SLIPS IN RELATION TO RAINFALL AND SOIL CHARACTERISTICS

R. J. JACKSON*

SUMMARY

Soil slips are relatively shallow mass movements involving loss of soil and subsoil and leaving the underlying material exposed to processes of soil formation. Three examples are described with emphasis on the factors that reduce the margin of safety of a slope and those that initiate the movement.

(1) The forest slides in Fiordland are debris avalanches that are part of a natural cycle of forest growth, sliding and re-colonization and are initiated by slight abnormalities in the local climate.

(2) Slips that followed intensive rainfall on the Eastern Hutt hills in Wingate Hill soil derived from loessial drift. They are related to the nature of the material and probably to vegetation changes, and appear to be iniated by a combination of unusual weather conditions.

(3) Soil slipping on mudstone in the Eastern Wairarapa appears to have been accelerated by conversion from forest to pasture and is believed to be iniated by heavy rain falling in fissured soils. Tunnel gullying may be contributing to instability in some cases.

Current work to investigate further the mechanism of slipping and its relation to soil properties and climate is outlined.

INTRODUCTION

Mass movements have been classified into those in which a shearing stress produces continuous deformation or flow (as in creep), solifluxion or earthflow, and those in which occurs rupture that results in sliding along a well-defined surface e.g. slumps and debris slides (Sharpe, 1938; Terzaghi, 1950). However, it is usually recognized that no sharp boundaries between these groups exist. In his classification of the erosion forms found in New Zealand, Campbell (1951) includes compound types such as 'slip and earth-

* Soil Bureau, D.S.I.R.

flow' and 'creeping earthflow' as well as the simple types creep, flow and slip. In the present paper the term 'soil slip' is used for any relatively shallow movement involving the soil and subsoil, which leaves the underlying material exposed to the processes of soil formation or further erosion. The actual movement may be slip or flow or both, either together or in succession.

In New Zealand slipping of soil commonly occurs during or following heavy rain. Soil on a slope is subject to stress, as a component of its weight acts down the slope. The opposing forces are exerted by the soil further down the slope and by the shearing resistance provided by soil strength. Water entering the soil increases the tendency to instability, largely by reducing the effective stress component of strength and by increasing the disturbing forces of weight and seepage. This may result in acceleration of creep or flow already present or in a complete failure. However, while the climatic conditions initiating a slip may be abnormal e.g. a prolonged wet spell or heavy rain falling after a dry period, it is unlikely that they are without any precedent in the history of the slope. As Terzaghi (1950) points out, some other factor, either a gradual weathering or an unprecedented change in the conditions of existence of the slope (such as undercutting of its toe) must reduce the margin of safety before variations that are part of the routine of the slope initiate a slip. Slips occurring under a variety of conditions provide examples of these processes:

FOREST SLIDES IN FIORDLAND

These are included as examples of natural erosion. In Fiordland, under the prevailing cool and humid conditions that permit growth of forest on very steep slopes (over 50°), a cycle occurs in which debris avalanches are a normal occurrence closely linked to the succession of vegetation. Wright and Miller (1952) describe the process whereby the bare rock of an old erosion scar is first colonized by lichens, mosses and small herbs, and later by seedlings of scrub and forest species with the eventual establishment of a closed forest cover dominated by rata and beech. The underlying gneissic rock weathers slowly and soils are usually peaty with a very shallow mineral horizon. In time the growing forest becomes a heavy load for the steep slope and any slight abnormality in the local climate can lead to slipping with loss of the vegetation, soil and any boulders loosened by root action. The movement may begin as a debris slide, but is classified as a debris avalanche (Sharpe, 1938, p.61) since the steep slope, shallow soil and top-heavy load encourage the mass to flow rather than slide once motion has started. Wright and Miller note that these slips are reported to be more common during the first heavy rain following a period of drought.

These natural forest slides illustrate how a movement is caused by a gradual increase in stress as the mass of forest anchored on the steep slope increases, in combination with a slight but not unprecendented abnormality in climate. As the region is undeveloped the loss of plant nutrients and of moisture-storage capacity can be tolerated. While exposed the massive rock withstands further erosion and is recolonized to begin another cycle.

Similar slips may be seen on some steep slopes in the Tararua and Rimutaka ranges near Wellington, although here the consequences down-stream may be important if the underlying material erodes instead of being recolonized.

SLIPS ON THE EASTERN HUTT HILLS, 1966

During the autumn and winter of 1966, a number of slips occurred on the Eastern Hutt Hills. Examination of some of these at Taita and Naenae showed that a loessial drift had moved over a smooth slip surface at the junction, with the weathered greywacke underlying the drift. These slips usually occurred under a dense cover of gorse or manuka scrub on slopes of about 24°. Other than those resulting from undercutting of the toe of the slope, slips on these hills are fairly infrequent. Thus aerial photographs of the Soil Bureau Experimental Station at Taita, where two slips occurred in 1966, show that the previous slip occurred about 20 years ago.

