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Highway Rock Slope Reclamation and Stabilization Black Hills Region South Dakota Part II, Guidelines

Study SD94-09-G
Final Report

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DISCLAIMER

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16. Abstract

Numerous constructed rock slopes along highways traversing the Black Hills region require considerable maintenance every year. Many of these slopes are steeply inclined and are susceptible to the effects of erosion and possible instability. The objectives of the study are to (1) categorize existing constructed rock slope conditions in the Black Hills, (2) evaluate treatment methods presently used in the Black Hills, (3) evaluate other treatment methods with respect to Black Hills conditions, (4) develop site-specific rock slope treatment methods for several specific Black Hills rock slopes, (5) develop recommendations for improving rock slope stability and provide guidelines for cost-effective implementation of those recommendations.

The report provides recommendations for treatment methods for sites identified by the SDDOT and also provides "problem-specific" guidelines for selecting treatment methods that may be applied to other sites. Twenty-five study site were selected from highway sections identified by the SDDOT, which include sections of US85, US385, US16, US16A, and SR71. The sites were selected to give a representative cross section of cut slope performances.

Rock and soil units represented in the 25 site studies are grouped into six categories based on rock and soil engineering characteristics, slope failure mechanisms, optimum stable slope ranges, and applicable slope treatment methods.

The report consists of two parts, each bound separately. Part I provides a detailed discussion of the site conditions, research methods and results, and suggestions for continuing studies; the Appendix to Part I contains information and photographs compiled during field reconnaissance for the 25 study sites. Part II of the report provides a detailed discussion of the "problem-specific" guidelines, and references; the Appendix to Part II contains blank site reconnaissance forms and examples of completed forms.

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Highway Rock Slope Reclamation and Stabilization
Black Hills Region, South Dakota
Part II

January 5, 1995

For
South Dakota Department of Transportation

CONTENTS

ROCK SLOPE STABILIZATION GUIDELINES
HIGHWAY ROCK SLOPE RECLAMATION AND STABILIZATION
BLACK HILLS REGION, SOUTH DAKOTA
FOR
SOUTH DAKOTA DEPARTMENT OF TRANSPORTATION

INTRODUCTION

This portion of the report, Part II, presents the guidelines developed to aid in the examination of rock cut slopes and the evaluation of treatment methods appropriate for stabilizing those slopes. The guidelines are intended to be used for the examination of existing slopes as well as part of the design process for slopes in new construction. The guidelines are structured to lead the user to the final design stage, at which point final considerations of costs, materials, construction techniques, and a myriad of other considerations must be included in the design process. The purpose of the guidelines then, is to lead the user through the process to the point of selection of slope treatment methods most appropriate to the given conditions for each particular slope.

The guidelines are structured for ease of use by a variety of users and for a variety of situations. The guidelines should allow for the scoping of a particular problem site by any engineering personnel through a preliminary site reconnaissance. Communication between key engineering disciplines will be required to determine the detail of geotechnical investigation needed and select appropriate rock slope treatment methods. An outline of the guidelines is presented on page II-2. A listing of the major considerations of each step of the guidelines is presented on pages II-3 through II-5. Finally, detailed discussions of the individual elements in the steps are presented on pages II-6 through II-36. Photographs are included where necessary to illustrate a particular slope condition or treatment method. The complete list of references developed for this study is included at the end of this report. Those references that, in our opinion, are most applicable are also listed at the end of the discussion of each step in the guidelines where they most likely will be used.

It is not likely that every step listed in the guidelines will occur in the process of examination of every slope. Also, in the normal selection process frequent iterations will be necessary as probable treatment methods are evaluated with respect to specific concerns and conditions.

Copies of the "Site Reconnaissance" forms developed for use with these guidelines are included in the Appendix. Examples of completed forms are also included to demonstrate how the forms are used.

The reader is referred to Part I of this report for examples of the use of the guidelines to evaluate specific sites in the Black Hills.

ROCK SLOPE STABILIZATION GUIDELINES

Step 1. List Concerns and Constraints; Rank Concerns and Constraints

Step 2. Investigate Site

Step 3. Determine Optimum Slope Range(s)

Step 4. Analyze Stability of Optimum Slopes Determined According To Standard Design and Construction Prescriptions

IF STABLE - Proceed to Step 7
IF NOT STABLE - Proceed to Step 5

Step 5. Select Treatment Methods To Match Optimum Slope Range and Site Conditions

Step 6. Analyze Treatment Methods To Verify That Stability Is Achieved

IF STABILITY HAS BEEN ACHIEVED - Proceed to Step 7
IF STABILITY HAS NOT BEEN ACHIEVED - Reevaluate concerns and constraints (Step 1) and develop compromise treatment solutions (Steps 5 and 6) for the "unstable" slope. Proceed to Step 7

Step 7. Define Design for Each Identified Potential Alternative

Step 8. Complete Preliminary Design and Cost Analysis for Each Identified Potential Alternative

Step 9. Select Preferred Treatment Methods

Step 10. Complete Final Design

Step 1

List Concerns and Constraints

- Safety
- ROW
- Aesthetics
- Maintenance
- Funding
- Constructability
- Standards
- Acceptability
- Etc.

Rank Concerns and Constraints

- Matrix
- Choosing by Advantages
- Etc.

Step 2

Investigate Site

Always Done

- Site Information Forms
- Field Developed Cross Sections
- Review Historical Data
  - Geologic
  - Maintenance
  - Weather
  - Etc.
- Vegetation
- Surface and Subsurface Water

Done Only When Necessary

- Geophysical
- Coring or Drilling
- Aerial Photographs
- Laboratory Testing
  - Classification
  - Strength
  - Agricultural
  - Physical Characteristics

Step 3

Determine Optimum Slope Range(s)

- Satisfy Concerns

Step 4

Analyze Stability of Optimum Slopes Determined According To Standard Design and Construction Prescriptions

- Rock Slope Stability
- Soil Slope Stability
- Experience

IF STABLE - Proceed to Step 7

IF NOT STABLE - Proceed to Step 5

Step 5

Select Treatment Methods To Match Optimum Slope Range and Site Conditions

- Grading
- Mechanical
- Structural
- Vegetative
- Combinations

Step 6

Analyze Treatment Methods To Verify That Stability Is Achieved

IF STABILITY HAS BEEN ACHIEVED - Proceed to Step 7

IF STABILITY HAS NOT BEEN ACHIEVED - Reevaluate concerns and constraints (Step 1) and develop alternatives to accommodate "unstable" design and reduce objections (Steps 5 and 6). Proceed to Step 7.

Step 7

Define Design Details for Each Identified Potential Alternative

- Slope Angles
- Dimensions - Benching, Slope Breaks, Ditches
- Drainage
- Structure Dimensions
- Vegetative Patterns, Techniques, Materials

Step 8

Complete Preliminary Design and Cost Analysis for Each Identified Potential Alternative

- Life Cycle Cost
- Construction Costs
- Constructability
- Maintenance Costs
- Maintainability
- Acceptability
- "Political" Costs
- Liability

Step 9

Select Preferred Treatment Methods

- Results of Cost Analysis
- Compare to Concerns and Constraints
- Constructability
- Maintainability
- "Political" Concerns
- Capitalize on Features, Not Hide

Step 10

Complete Final Design

STEP 1 - LIST CONCERNS AND CONSTRAINTS

The purpose of this first step is to identify all of those items that affect the final slope design. Many items are part of the "standard" process and may preclude a stable, cost-effective design. For example, if right-of-way constraints dictate a slope that is too steep to be stable for the local conditions, design alternatives may be severely limited. Or if design "standards" prescribe a 1H:1V (horizontal to vertical) slope in material that is unstable at that slope, design alternatives are again limited. A third example might be a local situation that dictates vegetated slopes for aesthetic reasons. Again, this criterion will limit the choice of alternatives available for final design because the slope or portion of the slope must be flat enough to support the growth of vegetation.

It is important in this step not to include design details. The development and evaluation of design details will be accomplished in later steps of the guidelines. The objective of this step is to remind the designer to consider all of the concerns that affect the choice of final design and to arrange them according to their relative importance. The second part of this step is very important in that the user objectively ranks the concerns according to their importance to the specific project. This ranking also is essential when it is necessary to compromise concerns with realities of cost, constructability, existing site conditions, etc. Use of a matrix system is helpful for this operation. We recommend the Trade-Off Evaluation Process, a very powerful tool for evaluating and ranking criteria according to their importance to a particular project or operation. References to help with this operation include the following:

8. Caraher, D. 1989. The tradeoff evaluation process: a brief description. Unpublished paper.

49. Suhr, J. 1984. A conversation about the tradeoff evaluation process. SAVE conference proceedings, 1984. Society of American Value Engineers.

STEP 2 - INVESTIGATE SITE

This is a very critical step in that the information collected at this time has a direct influence on every other step of the process. It is also the step frequently passed over because of lack of funds, absence of time, unavailability of trained personnel, or lack of appreciation of the importance of the information. The investigation for each site must be appropriate for the conditions of that site and the needs of the proposed project. All of the techniques listed are not necessary for each site and some sites may require use of techniques that are not listed. The investigation should be conducted by trained, experienced personnel who are able to recognize the conditions encountered and understand the effect of those conditions on the success of the proposed project. The minimum level of investigation of any site should include a reconnaissance and with recorded observations on the appropriate portions of the data collection sheets. This initial reconnaissance may be performed by any engineering personnel. During the completion of the data sheets it should be apparent if more detailed investigation is warranted.

Numerous references are available that discuss investigation techniques and procedures. References that we recommend include the following:

19. FHWA; Rock Slopes: Design, Excavation, Stabilization. 1989. Publication No. FHWA-TS-89-045. US Department of Transportation, Federal Highway Administration, McLean, VA.

34. NAVFAC; Soil Mechanics - Design Manual 7.01. 1986. Navy Facilities Engineering Command. Alexandria, VA. GPO

35. NAVFAC; Foundation and Earth Structures - Design Manual 7.02. 1986. Navy Facilities Engineering Command. Alexandria, VA. GPO

53. USDA Forest Service, Slope Stability Reference Guide for National Forests in the United States. 1994. Washington, DC: EM-7170-13.

STEP 3 - DETERMINE OPTIMUM SLOPE RANGE(S)

In this step, the designer determines the slope ranges that are best suited to the conditions evident from the site investigation and most nearly satisfy the concerns listed in Step 1. This does not mean at this point that the optimum slopes will be stable under all conditions. That evaluation of overall stability will be determined in Steps 4 and 6. For the sites studied in the Black Hills, the conditions observed have been grouped into six problem categories generally based on the failure mechanisms typical to each of those categories. A more complete discussion of these categories is presented on pages 11 through 29 in Part I of the report. For each of those categories, the following slope ranges are typically used:

- Rock Unit A - Slopes of 1/2H:1V or steeper for favorable discontinuity orientation, 1.2H:1V to 1/2H:1V for unfavorable discontinuity orientation
- Rock Unit B - Slopes of 1H:1V or flatter
- Rock Unit C - Slopes of 1½H:1V to 1/2H:1V depending on weathering
- Rock Unit D - Slopes of 1½H:1V to 3/4H:1V depending on ground water
- Soil Unit Sand - Slopes of 1H:1V or flatter
- Soil Unit Clay - Slopes of 2H:1V or flatter depending on ground water (will likely require drainage or structure support)

Step 5 of these Guidelines describes treatment methods and examples for slopes in each of these problem categories.

STEP 4 - ANALYZE STABILITY OF OPTIMUM SLOPES DETERMINED ACCORDING TO STANDARD DESIGN AND CONSTRUCTION PRESCRIPTIONS

In this step, the designer evaluates the stability of the slopes selected in Step 3 to meet the identified concerns for the actual site conditions indicated by the site investigation. In these guidelines, stability refers to stability against deeper-seated movement of the slope materials. It does not include the shallow sloughing, ravelling, or erosion that may occur on slopes. However, evaluation of treatment methods in Steps 5 and 6 will include consideration of all forms of movement of slope materials. The purpose of this step is to identify those slopes that are indicated to be stable if constructed according to "standard" design prescriptions. Such slopes will not require any extraordinary treatment. This step will also identify those slopes that are likely to be unstable given the project concerns and to require "special" treatment. Examples of slopes that may satisfy the listed concerns but are unstable include slopes that are steepened to satisfy ROW limitations but are too steep to prevent rock fall. Another example would be a soil slope that analysis indicated would be stable, but erosion and ravelling would require some "special" treatment.

The techniques used to evaluate the stability of the optimum slopes include experience with similar slopes in similar materials, use of published slope stability tables and charts, soil slope stability analysis and rock slope stability analysis.

Many good references are available that discuss slope stability evaluation techniques. References that we specifically recommend include the following:

19. FHWA; Rock Slopes: Design, Excavation, Stabilization. 1989. Publication No. FHWA-TS-89-045. US Department of Transportation, Federal Highway Administration, McLean, VA.

34. NAVFAC; Soil Mechanics - Design Manual 7.01. 1986. Navy Facilities Engineering Command. Alexandria, VA. GPO

35. NAVFAC; Foundation and Earth Structures - Design Manual 7.02. 1986. Navy Facilities Engineering Command. Alexandria, VA. GPO

37. Pfeiffer, T.J.; Higgins, J.D. 1988. Colorado Rockfall Simulation Program Users Manual Final Report: prepared for the Colorado Department of Highways and Federal Highway Administration, Department of Geology and Geological Engineering. Colorado School of Mines, Golder, CO.

38. Pierson, L.A. 1993. The Rockfall Hazard Rating System. Transportation Research Board, 72nd Annual Meeting, January 1993. Washington, DC, 15 p.

39. Pierson, L.A.; Davis, S.A.; Van Vickle, R. 1990. The Rockfall Hazard Rating System Implementation Manual. Oregon State Highway Division, Publication FHWA-OR-EG-90-01. U.S. Federal Highway Administration, Washington, DC.

44. Rockslope stability computerized analysis package (ROCKPACK) Ver. 11. 1988. Radford, VA: C.F. Watts & Associates.

47. Sharma, S. 1994. XSTABL, An Integrated Slope Stability Analysis Program for Personal Computers. Reference Manual Version 5.0: Interactive Software Designs, Inc. Moscow, ID.

48. Sharma, S. 1992. A technical manual for slope analysis with XSTABL. Final Report on USDA Forest Service Contract INT-89416-RVV. Ogden, UT: USDA Forest Service, Intermountain Research Station. 149 p.

53. USDA Forest Service, Slope Stability Reference Guide for National Forests in the United States. 1994. Washington, DC: EM-7170-13.

STEP 5 - SELECT TREATMENT METHODS TO MATCH OPTIMUM SLOPE RANGE AND SITE CONDITIONS

In this step, the designer will develop treatment methods that will satisfy the stability concerns identified by the stability evaluations. For most slopes, several alternative treatment methods will be identified. Examination of treatment methods will be necessary to verify satisfaction of the concerns and constraints. In many situations, combinations of treatment methods may provide the best solution. For example, combining structural methods with vegetative treatments may be the best method to satisfy both stability and aesthetic concerns.

Available treatment methods may be divided into four general categories: grading, mechanical, structural, and vegetative. Each of these categories is discussed in greater detail in the following paragraphs.

GRADING

This category includes all actions to configure a stable slope by grading. The following are all considered grading options.

1. **Serrating** - The cutting of regular, low-height benches into a slope. Generally the benches are about 2 to 3 feet in height and width and extend over the full height of the slope. This technique is most frequently used where vegetation is expected to become established, but ravel must be constrained until vegetation can take root and grow. Careful consideration must be given to drainage of water that may accumulate on the benches. In areas of low to moderate rainfall, it may be advantageous to inslope the benches and construct them on a grade such that water would be directed to stabilized drainageways down the slope. In wetter climates, outsloping of the benches may be preferred to prevent collecting of water on the bench and infiltration of water into the hillside soils. In any design, accommodation of the drainage from the benches must be carefully evaluated and a design developed that reduces the risk of slope damage.

   Photos II-1 and II-2 are examples of serrated slopes constructed in ravelling soils. As evident in the photos, the treatment method has been successful in preventing severe ravelling and erosion and encouraging the growth of vegetation.

Photo II-1. Serrated slope in ravelling soils.

Photo II-2. Serrated slope in ravelling soils.

2. **Benching** - Benching is most frequently used on cut slopes in rock where a break in slope is needed to match structural fractures in rock or retain rock fall. Benching is also useful in breaking up the expanse of a high rock cut and helping to make the slope appear more natural. Benches may be as great as 10 to 20 feet in height and width. It is recommended that overdrilling and blasting be planned when constructing benches in rock. This creates fracturing below the surface of the bench, which results in a material more conducive to the growth of vegetation and permits the entry of water from rain and snow. Benches collect snow and water, thus encouraging the growth of vegetation. This may be especially advantageous in drier climates. However, proper drainage of water from the benches must be considered in the design of the slopes. Also, benches must be constructed so that they can be maintained, if necessary. Rock benches do not necessarily need to be level. In fact, the benches may blend better with other topographic features if they are constructed parallel with the ground surface or particular strata. Photos II-3, II-4, II-5 and II-6 illustrate effective construction of benches constructed in this fashion.

   Reference No. 19 listed at the end of this section, presents other concerns to consider in the design of benches in rock slopes. Many of those concerns can be alleviated if the design is appropriate to the topographic and geologic conditions specific to each site.

3. **Matching Dip of Bedding** - In certain rock types, stable slopes can be achieved by matching the slope angle to the dip of the bedding or joints in the rock. This may be especially effective in thinly bedded shale, limestone, sandstone, phyllite, etc. For high slopes, benches may be included to break up the expanse of a high, smooth face. Photos II-7 and II-8 illustrate sites where the cut slope is parallel to the bedding or foliations. Other problems may arise because of compression failure or scabbing of thinly bedded rock. However, such problems are frequently accommodated by widening ditches to contain any fallen rock.

4. **Irregular Shot Patterns** - Cut slopes in massive rock cuts may be made to appear more "natural" by designing an irregular pattern of drill holes and shooting so as to leave an irregular slope face. This method may result in more potential for rock fall, which must be considered in the design. The pattern of drilling may be designed to follow the fracture or joint patterns in the rock. Frequently, benches are included in this treatment to break up the expanse of the slope and also to trap fallen rock and encourage the growth of vegetation. Photos II-9, II-10, II-11 and II-12 are examples of slopes that demonstrate the effective use of this treatment method. The successful application of this treatment method requires a complete investigation of the slope and a good understanding of the critical geologic characteristics of the rock in the slope.

Photo II-3. Bench with vegetation getting established.

Photo II-4. Benches with vegetation well-established.

Photo II-5. Bench constructed parallel with the ground line.

Photo II-6. Bench constructed parallel with the ground line.

Photo II-7. Slope parallel to the bedding planes.

Photo II-8. Slope constructed parallel to planes of foliation.

Photo II-9. Slope constructed with offset drill holes.

Photo II-10. Slope constructed with offset drill holes.

Photo II-11. Shallow benches combined with slope parallel to bedding planes.

Photo II-12. Shallow benches combined with slope parallel to bedding planes.

MECHANICAL

Mechanical methods of slope treatment are methods that alter or protect the slope face to increase the stability of the slopes. Common methods used include the following:

1. **Protective Blankets** - The primary purpose of this method is to prevent or reduce ravelling and erosion so that vegetation can become established. Jute matting, geotextiles, and excelsior blankets are the most commonly used materials. These materials are usually pinned to the slopes and combined with seed and fertilizer. The pinning used to hold the blankets in place may be designed to "anchor" the upper 1- to 2-foot thickness of the slope materials in place until the vegetation takes root. There are many proprietary products that fall into this category of slope treatment. Photos II-13 and II-14 show an example of a slope successfully treated with an excelsior blanket reinforced with a polypropylene netting.

2. **Geoweb and Timber or Concrete Grids** - These are materials with open cells that are placed on the slope to prevent or reduce erosion and ravelling. The open cells are frequently filled with topsoil to provide a growing medium for vegetation. As with the protective blankets, there are a great number of proprietary products of this type available for treatment of eroding or ravelling slopes. The treatment method is not appropriate for slopes where deeper-seated stability is the problem. Generally, the webbing or grid materials are sturdier than protective blankets. As such, they are more appropriate to sites where erosive forces may be more severe. They are frequently used for sites where occasional traffic, either vehicular or pedestrian, may travel over the surface. References 13 and 24 include descriptions and photos illustrating this treatment method.

3. **Wire Netting Slope Screening** - This treatment method consists of draping or pinning wire netting (chain link fencing is most frequently used) over steep rock slopes to prevent rock fall and ravel from bouncing off the slope face onto the traveled way below. On flatter slopes, the netting may be designed and installed to hold the loose material in place and prevent it from moving downslope. On steeper slopes, the netting is designed and installed to contain falling material and prevent it from bouncing off the slope. Vegetation may be included in this treatment method to make the treated slope more attractive visually and to help stabilize the loose, ravelling slope materials. Photos II-15, II-16, II-17 and II-18 illustrate sites where this treatment method has been used effectively.

Photo II-13. Excelsior and polypropylene netting over seed and fertilizer.

Photo II-14. Two types of excelsior and polypropylene netting.

Photo II-15. Wire netting on variable slope with vegetation.

Photo II-16. Wire netting on vertical slope.

Photo II-17. Wire netting with vegetation growing through.

Photo II-18. Wire netting with vegetation growing through.

STRUCTURAL

This category includes those methods that reinforce the structure of the rock at the slope face or provide a structure that supports the slope. A variety of types of structural treatments is available to the designer. Selection of a particular structural type will include consideration of cost, aesthetics, constructability, maintainability and safety. The references at the end of this section provide a more detailed discussion of the variety of structural treatment methods and suggestions to assist in the selection of methods appropriate for specific conditions. The following described methods are examples of techniques frequently used.

1. **Rock Bolts or Anchors** - This method consists of drilling rock bolts into the slope face to "tie" the materials at the face into a single mass. It is most commonly used where sections of the slope face must be fastened to the mass of rock behind the face. It can be very effective where plane or wedge failures are likely to occur. The effective use of this treatment method also requires a complete investigation of the slope area and a thorough understanding of the underlying geology. Generally, this treatment method is relatively expensive. However, it may be the most effective treatment option where space is limited or where existing features must be protected. Photo II-19 illustrates the use of rock bolts to stabilize a wedge-type failure of a rock slope.

2. **Gunite or Shotcrete** - For this treatment, a portland cement grout is sprayed or pumped onto the slope face to seal the face and to bind together the small fragments on the face. It is most often used where slaking or weathering of the exposed rock produces continuous failure from the slope face. The most frequent objections to this method are for aesthetic reasons. For some situations, the method is combined with rock bolting. The rock bolts stabilize the larger blocks of rock within the slope and the gunite or shotcrete protects the face from slaking and ravelling. It is possible to add coloring agents to the grout to provide a surface that more closely blends in with the surrounding rock. An example of this treatment method is illustrated in Photo II-20.

3. **Soil Nailing** - Reinforcing steel or tendons may be placed in drilled and grouted holes, connected to steel mesh on the slope face, and the mesh covered with shotcrete. This technique, called soil nailing, may be used to structurally reinforce a slope as it is being excavated or an existing slope that is unstable. The technique is used primarily for the protection and reinforcement of soil slopes. As such, it may be appropriate for consideration as a stabilization method for slopes in highly weathered or decomposed rock. The cost of this treatment method will likely be greater than for other alternatives, but it may be appropriate for consideration where existing structures or confined working spaces are a concern.

Photo II-19. Rock bolts stabilizing a wedge failure.

Photo II-20. Tinted shotcrete on rock cutslope.

4. **Retaining Walls** - Retaining walls are most frequently used to stabilize slopes where deeper-seated movements are occurring or may occur. They may be especially effective where right-of-way or other constraints restrict the room needed for flatter slopes. Retaining structures may also be used to contain ravel or rock fall and prevent it from reaching the roadway. For this application, the structure is usually placed far enough from the toe of the slope to allow room for maintenance equipment to remove the accumulated material periodically. There are a great number of types of retaining walls available for consideration for slope stabilization. Many involve the use of proprietary materials and methods. Others are traditional designs that have been employed over many years in highway construction. Reference 16 presents a detailed listing of types of retaining structures together with design methods and suggestions for selecting appropriate structures for a variety of slope conditions. Photos II-21 and II-22 show combinations of structures used to retain ravel at the toe of steep slopes.

5. **Rock Buttress** - Rock buttresses can be very effective in stabilizing slopes in badly weathered rock and soil. Usually a wedge of material is removed from the toe of the slope and replaced with rock (heavy, loose riprap). As with many of the other treatment methods, a complete site investigation and analysis is necessary to ascertain the need for a rock buttress and to develop the details to adequately design a buttress. In many cases, vegetative plantings can be incorporated into a buttress. When vegetation is established on a rock buttress, this treatment method may appear to be a "natural" slope rather than a structure. Successful rock buttresses are illustrated in Photos II-23 and II-24.

Photo II-21. Combination of concrete structure and gabions at toe of steep, ravelling slope.

Photo II-22. Combination of metal bin wall with wire netting to retain ravelling slope.

Photo II-23. Rock buttress with vegetation.

Photo II-24. Rock buttress with vegetation getting established.

VEGETATIVE

There are many treatment methods that use vegetation to improve the stability of slopes. Generally, these methods are most successful when shallow instability such as ravelling and erosion is involved. Slopes with deeper instability must be treated with other methods. However, it may be appropriate to combine vegetative treatment with another treatment method for the benefit of aesthetics as well as the improvement in stability gained by using vegetation. With any type of vegetative treatment, it is essential that selected plant species will grow well at the selected site. It is also important to assess the weather conditions typical for the site to assure they are conducive to the growth of vegetation. In addition to normal seeding and mulching, the following methods have proven successful when appropriately applied.

A special form of vegetative treatment incorporates the planting of trees or other large woody plants. Such plants are beneficial in "softening" the appearance of a cut slope to make it appear more "natural." This is especially effective when indigenous species are planted and the slope takes on the appearance of adjacent uncut slopes. There are differing opinions as to the effect of trees and large woody plants on cut slopes. However, examination of existing slopes demonstrates that such plants frequently enhance the stability of the near-surface materials as well as improve the aesthetics of the cut slopes. On some rocky slopes, such plants may cause ravelling and other failures by the roots wedging between the joints and discontinuities in the rock. Generally, however, the effects of such plants on slopes appears to be beneficial rather than detrimental. References 13 and 24 discuss the effects of vegetation on slopes in great detail including studies that specifically examined the effects on stability of the slopes.

1. **Wattling** - This method involves bundling cuttings of live vegetation that will root easily and embedding the bundles in parallel rows along contours on the slope. The cylindrical or cigar-shaped bundles of cuttings are placed continuously across the slope on shallow benches cut into the hillside. After staking the bundles to the slope, the bundles are covered with slope materials. The stakes used may be live cuttings or prepared stakes. The bundles of cuttings mechanically stabilize the slope until the root systems develop and reinforce the slope materials. If live cuttings are used for stakes, they will sprout and also extend root systems to help stabilize the slope. References 13 and 24 include photos that illustrate successful application of this treatment method to unstable slopes.

2. **Brush Layering** - This method, also called contour brush layering, involves embedding green branches of trees or shrub species that will root easily, on successive contours on the slope. The benches may be cut on the slope face using small track-type equipment. Because the woody stems are placed perpendicular to the strike of the slope and they extend farther into the slope, brush layering may be more effective than wattling for stabilizing some slopes. Also, it is less labor intensive in that the brush is not tied into bundles. References 13 and 24 present a thorough discussion of this treatment method.

3. **Terracing** - Live plants, trees or woody shrubs, may be planted closely together on slope contours in rows spaced 2 to 4 feet apart. The plants are placed very closely together so that ravel is trapped upslope of the plants. This technique is more appropriate for slopes that are not ravelling rapidly, as the plants must root and grow without being buried under ravelled slope materials. The technique is most successful when using rapid-growing plants on sites that are conducive to good plant growth. Photos II-25 and II-26 illustrate two sites where this treatment method has been used.

Photo II-25. Terracing with tree seedlings on badly ravelling slope.

Photo II-26. Successful use of terracing with tree seedlings on ravelling slope.

4. **Other Methods** - Since its inception in 1958, hydroseeding has seen many variations utilized in its application and utilization. Some more recent developments include the use of coverings and tackifiers to help hold the material in place and to aid in germination of seeds. As with all such developments, the products have certain limitations in their use and effectiveness.

Polymers are used in hydroseeding to coat the seeds, help bind the mulch together, and bind the soil particles on the ground surface. Most polymers cannot be applied when temperatures are below about 50° F or in wet or rainy weather conditions. They have been used very successfully with fiber mulch and hydroseed. They have not been successful when applied directly to bare soil. Most commercial hydroseeding suppliers and applicators have proprietary, polymer-based products for use in appropriate situations.

A new proprietary product has recently been introduced to the market. The product, called Soil Guard, is intended to provide better establishment of vegetation on slopes than conventional hydro-mulch. The product is primarily wood fiber with a tackifying agent derived from plants. The product forms a thick, flexible coating that adheres to the slope materials. Test results suggest the material, when properly applied, is much more effective in reducing erosion and promoting growth of vegetation than conventional hydro-mulch. It is possible to include seeds of trees and shrubs with the other vegetation seeds when applying the mixture to the slopes.

Another development that may be appropriate for specific situations is a device called the steep slope seeder. This is a mechanical seeding device, actually a form of seed drill, that has been adapted to be mounted on the arm of a Gradall excavator. The device has been demonstrated to be very effective for seeding slopes that are too steep for conventional seeding equipment. This device was developed by the US Forest Service Equipment Development Center, but has not been commercially produced. Two papers (references 31 and 50) describing the steep slope seeder are included in the list of references at the end of this section.

COMBINATIONS

At many sites, a combination of treatment methods may be the most effective solution for stabilization of the slopes. Vegetative treatment should be considered in combination with almost all of the other methods. This might include mulch, fertilizer, and seed, including tree seed, together with benching of rock cuts or planting tree slips in the voids of a rock buttress. Or it might mean designing a retaining structure with benches on the face and planting vegetation on the benches to improve the appearance of the structure. Frequently, vegetation is combined with geotextile to produce treatment methods that are effective from the standpoint of improving stability as well as aesthetics.

Many references are available for assisting in the selection, design and construction of treatment methods. Several of these references are as follows:

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13. Coppin, N.J. Richards, I.G. 1990. Use of Vegetation in Civil Engineering. Construction Industry Research and Information Association. London, England: Butterworths, 292 p.

18. Feldman & Heimlich. 1980. Black Hills, Field Guide. Dubuque, Iowa: Kendall/Hunt Publishing Co., 190 p.

24. Gray, Donald H.; Leiser, Andrew T. 1982. Biotechnical Slope Protection and Erosion Control. New York, NY: Van Hostrand Reinhold, 271 p.

37. Pfeiffer, T.J.; Higgins, J.D. 1988. Colorado Rockfall Simulation Program Users Manual Final Report: prepared for the Colorado Department of Highways and Federal Highway Administration, Department of Geology and Geological Engineering. Colorado School of Mines, Golder, CO.

39. Pierson, L.A.; Davis, S.A.; Van Vickle, R. 1990. The Rockfall Hazard Rating System Implementation Manual. Oregon State Highway Division, Publication FHWA-OR-EG-90-01. U.S. Federal Highway Administration, Washington, DC.

51. U.S. Army Corps of Engineers. 1980. Engineering and Design, Rock Reinforcement, EM 1110-1-2907, Washington, DC.

52. U.S. Federal Highway Administration. 1993. Advanced Technology for Slope Stability, Manual and training materials developed for a 32-hour course, pilot sessions conducted, future sessions pending. Contact Chien-Tan Chang, FHWA, 202-366-6749, for additional information.

53. USDA Forest Service, Slope Stability Reference Guide for National Forests in the United States. 1994. Washington, DC: EM-7170-13.

STEP 6 - ANALYZE TREATMENT METHODS TO VERIFY THAT STABILITY IS ACHIEVED

The designer must verify in this step that the selected treatment methods will indeed stabilize the slope. If the evaluation shows the slope will be stable, the process moves on to the next step. However, if the slope will not be stable, it will be necessary to reevaluate the concerns to see if a compromise may be feasible. One example is a rock cut that cannot be flattened because of ROW limitations, but continuing ravel and rock fall is expected to occur. Upon reevaluation of the concerns, it may be found acceptable to widen the ditch, construct a retaining structure along the roadway, and allow the rock fall to accumulate in the ditch behind the structure. Another example is a soil slope that analysis indicates will be stable, but erosion and ravelling are expected to occur until vegetation is established on the slope. For this situation, special treatment methods such as wattling or brush layering may be necessary.

Examples specific to the highways in the Black Hills are described in the Appendix in Part I.

STEP 7 - DEFINE DESIGN DETAILS FOR EACH IDENTIFIED POTENTIAL ALTERNATIVE

The preceding steps will identify the general requirements for treatment methods that will stabilize the slopes. The designer must now define the details that will control the design of the selected treatment alternatives. The details include such things as slope angles, slope dimensions, aesthetic concerns, structure types, structure dimensions, vegetation requirements, drainage details, etc. In this step the designer develops the project from the geotechnical recommendations to the specific design. The designer must be satisfied that the recommendations can actually be accomplished "on the ground." For example, if benches are recommended, the designer must ascertain that they can actually be constructed to fit on the slope. Typical considerations that must be addressed at this time include: What width of bench is practical from the standpoint of the equipment that may be used to construct the bench; how long should the benches be; what is the grade of the benches; should they be insloped or outsloped; what plants are most suited to a particular site and treatment method. A similar process should be followed with regard to each of the recommendations. If the recommendations appear to be impractical or inappropriate for a specific design situation, alternative recommendations will need to be developed.

STEP 8 - COMPLETE PRELIMINARY DESIGN AND COST ANALYSIS

In this step, the design of the selected treatment methods must be completed to the point that preliminary cost estimates can be performed. At that time, analysis of costs of the different methods can be performed using life cycle cost techniques. It is important in this step to critically evaluate constructability and ease of maintenance in addition to construction costs.

References that give examples of typical cost ranges for various solutions are listed below. Other agencies with recent experience can also provide cost information.

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16. Driscoll, David D. 1979. Retaining wall design guide. USDA Forest Service, Region 6. Portland, Oregon.

24. Gray, Donald H.; Leiser, Andrew T. 1982. Biotechnical Slope Protection and Erosion Control. New York, NY: Van Hostrand Reinhold, 271 p.

39. Pierson, L.A.; Davis, S.A.; Van Vickle, R. 1990. The Rockfall Hazard Rating System Implementation Manual. Oregon State Highway Division, Publication FHWA-OR-EG-90-01. U.S. Federal Highway Administration, Washington, DC.

53. USDA Forest Service, Slope Stability Reference Guide for National Forests in the United States. 1994. Washington, DC: EM-7170-13.

STEPS 9 AND 10 - SELECT PREFERRED TREATMENT METHODS AND COMPLETE FINAL DESIGN

At these steps, the design team selects the preferred treatment method(s) and proceeds with the design following normal design procedures.

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14. Cousins, B.F. 1978. Stability charts for simple earth slopes. American Society of Civil Engineers, Journal of the Geotechnical Engineering Division. Paper 13572. 104(GT1):267-279.

