Landslide Investigation and Correction

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The highlights of the background on this subject and some case histories on the investigation and design of landslide corrections were presented by W. J. Sisiliano. The construction aspects of the case histories discussed along with the state's first horizontal drain installation on I-74 near St. Leon were presented by Phil Jones.

GENERAL INTRODUCTION

We have all seen evidence of the effects of landslides in costs, inconvenience and possible safety hazards or danger to the travelling public in our travels throughout Indiana and the United States.

A determined effort has been underway for a few years to correct these landslides on a priority basis as the need arises and as time is available. Landslide investigations are very time consuming to be properly and thoroughly accomplished. It takes very close cooperation between the district construction or maintenance engineer initiating the request for landslide investigation through proper channels, the soils engineer and the assigned design engineer. Certain information should accompany any request for landslide investigations as follows:

1. A letter requesting that a landslide investigation be made. In this letter should be included all the known history of events associated with the landslide including maintenance and resurfacing records.
2. This letter should be processed through appropriate channels.
3. Map of plan view of slide limits showing cracks and scarps.
4. Cross sections throughout the slide area and in undisturbed areas on either end.

GENERAL CAUSES OF LANDSLIDES

A famous soils engineer once said, "The major causes of landslides in order of importance are water, water and more water." This is no exaggeration. I interpret this as meaning surface water, subsurface water and inherent water in the soil or its natural moisture content. Water actually affects some of the additional causes which follow later.

Very seldom, if ever, can a slide be attributed to a single definite cause. In most cases a number of causes exist simultaneously, and so attempting to decide which one finally produced failure is not only difficult but almost impossible. Often the final factor is nothing more than a trigger that set in motion an earth mass that was already on the verge of failure. Calling the final factor *the cause* is like calling the match that lit the fuse that detonated the dynamite that destroyed the building *the* cause of the disaster.

Principal Factors Causing Instability of Earth Materials

1. Those contributing to high shear stress:
   - A. Removal of lateral support by stream erosion or undercutting, and making cuts for: highways, quarries or canals, construction of dams and reservoirs.
   - B. Adding load by: construction of fills or other structures, stockpiling ore, rock or waste products.
   - C. Earthquake forces.
   - D. Regional tilt of underlying bedrock.
   - E. Removal of underlying support by: solutioning in rock, mining of coal or other raw materials.
   - F. Lateral pressure due to: water in cracks freezing, swelling of soils, etc.
2. Those contributing to low shear strength:
   - A. Composition, texture and structure of initial state.
   - B. Changes in soil or rock due to: disintergration, hydration, drying, and removal of cementing agents by solutioning.
   - C. Changes in intergranular forces due to: excess pore water pressure, buoyancy, capillary tension, or seepage forces.
   - D. Changes in structure due to disturbance of: fissured preconsolidated clay, sensitive clays, loose sands, or loessial materials.

GENERAL PREVENTION OF LANDSLIDES

In general, landslides can be minimized by making complete roadway soil surveys in questionable areas, making adequate provisions to handle surface and subsurface water, by reducing the activating forces, and by increasing the resisting forces, or in limited cases by avoidance of the area or relocation of the route.

This is usually done by recognizing the potential problem before or during the design stage. At that time relocation can be accomplished, or if the alignment must be maintained, excavation at the head to reduce driving forces, providing drainage or construction of restraining or retaining structures at the toe can be accomplished. In addition flattening slopes, lowering grades, complete excavation, or in limited cases, blasting can be considered.

It is possible that future construction could affect the stability of existing slopes. If the engineer keeps proposed or future construction in mind, and evaluates the effect which this construction may have on the soil profile, the underlying rock and ground water conditions, he will have gone a long way toward recognizing a potential landslide problem and will be able to make plans to avoid or to stabilize the sensitive mass. Typical situations that should be looked for in this connection are as follows:

1. Restriction of ground water flow by sidehill fill.
2. Overloading of relatively weak underlying soil layer by fill.
3. Overloading of sloping bedding planes by heavy sidehill fill.
4. Oversteepening of cuts in unstable rock or soil.
5. Removal, by cut, of thick mantle of pervious soil if the latter is a natural restraining blanket over a softer core.
6. Increase in seepage pressure by cut or fill that changes direction or character of ground water flow.
7. Exposure, by cut, of stiff fissured clay that may soften when exposed to surface water.
8. Removal of mantle of wet soil by sidehill cut; such a cut may remove toe support, causing soil above cut to slide along its contact with stable bedrock.
9. Increase in hydrostatic head below surface or a cut in silt or permeable clay if surface is allowed to freeze or to become covered with impervious slough material.

During our analysis and correction work on some slides which have already been corrected, we have encountered certain factors which caused instabilities in localized areas primarily. These possible causes for embankment failure are shown in Figures 1, 2 and 3.

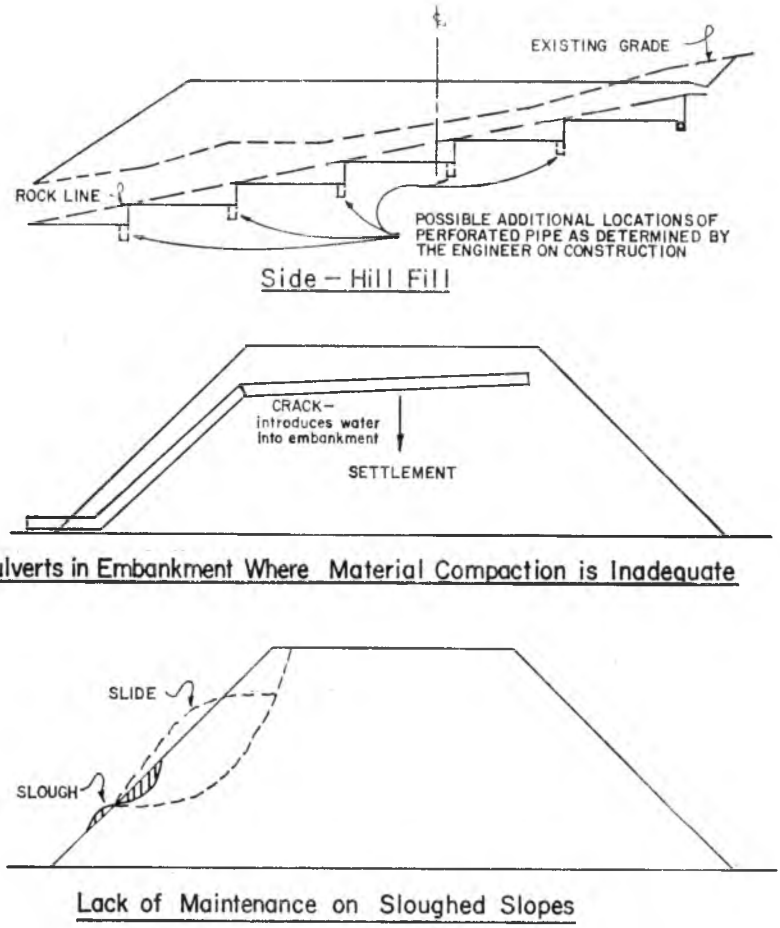

Fig. 1. Some possible causes for embankment failure.

