Slope Form and Stability

in the Northwest portion of the Mount Lemmon Quadrangle, Pima County

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Introduction

During the past two decades, the public has become increasingly aware of catastrophic events involving the mass movement of rock and soil within urban areas. The problem of landslides has been particularly severe in the Greater Los Angeles region. In one period in 1952, two people were killed and over 100 houses were damaged there by landslides; the monetary loss was almost 7.5 million dollars. Up until that time, landslides had constituted only a minor hazard, but with the advent of denser housing on steeper slopes, massive slides of rock and soil were triggered by an abnormally rainy season.

The study of landslides in urban areas has been gravely neglected for years by both professional and public groups alike. As one of the deans of engineering geology, Charles P. Berkey, wrote prophetically in 1937:

> "I am convinced that the question of landslides is a matter of much larger importance than is usually assumed. Recent experience lends to the belief that it is of special significance in connection with many practical problems, particularly those connected with engineering projects. In my own case, some of these features were for a long time overlooked, and it is clear that a better understanding of them would have been useful." (Personal communication to C.F. Sharpe, March 31, 1937).

Yet it wasn't until after the devastating landslides of 1952 that responsible elected officials acknowledged the need to limit construction on unstable ground by enacting restrictive legislation. Special grading codes, designed to withhold building permits from hillside lots until conditions were shown to be safe by the geologist and civil engineer, were initiated. These restrictions have since resulted in a marked reduction in damage and in most cases a decrease in surface erosion.

Following the example made in past years by officials from the West Coast, individuals and groups in other parts of the country have forseen the need to delineate potentially unstable slopes. Arizona, witnessing the fastest growth rate in the nation and a decrease in suitable land for development within urban locations, is no exception. Future developments on steeper slopes and ridge lines necessitate the need for a thorough site examination to maximize safety and eliminate destructive erosion. The Arizona Bureau of Mines is currently exploring this topic of potentially unstable slopes with a grant provided by the U.S. Geological Survey. The project is designed to study a group of related geologic hazards, including slope stability, whose impact on Arizonans must be examined.

Area of Study

A portion of the Mount Lemmon 15-minute quadrangle was one such area chosen for a slope stability analysis (see Figure 6). The growing communities of Oro Valley and Vista Catalina are located within this quadrangle. Construction of single dwellings and large, tract-type housing developments is progressing rapidly. The area covers approximately 61 square miles, and is bounded by the Coronado National Forest on the east, the Pinal County line to the north, and Ina Road to the south. Physiographically, the region encompasses a wide range of geomorphic features, including the floodplain of the Canada del Oro and the steep, precipitous cliffs of the Santa Catalina forerange. Altitudes range from 2480 feet to 4400 feet above sea level, and local relief is highly variable. Home sites can be found on various terrain features, ranging from major floodplains to steep mountain ridges in the Tortolita Mountains. The general area is expected to have a large population influx by the year 2000.

The study region thus represents a unique situation whereby the dependency of home sites upon the geologic environment can be analyzed for future safety and design criteria.

Geology of the Area

The geology of the study area is comprised almost wholly of unconsolidated sediments, although some crystalline bedrock crops out locally. An understanding of the relationships between the types of materials present and the stability of the natural slopes in the area is critical in order to objectively assess the potential for hazardous conditions. A brief review of the rock and soil units recognized in the area follows.

Tinaja beds. The Tinaja beds are only exposed along the margins of the Santa Catalina front where erosion has removed the overlying coarse gravels. The maximum thickness of the beds is unknown but is thought to be as great as 5,000 feet in some areas (Davidson, 1973). These beds unconformably overlie the Pantano Formation and in turn are unconformably overlain by the Fort Lowell Formation. Correlation of the Tinaja beds with the Rillito 2,3 formation of Pashley (1966) seems probable.

Generally, the Tinaja beds consist of sand and gravel, gypsiferous clayey silt, and mudstone. Basaltic andesite flows and dacite tuffs also occur within the unit. In the Mount Lemmon quadrangle the beds exposed are thought to be the uppermost part of this formation and are collaborative with Rillito 3 of Pashley. These beds contain abundant granitic fragments in a feldspathic, clay-sand matrix. The unit is poorly bedded, but locally dips up to 28° toward the mountain front have been observed. No structural deformation was found in the Mt. Lemmon quadrangle although the typical section, found in the Tucson Basin, contains numerous faults.

These grayish-white beds contain a large amount of montmorillonite clay and are only poorly consolidated and weakly cemented. The average slope stands at 15 percent and is easily eroded, as evidenced by extensive rilling and gullying.

Fort Lowell Formation. The Fort Lowell Formation, referred to as "basin fill" by Pashley (1966), outcrops extensively along the margin of the Santa Catalina Mountains where up to 400 feet have been removed by post-Fort Lowell erosion (Davidson, 1973). The formation may be as much as 1,200 feet in the valley, and it thins toward the mountains and headwaters of Canada del Oro. The similarity in lithology between the base of the Fort Lowell and the top of the Tinaja beds makes delineation difficult in most areas.

The Fort Lowell Formation can be identified on the basis of its grain size, lithology, and to a certain extent its color. The deposit is generally flat-lying, crudely bedded, and reddish-brown in color. The lithology of the basin fill reflects the nature of the surrounding bedrock outcrops, and consists primarily of gneissic and granitic cobbles in a sandy gravel matrix. The beds are generally moderately to poorly cemented, weakly packed, and very porous. Imbrecation directions on a statistically significant number of samples indicate a direction of deposition in a closed basin environment into a series of low-lying lakes and playas. Structurally, the beds are gently dipping and relatively undeformed.

