

# Field Evaluation of Rapid Data Collection System for Rock Slope Stability Analysis

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A system for rapid collection and evaluation of geologic-structure data for rock slope stability analysis developed by the engineering geology group at Purdue University is described. The data collection system allows for rapid, direct collection of field data and provides a preliminary computer analysis of the slope while on site. It consists of (a) a lightweight data collection package carried in the field that stores on magnetic tape orientations and characteristics of rock discontinuities; (b) a specially designed computer and software interface that provides data exchange from collection package to microcomputer; and (c) a fairly inexpensive, portable microcomputer maintained in a field vehicle or motel room. Field testing of the system began in May 1981 in the Valley and Ridge Province of Virginia with the cooperation of the Virginia Department of Highways and Transportation. Three highway road cuts were examined in detail. As a result of information obtained during the testing process, a number of changes to the standard data collection procedure are recommended that tend to streamline collection of structural rock slope information. The efficiency of the rapid data collection system is compared with that of standard methods. The advantages of the new system are enumerated.

The complete stability analysis of a given rock slope depends on a detailed survey of the orientations and characteristics of discontinuities within the rock mass. A discontinuity is defined as a structural weakness plane or surface along which movement can take place. Types of rock discontinuities are joints, faults, shear zones, bedding surfaces, and foliations. The significant characteristics of discontinuities are (a) geometry, (b) continuity, (c) spacing, (d) surface irregularities, (e) physical properties of adjacent rock, (f) infilling material, and (g) groundwater (1). Field surveys conducted to collect these data are extremely time consuming, and there are generally significant time lapses between the mapping and the

detailed analysis of the data.

A computer-based system for rapid collection and evaluation of geologic-structure data for rock slope stability analysis has been developed by the engineering geology group at Purdue University. It was field tested during the 1981 summer season with the cooperation of the Virginia Department of Highways and Transportation. The prototype system has been described in considerable detail by Watts and West (2).

The rapid data collection and evaluation system consists of three components (see Figure 1):

1. A lightweight data collection package carried in the field that stores on magnetic tape orientations and characteristics of rock discontinuities (Figure 2);

2. A specially designed computer hardware and software data interface that provides for data ex-

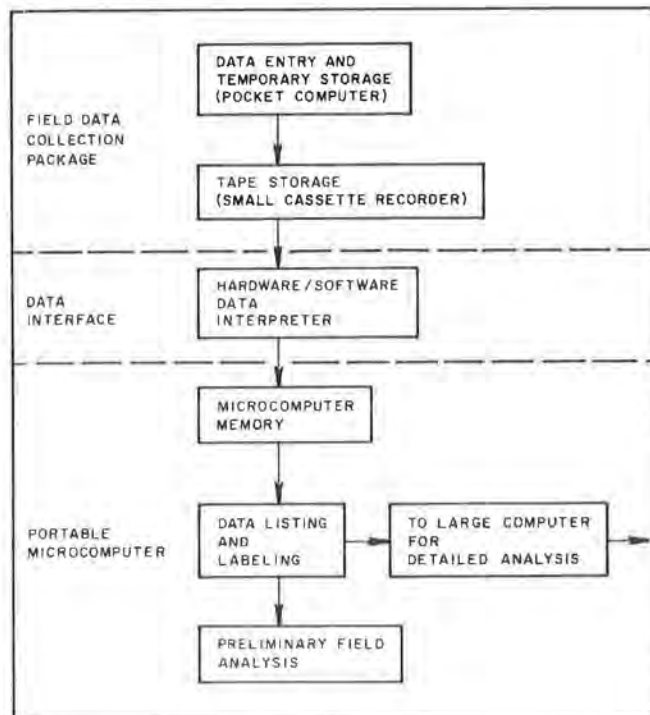
Figure 2. Computerized data collection field package which interfaces to microcomputer system.



Figure 3. Portable microcomputer system used for data analysis.



