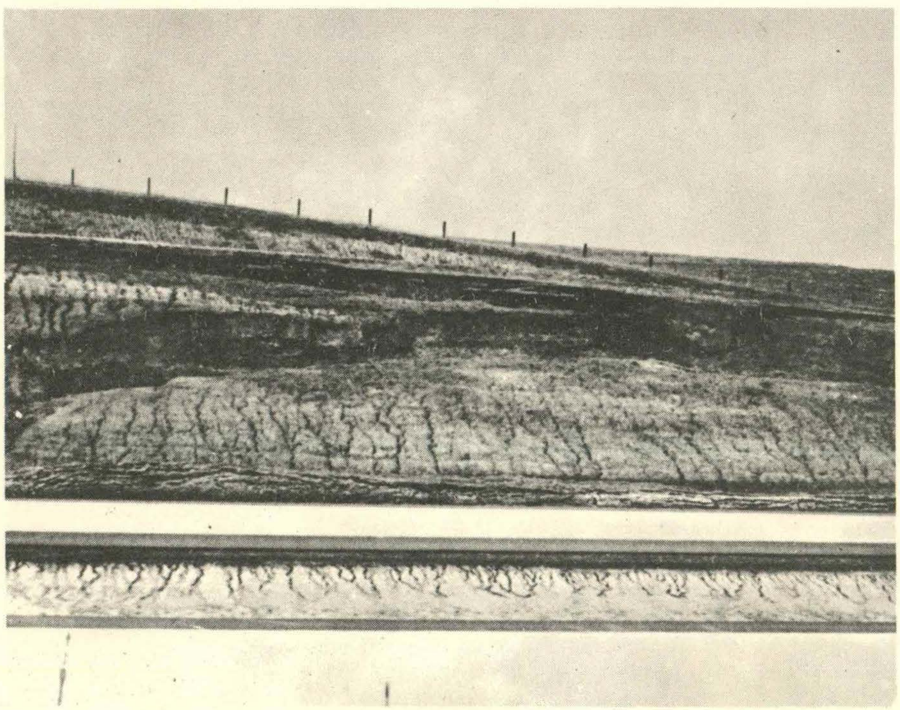
PRE-CONSTRUCTION PROBLEMS OF SLOPE STABILITY



IOWA STATE HIGHWAY COMMISSION

AMES IOWA

DESIGN DEPARTMENT-SOILS DIVISION

JANUARY 1962

STATE OF IOWA

IOWA STATE HIGHWAY COMMISSION

PRE-CONSTRUCTION PROBLEMS OF SLOPE STABILITY

REPORTED BY

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AMES, IOWA

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INTRODUCTION

The engineer must deal with many many practical problems which involve the stability of earth slopes, and it is important that he have as much information as possible regarding the stability of slopes in the area under consideration. Some common examples include the slopes along existing highways and railroads, banks of streams, natural slopes, and slopes maintained during various types of construction operations. If the water table and geologic cross section is also known, these slopes may be analyzed for stability and reasonable results can be obtained. There are times, however, when shearing strengths cannot be determined within a satisfactory degree of accuracy.

There are many factors which introduce complications into stability analyses. Most embankments are made up of heterogeneous soils of many different types. Many of the factors which affect the shearing strengths of the soils are often unknown or known only approximately, including such things as the boundary conditions of the ground water and variations within the stratigraphic sequence.

These and other complications usually necessitate the use of simplified conditions in the analyses which are nearly representative of actual conditions but which remove minor irregularities and minor details. An average or typical cross section is used, and the section is assumed to be made up of uniform soils, each having constant properties. It is assumed that the shearing strength of each soil represented in the cross section may be determined by the equation

$$S = c + \rho \tan \phi$$

where c represents the shearing strength due to cohesion and $\rho \tan \phi$ represents the shearing strength due to friction.

All stability analyses are based on the concept that slope failure will occur unless the resultant shearing strength is greater than the resultant shearing stress along the critical surface or the surface along which failure is most likely to occur.

The most critical conditions of slope stability usually occur in saturated soils where the shearing strength due to friction is neglegible and stability depends upon the cohesive strength of the soils only. Figure 1 shows a comparison of safe embankment heights for various slopes in saturated soils with different cohesive strengths. The graphs are all based upon a factor of safety of 1.20.

