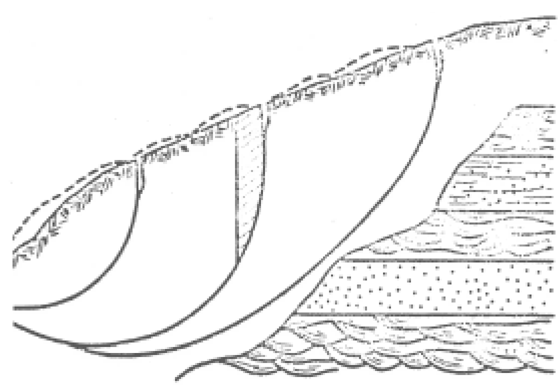
HRC14

ARKANSAS STATE HIGHWAY DEPARTMENT

A STUDY OF LANDSLIDES



RESEARCH PROJECT 14

LANDSLIDE STUDIES

Highway Research Project 14

FINAL REPORT

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Civil Engineering Department
University of Arkansas

in cooperation with

Arkansas Highway Department

and

Department of Commerce
Bureau of Public Roads

FINAL REPORT

Highway Research Project No. 14

LANDSLIDE STUDIES

INTRODUCTION

The project was approved by the Bureau of Public Roads effective March 1, 1963. The purpose of this study as contained in the original proposal is

> "It is the goal of this project to obtain from literature, through investigation of actual movement, and by conferences with others, information that will assist highway designers and maintenance engineers in Arkansas to recognize slide prone areas and to remedy actual slides."

This investigation is one of the Projects under the Basic Agreement between the University of Arkansas and the Arkansas Highway Department and is sponsored jointly by the Arkansas Highway Department and the Department of Commerce, Bureau of Public Roads.

The literature on this subject is voluminous. There is much valuable information buried in this mass of literature, but it is not immediately available for the busy engineer who is called upon to decide how to construct our highways. This project summarizes the pertinent literature so that it can be easily scanned by the practicing engineer. Typical slides and movements are investigated and reported along with correction methods and treatments that have been used to stabilize them.

Detailed investigations have been made of typical slides. Sketches, profiles, soil data and pictures are presented on some of these. Locations of recent slides are indicated by map.

This report has been made as brief as possible because the Location, Design, Construction, and Maintenance Engineers who will benefit from it are busy people and have very little time to devote to additional study. Benefit from this study can only be obtained when the people concerned with building our highways put this information to use. We believe that brevity will encourage wider readership.

The bibliography and abstracts are by no means complete. The articles listed in the bibliography and those summarized are only a selected few from the mass of literature. These particular ones were selected because they are concerned with conditions similar to those encountered in Arkansas. The abstracts of articles are intended only as a guide for engineers who wish to read further in the literature.

This report is not a product of the Principal Investigator alone, but is a cooperative effort of the entire Project Sub-committee. The Sub-committee has taken an active part in all investigations and studies and has been of tremendous help to the Principal Investigator during the entire investigation. All of the geological information is the product of Sub-committeeman Jake Clements, Jr.

SUMMARY OF

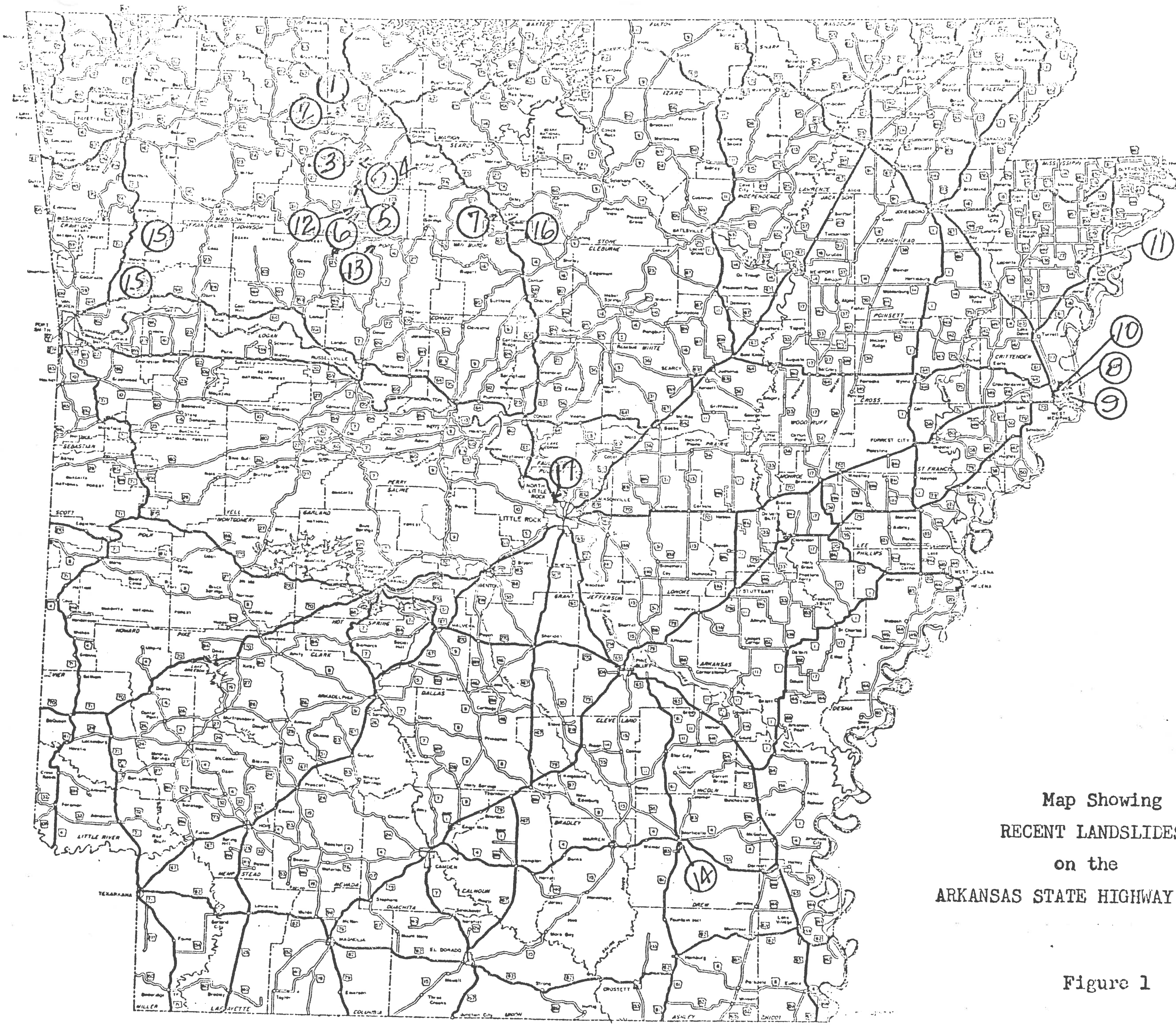
RESULTS AND RECOMMENDATIONS

It can be seen from the map Figure 1 that the slide prone areas of Arkansas are the Ozarks of Northwest Arkansas and the embankments constructed from the soils of the Mississippi River Delta. There is a possibility of a slide on any highway constructed in the Ozarks of Northwest Arkansas. It can be expected that there will be many slipouts and failures of the backslopes on sidehill construction. These failures can be expected in any location where shales and other sedimentary rocks are interbedded. In all such locations provision should be made in the design for these slide conditions.

The major factors causing these slides are a combination of ground water and shales and clays. Flatter backslopes will alleviate some of the condition but there will still be some movements causing unsightly back slopes. The only complete answer is to intercept the seepage water before it approaches the surface of the back slope, or gets under the embankment.

The most satisfactory method of intercepting the ground water is by the use of horizontal drilling and installation of perforated pipe. This method has proved effective in the prevention and stabilization of slides under conditions very similar to those encountered in Northwest Arkansas.

Two rules of thumb have often been quoted as being effective in slide prevention. First of these is: never build the roadway on part excavation and part fill. The entire road should be placed on a cut section. Secondly, the north side of hills and ridges are the worst from the standpoint of slides. The reason for this is that the north side of the hill is always the wettest and is more likely to have a higher ground water table.



Map Showing
RECENT LANDSLIDES
on the
ARKANSAS STATE HIGHWAY SYSTEM

Figure 1

A geological study of locations in the slide prone areas of Northwest Arkansas is necessary if there is to be any reduction in the number of slides occurring on our highways.

The only real means of preventing slides on the embankments in the Mississippi River valley is to maintain a low water content in the embankment. This can be accomplished only by keeping water from entering the embankments after they are constructed. Care must be taken in any method used to waterproof the end of the embankment to insure that there are no cracks, regardless of how small, that would allow the water to get under the water proofing material. Secondly, steps must be taken to prevent water from entering the embankment at the end of bridges.

Prevention of slides is directly related to recognition of slide prone areas. Ability to recognize slide prone areas is essential to the location engineer. Unstable areas can be recognized by the presence of hummocky ground, old escarpments with bulges below, leaning trees, tension cracks around boulders or trees, and excessive water flow especially from the top of shale beds or other clay formations.

There is no justification for using preventive measures unless there is some indication that sliding might occur. It is hard to economically justify the spending of large amounts of money on preventive measures because it can seldom be proven that sliding would have occurred if no steps had been taken to prevent it. In cases where there is danger of loss of life or property due to sliding, preventive measures are easier justified than are the usual landslides on highways. Although landslides along highways are usually only a maintenance or construction problem, they may endanger lives or property. Every effort should be made to prevent slides of this kind. Slides that are considered to be only a construction or maintenance problem may be very expensive to control and the usual preventive measures will frequently cost much less than the correction of the sliding area after failure.

The services of a qualified geologist are a must when locations and designs are made in slide prone areas. A geologic interpretation of the formations will identify places where slides are likely to occur and what can be done to prevent them. Landslides are not a problem of the soil only but a combination of the soil mantle and the geologic formations on which the soil rests.

RECENT SLIDES IN ARKANSAS

The following is a list of the slides inspected as a part of this investigation. Figure 1 shows the locations of these slides.

1. State Highway 43, eight miles southwest of Harrison at Gaither Mountain.

2. State Highway 43, eight miles southwest of Harrison at Gaither Mountain. Same vicinity as slide No. 1. Two different movements of embankment on sidehill and, in addition, some movement of backslope above roadway.

3. State Highway 7, one mile south of Jasper. Backslope slipped due to seepage pressures.

4. State Highway 7, two miles south of Jasper. Slides of embankment and backslopes on sidehill.

5. State Highway 7, 10.6 miles south of Jasper, slide in fill on sidehill.

6. State Highway 7, 6.3 miles south of junction with State Highway 16. Slide in fill on sidehill.

7. U. S. Highway 65, one mile south of Leslie, slide in backslope.

8. Interstate Highway 40, Frisco overpass near West Memphis, slide of embankment at bridgehead.

9. Interstate Highways 40 and 55 Wye, slide in embankment at bridgehead of grade separation.

10. Interstate Highway 55 near Marion. Slide in embankment.

11. Interstate Highway 55 and State Highway 181, grade separation two miles south of Keiser. Slide in embankment at bridgehead.

12. State Highway 7, 0.6 miles south of junction with State Highway 16. Sidehill movement.

13. State Highway 7 near Sand Gap north of Dover. Sidehill movement.

14. U. S. Highway 81, by pass at Monticello. Backslopes sliding due to seepage pressure of water flowing from slope.

15. U. S. Highway 71 near Mountainburg. Backslopes sliding due to seepage pressures.

16. U. S. Highway 65, Leslie, south. Backslopes of new construction sliding due to seepage pressures. Many slides along entire length of project. See (7) above.

17. Interstate 40, one mile west of North Little Rock. Slide in backslope due to seepage pressure.

DESCRIPTION OF SLIDES

Slide Number 1

This slide occurred during the construction of the Highway. It was corrected by flattening the fill slope and deepening the uphill ditch to intercept the water. This location is about 800' east of Slide Number 2. All of the conditions are similar to those of slide Number 2.

Slide Number 2

This slide is typical of the many slides in Boone and Newton Counties. The highway was rebuilt in 1961-1962 along the location of an existing road. At the site of this slide the road had been in use for some thirty-five years before reconstruction began. During this period no serious sliding occurred; however, the road was narrow and there was very little fill on the hillside. Some movement of the fill side of the highway was observed during construction and shortly after. Within one year considerable movement of the embankment on the side-hill was observed at this location; however, no serious faulting of the highway itself was observed. A few cracks and a downward movement of approximately two feet occurred before remedial measures were taken. At the time of this movement it was observed that water was seeping from the backslope on the uphill side of the road and running down the roadway ditch. A corrugated metal pipe was installed to take this water across the road and the ditch was paved to prevent the water from seeping downward under the road. This apparently stopped the movement at this particular location.