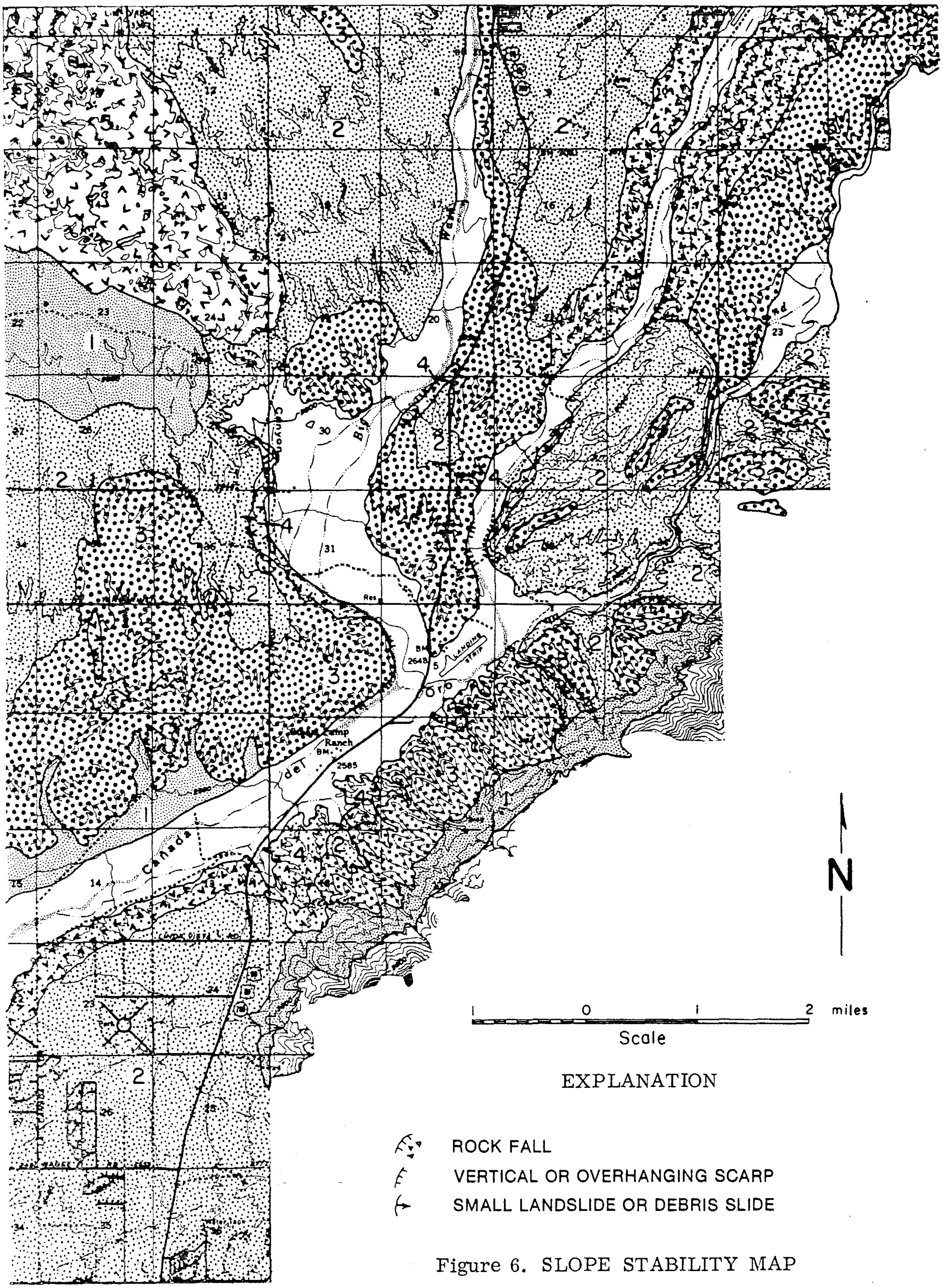

Figure 6. SLOPE STABILITY MAP

Map Unit	Remarks
Zone 1	Highest stability — near-flat to moderate slopes (<25%) underlain by hard rock. Locally bare to thin cover of surficial material. No significant downslope movement of material.
Zone 2	Hign stability — gentle to moderately gentle surficial alluvial slopes (5%-15%); moderate slopes (15%-25%) underlain by Fort Lowell Formation consisting of moderately cemented coarse gravel, sand, silt, and clay. Small probability of downhill movement of material except in areas adjacent to incised streams which have eroded a vertical erosional scarp. Undercutting of the scarp's toe will produce a total loss of stability on an intermittent but continuing basis.
Zone 3	Moderate stability — very steep competent rock slopes up to 100%; slopes in poorly-consolidated fine-grained alluvium up to 45%; loose, well-rounded, surficial deposits overlying moderate (15%-25%) to steep (25%-45%) well-cemented Fort Lowell Formation. Slopes subject to minor debris slides in well-rounded alluvial material; minor soil slumps in fine-grained deposits where highly saturated with water.
Zone 4	Generally low stability — moderate slopes (up to 25%) in poorly consolidated fine-grained alluvial deposits containing a high percentage of clay material. Subject to slumping and high soil erosion during saturation. Very steep slopes (up to 100%) bordering floodplain scarps or deeply incised highland drainages. Block glide soil failure in moderately cemented alluvium; soil fall in nonresistant soil; rotational block slump failure rare but may be locally present. Soil failure on slopes with vegetation, producing small terrace-like features or terracettes. Very steep rock slopes containing a thin surficial deposit of taluvium (rock rubble and weathered soil-size particles).
Zone 5	Low stability — very steep to precipitous slopes in highly fractured and weathered rock. Subject to rock falls which in some instances may produce large volume of material. Debris flows common.