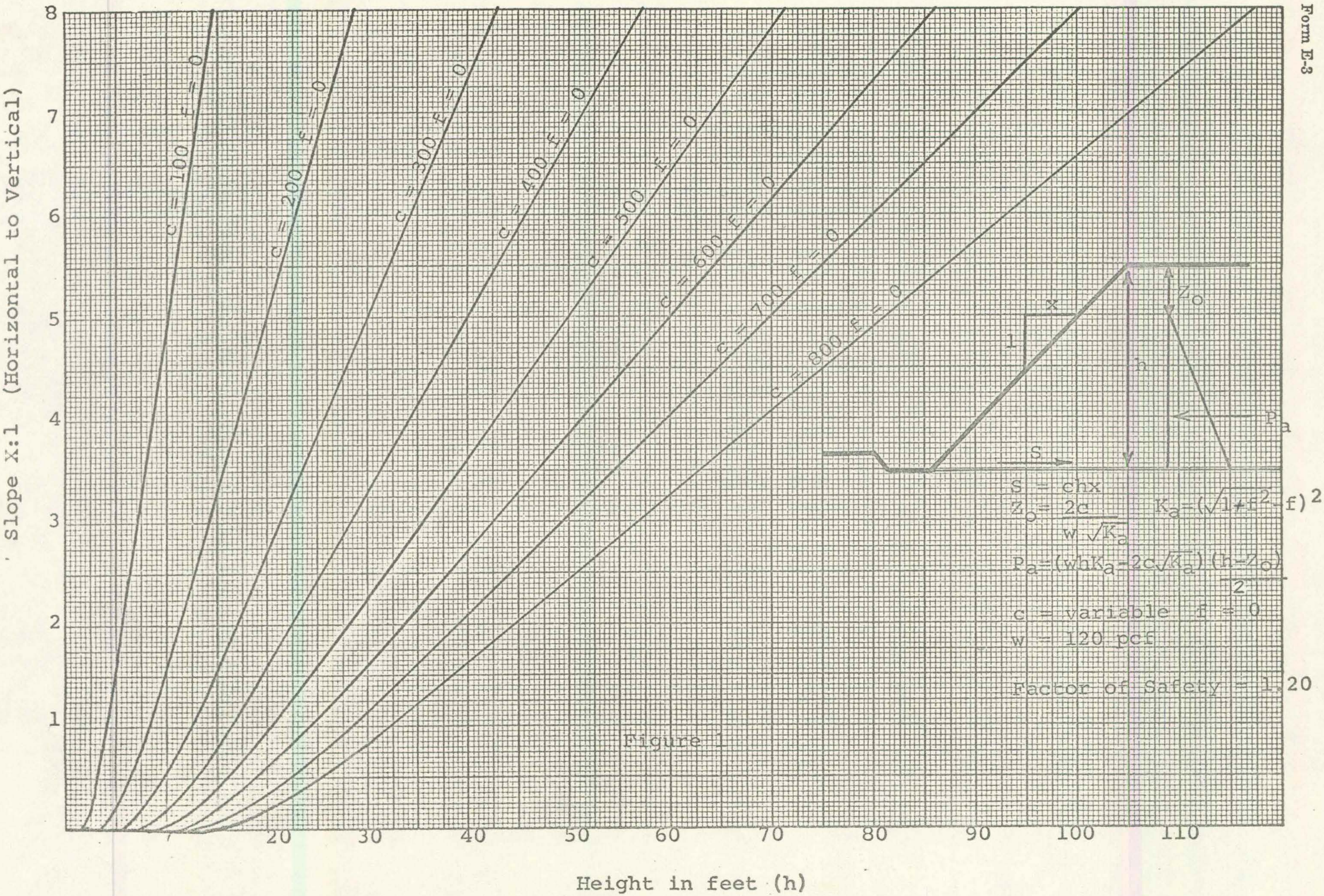
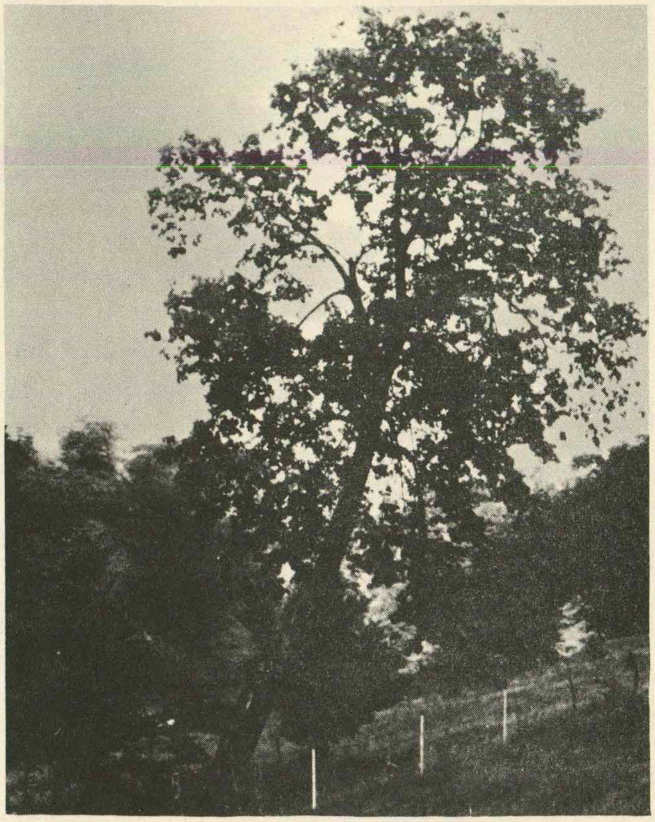
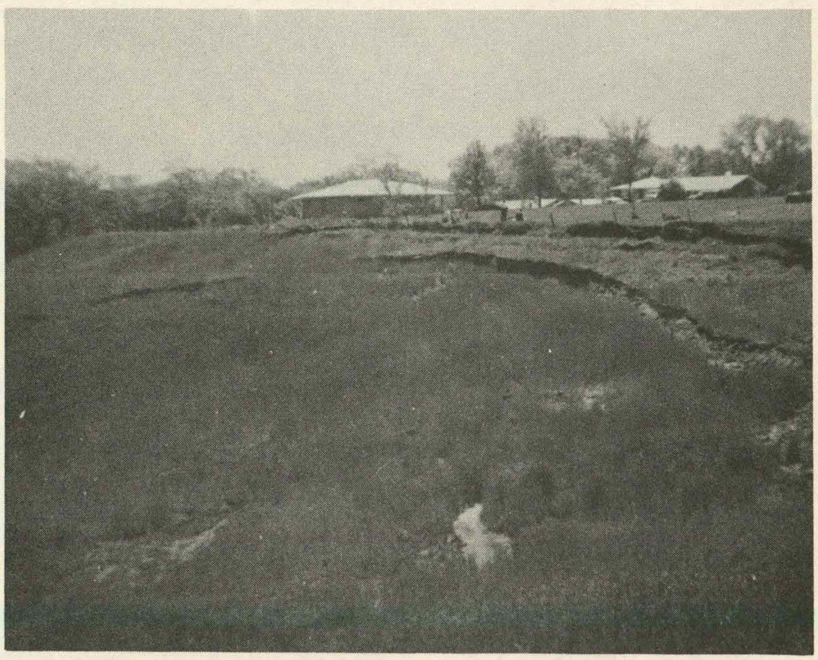

Slope X:1 (Horizontal to Vertical)
Height in feet (h)
c = 100 f = 0
c = 200 f = 0
c = 300 f = 0
c = 400 f = 0
c = 500 f = 0
c = 600 f = 0
c = 700 f = 0
c = 800 f = 0
x
1
h
Zo
Pa
S
S = chx
Zo = 2c / w √Ka
Ka = (√1+f² - f)²
Pa = (whKa - 2c√Ka)(h-Zo) / 2
c = variable f = 0
w = 120 pcf
Factor of Safety = 1.20
8
7
6
5
4
3
2
1
20
30
40
50
60
70
80
90
100
110

Figure 1



A tree on a sideslope near Boone, Iowa. A typical indication of movement which may be readily recognized in the field.

Plate 2



Failure of slopes as a result of effluent water from nearby dwellings. Top - U.S. 20 in Dubuque, Iowa. Bottom - Highway borrow area near Des Moines, Iowa.

Plate 3

GENERAL DISCUSSION

Decisions as to preventative, corrective, or maintenance work on potential landslides in an area of proposed or future construction rely on the judgement of the engineer. Where human life is at stake it is common practice to furnish adequate protection no matter what the cost. High property values in the vicinity, such as are encountered in urban areas, will justify much greater expenditures than will the lower property values which are more common in rural areas. It is not usually economical on new construction to design slopes that will insure stability over the entire project for the worst possible conditions that may be encountered. If embankments are properly designed and constructed, however, embankment failures will be infrequent.

There are many different kinds of landslides, and the problems of recognition and identification of landslides are as complex as the materials and processes that cause them. The conditions that favor landslides depend on the character and structure of the rocks and soils, topography, climate, vegetation, and surface and underground waters. The landslides involve soils, rocks and combinations of soils and rocks. Movement takes place on nearly horizontal slopes as well as on steep bluffs, and the rate of movement varies from almost instantaneous to extremely slow.

All landslides involve shear failures of natural materials so that the causes of all landslides are due to factors which either decrease shear strength or increase shear stress. Because there are so many variables involved in the production of landslides, it is impossible to predict all slope failures. However, the following situations are typical of those which should be looked for in evaluating areas for potential slope failures.

1. Cut slopes too steep in weak or unstable rock or soil.

   Generally, it is usually considered to be more economical to construct the slopes at angles which will be reasonably safe under most conditions rather than to construct for the worst possible conditions, except where local conditions are such that human life or high property values might be at stake. It should be remembered, also, that changes sometimes occur within the soil over a period of years whereby failures may develop in slopes that were stable when constructed.

2. Overloading by fill of relatively weak soil layers at or beneath the natural ground surface.

   Both disturbed and relatively undisturbed samples are taken of such layers and these samples are tested in the laboratory. On the basis of the laboratory tests, such things as critical fill height, safe slope, and height and width of necessary berms or buttresses may be calculated by mathematical analysis.

3. Overloading of sloping bedding planes by heavy fill or removal of support in cuts (bedding planes sloping in same direction as natural ground slope).

   This situation is particularly dangerous and care must be taken to insure that sufficient data is accumulated in the field for thorough evaluation of shear stresses, etc. Landslide potential is often high calling for steps to be taken against excess shear stresses.