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SITE RECONNAISSANCE

State Highway ______________________ Date ____________

M.P. ____________ Length ____________ Name Research Team ____________

Site Designation ____

PURPOSE OF INVESTIGATION

CONCERNS AND CONSTRAINTS (Step 1)

PRECONSTRUCTION, CONSTRUCTION, MAINTENANCE HISTORY

EXISTING CUT SLOPE

Angle____________ Height____________

Observed Slope Failure Mechanism

ENGINEERING ROCK AND SOIL UNITS

OPTIMUM SLOPE RANGE(S) (Per Rock and/or Soil Unit)

VEGETATION

POSSIBLE TREATMENT METHODS

PRELIMINARY EVALUATION

SITE RECONNAISSANCE

Site Designation ______________________________

CROSS SECTIONAL SKETCH

SITE RECONNAISSANCE

Site Designation ____

Photo 1:

Photo 2:

SITE RECONNAISSANCE

Site Designation ____________________

Photo 3:

Photo 4:

SITE RECONNAISSANCE

Site Designation ____

SLOPE STABILITY ATTACHMENT

I. ROCK (Provide details on Cross Section)

A. DISCONTINUITY FAILURE

Discontinuities (Dip/Dip Direction)	Infilling	Friction Angle
Primary		
Secondary I		
Secondary II		
Secondary III		

Road Azimuth ______________ Propose Cut Angle ______________

Anticipated Failure Type: Plane __________ Wedge ____________

B. TOPPLING FAILURE

Column Width ___________ Height ___________ Base Angle ___________

C. COLLAPSE FAILURE

Differential Weathering Rating: High ______ Medium ______ Low ______

II. SOIL AND DECOMPOSED ROCK (Provide details on Cross Section)

Current or Anticipated Failure (for stability analysis) ______________________________

Ground water (if present, type of aquifer and where located) ______________________________

Estimated Soil Parameters (for each soil unit on Cross Section) ______________________________

III. RECOMMENDATIONS FOR SUBSURFACE INVESTIGATION, LABORATORY AND STABILITY ANALYSES: ______________________________

IV. POSSIBLE STABILIZATION ALTERNATIVES: ______________________________

SITE RECONNAISSANCE

Site Designation ____________________

ROCKFALL HAZARD ATTACHMENT

M.P. __________ Length __________ Posted Speed Limit __________

Preliminary Rating: Cut Class A or B *
Proposed Correction __________
____

ADT __________
Rater __________
Detailed Rating Score __________

Cost Estimate __________

Preliminary Rating Remarks: (Continue on Back) ____________________
____
____

DETAILED RATING

Slope Height Score __________
Slope Height in Feet __________

Ditch Effectiveness Score __________
Catchment Letter G M L N *

Average Vehicle Risk Score __________
Percent of Time __________

Site Distance Score __________
Percent Design Value __________
Site Distance __________
Roadway Width Score __________
Roadway Width in Feet __________

GEOLOGIC CHARACTER CASE 1

Structural Condition Score __________
Fracture Letter D C *
Orientation Letter F R A *

Rock Friction Score __________
Friction Letter R I U P C S *

GEOLOGIC CHARACTER CASE 2

Structural Condition Score __________
Erosion Feature Letter F O N M *

Diff in Erosion Rate Score __________
Diff in Erosion Rate Letter S M L E *

Block Size/Quantity Per Event __________
Block Size in Feet __________
Quantity in Cubic Yards __________

Climate and H_2O Score __________
Precipitation Letter L M H *
Freezing Period Letter N S L *
Water Letter N I C *

Rockfall History Score __________
Rockfall History Letter F O M C *

*Circle One

TOTAL SCORE __________

Remarks: ____________________
____
____
____
____

SITE RECONNAISSANCE

State Highway US 385 Date 07/14/94

M.P. 37.0 Length ______ Name Research Team

Site Designation Site 15 (Road Segment 3, Stop 1)

PURPOSE OF INVESTIGATION

Research; document wedge failure in RUA.

CONCERNS AND CONSTRAINTS (Step 1)

N/A

PRECONSTRUCTION, CONSTRUCTION, MAINTENANCE HISTORY

This is an older cut with no documented history. The ditch apparently requires only minimal maintenance, although a mound of talus has accumulated near the base of the slope (see Photo 1).

EXISTING CUT SLOPE

Failure slope:

Angle 35° to 45° Height 62 ft.

Observed Slope Failure Mechanism: Wedge failure. Minor rockfall and ravelling from the overlying colluvial soil units, occasional rockfall and possible toppling from RUA typically occur mostly in response to dislodgement by frost wedging. Based on amount of vegetation growing on talus pile, it appears the rate of rockfall is dropping off.

ENGINEERING ROCK AND SOIL UNITS

RUA with thin SUS colluvial layer.

OPTIMUM SLOPE RANGE(S) (Per Rock and/or Soil Unit)

The optimum slope range is 1/2:1 or steeper provided that discontinuity dip angles are favorable. Because dip angles are not favorable, the slope must be flattened to 40° or less to achieve stability (see stability analysis).

VEGETATION

Grasses and ponderosa pines sparsely vegetate the talus mound and the perimeter of wedge feature.

POSSIBLE TREATMENT METHODS

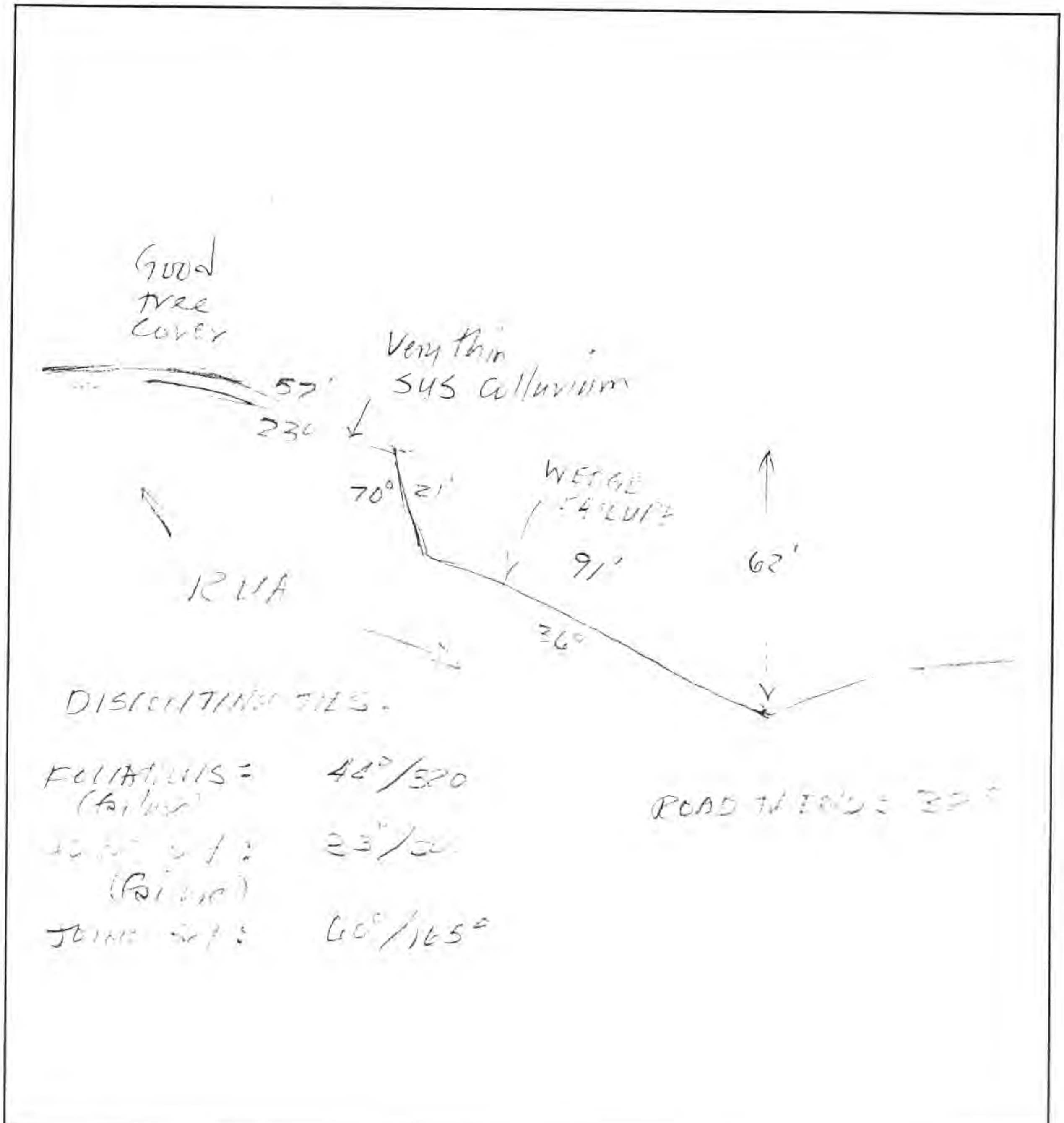
No treatment methods are required at this time.

PRELIMINARY EVALUATION

Rockfall from the wedge feature in RUA and from the SUS colluvial layer does not appear to be a major hazard. Talus accumulation in the ditch can be managed with occasional cleaning.

Site Designation <u>Site 15 (Road Segment 3, Stop 1)</u>

<u>CROSS SECTIONAL SKETCH</u>



Site Designation Site 15 (Road Segment 3, Stop 1)

Photo 1: View of wedge failure.

Photo 2: Close-up of small wedge failure showing discontinuity intersections similar to the large one in Photo 1.

SITE RECONNAISSANCE

Site Designation Site 15 (Road Segment 3, Stop 1)

SLOPE STABILITY ATTACHMENT

I. ROCK (Provide details on Cross Section)

A. DISCONTINUITY FAILURE

Discontinuities (Dip/Dip Direction)		**Infilling**	**Friction Angle**
Primary (foliation failure)	44/320	None	40°
Secondary I (failure)	83/262	None	40°
Secondary II			
Secondary III			

Road Azimuth 32° Existing Failure Angle 35° - 45°

Anticipated Failure Type: Plane ________ Wedge Existing

B. TOPPING FAILURE

Column Width ________ Height ________ Base Angle ________

C. COLLAPSE FAILURE

Differential Weathering Rating: High ______ Medium ______ Low ______

II. SOIL AND DECOMPOSED ROCK (Provide details on Cross Section)

Current or Anticipated Failure (for stability analysis) ________

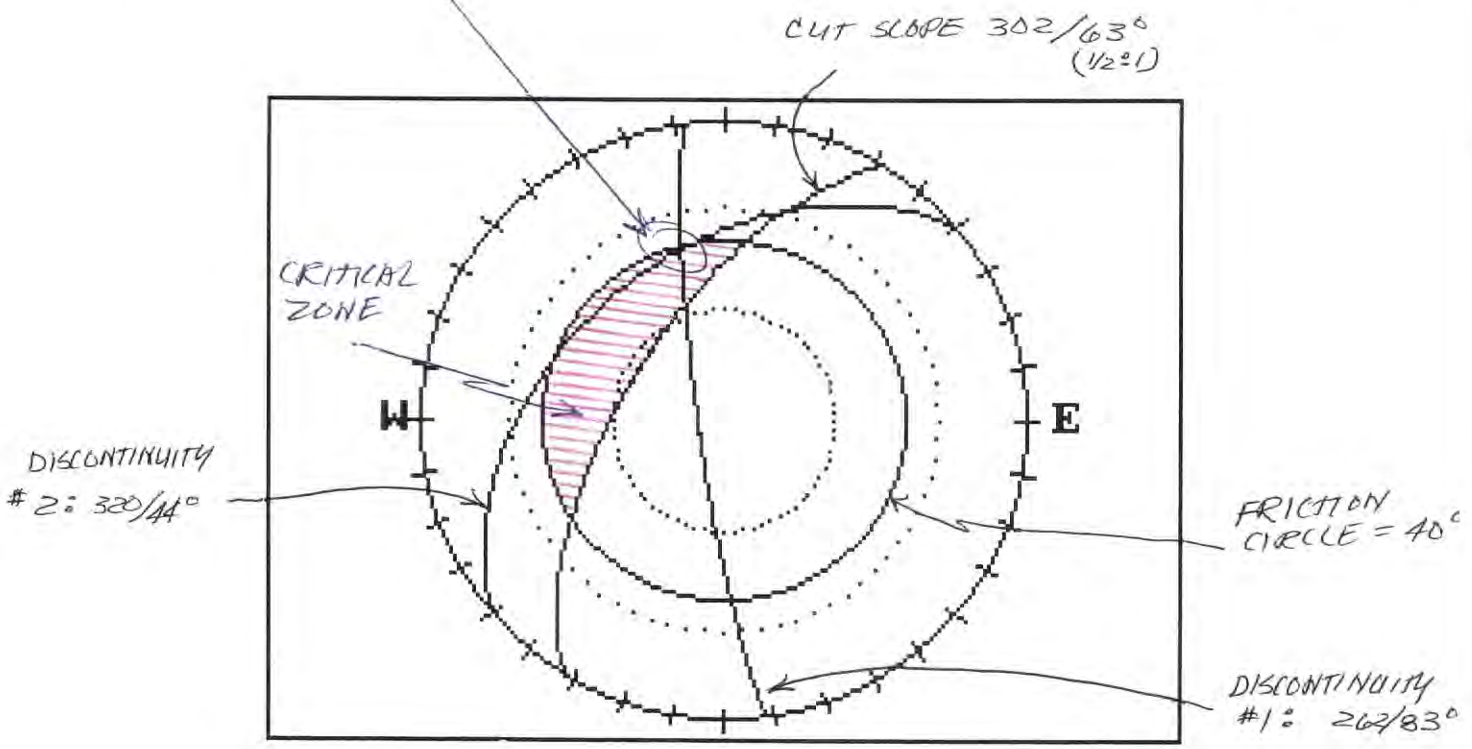
Ground water (if present, type of aquifer and where located) ________

Estimated Soil Parameters (for each soil unit on Cross Section) ________

III. RECOMMENDATIONS FOR SUBSURFACE INVESTIGATION, LABORATORY AND STABILITY ANALYSES: No further geotech work recommended unless planned for reconstruction.

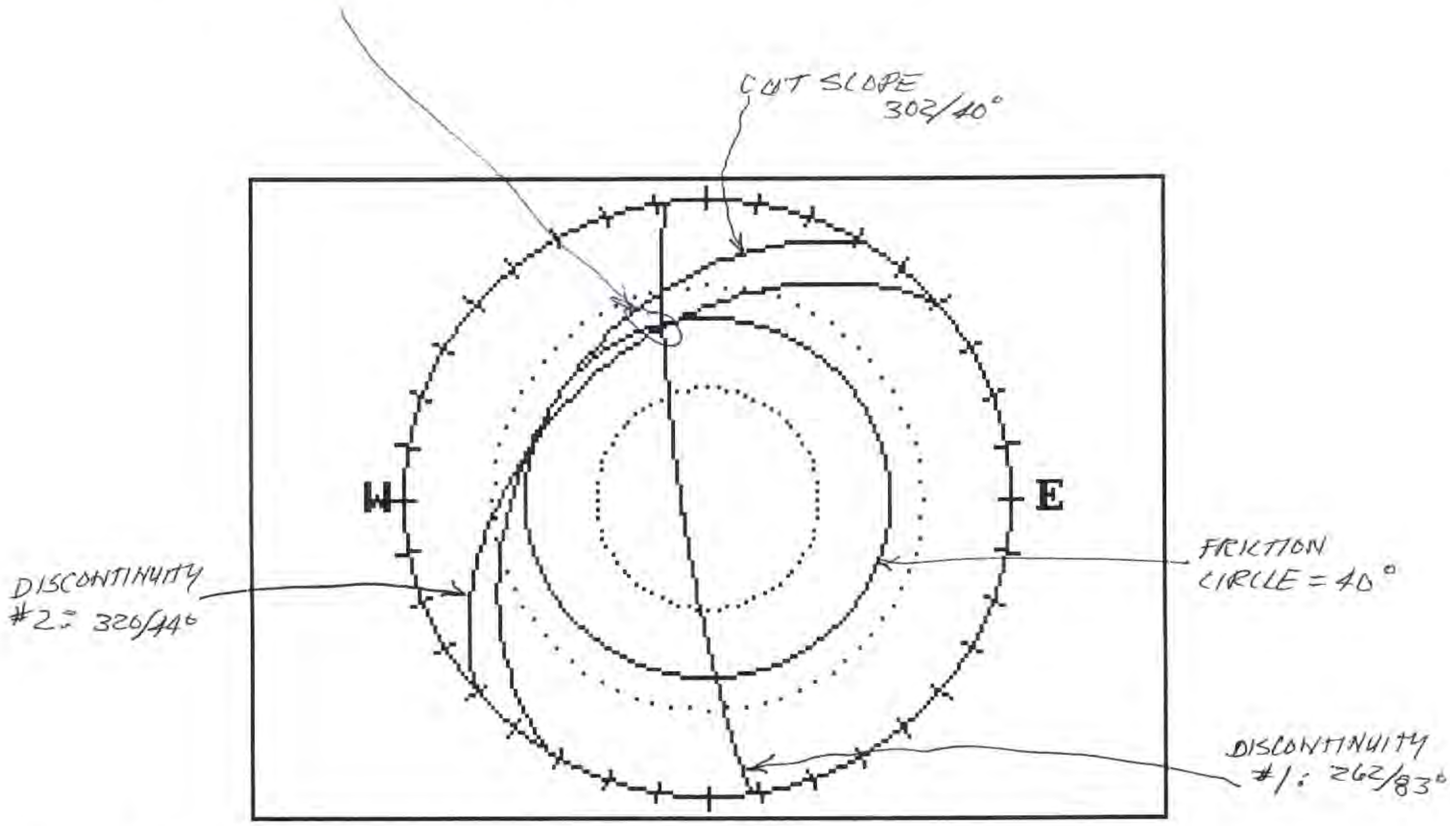
IV. POSSIBLE STABILIZATION ALTERNATIVES: See stereonet analysis; slopes 40° or flatter should be stable. Rock bolting possible for stabilization of steep angled cut slopes.

STEREONET ANALYSIS: Failure by "wedge" likely for 63° (1/2:1) Cut slope with intersection of discontinuities in critical zone.



MARKLAND WEDGE ANALYSIS: c:\rkpk2-0
Friction Angle = 40 degrees
Slope dip direction = 302 degrees / 63 degrees
Sets: 262 / 83 320 / 44

STEREONET ANALYSIS: No critical zone and failure by "wedge" unlikely for cut slopes 40° or flatter.



MARKLAND WEDGE ANALYSIS: c:\rkpk2-0
Friction Angle = 40 degrees
Slope dip direction = 302 degrees/40 degrees
Sets: 262 / 83 320 / 44

SITE RECONNAISSANCE

State Highway US 385 Date 07/13/94

M.P. 119 Length 270 ft. Name Research Team

Site Designation Site 7 (Road Segment 2, Stop 1)

PURPOSE OF INVESTIGATION

Research; document rockfall in RUB and provide an example of the ODOT rockfall hazard rating method.

CONCERNS AND CONSTRAINTS (Step 1)

N/A

PRECONSTRUCTION, CONSTRUCTION, MAINTENANCE HISTORY

This is an older cut slope with very little ditch. Every spring rocks fall on the roadway and must be removed and the ditch requires frequent cleaning.

EXISTING CUT SLOPE

Angle 62° Height 28 ft. (see sketch)

Observed Slope Failure Mechanism: Ravelling. The rock unit is extensively jointed and prone to root and frost wedging. Rockfall material accumulates in the ditch as talus (see Photo 1).

ENGINEERING ROCK AND SOIL UNITS

RUB with very little soil cover.

OPTIMUM SLOPE RANGE(S) (Per Rock and/or Soil Unit)

The optimum slope range is 1:1 or flatter.

VEGETATION

Sparse grass and ponderosa pine grow on the cut slope.

POSSIBLE TREATMENT METHODS

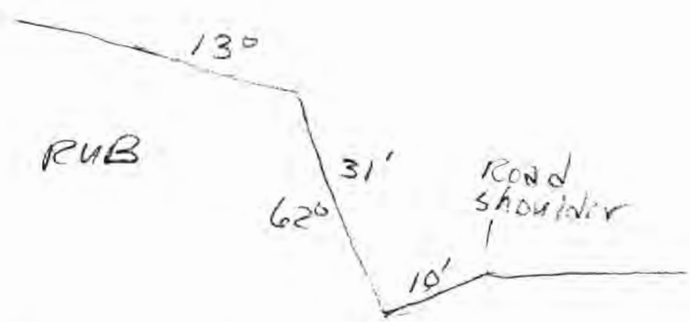
Regrading followed by revegetation using techniques such as hydroseeding or Soilguard.

PRELIMINARY EVALUATION

"Root and frost wedging" are probably the primary cause of rockfall on this slope. The slope is not high and natural slope above is relatively flat (about 13°). Regrading the slope to 1:1 and widening the ditch should eliminate the rockfall hazard and improve the sight distance in this section of highway.

Site Designation <u>Site 7 (Road Segment 2, Stop 1)</u>

<u>CROSS SECTIONAL SKETCH</u>



DISCONTINUITIES ROAD TREND: 185°

JOINT SET: 72°-76°/125°-130°

JOINT SET: 85°-90°/210°-230°

JOINT SET: 58°-65°/320°-340°

Site Designation Site 7 (Road Segment 2, Stop 1)

Photo 1: Profile view. Note the blocky weathering of this RUB unit, and the formation of the talus slopes in the ditch.

Photo 2: Close-up of face. Note how tree growth in open joints causes "root wedging." Root growth and expansion within joints wedges rocks further apart, causing rockfall failure.

SITE RECONNAISSANCE

Site Designation Site 7 (Road Segment 2, Stop 1)

ROCKFALL HAZARD ATTACHMENT

M.P. 119 Length 270 ft. Posted Speed Limit 55 mph

Preliminary Rating: Cut Class A or B*
Proposed Correction Regrade to 1:1, widen ditch and revegetate.

ADT 2840
Rater Prellwitz
Detailed Rating Score 287

Cost Estimate ______

Preliminary Rating Remarks: (Continue on Back) Rockfall on roadway is common each spring in this road section.

DETAILED RATING

Slope Height Score 4
Slope Height in Feet 28 ft.

Ditch Effectiveness Score 10
Catchment Letter G M L N *

Average Vehicle Risk Score 3
Percent of Time 11%

Site Distance Score 100
Percent Design Value 21%
Site Distance 181 ft.
Roadway Width Score 62
Roadway Width in Feet 22 ft.

GEOLOGIC CHARACTER CASE 1

Structural Condition Score 81
Fracture Letter D C *
Orientation Letter F R A *

Rock Friction Score 27
Friction Letter R I U P C S *

GEOLOGIC CHARACTER CASE 2

Structural Condition Score ______
Erosion Feature Letter F O N M *

Diff in Erosion Rate Score ______
Diff in Erosion Rate Letter S M L E *

Block Size/Quantity Per Event ______
Block Size in Feet ______
Quantity in Cubic Yards ______

Climate and H_2O Score ______
Precipitation Letter L M H *
Freezing Period Letter N S L *
Water Letter N I C *

Rockfall History Score ______
Rockfall History Letter F O M C *

*Circle One

TOTAL SCORE 287

Remarks: Although the rating at this site is about the same as for Site 8, the hazard here appears greater due to the 6% downgrade in the inside lane where rocks are most likely to accumulate. If funds are limited, treat this one first.

SITE RECONNAISSANCE

State Highway US 18 Date 07/12/94

M.P. 42 Length 400 ft. Name Research Team

Site Designation Site 24 (Road Segment 8, Stop 1)

PURPOSE OF INVESTIGATION

Research; document rockfall due to differential weathering in RUC.

CONCERNS AND CONSTRAINTS (Step 1)

N/A

PRECONSTRUCTION, CONSTRUCTION, MAINTENANCE HISTORY

This is an older cut slope. The ditch is effective and rocks are seldom on highway. Jeff Borah (maintenance) told us that the ditch requires rockfall cleanout two to three times a year.

EXISTING CUT SLOPE

Angle 60 - 62° Height 82 ft.

Observed Slope Failure Mechanism: Collapse failure of the more competent rock as a result of erosion and undermining of less competent rocks.

ENGINEERING ROCK AND SOIL UNITS

RUC

OPTIMUM SLOPE RANGE(S) (Per Rock and/or Soil Unit)

The optimal slope range is 1/2:1 or steeper in competent rocks; 1:1 or flatter in less competent rocks.

VEGETATION

The ditch and cut slope are sparsely vegetated with grass.

POSSIBLE TREATMENT METHODS

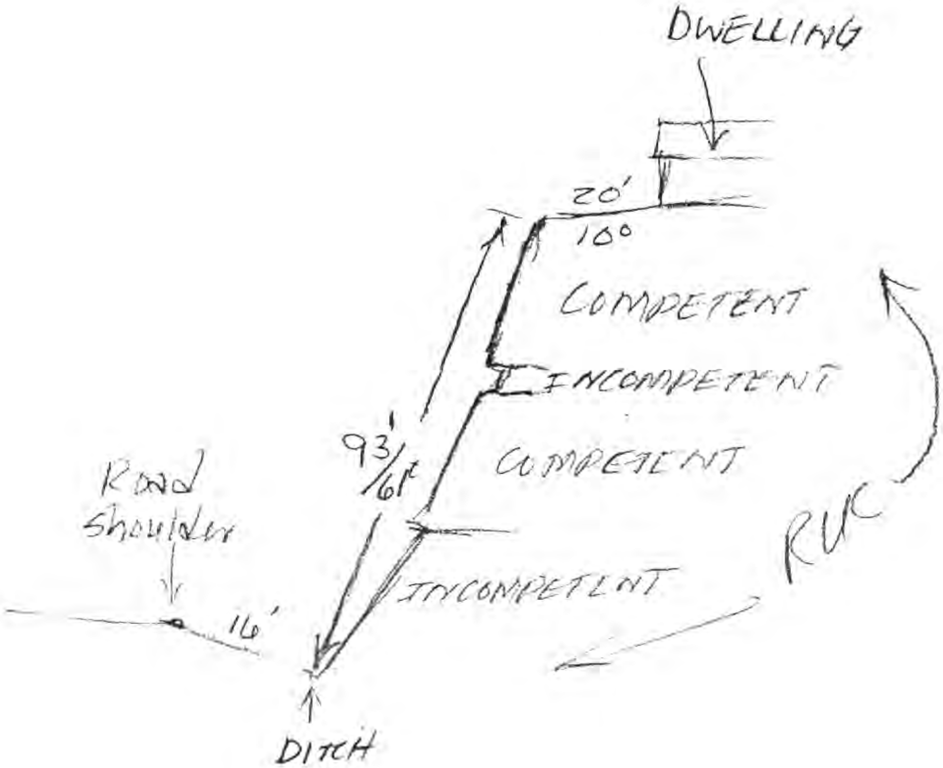
Recommended treatment for rockfall and differential weathering: scaling overhangers, screening, rock barriers, shotcrete or buttressing, and vegetation treatment (wattling) applied to less competent beds.

PRELIMINARY EVALUATION

Currently, the maintenance effort to clean rockfall from ditch appears adequate to control the rockfall hazard. As differential weathering continues, the hazard will worsen, in which case rockfall hazard reduction measures should be considered. Regrading the lower incompetent section to 1:1 or flatter would be required to stabilize the slope. However, this would be difficult within the current right-of-way, and the proximity of the dwelling near the top of the slope. An alternative approach to this site is to develop it as a "Geologic Point of Interest."

Site Designation Site 24 (Road Segment 8, Stop 1)

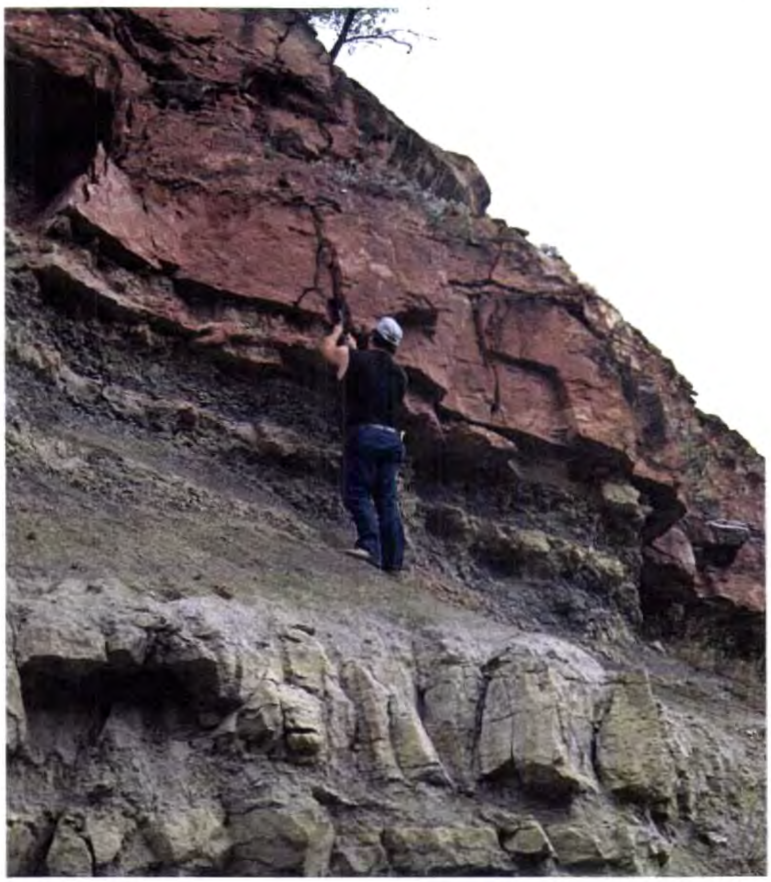
CROSS SECTIONAL SKETCH



Site Designation Site 24 (Road Segment 8, Stop 1)

Photo 1: View of cut slope from across the highway.

Photo 2: Close-up view of differential weathering.



SITE RECONNAISSANCE

State Highway US 385 Date 07/14/94

M.P. 95.0 Length 1,400 ft. Name Research Team

Site Designation Site 9 (Road Segment 3, Stop 2)

PURPOSE OF INVESTIGATION

Research; document stable cut slope in RUA with vegetated bench.

CONCERNS AND CONSTRAINTS (Step 1)

N/A

PRECONSTRUCTION, CONSTRUCTION, MAINTENANCE HISTORY

The "bench" was probably cut to provide borrow for construction of the dam.

EXISTING CUT SLOPE

See sketch.

Angle 44° above bench Height about 90 ft. total

71° below bench

No Observed Slope Failure Mechanism: Steep-angled discontinuities show little evidence of failure in section below bench, although minor wedging may have occurred during construction. Rock in the upper section is more weathered and was flattened to achieve a stable slope.

ENGINEERING ROCK AND SOIL UNITS

RUA in the lower section; RUC in the upper section.

OPTIMUM SLOPE RANGE(S) (Per Rock and/or Soil Unit)

The optimum slope for the lower section is 1/2:1 or steeper. The optimum slope for the upper section is probably 1:1, where the slope has presently stabilized.

VEGETATION

The bench and ditch are well vegetated with trees. Grass is well established in ditch section. Little vegetation on steep cut slopes.

POSSIBLE TREATMENT METHODS

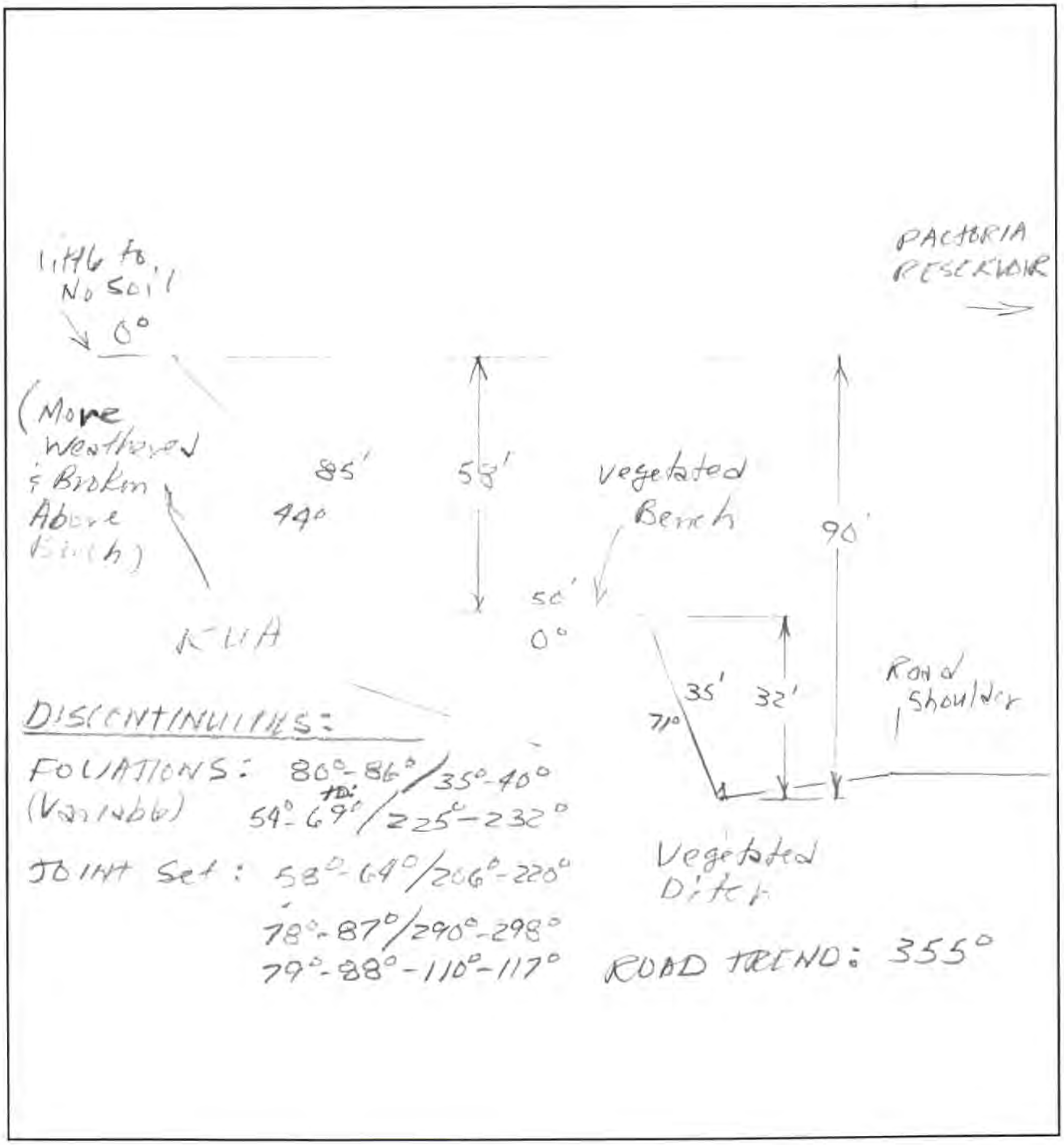
None required.

PRELIMINARY EVALUATION

This site was selected to document a site where a large cut was constructed near a recreational area and through benching, construction of stable slopes, and natural revegetation with trees has not created a great impact on the aesthetics of the location (refer to Photos 3 and 4). This site is an excellent candidate for a "Geologic Point of Interest."

Site Designation __Site 9 (Road Segment 3, Stop 2)__

CROSS SECTIONAL SKETCH



Site Designation Site 9 (Road Segment 3, Stop 2)

Photo 1: View of slope. Note the large ponderosa pine growing in the ditch and the very small accumulation of rockfall at the base of the slope.

Photo 2: Close-up of the steep-angled discontinuities in the rock section below the bench.

SITE RECONNAISSANCE

Site Designation Site 9 (Road Segment 3, Stop 2)

Photo 3: View of bench, the well-vegetated upper slope and the ditch from near the entrance to the visitor parking area.

Photo 4: View of slope, bench and dam from above. Note the well-vegetated slopes.

SITE RECONNAISSANCE

State Highway US 385 Date 07/14/94

M.P. 44.5 Length 200 ft. Name Research Team

Site Designation Site 13 (Road Segment 3, Stop 4)

PURPOSE OF INVESTIGATION

Research; document wedge failure and demonstrate stereonet analysis in selection of cut slope ratio.

CONCERNS AND CONSTRAINTS (Step 1)

N/A

PRECONSTRUCTION, CONSTRUCTION, MAINTENANCE HISTORY

None documented. The wedge may have failed during or shortly after construction. Ditch is well vegetated and apparently requires little maintenance.

EXISTING CUT SLOPE

Angle 58° Height 24 ft.

Observed Slope Failure Mechanism: Wedge failure.

ENGINEERING ROCK AND SOIL UNITS

RUA

OPTIMUM SLOPE RANGE(S) (Per Rock and/or Soil Unit)

Optimum slope range is 1/2:1 or steeper, but discontinuities not favorable. See wedge failure analysis: 55° or flatter would be stable.

VEGETATION

None on cut slope. Ditch is well vegetated by grass seeding.

POSSIBLE TREATMENT METHODS

None required.

