The Evaluation of Slope Failure in Baldwin Hills, Los Angeles County, California

Presented in Partial Fulfillment of the Requirements for Bachelor of Science Degree of Ohio State University

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1986

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ABSTRACT

The Baldwin Hills area has suffered widespread damage from slope failures in the past. The problems of slope instability are particularly severe in the area for two reasons. First, the development of the hills was prior to the enactment of grading codes by local government. Second, the terrain consisted of steep slopes underlain by soft sedimentary rocks.

Slope failures in the Baldwin Hills have occurred in the form of landslides and erosion, associated with unusually heavy winter rainfall. The landslides are in form of mudslides with soil slips and mudflows. These failures are derived partly from the mantle of soil and slope wash that overlies the bedrock of clay-rich material on natural slopes. Slopes underlain by Culver sand are particularly vulnerable to erosion.

In the most densely developed areas of Baldwin Hills that have suffered slope damage in the past, 345 (about 21%) of 1668 residential properties are known by the California Division of Mines and Geology (CDMG) to have been damaged by slope failure. Additionally, about 93% of the 1668 residential lots apparently have potential for at least minor damage from slope failure in the future, unless measures are taken to stabilize slopes that include or endanger these properties (Weber, 1982).
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INTRODUCTION

The existance of wide-spread landslides in the Los Angeles metropolitan area has been of increasing concern. It is estimated that the accumulated property damage in California by landsliding will amount to $9.9 billion by the year 2000 (CD:\G, 1973). The area of Baldwin Hills, the alluvial hills of the Los Angeles Coastal Plain, is of high potential for slope instability. This report describes the evaluation of slope failure and measures for their alleviation, in Baldwin Hills, Los Angeles County, California.

Slope failures have been classified in various ways using different criteria, but three types are commonly recognized: falls - movement of debris through the air; slides - downslope movement along slip or shear surfaces; and flows - downslope displacement of material as a viscous fluid (Varnes, 1958). In southern California, the major phenomena are slides, especially soil slips, and landslides, with debris flows and slope erosion. The different types of slope failure are found chiefly in the mountain areas, in the intermediate hilly uplands (Baldwin Hills), and along the coast (Cooke, 1984).
URBAN SETTING OF BALDWIN HILLS

The Baldwin Hills, named after E.J. "Lucky" Baldwin, who once owned part of the hills before they were developed, lie within the Los Angeles Coastal Plain (Fig. 1). Located about nine miles southwest from downtown Los Angeles, the Baldwin Hills are a modest upland area of bedrock raised by relatively recent tectonic movement. The study area encompasses about six square miles of the Hills, rectangular in shape (Fig. 2).

FIGURE 1. The major geomorphological regions of Los Angeles County, (after Cooke, 1984).
FIGURE 2. Detail of Figure 1 showing study area. (Faults: N-I, Newport-Inglewood; SM-H-R, Santa Monica-Hollywood-Raymond) (after CDMG, 1982).

The study area includes the jurisdictions of the County of Los Angeles, the city of Los Angeles, and the City of Culver City. The city of Inglewood borders the study area to the south (California Census, 1985).
GENERAL FEATURES OF SLOPE FAILURE

Geologic Setting and Topography

The Baldwin Hills are situated as a upland area of bedrock raised by relatively recent tectonic movement in the Los Angeles Coastal Plain. Located along the Newport-Inglewood structural zone (Fig. 3), the hills have a maximum elevation of 511 feet, near the center of the hills. Towards the south end, the hills range between 150-200 feet high.

The Newport-Inglewood structural zone, a complex system of faults and folds that extends from west Los Angeles southeastward through the Inglewood-Long Beach areas of Los Angeles County into Orange County, essentially bisects the study area from north-northwestern to south-southeast. The Baldwin Hills consist of a 'gently arched dome, slightly elongated in a northwesterly direction, which is breached by a north-northwest trending graben' (CDMG 1982).