4. Removal of soil mantle over sloping surface of stable bedrock in side hill cut.

   This situation is frequently encountered. Removal of wet soil by sidehill cut may remove toe support causing the soil above to slide along its contact with the surface of the stable rock.

5. Increase in hydrostatic head below the surface of a cut in a permeable soil if the surface is allowed to freeze or become covered with an impervious material.

   This situation usually results in failures of the slump or earth flow variety. Most of the failures of this type will be on a smaller scale and can often be corrected by maintenance crews by means of subsurface drains and erosion control techniques.

6. Changes in the character or direction of ground water flow by cut, fill, or construction features.

   In areas where dangers might arise due to increase in seepage pressures and the like, it is best to install subsurface drains or some means of controlling the limits of the effect on ground water in the area of the proposed construction so that designs may proceed on the basis of established limits.

7. Exposure of materials that may soften and lose shear strength when exposed to surface waters, freezing and thawing, etc.

   Indications that this situation might exist in an area may be obtained from old cut slopes, stream channels, core drilling, etc. Highly fissured materials are the most susceptible and often result in considerable sluffing and slumping.

8. Exposure by cut of materials that are inherently weak. This situation, often very difficult to detect, involves removing the support of weak materials or, in effect, creating an unbalance of shear stress in a material of low shear strength.

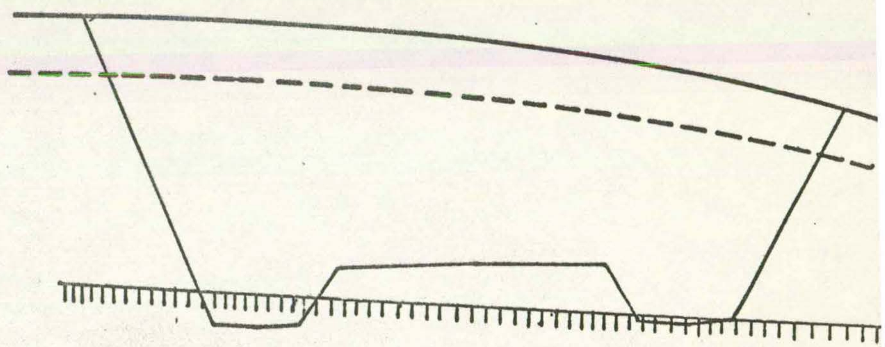
The presence or absence of any of the conditions listed still does not mean that the danger of a potential slope failure is very great. It is the association of items like the ones listed that must be reviewed and studied by a person that has been trained in soils, soil mechanics and geology.

COMMON TYPES OF SLOPE FAILURE WHICH WARRANT PREVENTATIVE SLIDE CONTROL MEASURES

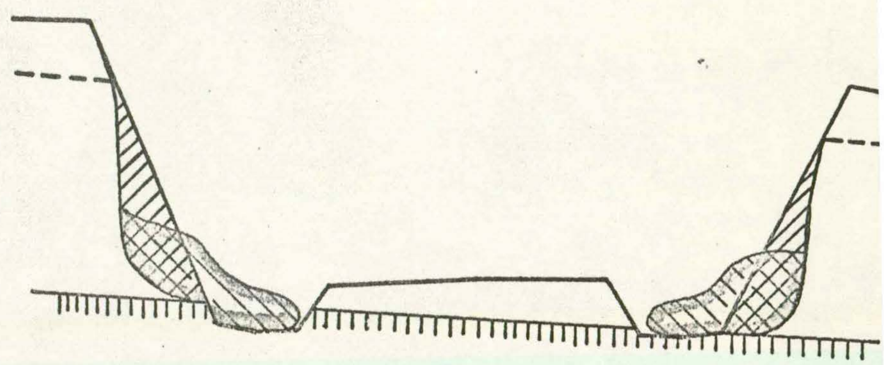
The foregoing discussion concerned generalized and simplified conditions of unstable slopes. The following discussions will deal with some typical situations that occur in the State of Iowa and the factors that must be taken into consideration when determining whether or not preventative measures against slope failures are warranted. No attempt is made to specify the preventative measures to correspond with a given condition as each individual situation must be considered separately and no two situations are ever found to be exactly alike.

Condition Diagrams

Before Construction



After Construction



Summary of Conditions Leading to Instability

1. High Water Table being held up by an impervious surface.
2. Saturated, weak materials below natural water table and above impervious surface.
3. Lateral support of weak materials removed by construction.

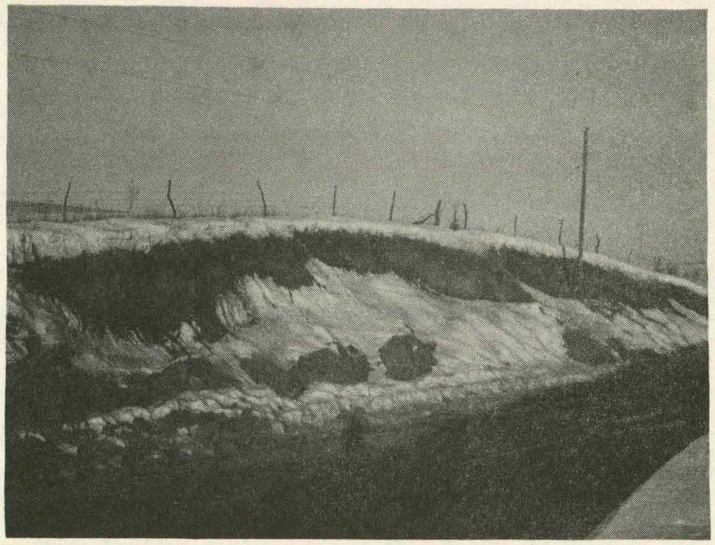
DISCUSSION OF SLOPE FAILURE TYPE I

Earth flows of the type shown in the diagram are the most common type of slope failure encountered in the State of Iowa. They usually occur in loess type soils, but they may occur in many differenty types of soils if they are dominantly fine grained in character and poorly consolidated.

Impervious layers beneath the surface of the ground retard the natural downward movement of underground water. The result is a higher water table and a reduction of shear strength in the saturated soils above.

Construction such as the roadway cut indicated in the diagram removes the lateral support from the saturated soils and creates an elevation head on the subsurface waters of the backslope. The increase in elevation head increases the seepage forces of the groundwater and thereby increases the shear stresses in the saturated soils. The result is movement by earth flow of soils between the impervious layer and the natural groundwater level from the roadway backslope toward the roadway ditch. If the movement is allowed to proceed unchecked the dryer, stronger soils above the groundwater table will be undermined and will probably slump downward and toward the roadway ditch.

Scars of old flows or landslides in an area of proposed construction are often a good indication that slope stability problems of this type may be encountered.



Typical earthflow in highway backslope resulting from impervious clay layer holding up natural water table. U.S. 34 near Tenville, Iowa.