GENERAL CORRECTION OF LANDSLIDES

There are no hard and fast rules or so called cook-book engineering procedures for correcting slides. Each slide area must be considered on its own merits, the conditions defined and the causes isolated before an effective correction can be designed with confidence. The procedure to follow in any slide correction is to:

1. Make a request for slide correction (sending information previously mentioned).
2. Review this data and schedule a field reconnaissance.
3. Plan a field investigation to make borings, to obtain samples and to install field instrumentation including settlement sensors,

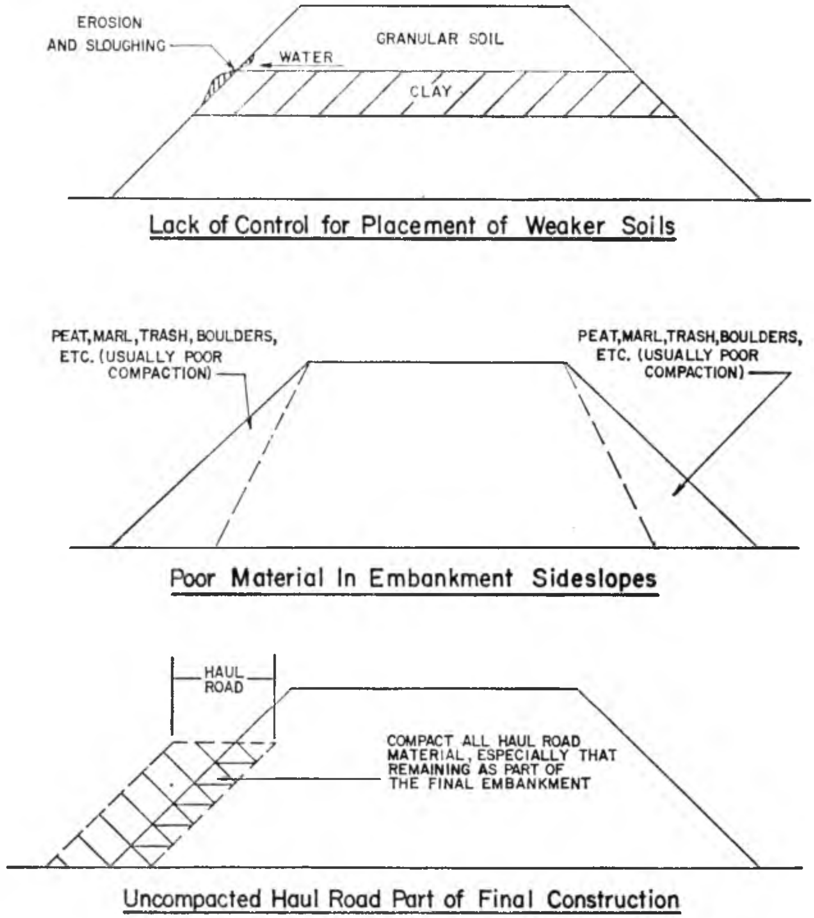

Fig. 2. Some possible causes for embankment failure.

piezometers to measure excess pore water pressure, and slope indicators to measure lateral movement and determine the depth of the failure plane. The instrumentation will be monitored until sufficient information is developed for use in the design of a slide correction.

4. Plan a laboratory investigation to test the samples taken within each stratum to define their physical characteristics including composition, strength and compressibility.
5. Perform necessary stability analyses for various type corrections (Involves trial and error procedures and is time consuming).
6. Write a report of slide correction generally with several alternate solutions. After the design department makes cost studies, the most economical correction is usually accepted.

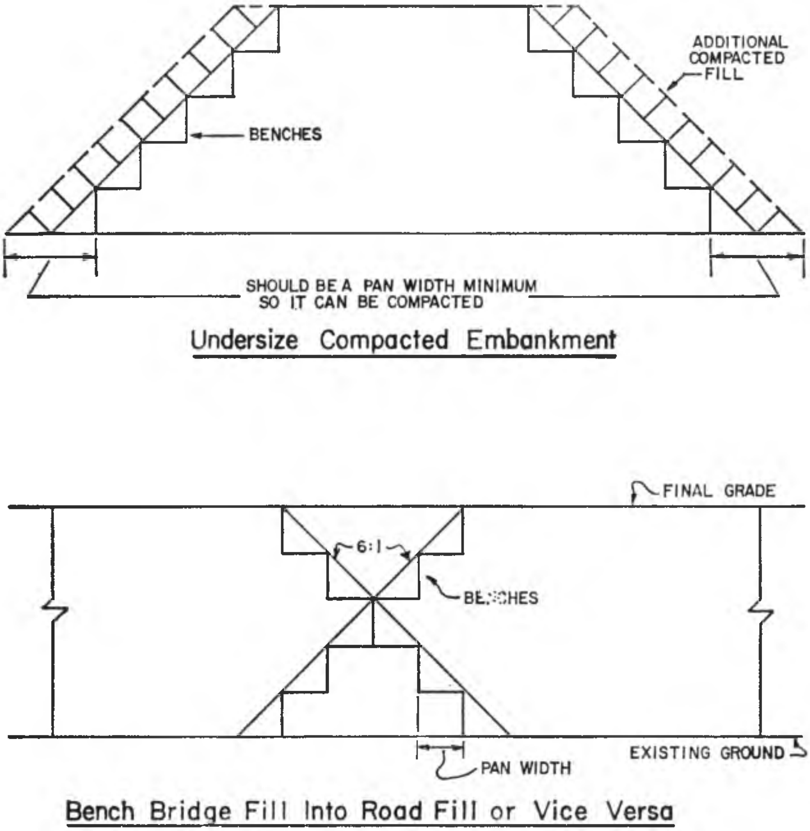

Fig. 3. Some possible causes for embankment failure.

Similar methods are used in the correction of slides as were mentioned for the prevention of slides, that is, flattening slopes, lowering grades, providing surface and subsurface drainage, decreasing driving forces, increasing resisting forces, building restraining or retaining structures, complete excavation or relocation of that section of roadway. Two examples of methods used for slide corrections are shown in Figure 4.

LANDSLIDES IN INDIANA

A portion of a research study by Sisiliano and Lovell has shown that slides occur in primarily two physiographic regions in the state of Indiana. The physiographic regions in the state are shown in Figure 5.

The Dearborn Upland in the Seymour District is the most slide prone area in the state. Its underlying consolidated formations (bedrock) are primarily interbedded shale and limestone of Ordovician Age.

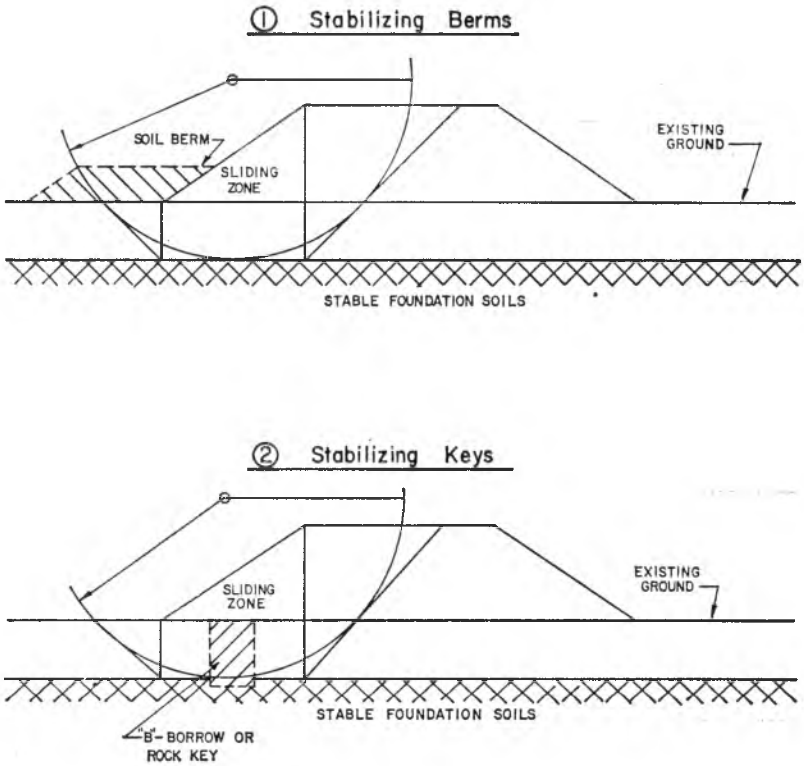

Fig. 4. Methods of slide correction.

