Chapter 7

FACTORS OF LANDSLIDES IN BERKELEY, CALIFORNIA

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Introduction

Slope instability is potentially the most dangerous and damaging geological hazard threatening residents of hillside areas. Landsliding not only causes damage to man-made structures, but also impairs the usefulness of the land itself. Slope failures have caused millions of dollars worth of damage in the San Francisco Bay Area alone.

The North Berkeley Hills area is a prime location for landsliding because of the high clay content of the soils, steep slopes, and periodic heavy storms. This paper examines three heavy storm periods--February 1940, October 1962, and January 1982--and the landslides that occurred in Berkeley during those times.

Factors Affecting Landslides

There are many variables involved with slope failures. They may be natural, or man-induced, or both. Some of the main factors contributing to landsliding include bedrock and soil conditions, the presence of ancient landslide deposits, the steepness of the slope, and the amount of rainfall.

Soil type - Types of soil include sand, loam, silt, and clay. THis report stresses clay soils, since the Berkeley Hills soils are high in clay content. Clay soil consists of 40 percent or more clay, less than 45 percent sand, and less than 40 percent silt. The presence of large amounts of clay in the soils is a major factor causing landslides since it affects the stability of the soils when wet.

Clay has a great water-holding capacity, both upon the surface of the particles and within the cellule of the colloid. The absorption of water results in an increase in soil volume, frequently approaching 20 percent (Thomas, 1939). Volume changes give clay soil a high shrink/swell potential. The long dry summer dries out these soils, which then undergo great shrinkage, creating many large and small cracks in the soil. This allows atmospheric gases and winter rains to penetrate into the lower soil horizons. The gases cause mixing of the soil, while the rain causes the clay to swell and expand in volume, resulting in slow, downslope movement. This annual shrinking and swelling is an important factor in the deep weathering of the soil as well as its downslope movement (Thomas, 1939).

Another major characteristic of clay is plasticity, which causes the soil to undergo permanent deformation and lose much of its solidness. Smectite, a predominant clay mineral in soils, has a high plasticity and cohesive factor which rapidly decreases the shear strength along with slight increase of water content due to the slow drainage rate in the soil. The colloidal clay complex, which makes up a large portion of hillslopes in this area, has certain characteristics such that when subjected to heavy and continued rainfall, it promotes slope instability.

In summary, clay soils are a major factor promoting landslides due to their absorption of great quantities of water, slow drainage, high expansion potential, great shrink/swell potential, high plasticity, and subsequent loss of shear strength.

Ancient landslide deposits - Landslides that cause damage to man-made structures in the East Bay area frequently occur in pre-existing ancient landslide deposits. The renewed movements in the areas underlain by ancient landslide deposits may result either from movements of the ground in response to rainfall, erosion, other natural factors, or from movements caused by the modification of the natural ground surface by man, such as cutting and filling, diversion of drainage runoffs, removal of vegetation, addition of weight to the slopes, and other man-induced changes in the natural environment. Construction on ancient landslide deposits appears to have contributed to much of the recent landslide activity. This is hard to determine, however, because ancient landslide deposits are generally very difficult to map in extensively urbanized areas, not only because of the surface covering of buildings and streets, but also because the geomorphic features that permit the deposits to be recognized, such as scarps and toes, have generally been so strongly modified by cutting and filling (Nilsen and Turner, 1975).

Steepness of slope - About 85 percent of the recent landslides that have damaged man-made structures or have caused the devaluation of land in the East Bay area developed on natural slopes steeper than 15 percent (USGS, 1972). Slope is the most important site characteristic associated with the occurrence of soil slips, which are landslides involving only the material above the unweathered bedrock surface. The incidence of slips is found to increase with increasing slope and to decrease with increasing soil depth. Approximately four times as many slips occur on slopes over 70 percent as on slopes 50 to 70 percent. Soils that are typically shallow and rocky and rest on slopes that exceed the angle of repose for unconsolidated soil are extremely prone to slippage. Over-steepened slopes, formed when water content increases, or by cutting operations for roadways or building foundations, have influenced landslide occurrences. Heavy and prolonged rainfall over steep slopes increases the chance of slope failure substantially by adding weight on the slope and by washing away the supporting toe of the slope. As a result, landsliding is a major geological process on both natural and modified slopes greater than 15 percent.