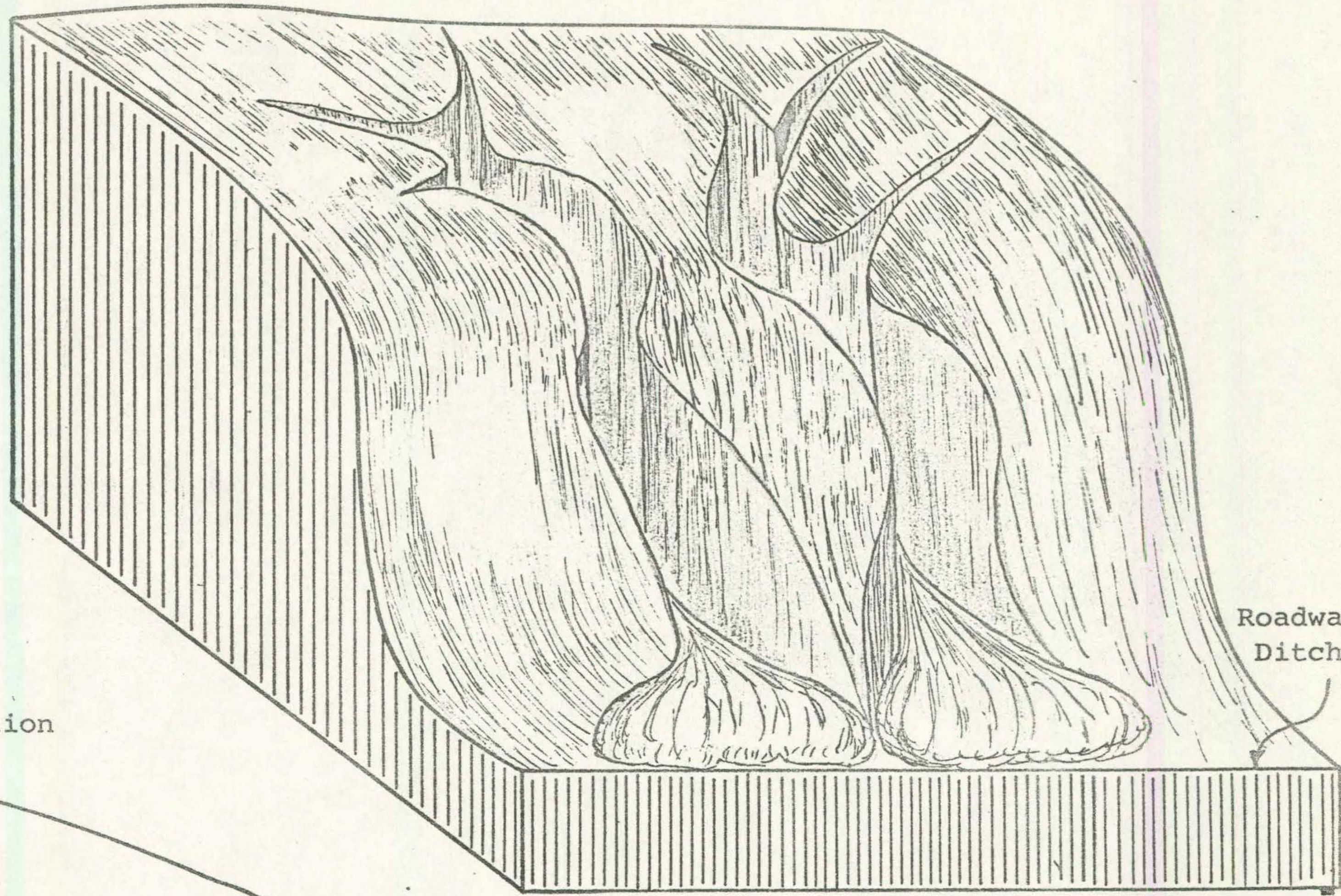
Plate 4

Failure in highway foreslope and bordering natural slope resulting from water table being held up by impervious clay layer. Iowa State Highway 333 west of Hamburg, Iowa.

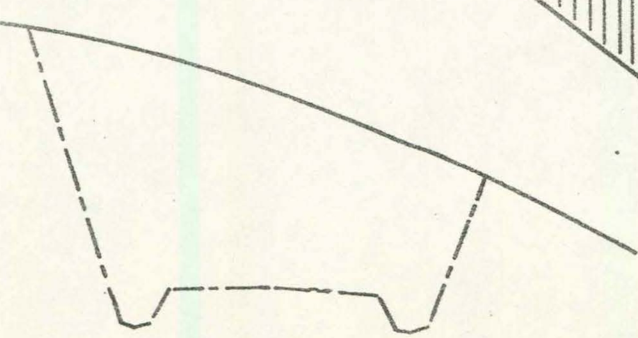
Plate 5

Condition Diagrams

SLOPE FAILURE TYPE II



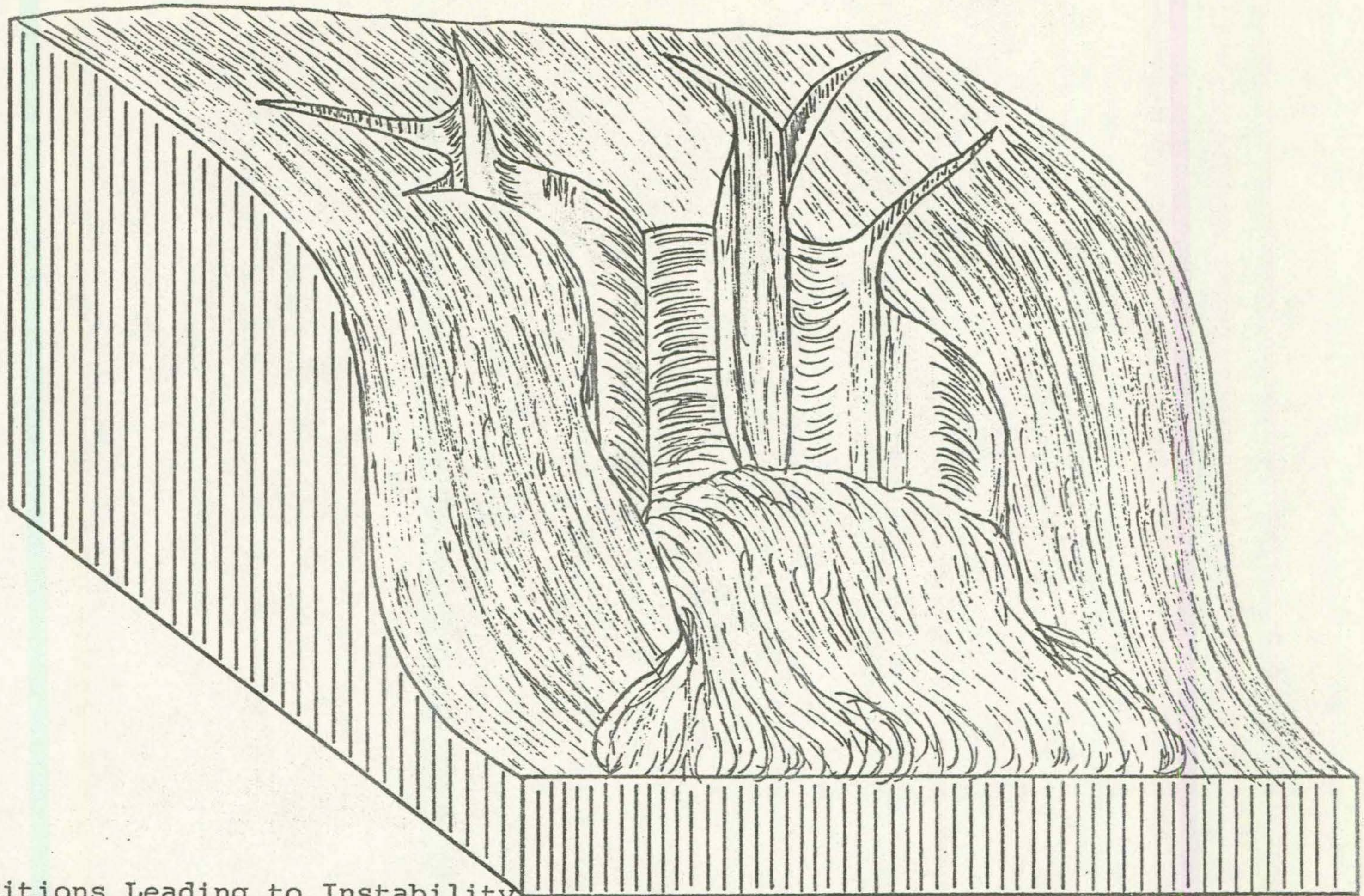
Before Construction



After Construction
(a) Block diagram showing erosional effect of surface runoff and interuption of free drainage in ditch.

