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16. Abstract

A total of 242 embankments were examined along a 122-mile transect of I-10 AND I-20 highways in Louisiana. A total of 99 slope failures had occurred 8-15 years after construction (mean volume = 15,105 cubic feet). Most of the failures occurred on slopes greater than 16 degrees. Over 70% of the failures were found in modern alluvium parent material as compared to loess, sandy alluvium and Priairie Terrace alluvium. It is believed that the high amount of smectite in these soils created most of failures when the slope moisture content rose. A predictive model for the first 15 years after construction was developed. A high-rise slope has an 85-90% chance of failure and is constructed of soil with: 47% clay content, a plasticity index (PI) 29%, a liquid limit (LL) 54%, and net smectite 33%. Low-risk slopes have a chance of less that 5% of failure and are constructed of soils with: 32% clay, 16% PI, 36% LL, and net smectite 18%. Determination of the risk category can be done easily in the laboratory using Atterberg limits. Control of slope stability depends upon control of expansive clays in the high- and intermediate-risk slope soils. It is recommended to lime stabilize these soils or use a new slope design. A map of the distribution of these soils in Louisiana is included. Four different design nomographs based on a stability model of the slopes is presented for soils in the high- and intermediate-risk categories. Depending upon the availability of space and economy, the designs include constant slope configuration, broken-back design, and soil-stabilized layers below the above two.

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DEVELOPMENT OF DESIGN CRITERIA FOR PREVENTION OF SLOPE FAILURES

DESIGN GUIDE

by

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DESIGN CRITERIA FOR PREVENTION OF SLOPE FAILURES

DESIGN GUIDE

A. INTRODUCTION

An enduring problem which plagues many regions throughout the United States is slope instability on embankments along interstate highway systems. In Louisiana in the last ten years, over 100 embankments have failed along the state's two major highway systems, primarily between Lake Charles and Lafayette along I-10 and in Madison Parish along I-20. Over 200 total landslides have been noted during that same time in the state.

The objectives of this study were to determine why these slopes failed, to develop a model for identifying these problem soils, and to recommend ways of repairing the failed slopes and preventing failures on new slopes. A total of 242 embankments were examined along a 122-mile transect of I-10 and I-20 highways in Louisiana.

It was determined that failures occurred most often in slopes constructed of soils high in smectite (shrink-swell clays previously known as montmorillonite). Therefore, control of slope stability depends upon control of these clays.

This report summarizes the method of determining if there is a problem soil, and also provides two alternatives to slope construction. One method is lime stabilization of the problem soil to inactivate the shrink-swell clays. The second method is to redesign the slope and use the natural soil material without lime stabilization. Four methods of redesign are noted.

These methods can be used for the initial design of the slope, the repair of a failed slope, and the recognition of slopes that are highly prone to failure in the future.

B. DETERMINATION OF PROBLEM EXPANSIVE SOILS

Atterberg limits and clay content should be calculated for any soil to be used to make an embankment. Each of the values should be compared to the risk model (Table 1) and categorized as high-, intermediate-, or low-risk. The overall risk category for the slope is determined from the category which has at least two of the samples in it. For instance, a sample with the liquid limit and the clay content in the high-risk category and the plasticity index in the intermediate-risk category is considered to be a high-risk slope. In most cases, the Atterberg limits should provide sufficient information for classification. The clay content does not have to be run unless the two Atterberg limits fall into different classifications.

If the overall slope classification falls into the low-risk category, the chances of slope failure in the next 15 years are low. Traditional slope design methods can be used for these soils. If the classification falls into the intermediate- or high-risk category, then the soil is considered a "problem expansive soil" and the chances of slope failure in the next 15 years after construction are 60-90%. These soils must be treated or the slope design must be altered.

Why is there a differentiation between high- and intermediate-risk categories? This is primarily for determining priorities in repair and showing which soils are most prone to failure. If slopes that have not failed yet are sampled and the soil falls into the high-risk category, there is a much higher chance of failure during the next large rainfall than a slope of intermediate-risk category.

TABLE 1

SLOPE STABILITY RISK CATEGORIES FOR EMBANKMENT SOILS

GEOTECHNICAL TEST	HIGH* RISK	INTERMEDIATE* RISK	LOW* RISK
LIQUID LIMIT	> 54 %	36 - 54 %	< 36 %
PLASTICITY INDEX	> 29 %	16 - 29 %	< 16 %
CLAY CONTENT	> 47 %	32 - 47 %	< 32 %

* : HIGH-RISK CATEGORY: 85-90% chance of failure 8-15 years after construction

INTERMEDIATE-RISK CATEGORY: 55-60% chance of failure 8-15 years after construction

LOW-RISK CATEGORY: < 5% chance of failure 8-15 years after construction

C. RECOGNITION OF EXPANSIVE SOILS IN THE FIELD

In the field, the following characteristics in the soils generally indicate that they are expansive soils, and they might be high- or intermediate-risk soils for slope construction:

1) Very sticky to the touch when wet,
2) Polygonal cracks form on the surface when the soil dries out,
3) Gray color with red mottles (patches of red).

D. DISTRIBUTION OF EXPANSIVE SOILS IN LOUISIANA

Use the map of the distribution of shrink-swell clay soils in Louisiana before starting work in a new region to determine if expansive soils are found there (Figure 1). For more exact information, consult the soil survey of that particular parish and look for the soil series listed in Table 2. If shrink-swell soils are found in that region on the map, there is a chance for high- and intermediate-risk soils being present. Sampling of the actual slope material to determine Atterberg limits must be done for each site.

E. LIME STABILIZATION OF HIGH- AND INTERMEDIATE-RISK SOILS

If the soil sample for a slope was determined to be a high- or intermediate-risk soil, then one alternative is to lime stabilize the soil as the slope is being constructed or to remove the soil from a failed slope, lime stabilize it, and rebuild the slope.

F. SLOPE STABILITY MODEL FOR STUDY AREA IN LOUISIANA

The slope stability model developed in this project (Figure 2) adequately characterizes the embankment cross sections and more importantly, accurately predicts embankment slope stability. The model, when applied to slopes in the I-20 study area, predicted slope failures in all of the 11 slopes used as examples. When applied to 20 stable slopes in the same area, it predicted stability in 17 of the examples. The three examples where failure was predicted had safety factors just below 1.0, and so were very close.

