# EARTHFLOWS IN THE COAST RANGES OF CENTRAL CALIFORNIA: PRELIMINARY REPORT

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# INTRODUCTION

I have chosen the term "earthflow" to describe a distinctive type of mass movement feature which is common on slopes of the Coast Ranges of central California. In this area, an earthflow consists of a long, narrow tongue of clay-rich debris with discrete lateral boundaries. It moves downslope at a rate ranging from a few millimeters per day to several meters per day, and it comes to rest either on or at the foot of the slope on which it originated.

I am studying earthflows using a combination of field observation, field instrumentation, and laboratory testing of earthflow material. A model of earthflow behavior will be developed from these studies. The field measurements described below are confined to a small number of earthflows. It is anticipated that the applicability of the model deduced from intensive study of a small number of earthflows can be extended to others by detailed comparisons of morpholgy and, perhaps, by the use of a few laboratory and field measurements.

The central Calfornia coast has a climate characterized by warm, dry summers and cool, rainy winters; and most earthflows as well as landslides of other types in this region are active only during the winter months. During the autumn of 1974, four sites, each of which contains several earthflows, were chosen for field studies. During the winter of 1974-1975, measurements of surface and subsurface displacements, of groundwater levels, and of some soil properties were made at these sites. During the summer and autumn of 1975, additional instruments were installed on two sites in anticipation of renewed movements during the winter of 1975-1976. This report describes field work carried out from August 1974 to November 1975.

## DESCRIPTION OF AN IDEALIZED EARTHFLOW

Figure 1 is a sketch of an idealized earthflow. The source area supplies material to the head of the earthflow. Commonly, the source area is part of another earthflow or of a landslide of another type. A steep, crescent-shaped head scarp divides the source area from the earthflow itself.

The earthflow is divided into two parts: a head and a toe. The surface of the head has subsided to an elevation below that of the original ground surface, whereas the toe bulges above the surrounding ground. The head is bounded laterally by a pair of shear walls which contain striations plunging in the apparent direction of movement. The toe is bounded by a pair of lateral ridges whose crests rise above its surface. The ridges are composed of en echelon segments. They, too, are striated on their inward-facing flanks. The snout is the downslope boundary of the earthflow. In plan, it is smoothly curved, with the concave side facing upslope. In profile, it is steep and smoothly curved concave downward.

The length of an earthflow, as measured from the base of the head scarp to the snout, is greater than its width, and its width is greater than its depth. The lateral boundaries are nearly parallel. In overall shape, it closely resembles a long tongue. There is no idealized size for an earthflow. Lengths of those I have examined range from 10 to 500 meters, widths range from 5 to 50 meters, and depths range from 46 centimeters to 10 meters.

On a large scale, the surface of an earthflow slopes smoothly from head scarp to snout. The longitudinal profile of the head is planar to slightly concave upward, whereas that of the toe is planar to convex upward. In detail, small bumps, hummocks, and closed depressions are present. During the summer, an earthflow surface consists of polygonal blocks of soil bounded by gaping cracks.

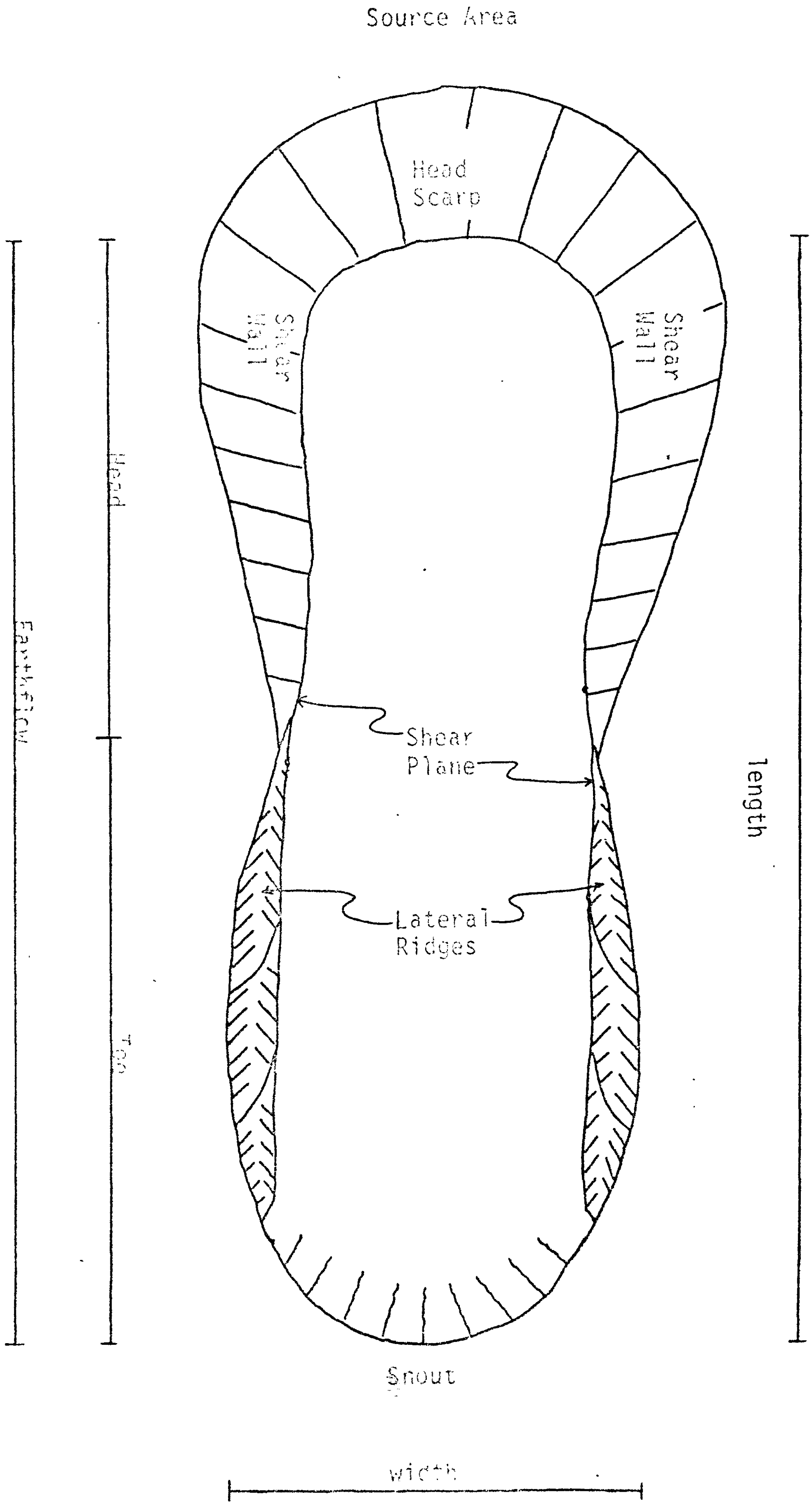


FIGURE 1: IDEALIZED EARTHFLOW

Material within an earthflow consists primarily of unconsolidated debris. Clay and silt-sized particles make up a majority of the volume.

The head and much of the toe of an earthflow move within a broad, shallow channel (Figure 2) which is bounded by a distinct shear plane. The snout itself may override the pre-existing ground surface.

Earthflows occur on moderately steep slopes in central Coast Ranges. They do not originate on valley floors. It is not known if there is a minimum slope necessary for their formation, but they have been reported on slopes as gentle as 7° (Krauskopf et al., 1939). Many earthflows come to rest before reaching the bases of the hillsides on which they originated.

Movement on earthflows is recurrent. It is reinitiated during the rainy winter months, and it stops during the summer. When active, earthflows move with average velocities ranging from a few millimeters to several meters per day. Short surges of much higher velocity, however, may also occur.

## SELECTION OF STUDY SITES

In order to identify regions within the central California Coast Ranges in which earthflows are present, I conducted an aerial reconnaissance on September 3, 1974, accompanied by Prof. Arvid Johnson of Stanford University. We searched several mountain ranges in close proximity to San Francisco Bay and identified six areas containing large numbers of active appearing earthflows. These areas are located on the index map, Figure 3. The clustering of large numbers of earthflows into these scattered areas is quite striking. The aerial search was followed by ground reconnaissance in all of the areas with abundant earthflows.

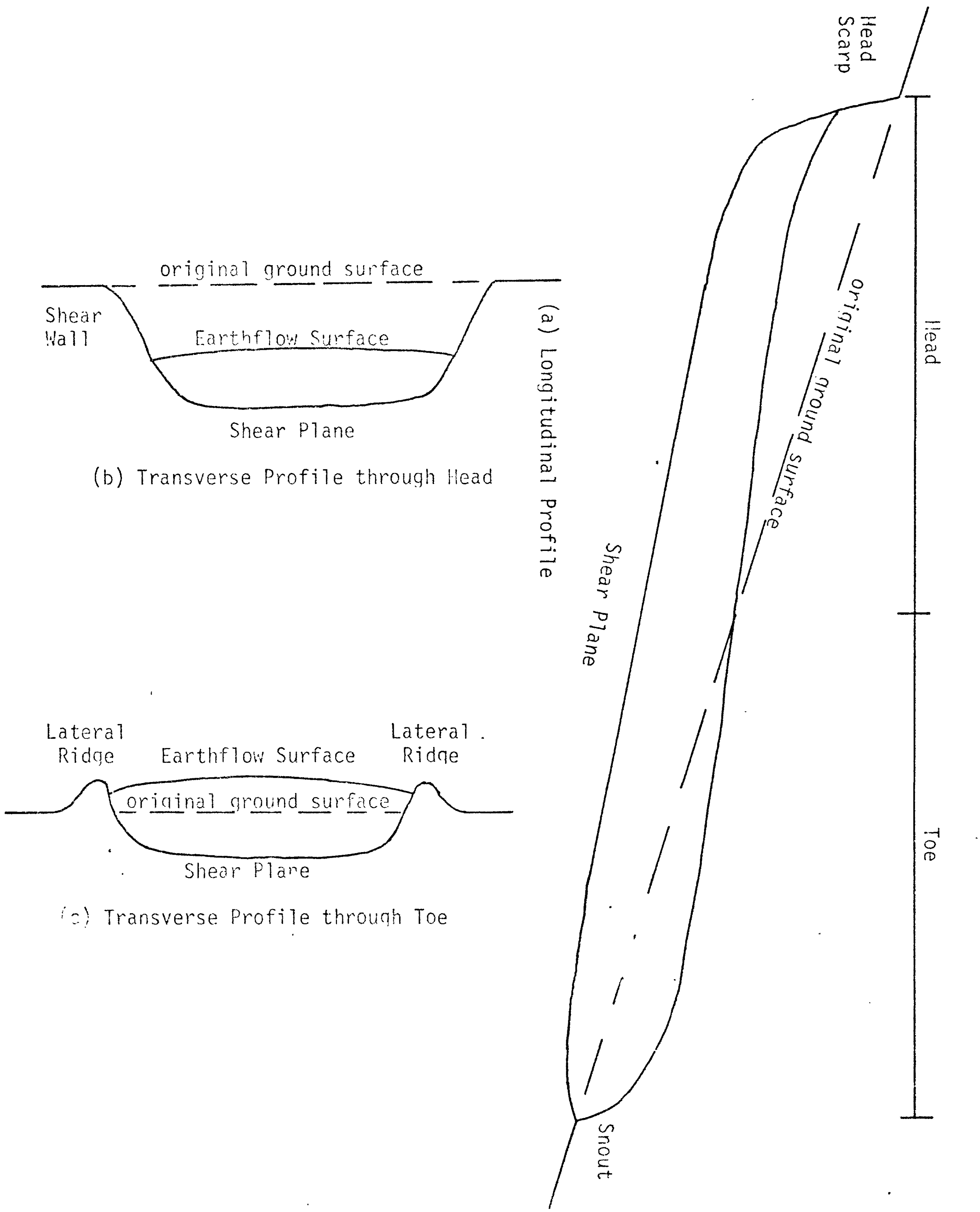


FIGURE 2: CROSS SECTIONS THROUGH IDEALIZED EARTHFLOW


FIGURE 3: AREAS NEAR SAN FRANCISCO BAY CONTAINING LARGE NUMBERS OF EARTHFLOWS

Scale 1: 1,000,000

Base Map: U.S.Geological Survey, 1970, State of California

In the central Coast Ranges, individual earthflows nearly always occur in conjunction with other earthflows and with landslides of other types. These earthflow and landslide complexes, hereafter called slides for the sake of brevity, can give large areas of a hillside a generally disrupted, jumbled, and chaotic appearance. Several such slides were examined in detail, and four were chosen for preliminary instrumentation. Examination on the ground showed that aerial observation had led to an overestimate of the number of earthflows which had been recently active. Since this field work was carried out near the end of central California's dry season, none of the earthflows were moving when they were first visited. All those slides chosen for instrumentation, however, showed abundant signs of recent activity, including steep, unvegetated scarps which had not been modified by erosion, general disruption of vegetation, and surfaces broken by abundant cracks of fresh appearance.

## DAVILLA HILL SLIDE

### Description

The Davilla Hill Slide is in the Eden Canyon area (Figure 3) near the head of Eden Canyon in northern Alameda County, California. It is approximately three miles WNW of the town of Dublin in the SE 1/4 of Sec. 29, T2S R1W, on the Dublin, California 7.5' topographic quadrangle. The slide occupies the floor of a small gentle valley which is a tributary of Eden Canyon. Plane table mapping (Figure 4) has delineated at least thirty different earthflows within this slide. Of these, at least four were active during the winter of 1974-1975. The entire slide is approximately 140 meters long and has a maximum width of approximately 25 meters. Measured depths of active earthflows ranged from 0.5 meters to greater than 1.1 meters.

The head of the valley above the earthflow tongues is covered with shallow debris slide* scars and is incised by two gullies, one of which contains a small earthflow. Downslope from the debris slides, in the axis of the valley, there are several earthflows. Their shear walls and lateral ridges rise more than a meter above the present earthflow surfaces. Some of the earthflows spill over onto the relatively flat surface of a landslide block. The downslope boundary of this block is the head scarp of another earthflow. This earthflow is bounded by a pair of shear walls. Outside of the shear walls, there are five old, revegetated earthflows. The two largest of these have piled up behind obstructions consisting of a fence, a group of bushes, and a large eucalyptus tree (Figure 4).