In March 1964 a large slide occurred in the fill portion of the roadway immediately east of and adjoining the previous slide. In this second movement the outside one-fourth of the roadway dropped down a distance of about twenty feet and the entire mass of soil and rock moved down the slope for a distance of about 250 feet. Figure 2 is a cross section of the road at this slide location. The mass of earth and rock in the slide was very wet and pools of water were observed at several locations within the slide area. Some water was flowing out of the hillside at the upper edge of the slide. At the same time movement of the backslope of the uphill side of the road was observed. It was also observed that water was flowing out of the

CROSS SECTION AT SLIDE No. 2

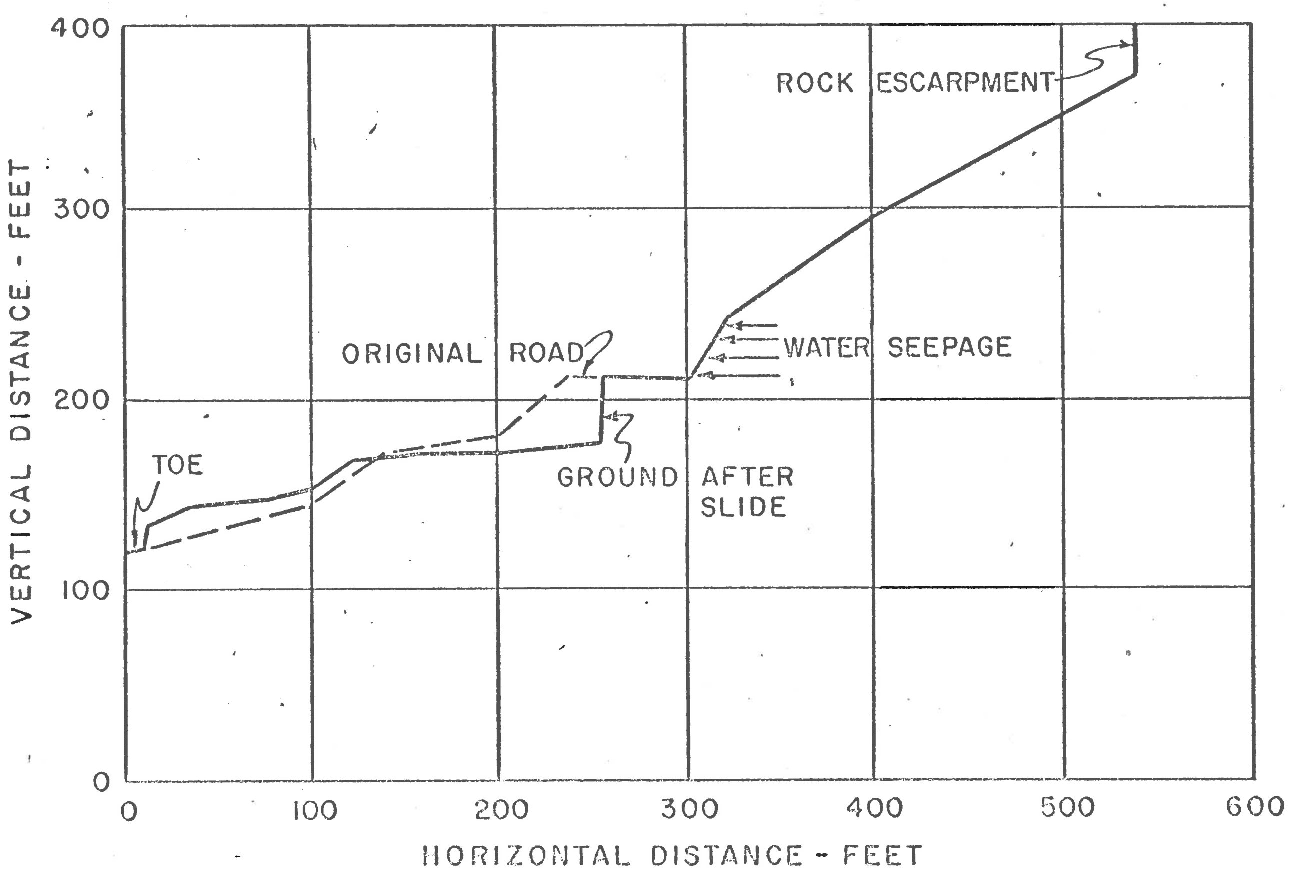


FIGURE 2

backslope at this location.

All of this movement is at a location where the highway crosses a small gulley. This gulley extends up the hill-side to the foot of the caprock. This is a natural drain and water flows off of the top of the hill for long periods of time after rains. Some seepage is noted at the foot of this caprock, even in the driest seasons of the year. The gulley has been partially filled with an alluvium consisting of a mixture of small stone and silty clay soil in a very loose condition.

It appears that the cause of failure at this point is due to the seepage of water from the hilltop. All of the movements appear to be along the interface between the new embankment and the original ground surface under the recent alluvium.

The corrective measures taken in this case were to deepen and widen the ditch on the upstream side to intercept as much water as possible and carry it across the road in pipes. The center line of the road was moved toward the hillside to place all of the road on excavation and eliminate the fill. In this case there will still be a short section of the road, approximately fifty feet on the recent alluvium that has filled the gulley. It is estimated that the corrective measures taken to date have cost well over $10,000.

Slide Number 3

This slide occurred in the backslope during the construction of the road. Within a few days after the roadway was excavated, the backslope for a distance of about fifty feet was observed to be moving toward the roadway. This movement was slow and took the form of a plastic flow rather than a slide. The material at the top of the slide sunk downward about three or four feet and the toe bulged at the ditchline in a typical slide pattern. The first slide occurred in the lower half of the slope. There were then subsequent slides in which the top of each of the later slides started higher up the hill, until the last movement started at the top of the hill. All the movements took place over a period of about forty-eight hours. During the period of the movement it was observed that the entire slide area was very wet and a person walking on this material would sink to his knees.

The interesting thing of this particular slide was that it occurred on the side of a round knoll and the top of the slide extended to the top of the knoll. High seepage pressure was the immediate cause of this failure, yet because of the shape of this knoll there is no apparent reason for the high water table in this area. The water could only be due to a local artesian condition in which it is being fed from a hillside to the south, under a saddle, then upward into this knoll. The only remedial measure taken was to place a line of heavy boulders at the toe of the slope of the slide to restrain it. These boulders were pushed into place with a bulldozer and were several cubic yards in volume. The only movement visible since these boulders were placed at the toe of the slide has been an outward bulging of the line of boulders. The line of boulders is now curved outward at about the center of the slide. No movement of these boulders has been observed in the last three years.

Slide Number 4

Slide Number 4 is actually a series of slides that occurred during construction of the highway and at various times since then. Some local movements have been observed along the entire hillside for a distance of about two miles of highway. In all cases these are movements similar to that described for Slide Number 2. All of these slides are in the detritus and soil mantle that covers the slope.

An examination of this mountain indicates that there have been slides in the natural rock and soil mantle for long periods of time. Some scars were observed that have occurred as recently as one or two years back. Other slide scars were evident that had large oak trees growing from them, indicating that these scars were very old.

The slides along this sidehill have been a continual maintenance problem since the road was constructed. The usual corrective measures consist of removing the material that slides onto the road from the backslopes and filling the scars left by slides on the downhill side of the road. In several instances the centerline of the road has been moved toward the hillside so that all of the roadway is on natural ground. In these instances the movements have ceased. Perforated pipe was installed in the up-hill ditch and drained across the road at the lower end of the movement at one location. This work stabilized this particular movement. There is no good estimate of the costs that have been incurred by these slides. One major slide that occurred during construction cost approximately $35,000 to correct.

All of the slides on this hillside are due to the weakening effect of water seeping down the hillside through the loose mantle of soil covering the natural rock.

Slide Number 5

The slide occurred in the fill portion of a sidehill cut where the roadway crossed a small gulley. The conditions at this location are very similar to those of Slide Number 2 except that Slide Number 5 is nearer the top of the hill; however, water is observed seeping from the backslope and hillside above the roadway. The corrective action at this location consisted of moving the roadway so that it could all be placed on the natural ground eliminating any fill.

Slide Number 6

The roadway at this location is on fill for the entire width of the cross section. The fill at the left shoulder line is about two feet and at the right shoulder line it is about thirty feet. The embankment is placed on a stratum of shale. The portion of embankment that is moving is at the point where the roadway goes from a cut section to a fill section. The toe of the slide is approximately 100' from the center line of the road and at an elevation of about fifty feet below the roadway. Water is seeping from the shale in the cut section on the uphill side of the roadway. See Figure 3.

A deep ditch was excavated into the shale on the uphill side of the roadway to intercept as much of the water as possible, but this has not entirely corrected the movement. There is still some movement and cracks can be observed in the roadway pavement indicating some additional movement at this time. Considerable water is seeping from the toe of the slide. It appears that this water may be flowing out of the hillside at some depth below the roadway in a diagonal direction across the roadway from the cut causing a movement of the fill on top of the shale.

Slide Number 7

This slide occurred in the backslope during construction.

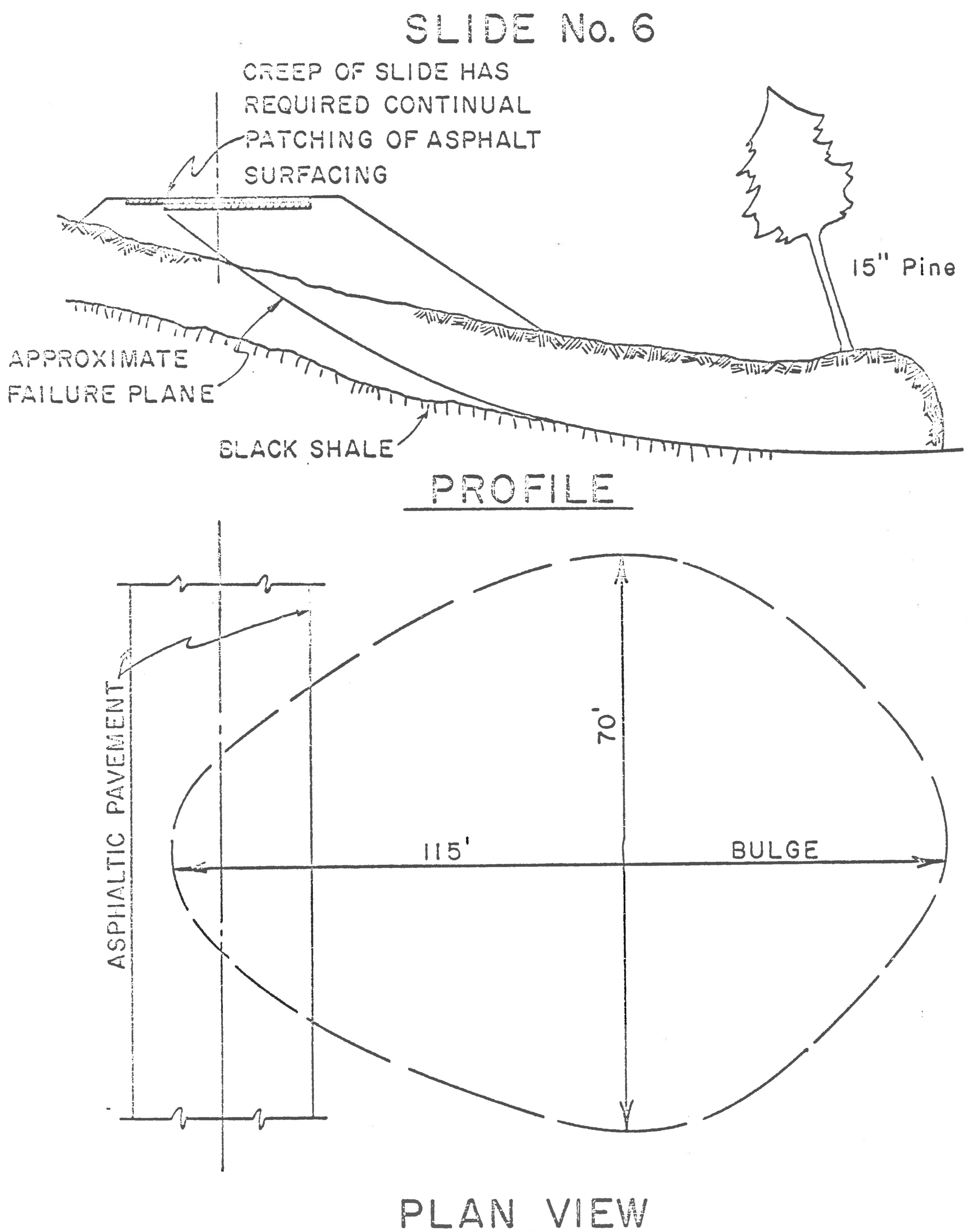

SLIDE No. 6
CREEP OF SLIDE HAS REQUIRED CONTINUAL PATCHING OF ASPHALT SURFACING
15" Pine
APPROXIMATE FAILURE PLANE
BLACK SHALE
PROFILE
ASPHALTIC PAVEMENT
70'
115'
BULGE
PLAN VIEW

FIGURE 3

Figure 4 shows a cross section of the highway prepared during construction as a part of a field change to the original contract. The original backslope was to be 1:1, as shown by the dashed line. The first slide occurred immediately after the contractor excavated the slope. The slope was then flattened by field change to a 2:1 slope with two 10 foot berms. Again the slope failed almost as soon as it was excavated. There have been some recent movements of this slope. The only work done at this location since the contractor completed the job is to remove the material that slides into the roadway ditch. Figure 5 is a picture of the backslope at this time. The cost of the field change was approximately $19,855 plus additional right-of-way.

Examination of the slope at this location shows that there is an outcrop of shale near the bottom of the slope. Water is flowing from the backslope along the top of this stratum of shale. The material of the slide is a clay silt with some loose rock.