The slope stability model cross section (Fig. 2) is composed of three distinct soil layers. The top layer consists of vegetation covering the embankment top and sides, is approximately one foot thick, and provides no structural support. Soil layer 2 consists of the embankment fill material and is considered cohesive clay with a cohesive strength of 175 psf. Layer 3 is the natural soil surface upon which the embankment has been constructed and is primarily cohesive clay with a cohesion of 350 psf.

Two important conclusions were made from computer characterizations of the I-20 slopes. About two-thirds of the cases investigated resulted in failure surfaces extending well below the surrounding ground surface (deep-seated failures). Also, the predicted failure surface originated well back of the top of the embankment slope (i.e., approximately 6 - 8 feet from the top of the slope in the direction of the pavement edge) and approached the edge of the pavement shoulder. This information leads one to conclude that repair and rehabilitation schemes which only designate improvements above the existing ground elevations and from the top of the slope to the toe of the embankment slope may not alleviate the slope stability problem since deep-seated failures could possibly develop behind and underneath the improved embankment. In the field no evidence of this deep-seated failure mechanism has been located as of yet.

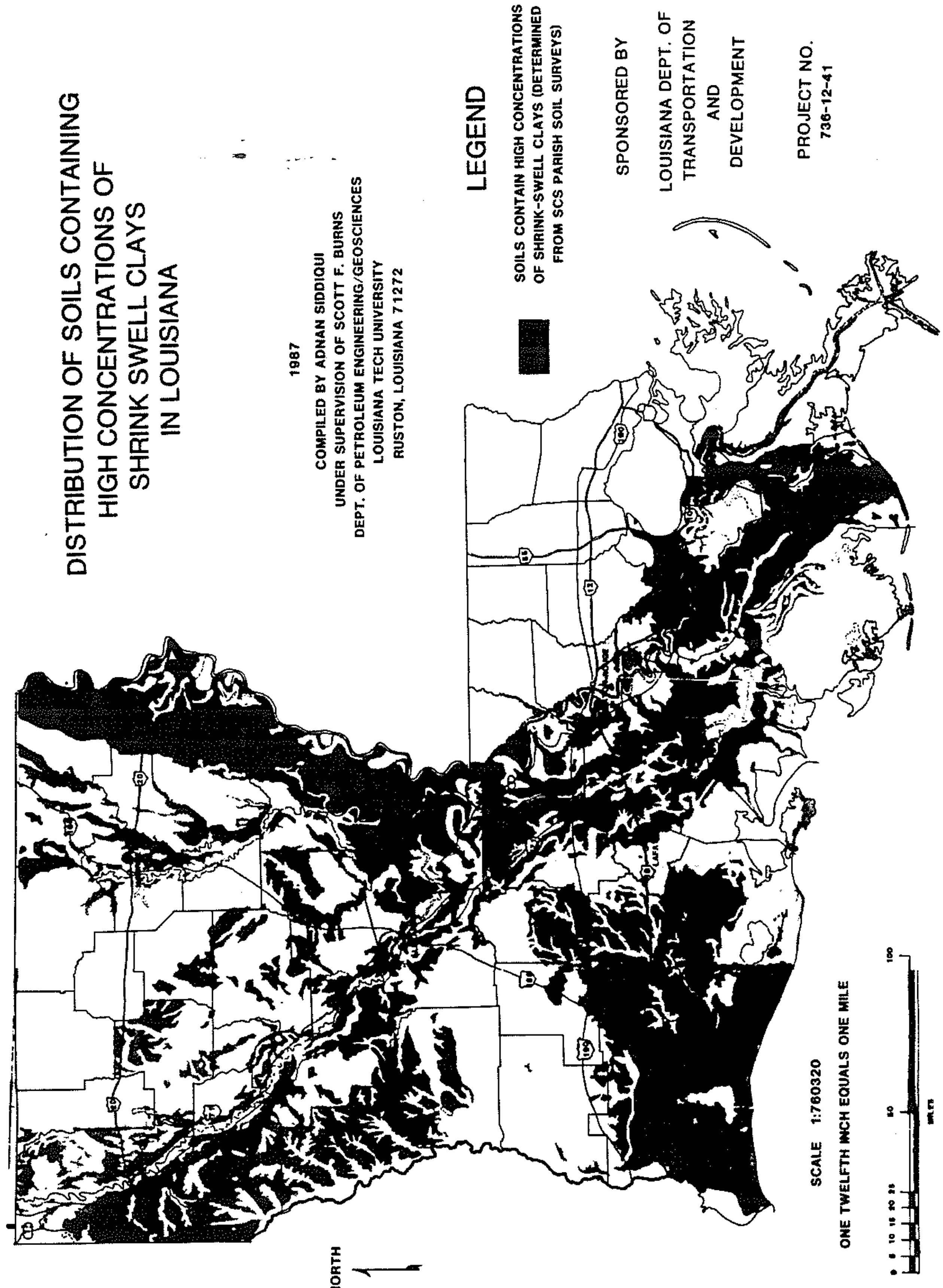

Figure 1. Map of distribution of expansive soils in Louisiana.

TABLE 2

SOIL SERIES IN LOUISIANA CONTAINING SHRINK-SWELL CLAYS

Acadia	Ijam	Sharkey
Allemands	Judice	Solier
Alligator	Kaufman	Sostien
Anacoco	Kisatchie	Susquehanna
Baldwin	Larose	Sumter
Barbary	Latanier	Tensas
Bayoudan	Lebeau	Tunica
Beaumont	Litro	Una
Bellpass	Mayhew	Vaiden
Bellwood	Midland	Watsonia
Buxin	Moreland	Westwego
Clovelly	Morse	Woodtell
Eutaw	Natchitoches	Wrightsville
Fausse	Newellton	
Forbing	Oktibbeha	
Forestdale	Oula	
Ged	Perry	
Gentilly	Placebo	
Harahan	Pledger	
Harris	Portland	
Hollywood	Rita	
Houston	Roebuck	
Iberia	Scatlake	