Figure 1. Flow chart of data collection and evaluation system.



change from the collection package to the microcomputer; and

3. A fairly inexpensive, portable microcomputer maintained in a field vehicle or motel room (see Figure 3).

The purpose of the system is to speed up the data collection process and to place the data into computer memory for analysis as quickly and as simply as possible. A number of different procedures and philosophies exist for the collection of geologic-structure data. Among these are the procedures outlined in two Federal Highway Administration (FHWA) short-course publications (3,4). The rapid data collection and evaluation system can be incorporated into any procedure dictated by personal preference and by site characteristics.

PRELIMINARY INVESTIGATION

The Virginia Department of Highways and Transporta-

tion selected three possible sites in Virginia for the field testing. This paper deals primarily with the first two sites; the third is mentioned briefly later. The two initial sites are located less than 0.75 mile from each other on US-460 near the town of Cedar Bluff. Prior to detailed mapping, a preliminary site investigation was conducted to give a sense of the regional geology and a feeling for the general structure of the site.

The sites are located in the folded and faulted sedimentary rock of the Valley and Ridge Province in southwestern Virginia. Figure 4 illustrates the general structure of that portion of the valley and ridge, and Figure 5 (modified from a field trip guide of the area by C. Ashbrook) shows a generalized geologic cross section near the sites.

Both of the cut slopes are in the Honaker dolomite group. The Maryville limestone member appears to make up the southernmost of the two slopes, and the Rogersville shale member is responsible for the

Figure 4. Major faults and folds of area surrounding the test site.

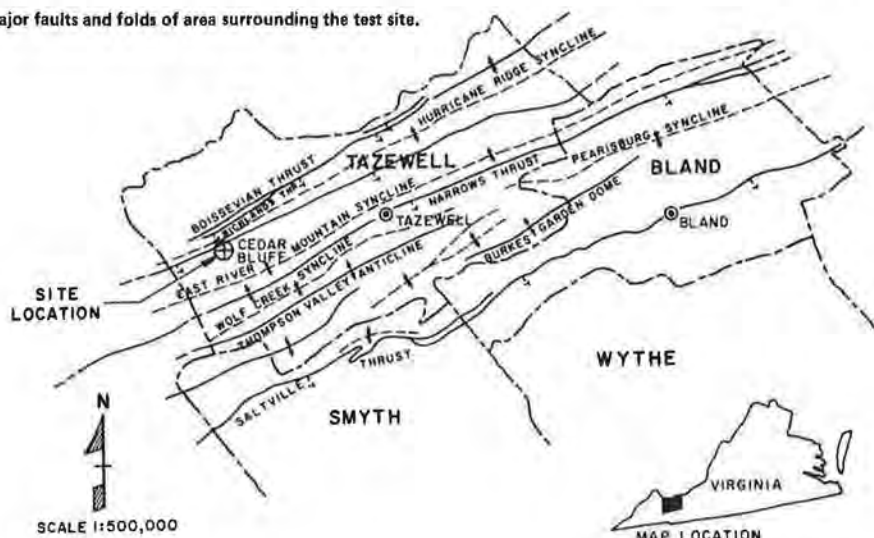
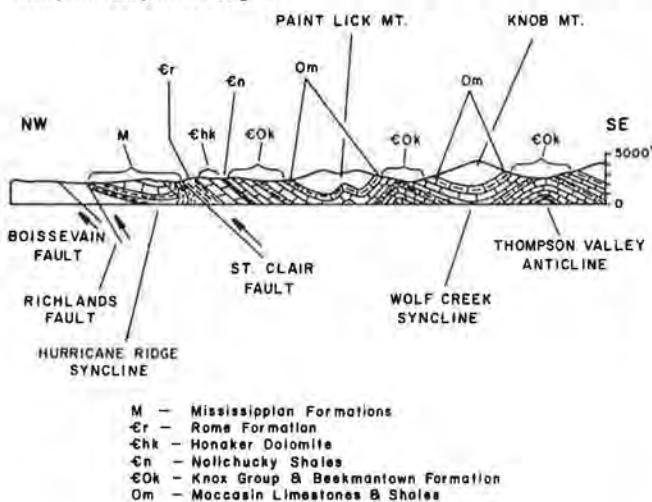


Figure 5. Generalized geologic cross section of Cedar Bluff, Ward Cove, and Thompson Valley area of Virginia.