Below the fence (Figure 4), the Davilla Hill Slide consists of a series of earthflows confined, for the most part, between well defined shear walls and lateral ridges. The lateral ridges themselves are composite features. Each ridge consists of several <u>en echelon</u> segments. In several places, the material forming the ridges has flowed around obstructions (generally trees) and formed a number of distinct, small tongues. Both walls of the lateral ridges are characteristically steep, and the tops are rounded. They rise to heights of up to 0.6 meters above the earthflow surfaces. The downslope boundary of the Davilla Hill Slide consists of two distinct earthflow snouts with blunt ends 0.6 to 1.0 meters high.

The earthflow surfaces are broken by internal scarps and by gashes up to several centimeters wide and 0.6 meters deep. Upslope from the fence (Figure

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*A debris slide is a shallow, planar landslide involving unconsolidated debris which moves rapidly and with a great amount of internal deformation.

4), the slide surface generally retains the cover of grasses and thistles characteristic of the surrounding hillside. Below the fence, the surface is primarily bare clay with scattered thistles and patches of grass. There, it is shaded by California bay laurels, eucalyptus trees, and poison oak bushes.

Inactive portions of the slide remained firm throughout the year. As earthflows became active, however, their surfaces became soft, so that a person would sink up to his knees in mud in many places. In fact, sheep often become mired down and die in active earthflows in Eden Canyon (Mrs. Perry Davilla, 1975, oral commun.). The boundaries of active earthflow movement could be mapped in a general way simply by testing the firmness of the surface. It was noticed, however, that many uncased auger holes in moving earthflows remained open and relatively undeformed while they were transported several centimeters downslope.

The Davilla Hill Slide is underlain by bedrock belonging to the Orinda Formation (Hall, 1952). In the Eden Canyon Area, the Orinda Formation is made up of poorly consolidated, thinly interbedded, non-marine shales, mudstones, siltstones, sandstones, conglomerates, and limestones of Pliocene age. In the vicinity of the slide, the dip of the beds is steep to overturned, and the strike is sub-parallel to the axis of the small valley in which the Davilla Hill Slide is located. Beneath and immediately adjacent to the slide, auger borings penetrated into bedrock at depths of 2.2, 2.5, and 4.2 meters (Borings I, VI, and IX, respectively, on Figure 4). In and above the debris slide scars (Figure 4), weathered sandstone and shale is present beneath a cover of top-soil approximately 0.3 meters thick. Rock is exposed in one of the gullies in the head of the valley. There it consists of highly weathered, very closely fractured, very soft, medium gray, calcareous shale. As encountered in borings, the bedrock consists of soft shales, mudstones, and fine grained sandstones.

Material in the earthflows consists of a clayey silt to silty clay matrix, with crumbling pebbles of shale, mudstone, and sandstone forming a small fraction of the volume. There are no significant differences between the composition of the material involved in recent earthflows and that of material beneath and beside them, and it is probable that much of the unconsolidated material in the small valley is composed of old earthflow deposits. Several borings, including one not on the slide, encountered horizons rich in organic material, and these are interpreted as being old topographic surfaces which have been overridden by earthflows. In boreholes on active earthflows, shear planes were marked by color changes and by sharp increases in stiffness.

## Observations and Measurements of Displacements

### Surface Displacements

Several lines of stakes were placed transversely across earthflows on the Davilla Hill Slide in order to measure surface displacements during the winter of 1974-1975. The end points of the lines rested outside the observable limits of active movement. To measure displacements, a surveyor's tape was stretched between the two end stakes of each line. The displacement of each stake in the horizontal plane was then measured using a plumb line and folding ruler. By using this method, many measurements of the positions of stakes could be made by one or two people in a short time. Errors in individual measurements were less than three centimeters where the total displacement was less than one meter. Where the displacement exceeded one meter, however, errors in measurement may have been as large as 15 centimeters. Measurements were begun on October 3, 1974, and a total of six lines of stakes (Figure 4) were placed across the slide prior to April 1975. Some of the stakes were buried by moving earthflows, and some were trampled or carried off by livestock.

The first measurable surface displacements were recorded on February 21, 1975. The seasonal onset of movement can be definitely bracketed between February 4 and February 21 and probably followed heavy rains of February 13 and 14. Displacements of the stakes in three lines are plotted in Figures 5-8. The ordinates of these plots are exaggerated in order to show the downslope movements more clearly, and this exaggeration causes a line of stakes to appear more curved than it actually is.

Stake Line # 1 (Figure 4) crossed the toe of one earthflow and the source area of another. Three stakes on the earthflow toe recorded downslope displacements of 6, 9, and 11 centimeters between October 3, 1974 and April 23, 1975. These displacements were due to small scale local slumping and not to renewed movement on the earthflow. Displacements of the other stakes were smaller than the limit of error in measurement.

Stake Line # 2 (Figure 4) crossed the toe of an earthflow. The only two stakes on the earthflow were buried by livestock and lost between February 25 and March 8. Before they were buried, they recorded displacements of 60 and 62 centimeters. Stake Line # 2A (Figure 4) was placed on this tongue on March 8. Displacements of stakes in this line are plotted in Figure 5. Movements on this earthflow ceased between April 23 and June 19, 1975.

The earthflow crossed by Lines # 2 and 2A forms the source area of another earthflow. Movements of the latter were monitored by a single stake. Displacements of this stake, identified as "yellow flag", are plotted in Figure 8.

Movements of third earthflow were monitored by Stake Lines # 3 and 3A. Displacements of stakes in these lines are plotted in Figures 6 and 7 respectively. Several observations were made while this tongue was active. First, its head scarp grew from an initial height of a few centimeters to a final