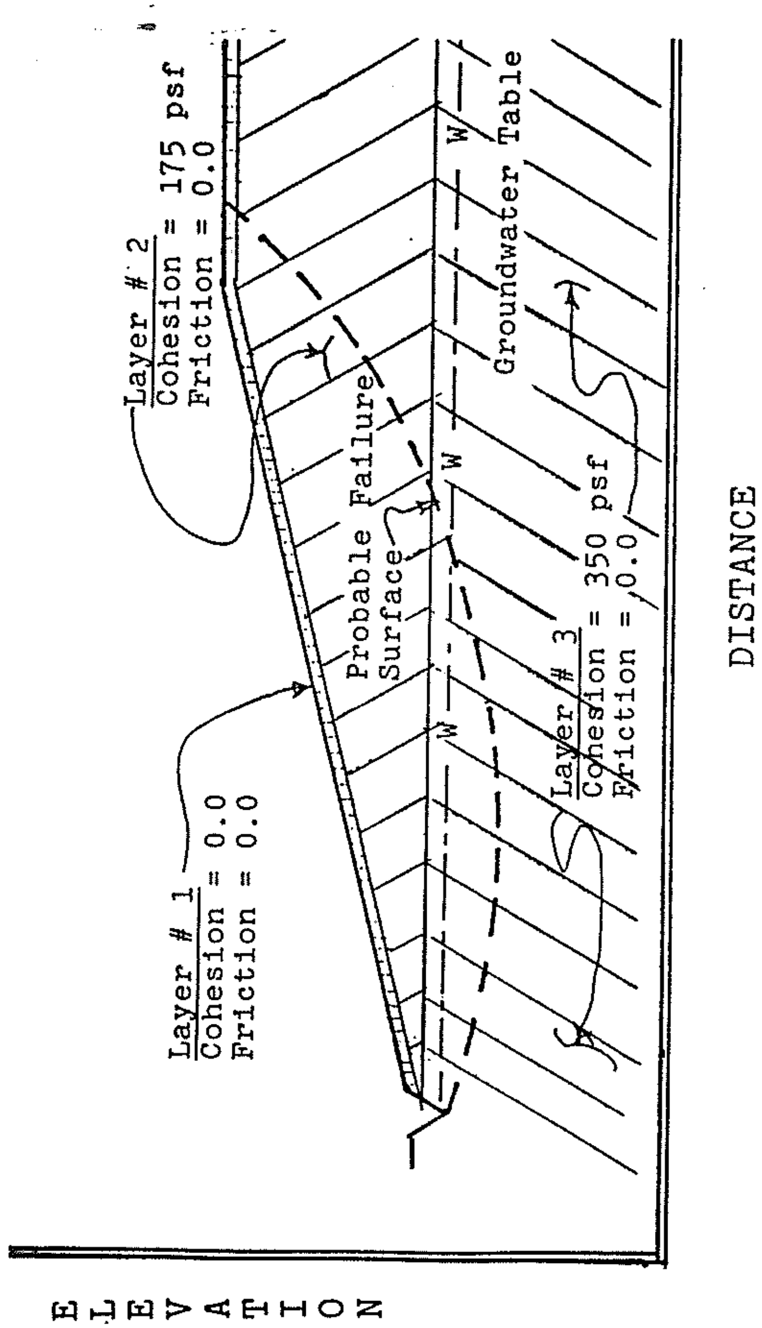

Figure 2. General soil-embankment conditions and slope stability model cross section.

G. DESIGN OF SLOPES WITH HIGH- AND INTERMEDIATE-RISK SOILS

If the soil sample for a slope is determined to be a high- or intermediate-risk soil, then another alternative is to use a different slope design to construct a new slope or reconstruct a failed slope. These designs are based on the slope stability model presented in the last section.

The options considered in the selection and evaluation process will depend upon space and economy, as well as existing or projected soil strength. The amount of available or acquirable right-of-way would certainly delineate those design options which would be viable alternatives. Economy of construction would also be a consideration in the selection process, along with embankment height and soil strength. As a result, no rule of thumb can be offered concerning an appropriate design option. The circumstances surrounding a particular job site would therefore determine to a great extent the design option or options that would meet the project requirements.

These designs are applicable for the specified cases within the limits of PCSTABL4. Applicability to other sites requires further investigation by a geotechnical engineer. No slope design or redesign should be attempted using this method alone.

1) Constant embankment slope configuration

The design nomograph for constant embankment slope is presented in Figure 3. This configuration would be utilized in those situations where acquisition of right-of-way is not a problem and where low slope angles can be used. This method would be cheaper than the lime stabilization method as the natural soils would only be compacted, not limed.

The input for this nomograph would include the height of the embankment, H, and desired stability number (safety factor). The intersection of a horizontal line through the stability number with a vertical line through the height, H, would yield the minimum acceptable embankment slope, S.

2. Broken-back embankment configuration

This configuration (Figure 4) was developed for the case of limited right-of-way or reconstruction of an existing embankment where lime stabilization is not wanted. The broken-back term describes an embankment configuration consisting of two different slopes. The upper slope is the steeper of the two. This configuration was selected because it represented an opportunity to reduce the mass of earth captured within the failure surface and should result in a lesser driving force and corresponding higher stability number.

The nomograph (Figure 4) is used in a fashion similar to that described in the constant slope configuration case above. A vertical line would be constructed from the height of embankment, H, while a horizontal line would be constructed from the desired stability number (safety factor). The intersection of these two lines would yield the combination of slopes S1 and S2, which meets the stability requirement.

3) Broken-back embankment with stabilized soil layer

In the two previous design configurations, the failure surface dipped quite a bit down into the subgrade or third soil layer. This third configuration was established to create a situation in which a stabilized soil layer would limit the intrusion of the predicted failure surface into the subgrade or bottom soil layer. The stabilized layer would offer an additional advantage in that it would substantially reduce the movement of soil moisture from the subgrade or bottom layer to the upper embankment layer. It is more expensive than the above two methods and would require stabilization of the lower soil layer, probably by lime stabilization.

