Implementation for Slope Stability of Certain Selected Colluvial Soils

Research and Development Division
Oklahoma Department of Transportation

Implementation Package for

SLOPE STABILITY OF CERTAIN SELECTED COLLUVIAL SOILS

by

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16. Abstract

The purpose of this report is to inform State Design, Construction, and Maintenance Engineers of accepted procedures for the investigation and design of potential landslide prone areas. State Materials and Geotechnical Engineers should be consulted for design recommendations.

This report contains a sequential procedure for determining areas of landslide potential. The sequence begins with observations which can be made in the office progressing through field reconnaissance and testing to roadway design. Some sample specifications relating to internal drainage methods are offered in the appendicies.

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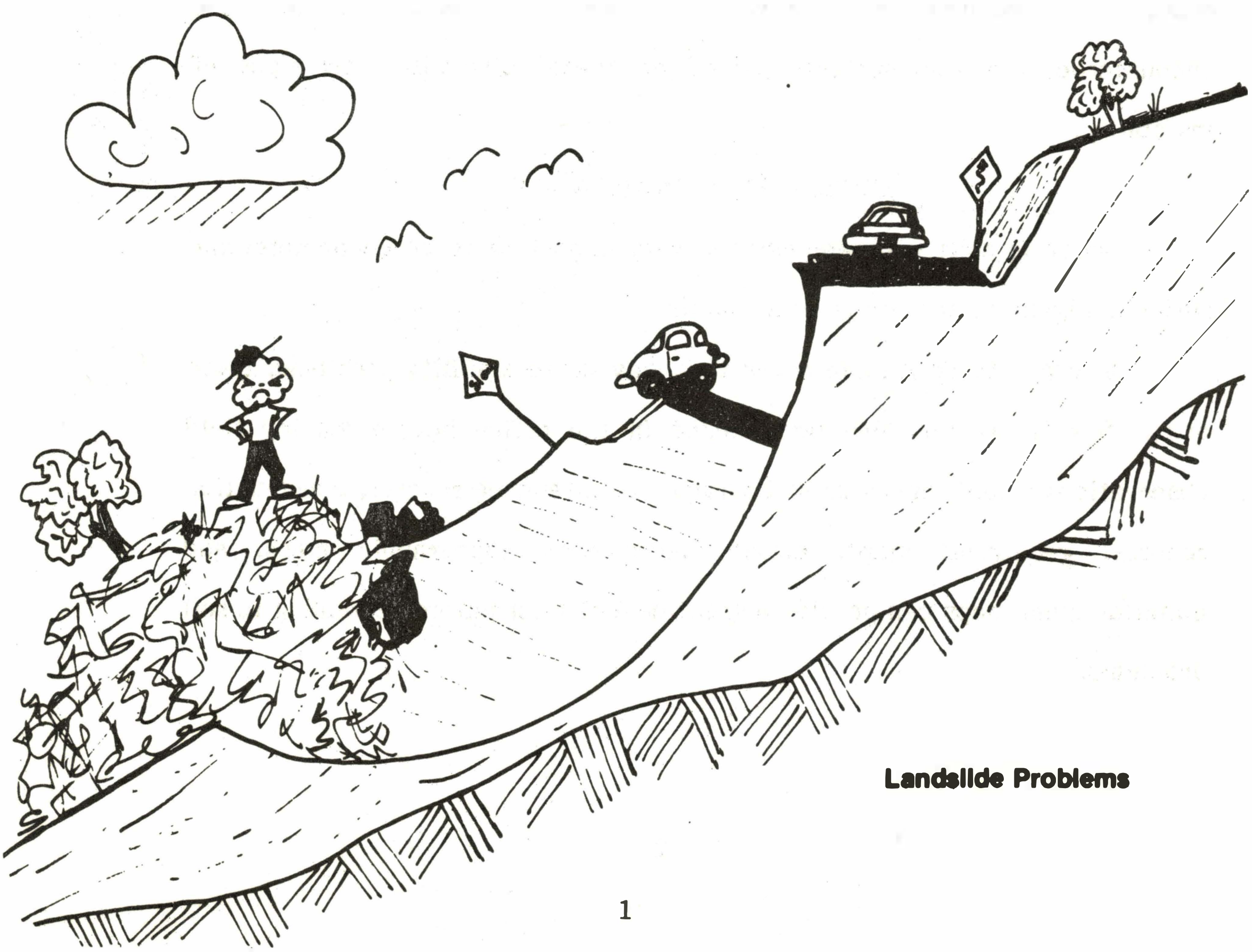
SUMMARY

The techniques and procedures listed herein were developed to assist highway engineers in the development of a better way to control soil stability and internal drainage problems. The location and isolation of problem areas are necessary in the generation of proper designs to meet specific stability problems. An intelligent use of soil, geological, and other maps combined with field reconnaissance, field and laboratory testing can provide the engineer with responsible choices in roadway location and drainage design. Internal drainage techniques, such as horizontal and vertical drains, can solve many of the ground water problems associated with unstable soils.

SLOPE STABILITY OF CERTAIN SELECTED COLLUVIAL SOILS
IMPLEMENTATION

INTRODUCTION

Weak soils are becoming more and more a problem as modern roadways are designed and built. Luckily, most of Oklahoma is relatively flat and poses little risk of landslide failure. However, the eastern one-third of the state contains considerable areas of mountainous relief along with rainfalls exceeding 40 inches (102 cm) annually. The combination of geological and climatic conditions cause the rock strata to weather into colluvial soils which are often unstable. Colluvium is loose soil material that is usually at or near the foot of a slope and is brought there chiefly by gravity.



Landslide Problems

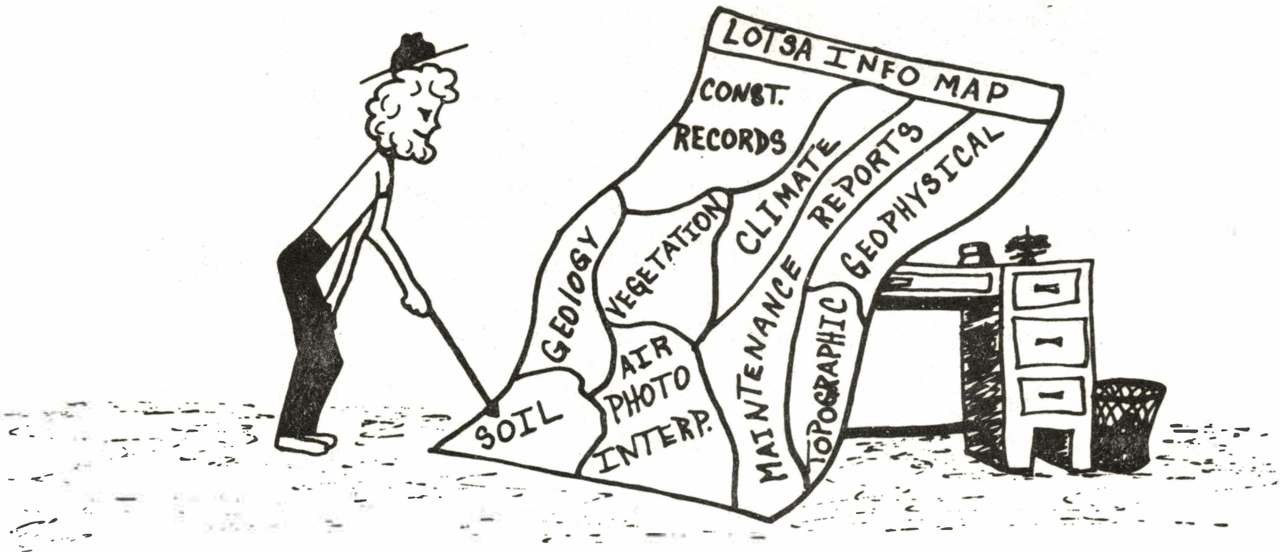
Engineers constructing highways in the southeastern part of Oklahoma are constantly plagued by water table and soil stability problems. Areas that appear to be dry quickly develop water problems, especially during wet seasons. Construction workers and local residents note that some springs and seeps drain only during or just after heavy rains. Other springs in the area are known to be seasonal, and still others run constantly. The variability of water table conditions causes great problems with embankment and cut slope designs and their stability during and after construction.

The location and amount of underdrainage to be used, as well as underdrain types, has been difficult to determine. Most of the construction work is done during the dry summer season, or at least during dry spells between rainy periods. Therefore, a great many of the seeps and wet areas that may cause problems at a later date are not noticed. In almost every case, where colluvial soil material and high water table conditions are encountered, the embankments placed on these soils will show signs of instability.

OFFICE RECONNAISSANCE

Locating soils geographically is very important to an economical and rational alignment and design of a roadway.

In order to determine areas that may cause stability problems, there are a few items that can be checked in the office before making field observations. Such things as soil surveys, maintenance records, construction records, geological maps, aerial photographs, topographic maps, and climatological maps can provide a great deal of information pertaining to soil problems.



Office Reconnaissance

Soil Surveys may be the most useful tool in locating potentially unstable soils. These surveys with their accompanying maps, provide highly detailed information regarding the location and properties of many diverse surficial soil types.

The Soil Conservation Service (SCS) has published county soil survey reports for about 50 of the 77 counties in Oklahoma. (See Appendix A.) These reports contain soil maps made on aerial photographs (See Figure 1.) The maps completely encompass the entire county at a scale of 3.14 inches equals one mile (1:20,000). These maps were made by soil scientists who are trained to recognize subtle differences in soil properties, e.g., particle size, color, and others.

Figure 1. A portion of a soil survey of McCurtain County Oklahoma courtesy of the U.S. Department of Agriculture, Soil Conservation Service.

Certain soils are known to occur in association with landslides. The Carnasaw soil series is one such example. By reading the description of the soil series a word picture is generated illustrating engineering, agricultural, and other properties of the soil.

The soil series Carnasaw is described by SCS as a soil occurring.... "on ridge tops, side slopes, and footslopes. Slope gradients range from 1 to 12 percent, with dominant slopes between 2 and 5 percent." (See Appendix B.) The description gives a clue as to the landscape position of these soils. Locating these soils on a soils map can automatically indicate an area of potential landslide hazard.

It is not necessary for the highway engineer to be thoroughly familiar with a soil survey or the soil series description in order to obtain useful information from them. Some important clues relating to slope stability are contained within the description. The following information is found underlined in the soil description sheet on page 33 and relates to the landslide potential of a mappable soil unit:

1. Particle size (clayey)
2. Soil depth (52 inches or 1321 mm)
3. Wetness properties (mottles; occasionally wet)
4. Slope (3 to 45%)
5. Location - is it near known landslides? (McCurtain County area)
6. Precipitation (40 to 50 inches or 1015 to 1270 mm per year)
7. Competing soils and associated soils - are any closely related soils present that are associated with known occurrences of landslides?

Clay soils and clayey silts can become very unstable when wetted. Thus, the Carnasaw soil has some landslide potential simply by virtue of the soil being clayey.

If the clayey soil is fairly thick, this further promotes its chances of being unstable. Note that the Carnasaw soil is moderately thick. It ranges up to 60 inches (1524 mm) in thickness.

A thick clayey soil is not necessarily unstable. In fact, thick, dry clay is very stable material. If soil is constantly wet or seasonally wetted, mottling (spots of color) will occur. The description of the B3 horizon points out that mottles are present.

Carnasaw occurs on steep slopes. A reproduction of an entire SCS soil description sheet without editing may be seen in Appendix B.