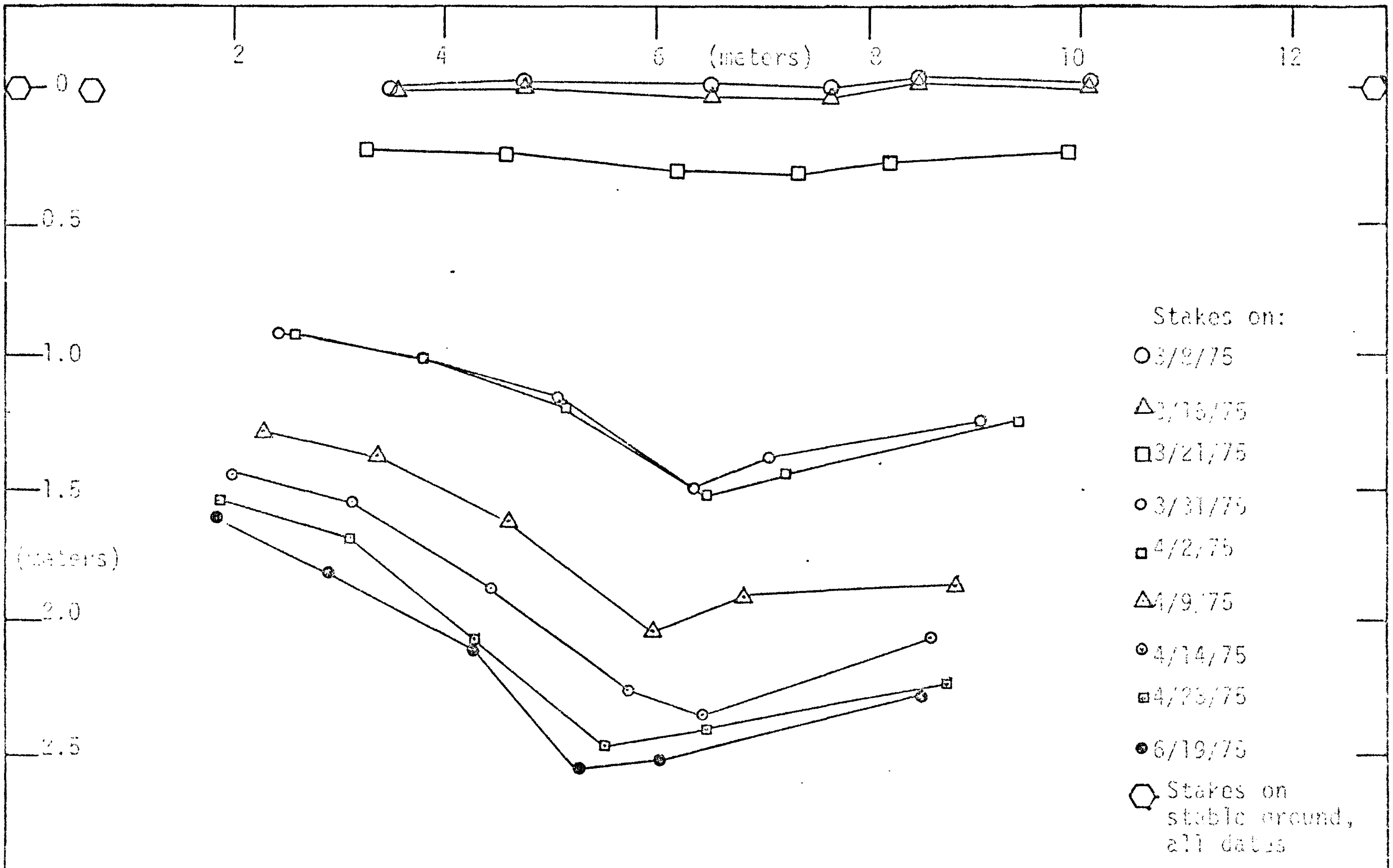


FIGURE 5: DAVILLA HILL SLIDE, STAKE LINE 2A

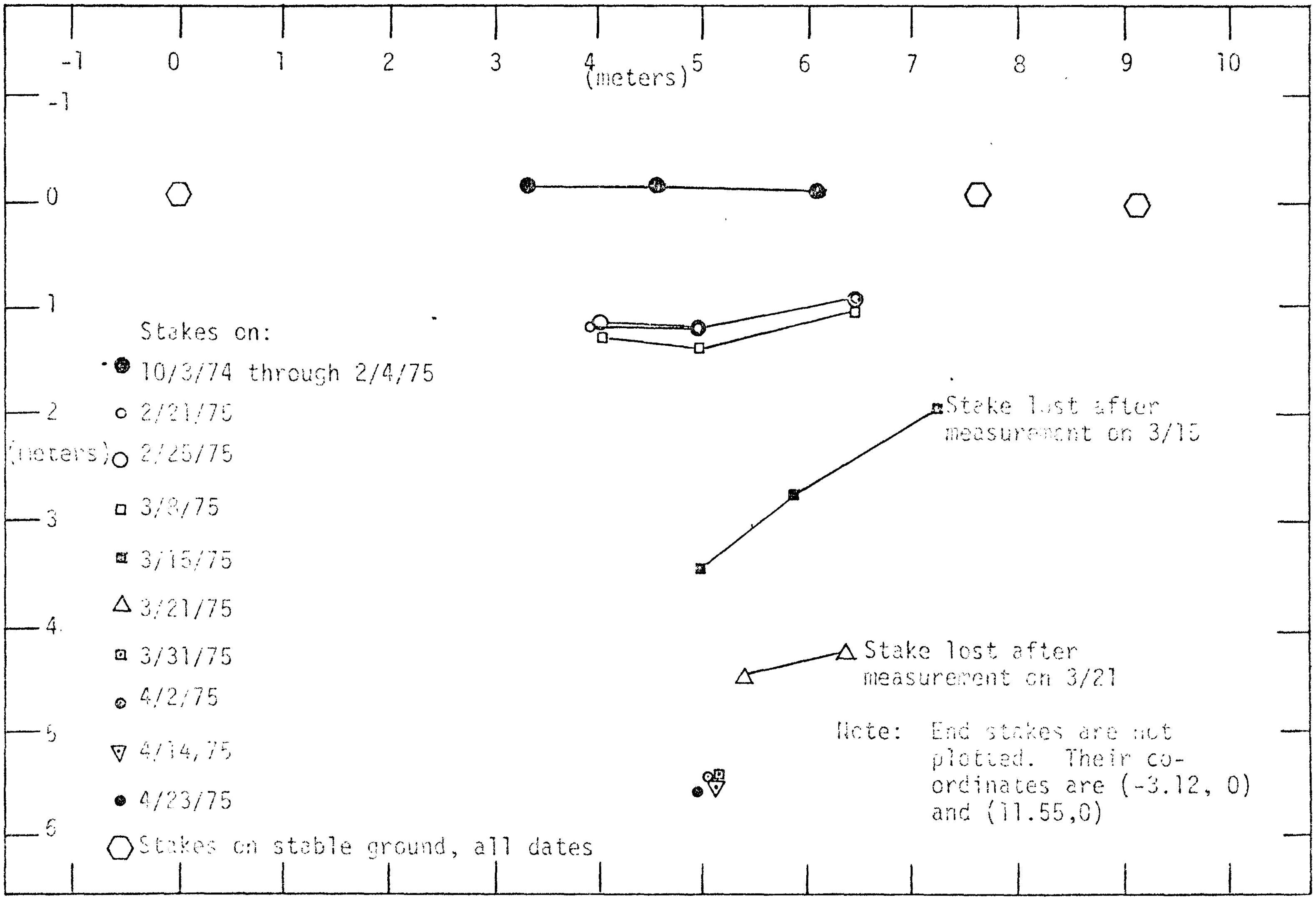


FIGURE 6: DAVILLA HILL SLIDE, STAKE LINE 3

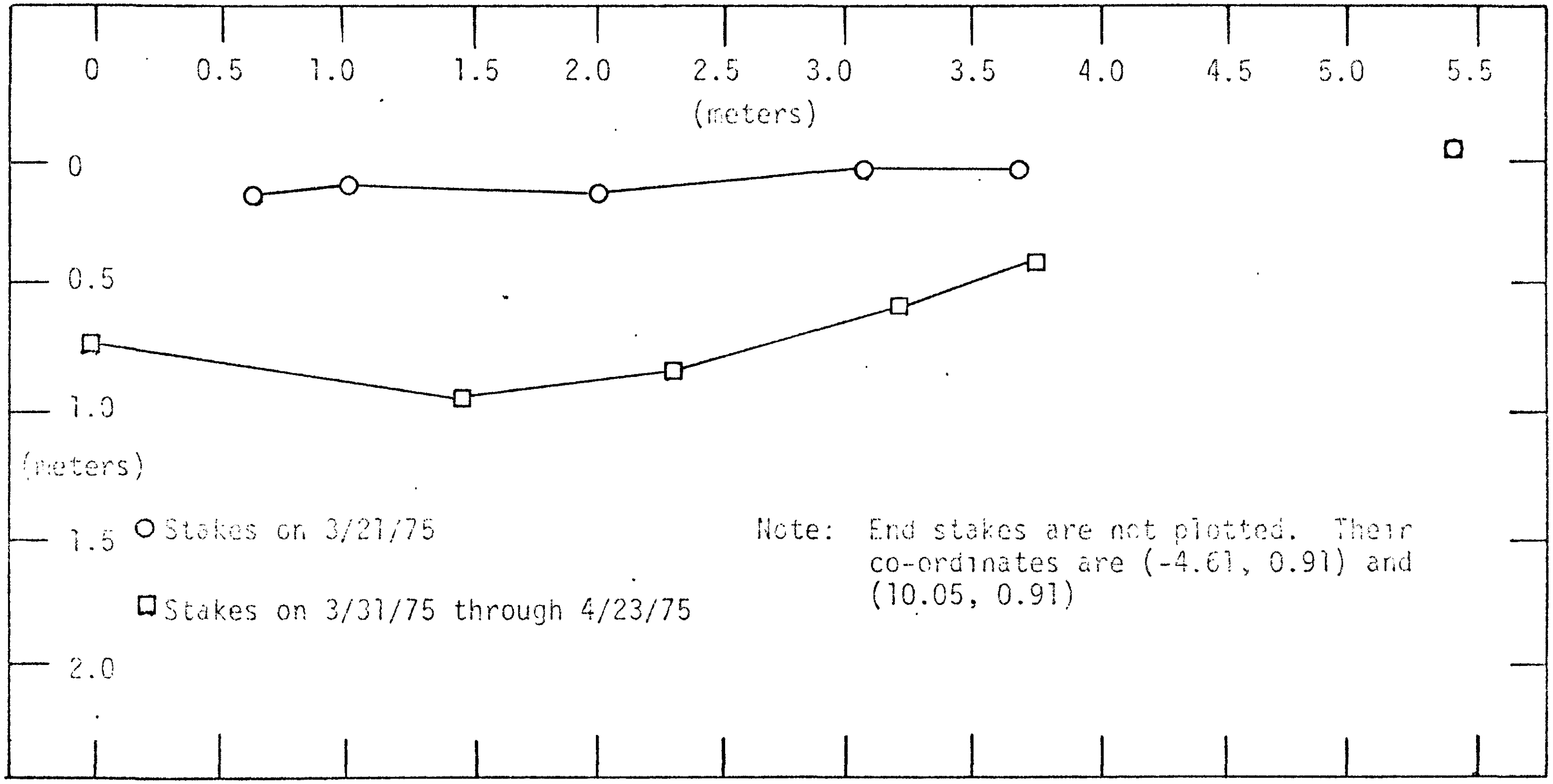


FIGURE 7: DAVILLA HILL SLIDE, STAKE LINE 3A

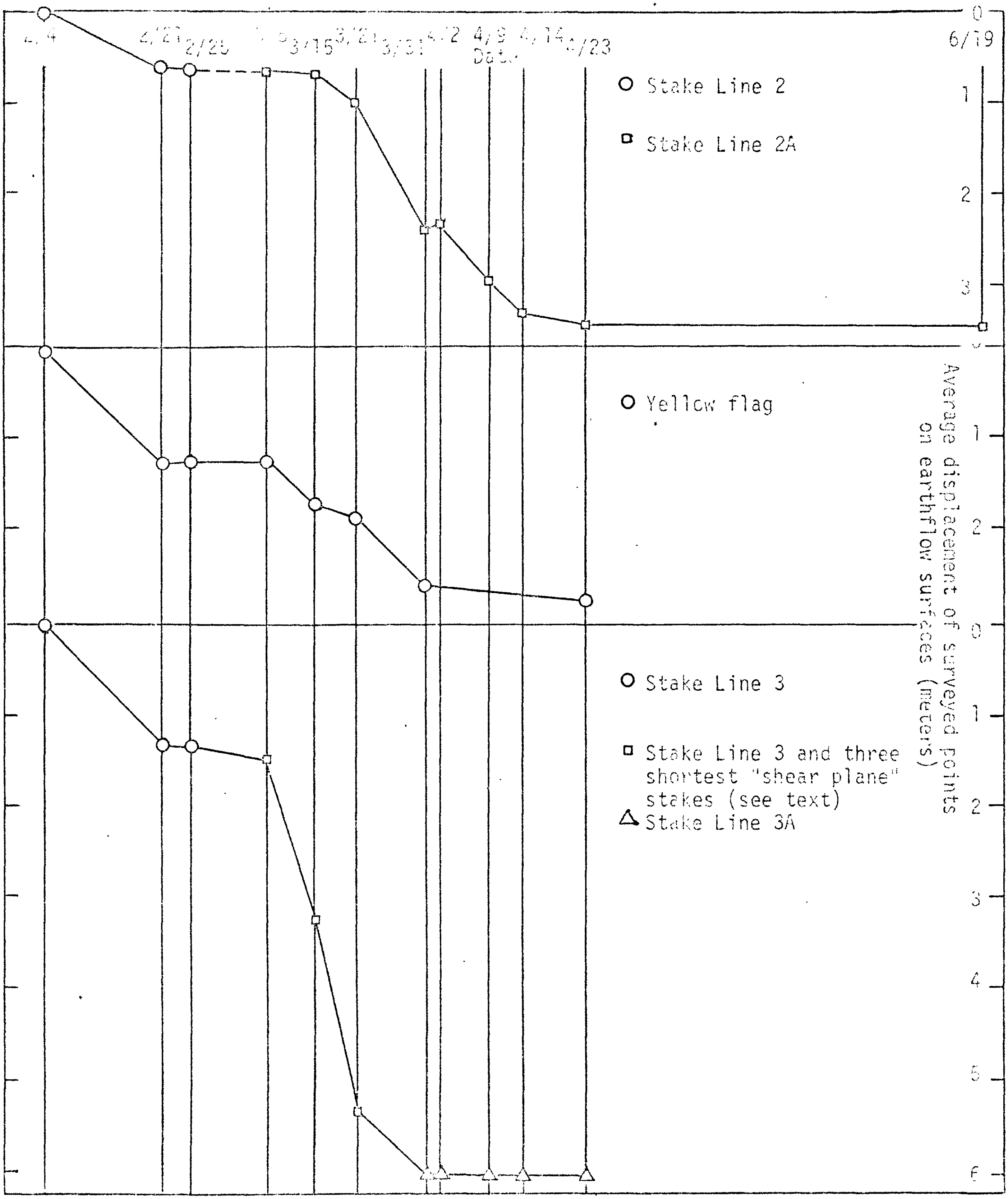


FIGURE 8: CUMULATIVE [illegible] DISPLACEMENTS OF THREE EARTHFLOW TONGUES, [illegible] SLIDE, FEB[illegible]–JUNE 19, 1975

height of greater than two meters. Second, stakes in Line # 3 tilted progressively forward until they were nearly horizontal and then were buried by advancing mud. Elsewhere in the Davilla Hill Slide, stakes in active earthflows remained nearly vertical. Third, movement of this earthflow had ceased by March 31, 1975. Sometime between March 21 and March 31, a gully was cut through it, and drainage provided by the gully probably was intrumental in stabilizing it.

Stake Line # 4 is immediately downslope from the snout of the earthflow crossed by Lines 3 and 3A. Two stakes lie on the old earthflow surface between the lateral ridges (Figure 4). Both of these stakes moved downslope 14 centimeters between March 21 and March 31, 1975. On March 31, a layer of mud five centimeters deep was covering one of the stakes. There were no other movements of stakes in Line 4.

Figure 8 is a plot of the total horizontal displacements as functions of time for three of the active tongues on the Davilla Hill Slide. Comparison of the plots shows that the rates of movement were not consistent from earthflow to earthflow. For instance, the earthflow crossed by Lines 3 and 3A moved a great deal between February 4 and 21 and between March 8 and 21. Its movement slowed from March 21 to 31, and it moved very little between February 21 and March 8 or after March 31. The earthflow crossed by Line 2A moved little between March 8 and March 15. Then its velocity increased and reached a fairly high rate which continued through April 14.

No stake lines crossed the fourth active earthflow. Its activity was inferred from the dramatic softening of the material which was first noted on March 15.

## Subsurface Displacements

Subsurface displacements within one earthflow in the Davilla Hill Slide were measured by placing a stack of plywood disks in borehole DHS 10 (Figure 4) on April 9, 1975. The disks were 3.33 centimeters in diameter and 1.27 centimeters thick. They had small holes drilled through their centers. The stack was assembled by passing a string through the small holes and taping the string to the bottom disk. The stack was then placed in a length of plastic pipe which was taped shut at one end. The assembly was placed in the hole augered to a depth of 79 centimeters. The hole was checked with a plumb bob and was found to be vertical. The tape was broken, and the casing and string were removed so that the chips were free to move relative to each other. When viewed on April 14, the top three chips were exposed above the ground surface and were riding on top of the buried portion of the stack.

The disks were excavated on July 25, 1975. Figure 9 is a plot of the total displacement of each disk as a function of depth. A distinct plane, marked by prominent slickensides, existed at a depth of 49 centimeters. Ninety-four percent of the total displacement on this part of the earthflow took place on the shear plane. Below the shear plane, the disks had not moved, and the annular space created by the removal of the casing was still open.

Subsurface displacements of another earthflow on the Davilla Hill Slide were measured by driving stakes made of aluminum angle bar to different depths along a section of Line # 3 (Figure 4) and measuring their tilts. Stakes, spaced 15 to 60 centimeters apart, were driven to depths of 15, 30, 46, 71, and 91 centimeters on February 25, 1975. When observed on March 8, the shortest stake had fallen over due to the softness of the mud near the surface. Stakes 30 and 46 centimeters long had tilted 1° and 2° respectively, whereas

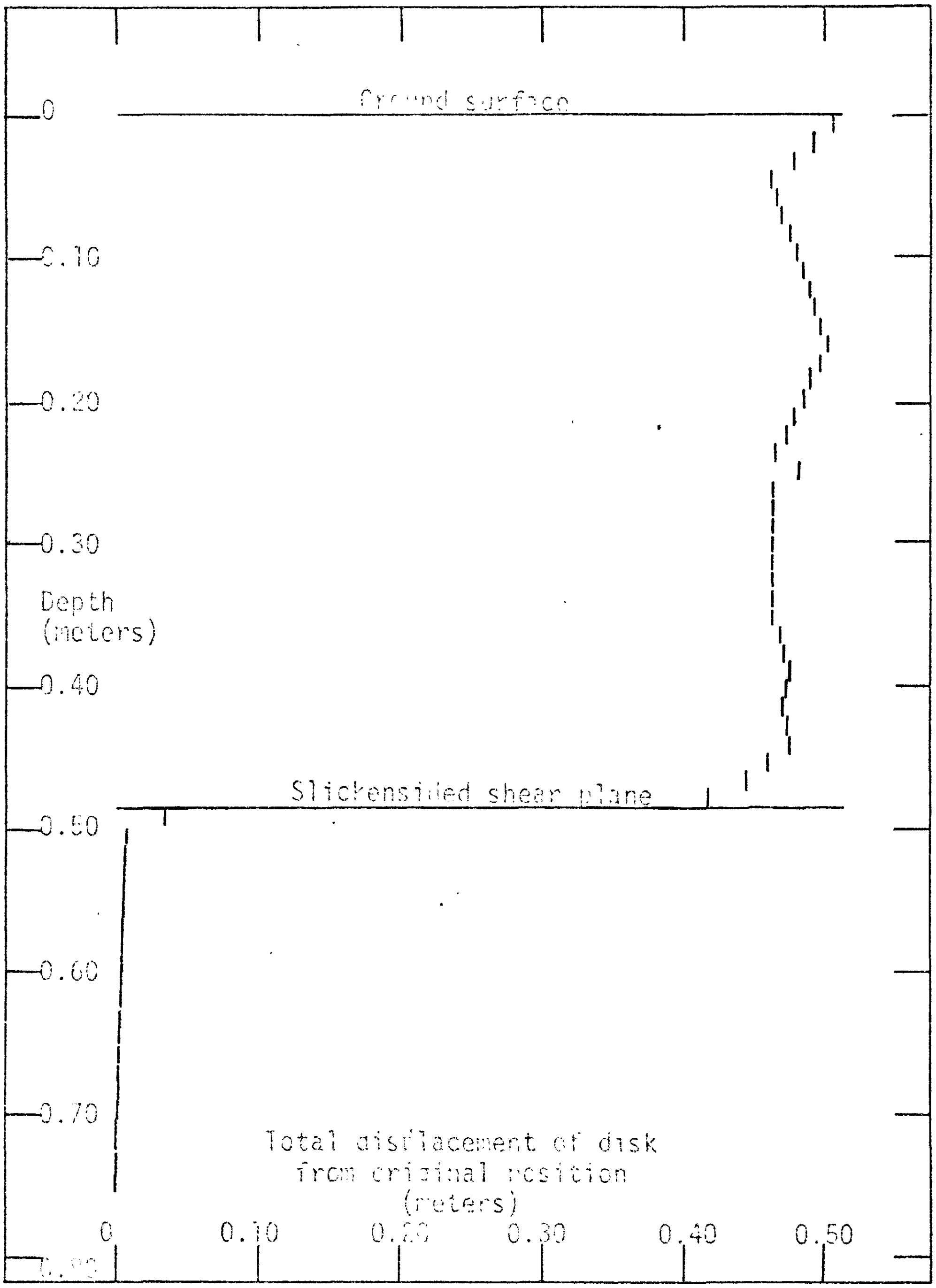


FIGURE 9. POSITION OF WOODEN DISKS DEFORMED
BY EARTHFLOW MOVEMENT, DAVILLA HILL SLIDE

the two longest stakes had tilted 14° and 15° respectively. By March 15, the 30 and 46 centimeter stakes had tilted 14° and 15° respectively, and the longer stakes were tilted nearly horizontal and almost buried by mud. These measurements established that the depth of the shear plane was between 46 and 71 centimeters.

