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# DEFORMATIONAL FEATURES RESULTING FROM SLOPE MOVEMENT IN THE MANOA VALLEY, CITY AND COUNTY OF HONOLULU, HAWAII

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## PLATES

# Deformational features resulting from slope movement in the Manoa Valley, City and County of Honolulu, Hawaii

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*ABSTRACT* Deformation of man-made structures in and adjacent to the public right-of-way in the Manoa Valley was mapped to locate existing and incipient slow-moving landsliding. The results are shown on two kinds of maps. One map consists of four sheets that show field observations. The other, an interpretive map, shows locations where there is evidence of landslide movement.

No slow-moving landslides were found that are similar in size and degree of development to the existing Alani-Paty or Hulu-Woolsey landslides. Nine areas, however, were found where deformation might be related to such movement, including five sites of small landslides in fill and four sites where deformation is consistent with the early stages of development of a larger landslide.

Locations of all nine areas that show evidence of recent or incipient movement are plotted on the interpretive map. For these areas, possible courses of mitigation range from no action to monitoring and remediation. Four areas that have the greatest potential for enlargement and movement are in Woodlawn and within several hundred feet of the existing Alani-Paty and Hulu-Woolsey landslides.

## INTRODUCTION

This text accompanies maps of deformational features along the public right-of-way in the Manoa Valley, Honolulu, Hawaii. The deformational features consist of damage to man-made structures such as walls, sidewalks, foundations and streets. The purpose of mapping these features was to locate any unrecognized or incipient slow-moving landslides in the Manoa Valley.

Two different kinds of maps were prepared. One map, plate 1, which consists of four separate sheets, contains field notes that document deformation and damage that was observed. The second map, plate 2, is an interpretative summary of the field information. The preparation of these maps, their limitations and results, and options for mitigation of developing landslides are described below.

## BACKGROUND

In 1989, the U.S. Geological Survey (USGS), in cooperation with the City and County of Honolulu, Department of Public Works, began a study of different kinds of landslides that occur in the Honolulu area. Part of the investigation focused on two large, slow-moving landslides in the Woodlawn area of the Manoa Valley. A map was prepared of the boundaries and some internal features of those landslides, which are called the Alani-Paty and Hulu-Woolsey landslides (Baum and others, 1989). Subsequently, reports were prepared on the physical characteristics of the materials and on detailed analysis of movement in the Alani-Paty landslide (Baum and others, 1990, 1991), followed by a final report on the analysis of this landslide (Baum and Reid, 1992). In addition, Peterson and others (1993) used aerial photographs to map the locations of past debris flows and other types of slope movement on natural hillslopes in the Honolulu District of Oahu, including the Manoa Valley.

## Evidence for Progressive Failure

During the mapping of the boundaries of the Alani-Paty and Hulu-Woolsey landslides by Baum and others (1989), property owners described a long history of damage to their homes and to nearby streets. Our own observations of sequential patching of streets, curbs, and foundations indicated that downslope movements had occurred over a period of years. These observations and reports suggested that the slow-moving landslides form over a period of years to perhaps decades. Evidence also suggests that the landslides enlarge progressively from one or more small, localized areas. The concept of slow and progressive development forms the basis for this study.

Geotechnical engineers for years have recognized that hillslopes can fail progressively (see, for example, Skempton, 1964; Bjerrum, 1967). Engineers also distinguish between first-time failures of hillslopes and reactivations of previous failures. For first-time failures, a continuous surface of sliding must develop in previously unfailed soil at the base of the landslide. For reactivations of old landslides, a continuous failure surface already exists, and renewed movement occurs, at least in part, along previously determined boundaries.

First-time failures of hillslopes are different from reactivations of old landslides in their resistance to sliding. First-time failures occur when the hillslope soil is at its maximum or "peak" resistance. Reactivations occur when the soil resistance has been reduced to near the minimum or "residual" value. For clayey soils like those in the Manoa Valley, peak and residual shearing resistance differ by at least a factor of two. This difference between peak and residual strength promotes progressive failure of hillslopes. In concept, the initial localized failures occur in places where the peak strength of a soil has been exceeded. Once a localized failure has occurred, the surrounding materials must carry the additional load imposed by the local reduction of shearing resistance from peak to residual values. If the soils cannot support the additional load, the localized failure spreads, and thereby imposes an even larger burden on adjacent, unfailed soil. In this way, failures tend gradually and progressively to enlarge as the resistance to sliding changes from peak to residual values.

