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**16. ABSTRACT**
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# DESIGN VARIABLES FOR CUT SLOPES

FINAL REPORT # FHWA/CA/TL-73/27

CALTRANS STUDY # D-5-30

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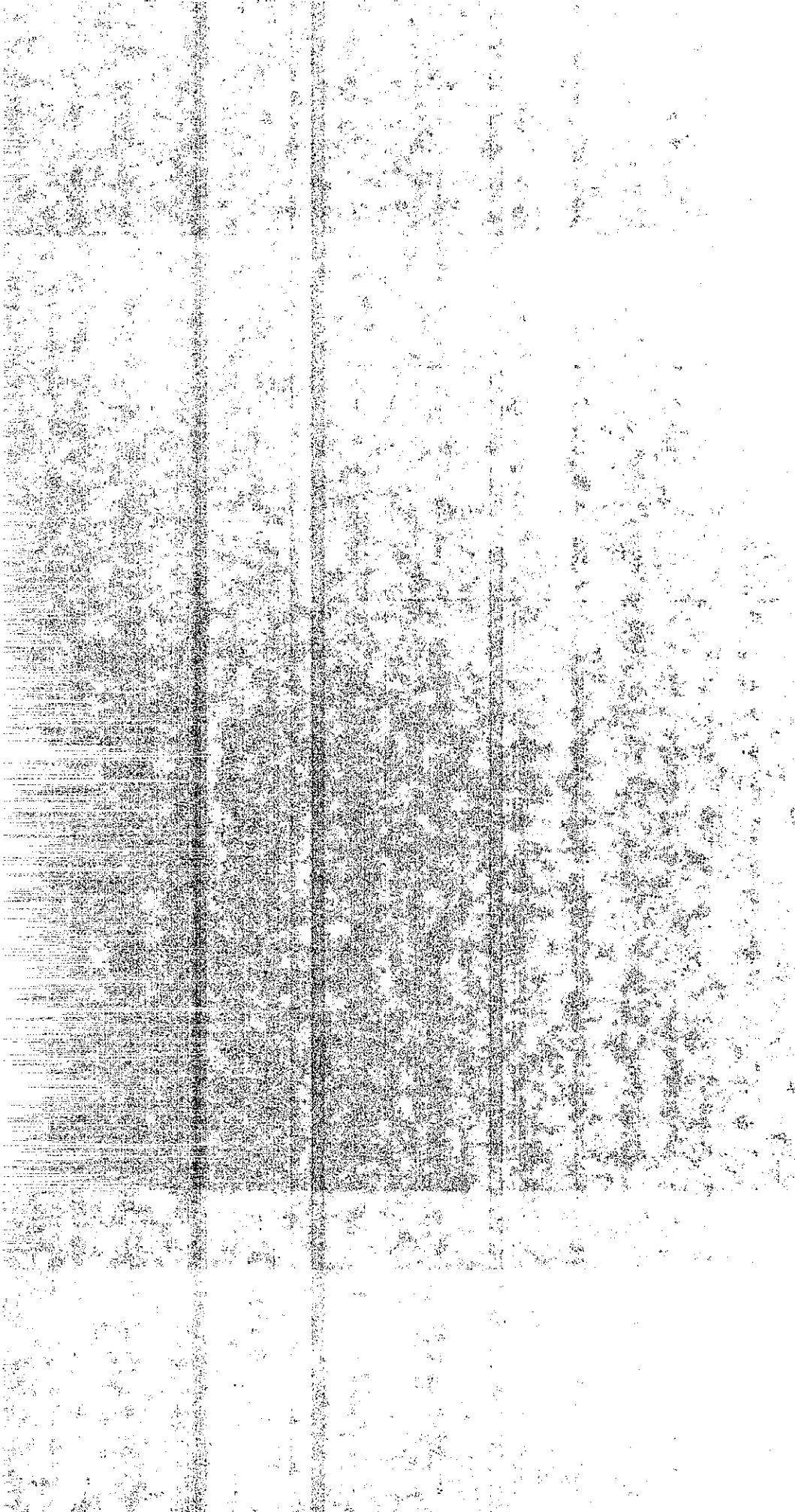

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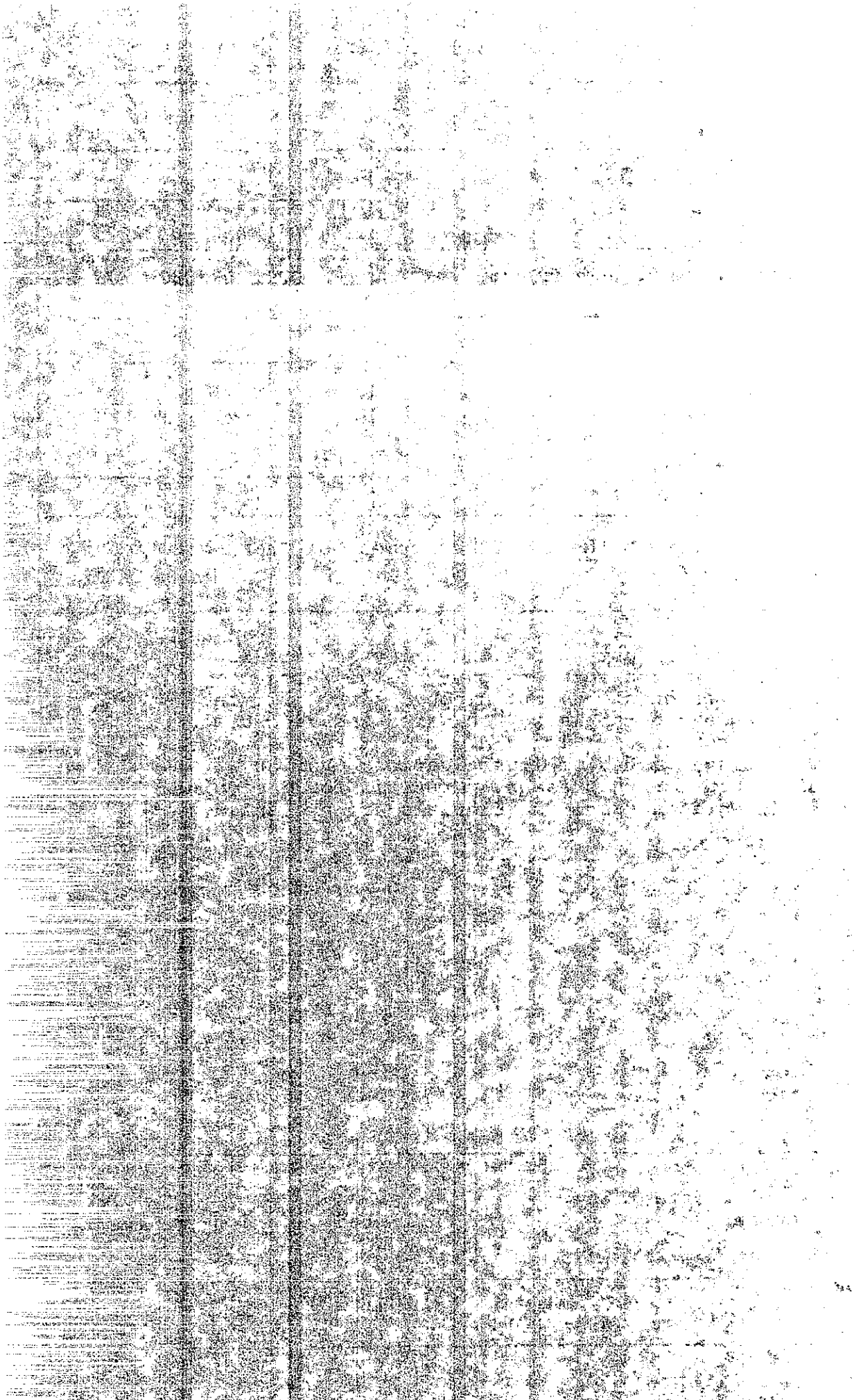

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DEPARTMENT OF TRANSPORTATION
DIVISION OF HIGHWAYS
TRANSPORTATION LABORATORY
5900 FOLSOM BLVD., SACRAMENTO 95819

September 1973

Research Project
T.L. 632882
D-5-30

Mr. R. J. Datel
State Highway Engineer

Dear Sir:

Submitted herewith is a research report titled:

DESIGN VARIABLES
FOR
CUT SLOPES

Thomas P. Hoover
Co-Investigator

Ronald Mearns, E. G.
Principal Investigator

Under the Supervision of
Marvin L. McCauley, E. G.

Very truly yours,

JOHN L. BEATON
Laboratory Director

Attachment

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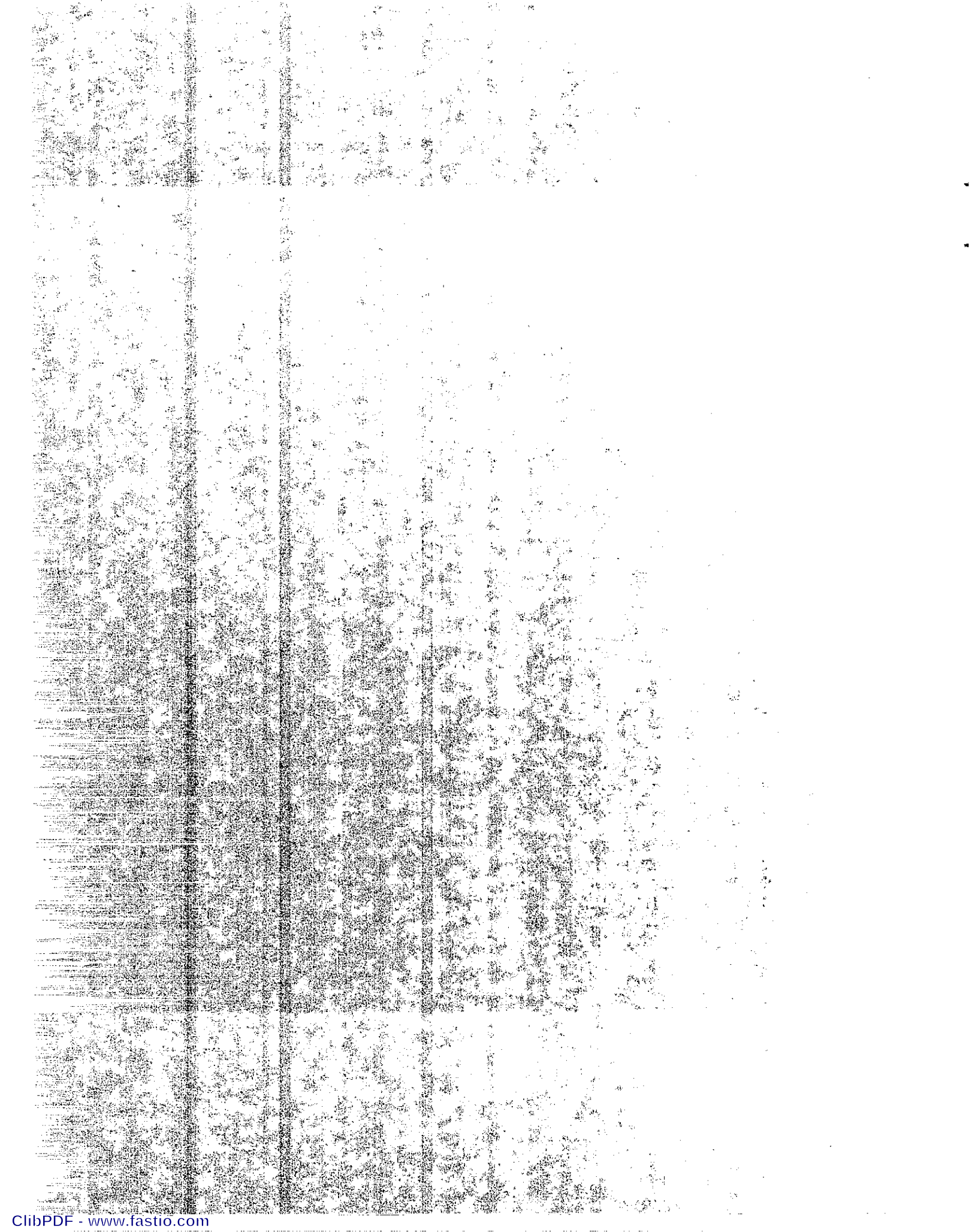

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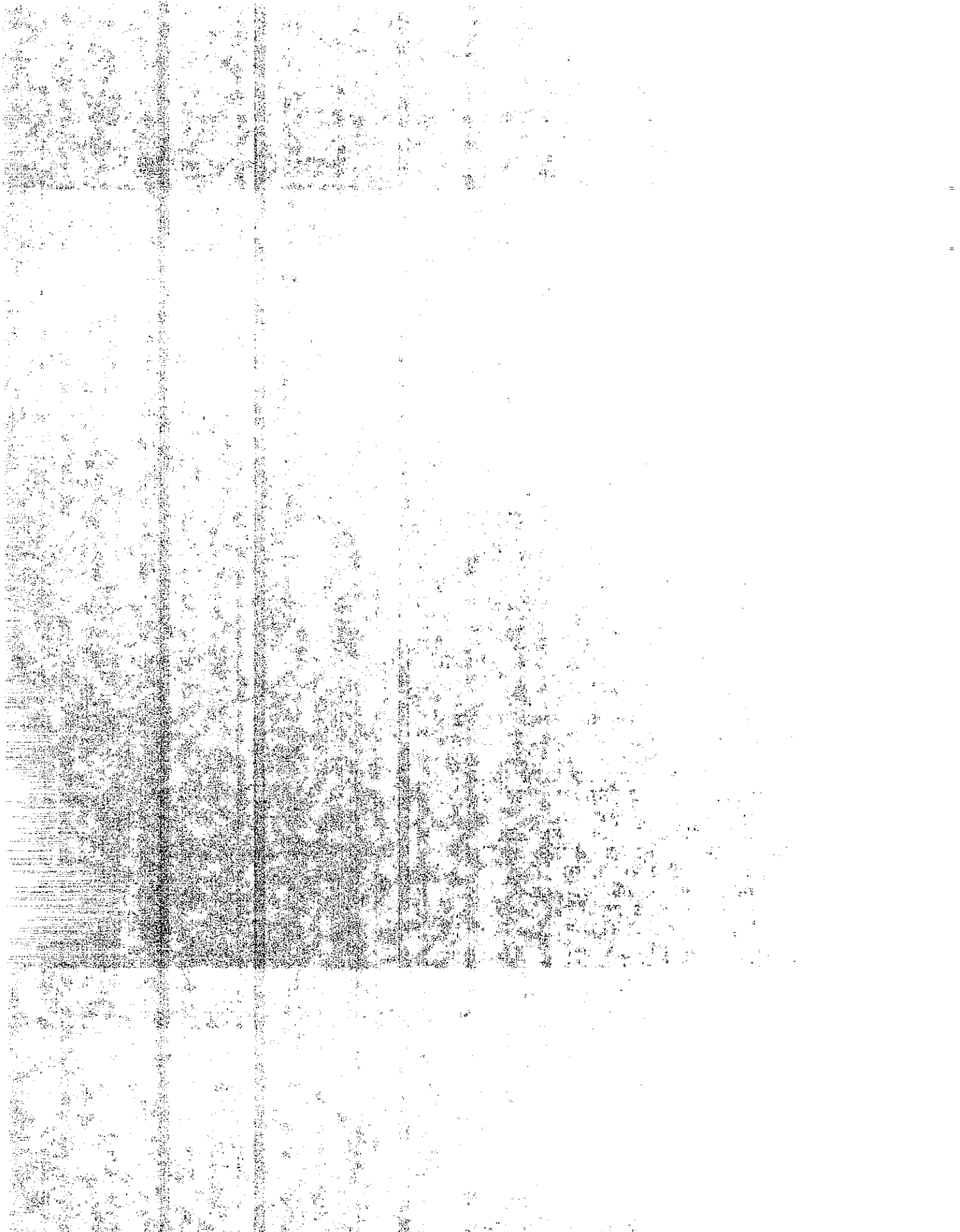

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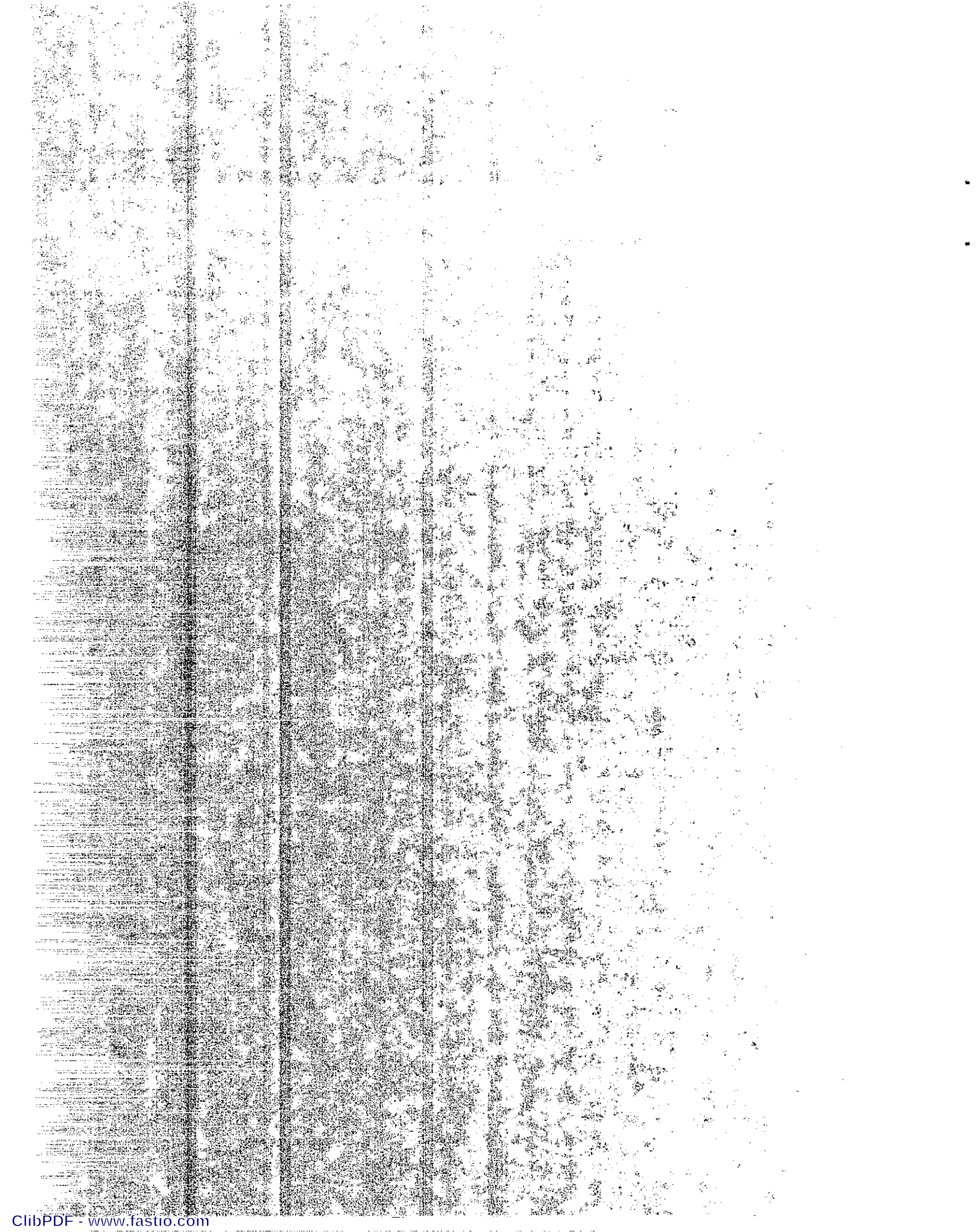