In a survey of the soils of Taita Experimental Station, Atkinson (in prep.) recognized that on the hills there are, in addition to the Taita-Tawai soils derived from graywacke, other soils derived mainly from loess. Among these the Wingate hill soils occur on moderately steep slopes, on ridge tops and infill basins at the heads of streams. The Wingate hill soils have mottled brownish-yellow and greyish-yellow clay loam subsoils with weakly-developed coarse, nutty and prismatic structures, whereas the subsoils of Taita hill soils are brownish-yellow clays with more strongly developed medium or coarse, nutty structure and are often stony. Tunnel gullies occur in the Wingate hill soils, and one was noted in the Exotic Forest Catchment in a Wingate deposit that slipped in July, 1966.

The first of the 1966 slips occurred during heavy rain on 25-26 April. The rainfall during March was well below normal and 24 days without rain produced thorough drying of the soils at Taita. Gypsum block measurements in Wingate hill soil under a dense, 10 ft tall scrub composed of pines, manuka and spanish heath showed drying to wilting point (pF 4.2) to a depth of 2 feet and considerable drying (pF 3.6 - 3.8) to 4 ft. Three inches of rain which fell in a series of small falls during late March and early

April had little effect beyond the surface foot and even there it was irregularly distributed. The storm of April 25 - 26 gave thorough wetting of the surface foot. At depths from two to six feet moisture contents varied greatly alhough some water penetrated to ten feet. The total fall during this storm was 5.20 in. in 48 hours, and records at the meteorological station at Taita show that intensities for some periods were very high. Table 1 compares the rainfall depths recorded with those expected with return periods of 2, 10 and 50 years at Lower Hutt, taken from the depth-duration frequency tables of Robertson (1963.)

RAINFALL DEPTH-DURATION DATA

Duration	Maximum Depth (Inches) Recorded at Taita, 25-26 April, 1966	Depth Expected* for Return Period Stated 2yrs	10yrs	50yrs
20 min	0.64	0.40	0.63	0.84
30 min	0.80	0.49	0.68	0.86
1 hour	1.13	0.68	1.03	1.34
2 hours	1.70	0.94	1.39	1.79
6 hours	3.26	1.69	2.21	2.68
12 hours	3.79	2.23	3.03	3.73
24 hours	4.35 110.5	2.89 72.6	4.51 114.6	5.93 150.6
48 hours	5.20	3.67	5.95	7.95

* These figures are for Lower Hutt, taken from Robertson (1963).

Some slips occurred on the Eastern Hutt Hills during this storm, while others happened later. The first slip at Taita occurred in mid June. The second occurred in the Exotic Forest Catchment on 9 or 10 July, 2.1 inches of rain having fallen in 13 hours in a north-westerly storm on 6-7 July and 3.7 inches in 30 hours in a southerly storm on 8-9 July. Both storms had maximum intensities less than those with two-year return periods. The effect of the slip in the Exotic Forest Catchment on sediment discharge is being investigated.

The slips of this type investigated at Taita and elsewhere have a number of common features, illustrated by the first slip observed at Taita (Fig. 1). This occurred on a slope of 25° beneath 10 to 15 foot tall scrub dominated by manuka but containing some broadleaf species. At the head of the slip a depth of 2 to 4 feet of Wingate drift remains in a vertical or slightly overhanging wall. A smooth, undulating bed is revealed over the area of the slip which is 25 feet wide and 60 feet long, and has a broad U-shaped cross section. The debris was arrested by the vegetation further down the slope as a jumbled heap of soil blocks with vegetation intact and with semi-liquid soil among them. At the sides of the upper part of the slip blocks of soil are detached and are moving into the slip area, while at the lower part the original ground surface has been over-ridden with formation of lateral ridges of soil overturned against standing trees. The jumbled debris deposited at the bottom, the lateral ridges, and the vertical head appear to be characteristic of this type of slip and tracks of old slips may easily be recognized. The underlying material that forms the smoothed bed of the slip consists largely of weathered greywacke and resists further erosion. A slip, which aerial photographs indicate occurred about 20 years ago, in No. 4 catchment at Taita, now has its bed covered by lichens and mosses with some stunted gorse and manuka. However the slip debris may be a major source of sediment, especially if it reaches a stream channel.

Fig. 1 — A SLIP IN WINGATE HILL-SOIL, No. 6 Station, Taita Experimental Station — June, 1966.