Baum and others (1989) noted several areas that were just outside the well-developed margins of the active slow-moving landslides in Woodlawn appeared to be examples of first-time failure of a progressively enlarging landslide. In these areas, surface cracks tended to be small and discontinuous, and offsets were very small. Such observations indicate that progressive failure consists partly of spatial enlargement.

Progressive failure is also a time-dependent process. The concept that slow-moving landslides in the Manoa Valley develop progressively over time is supported by data on water-main breaks furnished by the Honolulu Board of Water Supply. During the period 1972-89, 145 water-main breaks occurred in the Manoa Valley, of which at least 74 occurred within the mapped boundaries of the two active landslides in Woodlawn (the Alani-Paty and Hulu-Woolsey landslides). Seven breaks were concentrated near the intersection of Alani Drive and Paty Drive during 1978-79. Similarly, eight breaks occurred during the period 1981-82 in the area near Hulu Place and Woolsey Street. All these breaks occurred where we now recognize cracks on the landslide boundaries or within the uppermost parts of these landslides. Before those years, water-main breaks do not appear to be concentrated in these areas; only four of the 74 breaks that occurred in the landslide areas happened before 1978-79 at Alani-Paty and before 1981-82 at Hulu-Woolsey.

Beyond the active landslide areas in Woodlawn, there have been about four water-main breaks per year in the Manoa Valley during the period 1972-1989. Whether the four water-main breaks that occurred in the Woodlawn area before the dramatic increase in numbers represent incipient slope movement, corrosion of pipes, construction accidents, or other causes is unknown. What is clear is that the breaks to the water lines after 1978 at Alani-Paty and after 1981 at Hulu-Woolsey were the beginning of a pattern of increasing numbers of breaks that reflects accelerated movement, and probably progressive failure of both landslides.

To summarize, four observations--homeowner reports, patterns of patches and repairs, the direct observation of enlargement of the Alani-Paty landslide, and the temporal pattern of broken water lines--are evidence that the landslides in Woodlawn form by progressive failure. One implication of these observations is that it might be possible to identify areas of similar incipient landsliding while they are small and readily correctable. With this aim, I examined all the public right-of-way in the Manoa Valley to look for areas that might be developing into large, slow-moving landslides.

## Past Landslides in Manoa

Other studies have identified evidence of past landsliding in Manoa Valley. Most of these landslides were relatively fast moving and different from slow, progressive failures that are the subject of this report. The fast-moving landslides typically move completely out of the place where they originate and leave a scarp and large void in the source area. Rates of movement may be as large as several feet per minute compared to the top rate of a few inches per day for slow-moving landslides. We did not specifically study the faster moving landslides, but two of the three cases from the Manoa Valley discussed in theses by De Silva (1974) and Jellinger (1977) are of the fast-moving type. Additional locations and inferences about types of past landslides have been recognized during the cooperative study between the USGS and the City and County of Honolulu (Peterson and others, 1993).

Three locations of past landsliding in the Manoa Valley were noted by Jellinger (1977) and De Silva (1974). Included are an active, slow-moving landslide within the present boundary of the Hulu-Woolsey landslide (slides #8 and #9 of De Silva, 1974). The other two, at Woodlawn Terrace Place and at Pinaoula Street, were fast-moving landslides. The landslide at Woodlawn Terrace Place (Slide #10 of De Silva, 1974) moved in three separate episodes. The last episode occurred during a major rainstorm in the period of November 14-16, 1965. A property owner, who had been living near the site of this landslide in 1965, did not recall the first two episodes of movement mentioned by De Silva (1974) but vividly recalled the 1965 episode. Trees were transported downslope at a rate of several feet per minute. The landslide traveled more than 100 ft from the source to the lower part of Woodlawn Terrace Place where it blocked the street. During 1992, I examined the area and found no evidence of significant hillslope deformation adjacent to the landslide scar that formed in 1965. The material that had failed appeared to be a dark red soil overlying highly weathered bedrock, and fill appears to have been involved as well (De Silva, 1974).

