CHAPTER XIII

LANDSLIDES IN LATERITIC TERRAIN
Introduction:

Movement of earth mass along a definite plane of separation or along a system of sliding planes, largely under influence of gravity, cause landslides. The slides normally result into rapid, slow or long term deformation of slopes. They are considered as vagaries of nature and have been a subject of interest because of their socio-economic and scientific aspects. They may cause great loss to life and property, especially when civil engineering structures are erected on slopes without paying heed to the stability conditions.

Since quite a large number of landslides of various magnitudes have been reported from the laterite capped portions of Western Ghats of Maharashtra causing loss to property and life and obstruction to the communication systems, it was considered desirable to study in depth the landslide phenomena in the lateritic terrain of western Maharashtra. This chapter therefore presents results of such studies, especially from the geological and engineering considerations. An attempt has been made to recognise the causes and characters of landslides, identifying horizons of possible slips, and evaluating corrective measures.

Classification of Landslides:

Various classifications of landslides have been considered during last hundred years. They are based on the forms of sliding surfaces, characteristics of slided materials, modes and rates of movements etc. (Heim, 1882, Howe, 1909, Almagia, 1910, Terzaghi, 1925, Ladd, 1935, Sharpe, 1938, Emelyanova, 1952 and Vernes, 1958). Of these, the classification proposed by Zaruba and Mencel (1969) is perhaps the most comprehensive and has been adopted in the present studies. The classification is presented in a tabular form (Table 13.1), and the various type are briefly described below:
Table 13.1

Classification of landslides

(Adopted after Zaruba and Mencl, 1969)

<table>
<thead>
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<th>LANDSLIDES</th>
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<tr>
<td>Slides In Surfacial Material</td>
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<tr>
<td>Creep</td>
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<tr>
<td>Sheet Slide</td>
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<tr>
<td>Debris flow</td>
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<td>Earth flow</td>
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Slides in Surfacial Material:

Creep: It is the slow imperceptible down slope movement of earth mass which leads to bending of strata. It develops along a zone of a system of partially sliding planes.

Sheet slide: The term denotes the movement of slope debris, loams, and weathered material along the surface of bed rock which is shallow.

Debris flow: It is the rapid movement of slope debris and occasionally of volcanic ash, provoked by torrential rain and sudden floods.

Earth flow: It is the movement of loose mass in the form of a narrow flow towards the foot of a slope.

Slides in consolidated or unconsolidated rocks:

Slide along cylindrical surface: It is the movement of consolidated or semiconsolidated or weathered material along ancient slide surface or lithological discontinuities.

Slides due to squeezing of soft rocks: It is slow movement of consolidated or semiconsolidated material along a system of partial slide surfaces due to plastic deformation.

Slides in Solid Rocks:

Rock slide: It is the downslope movement of rocks along the planes of separation like bedding, joints, low dipping fault planes etc. with the continuity being disturbed at the foot of the slope.

Rock fall: It designates abrupt movement of loosened blocks or beds of solid rocks in the form of free falls.

Slow gravitational slide: It is componental movement of rock material due to residual stress without development of continuous slide.

Miscellaneous Slides:

Solifluction: Solifluction is slipping and flowage of surface layers on perennially frozen ground.
Subaqueous slide: It is the movement of sediments in the lakes and on sea shores deltaic deposits on a fairly steep sea floor stimulated by seismic or other shocks.

Viscous flow: It is rapid movement of clays deposited under marine environments and behaviour as viscous fluid.

Landslides in Lateritic Terrain:

Landslides of varying dimensions frequently take place in the Western Ghats. They are seen in the form of creeps, rock slides, etc. They appear to be more common in sections where laterite profiles are well developed and their manifestations appear to differ due to geomorphic conditions. Rock falls and block slides occur at higher elevation along escarpments towards the margins of plateaux, while creeps, rock slides, debris flows and slumps occur at all elevations either alone or in combinations. Landslides have been commonly observed in Ratnagiri and Sindhudurg districts and less frequently in the laterite capped areas of Kolhapur, Sangli and Satara districts (Tandale, 1985, 1985).