Slide Number 8

The shape of this slide is shown in Figure 6. Figure 7 is a profile of this slide in the direction of move-

CROSS SECTIONS SLIDE No. 7

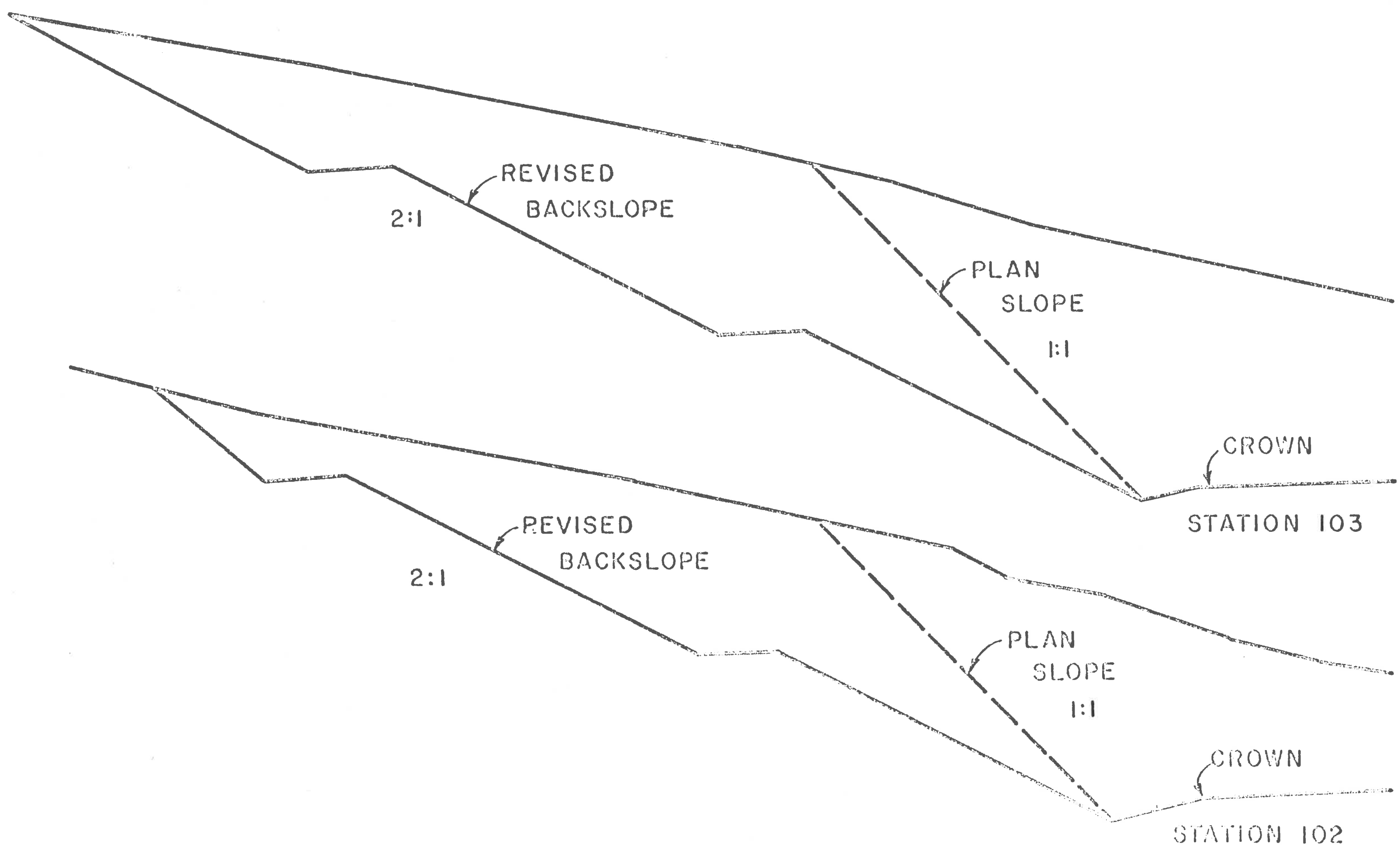


FIGURE 4

Slide No. 7

Fig. 5

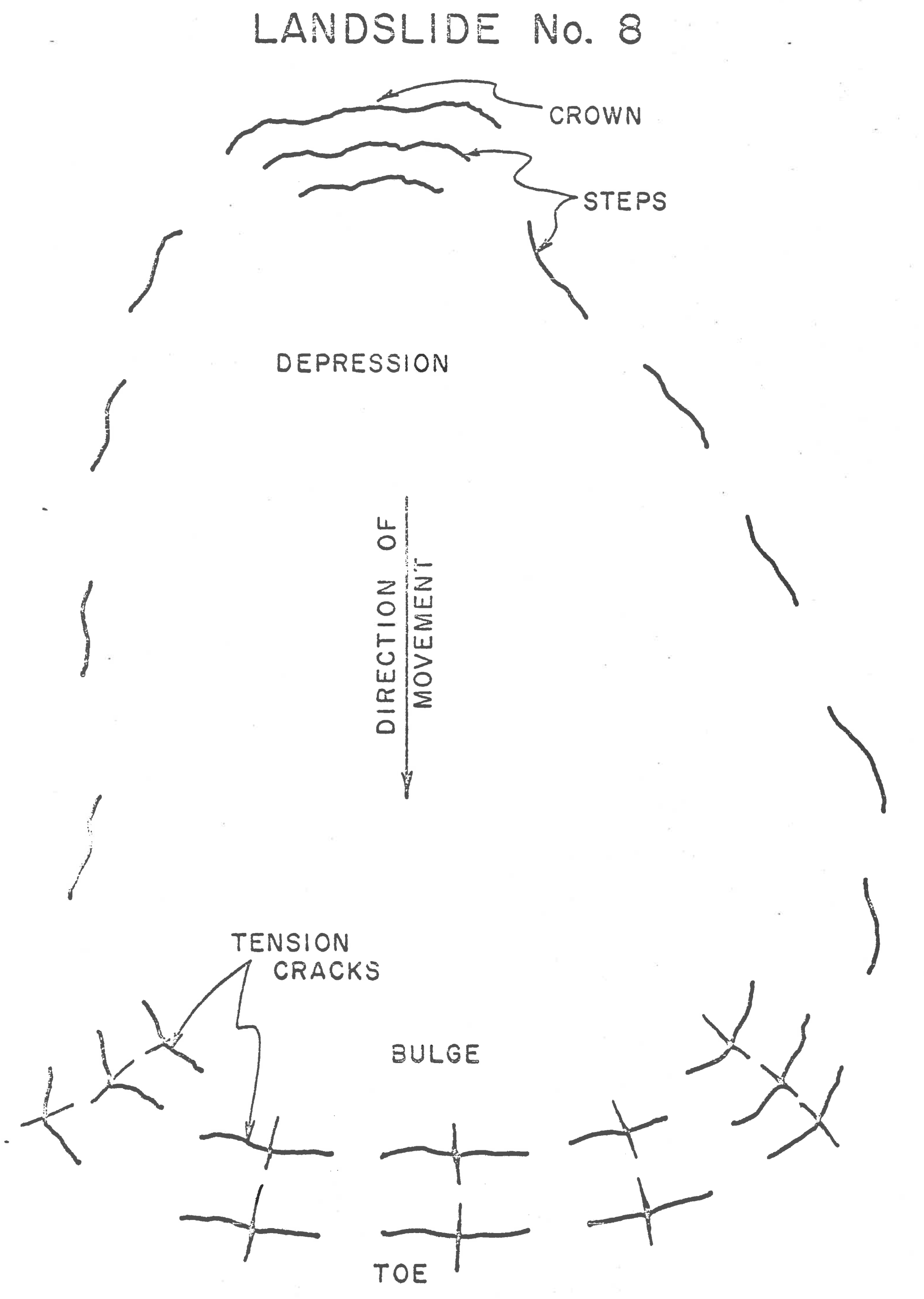

LANDSLIDE No. 8
CROWN
STEPS
DEPRESSION
DIRECTION OF MOVEMENT
TENSION CRACKS
BULGE
TOE

FIGURE 6

PROFILE SLIDE No. 8

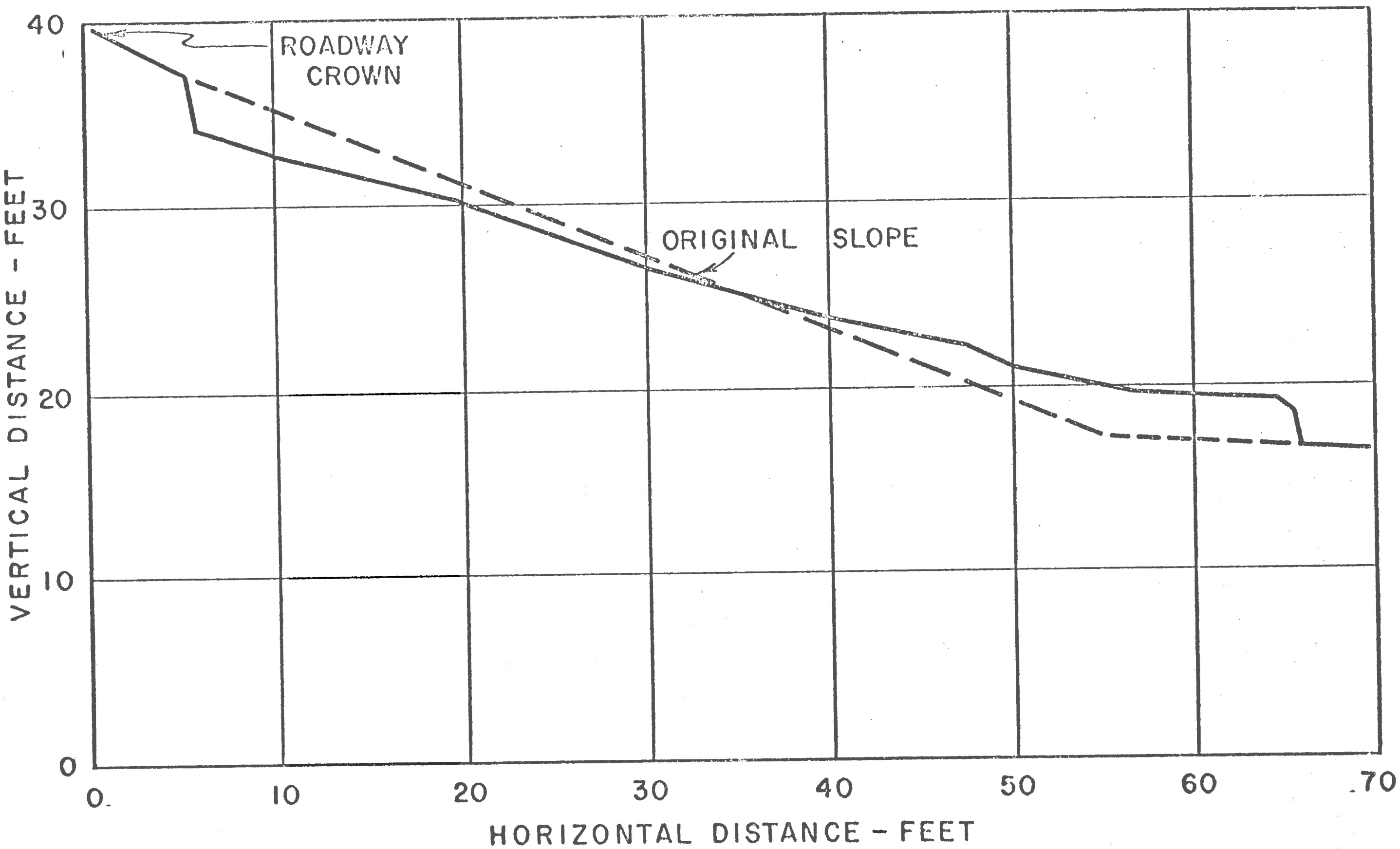


FIGURE 7

ment, and Figure 8 is a picture of this slide. This movement occurred shortly after construction was completed and was comparatively rapid. No one witnessed this slide but all evidence indicates that it occurred in a matter of an hour or less. Tables 1 and 2 present the pertinent test information for the soils in this embankment. Physical evidence at this site indicates that there is considerable water flowing over the embankment at this location. It is the water that falls on the bridge and is concentrated at this point. The only corrective action taken at this location was to redress and reshape the slope. No attempt has been made to add extra stabilization or take any other corrective action.

Slide Number 9

The conditions surrounding this slide are identical with those of Slide Number 8. Figure 9 shows the shape of this slide. Figure 10 is a profile of this slide taken along a center line in the direction of movement. Tables 1 and 2 present test data for this soil.