FIGURE 3. Cross section from southwest to northeast through the Baldwin Hills. (Qi, Inglewood Formation; Qb, Baldwin Hills sandy gravel; Qc, Culver sand; Qf, Fox hills relict paleosol; Qfp, flood plain deposits; P, sands from which petroleum has been recovered.) (after CDMG, 1982).
The terrane of the Baldwin Hills consists of Quaternary sediments. The recent uplift of the hills from below sea level attests to continuing tectonic activity in the area during latest Quaternary time (CDEG, 1982). The sediments are very weakly indurated and compacted, and combined with the steep topography it makes this area extremely vulnerable to slope failure, effected principally by sustained, heavy rainfall.

Rainfall

The amount of rainfall is a very important factor for sustaining slope instability. Since 1950, 19 or more inches of rain have fallen in the Baldwin Hills area during the winters of 1951-52, 1957-58, 1968-69, 1977-78, and 1979-80 (CDEG 1982). Graphs (Fig. 4a & 4b) show the recorded rainfall during the winters 1968-69 and 1977-78. In each of these winters the amount of rainfall shows that the rainfall covers in great spurts as much as 10 inches in one week. The months of January and February show the greatest abundance of rainfall.

In conclusion, it is difficult to forecast the occurrence of such rainfall at the beginning of winter. In addition, in some years very rainy periods may occur even though the months of January and February have been relatively dry.
FIGURE 4a. Principal precipitation during 1968-69 of Baldwin Hills (after CDME, 1982).

FIGURE 4b. Principal precipitation during 1977-78 of Baldwin Hills (after CDME, 1982).
Rock Units

The following criteria are generalized descriptions of the lithology and slope stability characteristics of the rock units of the Baldwin Hills area (Fig. 6).

1. Inglewood Formation (Qi)

The Inglewood Formation is of marine deposits that consist mainly of well-bedded siltstone with interlayered beds of very fine-grained sandstone. Calcareous and limonitic concretions are locally abundant. They are exposed mainly in the lower portions of steep slopes in the northern area and in slopes along the east side of the Inglewood fault (Fig. 5). Most of the bedrock landslides in the Baldwin Hills are derived from these rocks, apparently because of their clay content and because they are thinly-bedded, more fractured than the overlying rocks, and commonly dip adversely downward out of slopes (CDMG, 1983).

2. Culver Sand (Qc)

Culver sand is marine deposits that range from moderately sorted and crudely stratified sand and gravel with large-scale cross bedding to well-sorted and well-laminated sand with minor gravel and silt. Coarse clasts typically are well-rounded to subrounded. It is exposed mainly in the northwestern and western parts of the hills, where it rests unconformably on the Inglewood Formation (Fig. 5). The unit reaches a maximum thickness of about 100 feet.

3. Baldwin Hills Sandy Gravel (Qb)

The Baldwin Hills sandy gravel consists of nonmarine deposits that range from gravelly sand to sandy gravel. They are poorly sorted and crudely stratified, and are interlayered with lenses
FIGURE 5. Topographic map of Baldwin Hills (after CDMG, 1982).

- Baldwin Hills sandy gravel
- Culver sand
- Inglewood Formation

and beds of clayey silt and clay. It is the most widely exposed rock in the Baldwin Hills, occupying nearly two-thirds of the area, commonly capping ridges (Fig. 5). Towards the west area, it rests on Culver sand, in both erosional and transitional contact. Eastward, it unconformably overlies the Inglewood Formation. The thickness of this unit ranges from 50 to 100 feet. The Baldwin Hills sandy gravel is very prone to erosion thus forming 'badland topography and gullies' (CDMG 1982).