In the "setting" paragraph of the soil description, it can be seen that the Carnasaw soil occurs on slopes up "through 45%." The combination of particle size, thickness, moisture, and slope are enough to cause reasonable concern about slope stability.

Sometimes it can be determined that landslides have occurred on these soil units in the past. If so, then this is further evidence for instability. By reading the paragraph concerning "Competing Soils" and "Associated Soils", it may be possible to find that one of the relatives to this soil has exhibited instability.

Maintenance records often show areas where landslides have occurred after construction. An examination of these areas or personal communication with people that have observed these areas, might aid in determining if the same or a similar soil may occur on new construction in a nearby area.

Construction records are a good source of soil information. Many times when wet areas are encountered, special methods are employed to drain or "dry up" the area. Such procedures may be recorded in diaries. Slumps large enough to cause overruns or extra work are usually documented.

Geological maps are another useful tool in locating potential landslide areas. About 35 percent of the land surface of Oklahoma has been geologically mapped in detail. Thanks to an interest in mountainous areas, the geologists have mapped a large percent of the areas in Oklahoma where landslides are likely to occur. The bulletins and circulars provided by the Oklahoma Geological Survey give information relating to the kinds of topography, rock quality, attitude of bedding, faulting, and other items of engineering significance.

Large thick deposits of colluvial material are usually noted and mapped by geologists. Such areas include rock flows as well as rock and soil mixtures. So, if areas of colluvium are near or lying across a proposed alignment, further investigation is warranted.

Aerial photograph interpretation is another good way to locate hazardous materials. Old landslides and wet areas can usually be observed. Things easily observed are old scarps, tilted trees, water-loving vegetation, and drainageways along with seeps and springs.

Topographic maps often provide clues to areas that might cause trouble. Things to look for on the topographic maps include, steep slopes, long slopes, springs, and mountainous terrain.

Climatological maps show areas of high precipitation. These are generally areas where high water tables occur. Although the water tables may not stay in the soil for long, they can stay long enough to promote conditions of instability - even if its for only a few hours. In Oklahoma, soils in the 30 inches (762 mm) plus rainfall zone can possess wetness conditions that may produce landslides. Rainfalls in the 40 inches (1016 mm) plus zone have an even higher potential.

FIELD RECONNAISSANCE AND PROCEDURE

Field reconnaissance should be used in conjunction with office information when looking for unstable soils. In the field one might expect to see tilted trees, scarps, and cracks if you came across an unstable soil area. This is not necessarily so. Unstable soils can very easily look like any other soil, particularly in a forested area. What should be observed are the soil types and thicknesses in the drainageways and footslope or toeslope landscape positions. While soils next to small drainageways may look harmless, these areas often contain clayey and bouldery colluvial accumulations. In Oklahoma and adjacent areas, colluvial material usually tends to collect in drainageways like a very thick viscous fluid. A

FIELD RECONNAISSANCE

hummocky or uneven appearance of the soil in or near a drainageway usually indicates significant thickness of unstable soil. Areas near the base of hills or mountains usually possess considerable accumulation of colluvial material.Rock outcroppings on the slopes may also cause some accumulation of colluvial material. The observation of the above items is adequate evidence to warrant further investigation.

SOIL TESTING

Once the unstable soil has been located, it can now be sampled and tested. Undisturbed and disturbed soil samples can be taken and sent back to the Materials Laboratory for testing.

Undisturbed soil samples usually give the best information. Such samples are taken with thin-wall "Shelby" tubes. The soil is then carefully extracted from the tube, sealed, and transported to the laboratory. The samples are then subdivided and trimmed for use in the testing machines.

Design recommendations based on laboratory test results may be made by a Soils and Foundations Unit or the data can be furnished to other departments for analysis and interpretation. Some tests ran by the Oklahoma Department of Transportation's Materials Division on undisturbed soil samples include:

1. Triaxial shear
2. Direct shear
3. Unconfined compression
4. Consolidation
5. Density - Specific gravity

Disturbed soil samples are taken to assist in classifying the soils and to learn something about the relationships of soil moisture, particle size, swelling, and plastic properties of the soil. Some disturbed tests giving useful engineering information include:

1. Sieve analysis (gradation)
2. Atterberg limits
3. Hydrometer analysis
4. Compacted density (Proctor)
5. Moisture content
6. Shrinkage
7. Free swell

Some tests can also be run in the field. Quite often, undisturbed samples can not be taken due to rocks or roots in the soil. Field tests might then be the only source of test data concerning soil stability. At the present time, the Oklahoma Department of Transportation has the ability to run standard penetration tests, Texas cone penetrometer, bore hole permeability tests, piezometric tests, and install inclinometers. The vane shear and Iowa bore hole devices work well in certain soils. Piezometers can be installed to determine pore pressures or water table levels. The bore hole permeability test is a very important tool in determining the degree of saturation of the soil as well as the rate of water movement within the soil. A bore hole inclinometer may be installed to determine soil movement. Penetration tests yield in-situ soil strength data, as do the vane shear, Iowa bore hole device, and dutch cone.

STABILITY ANALYSIS

A stability analysis can be performed once the proper strength tests have been completed. The causes of soil movement relate to the cohesion and shear strength of the soil in conjunction with the driving forces on the colluvial soil mass.

So, to develop a rational method of analysis one must at least consider: slope, soil strength, cohesion, ground water, and boundary conditions.

STABILITY ANALYSIS

There are several text books, manuals, and research papers written concerning slope stability. The conditions causing landslides are many and seem to vary slightly at each site. This situation has caused several methods of stability analysis to be derived. The Department of the Navy, Bureau of Yards and Docks has an excellent Design Manual DM-7(3) which lists the broad types of analyses used by most engineers today. The list includes procedures of analyzing: rotational failure ($\emptyset = 0$), rotational failure ($\emptyset$ and C strength), translation failure, embankments on soft clay, and structures founded on clay. The methods can be reduced to the effective stress method and total stress method.

The Oklahoma Department of Transportation now has a computer program which can generate a valid stability analysis. Either the effective stress or total stress methods can be performed in the program. The procedures have been used to develop corrective measures for landslides that have occurred in Oklahoma. So far, they have been successful and it appears that they will continue to be successful.

The analysis results give a good indication of the degree of stability of the soil mass under investigation. While many investigators will recommend designs based on the results of these and similar programs, all conditions affecting the soil properties must be considered. A good recommendation will also consider such diverse items as those listed below.

1. Total annual precipitation
2. Rainfall intensity
3. Irregularities in the underlying strata
4. Discontinuities in the soil mass
5. Effects of vegetation
6. Presence of ground water
7. Tilt (dip) of underlying geolgoical strata
8. Effects of entrained boulders
9. Integrity of underlying geological strata
10. Topography of buried surfaces

A good stability analysis can only be accomplished by trained people with a keen eye. A relatively simple item such as discontinuities in a soil mass can easily render safety factors of less than one. Such discontinuities include fissures (cracks), voids, joints, animal/insect burrows, root channels, pores, and old or new slippage planes. These items must be recognized in the field. It is very important that all the elements affecting soil stability be observed and considered.

DESIGN FOR STABILITY

There are several things that can be done in the design phase to help solve stability problems. These include consideration of drainage, slopes, retaining structures, and soil modification or removal.

Quite often, drainage control is the most effective way of preventing or correcting instability problems. There is a strong tendency to reduce or eliminate drainage structures for economic reasons but these may be the most cost effective elements in obtaining soil stability. Drainage structures affecting stability can be surface or subsurface types, often both are used.

Surface drainage involves the use of interceptor ditches, or grading of critical areas. (See Figure 2.) Surface ditches are built to carry water away from a hazardous area. If the soil or rock contains fissures, the ditch should be paved. The discharge end of the ditches should carry the water completely away from the unstable soil area.

Subsurface drainage generally consists of three kinds of drains: horizontal,vertical, and trench. Each of these types or combinations of types can be effective in controlling seepage depending on the circumstances. In Oklahoma the trench type is currently the most common. (See Figure 3.) Here, a trench 3-12 feet (1-4 m) deep might be dug on the uphill side of a fill or other potential landslide area. A perforated pipe is laid in the bottom of the ditch to intercept and carry away any ground water coming down the hillside within the soil. Trench type drains work well if the water bearing soil does not exceed about 8 feet (2.4 m) in thickness (depth). Trenching in soft wet soil becomes increasingly difficult below these depths. Care must be taken to insure that the drain is placed at the bottom of the water bearing soil so that no water can escape by going under the drain. The slope of the drain must be adequate to avoid any low spots.

Horizontal drains have been used in Oklahoma with success. (See Figure 4.)

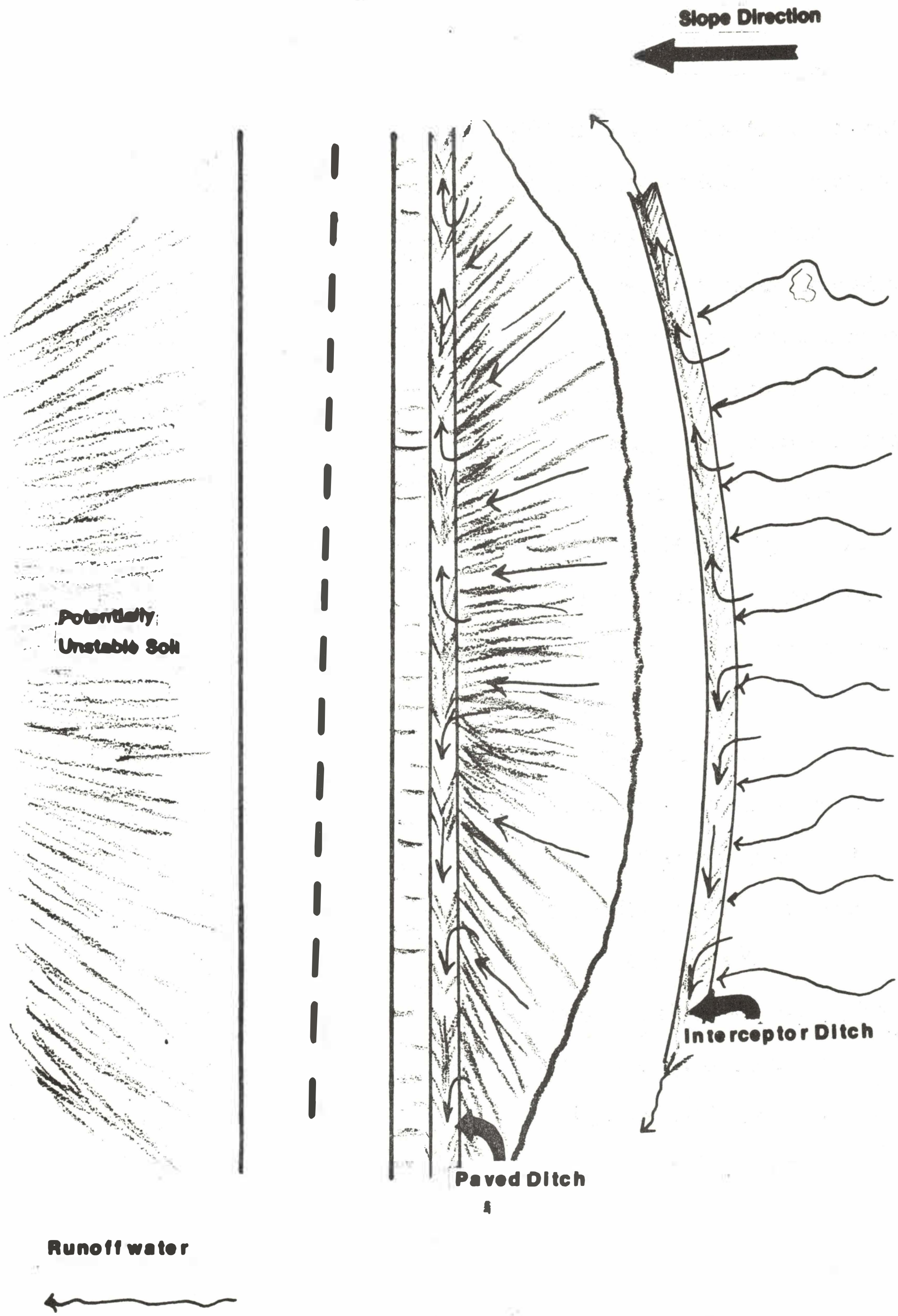


Figure 2. Ditches intercept runoff which can cause stability problems.