Another landslide, on private property between Pinaoula Place and Pinaoula Street (Slide #11 of De Silva, 1974) in the upper part of the valley also apparently occurred during the storm of mid-November 1965 (Jellinger, 1977; De Silva, 1974). Failure was largely in fill (De Silva, p. 203, 1974). I saw no evidence of this landslide during my examination in 1992. There are three new homes on Pinaoula Place, and all are apparently on pier foundations. Uphill from the new homes, on the northeast side of the street, weathered bedrock is exposed. Streets, curbs and gutters are all in good repair, and there are no cracks or offsets in the concrete curbs/aprons. The soil is reddish colored and clay rich similar to that at Woodlawn Terrace Place and elsewhere in the upper part of the valley.

Evidence suggestive of other past landslides was recognized during the cooperative study between the USGS and the City and County of Honolulu. Most of this evidence appears to have resulted from fast-moving landslides and debris flows and includes historical debris flows, large fan-shaped deposits that probably result from a succession of past debris flows, and a large debris-avalanche deposit from the flank of Round Top (see pl. 1 and fig. 6 of Peterson and others, 1993). Several additional areas, however, displayed irregular landforms that might be suggestive of old slow-moving landslides. These areas were identified by S. D. Ellen of the USGS during examination of aerial photographs taken in the early stages of residential development. The areas of irregular topography are along the west side of the valley in the general vicinity of Oahu Avenue, Huelani Drive, Keahi Street, and Loulu Street. These areas lack consistent deformational evidence for recent or current movement and consequently are not shown on the map.

With the likely exception of the areas of possible past landsliding along the west side of the valley recognized by S. D. Ellen, the past landslides described in this section have formed abruptly and moved rapidly, at a rate of at least several feet to tens of feet per minute. They typically have slid or flowed completely out of the place where they originated. Thus, the concept of slow, progressive failure probably is not relevant to these landslides. I did not notice any unusual amount of deformation to streets, walks, or driveways in the areas near these landslides. Because these landslides occurred in different materials and behaved differently from the Alani-Paty and Hulu-Woolsey landslides, the prediction of locations of landslides of this type is outside the scope of this study.

## Patterns of Deformation

In the process of looking for evidence of slope movement in the Manoa Valley, different kinds of deformation to man-made features were examined and noted on the maps. There are many indicators of ground movement in Manoa Valley, ranging from cracked streets, curbs, and sidewalks to tilted signs and utility poles. These indicators in themselves do not necessarily indicate sites of developing landslides. Clay-rich soils like those in the Manoa Valley can cause damage by several other means, including shrink-swell, downslope creep, and settlement of fill.

When we earlier mapped the Alani-Paty and Hulu-Woolsey landslides in Woodlawn (Baum and others, 1989), we noted a consistent pattern to the deformation. In the upper part of the landslides, where moving ground was pulling away from stationary ground farther uphill, the indicators of movement consistently showed stretching. Stretching was also evident in sidewalks, curbs, and in walls that trended downslope; these rigid structures were pulled apart. Along the sides or flanks of the landslides, deformation to structures largely reflected shearing displacement; streets, walls, and curbs were simply offset without one side being raised relative to the other. Farther downslope, near the toes of the landslides, the deformation features were produced by shortening, such as buckling or thrusting. When all the features of stretching, shearing, and shortening were compiled on a base map, a clear pattern emerged that distinguished sliding ground from stationary ground.

A similar arrangement of deformation features in other parts of the Manoa Valley should characterize developing landslides. For example, pull-apart fractures should dominate the deformation in the upper part of a developing landslide, and buckling and other compressional features should dominate the downslope end of an incipient landslide. The flank of a developing landslide should exhibit shear offset of manmade features.

For any deformation feature, whether it be stretching, shortening, or shearing, there are several possible causes. In general, there are more potential causes for simple stretching and shortening than for shearing. Stretching and shortening are commonly associated with settlement of fill, hillslope creep, and deformation imparted by tree roots or heavy vehicles. Evidence for shearing is less common, and I looked closely for compatible kinds of deformation wherever a shear offset was found.

## HOW THE MAPS WERE MADE

The map of deformation features (pl. 1, 4 sheets) was made by walking all the streets in the Manoa Valley and noting damage to streets, sidewalks, curbs, and other structures along the public right-of-way. Observations were recorded in the form of simple notes or symbols on a planimetric base map at a scale of 1 in. = 100 ft (1:1,200) provided by the Department of Public Works of the City and County of Honolulu. Private property was examined only from the street. Where damage along the public right-of-way was uncommonly abundant, nearby private property was studied more closely from the street to determine whether a consistent pattern of deformation could be identified beyond the public right-of-way.