4. Fox Hills Relict Paleosol (Af)

The Fox Hills Relict Paleosol is a reddish-brown, well-cemented and resistant paleosol developed on erosional surface underlain by
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<td>Artificial fill af</td>
<td>Rock material derived from geologic unit adjacent to fill site as shown on Plate 1. Locally may include trash and other inert debris.</td>
<td>Moderate to high; erosion gullies common.</td>
<td>High in improperly compacted or loose fill. Low to moderate for compacted fill.</td>
<td>May be subject to massive failure if not properly benching into fill bedrock.</td>
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<td>Undivided colluvial and alluvium within and around periphery of the Baldwin Hills Q6o</td>
<td>Mainly unconsolidated, poorly sorted and poorly bedded sand, gravel and silt. Deposits derived from Qb and Qc are more gravelly and sandy than those derived from Q1. Deposits in the area of low relief north and west of the Baldwin Hills are more indurated than those in the hills.</td>
<td>Moderate to high; erosion gullies common in sandy alluvium and colluvium.</td>
<td>Moderate to high; erosion gullies common in stream banks.</td>
<td>Small slumps may occur in stream banks.</td>
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<td>Floodplain, stream channel and marsh deposits of Baldwin Creek Qf, Qfpm and Ufpu</td>
<td>Ufp: chiefly well-sorted and moderately well-bedded fine to medium grained unconsolidated to very poorly consolidated sand; locally underlain at depths of 5-10 feet by clean gravelly material. Ufpm: slightly uplifted and more indurated than Ufp. Qfpm: historically may be even ground underlain by deposits rich in organic material.</td>
<td>Moderate soil development up to 6 feet thick of loamy clay; &quot;A&quot; horizon probably less than 2 feet in thickness.</td>
<td>Low to moderate; erosion gullies common.</td>
<td>Very high in banks of gullies and channels.</td>
<td></td>
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<tr>
<td>Pre-development landslides Ql2</td>
<td>Lithology is variable, depending on geologic units from which derived. Most pre-development landslides consist of deep-seated masses of intact or brecciated bedrock; some consist of shallow masses of soil and colluvium (Locality 134, Plate 1, for example).</td>
<td>See, elsewhere in column, units from which landslides are derived.</td>
<td>Higher than in source rocks from which landslides are derived.</td>
<td>Moderate to high.</td>
<td>Reactivation of pre-deposition landslides may be caused by such factors as heavy loading on surface and excessive infiltration of water into slide plane.</td>
</tr>
<tr>
<td>Fox Hills relict paleosol Qf</td>
<td>Reddish brown silty sand with scattered gravel. Clay binder common. Very well-cemented and hard. Generally massive to crudely stratified. Locally well laminated.</td>
<td>None to poorly developed. &quot;A&quot; horizon is generally less than 2 feet in thickness.</td>
<td>Low for well cemented materials; moderate to high for weathered zones.</td>
<td>Very low. Weathered zone may be subject to debris flows.</td>
<td>Cut slopes 3:1 or steeper and 15 feet high have been known to stand for one year without failure.</td>
</tr>
<tr>
<td>Baldwin Hills sandy gravel Qb</td>
<td>Predominantly brownish gravelly, silty sand with lenses of gravel and thin beds of silt and clay. Coarse beds are generally massive to crudely stratified and are generally more massive than moderately cemented but may contain clay loose sand. Clasts of gravel are generally angular. Silt and sandy clay are generally well-bedded, dense and hard.</td>
<td>Moderate soil development. Soil developed on sand and gravel is sandy. &quot;A&quot; horizon is generally less than 2 feet thick. Weathering zone is generally less than 3 feet but locally is greater than 10 feet in depth.</td>
<td>Moderate to high; badland topography is common.</td>
<td>Moderate to high.</td>
<td>May be subject to blockglides where underlain by clay or silt with adverse dip (2).</td>
</tr>
<tr>
<td>Culver sand Qc</td>
<td>Predominantly interbedded gravelly and gravelly silty sand with minor silt lenses. Sands are fine to coarse-grained, loose to slightly cemented. Massive to crudely stratified. Gravel clasts are typically well-rounded. Iron stains and cementation are common.</td>
<td>Poor to moderate soil development. &quot;A&quot; horizon is generally about 1 foot thick. Weathering zone may be less than 6 feet in depth.</td>
<td>High to very high; badland topography common.</td>
<td>Moderate to high.</td>
<td>Low to moderate.</td>
</tr>
<tr>
<td>Inglewood Formation Q1</td>
<td>Chiefly light brown to light brown-gray silt to very fine-grained sand with local clay. Generally well-bedded and moderately well-consolidated. Loose fine sand is abundant in the higher part of the succession, especially in the northwest corner of the hills. Calciteous and iron concretions are locally abundant. Rocks are locally well-jointed.</td>
<td>Moderate soil development. &quot;A&quot; horizon is generally 1-3 feet thick but weathering may be as deep as 10 feet or more. Soil developed contains more clay than soil developed on other units.</td>
<td>Moderate to low.</td>
<td>Moderate to high.</td>
<td>Moderate to high; several probable, ancient landslides identified on aerial photographs during this study and shown on Plate 1 are located in terrain underlain by this unit.</td>
</tr>
</tbody>
</table>