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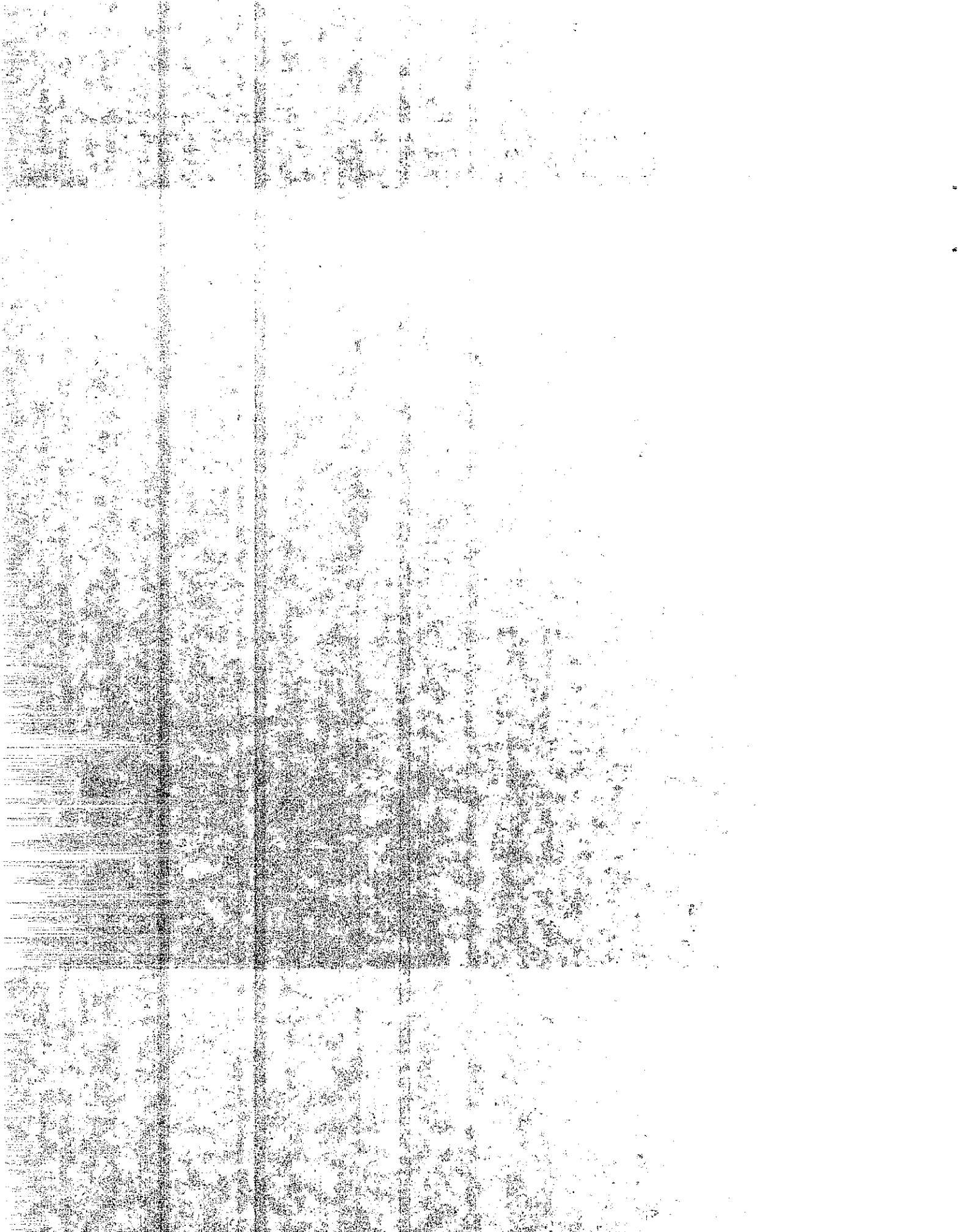

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# INTRODUCTION

The development of larger and more powerful earthmoving equipment coupled with improvements and innovations in construction methods have made possible the construction of highway cut slopes of heretofore unimagined magnitude. The technique of designing cut slopes which will remain stable has not kept pace with the improvements in construction equipment and methods. This research was initiated to provide data for a more objective cut slope design technique.

Theoretically, there are a large number of potentially significant variables. This study was undertaken in an attempt to determine if any of the more readily measurable variables correlate with cut slope performance and might therefore prove useful in designing cut slopes.

The general procedure followed in conducting this study consisted of inspecting cuts in all geographic areas of the state. Nearly all cut slopes involved only a single rock type and some cuts in each major rock type were included. Because of this selection process, the sampling is not random and statistical analysis methods cannot be relied upon to provide meaningful cut slope design criteria. The lack of randomness was not considered to be a problem for this study since its basic objective was guidance only in determining the direction for future research.

A total of 276 cut slopes were inspected by experienced engineering geologists on the staff of the Transportation Laboratory. Of these cuts 164 were side hill cuts and 112 were through cuts. The distribution of these cuts is shown in Figure 1 and listed in Table 1. Table 2 lists the designers of the cut slopes included in the study. All cuts included in this study were constructed between 1920 and 1968.

An edge punch data retrieval system was used for storage of all the data. A complete description of the system and its use is included in Appendix A.

The data collection process is described in Appendix B.

Because of the necessity to develop the data retrieval system prior to data collection, certain problems were encountered. It was originally intended to obtain representive samples of the materials for laboratory testing. Variations in the material within a given cut, such as grain size, degree of weathering and mineral composition were found to be much greater than was thought. Because of this condition, the sampling and testing portion of this study was discontinued.



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As a result of some early work on this project and experience gained on routine seismic investigations, an apparent correlation between cut slope stability in disintegrated granitic rocks and seismic velocities was noted. To investigate this relationship and to put the findings into effect as soon as possible, research funds were obtained from the California Division of Highways. The results of this correlation study are presented in Appendix C and have proven to be a useful and reliable method of arriving at stable cut slope designs in disintegrated granitic rocks.



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TABLE 1

DISTRIBUTION OF CUTS

| District | County | | No. of Cuts |
|---|---|---|---|
| 01 | | | 17 |
| | Del Norte | - 7 | |
| | Humboldt | - 5 | |
| | Mendocino | - 5 | |
| 02 | | | 37 |
| | Lassen | - 6 | |
| | Modoc | - 10 | |
| | Plumas | - 7 | |
| | Shasta | - 4 | |
| | Siskiyou | - 7 | |
| | Tehama | - 3 | |
| 03 | | | 55 |
| | Butte | - 14 | |
| | El Dorado | - 17 | |
| | Nevada | - 8 | |
| | Placer | - 7 | |
| | Sacramento | - 1 | |
| | Sierra | - 4 | |
| | Yuba | - 4 | |
| 04 | | | 20 |
| | Alameda | - 5 | |
| | Contra Costa | - 1 | |
| | Marin | - 6 | |
| | Santa Cruz | - 2 | |
| | San Mateo | - 3 | |
| | Sonoma | - 3 | |
| 05 | | | 32 |
| | Monterey | - 8 | |
| | Santa Barbara | - 13 | |
| | San Benito | - 4 | |
| | San Luis Obispo | - 7 | |
| 06 | Tulare | - 2 | 2 |
| 07 | | | 22 |
| | Los Angeles | - 18 | |
| | Orange | - 3 | |
| | Ventura | - 1 | |



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TABLE 1 (Continued)

DISTRIBUTION OF CUTS

| District | County | No. of Cuts |
|---|---|---|
| 08 | | 25 |
| | Riverside - 2 | |
| | San Bernardino- 23 | |
| 09 | | 16 |
| | Inyo - 1 | |
| | Kern - 4 | |
| | Mono - 11 | |
| 10 | | 35 |
| | Alameda - 7 | |
| | Alpine - 7 | |
| | Amador - 5 | |
| | Calaveras - 5 | |
| | Merced - 2 | |
| | Solano - 1 | |
| | Tuolumne - 8 | |
| 11 | | 15 |
| | Imperial - 6 | |
| | San Diego - 9 | |
| TOTALS 11 | 43 | 276 |



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TABLE 2

CUT SLOPE DESIGN AGENCY

| Agency | | No. of Cuts |
|---|---|---|
| California Department of Transportation | | |
| District 01 | | 11 |
| District 02 | | 29 |
| District 03 | | 36 |
| District 04 | | 14 |
| District 05 | | 22 |
| District 06 | | 2 |
| District 07 | | 14 |
| District 08 | | 23 |
| District 09 | | 16 |
| District 10 | | 35 |
| District 11 | | 15 |
| El Dorado County | | 1 |
| Los Angeles County | | 8 |
| Mendocino County | | 3 |
| Monterey County | | 5 |
| Marin County | | 3 |
| Riverside County (Prisoners) | | 2 |
| Sacramento County | | 1 |
| San Benito County | | 2 |
| San Luis Obispo County | | 1 |
| Santa Barbara County | | 2 |
| Sonoma County | | 3 |
| Federal Highway Administration | | 11 |
| California Department of Water Resources | | 14 |
| Corps. of Engineers | | 1 |
| Contractors (Not Designed) | | 2 |
| Totals: | 26 | 276 |



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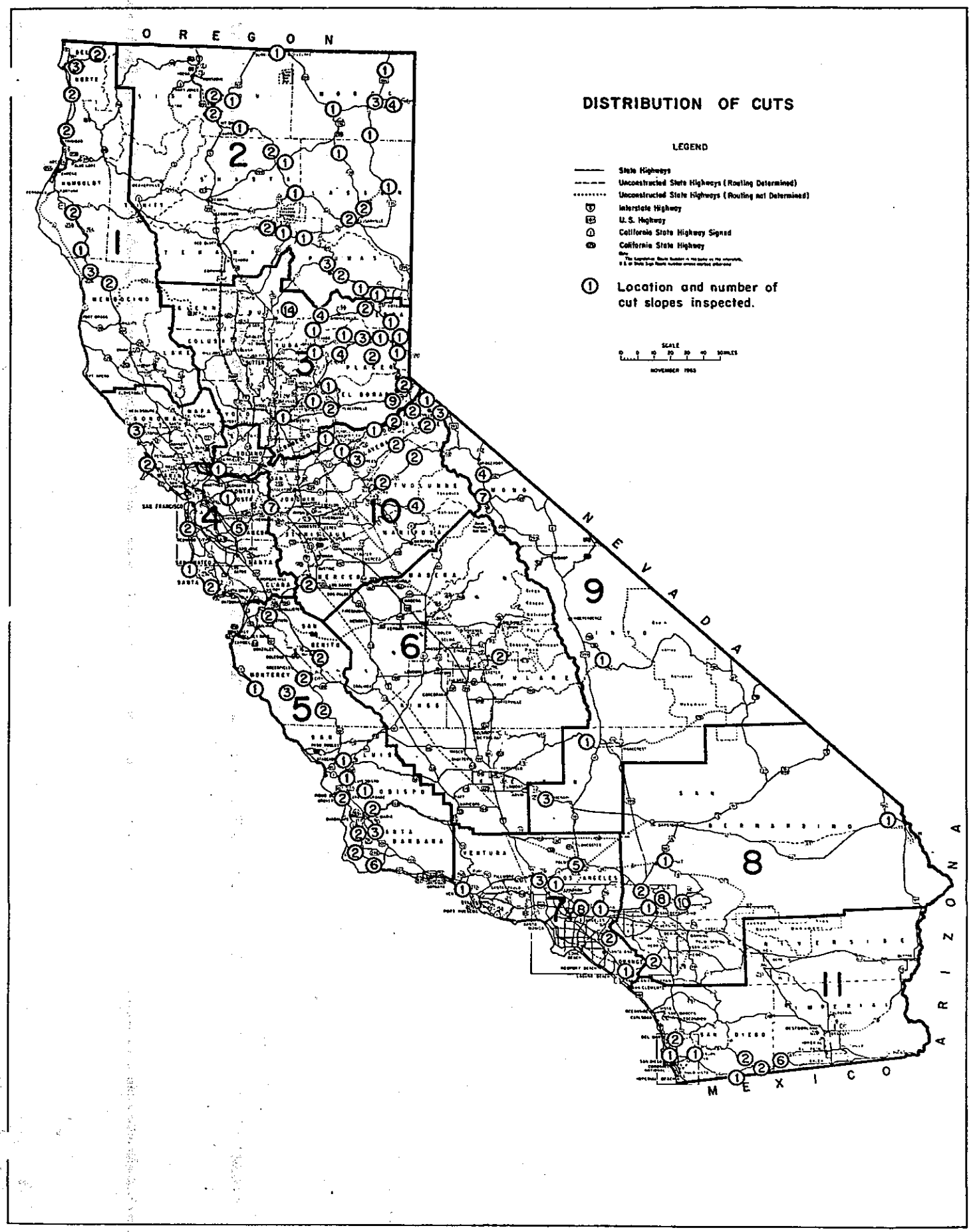
Figure 1



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## CONCLUSIONS

The cut slopes included in this study were not randomly selected, however, the sample is considered of sufficient magnitude and representation of the diversity of rock types and locations on California Highways as to constitute a reliable indicator of relationships which warrant further research.

Further investigation of the factors listed below should define a number of relationships which would be useful in the design of stable cut slopes. The factors are divided into three categories for this discussion.

Geographic information, i.e. rainfall, environment, and topography, appears to be related directly to both slope design and performance.

Geologic information, i.e. lithology, mineralogy, geologic structure, seismic refraction data, and groundwater, also relate directly to both slope design and performance.

Certain relationships between various cut slope descriptors, e.g. cut slope angle, cut slope height, bench data, failures, performance and cut slope age also need to be defined in order to permit the design of stable cut slopes.

## IMPLEMENTATION

The data that was collected for this report and the findings contained in Appendix C are being used by the Engineering Geology Group and by some of the Transportation District's to design more stable and economical cut slopes.

Further implementation will require a more comprehensive study of the variables involved. This project has provided the basis for the detailed investigation of the design of highway cuts in intermediate quality rock as well as the relationship of planar features to highway orientation.



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## RECOMMENDATIONS

To obtain the benefits of an objective approach to cut slope design, the above listed factors are recommended for immediate investigation. Such investigation must be based on a statistically random sample and should be set up to permit data accumulation and analysis by computer. The random sample is necessary to assure the widest possible applicability of the resultant design criteria.

It is also recommended that multifactor analysis of the existing data be performed to determine if similar analysis of the statistically significant data recommended above is warranted. The potential for this type analysis should be incorporated into the computer program at the time of its development.

It is recommended that the angular relationships between the geologic structural features present and the cut slope face be investigated. Such features are a significant factor in slope stability and there is insufficient data available to permit their consideration in cut slope design.

The problems experienced with the edge punched data retrieval system on the project were significant in magnitude and, as a result, it is recommended that for either large numbers of variables or for large data sets that only computer storage and analysis be considered.



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## ANALYSIS AND RESULTS

The data gathered for this project are summarized in Tables 3 through 13. These tables are self explanatory and describe the data available for the analyses described below. The total number of cuts in some tables exceeds 276, the number of cuts inspected. This occurs because some cuts are included in more than one category.

