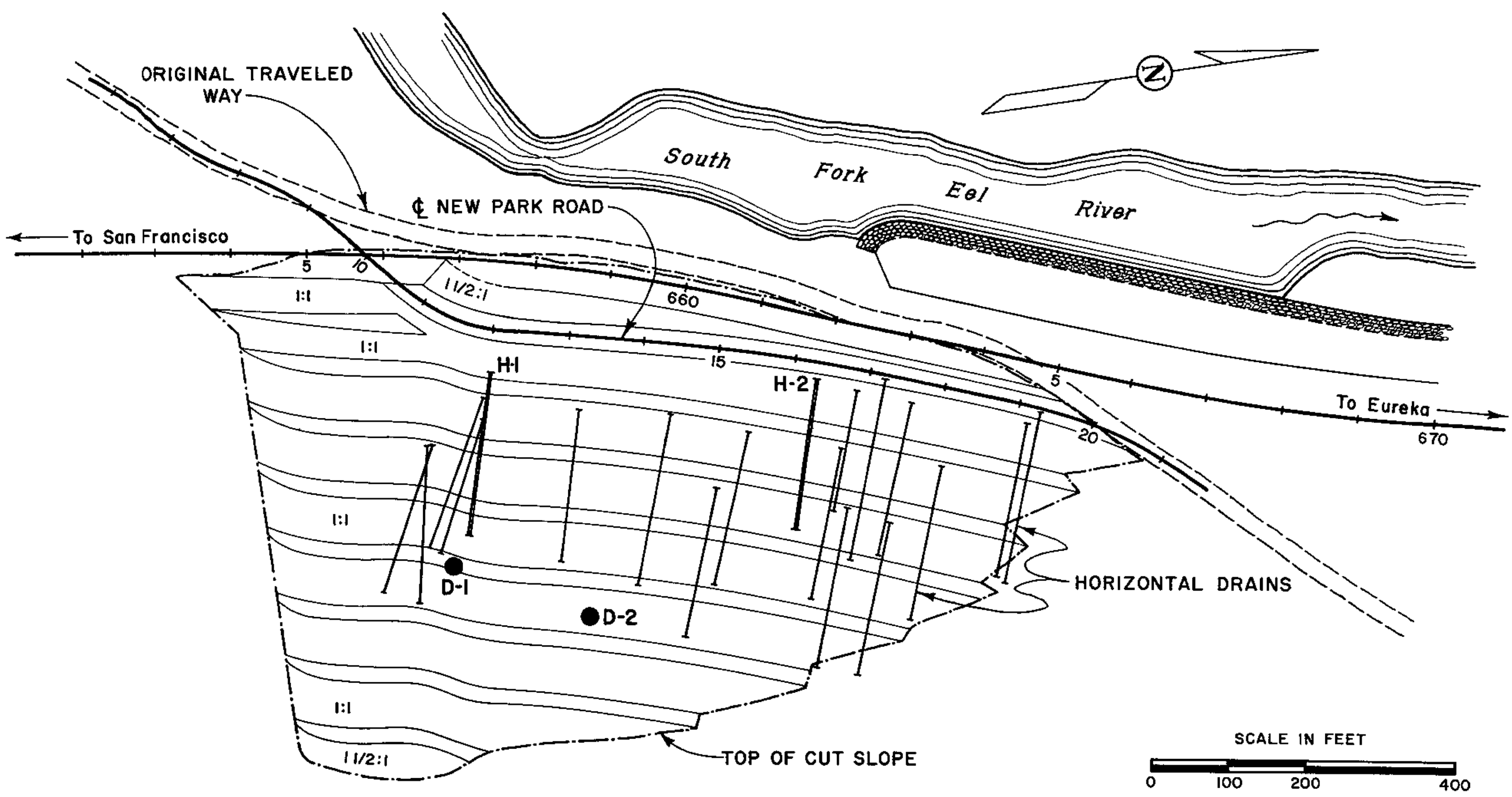


FIG. 2 PLAN OF DYERVILLE CUT SHOWING HORIZONTAL DRAINS AND BORINGS

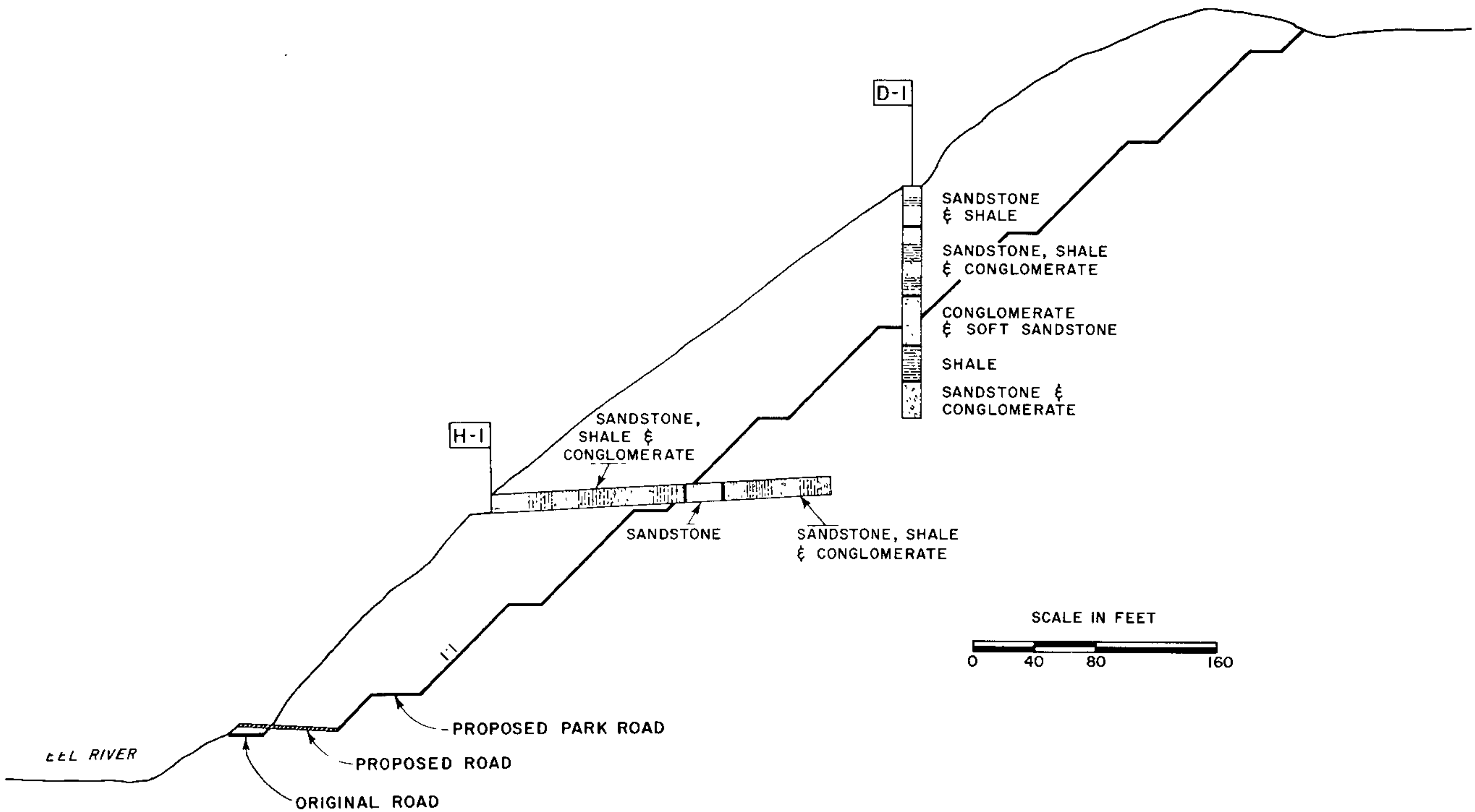


FIG. 3 TYPICAL SECTION OF DYERVILLE CUT SHOWING BENCHED DESIGN AND SIMPLIFIED BORINGS

Fig. 4 - Aerial View of Completed Carquinez Cut and Southern Approach to Twin Bridges