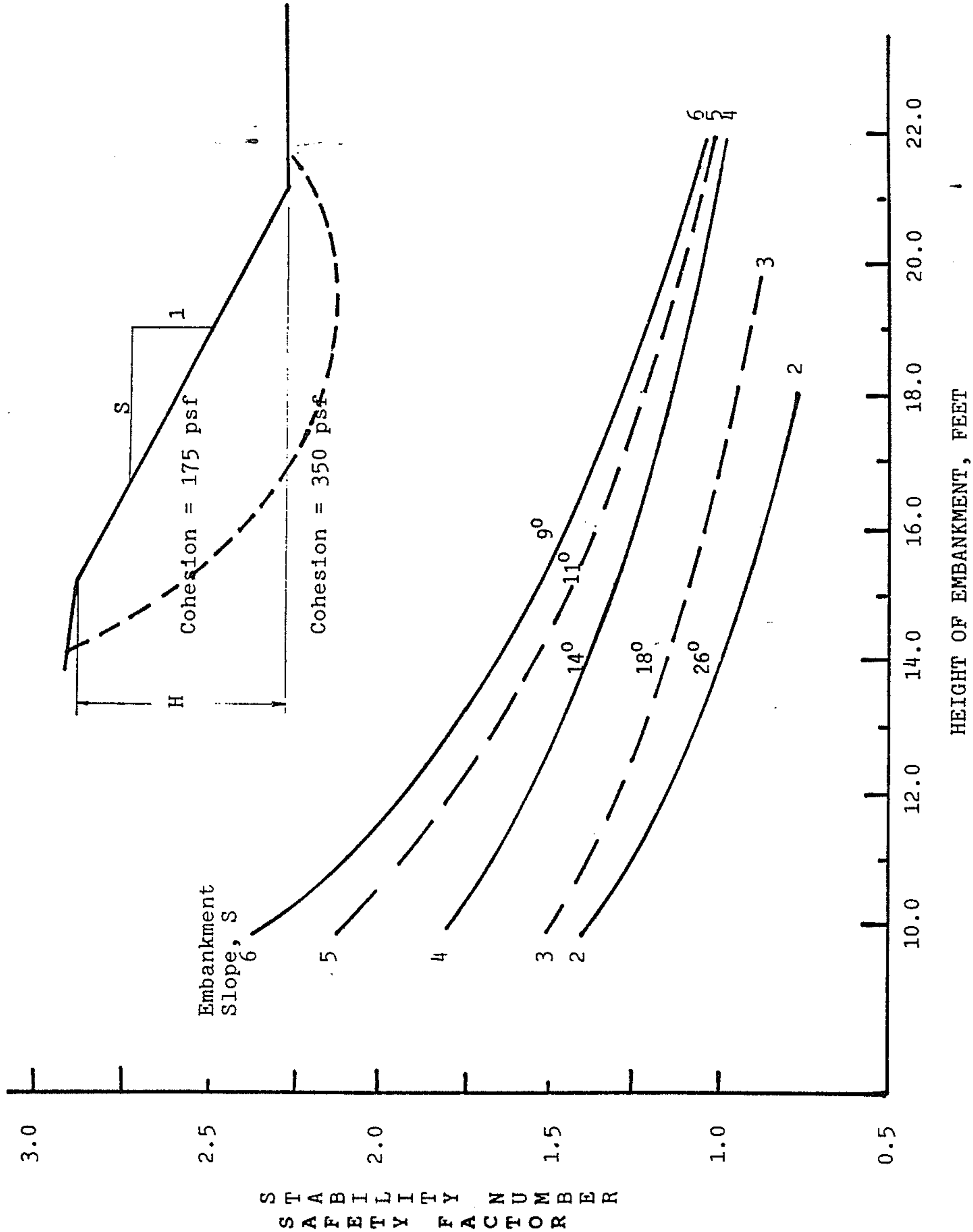

Figure 3. Stability numbers (safety factors) for constant slope of embankments and embankment height. No slope design or redesign should be attempted using this method alone.