TABLE 3

CUT SLOPE ANGLE

| Angle | No. of Cuts |
|---|---|
| 1/8:1 | 2 |
| 1/4:1 | 11 |
| 1/2:1 | 52 |
| 3/4:1 | 68 |
| 1:1 | 88 |
| 1 1/4:1 | 9 |
| 1 1/2:1 | 45 |
| 2:1 | 15 |
| 3:1 | 3 |
| 4:1 | 1 |

TABLE 4

CUT SLOPE HEIGHT

| Height Range (ft.) | No. of Cuts |
|---|---|
| 39 or less | 32 |
| 40 through 80 | 121 |
| 81 through 120 | 52 |
| Greater than 120 | 71 |

TABLE 5

BENCH DATA

| No. of Benches | Height Between Benches | No. of Cuts |
|---|---|---|
| None | - - | 185 |
| 2 or Less | 49 ft. or less | 19 |
| | 50 ft. or more | 6 |
| 3 or More | 49 ft. or less | 33 |
| | 50 ft. or more | 33 |



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TABLE 6

SPECIAL TREATMENTS

| Type | No. of Cuts |
|---|---|
| Widening at Grade | 68 |
| Plantings | 22 |
| Horizontal Drains | 10 |
| Fences | 7 |
| Slope Rounding | 4 |
| Strut Fills | 2 |
| Presplitting | 1 |
| Underdrains | 1 |

TABLE 7

FAILURES

| Type | No. of Cuts |
|---|---|
| Ravelling | 125 |
| Rockfall | 78 |
| Erosion | 63 |
| Surface Slides | 48 |
| Deep Slides | 3 |
| Other (Sloughing, etc.) | 33 |
| None | 20 |

TABLE 8

ENVIRONMENT

| Type | No. of Cuts |
|---|---|
| Desert | 7 |
| Coast | 30 |
| Low Mountains | 132 |
| High Mountains | 107 |



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TABLE 9

RAINFALL

| Amount (Inches) | No. of Cuts |
|---|---|
| Less than 15 | 72 |
| 15 through 50 | 163 |
| Greater than 50 | 41 |

TABLE 10

GEOLOGIC DATA

| Type | No. of Cuts |
|---|---|
| Joints | 145 |
| Faults | 78 |
| Foliations | 50 |
| None of These | 110 |
| Clay Minerals Present | 167 |
| Weathering | |
| Fresh | 28 |
| Slightly Weathered | 53 |
| Moderately Weathered | 147 |
| Weathered | 85 |
| Very Weathered | 83 |
| Seismic Velocity Obtained | 38 |
| Groundwater Data | |
| Watertable | 19 |
| Fracture Water | 11 |
| Springs and Seeps | 50 |
| Unknown | 257 |



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TABLE 11

LITHOLOGY

| Rock Type | No. of Cuts |
|---|---|
| Granite | 67 |
| Diorite | 19 |
| Ultrabasic | 2 |
| Gabbro | 1 |
| Andesite | 17 |
| Volcanic Mudflow | 11 |
| Basalt | 8 |
| Agglomerate | 7 |
| Tuff | 3 |
| Rhyolite | 2 |
| Greenstone | 18 |
| Schist | 6 |
| Serpentine | 6 |
| Slate | 3 |
| Metagranitic | 3 |
| Metavolcanic | 2 |
| Meta Sandstone | 1 |
| Sandstone | 29 |
| Shale | 20 |
| Unconsolidated Sediments | 18 |
| Moraine | 12 |
| Conglomerate | 7 |
| Siltstone | 6 |
| Terrace | 6 |
| Talus | 2 |

TABLE 12

NATURAL SLOPES

| Slope Angle (Degrees) | Slope Height (Feet) | No. of Cuts |
|---|---|---|
| Less than 32 | Less than 100 | 46 |
| | 100 or greater | 103 |
| 32 or Greater | Less than 100 | 30 |
| | 100 or greater | 88 |
| Unknown | - - - - - - - - - | 9 |



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TABLE 13

CUT SLOPE PERFORMANCE

| Performance | No. of Cuts |
|---|---|
| Very Good | 61 |
| Good | 133 |
| Marginal | 47 |
| Unsatisfactory | 35 |

The following analysis is expressed only in general terms. The conclusions expressed are observations based on this set of data. They are presented to indicate the direction for future studies and not necessarily as guidelines for cut slope design. Only the observations which are considered significant or which suggest possible useful correlations are included in the following discussion.

The following observations are all based on simple two factor comparisons because the analysis of more than two factors was too time consuming and difficult to obtain with the edge punch system. Multifactor analysis should be explored in future projects as additional useful data would probably be developed.

The use of the term "Failures" as one of the cut slope descriptors requires some explanation. "Failures" would more properly be termed "Problems" as they refer to any of a group of conditions which contribute to maintenance problems and costs, result in hazards or pollution, or which create unsightly conditions. These "Failures" are not to be confused with cut slope perfomance. Cut slope performance could have been judged very good and yet the cut slope could exhibit one or more of the "Failures".

Soil creep was one of the categories of "Failures" included when the data collection system was established. This category was not used by any inspector to describe any cut. The absence of this type of failure probably results from the removal of soil in constructing the cut slope and, because the cut slopes are generally steeper than natural slopes, they exhibit a rate of failure too rapid to be considered as soil creep.

In attempting to perform the following analyses certain comparisons could only be made with considerable manual tabulation. Limitations in time and funds precluded completing many of these



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analyses. The most promising of these comparisons should be completed as part of future research projects. Those comparisons which show the most promise and for which further study is recommended will be preceeded by an asterisk (*).

The first analyses consisted of comparing each of the variables listed in Appendix A with each of the descriptors in the same listing. It was hoped that suspected relationships could be substantiated or that perhaps new useful relationships could be discovered. Only those comparisons which were believed potentially useful were undertaken as described as follows.

## Variables

### Rainfall

The cut slopes were originally grouped into three rainfall categories: less than 10 inches; 10-20 inches; and greater than 20 inches. These groupings were arbitrarily selected and during the analysis, it was decided to change the different arbitrary groupings: less than 15 inches; 15-50 inches; and greater than 50 inches. These groupings in general correspond to main geographic areas of California: the desert and portions of Southern California; the central valley and much of the coastline; and the north coast and high mountains.

The data used for this portion of the project was based on the most recent annual report from the U. S. Weather Service reporting station nearest to the cut slope. This distance is sometimes considerable and errors undoubtedly exist as a result. It should also be pointed out that this information is based on annual totals and no evaluation of rainfall intensities is included.

The data for comparing rainfall to the cut slope descriptors are included in Tables 14 through 20.

TABLE 14

RAINFALL VS CUT SLOPE ANGLE

| Rainfall | Cut Slope Angle | | | | |
|---|---|---|---|---|---|
| | ≥ 1/2:1 | 3/4:1 | 1:1 | 1 1/2:1 | ≤ 2:1 |
| <15 | 12 | 11 | 23 | 15 | 11 |
| 15-50 | 38 | 43 | 47 | 30 | 5 |
| >50 | 11 | 8 | 17 | 4 | 1 |



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TABLE 15

RAINFALL VS CUT SLOPE HEIGHT

| | Cut Slope Height | | | |
|---|---|---|---|---|
| Rainfall | <40 | 40-80 | 81-120 | > 120 |
| <15 | 9 | 21 | 18 | 24 |
| 15-50 | 19 | 77 | 28 | 39 |
| >50 | 4 | 23 | 6 | 8 |

TABLE 16

RAINFALL VS CUT TYPE

| | Cut Type | |
|---|---|---|
| Rainfall | Through | Sidehill |
| <15 | 40 | 32 |
| 15-50 | 63 | 100 |
| >50 | 9 | 32 |

TABLE 17

RAINFALL VS NO. OF BENCHES

| | No. of Benches | | |
|---|---|---|---|
| Rainfall | ≤2 | ≥3 | 0 |
| <15 | 19 | 4 | 49 |
| 15-50 | 42 | 19 | 102 |
| >50 | 5 | 2 | 34 |



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TABLE 18

RAINFALL VS BENCH HEIGHT

| | Bench Height | |
|---|---|---|
| Rainfall | ≤49 | ≥50 |
| <15 | 10 | 13 |
| 15-50 | 40 | 21 |
| >50 | 1 | 6 |

TABLE 19

RAINFALL VS FAILURES

| | Failures | | | | | | |
|---|---|---|---|---|---|---|---|
| Rainfall | Erosion | Ravelling | Rockfall | Surface Slides | Deep Slides | Others | None |
| <15 | 14 | 29 | 27 | 12 | 0 | 5 | 6 |
| 15-50 | 38 | 77 | 36 | 32 | 2 | 22 | 13 |
| >50 | 11 | 19 | 15 | 4 | 1 | 6 | 1 |

TABLE 20

RAINFALL VS PERFORMANCE

| | Performance | | | |
|---|---|---|---|---|
| Rainfall | Very Good | Good | Marginal | Unsatisfactory |
| <15 | 21 | 31 | 10 | 10 |
| 15-50 | 31 | 78 | 32 | 22 |
| >50 | 9 | 24 | 5 | 5 |



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*The comparison between rainfall and cut slope angle discloses the disproportionate number of flat slope angles in the less than 15 inches of rainfall areas.

*There is an extremely high percentage of sidehill type cuts in the greater than 50 inches of rainfall areas and there appears to be a disproportionate percentage in the 40 to 80 foot heights. It is probable that roadway design criteria and natural slope conditions are related to these observations.

Erosion was found to vary directly with rainfall while ravelling appears to occur independently of the amount of rainfall. More cut slopes in the areas of high rainfall exhibit failures than in the lower rainfall areas. These observations confirm previous opinions and can serve as guides in considering cut slope designs.

Environment

This variable was arbitrarily divided into four categories: Desert; Coast; Low Mountains; and High Mountains. These categories do not relate to geographic areas and all except the Coast are found throughout the state. The purpose for including this variable was to incorporate such factors as humidity, temperature, wind, vegetation, animals, etc., into the study. It is obvious that the categories selected are limited in their capability to do this and subsequent analysis of the data confirmed this statement. Future studies of this type should have a more sophisticated system of describing an environment.

Tables 21 through 27 present the data on environment.

TABLE 21

ENVIRONMENT VS CUT SLOPE ANGLE

| | Cut Slope Angle | | | | |
|---|---|---|---|---|---|
| Environment | ≥1/2:1 | 3/4:1 | 1:1 | 1 1/2:1 | ≤2:1 |
| Desert | 2 | 2 | 1 | 1 | 1 |
| Coast | 8 | 6 | 7 | 6 | 3 |
| Low Mountains | 31 | 31 | 34 | 24 | 12 |
| High Mountains | 20 | 23 | 45 | 18 | 1 |



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TABLE 22

ENVIRONMENT VS CUT SLOPE HEIGHT

| | Cut Slope Height | | | |
|---|---|---|---|---|
| Environment | <40 | 40-80 | 81-120 | >120 |
| Desert | 4 | 2 | 1 | 0 |
| Coast | 6 | 10 | 3 | 11 |
| Low Mountains | 7 | 49 | 27 | 49 |
| High Mountains | 15 | 60 | 21 | 11 |

TABLE 23

ENVIRONMENT VS CUT TYPE

| | Cut Type | |
|---|---|---|
| Environment | Through | Sidehill |
| Desert | 4 | 3 |
| Coast | 6 | 24 |
| Low Mountains | 57 | 75 |
| High Mountains | 45 | 62 |

TABLE 24

ENVIRONMENT

| | No. of Benches | | |
|---|---|---|---|
| Environment | ≤2 | ≥3 | 0 |
| Desert | 0 | 1 | 6 |
| Coast | 6 | 4 | 20 |
| Low Mountains | 41 | 17 | 74 |
| High Mountains | 19 | 3 | 85 |



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TABLE 25

ENVIRONMENT VS BENCH HEIGHT

| Environment | Bench Height ≤ 49 | Bench Height ≥ 50 |
|---|---|---|
| Desert | 1 | 0 |
| Coast | 1 | 9 |
| Low Mountains | 37 | 21 |
| High Mountains | 12 | 10 |

TABLE 26

ENVIRONMENT VS FAILURES

| Environment | Failures: Erosion | Ravelling | Rockfall | Surface Slides | Deep Slides | Other | None |
|---|---|---|---|---|---|---|---|
| Desert | 2 | 2 | 3 | 1 | 0 | 0 | 1 |
| Coast | 15 | 10 | 1 | 5 | 1 | 3 | 3 |
| Low Mountains | 18 | 69 | 22 | 28 | 2 | 11 | 15 |
| High Mountains | 28 | 44 | 52 | 14 | 0 | 19 | 1 |

TABLE 27

ENVIRONMENT VS PERFORMANCE

| Environment | Performance: Very Good | Good | Marginal | Unsatisfactory |
|---|---|---|---|---|
| Desert | 0 | 5 | 1 | 1 |
| Coast | 4 | 19 | 5 | 2 |
| Low Mountains | 37 | 54 | 23 | 18 |
| High Mountains | 20 | 55 | 18 | 14 |



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The distribution of each cut slope angle in each environment is remarkably similar with two exceptions: The use of 1:1 cut slopes in High Mountains was disproportionately high and in Low Mountains was disproportionately low; and the use of 2:1 cut slopes in Low Mountains was extremely high and in High Mountains was extremely low.

Cut slopes in the Desert had low heights.

A majority of cut slopes in High Mountains were in the 40-80 foot height group.

An extremely high percentage of cut slopes in the Coast category were sidehill cuts.

Most cuts were unbenched but extremely high percentages of both the Desert and High Mountains categories were unbenched.

Half of the cuts in the Coast category experienced erosion.

Most Erosion, Ravelling and Rockfall, occurs in either High or Low Mountains.

*Only one percent of the High Mountain cut slopes exhibited no failures. The other environments were 10 to 15% without failures.

Lithology

Although detailed lithologic data was gathered, it was decided to analyze the data on only the four major categories of Igneous Intrusive, Igneous Extrusive, Metamorphic, and Sedimentary. The data for this analysis is contained in Tables 28 through 34.

TABLE 28

LITHOLOGY VS CUT SLOPE ANGLE

| | Cut Slope Angle | | | | |
|---|---|---|---|---|---|
| Lithology | ≥1/2:1 | 3/4:1 | 1:1 | 1 1/2:1 | ≤2:1 |
| Igneous Intrusive | 36 | 26 | 17 | 8 | 2 |
| Igneous Extrusive | 8 | 7 | 23 | 10 | 0 |
| Metamorphic | 8 | 10 | 15 | 6 | 0 |
| Sedimentary | 9 | 19 | 32 | 25 | 15 |



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TABLE 29

LITHOLOGY VS CUT SLOPE HEIGHT

| Lithology | Cut Slope Height | | | |
|---|---|---|---|---|
| | <40 | 40-80 | 81-120 | >120 |
| Igneous Intrusive | 14 | 40 | 25 | 10 |
| Igneous Extrusive | 11 | 26 | 7 | 4 |
| Metamorphic | 1 | 14 | 7 | 17 |
| Sedimentary | 6 | 41 | 13 | 40 |

TABLE 30

LITHOLOGY VS CUT TYPE

| Lithology | Cut Type | |
|---|---|---|
| | Through | Sidehill |
| Igneous Intrusive | 36 | 53 |
| Igneous Extrusive | 27 | 21 |
| Metamorphic | 17 | 22 |
| Sedimentary | 32 | 68 |

TABLE 31

LITHOLOGY VS NO. OF BENCHES

| Lithology | No. of Benches | | |
|---|---|---|---|
| | ≤2 | ≥3 | 0 |
| Igneous Intrusive | 17 | 3 | 69 |
| Igneous Extrusive | 7 | 0 | 41 |
| Metamorphic | 14 | 11 | 14 |
| Sedimentary | 28 | 11 | 61 |



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TABLE 32

LITHOLOGY VS BENCH HEIGHT

| Lithology | Bench Height ≤49 | Bench Height ≥50 |
|---|---|---|
| Igneous Intrusive | 11 | 9 |
| Igneous Extrusive | 4 | 3 |
| Metamorphic | 18 | 7 |
| Sedimentary | 18 | 21 |

TABLE 33

LITHOLOGY VS FAILURES

| Lithology | Failures: Erosion | Ravelling | Rockfall | Surface Slides | Deep Slides | Other | None |
|---|---|---|---|---|---|---|---|
| Igneous Intrusive | 24 | 33 | 32 | 18 | 0 | 12 | 7 |
| Igneous Extrusive | 7 | 19 | 28 | 3 | 0 | 9 | 1 |
| Metamorphic | 2 | 21 | 4 | 12 | 1 | 5 | 3 |
| Sedimentary | 30 | 52 | 14 | 15 | 2 | 7 | 9 |

TABLE 34

LITHOLOGY VS PERFORMANCE

| Lithology | Performance: Very Good | Good | Marginal | Unsatisfactory |
|---|---|---|---|---|
| Igneous Intrusive | 20 | 35 | 17 | 17 |
| Igneous Extrusive | 12 | 27 | 5 | 4 |
| Metamorphic | 3 | 23 | 8 | 5 |
| Sedimentary | 25 | 49 | 17 | 9 |



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*Most cut slopes in Igneous Intrusive rocks are 3/4:1 or steeper. Most cut slopes in Igneous Extrusive and Metamorphic rocks are 1:1 or steeper. Cuts in Sedimentary rock are found at all angles included in this study. Nearly all 2:1 or flatter slopes were encountered in Sedimentary rocks.

An unusually high percentage of Igneous Extrusive rocks are through cuts, and an unusually high percentage of cuts in Sedimentary rocks are sidehill cuts.

An extremely high percentage of cuts in Igneous Extrusive rocks are unbenched. An unusually high percentage of cuts in Metamorphic rocks are benched, and the vertical spacing between benches is primarily less than 50 feet.

*Cuts in Igneous Extrusive rocks exhibit the lowest percentage without some Failures. Sedimentary and Igneous Intrusive rocks are more erodible than the Metamorphic and Igneous Extrusive. Most of the Failures other than erosion for all types of rock are Ravelling and Rockfall.

*Sedimentary and Igneous Intrusive rocks were encountered in 75% of the cuts judged unsatisfactory. This observation may be related to the one above.

Seismic Refraction Data

In developing this project, a knowledge of seismic velocities was included because it was desired to determine if more effective design of cut slopes could be obtained when seismic velocities were used. Insufficient data was gathered to make such a determination. The bulk of the seismic data was obtained in Igneous Intrusive rocks, and additional analysis of this data is contained in Appendix C. Data for this analysis is contained in Tables 35 through 41.