**FIGURE 6. Descriptions of rock units in Baldwin Hills (after Hsu, 1982).**
Baldwin Hills sandy gravel (Qb), which ranges from silty sand to sandy silt. The thickness of the paleosol ranges from 5 to 10 feet. The unit is of very low permability (CDMG 1982).

5. Pre-development Landslides (Qls)

Mostly ancient, massive, deep-seated landslides derived from bedrock (Qb, Qc, Qi); also, shallower landslides, mainly derived from thick deposits of soil and colluvium.

6. Older Alluvium (Qfpu)

Older alluvium consists of deposits of Ballona Creek floodplain that have been slightly uplifted tectonically.

7. Younger Alluvium and Collovium (Qco, Qfp, Qfpn)

Younger alluvium and collovium consist of modern, unconsolidated and poorly sorted deposits of clay, silt, sand, and gravel. Alluvium deposits are widespread in the interior canyons of the hills while colluvium extends up ravines, swales, and conformable slopes.

8. Artificial Fill (af)

Artificial fill consists of any undifferentiated compacted and uncompacted fill that is placed for construction purposes. These are composed of material derived from the specific site of the fills of from immediately adjacent areas.

Geologic History

The Los Angeles region, which is tectonically very active, consists of hills and mountains formed during withdrawal of the sea to the present coast, from as far as downtown Los Angeles. Baldwin Hills grew, perhaps as recently as the past 100,000-150,000 years, with other hills along the northwest to southeast striking Newport-Inglewood zone of faults and folds (Barrows, 1974).
The Baldwin Hills lie within the Los Angeles Coastal Plain, which is the site of deposition of an immense thickness of marine sediment of Recent and Quaternary sediments. These sediments rest on igneous and metamorphic rocks of Miocene age. Basement rocks beneath the Baldwin Hills are buried by slightly more than 10,000 feet of sedimentary rocks, which represent units of shale and sandstone mainly of Tertiary age.
GENERAL FEATURES OF SLOPE FAILURE

Landslides and Erosion

Since the development of residential areas in the Baldwin Hills in the late 1940's and 1950's, damage has resulted by effects of landsliding and erosion, caused by heavy sustained rainfall. Damaging landslides have been and are expected to continue to be a major geologic hazard in this area.

Slope failure in the Baldwin Hills has consisted of surficial landslides and erosion. Surficial landslides comprise shallow slumps and debris slides and flows, including soil slips, (Fig. 7) that consist of water and sediment mixtures from soil and rock material transported downslope, and vegetation that grows on bedrock or fill. These failures are less than 5 to 10 feet in depth and occur when heavy rainfall has saturated the terrain. Surficial landslides may slide relatively slowly or flow rapidly.

FIGURE 7. The principal features of a soil slip (after Cooke 1984).
The occurrence of surficial landslides is more likely to occur in steeper slopes of 30° or more, than gentler slopes of 20° or less. Studies have shown that surficial slides and flows occur most commonly on slopes with angles between 26° and 45° and rarely in slopes with angles less than 18° (Campbell, 1975).

Erosional features include rilling, where water is spread out while flowing down a slope, and gully ing, where the flow is channeled. The slopes of the foothills and isolated upland areas are primarily eroded near their bases by these gullies, where surface runoff and soil moisture is greatest.

Most of the geologic units of the Baldwin Hills are susceptible to slope failure. The most susceptible is the Inglewood Formation (Qi), which underlies the lower parts of many of the steeper slopes, because it contains sufficient clay to yield clayey soils and slope wash. These slopes are vulnerable to soil-slips and debris flows.

Slope failure is also triggered by the presence of faults. There are many potentially unstable, smooth, continuous planes of weakness within and between rock units — bedding planes, faults, unconformities, fractures and foliation surfaces — all which provide loci for potential movement (Cooke, 1984).