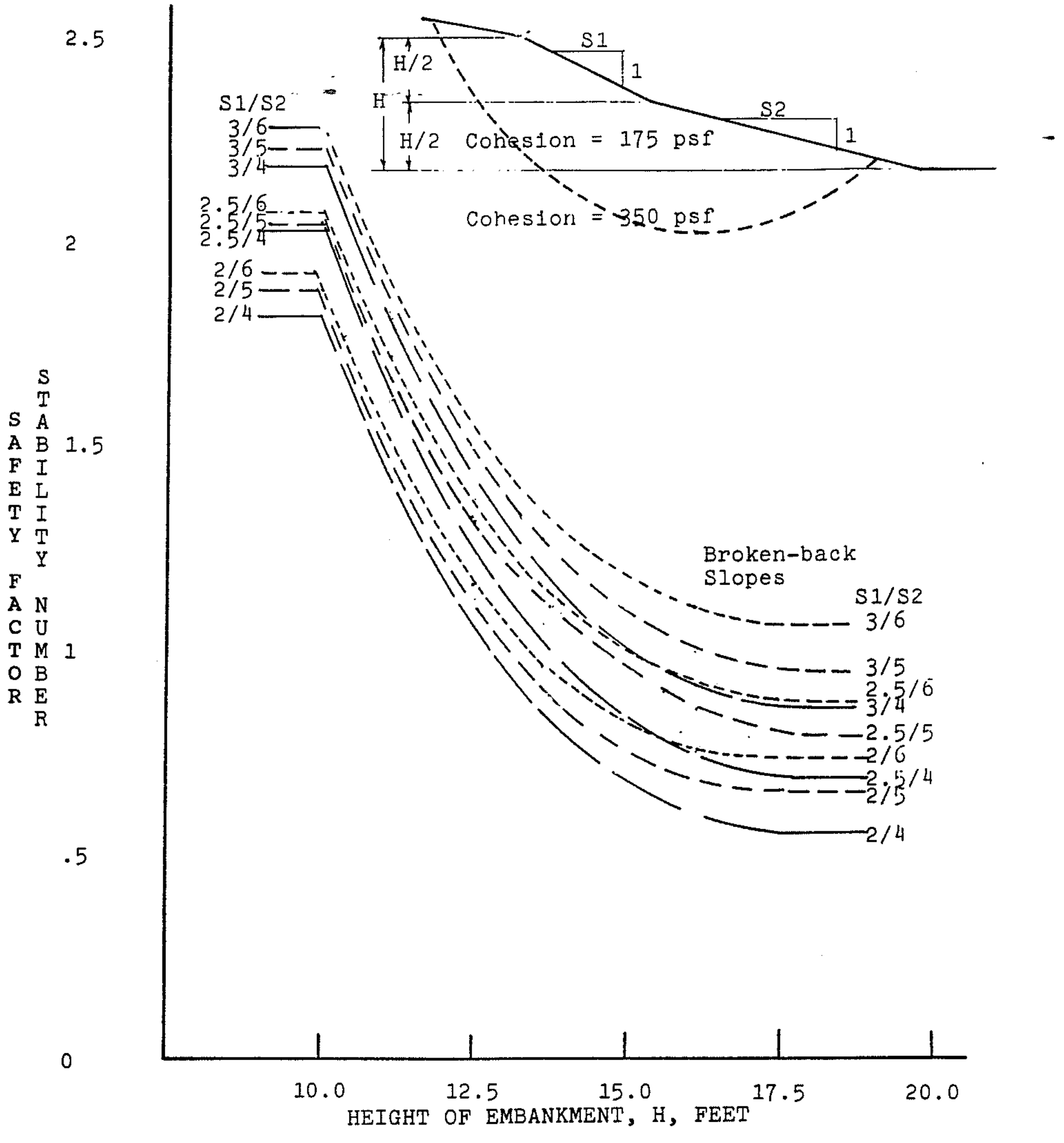

Figure 4. Stability numbers (safety factors) for broken back embankment configuration with varying heights and slopes. No slope design or redesign should be attempted using this method alone.

The nomograph (Figure 5) is used in the same fashion as the preceding one. The stabilized soil layer would have to have a minimum thickness of 18 inches. Economics would, of course, play a major role in evaluating this option.

4) <u>Constant slope configuration with stable subgrade</u>

The fourth case involves the placement of a clay material as embankment over a stable subgrade with a cohesive strength of 700 psf or more. This would represent a case in which the in situ soil material would be stable and unaffected by available groundwater (not a very active clay).

Minimum embankment slopes for this situation can be obtained by the appropriate entry of the nomograph (Figure 6) with embankment height, H, and desired stability number (safety factor).

5) <u>Additional designs for different cohesive strengths</u>

For those cases where soil moisture movements can be controlled and soil cohesive strength is estimated from either Figure 7 or 8, these four nomographs presented in Figures 3-6 can also be used in establishing minimum embankment slopes. The correction for the effect of increased cohesion would be handled by adjustments to desired stability number (safety factor), since an increase in soil cohesive strength would yield higher stability numbers. Consequently, the nomographs could be used in the present form by multiplying the desired stability number by the ratio of 175 to the estimated cohesive strength.

For instance, a soil cohesive strength is estimated to be 280 psf and a desired stability number of 1.3 is established. An adjusted stability number of 0.81 (adjusted stability number equals 175 x 1.30 / 280, or 0.81) would then be used with an appropriate design nomograph to establish a minimum slope or slopes.

H. <u>RECOMMENDATIONS COMMON TO ALL SLOPES</u>

Based on our work, the following suggestions are made for new construction or reconstruction of repaired slopes:

1) Do not use pilings to repair slopes that are constructed of high- or intermediate-risk soils. They merely become conduits for moisture to enter the slope and actually increase the chances of slope instability.

2) Extend the revetment of overpasses around the sides of the embankment (Figure 9).

3) Provide ample drainage to keep water off of the slope.

4) Vegetate the slope not with grass, but with pampas grass (<u>Cortaderia selloana</u>) if it is available (Figure 10). Unlike grass, pampas grass will not require mowing and thus will further stabilize the slope.

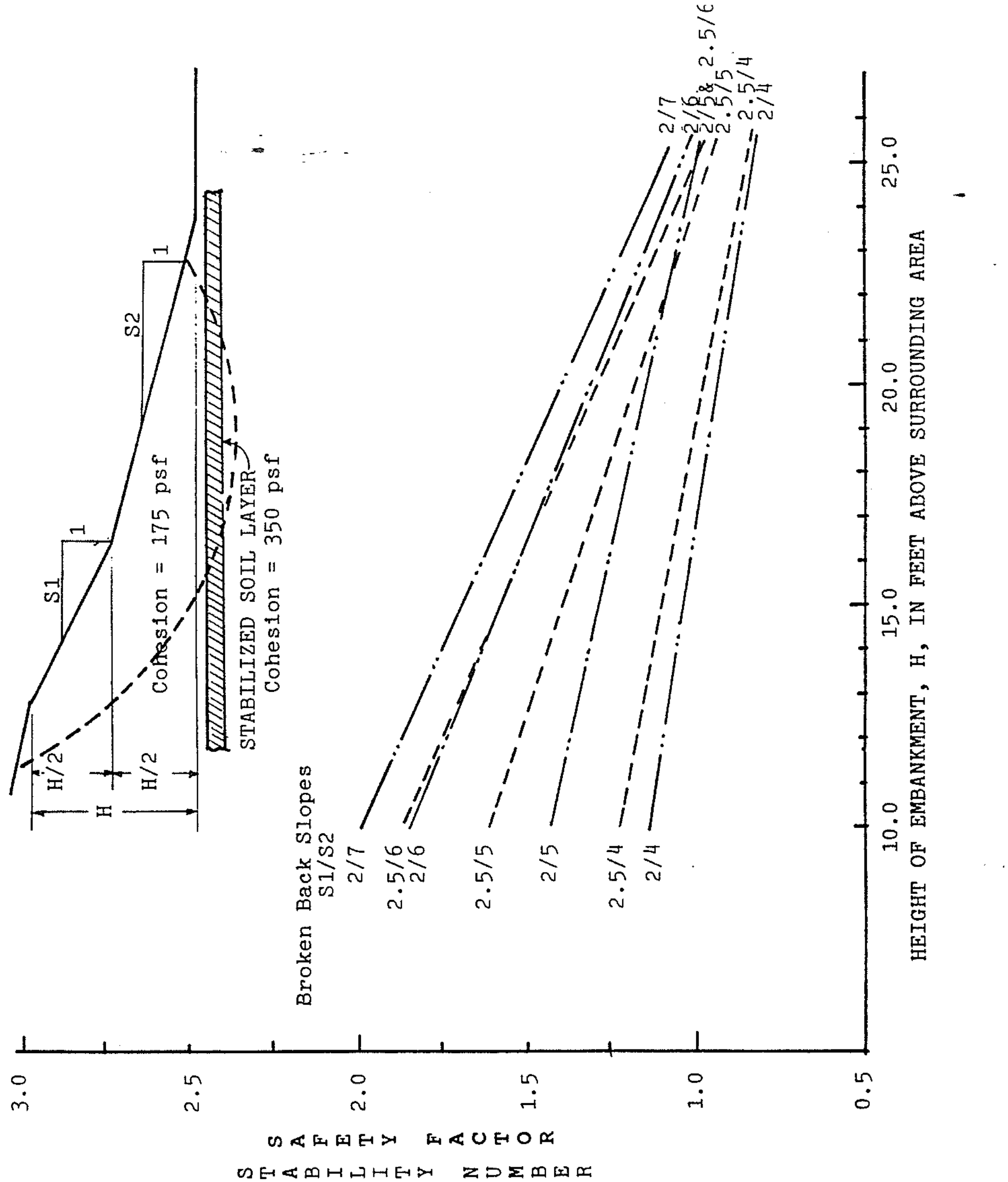

Figure 5. Stability numbers (safety factors) for broken back embankment configuration and stabilized soil layer at toe of slope; consideration of height, H, and slopes, S1 and S2. No slope design or redesign should be attempted using this method alone.