- M - Mississippian Formations
- Cr - Rome Formation
- Chk - Honaker Dolomite
- En - Nolichucky Shales
- Ok - Knox Group & Beekmantown Formation
- Om - Moccasin Limestones & Shales

Mountain tops are composed of sandstones and quartzites. (Clinch or Tuscarora Sandstones)

Figure 6. Contorted bedding and associated faulting near the St. Clair Fault in the roadcut.

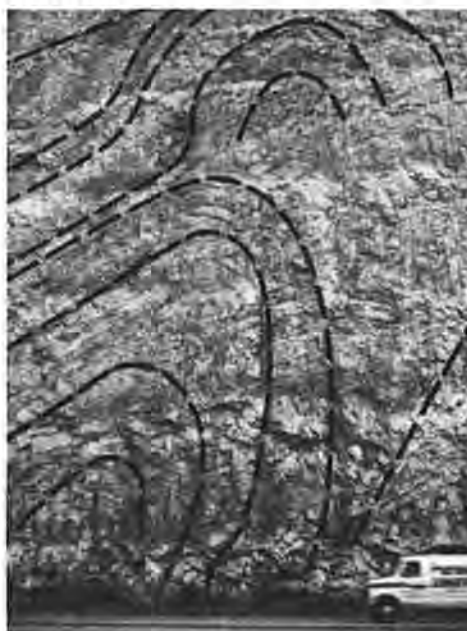






Figure 9 illustrates some of the data that were collected in this study. It closely follows the format found in Part G of Rock Slope Engineering (3). The same data format can be used for both window mapping and line mapping. Data can easily be omitted if they are not relevant to the mapping method being used. Finally, since some of the data are highly repetitive in nature, it is desirable not to reenter those data that are unchanged. If no entry is made for any prompt by the pocket computer and ENTER is pressed, the computer will simply assume that there has been no change in that item since the last entry. This feature helps to speed up the data collection process and to relieve some of the tedium of line mapping.

The actual amount of time saved in data collection by using the computerized method depends on the type of mapping undertaken and the specific procedures being followed. In this study, the computerized package appeared to reduce the data collection time by somewhere between 20 and 50 percent. However, the real time savings are not in data collection but in data listing and preliminary data analysis.

DATA LISTING AND PRELIMINARY ANALYSIS

The field data collected on cassette tape at the Cedar Bluff sites were loaded into the microcomputer and analyzed via the computer interfacing program. Each detailed line contained 100 joint readings. The data from the first detailed line were read into the computer, listed, and plotted on rectangular dip plots in about 30 min. A later, improved computer interfacing program reduced that time to about 20 min. Figure 9 illustrates a typical data listing. The rectangular dip plot for each line was automatically stored in computer memory for later use.

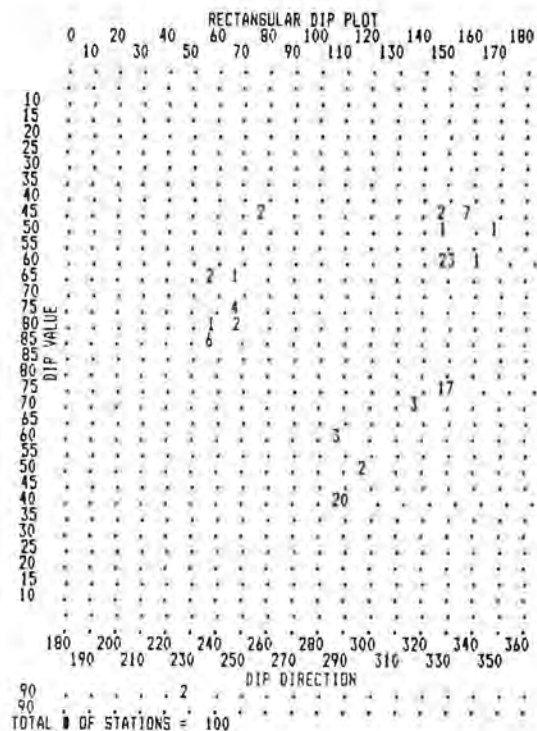
Next, the computer produced an equal area net plot of the poles of all of the discontinuities measured (see Figure 10). This is generally done to enable the slope investigator to pick out groupings or clusters of points that represent specific joint sets. The orientations of the clusters with respect to the slope face indicate which types of failures are likely to be present. Circular, planar, wedge, and toppling failures are possible, and various analytic techniques exist for each. Additional details regarding these failure modes and stereonet