Full Settlement

Another common type of slope failure in the Baldwin Hills is fill settlement. This occurs where fill has not been properly emplaced or compacted. Also, the fill material may contain trash or vegetational debris, thus enhancing higher potential for slope instability. Improper design and compaction may lead to failure of a slope on the fill or a slope directly below the fill slope,
where water may percolate out (CDMG, 1982). Fill settlement is a problem in many areas of the hills, especially the north side.

Seismic Hazards

The movement along the Inglewood fault is expressed by a well-developed scarp that lies along the east side of a graben in the central Baldwin Hills. This fault is displaced slightly to the northeast by a series of northeast-trending faults. These faults are considered to be capable of rupturing the ground during moderate to large earthquakes (Hart, 1980), but there has not been any evidence of surface faulting caused by historic earthquakes along the Inglewood or other faults in the study area.

Under severe ground shaking, landslides would be relatively widespread, especially if the ground is saturated by rainfall. Fill slumps and settlement would be common.

In the past, damaging earthquakes have occurred along the Newport-Inglewood structural zone, but not in Baldwin Hills. The closest earthquake occurred in 1920 damaging the business district of Inglewood. The magnitude hit 5.9 and occurred at relatively shallow depth. The Baldwin Hills were undeveloped at the time, but small surficial landslides occurred in the steeper slopes.
DESCRIPTION OF SLOPE FAILURE IN BALDWIN HILLS

Introduction

The study area was divided into six geographical sub-areas of Baldwin Hills: Northwestern; North-central; Northeastern; Southwestern; Central; and Southeastern (Fig. 8). These areas were investigated by J.A. Treiman; E.Y. Hsu; S.S. Tan; R.E. Saul; and F.H. Weber Jr. of the California Division of Mines and Geology. The descriptions that follow are derived from their 1982 report.

FIGURE 8. Sub-areas 1-6 were investigated for this study (after CDMG, 1982).
Sub-Area 1 - Northwestern Area

Residential and commercial development began in the late 1940's, but the grading for hillside residential development started from 1950 to 1958. The quality of this grading has proven to be extremely variable.

This area consists of bedrock of primarily sandstone and siltstone of the Inglewood Formation (Qj), overlayed by Culver sand (Qc) and Baldwin Hills sandy gravel (Qb). Saturation from heavy rainfall, coupled with the steepness of the cut slopes, have been the main causes of slope problems in this area. Also reported was slope failure attributable to full settlement and creep, which may be indicative of poor control of the original grading. The fill was not engineered as measures to control surface runoff, erosion, and infiltration of water.

During grading, most fill (af) was placed on residential lots on the lower portions of the slope, higher lots were cut in the in the Inglewood Formation (Qj) and Culver sand (Qc). Failure in a steep cut slope may be related to weak rock in proximity to the northwest-trending fault. Grading also produced descending rows of cut and fill lots superimposed on cut ridges and canyon fills.

Sub-Area 2 - North-central Area

The development of this area was the same as the previous one. Much of the grading involved more extensive alteration of the terrain, including trimming of ridge tops and filling of canyons and gullies. The main causes of slope problems are steep slopes, inadequate control of runoff and saturation of artificial fill. The presence of gophers and other burrowing rodents are also contributing factor for slope instability, most notably in this sub-area.
This area consists mainly of Inglewood Formation (Qi) in the higher slopes with ancient massive, deep-seated landslides (Qls). The lower parts of the hills are primarily made up of colloviu and alluvium deposits (Qco) and undifferentiated compacted and uncompacted fill (af).

Sub-Area 3 - Northeastern Area

Development began in 1927 on the lower slopes of the area. The steep-sloped terrain was carried out using cut and fill to grade canyons and ridges for placement of building pads. Grading was done mainly by following the natural configuration of the terrain. Such streets were constructed along the bottoms of pre-existing canyons. The steep natural slopes along the sides of the canyon bottoms were cut back to develop rows of houses on each side of the street. This method of development caused already steep natural slopes to be made even steeper.