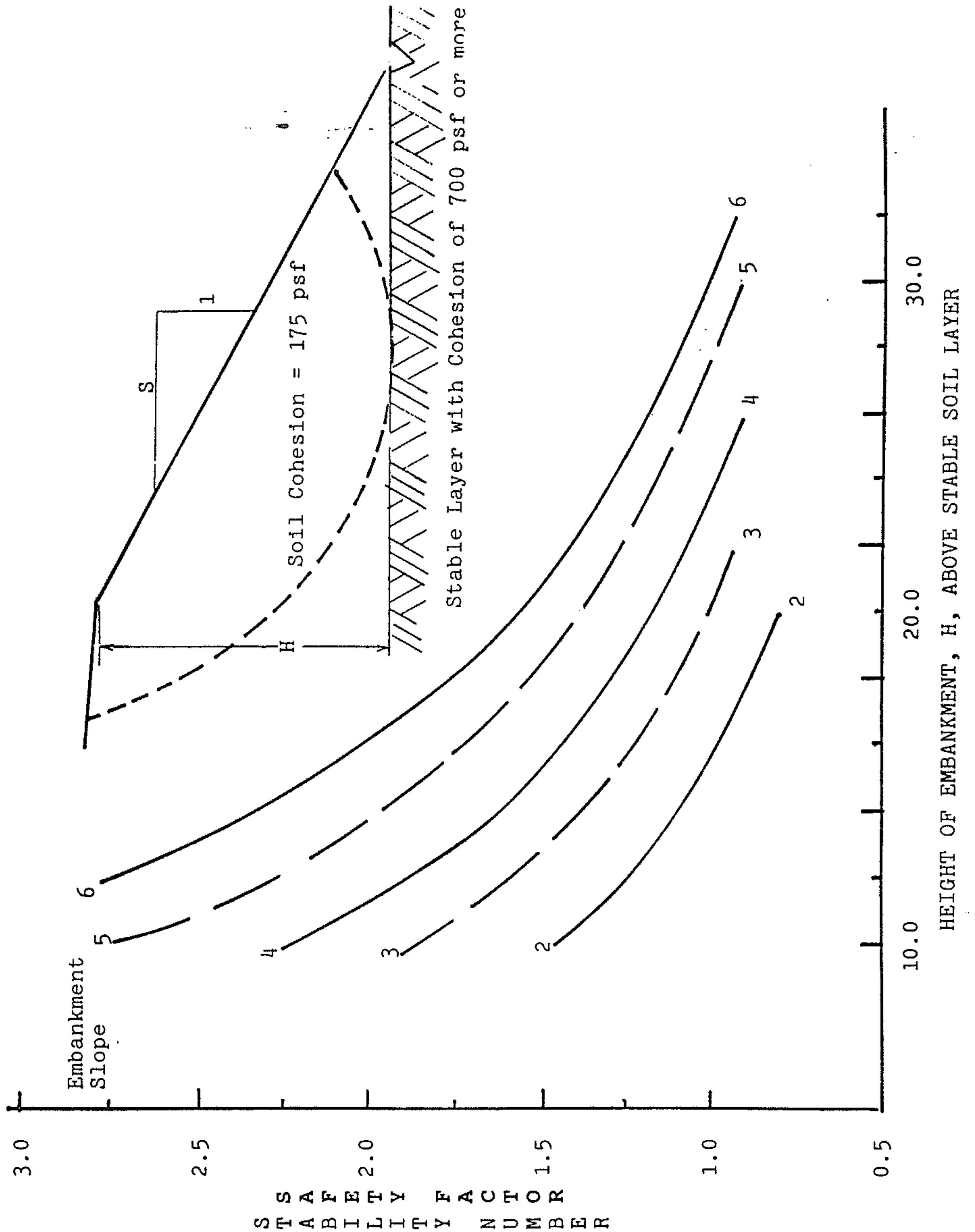

Figure 6. Stability numbers (safety factors) for embankment founded on stable subgrade. No slope design or redesign should be attempted using this method alone.