The Crawford Upland in the Vincennes District is the second most slide prone area in the state. The underlying bedrock is primarily interbedded shale, limestone and sandstone of Mississippian Age. A tabulation of slide occurrences per physiographic region is shown in Table 1.

SOME CASE HISTORIES

Case History No. 1—Cut Backslope Figures on I-64 near Sulphur Indiana

Introduction

These cut slopes failed during construction. Photograph 1* was on contract R-8828, where the cut slope failed at the interface between soil and shale; photograph 2 was on contract R-8742 where the cut slope failure was in soil.

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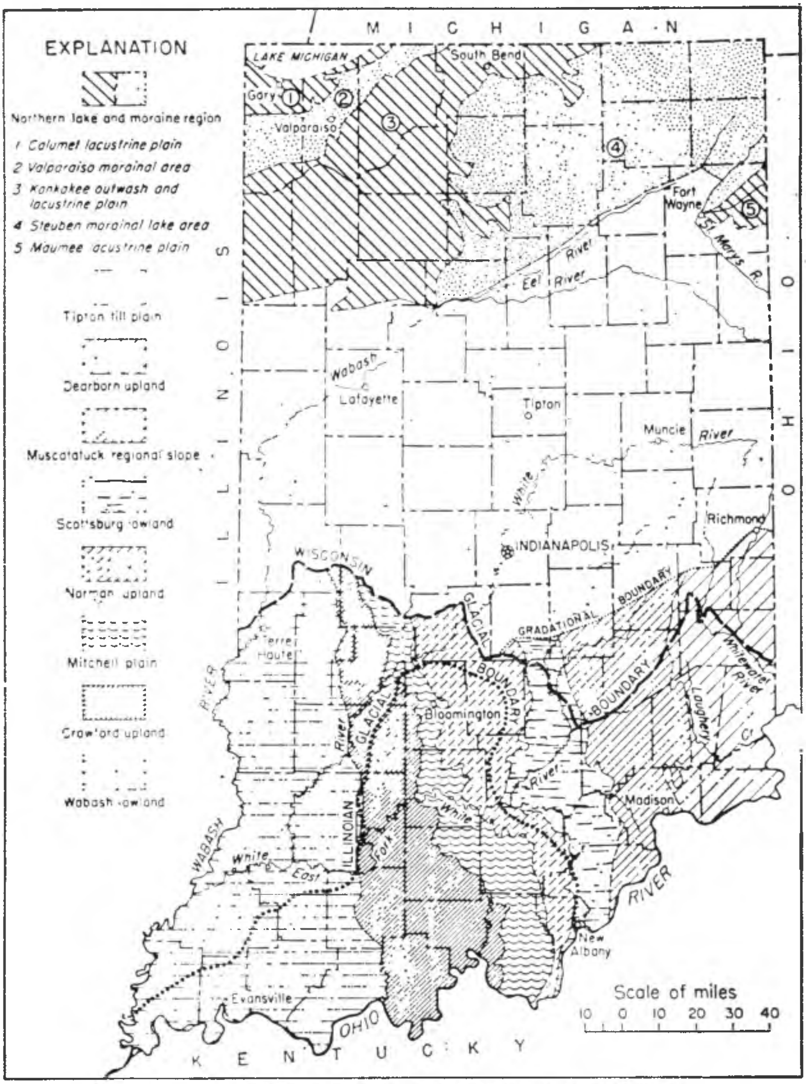
* **[Editor's Note—All photographs herein were copied from color photographs and reproduction is not the best.]**



Map of Indiana showing regional physiographic units based on present topography. Modified from Malott, 1922, pl. 2.

Fig. 5. Map of physiographic regions in Indiana.

Possible Causes of the Cut Backslope Failures

The cut backslopes were constructed on 2:1 slopes which proved to be too steep for the strength of the soils encountered, the dip of the underlying shale and the ground water conditions encountered.

TABLE 1. SUMMARY OF LANDSLIDES

Physiographic Region	Number of Landslides
1. Northern Lake and Moraine Region	
A. Calumet Lacustrine Plain	0
B. Valparaiso Morainal Area	1
C. Kankakee Outwash & Lacustrine Plain	0
D. Steuben Morainal Lake Area	2
E. Maumee Lacustrine Plain	0
2. Tipton Till Plain	1
3. Dearborn Upland	16
4. Muscatatuck Regional Slope	0
5. Scottsburg Lowland	4
6. Norman Upland	2
7. Mitchell Plain	2
8. Crawford Upland	10
9. Wabash Lowland	3
Total	41

Photo 1. Cut backslope failure on I-64.

Proposed Slide Corrections

The correction of these slides was to flatten the slope and to provide backslope interceptor drains.

Proposed Slide Corrections

Several methods for slide correction were proposed as follows:

1. Removal of slide material and replacement with No. 2 stone.
2. Removal of slide material and flattening slope to 3:1 with more and deeper sod pegs, compacting the outer portion of the sideslope, using a dry density and moisture control specification. This solution would require purchasing additional right-of-way and would result in considerable delay.
3. Removing slide material and flattening to 3:1 within existing right-of-way using a bin wall, crib wall, reinforced concrete retaining wall or reinforced earth retaining structure.

Case History No. 3—Embankment Failures on I-74 near St. Leon

General Introduction

Several landslides occurred and were corrected during construction in the early 1960's on the section of I-74 between SR 1 and US 52 near St. Leon. Additional embankment failures were brought to the attention of the soils department starting in the fall of 1970 with the River Slide, in the winter of 1971 with the Big Slide, and in the spring of 1972 with the Chicken Slide.

The general landslide location is shown in Figure 6. The specific location of embankment failures corrected to date are shown in Figure 7.