Slide No. 8

Fig. 8

LANDSLIDE No. 9

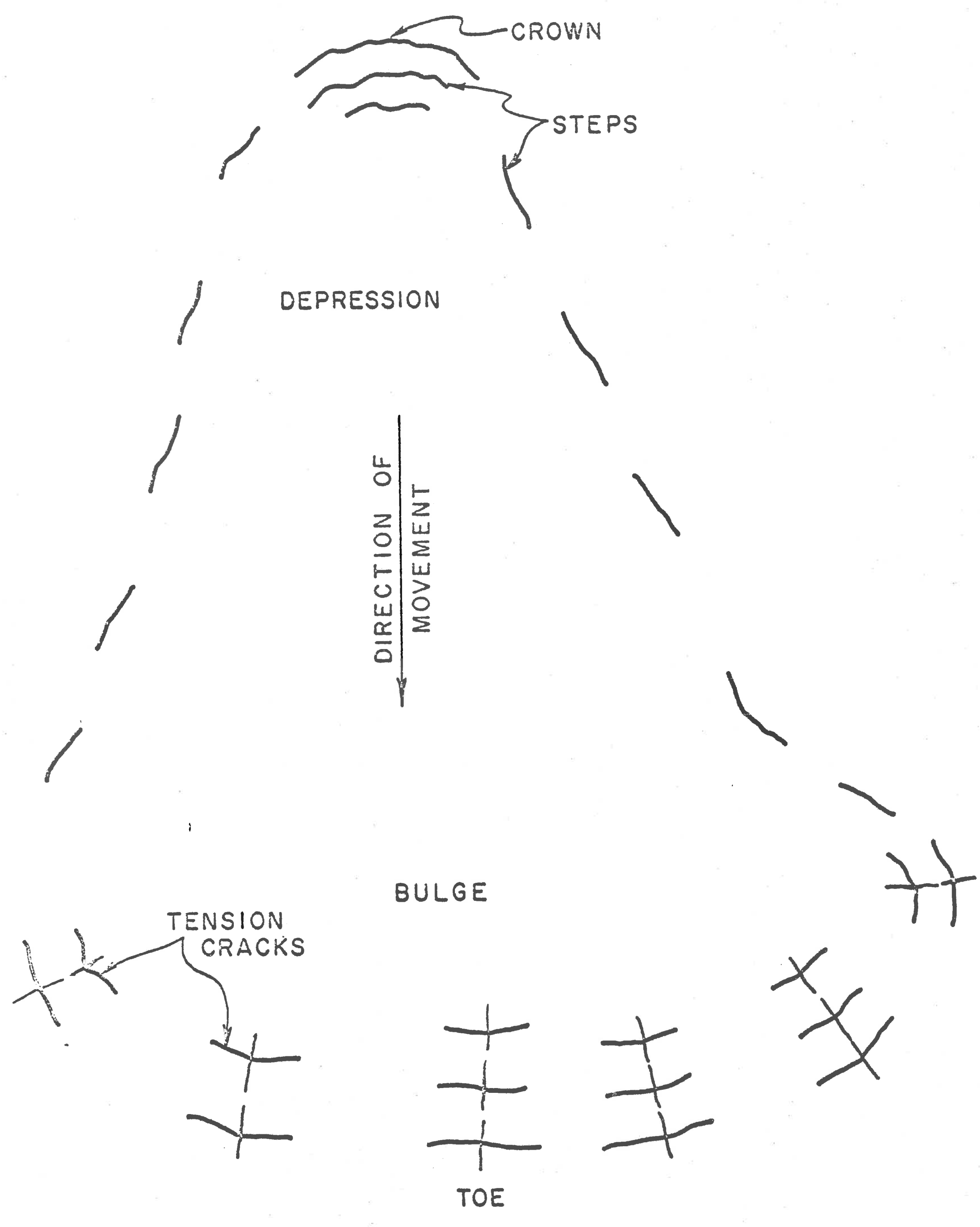


FIGURE 9

PROFILE SLIDE No. 9

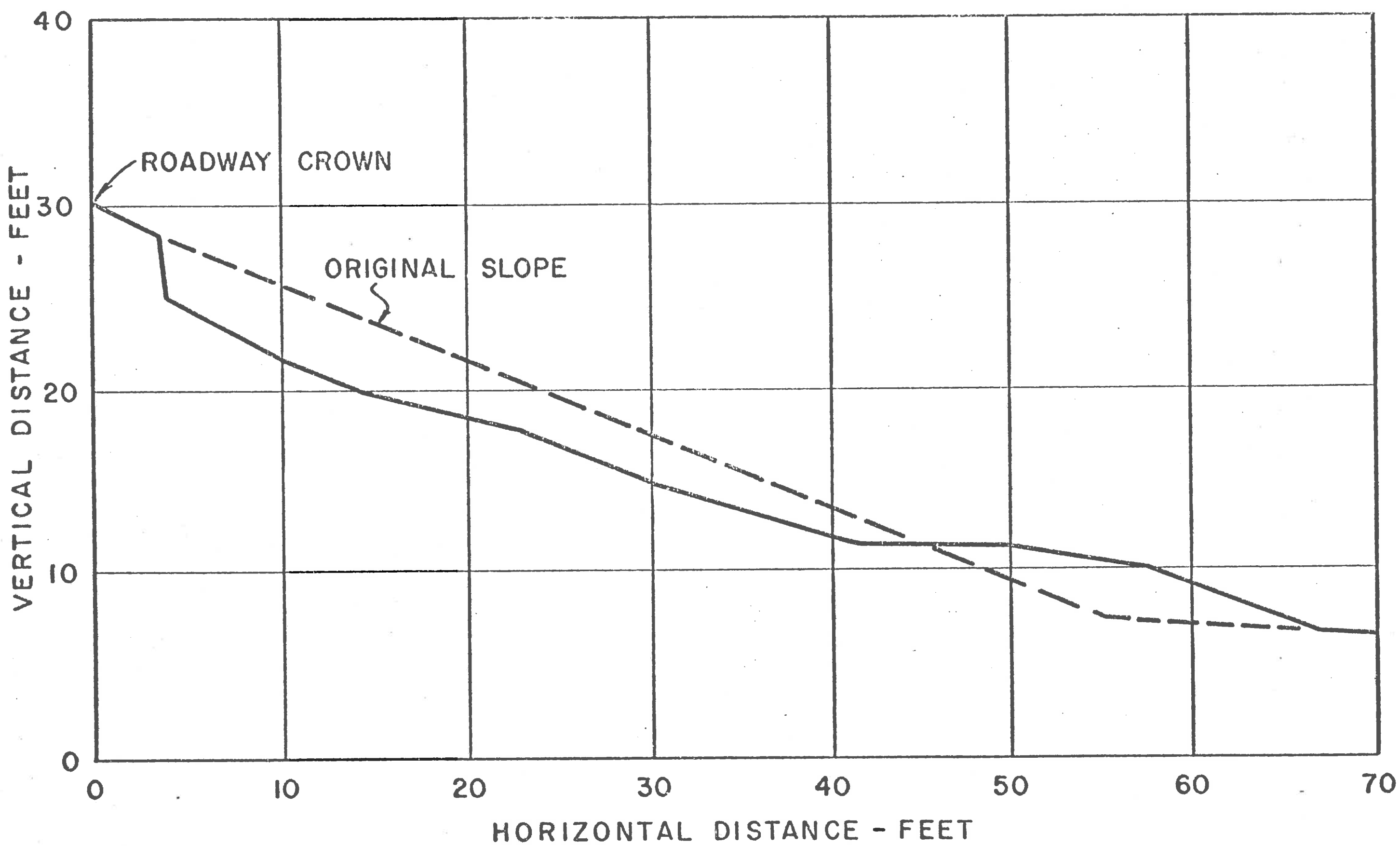


FIGURE 10

TABLE 1

PHYSICAL PROPERTIES OF EMBANKMENT SOILS

Landslide Number	Density (pcf) AASHO T 180		Moisture (%)		Liquid Limit	Plasticity Index
	Max.	In-Place	Opt.	In-Place		
8	109	76	19	30-45	80	45
9	111	71	17	30-45	67	41
10	---	78	--	33	--	--
11	---	72	--	40	79	44

Landslide Number	Volumetric Shrinkage (% dry vol.)	Shrinkage Limit (%)	Specific Gravity	Silt Size (%)	Clay Size (%)
8	129	12	2.73	26	74
9	141	10	2.77	34	66
10	---	--	--	--	--
11	157	13	--	--	--

TABLE 2

SHEAR STRENGTH

Undisturbed Samples

Landslide Number	[1]Shear Strength Ton/SF	Unconfined Compression Ton/SF	[2]Friction Angle (degrees)	[2]Cohesion (Tsf)
8	0.38	0.94	2.5	0.4
9	0.40	0.85	---	0.4
10	0.48	---	---	---
11	0.34	0.66	---	---

[1]Direct shear apparatus normal load 120 lb/S.F.

[2]Triaxial compression

Slide Number 10

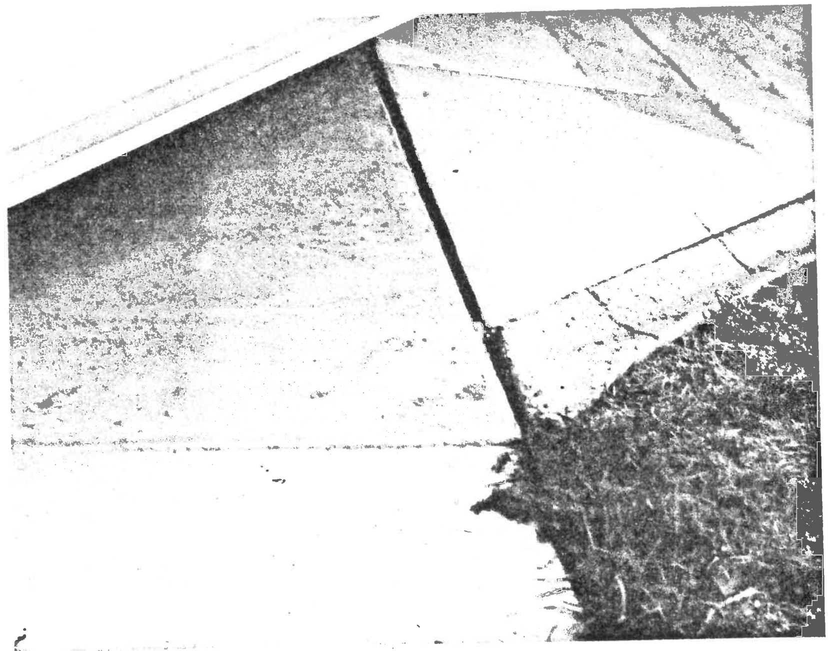
The soil conditions at this location are generally the same as those at Slides 8 and 9. The only difference in this slide is that it occurs in the embankment slope approximately 200 feet from the end of the bridge. An attempt was made to stabilize this slope by driving piling into the embankment at the foot of the slide. There has been no further movement at this point; however, some of the piling now lean outward. The embankment slopes three horizontal to one vertical.

Slide Number 11

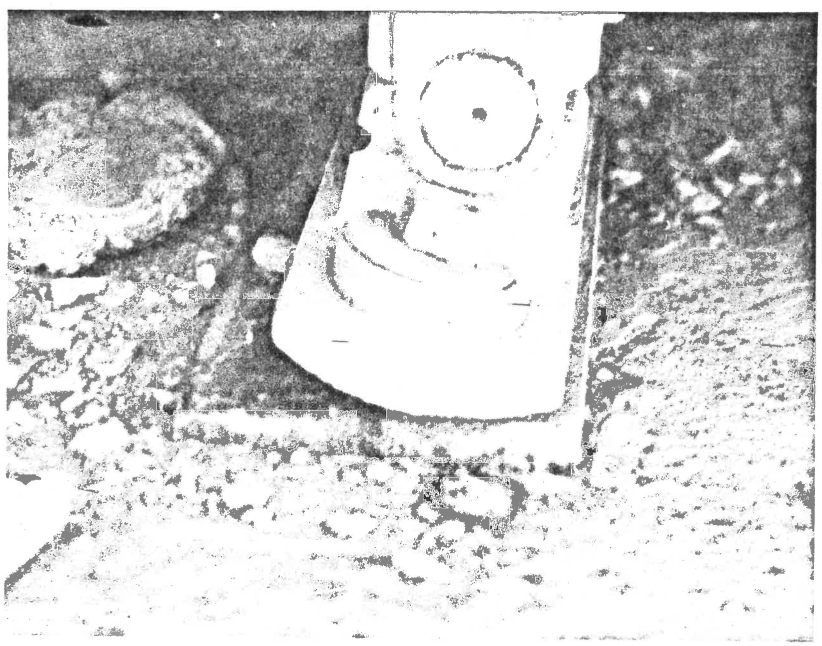
The conditions surrounding this slide are essentially the same as those at locations 8 and 9. Tables 1 and 2 show the soil test data for samples taken at this location. An attempt was made to take undisturbed samples from the slide material, but this attempt was not successful because the soil was so soft that it could not be retained in a thin wall sampling tube. The water content of the material in the slide varied from 50 to 53 per cent on three samples. The undisturbed samples for shear test were taken from the embankment approximately five feet from the edge of the slide and at a depth of twenty-four inches below the surface of the slope. Much of the slide material completely liquified during the movement and flowed past the toe of the slope and across State Highway 181 which passes close to the toe of the slope at this point. The evidence of excess water flowing down the slope at this point is very pronounced. The concrete slope protection under the bridge shows considerable movement. See cracks shown in Figure 11. This movement of the slope protection appears to have pushed the first interior bent out of line as indicated by the position of the expansion shoe shown in Figure 12. The expansion joint at the end of the bridge is of the sliding plate type and has opened much wider than normal. This apparently is funnelling all of the water from the end span of the bridge onto the bridge head at this location.

The amount of water during any one shower is not excessive but the end bridge span has no scuppers so that all of the water from even a light shower flows onto the embankment. The embankment at this point is kept much wetter than the remainder of the embankment.

There are a total of seven slides in the embankments in the vicinity of West Memphis in addition to Slide Number 11. Six of the slides on the interstate System near West Memphis occur in similar locations. This location is in the curve of the



Slide No. 11



Slide No. 11

Fig. 12

slope at the end of the bridge. All six are in the location where the water from the bridge flows over the bridgehead soil. All of the soils are approximately the same.

only 11 reported

The foregoing 17 slides can be divided into three groups. The first group is often referred to as slipouts. Usually part of the roadway is lost. This creates a special hazard to traffic. Slides Number 1, 2, 4, 5, 6, 12, and 13 are of this type. Slide number 1 and several of the slides that are listed together as Slide number 4 occurred during construction. There is some continual movement on the sidehill south of Jasper called Slide number 4. Slide number 2 is typical of all of these.