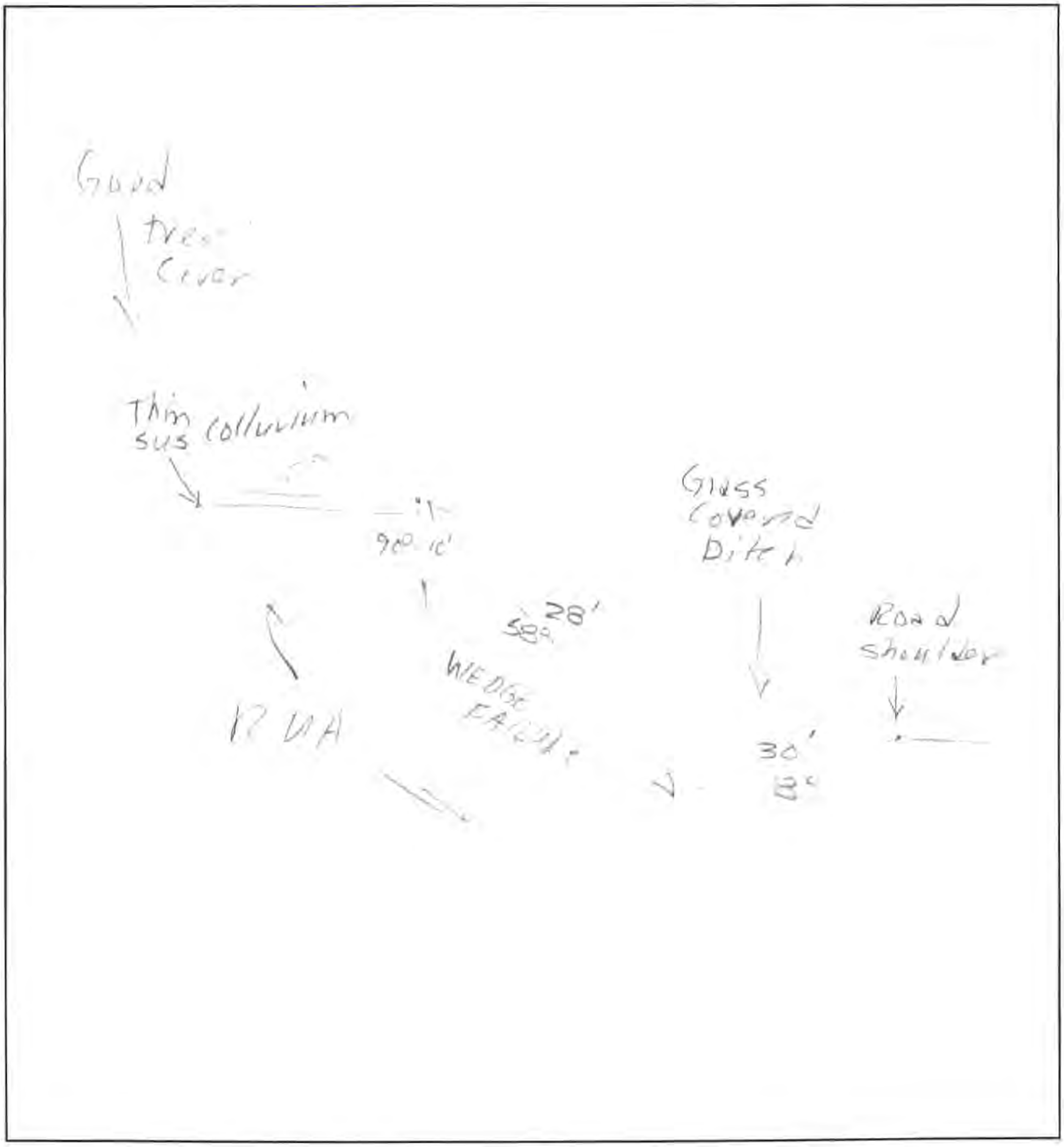
PRELIMINARY EVALUATION

Wedge probably failed during or shortly after construction. Rock presplitting looks successful with little evidence of recent rockfall in ditch. Wide ditch should be effective in controlling anticipated future rockfall.

SITE RECONNAISSANCE

Site Designation Site 13 (Road Segment 3, Stop 4)

CROSS SECTIONAL SKETCH



Site Designation Site 13 (Road Segment 3, Stop 4)

Photo 1: View of slope from across highway.

Photo 2: Close-up view of wedge failure.

Site Designation Site 13 (Road Segment 3, Stop 4)

SLOPE STABILITY ATTACHMENT

I. ROCK (Provide details on Cross Section)

A. DISCONTINUITY FAILURE

Discontinuities (Dip/Dip Direction)		**Infilling**	**Friction Angle**
Primary Foliations	58/104	None	40°
Secondary I (Failure)	79/210	None	40°
Secondary II (top)	88/125		
Secondary III			

Road Azimuth 77° Existing Cut Angle 63°

Anticipated Failure Type: Plane ________ Wedge Existing

B. TOPPING FAILURE

Column Width ________ Height ________ Base Angle ________

C. COLLAPSE FAILURE

Differential Weathering Rating: High _____ Medium _____ Low _____

II. SOIL AND DECOMPOSED ROCK (Provide details on Cross Section)

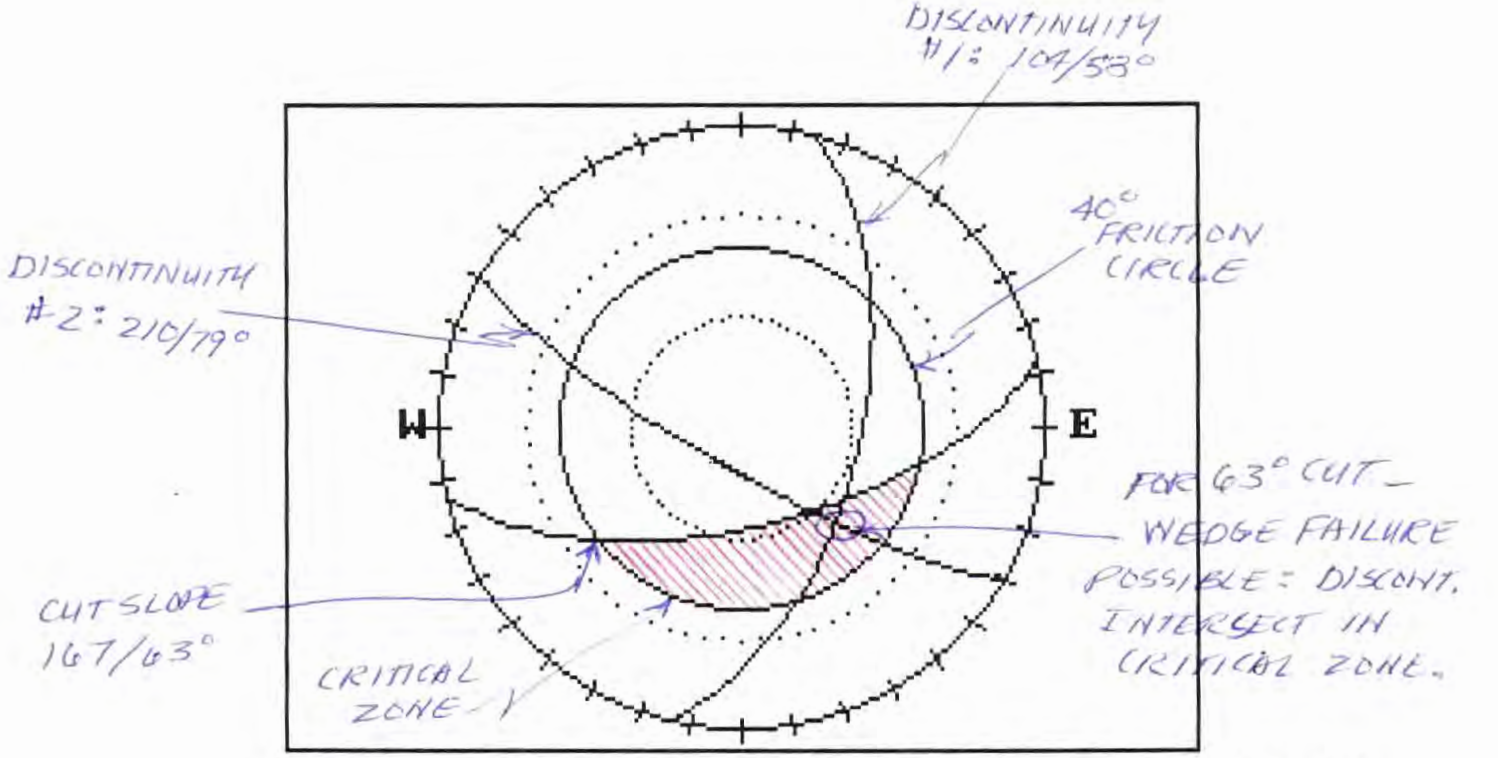
Current or Anticipated Failure (for stability analysis) ________

Ground water (if present, type of aquifer and where located) ________

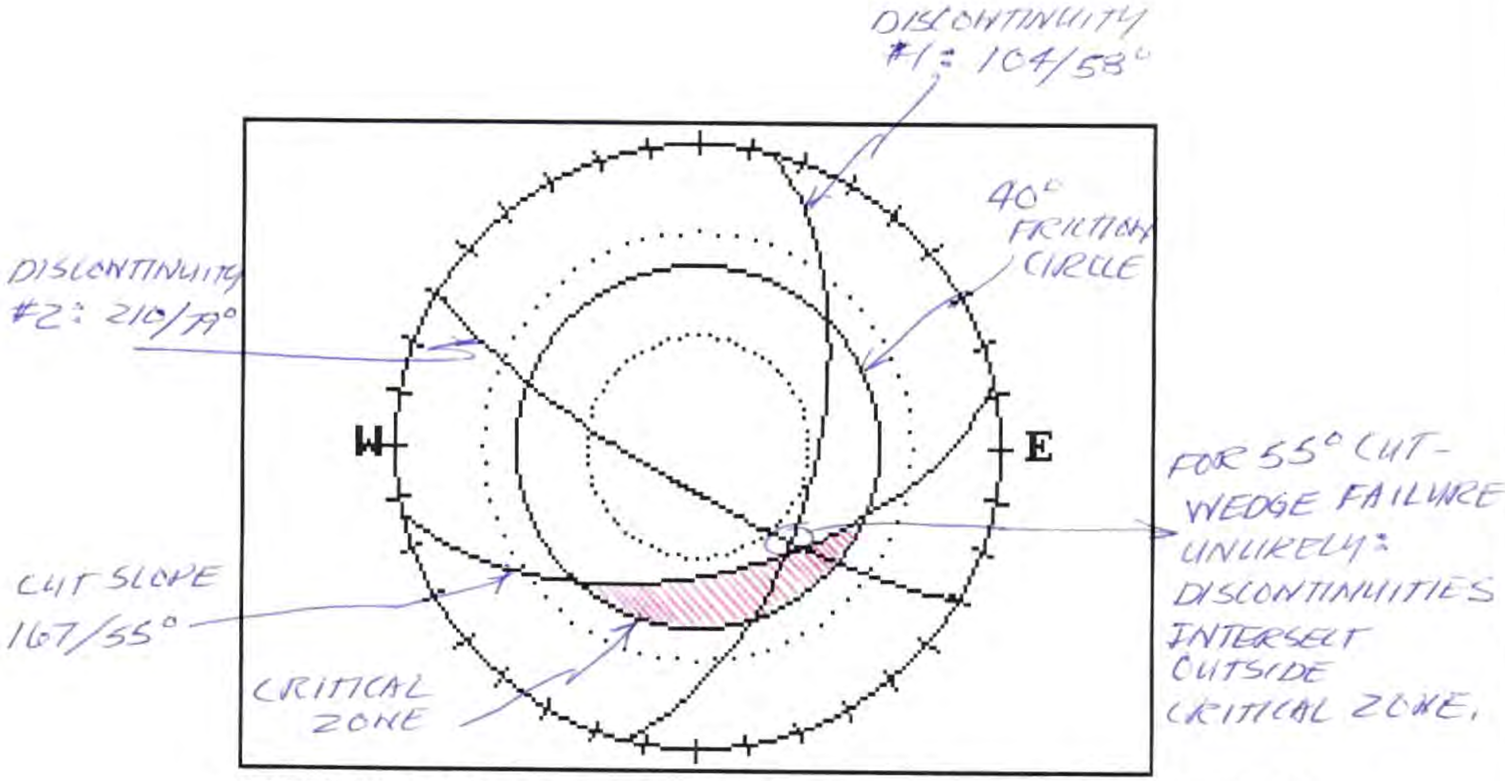
Estimated Soil Parameters (for each soil unit on Cross Section) ________

III. RECOMMENDATIONS FOR SUBSURFACE INVESTIGATION, LABORATORY AND STABILITY ANALYSES: Wedge analysis by stereonet to test 40° friction angle assumption.

IV. POSSIBLE STABILIZATION ALTERNATIVES: Anticipate failure occurred during construction. No stabilization appears necessary unless recut. In that event, use cut slope of 55° or flatter (see stereonet analysis) or rock bolt.




```
MARKLAND WEDGE ANALYSIS: c:\rkpk2-0
 Friction Angle =  40 degrees
 Slope dip direction =  167 degrees/63 deg.
 Sets: 104 / 58  210 / 79
```



MARKLAND WEDGE ANALYSIS: c:\rkpk2-0
Friction Angle = 40 degrees
Slope dip direction = 167 degrees/55 deg.
Sets: 104 / 58 210 / 79

SITE RECONNAISSANCE

State Highway SH 244 Date 07/11/94

M.P. 0.1 (?) Length 335 ft. Name Research Team

Site Designation Site 14 (Road Segment 3A)

PURPOSE OF INVESTIGATION

Research; document plane failure and demonstrate plane failure analysis.

CONCERNS AND CONSTRAINTS (Step 1)

N/A

PRECONSTRUCTION, CONSTRUCTION, MAINTENANCE HISTORY

This slope was constructed in 1960s. The failure probably occurred during or shortly after construction. The ditch contains abundant talus.

EXISTING CUT SLOPE

Angle 44° (failure) Height 65 ft.

Observed Slope Failure Mechanism: Plane failure. Frost wedging, occasional root wedging, and buckling (Photos 2, 3 and 4) dislodge slabs and fragments of rock from the cut face.

ENGINEERING ROCK AND SOIL UNITS

RUA

OPTIMUM SLOPE RANGE(S) (Per Rock and/or Soil Unit)

The optimum slope range is 1/2:1 or steeper, provided that failure surfaces dip into the slope. However, the failure surface at this site is a plane failure at the dip angle down to the ditch line.

VEGETATION

Very little on slope or in ditch.

POSSIBLE TREATMENT METHODS

Rockfall and slope failure appear minor in present condition and is probably handled well by maintenance. If recut, use steep cut and rock bolt slope above (see stability analysis).

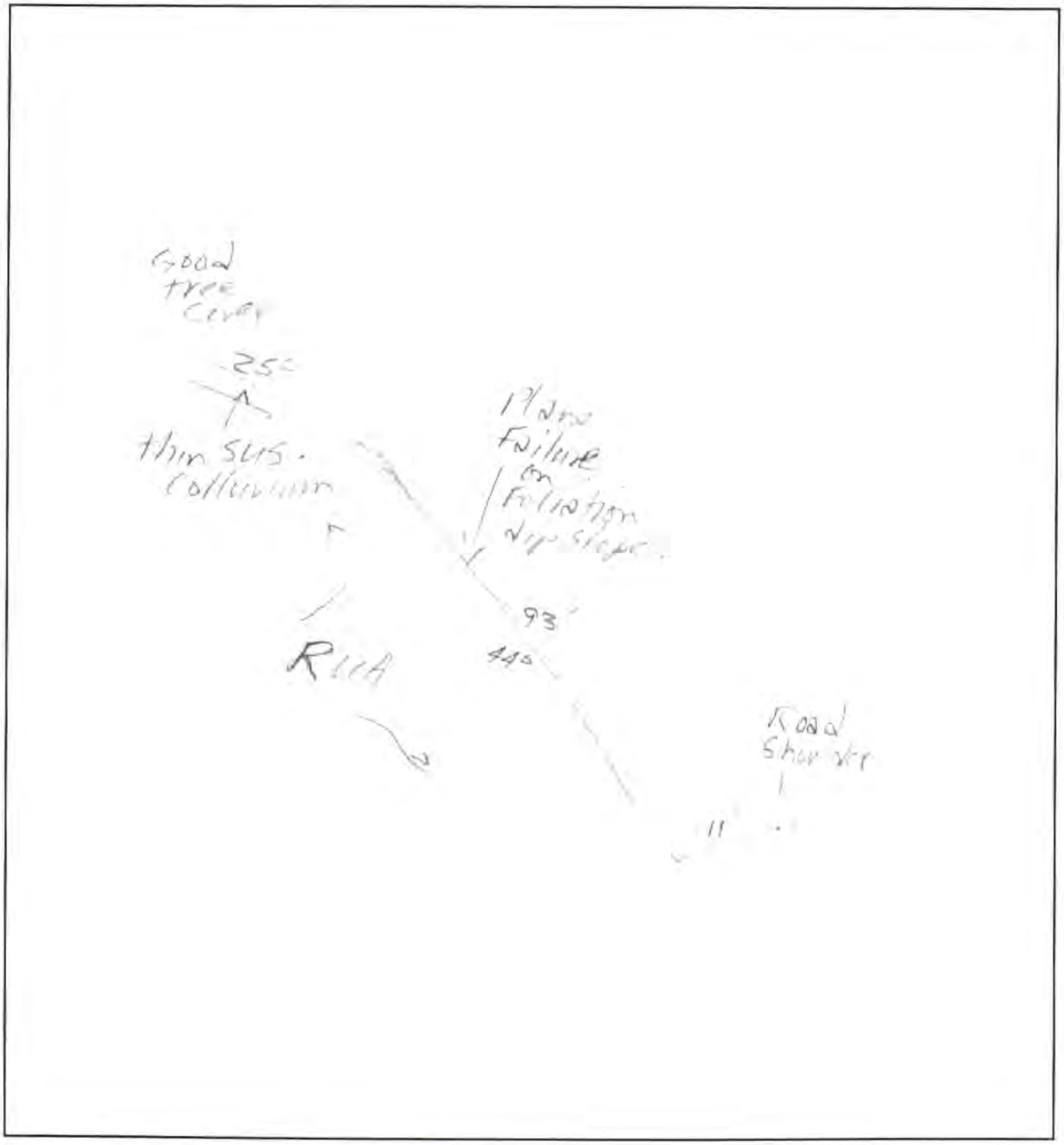
PRELIMINARY EVALUATION

Slope does present a big maintenance or rockfall hazard problem in present condition. Slope stability analysis illustrates a hypothetical example for future widening and recutting with rock bolts.

SITE RECONNAISSANCE

Site Designation <u>Site 14 (Road Segment 3A)</u>

CROSS SECTIONAL SKETCH



SITE RECONNAISSANCE

Site Designation <u>Site 14 (Road Segment 3A)</u>

Photo 1: View of plane failure as viewed from across the road.

Photo 2: Close-up view of rock failure surface caused by "buckling."

Site Designation Site 14 (Road Segment 3A)

Photo 3: Close-up of "buckling" failure that is progressing up slope.

Photo 4: Close-up of a juvenile tree rooted in a failure surface. The growth of trees on this slope causes root wedging and is detrimental to slope stability.

SITE RECONNAISSANCE

Site Designation Site 14 (Road Segment 3A)

SLOPE STABILITY ATTACHMENT

I. ROCK (Provide details on Cross Section)

A. DISCONTINUITY FAILURE

Discontinuities (Dip/Dip Direction)	Infilling	Friction Angle
Primary (foliations) 44/350	None	40°
Secondary I		
Secondary II		
Secondary III		

Road Azimuth 350 Probably original = 1/2:1 or steeper
Cut Angle 44° = existing failure slope

Anticipated Failure Type: Plane Existing Wedge ____________

B. TOPPING FAILURE

Column Width ____________ Height ____________ Base Angle ____________

C. COLLAPSE FAILURE

Differential Weathering Rating: High ______ Medium ______ Low ______

II. SOIL AND DECOMPOSED ROCK (Provide details on Cross Section)

Current or Anticipated Failure (for stability analysis) ____________

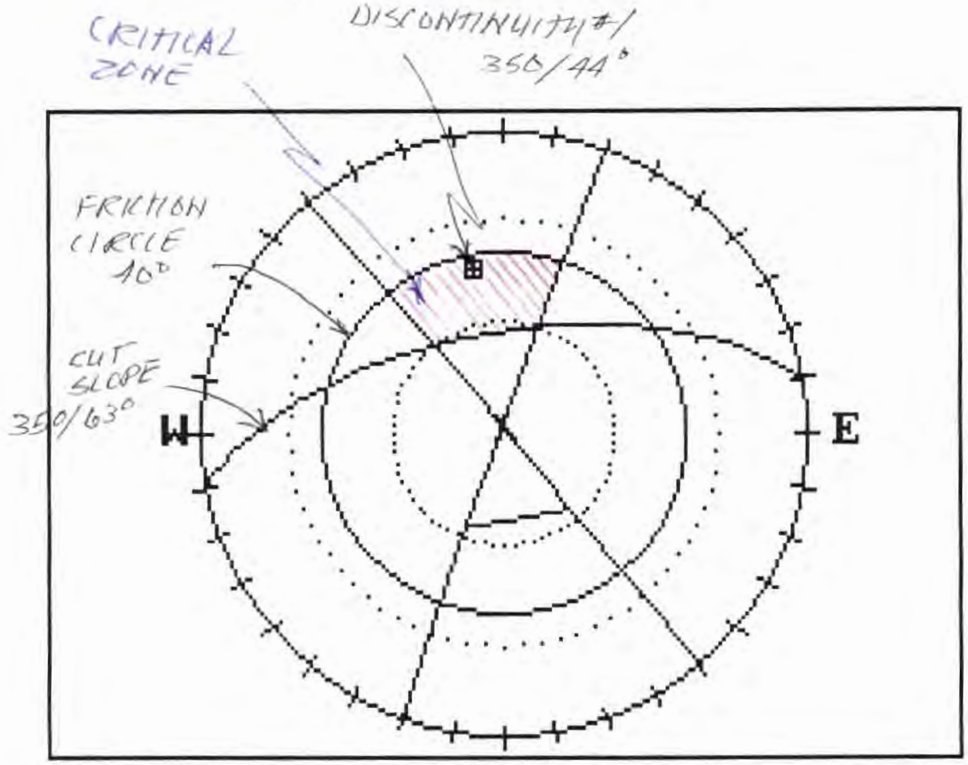
Ground water (if present, type of aquifer and where located) ____________

Estimated Soil Parameters (for each soil unit on Cross Section) ____________

III. RECOMMENDATIONS FOR SUBSURFACE INVESTIGATION, LABORATORY AND STABILITY ANALYSES: See attached plane failure analysis. No additional geotech work recommended unless proposed for regrading.

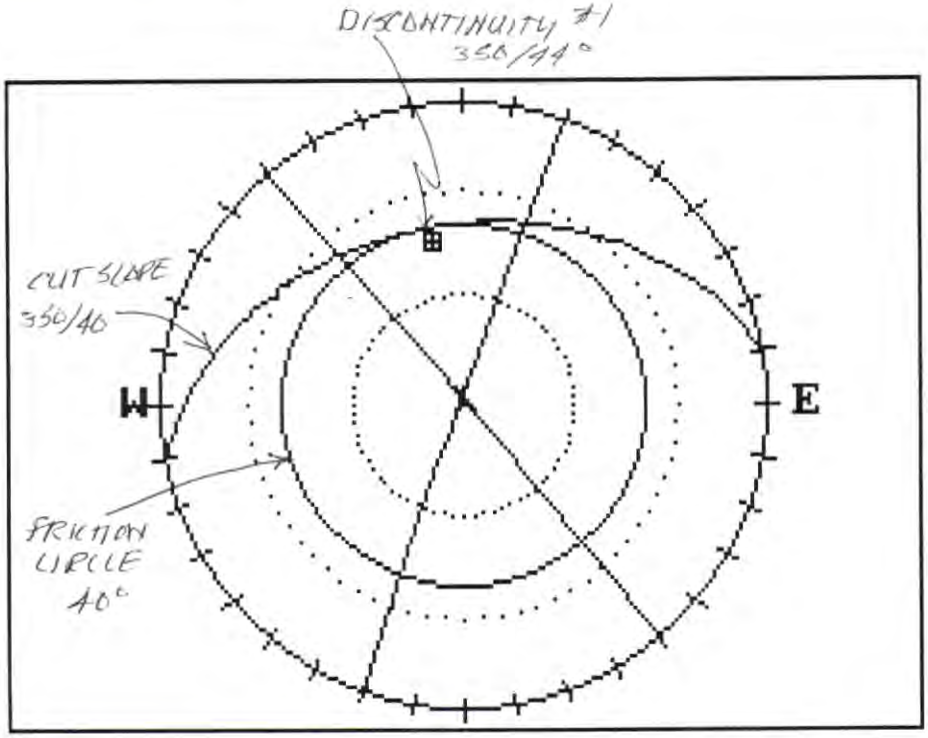
IV. POSSIBLE STABILIZATION ALTERNATIVES: See attached hypothetical example numeric plane failure analysis of recut at 1/4:1 (76°) to provide 20 feet of additional width. Preinstalled rock bolts required to stabilize slope above.

ROCKPACK
STEREONET: Plane failure likely for ½:1 cut slope (63°) since discontinuity is in critical zone.

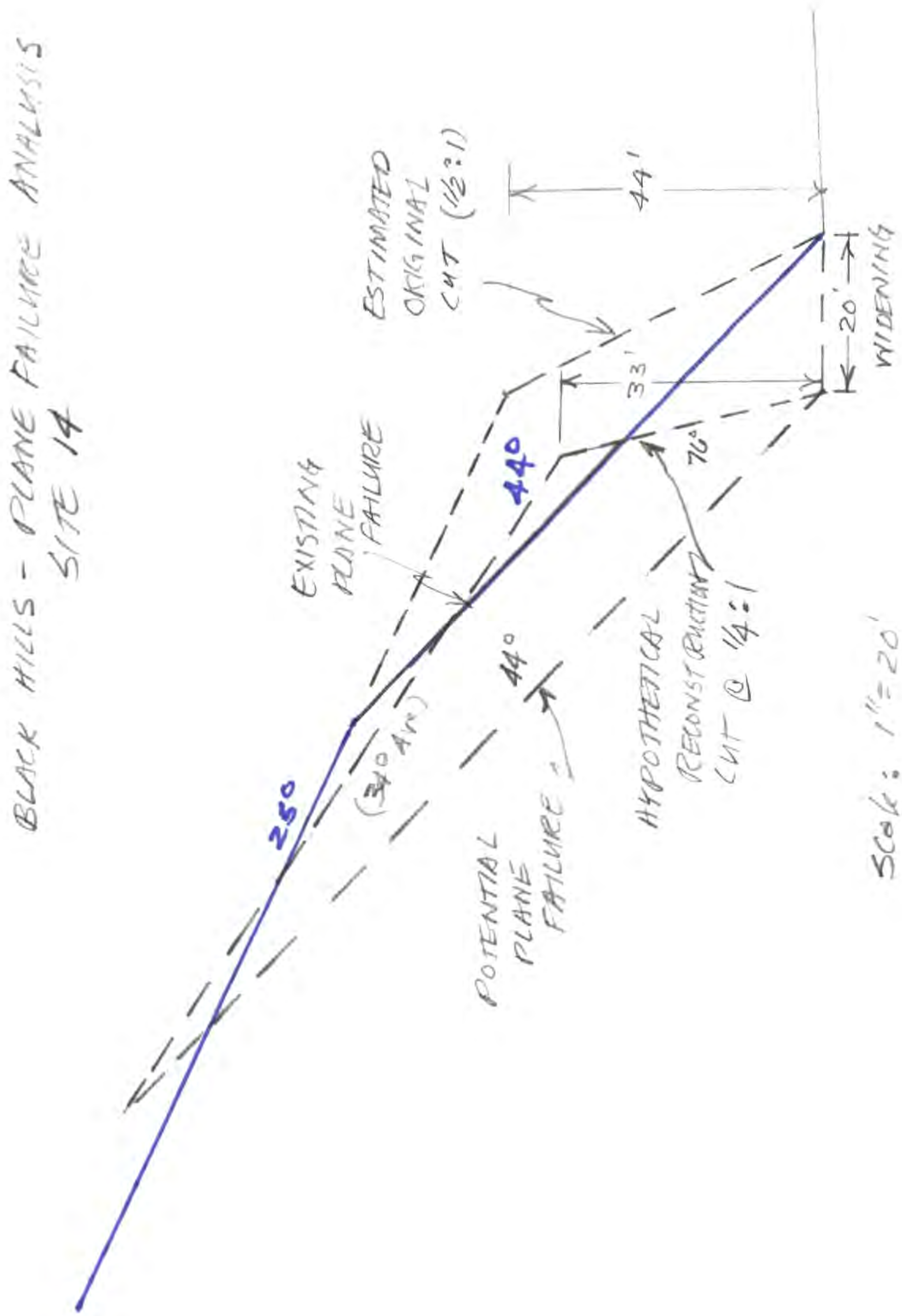


MARKLAND TEST PLOT: c:\rkpk2-04\dat
Friction Angle = 40 degrees
Slope dip direction = 350 degrees / 63 degrees
Number of Stations = 1

STEREO NET: No critical zone and unlikely plane failure for cut slopes 40° or flatter.



MARKLAND TEST PLOT: c:\rkpk2-04\dat
Friction Angle = 40 degrees
Slope dip direction = 350 degrees/40 degrees
Number of Stations = 1


BLACK HILLS - PLANE FAILURE ANALYSIS
SITE 14
ESTIMATED ORIGINAL CUT (½:1)
44'
20'
WIDENING
33'
76°
44°
EXISTING PLANE FAILURE
44°
25°
POTENTIAL PLANE FAILURE
HYPOTHETICAL RECONSTRUCTION CUT @ ¼:1
Scale: 1" = 20'

HYPOTHETICAL RECONST. CUT

```
GENERAL  SLOPE  GEOMETRY
 HEIGHT = 33
 ANGLES:  Slope = 76 ,  Upper Slope = 34 ,  Fail.Sfc. = 44
 STRENGTH:  Cohesion = 0   Friction = 40
 UNIT WEIGHTS:  Rock =  160 ,  Water =  62.4
 MISC:  Horizontal Accl. =  0 ,  Rockbolt Tension =  0
        Rockbolt inclination =  0
 Weight of Block = 188955.7
  Additional Vertical Surcharge   =  0
  Additional Horizontal Surcharge =  0
 Contact area along discontinuity =  131.05

 TENSION CRACK (None)
  Horizontal Distance,  Crest to Failure Surface =  86.04
 Failure Surface is  * DRY *.

         FACTOR OF SAFETY = 0.869
```

NUMERIC (FACTOR OF SAFETY) ANALYSIS BY ROCKPACK

ESTIMATED ORIGINAL CUT

```
GENERAL  SLOPE  GEOMETRY
 HEIGHT = 44
 ANGLES:  Slope = 63 ,  Upper Slope = 25 ,  Fail.Sfc. = 44
 STRENGTH:  Cohesion = 0   Friction = 40
 UNIT WEIGHTS:  Rock =  160 ,  Water =  62.4
 MISC:  Horizontal Accl. =  0 ,  Rockbolt Tension =  0
        Rockbolt inclination =  0
 Weight of Block = 120109
  Additional Vertical Surcharge   =  0
  Additional Horizontal Surcharge =  0
 Contact area along discontinuity =   93.38

 TENSION CRACK (None)
  Horizontal Distance,  Crest to Failure Surface =  44.76
 Failure Surface is  * DRY *.

         FACTOR OF SAFETY = 0.869
```

MECHANICAL REINFORCEMENT FOR RECONST. SLOPE

** G E N E R A L   S L O P E   C H A R A C T E R I S T I C S **

SLOPE HEIGHT =	33
SLOPE ANGLE =	76
UPPER SLOPE ANGLE =	34
FAILURE SURFACE DIP =	44
CONTACT AREA =	131.0541
COHESION =	0
FRICTION ANGLE =	40
UNIT WEIGHT ROCK =	160
UNIT WEIGHT WATER =	62.4
BLAST OR E'QUAKE ACCL. =	0
WEIGHT OF SLIDING MASS =	188955.7
ADDITIONAL VERTICAL SURCHARGE =	0
ADDITIONAL HORIZONTAL SURCHARGE =	0

NO TENSION CRACK:

HORIZONTAL DISTANCE, CREST TO FAILURE SURFACE = 86.04

FAILURE SURFACE IS *DRY* .

** S A F E T Y   F A C T O R   T A B L E S **

BOLT ANGLE (from normal) (to fail. sfc.)	BOLT ANGLE (from) (horizontal)	TENSION	SAFETY FACTOR
-5	51	100000	1.411992
0	46	100000	1.50818
5	41	100000	1.612839
-5	51	125000	1.537356
0	46	125000	1.667997
5	41	125000	1.815654
-5	51	150000	1.658936
0	46	150000	1.827814
5	41	150000	2.025948
-5	51	175000	1.776899
0	46	175000	1.98763
5	41	175000	2.24414
-5	51	200000	1.891405
0	46	200000	2.147447
5	41	200000	2.470686

SITE RECONNAISSANCE

State Highway US 385 Date 07/14/94

M.P. 37.0 Length ______________ Name Research Team

Site Designation Site 15 (Road Segment 3, Stop 1)

PURPOSE OF INVESTIGATION

Research; document wedge failure in RUA.

CONCERNS AND CONSTRAINTS (Step 1)

N/A

PRECONSTRUCTION, CONSTRUCTION, MAINTENANCE HISTORY

This is an older cut with no documented history. The ditch apparently requires only minimal maintenance, although a mound of talus has accumulated near the base of the slope (see Photo 1).

EXISTING CUT SLOPE

Failure slope:

Angle 35° to 45° Height 62 ft.

Observed Slope Failure Mechanism: Wedge failure. Minor rockfall and ravelling from the overlying colluvial soil units, occasional rockfall and possible toppling from RUA typically occur mostly in response to dislodgement by frost wedging. Based on amount of vegetation growing on talus pile, it appears the rate of rockfall is dropping off.

ENGINEERING ROCK AND SOIL UNITS

RUA with thin SUS colluvial layer.

OPTIMUM SLOPE RANGE(S) (Per Rock and/or Soil Unit)

The optimum slope range is 1/2:1 or steeper provided that discontinuity dip angles are favorable. Because dip angles are not favorable, the slope must be flattened to 40° or less to achieve stability (see stability analysis).

VEGETATION

Grasses and ponderosa pines sparsely vegetate the talus mound and the perimeter of wedge feature.

POSSIBLE TREATMENT METHODS

No treatment methods are required at this time.

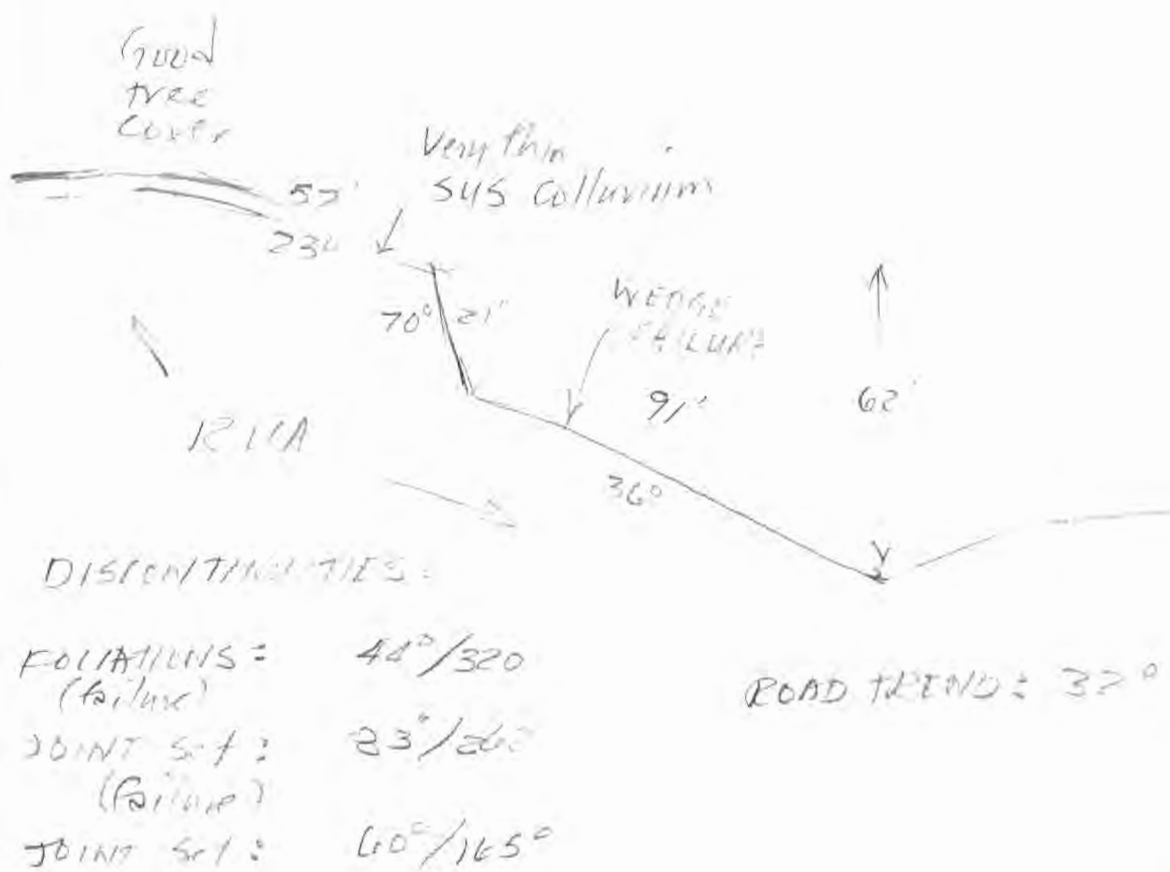
PRELIMINARY EVALUATION

Rockfall from the wedge feature in RUA and from the SUS colluvial layer does not appear to be a major hazard. Talus accumulation in the ditch can be managed with occasional cleaning.