Amount of rainfall - As water content is often mentioned as a factor in slope failure, it is evident that rainfall plays a major role in causing landslides. Only during or immediately after periods of very intense rainfall has abundant landsliding occurred in Berkeley. Correlation between mean annual rainfall and landsliding is weak; the timing and intensity of rainfall is more important in understanding landslides. The three main features in the pattern of rainfall are (1) the intensity of individual storm periods, (2) the amount of rainfall accumulated prior to the onset of the storm, and (3) the duration of the storm period. Most landslides occur during or immediately after storm periods in which more than seven inches of rain fell, particularly if the ground is already wet and saturated from previous storms. Since more than 90 percent of the precipitation in Berkeley occurs during the rainy season between November and April, this is when most landsliding occurs (Nilsen and Turner, 1975).

The spacing of the storms during the rainy season significantly affects landslide activity. If the timing of precipitation differs between two seasons, the number of landslide occurrences usually differs greatly even when the seasons had similar cumulative inches of precipitation. Intense storms of even very short duration are capable of generating widespread landslide activity. Storms occurring after large amounts of rain have already fallen generate more landslides than storms occurring at the beginning of the rainy season. A higher rainfall intensity is probably required to generate landslides during the early months of the rainy season, since landsliding occurs more easily when the ground is saturated and the groundwater table is high. The records of landsliding during the past 12 years indicate that storm totals of more than seven inches of rainfall have generated large numbers of landslide when the ground has already received close to ten inches or more of rainfall without long intervening dry periods (Nilsen and Turner, 1975). The alternating wet and dry periods during the rainy season are also an important factor affecting landslide activity, because during the dry periods, the amount of accumulated groundwater decreases as a result of evapotranspiration and drainage. This reduction in ground moisture content increases the future storm threshold in the season, decreasing the potential of future landslides. In conclusion, the distribution, amount, and intensity of rainfall exert a strong influence on landsliding.

Landslides in Berkeley

Climate in the Bay Area, including Berkeley, is variable and relatively mild. This makes climate-related hazards in Berkeley quite rare, but not altogether absent. Landslides do occur, especially in the North Berkeley Hills where there is high clay content and steep slopes. Each major storm has caused damages of at least $100,000 to the University campus alone. Many residential areas in the hills have also suffered considerable damages. Intense storms in February 1940, October 1962, and January 1982 had record-breaking precipitation of up to 6.97 inches in one day. During or immediately after these storm periods, many landslides occurred in Berkeley, showing a correlation between the amount of rainfall and the amount of landslides.

In February 1940, there were several consecutive days where precipitation was above 2 inches per day. The storm occurred between February 24 and 29, bringing the month's total precipitation to 10.02 inches (Table 1). During this storm period, more than 35 slides occurred in the hill area, some

TABLE 1

February, 1940

DATES	PPT (inches)
22	0.00
23	0.04
24	0.29
25	0.80
26	2.08
27	2.18
28	2.03
29	0.05
Monthly Total	10.02

(USDA, 1940)

of them seriously threatening homes. Most severe damages occurred during the morning before dawn on February 28, when the soils were already saturated with water and the storm was most intense. The extreme increase of water content in a short period was the main cause of landslides and flooding in Berkeley (see paper by Lawler, this report). Some residents evacuated during the night when the hill-side across the street from 708 Euclid Avenue near Poplar Street gave way, and the earth slid away under the sidewalk on the lower side of the street, forming a river of mud that swept down the steep incline to the backyards of Cragmont Avenue homes below. At Cragmont Avenue, near Shasta Road, the sidewalk sank approximately 4 to 10 inches in several places. A tall concrete wall threatened to topple at the rear of 1160 Cragmont Avenue. There were many slides that covered sidewalks, damaged pavements, and blocked garages. These included areas such as Sterling and Twain Avenues, 1507 Grant Street, 755 Hilldale Avenue, 1019 Miller Avenue, 86 El Camino Real, 48 Mosswood Road, and 1015 Cragmont Avenue. Other slides were reported at Keller and Forest Avenues, 2683 Shasta Road, Glendale and La Loma Avenues, Fairlawn Avenue and Queens Road, Bret Harte Road and Keeler Avenue, Hilldale Avenue and Poppy Lane. Other slides occurred on Alvarado Road, Santa Barbara Road east of Spruce Street, 165 Panoramic Way, Rose Street east of Bonita, Olympus Avenue south of Avenida Road, Del Mar Avenue, Grizzly Peak Boulevard south of Avenida Road, and north of Queens Road (Berkeley Gazette, February 1940) (Figure 1).