The second group of slides are those that occur in the back-slopes during or shortly after construction. Slide number 7 at Leslie is the most serious of these. The slides included in this group are Slides number 3, 7, 14, 16, and 17. All of these slides are due to excessive seepage pressures and steep backslopes. These slides rarely create serious traffic hazards, however there is always a possibility that some of them may flow into the roadway, blocking part of the road.

The third group of slides are those that occur in newly constructed embankments. All of these have occurred in the embankments constructed in the vicinity of West Memphis and are constructed with the same kind of material. Slides number 8, 9, 10, and 11 are of this type.

INSPECTION TRIP

TO

TALIHINA AND WILBURTON, OKLAHOMA

An inspection was made of several slides in LeFlore and Latimer Counties. The principal slides in LeFlore County were on U. S. 271 approximately nine miles northeast of Talihina, Oklahoma. The slides near Wilburton were on State Highway 2 at Robbers Cave State Park in Latimer County.

SLIDE NORTHEAST OF TALIHINA, OKLAHOMA, ON U.S. 271

This slide occurred in the backslope of the highway where there was side hill construction. The slope itself was in the coluvial material of a small gulley formed by water flowing from the top of the hill. Approximately 1,000 feet of 2 inch black perforated pipe and 500 feet of galvanized pipe were used to drain the water from this slide. This work was accomplished during the year 1959 at a cost of $12,222. It was reported that water has flowed from the pipe in this slide continuously since it was installed in 1959. At the time of inspection, the two inch header pipe was flowing approximately one-fourth full. The Division Engineer of the Oklahoma Highway Commission stated that the installation of this perforated pipe resulted in this fill being stabilized. There had already been considerable movement before these installations were made but no movement had been observed since the pipe was installed. It was estimated that it would have cost $50,000 to correct the situation had the slide not been stopped by this drainage process. Water flowed from about seventy per cent of the holes that were drilled in this slide.

SLIDE AT ROBBERS CAVE STATE PARK, STATE HIGHWAY 2

The work at Robbers Cave State Park on State Highway 2 was accomplished in 1958. These slides were in sidehill construction. That portion of the road constructed on the fill was sliding. Actual movement had occurred for a considerable length along the embankment to the extent that the soulder had faulted to a depth of about four feet in some cases. In other cases it was observed that the usual tension cracks were showing along the pavement at about the quarter point of the outside traffic lane. The writer inspected this location in 1958 while the drilling was in operation and observed the extent of the sliding that had taken place. At the present time there is on evidence of additional sliding. It was reported that the fill has been completely stabilized. A small amount of water was flowing from some of the drain pipes at this time. It was further reported that in almost every case considerable water was observed to flow from the pipes shortly after periods of rainfall. About sixty per cent of the pipes in this embankment obtained a flow of water. The cost of installation of pipes at this location was $13,096 for a length of embankment of approximately 1,000 feet. Again in this case is was very evident that the installation of these pipes was a major factor if not the entire cause of stabilizing this embankment at a saving of many times the cost of the operations.

The perforated pipe was installed by using a specially built horizontal drill. A hole was drilled into the embankment after which the perforated pipe was installed. The operator had no difficulty with the holes caving before the pipe was installed. It was reported that the operator of the drill could control the direction of the drill both horizontally and vertically to the extent that the forward end of the pipe could be placed within a foot or two of the desired location at a distance of 100 feet from the machine.

The Division Engineer used an interesting method of determining movements of a slide by installing plastic tubes. These plastic tubes were installed vertically through the embankment at about the shoulder line for the purpose of determining any movements that might be taking place in the embankment. The tubes were approximately three-fourths inch inside diameter. In checking if there were any movement, the pipe is filled with water to determine whether movement has collapsed or broken the pipe.

In one case Oklahoma found that they were getting movement on an embankment on a bed of shale and clay some distance below the roadway. In this case the movement was stopped by the use of lime. Vertical holes were drilled down to the clay. Lime was put in these holes and flushed down with water. The use of the lime in this case reduced the softening effect of the water and reduced the plasticity of the clay.

GENERAL GEOLOGY OF SLIDE AREAS IN OKLAHOMA

Jake Clements, Jr.

The slide areas are located in the northern portion of the Ouachita Highland physiographic province. The geology of this area is similar to the Ouachita Mountain province of Arkansas. The general topography is of sandstone ridges and valleys formed in shale. Crystal deformation is conspicuous by the extensive folding and faulting of rock visible in the area. Most all of the rocks exposed are of a sedimentary origin and the outcrops indicate dips of the beds to be steep. The stratigraphic column was not investigated but surface geologic formations are lower Pennsylvanian in age. Seepage water in backslopes of road cuts was very noticeable. The slides in backslopes of side hill construction were in colluvial deposits with outcrops of sandstone overlying clays and soft shales.

RESULTS AND RECOMMENDATIONS

The slide prone areas of Arkansas are the Ozark Mountains in the Northwestern part of the State. The Map of Figure 1 shows this very distinctly. Those shown on this map are by no means all of the slides that have occurred. A casual inspection of the backslopes of any of the highways traversing this region will show many slides. Some are small while others are rather large in extent. Only those on high backslopes have created serious problems. This does not mean that the slides on lower backslopes are no problem. All of them are troublesome and expensive to correct. The cost of correcting these slides and dressing the backslopes is a very large maintenance item. No solution for these so called small slides is presented. It appears that the most economical method of caring for these is to provide flat slopes, greater than 2:1 where possible and make allowance in the maintenance budget for the extra work that is required to make the slopes presentable.

Many of these slope failures occur during construction. The problem then becomes one of determining responsibility and whether the failure is to be corrected by the contractor or to be left for the Maintenance Division. Such a case was slide No. 7. About $20,000 was spent by a field change but the slide still exists.

Slide number 2 is typical of the slipouts found in Northwest Arkansas and is a good location for draining by horizontal drilling and installation of perforated pipe. It will be necessary to drill horizontal drain holes in the backslope of the roadway and also near the toe of the slope below the roadway. The chances of this procedure stabilizing the other fills of this group are good. This is especially true in the case of slide number 6 as it seems that all of the water causing this movement is flowing on top of the black shale. In every case of a slide it will be desirable if not necessary to do some vertical drilling to determine the location of the water bearing stratum before a satisfactory horizontal drilling program can be planned. The slides of this type are found on sidehill construction where the slope is covered with a mantle of soil and rock. The soil is usually clay to silty clay and is derived from interbedded layers of shale and either limestone or sandstone. The movement usually taking place on top of the impervious shale. No program of horizontal drilling and drainage should be planned without the help of a geologist. Much saving of time and money can be realized by a geological study of the location before any drilling work is begun.

The cause of the slides of group two are the same as those of group one, that is a combination of seepage water and a weak soil mantle on top of the parent material.

The failures of backslopes combined into group two are less serious than the slipouts of group one, but these failures do cause an expensive maintenance problem. They are unsightly and often require the purchase of extra right-of-way. Flatter slopes do not appear to be the whole answer to this problem. In some cases the flatter slopes may not be needed. In other cases the flatter slopes do not prevent slides. The seepage water causing these failures is usually due to a high ground water table that has been intersected by the excavation of the backslope. In some cases a ditch at the top of the backslope will intercept water and keep it from flowing over the slopes. In many cases the only sure cure for these backslope failures is horizontal drilling to intercept the water at some distance from the surface of the slope. This method of drainage appears to be justified for a slide such as Number 7, however there are many small backslope slides that are too small to justify this kind of expenditure. Most of the slides such as those listed as Numbers 14, 15, and 16, and possibly Number 3 can be treated as maintenance problems. In this case the only immediate work required will be to remove any material blocking drainage ditches. The slides will generally stabilize themselves.

After a period of time the slopes can then be dressed and made to present a better appearance. One possible exception to this would be the slope such as Number 17; this is on the Interstate System where it is more important that the slope make a good appearance. Also, if there is serious movement here, some of the traffic lanes may be blocked. In this case remedial action such as drainage and flattening or benching will be justified.

Perforated pipe installed in deep ditches will sometimes intercept sidehill water and prevent or stabilize movements. It is important that the pipe be installed deep enough that it intercepts all of the water, otherwise the pipe will be useless. This will require that the trench for the pipe be excavated into the impervious layer. The trench should be filled to near the surface with a graded filter material and covered with an impervious layer of soil. This method is satisfactory for intercepting ground water and should be considered. Economics will determine whether this method or the horizontal drilling method is more satisfactory.

The slope failures of Group Three are generally more of a maintenance nuisance than a serious traffic hazard; however, Slide Number 11 did block one traffic lane of State Highway 181. Seven slides have occurred in this general area and six of these slides occurred in the same relative location with respect to the end of the bridge. It can be seen from Tables 1 and 2 that the soils of all of these embankments are the same. Analyses of these slopes indicate that the factor of safety is above two and in most cases near three. The shearing stress at which most of the slides occur is below 300 pounds per square foot, yet all of the shear tests: Unconfined compressive, triaxial, and direct shear indicate that the shearing stress is in the vicinity of 800 to 1,000 pounds per square foot, which shows that the slopes have a factor of safety of 3. This leads to the conclusion that there is some external cause other than the steepness of the slope. In this case it appears to be that there is a high concentration of water at these locations, otherwise the slope could be expected to fail at any location along the embankment. The frequency of wetting is as important as the total amount of water.

Some of the failures on embankments in the vicinity of West Memphis may be because of unusual climatic conditions during the summer and fall of 1963. There was little or no rainfall. Many cases were observed where large shrinkage cracks appeared in the embankment. Some of these cracks were as much as two inches wide and penetrated to a depth of several feet. The failures followed then when an unusually large amount of water was funnelled over the embankment at one location. There have been three recent slides where previous rains had closed most of the cracks.

Inspection at the ends of bridges indicate that there is a good possibility of water being concentrated on the embankment at this point. Water is flowing through the expansion joint and onto the embankment. This accounts for the large number of slides occurring in the same relative location. If the failures were due to the usual rainfall the failures would not be concentrated in this same relative location.

Figure 12 shows another result of water running through the expansion device at the end of the bridge. The expansion shoe on the first interior span is on the first interior bent and is leaning in the opposite direction, indicating that the first interior bent has moved away from the abutment. This is on Interstate Highway 55 grade separation over Highway 181 two miles south of Keiser. The embankment under the bridge is protected by precast concrete rip-rap. It appears that this rip-rap is moving downhill as indicated by the crack that has opened, see Figure 10. The force of this rip-rap pushing against the first interior bent appears to be moving the bent away from the abutment thus causing the expansion joint at the end of the bridge to open unduly wide.

The solution to the problem of these slides on bridgeheads is to prevent the water from the bridge flowing over the embankment. Two methods of accomplishing this may be used. The first may be to build the bridges with no expansion joints at the abutments and to provide water-tight joints. The water can then be carried by gutters along the embankment for some distance before discharging into pipes leading to the toe of the embankment. The second method would be to provide a gutter immediately below the expansion joint to intercept the water before it reaches the bridgehead. This gutter could intercept the water and discharge it into pipes.

One slide that occurred near Marion several years ago is of special interest. The embankment was about four or five years old at the time this slide occurred. Investigation revealed that the embankment at this location was honey-combed with holes dug by rats. Apparently the rats had dug into the embankment to establish dens for the winter. The holes and burrows then became filled with water, creating unusually high seepage pressures and reducing the shearing strength. This failure has led to a common maintenance procedure which is to spread rat poison around the bridgeheads in this vicinity each winter.

FUTURE STUDIES

It is recommended that the Arkansas Highway Department initiate a research project to evaluate the installation of perforated pipe by horizontal drilling, as a method of stabilizing slides both of backslopes and slipouts of roadways. This work should consist of geological studies along with some vertical drilling for exploration followed by installation of horizontal drains in typical backslopes such as Slides No. 2 and No. 7 of this study

4. Shepard, C.H., Mason, H.Z., and Ray, Dorothy J., "A Problem in Highway Slope Stability." Highway Research Board Bulletin No. 309. 1961

This article discusses the causes, the testing procedures used, and the corrective measures used on a slide of approximately 65,000 cubic yards. The slide occurred on the slope of a Highway cut of 45 feet. The material showed high strength except for the clay layer between the bedrock and the upper layer of sand and silt. The slide was corrected by flattening the slope and benching with subsurface draining. The slide occurred in Ohio in 1960.

Conclusions:

1. A thorough and carefully planned drilling program is of utmost importance. Pressed, undisturbed samples often offer most reliable information.
2. Field observations of environmental factors and boundary conditions are necessary.
3. The use of a specialist in theoretical and applied soil mechanics may be justified.

The primary cause of failure was an unusually high moisture content of the backslope due to a high water table. Analysis of the original slope showed that the factor of safety was less than one. The slope was flattened to produce a factor safety of slightly over 1.2. The failures in the backslope of the bypass around Montecello were of this type and due to the same causes.

5. Krynine, D.P., "On the Methodology of Landslide Investigations in Soviet Russia." Highway Research Board Bulletin No. 236. 1960.

This article discusses the procedures used to observe and analyze slides in Russia. It makes no mention of particular slides and does not suggest procedure for slide correction.

6. Landau, R.E., "Mathematical Expressions for the Circular Arc Method of Stability Analysis." Highway Research Board Bulletin No. 236. 1960.

This article discusses methods for analyzing different types of slopes with variation in load and slope material.