SITE RECONNAISSANCE

Site Designation <u>Site 15 (Road Segment 3, Stop 1)</u>

<u>CROSS SECTIONAL SKETCH</u>



Site Designation Site 15 (Road Segment 3, Stop 1)

Photo 1: View of wedge failure.

Photo 2: Close-up of small wedge failure showing discontinuity intersections similar to the large one in Photo 1.

SITE RECONNAISSANCE

Site Designation Site 15 (Road Segment 3, Stop 1)

SLOPE STABILITY ATTACHMENT

I. ROCK (Provide details on Cross Section)

A. DISCONTINUITY FAILURE

Discontinuities (Dip/Dip Direction)		Infilling	Friction Angle
Primary (foliation failure)	44/320	None	40°
Secondary I (failure)	83/262	None	40°
Secondary II			
Secondary III			

Road Azimuth 32° Existing Failure Angle 35° - 45°

Anticipated Failure Type: Plane ________ Wedge Existing

B. TOPPING FAILURE

Column Width ________ Height ________ Base Angle ________

C. COLLAPSE FAILURE

Differential Weathering Rating: High ______ Medium ______ Low ______

II. SOIL AND DECOMPOSED ROCK (Provide details on Cross Section)

Current or Anticipated Failure (for stability analysis) ________

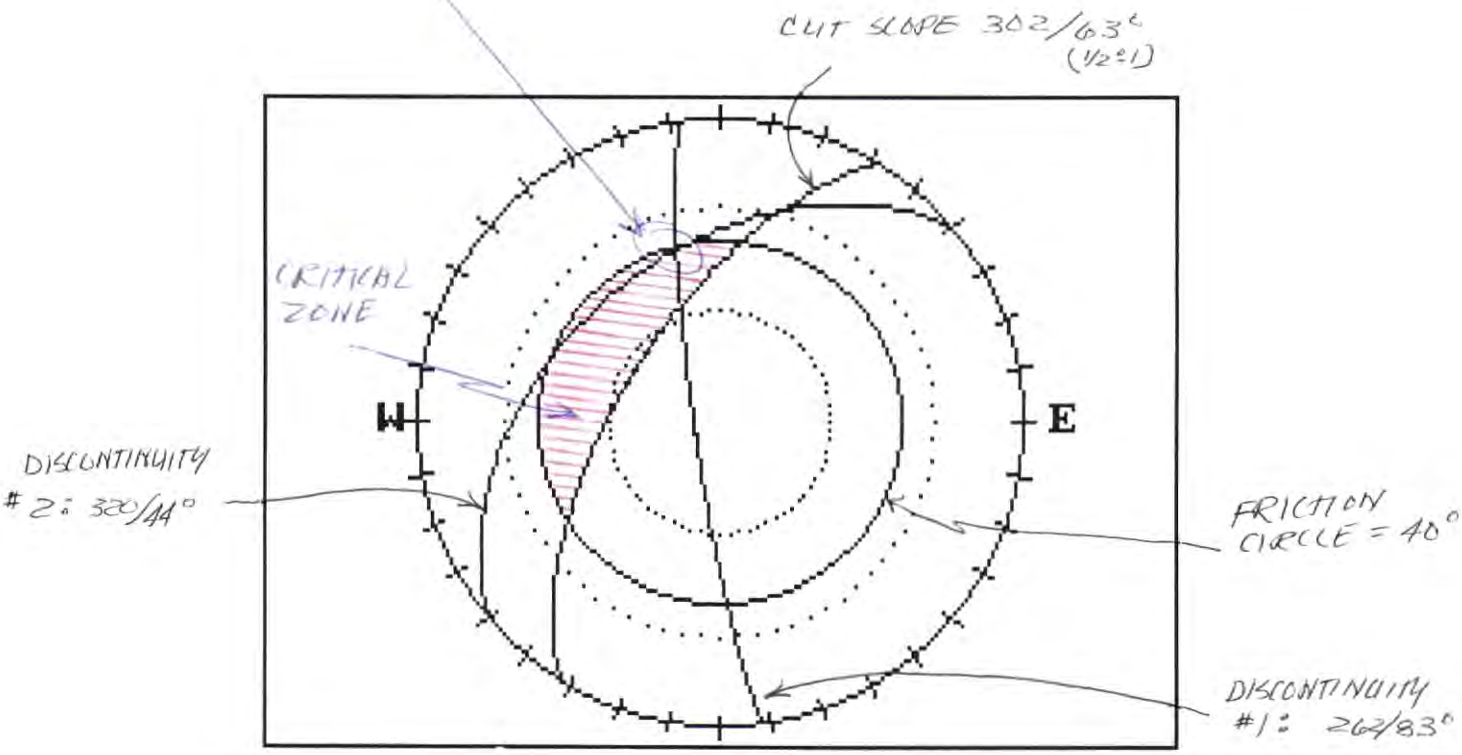
Ground water (if present, type of aquifer and where located) ________

Estimated Soil Parameters (for each soil unit on Cross Section) ________

III. RECOMMENDATIONS FOR SUBSURFACE INVESTIGATION, LABORATORY AND STABILITY ANALYSES: No further geotech work recommended unless planned for reconstruction.

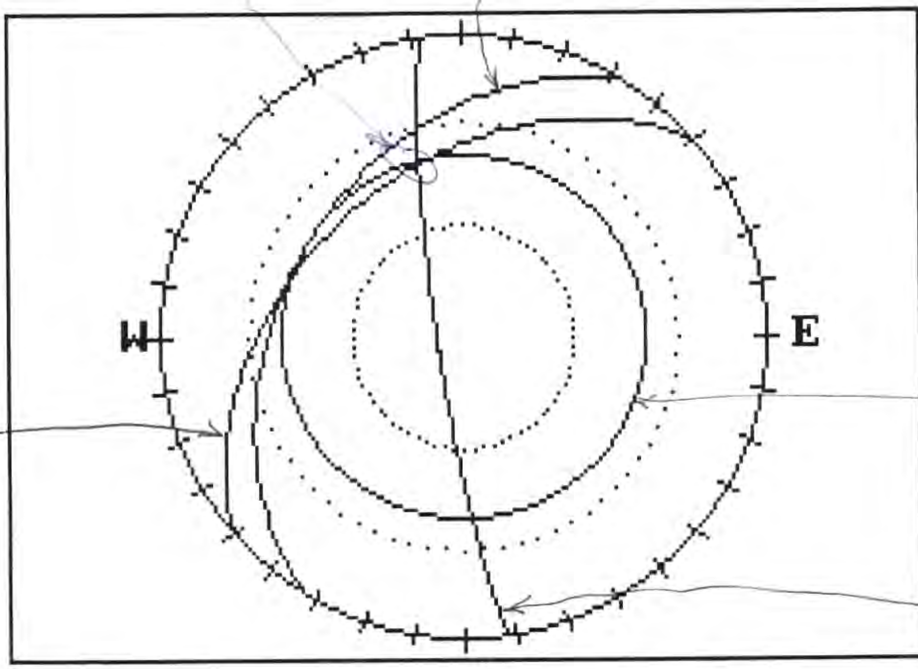
IV. POSSIBLE STABILIZATION ALTERNATIVES: See stereonet analysis; slopes 40° or flatter should be stable. Rock bolting possible for stabilization of steep angled cut slopes.

STEREONET ANALYSIS: Failure by "wedge" likely for 63° (½:1) Cut slope with intersection of discontinuities in critical zone.



MARKLAND WEDGE ANALYSIS: c:\rkpk2-0
Friction Angle = 40 degrees
Slope dip direction = 302 degrees / 63 degrees
Sets: 262 / 83 320 / 44

STEREONET ANALYSIS: No Critical zone and failure by "wedge" unlikely for cut slopes 40° or flatter.



MARKLAND WEDGE ANALYSIS: c:\rkpk2-0
Friction Angle = 40 degrees
Slope dip direction = 302 degrees / 40 degrees
Sets: 262 / 83 320 / 44

SITE RECONNAISSANCE

State Highway US 16A

Date 07/11/94

M.P. 59 Length 153 ft. Name Research Team

Site Designation Site 17 (Road Segment 9, Stop 1)

PURPOSE OF INVESTIGATION

Research; document successfully constructed benched cut and provide a demonstration of the Colorado Rockfall Simulator Program (CRSP).

CONCERNS AND CONSTRAINTS (Step 1)

N/A

PRECONSTRUCTION, CONSTRUCTION, MAINTENANCE HISTORY

This slope was constructed in 1990. The slope is double-cut with a 10-foot-wide bench. There were apparently no problems with the controlled blasting. Very little rockfall has accumulated on the bench or in the ditch at the base of the slope.

EXISTING CUT SLOPE

1:1 above bench
Angle 1/2:1 below bench Height 73 ft. total

No Observed Slope Failure Mechanism: However, we anticipate that only minor ravelling is occurring along the upper slope.

ENGINEERING ROCK AND SOIL UNITS

RUA

OPTIMUM SLOPE RANGE(S) (Per Rock and/or Soil Unit)

The optimum slope range is 1/2:1 or steeper for RUA with favorable discontinuities such as these.

VEGETATION

The ditch and bench are well vegetated with grass.

POSSIBLE TREATMENT METHODS

No treatment methods are required at present; however, the bench should be monitored periodically for rockfall. If rockfall increases, the installation of a short barrier at the base of the slope would stop nearly all rockfall from entering travelled way (see CRSP analysis and Photo 4).

PRELIMINARY EVALUATION

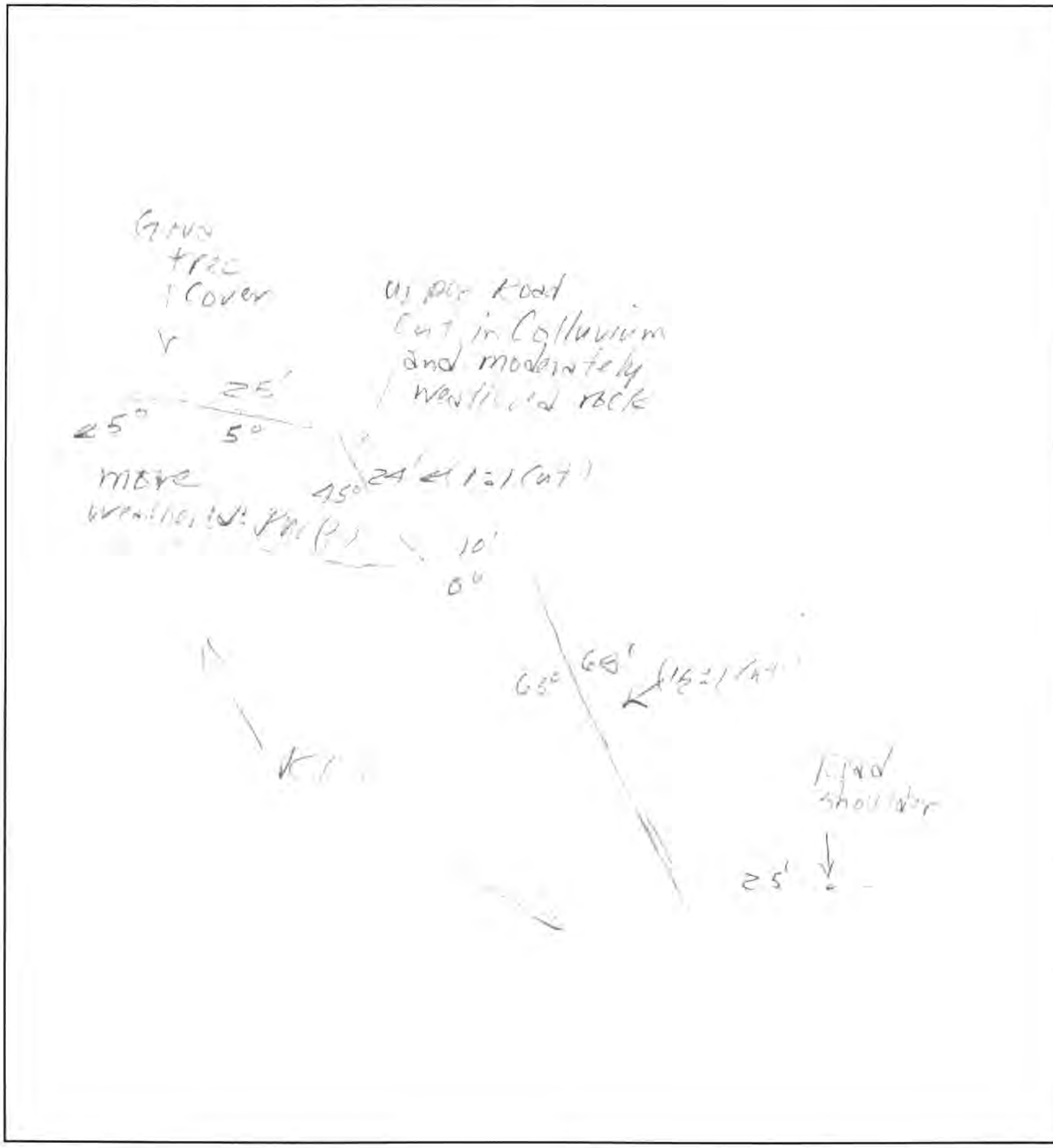
This slope is successful for a few reasons:

1. The upper part of the slope was constructed at 1:1 through the less competent rock, which is nearly stable.
2. The bench catches most of the material that does ravel from the upper slope (see CRSP analysis).
3. The controlled blasting was well done and loosened very little material below the bench.

SITE RECONNAISSANCE

Site Designation Site 17 (Road Segment 9, Stop 1)

CROSS SECTIONAL SKETCH



Site Designation Site 17 (Road Segment 9, Stop 1)

Photo 1: Profile view. Note grass cover and the very small accumulation of rockfall on the bench.

Photo 2: View of slope from across the highway.

Site Designation <u>Site 17 (Road Segment 9, Stop 1)</u>

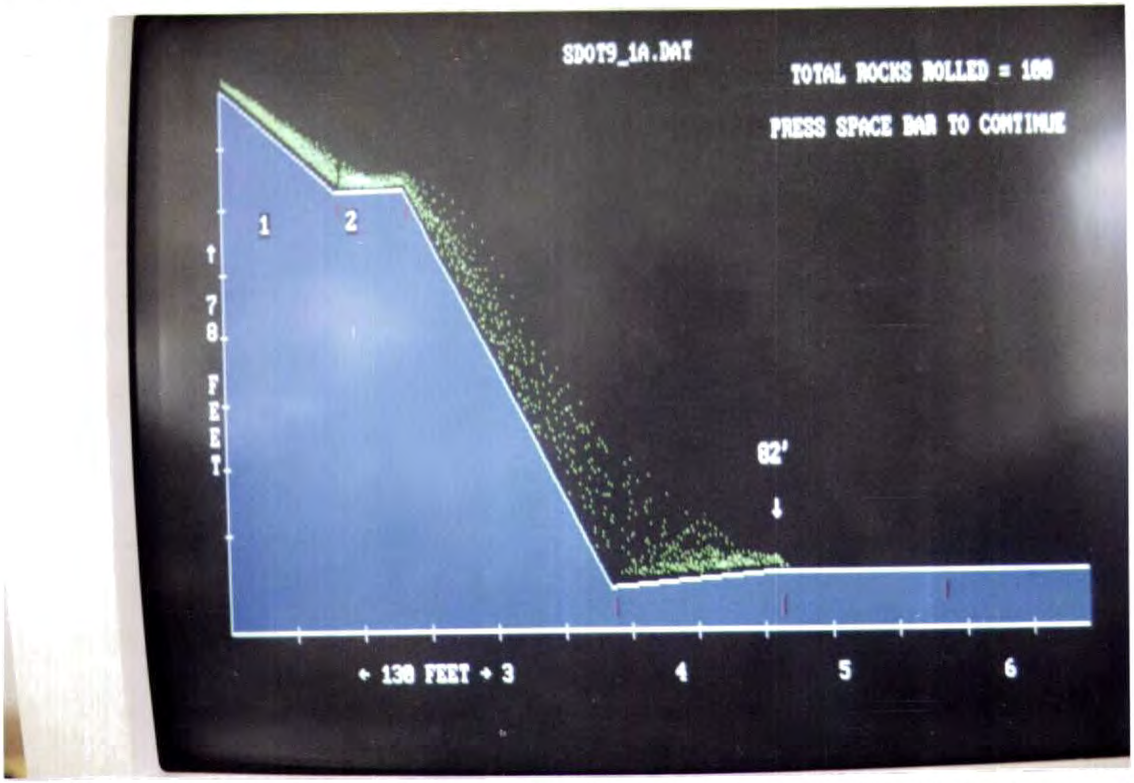


Photo 3: Computer screen display showing results of the Colorado Rockfall Simulation Program for the benched slope without a highway barrier.

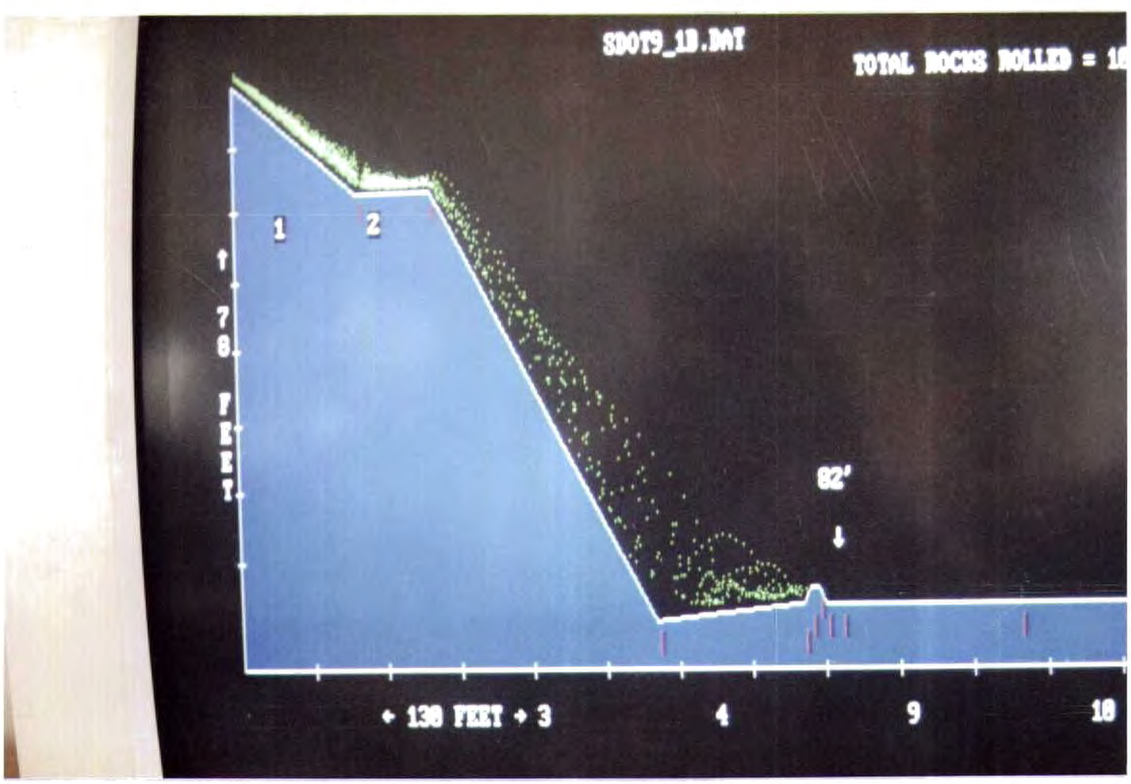
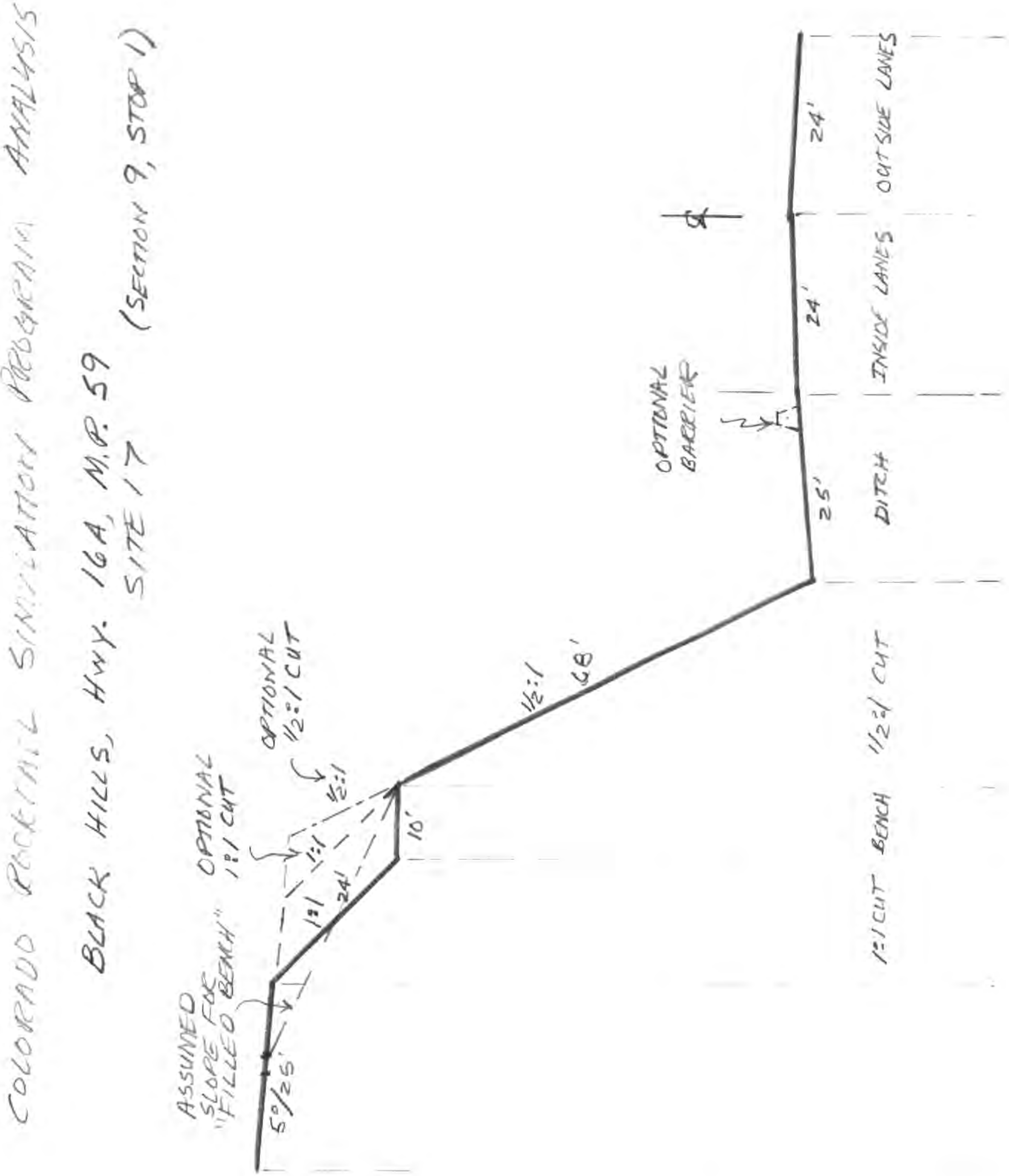


Photo 4: Computer screen display showing results of the Colorado Rockfall Simulation Program for the benched slope with a highway barrier.


COLORADO ROCKFALL SIMULATION PROGRAM ANALYSIS
BLACK HILLS, HWY. 16A, M.P. 59
SITE 17
(SECTION 9, STOP 1)
ASSUMED SLOPE FOR "FILLED BENCH"
OPTIONAL 1:1 CUT
OPTIONAL 1/2:1 CUT
OPTIONAL BARRIER
5°/25'
1:1
24'
1:1
1/2:1
10'
1/2:1
68'
25'
24'
24'
1:1 CUT
BENCH
1/2:1 CUT
DITCH
INSIDE LANES
OUTSIDE LANES

CELL DATA OUTPUT

SDDOT17A.DAT

REMARKS: Black Hills, SITE 17, 1:1, Bench, .5:1

DATA COLLECTED AT END OF EACH CELL

CELL #	MAXIMUM VELOCITY (ft/sec)	AVERAGE VELOCITY (ft/sec)	STANDARD DEVIATION VELOCITY	AVERAGE BOUNCE HEIGHT (ft)	MAXIMUM BOUNCE HEIGHT (ft)
1 (1:1 CUT)	28	20	4.55	1	4
2 (BENCH)	16	9	3.39	0	1
3 (1/2:1 CUT)	62	45	7.75	10	19
4 (DITCH)	24	13	5.05	0	1
5 (INSIDE LANE)	21	11	4.82	0	0
6 (OUTSIDE LANE)	18	11	3.97	0	0

X INTERVAL	ROCKS STOPPED
0 ft TO 10 ft	4
10 ft TO 20 ft	14
20 ft TO 30 ft	46
50 ft TO 60 ft	5
60 ft TO 70 ft	7
ROAD 70 ft TO 80 ft	7
SHOULDER 80 ft TO 90 ft	1
90 ft TO 100 ft	2
100 ft TO 110 ft	3
110 ft TO 120 ft	1
120 ft TO 130 ft	4

17 ROCKS PAST ROAD SHOULDER INTO TRAVELLED WAY.

CELL DATA OUTPUT

SDDOT17B.DAT

REMARKS: Black Hills SITE 17, Filled Bench/.5:1

DATA COLLECTED AT END OF EACH CELL

CELL #	MAXIMUM VELOCITY (ft/sec)	AVERAGE VELOCITY (ft/sec)	STANDARD DEVIATION VELOCITY	AVERAGE BOUNCE HEIGHT (ft)	MAXIMUM BOUNCE HEIGHT (ft)
1 (UPPER FILLED BENCH)	7	7	0.00	0	0
2 (1/2:1 CUT)	33	33	0.00	5	5
3 (DITCH)	22	22	0.00	1	1
4 (INSIDE LANE)	20	20	0.00	0	0
5 (OUTSIDE LANE)	17	17	0.00	0	0

X INTERVAL	ROCKS STOPPED
0 ft TO 10 ft	93
10 ft TO 20 ft	3
20 ft TO 30 ft	3

· ROCK PAST ROAD SHOULDER INTO TRAVELLED WAY.

CELL DATA OUTPUT

SDDOT17C.DAT

REMARKS: Black Hills SITE 17, 1:1/.5:1

DATA COLLECTED AT END OF EACH CELL

CELL #	MAXIMUM VELOCITY (ft/sec)	AVERAGE VELOCITY (ft/sec)	STANDARD DEVIATION VELOCITY	AVERAGE BOUNCE HEIGHT (ft)	MAXIMUM BOUNCE HEIGHT (ft)
1 (1:1 CUT)	28	19	4.23	1	4
2 (1/2:1 CUT)	65	47	9.01	10	25
3 (DITCH)	23	13	4.55	0	2
4 (INSIDE LANE)	21	12	3.20	0	0
5 (OUTSIDE LANE)	18	9	3.12	0	0

	X INTERVAL	ROCKS STOPPED
	0 ft TO 10 ft	3
	40 ft TO 50 ft	12
	50 ft TO 60 ft	18
ROAD	60 ft TO 70 ft	11
SHOULDER	70 ft TO 80 ft	6
	80 ft TO 90 ft	6
	90 ft TO 100 ft	3
	100 ft TO 110 ft	3
	110 ft TO 120 ft	9

56 ROCKS PAST ROAD SHOULDER INTO TRAVELLED WAY.

CELL DATA OUTPUT

SDDOT17D.DAT

REMARKS: Black Hills SITE 17, .5:1 Only

DATA COLLECTED AT END OF EACH CELL

CELL #	MAXIMUM VELOCITY (ft/sec)	AVERAGE VELOCITY (ft/sec)	STANDARD DEVIATION VELOCITY	AVERAGE BOUNCE HEIGHT (ft)	MAXIMUM BOUNCE HEIGHT (ft)
1 (½-1 CUT)	65	48	8.71	12	26
2 (DITCH)	27	16	6.43	0	2
3 (INSIDE LANE)	26	14	6.68	0	0
4 (OUTSIDE LANE)	24	15	5.58	0	0

X INTERVAL			ROCKS STOPPED
30 ft	TO	40 ft	4
40 ft	TO	50 ft	24
ROAD 50 ft	TO	60 ft	20
SHOULDER 60 ft	TO	70 ft	7
70 ft	TO	80 ft	2
80 ft	TO	90 ft	5
90 ft	TO	100 ft	6
100 ft	TO	110 ft	6

48 ROCKS PAST ROAD SHOULDER INTO TRAVELLED WAY.

CELL DATA OUTPUT

SDDOT17E.DAT

REMARKS: Black Hills SITE 17, 1:1/.5:1 w/ 3 ft. Barrier

DATA COLLECTED AT END OF EACH CELL

CELL #	MAXIMUM VELOCITY (ft/sec)	AVERAGE VELOCITY (ft/sec)	STANDARD DEVIATION VELOCITY	AVERAGE BOUNCE HEIGHT (ft)	MAXIMUM BOUNCE HEIGHT (ft)
1 (2:1 CUT)	27	20	3.97	1	4
2 (½:1 CUT)	65	45	8.55	12	26
3 (DITCH)	29	14	6.04	0	3
4 (BARRIER)	20	20	0.00	0	0
5 (BARRIER)	20	20	0.00	0	0
6 (BARRIER)	20	20	0.00	3	3
7 (BARRIER)	20	20	0.00	3	3
8 (INSIDE LANE)	19	19	0.00	0	0
9 (OUTSIDE LANE)	16	16	0.00	0	0

X INTERVAL			ROCKS STOPPED
0 ft	TO	10 ft	3
40 ft	TO	50 ft	9
50 ft	TO	60 ft	14
(ROAD SHOULDER) 60 ft	TO	70 ft	73

1 ROCK PAST ROAD SHOULDER INTO TRAVELED WAY.

CELL DATA OUTPUT

SDDOT17F.DAT

REMARKS: Black Hills, SITE 17, 1:1, Bench, .5:1 w/ 2 ft. Barrier

DATA COLLECTED AT END OF EACH CELL

CELL #	MAXIMUM VELOCITY (ft/sec)	AVERAGE VELOCITY (ft/sec)	STANDARD DEVIATION VELOCITY	AVERAGE BOUNCE HEIGHT (ft)	MAXIMUM BOUNCE HEIGHT (ft)
1 (1:1 CUT)	29	20	4.35	1	4
2 (BENCH)	15	9	4.02	0	1
3 (½:1 CUT)	58	44	7.88	10	22
4 (DITCH)	26	13	5.69	0	2
5	NO ROCKS PASSED POINT (BARRIER IN DITCH)				
6	NO ROCKS PASSED POINT (BARRIER IN DITCH)				
7	NO ROCKS PASSED POINT (BARRIER IN DITCH)				
8	NO ROCKS PASSED POINT (BARRIER IN DITCH)				
9	NO ROCKS PASSED POINT (INSIDE LANE)				
10	NO ROCKS PASSED POINT (OUTSIDE LANE)				

X INTERVAL			ROCKS STOPPED
0 ft	TO	10 ft	2
10 ft	TO	20 ft	18
20 ft	TO	30 ft	45
50 ft	TO	60 ft	5
60 ft	TO	70 ft	6
ROAD SHOULDER 70 ft	TO	80 ft	24

NO ROCKS PAST ROAD SHOULDER INTO TRAVELLED WAY.

SITE RECONNAISSANCE

State Highway US 16A   Date 07/11/94

M.P. 58.4   Length 400 ft.   Name Research Team

Site Designation Site 18 (Road Segment 9, Stop 2)

PURPOSE OF INVESTIGATION

Research; document a successfully constructed benched cut slope.

CONCERNS AND CONSTRAINTS (Step 1)

N/A

PRECONSTRUCTION, CONSTRUCTION, MAINTENANCE HISTORY

Same as Site 17.

EXISTING CUT SLOPE

41° above bench
Angle 65° below bench   Height 105 ft. total

Observed Slope Failure Mechanism: A small wedge failure near the top of the 1/2:1 slope, at the bench.

ENGINEERING ROCK AND SOIL UNITS

RUA

OPTIMUM SLOPE RANGE(S) (Per Rock and/or Soil Unit)

The optimum slope range is 1/2:1 or steeper for RUA with favorable discontinuities such as these.

VEGETATION

The ditch is well vegetated. Sparse grass is growing on the bench.

POSSIBLE TREATMENT METHODS

No treatment methods are required at this time. The bench should be monitored periodically for rockfall. If rockfall from small wedge failures increases, installation of a short barrier at the base of the slope will stop rocks from entering the travelled way (see Site 17 - Photo 4).

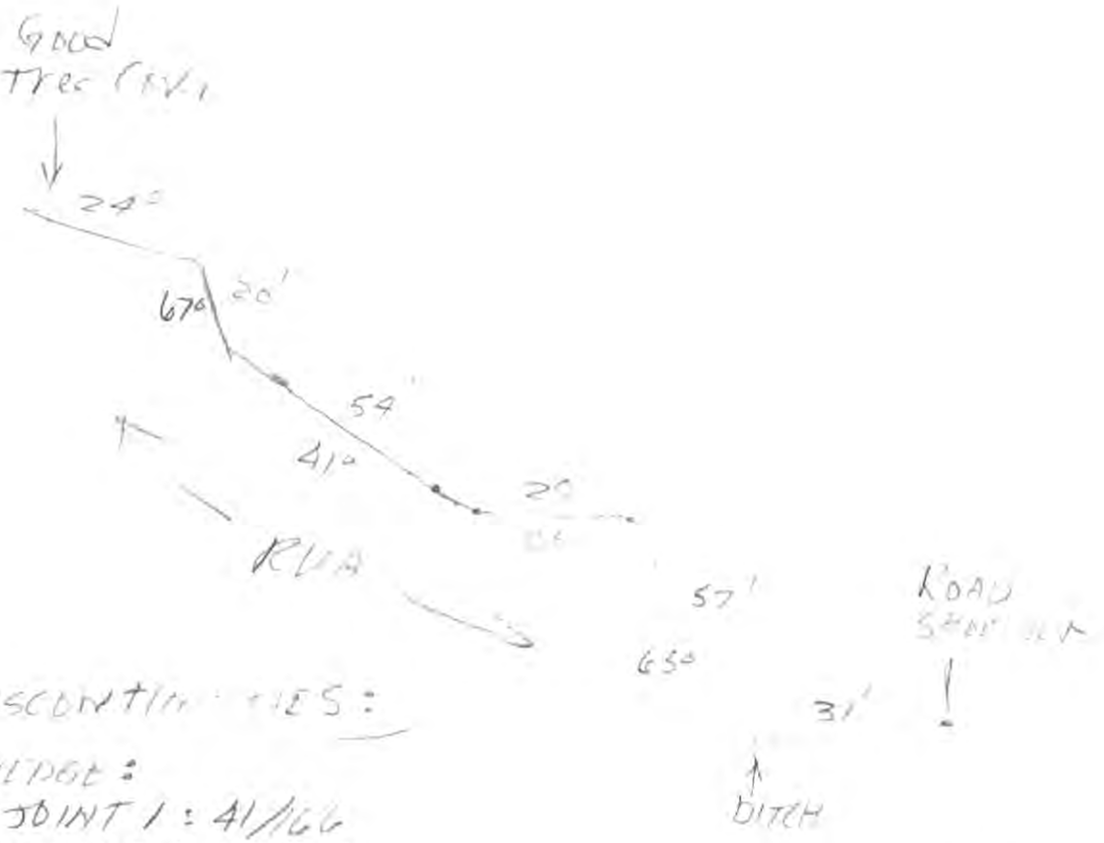
PRELIMINARY EVALUATION

Small wedge failures in the upper part of the slope may occur periodically. However, these failures do not represent a rockfall hazard and will require only minor maintenance. This site evaluation is virtually identical to Site 17.

SITE RECONNAISSANCE

Site Designation Site 18 (Road Segment 9, Stop 2)

CROSS SECTIONAL SKETCH



DISCONTINUITIES:

WEDGE:
JOINT 1: 41/166
JOINT 2: 62/55

ROAD TREND: 6°

FOLIATIONS: 78-80/80
JOINT SET: 10-29/260-316

Site Designation Site 18 (Road Segment 9, Stop 2)

Photo 1: View of slope from across highway.

Photo 2: Close-up view of rock discontinuities in RUA.

SITE RECONNAISSANCE

State Highway US 385 Date 07/12/94

M.P. 62.5 Length 200 ft. Name Research Team

Site Designation Site 21 (Road Segment 6, Stop 3)

PURPOSE OF INVESTIGATION

Research; document the performance of a recently constructed slope in RUA and RUD with a favorable rock discontinuity dip.

CONCERNS AND CONSTRAINTS (Step 1)

N/A

PRECONSTRUCTION, CONSTRUCTION, MAINTENANCE HISTORY

This slope was constructed in 1993. This site is similar to Sites 22 and 23 but is on opposite side of highway. No apparent problems were encountered during construction.