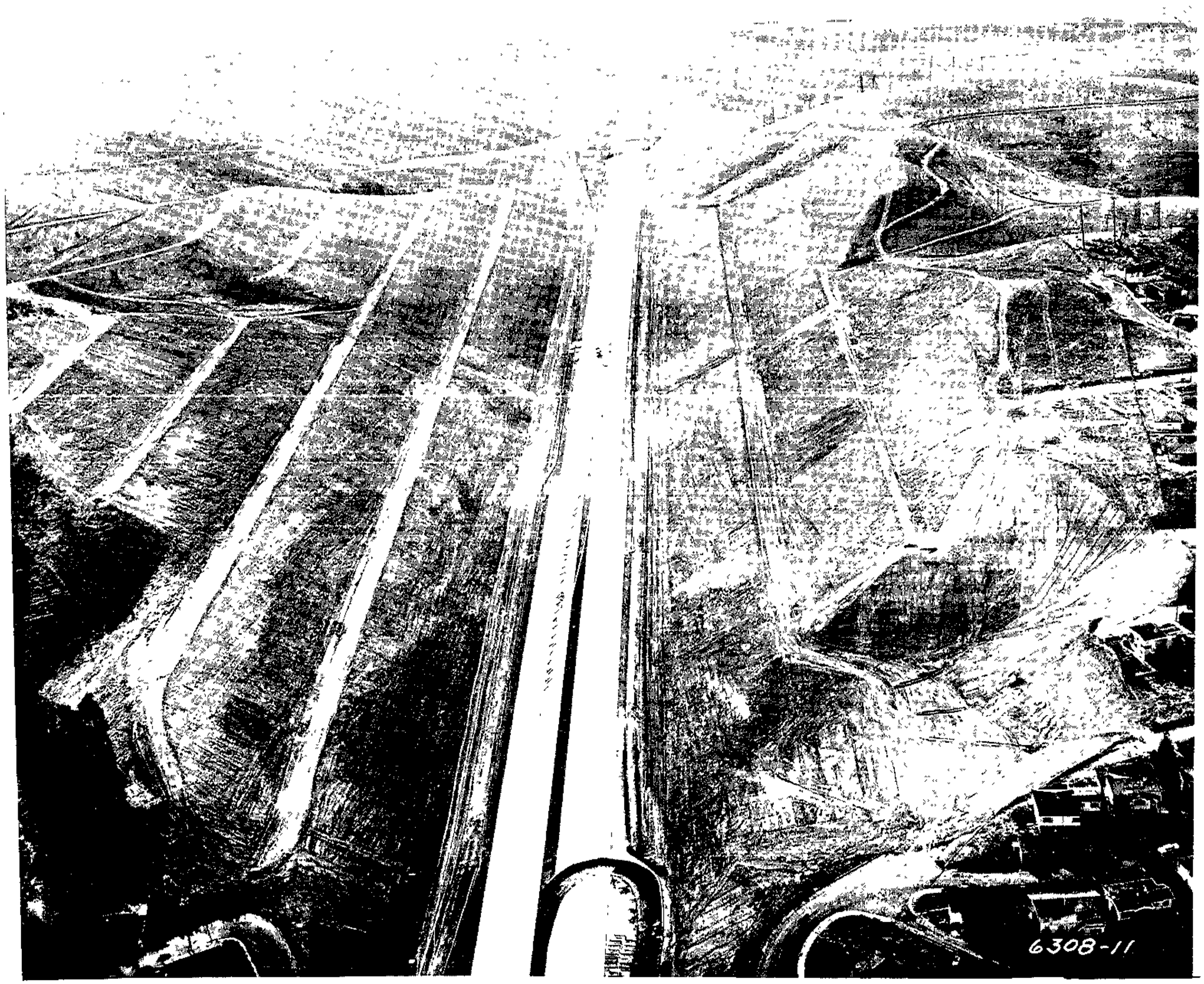


Fig. 5 - Aerial View Showing Magnitude of Carquinez Cut

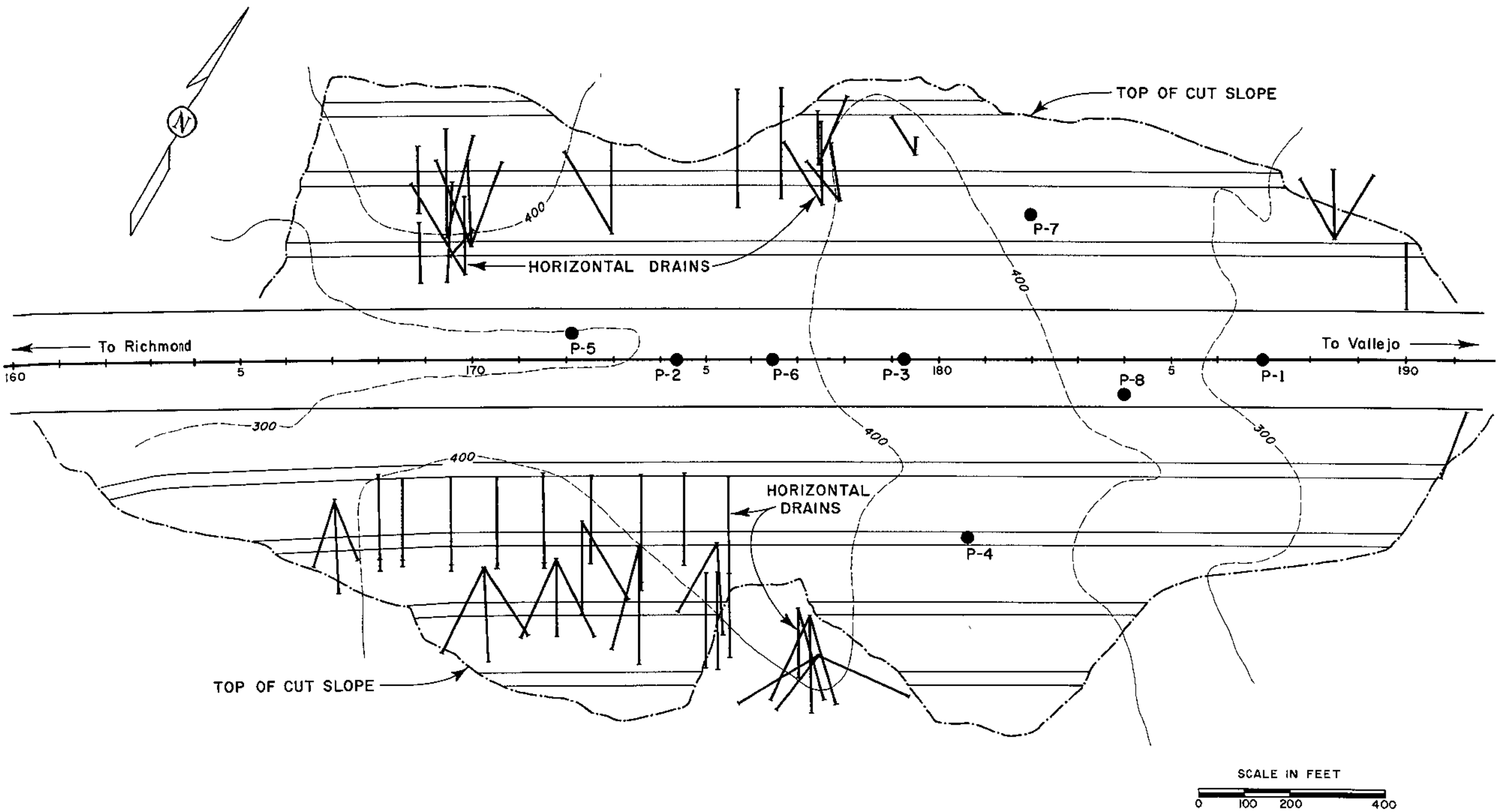


FIG. 6 PLAN VIEW OF CARQUINEZ CUT SHOWING HORIZONTAL DRAINS AND BORING LOCATIONS

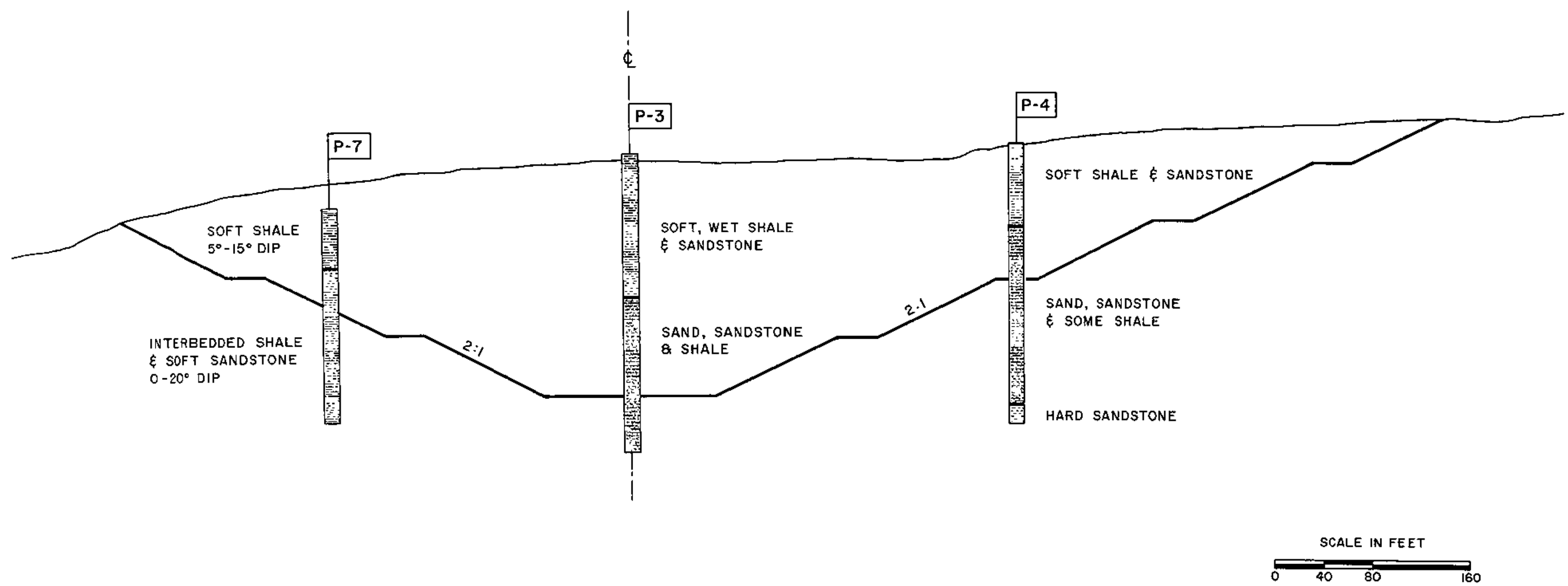


FIG. 7 TYPICAL SECTION OF CARQUINEZ CUT WITH SIMPLIFIED BORINGS