General Causes for Embankment Failures

Several general causes for the enbankment failures on this section of I-74 follows:

1. It has been determined that the present alignment of this section of road was selected because it was felt by Federal Highway Administration personnel that a scenic highway could be built with sidehill fills and variable elevation of lanes. Our present knowledge and experience tells us that it would be very difficult and expensive to build a stable roadway under these conditions in the most slide-prone physiographic region in Indiana.
2. A complete roadway soil survey was not made as a part of the design phase of this project. The project was designed prior to the state's policy of making roadway soil surveys as a routine part of preliminary engineering.
3. The standard embankment sideslopes at that time were 2:1 for embankments of the heights involved on this project. Experience has shown, along with observations of natural slopes, that a 2:1 sideslope is much too steep for the materials in this area, which

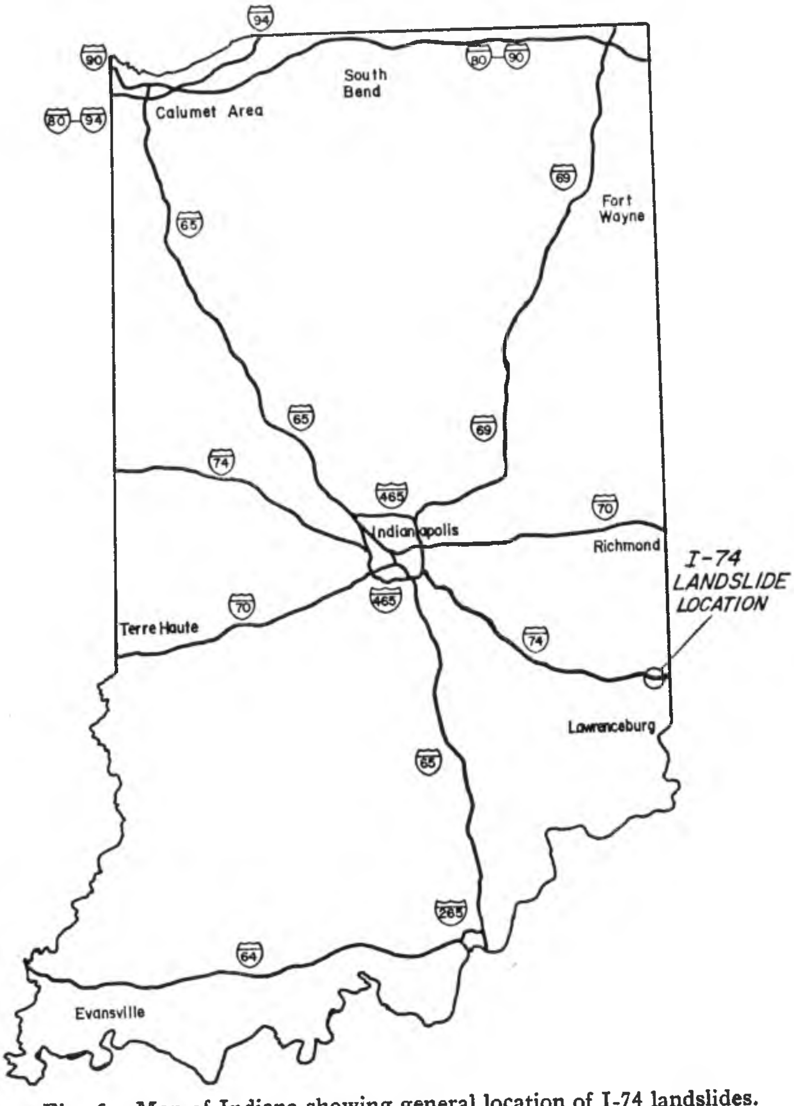


Fig. 6. Map of Indiana showing general location of I-74 landslides.

are of Ordovician Age. The materials encountered are typical of those encountered within the Dearborn Upland physiographic region.

In addition, stability analyses indicate that as the embankment height increases, a flatter slope is needed to maintain an adequate factor of safety against a slope failure, something on the order of 4:1 for projects within this physiographic region.

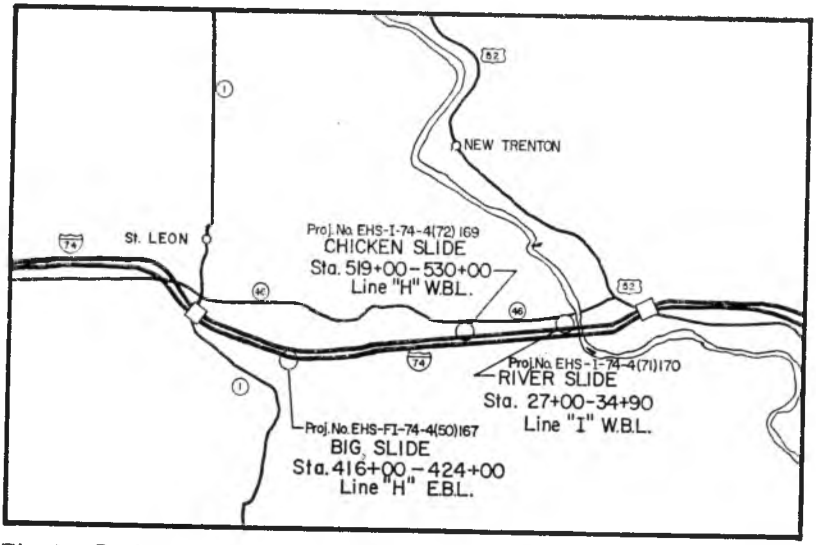


Fig. 7. Project site plan showing actual locations of I-74 corrected landslides.

4. An attempt was made to bench into the underlying soils in areas where sidehill fills were to be constructed. To be effective, these benches probably should have been much deeper, extending into the underlying shale-limestone formation wherever possible.
5. Subsurface drains probably should have been provided on these benches to intercept any water seeping or percolating into the sidehill embrankment area.
6. The Standard Specifications and Special Provisions were not adequate to provide a dense compacted embankment using the on-site predominantly shale-limestone Ordovician materials. There may have been some question during construction as to whether this material could be placed as a rock fill, since some of the limestone slabs were apparently relatively large. The specifications allowed rock fills to be placed by end-dumping and dozing the material into place. These lifts could be as thick as four feet or less depending on the way the material was breaking down during excavation from the adjacent cuts.

Since the shale was considerably dry of optimum, the lifts were too thick, and the limestone slabs created a bridging action against the compaction attempts, the embankment was probably constructed with considerable voids and in a less than dense condition. This allowed surface and subsurface waters to percolate through the fill, to saturate the shaley materials, and to cause them to slake or break down.

7. When the shaley materials began to break down, vertical movements probably occurred, showing up as settlement of the guard rail and a dip in the pavement. As time went on, the shaley materials broke down more and the surficial evidence in the guard rail and pavement became more pronounced and serious.
8. It is considered that at this point in time, the surface drainage structures and the subsurface drains along the edge of pavement began to malfunction. This probably happened in several ways as follows:
   (a) As the excessive settlements occurred, the subsurface drains at the pavement edge could not function as originally designed. The only outlet for the water was down into the embankment.
   (b) Surface waters were generally designed to channel into drop inlets, to be carried to the shoulder, and to flow into a pipe which paralleled the sideslope. When excessive settlements occurred within the embankments, cracks could have developed at the drop inlets, at joints, or near the shoulder point where the pipe began to slope steeply downward. This again may have allowed large quantities of water to infiltrate into the embankment.
9. With these surface waters entering the embankment, the fill materials became saturated in localized zones, seepage and localized sloughing probably occurred on the sideslope, and a progressive failure subsequently occurred.

Case History No. 3A—River Slide

Introduction

This was the first slide brought to the attention of the soils department after construction of this section of roadway. An attempt by district maintenance forces to correct this slide using piling was unsuccessful since movement continued to occur after their correction was completed. It was necessary at times to close the outside land of the westbound pavement.

This area has a typical sidehill cut-to-fill cross-section. The eastbound lane is essentially in cut and the westbound lane is essentially on embankment.

Field and Laboratory Investigations

Sufficient soil borings were made, samples obtained, instrumentation installed and laboratory tests performed to determine the subsurface stratification, the parameters required for analysis for each stratum and the location of the failure plane.