The landslides generally occur during rainy season and especially during the high rainfall periods. However, they have also been reported during dry seasons at places. The maximum precipitation zone is in southern part of the Konkan belt (i.e. south of Raigad district), where the maximum rainfall is recorded during July of each year. More than two hundred landslides of varying dimensions were recorded in laterite and non-laterite areas of this region during July, 1983.

As stated earlier the landslides under review occurred largely in areas of steep to moderate slopes and were more or less confined to slopes showing presence of lithomargic clay and / or saprolite horizons. Debris flows were common along steep to moderate slopes, and slumps were confined to moderate to gentle slopes of saprolite horizons. Moreover the landslides were commonly noticed in the area where toe support was removed by natural agencies or cultural activities.
As indicated in Chapter II, laterite profiles in the area under study are developed over Precambrian crystallines, isolated inliers of the Kaladgi (Algonkian) sediments, and on Cretaceous - Eocene Deccan basalts. The laterite duricrusts are scarce and comparatively thin on Precambrian crystallines and the Kaladgi sediments, but the underlying lithomargic clay and saprolite horizons derived from these rocks are wide spread and thick. The Precambrian terrain is undulating at lower elevations where landslides often take place along the dip of beds where plastic lithomargic clay and saprolite horizons are present and facilitate movements. Debris flows, which occur along moderate to steep slopes of underlying rocks, are characterised by notable proportion of plastic lithomargic clay and saprolite. In case of Deccan basalt terrain, the landslides occur in the lithologic units underlain by red bole, volcanic breccia, or highly amygdaloidal-vesicular horizons suggesting that the under cutting of rock sections along these soft horizons facilitates separation of the overlying mass, which ultimately collapses under influence of gravity. In order to illustrate different types of landslides and their mechanism, a few specific case studies are presented in the following paragraphs.

**Slope failure along cylindrical surface and earlier slide plane at Tillari power canal:**

The slope failure on southern side of power canal was combination of two types i.e. slope failure along cylindrical surface and earlier slide plane. Tillari power canal, aligned east west had been under excavation across the upper moderate slope of the laterite capped massif rising to the level of 750 m representing the western side of the continental divide at about 750 m msl in Chandgad tahsil of Kolhapur district. The landslide occurred along the southern side of canal excavation towards the end of summer season i.e. on 1st June 1980 (Phadke, 1982, Tandale, 1985). The power canal was designed to carry discharge of 7.90 cum/sec. It was designed with slopes 1:1 with berms of 1.5 m width at vertical interval of 6 metres. The slope on south side was about 2.6:1, while on north
side was 1:1 with 1.5 m berm at 6 m vertical interval at the time of sliding. As the monsoon started by the middle of June, further excavation was stopped. The slide recurred with more severity during high rainfall period. A conspicuous feature was that the northern side of the canal remained undisturbed during both the events. The slide was about 150 m long following the canal alignment and was about 30 m deep. At the event of recurrence of sliding, slow upheaval of the canal bed became conspicuous simultaneous with further excavation.

Geology of the area is represented by the Deccan basalt flows of Cretaceous-Eocene age. The lava flows are capped with laterite duricrusts at higher elevations, while thick reworked laterite occupy hill slopes and valley portions. Geological section exposed on southern side of the canal revealed the following succession:

- 750 to 765 m: Laterite duricrust, reworked laterite, lateritic soil.
- 735 to 750 m: Lithomargic clay.
- 723 to 735 m: Saprolite.
- Below 723 m: Basalt.

The slid material consist of a mixed portion of laterite duricrust and reworked laterite, lithomargic clay and saprolite.

Outcrops of fresh insitu basalt juxtaposed the slid laterite profile (Fig. 13.1). The comparison between surficial shapes of pre-existing profile and resultant profile of debris after slide suggest that the entire area where canal has been aligned, has been perhaps undergone major sliding in the past, with establishment of subsequent stability. The present excavation might have triggered the slide along the pre-existing weak zone. Fig. 13.2 A shows unstable landform, slid debris filled in the then existing valley portion and forms bulging portion which simulates a small hill across which canal alignment was laid, Fig. 13.2 B elucidiates section along the earlier sliding plane.
Fig. 13.1 Geological section along the slided portion