SLOPE MAP UNIT	GEOLOGIC MAP UNIT				
	BEDROCK		ALLUVIAL DEPOSITS		
	Metamorphic rocks		Tinaja	Ft. Lowell	Surficial
	Tortolita granodiorite	Catalina gneiss/granite			
less 5%	1	1	2	1	2
5- 15%	1	1	2	1	2
15- 25%	1	1	3	2	3
25- 45%	2	2	4	3	4
45-100%	4	3	5	4	5

Surficial deposits. Surficial deposits (locally-derived alluvium deposited by fluvial processes) cover much of the mapping area and can be differentiated on the basis of this relationship to older units. Deposition of these units reflects a change in basin morphology from a closed basin environment to a through-going drainage system. These deposits were laid down on an erosion surface resulting from the lowering of the base level of nearby streams (Smith, 1938). Surficial alluvium up to 50 feet in thickness can be found locally overlying all units in the area; the alluvial deposits generally pinch out toward the mountain fronts.

The surficial deposits generally reflect detritus being presently eroded from the nearby mountain fronts. These sediments are mainly coarse gravel and gravelly sand with local lens of sandy silt. Cobbles up to 2 feet in diameter are sporadically encountered. Granite and gneiss fragments dominate, although minor amounts of volcanic and sedimentary fragments are also represented. The principal basis for differentiating the surficial sediments from the older material is their characteristic weathered, yellow-brown stained surface.

The first to divide these surficial deposits into definable groups was Smith (1938), who identified four primary sequences as: University, Cemetery, and Jaynes terraces, and bottomland. These units, lying in an erosional trough on basin fill or older sediments, can be identified on the basis of their topographic relationships. Generally, in the area studied, the Cemetery terrace covers the largest area. The eastern pediment of the Tortolitas contains gravels tentatively correlated with this sequence. The University terrace is found in two areas: the Cordonnes region, where it lies on top of the Fort Lowell Formation, and in an exposure on the high dissected foothills buttressing the west side of the Santa Catalina Mountains. Identification was based on a thick caliche bed that is characteristic of the University terrace, and a coarse, bouldery, highly dissected surface. The Jaynes terrace and bottomland are usually found adjacent to the main tributary drainages, though one or two isolated exposures occur next to Canada del Oro.

The degree of cementation and packing of the deposits generally decreases from oldest to youngest. While the University terrace is well cemented and packed, the Cemetery and especially the Jaynes and younger deposits are essentially unconsolidated. The high porosity and permeability allows these gravels to be well drained.

Two Approaches to a Slope Stability Analysis

The analysis of slope stability is of interest to both geologists and engineers, but from differing viewpoints. Whereas the geologist examines slopes from the point of view of shape and the process by which they were formed, engineers take a quantitative approach and examine such problems as maximum angle of excavation, landslide potential and prevention, and methods of stabilizing existing slopes. In order to reach a valid conclusion regarding the stability of a slope, a combination of both approaches is needed. The quantitative determinations of the engineer must be based on a thorough geologic examination of the structure and form of the slope-forming materials, and the geologist will benefit from the results of physical tests made of the soil and rock materials by the engineer.

Geomorphological approach to slopes. The geomorphologist, a geologist who studies the physical characteristics of the landscape, is interested in the form and processes which control the shape of the terrain. The configuration of any slope is eventually determined by the relationship

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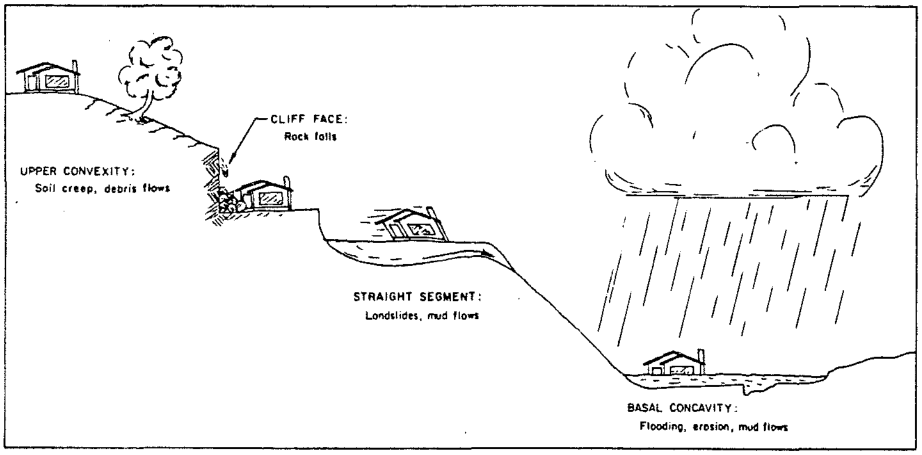


Figure 1. Idealized slope profile showing major components and processes likely to occur for that segment.