Specific Causes of Landslide

A field reconnaissance of the project site indicated that the earth slide or slope failure appears to have occurred in the mass of overburden soils extending from the westbound lane of I-74, north to Logan Creek. The Logan Creek channel makes an elbow bend at just about the western slide limit. Waters in the creek flow generally south, then east and gain velocity on the outside of this approximate 90 degree bend. It is speculated that this natural phenomenon created erosion and undercutting of the south creek bank, precipitating localized sloughing of minor proportions, which in turn progressed to sloughs of larger proportions to the south and eventually became a contributing factor for the slide.

It is also considered that while the above process was in progress, a natural ground water flow originating in the hill to the south and flowing northward toward Logan Creek, was saturating the overburden soils and lowering their shear strength. These two factors are considered to be the main basic causes for the occurrence of this slide. The embankment construction is considered to be the triggering device rather than the basic cause of the slide.

Typical Correction of Landslide

The embankment making up the westbound lane failed at the interface between the soil overburden and the underlying shale. The slide correction which proved to be the most economical was complete removal of the sliding mass, deep benching into the underlying shale, installation of a positive subsurface drainage system and reconstruction of the embankment with soil and shaley material compacted to more stringent requirements than used previously. The typical slide correction is shown in Figure 8 Photograph 3, showing the benching operation during construction, has been included along with photograph 4 of the basic filing operation.

Case History No. 3B—Chicken Slide

Introduction

This slide involves a high sidehill fill on the order of 100 feet. A minor slough occurred near the toe of slope.

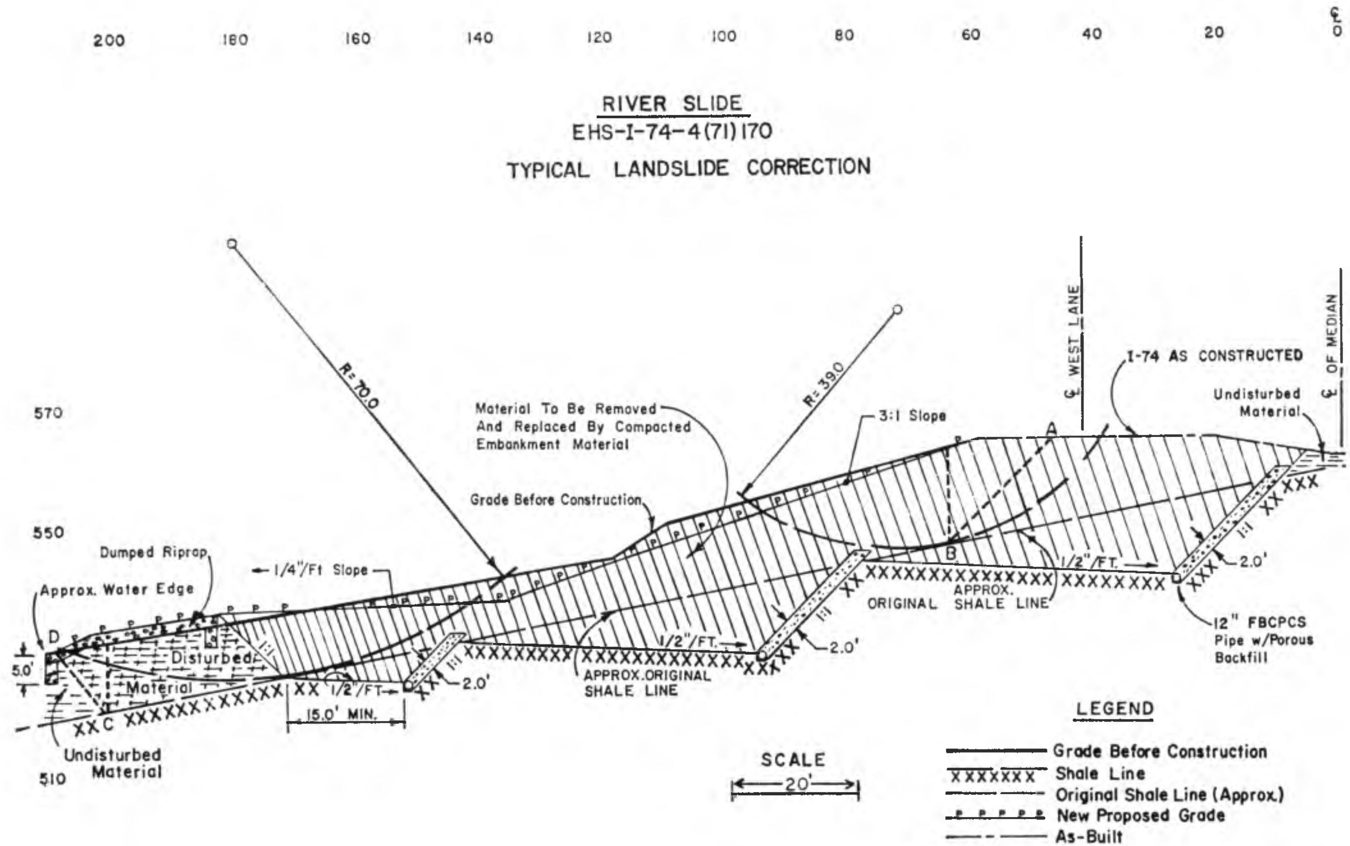


Fig. 8. Typical landslide correction—River Slide.

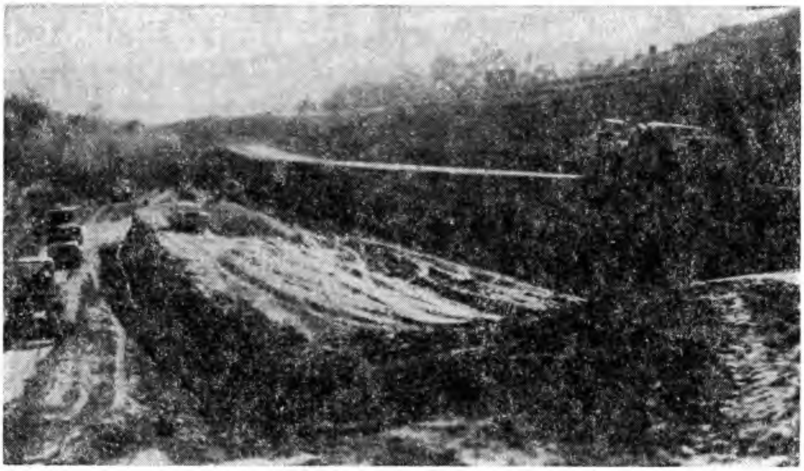


Photo 3. Construction benching operation on I-74 River Slide.

Photo 4. Embankment construction operations on I-74 River Slide.

Then as time passed, larger sloughs occurred, the shoulder began to settle excessively and to move outward, and the outside lane of the westbound pavement moved outward with the joint between lanes separating several inches. Therefore, the outside lane was closed to traffic until a correction could be designed and construction gotten under way.

Field and Laboratory Investigation

Once again, borings and samples were obtained and instrumentation installed to develop necessary data and information for analysis.