Most of the features observed in the field have been recorded on the map of deformation features either as notes or symbols. A few features noted in the field were not included on the maps because they were later found to be of minimal significance. For example, in some areas I noted different types of curbing. Some curbs were made from quarried basaltic rock and apparently were quite old. Other, newer curbs were made of precast concrete, formed-in-place concrete, or asphalt. The types of curbs thus provide a rough estimate of the length of time that the curb has been in place, and newer curbs could represent a repair of damage caused by slope movement. Where new curbs were evident, other nearby structures were examined more closely. Although this strategy seemed reasonable, it did not identify any consistent patterns of deformation, and notations about the types of curbs were mostly omitted from the map.

The interpretive map (pl. 2) was made largely from the maps of deformation features. The base for this map was prepared by Ms. Laverne Higa of the City and County of Honolulu from their Geographic Information Systems (GIS) database. The base has an approximate scale of 1 in. = 400 ft (1:4,800) and shows contour lines (40-ft interval), property boundaries, and streets. Locations of areas that could represent developing landslides were sketched on this base map. These areas include small landslides in fill and deformation features consistent with formation of new landslides.

## SCALE AND LIMITATIONS OF THE MAPS

I originally intended to draw cracks, offsets, pull aparts, bulges, and other features at their true scale and in their true position on an enlargement of the 1 in. = 100 ft base map. For an area in Woodlawn, I tested making a map of features at a scale of 1 in. = 20 ft. Two problems rendered this experiment unworkable. First, the base map lacked sufficient detail to accurately draw cracks and other features in their true position and size. Second, the time required to map all the features in the Manoa Valley in this manner would be enormous. About nine person-weeks of field work were required to map the relatively small area occupied by the Alani-Paty and Hulu-Woolsey landslides in Woodlawn (Baum and others, 1989), which were mapped at a similar level of detail.

For future mapping studies of this type, I suggest mapping a study area such as the Manoa Valley at a scale of about 1 in. = 200 ft. Then, within this area, detailed maps at a scale of 1 in. = 20 ft should be prepared of any areas where deformation features suggest that a landslide may be forming. For these detailed maps, both public and private property should be mapped so that all relevant evidence is included.

In preparing the maps of this report, I have distinguished observations from interpretations. Plate 1 (4 sheets) contains observations; plate 2 (1 sheet) contains interpretations. The observations recorded on Plate 1 are incomplete for two principal reasons. First, emphasis on certain features changed during the mapping. For example, some features were mapped on the northwest side of the valley that were not mapped on the southeast side. Because indications of slope movements are more abundant on the southeast side of Manoa Valley, mapping there emphasized the opening of cracks and kinds of motion required to produce the openings. On the northwest side of the valley, minor cracks in driveways and sidewalks received more attention because other evidence for movement was less common.

Second, the condition of houses, streets, and yards in the Manoa Valley changes rapidly over time. Many of the streets were repaved during the three years of our study. Furthermore, damage to homes is typically repaired promptly, which complicates the task of mapping and interpreting damage patterns. On the positive side however, prompt repair of pavements may reduce infiltration of surface water and contribute to stability of the slopes.

The maps are experimental. To the best of my knowledge, mapping of this type has not been attempted before, and these maps are without precedent. Consequently, there is no prescribed method for deciding which features to show on the maps or how to show them. Likewise, there are no standard recommendations for how to utilize the information on the maps. Therefore, these maps should not be used as the sole basis for assessing stability of hillslopes in the Manoa Valley, but rather should be used in conjunction with other, independently obtained information. Examples of independent information might include deflections of survey lines, increased incidence of water-main breaks, and corroborating data from private property.

## RESULTS

The mapping of deformation revealed no landslides similar in size and degree of development to the Alani-Paty and Hulu-Woolsey landslides. Data on the four sheets of Plate 1 reveal that deformational features are common throughout the Manoa Valley. Deformation to streets, sidewalks, and walls is common and widespread. However, the patterns of cracks and the sense of deformation associated with them do not suggest landsliding except in a few places. There are nine areas with evidence that might be related to slow-moving landsliding, and these are shown on the interpretive map (pl. 2). Outlines of the active Alani-Paty and Hulu-Woolsey landslides are shown in addition to these areas to provide a frame of reference.