Slope Stability *continued*

between the disintegration of the underlying material and the rate of removal of this debris from the sloping surface. The erosional processes of water, wind, and mass movement further control the shape of a slope. These properties may work in combination or independently on any segment of the slope. Thus, a stream cutting the base of a hillside may exercise the dominant control on the actual form assumed by the surface. By using a qualitative and sometimes quantitative examination of slope forms and processes, conclusions can be reached on the evolution and stability of hillside elements.

Investigators of slope form are often interested in the profile of the land surface. In this case, measurements are recorded along selected lines of traverse, and the corresponding slope profile is then drawn up for inspection and interpretation. An idealized slope profile containing four components was used by Wood (1942) for an attempt to arrive at a general theory of slope formation in arid and semi-arid climates (Figure 1). Though much controversy has resulted from his classification, it still provides the user with a general scheme in which to study slope profiles. In the following section, each component of his classification will be briefly discussed and analyzed for the indirect evidence it provides in a slope stability study. These components are an upper convexity (waxing slope), cliff face (free face), straight segment (constant slope), and basal concavity (waning slope).

Upper convexity. Arid topography is characteristically stepped, with a succession of low-gradient surfaces separated by steep slope segments above and below. Two types of upper convexity, or waxing slopes, can be observed (though many intermediate steps may be present). These are: (1) a convexity bounded between two straight segments, and (2) a convexity at the upper edge of a scarp. Due to the action of such weathering processes as rain splash and sheetwashing, the rate of surface-lowering must increase toward the steep cliff face. The process of rainsplash operating on the slope will thus remove the material at a rate comparable to that of soil creep. Though mass movement on this particular segment is not generally as prominent as on other segments (straight segments, for instance), the constant wearing back of this slope can increase the surface gradient, thus affecting its stability.

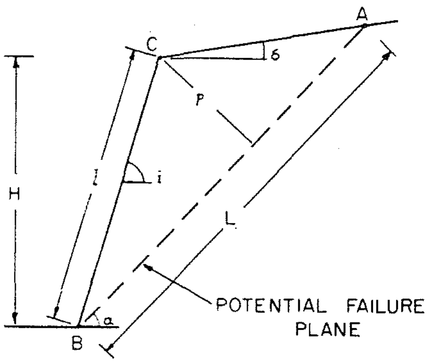
Cliff face. Probably the most dominant and striking slope segment found in semi-arid climates is the cliff face (see photograph 1). In terms of hillside stability, this segment contributes much debris to lower slopes in the form of rock falls. Weathering processes will tend to weaken the strength of the material along such geologic features as joints and faults. The size of the boulders released is therefore dependent upon the spatial relationship of the planes of weakness, and ranges from small granular particles to large individual blocks. Depending upon the strength of the material and the distance of falling, the rock will remain either relatively intact or disintegrate into a myriad of smaller pieces upon impact. Accumulation of this debris will form a talus, or loose rock slope, at the base of the cliff. Active retreat of the cliff face only occurs when the slide rock accumulation can be removed and bare rock slopes at the base are again established (Koons, 1955).

The precipitous cliff faces on the western side of the Santa Catalina Mountains lack appreciable talus slopes at their bases. It is therefore presumed that active rock falls can be anticipated in the future. Due east of the town of Vista Catalina, two varieties of rock falls are seen. The first is exfoliation of the granitic outcrops which resemble the layers of an onion. Sheets of rock up to four feet thick and tens of square feet in area have been shed from the underlying slopes. The second type involves the differential weathering of the rock into spherical boulders. These pieces of rock may be attached to the underlying surface by only a few inches of material. Many have evolved to such an extent that they are no longer connected to the underlying surface and any disruption of the block will set them into motion. A few single residences have already been built below this zone.

On the eastern side of the Tortolita Mountains, unstable rock slopes where the material falls into blocky rubble are widespread and similar hazardous conditions exist (see photographs 2 and 3).

The straight segment. The straight segment, situated below the cliff face, is similar in appearance to a talus slope but differs in that the boulders on it usually form only a veneer on a slope which otherwise consists of bedrock (Carson, 1972) (see photograph 1). The gradient of this segment is slightly less than the angle of repose or angle at which the material will come to rest under a given set of physical conditions. The physical conditions responsible for maintaining this angle are the angularity, composition, production or detachment of fragments from the bedrock, and climatic conditions. Measured angles of debris-covered hillsides within the Tucson basin peak at two values: 28.5 degrees and 34 degrees (Melton, 1965). Both stability angles seem to be related to the frictional properties of the material. The lower value coresponds to the static friction angle and the upper value to the sliding friction angle. Thus, on the upper and steeper slopes, only the mechanism of gravity would be required to set debris into motion, whereas on the more gentle segment, hydraulic forces predominate. As the slope angle flattens, the hydraulic factor becomes more important in the mass movement of surface material. Thus, straight-slope segments constitute potentially unstable areas where mass movement of material would be more likely to occur; construction on a straight-line slope usually requires cuts for roads and housing pads. This tends to oversteepen the slope both above and below the site, resulting in accelerated erosion and landsliding.