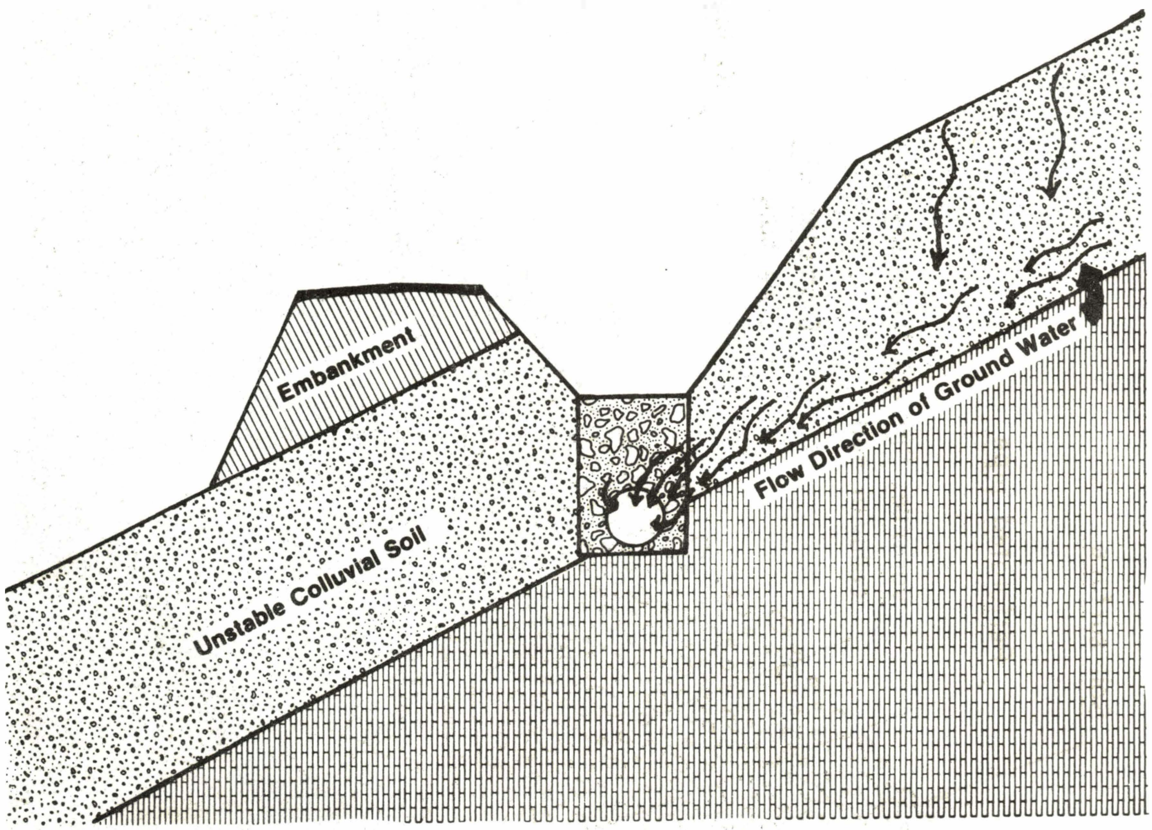


Figure 3. Trench type underdrain installation intercepting seepage flow.

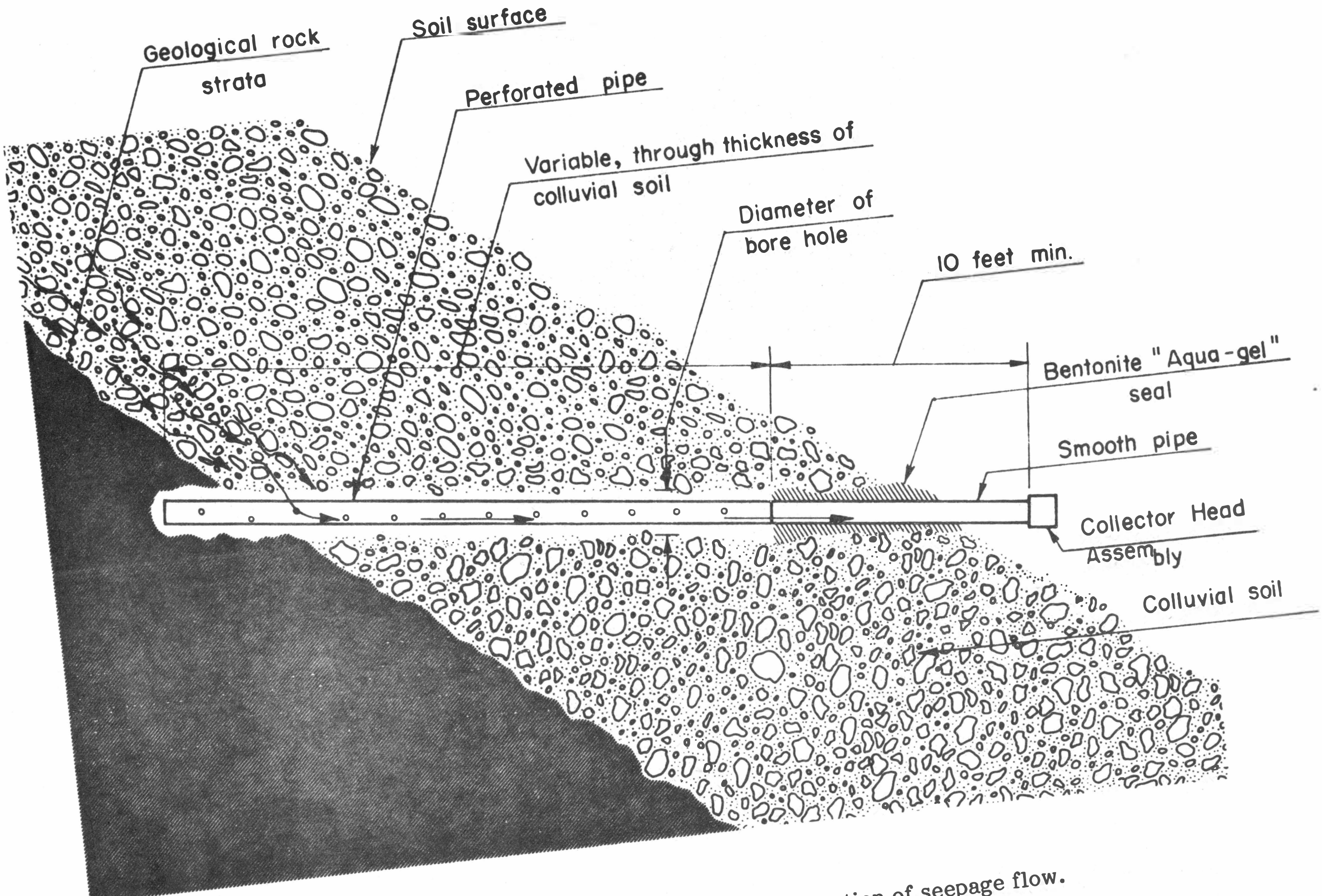


Figure 4. Horizontal type underdrain intercepting a portion of seepage flow.

They control the buildup of large seepage forces by reducing water table levels. While horizontal drains may not pick up all the ground water in a soil or fill, they can increase the factor of safety by a considerable amount.

Horizontal drains are fairly easy to install. A horizontal drilling rig is usually placed at the base of a fill. Holes are advanced by standard air or mud drilling procedures. After the drill stem is withdrawn, a perforated pipe is inserted. Often, a bit is placed on the end of perforated drill pipe leaving the pipe string in place after drilling is completed. The outermost 6-10 ft. (1.8-3.0 m) or so of the installation is smooth pipe. A bentonite seal is placed in the annular space where the drain enters the soil. A manifold arrangement is built to collect the drainage and take it away to be discharged in an area away from the fill. (See Appendix C.)

Vertical drains have been used to stabilize fills on Talimena Drive (S.H. 1, LeFlore County) and to stabilize shoulders in several maintenance divisions. (See Figure 5.) A hole is advanced through the fill into underlying pervious soil or geological rock strata. The holes can be filled with sand, gravel, or lime. The ground water entering the bore holes will be discharged into the underlying material below the fill.(8)

Vertical drains are very easy to install. All that is required is drilling rig capable of boring a 9-12 in. (229-305 mm) hole up to 100 ft. (30 m) deep. The hole spacing can be variable depending on moisture conditions and the permeability of the underlying geological formation. The underlying geological formation must permeable enough to accept the water gathered from the fill by the drains. (See Appendix D.)

The type of cross drain used in mountainous area is also an important consideration. In past years it has been thought that rigid material, e.g., Portland cement (PC) concrete box culverts were the best type of culvert material for mountains. It seems logical because of the highly abrasive and corrosive conditions that are present relative to the abrasion/corrosion resistant properties of Portland cement concrete.

But there is one very large disadvantage to P.C. concrete boxes and pipes, they crack and pull apart. (See Figures 6 and 7.) When this happens, surface water which had previously been controlled now enters the fill through cracks or construction joints. As luck would have it, these cracks allow water to enter the fill and help saturate the critical lower part of the fills. This is the worst zone in a fill in which to develop ground water conditions. This is where settlement and slumping starts. "Broken back" box culverts are highly susceptible to pulling apart and should not be used in mountainous areas where landslides may be a problem.

A water tight cross drain is essential. One of the best answers we have so far is the corrugated steel pipe. The pipes can be fabricated in a spiral form with a lock seam joint. The seams and connections can be made water tight. If the soil is corrosive, a polymeric precoating material, e.g., "Nexon", will work. If abrasion is a problem, the pipe can be paved with bituminous (asphalt) material.

Broken-back cross drains should be avoided with either rigid or flexible culverts. The stresses imposed on a culvert from settlement seem to pull the culverts apart where it changes grade. Skewing the culverts seems to be a fairly easy way of avoiding long and broken-back culverts. (See Figure 8.) Skewing the cross drains usually can also allow a discharge of water away from a critical area.