It is not known to what extent movement occurred before the slip took place, but the fact that the smooth slip surface extends up slope beyond the head-wall may indicate some prior movement, either as a result of the April 25-26 storm or earlier. The rainfall associated with slipping in June and July was not exceptional, and although the early winter months were generally wetter than normal, a high variability is characteristic of the region. Thus it seems that the prolonged dry spell in March, the intense rainfall in the April storm (which produced slips on some slopes in the Hutt Valley) and the persistent wet conditions which followed have all contributed. These conditions are, however, unlikely to be without precedent and some other factor must be contributing for slips not to have occurred before on these sites. The probable factors are the clearing of the original forest, the repeated destruction of vegetation by fires, and processes such as tunnel-gullying or gradual movement which may have brought the mass to a position which slipping became possible.

SLIPS ON MUDSTONE IN THE WAIRARAPA

Grange and Gibbs (1947) in their survey of erosion in the southern half of the North Island subdivided slips according to the nature of the underlying material and its ease of revegetation or liability to further erosion. The present group was noted to weather readily and allow re-establishment of pasture.

The processes that seem to be involved in shallow slips on mudstone in the yellow-grey earth zone have been described by Pohlen (1947). The slipping occurs during intensive rain, especially after a dry spell when the soil is deeply cracked because of dessication and allows rapid access of water to a depth where it moves laterally above a relatively impermeable layer. The soil tends to move in blocks as a result of the reduced cohesion following cracking and the reduced shearing resistance of the subsoil. These processes are very similar to those described in the previous section. The east coast of the North Island has a very high variability of rainfall (Seelye, 1946) and the climatic conditions under which slipping may occur seem likely to recur fairly often. Thus, again, some other factors must be sought. In the present case the change from a tall dense natural vegetation to closely grazed pasture appears to be an important factor.

The soil moisture regime of the yellow-grey earth soils in the Eastern Wairarapa (Fig. 2) alternates between extensive drying to the depth of the pan in late summer (with moisture content well below wilting point) and very wet conditions through the winter. It would seem likely that the change to closely grazed pasture would accentuate these conditions, especially of the ground-cover is poor and some sheet erosion occurs.

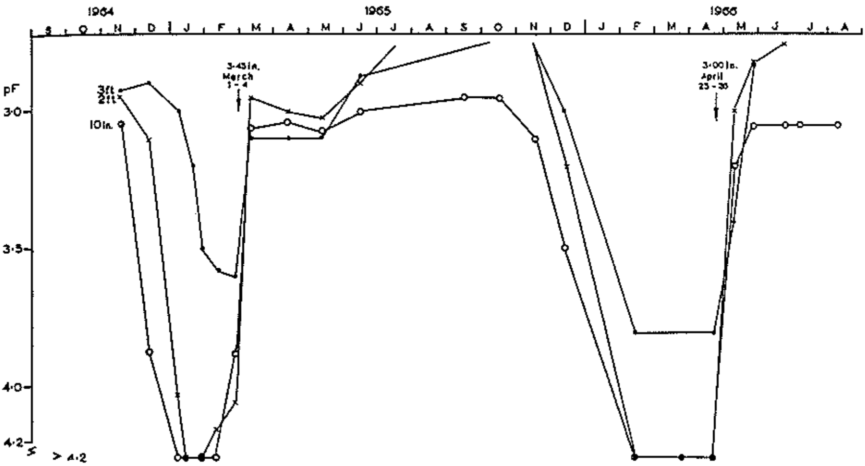

Fig. 2 — **SOIL MOISTURE RECORD, derived from gypsum-block resistance measurements in Wharekaka silt loam, Ponotahi, Eastern Wairarapa, 1964-6.**

Water does not readily enter the soil, which is compact and may also show some water repellence as a result of high wetting angles in very dry topsoils. This would result in greater surface run-off and increase the amount of water able to run down cracks. There is also a possibility that drying by evaporation and transpiration may be increased under short pasture. Mitchell and Closs (1958) have suggested that under conditions of high radiation the region of maximum heat-transfer is concentrated near the ground surface, resulting in high leaf-temperatures and increased transpiration by short pasture.

There may also be an indication that particularly dry conditions are conducive to slipping in the apparent concentration of slips on dry sites such as the upper parts of slopes and on north-facing slopes. Thus it appears that in very dry areas slips are fairly uniformly distributed with respect to aspect, but on moving to slightly wetter areas there is an increasing concentration of slips on the north-west slopes. However this needs checking by a survey of the frequency of slipping, as distinct from the fraction of a slope showing soil bared by slips as this latter may also reflect slower grass establishment on drier sites. Aspect may also be important in relation to storm direction and to concentration of stock on sunny faces.