Lower concavity, or break in slope. In the region surrounding Tucson, the lower concavity is the most important landform in terms of area involved. Concave desert plains may consist of thick, alluvial accumulations or may have a nearly smooth bedrock plane, called a pediment, close to the surface. These low gradient slopes are more affected by surface



THE CULMANN APPROACH TO SLOPE STABILITY

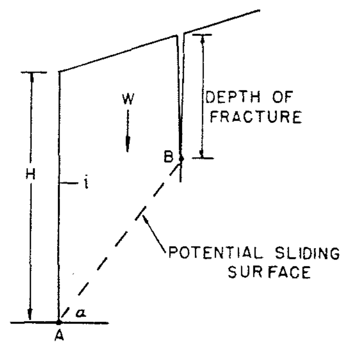
Figure 2a. A quantitative approach to slope stability assuming a potential plane failure passing through the toe of the slope.

drainage systems than by any other erosional process. Mass movement on these slopes is nil except where streams have been deeply incised. In this situation, planar failure of soil, whether in stream channels or in cut slopes behind houses, constitutes the main type of mass movement.

Engineering Approach to Slope Stability in Soil

We have seen in the previous section how a geologist's understanding of the shape of slopes can lead to indirect conclusions regarding the stability of the material. But what will happen if the natural shape, or angle of the slope, is altered by man? Soil engineers have long been interested in the problems of mass movement of material in cases where it becomes necessary to modify natural slopes or create new ones, as in embankment cutting and other excavations. By creating new slopes which are higher or steeper, landslides can be induced because the shear stresses in the soil mass are increased. An understanding of the mechanics of mass movement and the physical properties of various soil materials has thus enabled the engineer to redesign slopes for maximum safety.

The most prominent and widespread type of slope failure within the study area is slab failure. The simplest example of this process is the slumping of bank material along a stream channel or from a cut bank excavated for a highway cut or homesite (see photograph 4). The reason that river banks or cut slopes can remain vertical and do not become unstable up to certain heights is that they possess cohesion. There remains, however, a maximum height at which the soil will stand before it fails. Various methods have been designed in the attempt to predict their maximum height for an embankment. Assuming that we have a



THE INFLUENCE OF TENSION FRACTURE ON SLOPE STABILITY

Figure 2b. Tension features developing parallel to the edge of the slope will intercept the failure plane and reduce the critical height of the slope.

planar failure passing through the toe of the slope, the Culmann method (Terzaghi, 1967) can be used to determine this critical height (Figure 2a). Important parameters used to determine this critical height is the cohesion (C), angle of internal friction (Ø), bulk weight of the material, and angle of the sloping surface (i).

The results of this method can be interpreted in two ways. As the slope angle (i) becomes increasingly steeper, the critical height (Hc) will become smaller. Secondly, the critical angle becomes smaller as the cut becomes increasingly deeper.

Therefore, as the potential failure plane is inclined at a higher angle, a smaller depth of slope is necessary to produce a mass movement. But within the Mt. Lemmon quadrangle area, we find many vertical slope (scarps) which have been cut by incising streams or artificial excavations. Thus, the value of slope angle (i) is 90° and tension cracks may develop. These cracks will intercept the failure plane before the critical height is reached, and will reduce the height by 50 percent (see Figure 2b).

Substituting physical testing parameters in this method can sometimes accurately predict the maximum height of a cliff or embankment. Lohner and Handy (1968), for instance, working in the loess area of Iowa, found close agreement between actual and theoretical height based on the above method.

The application of the above case is limited to certain models. Slopes that fail in circular arcs, or in rock, would be treated differently. As we will see later, the effects of the water pore pressure is an important parameter determining the stability of slopes. Regardless of the present difficulty in duplicating actual field conditions in the laboratory, soil mechanics offers the most realistic quantitative basis for analyzing slopes in engineering terms.

Slope Failures Caused By Artificial Modifications

Man's modifications of natural slopes for construction purposes is the chief cause of many mass movements in rock and soil. The use of design methods

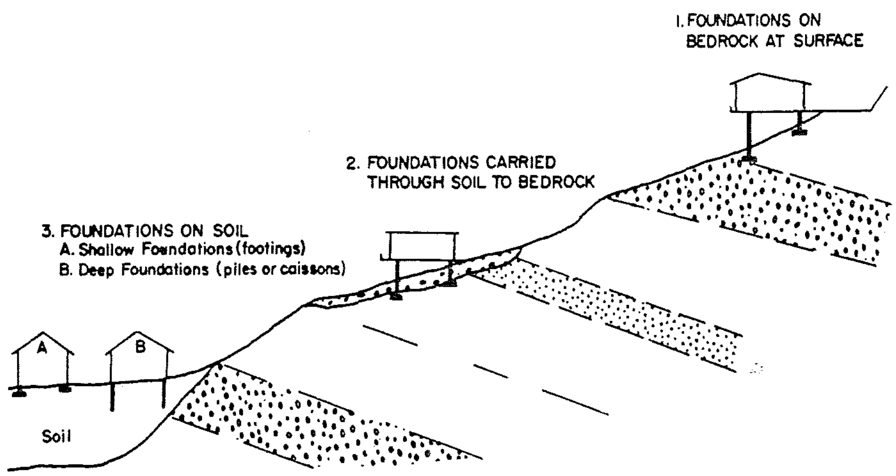


Figure 3. THREE GENERAL GROUND CONDITIONS FOR ESTABLISHING SAFE STRUCTURAL FOUNDATIONS ON NATURAL SLOPES.
CASE 1. Stable bedrock exposed at ground surface or close to it; foundations can be shallow.
CASE 2: Stable bedrock lies below deposits of unconsolidated soil; foundations are carried through the soil which might be remnants of a soil failure or an old stream; other alternatives are stablizing the soil and placing shallow foundations or removing the soil in the process of building a multi-level house.
CASE 3. Stable bedrock lies too deep to reach economically with foundations; foundations needed might be shallow as in House A. where high bearing strength has been determined by soils engineer, or deep as in House B where poor soil conditions exist (after Leighton, 1966).