The nine areas can be classified into three categories, two of which indicate potentially significant slope movements. Category 1 is minor fill failure. Failures of this type generally lack the potential to develop into large, slow-moving landslides. Categories

2 and 3, however, have the potential to become enlargements of the active landslides in Woodlawn or similar, but independent, landslides. Locations for other past landslides are not shown because the recent or current movement was not revealed in the deformational features mapped for this report. Locations of most of these other past landslides are shown in Jellinger (1977), De Silva (1974), and Peterson and others (1993).

## Category 1. Small Side-Hill Failures of Fill

There are five areas shown on the map where a side-hill fill that underlies a street or walkway shows signs of failure. Evidence for the small failures is noted on Plate 1. In each case the deformation appears to involve only fill and an adjacent retaining wall, and thus does not suggest potential enlargement into large landslides. The five areas and their characteristics are as follows:

1. **The south side of Metcalf Street just uphill from Teachers College (pl. 1, sheet 1).** Small retaining walls, which support an adjacent sidewalk and Metcalf Street, have failed locally. These failures appear superficial; the retaining walls are not failing at locations where massive concrete steps leading down to the campus from Metcalf Street provide additional support. North of Metcalf Street, along lower Hunnewell Street, there is abundant evidence of downhill creep of soil but no consistent pattern that would suggest a large developing landslide.

2. **The southeast side of University Avenue just north of intersection with Vancouver Drive (pl. 1, sheet 1).** Side-hill fills supported by retaining walls on the campus of the University of Hawaii show signs of local failure. Sidewalk sections are offset, and curbs and gutters are stretched. There is no evidence that these local failures are indicators of potential large landslides.

3. **The north part of Huelani Drive (pl. 1, sheet 2).** There is a small sag in the street where it is supported by fill along the axis of a drainage that crosses Huelani Drive. No shears have developed, and deformation is small.

4. **Access road to water tank off of Loulu Place in northern part of valley (pl. 1, sheet 2).** The access road to a water tank off of Loulu Place is supported by a low retaining wall on its southeast side. There is a sag in the fill, and the curbs are offset about 1/8-in. on both ends of the sagging part. The retaining wall appears undeformed. This pattern of deformation is consistent with failure of the fill and wall, and the potential for enlargement is small.

5. **Downhill side of Awoa Street, southwest from intersection with Lowery Avenue (pl. 1, sheet 4).** Sags and offsets occur in a sidewalk adjacent to a small stream. This feature appears to result from several small landslides forming in the fill. Potential for enlargement is small.

## Category 2. Small Developing Landslide

**Along Paty Drive, just northeast of the head of the active Alani-Paty landslide (pl. 1, sheet 3),** is a concentration of deformation that appears to be a developing landslide. In Paty Drive, the fill along the downhill side of the street has sagged. There are large (3 to 4 in) pull aparts between the curb and gutter, and there are arcuate cracks in Paty Drive that are approximately centered on the area of sagging on the edge of the street. Immediately downhill, along Alani Drive, a stone retaining wall is deformed and the gutter on the uphill side of Alani Drive has been compressed. The amount of shortening at the toe of this feature, near Alani Drive, is similar to the three or four inches of stretching at the top near Paty Drive. In addition, samples from boring #17, located at the intersection of Alani Drive and Puhala Rise, were distinctly softer than materials from other borings off of the active Alani-Paty landslide (Baum and Reid, 1992). This feature, extending between Paty Drive and Alani Drive and only 100 ft northeast of the existing Alani-Paty landslide, has the characteristics of a small, developing landslide that has a potential to enlarge.

### Category 3. Areas of Compressional Features

There are three areas of concentrated compressional features that could represent toes of developing landslides. All are in Woodlawn. One of the three could be an extension of active movement of the Hulu-Woolsey landslide. The other two areas are within 800 ft of the active Alani-Paty landslide.

1. **Intersection of Kalawao Place and Awoa Street (pl. 1, sheet 4).** This area contains abundant evidences of shortening, including thrusting of a sidewalk slab over an adjacent slab and buckling of curb and gutter. Stone walls on lower Kalawao Place contain compressional fractures. This area could be an extension of the Hulu-Woolsey landslide.

2. **Woodlawn Drive and lower Puhala Rise (pl. 1, sheet 3).** Several clear evidences of shortening occur along Woodlawn Drive just northeast of Kahaloa Drive. Driveways are pushed into the street, and there are bumps in lawns and cracks in building foundations that appear to be due to shortening. Along the lower part of Puhala Rise, there are several springs and broken walls as well as wavy curb lines. A slope inclinometer casing was installed in boring #25 in Puhala Rise by the USGS a few feet uphill from the zone of compressional damage; that inclinometer did not record any deformation between June 28, 1990 and March 29, 1991 (Baum and others, p. 95, 1991).