TABLE 35

SEISMIC REFRACTION DATA VS CUT SLOPE ANGLE

| | Cut Slope Angle | | | | |
|---|---|---|---|---|---|
| Seismic Data | ≥1/2:1 | 3/4:1 | 1:1 | 1 1/2:1 | ≤2:1 |
| Yes | 12 | 12 | 6 | 7 | 1 |
| No | 49 | 50 | 81 | 42 | 16 |



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TABLE 36

SEISMIC REFRACTION DATA VS CUT SLOPE HEIGHT

| | Cut Slope Height | | | |
|---|---|---|---|---|
| Seismic Data | <40 | 40-80 | 81-120 | >120 |
| Yes | 8 | 20 | 6 | 4 |
| No | 24 | 101 | 46 | 67 |

TABLE 37

SEISMIC REFRACTION DATA VS CUT TYPE

| | Cut Type | |
|---|---|---|
| Seismic Data | Through | Sidehill |
| Yes | 12 | 26 |
| No | 100 | 138 |

TABLE 38

SEISMIC REFRACTION DATA VS NO. OF BENCHES

| | No. of Benches | | |
|---|---|---|---|
| Seismic Data | ≤2 | ≥3 | 0 |
| Yes | 7 | 2 | 29 |
| No | 59 | 23 | 156 |



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TABLE 39

SEISMIC REFRACTION DATA VS BENCH HEIGHT

| | Bench Height | |
|---|---|---|
| Seismic Data | ≤49 | ≥50 |
| Yes | 3 | 6 |
| No | 48 | 34 |

TABLE 40

SEISMIC REFRACTION DATA VS FAILURES

| | Failures | | | | | | |
|---|---|---|---|---|---|---|---|
| Seismic Data | Erosion | Ravelling | Rockfall | Surface Slide | Deep Slide | Other | None |
| Yes | 20 | 17 | 3 | 8 | 1 | 3 | 3 |
| No | 43 | 108 | 75 | 40 | 2 | 30 | 17 |

TABLE 41

SEISMIC REFRACTION DATA VS PERFORMANCE

| | Performance | | | |
|---|---|---|---|---|
| Seismic Data | Very Good | Good | Marginal | Unsatisfactory |
| Yes | 8 | 14 | 12 | 4 |
| No | 53 | 119 | 35 | 31 |



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*A higher percentage of cut slopes are 3/4:1 or steeper when designed using seismic velocities than when designed without them.

*Those cuts designed without seismic data exhibited substantially higher percentages of every type of Failure included in this study. At the same time these cuts were judged to have performed better than the cuts designed with seismic data.

Geologic Structure

Joints, Faults, and Foliations or the lack of any of these was investigated to determine their relationship to cut slope design. Tables 42 through 48 present the data used in determining these relationships.

TABLE 42

GEOLOGIC STRUCTURE VS CUT SLOPE ANGLE

| | Cut Slope Angle | | | | |
|---|---|---|---|---|---|
| Geologic Structure | ≥1/2:1 | 3/4:1 | 1:1 | 1 1/2:1 | ≤2:1 |
| Joints | 56 | 40 | 36 | 12 | 1 |
| Faults | 30 | 25 | 18 | 5 | 0 |
| Foliations | 12 | 18 | 14 | 6 | 0 |
| None | 3 | 19 | 38 | 34 | 16 |

TABLE 43

GEOLOGIC STRUCTURE VS CUT SLOPE HEIGHT

| | Cut Slope Height | | | |
|---|---|---|---|---|
| Geologic Structure | <40 | 40-80 | 81-120 | >120 |
| Joints | 17 | 64 | 34 | 30 |
| Faults | 9 | 23 | 22 | 24 |
| Foliations | 1 | 15 | 17 | 17 |
| None | 13 | 47 | 14 | 36 |



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TABLE 44

GEOLOGIC STRUCTURE VS CUT TYPE

| | Cut Type | |
|---|---|---|
| Geologic Structure | Through | Sidehill |
| Joints | 53 | 92 |
| Faults | 29 | 49 |
| Foliations | 19 | 31 |
| None | 47 | 63 |

TABLE 45

GEOLOGIC STRUCTURE VS NO. OF BENCHES

| | No. of Benches | | |
|---|---|---|---|
| Geologic Structure | ≤2 | ≥3 | 0 |
| Joints | 31 | 16 | 98 |
| Faults | 18 | 15 | 45 |
| Foliations | 19 | 11 | 20 |
| None | 30 | 8 | 72 |

TABLE 46

GEOLOGIC STRUCTURE VS BENCH HEIGHT

| | Bench Height | |
|---|---|---|
| Geologic Structure | ≤49 | ≥50 |
| Joints | 27 | 20 |
| Faults | 20 | 13 |
| Foliations | 24 | 6 |
| None | 21 | 17 |



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TABLE 47

GEOLOGIC STRUCTURE VS FAILURES

| Geologic Structure | Failures | | | | | | |
|---|---|---|---|---|---|---|---|
| | Erosion | Ravelling | Rockfall | Surface Slides | Deep Slides | Others | None |
| Joints | 15 | 67 | 53 | 25 | 2 | 11 | 12 |
| Faults | 8 | 38 | 23 | 20 | 1 | 6 | 8 |
| Foliations | 4 | 26 | 7 | 12 | 1 | 4 | 5 |
| None | 45 | 47 | 20 | 19 | 0 | 19 | 5 |

TABLE 48

GEOLOGIC STRUCTURE VS PERFORMANCE

| Geologic Structure | Performance | | | |
|---|---|---|---|---|
| | Very Good | Good | Marginal | Unsatisfactory |
| Joints | 26 | 78 | 22 | 19 |
| Faults | 8 | 40 | 18 | 12 |
| Foliations | 9 | 25 | 9 | 7 |
| None | 30 | 46 | 21 | 13 |



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It appears that the absence of structural features is related to the flatter cut slopes, and conversely steeper cut slopes are found in those cuts exhibiting the geologic features. This is probably due to the fact that the materials requiring a flat slope for stability are too weathered to permit observations of geologic structure, while the less weathered rock which will stand at the steep angles will permit observation of structure.

The above explanation also accounts for the observation that the absence of structure is related to the occurrence of Erosion, while Rockfall occurs in those cuts with Geologic Structure.

*The presence of Faults in the cut slope material appears to correlate with poorer performance evaluations.

Natural Slope Data

The angle and height of natural slopes in the area of each cut was recorded to evaluate their relationship to cut slope design.

The Natural Slope Angle was originally divided into two groups, less than 45° and 45° or greater. For purposes of analysis, these groups were changed to less than 32° and 32° or greater, because of an apparent gap in the distribution of natural slope angles.

The Natural Slope Height was arbitrarily divided into two groups less than 100 feet and 100 feet or greater. These groups were used to complete the analysis.

Tables 49 through 55 contain the data used in this analysis.

TABLE 49

NATURAL SLOPE DATA VS CUT SLOPE ANGLE

| | Cut Slope Angle | | | | |
|---|---|---|---|---|---|
| Natural Slope Angle | ≥1/2:1 | 3/4:1 | 1:1 | 1 1/2:1 | ≤2:1 |
| <32 | 17 | 26 | 51 | 40 | 15 |
| ≥32 | 39 | 34 | 35 | 9 | 1 |
| None | 5 | 2 | 1 | 0 | 1 |
| Natural Slope Height | | | | | |
| <100 | 14 | 17 | 30 | 10 | 5 |
| ≥100 | 42 | 43 | 56 | 39 | 11 |
| None | 5 | 2 | 1 | 0 | 1 |



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TABLE 50

NATURAL SLOPE DATA VS CUT SLOPE HEIGHT

| | Cut Slope Height | | | |
|---|---|---|---|---|
| Natural Slope Angle | < 40 | 40-80 | 81-120 | > 120 |
| < 32 | 18 | 68 | 25 | 38 |
| ≥ 32 | 10 | 48 | 27 | 33 |
| None | 4 | 5 | 0 | 0 |
| **Natural Slope Height** | | | | |
| < 100 | 20 | 49 | 3 | 4 |
| ≥ 100 | 8 | 67 | 49 | 67 |
| None | 4 | 5 | 0 | 0 |

TABLE 51

NATURAL SLOPE DATA VS CUT TYPE

| | Cut Type | |
|---|---|---|
| Natural Slope Angle | Through | Sidehill |
| <32 | 75 | 74 |
| ≥32 | 33 | 85 |
| None | 4 | 5 |
| **Natural Slope Height** | | |
| <100 | 39 | 37 |
| ≥100 | 69 | 122 |
| None | 4 | 5 |



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TABLE 52

NATURAL SLOPE DATA VS NO. OF BENCHES

| | No. of Benches | | |
|---|---|---|---|
| Natural Slope Angle | ≤2 | ≥3 | 0 |
| <32 | 30 | 11 | 108 |
| ≥32 | 35 | 14 | 69 |
| None | 1 | 0 | 8 |
| **Natural Slope Height** | | | |
| <100 | 9 | 2 | 65 |
| ≥100 | 56 | 23 | 112 |
| None | 1 | 0 | 8 |

TABLE 53

NATURAL SLOPE DATA VS BENCH HEIGHT

| | Bench Height | |
|---|---|---|
| Natural Slope Angle | ≤49 | ≥50 |
| <32 | 23 | 18 |
| ≥32 | 27 | 22 |
| None | 1 | 0 |
| **Natural Slope Height** | | |
| <100 | 9 | 2 |
| ≥100 | 41 | 38 |
| None | 1 | 0 |



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TABLE 54

NATURAL SLOPE DATA VS FAILURES

| | Failures | | | | | | |
|---|---|---|---|---|---|---|---|
| Natural Slope Angle | Erosion | Ravelling | Rockfall | Surface Slides | Deep Slides | Other | None |
| <32 | 40 | 64 | 42 | 28 | 1 | 25 | 10 |
| ≥32 | 21 | 59 | 33 | 20 | 2 | 8 | 8 |
| None | 2 | 2 | 3 | 0 | 0 | 0 | 2 |
| **Natural Slope Height** | | | | | | | |
| <100 | 22 | 34 | 24 | 4 | 1 | 13 | 5 |
| ≥100 | 39 | 89 | 51 | 44 | 2 | 20 | 13 |
| None | 2 | 2 | 3 | 0 | 0 | 0 | 2 |

TABLE 55

NATURAL SLOPE DATA VS PERFORMANCE

| | Performance | | | |
|---|---|---|---|---|
| Natural Slope Angle | Very Good | Good | Marginal | Unsatisfactory |
| <32 | 42 | 66 | 25 | 16 |
| ≥32 | 15 | 64 | 22 | 17 |
| None | 4 | 3 | 0 | 2 |
| **Natural Slope Height** | | | | |
| <100 | 20 | 42 | 9 | 5 |
| ≥100 | 37 | 88 | 38 | 28 |
| None | 4 | 3 | 0 | 2 |



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*Although Natural Slope Height showed no relationship with cut slope angle, the Natural Slope Angle did. The flatter cut slopes were in areas of flatter natural slopes, and the steeper cut slopes were in areas of steeper natural slopes.

Groundwater

The presence or absence of water in a hill is definitely a factor in determining stability. In this study, an attempt was made to identify this relationship by indicating the presence of water. The categories used are Unknown, Springs and Seeps, Fracture Water and Water Table. The data collected for this analysis is presented in Tables 56 through 62. The category titled Unknown refers only to Water Table.

TABLE 56

GROUNDWATER VS CUT SLOPE ANGLE

| | Cut Slope Angle | | | | |
|---|---|---|---|---|---|
| Groundwater | ≥1/2:1 | 3/4:1 | 1:1 | 1 1/2:1 | ≤2:1 |
| Unknown | 59 | 50 | 83 | 48 | 17 |
| Springs & Seeps | 10 | 9 | 18 | 9 | 4 |
| Fracture Water | 5 | 2 | 4 | 0 | 0 |
| Water Table | 2 | 12 | 4 | 1 | 0 |

TABLE 57

GROUNDWATER VS CUT SLOPE HEIGHT

| | Cut Slope Height | | | |
|---|---|---|---|---|
| Groundwater | <40 | 40-80 | 81-120 | >120 |
| Unknown | 32 | 117 | 48 | 60 |
| Springs & Seeps | 4 | 20 | 9 | 17 |
| Fracture Water | 2 | 4 | 0 | 5 |
| Water Table | 0 | 4 | 4 | 11 |



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TABLE 58

GROUNDWATER VS CUT TYPE

| | Cut Type | |
|---|---|---|
| Groundwater | Through | Sidehill |
| Unknown | 103 | 154 |
| Springs & Seeps | 17 | 33 |
| Fracture Water | 4 | 7 |
| Water Table | 9 | 10 |

TABLE 59

GROUNDWATER VS NO. OF BENCHES

| | No. of Benches | | |
|---|---|---|---|
| Groundwater | ≤2 | ≥3 | 0 |
| Unknown | 60 | 19 | 178 |
| Springs & Seeps | 11 | 6 | 33 |
| Fracture Water | 3 | 2 | 6 |
| Water Table | 6 | 6 | 7 |

TABLE 60

GROUNDWATER VS BENCH HEIGHT

| | Bench Height | |
|---|---|---|
| Groundwater | ≤49 | ≥50 |
| Unknown | 40 | 39 |
| Springs & Seeps | 10 | 7 |
| Fracture Water | 1 | 4 |
| Water Table | 11 | 1 |



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TABLE 61

GROUNDWATER VS FAILURES

| | Failures | | | | | | |
|---|---|---|---|---|---|---|---|
| Groundwater | Erosion | Ravelling | Rockfall | Surface Slide | Deep Slide | Other | None |
| Unknown | 62 | 110 | 77 | 42 | 3 | 33 | 20 |
| Springs & Seeps | 10 | 17 | 15 | 12 | 2 | 7 | 4 |
| Fracture Water | 2 | 5 | 2 | 2 | 0 | 0 | 1 |
| Water Table | 1 | 15 | 1 | 6 | 0 | 0 | 0 |

TABLE 62

GROUNDWATER VS PERFORMANCE

| | Performance | | | |
|---|---|---|---|---|
| Groundwater | Very Good | Good | Marginal | Unsatisfactory |
| Unknown | 60 | 120 | 43 | 34 |
| Springs & Seeps | 9 | 26 | 6 | 9 |
| Fracture Water | 2 | 7 | 2 | 0 |
| Water Table | 1 | 13 | 4 | 1 |



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It was difficult to obtain information on groundwater and only a few cut slopes are included in this portion of the study. Fracture Water and Water Table data is especially limited. The following observations are definitely limited by this factor.

*Fracture Water was observed only in 1:1 and steeper slopes, probably because the steep slopes are constructed in rock, a material which can be and usually is fractured. Springs and seeps were observed in all cut slope angles, while Water Tables were found mostly in the steep cut slopes.

Water Table data was available in the higher cuts. Water Table data was also found to correspond to an unusually high use of benching in cut slope design.

*Those cut slopes in which Fracture Water was detected appear to have received better performance evaluations.

Clay

Because the presence of clay is a factor in stability, its presence was included in the study. Any clearly identifiable clay mineral whether in the rock mass or in seams, fractures or faults was included. No tests were performed on most of these clays so they cannot be identified as to type. Tables 63 through 69 contain the data used in this analysis.

TABLE 63

CLAY VS CUT SLOPE ANGLE

| | Cut Slope Angle | | | | |
|---|---|---|---|---|---|
| Clay | ≥1/2:1 | 3/4:1 | 1:1 | 1 1/2:1 | ≤2:1 |
| Yes | 25 | 33 | 61 | 36 | 12 |
| No | 36 | 29 | 26 | 13 | 5 |



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TABLE 64

CLAY VS CUT SLOPE HEIGHT

| | Cut Slope Height | | | |
|---|---|---|---|---|
| Clay | <40 | 40-80 | 81-120 | >120 |
| Yes | 19 | 78 | 31 | 39 |
| No | 13 | 43 | 21 | 32 |

TABLE 65

CLAY VS CUT TYPE

| | Cut Type | |
|---|---|---|
| Clay | Through | Sidehill |
| Yes | 71 | 96 |
| No | 41 | 68 |

TABLE 66

CLAY VS NO. OF BENCHES

| | No. of Benches | | |
|---|---|---|---|
| Clay | ≤2 | ≥3 | 0 |
| Yes | 37 | 11 | 119 |
| No | 29 | 14 | 66 |



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TABLE 67

CLAY VS. BENCH HEIGHT

| Clay | Bench Height ≤49 | Bench Height ≥50 |
|---|---|---|
| Yes | 28 | 20 |
| No | 23 | 20 |

TABLE 68

CLAY VS FAILURES

| Clay | Failures: Erosion | Ravelling | Rockfall | Surface Slide | Deep Slide | Other | None |
|---|---|---|---|---|---|---|---|
| Yes | 49 | 76 | 45 | 31 | 0 | 30 | 9 |
| No | 14 | 49 | 33 | 17 | 3 | 3 | 11 |

TABLE 69

CLAY VS PERFORMANCE

| Clay | Performance: Very Good | Good | Marginal | Unsatisfactory |
|---|---|---|---|---|
| Yes | 48 | 73 | 29 | 17 |
| No | 13 | 60 | 18 | 18 |



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The study of disintegrated granitic rocks reported in Appendix C includes some information on the presence of clay.

*Clay was found more often in the flatter cut slopes and less often in the steeper slopes. This information proved useful in designing slopes in disintegrated granitic rocks. Perhaps this relationship exists for other rock types.

Weathering

Weathering is a geologic term which includes a number of variables such as type of material, climate, and water. The categories used for this analysis are Fresh, Slightly Weathered, Moderately Weathered, Weathered and Very Weathered. The data for this analysis is presented in Tables 70 through 76.

The weathering category titles are common geologic terms and their application was left to the discretion of the inspecting geologist. Some variations are certain to exist and in future studies, a single inspector should be used or precise objective definitions should be developed.