Slope treatment is another common way to increase the factor of safety of slopes. (See Figure 9.) There are essentially three things that can be done to a slope to increase stability. First, flatten the entire slope; second, remove a portion of the material at the top of the slope; and third, add material to the toe of the

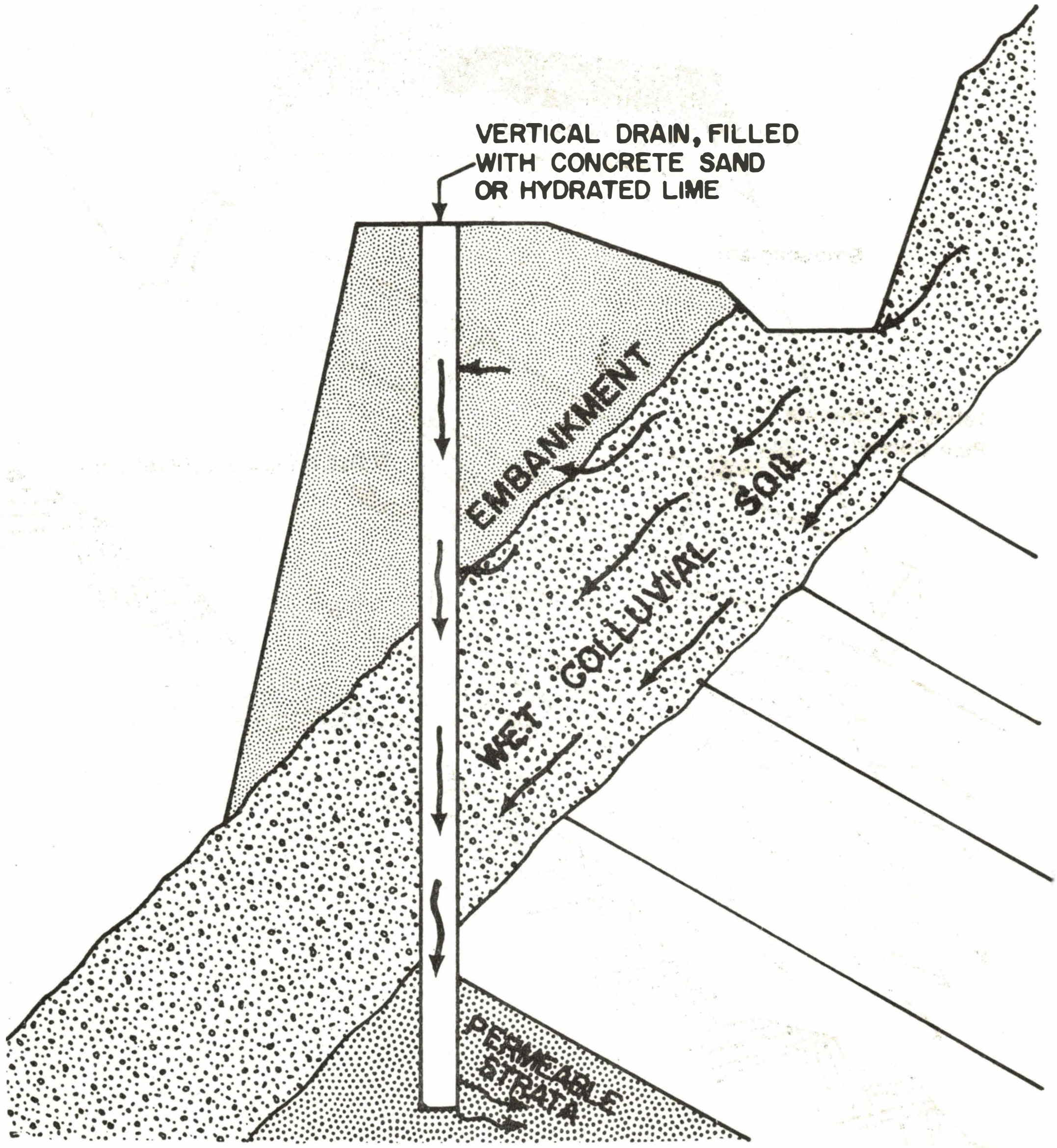


Figure 5. Vertical drain collecting seepage from embankment and colluvial soils.

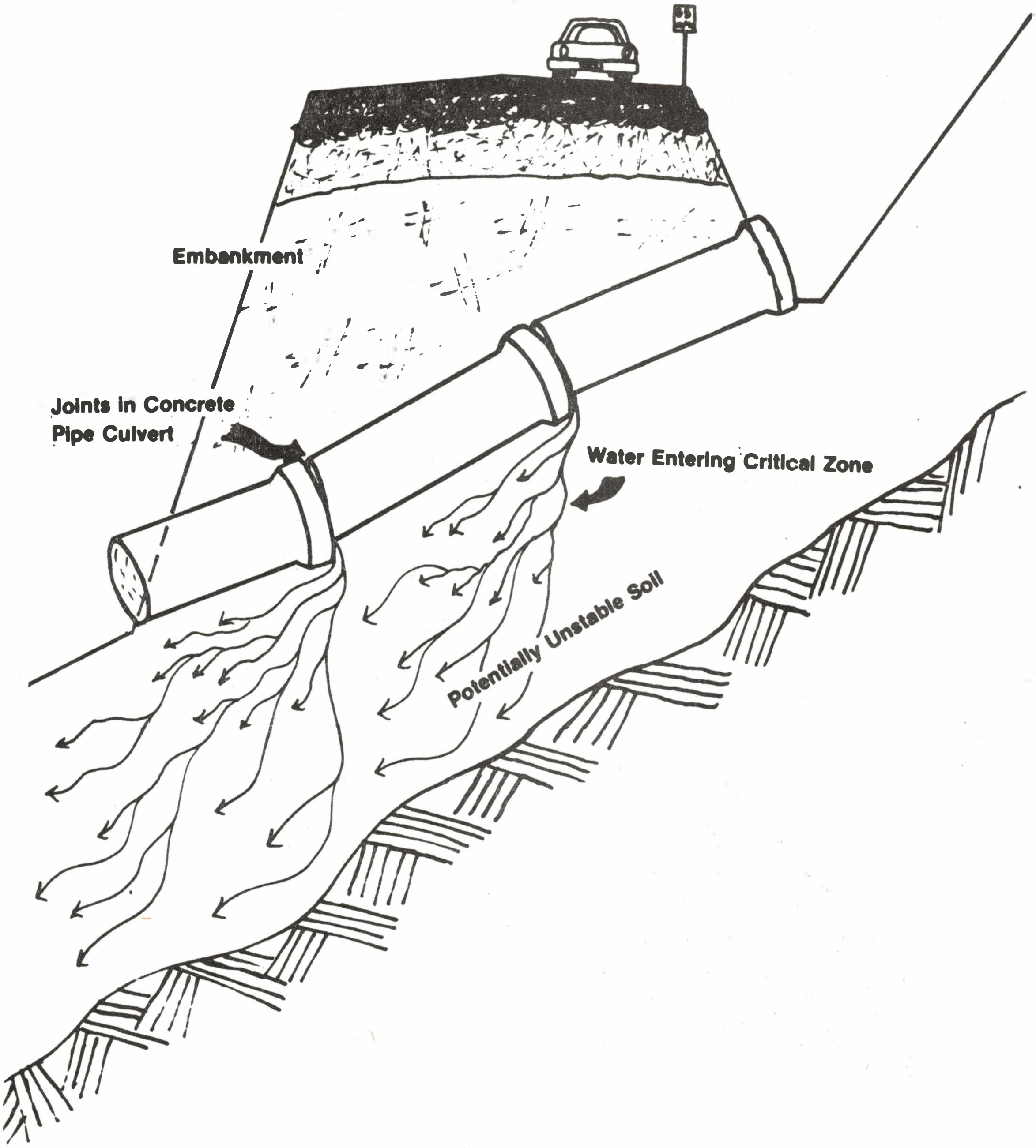


Figure 6. Leaks in joints of concrete pipe culvert.

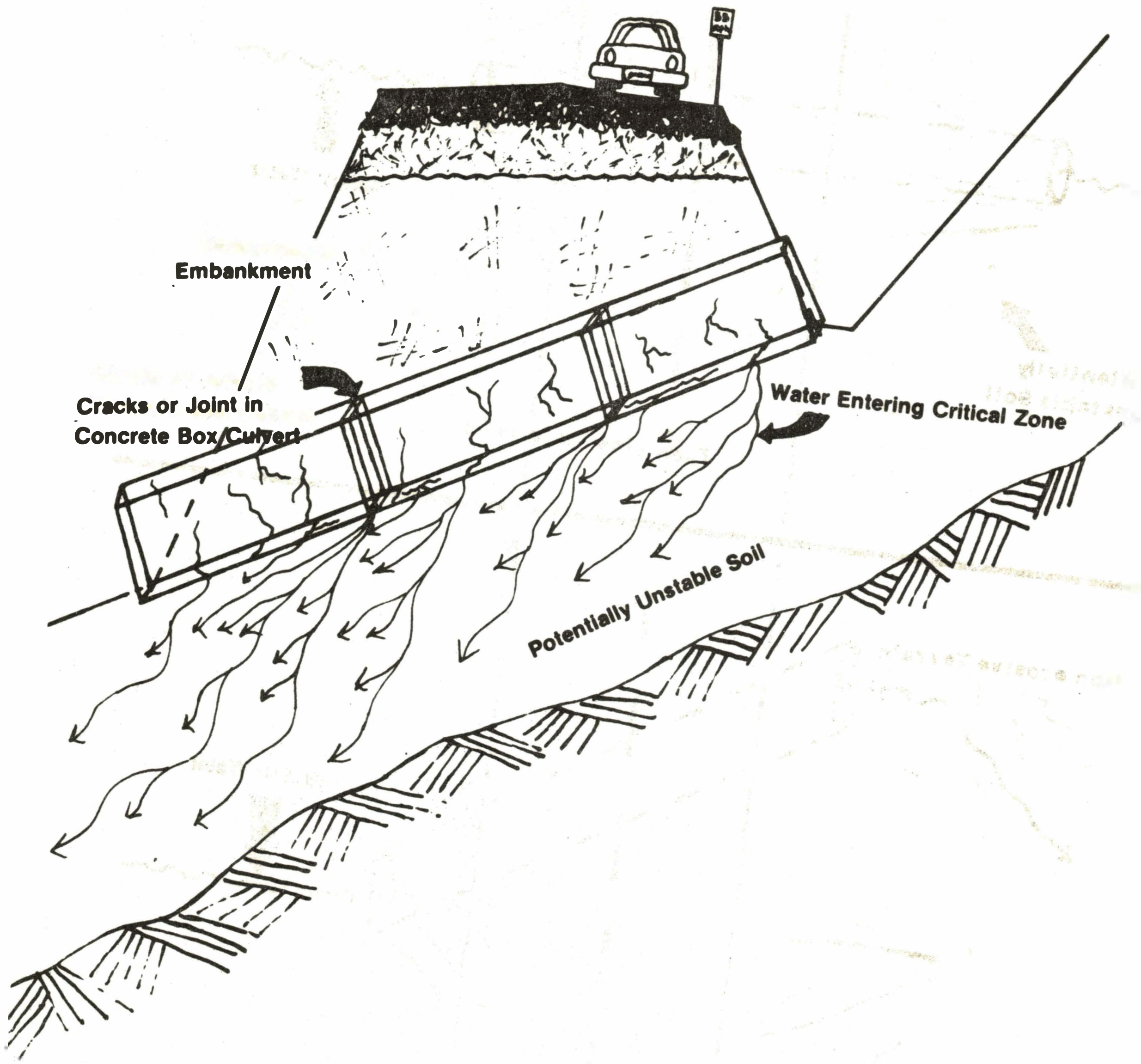


Figure 7. Leaks in cracks and joints of a concrete box culvert.