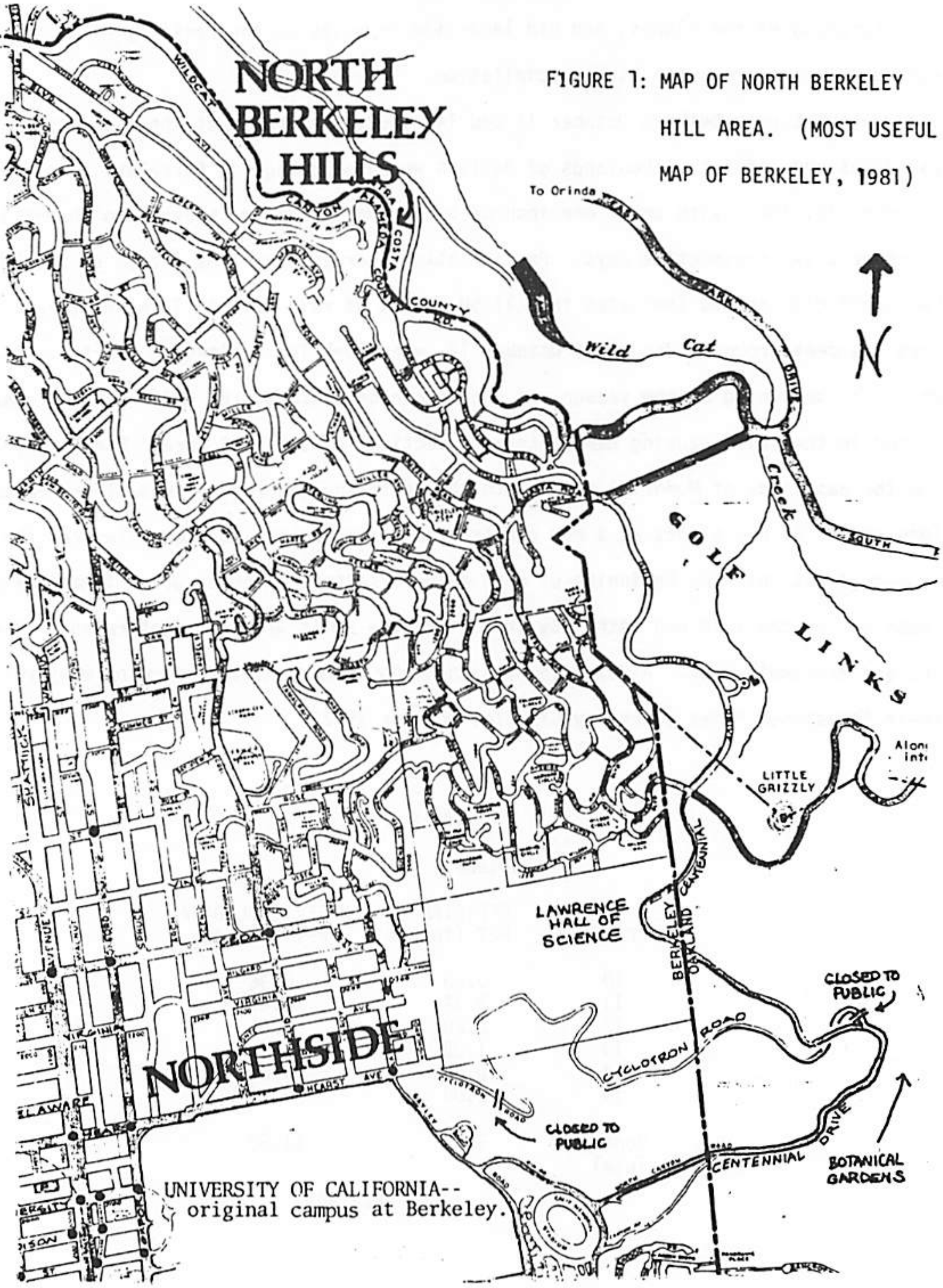

FIGURE 1: MAP OF NORTH BERKELEY HILL AREA. (MOST USEFUL MAP OF BERKELEY, 1981)