EXISTING CUT SLOPE

Angle 45° to 50° Height 27 ft.

Observed Slope Failure Mechanism: Surface erosion (rilling and gullying) in RUD section.

ENGINEERING ROCK AND SOIL UNITS

RUA and RUD.

OPTIMUM SLOPE RANGE(S) (Per Rock and/or Soil Unit)

The optimum slope range is 1/2:1 or steeper in RUA, and 1:1 in RUD.

VEGETATION

The ditch is vegetated with an excellent first-year crop of grain. Sparse grasses vegetate the cut slope (see Site 23 for a description of the revegetation method).

POSSIBLE TREATMENT METHODS

None required at this time; however, the surface erosion of the RUD unit must be monitored. If the size of erosional rills increases, we recommend revegetation techniques such as hydroseed or Soilguard be used to retard erosion.

PRELIMINARY EVALUATION

The rock discontinuity angle on this side of the highway is favorable (dipping into the slope); therefore, a cut slope of 1/4:1 could have been used in the RUA section. However, a slope of 1:1 or flatter was necessary to stabilize the RUD section and was correctly selected for the cut slope ratio.

SITE RECONNAISSANCE

Site Designation Site 21 (Road Segment 6, Stop 3)

CROSS SECTIONAL SKETCH

Good Tree Cover

very thin soil colluvium cover

RCA Novel w/ Abrupt Change in RCD (South) Possible Fault Zone

48° 36'

Good Grain Paregeration

Hand Shoulder

34'

Ditch

DISCONTINUITIES

FOLIATIONS: 75-83/268-273

JOINT Sets: 10-30/160-190

JOINT Set: 83-90/160-185

ROAD TREND: 25°

Site Designation Site 21 (Road Segment 6, Stop 3)

Photo 1: View of slope from across the highway. Note the sharp change from RUA on left to RUD on right.

Photo 2: Close-up of RUA. Note the favorable discontinuity of dip angle with respect to the slope.

SITE RECONNAISSANCE

State Highway US 385 Date 07/12/94

M.P. 62.1 Length 283 ft. Name Research Team

Site Designation Site 22 (Road Segment 6, Stop 2)

PURPOSE OF INVESTIGATION

Research; document the performance of a recently constructed cut slope in RUA.

CONCERNS AND CONSTRAINTS (Step 1)

N/A

PRECONSTRUCTION, CONSTRUCTION, MAINTENANCE HISTORY

This slope was constructed in 1993. Minor planar failures developed during construction. The ditch was revegetated with grain and grass using a "drill seeder."

EXISTING CUT SLOPE

Angle 63° to 65° Height 45 ft.

Observed Slope Failure Mechanism: Minor plane failures.

ENGINEERING ROCK AND SOIL UNITS

RUA

OPTIMUM SLOPE RANGE(S) (Per Rock and/or Soil Unit)

The optimum slope range is 1/2:1 or steeper.

VEGETATION

The ditch is well vegetated with grain and grass (see Site 23 for a description of the revegetation method).

POSSIBLE TREATMENT METHODS

None presently required.

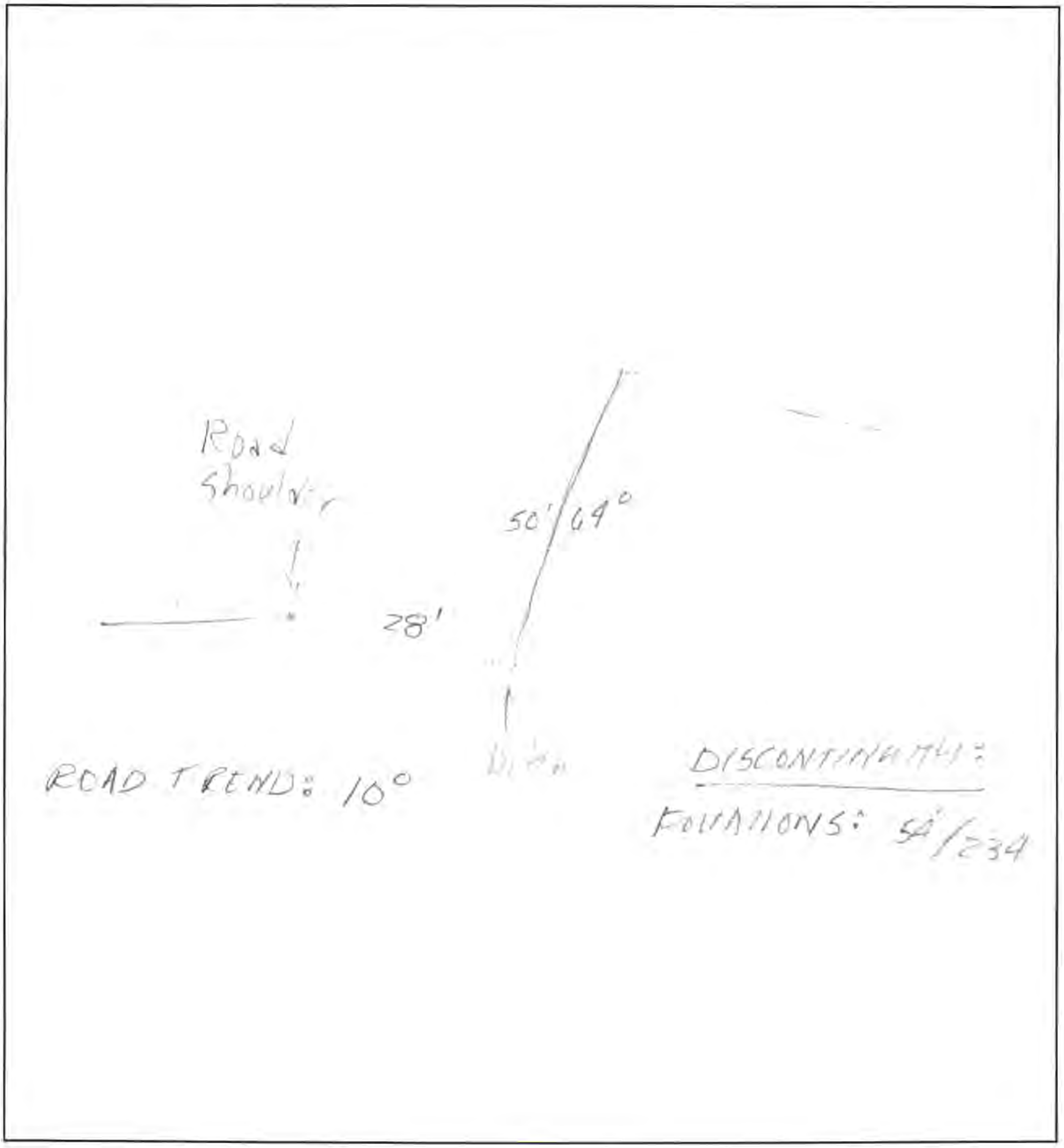
PRELIMINARY EVALUATION

The slope appears to be stable; however, several minor plane failures have developed since construction. These small failures do not represent a rockfall hazard. The ditch will require only minor maintenance. Also, this site is an excellent candidate as a "Geologic Point of Interest."

SITE RECONNAISSANCE

Site Designation Site 22 (Road Segment 6, Stop 2)

CROSS SECTIONAL SKETCH



Site Designation Site 22 (Road Segment 6, Stop 2)

Photo 1: View of cut slope from across the highway. Note the minor plane failures at left.

Photo 2: View of cut slope and revegetated ditch. Note the near absence of rockfall and dense growth of wheat in ditch.

SITE RECONNAISSANCE

State Highway US 385 Date 07/12/94

M.P. 61.7 Length 215 ft. Name Research Team

Site Designation Site 23 (Road Segment 6, Stop 1)

PURPOSE OF INVESTIGATION

Research; document a recently constructed slope with plane failures in RUA.

CONCERNS AND CONSTRAINTS (Step 1)

N/A

PRECONSTRUCTION, CONSTRUCTION, MAINTENANCE HISTORY

The slope was constructed in 1993. Many plane failures developed during and after construction. The ditch contains moderate amounts of talus from the plane failures.

EXISTING CUT SLOPE

Failure slope angle 59° to 65° Height 31 ft.

Observed Slope Failure Mechanism: plane failures to about 59°.

ENGINEERING ROCK AND SOIL UNITS

RUA

OPTIMUM SLOPE RANGE(S) (Per Rock and/or Soil Unit)

The optimum slope range is 1/2:1 or steeper, provided that failure surfaces dip into the slope. However, the failure surfaces at this site are unfavorable. Under these conditions, a cut slope of about 59° would be stable.

VEGETATION

Cut slopes were hydromulched with wheat grass and red clover. The ditches were drilled with wheat initially; later on wheat grass and red clover will be planted. The ditch is presently well vegetated with wheat.

POSSIBLE TREATMENT METHODS

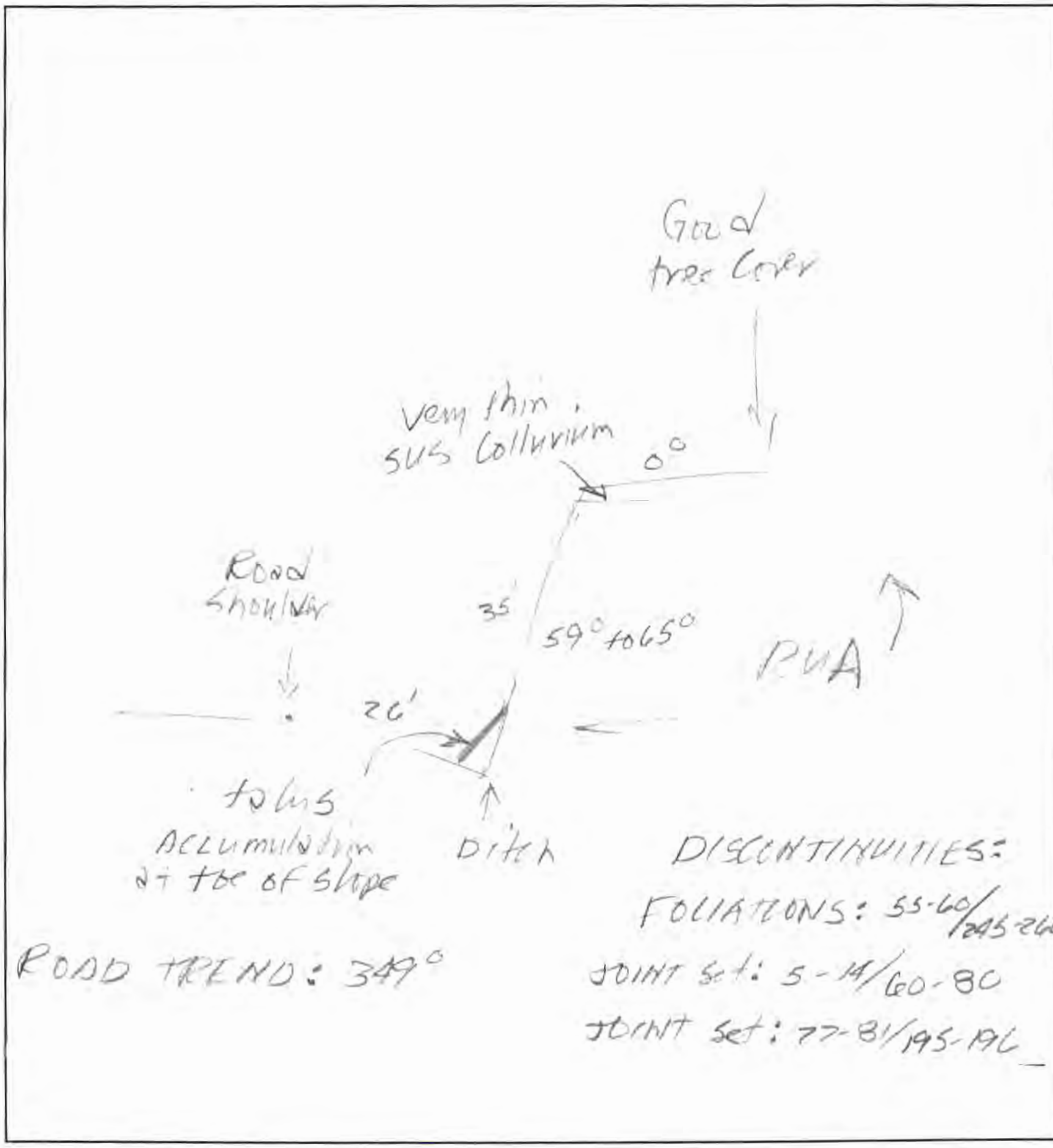
None presently required.

PRELIMINARY EVALUATION

Plane failures are still occurring as evidenced from the talus accumulation at the base of the cut slope. We anticipate that such failures will subside, since the overall cut slope is very near the foliation dip angle (about 60°). Rockfall is minimal and the ditch should capture the small hazard to the travelled way.

Site Designation Site 23 (Road Segment 6, Stop 1)

CROSS SECTIONAL SKETCH



Site Designation Site 23 (Road Segment 6, Stop 1)

Photo 1: Profile view. Note the talus accumulation at base of slope and the dense growth of wheat resulting from revegetation efforts.

Photo 2: View of cut slope showing plane failures.

SITE RECONNAISSANCE

State Highway US 385 Date 07/13/94

M.P. 119 Length 270 ft. Name Research Team

Site Designation Site 7 (Road Segment 2, Stop 1)

PURPOSE OF INVESTIGATION

Research; document rockfall in RUB and provide an example of the ODOT rockfall hazard rating method.

CONCERNS AND CONSTRAINTS (Step 1)

N/A

PRECONSTRUCTION, CONSTRUCTION, MAINTENANCE HISTORY

This is an older cut slope with very little ditch. Every spring rocks fall on the roadway and must be removed and the ditch requires frequent cleaning.

EXISTING CUT SLOPE

Angle 62° Height 28 ft. (see sketch)

Observed Slope Failure Mechanism: Ravelling. The rock unit is extensively jointed and prone to root and frost wedging. Rockfall material accumulates in the ditch as talus (see Photo 1).

ENGINEERING ROCK AND SOIL UNITS

RUB with very little soil cover.

OPTIMUM SLOPE RANGE(S) (Per Rock and/or Soil Unit)

The optimum slope range is 1:1 or flatter.

VEGETATION

Sparse grass and ponderosa pine grow on the cut slope.

POSSIBLE TREATMENT METHODS

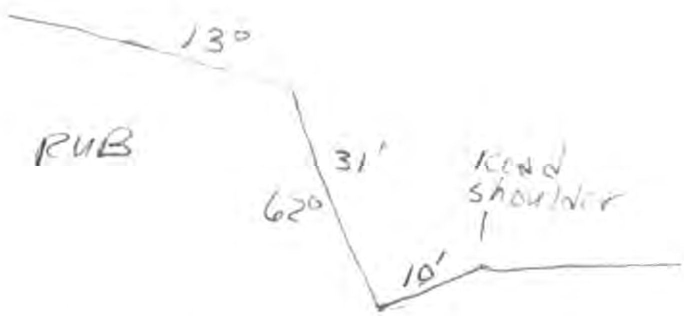
Regrading followed by revegetation using techniques such as hydroseeding or Soilguard.

PRELIMINARY EVALUATION

"Root and frost wedging" are probably the primary cause of rockfall on this slope. The slope is not high and natural slope above is relatively flat (about 13°). Regrading the slope to 1:1 and widening the ditch should eliminate the rockfall hazard and improve the sight distance in this section of highway.

Site Designation <u>Site 7 (Road Segment 2, Stop 1)</u>

<u>CROSS SECTIONAL SKETCH</u>



DISCONTINUITIES ROAD TREND: 135°

JOINT SET: 72°-76°/125°-130°
JOINT SET: 85°-90°/210°-230°
JOINT SET: 58°-65°/320°-340°

Site Designation Site 7 (Road Segment 2, Stop 1)

Photo 1: Profile view. Note the blocky weathering of this RUB unit, and the formation of the talus slopes in the ditch.

Photo 2: Close-up of face. Note how tree growth in open joints causes "root wedging." Root growth and expansion within joints wedges rocks further apart, causing rockfall failure.

SITE RECONNAISSANCE

Site Designation Site 7 (Road Segment 2, Stop 1)

ROCKFALL HAZARD ATTACHMENT

M.P. 119 Length 270 ft. Posted Speed Limit 55 mph

Preliminary Rating: Cut Class A or B*
Proposed Correction Regrade to 1:1, widen ditch and revegetate.

ADT 2840
Rater Prellwitz
Detailed Rating Score 287

Cost Estimate ______

Preliminary Rating Remarks: (Continue on Back) Rockfall on roadway is common each spring in this road section.

DETAILED RATING

Slope Height Score 4
Slope Height in Feet 28 ft.

Ditch Effectiveness Score 10
Catchment Letter G M L N *

Average Vehicle Risk Score 3
Percent of Time 11%

Site Distance Score 100
Percent Design Value 21%
Site Distance 181 ft.
Roadway Width Score 62
Roadway Width in Feet 22 ft.

GEOLOGIC CHARACTER CASE 1

Structural Condition Score 81
Fracture Letter D C *
Orientation Letter F R A *

Rock Friction Score 27
Friction Letter R I U P C S *

GEOLOGIC CHARACTER CASE 2

Structural Condition Score ______
Erosion Feature Letter F O N M *

Diff in Erosion Rate Score ______
Diff in Erosion Rate Letter S M L E *

Block Size/Quantity Per Event ______
Block Size in Feet ______
Quantity in Cubic Yards ______

Climate and H_2O Score ______
Precipitation Letter L M H *
Freezing Period Letter N S L *
Water Letter N I C *

Rockfall History Score ______
Rockfall History Letter F O M C *

*Circle One

TOTAL SCORE 287

Remarks: Although the rating at this site is about the same as for Site 8, the hazard here appears greater due to the 6% downgrade in the inside lane where rocks are most likely to accumulate. If funds are limited, treat this one first.

SITE RECONNAISSANCE

State Highway US 385 Date 07/15/94

M.P. 117.9 Length 118 ft. Name Research Team

Site Designation Site 8 (Road Segment 2, Stop 2)

PURPOSE OF INVESTIGATION

Research; document rockfall in RUB and provide an example of the ODOT rockfall hazard rating method.

CONCERNS AND CONSTRAINTS (Step 1)

N/A

PRECONSTRUCTION, CONSTRUCTION, MAINTENANCE HISTORY

This is an older cut slope with very narrow ditch. Every spring rocks that fall onto the roadway must be removed.

EXISTING CUT SLOPE

Angle 50° Height 34 ft. (see sketch)

Observed Slope Failure Mechanism: Ravelling and rockfall. The RUB unit is composed of broken rock caused by structural deformation. Rockfall material is accumulating in the ditch as a talus slope (see Photo 1).

ENGINEERING ROCK AND SOIL UNITS

RUB with little soil cover.

OPTIMUM SLOPE RANGE(S) (Per Rock and/or Soil Unit)

Optimum slope range is 1:1 or flatter.

VEGETATION

Sparse grasses growing on talus slopes.

POSSIBLE TREATMENT METHODS

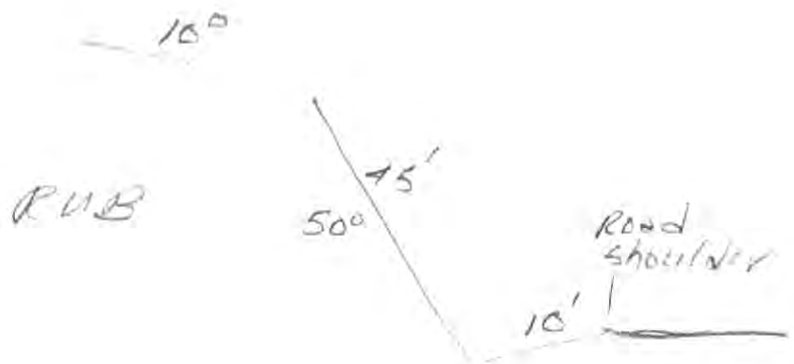
Recommended treatment method: Regrade slope to 1:1. Revegetate slope using hydroseed or Soilguard treatment methods and widen ditch.

PRELIMINARY EVALUATION

This site is similar to Site 7. We anticipate that regrading and revegetating the slope should eliminate the rockfall hazard and improve the sight distance. As an alternative, we recommend considering this site as a "Geologic Point of Interest."

Site Designation Site 8 (Road Segment 2, Stop 2)

CROSS SECTIONAL SKETCH



DISCONTINUITIES:

ROAD TREND: 275°

FOLIATIONS: 52°-58°/222°-226°

JOINT SET: 69° 75°/255°-264°

JOINT SET: 55°-59°/123°-140°

JOINT SET: 39°-49°/327°-332°

Site Designation Site 8 (Road Segment 2, Stop 2)

Photo 1: View of slope. Note the overturned structure in RUB and the formation of talus slopes in the ditch.

Photo 2: Close-up of overturned and broken structure in RUB.

SITE RECONNAISSANCE

Site Designation Site 8 (Road Segment 2, Stop 2)

ROCKFALL HAZARD ATTACHMENT

M.P. 117.9 Length 118 ft. Posted Speed Limit 55 mph

Preliminary Rating: Cut Class A or B *
Proposed Correction Regrade to 1:1, widen ditch and revegetate.

ADT 2840
Rater Prellwitz
Detailed Rating Score 281

Cost Estimate ______

Preliminary Rating Remarks: (Continue on Back) Rockfall on roadway is common in the spring on this section of highway.

DETAILED RATING

Slope Height Score 5
Slope Height in Feet 34 ft.

Ditch Effectiveness Score 10
Catchment Letter G M L N *

Average Vehicle Risk Score 3
Percent of Time 5%

Site Distance Score 100
Percent Design Value 15%
Site Distance 132 ft.
Roadway Width Score 55
Roadway Width in Feet 23 ft.

GEOLOGIC CHARACTER CASE 1

Structural Condition Score 81
Fracture Letter D C *
Orientation Letter F R A *

Rock Friction Score 27
Friction Letter R I U P C S *

GEOLOGIC CHARACTER CASE 2

Structural Condition Score ______
Erosion Feature Letter F O N M *

Diff in Erosion Rate Score ______
Diff in Erosion Rate Letter S M L E *

Block Size/Quantity Per Event ______
Block Size in Feet ______
Quantity in Cubic Yards ______

Climate and H_2O Score ______
Precipitation Letter L M H *
Freezing Period Letter N S L *
Water Letter N I C *

Rockfall History Score ______
Rockfall History Letter F O M C *

*Circle One

TOTAL SCORE 281

Remarks: Nearly the same as Site 7, but treat Site 7 first since this is 6% upgrade in inside lane. Traffic can stop or slow easier to avoid rockfall which is likely to accumulate in this lane.

SITE RECONNAISSANCE

State Highway US 385 Date 07/14/94

M.P. 94.5 Length (not measured) Name Research Team

Site Designation Site 10 (Road Segment 3, Stop 3)

PURPOSE OF INVESTIGATION

Research; document well-vegetated, stable slope in RUB.

CONCERNS AND CONSTRAINTS (Step 1)

N/A

PRECONSTRUCTION, CONSTRUCTION, MAINTENANCE HISTORY

This is an older cut slope that was flattened to a stable angle and allowed to revegetate naturally with grass, ponderosa pines and deciduous trees.

EXISTING CUT SLOPE

Angle 34° Height ______

No Observed Slope Failure Mechanism: We anticipate that minor ravelling is occurring on the slope causing a minor accumulation of small talus along the base of this slope.

ENGINEERING ROCK AND SOIL UNITS

RUB

OPTIMUM SLOPE RANGE(S) (Per Rock and/or Soil Unit)

The optimum slope range is 1:1 or flatter.

VEGETATION

The slope is well vegetated with ponderosa pine on cut slope and grass seeding in ditch.

POSSIBLE TREATMENT METHODS

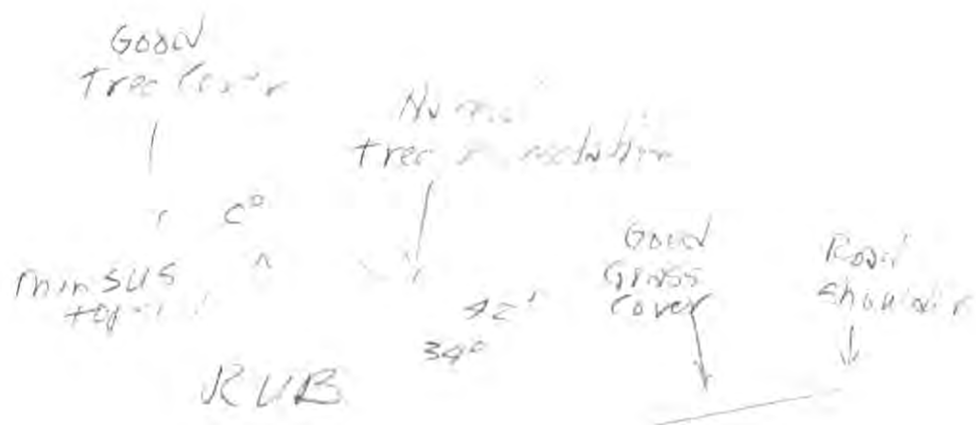
None required.

PRELIMINARY EVALUATION

The cut slope is apparently very stable (<40°), allowing for excellent revegetation opportunities.

Site Designation __Site 10 (Road Segment 3, Stop 3)__

CROSS SECTIONAL SKETCH



Site Designation Site 10 (Road Segment 3, Stop 3)

Photo 1: Profile view showing tree growth on the slope and grass in ditch.

Photo 2: View of slope.

SITE RECONNAISSANCE

State Highway US 385 Date 07/14/94

M.P. 93.5 Length (not measured) Name Research Team

Site Designation Site 11 (Road Segment 3, Stop 6)

PURPOSE OF INVESTIGATION

Research; document natural tree revegetation on slope steeper than 1:1.

CONCERNS AND CONSTRAINTS (Step 1)

N/A

PRECONSTRUCTION, CONSTRUCTION, MAINTENANCE HISTORY

This is an older slope cut, probably constructed about the same time as Site 10. The ditch contains abundant talus.

EXISTING CUT SLOPE

Angle 49° Height Not measured (about 30 ft.)

Observed Slope Failure Mechanism: Ravelling and minor rockfall. The rock unit is extensively jointed and prone to root and frost wedging. Rock fragments accumulate as talus in the ditch (see Photo 1).

ENGINEERING ROCK AND SOIL UNITS

RUB with very little soil cover.

OPTIMUM SLOPE RANGE(S) (Per Rock and/or Soil Unit)

The optimum slope range is 1:1 or flatter.

VEGETATION

Sparse ponderosa pines and occasional grasses vegetate the slope.

POSSIBLE TREATMENT METHODS

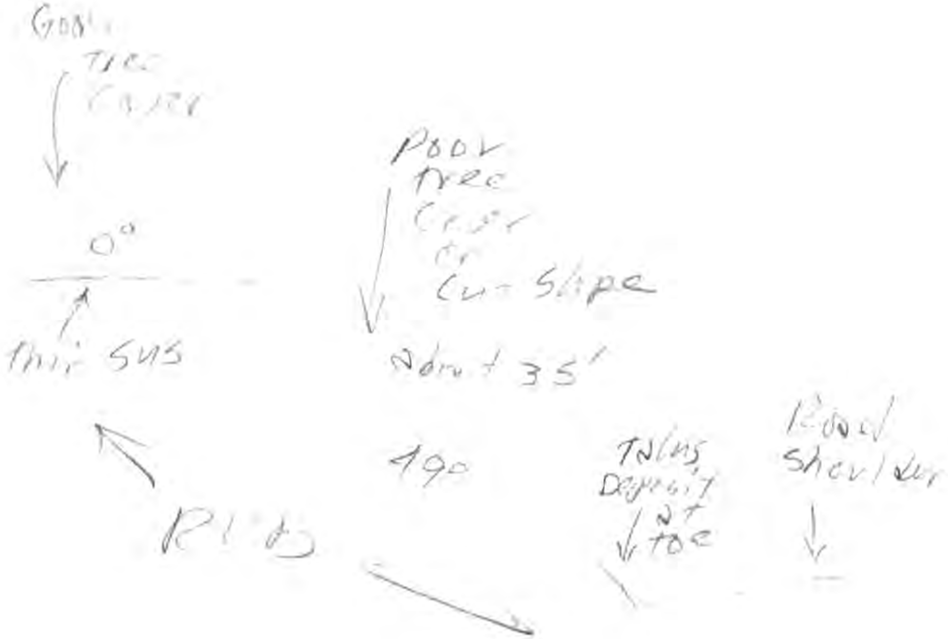
Probably none required. No treatment methods required at this time; however, the ditch will require occasional cleaning.

PRELIMINARY EVALUATION

Slope is not as stable as Site 10. Tree growth is not necessarily good as a slope stabilizer (see Photo 2). "Root wedging" has caused displacement of the rock, exposing tree roots and "toppling" of the young tree. Root and frost wedging are the primary causes of talus accumulation on this slope. Trees growing in vertical joint sets loosen and displace rock fragments and eventually topple. Because of the size of material typically developed, we anticipate only minimal rockfall hazard. The ditch will require occasional cleaning.

Site Designation Site 11 (Road Segment 3, Stop 6)

CROSS SECTIONAL SKETCH



SITE RECONNAISSANCE

Site Designation Site 11 (Road Segment 3, Stop 6)

Photo 1: View of slope.

Photo 2: Close-up of "root wedging" and "toppled" tree.

SITE RECONNAISSANCE

State Highway US 385 Date 07/15/94

M.P. 90.8 Length (not measured) Name Research Team

Site Designation Site 12 (Road Segment 3, Stop 5)

PURPOSE OF INVESTIGATION
Research; document natural revegetation of stable slopes.

CONCERNS AND CONSTRAINTS (Step 1)
N/A

PRECONSTRUCTION, CONSTRUCTION, MAINTENANCE HISTORY
This is an older slope cut similar to Sites 10 and 11. The slope was flattened to a stable angle and allowed to revegetate naturally with grass and ponderosa pines.

EXISTING CUT SLOPE

Angle 34° Height 32 ft.

No Observed Slope Failure Mechanism: The slope is stable.

ENGINEERING ROCK AND SOIL UNITS
RUB

OPTIMUM SLOPE RANGE(S) (Per Rock and/or Soil Unit)
The optimum slope range is 1:1 or flatter.

VEGETATION
Grass and ponderosa pines vegetate the cut slope and grass vegetates the ditch.

POSSIBLE TREATMENT METHODS
None required - no rockfall is accumulating in the ditch.

PRELIMINARY EVALUATION
The slope was constructed flatter than 1:1 and is stable, allowing for excellent revegetation opportunities.

SITE RECONNAISSANCE

Site Designation Site 12 (Road Segment 3, Stop 5)

CROSS SECTIONAL SKETCH

Site Designation Site 12 (Road Segment 3, Stop 5)

Photo 1: View of slope from across the road.

Photo 2: View of slope showing grass cover in ditch and on cut slope.

SITE RECONNAISSANCE

State Highway US 85 Date 07/13/94

M.P. 34.0 Length 170 ft. Name Research Team

Site Designation Site 1 (Road Segment 1, Stop 6)

PURPOSE OF INVESTIGATION

Research; document performance of recently constructed cut slopes.

CONCERNS AND CONSTRAINTS (Step 1)

N/A

PRECONSTRUCTION, CONSTRUCTION, MAINTENANCE HISTORY

The slope was recently constructed; the ditch contains very little rockfall material.

EXISTING CUT SLOPE

Angle 74° Height 56 ft.

Observed Slope Failure Mechanism: The massive upper unit is open-jointed and is subject to rockfall, toppling, or collapse due to differential weathering of lower units.

ENGINEERING ROCK AND SOIL UNITS

RUC.

OPTIMUM SLOPE RANGE(S) (Per Rock and/or Soil Unit)

The optimum slope range is 1/2:1 or steeper provided that the weathering of lower units is controlled.

VEGETATION

None on slope.

POSSIBLE TREATMENT METHODS

Recommended treatment methods for rockfall: shotcrete, buttressing, screening.

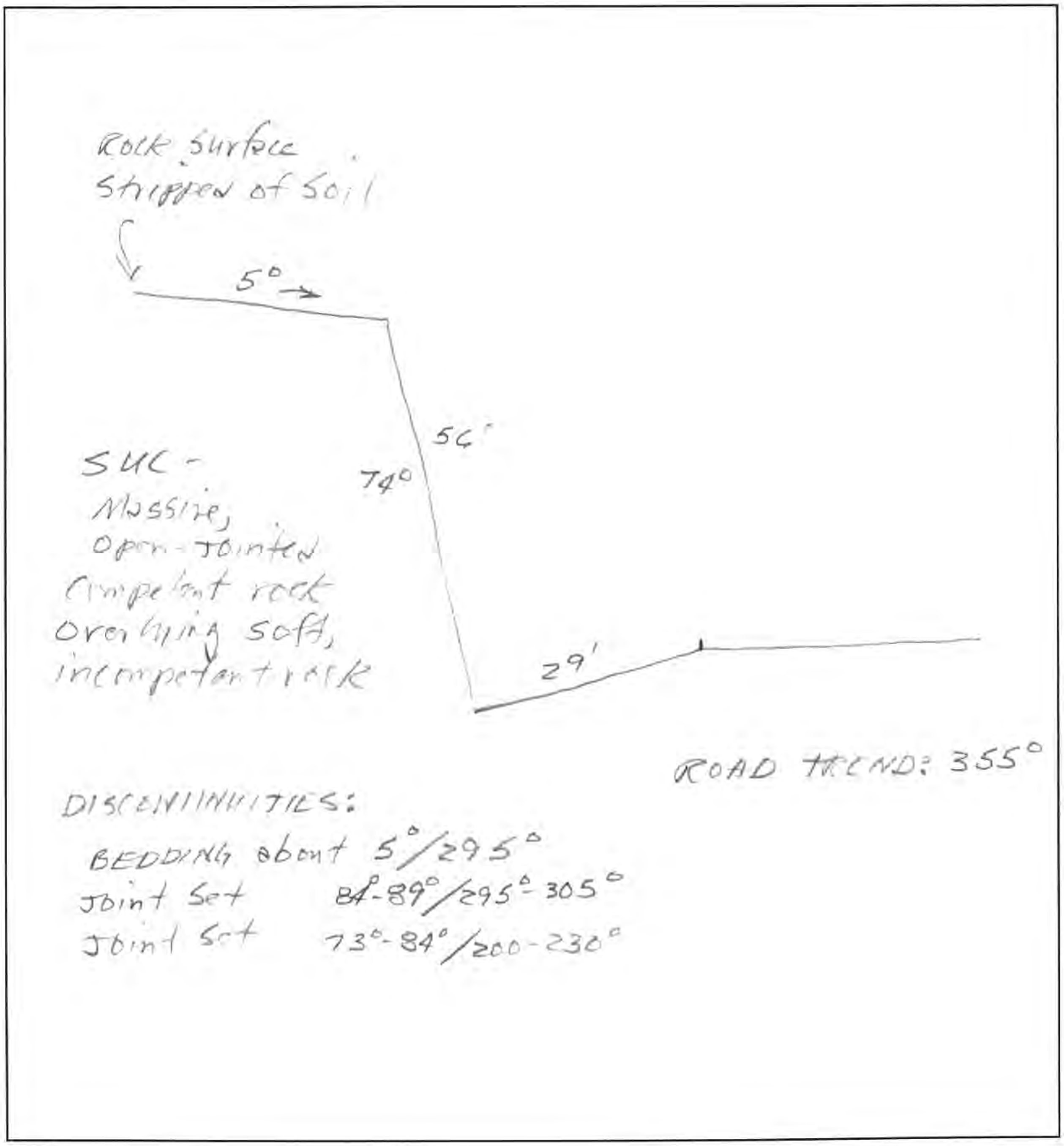
PRELIMINARY EVALUATION

We anticipate that weathering of the lower, less competent rock units is slow. The ditches are sufficiently wide, effectively containing rockfall. We anticipate low rockfall hazard and minimal maintenance until differential weathering progresses, at which time shotcrete, buttressing or screening should be considered.

SITE RECONNAISSANCE

Site Designation Site 1 (Road Segment 1, Stop 6)

CROSS SECTIONAL SKETCH



Site Designation Site 1 (Road Segment 1, Stop 6)

Photo 1: View of open-jointed, massive, competent rock overlying less competent rock.

Photo 2: View of differential weathering in lower, less competent rock.

SITE RECONNAISSANCE

State Highway US 85 Date 07/13/94

M.P. 32.0 Length 218 ft. Name Research Team

Site Designation Site 2 (Road Segment 1, Stop 5)

PURPOSE OF INVESTIGATION
Research; document performance of recently constructed cut slope.