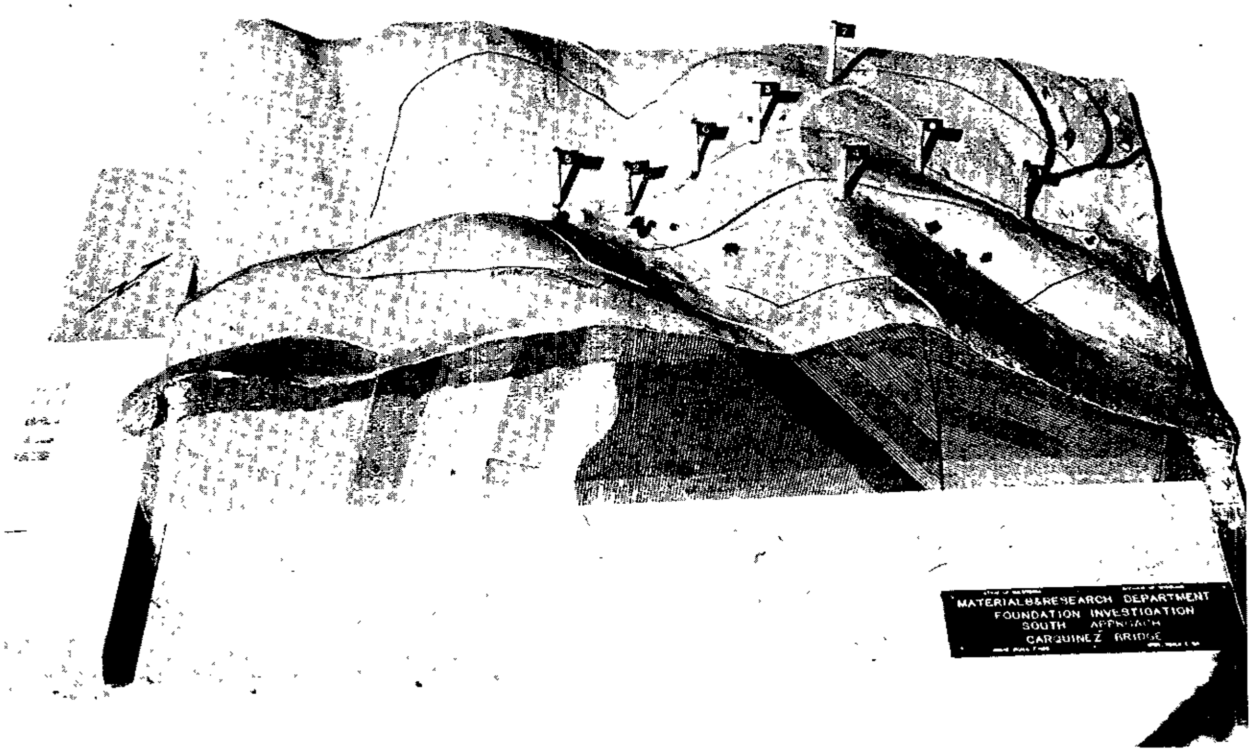


Fig. 8 - View of Model Showing Original Topography of Site of Carquinez Cut

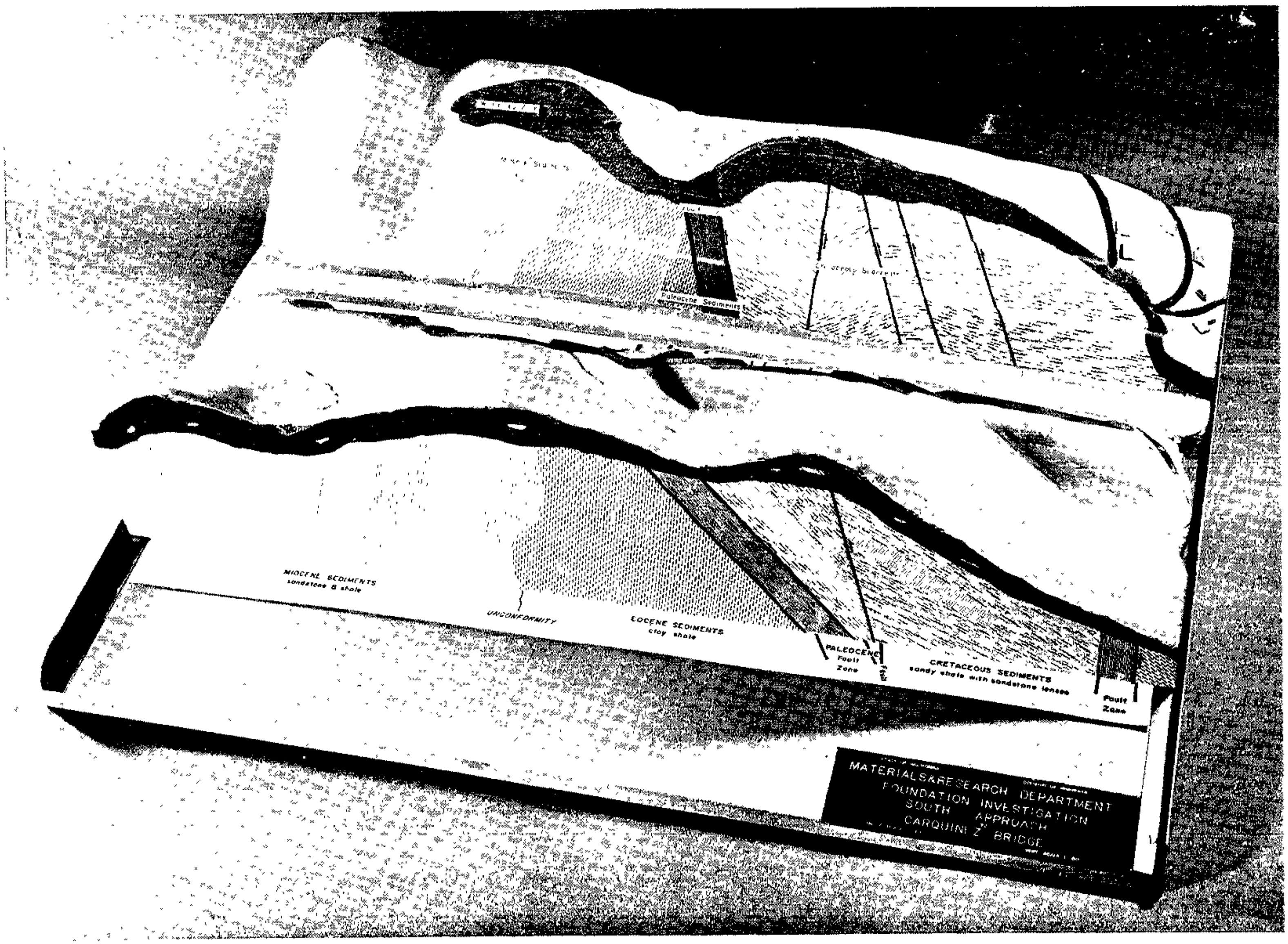


Fig. 9 - View of Model Showing Preliminary (Front Profile) and Actual (Rear Profile) Geology of Carquinez Cut