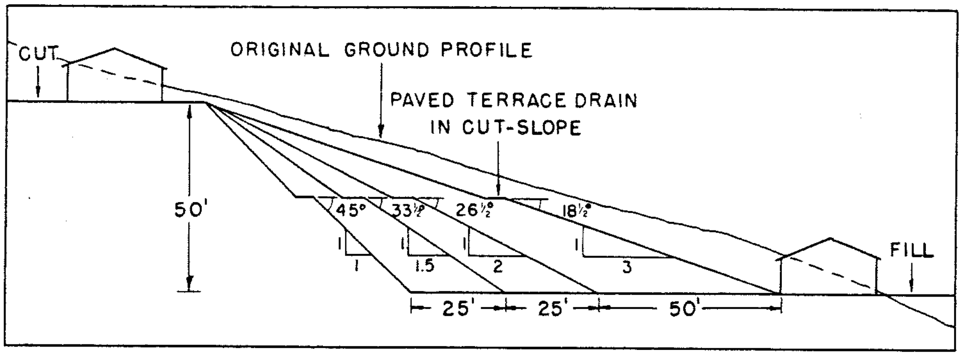


Figure 4. FOUR DIFFERENT CUT-SLOPE ANGLES (1:1, 1.5:1, 2:1, and 3:1). A 2:1 slope has a horizontal length twice the vertical height. A safe cut slope angle is the most vital requirement for stability. Some cut slopes in residential development are stable at 1:1, others at 1.5:1, others at 2:1, or 3:1 and still others have to be even flatter (or retained). The steeper the cut slope angle, the more level lot pad space is created and the more material has to be excavated. Grading in most residential hillside developments involves cutting the hilltops and placing this material in the canyons and along the lower hillside slopes as fill. In most cases civil engineers believe that it is more economical to produce cut and fill lots by earth-work than to construct tracts of homes on the natural slopes (after Leighton, 1966).

presented previously can help an engineer to estimate areas of potential failure. The construction of houses or engineering structures on relatively stable ground can alter conditions to such an extent that failure is likewise inevitable. Three construction conditions that will have an effect on the stability are loading, cutting, and filling of a slope.

Loading. The placing of a weighted mass on a slope, such as a fill to extend the backyard of a house, is the most common type of overloading. The increased loading can cause the formation of surfaces of rupture in underlying soil and rock, resulting in failure. Structures also are loading factors (see Figure 3). In places where soil conditions are weak, foundations must be properly reinforced to distribute the weight of the structure evenly to avoid concentrating stress and thus initiating a failure.

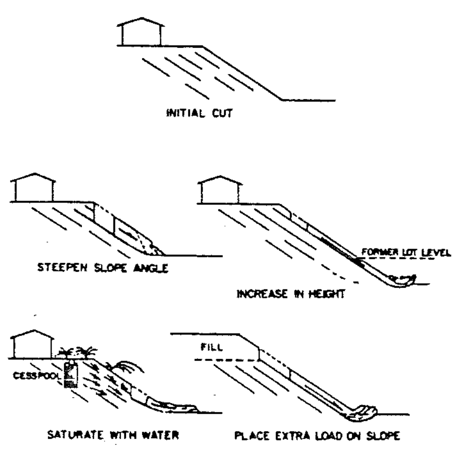


Figure 5. FOUR WAYS TO MAKE A STABLE CUT SLOPE UNSTABLE. The small slides shown have developed from the stable initial cut at the top by man's modification of the slope (after Leighton, 1966).

Cutting into a slope. Because the valley floors of the region are sometimes rather narrow, excavation at the foot of a slope to make more flat ground is very common. The prime requirement for the stability of cut-back slopes is that they are graded at a safe angle (Leighton, 1966). Proper design of the cut should minimize rilling and gullying while at the same time yield the greatest possible area for the housing surface (Figure 4). It is obvious from the figure that by steepening the cut, more flat area can be developed for a given lot size. In the Mt. Lemmon study area, the Fort Lowell Formation can stand at 1:1 while the maximum angle of cut for the surficial deposits is 1:1½ or 1:2. The Tinaja beds elsewhere in the Tucson basin will remain stable at 1:1 but in the study area only at 1:3 due to its weathered condition and the presence of clay. Slides that occur after grading are often an indication that the problem was not detected during excavation. Four ways that a stable cut slope can be made unstable are illustrated in Figure 5.

Fills. The improper design of fills on which foundations are placed can result in severe settlement of the structure (see photographs 5 and 6). This can be caused by

(1) Situating the fill on existing vegetation or compressible soil;

(2) Inadequate drainage of the fill, causing seepage and saturation of the building site;

(3) Improper compaction of the fill.

In order to avoid excessive erosion of the fill, vegetation should be planted as quickly as possible. Placing fragments of rock to minimize surface erosion on the sloping sides should be avoided, as this will tend to initiate small-scale failures on poorly consolidated fill.