Fig. 13.2 Block diagrams showing ancient slide
(a) Topographic features after ancient slide
(b) Cross section showing sliding plane
Fig. 13.3 shows landslide of an unusual nature (Plate 13.1, Photo 1 and 2). It took place at the end of the summer season along the southern side of the power canal under excavation, while the northern side remained in undisturbed state, in spite of its comparatively steeper slope. A slip circle has been plotted on the basis of locations of slip surfaces identified in the field. The main cause of slide that took place towards the end of summer season appears to be due to significant decrease in shear strength of lithomargic clay, a unit of the laterite profile owing to loss of water content of the montmorillonite present in this horizon (Sahasrabudhe, 1979). Absorbed water in montomorillonite evaporates during summer giving rise to macro and micro tensile cracks which consequently decrease the shear strength. The factor of safety has been computed from the following equation (Terzaghi et al, 1948) after the slide took place towards the end of the summer season. Plate 2.2, Photo 2 shows caving in lithomargic clay at Tillari Nagar due to decrease in cohesion owing to loss of moisture.

\[
\text{Factor of safety} = \frac{\text{Moment of resisting force}}{\text{Moment of driving force}}
\]

\[= 1.0008\]

The slide was temporarily stabilized. It recurred in the subsequent rainy season due to increase in pore water pressure, swelling pressure developed by montmorillonite rich lithomargic clay, hydrostatic pressure, and also the movement of groundwater.

**Landslide along cylindrical surface at Patgaon:**

The slope failure took place along cylindrical surface on northern side of the canal outlet under excavation at Patgaon Irrigation Project towards end of February 1985, when there was no spell of rains.

The profile of excavated canal outlet consists of reworked laterite and lateritic soil (3 m thick) underlain by lithomargic clay.
Fig. 13.3 Landslide showing slip circle

Fig. 13.4 Relation of landslides with planation surface
(1 m thick) and then by saprolite. The slide took place due to decrease in shear parameters caused by tensile cracks in lithomargic clay owing to the moisture loss.

**Slumping and rock falls at Vapholi:**

An open channel bar type waste weir of 32 m width was constructed on left side of the dam to carry maximum designed flood discharge of 2408 cusecs at reservoir at Vapholi near Banda in Sindhudurg district. The length of the tail channel was about 200 m and average surface gradient was about 6°.

In the tail channel indurated ferricrete traversed by vertical/sub-vertical joints was exposed over a length of about 70 m downstream of waste weir and was further followed by irregular exposures of soft induced concretionary laterite. A few isolated outcrops of amphibolite were seen in the portion between downstream toe of the dam and confluence of the tail channel with the main nala.

The functioning of waste weir commenced in 1976. The erosion of the bed of the tail channel was initially due to the flowage water over it. Subsequently, the headward and sideward erosion started taking place in tail channel, due to combination of slumps and rock falls. (Plate 2.6, Photo 1). The erosion in the tail channel due to combination of slumps and rock falls during high rainfall periods. On supersaturation, due to groundwater movement and increase in pore water pressure, texture and structure of induced laterite and saprolite, derived from amphibolite, got disturbed. In certain horizons of mica rich amphibolite, the mica flakes were carried by the flow of water in the tail channel leaving the non-dispersive earthmass behind. Thus the upper semi-plastic mass of slide transferred into slump followed by rockfalls of ferricrete due to the overhanging. At the end of seven years, the erosion was so severe that it was feared that it may damage the main structure.
Rockfalls and block slides at Panchagani:

Panchgani is a hill resort situated on eastern extremity of Mahabaleshwar plateau, in the Satara district. It consists of broad table land of laterite with vertical marginal cliffs of about 30 to 40 m height. The laterite is traversed by vertical to sub-vertical joints and is underlain by about 10 m thick horizon of lithomargic clay. The block slides and rock falls are observed along margins of the laterite plateau, and in majority of cases they were conspicuous along the joints in laterite along which plastic soil was noticed, probably due to earlier joint fillings (Plate 2.1, Photo 1).

Rainy season followed by summer cause alternate wetting and drying of lithomargic clay and results into loss of cohesion and shear strength, and the clays are under cut during high rainfall periods resulting into overhanging of the laterite. Increase in hydrostatic pressure in addition to groundwater movement finally results into separation of laterite blocks along pre-existing joints and they get dislodged.