After Construction

(b) Block diagram showing failure of loess between erosion channels.



Summary of Conditions Leading to Instability

1. Deep loess deposit.
2. Insufficient erosion control.
3. Water pooled in roadway ditch and erosion channels and allowed to saturate and weaken loess material at base of slope.
4. Block of loess material between erosion channels fails due to insufficient strength at base.

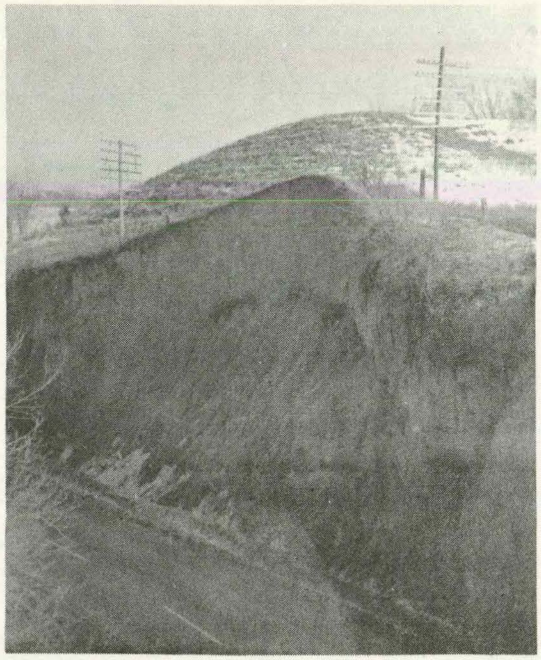
Figure 3b

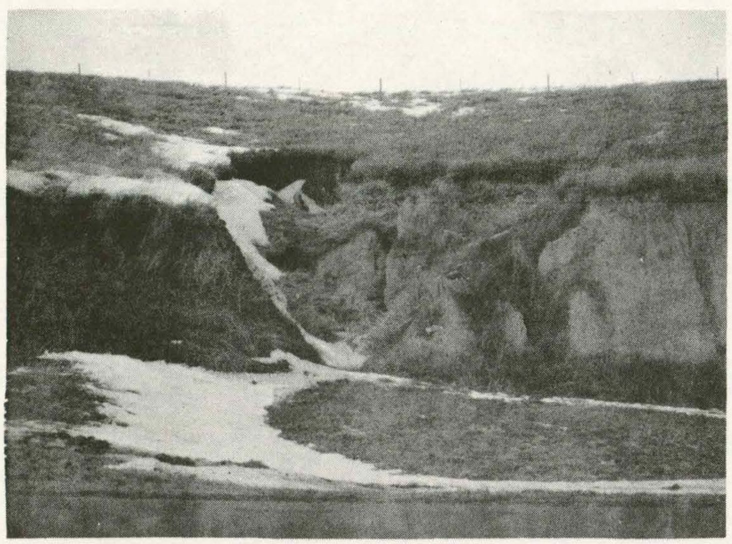
DISCUSSION OF SLOPE FAILURE TYPE II

The relatively homogeneous character of loess and its extreme susceptibility to erosion sometimes leads to unusual problems in slope stability. Slopes that are exposed to the direct action of wind and surface water present real dangers from potential landslides. Where coverage or protection such as sod covers the loess the natural slopes may be very steep for a considerable height.

High steep slopes such as those in the diagram, are very susceptible to erosional forces which tend to undermine and remove support from the overlying loess. The shear strength of natural loess is greatly affected by moisture content. The low density of loess enables it to soak up considerable moisture, and as in all plastic soils, the shear strength is greatly decreased with an increase in moisture content. The availability of exess moisture at the base of the erosion gully as from retarded surface run off and melting snow increases the danger of a potential slope failure.

The extreme susceptibility of loess to erosion is also of vital concern in the location and design of channel changes, bridge foundations, or any kind of proposed or future construction where loess might be subjected to direct stream action.



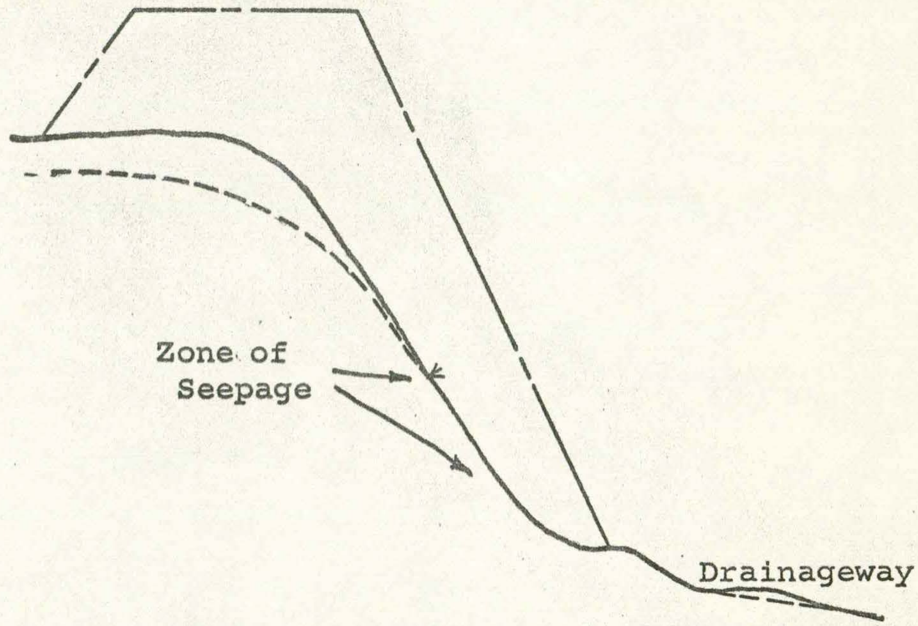


Typical failures in loess backslopes resulting from erosion and weakening near the base. Top-U.S. 30A near Honey Creek, Iowa. Bottom - Iowa State Highway 37 near Soldier, Iowa.