Slope Stability Map

A relative slope stability map was prepared for the northwest quarter of the Mount Lemmon quadrangle (see Figure 6). The ability of a slope to remain stable is dependent on the slope angle, type of material, geologic structure, and water table condition. Slope stability was classified into 5 major groups, from most stable to least stable. Interpretation was based on field observation of hillsides subject to failure and their probable response to excavations. Slopes seemingly stable in natural cuts were many times found to be rendered unstable during excavation.

The relationship between stability units and geologic material is outlined in the table.

Generally, the stability of slopes in the study area is considered high when compared to areas outside the arid southwest. Although unstable conditions in some areas are widespread, landsliding phenomena as encountered in California and on the East Coast have not been observed in the Mt. Lemmon area. This may be due to the following factors:

(1) An analysis of the natural slope angles indicates that the alluvium is in a period of equilibrium. Coatings of desert varnish, staining some surficial alluvium, indicate that they have remained in place for at least a few hundred years.

(2) There is a general lack of clay in the sediments. Clay has a high tensile strength when dry and almost no strength when wet. This material, in the wet state, acts as a lubricant and is often the triggering mechanism in landslides.

(3) Rainfall is relatively low. Water can serve as a cumulative driving force by causing seepage, adding weight, and lubricating or hydrating clay minerals.

Conclusion

The development of hillside areas in Southern Arizona will continue to increase as the availability of flat-lying areas decreases. The construction problems encountered when building on flat, low-lying land are only magnified when applied to sloping regions. The stability of the natural slopes, then, should be a prime consideration during the preconstruction phase in order to minimize costly problems in the future.

An analysis of hillside elements in the Mt. Lemmon quadrangle indicates that a much larger area of potentially unstable slopes exists than was previously realized. Further development of interpretive maps, as provided in this text, will benefit both engineers and land-use planners in future decision-making roles. Enactment of local slope ordinances should strive to meet both the safety and economic requirements of the public.

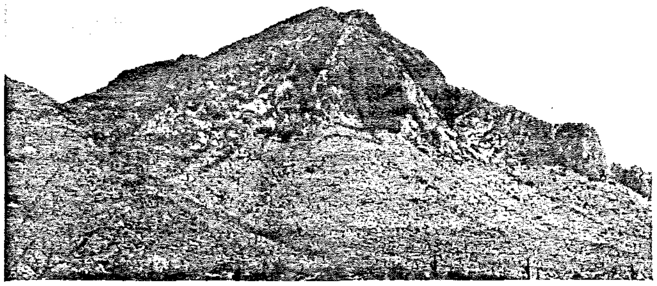


Photo 1. Shear cliff face in Santa Catalina Mtns. with straight segment below.

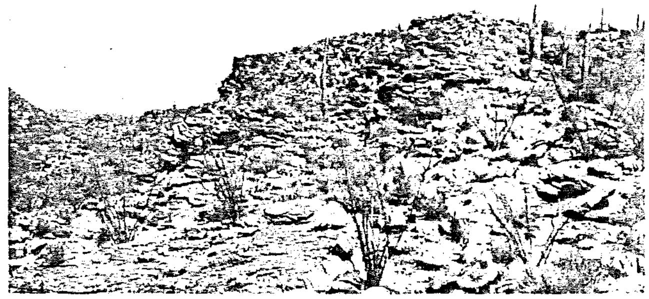


Photo 2. Slope in Tortolita Mtns. Debris slides predominate in this material.

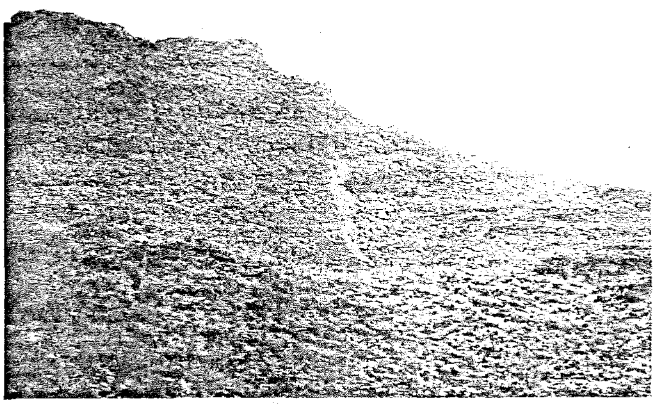


Photo 3. Slide in undifferentiated Tortolita granodiorite.

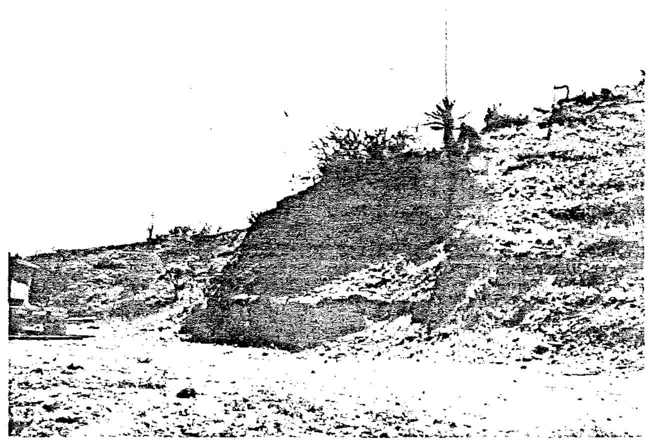


Photo 4. Failure of a cut-back slope. During the summer rains of 1973, many tons of material were released into the backyard. Rilling and piping erosion is now causing further instability.