Specific Causes of the Landslide

The following are considered to be the factors contributing to this landslide:

1. Embankment slopes were designed too steeply for the height of embankment involved.
2. Benches into foundation material were not deep enough to be effective.
3. Drains were not installed on benches, to intercept water flowing in the foundation materials.
4. Shale-limestone material used in the embankment was placed as a rock fill instead of being compacted, etc., like an earth fill, thus allowing breakdown of the shaley materials and excessive settlement of the fill to occur. Then drainage structures and pavement edge drains probably mal-functioned.
5. Eventually saturated zones in the fill sloughed out and the landslide developed.

Conventional Slide Correction.

The failure was considered to occur between the soil overburden and the shale. This conventional slide correction, as shown in Figure 9, consisted of the following:

1. Unloading upper portion of the embankment.
2. Construction of a stabilizing keyway near the toe of sideslope.
3. Installation of horizontal drains to intercept water in the foundation material. This is the first project in Indiana in which horizontal drains were installed. Photograph 5 shows the horizontal drains being installed and photograph 6 shows the drains after installation.
4. Spreading a 3-ft thick B borrow blanket over the entire slide correction area.
5. Construction of a stabilizing berm system, with a shale-placement special provision.
6. Reconstruction of the pavement.

Alternate Slide Correction with Reinforced Earth Structure

This correction as shown in Figure 10 was basically similar to the conventional method except that a reinforced earth structure replaced a large portion of the stabilizing berm used in the conventional method. In this method, resistance is developed between the metal strips and the granular soil surrounding it. The wall was designed by the Reinforced Earth Company. Both alternates were put up for bid and the conventional method was bid at less cost, thus it was constructed.

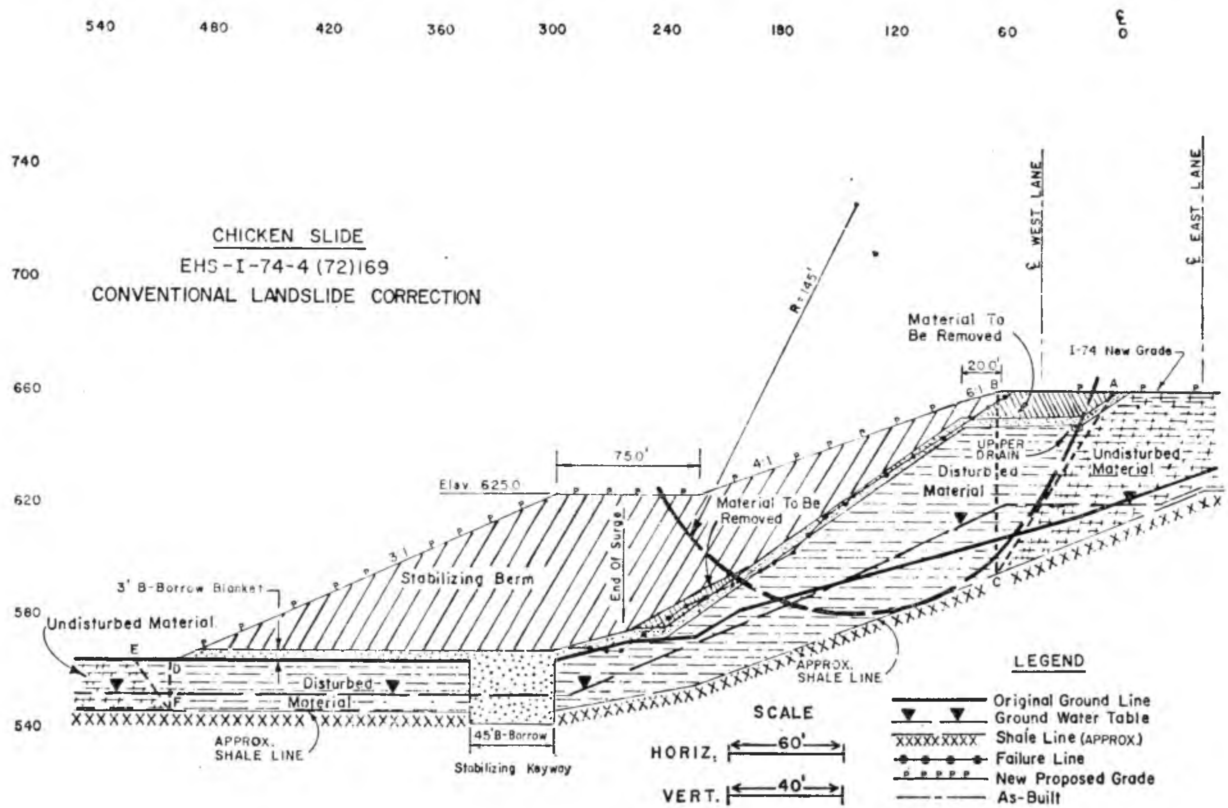


Fig. 9. Conventional landslide correction—Chicken Slide.

Photo 5. Horizontal drains being installed in I-74 Chicken Slide.

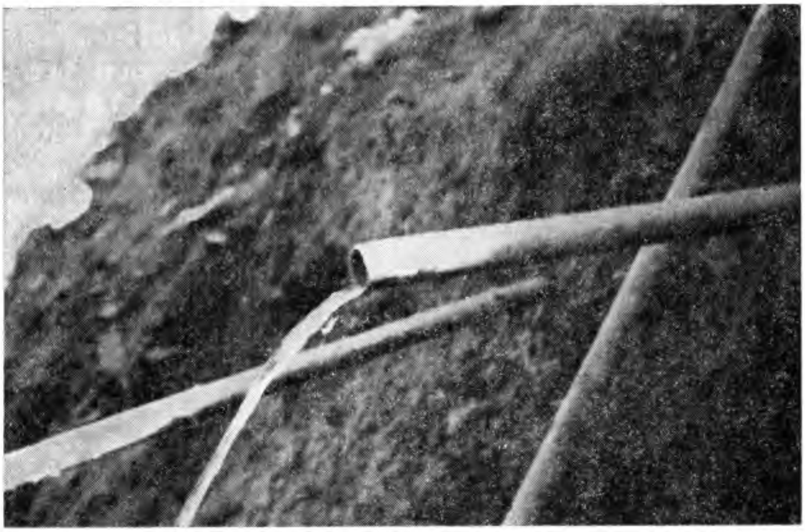


Photo 6. Horizontal drains after installation on I-74 Chicken Slide.

Photograph 7 shows a reinforced earth structure being constructed in Anniston, Alabama. Photograph 8 shows a front view of the partially completed structure. Precast panels were used for this project.