Tunnel gullying has been observed on some sites on mudstone and further work is need to see to what extent it contributes to slipping, by undermining or by allowing rapid access of water to slip-prone areas. However, the conditions under which tunnel gullies develop (Gibbs, 1945) are very similar to those thought to induce slipping so that the occurrence of both on the same site need not imply a cause and effect relation.

DISCUSSION

As Schumm (1965) has pointed out, erosion problems in New Zealand may be viewed from two perspectives: that of the conservationist to whom erosion is an unhappy problem, and that of the geomorphologist to whom the erosion problems are a potentially fascinating area of research. The rates and processes of erosion on the hillslopes and in the water courses of a drainage basin are intimately linked to the morphology of the landforms and soils, and to the hydrology of the basin. A natural cycle such as that found in Fiordland is a consequence of this linking and will continue while the environment and the materials on which it works remain unchanged. In contrast the loess from which the Wingate hill soils are derived is believed to have been deposited during the last glaciation and erosion of it must eventually decrease as it is removed from the steeper slopes, although a change in land use could induce a radical change in the erosion rate.

In the case of the mudstone areas of the Eastern Wairarapa it appears that changed land use has been a major factor in increasing erosion as a reaction of the hillslopes to a change in their hydrology. The rapid weathering and ease of regrassing mean that loss of productivity need not be permanent (Gibbs, 1962). However slips will deliver large amounts of sediment to the streams and the bare sites will be sources of rapid run-off. Grange and Gibbs (1947, p.25) found that on a site they investigated about 8 - 10% of the surface was bare ground. A cycle of slipping, weathering and soil development followed by renewed slipping was envisaged and is in some ways similar to that occurring in Fiordland. Thus the problem may really be one of adjusting management to reduce the rate of slipping or to increase the rate of revegetation to give a smaller proportion of the slope occupied by slip scars producing high run-off and to reduce the rate of sediment delivery to streams.

The current work is intended to obtain information on the relation of slipping to environmental factors and soil properties. The environmental factors being studied are rainfall, evaporation and the soil-moisture regime. It is essential that field work be located where frequent measurements are possible and be reasonably close to a climate station. The present sites are at Taita and the Mangahuia valley near Gladstone. A number of soil properties appear to be involved, in particular water acceptance and retention, soil structure and the formation of fissures. The latter, which could also be of significance in initiating tunnel gullies, requires a study of soil shrinkage and of dispersion and scouring of the faces of peds. In a study of the mechanics of the slipping process, the recording of movements on pegged slopes, and measurements of soil moisture tensions or pore pressures during rainstorms are being tested.

REFERENCES

Atkinson, I. A. E. (in preparation): **Soils of Taita Experimental Station.** N.Z. Soil Bur. Bull. 32.

Campbell, D. A. 1951: Types of soil erosion prevalent in New Zealand. **I.A.S.H., Brussels.** Vol. 2., pp.82-95.

Gibbs, H. S. 1945: Tunnel-gully erosion on the Wither hills, Marlborough. **N.Z. J. Sci. Tech.** 27A, pp.135-46.

Gibbs, H. S. 1962: Steepland soils and their problems. **Trans. Jt. Meet. Comm. 4 and 5,** Int. Soc. Soil Sci., pp665-79.

Grange, L. I.; Gibbs, H. S. 1947: **Soil erosion in New Zealand.** Part 1 — Southern half of North Island. N.Z. Soil Bur. Bull. 1, 22 pp.

Mitchell, K. J.; Closs, R. L. 1958: Loss of moisture from vegetation. **Nature** 181, pp1619-20.

Pohlen, I. 1947: **Soils and some related aspects of agriculture of Mid-Hawke's Bay.** N.Z. D.S.I.R. Bull. 94.

Robertson, N. G. 1963: **The frequency of high intensity rainfalls in New Zealand.** N.Z. Meteorological Service Misc. Pub. 118, 53 pp.

Schumm, S. A. 1965: Geomorphic research — application to erosion control in New Zealand. **Soil and Water,** Vol. 1, No. 4, pp21-3.

Seelye, C. I. 1946: Variations of monthly rainfall in New Zealand. **N.Z. J. Sci. Tech. 27B,** pp397-405.

Sharpe, C. S. F. 1938: **Landslides and related phenomena.** Columbia University Press., 138pp.

Terzaghi, K. 1950: Mechanism of landslides in **Application of geology to engineering practice,** Berkley Volume, Geological Society of America., pp.83-123.

Wright, A. C. S.; Miller, R. B. 1952: **Soils of South-West Fiordland.** N.Z. Soil Bur. Bull. 7., 36pp