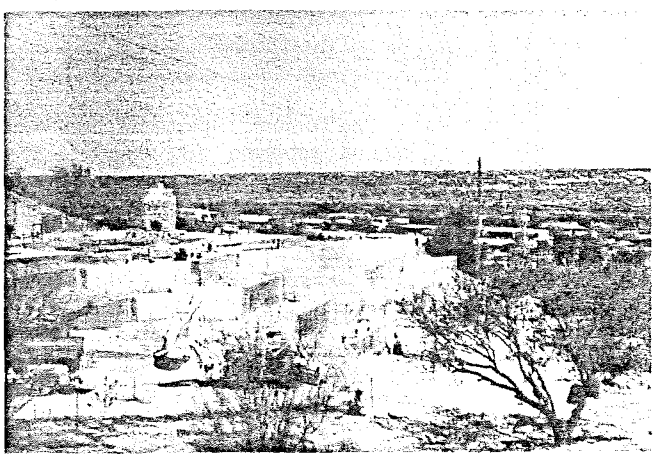


Photo 5. Series of retaining walls to stabilize fill slope. Home being constructed on fine-grained recent alluvium overlying Ft. Lowell Formation in map unit 4.

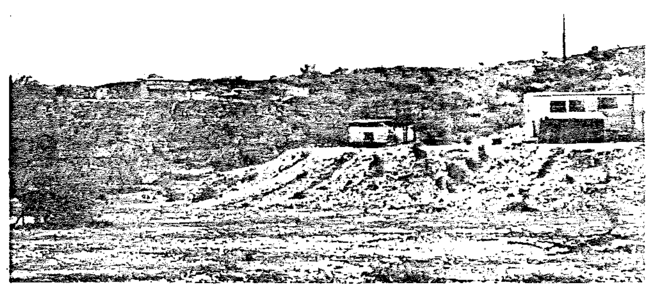


Photo 6. Improper maintenance of fill sites. Erosion of the slope may cause future instability, while lowering the aesthetic value of the property.

Photo 7. Landslide in surficial alluvium. Failure of material similar to model in figure 2a.

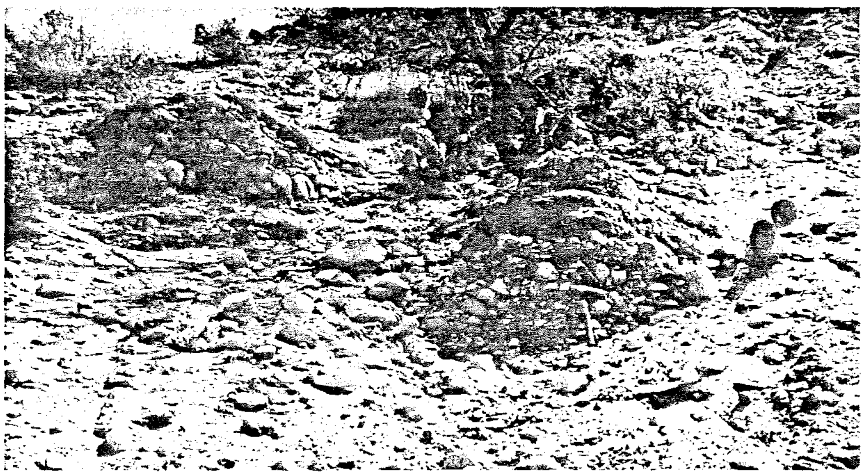


Photo 8. Close-up of photo 7. Looking into failure plane. More resistant flatlying coarse beds remain in place. Failure plane inclined at 35°

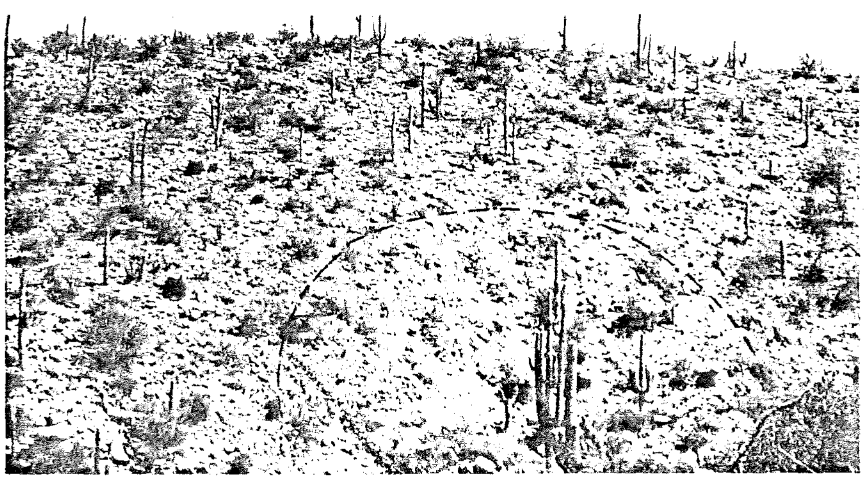


Photo 9. Outline of slope failure in Fort Lowell Formation adjacent to Pusch Ridge, Santa Catalina Mtns.

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