CONCERNS AND CONSTRAINTS (Step 1)
N/A

PRECONSTRUCTION, CONSTRUCTION, MAINTENANCE HISTORY
The slope was recently constructed; possible overblasting caused extensive rockfall. The ditch contains abundant rockfall material.

EXISTING CUT SLOPE

Angle 65° Height About 80 ft. (?) (not measured)

No Observed Slope Failure Mechanism: We anticipate that ravelling and rockfall are presently occurring and that possible toppling or collapse may result as differential weathering progresses.

ENGINEERING ROCK AND SOIL UNITS
RUC

OPTIMUM SLOPE RANGE(S) (Per Rock and/or Soil Unit)
The optimum range is 1/2:1 or steeper provided that the differential weathering of lower, less competent rocks can be controlled.

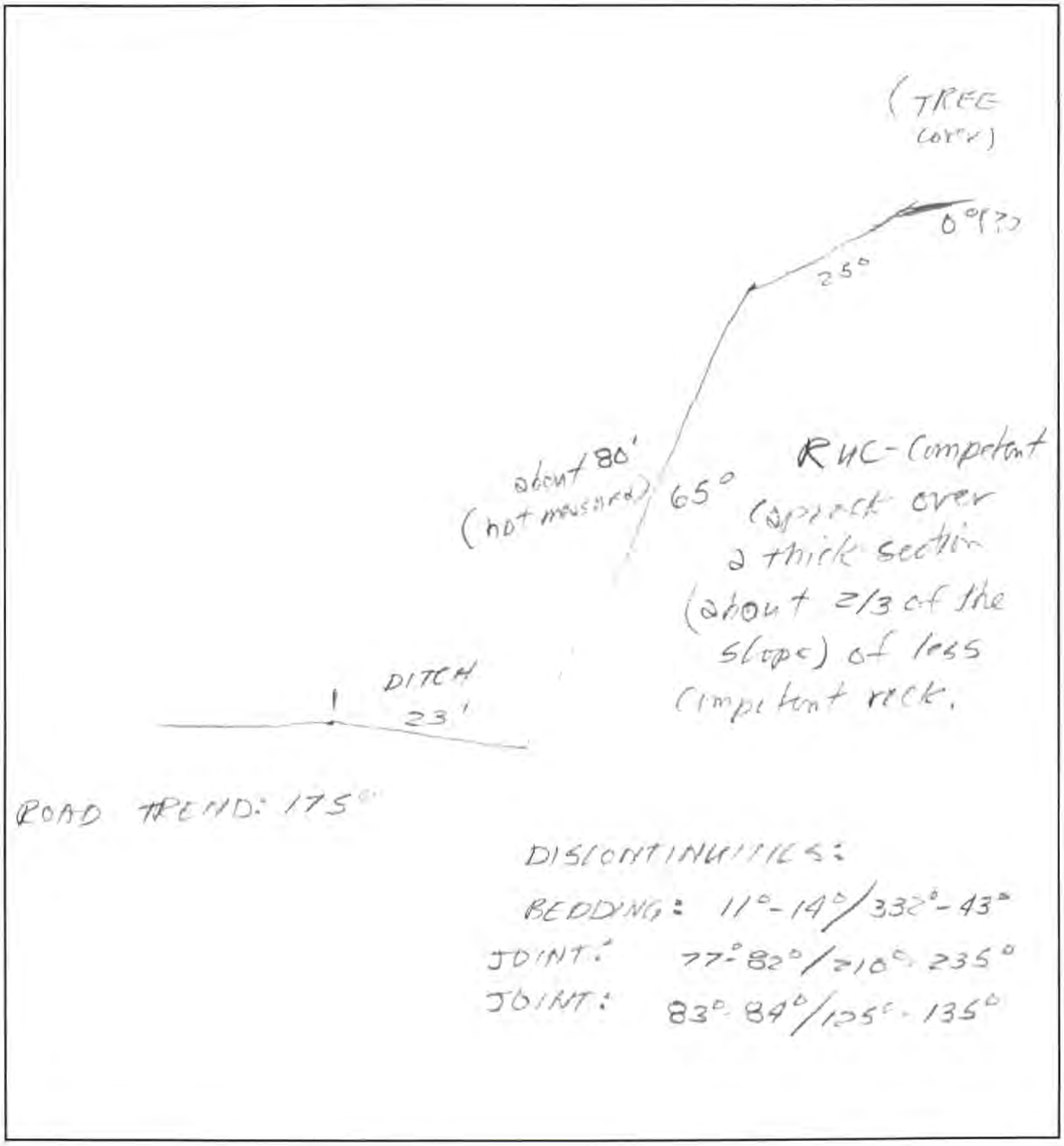
VEGETATION
None on slope.

POSSIBLE TREATMENT METHODS
Recommended treatment methods for rockfall includes screening, rock fences and revetment barriers.

PRELIMINARY EVALUATION
Mass failure of the slope does not appear likely. Rockfall from ravelling in the lower, less competent beds should be moderate but may become more serious as differential weathering continues. May be able to control the differential weathering if confined to specific zones. RHRS and CRSP should be useful to evaluate the rockfall hazard and possible treatment methods.

Site Designation Site 2 (Road Segment 1, Stop 5)

CROSS SECTIONAL SKETCH



Site Designation Site 2 (Road Segment 1, Stop 5)

Photo 1: View of competent caprock (RUC) overlying less competent rock.

Photo 2: Close-up view showing less competent lower rock units.

SITE RECONNAISSANCE

State Highway US 85 Date 07/13/94

M.P. 30.9 Length 200 ft. Name Research Team

Site Designation Site 4 (Road Segment 1, Stop 3)

PURPOSE OF INVESTIGATION

Research; document ground water-related rock slope failure in recently constructed cut slope.

CONCERNS AND CONSTRAINTS (Step 1)

N/A

PRECONSTRUCTION, CONSTRUCTION, MAINTENANCE HISTORY

Minor rockfall occurred both during and after construction through the end of the dry season. However, once the wet season started, large blocks of rock began falling from the cut face. Since the completion of roadway construction, rockfall debris has been removed from the ditch and barriers have been installed. The ditch was filled with rockfall debris at the time of our visit.

EXISTING CUT SLOPE

See sketch.

Angle 1/2:1 or steeper Height About 40 ft. for 1/2:1

Observed Slope Failure Mechanism: Ground water-related rockfall and slumping. Ground water is confined within SUC clay layers interbedded with weathered shale beds. The weak SUC layer(s) contribute to low shear strength failures.

ENGINEERING ROCK AND SOIL UNITS

RUC caprock with thin SUC clay layer(s) interbedded with less competent shale beds.

OPTIMUM SLOPE RANGE(S) (Per Rock and/or Soil Unit)

1/2:1 or steeper would be stable if the ground water and weak SUC layer(s) were not a problem in the incompetent lower beds.

VEGETATION

None on cut slope; however, the upper (15°) slope is well vegetated by grass (see Photos 1 and 2).

POSSIBLE TREATMENT METHODS

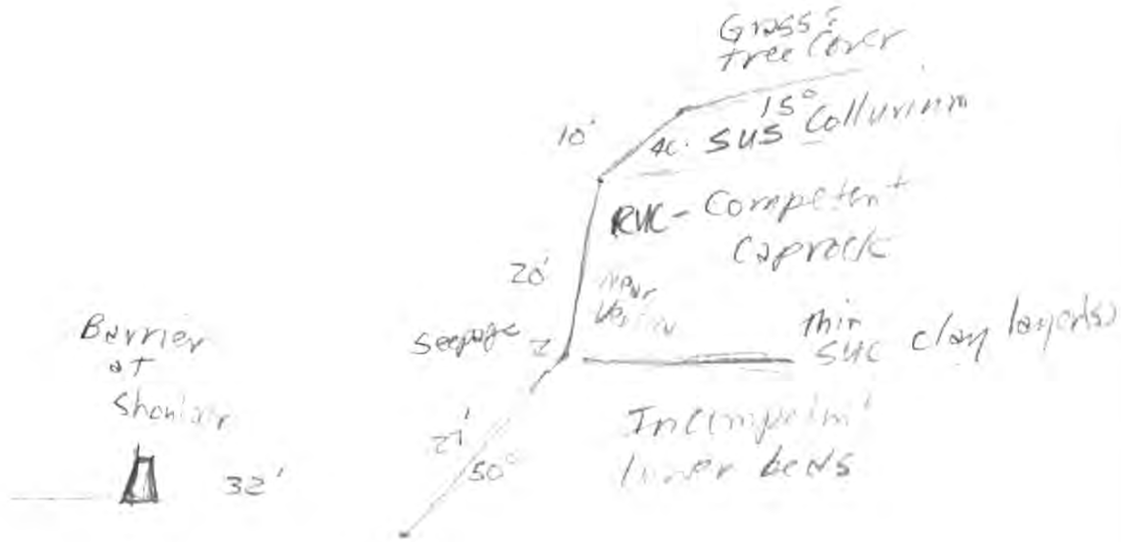
Drained rock buttress or retaining structure.

PRELIMINARY EVALUATION

Recommended Treatment Methods: Because the failure zone is thin, it is possible that the more competent caprock may slow or stop the upslope progression of collapse and slumping. The impacts of this year's high fall and spring ground water levels on the performance of the slope should indicate the seriousness of the problem. If failures continue or increase then a drained buttress or retaining structure must be installed.

Site Designation __Site 4 (Road Segment 1, Stop 3)__

CROSS SECTIONAL SKETCH



ROAD TREND: 13°

DISCONTINUITIES:

BEDDING about 6°-12°/305°-340°

JOINT Set 82°-90°/120°-155°

JOINT Set 77°-88°/35°-50°

Site Designation Site 4 (Road Segment 1, Stop 3)

Photo 1: View of slope. The horizontal SUC clay layer at the base of the competent caprock (tan).

Photo 2: Distance view of site. Note continuity of the horizontal gray SUC clay layer.

SITE RECONNAISSANCE

State Highway US 85 Date 07/13/94

M.P. 29 Length 460 ft. Name Research Team

Site Designation Site 6 (Road Segment 1, Stop 1)

PURPOSE OF INVESTIGATION

Research; document performance of recently constructed cut slope.

CONCERNS AND CONSTRAINTS (Step 1)

N/A

PRECONSTRUCTION, CONSTRUCTION, MAINTENANCE HISTORY

The slope was recently constructed.

EXISTING CUT SLOPE

Angle 78° Height 35 ft.

Observed Slope Failure Mechanism: Differential erosion. The upper, more massive rock unit is failing by toppling and collapse resulting from erosion of weaker lower beds.

ENGINEERING ROCK AND SOIL UNITS

RUC unit (fairly competent caprock overlying less competent lower beds) overlain by SUS (colluvium).

OPTIMUM SLOPE RANGE(S) (Per Rock and/or Soil Unit)

Stable to 1/2:1 or steeper if erosion of weaker beds can be controlled. This would be difficult. The optimal slope range for this rock unit is 1:1 or flatter under existing conditions.

VEGETATION

None on cut face but natural grass covers slope above cut.

POSSIBLE TREATMENT METHODS

Recommended treatment methods for rockfall: Screen, fence, or barrier if ditch is ineffective.
Recommended treatment methods for slope stability: Possible benching to reduce column height and toppling potential.

PRELIMINARY EVALUATION

The extent of rockfall hazard should be more apparent after the next spring thaw. If rockfall is not extreme, any of the treatments to reduce the hazard can be implemented. If rockfall or toppling and collapse are excessive, ROCKPACK and CRSP can be used to evaluate toppling failures and to consider a strategically positioned bench in the upper part of the slope.

SITE RECONNAISSANCE

Site Designation Site 6 (Road Segment 1, Stop 1)

CROSS SECTIONAL SKETCH

ROAD TREND: 65°

DISCONTINUITIES:

BEDDING: 4°-11°/12°-28°

JOINT SET: 81°-82°/210°-225°

JOINT SET: 85°-86°/90°-115°

Site Designation Site 6 (Road Segment 1, Stop 1)

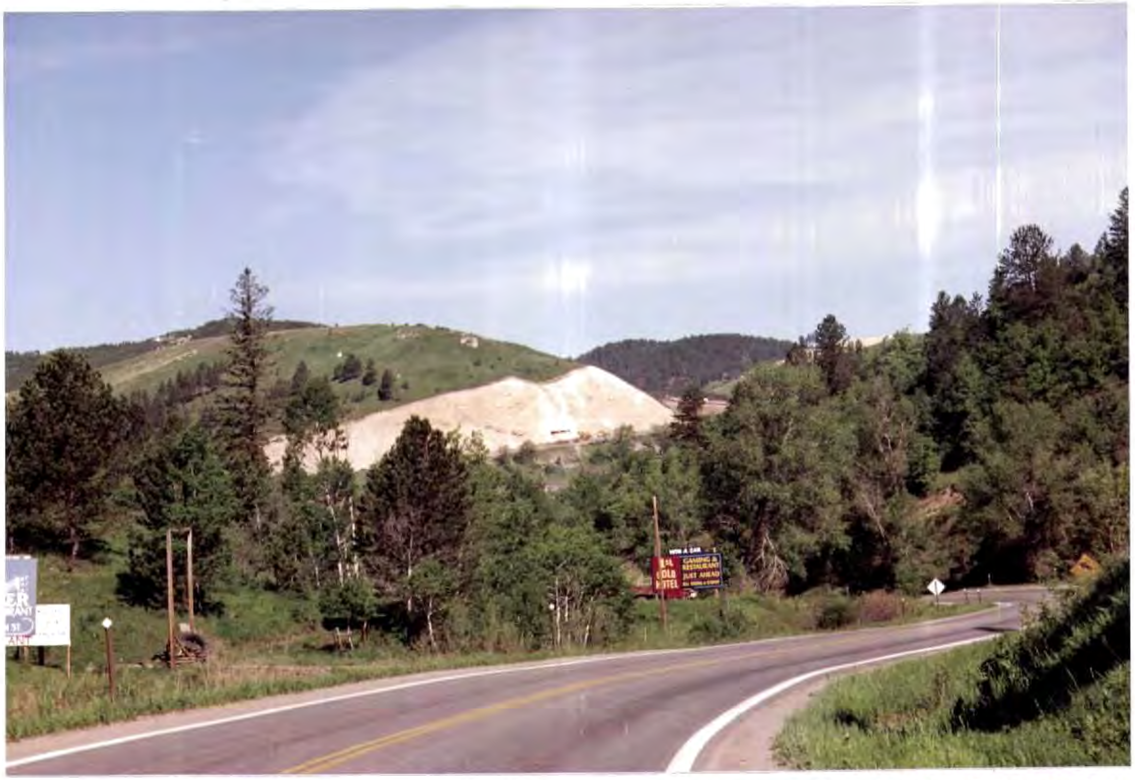


Photo 1: View of slope from across canyon. Measured profile is near the left side of the cut, below the tree-covered slope.

Photo 2: View of open joints in the massive rock section of the cut, indicating potential toppling failures.

Site Designation Site 6 (Road Segment 1, Stop 1)

Photo 3: View of competent but jointed rock with low base angle (dip) overlying weak incompetent rock. These are ideal conditions for toppling or collapse failures.

Photo 4: Relatively thick SUS colluvium overlying RUC rock. Note evidence of ground water seepage at the contact between SUS and RUC units.

SITE 6 - SUMMARY OF TOPPLING MOMENT ANALYSIS FOR TYPICAL COLUMN DIMENSIONS AND BASE ANGLES

TOPPLE DATA

INFORMATION GIVEN:

Height of block =	10.000
Width of block =	1.000
Angle of the block =	4.000
Unit weight of water =	62.400
Unit weight of rock =	155.000
Tension of rock bolt =	0.000
Height of water in tension crack =	0.000
Height of bolt in block =	0.000

THE SUM OF THE MOMENTS = -232.500

*THIS INDICATES THAT THE SLOPE IS SAFE (NEGATIVE MOMENT)

TOPPLE DATA

INFORMATION GIVEN:

Height of block =	10.000
Width of block =	2.000
Angle of the block =	6.000
Unit weight of water =	62.400
Unit weight of rock =	155.000
Tension of rock bolt =	0.000
Height of water in tension crack =	0.000
Height of bolt in block =	0.000

THE SUM OF THE MOMENTS = -1,462.827

*THIS INDICATES THAT THE SLOPE IS SAFE (NEGATIVE MOMENT)

SITE 6 - SUMMARY OF TOPPLING (continued)

TOPPLE DATA

INFORMATION GIVEN:

Height of block =	10.000
Width of block =	2.000
Angle of the block =	12.000
Unit weight of water =	62.400
Unit weight of rock =	155.000
Tension of rock bolt =	0.000
Height of water in tension crack =	0.000
Height of bolt in block =	0.000

THE SUM OF THE MOMENTS = 190.373

*THIS INDICATES THAT THE SLOPE IS UNSAFE (POSITIVE MOMENT)

TOPPLE DATA

INFORMATION GIVEN:

Height of block =	10.000
Width of block =	1.000
Angle of the block =	6.000
Unit weight of water =	62.400
Unit weight of rock =	155.000
Tension of rock bolt =	0.000
Height of water in tension crack =	0.000
Height of bolt in block =	0.000

THE SUM OF THE MOMENTS = 39.341

*THIS INDICATES THAT THE SLOPE IS UNSAFE (POSITIVE MOMENT)

SITE RECONNAISSANCE

State Highway US 16 Date 07/11/94

M.P. 60 Length 226 ft. Name Research Team

Site Designation Site 16 (Road Segment 5, Stop 1)

PURPOSE OF INVESTIGATION

Research; document a successfully revegetated cut slope in RUC/RUD.

CONCERNS AND CONSTRAINTS (Step 1)

N/A

PRECONSTRUCTION, CONSTRUCTION, MAINTENANCE HISTORY

This slope was cut in 1966 and treated with roving and grass seed in 1967 and 1968. Jim Cassidy (maintenance) told us that the ditch along the untreated portion of the slope requires occasional cleaning. The revegetation effort included the importation and spreading of topsoil over the existing RUC slope to a 1.3:1 slope. The regraded slope was seeded and covered with fiberglass roving.

EXISTING CUT SLOPE

Untreated section: Angle 42° to 48° Height 145 ft.
Treated section: About 1.3:1 to about same height.

Observed Slope Failure Mechanism: Differential weathering and collapse. Erosion of shales undermines the upper, more resistance beds resulting in collapse and rockfall.

ENGINEERING ROCK AND SOIL UNITS

RUC in upper units; RUC/RUD in lower units.

OPTIMUM SLOPE RANGE(S) (Per Rock and/or Soil Unit)

The optimum slope range is 1:1 or flatter for less competent rock and 1/2:1 or steeper for the more competent caprock.

VEGETATION

Very successful grass seeding and roving revegetation on flatter 1.3:1 slope. The treated portion of the slope is well vegetated.

POSSIBLE TREATMENT METHODS

No treatment method is presently required for stability. However, brush layering or wattling may be considered to reduce erosion of less competent beds.

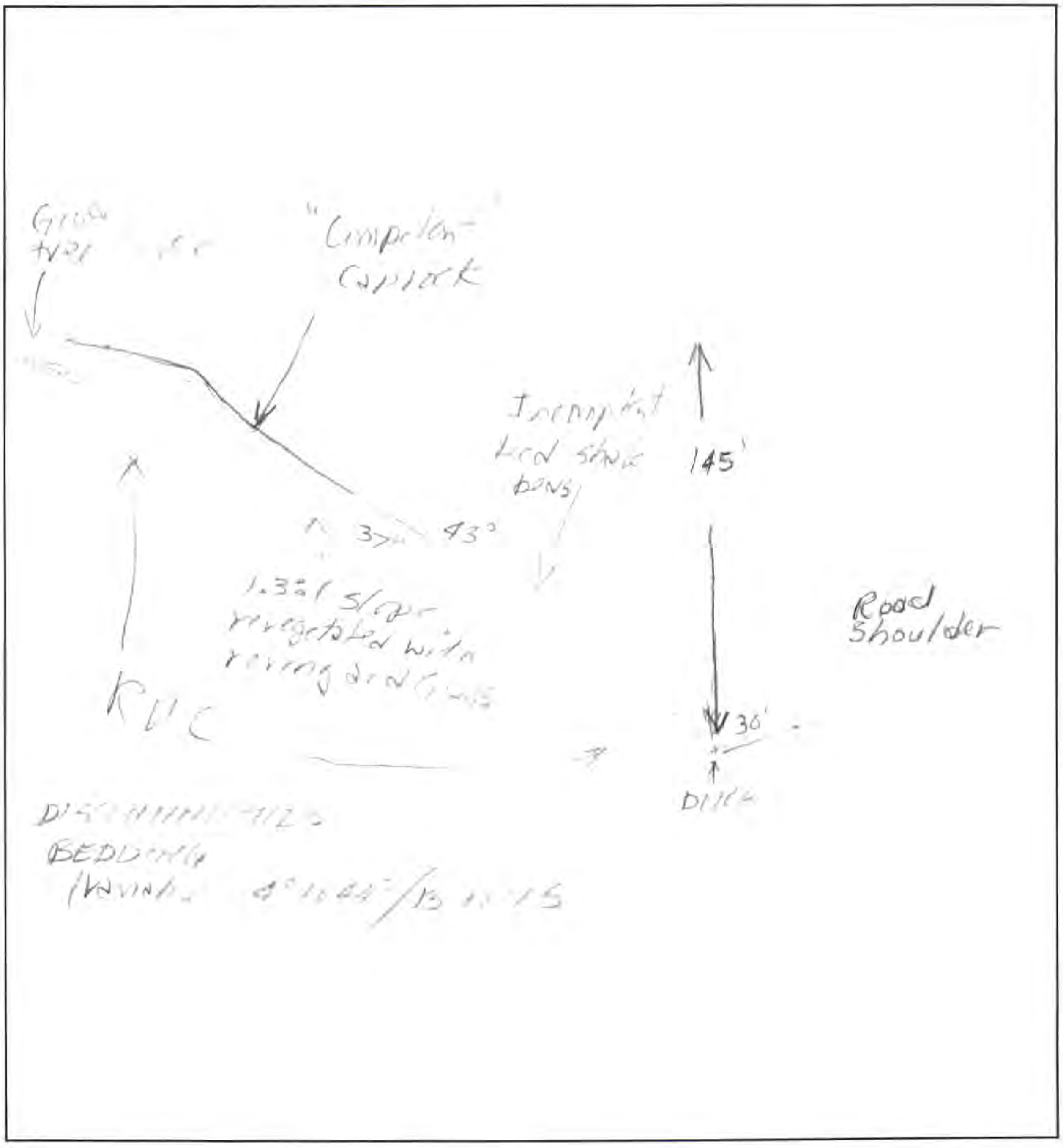
PRELIMINARY EVALUATION

Rockfall from the untreated portion of the slope is presently minimal. However, rockfall and collapse resulting from the undermining of competent rock bed may become more serious as differential weathering progresses. The exposed portion of the cut slope is an excellent candidate as a "Geologic Point of Interest."

SITE RECONNAISSANCE

Site Designation <u>Site 16 (Road Segment 5, Stop 1)</u>

<u>CROSS SECTIONAL SKETCH</u>



Site Designation Site 16 (Road Segment 5, Stop 1)

Photo 1: View of the slope from across highway. Note effectiveness of revegetation in controlling weathering of lower red shale beds.

Photo 2: View showing contrast between revegetated and weathering sections of the slope.

SITE RECONNAISSANCE

State Highway US 16 Date 07/14/94

M.P. 14 Length 126 ft. Name Research Team

Site Designation Site 20 (Road Segment 7, Stop 1)

PURPOSE OF INVESTIGATION

Research; document high rockfall hazard in RUC with SUS colluvial layer.

CONCERNS AND CONSTRAINTS (Step 1)

N/A

PRECONSTRUCTION, CONSTRUCTION, MAINTENANCE HISTORY

This slope was built some time ago. It is scheduled to be regraded. The maintenance ditch is narrow and must be cleaned every morning during spring.

EXISTING CUT SLOPE

Failed back to:
Angle 52° to 55° Height 42 ft.

Observed Slope Failure Mechanism: Ravelling in weathered rock (RUC) and overlying colluvium (SUS). Gordon Stolp (maintenance) told us that rock fall from the SUS layer occurs frequently in the spring. Failure of SUS colluvium is primarily the result of ground water seepage along the rock and colluvium contact.

ENGINEERING ROCK AND SOIL UNITS

RUC with zones of RUD, overlain by SUS colluvium.

OPTIMUM SLOPE RANGE(S) (Per Rock and/or Soil Unit)

The optimum slope range is 1:1 or flatter for the less competent rock units. The slope range for the more competent rock sections is 1/2:1 or steeper.

VEGETATION

Very little vegetation is growing in the ditch or on the cut slope because of constant ravelling.

POSSIBLE TREATMENT METHODS

Recommended treatment method: regrade to the optimum slope range and widen ditch or install barrier.

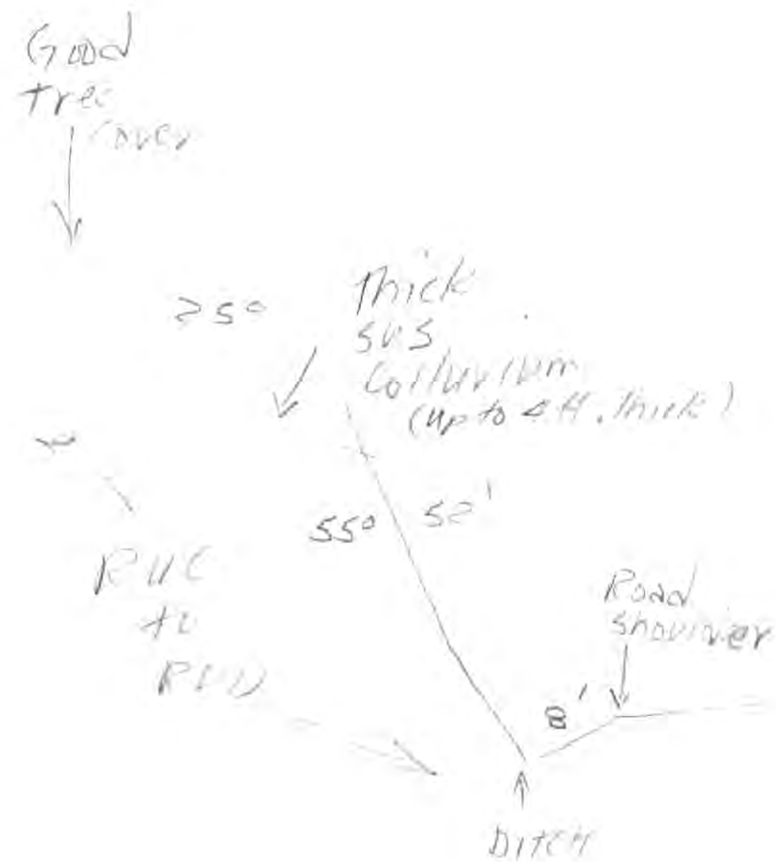
PRELIMINARY EVALUATION

This slope is cut on a relatively sharp curve. Consequently, visibility is low and the rockfall hazard is very high. Regrading the slope should reduce both the hazard and the maintenance effort required in the spring. We recommend slope ranges of 1:1 or flatter in decomposed rock section and 2:1 or flatter in colluvium because of ground water effects.

SITE RECONNAISSANCE

Site Designation Site 20 (Road Segment 7, Stop 1)

CROSS SECTIONAL SKETCH



Site Designation Site 20 (Road Segment 7, Stop 1)

Photo 1: View of slope from across the highway.

Photo 2: View of slope; note the thick colluvial deposit overlying the RUC unit.

SITE RECONNAISSANCE

State Highway US 18 Date 07/12/94

M.P. 42 Length 400 ft. Name Research Team

Site Designation Site 24 (Road Segment 8, Stop 1)

PURPOSE OF INVESTIGATION

Research; document rockfall due to differential weathering in RUC.

CONCERNS AND CONSTRAINTS (Step 1)

N/A

PRECONSTRUCTION, CONSTRUCTION, MAINTENANCE HISTORY

This is an older cut slope. The ditch is effective and rocks are seldom on highway. Jeff Borah (maintenance) told us that the ditch requires rockfall cleanout two to three times a year.

EXISTING CUT SLOPE

Angle 60 - 62° Height 82 ft.

Observed Slope Failure Mechanism: Collapse failure of the more competent rock as a result of erosion and undermining of less competent rocks.

ENGINEERING ROCK AND SOIL UNITS

RUC

OPTIMUM SLOPE RANGE(S) (Per Rock and/or Soil Unit)

The optimal slope range is 1/2:1 or steeper in competent rocks; 1:1 or flatter in less competent rocks.

VEGETATION

The ditch and cut slope are sparsely vegetated with grass.

POSSIBLE TREATMENT METHODS

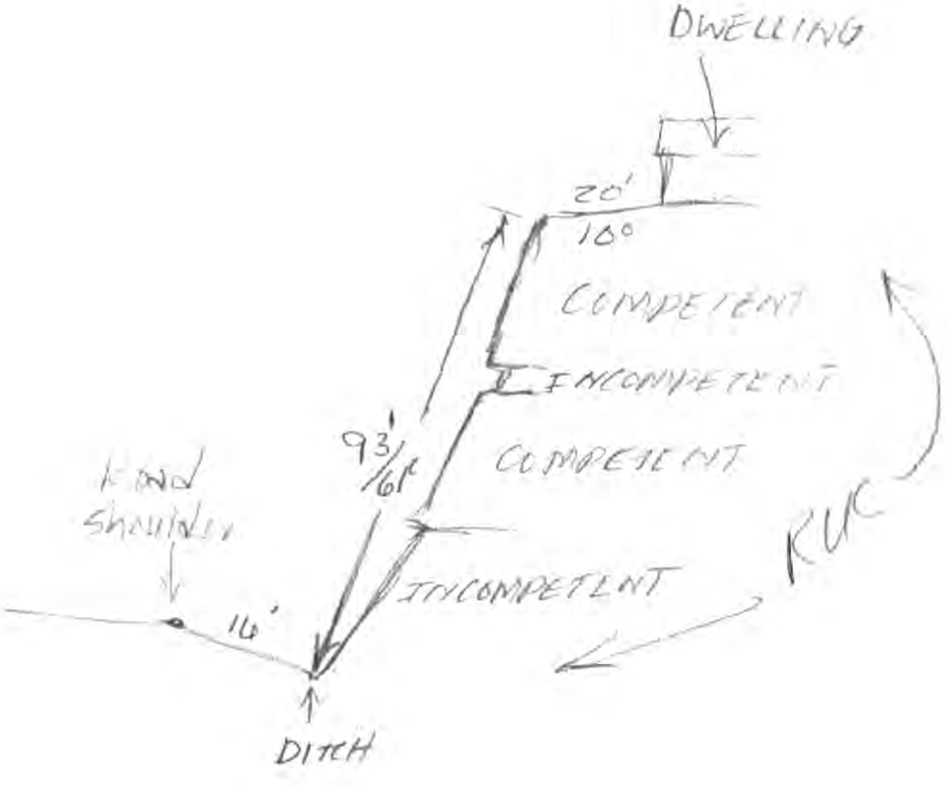
Recommended treatment for rockfall and differential weathering: scaling overhangers, screening, rock barriers, shotcrete or buttressing, and vegetation treatment (wattling) applied to less competent beds.

PRELIMINARY EVALUATION

Currently, the maintenance effort to clean rockfall from ditch appears adequate to control the rockfall hazard. As differential weathering continues, the hazard will worsen, in which case rockfall hazard reduction measures should be considered. Regrading the lower incompetent section to 1:1 or flatter would be required to stabilize the slope. However, this would be difficult within the current right-of-way, and the proximity of the dwelling near the top of the slope. An alternative approach to this site is to develop it as a "Geologic Point of Interest."

Site Designation Site 24 (Road Segment 8, Stop 1)

CROSS SECTIONAL SKETCH



Site Designation Site 24 (Road Segment 8, Stop 1)

Photo 1: View of cut slope from across the highway.

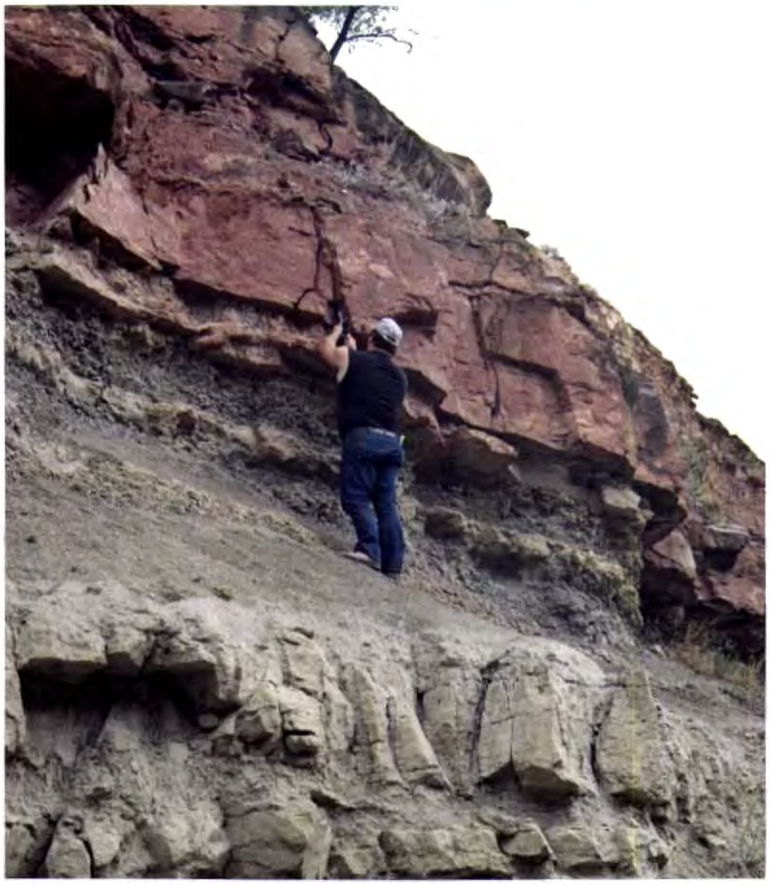


Photo 2: Close-up view of differential weathering.

SITE RECONNAISSANCE

State Highway US 16 Date 07/14/94

M.P. 18.5 Length ______ Name Research Team

Site Designation Site 19 (Road Segment 7, Stop 2)

PURPOSE OF INVESTIGATION
Research; document a bench failure in RUD.

CONCERNS AND CONSTRAINTS (Step 1)
N/A

PRECONSTRUCTION, CONSTRUCTION, MAINTENANCE HISTORY
This slope was reconstructed in 1989. The slope was cut at 1/2:1, with a bench about halfway up slope. The slope has failed back to 48° at one location and is ravelling throughout.

EXISTING CUT SLOPE

Angle 58° to 65° Height 52 ft. total

Observed Slope Failure Mechanism: Slumping and mass failure of decomposed rock. Slumping may have occurred along a discontinuity at the failure surface.

ENGINEERING ROCK AND SOIL UNITS
RUD

OPTIMUM SLOPE RANGE(S) (Per Rock and/or Soil Unit)
The optimum slope range is 1:1 or flatter for RUD under existing conditions.

VEGETATION
The ditch is well vegetated with grass. Very little grass is present on the cut slope and bench because of instability of the slope.