7. "Cut Slope is Prestressed with Beams and Anchors." Engineering News Record, p. 52. October 20, 1960.

This article is a special case (expensive, too). Because no other method of bank stabilization was thought to be effective in this case, concrete beams were laid on the cut slope and prestressed so that the slide prone slope would be stressed and remain stable. The article contains diagrams on how this was accomplished. Beams placed on the slope were held in place by anchors set in deep holes. Anchor rods are tensioned.

8. Baker, Robert F. and Chieruzzi, Robert, "Regional Concept of Landslide Occurence." Highway Research Board Bulletin No. 216. 1959.

This article is concerned with classification of landslides and determining the types of landslides that occur in a given geographic region. Suggests that physiographic provinces control type and possibilities of landslides. Certain types of geology will produce a single type of landslide, and some geological formations are slide prone.

9. Hennes, R.G., Hawkins, S.E., and McCoy, E.L., "An Appraisal of Measures for Improvement of Slope Stability." Highway Research Board Bulletin No. 216. 1959.

This article considers the evaluation of a slope as to factor of safety and how the slope may be made more stable by drainage and benching. It also discusses the comparison between benching and draining, and the change in factor of safety associated with each. Flattening the slope is much less effective than benching per unit of excavation. The benching removes material from top of slope thus unloading the driving part of slide.

Presents useful graphs to aid in draining slopes.

10. LeClerc, Roger V. and Hansen, Robert J., "Computer Solution of Swedish Slip Circle Analysis for Embankment Foundation Stability." Highway Research Board Bulletin No. 216. 1959.

Presents a program for IBM 650 which will analyze embankment stability. Program may be used to investigate a given range of slopes and to investigate a range of slopes in individual analyses for each slope.

11. "Horizontal Drains Avert Landslides in Alberta." Engineering News Record, p. 36. November 6, 1958.

This article contains no worthwhile information. It may be of value only as a reinforcement of California's success in using horizontal drains in slide control, as described in Abstract No. 13.

12. Committee on Landslide Investigations, "Landslides and Engineering Practice." Highway Research Board Special Report No. 29. 1958.

This book is a complete treatise on landslides, each chapter of which is written by an outstanding authority on that part of landslides covered in that chapter. The book is a compilation and summary of all of the information known on landslides up until the time it was published. It classifies landslides by type and conditions and then treats methods of recognition, identification, laboratory work, and finally, methods of control and correction as well as methods of prevention.

This book is required reading for any serious student of landslides.

13. Smith, T.W., and Stafford, G.V., "Horizontal Drains on California Highways." Proceedings, American Society of Civil Engineers, Vol. 83, July 1957, Soil Mechanics and Foundations Division.

This paper deals with the installation, use, and effectiveness of horizontal drains in highway cuts in California.

California has been using horizontal drains since 1939, so they have accumulated some knowledge on the use of them. The author points out some of the things to consider during installation and after. He describes the equipment used for installation and how it has been modified over the years. He discusses six representative installations where horizontal drains were used to control sliding.

The author feels that horizontal drains have a definite place in the correction and prevention of slides in the designing, construction, and maintenance of embankments and cuts, and when properly planned, installed and maintained, they are effective.

14. Terzaghi, Karl, and Peck, Ralph B., "Stabilization of an Ore Pile by Drainage." Soil Mechanics and Foundations Division; ASCE Proceedings, Vol. 83. January 1957.

This paper deals with the instability of the track supporting ore and of an ore bridge in a steel plant in eastern Ohio. The instability was caused by excess porewater pressures in a layer of silt.

Piezometers were used to check the effects of a load of ore on pore pressure. The slow sliding of this area was stopped by installation of a vacuum system of well points thereby reducing the water content of the silt.

15. Parrott, W.T., "Control of Slides by Vertical Sand Drains." Highway Research Board Bulletin No. 115. 1955.

This article discusses how vertical sand drains were used to control a slide in Virginia. The slope consisted of sandy soils with a horizontal bed of clay below the sand. The vertical drains were drilled through the clay layer so that the subsurface water could drain through the layer of clay to the sandy material below. The bottom of the drains were blasted to further enhance draining.

16. Root, A.H., "Correction of Landslides and Slipouts."

ASCE Transactions, Vol. 120, p. 201. 1956.

The author presents several methods of landslide and slipout correction. He is concerned primarily with those which have occurred in California. He cites various examples of landslides that have occurred in California, and how they were corrected. Of particular interest is his discussion of highway slipouts, since most literature does not specifically describe slipout corrections.

Slipout: "one type of landslide most troublesome to highway engineers is the slipout - a landslide occurring at or below roadway grade."

17. "Army Engineers Attack Landslides at Oahe Dam." Engineering News Record, p. 25. December 9, 1954.

This article, as did articles before this, illustrates how horizontal drains were used to help stabilize a steep slope that was threatened with excess hydrostatic pressure. Where large quantities of earth are concerned, drains seem to be much less expensive than excavating the slopes to a flatter grade.

18. Baker, R.F., "Analysis of Corrective Actions for Highway Landslides." ASCE Transactions Vol. 119, p. 665. 1954.

This paper presents a very general discussion of most forms of landslides. The author has attempted to cover all phases of landslides including correction, identification, causes, etc.

He lists investigation procedures that should be used in landslide evaluation. The discussion following the paper also adds to the general consideration of landslides.

19. Krynine, D.P., and Woodward, Richard J., "Experiences with Subsurface Water." Highway Research Board Proceedings. 1953.

The slides considered in this discussion occurred in California around the San Francisco Bay Area. The slides considered occurred during the rainy season when ground water pressure (Hydrostatic Pressure) was excessive. Hydraugers (Horizontal Pipes) and vertical wells were used to drain these areas of excess pore water. The author suggests that excavations in impervious soils at the base of a hilly area for highways require special care since such excavation may cause sliding or slumping. He also suggests that in preventing slides the subsurface water should be stopped as close to the source as possible.

There is some similarity between the conditions as described in this article and those encountered around Harrison, Arkansas.

20. Larew, H.G., "Use of Field, Laboratory and Theoretical Procedures for Analyzing Landslides." Highway Research Board Bulletin No. 49. 1952.

This paper presents field and laboratory data obtained from three slides. The data was used to check the validity of the circular arc mehtod of slope analysis.

These slide analyses proved very little about the validity of the circular arc method. In fact, it indicates that not enough is known about action of soils to make a good analysis.

The writer feels that a better understanding of the shear strength of clay-like soils, progressive failures, the effect of seepage forces, tension, cracks, and impact loads is more important than having new ways of analysis.

21. Baker, R.F., "Determining Corrective Action for Highway Landslide Problems." Highway Research Board Bulletin No. 49. 1952.

This bulletin covers the various methods that have been proposed for analyzing slides. It discusses different mehtods that should be used in analyzing slides. It discusses different methods of stabilizing slides and compares the economy of each. It also cites various examples of slides and how they were analyzed. The author suggests that at the time of writing of this article there is no other method of analyzing slides that give unquestionable results.

22. Palmer, L.A., Thompson, James B., and Yeomans, Clifford M., "The Control of a Landslide by Subsurface Drainage." Highway Research Board Proceedings. 1950.

The slides considered in this article are small slides of about 4000 cubic yards. They were located in Seattle, Washington. They were caused by infiltration of surface water which developed local hydrostatic heads within sand lenses irregularly dispersed throughout the clay soil of the embankment. The slides were controlled by installing vertical wells and horizontal drain pipes into the sand lenses, thereby relieving the excess water pressure.

23. Forbes, Hyde, "Landslides Investigation and Correction." ASCE Transactions, Vol. 112, pp. 377-442, 1947.

This paper contains an extensive coverage of landslides, along with several examples of landslides and the corrective measures used. A long series of discussions also adds to the informative natures of the article.

The author describes several different types of slides and how investigation and corrective analysis were made. It appears that most of the slides discussed in this article were caused by overloading and or excess moisture which may have caused excess hydrostatic pressure. Most slides described were corrected by some sort of drainage system, usually gravel-filled trenches, tunnels and perforated pipe.

24. Nutting, M.T., "Prevention and Correction of Landslides." ASCE Transactions, Vol. 110, p. 281. 1945.

This article contains a short general discussion of landslides. The article does not discuss any specific slide or correction. The author discusses primarily the causes of landslides and suggests that avoiding a questionable landslide area may be best and least costly in the long run.

25. Middlebrooks, T.A., "Fort Peck Slide". American Society of Civil Engineers Transactions, Vol.107, p.723. 1942.

This article presents a detailed analysis and arguments on why the slide did occur on this hydraulic filled earth dam. The article is more leaned toward dam slides than slides in general. It does contain much information on subsurface analysis and possible causes of slides.

26. Smith, C.E., "Report on Cause and Correction of Foundation Troubles of Box Factory at Nachez, Mississippi." ASCE Transactions, Vol. 83, p. 1289. 1919-1920.

The author gives three examples of landslides along the Mississippi River and discusses the causes and corrective measures used in each case. The slides were all corrected by subsurface drainage. This was accomplished using tile pipe and wooden box pipe, although it may have been a little crude, they employed the same technique used today to correct many landslide areas.

27. Clarke, D.D., "A Phenomenal Landslide - Supplement." ASCE Transactions, Vol. 82, p. 767. 1918.

The landslide discussed in this article involves several acres. The slide moved slowly over a period of years and caused damage to two reservoirs. The author describes the method of correction which consisted of constructing a network of drainage tunnels.

28. Webwo, William G., Jr., "Construction of a Fil by a Mud Displacement Method." Highway Research Board Proceedings, Vol. 41. 1962.

This article describes the method used to displace mud in an open water cove on the west side of the San Francisco Bay. As much as 60 feet of mud was displaced by the weight of the fill. The fill was constructed by end dumping. The shape of the nose of the fill and the rate of fill were determined to be the main factors in getting a good uniform mud displacement. After three years of service, the pavement has a wavy surface.

BIBLIOGRAPHY

1. Philbrick, Shailer S., "Design of Rock Slopes." Highway Research Record 17. 1963.

2. Ritchie, Arthur M., "Evaluation of Rockfall and its Control." Highway Research Record 17. 1963.

3. Hardy, R.M., "The Peace River Highway Bridge - A Failure in Soft Shales." Highway Research Record 17. 1963.

4. O'Neill, A.L., "Slope Failures in Foliated Rocks, Butte County, California." Highway Research Report 17. 1963.

5. Rausch, D.O., Sederberg, A., and Hubbard, S.J., "Progress in Rock Slope Stability Research." Highway Research Report 17. 1963.

6. Nordlund, R.L., "Stress-Dilatancy, Earth Pressure, and Slopes." American Society of Civil Engineers, Proceedings, Vol. 89, Journal of the Soil Mechanics and Foundations Division. May 1963.

7. Goodman, L.E., and Brown, C.B., "Dead Load Stresses and the Instability of Slopes." American Society of Civil Engineers, Proceedings, Vol. 89, Journal of the Soil Mechanics and Foundations Division. May 1963.

8. Williams, W.G., Jr., "Construction of a Fill by a Mud Displacement Method." Highway Research Board, Proceedings, Vol. 41, p.391. 1962.

9. Brew, D.A., "Mechanics of Small Landslide Block, Wattner Lizum, Austria." Geological Society of America, Bulletin, Vol. 73, No. 10, pp. 1277-9. October 1962.

10. Hardy, R.M., Brooker, E.W., and Curtis, W.E., "Landslides in Over-Consolidated Clays." Engineering Journal, Vol. 45, No. 6, pp. 81-89. June 1962.

11. Osterman, J., "Theoretical Study of Failure Conditions in Saturated Soils." Swedish Geotechnical Institute, Proceedings, 20, 34pp. 1962.

12. Knight, D.K., "Oahe Dam: Geology, Embankment and Cut Slopes." American Society of Civil Engineers, Proceedings, No.39, Journal of the Soil Mechanics and Foundations Division. March 1962.

13. Kondo, S., "On Landslides Along River Hijikawa in Ehime Prefecture, Japan." Geological Survey, Bulletin, Vol. 12, No. 10, pp. 1 - 12. October 1961.

14. Redus, "Experiences with Expansive Clay in the Jackson, Mississippi, Area." Highway Research Board Bulletin No. 313. 1961.

15. Shepard, Mason, and Ray, "A Problem in Highway Slope Stability." Highway Research Bulletin No. 309. 1961.

16. Hutchinson, J.N., "Landslides on Thin Layer of Quick Clay at Furre, Central Norway." Geotechnique, Vol. 11, No. 2, pp. 69-94. June 1961.

17. Reynolds, H.R., "Landslides Investigation in Russia." Civil Engineer (London), Vol. 56, No. 658, 659, pp.603-610, 771-772. May and June 1961.

18. "Landslides Plague Pacific Coast Highway." Engineering News Record, p.20. May 11, 1961.

19. Cleves, A.B., Landslides Investigations. United States Bureau of Public Roads, July 1961. 67 pages. (Available from Superintendent of Documents, United States Government Printing Office, Washington 25, D.C., $.30.)

20. Jones, F.O., Embody, D.R., Peterson, W.L., and Hazlewood, R.L., "Landslides along the Columbia River Valley, Northwestern Washington." United States Geological Survey, Professional Paper 367, 1961. 98 pages.

21. Naylor, A.H., Stuart, J.G., and Edu, N.K., "Stability of Embankment of Frictional Materials Retaining Low Frictional Fill." Geotechnique, Vol. 11, No. 2, pp.116-120. June 1961.