Figure 9. Data listing of last 20 discontinuities of typical detailed line from Cedar Bluff site and rectangular dip plot for entire line.

JNT#	TRAV	DIST	RKTP	HDS	STR	#JNS	JNSP	DIPDR	DIP	JNTLN	CONT	FLT	FLTH	FLHDS	WTR	RGHNS	WAVILA	WAVLN
1281	356	21.1	2	04	04	00	00	146	62	100.0	2	003	1	60	2	2	000	000.0
1282	356	24.5	2	04	04	00	00	146	62	100.0	2	003	1	00	2	2	000	000.0
1283	356	25.5	2	04	04	00	00	146	62	100.0	2	003	1	00	2	2	000	000.0
1284	356	26.0	2	04	04	00	00	146	62	100.0	2	003	1	00	2	2	000	000.0
1285	356	26.3	2	04	04	00	00	146	62	100.0	2	003	1	00	2	2	000	000.0
1286	356	27.9	2	04	04	00	00	146	62	100.0	2	003	1	00	2	2	000	000.0
1287	356	31.7	2	04	04	00	00	146	62	100.0	2	003	1	00	2	2	000	000.0
1288	356	33.1	2	04	04	00	00	146	62	100.0	2	003	1	00	2	2	000	000.0
1289	356	35.0	2	04	04	00	00	146	62	100.0	2	003	1	00	2	2	000	000.0
1290	356	36.6	2	04	04	00	00	146	62	100.0	2	003	1	00	2	2	000	000.0
1291	356	38.5	2	04	04	00	00	146	62	100.0	2	003	1	00	2	2	000	000.0
1292	356	41.0	2	04	04	00	00	146	62	100.0	2	003	1	00	2	2	000	000.0
1293	356	05.6	2	04	02	00	00	065	78	002.0	2	003	1	00	1	3	000	002.0
1294	356	09.7	2	04	02	00	00	072	80	002.0	2	003	1	00	1	3	000	002.0
1295	356	12.8	2	04	02	00	00	068	80	002.0	2	003	1	00	1	3	000	002.0
1296	356	19.5	2	04	02	00	00	071	75	002.0	2	003	1	00	1	3	000	002.0
1297	356	21.5	2	04	02	00	00	075	66	002.0	2	003	1	00	1	3	000	002.0
1298	356	29.0	2	04	02	00	00	074	75	002.0	2	003	1	00	1	3	000	002.0
1299	356	35.6	2	04	02	00	00	074	75	002.0	2	003	1	00	1	3	000	002.0
1300	356	43.5	2	04	02	00	00	075	74	002.0	2	003	1	00	1	3	000	002.0

KEY

- JNT# = Joint number
- TRAV = Traverse trend
- DIST = Distance along traverse
- RKTP = Rocktype
- HDS = Hardness
- STR = Structure type
- #JNS = # of joints (within a given zone)
- JNSP = Joint spacing (within a given zone)
- DIPDR = Dip direction
- DIP = Dip
- JNTLN = Joint length
- CONT = Continuity (or persistence)
- FLT = Filling type
- FLTH = Filling Thickness
- FLHDS = Filling hardness
- WTR = Water
- RGHNS = Roughness
- WAVILA = Waviness (inter-lob angle)
- WAVLN = Wave length



representations are given by Hoek and Bray (6, p. 57). In this field testing situation, clusters were picked by eye. We have since developed several microcomputer programs that produce contoured output to assist in clustering (see Figure 11). Note that on the initial pole plot (Figure 10) the numbers indicate the number of poles falling at that point. If more than nine poles lie at the same point, let-

Figure 10. Pole plot of discontinuities from Cedar Bluff site (data points clustered by eye).