## Ground Water Levels

During the time when earthflows in the Davilla Hill Slide were active, water levels were measured in uncased boreholes. These observations provide only a rough measurement of the actual groundwater conditions because of effects such as the mixing of water from strata with different piezometric surfaces, long lag times for equilibration of the water level in an open borehole, filling of a borehole with runoff from the surface, and evaporation. Measured water levels are plotted in Figure 10. With one exception, water levels in active earthflows were within 23 centimeters of the ground surface. The exception, the measurement in DHS 3 on February 25, was made only four days after the hole was drilled, and the water level had probably not yet equilibrated. Water was generally standing at or near the surface in cracks on active earthflows. The water level in borehole DHS 1, located on a portion of the slide which was not active, was also quite close to the surface on all dates when it was measured. Water levels in other inactive portions of the slide, however, were generally more than 20 centimeters below the ground surface.

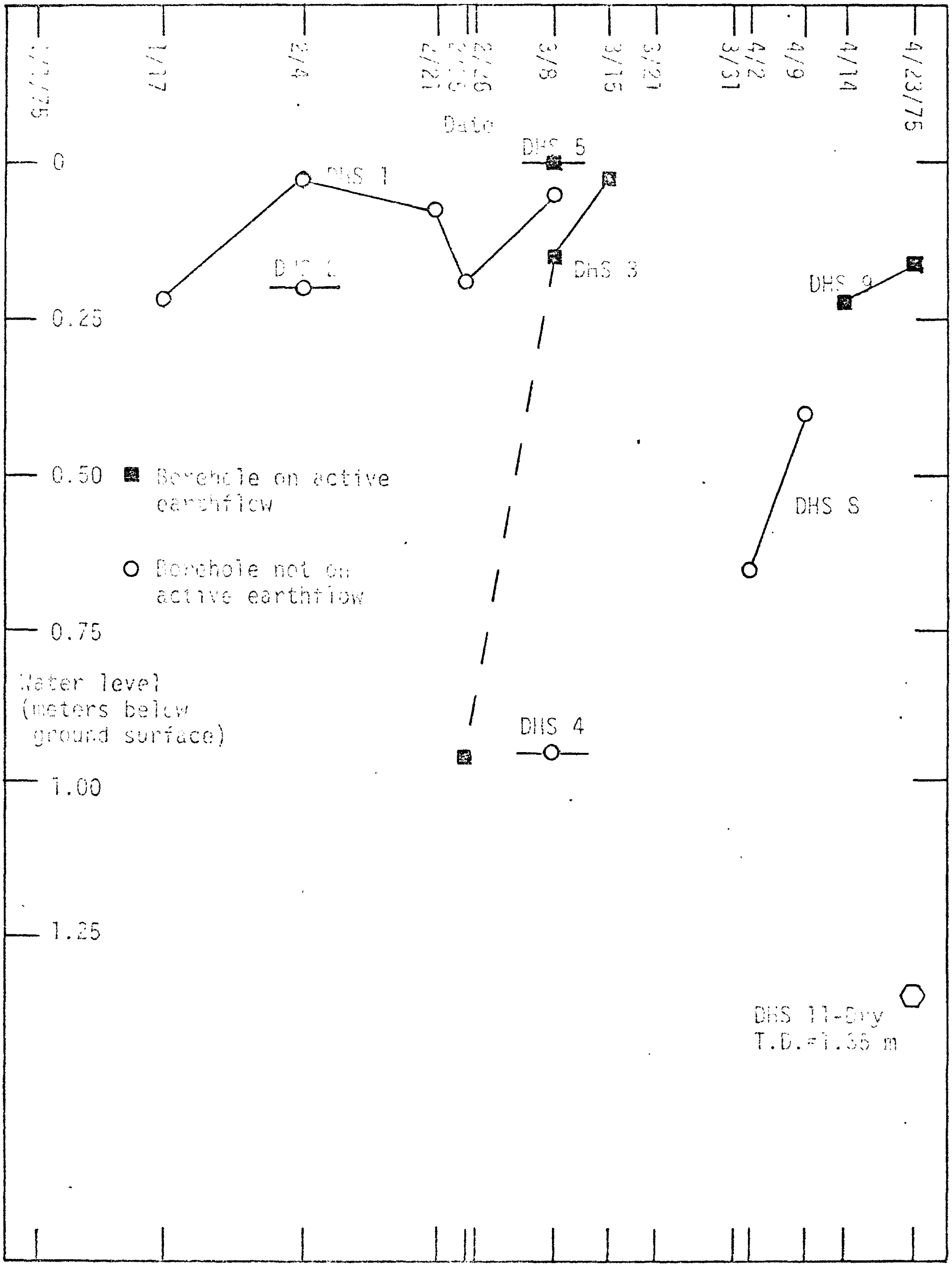


FIGURE 10: [illegible] HILL SLOPE, WATER LEVELS IN BOREHOLES

## Physical Properties Tests

Natural water contents, Atterberg limits, grain size distributions, and specific gravities were determined with samples from auger holes on the Davilla Hill Slide. In addition, shear strengths of material in active earthflows were measured with a field vane. "Field densities" were also measured for a small number of samples.

Natural water contents were measured by placing a sample, usually weighing between 50 and 120 grams, into an air tight can. The samples were weighed in the laboratory at the end of the day, were oven dried for at least 22 hours, and were weighed again. The natural water content was computed as the weight of water lost on drying divided by the weight of the dried soil.

Water content data are plotted in Figure 11. Figure 11(a) contains data for boreholes on the earthflow crossed by Stake Lines 3 and 3A, Figure 11(b) contains data from the earthflow crossed by Lines 2 and 2A, and Figure 11(c) compares water content profiles from an active earthflow (DHS 5) and an inactive earthflow (DHS 4). Results of the natural water contents are also listed in Table 1. The depths of shear planes were interpreted from color changes and from distinct increases in stiffness. Water contents of samples taken from active earthflows are marked with an asterisk in Table 1. Inspection of the table shows that, except for where the earthflow has overridden a horizon rich in organic matter, there is a sharp decrease in water content immediately below the shear plane. The average water content of 25 samples taken from the moving earthflows was 38.4%. That of 22 samples taken from inactive earthflows on the same dates, excluding samples rich in organic matter, was 31.4%. "Borehole" DHS 13 (the pit excavated to extract the wooden disks) is of special interest. Samples taken at or within one centimeter

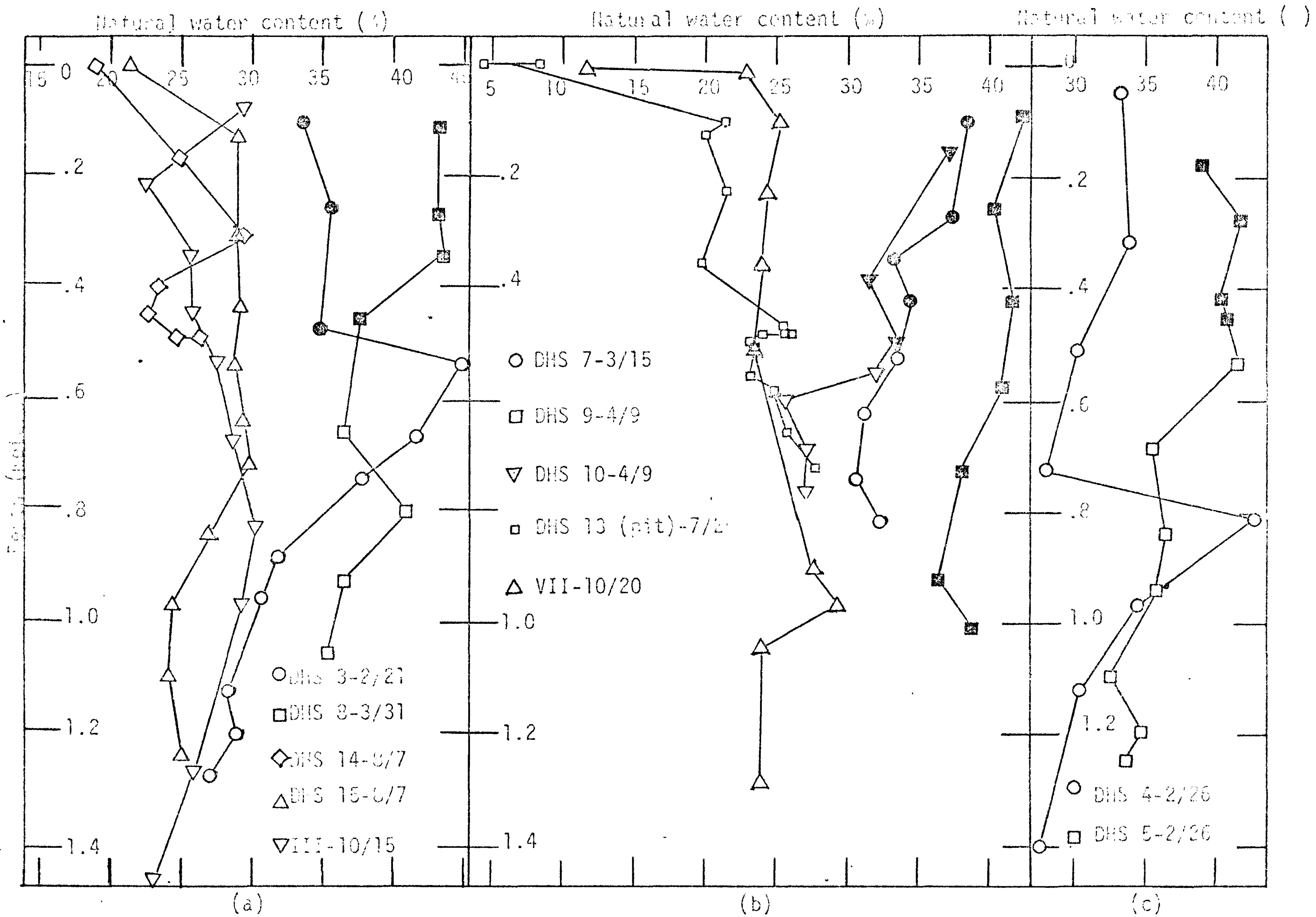


FIGURE 11: NATURAL WATER CONTENTS, DAVILLA HILL SLIDE
Solid symbols indicate samples within actively moving earthflows. All samples were taken in 1975.

TABLE 1. DAVILLA HILL SLIDE: NATURAL WATER CONTENTS

| Boring | Date drilled | Depth of shear plane (meters) | Depth of samples (meters) | No. of samples | Natural water content % ** Average | Range | Remarks |
|---|---|---|---|---|---|---|---|
| DHS-2 | 1/17/75 | unknown | 0.43 to 1.60 | 5 | 29.6 | 26.0-32.9 | |
| DHS-3 | 2/21/75 | 0.47 | 0.10 to 0.47* | 3 | 34.4 | 33.3-35.4 | |
| | | | 0.47 to 0.88 | 4 | 38.6 | 31.5-44.5 | Abundant organic material. |
| | | | 0.95 to 1.27 | 4 | 28.5 | 26.9-30.2 | |
| DHS-4 | 2/26/75 | 0.76 | 0.08 to 0.73 | 3 | 31.4 | 28.0-34.0 | Earthflow inactive on this date. |
| | | | 0.81 | 1 | 42.7 | | Abundant organic material. |
| | | | 0.97 to 1.40 | 3 | 30.6 | 27.4-34.3 | |
| DHS-5 | 2/26/75 | 0.47 | 0.18 to 0.46* | 4 | 40.4 | 39.0-41.7 | |
| | | | 0.66 | 1 | 41.5 | | Abundant organic material. |
| | | | | 6 | 34.8 | 32.5-36.4 | |
| DHS-6 | 3/15/75 | | 0.09 | 1 | 35.6 | | Not on earthflow. |
| | | | 0.24 | 1 | 33.5 | | |
| | | | 0.33 to 1.94 | 12 | 30.4 | 28.3-32.5 | |

** Natural water content $= \frac{\text{weight water}}{\text{weight solids}} \times 100\%$

* Material sampled within actively moving earthflow mass.