TABLE 70

WEATHERING VS CUT SLOPE ANGLE

| | Cut Slope Angle | | | | |
|---|---|---|---|---|---|
| Weathering | ≥1/2:1 | 3/4:1 | 1:1 | 1 1/2:1 | ≤2:1 |
| Fresh | 9 | 11 | 6 | 1 | 1 |
| Slightly Weathered | 24 | 10 | 10 | 7 | 2 |
| Moderately Weathered | 21 | 30 | 50 | 34 | 12 |
| Weathered | 22 | 18 | 31 | 12 | 2 |
| Very Weathered | 21 | 23 | 24 | 13 | 2 |

TABLE 71

WEATHERING VS CUT SLOPE HEIGHT

| | Cut Slope Height | | | |
|---|---|---|---|---|
| Weathering | <40 | 40-80 | 81-120 | >120 |
| Fresh | 6 | 11 | 8 | 3 |
| Slightly Weathered | 7 | 18 | 11 | 17 |
| Moderately Weathered | 13 | 54 | 34 | 46 |
| Weathered | 12 | 40 | 14 | 19 |
| Very Weathered | 9 | 39 | 17 | 18 |



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TABLE 72

WEATHERING VS CUT TYPE

| Weathering | Cut Type | |
|---|---|---|
| | Through | Sidehill |
| Fresh | 12 | 16 |
| Slightly Weathered | 23 | 30 |
| Moderately Weathered | 66 | 81 |
| Weathered | 36 | 49 |
| Very Weathered | 30 | 53 |

TABLE 73

WEATHERING VS NO. OF BENCHES

| Weathering | No. of Benches | | |
|---|---|---|---|
| | ≤2 | ≥3 | 0 |
| Fresh | 5 | 2 | 21 |
| Slightly Weathered | 9 | 6 | 38 |
| Moderately Weathered | 38 | 17 | 92 |
| Weathered | 18 | 11 | 56 |
| Very Weathered | 24 | 12 | 47 |

TABLE 74

WEATHERING VS BENCH HEIGHT

| Weathering | Bench Height | |
|---|---|---|
| | ≤49 | ≥50 |
| Fresh | 1 | 6 |
| Slightly Weathered | 4 | 11 |
| Moderately Weathered | 29 | 26 |
| Weathered | 18 | 11 |
| Very Weathered | 28 | 8 |



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TABLE 75

WEATHERING VS FAILURES

| | Failures | | | | | | |
|---|---|---|---|---|---|---|---|
| Weathering | Erosion | Ravelling | Rockfall | Surface Slide | Deep Slide | Other | None |
| Fresh | 2 | 9 | 17 | 4 | 0 | 2 | 2 |
| Slightly Weathered | 7 | 19 | 29 | 9 | 1 | 2 | 4 |
| Moderately Weathered | 32 | 68 | 46 | 20 | 0 | 17 | 12 |
| Weathered | 18 | 39 | 20 | 21 | 3 | 14 | 4 |
| Very Weathered | 26 | 40 | 8 | 24 | 1 | 12 | 5 |

TABLE 76

WEATHERING VS PERFORMANCE

| | Performance | | | |
|---|---|---|---|---|
| Weathering | Very Good | Good | Marginal | Unsatisfactory |
| Fresh | 2 | 12 | 10 | 4 |
| Slightly Weathered | 3 | 31 | 8 | 11 |
| Moderately Weathered | 39 | 73 | 18 | 17 |
| Weathered | 12 | 43 | 13 | 17 |
| Very Weathered | 14 | 40 | 17 | 12 |



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One problem with this analysis is the impossibility of applying a single word describing weathering to all materials exposed in the cut face. Obviously the soil layer is more weathered than the material in the heart of the cut. These comparisons do not offer results of sufficient meaning to justify further research at this time.

Erosion and Ravelling are characteristic of the more weathered materials. This was anticipated.

## DESCRIPTORS

Comparisons between certain cut slope descriptors were made in an attempt to define interrelationships that might affect cut slope design. These comparisons are described below.

### Cut Slope Angle

The Cut Slope Angles were divided into five groups: 1/2:1 and steeper; 3/4:1, 1:1; 1 1/2:1; and 2:1 and flatter. Tables 77 through 83 summarize the data used in these comparisons.

TABLE 77

CUT SLOPE ANGLE VS CUT SLOPE HEIGHT

| | Cut Slope Height | | | |
|---|---|---|---|---|
| Cut Slope Angle | <40 | 40-80 | 81-120 | >120 |
| ≥1/2:1 | 11 | 30 | 15 | 5 |
| 3/4:1 | 5 | 21 | 19 | 17 |
| 1:1 | 7 | 52 | 10 | 18 |
| 1 1/2:1 | 6 | 13 | 6 | 24 |
| ≤2:1 | 3 | 5 | 2 | 7 |

TABLE 78

CUT SLOPE ANGLE VS CUT TYPE

| | Cut Type | |
|---|---|---|
| Cut Slope Angle | Through | Sidehill |
| ≥1/2:1 | 15 | 46 |
| 3/4:1 | 27 | 35 |
| 1:1 | 45 | 42 |
| 1 1/2:1 | 18 | 31 |
| ≤2:1 | 7 | 10 |



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TABLE 79

CUT SLOPE ANGLE VS NO. OF BENCHES

| | No. of Benches | | |
|---|---|---|---|
| Cut Slope Angle | ≤2 | ≥3 | 0 |
| ≥1/2:1 | 12 | 3 | 46 |
| 3/4:1 | 20 | 6 | 36 |
| 1:1 | 21 | 8 | 58 |
| 1 1/2:1 | 12 | 8 | 29 |
| ≤2:1 | 1 | 0 | 16 |

TABLE 80

CUT SLOPE ANGLE VS BENCH HEIGHT

| | Bench Height | |
|---|---|---|
| Cut Slope Angle | ≤49 | ≥50 |
| ≥1/2:1 | 9 | 6 |
| 3/4:1 | 15 | 11 |
| 1:1 | 19 | 10 |
| 1 1/2:1 | 8 | 12 |
| ≤2:1 | 0 | 1 |

TABLE 81

CUT SLOPE ANGLE VS FAILURES

| | Failures | | | | | | |
|---|---|---|---|---|---|---|---|
| Cut Slope Angle | Erosion | Ravelling | Rockfall | Surface Slide | Deep Slide | Other | None |
| ≥1/2:1 | 6 | 27 | 22 | 11 | 0 | 4 | 4 |
| 3/4:1 | 8 | 37 | 18 | 6 | 1 | 6 | 3 |
| 1:1 | 15 | 44 | 30 | 14 | 1 | 16 | 4 |
| 1 1/2:1 | 27 | 14 | 8 | 13 | 1 | 7 | 4 |
| ≤2:1 | 7 | 3 | 0 | 4 | 0 | 0 | 5 |



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TABLE 82

CUT SLOPE ANGLE VS PERFORMANCE

| | Performance | | | |
|---|---|---|---|---|
| Cut Slope Angle | Very Good | Good | Marginal | Unsatisfactory |
| ≥1/2:1 | 15 | 22 | 10 | 14 |
| 3/4:1 | 11 | 30 | 17 | 4 |
| 1:1 | 13 | 56 | 9 | 9 |
| 1 1/2:1 | 15 | 20 | 10 | 4 |
| ≤2:1 | 7 | 5 | 1 | 4 |

TABLE 83

CUT SLOPE ANGLE VS CUT SLOPE AGE

| | Cut Slope Age | | |
|---|---|---|---|
| Cut Slope Angle | <5 | 5-15 | >15 |
| ≥1/2:1 | 20 | 17 | 24 |
| 3/4:1 | 20 | 13 | 29 |
| 1:1 | 24 | 32 | 31 |
| 1 1/2:1 | 17 | 24 | 8 |
| ≤2:1 | 12 | 5 | 0 |



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Generally, the steep slopes are lower in height, are sidehill cuts, and are unbenched.

*Generally, the failure groups defined in this study are most apparent in the 1:1 and the 1 1/2:1 cut slopes. It appears that these intermediate cut slope angles are more problem prone than the others. Especially significant is the high percentage of 1 1/2:1 cut slopes that exhibit erosion. A detailed analysis of the relationship between cut slope angle and erosion is strongly recommended.

The very steep and the very flat Cut Slope Angles are disproportionately high in the unsatisfactory performance category. Apparently, the use of extreme Cut Slope Angles occurs only under abnormal conditions that decrease the chance of successful cut slope performance.

It was observed that there is a general trend in Cut Slope Angle versus Cut Slope Age. The oldest cut slopes are the steepest. This may reflect a long term shift in cut slope design philosophy.

Cut Slope Height

Cut slope heights were divided into four arbitrary categories: less than 40 feet; 40 to 80 feet; 81 to 120 feet; and greater than 120 feet. Tables 84 through 89 contain the data used for this analysis.

TABLE 84

CUT SLOPE HEIGHT VS CUT TYPE

| | Cut Type | |
|---|---|---|
| Cut Slope Height | Through | Sidehill |
| <40 | 17 | 15 |
| 40-80 | 52 | 69 |
| 81-120 | 20 | 32 |
| >120 | 23 | 48 |



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TABLE 85

CUT SLOPE HEIGHT VS NO. OF BENCHES

| Cut Slope Height | No. of Benches ≤2 | ≥3 | 0 |
|---|---|---|---|
| ≤40 | 1 | 0 | 31 |
| 40-80 | 19 | 0 | 102 |
| 81-120 | 20 | 2 | 30 |
| >120 | 26 | 23 | 22 |

TABLE 86

CUT SLOPE HEIGHT VS BENCH HEIGHT

| Cut Slope Height | Bench Height ≤49 | ≥50 |
|---|---|---|
| <40 | 1 | 0 |
| 40-80 | 15 | 4 |
| 81-120 | 15 | 7 |
| >120 | 20 | 29 |



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TABLE 87

CUT SLOPE HEIGHT VS FAILURES

| | Failures | | | | | | |
|---|---|---|---|---|---|---|---|
| Cut Slope Height | Erosion | Ravelling | Rockfall | Surface Slide | Deep Slide | Other | None |
| <40 | 12 | 5 | 12 | 2 | 0 | 3 | 6 |
| 40-80 | 27 | 64 | 38 | 13 | 2 | 16 | 5 |
| 81-120 | 7 | 24 | 21 | 14 | 0 | 7 | 1 |
| >120 | 17 | 32 | 7 | 19 | 1 | 7 | 8 |

TABLE 88

CUT SLOPE HEIGHT VS PERFORMANCE

| | Performance | | | |
|---|---|---|---|---|
| Cut Slope Height | Very Good | Good | Marginal | Unsatisfactory |
| <40 | 6 | 19 | 4 | 3 |
| 40-80 | 28 | 59 | 20 | 14 |
| 81-120 | 11 | 18 | 10 | 13 |
| >120 | 16 | 37 | 13 | 5 |

TABLE 89

CUT SLOPE HEIGHT VS CUT SLOPE AGE

| | Cut Slope Age | | |
|---|---|---|---|
| Cut Slope Height | <5 | 5-15 | >15 |
| <40 | 6 | 12 | 14 |
| 40-80 | 33 | 38 | 50 |
| 81-120 | 19 | 16 | 17 |
| >120 | 35 | 25 | 11 |



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*An unusually high percentage of the higher cut slopes are benched and the larger bench spacings were used.

*The 81-120 ft. height cut slopes were judged to have unsatisfactory performance a disproportionate percentage of the time.

*In line with previous observations, it was found that the oldest cut slopes were low while the youngest cut slopes were high. A historical trend such as this, should be evaluated to determine its cause and to assure the necessity of the change.

Cut Type

Two types of cuts, through and sidehill, were investigated in this study. Tables 90 and 91 present the data for these analyses.

TABLE 90

CUT TYPE VS PERFORMANCE

| | Performance | | | |
|---|---|---|---|---|
| Cut Type | Very Good | Good | Marginal | Unsatisfactory |
| Through | 26 | 54 | 15 | 17 |
| Sidehill | 35 | 79 | 32 | 18 |

TABLE 91

CUT TYPE VS CUT SLOPE AGE

| | Cut Slope Age | | |
|---|---|---|---|
| Cut Type | <5 | 5-15 | >15 |
| Through | 34 | 47 | 31 |
| Sidehill | 59 | 44 | 61 |



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A disproportionately high percentage of sidehill cuts received marginal performance evaluations. Also a disproportionately low percentage of sidehill cuts were found to be of intermediate age.

Benches

In order to analyze bench data, the cut slopes were divided into groups as follows:

No Benches
Two or One Bench
Three or more Benches

A further division was made by difference in elevation between benches as follows:

Less than 50 Feet
50 Feet or Greater

All of these divisions were arbitrary and made in advance of the data collection. It is possible that other groupings would be more significant. Tables 92 through 95 present the data for these analyses.

TABLE 92

NO. OF BENCHES VS PERFORMANCE

| | Performance | | | |
|---|---|---|---|---|
| No of Benches | Very Good | Good | Marginal | Unsatisfactory |
| $\leq 2$ | 16 | 29 | 10 | 11 |
| $\geq 3$ | 5 | 14 | 3 | 3 |
| 0 | 40 | 90 | 34 | 21 |



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TABLE 93

NO. OF BENCHES VS CUT SLOPE AGE

| No. of Benches | Cut Slope Age <5 | 5-15 | >15 |
|---|---|---|---|
| ≤2 | 34 | 24 | 8 |
| ≥3 | 13 | 11 | 1 |
| 0 | 46 | 56 | 83 |

TABLE 94

BENCH HEIGHT VS PERFORMANCE

| Bench Height | Performance Very Good | Good | Marginal | Unsatisfactory |
|---|---|---|---|---|
| ≤49 | 13 | 29 | 1 | 8 |
| ≥50 | 8 | 14 | 12 | 6 |

TABLE 95

BENCH HEIGHT VS CUT SLOPE AGE

| Bench Height | Cut Slope Age <5 | 5-15 | >15 |
|---|---|---|---|
| ≤49 | 31 | 18 | 2 |
| ≥50 | 16 | 17 | 7 |



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*The use of benches is most common on the younger cuts. This is a reflection of trends in design philosophy. Analysis of the benefits derived from such trends is strongly recommended.

*Marginal performance evaluations were received by a disproportionately high percentage of cuts with higher differences in bench elevations.

*Trends in bench spacings with age were also detected.

Failures

The categories of Failures included in this study are: Erosion, Ravelling, Rockfall, Surface Slides, Deep Slides, Other and None. Tables 96 and 97 present the data for the following analyses.

TABLE 96

FAILURES VS PERFORMANCE

| | Performance | | | |
|---|---|---|---|---|
| Failures | Very Good | Good | Marginal | Unsatisfactory |
| Erosion | 14 | 29 | 12 | 8 |
| Ravelling | 30 | 71 | 19 | 5 |
| Rockfall | 9 | 39 | 13 | 17 |
| Surface Slide | 3 | 17 | 14 | 14 |
| Deep Slide | 0 | 0 | 1 | 2 |
| Other | 5 | 11 | 12 | 5 |
| None | 12 | 8 | 0 | 0 |

TABLE 97

FAILURES VS CUT SLOPE AGE

| | Cut Slope Age | | |
|---|---|---|---|
| Failures | <5 | 5-15 | >15 |
| Erosion | 16 | 26 | 21 |
| Ravelling | 41 | 39 | 45 |
| Rockfall | 23 | 25 | 30 |
| Surface Slide | 22 | 18 | 8 |
| Deep Slide | 0 | 2 | 1 |
| Other | 2 | 8 | 23 |
| None | 9 | 7 | 4 |



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*Rockfall and Surface Slides are the predominant failures on Unsatisfactory cut slopes. Ravelling is primarily found on slopes classified as Good and Very Good in performance. The focusing of one or two types of problems on cuts with a given performance is recommended for further investigation.

*Surface Slides appear to be concentrated on young cut slopes while "Others" appear to occur on old slopes.

Performance

Four categories of performance were used in this study: Very Good, Good, Marginal, and Unsatisfactory. These groupings are arbitrary and not clearly defined. Different people made the evaluations and differing evaluations undoubtedly occurred as a result. Table 98 contains the data used in this comparison.

TABLE 98

PERFORMANCE VS CUT SLOPE AGE

| | Cut Slope Age | | |
|---|---|---|---|
| Performance | <5 | 5-15 | >15 |
| Very Good | 23 | 19 | 19 |
| Good | 36 | 55 | 42 |
| Marginal | 16 | 9 | 22 |
| Unsatisfactory | 18 | 8 | 9 |



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*Most unsatisfactory cuts were young. This suggests current design practice should be investigated to assure its adequacy.

With the exception of Unsatisfactory, the anticipated trend of decreasing performance with increasing age was observed.

Geometric Relationships

The relationships between planar features of the geologic structure and the orientation of the cut slope were determined. The features included in this study were attitudes, joints, foliations and faults. The relationships were determined and grouped as shown in Table 99. These groupings were arbitrarily selected but were based in part on past experience and some theory from rock mechanics. Each of the groupings was then compared to some other factors to detect potentially useful relationships.

Tables 99 through 103 contain the data used in this study.