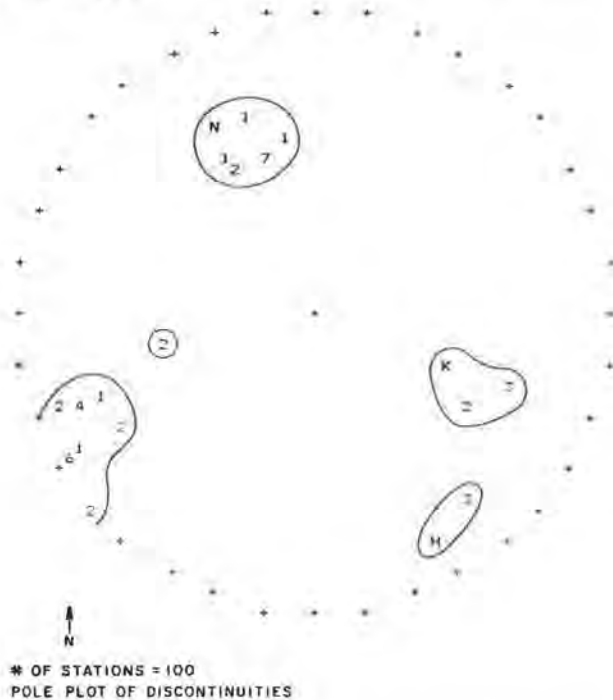
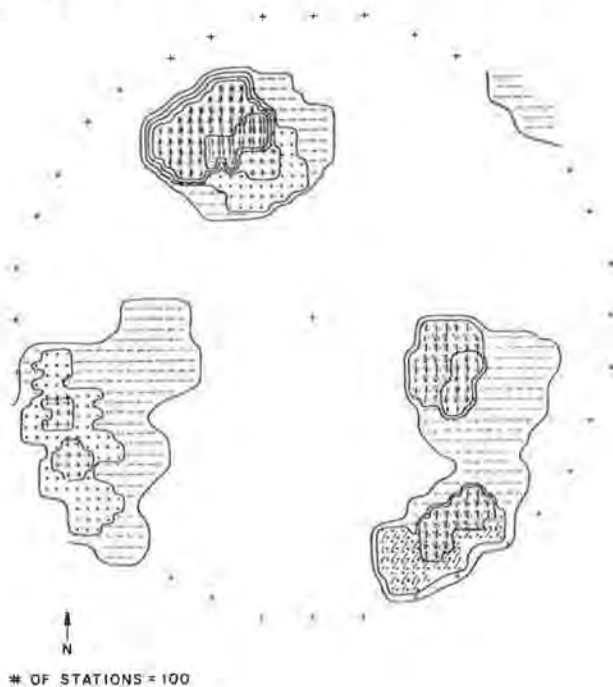


Figure 11. Data from Cedar Bluff computer contoured to assist in cluster recognition.