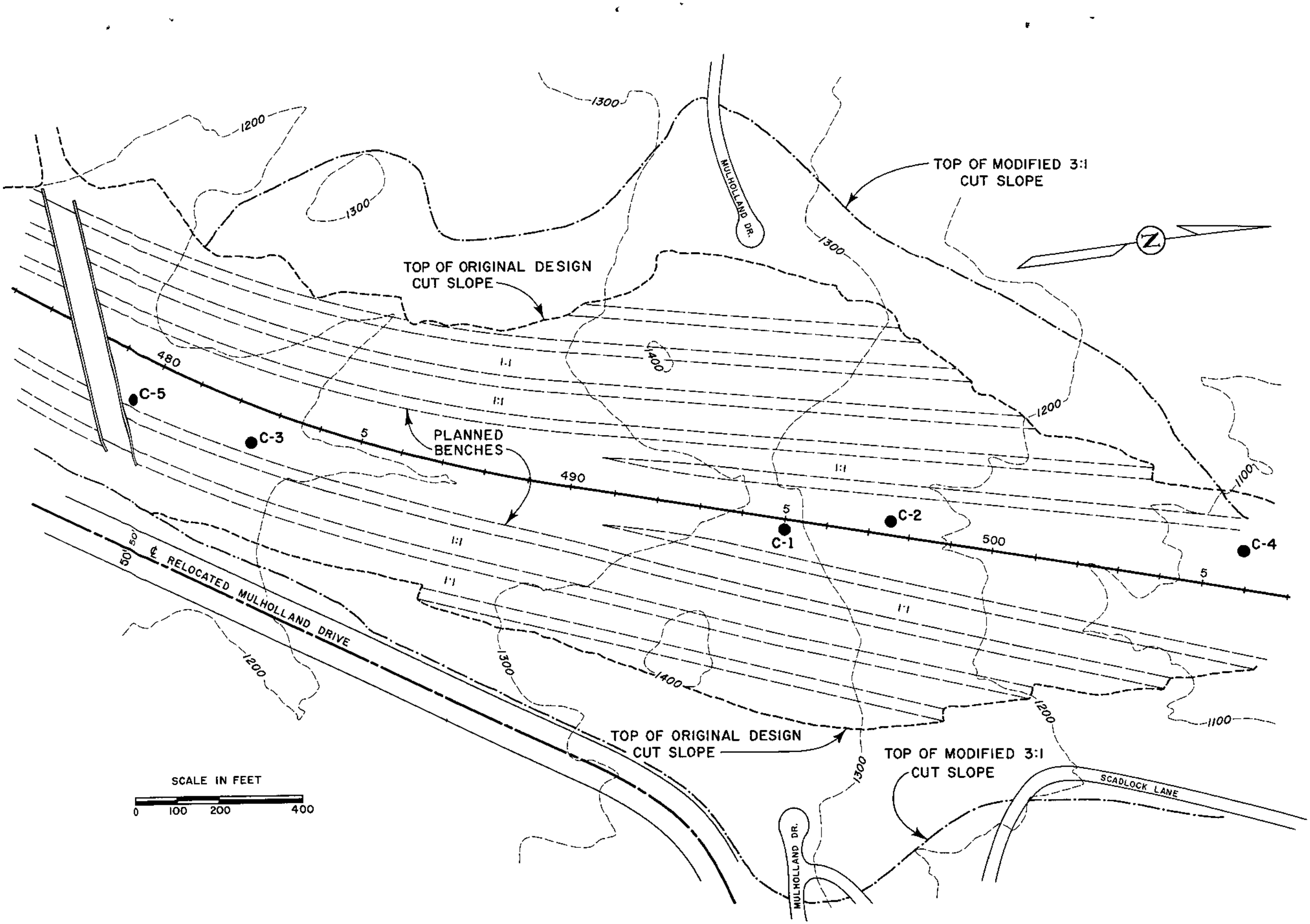


FIG. 10 PLAN SHOWING ORIGINAL AND MODIFIED SLOPE DESIGN OF MULHOLLAND CUT

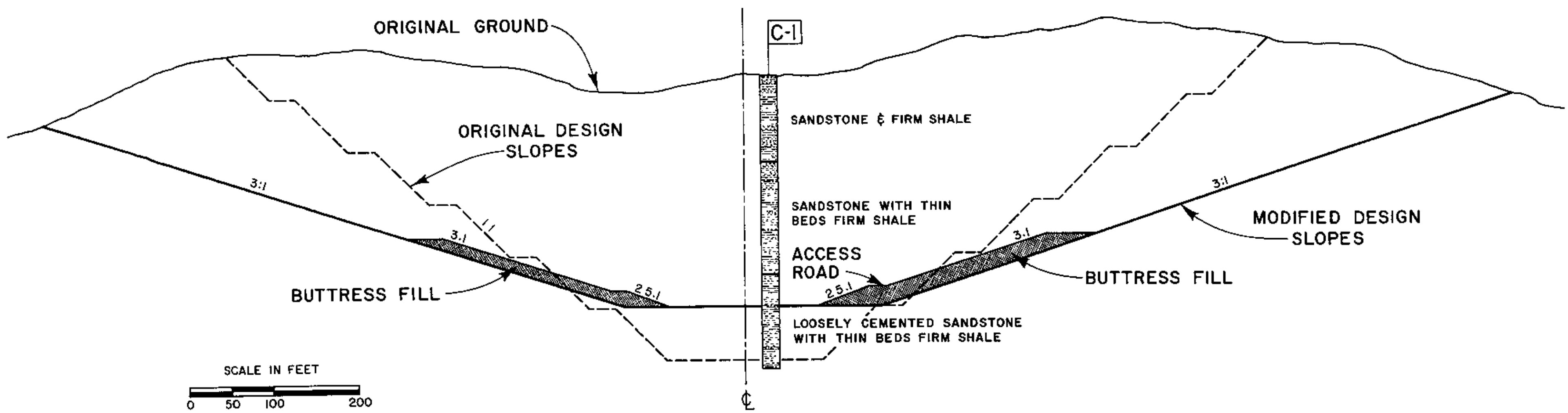


FIG. 11 TYPICAL SECTION OF MULHOLLAND CUT SHOWING ORIGINAL AND MODIFIED DESIGN

Fig. 12 - Aerial View of Mulholland Showing Failure of Partially Completed Cut and Limits of Modified Cut Slopes

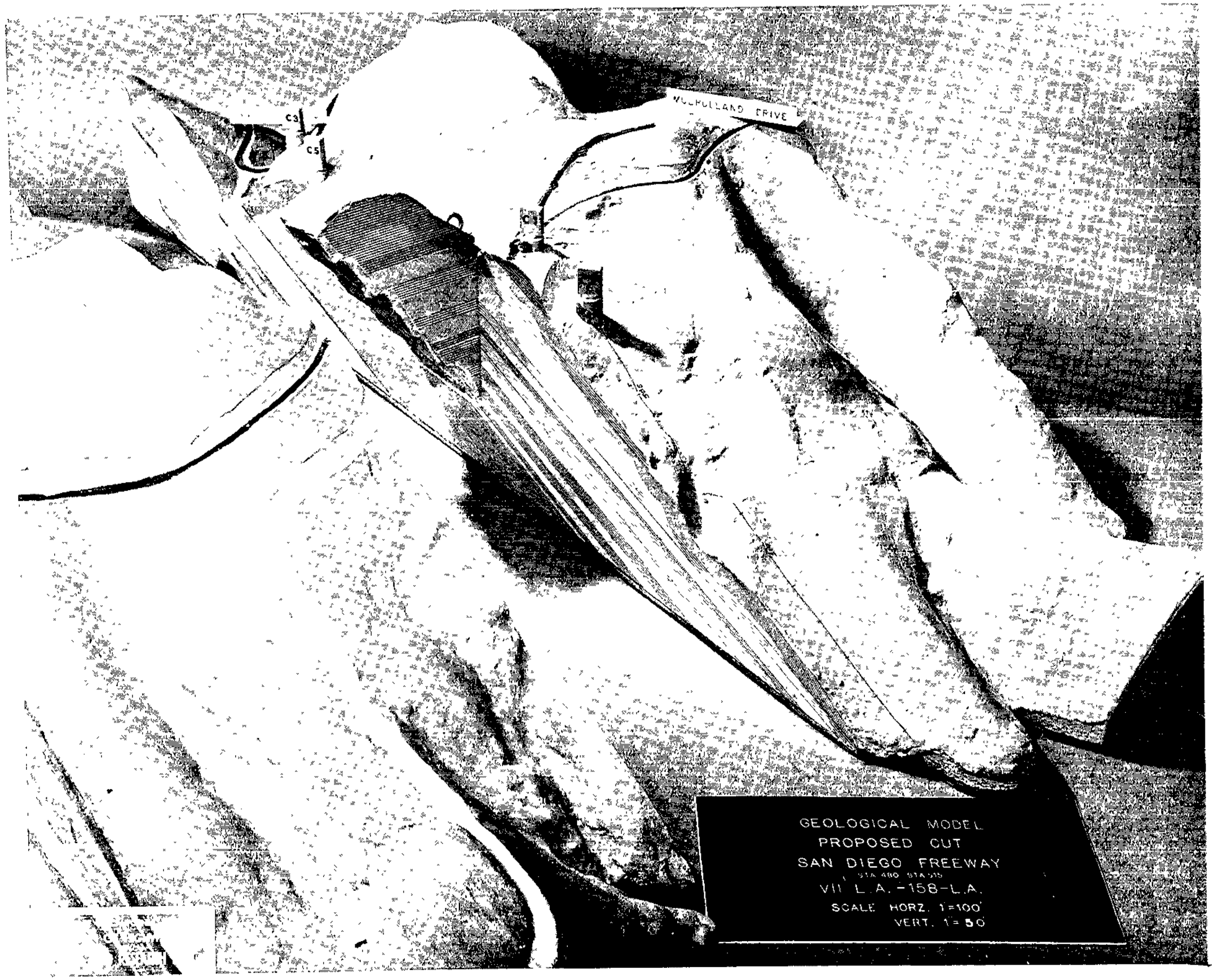


Fig. 13 - Photograph of Model Separated to Show Geologic Formations at Site of Mulholland Cut