Case History No. 3C—Big Slide

Introduction

This was the most massive landslide Indiana has had to date. It was necessary to close the eastbound lane to traffic after it occurred. The slide area consists of a sidehill cut-to-fill cross-section with the eastbound

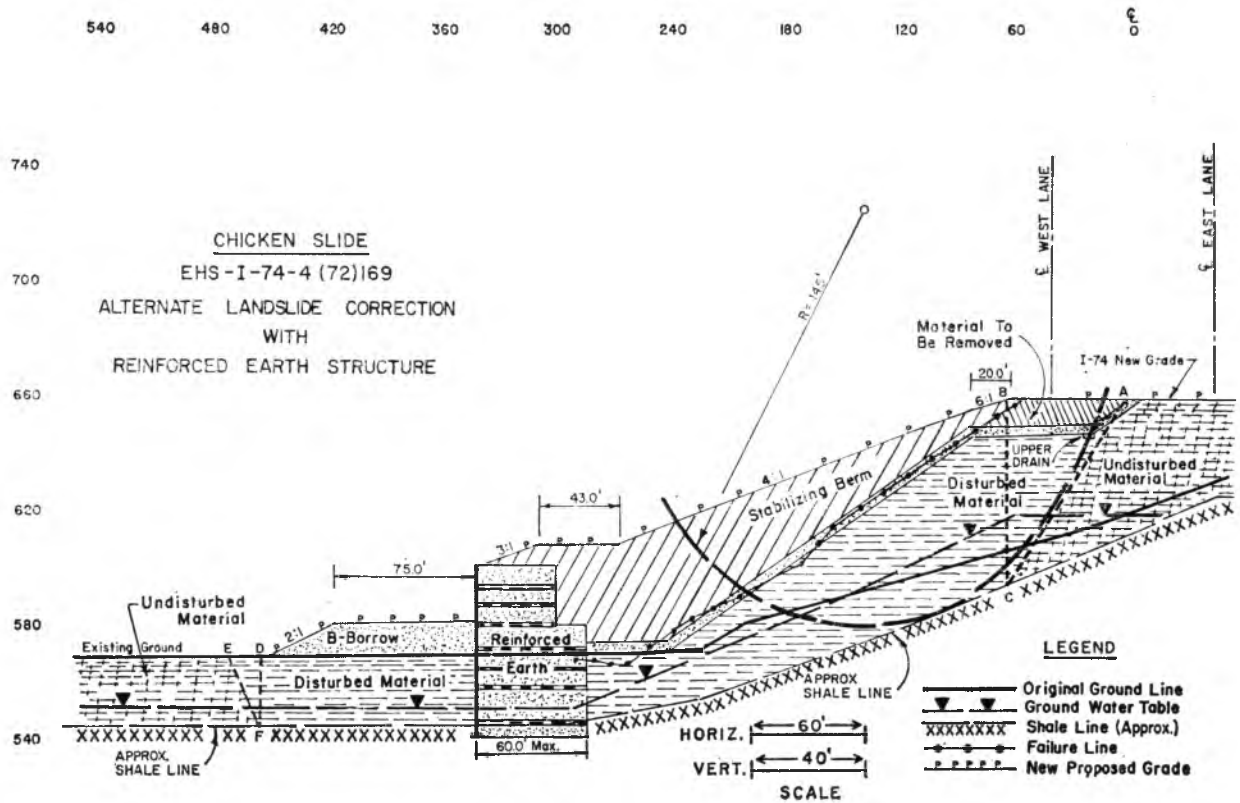


Fig. 10. Reinforced earth structure, alternate landslide correction— Chicken Slide.

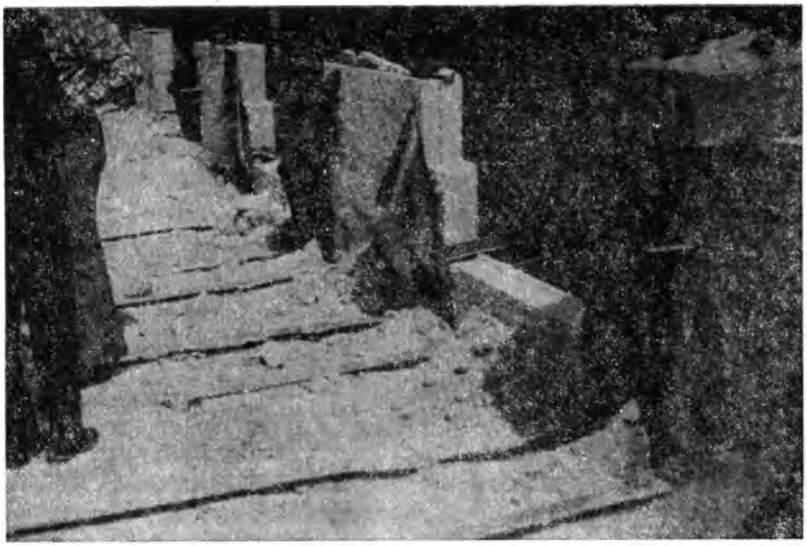


Photo 7. Construction of reinforced earth structure in Anniston, Alabama.

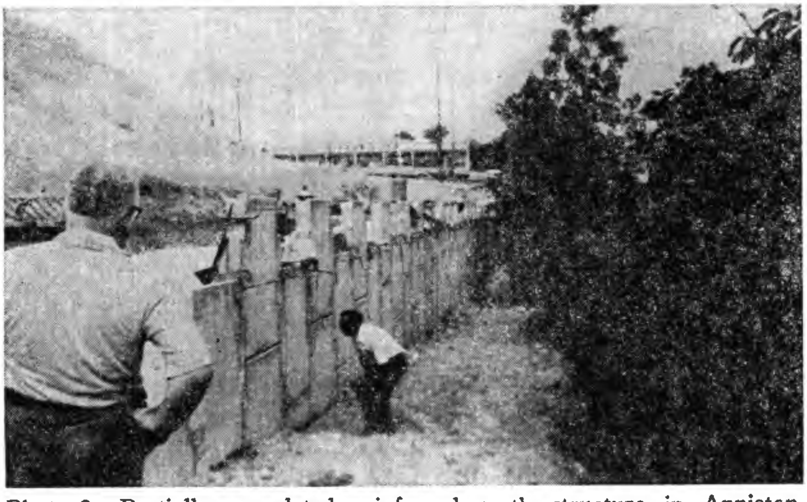


Photo 8. Partially completed reinforced earth structure in Anniston, Alabama.

lane being embankment and the westbound lane being in cut. Photographs 9 through 14 were taken in the slide area.

The first decision made was to seal off the inlet end of a culvert in the westbound lane ditch, which was allowing water to flow into the slide area. An emergency contract was let before the field soils

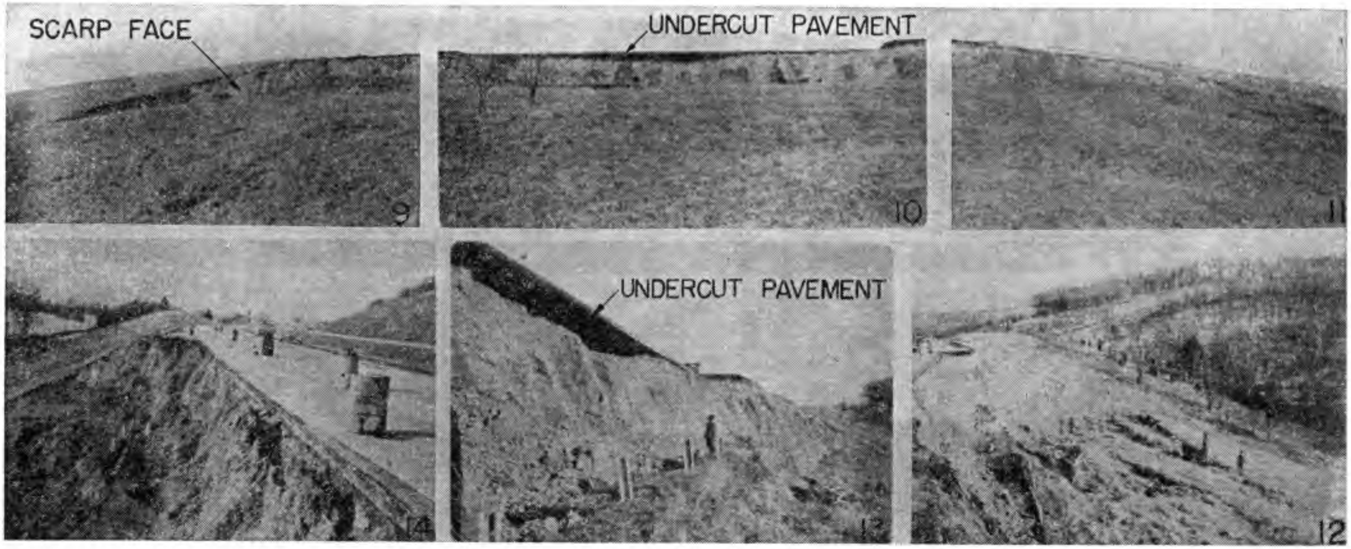


Photo 9. West side of failure scarp on I-74 Big Slide.
Photo 11. East side of failure scarp on I-74 Big Slide.
Photo 13. Failure scarp facing west on I-74 Big Slide.
Photo 10. Center of failure scarp on I-74 Big Slide.
Photo 12. Failed sideslope facing east on I-74 Big Slide.
Photo 14. Failure scarp facing west on I-74 Big Slide.