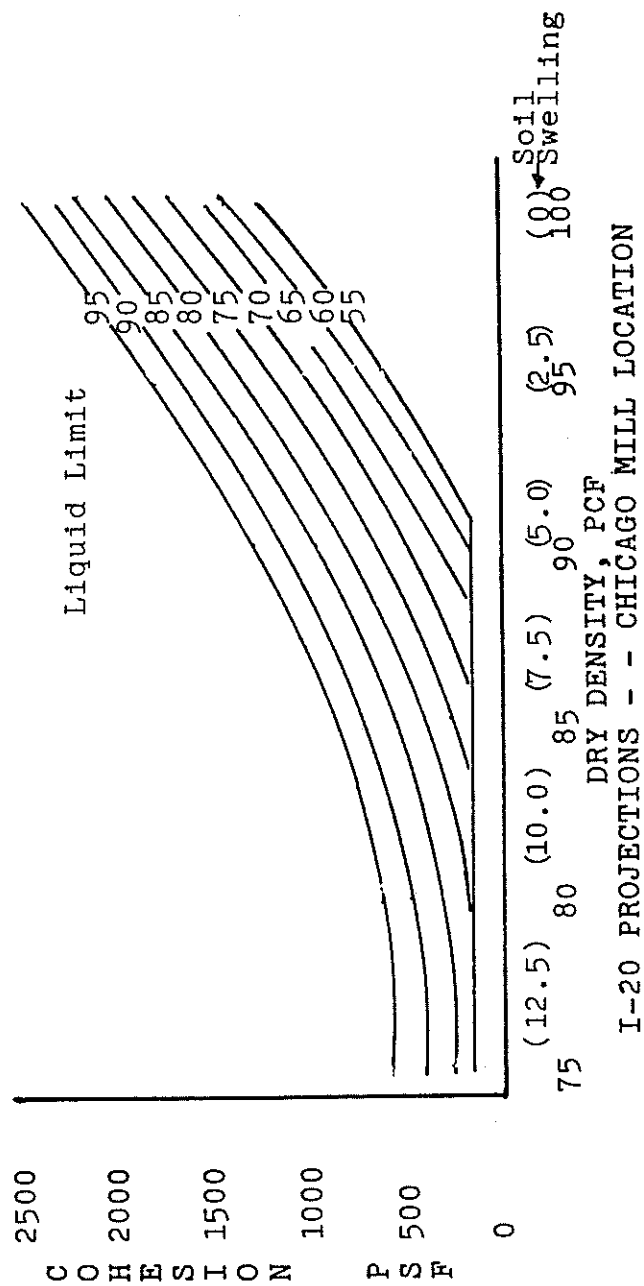

Figure 7. Soil cohesion estimates for high plasticity clays (CH) for varying density and liquid limits. No slope design or redesign should be attempted using this method alone.

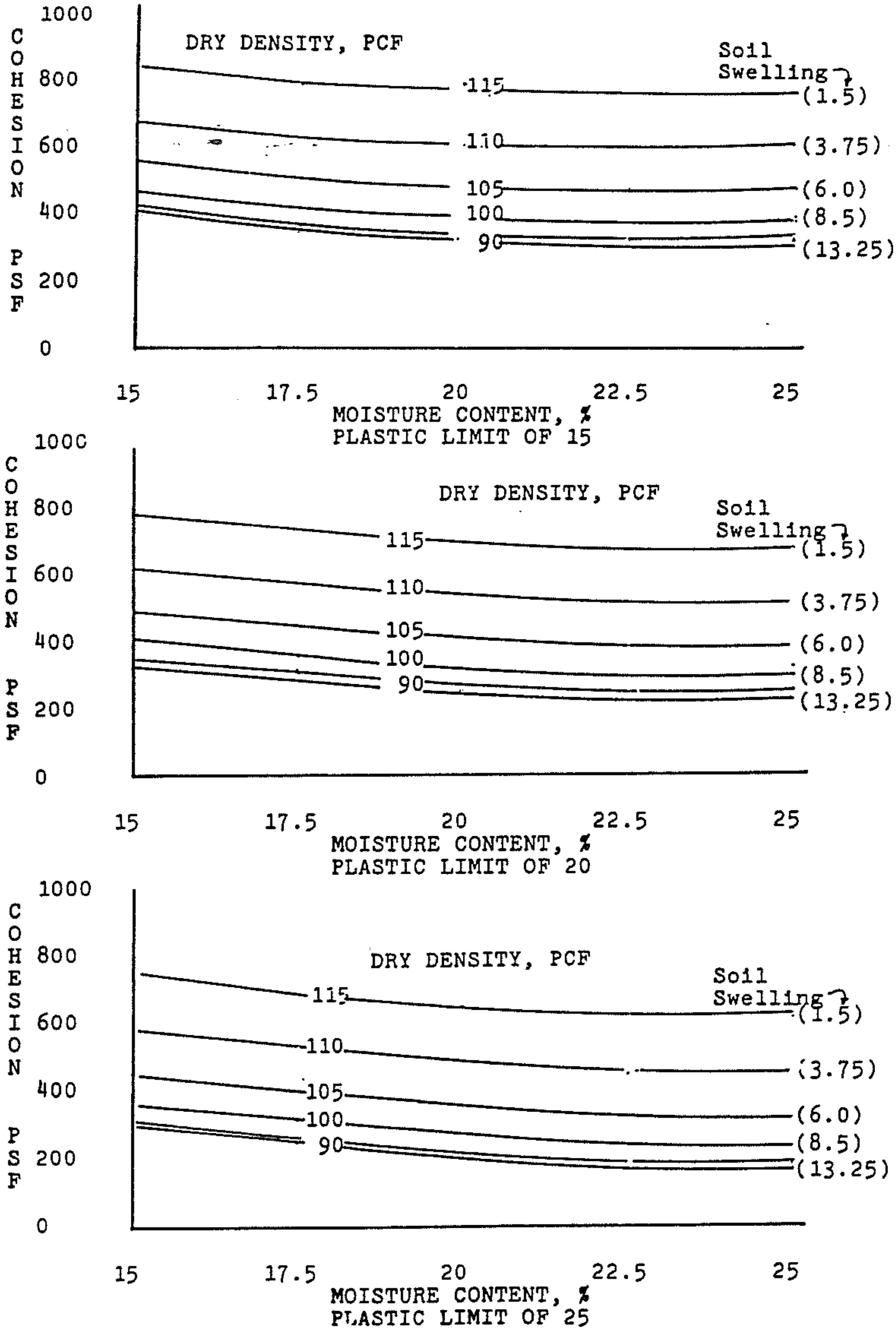

Figure 8. Soil cohesion estimates for low and medium plasticity clays (CL) for varying moisture, density and plastic limits. No slope design or redesign should be attempted using this method alone.

Figure 9. Wrap-around aprons on the revetments. This site has not failed and is located at the interchange at Rayne in the I-10 study area. This design is recommended to reduce the large number of header failures.