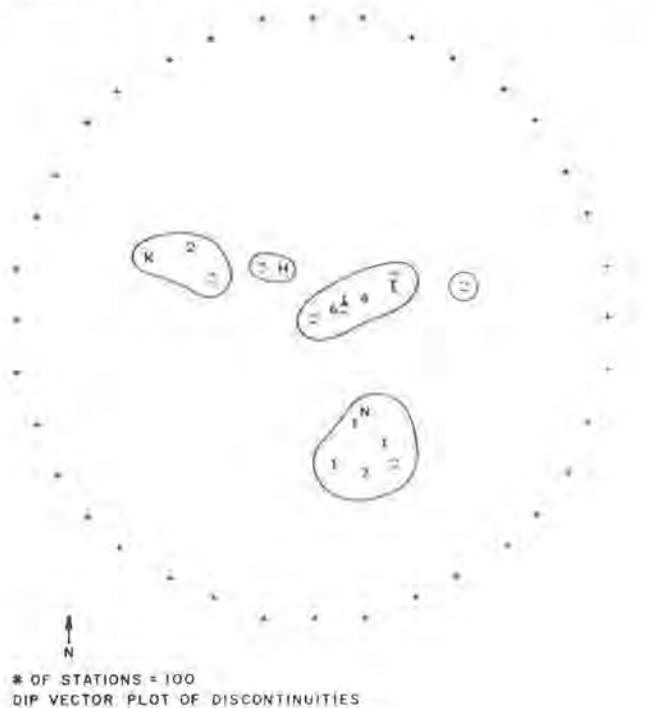


ters are used. For example, A is equal to 10, B is equal to 11, and so on.

It was also determined that an equal area net plot of dip vectors can be extremely valuable in the slope analysis (Figure 12). A dip vector can be thought of as the stereonet representation of a line drawn along the direction of maximum dip on an inclined plane. On a stereographic projection, it plots as a single point at the position of maximum dip for the plane. In other words, it lies at the midpoint of the great circle that represents the plane. Just as there is only one pole for a given inclined plane, there is also only one dip vector. Two valuable characteristics of dip vectors were noted. First, the clustering of joints into joint sets by eye is often more easily accomplished by using both the dip vector plots and the pole plots than by using pole plots alone. Clusters that are not readily apparent on the pole plots, due to scattering of the poles near the edge of the net, can become apparent in dip vector plots and vice versa. Second, the dip vector plot can be especially useful for the identification of potential plane failure surfaces (see Figure 13). Dip vectors that fall within the critical zone, defined by the slope face and the friction angle, represent a possible failure. In other words, if the discontinuities daylight on the slope face and are steeper than the friction angle, they warrant additional study. This is referred to as Markland's Test and is described by Hoek and Bray (6, pp. 56-59). The dip vectors in Figure 13 have been clustered and numbered for comparison with Figure 14. Three of the clusters fall within the critical zone.

The next step in the preliminary slope analysis was the plotting of planes, representing discontinuities, on the equal area net for a wedge analysis (see Figure 14). Each great circle represents a cluster determined earlier. In this type of plot, the numbers represent a specific plane. For example, a line drawn through all number 2's with a flexible straight edge is the equal area net plot of

Figure 12. Dip vector plot of discontinuities from Cedar Bluff (data points clustered by eye).



discontinuity number 2. The dip and dip directions of the various planes are listed in the lower left

Figure 13. Dip vector clusters from Figure 12 with friction circle and slope face also plotted.