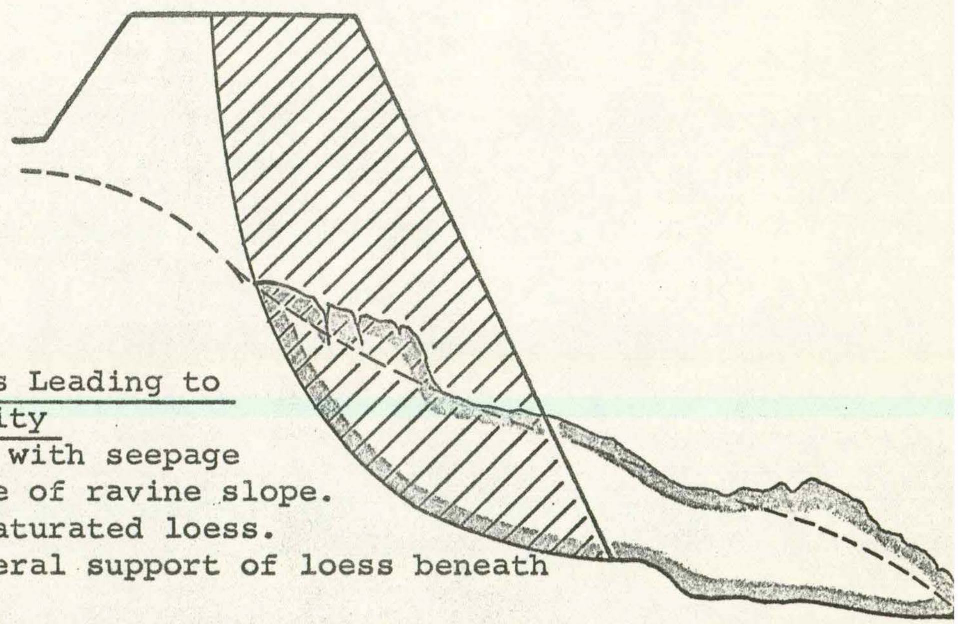
Plate 6

Condition Diagrams

Before Construction



After Construction



Summary of Conditions Leading to Instability

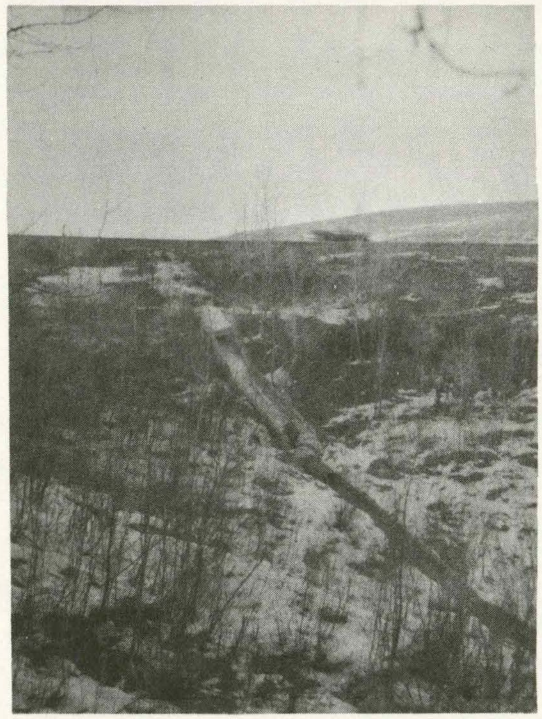
1. High water table with seepage evident near base of ravine slope.
2. Load placed on saturated loess.
3. Very little latteral support of loess beneath fill.
4. Material of foreslope portion of fill is saturated with seepage water.

DISCUSSION OF SLOPE FAILURE TYPE III

Elevated water tables such as the one indicated in the condition diagram are quite common along drainageways in loess type soil areas. Natural stream activity creates channels or stream valleys with bordering steep slopes and the elevated water tables commonly occur within these bordering steep slopes. The source of the underground water may be percolation waters from large runoff areas or minor surface streams entering the main stream valley.

Seepage forces on the water in the ravine slope are due primarily to an elevation head and are commonly in evidence as surface seepage near the base of the slope. Any fill material which is placed on top of a ravine slope such as this will almost inevitably become saturated in time. The low saturated strength of loess makes it a weak foundation material unless it is properly confined or drained. As the material of the fill becomes saturated its shear strength is reduced and its ability to confine the weak loess is lessened. Hence, a failure of the slump-earth flow type is imminent.

Where a situation such as the one described here occurs in the field preventative slide control measures may be warranted even though the elevated water table is not in evidence at the time of investigation or construction. Future wet seasons or changes in the character of the ground water table could result in the same conditions as those in the diagram.

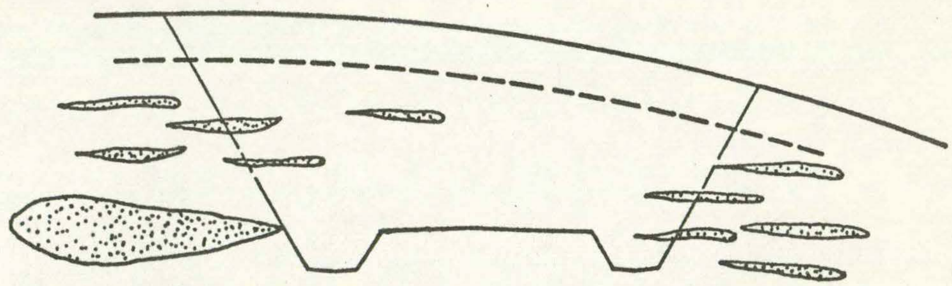


Typical foreslope failure resulting from elevated water table in loess. Note displacement of flume. Iowa State Highway 37 near Soldier, Iowa.

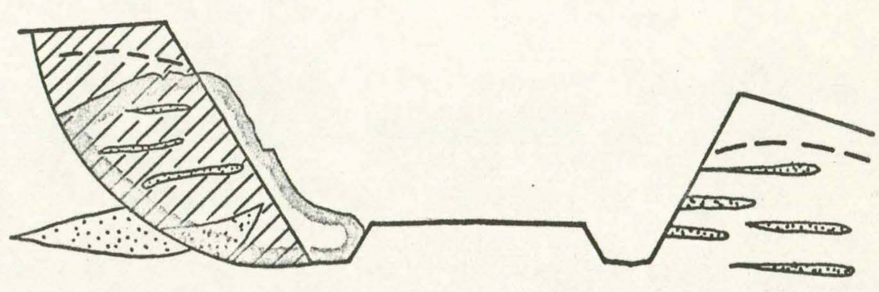
Plate 7

Condition Diagrams

Before Construction



After Construction



Summary of Conditions Leading to Instability

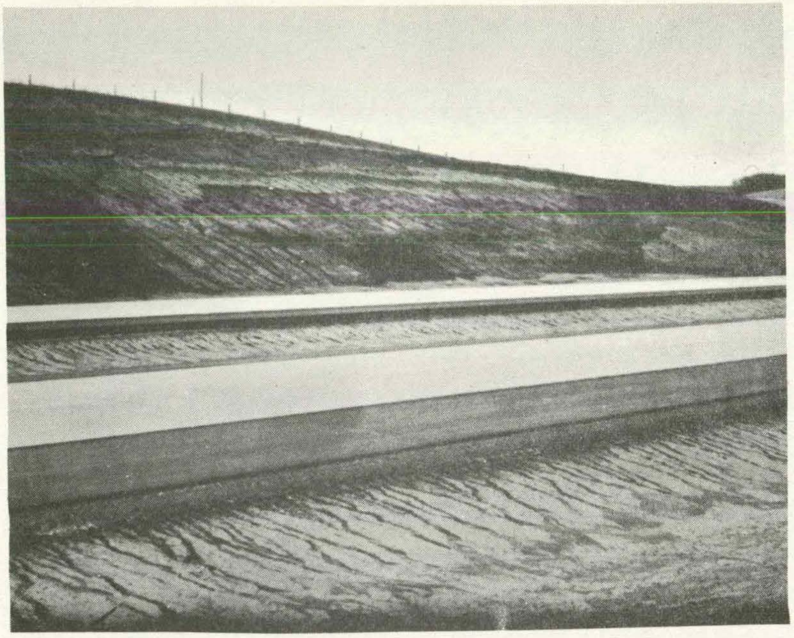
1. High water table
2. Fine grained cohesive soil
3. Large lenses of sand and discontinuous sand seams.