investigation was completed, based on preliminary stability analyses and slide correction. It was recommended that granular materials be dumped over the shoulder with a conveyor to prevent the slide from enlarging under the pavement toward the centerline of the roadway by retaining the vertical failed face.

Field and Laboratory Investigation

This investigation was about the same as that described for the Chicken Slide.

Specific Causes of Landslide

The causes of this landslide were similar to the causes for the other two. These are as follows:

1. Erosion occurred at the toe of embankment and water in foundation soils entering from cut to the north.
2. Slopes were designed too steeply for the height of embankment involved.
3. Benches were not deep enough and drains were not provided.
4. Embankment material used was not compacted adequately, settlement occurred and drainage structures mal-functioned.
5. Saturated zones sloughed and eventually the landslide occurred.

Typical Correction of Landslides

This failure was considered to occur at the interface between the soil overburden and the shale. The correction as shown in Figure 11 consisted of the following:

1. Relocation of stream through 72 in. culvert placed in the shale cut located to the south.
2. Placing a select granular material blanket over the entire landslide correction area.
3. Construction of a stabilizing berm system.

Several photographs of the construction operation have been included. Photograph 15 shows the stream location through the 72 -in. culvert in shale cut to the south. The construction of the stabilizing berm construction is shown in photograph 16, and the completed landslide correction is shown in photograph 17.

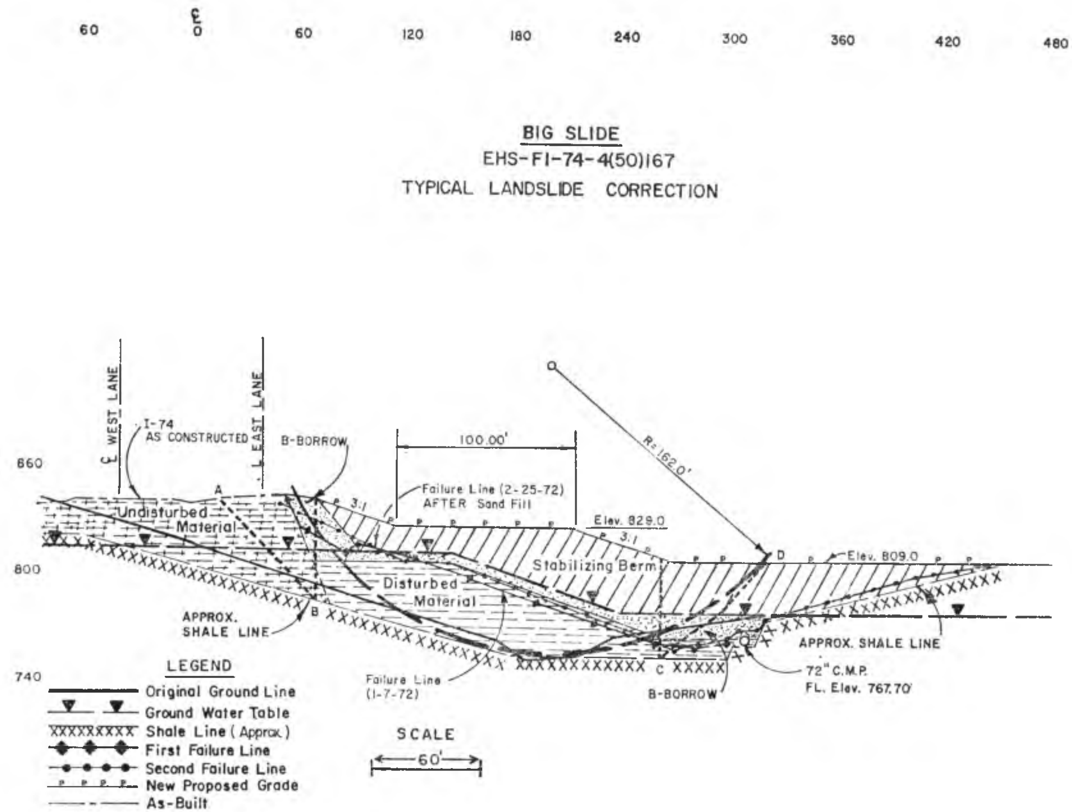


Fig. 11. Typical landslide correction—Big Slide.

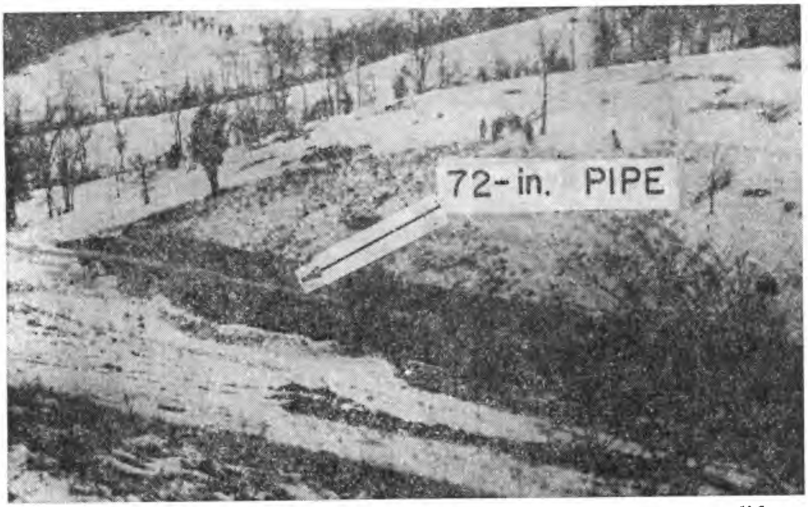


Photo 15. Stream relocation through 72-in. culvert on I-74 Big Slide.

Photo 16. Construction of stabilizing berm on I-74 Big Slide.

Photo 17. Completed landslide correction on I-74 Big Slide.

SUMMARY

Some background information on landslide investigation and correction was presented. A procedure was included for making requests for landslide investigations, which includes a letter sent through proper channels requesting that a landslide investigation be made. Accompanying the letter should be information as to the history of events associated with the landslide including maintenance and resurfacing records, and a plan view and cross-sections of the slide area showing all major cracks and scarps. Several case history's have been presented for landslides which have already been investigated and corrected. Included are the project characteristics, a discussion of the field and laboratory investigations, the probable causes of the landslides, and the recommended methods of correction.