TABLE 1. (Continued) DAVILLA HILL SLIDE: NATURAL WATER CONTENTS

| Boring | Date drilled | Depth of shear plane (meters) | Depth of samples (meters) | No. of samples | Natural water content % ** Average | Range | Remarks |
|---|---|---|---|---|---|---|---|
| DHS-7 | 3/15/75 | 0.47 | 0.10 to 0.27* | 2 | | 37.7-38.9 | |
| | | | 0.34 to 0.42* | 2 | | 33.5-34.7 | |
| | | | 0.52 to 0.81 | 4 | 32.1 | 30.9-33.7 | |
| DHS-8 | 3/31/75 | 0.61 | 0.12 to 0.48* | 4 | 41.9 | 37.8-43.4 | |
| | | | 0.66 to 1.05 | 4 | 37.3 | 35.3-40.9 | |
| DHS-9 | 4/9/75 | Below TD of boring | 0.09 to 0.57* | 4 | 41.5 | 40.5-42.5 | |
| | | | 0.73 to 1.05* | 3 | 38.0 | 36.6-39.0 | |
| DHS-10 | 4/9/75 | 0.53 | 0.15* | 1 | 37.3 | | Wood chip stack placed in this hole. |
| | | | 0.38 to 0.50* | 2 | | 31.8-33.9 | |
| | | | 0.54 to 0.76 | 4 | 28.15 | 25.8-32.1 | |
| DHS-11 | 4/14/75 | | 0.10 to 1.27 | 11 | 31.3 | 27.3-36.0 | On hillside above source area. |
| DHS-12 | 4/14/75 | | 0.06 to 1.16 | 11 | 23.7 | 20.7-30.5 | On hillside above source area. |

TABLE 1. (Continued) DAVILLA HILL SLIDE: NATURAL WATER CONTENTS

| Boring | Date drilled | Depth of shear plane (meters) | Depth of samples (meters) | No. of samples | Natural water content % ** Average | Range | Remarks |
|---|---|---|---|---|---|---|---|
| DHS-13 | 7/25/75 | 0.48 | Surface | 2 | | 4.6-8.3 | Pit excavation for wood chip stack. |
| | | | 0.13 to 0.36 | 4 | 20.9 | 19.8-21.5 | |
| | | | 0.48 | 3 | 25.4 | 24.2-26.3 | |
| | | | 0.47 | 1 | 25.6 | | Just above shear plane. |
| | | | 0.49 | 1 | 23.1 | | Just below shear plane. |
| | | | 0.51 | 1 | 23.7 | | |
| | | | 0.56 | 1 | 23.2 | | |
| | | | 0.58 to 0.71 | 3 | 25.9 | 24.9-27.1 | |
| DHS-14 | 8/7/75 | 0.46 | Surface | 1 | 19.0 | | |
| | | | 0.16 to 0.30 | 2 | | 25.0-29.3 | |
| | | | 0.39 to 0.48 | 4 | 24.3 | 22.9-26.3 | Abundant organic material. |
| DHS-15 | 8/7/75 | 0.46 | Surface | 1 | 21.6 | | |
| | | | 0.18 to 0.30 | 2 | 29.0 | 29.0-29.0 | |
| | | | 0.43 to 0.71 | 4 | 29.3 | 28.9-29.4 | Abundant organic material. |
| | | | 0.84 to 1.23 | 4 | 25.0 | 24.0-26.7 | |

TABLE 1. (Continued) DAVILLA HILL SLIDE: NATURAL WATER CONTENTS

| Boring | Date drilled | Depth of shear plane (meters) | Depth of samples (meters) | No. of samples | Natural water content % ** Average | Range | Remarks |
|---|---|---|---|---|---|---|---|
| I | 10/23/75 | 0.84 | 0.01 | 1 | 10.7 | | |
| | | | 0.05 to 0.42 | 4 | 24.8 | 22.7-25.9 | |
| | | | 0.74 | 1 | 32.8 | | |
| | | | 1.09 to 1.85 | 4 | 25.5 | 22.7-29.7 | |
| | | | 2.71 | 1 | 19.4 | | Bedrock |
| III | 10/15/75 | 0.48 | 0.08 to 0.44 | 4 | 26.0 | 22.7-29.5 | |
| | | | 0.53 to 0.97 | 4 | 29.1 | 27.7-29.5 | Varying amounts of organic material. |
| | | | 1.27 to 1.46 | 2 | | 26.0-23.3 | |
| IV | 10/22/75 | 0.71 | 0.003 | 1 | 11.1 | | |
| | | | 0.01 | 1 | 20.9 | | |
| | | | 0.13 to 0.57 | 4 | 26.5 | 25.5-28.5 | |
| | | | 0.70 | 1 | 31.9 | | |
| | | | 0.74 to 0.76 | 2 | | 35.9-32.4 | |
| V | 10/22/75 | unknown | 0.06 to 1.16 | 6 | 24.1 | 22.4-26.5 | |
| | | | 0.28 | 1 | 18.9 | | Shale pebbles. |
| | | | 1.40 to 2.05 | 6 | 29.1 | 26.7-30.5 | |

TABLE 1. (Continued) DAVILLA HILL SLIDE: NATURAL WATER CONTENTS

| Boring | Date drilled | Depth of shear plane (meters) | Depth of samples (meters) | No. of samples | Natural water content % ** Average | Range | Remarks |
|---|---|---|---|---|---|---|---|
| VII | 10/20/75 | 0.90 | 0.003 | 1 | 11.7 | | |
| | | | 0.01 to 0.51 | 5 | 24.0 | 23.0-25.1 | |
| | | | 0.90 to 0.97 | 2 | | 27.7-29.3 | Zone disturbed to movement on shear plane. |
| | | | 1.04 to 1.28 | 2 | 24.0 | 24.0-24.0 | |
| IX | 10/16/75 | | 0.25 to 1.60 | 6 | 23.2 | 21.5-28.5 | Not on earthflow. |
| | | | 3.58 | 1 | 31.0 | | |
| | | | 3.83 to 4.14 | 2 | | 24.6-25.2 | |
| | | | 4.29 to 4.37 | 2 | | 19.3-18.9 | Bedrock |
| X | 11/4/75 | | 0.01 | 1 | 29.1 | | Not on earthflow. |
| | | | 0.02 to 0.97 | 10 | 22.0 | 20.0-26.3 | |

above the shear plane had markedly higher water contents than samples taken outside this interval.

Table 2 summarizes Atterberg limit, grain size, and specific gravity measurements of samples from the Davilla Hill Slide. Grain sizes were determined using combined sieve and hydrometer analyses. Tests were performed using standard procedures described in Lambe (1951).

Table 3 lists field densities. Field density samples were obtained by pushing a thin walled aluminum cylinder 9.8 cm. in diameter and approximately 10.5 cm. high, into the soil and trimming around it in the field to obtain planar top and bottom surfaces. Samples were weighed, and the volumes of the cylinders were computed. Natural water contents were obtained from small samples of the trimmings. Values of specific gravity of solids were obtained from determinations in the nearest borehole. All samples were taken on April 23, 1975.

Shear strengths were measured at nine locations within active earthflows field vane. Nine determinations were made at depths of from 30 to 50 centimeters on April 9, 1975 and the results are shown in Table 4.

## Discussion

The Davilla Hill Slide contains remnants of many old earthflows which have been partially reworked by younger ones. All four earthflows active during the winter of 1974-1975 were mobilized out of old earthflow deposits. The measured displacements of the tongues were small compared with the overall length of the slide, so it appears that material is reworked several times before reaching the foot of the slide. As judged by visual inspection, Atterberg limits, and grain size distributions (Table 2), the slide material

TABLE 2

DAVILLA HILL SLIDE: ATTERBERG LIMITS, GRAIN SIZES, AND SPECIFIC GRAVITIES

| Boring | Sample | Depth (meters) | Plastic limit % of dry wt. | Liquid limit % of dry wt. | % Gravel by weight | % Sand by weight | % Silt by weight | % Clay by weight | Specific gravity of solids | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| DHS-2 | 1 | 0.52 | 29.8 | 49.4 | | | | | | |
| | 2 | 0.61 | | | 0.1 | 6.5 | 56.0 | 37.5 | | |
| | 3 | 0.88 | 28.9 | 57.5 | | | | | | |
| | 4 | 0.98 | | | 0.1 | 3.2 | 48.8 | 48.0 | | |
| | 5 | 1.43 | 30.9 | 58.7 | | | | | | |
| | 6 | 1.52 | | | | 5.5 | 53.0 | 41.5 | | |
| DHS-3 | 1 | 0.40 | 30.3 | 50.8 | 0.2 | 1.0 | 54.1 | 44.8 | 2.74 | Organic |
| | 2 | 0.67 | 32.0 | 64.5 | 0.04 | 5.0 | 35.2 | 59.8 | 2.63 | |
| | 3 | 0.82 | 30.9 | 67.7 | 0.01 | 3.3 | 52.8 | 43.9 | 2.72 | |
| | 4 | 1.07 | 28.9 | 58.4 | 0.1 | 2.7 | 56.7 | 40.6 | 2.73 | |
| DHS-4 | 1 | 0.15 | 31.0 | 58.8 | | 0.7 | 56.5 | 42.8 | 2.75 | |
| | 2 | 0.61 | 28.6 | 53.0 | 0.1 | 0.8 | 46.1 | 53.0 | 2.76 | Organic |
| | 3 | 0.91 | 38.8 | 68.4 | 3.3 | 7.7 | 43.8 | 45.2 | 2.60 | Organic |
| | 4 | 1.31 | 27.3 | 53.2 | 0.04 | 6.3 | 55.1 | 38.5 | 2.70 | |
| DHS-5 | 1 | 0.34 | 27.7 | 51.1 | 0.3 | 3.5 | 47.1 | 49.1 | 2.75 | |
| | 2 | 0.52 | 33.1 | 68.4 | 0.02 | 2.3 | 50.2 | 47.9 | 2.72 | |
| | 3 | 1.19 | 31.6 | 62.8 | 0.7 | 3.8 | 42.1 | 53.5 | 2.71 | |

TABLE 2 (Continued)

DAVILLA HILL SLIDE: ATTERBERG LIMITS, GRAIN SIZES, AND SPECIFIC GRAVITIES

| Boring | Sample | Depth (meters) | Plastic limit % of dry wt. | Liquid limit % of dry wt. | % Gravel by weight | % Sand by weight | % Silt by weight | % Clay by weight | Specific gravity of solids | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| DHS-6 | 1 | 0.40 | 28.0 | 57.2 | | 7.6 | 52.9 | 39.5 | 2.67 | |
| | 2 | 0.98 | 25.7 | 53.2 | | 7.8 | 51.6 | 40.6 | 2.71 | |
| | 3 | 1.46 | 27.5 | 50.0 | | 6.8 | 55.4 | 37.8 | 2.68 | |
| DHS-7 | 1 | 0.27 | 28.7 | 46.3 | | | | | 2.63 | |
| | 2 | 0.43 | 25.1 | 42.0 | | 9.0 | 58.2 | 32.8 | 2.68 | |
| | 3 | 0.76 | 29.4 | 55.6 | | 6.0 | 57.0 | 37.0 | 2.64 | |
| DHS-11 | 1 | 0.42 | 38.1 | 70.1 | | 1.1 | 48.3 | 50.6 | 2.65 | On hillside above source of earthflow. |
| | 2 | 0.85 | 32.3 | 63.3 | | 0.6 | 54.4 | 45.0 | 2.69 | |
| | 3 | 1.22 | 33.2 | 62.9 | | 0.6 | 54.3 | 45.1 | 2.75 | |
| DHS-12 | 100 | 0.29 | 24.0 | 45.9 | | 9.2 | 58.2 | 32.6 | 2.68 | On hillside above source of earthflow. |
| | 114 | 0.85 | 23.4 | 44.8 | | 10.0 | 57.0 | 32.0 | 2.68 | |
| | 117 | 1.12 | 23.2 | 42.0 | | 11.5 | 61.1 | 27.0 | 2.68 | |
| DHS-13 | 1 | 0 to 0.56 | 5.8 | 37.7 | | 7.9 | 65.1 | 27.0 | 2.70 | Oven dried. |
| | 2 | 0.56 to 0.74 | 23.6 | 46.1 | | 5.4 | 55.9 | 38.6 | 2.72 | Oven dried. |

TABLE 3. DAVILLA HILL SLIDE: FIELD DENSITIES

| Sample number | Depth (meters) | Total unit weight (grams/cm$^3$) | Natural water content % | Dry unit weight (grams/cm$^3$) | Specific gravity of solids | Void ratio | Saturation (%) | Unit sampled |
|---|---|---|---|---|---|---|---|---|
| 48 | 0.18 | 1.74 | 38.9 | 1.25 | 2.75 | 1.20 | 89.3 | Earthflow |
| 119 | 0.05 | 1.78 | 34.1 | 1.33 | 2.75 | 1.07 | 87.4 | Earthflow |
| 118 | 0.23 | 1.80 | 37.4 | 1.31 | 2.75 | 1.10 | 93.7 | Earthflow |
| A2 | 0.10 | 1.89 | 35.8 | 1.39 | 2.70 | 0.98 | 100 | Source area. |
| 64 | 0.12 | 1.72 | 29.3 | 1.33 | 2.69 | 1.03 | 76.7 | Hillside above |
| U3 | 0.12 | 1.66 | 27.0 | 1.31 | 2.69 | 1.06 | 68.7 | source area. |

Notes: 1/ Specific gravities used are those of the average of all samples from the borehole closest to the field density sample.

2/ $\text{Total unit weight} = \dfrac{\text{Total weight}}{\text{Total volume}}$

3/ $\text{Natural water content} = \dfrac{\text{Weight water}}{\text{Weight solids}} \times 100\ \%$

4/ $\text{Dry unit weight} = \dfrac{\text{Weight solids}}{\text{Total volume}}$

5/ $\text{Void ratio} = \dfrac{\text{Volume of pore spaces}}{\text{Volume of solids}}$

6/ $\text{Saturation} = \dfrac{\text{Volume of water}}{\text{Volume of pore spaces}} \times 100\ \%$

TABLE 4. DAVILLA HILL SLIDE:

FIELD VANE STRENGTH OF MATERIAL IN ACTIVE EARTHFLOWS

| | Average | Maximum | Minimum |
|---|---|---|---|
| Peak shear strength | 0.11 $kg/cm^2$ | 0.18 $kg/cm^2$ | 0.04 $kg/cm^2$ |
| Residual shear strength | 0.05 $kg/cm^2$ | 0.09 $kg/cm^2$ | 0.02 $kg/cm^2$ |
| Sensitivity | 2.7 | 7.0 | 1.2 |

Note: $\text{Sensitivity} = \frac{\text{Peak shear strength}}{\text{Residual shear strength}}$

is relatively homogeneous.

Lateral ridges are prominent features of the Davilla Hill Slide. Where they are well preserved, their outer flanks are smoothly curved in profile like earthflow snouts, and their inner flanks resemble shear walls. An *en echelon* pattern of lateral ridge segments is well preserved in the portion of the slide below the fence.

As observed in the earthflow crossed by Stake Lines 3 and 3A, the direction of movement of material within the earthflow was not parallel to the surface. The head of this earthflow subsided by as much as two meters between February 4 and March 31, 1975. In order to accommodate the mass displaced by this subsidence, the toe must have bulged up above the original ground surface.

Thinning of the head of another active earthflow is possibly indicated by the three wood chips which were riding above the ground surface after April 14. The relatively incompressible stack of wood would have prevented them from settling while the soft mud around them subsided. Swelling of the wood could also account for all or part of this effect.

Both surface and subsurface data (See Figures 5, 6, 7, and 9) indicate that boundary shear contributes more to earthflow movement than does internal deformation. The sub-surface data (Figure 9) show that, in a vertical profile, sliding along the basal shear plane accounted for nearly all of the movement. Lack of internal deformation is also indicated by the fact that uncased auger holes remained undeformed while being transported distances of several centimeters. In Figures 5 and 7, the stakes in the center of the lines show larger displacements than those near the end. This could have been caused by undetected internal shear planes or by internal flow.