Many of these slide areas were repaired and drainage systems installed to remove the excess water from their foundations. Unfortunately, due to the combination of other factors such as the high clay content, the steepness of the slopes, and old landslide deposits in the Berkeley Hills, many slides re-occurred during future storms with high precipitation.

The storm which struck between October 11 and 14, 1962, also known as the "Columbus Day Storm," took several lives and inflicted thousands of dollars worth of damage in Berkeley. The storm started slowly on October 12, 1962, with under one inch of rain, and increased to over two inches of precipitation for the next two consecutive days. Precipitation decreased to 1.82 inches on the 13th of October. An unofficial record indicates that 11.50 inches of rain fell in 72 hours (Table 2). The storm reached its peak around midnight of October 12, when Berkeley's disaster started. Due to the heavy storm at the beginning of the season and poor drainage systems, the water content rose rapidly and accumulated in the soil, causing damage in many sections of the hill area. North Canyon Road, leading from the east side of Memorial Stadium to the Radiation Laboratory, was closed because of a 600-foot-long series of mud slides at a new construction site about a quarter-mile from the laboratory gate. This damage was only the beginning of more major disasters which occurred immediately after the storm subsided on the 13th and 14th. By this time, the soils were over-saturated with water, low in cohesion, and extremely weak. A dozen foundations under houses shifted, forcing many residents to evacuate their threatened homes (Berkeley Gazette, October 1962).

TABLE 2

October, 1962

DATES	OFFICIAL PPT (inches)	UNOFFICIAL DATA PPT (inches)
10	0.53	0.36
11	2.34	3.87
12	2.29	3.80
13	1.82	3.41
14	0.04	0.00
15	0.00	0.00
Monthly Total	7.05	11.50

(USDA, 1962)

In the 200 block of Alvarado Road, where new houses were under construction, a huge mud slide swirled around four homes and plunged through a fifth home. The rear yard of 90 Evergreen Lane slid into the home, broke doors and windows, and piled mud hip-high in the living room. At Keeler Avenue and Bret Harte Road, the entire front yard of a home, which included the garage, steps, and garden, slid several feet, endangering the house. In the southeast section of the city, the heaviest damage incurred in the vicinity of Harwood Creek. A huge garden between 84 and 80 Vincente Road suddenly gave way and roared out into the street, engulfing a passing motorist and several parked cars. About 50 feet of the front wall surrounding the California School for the Deaf at Warring and Derby Streets collapsed on the sidewalk. Another huge retaining wall in front of 820 San Luis Road collapsed. The Caldecott Tunnel was closed for about five days because tons of mud, rock, trees, and debris collected inside. Tunnel Road also collapsed and remained blocked between the Uplands and the east city limits. Fish Ranch Road and LeRoy Avenue between Hearst Avenue and Ridge Road were closed with numerous slides. The slide that covered 600 feet of pavement on North Canyon Road, which started on the 12th, washed mud and debris down past Bowles Hall and onto Gayley Road, covering it with up to a foot of silt. More mud and water flowed down the slope into the basement of Cowell Hospital. International House, the Poultry Husbandry Laboratory, and Strawberry Canyon recreational center were surrounded by three feet of mud. The mud which ruined Strawberry Canyon came from slides farther up the hills on the side of the recreational center. The water rushed down faster than the pipe, ten feet in diameter, could catch and empty into Strawberry Creek. Instead, the water carried mud and debris down to the recreational center (Berkeley Gazette, October, 1962) (Figure 1).