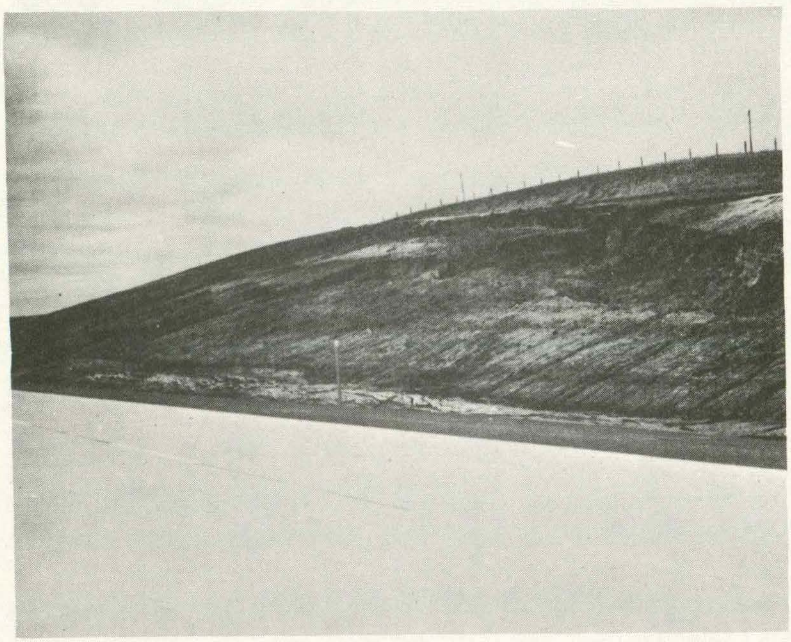
DISCUSSION OF SLOPE FAILURE TYPE IV

The sand lenses and discontinuous sand seams shown in the diagram act as reservoirs for water and help to hold up the natural water table. When the indicated roadway cut is made during construction lateral support is removed from the materials of the highway back slope and the soils which were originally beneath the natural water table lose the buoyant support of the water. The saturated soils of the backslope then become heavier, in effect, and increase the stress on the soils underlying them. The water being held in the voids of the sand deposits may drain off very slowly due to the fine grained character of the surrounding soils. Such a condition would tend to create excess hydrostatic pressures in the interstitial water and the result would be a failure of the type shown in the diagram.

If excess hydrostatic pressures of sufficient magnitude to cause failure do not build up, slope failure of the type shown in the diagram can still occur. The sand lenses and discontinuous sand seams which are acting as reservoirs may furnish water to the cohesive materials of the slope. As the moisture content of these plastic soils is increased their shear strength is decreased and, without lateral support, failure will occur.

The occurence of pockets, lenses or seams of sand or gravel is unpredictable in deposits of glacial origin, although the frequency of occurence is very high in some types of deposits such as morrains. Lenses of sand or sand pockets are equally as unpredictable in windblown deposits. The determination of the character and extent of sand or gravel deposits in the field will, at times, involve very extensive subsurface investigations. Even after considerable time and effort has been expended in this manner, many times large lenses or extensive thin layers of sand or gravel will go undetected. In highway construction it is usually more economical to design slopes for average conditions and to correct the infrequent slope failures after they occur. Such failures will usually occur or become evident before the new construction is completed and the highway opened to traffic.



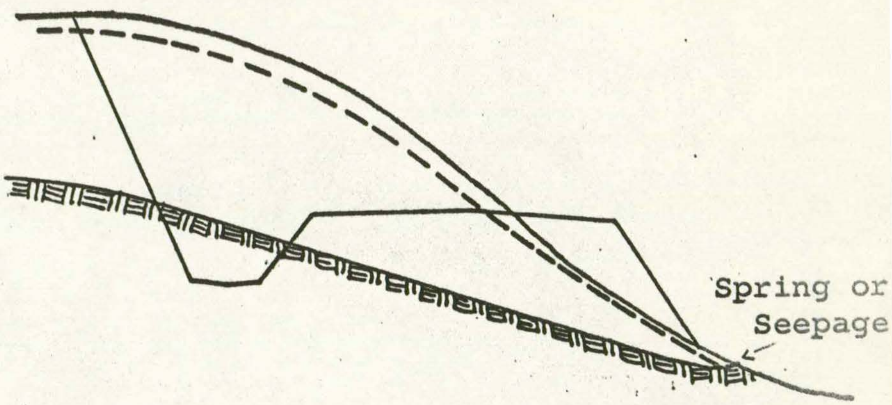


Highway backslope failures on Interstate 80 near Atlantic, Iowa interchange resulting from water trapped in sand lenses. Top-water seeping out onto slope from pockets of sand in glacial clay. Bottom - Main slide area with slump blocks at top and plastic earth flow at toe.

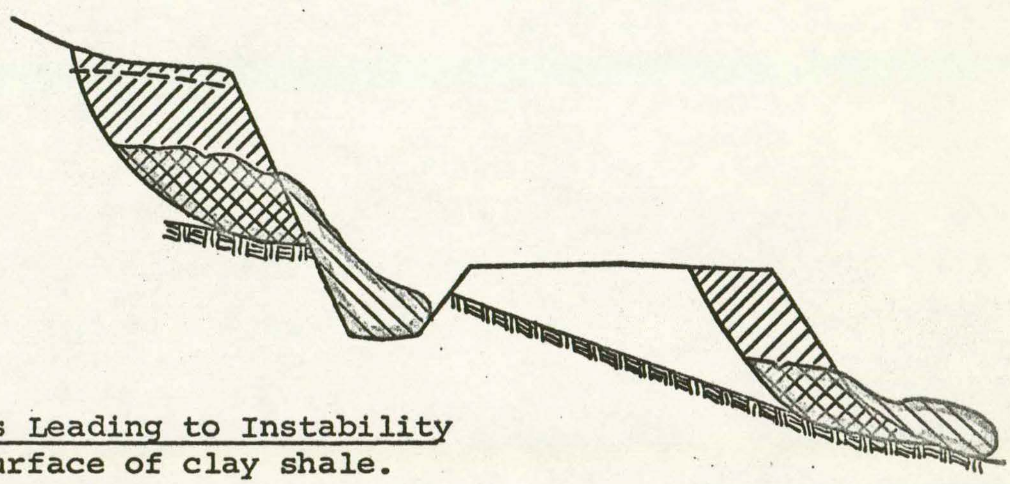
Plate 8

Condition Diagrams

Before Construction



After Construction



Summary of Conditions Leading to Instability

1. Sloping surface of clay shale.
2. High water table.
3. Spring at contact of shale and over-burden in outcrop on natural slope.
4. Lateral support removed by construction.

DISCUSSION OF SLOPE FAILURE TYPE V

Where the contact between a rock surface and the overlying soil is wet or might become wet the danger of a slope failure is very great when lateral support is removed. By far, the most critical rock surface is that of the clay shale where failures may occur with only small quantities of available moisture present. The initial failure in such a slope is usually in the upper part of the clay shale itself. As the expansive clay particles of the shale take on water they expand, lose shear strength and become more plastic. As the moisture content of the upper portion of the clay shale approaches its liquite limit failure will occur along the "plane" of the weakened material.