TABLE 99

ANGLE BETWEEN ℄ AND STRIKE OF STRUCTURE

VS

APPARENT DIP OF STRUCTURE

| | Angle Between ℄ and Strike of Structure | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | <20 | | | 20-30 | | | >30 | | |
| Apparent Dip of Structure | <30 | 30-40 | >40 | <30 | 30-40 | >40 | <30 | 30-40 | >40 |
| No. of Cuts | $A_{17}$ | $B_{18}$ | $C_{100}$ | $D_9$ | $E_6$ | $F_{64}$ | $G_{100}$ | $H_{41}$ | $I_{159}$ |



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TABLE 100

TABLE 99 VS CUT SLOPE ANGLE

| Table 99 Group No. | Cut Slope Angle ≥1/2:1 | 3/4:1 | 1:1 | 1 1/2:1 | ≤2:1 |
|---|---|---|---|---|---|
| A | 5 | 4 | 4 | 2 | 2 |
| B | 3 | 9 | 2 | 4 | 0 |
| C | 35 | 33 | 22 | 10 | 0 |
| D | 5 | 2 | 2 | 0 | 0 |
| E | 1 | 1 | 3 | 1 | 0 |
| F | 23 | 19 | 15 | 7 | 0 |
| G | 27 | 35 | 24 | 11 | 3 |
| H | 16 | 10 | 12 | 3 | 0 |
| I | 55 | 55 | 44 | 5 | 0 |

TABLE 101

TABLE 99 VS CUT SLOPE HEIGHT

| Table 99 Group No. | Cut Slope Height <40 | 40-80 | 81-120 | >120 |
|---|---|---|---|---|
| A | 1 | 6 | 2 | 8 |
| B | 0 | 3 | 8 | 7 |
| C | 8 | 40 | 28 | 24 |
| D | 0 | 3 | 3 | 3 |
| E | 0 | 3 | 1 | 2 |
| F | 7 | 31 | 14 | 12 |
| G | 5 | 40 | 18 | 37 |
| H | 2 | 13 | 12 | 14 |
| I | 21 | 70 | 35 | 33 |



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TABLE 102

TABLE 99 VS FAILURES

| Table 99 Group No. | Failures | | | | | | |
|---|---|---|---|---|---|---|---|
| | Erosion | Ravelling | Rockfall | Surface Slide | Deep Slide | Other | None |
| A | 5 | 6 | 4 | 3 | 0 | 1 | 2 |
| B | 3 | 10 | 5 | 6 | 0 | 0 | 0 |
| C | 11 | 49 | 31 | 23 | 2 | 13 | 4 |
| D | 0 | 4 | 4 | 2 | 0 | 0 | 1 |
| E | 0 | 2 | 1 | 0 | 1 | 1 | 1 |
| F | 8 | 32 | 26 | 15 | 0 | 1 | 2 |
| G | 18 | 54 | 24 | 17 | 3 | 4 | 8 |
| H | 5 | 25 | 9 | 6 | 1 | 1 | 3 |
| I | 19 | 73 | 56 | 26 | 2 | 16 | 9 |

TABLE 103

TABLE 99 VS PERFORMANCE

| Table 99 Group No. | Performance | | | |
|---|---|---|---|---|
| | Very Good | Good | Marginal | Unsatisfactory |
| A | 4 | 8 | 3 | 2 |
| B | 6 | 7 | 3 | 2 |
| C | 12 | 55 | 17 | 16 |
| D | 3 | 4 | 0 | 2 |
| E | 0 | 3 | 1 | 2 |
| F | 9 | 37 | 7 | 11 |
| G | 19 | 55 | 17 | 9 |
| H | 21 | 7 | 8 | 5 |
| I | 26 | 87 | 29 | 17 |



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*Before discussing these comparisons it should be stressed that, because of time and money limitations, the intersections of these planar features were not determined or studied. Experience has shown that such intersections are frequently the cause of unsatisfactory performance of cut slopes.

*The cut slopes with flatter angles appear to have been used in materials with flatter apparent dip angles. Further study of this observation should yield information directly applicable to cut slope design techniques.

*For the failure groups used in this project, it appears that high angles to centerline and high apparent dip angles both are significant factors.

*There is some indication that the cut slopes in materials with intermediate angles to ℄ and with intermediate apparent dip angles receive lower performance evaluations than the other groups.



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# APPENDIX A

## Data Retrieval System



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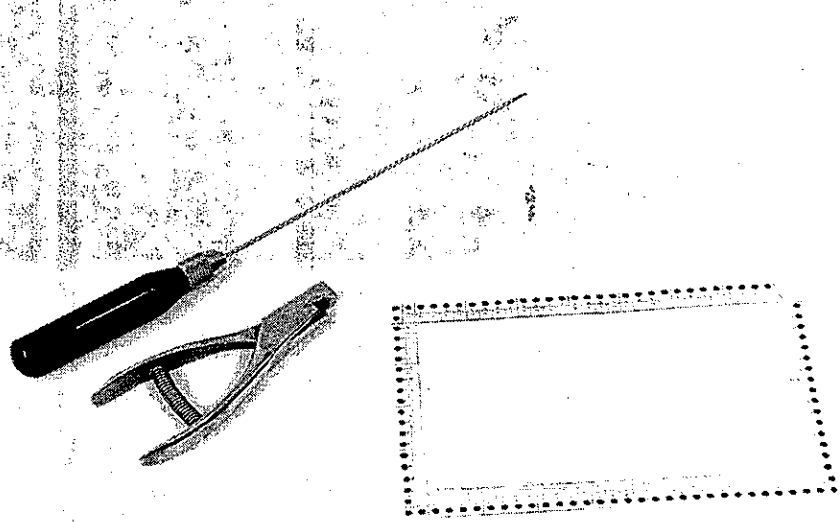
The data storage and retrieval system employed in this study was the Burroughs Corporation Unisort System. This system consists of 5 X 8 inch cards with 95 numbered holes around the edge. Data is recorded on the card and keyed to the holes which are then notched out. For data retrieval, a sorting needle is inserted into the hole keyed to the desired data and those cards which drop out of the card file are the ones desired. A blank card, the notching tool and a sorting needle are pictured below.





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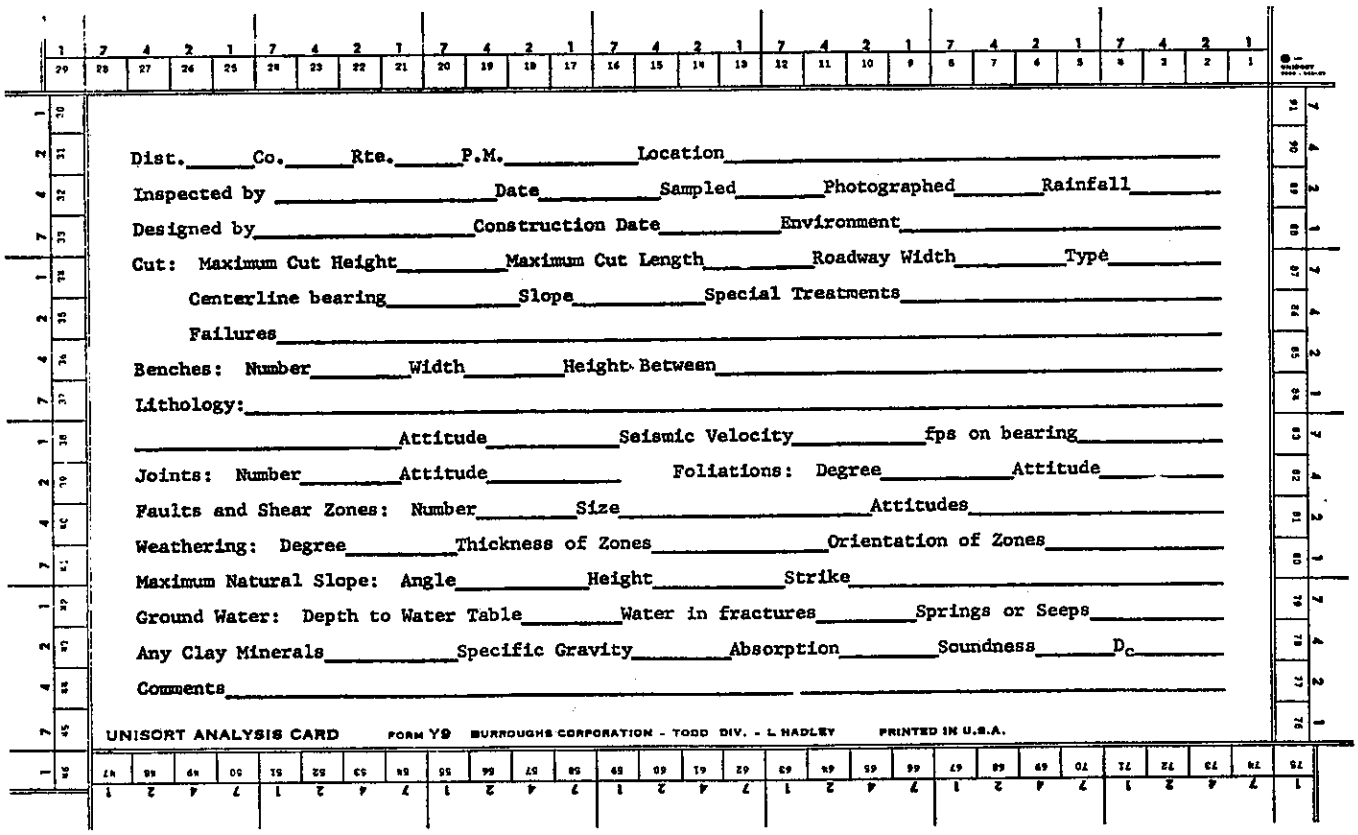
What data to gather for each cut included in this study was decided upon by the Engineering Geology staff. An appropriate form was then developed and imprinted on the front of the data analysis card. The type of data to be gathered and the layout of the card can be seen in the following photograph.



Dist._____Co._____Rte._____P.M._____Location_____

Inspected by _____Date_____Sampled_____Photographed_____Rainfall_____

Designed by_____Construction Date_____Environment_____

Cut: Maximum Cut Height_____Maximum Cut Length_____Roadway Width_____Type_____

Centerline bearing_____Slope_____Special Treatments_____

Failures_____

Benches: Number_____Width_____Height Between_____

Lithology:_____

_____Attitude_____Seismic Velocity_____fps on bearing_____

Joints: Number_____Attitude_____ Foliations: Degree_____Attitude_____

Faults and Shear Zones: Number_____Size_____Attitudes_____

Weathering: Degree_____Thickness of Zones_____Orientation of Zones_____

Maximum Natural Slope: Angle_____Height_____Strike_____

Ground Water: Depth to Water Table_____Water in fractures_____Springs or Seeps_____

Any Clay Minerals_____Specific Gravity_____Absorption_____Soundness_____$D_c$_____

Comments_____

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The data collected for each cut slope inspected can be divided into three categories: Locators; Descriptors; and Design Variables. The following table lists the items included under each category.



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## LOCATORS

District
County
Route
Post Mile
Geographic Location

## DESCRIPTORS

Cut Slope Type
Angle
Height
Length
Bearing

Bench Number
Width
Height
Roadway Width
Designer
Construction Date
Inspector
Inspection Data
Special Treatments
Failures
Performance Evaluation

## DESIGN VARIABLES

Rainfall
Environment
Lithology
Seismic Data
Joints
Foliations
Faults
Weathering
Natural Slopes
Groundwater Data
Clay

Because of space limitations it was frequently necessary to write on the back of the card. The back was also used for sketching those conditions that could not be clearly described on the front.



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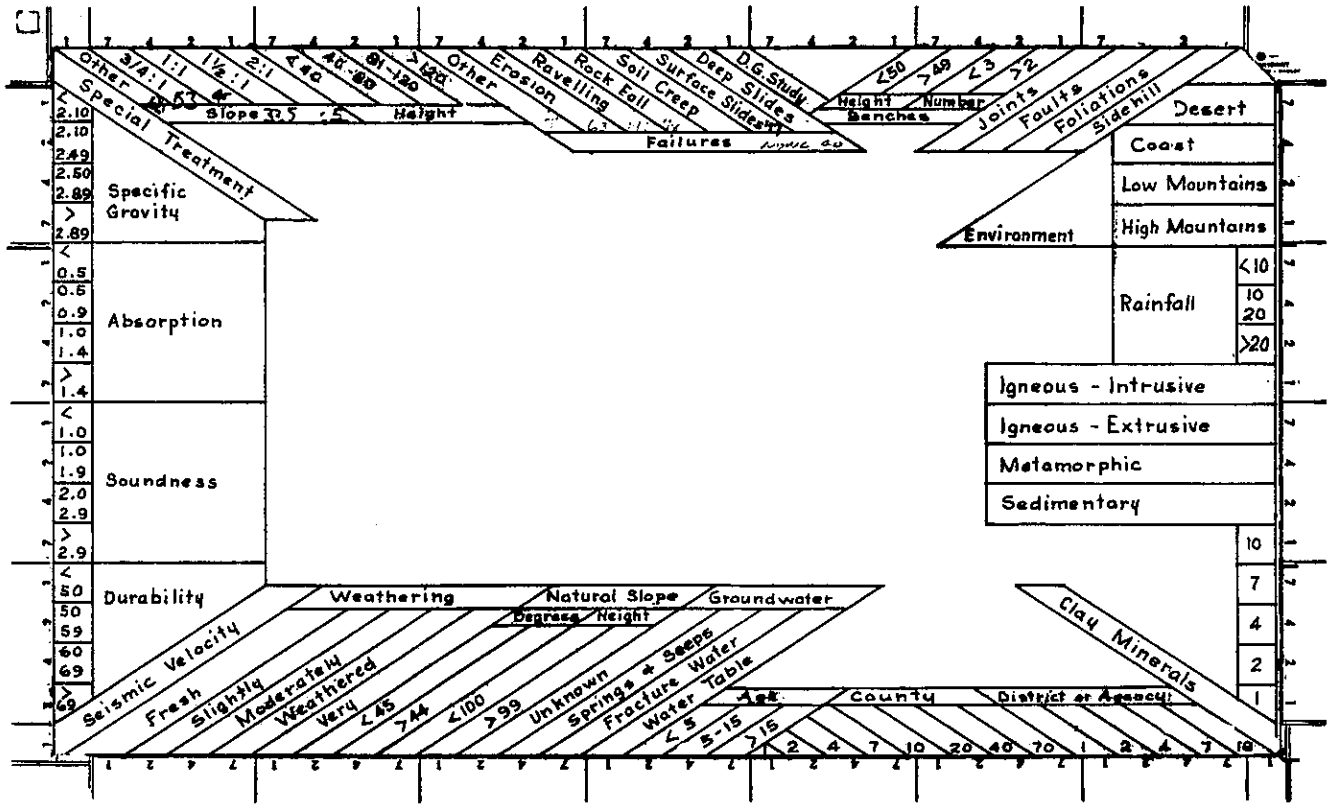
To facilitate the data retrieval an index card was developed. This card had the edge holes identified and could be placed in front of the card file to readily indicate the hole into which the needle should be inserted to retrieve the desired data. The index card is shown as follows:




Because the number of hole spaces was limited, it was necessary to use number codes to retrieve Design Agency, County or Rock Type. Retrieval of number coded data is accomplished by consecutively retrieving the numbers required to total the desired number. The digits required to utilize such a number coding are imprinted on the basic card and only include 1, 2, 4 and 7 to obtain any number from 1 through 9. A second series of these digits can be used to obtain any number from 10 through 99.



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The following table defines the number code used to describe the agency that designed the cut described on the card.

| Code Number | Design Agency |
|---|---|
| 1 | Department of Transportation District 01 |
| 2 | " " " " 02 |
| 3 | " " " " 03 |
| 4 | " " " " 04 |
| 5 | " " " " 05 |
| 6 | " " " " 06 |
| 7 | " " " " 07 |
| 8 | " " " " 08 |
| 9 | " " " " 09 |
| 10 | " " " " 10 |
| 11 | " " " " 11 |
| 12 | All Others |

The county in which the cut is located was number coded as indicated in this table.

1. Alameda
2. Alpine
3. Amador
4. Butte
5. Calaveras
6. Colusa
7. Contra Costa
8. Del Norte
9. El Dorado
10. Fresno
11. Glenn
12. Humboldt
13. Imperial
14. Inyo
15. Kern
16. Kings
17. Lake
18. Lassen
19. Los Angeles
20. Madera
21. Marin
22. Mariposa
23. Mendocino
24. Merced
25. Modoc
26. Mono
27. Monterey
28. Napa
29. Nevada
30. Orange
31. Placer
32. Plumas
33. Riverside
34. Sacramento
35. San Benito
36. San Bernardino
37. San Diego
38. San Francisco
39. San Joaquin
40. San Luis Obispo
41. San Mateo
42. Santa Barbara
43. Santa Clara
44. Santa Cruz
45. Shasta
46. Sierra
47. Siskiyou
48. Solano
49. Sonoma
50. Stanislaus
51. Sutter
52. Tehama
53. Trinity
54. Tulare
55. Tuolomne
56. Ventura
57. Yolo
58. Yuba



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Rock types were number coded as shown in this table.

Igneous Intrusive
1. Granite
2. Diorite
3. Gabbro
4. Ultrabasic
5. Diabase
6. Other

Igneous Extrusive
1. Rhyolite
2. Dacite
3. Tuff
4. Andesite
5. Basalt
6. Other

Metamorphic
1. Schist
2. Gneiss
3. Serpentine
4. Greenstone
5. Quartizite
6. Meta sandstone
7. Metavolcanic
8. Metagranitic
9. Metadiorite
10. Basic Metaigneous
11. Other

Sedimentary
1. Sandstone
2. Sandstone fossiliferous
3. Siltstone
4. Conglomerate
5. Limestone
6. Dolomite
7. Chert or cherty
8. Other

Since the number coding systems were set up in advance of data collection, they do contain some holes that were never used.

This type of data retrieval system is simple and inexpensive to set up but as has been mentioned it is limited as to how much data can be stored and retrieved. It also has the disadvantage requiring a committment to the retrievable data before any analysis has been completed. This feature means that to change the data retrieval groupings it is necessary to copy the data and re-notch the cards. This is time consuming and therefore expensive.

Two types of purely mechanical problems appear to be inherent with this system. Preparing and notching the cards is slow, tiring work and although several people were involved, numerous mistakes were made. The discovery of mistakes made a complete check of all data retrieval holes necessary. As a result of this check nearly a third of the cards had to be redone. The second problem is with too many cards in the file, the desired cards do not drop freely from the needle. Thus, when using more than about 100 cards, it was necessary to check carefully to assure that all the notched cards had dropped.

Although this project was completed with the Unisort system described above, it will probably not be used again. There are numerous punched card systems with much higher data capacity and which are easier to use.