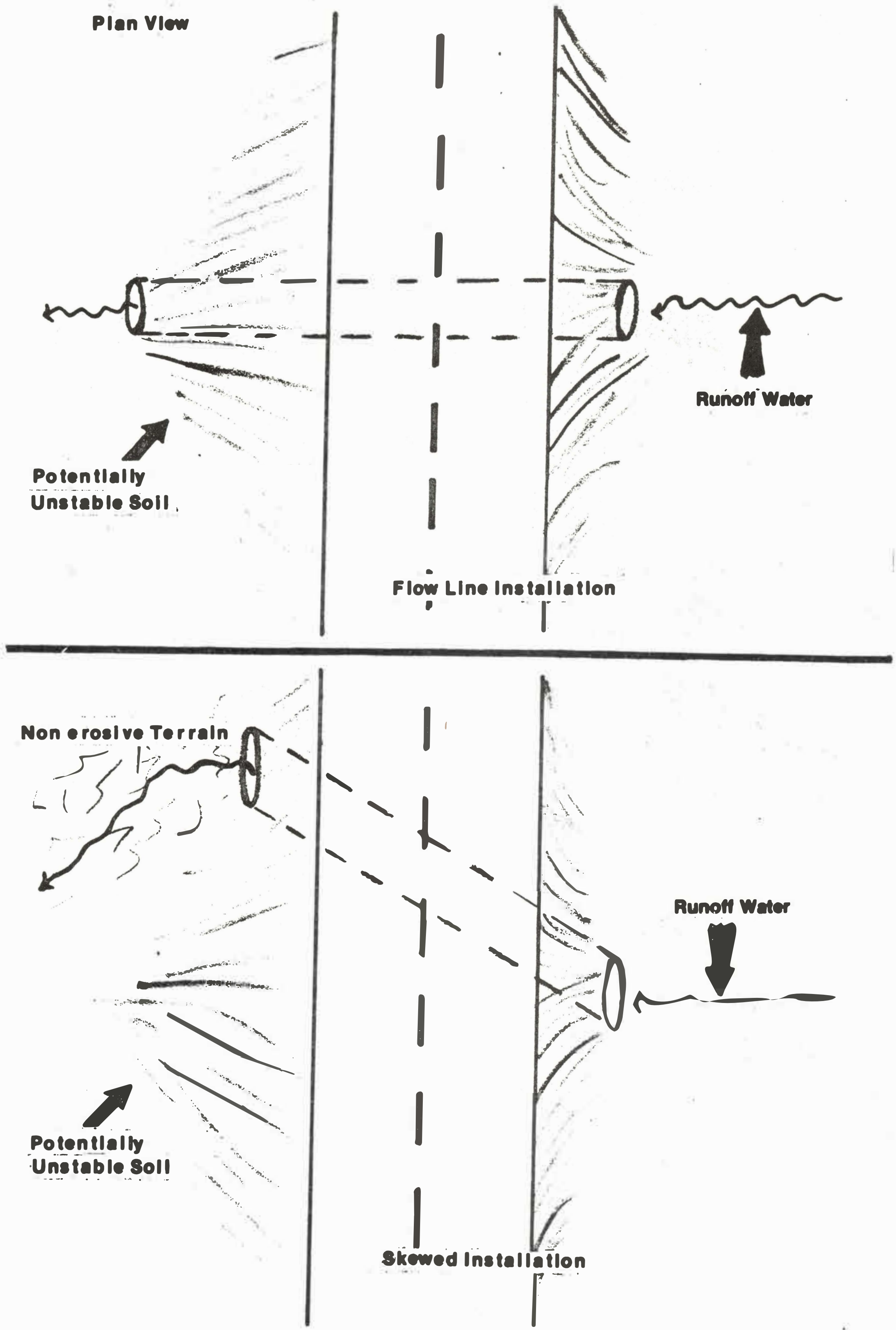
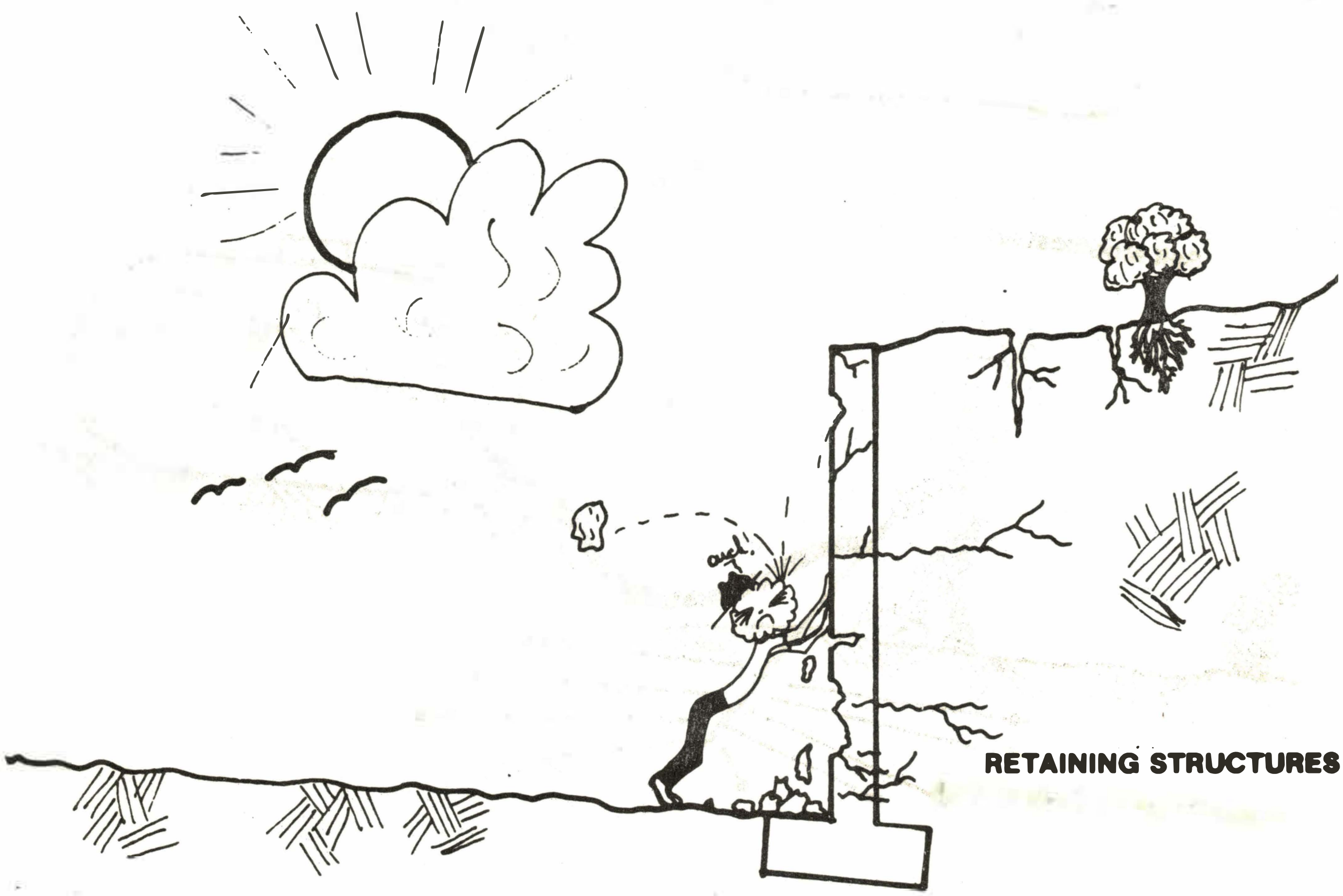


Figure 8. Skewed culvert diverting runoff onto a non-critical area.

slope. Sometimes combinations of the three are practical to use. Complete or partial removal of material that is obviously unstable is another way to obtain stability.

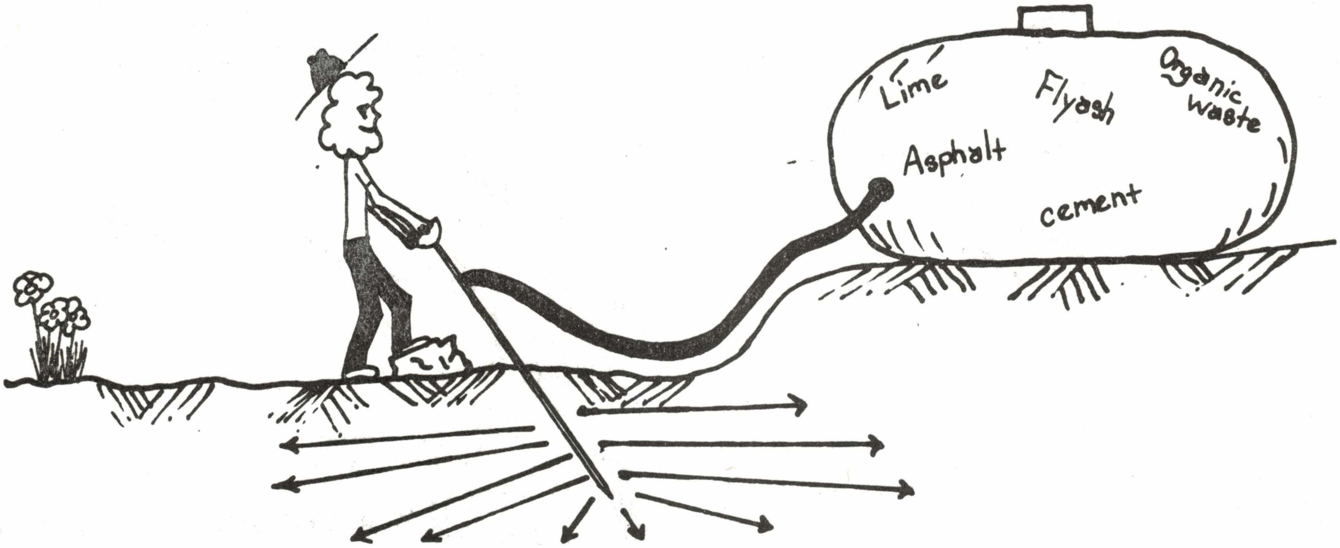
Retaining structures are sometimes practical to use. Some common retaining structures include: Rock/earth buttress, crib walls, pile walls, gabion walls, anchored or tieback walls, and a variation of the tie-back wall, reinforced earth, or Fondedile (root) piles. Rock buttresses have been used successfully on Talimena Drive in LeFlore County, crib walls have been used along SH 100 west of Stilwell in Sequoyah County. Gabion walls have been installed in Binger along SH 152 in Caddo County.



RETAINING STRUCTURES

Soil modification is another method of getting stability from soft soils. Grouting and cementing are sometines used. Filling vertical bore holes with dry lime (slake lime) or lime slurry appears to have worked on Talimena Drive and other places. The injection of lime, flyash, cement, asphalt, and organic materials may be useful methods but have not been tried in Oklahoma yet.