More earth movements on the 1400 block of Grizzly Peak Boulevard, at 800 Woodmont Avenue, and on Sunset Lane either threatened homes or forced their evacuation. There were slide problems on the 100 block of Keeler Avenue, and exposed foundations on Northgate Avenue, south of Quail Avenue. In the North Berkeley Hills area slides were reported on Shasta Road, Tamalpais Road, Prospect Avenue, Spruce STreet, Miller Avenue, Sterling Avenue, Quail Avenue, and La Loma Avenue. Most of those areas also had experienced landslides in the 1940 storm. Instability of ancient landslide deposits weakened the foundations and increased the potential for future landslide occurrences. The downpour was the main agent inducing the numerous landslides (Berkeley Gazette, October, 1962).

On January 4, 1982, the Berkeley weather station received a record-breaking 6.97 inches in 24 hours, which made 1981-82's seasonal average of 27.05 inches four inches more than Berkeley receives in a normal year. The soil, already saturated by the high precipitation in November and December of 1981, gave way on many slopes in the Berkeley Hills. A boulder 4 feet in diameter rolled onto Spruce Street near Santa Clara Road, partially blocking the road. Grizzly Peak Boulevard was also partly blocked by landslides. Centennial Drive was closed from Strawberry Canyon pool to the Lawrence Hall of Science. Water poured over the road and bank, causing the shoulder level to drop down several feet.

As a result, the road had to be reconstructed and repositioned at an approximate cost of $80,000. At least three road shoulder failures reported to the City of Berkeley occurred at Wildcat Canyon Road due to erosion by runoff from heavy rains on previously saturated soils (Glenn Carlos, May 1983). A private home at Hillview Road received damages from heavy rains that caused the foundation on one side to sink approximately seven inches. The eroded soil sloughed out onto Wildcat Canyon Road, obstructing traffic. Heavy precipitation was the main factor in all of the landslide activities. The 1982-83 season has produced a higher total precipitation than the previous year, but there have been less intense storms, resulting in fewer landslides.

<u>Summary</u>

From the landslide incidents described, a pattern of their occurrences emerges. They almost always occur during and immediately after a storm where at least 1 inch of precipitation has fallen in 24 hours. They tend to occur more frequently and more severely after December when water has already accumulated in the soil from the early winter months, though very heavy precipitation, such as occurred in October of 1962, can cause sliding at the beginning of the rainy season. Landslides are more abundant in the hills where the clay content is higher and the slope is steeper. Areas where landslides have occurred in the past have a greater potential of recurring. The most important and easily detected pattern is the correlation between the amount of precipitation and the amount of landsliding. With these factors in mind, landsliding damages can be mitigated or prevented with proper planning and engineering.

REFERENCES CITED

1. The Berkeley Gazette: February 28, 1940; October 12, 1962; October 15, 1962; and January 5, 1982.

2. Carlos, Glenn, Public Works, Engineering Department, City Hall of Berkeley. Personal communication, May 1983.

3. Daily Californian, January 17, 1980; March 6, 1980; and June 19, 1980.

4. Larson, Dave, Weather Observer, University of California, Department of Geography. Personal communication, April and May 1983.

5. Most Useful Map of Berkeley, California and Vicinity, 1981. Hotcake Press, Berkeley, California.

6. Nilsen, Tor H., F.A. Taylor, and E.E. Brabb, 1976. Recent Landslides in Alameda County, California (1940-71): An Estimate of Economic Losses and Correlations with Slope, Rainfall, and Ancient Landslide Deposits: U.S. Geological Survey Bulletin 1398.

7. Nilsen, Tor H., and Barbara L. Turner, 1975. The Influence of Rainfall and Ancient Landslide Deposits on Recent Landslides (1950-71) in Urban Areas of Contra Costa County, California: U.S. Geological Survey Bulletin 1388.

8. Thomas, E.S., 1939. Landslide Forms and Their Origin in the Middle Coast Ranges: Masters Thesis in Geography Department, Graduate Division of the University of California, Berkeley, pp. 37-48.

9. U.S. Department of Agriculture (USDA), Climatological Data, Weather Bureau: Department of Water Resources, State of California: 1940 and 1962.

10. U.S. Geological Survey (USGS), 1972. Slope map of the San Francisco Bay region: scale 1:125,000.

11. Warnke, Fred, Manager of Buildings and Grounds Services, University of California. Personal communication, May 1983.