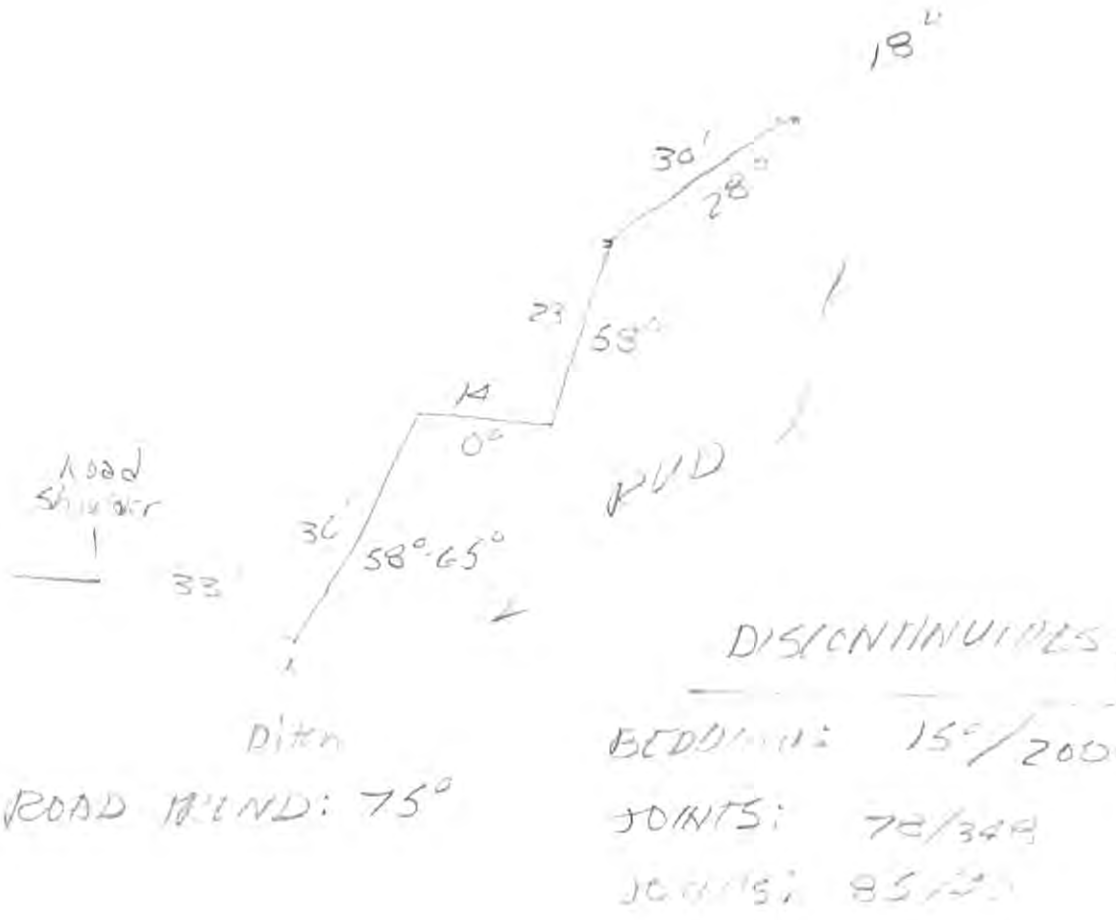
POSSIBLE TREATMENT METHODS
Recommended treatment methods: regrade slope to 48° or flatter, or install a rock buttress below the existing bench.

PRELIMINARY EVALUATION
The rock is badly decomposed and unstable at a slope of 1/2:1. Regrading the slope to 48° or flatter should yield stable slope, with or without bench. However, successful revegetation of the slope will probably require slopes flatter than 1:1.

SITE RECONNAISSANCE

Site Designation Site 19 (Road Segment 7, Stop 2)

CROSS SECTIONAL SKETCH



Site Designation Site 19 (Road Segment 7, Stop 2)

Photo 1: View of slope from across the highway.

Photo 2: Close-up view of decomposed rock in RUD along the failed bench.

SITE RECONNAISSANCE

Site Designation Site 19 (Road Segment 7, Stop 2)

SLOPE STABILITY ATTACHMENT

I. ROCK (Provide details on Cross Section)

A. DISCONTINUITY FAILURE

Discontinuities (Dip/Dip Direction)	**Infilling**	**Friction Angle**
Primary		
Secondary I		
Secondary II		
Secondary III		

Road Azimuth ______ Propose Cut Angle ______

Anticipated Failure Type: Plane ______ Wedge ______

B. TOPPING FAILURE

Column Width ______ Height ______ Base Angle ______

C. COLLAPSE FAILURE

Differential Weathering Rating: High ______ Medium ______ Low ______

II. SOIL AND DECOMPOSED ROCK (Provide details on Cross Section)

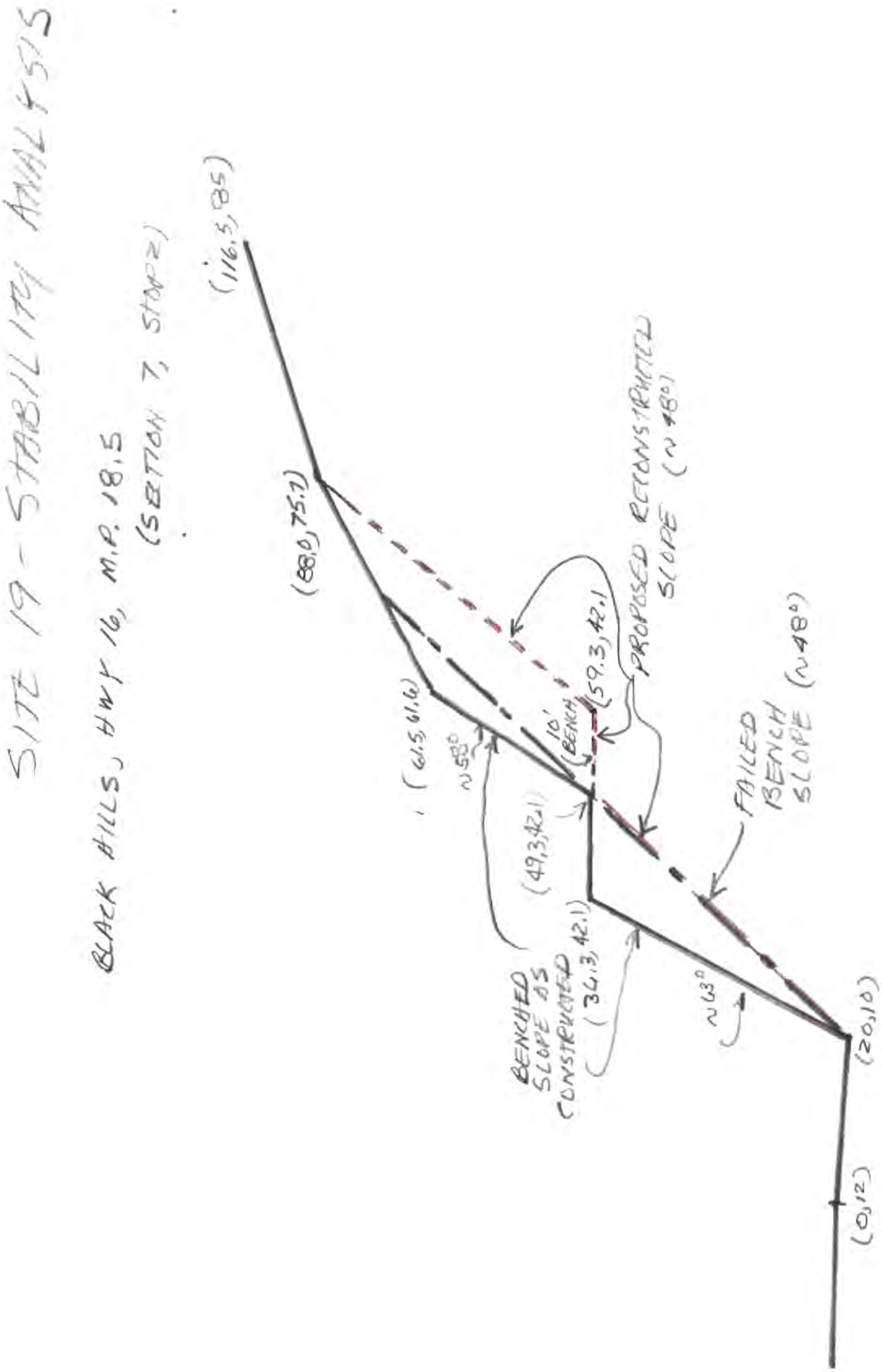
Current or Anticipated Failure (for stability analysis) Slump in decomposed rock.

Ground water (if present, type of aquifer and where located) None noted.

Estimated Soil Parameters (for each soil unit on Cross Section)
Decomposed Rock: $\gamma = 135$ pcf, C = 100 pcf, $\phi = 40°$

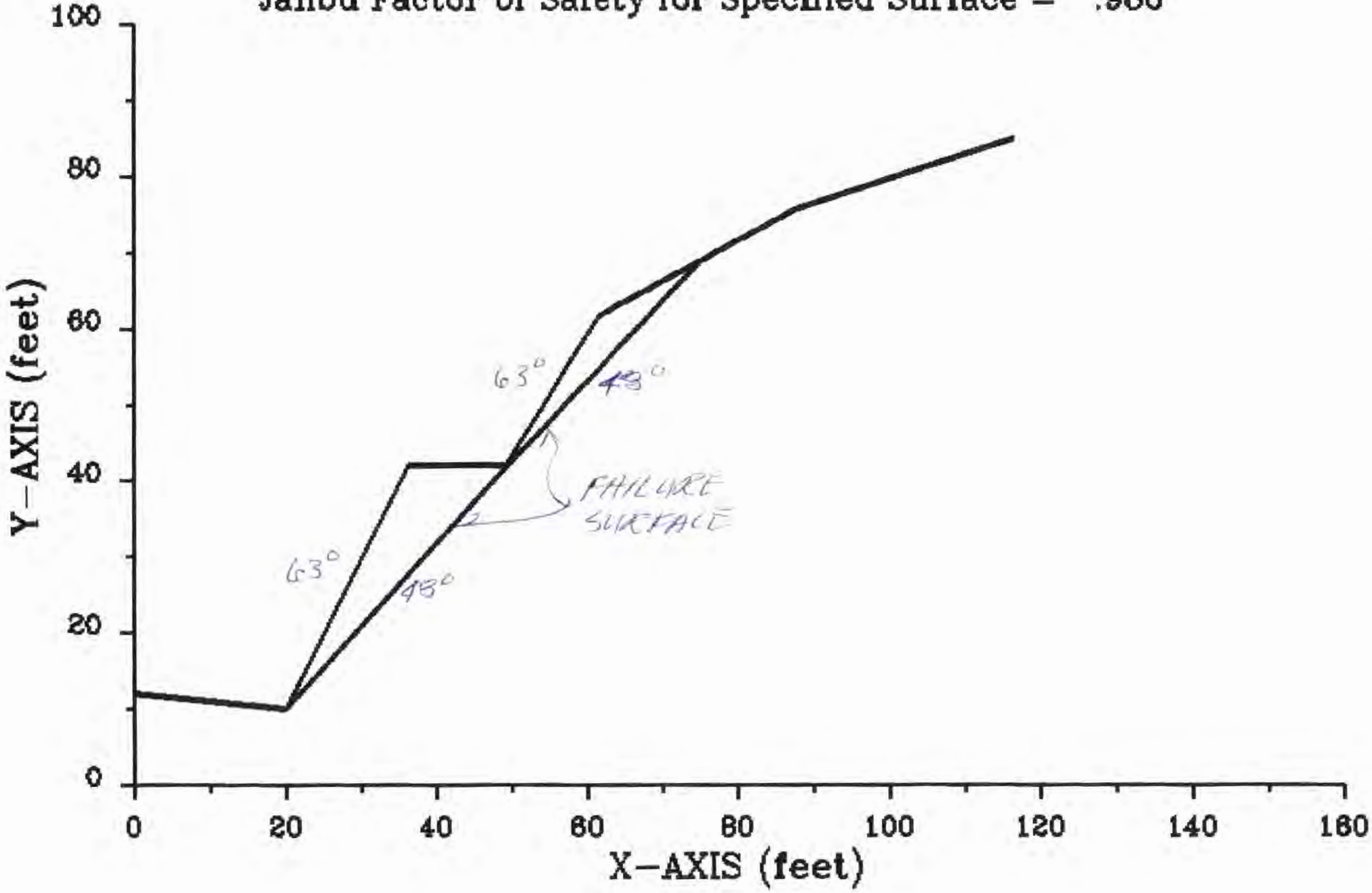
III. RECOMMENDATIONS FOR SUBSURFACE INVESTIGATION, LABORATORY AND STABILITY ANALYSES: See attached XSTABL results of prefailure (1/2:1 cut) and proposed 48° cut slopes.

IV. POSSIBLE STABILIZATION ALTERNATIVES: Regrade to 48° as shown on stability analysis sections or construct rock buttress below existing bench.


SITE 19 - STABILITY ANALYSIS
BLACK HILLS, HWY 16, M.P. 18.5
(SECTION 7, STOP 2)
(116.5, 85)
(88.0, 75.7)
(61.5, 61.6)
~58°
10' BENCH
(59.3, 42.1)
PROPOSED RECONSTRUCTED SLOPE (~48°)
(49.3, 42.1)
FAILED BENCH SLOPE (~48°)
BENCHED SLOPE AS CONSTRUCTED
(34.3, 42.1)
~63°
(20, 10)
(0, 12)

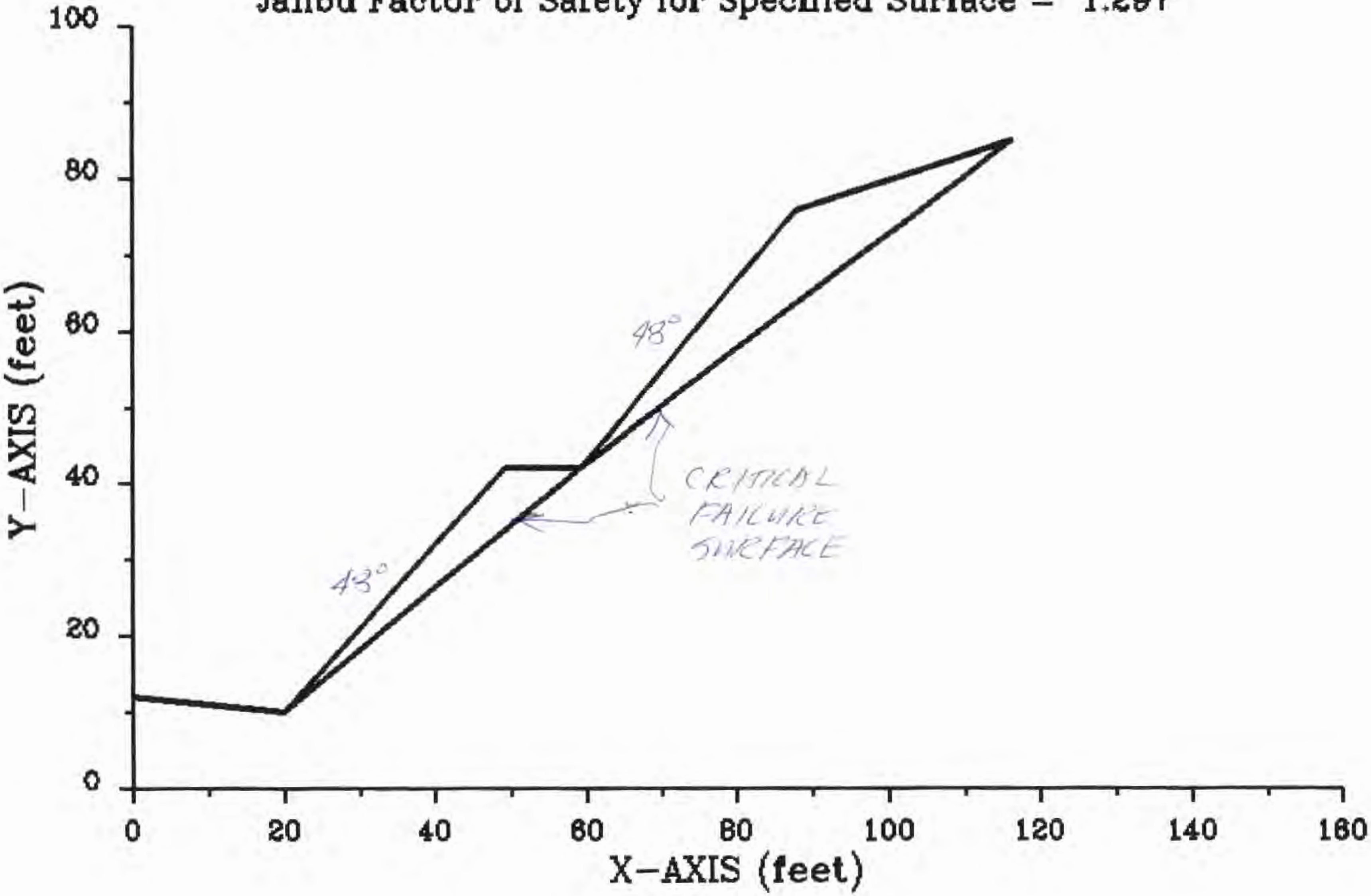
Black Hills, Hwy 16, M.P. 18.5

Janbu Factor of Safety for Specified Surface = .986



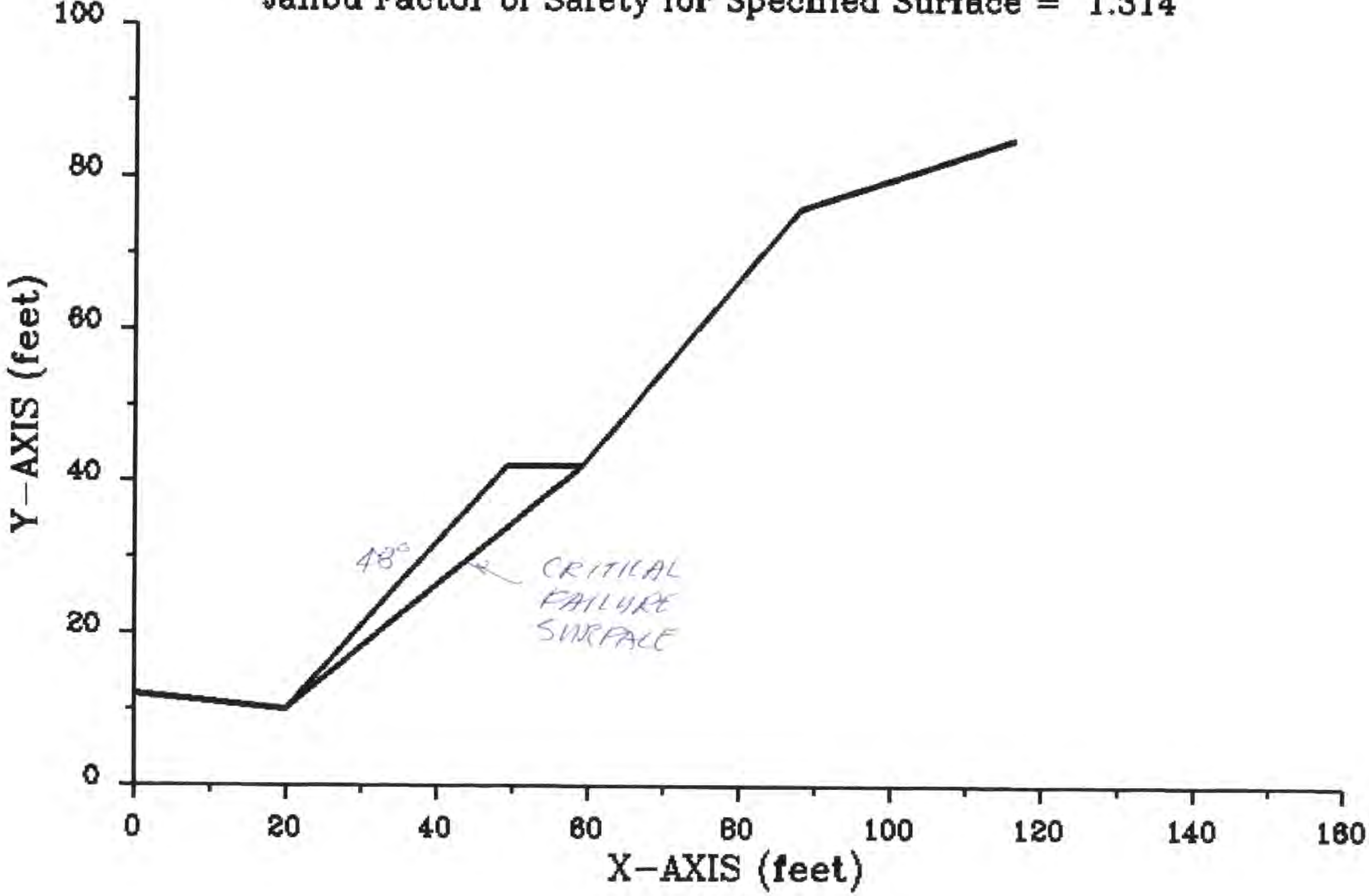
Black Hills, Hwy 16, M.P. 18.5

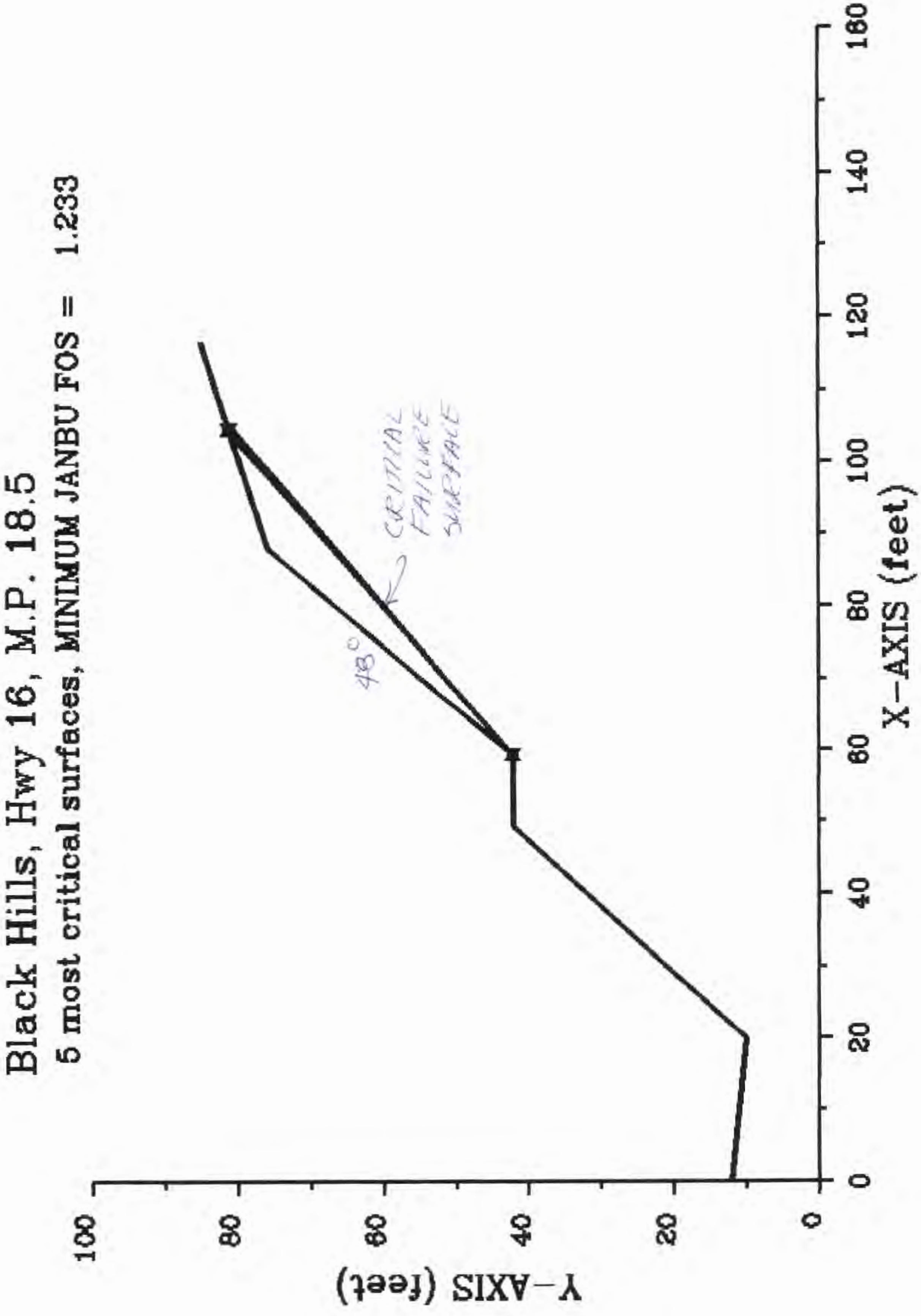
Janbu Factor of Safety for Specified Surface = 1.297



Black Hills, Hwy 16, M.P. 18.5

Janbu Factor of Safety for Specified Surface = 1.314




Black Hills, Hwy 16, M.P. 18.5
5 most critical surfaces, MINIMUM JANBU FOS = 1.233
CRITICAL FAILURE SURFACE
48°
X-AXIS (feet)
Y-AXIS (feet)
0
20
40
60
80
100
120
140
160
0
20
40
60
80
100

SITE RECONNAISSANCE

State Highway SR 71 Date 07/12/94

M.P. 27.5 Length 380 ft. Name Research Team

Site Designation Site 25 (Road Segment 4, Stop 1)

PURPOSE OF INVESTIGATION

Research; document cut slopes in RUD.

CONCERNS AND CONSTRAINTS (Step 1)

N/A

PRECONSTRUCTION, CONSTRUCTION, MAINTENANCE HISTORY

This is an older slope scheduled for reconstruction. The ditch is very narrow and partly filled with talus from shale.

EXISTING CUT SLOPE

Angle 67° Height 31 ft. (see sketch for overall slope profile)

Observed Slope Failure Mechanism: Differential weathering, slumping, minor collapse of less competent rock and surface erosion.

ENGINEERING ROCK AND SOIL UNITS

RUD

OPTIMUM SLOPE RANGE(S) (Per Rock and/or Soil Unit)

The optimum slope range is 1:1 or flatter.

VEGETATION

No vegetation is growing on the cut slope. The ditch is sparsely vegetated by grass. Slopes above the cut face are moderately to well vegetated with grass and ponderosa pine.

POSSIBLE TREATMENT METHODS

Recommended treatment: regrade to 1:1 or flatter and revegetate. We recommend brush layering to reduce surface erosion and minor slumping.

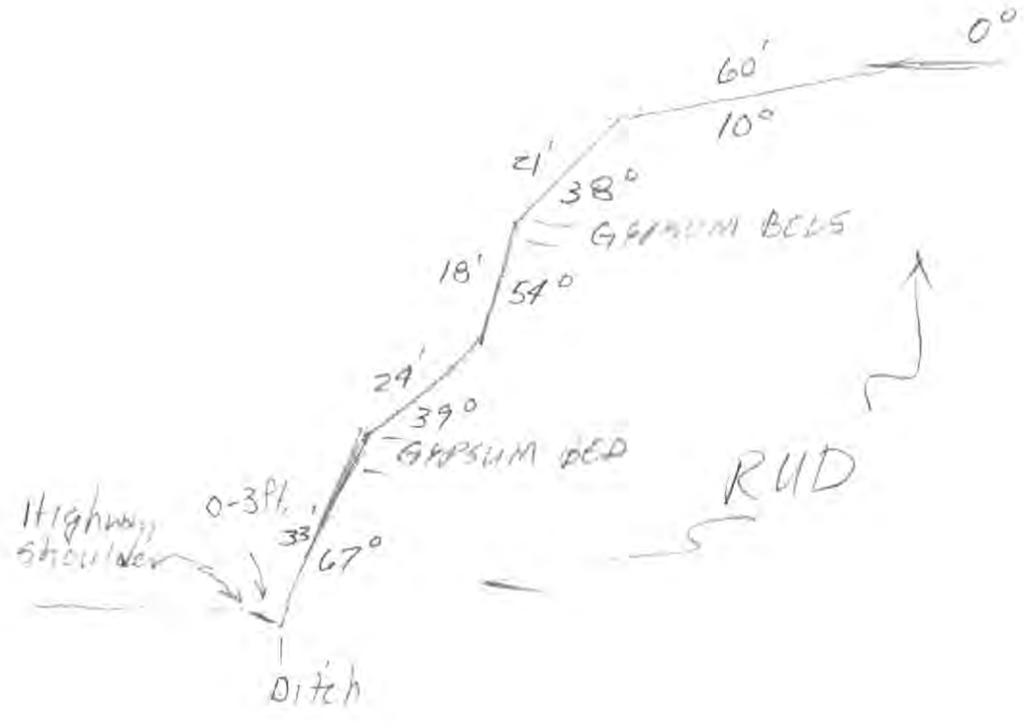
PRELIMINARY EVALUATION

This section has virtually no ditch to catch rockfall. Some realignment may be possible with fill construction to the outside of the road, but some cutting may still be required. Regrading to 1:1 or flatter and revegetating would probably be the most practical approach. The more competent rock unit (gypsum) may tolerate a steeper slope, but its thickness and location are erratic and it should not be depended upon to stabilize the slope.

SITE RECONNAISSANCE

Site Designation Site 25 (Road Segment 4, Stop 1)

CROSS SECTIONAL SKETCH



Site Designation Site 25 (Road Segment 4, Stop 1)

Photo 1: View of the slope from across the highway. Note the collapse of gypsum beds (white) in the red shale beds.

Photo 2: Close-up view of gypsum collapse features. Note the variable thickness of the gypsum beds. Also note the thick colluvium deposit in the draw on the left side of photo.

SOIL UNIT SAND (SUS)
AND
SOIL UNIT CLAY (SUC)

SITE RECONNAISSANCE

State Highway US 85 Date 07/13/94

M.P. 31.4 Length 108 ft. Name Research Team

Site Designation Site 3 (Road Segment 1, Stop 4)

PURPOSE OF INVESTIGATION
Research; document ground water-related failure of colluvial slope.

CONCERNS AND CONSTRAINTS (Step 1)
N/A

PRECONSTRUCTION, CONSTRUCTION, MAINTENANCE HISTORY
The slope was recently constructed and revegetated via hydroseed and fiberglass roving; the slope failed during construction and colluvium and shale filled the ditch. Slumped material was removed at a later time.

EXISTING CUT SLOPE
Prefailure:
Angle (45°) Height 21 feet (see sketch)

Observed Slope Failure Mechanism: The slope failed about halfway up cut slope. The failure apparently resulted from ground water in SUS colluvium on a thin SUC clay layer overlying red shale (see cross sectional sketch).

ENGINEERING ROCK AND SOIL UNITS
SUS (colluvium) over SUC (clay) layer on red shale (see sketch).

OPTIMUM SLOPE RANGE(S) (Per Rock and/or Soil Unit)
It may be impractical to achieve the optimal slope range for this soil category, which is from 2:1 to 3:1 under the existing condition. Optimal slope ranging from 1:1 to 1¼:1 may be achieved if the slope is stabilized using the method described below.

VEGETATION
Revegetation efforts were destroyed by slope failure. Although roving and grass seeding appear successful along sections that have not yet failed.

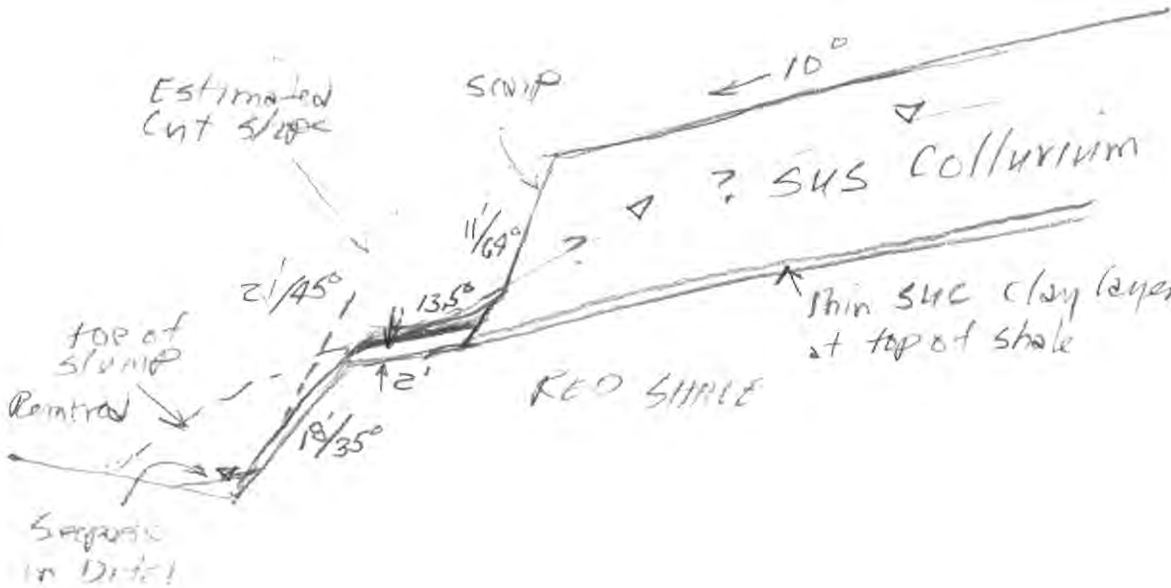
POSSIBLE TREATMENT METHODS
Recommended treatment method: Drainage and buttressing. Once the slope has been stabilized, hydroseeding should successfully revegetate the cut slope.

PRELIMINARY EVALUATION
See attached preliminary stability analysis. The removal of the SUC clay layer and the construction of a rock buttress with 1¼:1 fill will stabilize the slope. A geotextile fabric must be placed between the rock buttress fill and the soil unit to control piping of soil into the rock fill.

SITE RECONNAISSANCE

Site Designation Site 3 (Road Segment 1, Stop 4)

CROSS SECTIONAL SKETCH



SITE RECONNAISSANCE

Site Designation Site 3 (Road Segment 1, Stop 4)

Photo 1: Close-up view of sandy SUS slump. Note red shale and water seepage in ditch.

Photo 2: View of cut slope from across the highway. Note trace of the thin SUC clay (tan) at the top of the red shale unit.

Site Designation <u>Site 3 (Road Segment 1, Stop 4)</u>

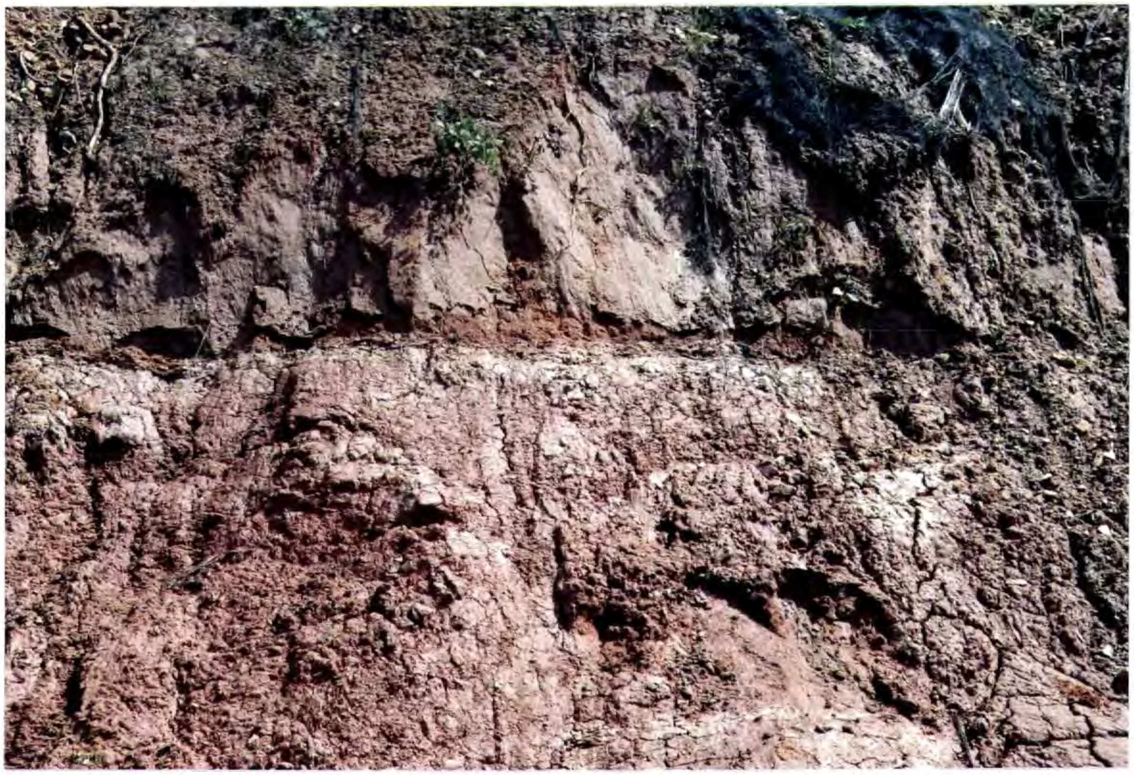


Photo 3: Close-up of the thin SUC clay layer between the red shale and the SUS colluvium.

Photo 4: Profile view showing slumped SUS colluvium over red shale. Note the damaging effects of the slump on fiberglass roving.

SITE RECONNAISSANCE

Site Designation Site 3 (Road Segment 1, Stop 4)

SLOPE STABILITY ATTACHMENT

I. ROCK (Provide details on Cross Section)

A. DISCONTINUITY FAILURE

Discontinuities (Dip/Dip Direction)	**Infilling**	**Friction Angle**
Primary		
Secondary I		
Secondary II		
Secondary III		

Road Azimuth ______ Propose Cut Angle ______

Anticipated Failure Type: Plane ______ Wedge ______

B. TOPPING FAILURE

Column Width ______ Height ______ Base Angle ______

C. COLLAPSE FAILURE

Differential Weathering Rating: High ______ Medium ______ Low ______

II. SOIL AND DECOMPOSED ROCK (Provide details on Cross Section)

Current or Anticipated Failure (for stability analysis) Translational slump of SUS colluvium over thin SUC clay layer on top of red shale.

Ground water (if present, type of aquifer and where located) Much ground water, perched (unconfined) in SUS by relatively impermeable SUC.