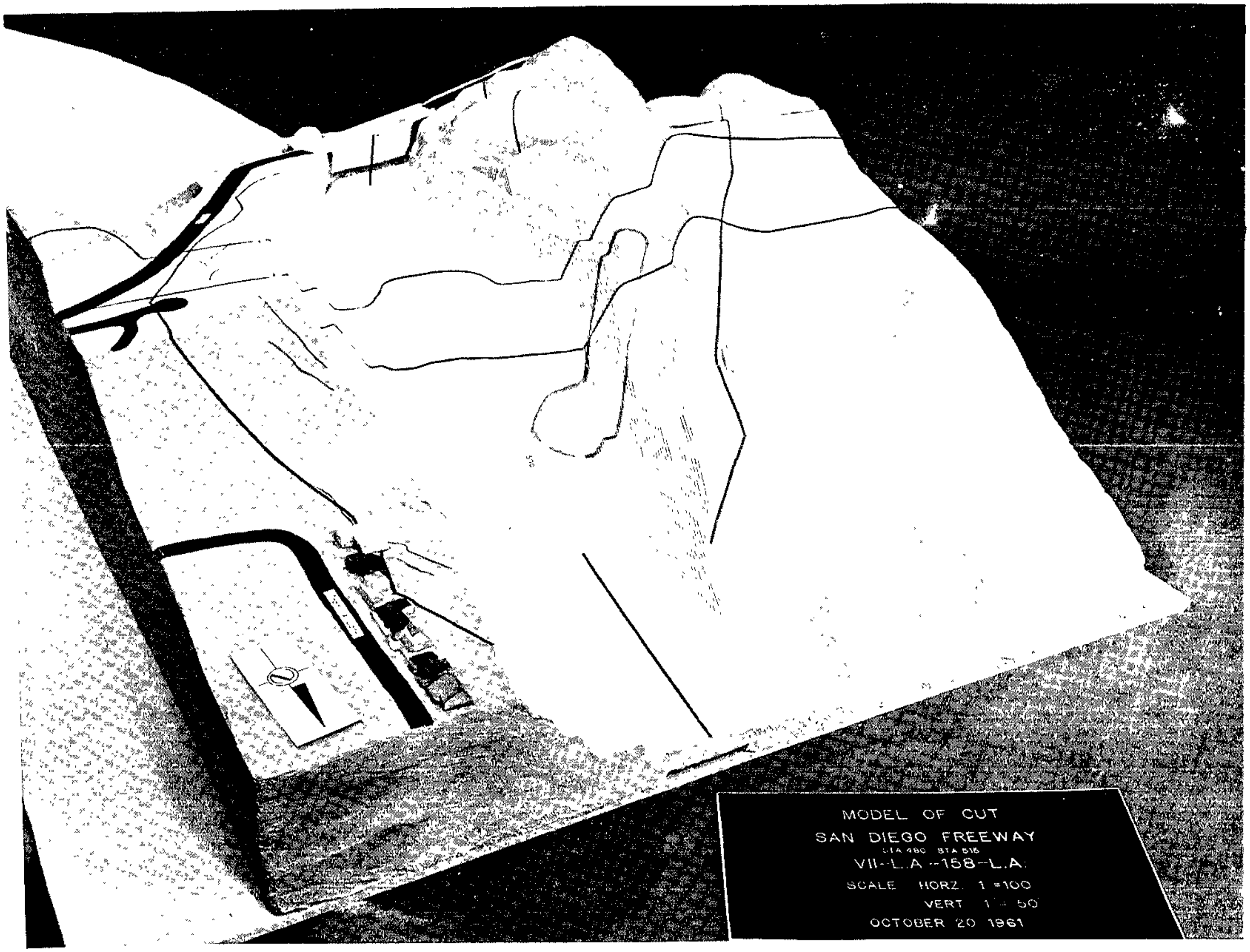


Fig. 14 - Photograph of Mulholland Cut Model Showing Status of Excavation at Time of Failure