The velocities of earthflows in the Davilla Hill Slide were probably controlled by local factors. Rates of movement were not consistent from one earthflow to another. One ceased to move entirely on March 31, whereas two others were still active three weeks later. The velocities computed for individual stakes range from 0.01 to 0.39 meters/day. These measurements taken several days apart, however, do not exclude the possibility that short surges of much higher velocity took place. Surges of this type have been recorded on earthflows in Northern Ireland (Prior and Stevens, 1971; Prior and Stevens, 1972; Hutchinson et al., 1974). Such surges in the Davilla Hill Slide would have been brief, however, because the greatest displacement of any stake measured between two successive dates was 3.2 meters.

As earthflows became active, the material in them softened dramatically, and its water content increased. Ground water levels within active earthflows were at or near the surface. Activiation, therefore, may be due both to an increase in pore pressure and to a decrease in shear strength. The dry unit weight of material in active earthflows was also slightly lower than that of material from source areas or of material undisturbed by sliding (Table 3), and this may reflect a slight swelling of dilatation of the earthflow material.

## CYCLE PARK SLIDE

### Description

The Cycle Park Slide is in the Cienega Valley Area (Figure 3) 7.1 kilometers south of the town of Hollister in San Benito County, California. It is 200 meters west of the crest of the Cienega Road and just north of the boundary of the Hollister Hills Cycle Park. It is located on the Hollister, California 7.5' topographic quadrangle.

The inset on Figure 12 shows the overall shape of the slide. The monitored portion of the slide (shaded on the inset) contains one large earthflow. Approximately 20 meters upslope from its snout, the earthflow tumbles over a bedrock cliff five meters high. This cliff, which extends beyond the boundaries of the earthflow, divides the Cycle Park Slide into two parts. The part upslope from the cliff is long and narrow and contains the head and some of the toe of the earthflow discussed above. At the foot of the cliff is a broad region containing the snouts of monitored earthflow, the snout of an older and larger earthflow, and a mass of undifferentiated landslide debris.

The head scarp, shear walls, and lateral ridges of the monitored earthflow separate it from ground undisturbed by sliding. The crescent shaped head scarp has a maximum height of six meters. Extension cracks are prominent for several meters upslope from the head scarp. The shear walls are approximately 65 meters long, and lateral ridges 20 meters long bound the portion of the toe above the cliff. The surface of the earthflow is broken by numerous internal scarps, extension cracks, and drying cracks. Two prominent closed depressions (Figure 12) are also present. In contrast to the Davilla Hill Slide, the surface of the earthflow was firm enough to walk on even when it was active.

Material within the earthflow is quite heterogeneous. Composition of the matrix ranges from clayey silt to sandy silt. Bedrock underlying the Cycle Park Slide belongs to the Purisima Formation (Taliaferro, 1948). The Purisima is made up of poorly consolidated clays, silts, sandstones, gravels, and lignites. It is non-marine for the most part and is of Pliocene age. Vegetation on the slide consists mainly of thick, tall growth of wild mustard.

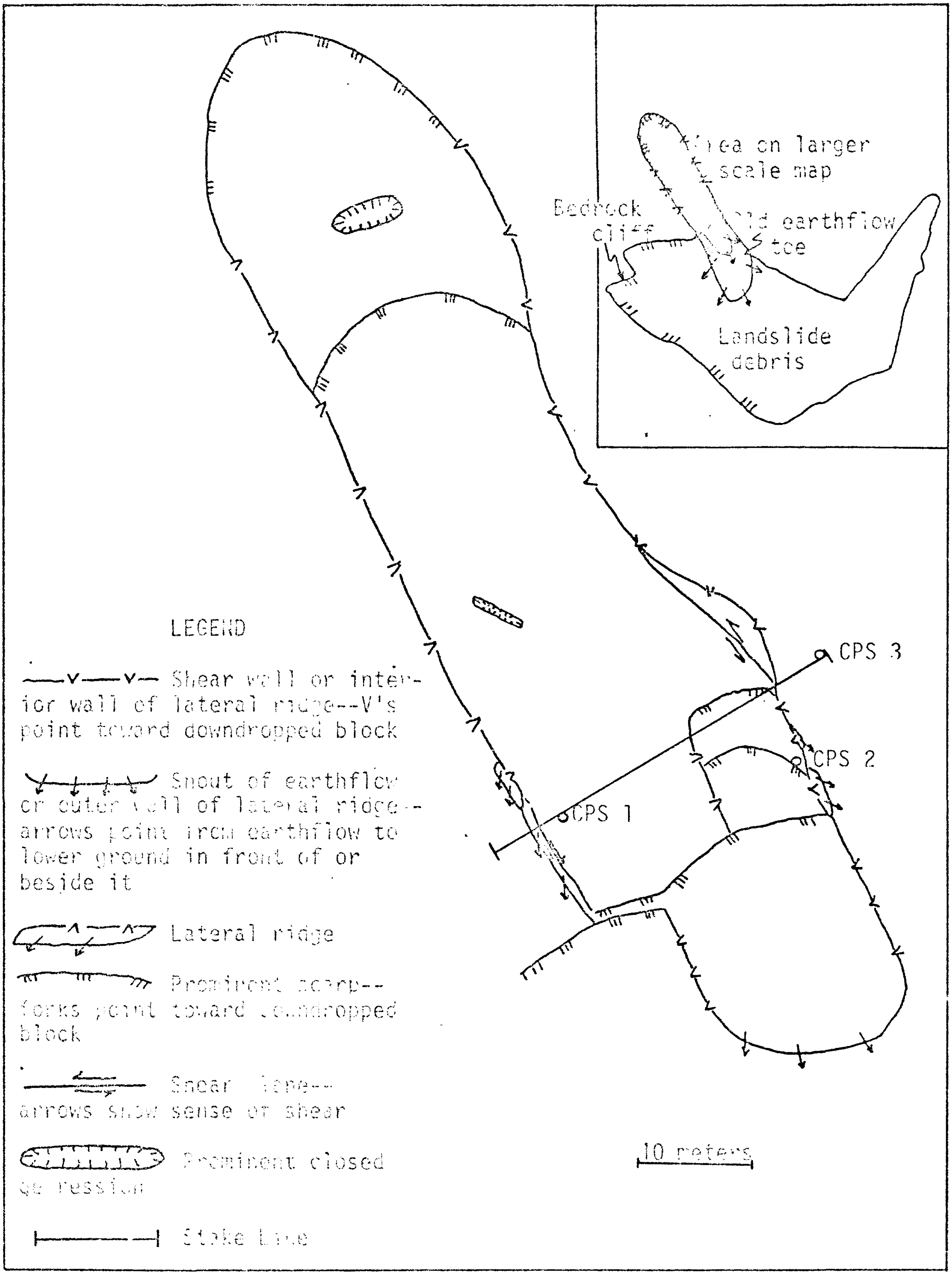


FIGURE 12. [illegible] OF [illegible] PARK SLIDE

## Surface Displacements

One line of stakes (Figure 12) was placed across the toe of the earthflow on the Cycle Park Slide. Displacements are plotted in Figure 13. The seasonal onset of movement on this earthflow occurred sometime between February 12 and March 19, 1975 and was continuing when the last measurement of the spring was made on April 13. Two stakes on the earthflow showed a surge in movement between March 19 and March 27. On March 27, the stakes were observed to be on a small mass which had broken away from the larger earthflow. The surface of this mass was broken by closely spaced scarps and extension cracks. After this initial surge, movement of the small mass was approximately equal to that of the large earthflow. The line of stakes on the large earthflow remained quite linear during its movement. Velocities computed from the displacements of individual stakes range from 0.02 meters/day to 0.21 meters/day.

## Subsurface Displacements, Water Levels in Boreholes, and Physical Properties Tests

An experiment similar to that described on the Davilla Hill Slide was attempted here. Lengths of aluminum angle bar were driven to depths of up to 1.75 meters in an area approximately six meters from one of the bounding lateral ridges of the active earthflow. Even though the stakes were displaced 0.6 meters by the earthflow over a period of 17 days, none of the stakes showed tilt of more than 1.5°. It was concluded from this that the depth of the shear plane at this location was greater than 1.75 meters.

Data on water levels in uncased boreholes on the site are listed on Figure 13. During periods of confirmed active movement, water levels in CPS 1

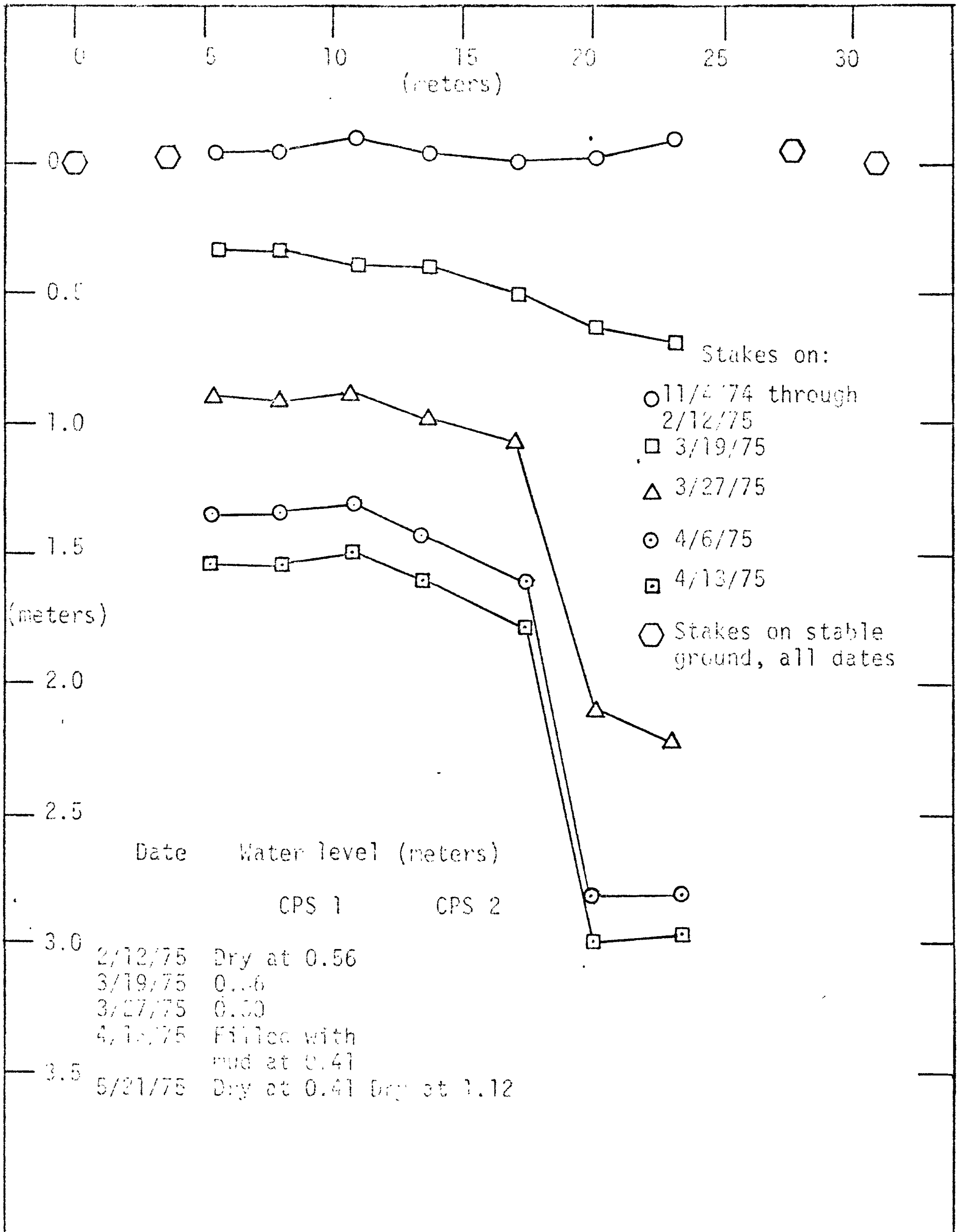


FIGURE 12. CYCLE PARK SLIDE, STAKE LINE AND WATER LEVELS IN BOREHOLES

were within 35 centimeters of the ground surface. Natural water contents are tabulated in Table 5. Other index properties are listed in Table 6.

## Discussion

Material in the earthflow on the Cycle Park Slide is more heterogeneous than the material in earthflows on Davilla Hill Slide. The fact that CPS 3, which was drilled on undisturbed ground beside the earthflow, encountered soil with a higher water content is probably due to this heterogeneity. In contrast to the Davilla Hill Slide, the material did not soften throughout the earthflow when it became active. The water levels in CPS 1 did rise to near the ground surface, and this earthflow was probably activated by increased pore pressures. This may have been combined with local softening of soil along the shear plane. The line of stakes crossing the earthflow remained quite straight. The lateral ridges in the toe are quite small and poorly developed. Combined with the lack of softening of the earthflow material, this suggests that the earthflow is behaving more rigidly than are the earthflows in the Davilla Hill Slide.

# MELENDY RANCH SLIDE

## Description

The Melendy Ranch Slide is in the Bear Valley Area (Figure 3) approximately ten kilometers north of Pinnacles National Monument. It is in the Bickmore Canyon 7.5' topographic quadrangle in the NW 1/4 of Sec 23, T15S, R7E, in San Benito County.