Soil Modification



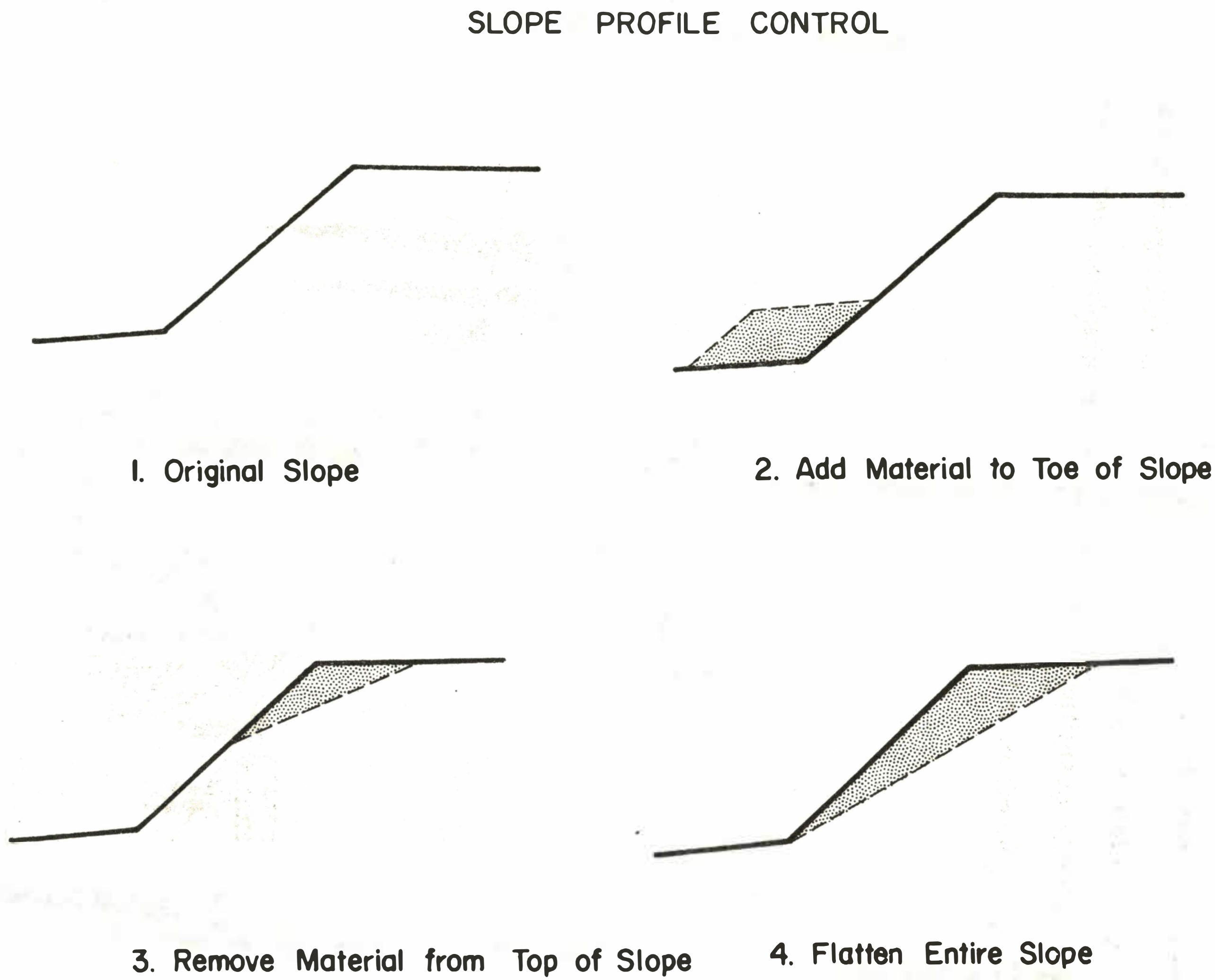
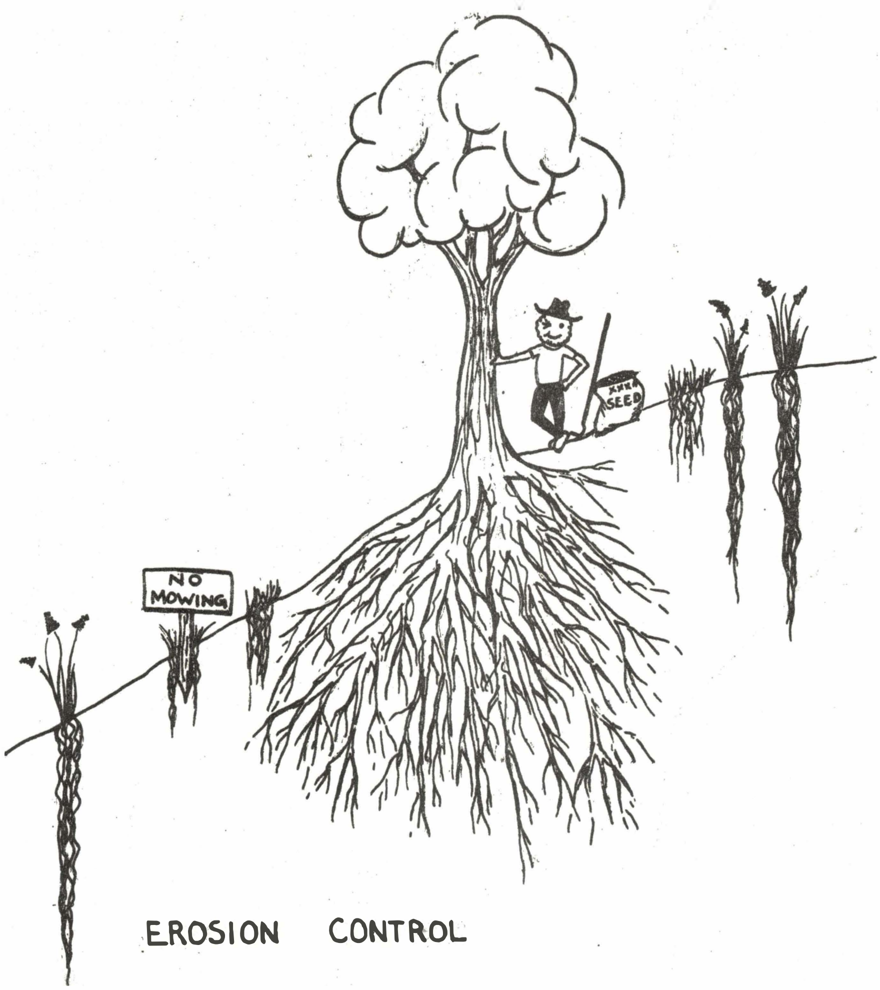


Figure 9. Methods to develop stability of slopes.

Erosion control measures usually help slope stability too. Surface waters diverted away from a critical slope will definitely be helpful. Leaving as much vegetation, especially trees, in a critical area will help. Such areas are just above the cut slope and at the toe of a fill. A good vigorous growth of native grasses, Weeping Love grass or other deep rooted grasses will also help. (See Figure 7.) Vegetation helps in two major ways, their roots tend to hold the soil together, plus they transpire considerable quantities of water into the atmosphere, and hence produce a drying/stabilizing effect in the soil.



EROSION CONTROL

Root (6) very adequately summarizes the methods used in controlling landslides in his Chapter 7 of HRB Special Report 29, "Landslides and Engineering Practice." (See Table 1.) Nearly all of the methods mentioned by Root have been tried in Oklahoma. Generally speaking, the methods used have been successful when properly installed or utilized. The major consideration in this phase of slope stability study is to implement the landslide information into design practice. The information can be utilized as design drawings, special provisions, specifications, or notes on plans.

Since slope and drainage construction are relative expensive, the treatment areas should be well defined and delimited. Soil surveys, geological maps, construction and maintenance records, topographic maps, aerial photographs, and climatological maps, and ground reconnaissance can all be used to develop soil stability information. Subsequent information from field reconnaissance and soil testing in the suspected critical locations will provide adequate information for effective and economical stability designs. (See Appendix E.)

Table 1

SUMMARY OF METHODS FOR PREVENTION AND CORRECTION OF LANDSLIDES

Effect on Stability of Landslide	Method of Treatment	General Use		Frequency of Successful-Use[1]			Position of Treatment on Landslide[2]	Best Applications and Limitations
		Prevention	Correction	Fall	Slide	Flow		
Not affected	I. Avoidance methods:							
	A. Relocation	x	x	2	2	2	Outside slide limits	Most positive method if alternate location economical
	B. Bridging	x	x	3	3	3	Outside slide limits	Primary highway applications for steep, hillside locations affecting short sections (parallel to c/L)
Reduces shearing stresses	II. Excavation:[3]							
	A. Removal of head	x	x	N	1	N	Top and head	Deep masses of cohesive material
	B. Flattening of slopes	x	x	1	1	1	Above road or structure	Bedrock; also extensive masses of cohesive material where little material is removed at toe
	C. Benching of slopes	x	x	1	1	1	Above road or structure	
	D. Removal of all unstable material	x	x	2	2	2	Entire slide	Relatively small shallow masses of moving material
Reduces shearing stresses and increases shear resistance	III. Drainage:							
	A. Surface:							
	1. Surface ditches	x	x	1	1	1	Above crown	Essential for all types
	2. Slope treatment	x	x	3	3	3	Surface of moving mass	Rock facing or pervious blanket to control seepage
	3. Regrading surface	x	x	1	1	1	Surface of moving mass	Beneficial for all types
	4. Sealing cracks	x	x	2	2	2	Entire, crown to toe	Beneficial for all types
	5. Sealing joint planes and fissures	x	x	3	3	N	Entire, crown to toe	Applicable to rock formations
	B. Subdrainage:							
	1. Horizontal drains	x	x	N	2	2	Located to intercept and remove subsurface water	Deep extensive soil mass where ground water exists
	2. Drainage trenches	x	x	N	1	3		Relatively shallow soil mass with ground water present
	3. Tunnels	x	x	N	3	N		Deep extensive soil mass with some permeability
	4. Vertical drain wells	x	x	N	3	3		Deep slide mass, ground water in various strata or lenses
	5. Continuous siphon	x	x	N	2	3		Used principally as outlet for trenches or drain wells
Increases shearing resistance	IV. Restraining Structures:							
	A. Buttresses at foot:							
	1. Rock fill	x	x	N	1	1	Toe and foot	Bedrock or firm soil at reasonable depth
	2. Earth fill	x	x	N	1	1	Toe and foot	Counterweight at toe provides additional resistance
	B. Cribs or retaining walls	x	x	3	3	3	Foot	Relatively small moving mass or where removal of support is negligible
	C. Piling:							
	1. Fixed at slip surface		x	N	3	N	Foot	Shearing resistance at slip surface increased by force required to shear or bend piles
	2. Not fixed at slip surface		x	N	3	N	Foot	
	D. Dowels in rock	x	x	3	3	N	Above road or structure	Rock layers fixed together with dowels
	E. Tie-rodding slopes	x	x	3	3	N	Above road or structure	Weak slope retained by barrier, which in turn is anchored to solid formation
Primarily increases shearing resistance	V. Miscellaneous Methods:							
	A. Hardening of slide mass:							
	1. Cementation or chemical treatment							
	(a) At foot		x	3	3	3	Toe and foot	Non-cohesive soils
	(b) Entire slide mass		x	N	3	N	Entire slide mass	Non-cohesive soils
	2. Freezing	x		N	3	3	Entire	To prevent movement temporarily in relatively large moving mass
	3. Electro-osmosis	x		N	3	3	Entire	Effects hardening of soil by reducing moisture content
	B. Blasting		x	N	3	N	Lower half of landslide	Relatively shallow cohesive mass underlain by bedrock Slip surface disrupted; blasting may also permit water to drain out of slide mass
	C. Partial removal of slide at toe	-	-	N	N	N	Foot and toe	Temporary expedient only; usually decreases stability of slide

[1] 1 = frequently; 2 = occasionally; 3 = rarely; N = not considered applicable.

[2] Relative to moving or potentially moving mass.

[3] Exclusive of drainage methods.

REFERENCES

1. Highway Research Board, Bulletin No. 13, "The Appraisal of Terrain Conditions for Highway Engineering Purposes", 1948.