Fig. 15 - View Looking Toward Railroad at Towle Landslide

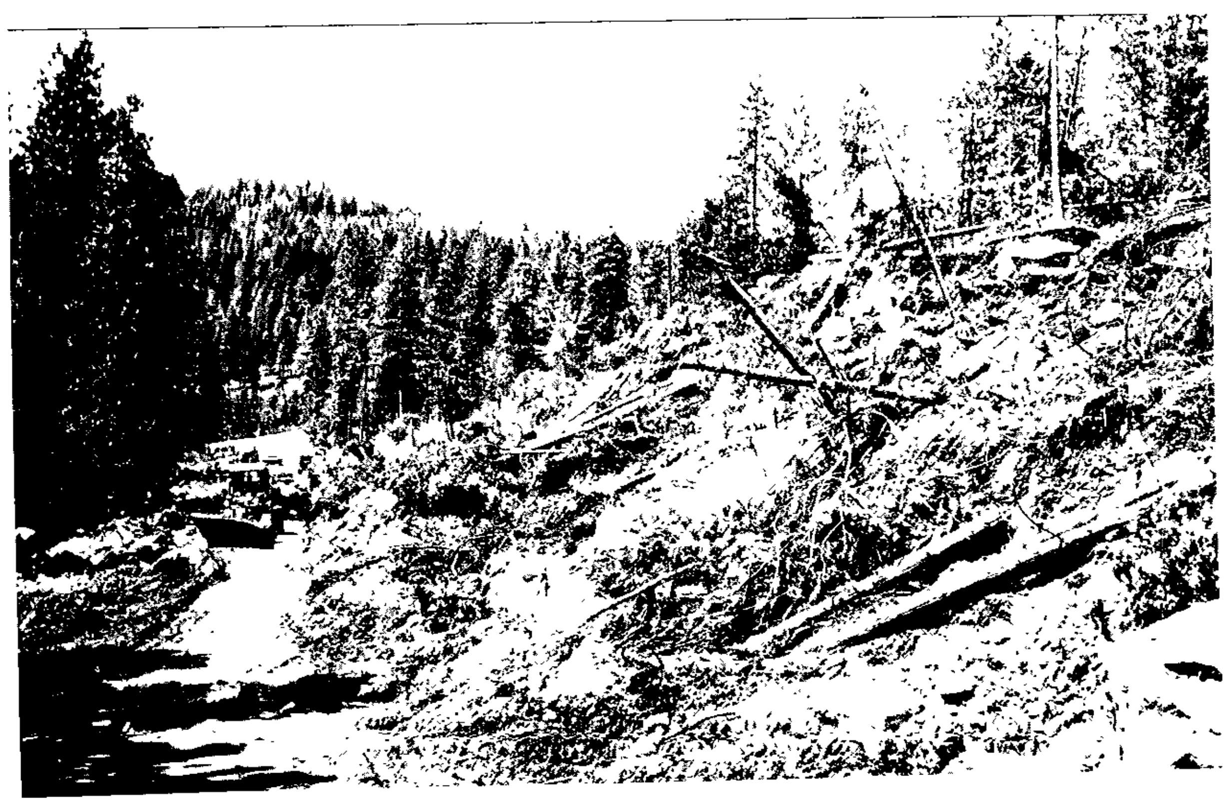


Fig. 16 - View Looking West Along Highway at Toe of Towle Slide

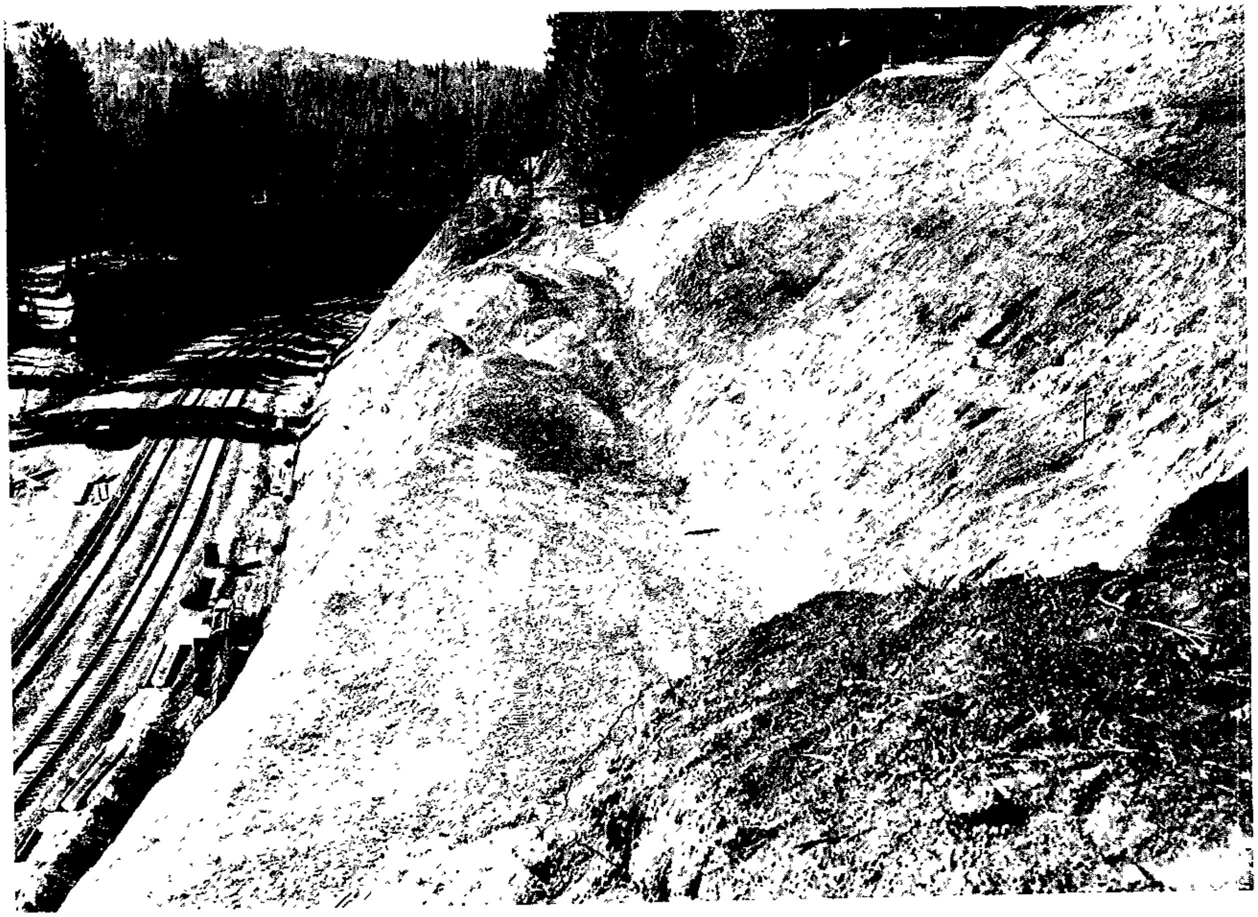