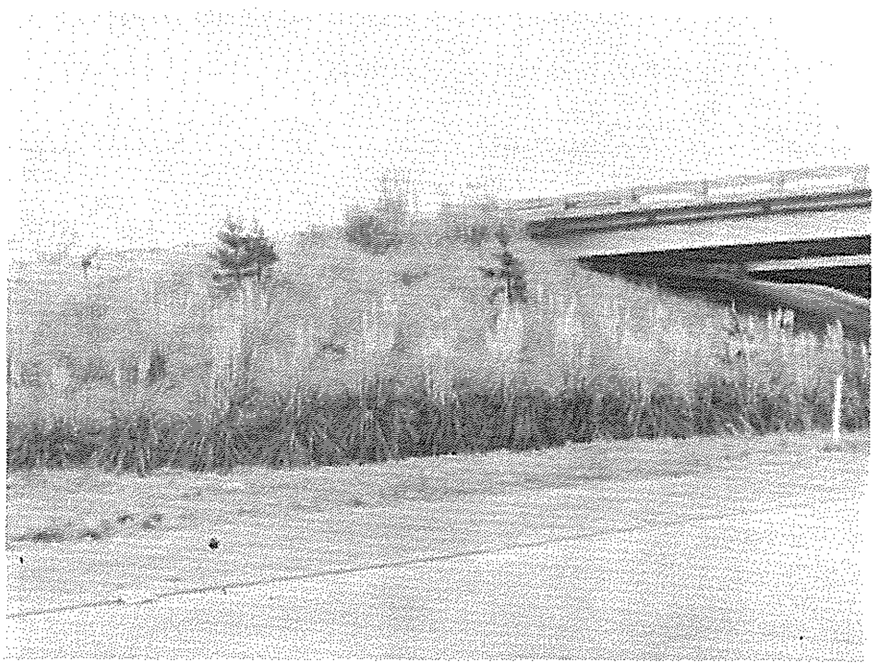

Figure 10. Slope stabilization with exotic vegetation. At this locality S1 in Calcasieu Parish in the I-10 study area, pampas grass has been successfully used to stabilize a repaired slope.

I. REDUCTION OF CUT-BANK SLOPE FAILURES

In the north-central and northwestern parts of Louisiana in the hill country on the Tertiary bedrock, slope failures in cut-bank slopes are common. Most of these result from making road-cuts into slopes that have a clay layer in it (Figure 11). These clay layers retard the passage of water from above, and after heavy rainfall, become failure surfaces upon which the slopes slide to failure. Over 90% of the slope failures in cutbanks in Louisiana occur where clay layers have formed the failure surface.

It is important to recognize these clay layers in slopes that have been cut. They are noted by gray or brown, fine-grained soil that usually is sticky. The soil is generally moist above the layer. During and just after rainstorms, springs will come out of the slope above the clay layer. These clay layers can be noted before incision of the roadcut by the presence of a moist area on a slope.

If such clay layers are present, the slope angle above the clay layer must be greatly reduced. It is recommended that the slope angle be less than 10 degrees (less than 4:1). Drainage tile can also be used to combat these failures when placed directly above the clay layer, but this method is very costly and is not recommended.

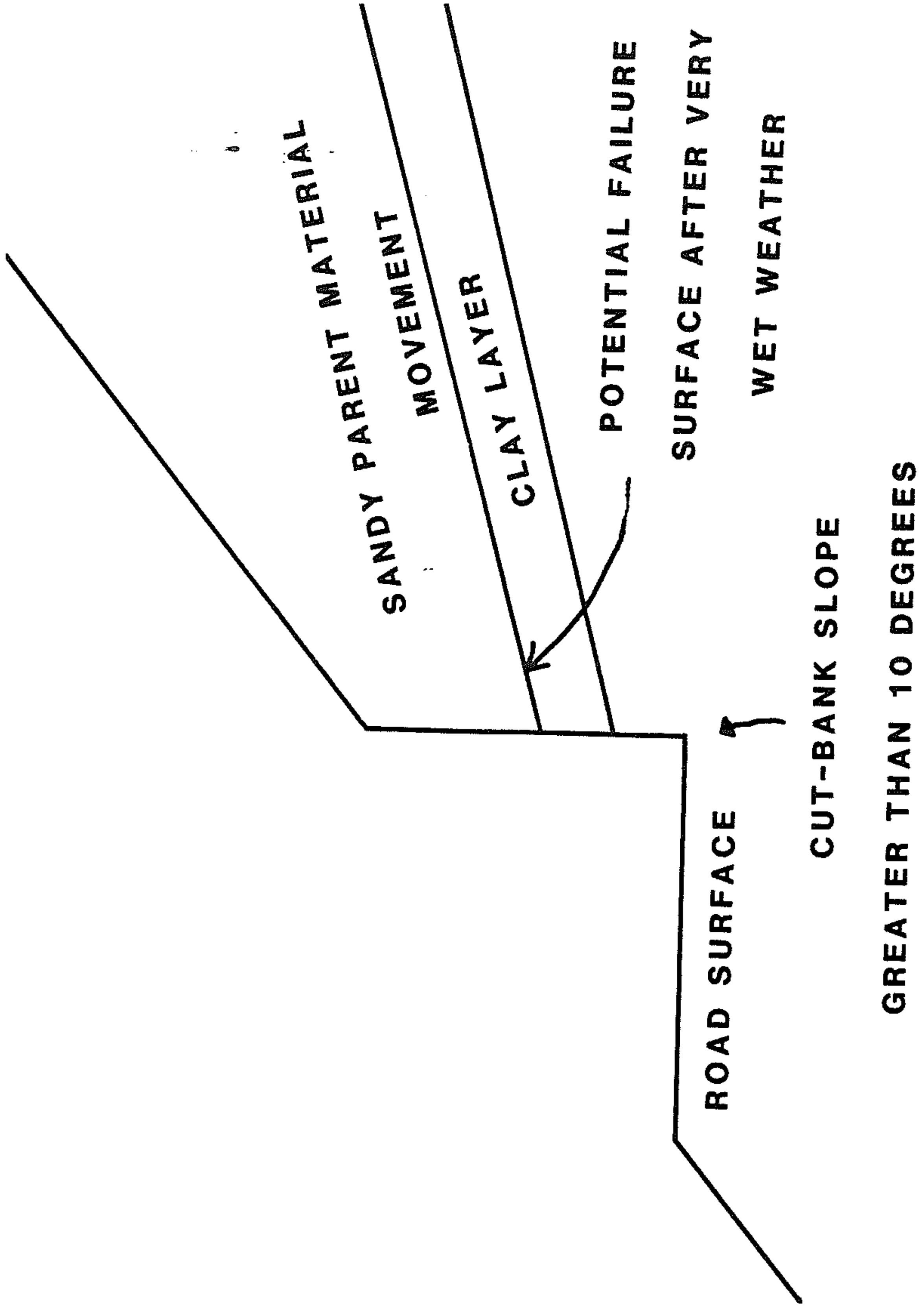

Figure 11. Potential landslide in cut-bank along a road.