Block slides at Mahabaleshwar:

Block slides took place during high rainfall periods along moderate slopes formed by laterite and underlying plastic lithomargic clay and saprolite horizons at Mahabaleshwar, a hill resort in Satara district.

Blocks of laterite duricrust traversed by open joints were dislodged during high rainfall periods due to increase in hydrostatic pressure and/or ground water movement and slowly rolled over the slopes of underlying soft and plastic horizons under the force of gravity, and where there was no passive resistance. Sometimes the blocks were sunk into the miniature valley like local depressions squeezing out the underlying soft and plastic lithomargic clay.

Rockslide at Sangameshwar, Sakharpa and Patgaon and Parashuram:

The landslides near Sangameshwar and Sakharpa in Ratnagiri Districts and at Patgaon (Plate 13.2, Photo 1) in Kolhapur district took
place on slopes of saprolite horizons derived from volcanic breccia with red bole and highly amygdular and vesicular horizons.

The rock slides occurred during high rainfall periods by development of plane of weakness in the top portion of the flow consisting of volcanic breccia rich in red bole, due to its cohesionless nature. The development of plane of weakness was as a result of combined effect of increase in pore water pressure, absence of toe support and downslope local dip of upper contact of underlying lava flow. Slicken sides were noticed along plane of sliding.

Creeps at Tillari hydro electric project:

Creeps were noticed in the waste weir excavations extending for about 100 m at the forebay dam of Tillari Hydro Electric Project in Chandgad tahsil of Kolhapur district in the saprolite derived from basalt flow, consisting of volcanic breccia rich in red bole. The creeps were witnessed by slicken sides along the plane of movement. The area presents undulating topography with moderate drainage density.

Debris flow at Sangmeshwar:

The debris flow on a moderate to steep slope which was covered with little vegetation, took place at about the elevation of 75 m above msl near Sangameshwar in the first week of July 1983, when there were rains of very high intensity. At the time of slide the people engaged in the works at the toe of the slide were buried into slided mass. The slided mass consisting of fine lateritic soil of high plasticity mixed with irregular blocks of different rock types. Causative factor of the debris flow appear to be due to increase in pore water pressure and movement of groundwater. In order to avoid further disaster, butraces are constructed across the slope (Plate 13.2, Photo 2).
Geotechnical Properties of Slide Prone Lithotypes

Results of geotechnical properties of slide prone lithotypes have been described in earlier chapters. However, with reference to the slides, they are described below:

(i) Lithomargic clay derived from amygdaloidal basalt and occurring at about 10 m below the base of laterite duricrust (the central portion of the profile) shows swelling pressure 0.4 kg/cm² (Phadke, 1982).

(ii) Saprolite derived from volcanic breccia with red bole is cohesionless and non-plastic, while the one, derived from similar nature of rock but without red bole is plastic and cohesive.

(iii) Saprolites of above types show good angle of internal friction. Thus the geotechnical properties of saprolite derived from volcanic breccia with red bole appear to be dependent on quantity of red bole present in the same.

(iv) Lithologic units of laterite profile developed over mica bearing rocks of Nilgiri mountain are reported to show very wide range of geotechnical properties except shrinkage limit (Sheshagiri et al 1982); e.g. PI 6.3 to 22.03 %, natural dry density 1.318 to 1.81 gm/cc, angle of internal friction 3° to 21° and abnormally high cohesion of 4 to 11 kg/cm².

Conclusion:

(i) Although the phenomena of landslides are taking place in all geological formations in Maharashtra, they are comparatively more recurrent in lateritic terrain of Western Ghats.

(ii) Rock falls and block slides are confined to the laterite duricrust and ferricrete, while the rock slides and creeps are restricted to the saprolite horizons, particularly derived from volcanic breccia due to its cohesionless property.
(iii) Lithomargic clay rich in montmorillonite and saprolite horizons of the laterite profile are comparatively more slide prone horizons.