Fig. 17 - View Showing Excavation for Railroad at Towle

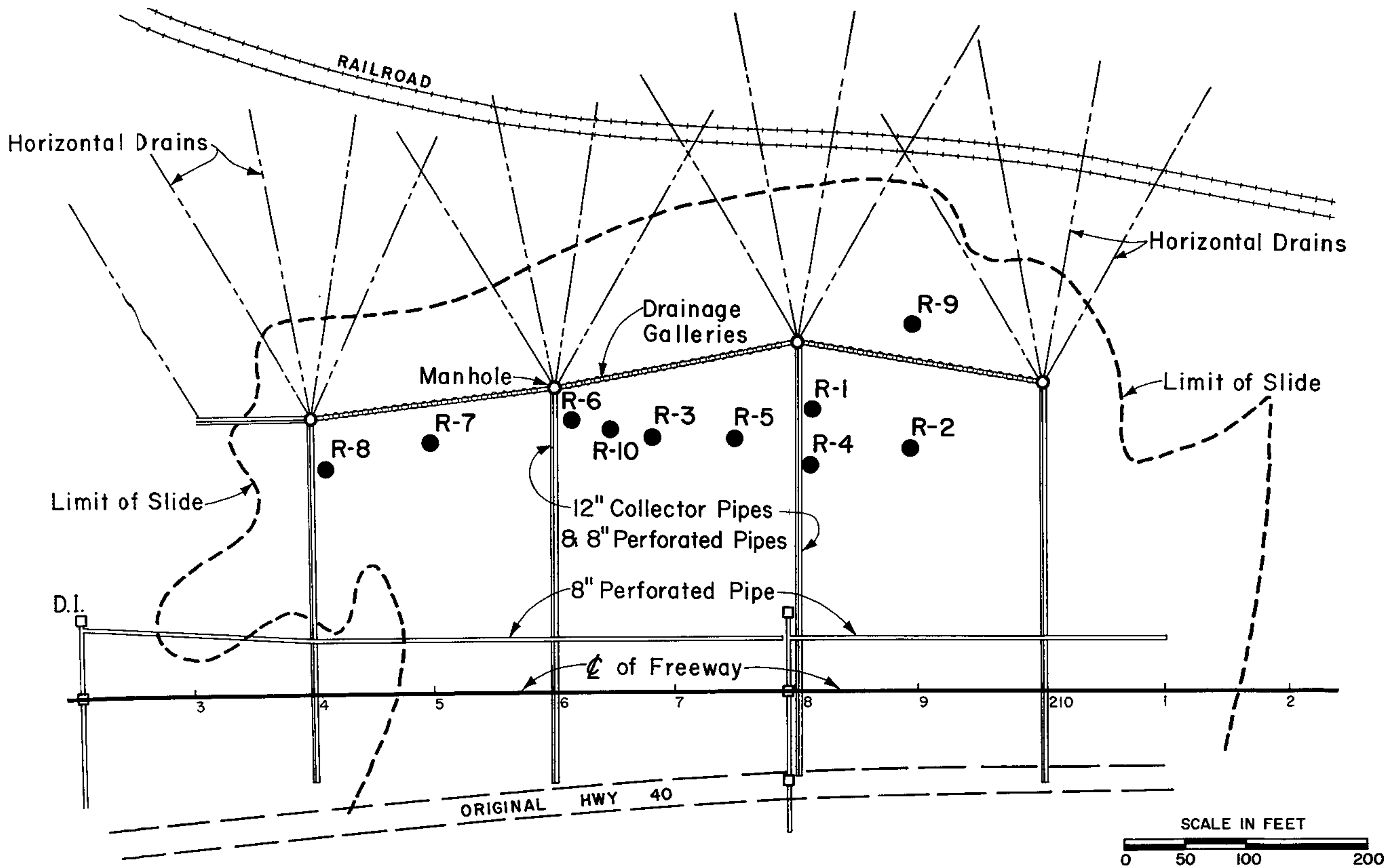
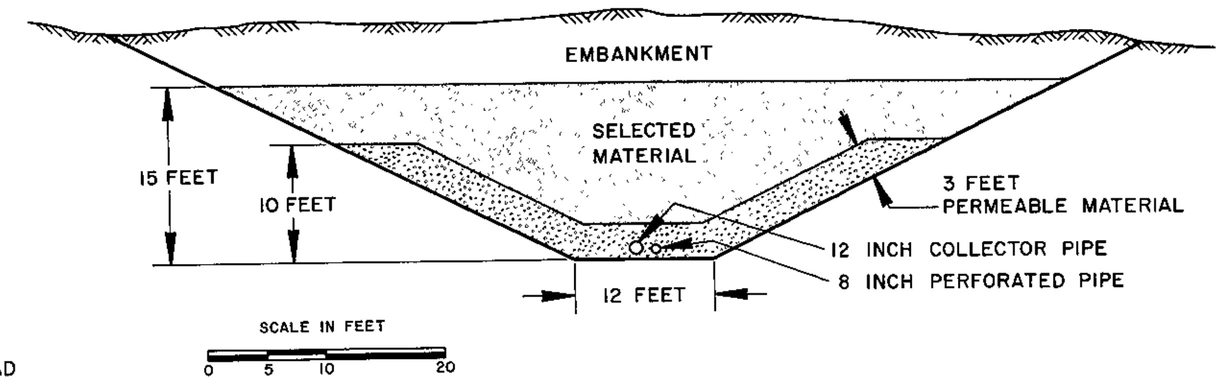
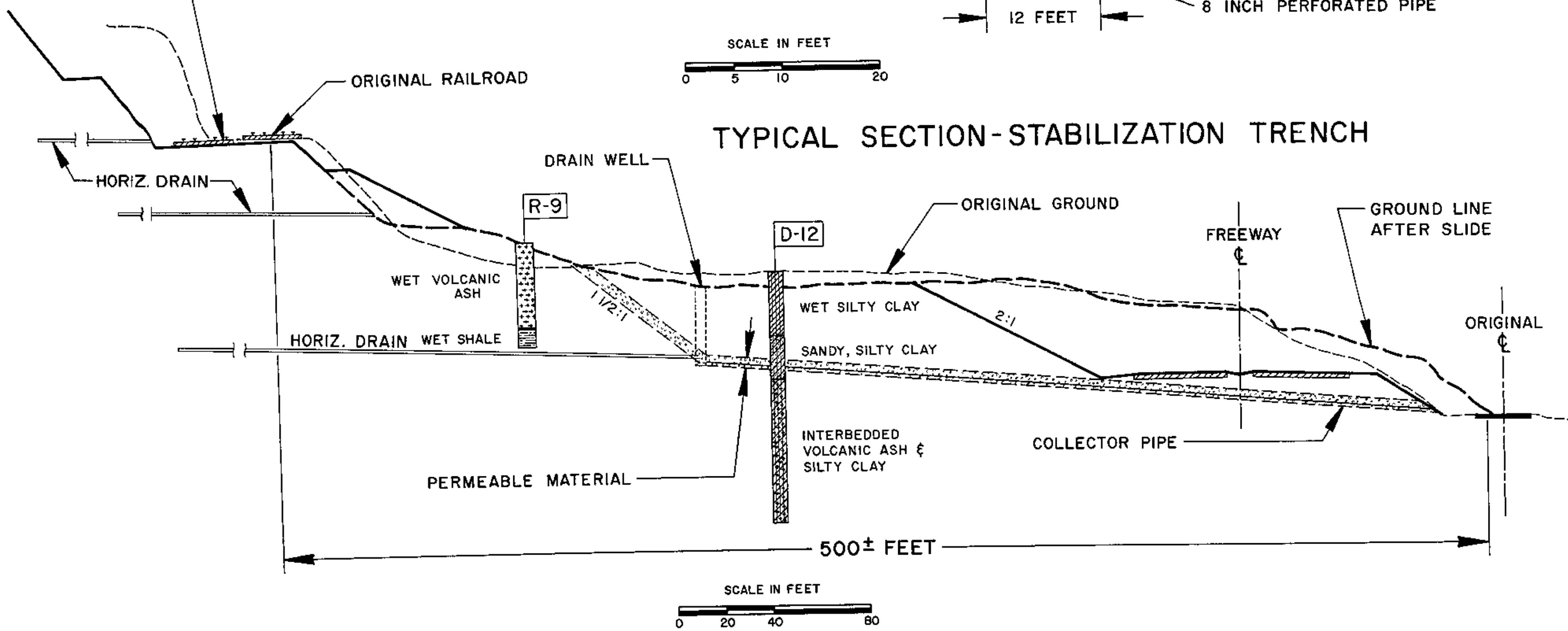