22. Scheidegger, A.D., "Theory of Rock Movement on Scree Slopes." Alberta Society of Petroleum Geologists, Journal, Vol. 9, No. 4, pp. 131-138, 140. April 1961.

23. "Cut Slope is Prestressed with Beams and Anchors," Engineering News Record, p. 53. October 20, 1960.

24. Merriam, R., "Portuguese Bend Landslide, Palos Verdes Hills, California." Journal of Geology, Volume 68, Number 2, pages 140-153. March 1960.

25. Bhattacharya, R.K., "Geometry of Slip Line Field in Soils." Geotechnique, Volume 10, Number 2, pages 75-81. June 1960.

26. Barney, K.R., "Madison County Slide." Civil Engineer (New York), Volume 30, Number 8, pages 72-75. August 1960.

27. Horn, J.A., "Computer Analysis of Slope Stability." American Society of Civil Engineers, Proceedings, Volume 86, Journal of the Soil Mechanics and Foundations Division, Number SM3, part 1, Paper Number 2501; pages 1-17. June 1960.

28. "Landslide and Foundation Investigations and Stability Analysis." Highway Research Board Bulletin Number 236. 1960. 68 pages.

29. Horn, John A., "Computer Analysis of Slope Stability." American Society of Civil Engineers, Proceedings, Volume 86, Journal of the Soil Mechanics and Foundations Division. June 1960.

30. Richart, F.E. Jr.,"Anchored Bulkhead Design by Numerical Method." American Society of Civil Engineers, Proceedings, Volume 86, Journal of the Soil Mechanics and Foundations Division. February 1960.

31. Arnold, M., "Slope Stability Analysis by a New Graphical Method." American Society of Civil Engineers, Proceedings, Volume 87, Journal of the Soil Mechanics and Foundations Division. February 1960.

32. Krynine, D.P., "On the Methodology of Landslides Investigation in Soviet Russia." Highway Research Board Bulletin Number 236. 1959.

33. Landua, Richard E., "Mathematical Expressions for the Circular Arc Method of Stability Analysis." Highway Research Board Bulletin Number 236. 1959.

34. Baker, R.F. and Chieruzzi, "Regional Concept of Landslide Occurence." Highway Research Board Bulletin Number 216. 1958.

35. Hennes, R.G., Hawkins, S.E., and McCoy, N.L., "An Appraisal of Measures for Improvement of Slope Stability." Highway Research Board Bulletin Number 216. 1958.

36. "Landslides and Engineering Practice." Highway Research Board Bulletin, Special Report 29. 1958.

37. LeClerc, R.V. and Hansen, R.J., "Computer Solution of Swedish Slip Circle Analysis for Embankment Foundation Stability." Highway Research Board Bulletin Number 216. 1958

38. "Horizontal Drains Avert Landslides in Alberta." Engineering News Record, p. 36. November 6, 1958.

39. Meyer, O.H., "Computation of the Stability of Slopes." American Society of Civil Engineers, Proceedings, Journal of the Soil Mechanics and Foundations Division. October 1958.

40. Meyer, O.H., "Computation of Stability of Slopes." American Society of Civil Engineers, Proceedings, Volume 84, Journal of the Soil Mechanics and Foundations Division, No. SM4, part 1, Paper Number 1824. 12 pages. October 1958.

41. Meyer, Otto H., "Computation of the Stability of Slopes." American Society of Civil Engineers, Proceedings, Volume 84, Journal of the Soill Mechanics and Foundations Division. October 1958.

42. West, R.C. and Springfield, V.T., "Relation of Geology to Drainage, Floods, and Landslides in Petersburg Area, West Virginia." Geologic and Economic Survey Report Investigations, Number 13. 19 pages. May 1958 (Received April 1960).

43. Day, R.,"Sliding Highway Gets Stabilization Treatment." Excavating Engineer, Volume 52, Number 3, pages 22-25, 61. March 1958.

44. Woods, H.D., "Causes of Gerra Point Landslide, Sonoma County, California." Geological Society of America, Engineering Geology Case Histories, Number 2, pages 41-42. March 1958.

45. Goldstein, M. and Ter-Stepanian, G., "The Long Term Strength of Clays and Deep Creep of Slopes." Fourth Conference of Soil Mechanics and Foundation Engineering, Proceedings (London), Volume 2, Paper 6/11. 1957.

46. Williams, P.J., "Direct Recording of Solifluction Movements." American Journal of Science, Volume 255, Number 10, pages 705 - 715. December 1957.

47. Parizek, E.J., and Woodruff, J.F., "Clarification of Definition and Classification of Soil Creep." Journal of Geology, Volume 65, Number 6, pages 653-656. November 1957.

48. Smith, T.W. and Stafford, G.V., "Horizontal Drains on California Highways." American Society of Civil Engineers, Proceedings; Journal of the Soil Mechanics and Foundations Division. July 1957.

49. Bjerrum L. and Kjaernsli, B., "Analysis of Stability of some Norwegian Natural Clay Slopes." Geotechnique, Volume 7, Number 1, pages 1-16. March 1957.

50. Meyerhoff, G.G., "Mechanism of Flow Slides in Cohesive Soils." Geotechnique, Volume 7, Number 1, pages 41-49. March 1957.

51. Hurtubise, J.E. and Rochette, D.A., "Causes of Landslides as Revealed by study of Nicolet Disaster." Roads and Engineering Construction, Volume 95, Number 3, pages 82, 84-86, 88-89. March 1957.

52. Terzaghi, K. and Peck, R.B., "Stabilization of an Ore Pile by Drainage." American Society of Civil Engineers, Proceedings; Journal of the Soils Mechanics and Foundations Division. January 1957.

53. Collin, A., "Landslides in Clay." Translation by W.R. Schriever, University of Toronto Press. 1956.

54. Sevaldson, R.A., "Slide in Lodalen." Geotechnique, Volume 6, Number 4, pages 167-182. December 1956.

55. Kallstenius, T. and Wallgren, A., "Pore Water Measurement in Field Investigations." Royal Swedish Geotechnical Institute (Stockholm), Proceeding Number 13. 1956. 58 pages.

56. Thurber, R.C., "Park Bridge Slide." Ninth Canadian Soil Mechanics Conference, Proceedings, December 15 and 16, 1955. Canadian National Research Council, Associate Committee on Soil and Snow Mechanics, Technical Memorandum Number 41. October 1956. 116 pages.

57. Davis, E.H., General Theory of Undrained Strength of Soils and Its Application to Stability Analysis." New Zealand Engineer, Volume 11, Number 8, pages 250-256. August 15, 1956.

58. Purbrich, M.C. and Ayress, D.J., "Uses of Aerated Cement Grout and Mortar in Stabilization of Slips in Embankments, Large Scale Tunnel Repairs, and Other Works." Institution of Civil Engineers, Proceedings, Volume 5, part 2, Number 1, pages 52-75 (discussion) 75-84. February 1956.

59. "Connected Wells Installed to Stabilize California Hillside." World Construction, Volume 9, Number 2, pages 19-22. February 1956.

60. Beaty, C.B., "Landslides and Slope Exposure." Journal of Geology, Volume 64, Number 1, pages 70-74. January 1956.

61. Root, A.W., "Correction of Landslides and Slipouts." American Society of Civil Engineers, Transactions, Volume 120, page 281. 1955.

62. "Drainage of Groundwater in Landslides." American Society of Civil Engineers, Transactions, Volume 120, pages [illegible], 285, 288. 1955.

63. Toms, A.H., "Soil Mechanics in Railway Civil Engineering." Engineering, Volume 180, Number 4677, pages 384 - 388. September 16, 1955.

64. Petterson, K.E., "Early History of Circular Sliding Surfaces." Geotechnique, Volume 5, Number 4, pages 275-296. December 1955.

65. Wood, A.M. Muir, "Folkestone Warren Landslips: Investigations, 1949-1950." Institution of Civil Engineers, Proceedings, Volume 4, part 2, Number 2, pages 410-441 (discussion) 441 - 466. June 1955.

66. Swaminathan, C.G., "Shear Failure in Anisotropic Materials." Indian Roads Congress, Journal, Volume 19, Number 2, pages 167-188. May 1955.

67. Spangler, M.G. and Mickle, J.L., "Lateral Pressures on Retaining Walls Due to Backfill Loads." Highway Research Board Bulletin Number 141. 1955.

68. Caldenius, C., Lundstrom, R., Fellenius, B., and Mohren, E., "Landslide at Surte on River Gota Alv." Stockholm Sveriges Geologiska Undersokning Ser Ca, Number 27. 1955. 63 pages.

69. Root, A.W., "Horizontal Drill - New California Approach in Landslide Control." California Highways and Public Works. March - April, 1955.

70. Nelson, A., "Effect of Landslides in Mining Operations in United Kingdom." Mining Journal (London), Volume 244, Number 2630, pages 41,42. January 14, 1955.

71. "Proceedings of European Conference on Stability of Earth Slopes held in Stockholm, September 20 - 25, 1954." Geotechnique, Volume 5, Number 1, pages 7 -126. March 1955.

72. "Army Engineers Attack Landslides at Oahe Dam." Engineering News Record, page 25. December 9, 1954.

73. "How Landslide Was Controlled at Venturia." World Oil, Volume 139, Number 5, page 226. October 1954.

74. Baker, R.F., "Analysis of Corrective Actions for Highway Landslides." American Society of Civil Engineers, Transactions, Volume 119, page 665. 1954. Discussion by D.P. Krynine and Richard J. Woodward; and R.F. Baker, page 690.

75. Baker, R.F., "Analysis of Corrective Actions for Highway Landslides." American Society of Civil Engineers, Transactions, Volume 119, page 665. 1954.

76. Krynine, D.P., "Experiences with Subsurface Water." Highway Research Board Proceedings, Volume 32, page 512. 1953.

77. Root, A.W., "California Experiences in Correction of Landslides and Slipouts." American Society of Civil Engineers, Proceedings, Volume 79, Separate Number 235. August 1953.

78. Hennes, R.G., "Shear Resistance is Prime Factor in Control of Landslides." Pacific Builder and Engineer, Volume 59, Number 8, pages 82, 125. August 1953.

79. Baker, R.F., "Analysis of Corrective Actions for Highway Landslides." American Society of Civil Engineers, Proceedings, Volume 79, Separate Number 190. May 1953. 25 pages.

80. Holmsen, P., "Landslides in Norwegian Quick-Clays." Geotechnique, Volume 3, Number 5, pages 187 - 194. March 1953.

81. Special Issue on Landslides. Japanese Journal of Railway Engineering Research, Volume 10, Number 6. March 25, 1953.

82. Root, A.W., "California Experience in Correction of Landslides and Slipouts." Paper presented at the American Society of Civil Engineers San Francisco Convention, March 1953.

83. Hauby, J.E., "Slide Stabilized by Drilling Horizontal Drains on Lookout Point Reservoir Relocation Work," Civil Engineering (New York), Volume 22, Number 10, pages 52-53. October 1952.

84. Barber, E.S. and Sawyer, C.L., "Highway Subdrainage," Highway Research Board Proceedings, Volume 31, page 643. 1952.

85. Crandell, D.R., "Landslides and Rapid-Flowage Phenomena Near Pierre, South Dakota." Economic Geology, Volume 47, Number 5, pages 548-568. August 1952.

86. Drucker, D.C., and Prager, W., "Soil Mechanics and Plastic Analysis or Limit Design." Applied Mathematics, Volume 10, Number 2, page 157 -165. July 1952.

87. Turnbull, J.M., "Shear Resistance of Soils." Commonwealth Engineer, Volume 39, Number 9, 10, pages 374-381. April 1952.

88. Lawrence, R.A., "Stabilization of Some Rockslides in Grainger County, Tennessee." Economic Geology, Volume 46, Number 3, pages 329-336. May 1951.

89. Wooltorton, F.L.D., "Movements in the Dissicated Alkaline Soils of Burma." American Society of Civil Engineers, Proceedings, Volume 116, page 433. 1951.

90. Murphy, V.E., "New Techniques for Investigating Stability of Slopes and Foundations." New Zealand Institution of Engineers, Proceedings, Volume 37. 1950-1951.

91. Palmer, L.A., Thompson, J.B., and Yeomans, C.M., "The Control of a Landslide by Subsurface Drainage." Highway Research Board Proceedings, Volume 30, page 503. 1950.

92. "Grouting as Slide Stopper Being Tried in Virginia." Roads and Streets, Volume 93, Number 8, page 47, August 1950.

93. Hirsch, A.D., "Stabilizing Earth Slopes Through Installation of Drains with Hydrauger Equipment." Paper presented at the Western Association of State Highway Officials Conference at Reno, Nevada, June 13, 1950.

94. Stratton, J.H., "Slides Experienced During Panama Canal Construction Period in Relation to Sea Level Conversion Plan." American Society of Civil Engineers, Transactions, Volume 114, pages 626, 743, 734, 871. 1949.

95. Frontard, J, "Discussion of Sliding Surfaces." Proceedings of the Second International Conference on Soil Mechanics and Foundation Engineering, Volume 6, pages 60-62, (Rotterdam). 1948.

96. Tan, Ek-Khoo, "Stability of Soil Slopes." American Society of Civil Engineers, Transactions, Volume 113, page 139. 1948.

97. Krynine, D.P., "Shearing Stresses in Supported and Unsupported Vertical Slopes." Highway Research Board Proceedings, Volume 28, page 443. 1948.

98. "California Plants Freeway Slide Slopes." Engineering News Record, Volume 140, Number 6, pages 180,181. February 5, 1948.