2. Highway Research Board, Bulletin No. 28, "Soil Exploration and Mapping", 1949.

3. Design Manual, "Soil Mechanics Foundations and Earth Structures", NAVDOCKS DM-7, Department of the Navy, Naval Facilities Engineering Command, 200 Stovall Street, Alexandria, Virginia 22322, 1971.

4. McAlprin, Jr., G. W. and Sinacori, M. N. , "Sand Drains for Embankment on Marl Foundations", HRB Bulletin No. 115, 1955.

5. McCurtain County Soil Survey, US Dept. of Agriculture, Soil Conservation Service, Robert Reasoner Soil Scientist, 1974.

6. Parrott, Wm. T., "Control of a Slide by Vertical Sand Drains", HRB Bulletin No. 115, 1955.

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8. Royster, D. L., "Some Observations on the Use of Horizontal Drains in the Correction and Prevention of Landslides", Tennessee Department of Transportation, 1977.

9. Webber, R., and Hill, W. C., "Modification of Sand-Drain Principle of Pressure Relief in Stabilizing Embankment Foundation", HRB Bulletin No. 115, 1955.

10. Witczak, M. W., "Relationships Between Physiographic Units and Highway Design Factors", NCHRP Program Report No. 132, 1972.

APPENDIX A

STATUS OF SOIL SURVEYS IN OKLAHOMA - SEPTEMBER 1975

Survey Areas Have Published Soil Surveys

Adair	Comanche	Haskell	Mayes	Roger Mills
Alfalfa	Cotton	Hughes	McCurtain	Sequoyah
Beaver	Craig	Jackson	Noble	Stephens
Blaine	Creek	Jefferson	Okfuskee	Texas
Caddo	Dewey	Kay	Oklahoma	Tillman
Cherokee & Delaware	Ellis	Kingfisher	Okmulgee	Washington
	Garfield	Lincoln	Ottawa	Woods
Cimarron	Greer	Logan	Pawnee	Woodward
Cleveland	Harmon	Love	Pittsburg	
Coal	Harper	Major	Pontotoc	

These 49 counties comprise 27,828,128 acres which is about 63 percent of the State.

Survey Areas Have Been Edited and Reviewed:

Wagoner (75) Custer (77)

These dates in parenthes esare the scheduled dates the manuscript is to be sent to GPO. These two counties comprise 1,367,110 acres which is about three percent of the state.

Survey Areas with Manscripts Being Edited:

Canadian (76) Kiowa (77) Pottawatomie (77)

These three counties comprise 1,735,104 acres which is about three percent of the state.

Additional Survey Areas Have Field Mapping Completed:

Bryan (77)	Atoka (78)	Johnston (77)	Osage (77)	Pushmataha (78)
Carter (78)	Grady (77)	Seminole (78)	Nowata (78)	Tulsa (77)

These ten counties are in various stages of correlation and manuscript preparation. These ten counties comprise 6,346,048 acres which is about 14 percent of the state.

SUMMARY:

Survey Areas Have Published Soil Surveys or Field Mapping Completed:

The total acreage in these 63 survey areas is about 37 million acres which is about 84 percent of the state.

Survey Areas Are Partially Completed And Field Work Is In Progress:

The 13 soil survey areas cover the balance of the state. The combined area covered by soil surveys in Oklahoma is about 41 million acres which is about 93 percent of the state.

STATE LONG-RANGE PLAN FOR SOIL SURVEYS

This plan includes plans for completing "once-over" soil surveys. It also includes plans for updating some counties which have "old" soil surveys that do not meet current user needs and demands.

On-Going Surveys

Area	Target Completion Dates
Beckham County	7-78
Latimer County	5-79
Marshall County	5-79
Murray County	9-79
Muskogee County	9-79
McIntosh County	4-80
Garvin County	6-80
LeFlore County	9-80
Cleveland County	10-80
Payne County	11-80
Grant County	12-81

Planned Surveys

Area	Target Completion Dates
Harmon County	7-81

This report courtesy of the U.S. Department of Agriculture, Soil Conservation Service. Taken from a report given at the 1975 Soil Survey Annual Planning Conference, Oklahoma.

APPENDIX B

Established Series
Rev. RCR:ECN
5/74

CARNASAW SERIES

The Carnasaw series is a member of the clayey*, mixed, thermic family of Typic Hapludults. These soils have very dark grayish brown and yellowish brown loam A horizons and yellowish red silty clay loam and silty clay B2t horizons. The B3 horizon extends into tilted, weathered, interbedded shale and sandstone.

Typifying Pedon: Carnasaw loam - forest.

(Colors are for moist soil unless otherwise stated.)

A1 - 0-3 inches, very dark grayish brown (10YR 3/2) loam; moderate medium and fine granular structure; very friable, many fine and medium roots; about 6 percent fine fragments of quartzite and thin fragments of sandstone; medium acid; clear wavy boundary. (2 to 6 inches thick)

A2 - 3-9 inches, yellowish brown (10YR 5/4) loam; weak medium and fine granular structure; very friable; many fine and medium roots; about 12 percent fine gravelly fragments of quartzite and thin flat fragments of sandstone; strongly acid; clear wavy boundary (3 to 8 inches thick).

B21t - 9-15 inches, yellowish red (5YR 5/8) silty clay loam; strong medium and fine subangular blocky structure; friable; common fine and medium roots; nearly continuous clay films of ped faces; few fine flat fragments of shale; and few fine rounded fragments of sandstone; very strongly acid; gradual smooth boundary. (5 to 21 inches thick).

B22t - 15-37 inches, yellowish red (5YR 4/8) silty clay; strong medium subangular blocky structure; firm; common fine roots; nearly continuous clay films on faces of ped; many peds coated with red (2.5YR 4/6); few thin flat fragments of shale; very strongly acid; gradual smooth boundary (15 to 32 inches thick).

B3 - 37-42 inches, yellowish red (5YR 4/8) gravelly silty clay, many fine and medium distinct strong brown (7.5YR 5/8) and red (2.5YR 4/6) mottles; moderate fine blocky structure; friable; common fine and few medium roots; patchy clay films on faces of peds; about 20 percent by volume of fragments of sandstone and shale; very strongly acid; clear irregular boundary (5 to 20 inches thick).

C - 42-52 inches, fractured shale bedrock laminated with layers of sandstone, tilted 30° from a horizontal plane; brown and reddish coatings along cleavage planes.

Type Location: McCurtain County, Oklahoma; about one mile north and .5 mile east of the entrance to Beaver Bend State Park on U.S. Highway 259 and 259A; 2500 feet east and 800 feet north of SW corner section 7, T. 5 S., R. 25 E.

Range in Characteristics: Stones occupy 0 to 20 percent of the surface. Solum thickness ranges from 30 to 60 inches and due to the irregular boundary between the Bt horizon and the underlying tilted bedrock is extremely variable within short distances. The A horizon ranges from medium to strongly acid unless limed; the B horizon ranges from strongly acid to very strongly acid.

*The underlined words and phrases refer to items pertinent to engineering aspects of roadway construction.

The Ap or A1 horizon is dark grayish brown (10YR 4/2), brown or dark brown (10YR 4/3; 7.5YR 4/2) and where less than 6 inches thick, includes very dark grayish brown (10YR 3/2) or dark brown (10YR 3/3; 7.5YR 3/2). The A2 horizon is brown (10YR 5/3; 7.5YR 5/4), yellowish brown (10YR 5/4, 5/6, 5/8), light yellowish brown (10YR 6/4), pale brown (10YR 6/3), strong brown (7.5YR 5/6, 5/8), or light brown (7.5YR 6/4). The A horizon is loam, silt loam, or fine sandy loam, or their gravelly or stone counterparts and contains 2 to 30 percent by volume of shale, sandstone, or quartzite, less than three inches diameter and 0 to 5 percent of the volume 3 to 10 inches diameter.

Fragments of sandstone and shale less than 3 inches diameter comprise 2 to 10 percent by volume of the B2t horizons. The B21t horizon is strong brown (7.5YR 5/6, 5/8), reddish yellow (7.5 YR 6/6, 6/8), yellowish red (5YR 5/6, 5/8), or reddish yellow (5YR 6/6,6/8). It is silty clay loam, clay loam, or clay. The B22t horizon is yellowish red (5YR 4/6, 4/8, 5/6, 5/8), or red (2.5YR 4/6, 5/6, 4/8, 5/8; 10YR 4/6, 5/6, 4/8, 5/8). Fine or medium mottles in shales of brown or yellow are common in some pedons. This horizon is silty clay or clay.

The B3 horizon is yellowish red (5YR 4/6, 4/8, 5/6, 5/8), strong brown (7.5YR 5/6, 5/8), or reddish yellow (7.5YR 6/6, 6/8). In some pedons, the B3 horizon is mottled in gray colors. It is gravelly silty clay or gravelly clay. This horizon contains 15 to 40 percent by volume of shale and sandstone fragments less than 3 inches diameter and 0 to 5 percent 3 to 10 inches diameter. The lower boundary is irregular with extensions 1/2 to 4 inches wide into the underlying rock at random intervals of about 4 feet or less.

The C horizon is interbedded sandstone and shale tilted 20° to 40° from the horizontal.

Competing Series and Their differentiae: These include the Alberville, Enders, Kirvin, Luverne, McQueen, Sweatman, Townley, and Vance series. All lack the irregular boundary and irregular extension of the Bt horizon into the tilted underlying rock.

Setting: These soils are on the uplands. Slope gradients are dominantly 5 through 18 percent but range from 3 through 45 percent. The regolith is residuum weathered from sandstone and shale. Mean annual air temperature is 57° to 75°F. Average annual precipitation is 40 to 50 inches. Thornthwaite P-E index is 72 to 80.

Principal Associated soils: These are the Goldston, Sacul, and Sherwood series. Goldston soils are less clayey and have more than 35 percent coarse fragments in the control section. Sacul soils have gray mottles in upper 24 inches of the Bt horizon. Sherwood soils are less clayey in the control section.

Drainage and Permeability: Well drained; Medium or rapid runoff; slow permeability.

Use and Vegetation: Used mainly as woodland. Some areas are used for cropland, tame pasture, or native pasture. Native forest vegetation is post oak, red oak, white oak, hickory, and shortleaf pine.

Distribution and Extent: Southeastern Oklahoma and Arkansas. Possibly in Louisiana, Mississippi, and Alabama. The series is of moderate extent.

Series Established: McCurtain County, Oklahoma; 1970.

Remarks: The Carnasaw soils formerly were included in the Enders series and classified in the Red-Yellow Podzolic great soil group. They were separated from Enders because of the irregular boundary of the Bt horizon above the tilted underlying bedrock.

National Cooperative Soil Survey

U.S.A.

This soil series description provided courtesy of the Soil Conservation Service of the United States Department of Agriculture.

*The underlined words and phrases refer to items pertinent to engineering aspects of roadway construction.

APPENDIX C

HORIZONTAL DRAINS

Description.-This work shall consist of furnishing and installing horizontal drains as shown on the plans or directed by the Engineer and as specified in these specifications and the special provisions.

Materials.-Horizontal drains shall, at the Contractor's option, be constructed of either steel or plastic pipe.

Steel Pipe.-Horizontal drains constructed of steel pipe shall consist of perforated, 2 inch (51 mm) standard weight, black steel, asphalt coated pipe and non-perforated 2 inch standard weight, galvanized, steel pipe.

Steel pipe shall conform to the specifications of ASTM Designation: A 120, except that the hydrostatic test will not apply.

Perforated black pipe may be furnished with threads or couplings. The entrance end of the pipeshall be cut, shaped and welded to form a rough point and shall be closed to prevent the entrance of foreign material.