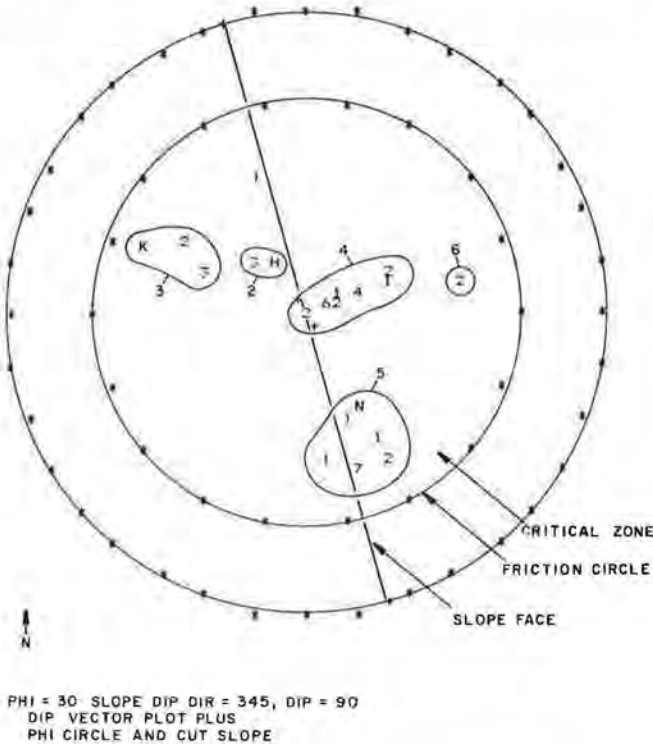
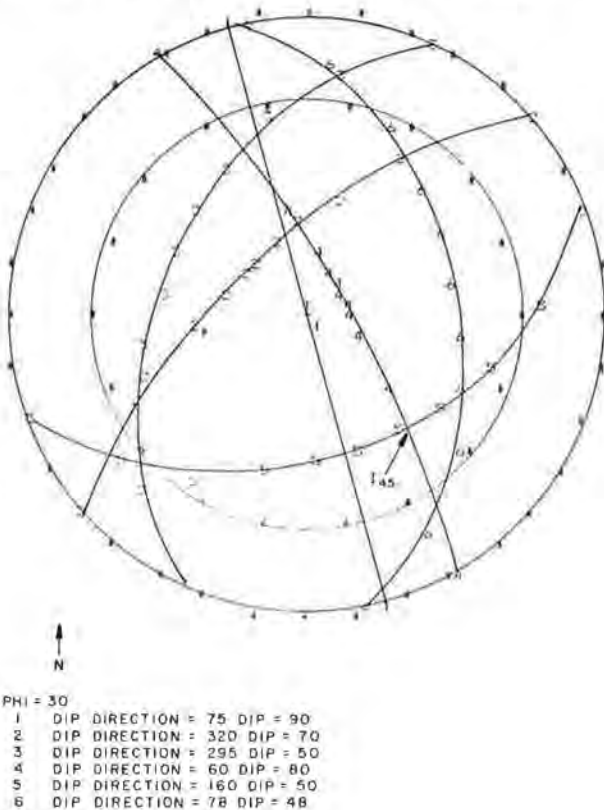


Figure 14. Computer plot of great circles representing discontinuities clustered in Figure 12 (great circle 1 represents vertical slope face).



corner of the printout. Plane 1 is usually reserved to represent the slope face. This plot is useful in a number of ways. Potential plane, wedge, and toppling failures can be identified on this plot if they exist in the data. The primary application of this plot involves the identification of the lines of intersection of discontinuities. If a point representing a line of intersection on the stereonet falls within the critical zone, defined once again by the slope face and the friction angle, then that point represents a potential wedge failure and warrants additional study.

At the time the study was conducted, the analysis plot just described was the last of the plots developed. Additional types of preliminary analysis are planned for the system. Among them are programs to locate and plot the points that represent wedge intersections directly and thus eliminate the required hand drawing to locate the intersections in Figure 14. Recently available programs include programs to perform cumulative sums analyses (7) and the data contouring programs previously mentioned. Even before this, however, truly significant time savings were realized by using the initial plotting routines. In this study, 600 individual joints were plotted on a number of different stereonets as both poles and dip vectors, were clustered, and then were checked for kinematically possible failure surfaces, all in a few hours. To accomplish this by hand would require several days, and to accomplish it back at the office on a large computer involves transportation time and time to have the data punched on computer cards or entered at a terminal.

SITE EVALUATION

The preliminary evaluations of the slopes at Cedar Bluff were based on both the equal area net plots of the detailed mapping and on visual observations of significant single features in the slopes. The equal area net plots give a good representation of the distribution and orientation of joints throughout most of the two rock slopes. The structure in the proximity of the St. Clair fault, however, is extremely complex. The bedding planes are contorted into tight folds, and a number of smaller faults have caused displacements of varying distances. These associated faults are not always planar and needed to be mapped individually.

The road cut that actually contains the St. Clair fault serves as a good example. Figures 9-14 represent the detailed lines from this slope. Note that three of the dip vector clusters in Figure 13 lie within the critical zone. Plane 6 is insignificant due to a lack of continuity. Figure 14 shows the plot of discontinuities in the slope. Visual examination of the plot indicates that there is a potential wedge failure at the intersection of planes 4 and 5. Once a potential failure is located, it can be assigned a factor of safety based on any of numerous techniques (4, Appendix 6; 6, Chapter 8). Due to the complexity of the structure in the north end of the road cut, the stereonet plot fails to show one other potential failure associated with the folding and faulting. This illustrates the importance of mapping significant individual features visually whenever possible (Figure 6). There also happen to be a few areas where blast damage has created features best noted by direct observation.