99. Khootan, E.K., "Stability of Soil Slopes." Chinese Institute of Soil Engineering, Proceedings, Volume 1, pages 49-73. October 1948.

100. Mullins, T.G., "Slips on Roads." New Zealand Engineer, Volume 3, Number 9, pages 402,403. September 10, 1948.

101. Ek-Khoo, "Stability of Soil Slopes." American Society of Civil Engineers, Proceedings, Volume 74, Number 2, pages 221-230. February 1948.

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

103. "Curing Slides with Drainage Tunnels." Roads and Streets, Volume 90, Number 4, pages 72,74,76. 1947.

104. Nelson, A., "Landslides." Colliery Engineering, Volume 24, Number 277, pages 90-93. March 1947.

105. Smith, E.C., "Factor of Safety of Clay Banks." Institution of Civil Engineers, Journal, Volume 18, Number 7, pages 293-296. June 1947.

106. Forbes, H., "Landslide Investigation and Correction." American Society of Civil Engineers, Proceedings, Volume 73, Number 3, pages 367-374. March 1947.

107. Khoo Tan, E.K., "Stability of Soil Slopes." American Society of Civil Engineers, Proceedings, Volume 73, Number 1, pages 19-38 (discussion), Number 5, pages 723-728, Number 6, pages 953-960, Number 7, pages 1119-11121. January, May, June, and September, 1947.

108. Forbes, Hyde, "Landslide Investigation and Correction." American Society of Civil Engineers, Transactions, Volume 112, page 377 (discussion) page 407. 1947.

109. "Pacific Coast Landslide Corrective Work." American Society of Civil Engineers, Transactions, Volume 112, pages 388, 391, 402. 1947.

110. Buckingham, E.M., Discussion of the paper by Hyde Forbes "Landslide Investigation and Correction." American Society of Civil Engineers, Transactions, Volume 112, 1947.

111. Forbes, Hyde, "Landslide Investigation and Correction." American Society of Civil Engineers, Transactions, Volume 112, page 377. 1947.

112. Forbes, H., "Landslide Investigation and Correction." American Society of Civil Engineers, Proceedings, Volume 72, Number 2, pages 169-198 (discussion), Number 5, pages 717-721, Number 7, pages 1070-1074, Number 9, pages 1229-1246, Number 10, pages 1387-1390. February, May, September, November, and December 1946.

113. Benson, W.N., "Landslides and their Relation to Engineering in Dunedin District, New Zealand." Economic Geology, Volume 41, Number 4, pages 328-347. June-July, 1946.

114. Worthington, E.L., "Slide Control." Roads and Streets, Volume 89, Number 5, pages 90-92, 98. May 1946.

115. Packshaw, S., "Earth Pressure and Earth Resistance." Institution of Engineers, Journal, Volume 25, Number 4, pages 233-256. February 1946.

116. Nelson, A., "Landslides and Their Causes." Iron and Coal Trades Review, Volume 151, Number 4047, pages 453-455, Number 4051, pages 587-589. September 21 and October 19, 1945.

117. Hunting, M.T., "Prevention and Correction of Landslides in Highway Engineering." American Society of Civil Engineers, Transactions, Volume 110, page 283. 1945.

118. Wagner, W.R.T., "Landslide Area in Little Salmon River Canyon, Idaho." Economic Geology, Volume 39, Number 5, pages 349-358. August 1944.

119. Hennes, R.G., "Analysis of Stresses in Cuts and Embankments." Highway Research Board, Proceedings, Volume 24, page 349. 1944.

120. Akers, J.C., "Drainage Cures Sliding Fill." Better Roads, Volume 14, Number 4, pages 23-25. April 1944.

121. Akers, J.C., "Drainage Cures Sliding Fill." Highway Magazine, Volume35, pages 162-164.

122. Terzaghi, Karl, Peck, R.B., and Housel, W.S., "Earth Pressure and Shearing Resistance of Plastic Clay." A symposium. American Society of Civil Engineers, Transactions, Volume 108, page 965. 1943.

123. Middlebrooks, T.A., "Fort Peck Slide." American Society of Civil Engineers, Transactions, Volume 107, page 723. 1943.

124. Nelson, A., "Landslides". Mine and Quarry Engineering, Volume 7, Number 10, pages 235-238. October 1942.

125. Carrillo, Nabor, "Investigations on Stability of Slopes and Foundations." A Doctor's Thesis, Graduate School of Engineering, Harvard University, Cambridge, Massachusetts. May 1942.

126. "Pipe Drains Stop Earth Slides." Engineering News-Record, Volume 128, Number 15, pages 339-350. April 9, 1942.

127. Johnson, W., "Earth Slide Control." Pacific Coast Gas Association, Proceedings, Volume 33, pages 49-52. 1942.

128. Barber, E.S., and Mershon, C.E., "Graphical Analysis of Stability of Soils." Public Roads, Volume 21, Number 8, pages 147-157. October 1940.

129. Duvivier, J., "Cliff Stabilization Works in London Clay." Institution of Civil Engineers, Journal, Volume 14, Number 8, pages 412-426. October 1940.

130. "Problems of Slide Control Handled at Grand Coulee." Western Construction News, Volume 15, Number 6, pages 204-206. June 1940.

131. Porter, O.J., "Treatments Prevent Slides and Slipouts in California." Roads and Streets, Volume 83, Number 4, pages 57-59, 62-64, 66, 70, 72. April 1940.

132. Harrown, Dale T., "Stability of Vertical Embankments." Highway Research Board Proceedings, Volume 20, page 751.

133. Larew, H.G., "Use of Field, Laboratory, and Theoretical Procedures for Analyzing Landslides." Highway Research Board Bulletin Number 49.

134. Baker, R.F., "Determining Corrective Action for Highway Landslide Problems." Highway Research Board Bulletin Number 49.

135. Brown, V.J., "Stopping Slides Tunnel Method as Used in Oregon." Roads and Streets, Volume 82, Number 6, pages 28-33. June 1939.

136. Krauskopf, K.B., et al, "Structural Features of a Landslide Near Gilroy, California." Journal of Geology, Volume 47, Number 7. 1939.

137. Allen, G.H., "Old Slide Compels Radical Remedy." Engineering News Record, Volume 123, Number 7, pages 70, 71. August 17, 1939.

138. "West Indian Landslide." Engineering News Record. December 1, 1938.

139. Sharpe, C.F.S., "Landslides and Related Phenomena." New York, Columbia University Press. 1938.

140. Seaton, J.H., "Engineering Problems Associated with Clay, with Special Reference to Clay Slips." Institution of Civil Engineers, Journal, Numbers 5 and 8, pages 457 - 474. April 1938.

141. Butler, M., "Elysian Park Slide in Los Angeles Collapses Viaduct." Engineering News Record. February 17, 1938.

142. "Hillside Lets Go in Los Angeles." Engineering News Record, Volume 119, Number 23, page 881. December 2, 1937.

143. Taylor, D.W., "Stability of Earth Slopes." Journal of the Boston Society of Civil Engineers. July 1937.

144. Allen, G.E., "Steel Baffles Stops Sliding Hill." Engineering News Record, Volume 119, Number 1, pages 32, 33. July 1, 1937.

145. Taylor, D.W., "Stability of Earth Slopes." Boston Society of Civil Engineers, Juornal, Volume 24, Number 3, pages 197-246. July 1937.

146. Young, H.W., "Coulee Landslide Stopped by Freezing." Contractors and Engineers Monthly, Volume 33, Number 5, pages 9 and 31. November 1936.

147. Allen, G.E., "Arresting Slide on Indiana Highway." Civil Engineering (New York), Volume 6, Number 6, page 384-385. June 1936. See also Highway Magazine, Volume 27, pages 188-190. August 1936.

148. Whitney, C.S., "Stabilizing Lake Michigan Bluff." Civil Engineering (New York), Volume 6, Number 5, pages 309-313, Volume 7, pages 469-470 (Discussion). May and July 1936.

149. Sharpe, C.F.S., "Landslides and Related Phenomena." New York, Columbia University Press. 1936. 66 pages.

150. Jaky, J., "Stability of Earth Slopes." Proceedings of the International Conference on Soil Mechanics and Foundation Engineering, Volume 2, Harvard University, pages 200-207. 1936.

151. Balsille, G.D., "Large Landslide Near Ulverstone, Tasmania, Arrested by Deep Drainage." Institution of Engineers (Australia), Journal, Volume 8, Number 10, pages 365-371. October 1935.

152. Terzaghi, K., "Critical Heights Factor of Safety of Slopes Against Sliding." Proceedings of the International Conference on Soil Mechanics and Foundation Engineering, Volume 1, Harvard University, pages 156-161. 1936.

153. Ladd, G.E., "Landslides, Subsidences and Rock-Falls." American Railway Engineering Association, Proceedings, Volume 36, pages 1091-1162. 1935.

154. Ladd, G.E., "Landslides, Subsidences and Rock-Falls as Problems for the Railroad Engineer." Proceedings of the American Railway Engineering Association, Volume 36, pages 1091-1162. 1935.

155. Bane, W.B., "Stabilizing Slipping Fill on Hillside Road." Engineering News Record, Volume 115, Number 6, pages 184-185. August 8, 1935.

156. Skeggs, J.H., "Skillful Work of Engineers Saved Highway in 200,000 Cubic Yard Slide." California Highways and Public Works, pages 22,23. April 1935.

157. Miyabe, N., "Study of Landslides." (Tokyo) Imperial University, Earthquake Research Institute Bulletin, Volume 13, part 1, pages 85-113. March 1935.

158. Hill, R.A., "Clay Stratum Dried Out to Prevent Landslips." Civil Engineering (New York), Volume 4, Number 8, pages 403-407. August 1934.

159. Ladd, G.E., "Bank Slide in Deep Cut Caused by Drought." Engineering News Record, Volume 112, Number 10, pages 324-326. May 3, 1934.

160. Sutton, C.H., "Andean Mud Slide Destroys Lives and Property." Engineering News Record, Volume 110, Number 18, page 562 - 563. May 4, 1933.

161. Krynine, D.P., "Some Theoretical Considerations on Landslides." Engineering News Record, Volume 107, Number 3, page 93. July 16, 1931.

162. Downs, W.S., "Earth Slip Hazards and Control in Highway Maintenance." Engineering News Record, Volume 104, Number 20, pages 794-798. May 15, 1930.

163. Ladd, G.E., "Stopping Landslides on Highway Fills." Contractors and Engineers Monthly, Volume 18, Number 1, pages 15-21. January 1929.

164. Ladd, G.E., "Landslide - Causes - Cures." Pure Iron Era, 9th Issue, pages 14,15. 1928.

165. Ladd, G.E., "Methods of Controlling Landslides." Engineering and Contracting, Volume 67, Number 12, pages 599-608. December 1928. See also: Roads and Streets, Volume 68, Number 11, pages 528-533. November 1928.

166. Day, C.A., and Easterday, E.E., "The Prospect Hill Landslide at St. Louis, Missouri." Engineering and Contracting, Volume 67, Number 11, pages 569-571. November 1928.

167. Alden, W.C.,"Landslide and Flood at Gros Ventre, Wyoming." American Institute of Mining and Metallurgical Engineers, Technical Paper, Number 140. October 1928. 14 pages.

168. Terzaghi, C., "Landslides." Highway Research Board Proceedings, Volume 7, part 1, page 122. 1927.

169. Ladd, "Landslides and their Relations to Highways." Public Roads, Volume 8, Number 2. April 1927.

170. "Protecting West Virginia Highways from Sliding Hill Damage." Engineering News Record, Volume 94, page 30. 1925.

171. Jones, R.H., "Water Seepage Along Fault Planes Causes Serious Clay Slide." Engineering News Record, Volume 188, Number 16, pages 648,649. April 20, 1922.

172. "Holding back the Bigelow Boulevard Landslide at Pittsburgh, Pennsylvania." Excavating Engineer, Volume 15, Number 2, pages 41,42. February 1921.

173. Scharff, M.R., "The Bigelow Boulevard Slide at Pittsburgh." Engineering News Record, Volume 85, Number 23, pages 1067-1080. December 2, 1920.

174. "Heavy Slide Badly Deranges Train Operation." Railway Age, Volume 69, Number 24, pages 1029,1030. December 10, 1920.

175. Smith, C.E., "Report on Cause and Correction of Foundation Troubles of Box Factory at Natchez, Mississippi." American Society of Civil Engineers, Transactions, Volume 83, page 1289. 1919-1920.

ABSTRACTS OF SELECTED ARTICLES

1. Phillbrick, Shailer S., "Design of Rock Slopes." Highway Research Record 17. 1963.

   This paper discusses the method of determining the needed information for rock slope design and recommends methods of designing slopes. Cut back slopes are determined on the basis of ability of individual stratum to resist sliding.

2. "Landslides Plague Pacific Coast Highway." Engineering News Record, p. 20. May 11, 1961.

   This article does not offer any solution to the many landslides along the coast highway in California, but it does illustrate the damage that a landslide can cause and the problem of providing a corrective measure.

   California has spent many millions of dollars as a result of landslides along highways.

3. Redus, J. F., "Experiences with Expansive Clay in Jackson (Mississippi) Area." Highway Research Board; Bulletin No. 313. 1961.

   This article is concerned with Yazoo Clay. It discusses the effects of moisture content on the clay. The main cause of sliding is the drying of the clay during construction. When dry, the clay slakes and shrinkage cracks occur. Upon wetting the slaked material slides.

   A sod mat placed before the clay dries is recommended for prevention of slides. Never allow the clay to dry.