(iv) The slide prone horizons though appear to occur at different elevations, yet they are correlatable to the once existing laterite duricrust levels marking the then existing planation surfaces (Sahasrabudhe et al, 1985). Fig. 13.4 suggests that the present slide prone lithotypes represent the saprolite horizons of the then existing laterite profiles.

(v) Headward and sideward erosion in saprolites derived from mica bearing rocks are caused alone or in combination of rock falls and slumps. Due recognition of these geological features is very essential before planning and designing canal alignment their excavation and proper functioning, to avoid problematic surprises. Excavation and functioning of canals would be very problematic in such horizons.

(vi) As large number of natural factors contribute in the phenomena of landslide, man has very little control over them. In order to prevent landslide and/or minimise intensity of danger and avoid such hazards, corrective measures including alternatives have been suggested on the basis of type of slope movement and geological conditions (Table 13.2). These are required to be studied and carried out in context with local geology and extent of movement.

(vii) Since study of landslides in laterites of Western Ghats is almost untouched branch, there is adequate scope for further research on the following lines:

(a) preparation of slide prone area maps,
(b) study of suitable plantation in slide prone areas, because landslide susceptibility value found to higher in tea and coffee planted zone than in other vegetation (Sheshagiri et al, 1982),
(c) study of geotechnical properties of slide prone horizons is necessary in order to select and design structures to prevent hazards due to landslides.
(d) prediction of time and place of landslides.

(viii) In landslide suspected areas, for construction of civil engineering structures, corrective measures and alternatives are suggested in Table 13.2.
## Corrective measure and alternatives with reference to slope movement and civil engineering structures

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Slope Movement</th>
<th>Engineering Structure</th>
<th>Corrective measures and alternatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Rockfalls</td>
<td>Rehabilitation canals, roads, tunnels</td>
<td>Rock bolting, anchoring, removal of laterite duricrust block margins.</td>
</tr>
<tr>
<td>2.</td>
<td>Block Slides</td>
<td>Canals, roads</td>
<td>Removal of loose blocks of laterite.</td>
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<td></td>
<td></td>
<td>Buildings</td>
<td>Removal of soft plastic horizons from foundations, pile foundations.</td>
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<tr>
<td>3.</td>
<td>Rock slides</td>
<td>Buildings</td>
<td>Retaining walls, gentle slope to be provided, removal of slide prone upper mass.</td>
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<tr>
<td></td>
<td></td>
<td>Canals, roads</td>
<td>Gentle slope to be provided, alternative alignment of canal or roads.</td>
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<td></td>
<td></td>
<td>Roads</td>
<td>Moment of resisting force of sliding prone horizons can be increased by suitable plantation and retaining walls.</td>
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<tr>
<td></td>
<td></td>
<td>Canals, roads</td>
<td>Removal of earth mass above the creep, retaining walls.</td>
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<tr>
<td></td>
<td></td>
<td>Roads</td>
<td>Moment of resisting force in slide prone horizons can be increased by suitable plantation and retaining walls.</td>
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<tr>
<td>5.</td>
<td>Slump</td>
<td>Buildings</td>
<td>Pile foundations.</td>
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<td></td>
<td></td>
<td>Canals, tail channel</td>
<td>Mica bearing saprolite should be protected by rip rap etc.</td>
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<tr>
<td></td>
<td></td>
<td>Roads</td>
<td>Alternative alignment.</td>
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<td>Sr. No.</td>
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<td>6.</td>
<td>Slope failure along cylindrical surface</td>
<td>Buildings, Canals, roads</td>
<td>Pile foundation, Gentle slope to be provided, box work structure. Suitable plantation in slide prone horizons to retain moisture content during dry season and increase moment of resisting force.</td>
</tr>
<tr>
<td>7.</td>
<td>Debris flow</td>
<td>Buildings, canals, roads</td>
<td>Drainage to be provided in slide prone zone, retaining wall, removal of debris, plantation.</td>
</tr>
</tbody>
</table>
Plate 13.1

Photo 1

Landslide in laterite at Tillari Power Canal

Photo 2

Landslide in laterite at Tillari Power Canal
(Note the sliding plane at the base)
Plate 13.2

Photo 1

Rock slide in saprolite at Patgaon

Photo 2

Debris flow at Sangameshwar, but traces across the slope