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# APPENDIX B

## Data Collection



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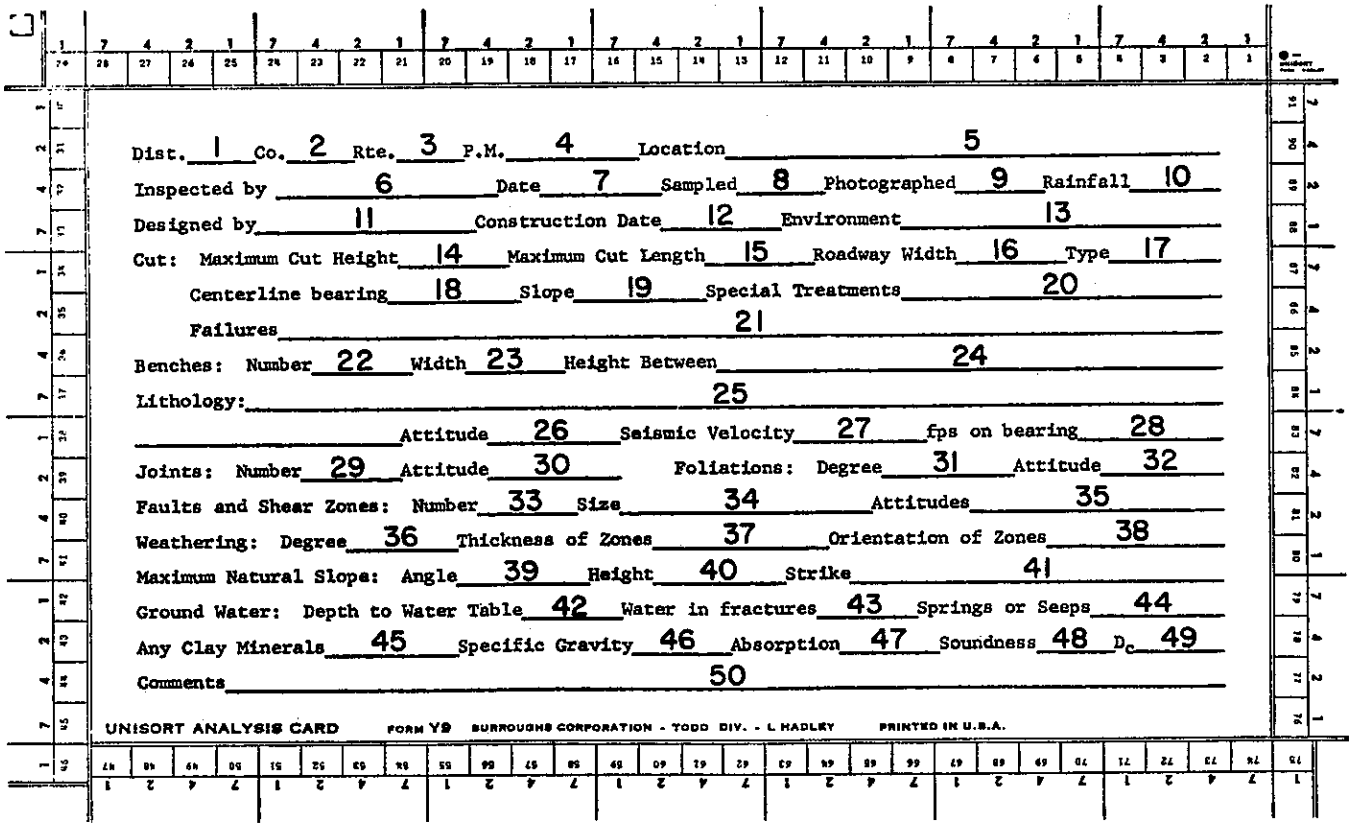
The data stored in the retrieval system described in Appendix A was obtained by personnel of the Engineering Geology unit of California Division of Highways, Transportation Laboratory. These geologists made detailed field and office studies in compiling the data.

To facilitate analysis, detailed procedures for recording the data were followed. These procedures discussed all of the information that was required and provided certain key words so that comparisons between individual cards could be made independently of the cut slope inspector.




The above sample data card has all the blanks number coded. The numbers are repeated below with appropriate directions for properly recording the desired data.

1. Transportation District in which cut is located.

2. County in which cut is located.

3. State highway route on which cut is located, if applicable.

4. Post Mile if applicable.



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5. A short geographic description of the location of the cut, particularly if it is not on a State highway.

6. Name of person or persons filling out the data card.

7. Date of field inspection.

8. Indicate number of samples that were taken.

9. Indicate number of photographs that were taken.

10. Approximate average annual rainfall based on nearest U.S. Weather Bureau Reporting Station.

11. Name of agency responsible for construction of the cut.

12. Year that cut was completed.

13. Use whichever of the following terms apply:

| | |
|---|---|
| Desert | - Colorado or Mojave Desert Geomorphic provinces. |
| Coast | - Within 8 miles of the ocean. |
| For all areas not in "Coast" or "Desert" | |
| Low Mountains | - Less than 3000 feet in elevation |
| High Mountains | - More than 3000 feet in elevation |

14. Difference in elevation between grade and highest point on cut slope.

15. Distance from beginning to end of cut.

16. Width of paved roadway.

17. Through or sidehill.

18. True bearing of center line.

19. Vertical angle between horizontal and cut slope.

20. Special treatments include such things as, but not limited to: horizontal drains, underdrains, plantings, etc.

21. Failures including, but not limited to: deep slides, surface slides, soil creep, rockfall, raveling, and erosion.



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22. Number of benches.

23. Width of benches.

24. Vertical difference in elevation between benches.

25. Lithology - includes, but not limited to: rock type, mineralogy, structure.

26. Strike and dip, if applicable.

27. Refracted seismic velocity, if known.

28. True bearing of seismic line from which the refracted seismic velocity was determined.

29. Number of sets of joints.

30. Strike and dip of each joint set, if applicable.

31. Degree of development of foliations.

32. Strike and dip of foliation, if applicable.

33. Number of faults and shear zones.

34. Size of faults and shear zones.

35. Strike and dip of faults and shear zones, if applicable.

36. Degree of weathering: fresh; slightly weathered; moderately weathered; weathered; very weathered.

37. Thickness of weathered zones.

38. Attitude of weathered zone contact.

39. Maximum vertical angle between horizontal and natural slope in similar material.

40. Height of the natural slope on which the angle was measured.

41. Strike of the natural slope (true bearing).

42. Depth to water table, if known.

43. Indicate if fracture water is present.

44. Indicate the presence of springs or seeps.



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45. Indicate the presence of clay minerals in the cut and identify, if possible.

46. Test result, if known.

47. Test result, if known.

48. Test result, if known.

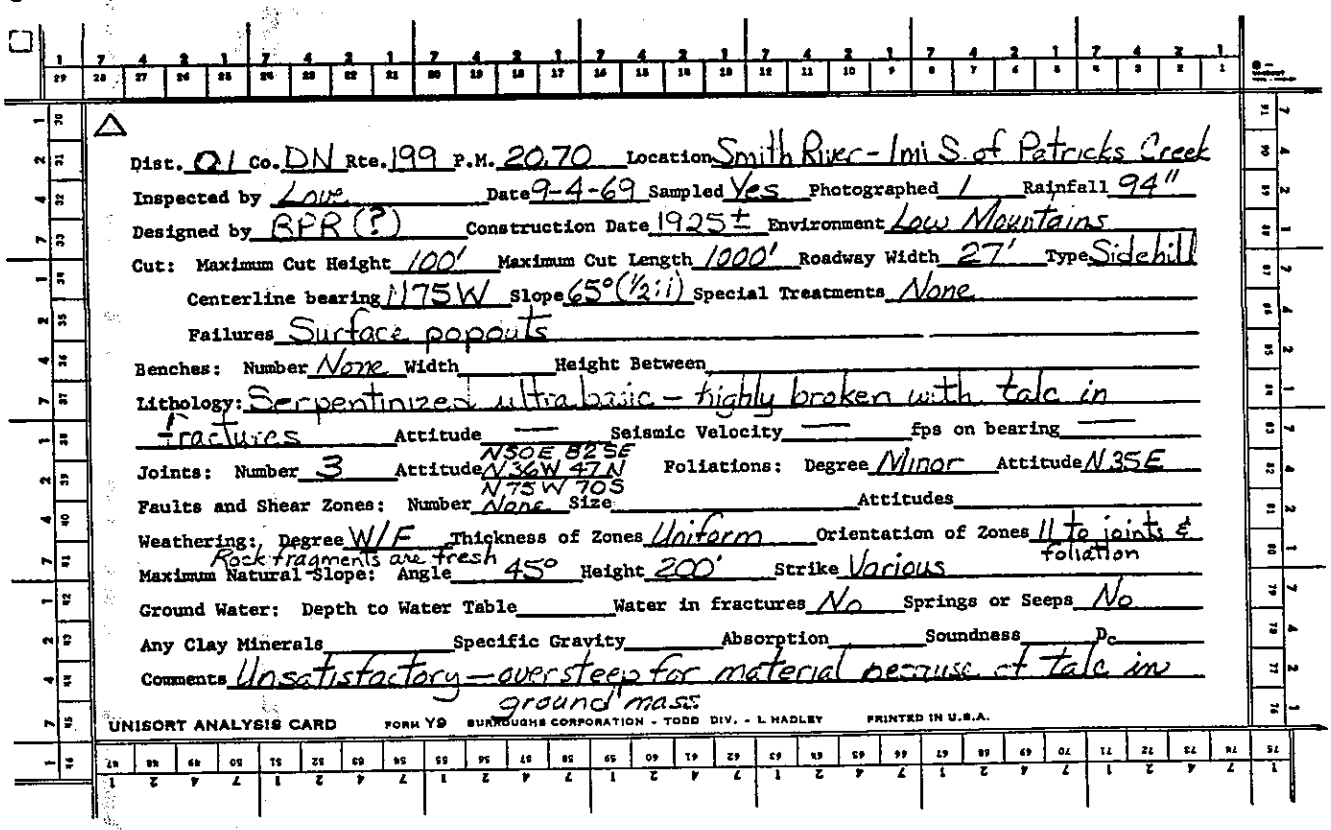
49. Test result, if known.

50. Any relevant comment and a performance evaluation using the following terms:

Very good.
Good.
Marginal.
Unsatisfactory.

For complex cuts, a sketch may be included on the back of card.

The data collection was accomplished between Feb. 1967 and Jan. 1970. The cuts included in this study were selected because of previous knowledge or after discussions with District personnel. The main considerations were the necessity of a single rock type in each cut, a variety of rock types in the study and a wide geographic distribution. Using these criteria, a total of 276 cut slopes were selected and inspected. This process was carried out with no significant difficulties.



Dist. 01 Co. DN Rte. 199 P.M. 20.70 Location Smith River - 1mi S. of Patricks Creek
Inspected by Love Date 9-4-69 Sampled Yes Photographed 1 Rainfall 94"
Designed by BPR (?) Construction Date 1925± Environment Low Mountains
Cut: Maximum Cut Height 100' Maximum Cut Length 1000' Roadway Width 27' Type Sidehill
Centerline bearing N75W Slope 65° (½:1) Special Treatments None
Failures Surface popouts
Benches: Number None Width ____ Height Between ____
Lithology: Serpentinized ultrabasic - highly broken with talc in fractures Attitude — Seismic Velocity — fps on bearing —
Joints: Number 3 Attitude N50E 82SE N36W 47N N75W 70S Foliations: Degree Minor Attitude N35E
Faults and Shear Zones: Number None Size ____ Attitudes ____
Weathering: Degree W/F Thickness of Zones Uniform Orientation of Zones ⊥ to joints & foliation
Maximum Natural Slope: Angle 45° Height 200' Strike Various Rock fragments are fresh
Ground Water: Depth to Water Table ____ Water in fractures No Springs or Seeps No
Any Clay Minerals ____ Specific Gravity ____ Absorption ____ Soundness ____ Pc ____
Comments Unsatisfactory - oversteep for material because of talc in ground mass

UNISORT ANALYSIS CARD FORM Y9 BURROUGHS CORPORATION - TODD DIV. - L HADLEY PRINTED IN U.S.A.



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The only problem encountered in using the system as described was the lack of information on which side of the road the geologic structure was determined. This information was absolutely essential to determine if geologic structure is related to the stability of the cut slope. It was necessary to determine, from the photographs or if necessary by returning to the cut, the relationship of geologic structure and roadway geometry.

In addition to its use in this research project, the card file has been useful in evaluating the performance of various designs in order to make recommendations for future projects.

Data developed on this project has also been used as background for initiating a research project covering slope design in intermediate quality rocks.

The report contained in Appendix C, as has been mentioned, also covers work which is based in part on data from this project.

In investigating certain aspects of the problem of erosion, the card file has been used to identify locations having certain desired conditions.

The data stored in this system thus has proven to be very useful in numerous ways not previously anticipated, and has added to the value of this research project.



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# APPENDIX C

## Slope Design in Disintegrated Granite



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State of California

Business and Transportation Agency

# Memorandum

To : Mr. Travis Smith

Date: June 16, 1970

File : 19107-641139-38155

From : **Department of Public Works—Division of Highways**
Materials and Research Department

Subject: Slope Stability in Disintegrated Granitic Rocks

During several years of working with seismic data including follow up studies, it was noticed that in disintegrated granitic materials, the seismic velocity seemed to correlate with slope stability. While compiling data for a BPR-financed research study entitled "Design Variables for Cut Slopes" the same correlation seemed to be developing.

This report is a compilation of data from past jobs, the above mentioned research project and some data gathered just for this report. The object of the compilation is to determine if the correlation between the seismic velocity in disintegrated granitic rocks and slope stability is consistent enough to permit slope design based on seismic velocity.

For purposes of this report disintegrated granitic rock is defined as the weathering product formed by the disintegration of igneous intrusive rocks having a mineral composition ranging from granite to diorite. The mass of material is in place, may exhibit some relic structural features and the bond between crystals has been weakened or destroyed.

A total of 26 cuts are included in this study. The areal distribution of these cuts is shown on the attached map of California. There are some cuts in each of the main environments in which granitic rocks are found: coastal; high mountains; and desert. The exact locations of the cuts are included in Table 1 along with the type of rock encountered. Table 2 includes a number of physical characteristics which were considered important. Appendix A includes appropriate sketches of each cut area along with location of seismic lines and seismic line profiles.



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Weathering

The degree of weathering included in Table 2 is based on analysis of the X-ray diffraction records and microscopic inspection of the material by an experienced Engineering Geologist.

% Clay Minerals

The reported percentages of clay minerals represents the percentage of the sample that is made up of clay minerals as identified by X-ray diffraction techniques using standard calibrated powders as references.

Seismic Velocity

Seismic velocity is reported in feet per second and was obtained using an Electro-Tech ER-75-12 12-channel seismic timer with both hammer blows and explosives as energy sources. In those cases where two distinctively different velocities were detected both are reported.

Slope Angle and Height

These physical characteristics are included to aid in describing the cut.

Visual Evaluation

This is a subjective evaluation of the performance of the cut as constructed. The geologist inspecting each cut made this evaluation in the field.

Only two of the cuts studied were found unsatisfactory. The failures were the result of excessive ground water and low permeability resulting in excessive pore pressures. This lack of failures suggests that cut slopes in disintegrated granitic rocks often may be flatter than necessary. This study is intended to provide an objective basis for the design of such slopes.

The first analysis used the field data as gathered and did not provide useful design guidelines. A second trial at developing useful guidelines utilized the concept of "the steepest stable slope." Since factual information of this type was not available, a team of engineering geologists including the one responsible for the field inspection of the cut estimated the "steepest stable slope" based on their pooled knowledge and experience. Table 3 shows the steepest stable slope for each of the cuts included in this study.

The coefficient of correlation between the steepest stable slope and each of the three physical characteristics was computed using a linear regression analysis. In order to perform these

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computations weathering and slope designs were number coded as follows:

| Very Weathered=1 | Weathered=2 | Moderately Weathered=3 |
|---|---|---|
| 1/4:1=1 | 1/2:1=2 | 3/4:1=3 |
| 1:1=4 | 1-1/2:1=5 | 2:1=6 |

The coefficients thus computed were:

| | |
|---|---|
| Steepest Stable Slope vs Seismic Velocity | = .42 |
| " " " vs % Clay Minerals | = .75 |
| " " " vs Weathering | = .62 |

These results are surprising in that the relationship to seismic velocity which started this research project is the poorest of those studied. Both weathering and percent of clay minerals are based essentially on the same information as interpreted by the same engineering geologist. Since % of clay minerals has a better correlation it was used instead of weathering. Data for these analyses are plotted in Figures 1, 2 and 3.

Analysis of the data gathered for this study yield the following guidelines for slope design in disintegrated granitic rocks.