This area consists of Baldwin Hills sandy gravel (Qb) with numerous placements of artificial fill (af). The slopes are underlaid by siltstone of Inglewood Formation (Qi). General areas of slope damage caused by erosion.

Sub-Area 4 - Southwestern Area

This area contains the steep western slope of the Baldwin Hills, which is part of a northwest trending ridge that borders the flood plain of Pallona Creek. The slope is about 200 feet high and has a natural slope of 35°. Residential development began between 1952 and 1956. The slope and ridge top were developed with only slight modification of their natural features. This included cutting back on the steep natural slope for building pads and access roads, but
little artificial fill was emplaced in gullies within the slope.

The steep slopes of the area are underlain mostly by Baldwin Hills sandy gravel (Qb) and underlying Culver sand (Qc). The contact trends north-northeasternly, dipping gently of 2° to 4°. Resistant Fov Hills relict paleosol (Qf) caps the ridge. Soil slips and surficial erosion comprise most of the slope failure in the area. Many failures were related to poor drainage control that resulted in extreme, down-slope runoff from slope above. In addition, gopher holes and improper vegetation cover were another factor considered for instability.

Sub-Area 5 - Central Area

This area comprises mostly of unincorporated territory with exception to an oil field that lies partly within the graben that adjoins the fault. Slope stability is not a major geologic hazard of this area, because the natural slopes are not as steep as those in Sub-areas 1-4. The most significant slope stability problem is erosion. The effects of erosion range from rilling to deep gullying. Erosion has been associated with terrain underlain by Culver sand (Qc), the rock most susceptible to erosion in the Baldwin Hills. The area has a west-facing scarp of the Inglewood fault that has been modified by erosion.

Sub-Area 6 - Southeastern Area

The terrain of the area is much more gentle than those in Sub-areas 1-4, thus slope instability consists mainly of surficial debris slides and flows including soil slips and erosional rills. The soil slips occurred in cut slopes, especially in road cuts. Also shallow failures on cut slopes behind residential buildings. The main factor
contributing to the shallow failures is over-steepened cut slopes that do not have adequate surface drainage control devices.
EVALUATION OF PROBLEMS OF SLOPE FAILURE IN THE BALDWIN HILLS AND RECOMMENDATIONS FOR STABILIZATION OF SLOPES

Causes of Slope Failure

After evaluating and investigating the slopes of the Baldwin Hills, several reasons have been concluded for the instability of slopes. The causes of most of the damaging slope failures in the Baldwin Hills are listed as follows (CDMG, 1982):

1. Slopes in several of the developed areas are excessively steep.
2. Slopes are underlain by easily erodible sandy material.
3. Fill of poorly compacted material placed on tops of slopes without subdrains.
4. Fills placed on slopes that were not benched.
5. Many homes placed to close to the slope edge, especially at the tops of slopes.
6. Gopher holes are common in slopes in undeveloped areas which facilitate infiltration of water during rainy seasons.
7. Graded slopes lack drainage terraces or benches.
8. Retaining walls were not properly designed, thus residential lots were vulnerable to debris damage.
9. Slopes are not planted with proper vegetation cover. Deep roots are needed to anchor the slope.

Methods of Reconstruction of Slopes

Application of Fill

Slopes damaged by surficial landsliding can be replaced by compacted, engineered fill (Fig. 9). This fill should be composed of granular material with a reasonable amount of silt or clay. In order to be keyed and benched into firm bedrock (Treiman, 1982). To prevent water buildup during rainy seasons, subdrains are necessary behind many engineered fills.
The placement of engineered fill should be supplied with sufficient binder, to hinder the possibility of erosion, even if properly compacted. A mixture of fill with portland cement can be very effective in slopes that are steep, but shows a barren appearance as this soil-cement mixture does not allow plant growth.

Slope Surface Covers

Slopes can be stabilized by covering the slope with gunite, a type of portland cement concrete that is sprayed. Problems can exist as gunite will not bind satisfactorily to certain rock units of the Baldwin Hills -- siltstone of the Inglewood Formation which is to
expansive and Baldwin Hills sandy gravel which may be too loose and not cohesive (CDMG, 1982).