FIG. 18 PLAN SHOWING STABILIZATION DETAILS AND BORING LOCATIONS AT TOWLE SLIDE



TYPICAL SECTION-STABILIZATION TRENCH



PROFILE ALONG STABILIZATION TRENCH

FIG. 19 PROFILE AND TYPICAL SECTION OF STABILIZATION TRENCH AT TOWLE SLIDE

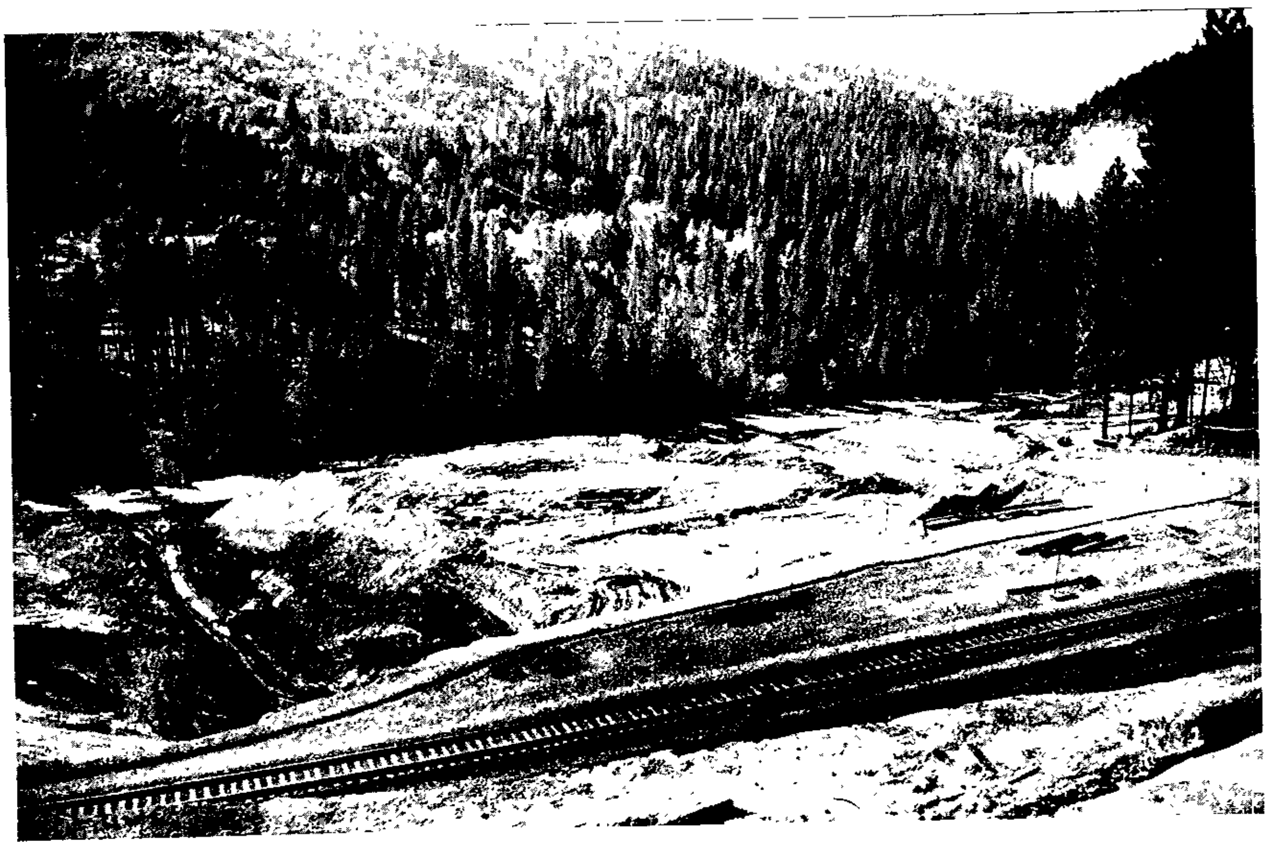


Fig. 20 - View Showing Stabilization Trench at Towle