The perforated black pipe shall have 3 rows of perforations with one row on each side of the pipe and the third row in the top. The perforations shall be 3/8 inch (10 mm) in diameter spaced at 3 inch (26 mm) centers with the top perforations or slots, equal to the above requirements, may be substituted upon written approval by the Engineer.

After perforating, the black pipe shall be uniformly coated by dipping, by a method that will not plug more than 10 percent of the perforations, in asphalt conforming to the following requirements:

Test Designation	AASHTO Test Method	Asphalt Specification
Flash Point, Cl. O. C. ^{o}F. Min.	T48	425
Penetration of Original Sample	T49	---
at 32^{o}F.—Min	—	20
at 77^{o}F.	—	30-40
at 115^{o}F. Max.	—	75
Softening Point ^{o}F	T53	190-220
Loss of Heating	T47	---
5 hr. at 325^{o}F., % Max.	—	0.75
Pen. after loss at 325^{o}F.	T49	—
% of Orig. Pen. Min.	—	80
Ductility	T51	—
at 32^{o}F. cm. Min.	—	1.5
at 77^{o}F. cm. Min.	—	2.0
Solubility in Trichloroethylene, % Min.	T44	99

$T_{o}C = (T_{o}F - 32)/ 1.8$

Non-perforated galvanized pipe, approximately 10 or more feet (3 m) in length, shall be provided at the mouth of the drain. The exact length will be determined by the Engineer. The projecting end of the galvanized pipe shall be threaded.

Plastic Pipe.-Horizontal drains constructed of plastic pipe shall consist of nominal 1 1/2 to 2 inch (38-51 mm), SChedule 80 PVC 2110 plastic pipe conforming to the specifications of ASTM Designation: D 1785, and shall be National Sanitation Foundation approved. Both plain and, at the Contractor's option, either slotted or perforated pipe shall be used.

Slotted pipe shall have 2 rows of slots cut circumferentially in the pipe on 2 of the third points (120 degrees apart). The average confirguations shall be from 22 slots, plus or minus one slot, per row, per foot (.3 m), using 0.050 inch (1 mm) wide slots, to 46 slots, plus or minus one slot, per row, per foot, using 0.010 inch (0.2 mm) wide slots. The number and width of slots will be as determined by the Engineer.

Perforated pipe shall have 3 rows of perforations with one row on each side of the pipe and the third row in the top. The perforations shall be 3/8 inch (10 mm) in diameter spaced at 3 inch (76 mm) centers with the top perforations staggered in relation with the holes on either side.

Slotted pipe shall have a minimum of 2.00 sq. inches (2581 mm^2) of opening per linear foot (.3 m). Other suitable perforations or slots, equal to the above requirements, may be substituted upon written approval by the Engineer.

Fittings for the PVC plastic pipe shall be Schedule 80 Type II PVC solvent weld type fittings conforming to the requirements in ASTM Designation: D 2467.

If plastic pipe is used for horizontal drains, unslotted or unperforated PVC plastic pipe, approximately 3 to 30 feet (1 to 9 m) in length, shall be provided at the outlet of the drain. The exact length will be determined by the Engineer.

Installing Horizontal Drains. The drains shall be installed as shown on the plans. The locations of horizontal drains shown on the plans are approximate only and the exact location and sequence of placing horizontal drains shall be as directed by the Engineer. Exploratory work required by the Engineer will be paid for as extra work.

Horizontal drains installed in embankment foundations shall be completed before any embankment material is placed over the drains. Horizontal drains installed at benches in excavation slopes shall be completed before any excavation is made more than 40 feet (12.2 m) below the elevation of the bench where the drains are to be installed.

The horizontal holes shall be drilled with rotary equipment capable of drilling 3 inch (76 mm) to 6 inch (152 mm) diameter holes up to 600 feet (183 m) in length to designated lines and grades through soil and rock formations.

Steel pipe shall be installed by jacking it into the hole with the perforations on top unless the Engineer directs the perforations to be placed otherwise.

Sections of steel pipe shall be joined by field or threaded welding with a full penetration. No weld metal will be permitted inside the pipe. The outside exposed surfaces of welded joints shall be coated with asphalt. After welding and before jacking the non-perforated galvanized pipe into the hole, the line of perforations on the black pipe shall be marked by welding a short piece of welding rod near the outlet end of the non-perforated pipe so that the rod will not interfere with the threads.

Prior to placing the non-perforated sections of steel pipe into the hole, a steel plate of sufficient size and shape to plug the hole without binding shall be welded to the non-perforated pipe not more than 12 inches (305 mm) from the welded connection to the perforated section of pipe.

Plastic pipe shall be installed in the same manner as steel pipe or, at the Contractor's option, shall be installed by inserting the pipe inside the drill rod and then retracting the drill rod so that the drilled hole is cased for the full depth. The entrance end of the plastic pipe shall be tightly plugged with a rounded or pointed extension which shall not extend more than 0.5 foot (152 mm) beyond the end of the pipe.

The casing operation of the drilled hole with plastic pipe shall be done in such a manner that the plastic casing will be cemented together where necessary to form a continuous tube and will not be telescoped or damaged to the extent that its drainage efficiency will be impaired when completed.

Each drain shall be identified by attaching securely to the outlet end of the non-perforated pipe a brass plate with a number assigned by the Engineer, or by some other permanent marking designated by him.

The space between the drilled hole and the pipe shall be tightly plugged with Bentonite clay ("aqua-gel" or equivalent) for a length of at least 2 feet (.6 m) at the outlet end of the hole.

The outlet ends of all drains shall be equipped with a tee, plug, street ell, and a length of galvanized or plastic pipe. The length of the pipe shall be varied to connect with the collector system. The exact length will be determined by the Engineer.

Plastic pipe for the outlet shall be PE 3306, Schedule 40, conforming to ASTM Designation: D 2447.

During the drilling operations, the Contractor shall determine the elevation of the drilled hole at the required intervals and also the elevation at the upper end of the completed drain hole. The measurements may be made by inserting tubes or pipes and measuring liquid levels or shall be by other means satisfactory to the Engineer. The Contractor shall furnish all labor, materials, tools, equipment, and incidentals necessary for determining the elevations.

Water used for drilling and water developed during drilling operations shall be disposed of by the Contractor in such a manner that no damage will result to the work.

Measurement.-Horizontal drains will be measured by the linear foot for furnishing and installing drain pipe and by the linear foot for drilling holes.

The quantity of furnishing and installing drain pipe shall be the length of pipe installed regardless of whether perforated or slotted pipe or non-perforated pipe is used, and also the length of pipe at the outlet end required to connect to the collector system.

The quantity of drilling holes to be paid for shall be the length of hole drilled, except that any hole drilled in which the drain pipe cannot be installed for the full length of the drilled hole will not be measured and paid for.

Payment.-Horizontal drains will be paid for at the contract price per linear foot for furnished and installed drain pipe (horizontal drain) and per linear foot for drill hole (horizontal drain), measured as provided in "Measurement," which payments shall include furnishing all water required for drilling holes and necessary tees, plugs and street ells required for connecting to the collector system.

The above prices and payments shall include full compensation for furnishing all labor, materials, tools, equipment, and incidentals, and for doing all the work involved in installing horizontal drains, complete in place, as shown on the plans, and as specified in these specifications and the special provisions, and as directed by the Engineer.

Unless otherwise provided in the special provisions, furnishing and installing a collector system will be paid for as extra work.

State of California, Business and Transportation Agency Standard Specifications, January 1978, pp. 343-346.

APPENDIX D

VERTICAL DRAINS

Description. This work shall consist of constructing one or more bore holes of relatively large size 9-18 inch (229-457 mm). These shall be placed according to specifications and the lines, spacing, and orientations in reasonable conformity with the plans or as established by the engineer. The holes shall be filled with a pervious backfill of concrete sand. These holes will accept ground water (seepage water) and conduct it downward to an underlying pervious aquifer which will accept the water and carry it away from the site.

The permeable materials should not be mixed with lime or flyash but must not be mixed with asphalt or Portland cement or other materials which would lithify and impede drainage. No large diameter rock greater than 2 inch (51 mm) shall be placed in the backfill or used as backfill.

MATERIALS. Material shall meet the requirements specified the following Subsections of Section 700-Materials. (Oklahoma Standard Specifications).

Cover Material (Backfill)	703.04(b)
Fine aggregate for PC Concrete	701.05 (AASHTO M-6-65)
Lime, hydrated	706.01

EQUIPMENT. Any drilling equipment capable of penetrating the material to be drained and the permeable underlying strata shall be acceptable.

CONSTRUCTION METHODS. Holes should be drilled into the permeable strata as shown on the plans or as directed by the Engineer. The holes may be advanced by means of a spiral auger or other types. The holes must be kept completely open to the designated depths. Casing may be advanced in order to keep the hole open.

Materials placed through water to the desired depth and shall be rodded or vibrated to prevent bridging and voids.

If the installation is to be made through pavement, the upper portion of the hole is to be plugged with bituminous or portland cement material at least the thickness of the pavement. The plug must be firm and neat and be able to withstand traffic.

MEASUREMENT. Vertical drains will be measured by the linear foot for drilling and for backfilling. The quantity for drilling shall be the depth of the hole. The quantity for backfill shall also be the depth of the hole.

PAYMENT. Vertical drains will be paid for at the contract price per foot of depth. Such payment shall include furnishing drilling holes, backfilling, and plugs if necessary.

The above payments shall include full compensation for furnishing all materials, tools, equipment, and incidentals and for doing all work involved in installing vertical drains, complete in place as shown on the plans as specified or as directed by the Engineer.

APPENDIX E

SOME SOURCES OF TERRAIN EVALUATION INFORMATION FOR UNSTABLE SOIL CONDITIONS

Soils

Soil Conservation Service (US Dept. of Agriculture)
Location: District Offices - usually in county seat cities.
Soil Conservation Service (USDA) State Office
Location: In Oklahoma the state office is in Stillwater.

Geology

U.S. Geological Survey
Location: In Oklahoma this agency is located at 200 NW Fifth and 214 NW Third, Oklahoma City.

Oklahoma Geological Survey
Location: University of Oklahoma, 830 Van Fleet Oval, Norman, OK

Oklahoma Water Resources Board
Location: Jim Thorpe Bldg., Oklahoma City.

Oklahoma City Geological Society
Location: Cravens Bldg., Oklahoma City

Tulsa, Oklahoma Geological Society
Location: Thompson Bldg., Tulsa, Oklahoma

Oklahoma Department of Mines
Location: 4040 N. Lincoln Boulevard
Oklahoma City.

Climate

National Oceanic and Atmospheric Administration (US Dept. of Commerce)
National Weather Service
Location: In Oklahoma this agency is located at Will Rogers Airport in Oklahoma City.

State Climatologist Office (None in Oklahoma)
Location: Usually the State Capitol

Topography

U.S. Geological Survey
Location: Denver, Colorado
Reston, Virginia

Oklahoma Geological Survey
Location: Norman, Oklahoma

Vegetation

Forestry Division, State Board of Agriculture
Location: State Capitol Bldg., Oklahoma City

Forest Service (US Dept. of Agriculture), Washington, D.C.
Location: Most states will have local offices.

Aerial Photographs

State Dept. of Transportation, Survey Division
Location: In Oklahoma 200 NE 21st, Oklahoma City

Agriculture Stabilization and Conservation Committee (US Department of Agriculture)
Location: Located in District Offices, usually in county seats.

Soil Conservation Service (US Dept. of Ariculture)
Location: District Offices, usually in county seats.