The use of building blocks can be utilized to prevent erosion, also vegetation can still fill in the holes of the blocks to make the slopes more appealing.

Revetment Systems

Damaged slopes can be stabilized with revetment structures, such as board and pipe structures (batterboards), railroad ties and other landscape devices (CDMG, 1982), (Fig. 10). For board and pipe systems, pipes are driven vertically into firm bedrock, to a depth sufficient to anchor them. Then railroad ties are placed and are backfilled with material. Subdrains within the backfill should be considered to reduce water build-up pressure and seepage erosion.

![Diagram of revetment system](image-url)

Figure 10. Diagrammatic cross section illustrating alternative remedial measures utilizing a revetment system to stabilize slopes in residential areas of the Baldwin Hills. (1) Construction of retaining wall—foundation of retaining wall should be properly designed and placed in firm bedrock (caissons or piles are frequently used). Permeable materials and proper drainage devices and relatively impervious surface blanket should be placed behind retaining wall to reduce hydrostatic pressure. (2) Revetment structures—these generally consist of vertical pipes and boards. Pipes are driven into competent bedrock; back fill placed behind boards should be compacted and provided with proper surface drainage devices and proper slope vegetation cover. (3) Cut-slope should be properly planted and stabilized by retaining structures which should have adequate freeboard and proper surface drainage device to prevent water/mud flow damage to property. (4) Surface water flow on the building pad should be directed away from the slope to the street, and water should not be allowed to flow from the pad down the slope. (Not drawn to scale.)

(after CDMG, 1982)
Retaining Walls

The construction of retaining walls provides support to improperly compacted fill on slopes (Fig. 11). These walls should be properly designed with wall footings in firm bedrock and the wall should be designed to withstand lateral or active pressure (CDMG, 1982). The backfill should consist of relatively permeable, inexpensive soil which should achieve at least 90% relative compaction (Campbell, 1975). If the fill is properly designed and emplaced behind the wall, along with proper subdrain devices, water will drain through the fill.

Figure 11. Diagrammatic cross section illustrating alternative remedial measures utilizing a revetment system and engineered fill to stabilize slopes in residential areas of the Baldwin Hills: (1) Properly designed retaining wall and drainage devices (such as granular backfill and drain pipe behind the wall and weep holes in the wall). (2) Loose soil and slide debris are removed, stabilization fill is then properly keyed and benched into firm bedrock as shown, and adequate subdrains should be provided. For steep slopes, soil-cement fill may be desirable. (3) Gunite or concrete bench drains that divert water to discharge outlet are constructed. (4) Retaining wall with adequate freeboard and a drainage device to prevent downhill earth movement and water/mud damage to property are constructed. (Not drawn to scale.)

(after CDMG, 1982)
Drainage Devices

The ability to stabilize slopes is determined how well runoff is controlled and whether the soil becomes oversaturated. The construction of surface drainage devices consist of terraced drainage benches and downslope drains (Fig. 12). These slope drains are important so that runoff during heavy rains can be collected and channeled. Rainwater should drain freely to existing streets and drains.

Vegetation Cover

Proper vegetation is a contributing factor in the stability of slopes. The ideal plants are ones that grow fast, have deep, strong root systems, and are drought resistant and fire-retardant (CDMG, 1982). The excessive steepness of slopes in the Baldwin Hills can hinder proper vegetation cover. Jute matting may be used to
assist planting and when properly installed, it cannot be lifted by flowing water, wind, or growing vegetation (Amimoto, 1978). A deep root system from vegetation cover acts somewhat as an anchoring system for the slope, reducing the possibilities of soil failure.

General Conclusion

The principal areas of slope instability in the Baldwin Hills occur mostly in residential localities in sub-areas 1-4. In contrast, Sub-area 5 consists mostly of flat ground with gentle slopes and Sub-area 6 constitutes an oil field. The beginning of slope failure all started when Sub-areas 1-4 developed before local grading codes were established.

With the wide occurrence of slope failure, recommended measures need to be taken into drainage control, slope stabilization, rodent control, fill stabilization, ground moisture control and debris protection. Following through these measures can overcome some degree of slope failure prevalent in the area.
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