The slide is similar to the composite mudflows described by Prior et al., (1968). It consists of bowl slide zone, a flow track, and a depositional toe

TABLE 5. CYCLE PARK, FIELD'S BARN, AND MELENDY RANCH SLIDES: NATURAL WATER CONTENTS

| Boring | Date drilled | Depth of shear plane (meters) | Depth of samples (meters) | No. of samples | Natural water content % * Average | Range | Remarks |
|---|---|---|---|---|---|---|---|
| | | | CYCLE PARK SLIDE | | | | |
| 1 | 1/22/75 | 1.65 | 0.08 to 1.42 | 8 | 37.4 | 28.1-42.2 | On inactive earthflow |
| | | | 1.65 | 1 | 41.5 | | |
| | | | 1.92 to 2.15 | 2 | | 37.2-26.6 | |
| 2 | 4/13/75 | unknown | 0.10 to 0.32 | 2 | | 41.6-42.0 | On active earthflow |
| | | | 0.42 | 1 | 21.0 | | |
| | | | 0.62 to 1.75 | 13 | 34.3 | 27.9-39.3 | |
| 3 | 4/13/75 | | 0.12 to 0.70 | 4 | 47.9 | 42.6-52.6 | On undisturbed ground beside active earthflow. |
| | | | 0.77 to 0.83 | 2 | | 44.6-40.9 | |
| | | | 0.91 to 1.12 | 4 | 29.9 | 28.1-34.5 | |
| | | | FIELD'S BARN SLIDE | | | | |
| 2 | 3/12/75 | unknown | 0.06 to 1.03 | 12 | 14.0 | 7.6-17.8 | |
| | | | MELENDY RANCH SLIDE | | | | |
| 1 | 12/12/75 | Below TD of boring. | 0.09 to 0.98 | 8 | 22.2 | 12.5-26.5 | On inactive earthflow |
| 2 | 3/19/75 | Below TD of boring. | 0.09 to 0.79 | 5 | 28.7 | 21.2-30.2 | On active earthflow |

* Natural water content = $\frac{\text{Weight water}}{\text{Weight solids}} \times 100\%$

TABLE 6

CYCLE PARK AND MELENDY RANCH SLIDES: ATTERBERG LIMITS, GRAIN SIZES, AND SPECIFIC GRAVITY

| Slide | Boring | Sample | Depth (meters) | Plastic limit % of dry wt. | Liquid limit % of dry wt. | % Gravel by weight | % Sand by weight | % Silt by weight | % Clay by weight | Specific gravity of solids | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cycle Park | 1 | 1 | 0.18 | | | | 8.9 | 29.3 | 61.8 | 2.63 | |
| | | 2 | 0.27 | 30.0 | 83.6 | | | | | | |
| | | 3 | 0.52 | | | 0.04 | 8.1 | 34.9 | 57.0 | 2.78 | |
| | | 4 | 0.67 | 33.6 | 67.5 | | | | | | |
| | | 5 | 0.85 | 29.6 | 54.1 | | 2.6 | 58.7 | 38.7 | 2.64 | |
| | | 6 | 1.16 | 21.7 | 48.0 | | 14.2 | 56.4 | 29.4 | 2.72 | |
| | | 7 | 1.25 | 28.0 | 60.4 | | 12.1 | 50.7 | 37.2 | 2.53 | |
| | | 8 | 1.55 | 30.5 | 79.3 | | 6.1 | 37.7 | 56.2 | 2.50 | |
| | | 9 | 1.77 | 32.6 | 80.2 | | 5.6 | 41.8 | 52.6 | 2.76 | |
| | | 10 | 1.95 | 30.1 | 82.7 | | 5.3 | 45.6 | 49.1 | 2.77 | |
| | 2 | 1 | 0.30 | 31.5 | 68.3 | | 8.3 | 42.0 | 49.7 | 2.72 | |
| | | 2 | 0.70 | 24.3 | 42.4 | | 8.1 | 71.9 | 20.0 | 2.68 | |
| | | 3 | 0.64 | 27.1 | 70.1 | | 13.4 | 45.1 | 41.5 | 2.65 | |
| | | 4 | 1.28 | 31.4 | 80.4 | | 8.2 | 48.1 | 43.8 | 2.61 | |
| | | 5 | 1.37 | 28.8 | 73.6 | | 11.5 | 42.1 | 46.4 | 2.63 | |
| | | 6 | 1.68 | 27.0 | 68.0 | | 7.7 | 52.9 | 39.4 | 2.68 | |
| | 3 | 1 | 0.46 | 32.9 | 77.4 | | 8.0 | 45.8 | 46.2 | 2.70 | |
| | | 2 | 0.82 | 41.0 | 81.7 | | 9.1 | 39.2 | 51.7 | 2.69 | |
| | | 3 | 1.07 | 34.1 | 63.2 | | 3.5 | 65.2 | 31.3 | 2.68 | |
| Melendy Ranch | 2 | 1 | 0.73 | Atterberg's could not be performed | | | 49.6 | 41.0 | 9.4 | 2.59 | |
| | | 2 | 0.00 to 0.91 | | | 10.6 | 39.6 | 35.7 | 14.0 | 2.59 | |

(Figure 14). The bowl slide zone is an amphitheater filled with large rotational slumps. This feeds into a long, narrow flow track which is bounded by lateral ridges. The flow track contains several earthflows. It empties into the broader, more gently sloping depositional toe. The slide is 500 meters long. The bowl slide zone is 120 meters wide, the central part of the flow track is 20 meters wide, and the depositional toe is 110 meters wide. Total depth of slide material in the depositional toe exceeds 10 meters. Both the flow track and the depositional toe contain numerous cracks, scarps, and shear planes. The surface of the slide is nearly devoid of vegetation.

The slide material consists of a soft matrix of bluish green sand, silt, and clay in which are embedded blocks of rock of all sizes. Grain size analyses of two samples showed that the matrix contains 50% by weight sand and gravel, 38% silt, and 12% clay. Atterberg limits could not be obtained.

The source of this material is a body of serpentinite which underlies the bowl slide zone. Both the flow track and the depositional toe are underlain by reddish brown conglomerates, sandstones, and shales belonging to the Etchegoin Group (Wilson, 1943), and little of this material has been incorporated into the slide. Material at the terminus of depositional toe, therefore, has traveled at least 430 meters downslope.

According to Wilson (1943), initial movement on this slide took place during the winter of 1938. Examination of air photos taken in subsequent years shows that the overall length of the slide has changed little since then. Movements measured during the winter of 1974-1975 (see below) were occuring on earthflows which formed out of the old slide material.

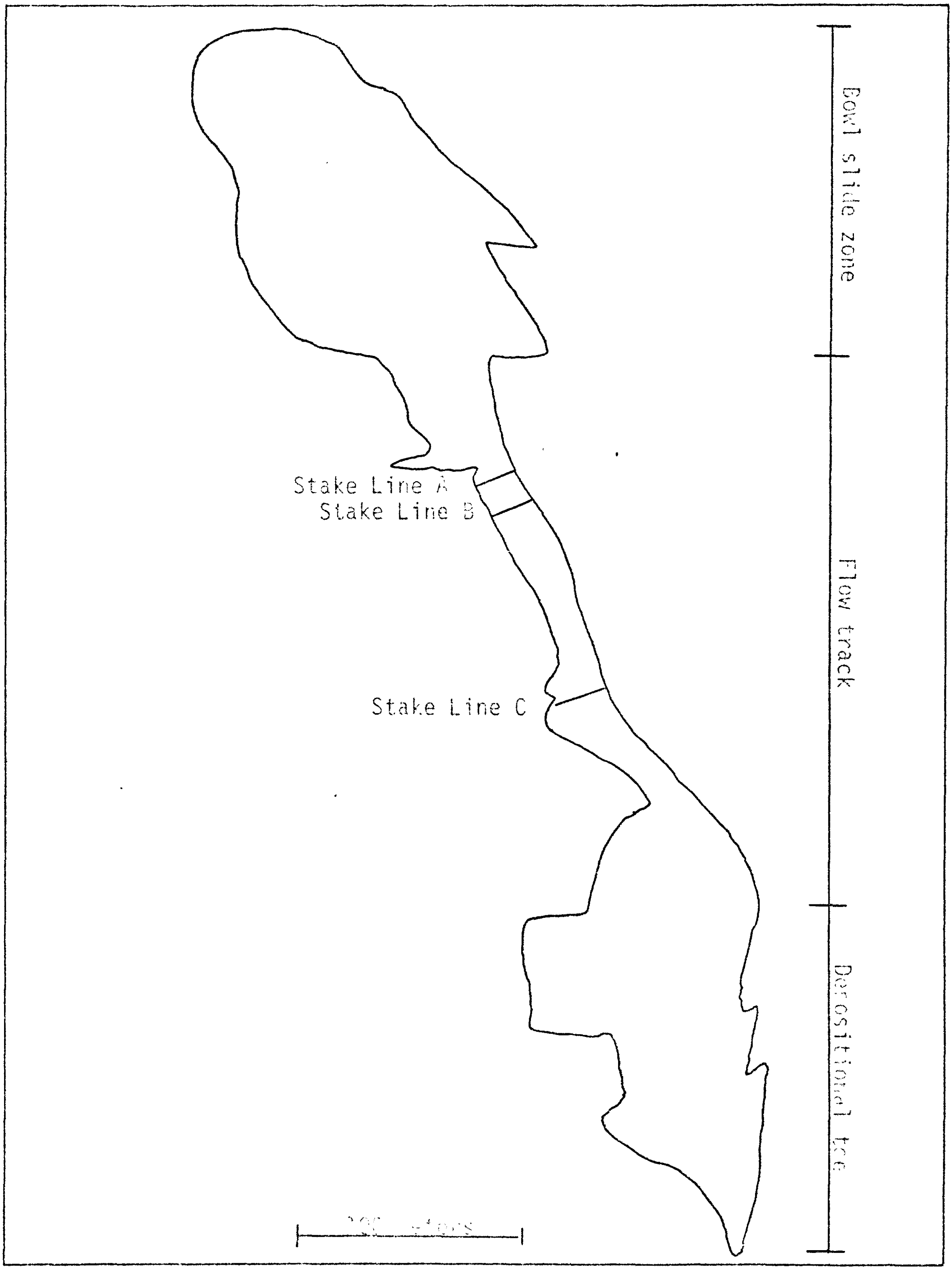


FIGURE 14    MELENDY RANCH SLIDE

## Surface Displacements

Three lines of stakes were placed across the flow track (Figure 14.) Stakes in Line A were redwood posts placed with their tops protruding 25 to 50 centimeters above the ground. Stakes in Line B were aluminum angle bars, approximately 30 centimeters long, with the top 10 centimeters exposed. Those in Line C were spikes, 18 centimeters long, buried to their heads. Displacements of stakes in Lines A, B, and C are plotted in Figures 15, 16, and 17 respectively.

Line A (Figure 15) is plotted as being a straight line on November 4, 1975 in order to clearly show the small downslope displacements which subsequently took place. This line was just upslope from the head scarp of two earthflows. Open extension cracks were observed on the surface upslope from the stake line on April 30, 1975.

The left end point of Line C (Figure 17) was on an active earthflow. Corrected end points were placed on March 19 and April 30 by aligning the surveyor's tape with the two stakes on the right end of the line which were off the active slide.

## Natural Water Contents

Natural water contents of samples of earthflow material were measured from depths of 0.1 to 1.0 meters on December 12, 1974, and on March 19, 1975. The sampled earthflow was active on the latter date. On December 12, the average water content of eight samples was 22.2%. On March 19, the average water content of five samples was 28.7%