SYSTEM EVALUATION AND RECOMMENDATIONS

Both window mapping and line mapping techniques were used in this study. The purpose was not to determine which technique is best but to determine whether the data collection system functioned better



with one rather than the other. No reliable criteria have been determined for deciding a preference between window mapping and line mapping. It remains a matter of site conditions and personal preference. A third site for testing the system was mentioned at the beginning of this paper. The site is located near Clifton Forge, Virginia, in the Iron Gate anticline. A large road cut is planned through the anticline, but currently rock exposures are poor along most of the planned construction. At a site such as this, detailed line mapping is not possible and window mapping appears to be the best alternative.

It was determined during the study that a combination of the window mapping and line mapping techniques is sometimes useful. At the Cedar Bluff sites, much of the two slopes was mapped by setting up 50-ft-long windows, 30-40 ft apart, but mapping within them as if doing detailed lines. This proved to be a satisfactory compromise between the two techniques for this particular location. As expected, the computer-based data collection system worked equally well for either technique, using the same data collection format for both. Some of the data were simply not collected depending on which procedure was being used.

The rapid data collection and evaluation system has been shown to provide a number of time-saving services. It decreases data collection time by about 20-50 percent and provides data plots for preliminary analyses in hours instead of days. It is also capable of transferring the collected data to a larger computer system for additional analysis by use of sophisticated FORTRAN programs.

A few changes could be made to the system to improve its ease of operation. The pocket computer data-collection program could be rewritten to allow a short remark to be recorded after each joint if desired. By using new knowledge, the prototype hardware interface can be rebuilt to provide a less complex form, which makes it simpler to use. In addition, a newer model of microcomputer could be used for the preliminary analyses and stereonet plotting. Microcomputers that are smaller, will connect to any television set, and are less complicated to disassemble and transport are now available

in the same price range. Finally, a number of programs are currently being written for the microcomputer system that will handle involved calculations of factors of safety for potential failures once they have been identified. The proposed changes will make this computer-based data collection system simpler to use while making it an even more powerful analytic tool.

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## The Malibu Landslide

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A case history of one of the most highly publicized landslides in the history of the California Department of Transportation is presented. In the spring of 1979, the recognition of an incipient and potentially dangerous massive slide above steep sandstone bluffs adjoining the Pacific Coast Highway (CA-1) between Malibu and Santa Monica necessitated closure of this vital transportation link. The installation of an extensive and unique warning system plus a rock fall catchment area permitted partial reopening one month later while the slide investigation proceeded. The correction ultimately selected involved a partial unloading and slope reinforcement. The four-way warning system proved to be extremely useful in permitting the partial reopening of the highway while providing for the general safety of the traveling public and adjacent home owners. The use of rock dowels for slope reinforcement reduced the required excavation to achieve stability by more than 1 million yd<sup>3</sup> in extremely difficult terrain.

What has become known in Southern California as "the Malibu landslide" is located adjacent to the Pacific

Coast Highway (CA-1) 1.5 miles west of Topanga Canyon in the central part of the Santa Monica Mountains between Santa Monica and Malibu. This area is characterized by steep natural slopes and rocky escarpments. Landsliding, a common occurrence along this part of the Pacific Coast Highway, is a natural process of bluff recession due to past oversteepening by wave erosion. The bluffs are composed primarily of thick-bedded sandstone with interbeds of siltstone and conglomerate. These sedimentary rocks have been intruded by volcanic rocks that are now highly altered. They have been folded and faulted to create a complex geological structure. Some of the joint patterns of the rock are oriented adversely and thus contribute to the instability of the slope.

Figure 1 is an oblique aerial photograph of the