Estimated Soil Parameters (for each soil unit on Cross Section)
SUS: γ = 110-120 pcf, C = 0-100 psf, ϕ = 35° SUC: γ = 110-120 pcf, C = 0 psf, ∅ = 15°
Shale: γ = 110-120 pcf, C = 0 psf, ϕ = 38°

III. RECOMMENDATIONS FOR SUBSURFACE INVESTIGATION, LABORATORY AND STABILITY ANALYSES: See preliminary stability analysis attached. Prefailure, postfailure and stabilization results appear realistic. No additional investigation or analysis warranted for this stabilization alternative.

IV. POSSIBLE STABILIZATION ALTERNATIVES: Rock buttress as detailed on Sheet 11 is recommended. Note design and construction.

BLACK HILLS, HWY 85, M.P. 31.4 (SECTION 1, STOP 4)

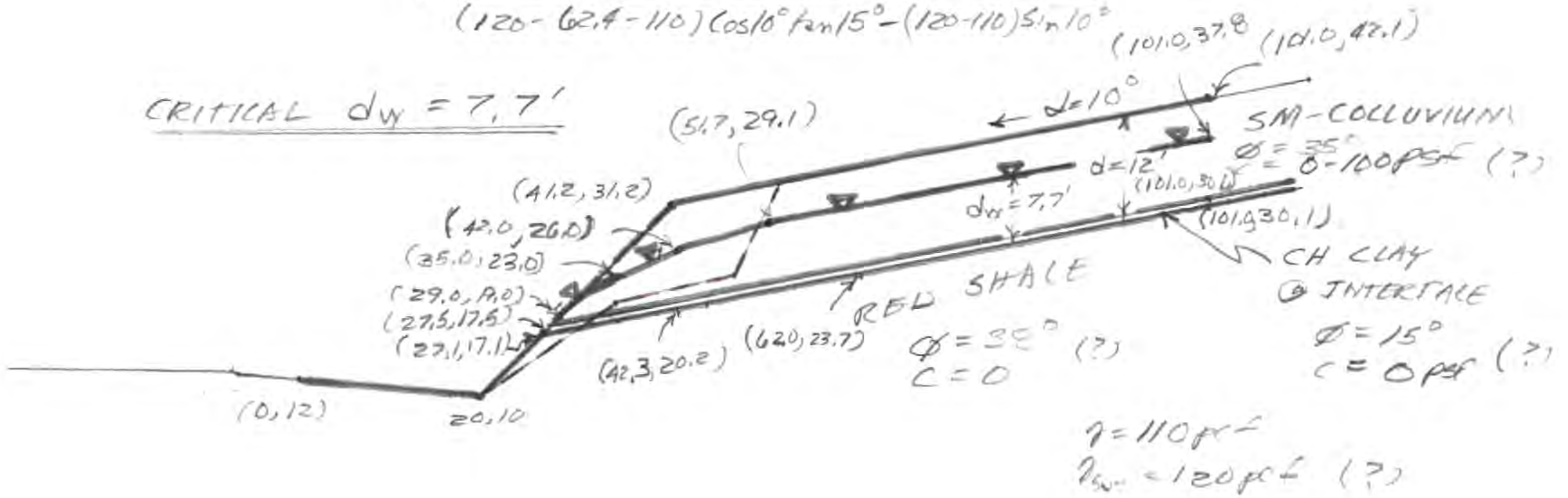
GW ?

BY INFINITE SLOPE:

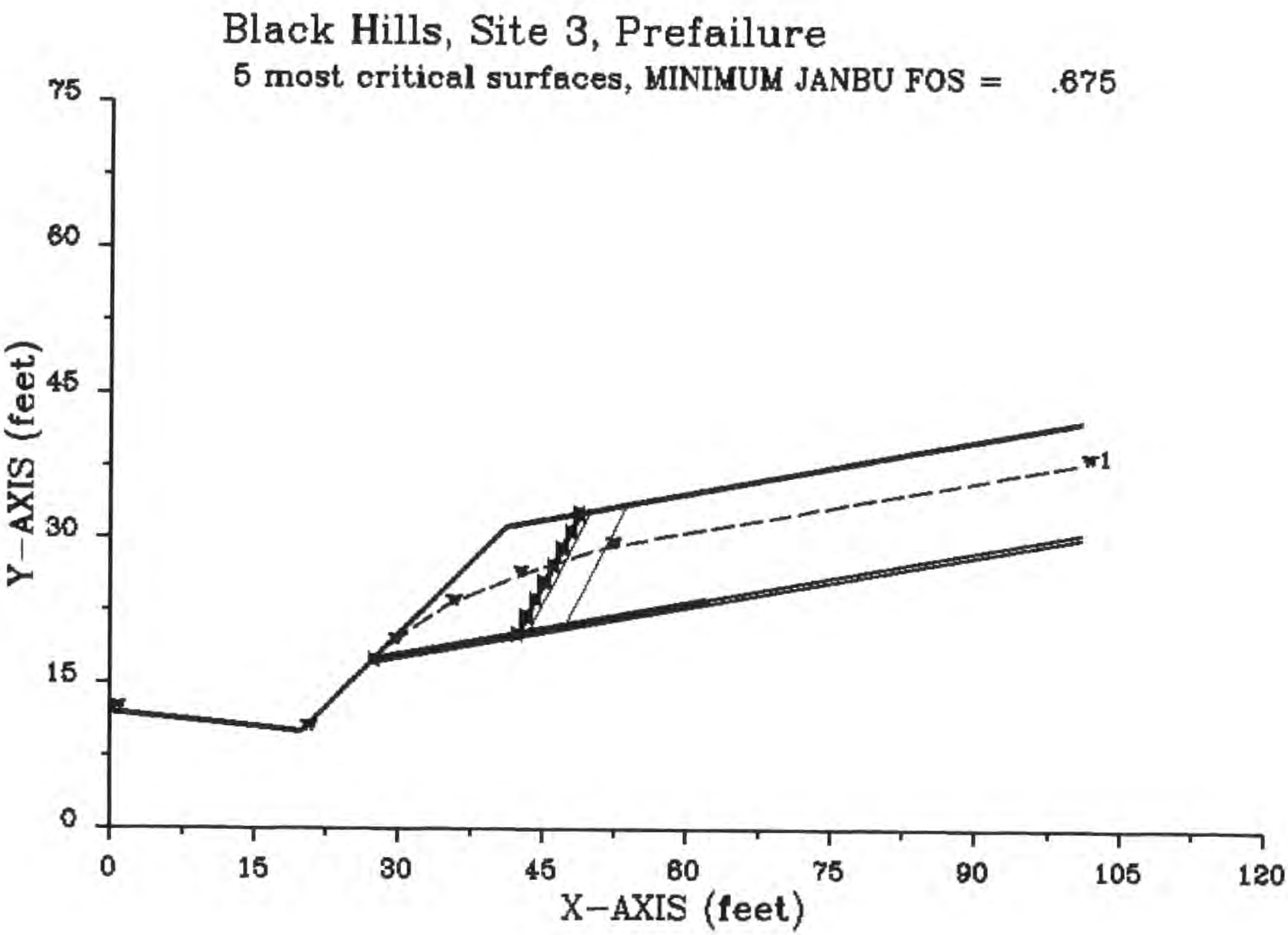
@ FS = 1.00 : $d_w = \dfrac{\gamma d(\sin\alpha - \cos\alpha \tan\phi) - C/\cos\alpha}{(\gamma_{sat} - \gamma_w - \gamma)\cos\alpha \tan\phi - (\gamma_{sat} - \gamma)\sin\alpha}$

$= \dfrac{110 \times 12 \times (\sin 10^\circ - \cos 10^\circ \tan 15^\circ)}{(120 - 62.4 - 110)\cos 10^\circ \tan 15^\circ - (120 - 110)\sin 10^\circ}$

CRITICAL d_w = 7.7'



PREFAILURE
(1" = 20')


Black Hills, Site 3, Prefailure
5 most critical surfaces, MINIMUM JANBU FOS = .675
Y-AXIS (feet)
75
60
45
30
15
0
X-AXIS (feet)
0
15
30
45
60
75
90
105
120
w1

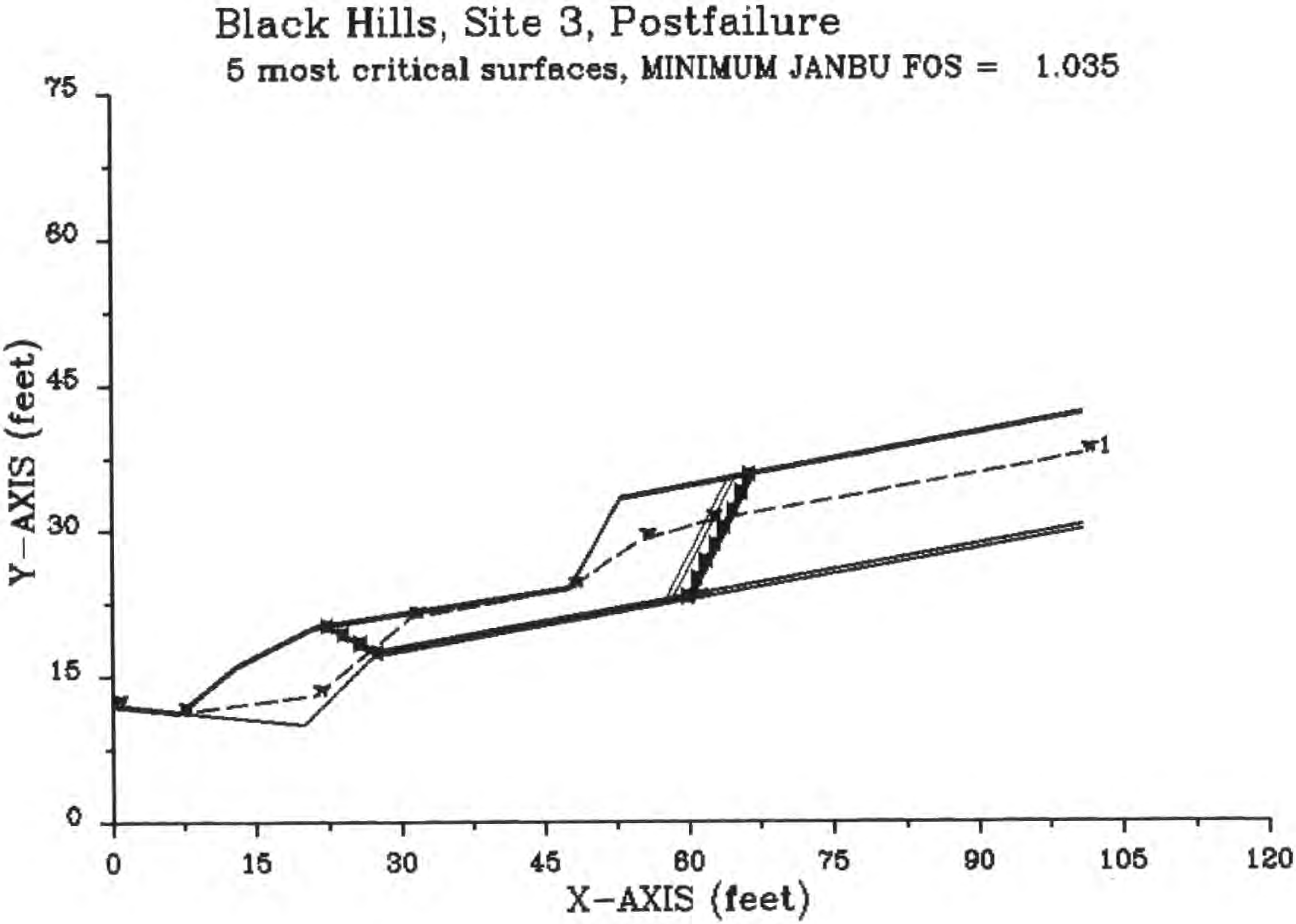
```
PROFIL                                                    FILE: SDOT3A       9-23-94
Black Hills, Site 3, Prefailure
   7     5
         .0           12.0          20.0          10.0    3
       20.0           10.0          27.1          17.1    3
       27.1           17.1          27.5          17.5    2
       27.5           17.5          41.2          31.2    1
       41.2           31.2         101.0          42.1    1
       27.5           17.5         101.0          30.6    2
       27.1           17.1         101.0          30.1    3
SOIL
  3
  110.0     120.0       50.0     35.00      .000          .0     1
  110.0     120.0         .0     15.00      .000          .0     1
  110.0     120.0         .0     38.00      .000          .0     1
WATER
  1       62.40
   7
           .0           12.0
         20.0           10.0
         29.0           19.0
         35.0           23.0
         42.0           26.0
         51.7           29.1
        101.0           37.8
BLOCK2
   50    2       2.0
         27.5           17.5           27.5          17.5          .0
         42.3           20.2           62.0          23.7          .2
```

The following is a summary of the TEN most critical surfaces

Problem Description : Black Hills, Site 3, Prefailure

	Modified JANBU FOS	Correction Factor	Initial x-coord (ft)	Terminal x-coord (ft)	Driving Force (lb)
1.	.675	1.081	27.50	48.84	6.194E+03
2.	.677	1.081	27.50	49.06	6.267E+03
3.	.679	1.081	27.50	49.16	6.294E+03
4.	.690	1.080	27.50	50.00	6.524E+03
5.	.727	1.079	27.50	53.86	7.596E+03
6.	.770	1.076	27.50	60.49	9.332E+03
7.	.775	1.075	27.50	61.09	9.492E+03
8.	.783	1.074	27.50	62.38	9.802E+03
9.	.799	1.073	27.50	65.09	1.046E+04
10.	.802	1.067	27.50	65.22	1.065E+04

* * * END OF FILE * * *


Black Hills, Site 3, Postfailure
5 most critical surfaces, MINIMUM JANBU FOS = 1.035
75
60
45
30
15
0
Y-AXIS (feet)
0
15
30
45
60
75
90
105
120
X-AXIS (feet)
w1

```
PROFIL                                              FILE: SDOT3B      9-23-94
Black Hills, Site 3, Postfailure
  11      6
       .0        12.0          7.0        11.3    3
      7.0        11.3         13.0        16.0    1
     13.0        16.0         21.0        20.0    1
     21.0        20.0         47.6        24.0    1
     47.6        24.0         53.0        33.3    1
     53.0        33.3        101.0        42.1    1
     27.1        17.1         27.5        17.5    2
     27.5        17.5        101.0        30.6    2
      7.0        11.3         20.0        10.0    3
     20.0        10.0         27.1        17.1    3
     27.1        17.1        101.0        30.1    3
SOIL
  3
  110.0    120.0     50.0    35.00     .000          .0    1
  110.0    120.0       .0    15.00     .000          .0    1
  110.0    120.0       .0    38.00     .000          .0    1
WATER
  1      62.40
   8
         .0        12.0
        7.0        11.3
       21.0        13.0
       31.0        21.0
       47.6        24.0
       55.0        29.0
       62.0        30.9
      101.0        37.8
BLOCK2
   50    2      2.0
       27.5        17.5        27.5        17.5        .0
       50.0        21.2        62.0        23.7        .2
```

The following is a summary of the TEN most critical surfaces

Problem Description : Black Hills, Site 3, Postfailure

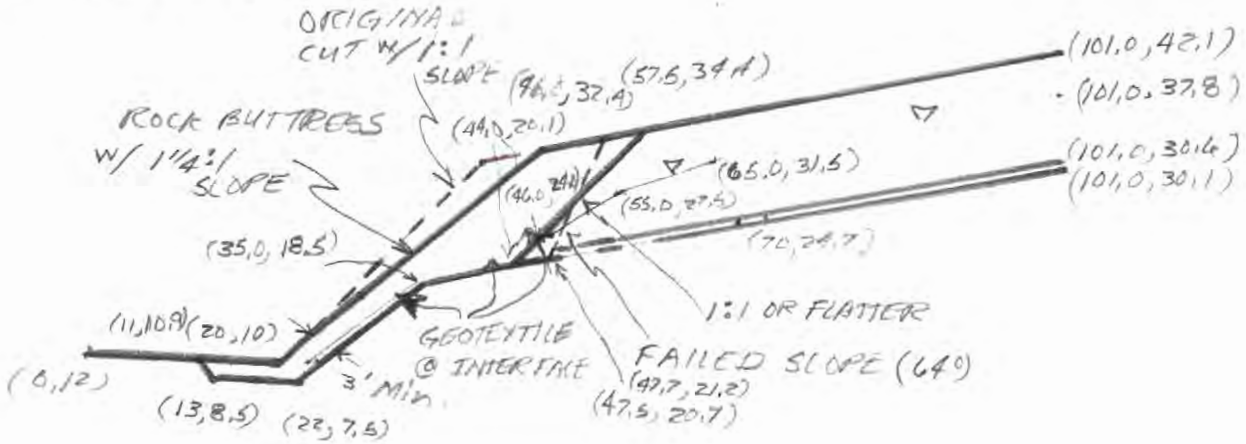
	Modified JANBU FOS	Correction Factor	Initial x-coord (ft)	Terminal x-coord (ft)	Driving Force (lb)
1.	1.035	1.074	22.32	66.48	8.213E+03
2.	1.035	1.073	22.32	66.82	8.280E+03
3.	1.036	1.073	22.32	67.10	8.332E+03
4.	1.037	1.075	22.32	64.87	7.845E+03
5.	1.038	1.076	22.32	64.11	7.674E+03
6.	1.038	1.074	22.32	66.03	8.071E+03
7.	1.040	1.073	22.32	66.23	8.098E+03
8.	1.040	1.075	22.32	64.42	7.713E+03
9.	1.040	1.076	22.32	63.75	7.567E+03
10.	1.041	1.074	22.32	66.04	8.038E+03

* * * END OF FILE * * *

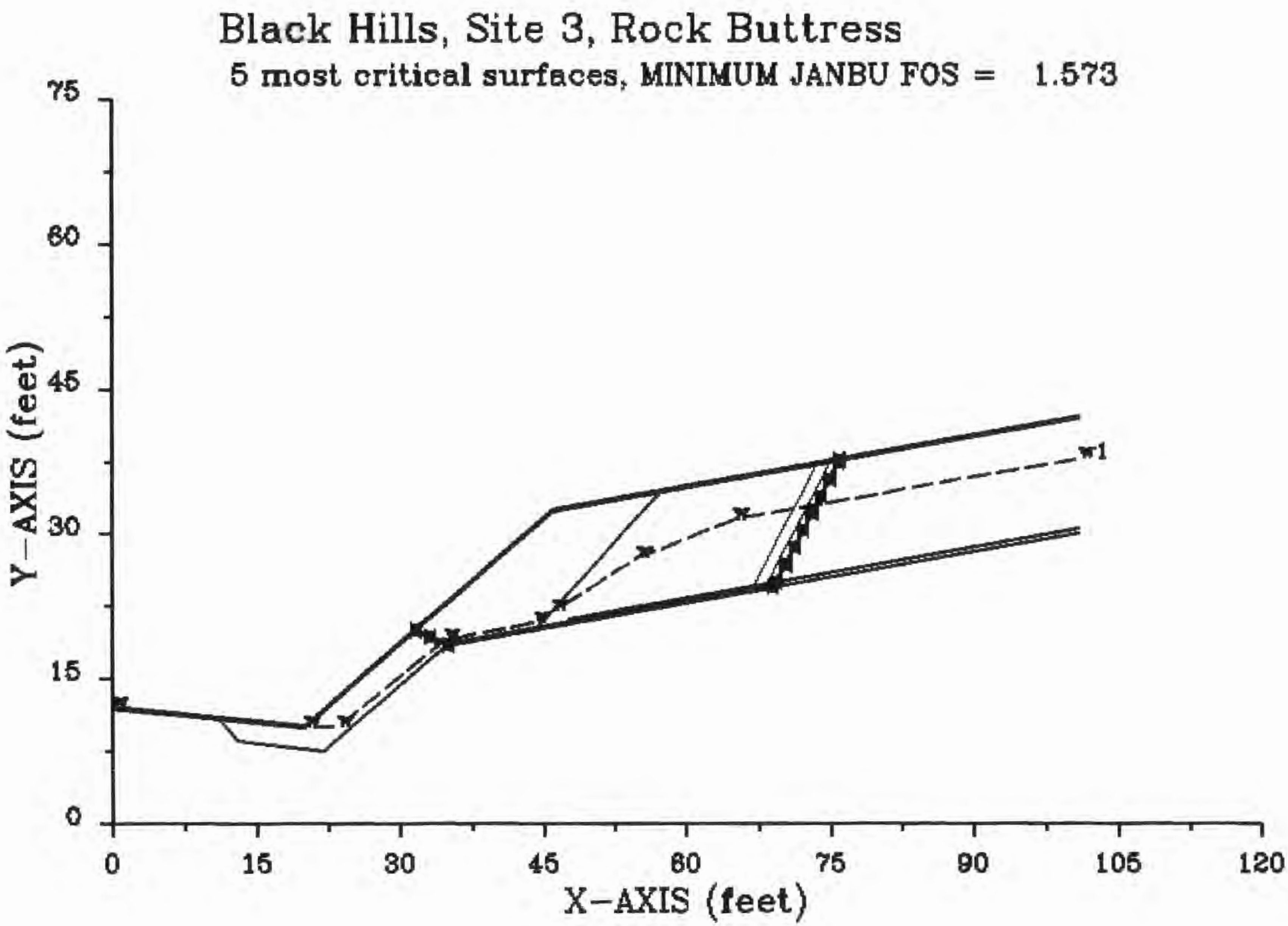
BLACK HILLS, HWY 85, M.P. 31.4 (SECTION 1, STOP 4)

DESIGN & CONSTRUCTION NOTES

1. Geotextile is a "must" at rock fill interface w/ soil to prevent piping of soil into the rock fill.
2. Check competency of shale on which rock is to placed. If soft and decomposed, excavate and extend buttress to below ditch line



ROCK BUTTRESS (1" = 20')

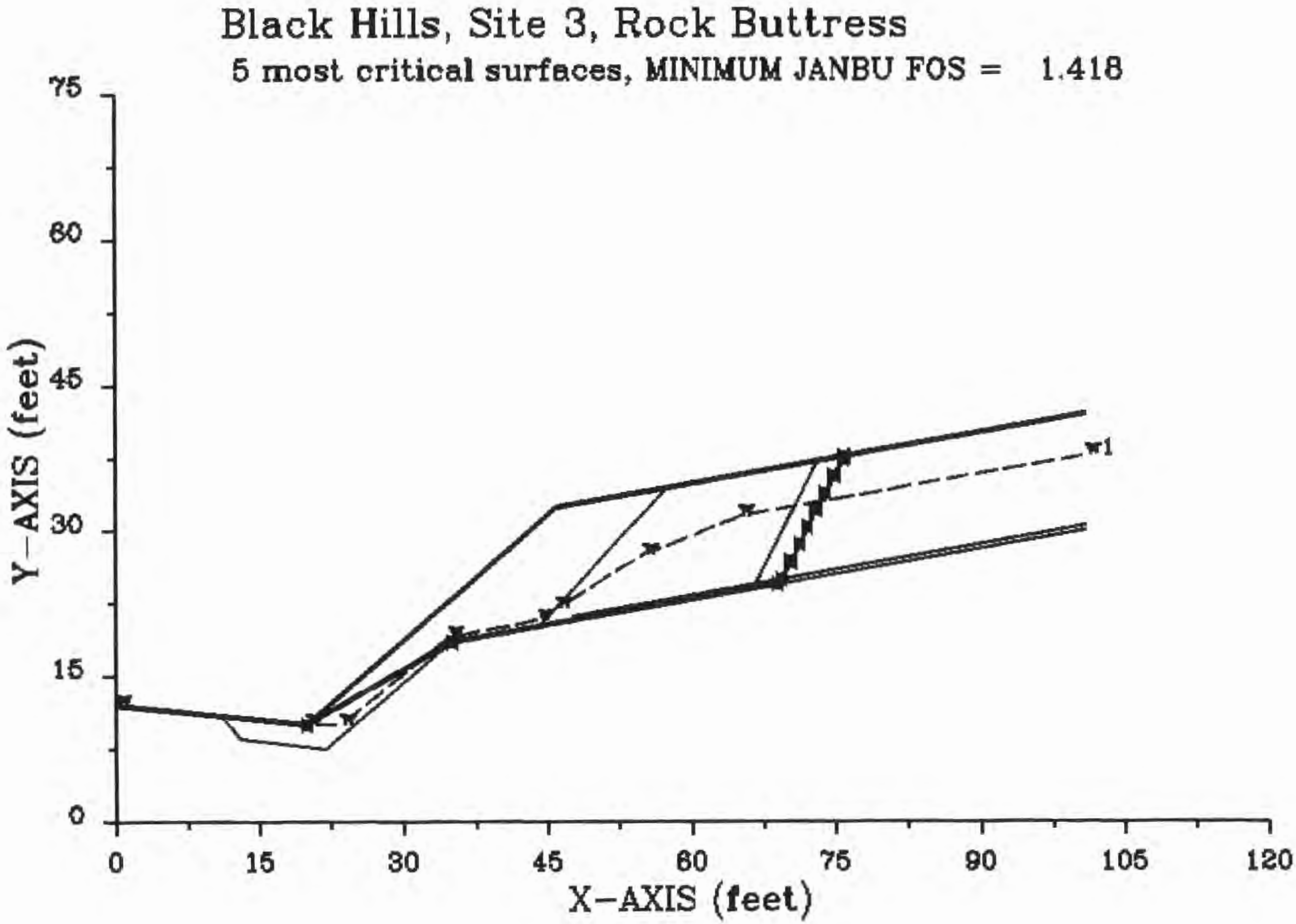

Black Hills, Site 3, Rock Buttress
5 most critical surfaces, MINIMUM JANBU FOS = 1.573
Y-AXIS (feet)
X-AXIS (feet)
75
60
45
30
15
0
0
15
30
45
60
75
90
105
120
w1

```
PROFIL                                              FILE: SDOT3C       9-23-94
Black Hills, Site 3, Rock Buttress
  14      5
        .0         12.0        11.0       10.9    3
      11.0         10.9        20.0       10.0    4
      20.0         10.0        46.0       32.4    4
      46.0         32.4        57.5       34.4    4
      57.5         34.4       101.0       42.1    1
      11.0         10.9        13.0        8.5    3
      13.0          8.5        22.0        7.5    3
      22.0          7.5        35.0       18.5    3
      35.0         18.5        44.0       20.1    3
      44.0         20.1        57.5       34.4    1
      44.0         20.1        47.5       20.7    3
      47.5         20.7        47.7       21.2    2
      47.7         21.2       101.0       30.6    2
      47.5         20.7       101.0       30.1    3
SOIL
  4
  110.0    120.0       50.0    35.00     .000          .0     1
  110.0    120.0         .0    15.00     .000          .0     1
  110.0    120.0         .0    38.00     .000          .0     1
  125.0    130.0         .0    40.00     .000          .0     1
WATER
  1       62.40
   9
          .0          12.0
        20.0          10.0
        23.5          10.0
        34.7          19.0
        44.0          20.8
        46.0          22.0
        55.0          27.5
        65.0          31.5
       101.0          37.8
BLOCK2
   50    2      2.0
        35.0          18.5          35.0          18.5           .0
        50.0          21.2          70.0          24.7           .2
```

The following is a summary of the TEN most critical surfaces

Problem Description : Black Hills, Site 3, Rock Buttress

	Modified JANBU FOS	Correction Factor	Initial x-coord (ft)	Terminal x-coord (ft)	Driving Force (lb)
1.	1.573	1.073	31.67	75.99	1.353E+04
2.	1.573	1.073	31.67	75.79	1.348E+04
3.	1.579	1.073	31.67	74.98	1.329E+04
4.	1.588	1.074	31.67	73.55	1.294E+04
5.	1.596	1.072	31.67	75.95	1.350E+04
6.	1.597	1.075	31.67	72.83	1.278E+04
7.	1.599	1.075	31.67	73.14	1.286E+04
8.	1.611	1.073	31.67	74.46	1.316E+04
9.	1.613	1.073	31.67	74.30	1.313E+04
10.	1.613	1.076	31.67	71.42	1.244E+04



Black Hills, Site 3, Rock Buttress
5 most critical surfaces, MINIMUM JANBU FOS = 1.418
Y-AXIS (feet)
X-AXIS (feet)
0
15
30
45
60
75
90
105
120
w1

```
PROFIL                                              FILE: SDOT3D      9-23-94
Black Hills, Site 3, Rock Buttress
  14      5
        .0          12.0          11.0          10.9    3
      11.0          10.9          20.0          10.0    4
      20.0          10.0          46.0          32.4    4
      46.0          32.4          57.5          34.4    4
      57.5          34.4         101.0          42.1    1
      11.0          10.9          13.0           8.5    3
      13.0           8.5          22.0           7.5    3
      22.0           7.5          35.0          18.5    3
      35.0          18.5          44.0          20.1    3
      44.0          20.1          57.5          34.4    1
      44.0          20.1          47.5          20.7    3
      47.5          20.7          47.7          21.2    2
      47.7          21.2         101.0          30.6    2
      47.5          20.7         101.0          30.1    3
SOIL
  4
  110.0     120.0       50.0     35.00       .000          .0     1
  110.0     120.0         .0     15.00       .000          .0     1
  110.0     120.0         .0     38.00       .000          .0     1
  125.0     130.0         .0     40.00       .000          .0     1
WATER
  1       62.40
   9
          .0          12.0
        20.0          10.0
        23.5          10.0
        34.7          19.0
        44.0          20.8
        46.0          22.0
        55.0          27.5
        65.0          31.5
       101.0          37.8
BLOCK2
   50    3      2.0
        20.0          10.0          20.0          10.0          .0
        35.0          18.5          35.0          18.5          .0
        50.0          21.2          70.0          24.7          .2
```

The following is a summary of the TEN most critical surfaces

Problem Description : Black Hills, Site 3, Rock Buttress

	Modified JANBU FOS	Correction Factor	Initial x-coord (ft)	Terminal x-coord (ft)	Driving Force (lb)
1.	1.418	1.056	20.00	75.99	1.594E+04
2.	1.432	1.057	20.00	73.31	1.530E+04
3.	1.433	1.057	20.00	73.14	1.527E+04
4.	1.435	1.056	20.00	76.19	1.598E+04
5.	1.436	1.056	20.00	76.11	1.596E+04
6.	1.437	1.056	20.00	75.99	1.592E+04
7.	1.438	1.056	20.00	75.78	1.587E+04
8.	1.438	1.057	20.00	72.89	1.522E+04
9.	1.450	1.057	20.00	74.02	1.546E+04
10.	1.452	1.057	20.00	73.71	1.539E+04

SITE RECONNAISSANCE

State Highway US 85 Date 07/13/94

M.P. 30.5 Length About 50 ft. Name Research Team

Site Designation Site 5 (Road Segment 1, Stop 2)

PURPOSE OF INVESTIGATION

Research; document ground water-related failure of a colluvium slope.

CONCERNS AND CONSTRAINTS (Step 1)

N/A

PRECONSTRUCTION, CONSTRUCTION, MAINTENANCE HISTORY

The slope was recently constructed and revegetated using hydroseed and fiberglass roving; the slope failed during construction as a wet slump.

EXISTING CUT SLOPE

Angle 1:1 (45°) prior to failure Height About 30 ft. (see sketch)

Observed Slope Failure Mechanism: The failure occurred in the upper one-third of cut slope. The failure is apparently a result of ground water in SUS colluvium perched on a thin SUC clay layer overlying shale.

ENGINEERING ROCK AND SOIL UNITS

SUS (colluvium) over a thin SUC (clay) layer resting on top of shale (see cross sectional sketch).

OPTIMUM SLOPE RANGE(S) (Per Rock and/or Soil Unit)

It may be impractical to achieve the optimal slope range (2:1 to 3:1) for this soil category under existing conditions. Optimal slopes ranging from 1:1 to 1¼:1 may be achieved if the slope is stabilized using the methods described below.

VEGETATION

Revegetation efforts were destroyed by the slope failure, although roving and grass seeding appear successful along sections that have not yet failed.

POSSIBLE TREATMENT METHODS

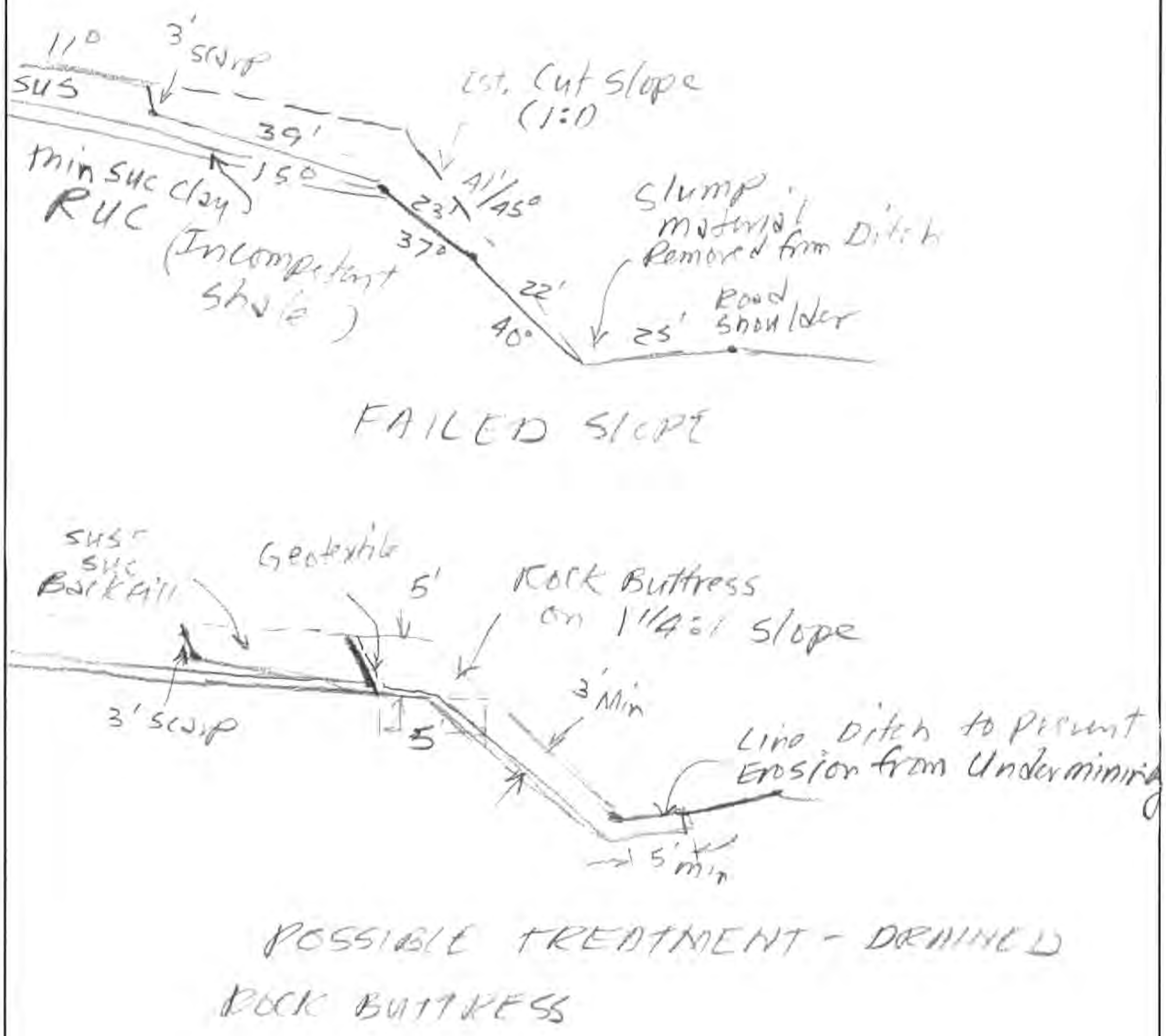
Recommended treatment methods: drainage and buttressing. Once the slope has been stabilized, hydroseeding or Soilguard may be used to revegetate the cut slope.

PRELIMINARY EVALUATION

This site is similar to site 3. A similar stability analysis should show that the removal of the SUC clay layer and the construction of a drained rock buttress with 1¼:1 fill would stabilize the slope. A geotextile fabric must be placed between the rock fill and the soil unit to allow drainage and prevent piping; use 0.8 to 1.0 base-width/height ratio for the upper part of the buttress and a 3-foot minimum thickness for lower "Reno Blanket" cover over shale. Remove shale if soft and highly weathered and extend buttress to ditch.

Site Designation Site 5 (Road Segment 1, Stop 2)

CROSS SECTIONAL SKETCH



Site Designation <u>Site 5 (Road Segment 1, Stop 2)</u>

Photo 1: View of failed slope. Note SUS debris (red to brown) and weathered shale (tan) in original cut slope.

Photo 2: View of the ditch line. Note seepage in ditch and the damaging effects of the failure on roving and revegetation efforts (center and left).