3. **Paty Drive just southwest of intersection with Beaumont Woods Place (pl. 1, sheet 3).** There are several indications of shortening along the curb/gutter of Paty Drive and in walls in the two properties just southwest of the junction of Paty Drive with Beaumont Woods Place. No evidence was found for pull-apart structures on Beaumont Woods Place that would further suggest development of a landslide.

## ALTERNATIVE APPROACHES TO UTILIZATION OF INFORMATION

Most strategies for coping with landslide problems fall into three general categories--legislative, monitoring, and stabilization. Legislative approaches may involve adopting ordinances for special zoning or grading requirements in areas of potential or developing problems. For example, some communities, such as Los Angeles, California, have designated certain parts of their cities as hillside areas, and in these areas they require special studies prior to the issuance of building permits. Similarly, where problems are already known to exist, local government can facilitate the formation of private trusts in which homeowners in an affected area share the cost of stabilization.

Monitoring of slope movements is typically undertaken where the type of movement and geometry of moving ground need clarification before the type of remedial action can be determined. Precise monitoring is particularly useful for detecting the very subtle movements and their patterns that indicate progressive failure and incipient landslide movement. The selection of any remedial action requires more information than the types of distress shown on plate 1, and a period of monitoring allows more informed decisionmaking.

Monitoring for developing landslides can be simple, such as periodic repeated descriptions of damage to structures such as walks or curbs. Another simple method involves scheduled, periodic checks of locations of water-main or other utility breaks and comparison with locations of known or suspected slope movements. Slightly more elaborate methods involve establishment of survey lines across areas of suspected movement. Such survey lines are typically resurveyed annually, and accumulated movements in the range of 0.1 to 0.2 ft are regarded as serious. More sensitive monitoring devices, such as inclinometers and extensometers, can be used to detect more subtle movements. These different kinds of monitoring can be suited to the different categories of potential slope movement described here.

Stabilization of a developing landslide requires much more information than I obtained from surface inspection of deformational features. A typical project requires separate data-gathering, analysis, and design in advance of construction. It is possible, however, to adopt some measures as a matter of course, without elaborate studies, because the measures are always beneficial. These include maintaining streets and utilities in good repair, including patching of cracks and ensuring that storm drains are functioning properly. We have learned that subsurface water is the destabilizing agent in the Alani-Paty landslide (Baum and Reid, 1992). Actions that inhibit infiltration of surface water into the subsurface will be generally beneficial to the overall stability of slopes in the Manoa Valley.

## SUMMARY AND CONCLUSIONS

I examined all public right-of-ways in the Manoa Valley for cracks and other deformational features that could indicate developing landslides. Two existing landslides in the Manoa Valley, the Alani-Paty and the Hulu-Woolsey landslides, have caused much property damage. The purpose of this investigation was to see if locations of any other potential landslides of this type could be identified before they become fully developed and implementation of corrective measures becomes extremely costly.

The findings of this study are contained on two maps and in this text. One map (pl. 1) contains field observations and notes about deformation features. The other map (pl. 2) contains interpretations of the field observations. The interpretative map was made by comparing the patterns of deformation mapped during this study to patterns on existing landslides in Woodlawn.

I detected no other landslides in the Manoa Valley that are similar to the active landslides in the Woodlawn area.

However, nine areas were identified as containing deformational features that might result from landsliding. The nine areas were combined into the following three categories:

1--Small side-hill failures of fill (five areas)
2--Small developing landslide (one area)
3--Areas of compressional features (three areas)

Category 1 features occur in fill and do not have damage patterns that suggest potential enlargement into landslides of the Alani-Paty type. Categories 2 and 3, in contrast, do show these patterns. Their proximity to the active Alani-Paty and Hulu-Woolsey landslides, which apparently developed by progressive failure, may be of particular concern.

There are several approaches to mitigate the effects of unstable hillslopes. In general, these can be divided into legislative, monitoring, and stabilization approaches. Legislative controls operate through building and grading regulations, zoning, and formation of special trusts. Monitoring is commonly applied where insufficient information is available to specify the severity of the problem. Actual stabilization of a developing landslide requires separate data-gathering, analysis, and design phases.

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