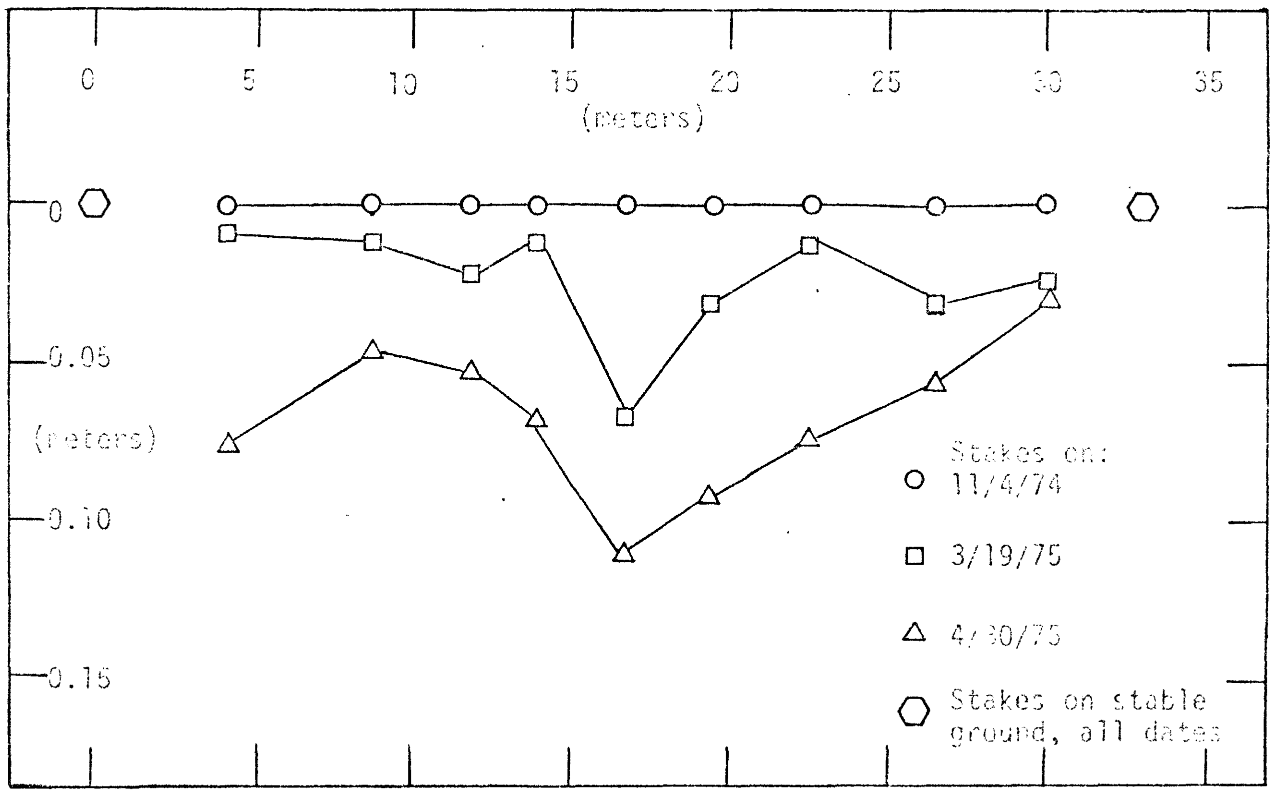


FIGURE 15: MELENDY RANCH SLIDE, STAKE LINE A

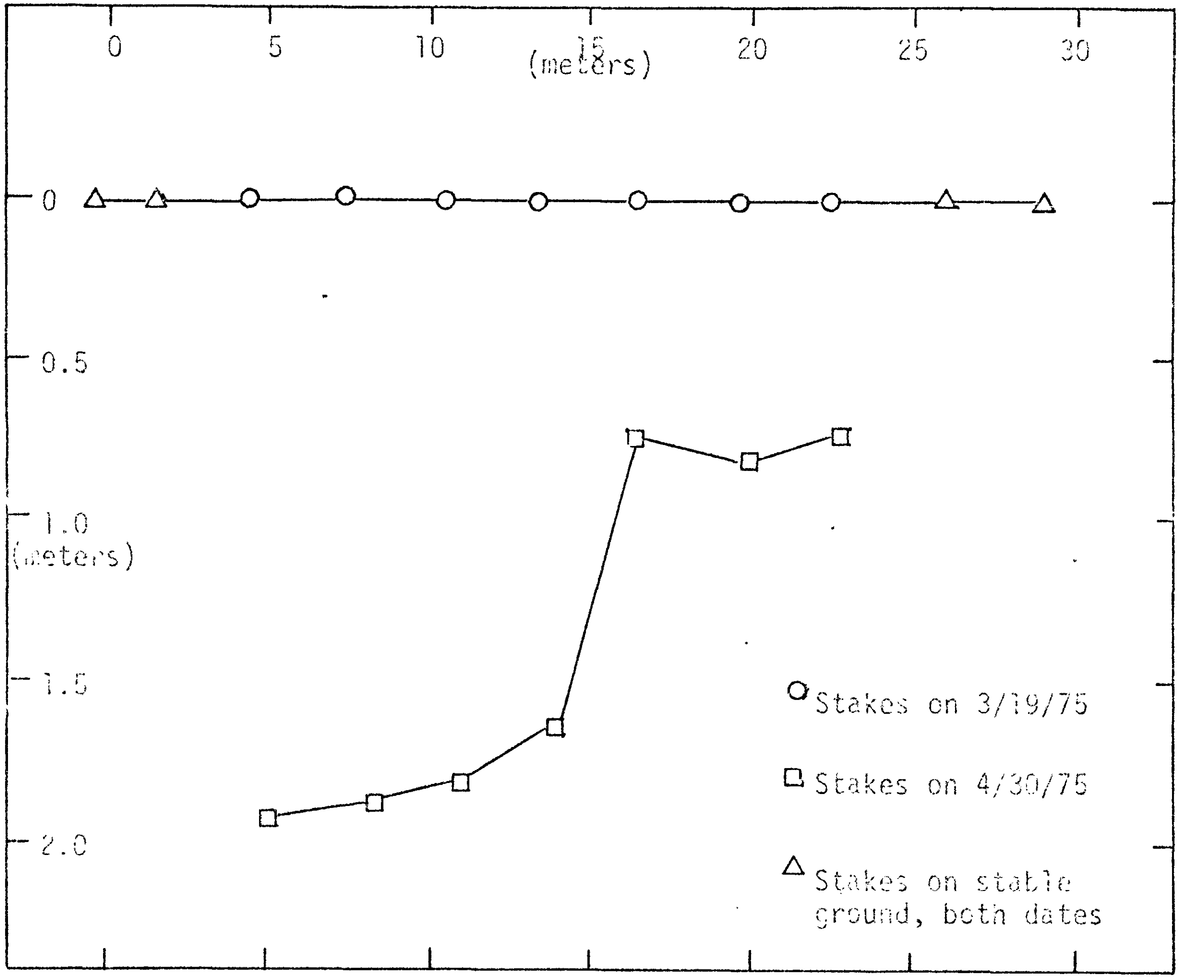


FIGURE 16: MELENDY RANCH SLIDE, STAKE LINE B

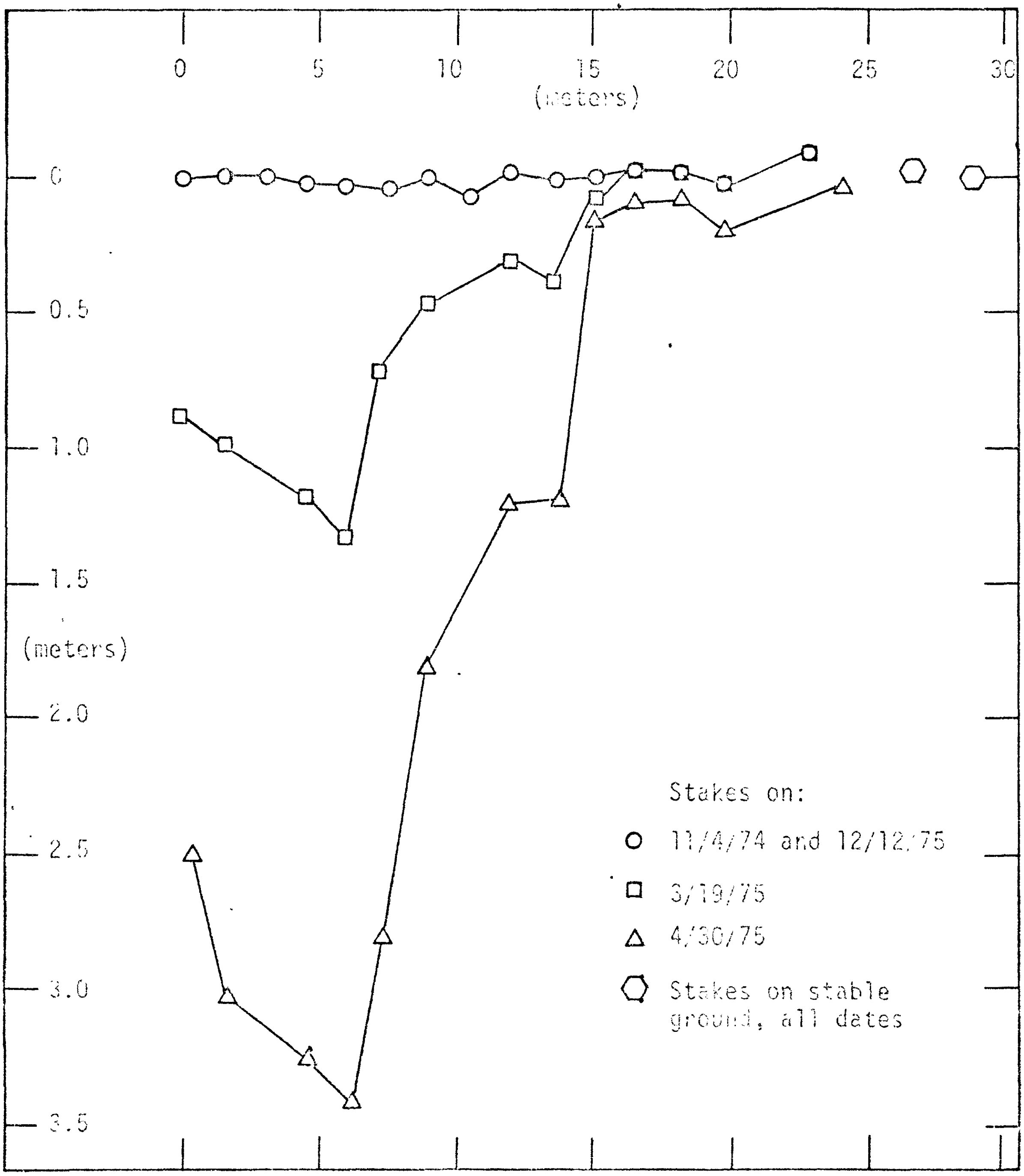


FIGURE 17. [illegible] RANCH SLIDE, STAKE LINE C

TABLE 7. FIELD'S BARN SLIDE: FIELD DENSITIES

| Sample number | Total unit weight (grams/cm$^3$) | Water content % | Dry unit weight (grams/cm$^3$) | Void ratio | Saturation (%) | Unit sampled |
|---|---|---|---|---|---|---|
| 64 | 1.93 | 24.2 | 1.56 | 0.74 | 95.3 | Earthflow |
| 118 | 1.81 | 29.8 | 1.39 | 0.94 | 93.1 | Earthflow |
| 48 | 1.94 | 18.1 | 1.64 | 0.64 | 90.6 | Material in head scarp |

Notes: 1/ Specific gravity of solids assumed to be 2.70 for all samples.

2/ For definitions of column headings, see Table 3.

## Discussion

Examination of the slide showed that stake Line B crossed the toes of two earthflows. The boundary between them was quite close to the middle stake in the line. Stake Line A was in the source area just upslope from the head scarps of these earthflows. Stake Line C also crossed two earthflows. The boundary between them crossed the stake line approximately 14 meters from its left end. On and after March 19, the fourth stake from the left was located on the bank of a small gully. The stakes to the left of this gully were on a portion of the earthflow where internal scarps, shear cracks, and extension cracks were prominent. Measurements of stakes on the Melendy Ranch Slide were made too infrequently to calculate average velocities which could be compared to those of earthflows in the other slides.

# FIELD'S BARN SLIDE

The Field's Barn Slide is near the Davilla Hill Slide in the Eden Canyon Area (Figure 3). It is within the Hayward 7.5' topographic quadrangle in the NW 1/4 of Sec. 29, T2S, R1W. It contains numerous small earthflows and rotational slumps. Material in the slide is derived from rocks belonging to the Orinda Formation (Robinson, 1956). None of the earthflows were re-activated during the winter of 1974-1975. Stakes on the slide did record displacements of as much as 29 centimeters. These displacements were due to shifting and tilting of blocks and sod. Three "field density" samples were taken from the Field's Barn Slide on April 16, 1975. Results are listed in Table 7.

DESCRIPTION OF ADDITIONAL FIELD INSTRUMENTS INSTALLED FOR THE WINTER OF 1975-1976

Water level recorders (Leupold and Stevens, Inc., Type F) have been modified in a manner similar to that described by Prior and Stephens (1971) and installed on the Davilla Hill and Cycle Park Slides. Each instrument provides a continuous record of the movement of a stake on the surface of an earthflow. They are equipped with an eight day spring driven clock and 1:1 gage scale gears so that displacement of a stake of one centimeter would cause a displacement of one centimeter on the drum of the instrument.

Porous tube piezometers have been installed in boreholes on the Davilla Hill and Cycle Park Slides to monitor ground water levels. Twelve of the piezometer tips (nine on the Davilla Hill Slide and three on the Cycle Park Slide) consist of porous ceramic cups six centimeters long and two centimeters in outside diameter with air entry values of two bars. In addition, four piezometers with porous tips 0.6 meters long have been installed on the Davilla Hill Slide. All the tips are attached to flexible plastic tubes 1.3 centimeters in diameter which lead to the ground surface. The porous tips are surrounded by a sand filter capped by a layer of bentonite.

Pore water pressures in the Davilla Hill Slide are also being measured with portable, water-filled tensiometers manufactured by Soilmoisture, Inc. (Catalogue no. 2900-C, Soilmoisture Probes). The tensiometer consists of a water-filled, T-shaped metal tube with a porous ceramic tip at the end of the stem, a pressure gage at one end of the top of the T, and a screw for adjusting the volume at the other end of the T. When placed in the ground, a small amount of water flows into or out of the porous tip until the pressure within the tensiometer, which can be read on the gage, matches the pressure in the ground. Pressures can be read to a precision of 0.01 bars.

These tensiometers are capable of measuring either positive or negative pore pressures up to a maximum value of one bar. Their maximum operating depth is approximately 0.6 meters. Nearly all pore pressures measured since the probes were first used on July 7, 1975 have been negative.

## CONCLUSION

The field studies described in this report are part of a continuing investigation of the behavior of earthflows. In the region surrounding San Francisco Bay, earthflows are abundant in six widely separated areas. The factors responsible for their occurrence in these areas are not yet known. Earthflows generally occur as parts of large, complex slides. Individual earthflows are identified on the basis of their distinctive morphologies. During the winer of 1974-1975, four slides were monitored, and earthflows became active on three of them at some time during the winter. When averaged over a period of several days, surface velocities were less than 0.40 meters per day on all earthflows. All active earthflows were reworking old slide material. At two of the three sites, material in active earthflows was softer and had a higher water content than did inactive slide material. Wherever measured, a rise in the water table within an earthflow accompanied mobilization of the earthflow.

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## REFERENCES CITED

Hall, Clarence A., Jr., 1956, The geology of the Pleasanton area, Alameda County, California: unpubl. Ph.D. dissertation, Stanford Univ.

Hutchinson, J. N., Prior, D. B., and Stephens, N., 1974, Potentially dangerous surges in an Antrim mudslide: Quart. Jour. of Eng. Geol., v. 7, no. 4, p. 363-376.

Krauskopf, K. B., Feitler, C., and Griggs, A. B., 1939, Structural features of a landslide near Gilroy, California: Jour. Geology, v. 47, no. 6, p. 630-648.

Lambe, T. W., 1951, Soil testing for engineers: New York, John Wiley and Sons, Inc., 165 p.

Prior, D. B., and Stephens, N., 1971, A method of monitoring mudflow movements: Eng. Geol., v. 5, no. 3, p. 239-246.

Prior, D. B., and Stephens, N., 1972, Some movement patterns of temperate mudflows: examples from north-east Ireland: Geol. Soc. of America Bull., v. 83, p. 2533-2544.

Prior, D. B., Stephens, N., and Archer, D. R., 1968, Composite mudflows on the Antrim coast of northeast Ireland: Geografiska Annaler, v. 50 (A), p. 65-78.

Robinson, G. D., 1956, Geology of the Hayward quadrangle, California: U. S. Geol. Survey Quadrangle Map no. GQ 88, scale 1:24,000.

Taliaferro, N. L., 1948, Economic mineral map of the Hollister quadrangle showing position of structure sections: Calif. Div. Mines and Geol., Bull. 143, Pl. 2 (text not publ.).

Wilson, I. F., 1943, Geology of the San Benito quadrangle, California: Calif. Div. Mines, Spec. Report 39, p. 183-270.