1) Seismic velocity 1800 fps or greater

1/2:1 or 1/4:1 for cuts less than 50'
3/4:1 for cuts up to 100'

2) Seismic velocity less than 1800 fps

3/4:1 for cuts less than 50'
1:1 for cuts from 50' to 80'
1-1/2:1 or flatter for cuts higher than 80'

3) Clay mineral content less than 10%

1/2:1 for cuts less than 50'
3/4:1 for cuts up to 100'

4) Clay mineral content greater than 10%

3/4:1 for cuts less than 50'
1:1 for cuts from 50' to 80'
1-1/2:1 or flatter for cuts higher than 80'

R. Mearns

RM:kk

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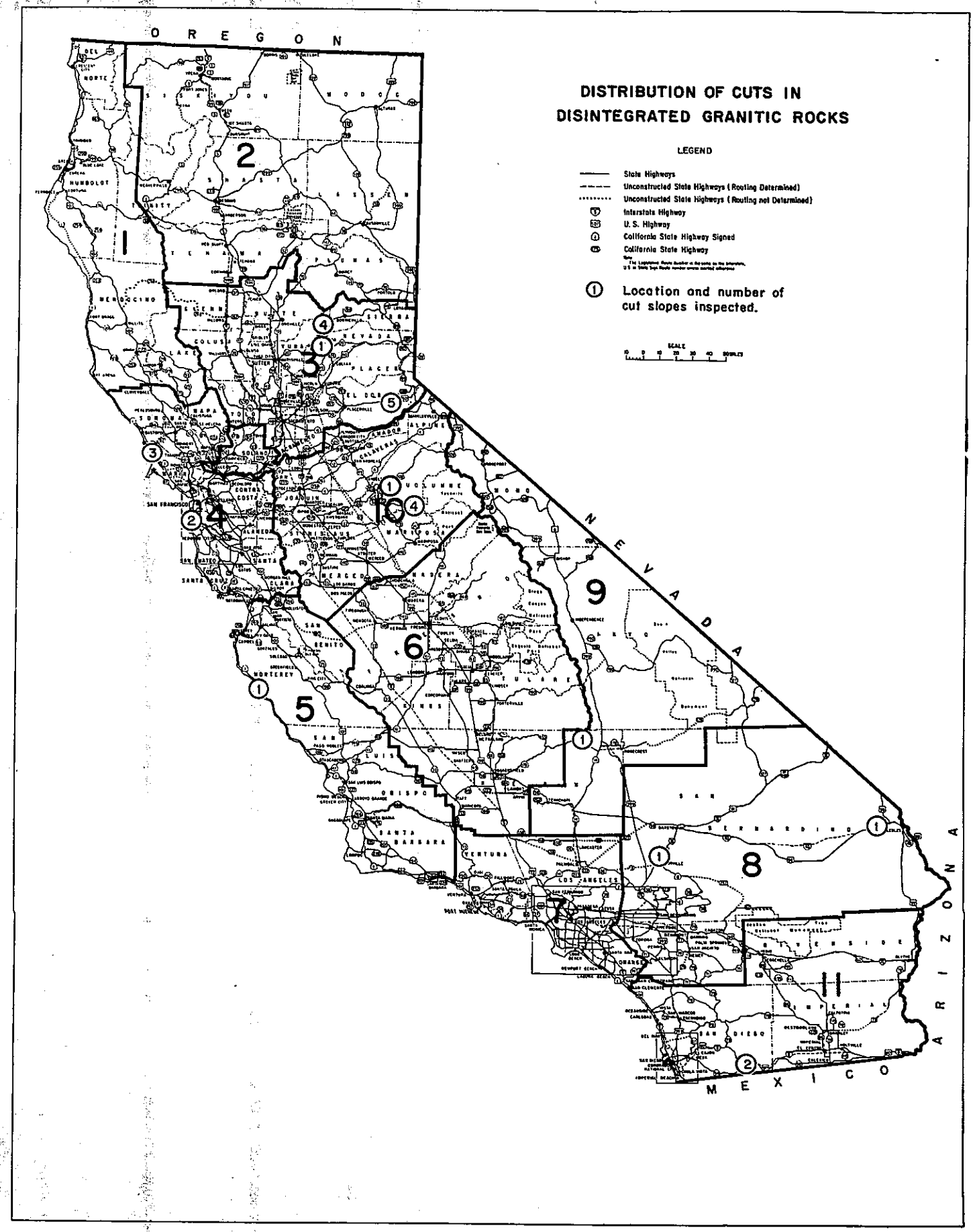


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TABLE 1

Location and Rock Type for Cuts Included in this Study

| Cut No. | Location | Rock Type |
|---|---|---|
| 1 | 03-Nev-49 - 31.46 | Quartz Monzonite |
| 2 | 03-Yub-49 - 1.02 | Quartz Diorite |
| 3 | 03-Yub-49 - 2.63 | " " |
| 4 | 03-Yub-49 - 2.63 | " " |
| 5 | 03-Yub-49 - 3.02 | " " |
| 6 | 03-ED-50 - 46.79 | " " |
| 7 | 03-ED-50 - 46.84 | Quartz Monzonite |
| 8 | 03-ED-50 - 49.94 | " " |
| 9 | 03-ED-50 - 49.98 | " " |
| 10 | 03-ED-50 - 51.00 | Granodiorite |
| 11 | 04-Mrn-109 - 27.28 | Quartz Monzonite |
| 12 | 04-Mrn-109 - 27.58 | " " |
| 13 | 04-Mrn-109 - 27.59 | " " |
| 14 | 04-SM-1 - 37.195 | Quartz Diorite |
| 15 | 04-SM-1 - 37.54 | " " |
| 16 | 05-Mon-1 - 42.95 | " " |
| 17 | 08-SBd-15 - 55.75 | Granodiorite |
| 18 | 08-SBd-40 - 134.12 | " |
| 19 | 09-Ker-178 - 80.30 | " |
| 20 | 10-Tuo-108 - 11.45 | Granite |
| 21 | 10-Tuo-120 - 48.45 | Quartz Monzonite |
| 22 | 10-Tuo-120 - 48.65 | Quartz Diorite |
| 23 | 10-Tuo-120 - 51.70 | " " |
| 24 | 10-Tuo-120 - 54.64 | " " |
| 25 | 11-SD-8 - 56.72 | " " |
| 26 | 11-SD-8 - 61.50 | Granodiorite |

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TABLE 2

Physical Characteristics of
Cuts Included in this Study

| Cut No. | Weathering* | % Clay | Seismic Velocity Ft/Second | Slope | | Visual** Evaluation |
|---|---|---|---|---|---|---|
| | | | | Angle | Height | |
| 1 | W | 10 | 1550 | 3/4:1 | 105 | G |
| 2 | MW | 5 | 1400 | 1:1 | 50 | G |
| 3 | W | 5 | 1900 | 3/4:1 | 78 | G |
| 4 | MW | 10 | 2150 | 1/4:1 | 65 | G |
| 5 | W | Trace | 1250 | 3/4:1 | 70 | G |
| 6 | W | 5-10 | 1600 | 1:1 | 38 | G |
| 7 | W | 10-20 | 1100-2200 | 3/4:1 | 54 | M |
| 8 | W | 10 | 1300-2400 | 1/2:1 | 43 | M |
| 9 | W | Trace | 1200 | 1/2:1 | 50 | G |
| 10 | VW | 10 | 1200 | 1/2:1 | 48 | G |
| 11 | W | 5-10 | 1400-2800 | 1/2:1 | 30 | G |
| 12 | W | 5 | 1450 | 1/2:1 | 35 | G |
| 13 | W | 5 | 1550 | 1/4:1 | 35 | M |
| 14 | W | 5 | 2050 | 3/4:1 | 48 | G |
| 15 | W | 5 | 2500 | 3/4:1 | 72 | G |
| 16 | W | 25-35 | 2200 | 3/4:1 | 90 | G |
| 17 | MW | 0 | 2900 | 2:1 | 28 | G |
| 18 | MW | 15-20 | 3350 | 3/4:1 | 23 | G |
| 19 | MW | 20-25 | 2600 | 1:1 | 8 | G |
| 20 | VW | 35 | 1200 | 1½:1 | 48 | G |
| 21 | VW | 30-45 | 1350 | 1½:1 | 80 | U |
| 22 | VW | 25-30 | 1750 | 1½:1 | 90 | G |
| 23 | VW | 15-20 | 1600 | 1½:1 | 25 | M |
| 24 | VW | 10-15 | 1000-1450 | 1½:1 | 75 | U |
| 25 | MW | 0 | 3100 | 1/2:1 | 50 | G |
| 26 | MW | 0 | 3150 | 1½:1 | 60 | G |

*VW - Very Weathered

W - Weathered

MW - Moderately Weathered

**G - Good

M - Marginal

U - Unsatisfactory

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TABLE 3

Estimated Steepest Stable Slope
For Cuts Included in this Study

| Cut No. | Slope |
|---|---|
| 1 | 1/2:1 |
| 2 | 3/4:1 |
| 3 | 3/4:1 |
| 4 | 1/4:1 |
| 5 | 3/4:1 |
| 6 | 3/4:1 |
| 7 | 3/4:1 |
| 8 | 1/2:1 |
| 9 | 1/2:1 |
| 10 | 1/2:1 |
| 11 | 1/4:1 |
| 12 | 1/2:1 |
| 13 | 1/2:1 |
| 14 | 1/2:1 |
| 15 | 3/4:1 |
| 16 | 3/4:1 |
| 17 | 1/4:1 |
| 18 | 3/4:1 |
| 19 | 3/4:1 |
| 20 | 1:1 |
| 21 | 2:1 |
| 22 | 1½:1 |
| 23 | 1:1 |
| 24 | 1:1 |
| 25 | 1/4:1 |
| 26 | 1/2:1 |

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# RELATIONSHIP BETWEEN STEEPEST STABLE SLOPE AND SEISMIC VELOCITY

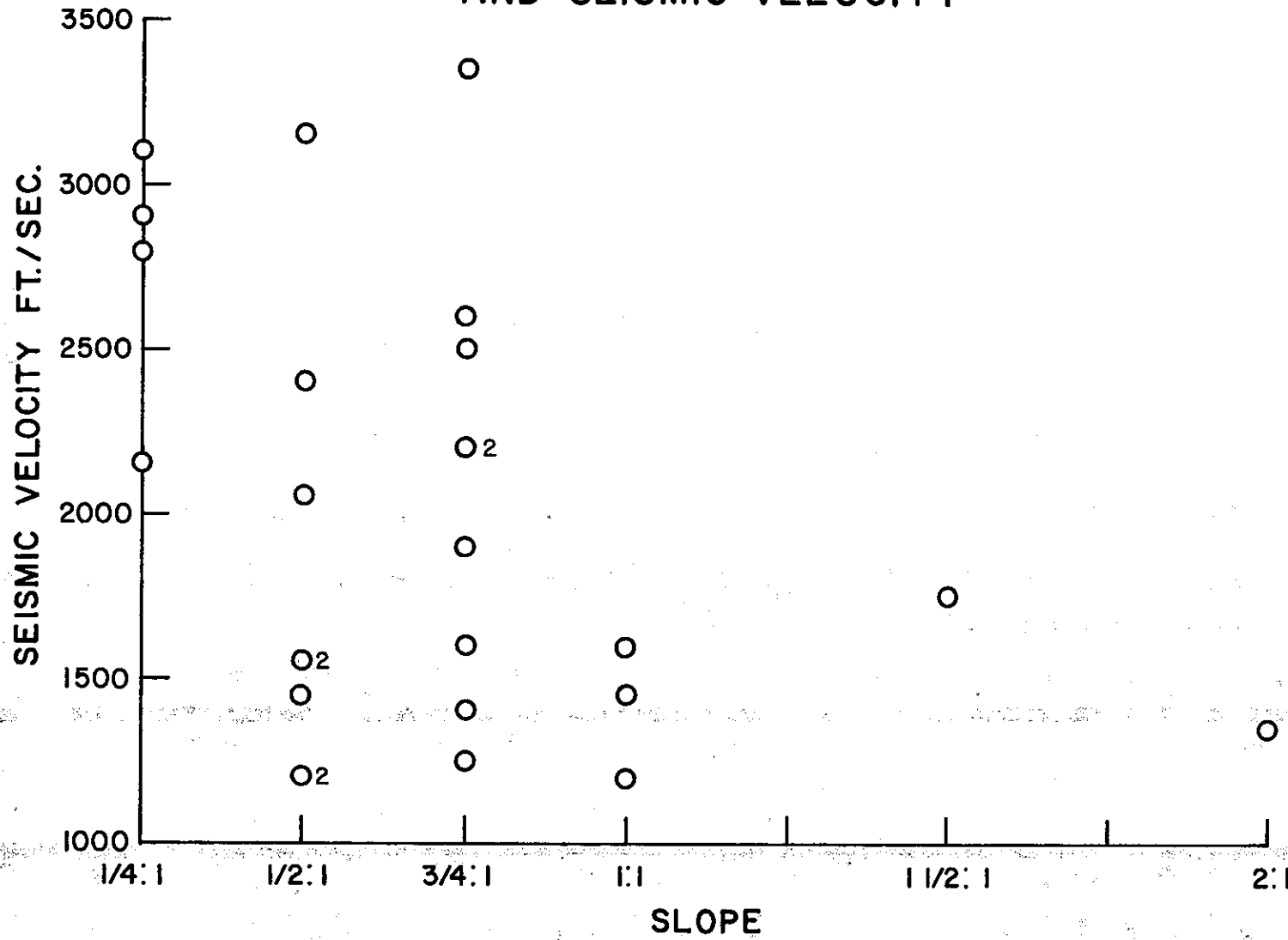


Figure 1

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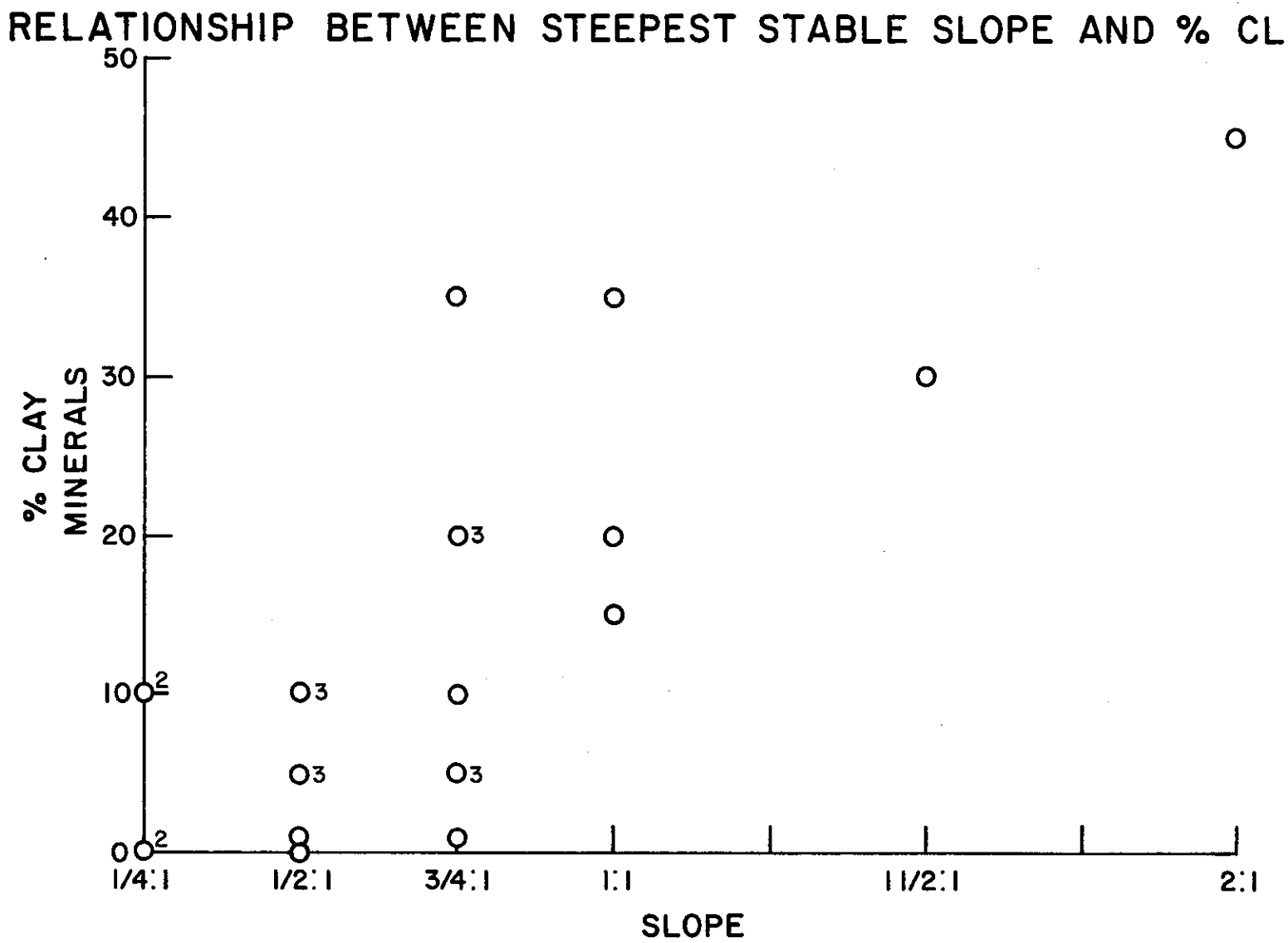


Figure 2

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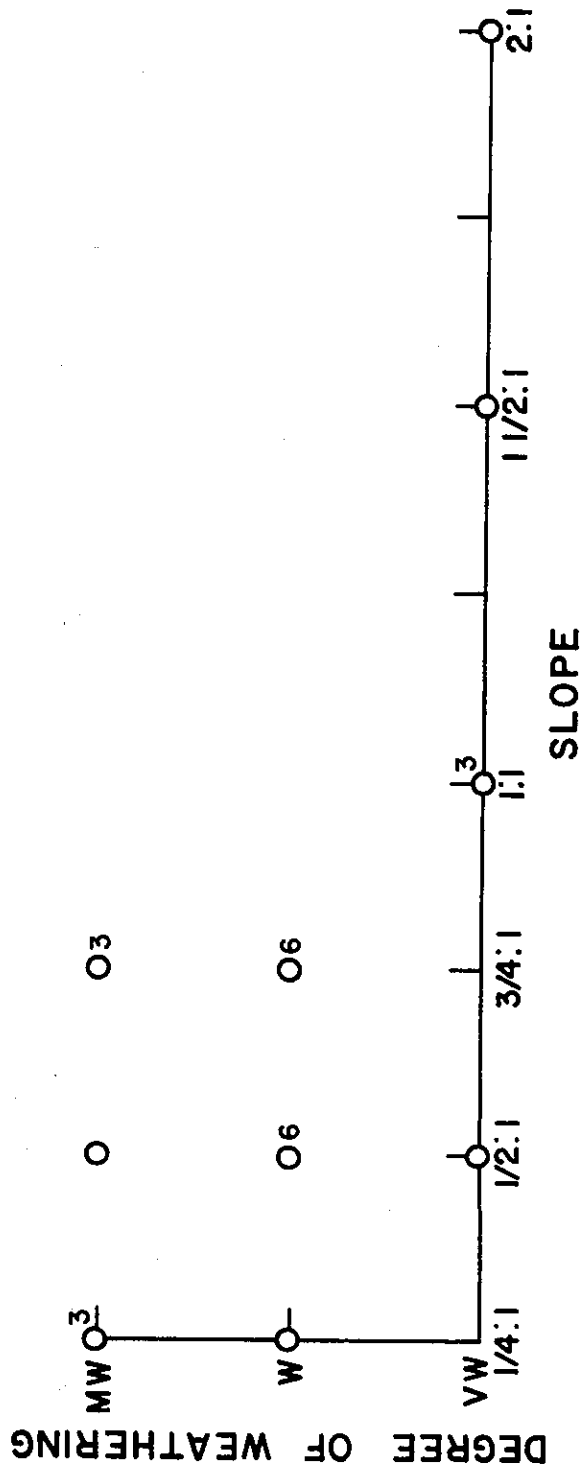
Figure 3

RELATIONSHIP BETWEEN STEEPEST STABLE SLOPE AND DEGREE OF WEATHERING



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