There are other slope failures which are similar to those of the sloping clay shale type diagramed. Although not as common, sloping subsurface layers of impervious clays or other rock will sometimes result in the same type of failure along a "plane" of weakness.

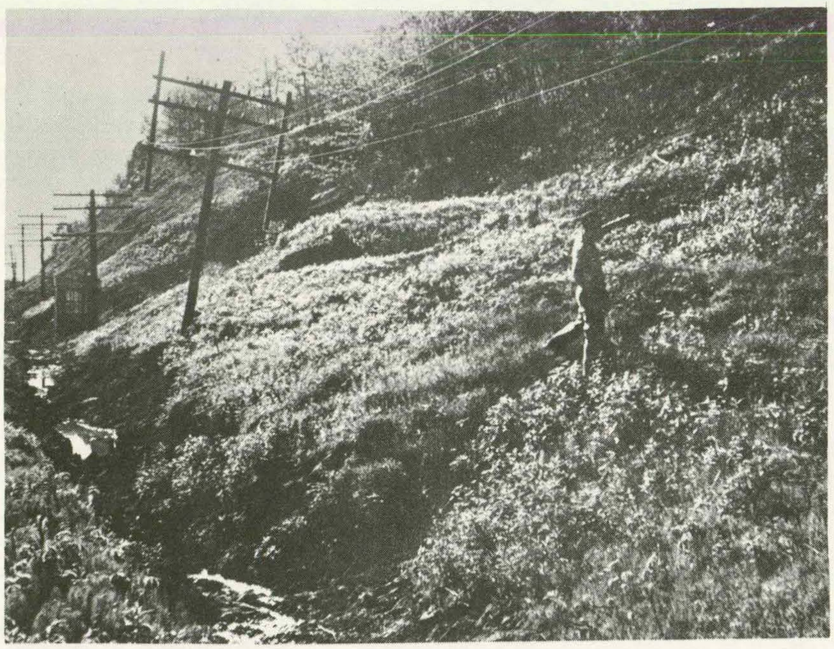
The "plane" of weakness does not necessarily have to be the surface of contact. A sloping clay shale layer, for example, may be some distance below the surface of the rock, and failure can still occur if moisture is available to the expansive clay particles.

Another type of slope failure which is related to the one already discussed is the block glide. Large masses of relatively undisturbed material will sometimes break loose from the parent material and move downhill along a shearing surface or plane of weakness.

Some areas may remain dry and stable even in wet rainy years, retaining a high shear strength even along what would appear to be planes of potential failure. Scars of old landslides or active landslides in an area will sometimes indicate that eventual slope failures are quite probable, whether or not conditions at the time of investigation indicate any immediate danger.

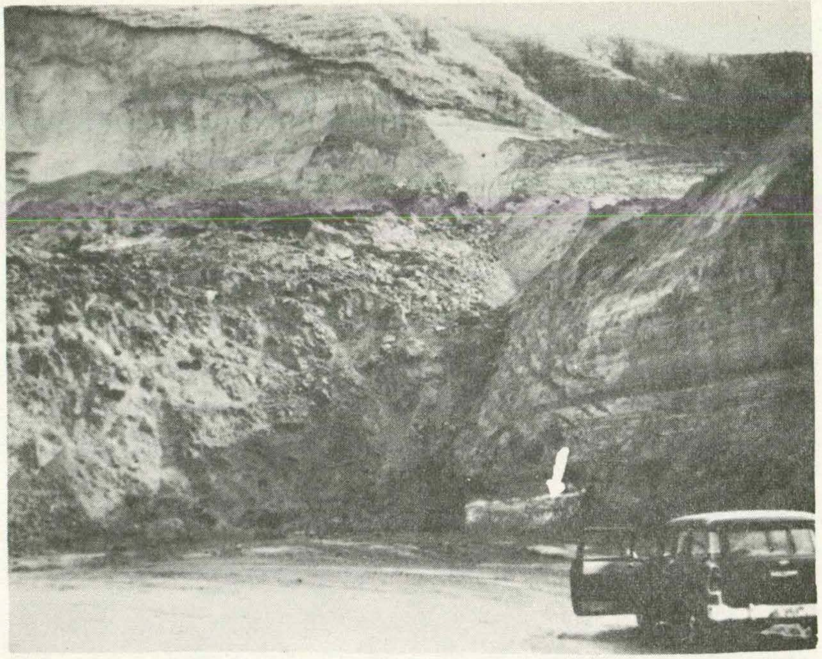
Roadway shoulder which has failed as a result of foreslope movement on a sloping clay shale surface. U.S. 67 south of LeClaire, Iowa.

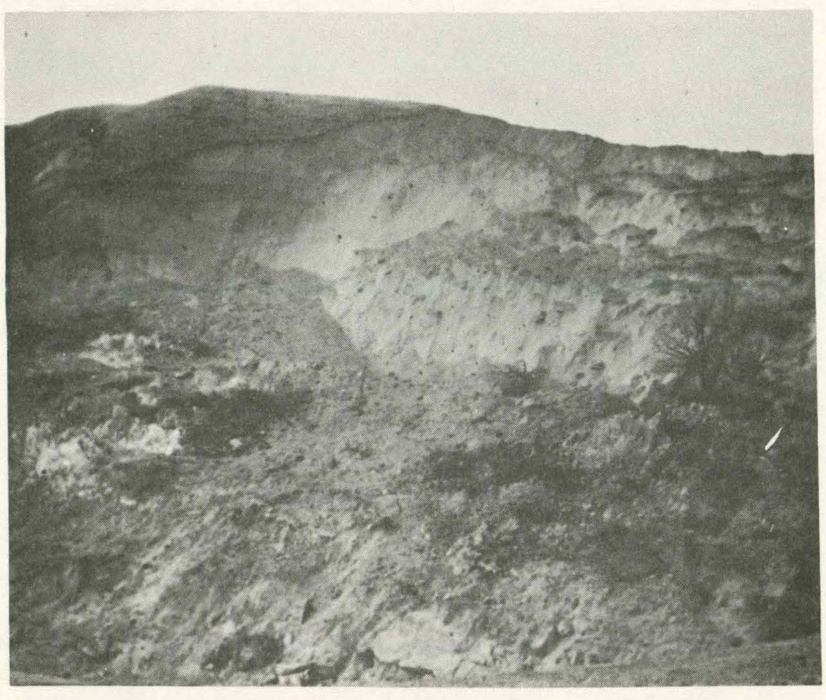
Plate 9



Failure in a foreslope overlying a sloping rock surface. Iowa State Highway 22 north of Muscatine, Iowa.

Plate 10





Large loess slide in gravel pit near Little Sioux, Iowa. Failure began as block glide along weak layer of volcanic ash (arrow).

Plate 11

CONCLUSION

Some potential slide areas may be evaluated quite adequately with field and laboratory techniques and the use of any of several different methods of mathematical or graphical stability analyses. With all of the refinements and advances that have developed in investigation, testing, and mathematical analysis of slope stability experience will no doubt remain as one of the most important guides for field use. Any cut or fill will change the local stress conditions and modify the existing erosional processes. The engineer must evaluate the effect which these changes may have on ground water conditions, the soil profile, and the under lying rock. It is impossible to foresee all eventualities and unexpected slope failures may occur even after the most extensive of investigations. In most rural areas it is usually considered to be more economical to design for average conditions and to take care of more critical areas if and when slope stability becomes a construction problem.

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