5. **DETAILED INVESTIGATION OF SOME SELECTED LANDSLIDES (CASE STUDY)**

For purposes of detailed studies three landslides are selected. The slides so chosen are all along the main road sides that have left a deep impact on inhabitants of Aizawl city and its surrounding areas.

5.1 **SAIRANG LANDSLIDE**

5.1.1 **LOCATION**

It is located (N. 23° 50' 27" Lat. and E92° 40' 15"Long) at about 27.4 km on Aizawl – Silchar road (NH-54) i.e. about 5.4 km north of Sairang village (Fig. 5.1) It lies at the junction of western aspect of a N-S trending hill range and a E-W trending spur.

NH 54 passes through the middle of hill and a small bridge has been constructed over a nallah that intersects the slide area at the middle. The left half of the area is covered with thick vegetation whereas right one is devoid of vegetation. The length, breadth and height of slide are 110m, 20m and 70m respectively. The material involved in the sliding are debris and small and large blocks of rocks. The supply of the material is from the 1-2m thick overburden and 125m high slope face composed of highly weathered and jointed rocks (Plate 5.1a-b).

5.1.2 **CONTOUR MAP OF THE SLIDED AREA**

Contour map of the slided area (Fig. 5.2) has been prepared using theodolite survey and Map Info GIS software at an interval of 1 metre. The map shows that the area south of the nalla has moderate slope whereas that of north has steep slope.
Fig. 5.1: Location Map of Sairang Landslide
Plate 5.1a: Synoptic view of Sairang Landslide

Plate 5.1b: Close view of crown area of Sairang Landslide
Fig. 5.2: Contour Map of the Landslide Area near 27.4 km post on Aizawl - Silchar Road
5.1.3 DIGITAL ELEVATION MODEL AND 3-D VIEW

The contours of the area were digitized and imported to the GIS software to obtain DEM and 3-D view of the area (Fig. 5.3, 5.4, 5.5, 5.6 and 5.7).

Fig. 5.3: Digital Elevation Model (DEM) of Landslide area Near 27.4 km post on Aizawl – Silchar Road
Fig. 5.4: 3-D of Sairang Landslide, Aizawl District, Mizoram (a)

Fig. 5.5: 3-D of Sairang Landslide, Aizawl District, Mizoram (b)
Fig. 5.6: 3D View of a part of Sairang Landslide site

Fig. 5.7: 3D View of entire Sairang Landslide site
### 5.1.4 GEOLOGY OF SAIRANG LANDSLIDE AREA

Sairang landslide area lies in the western limb of Aizawl anticline. The rocks exposed in the area belong to upper unit of Bhurban Formation of Surma Group. The dominant rock types exposed in the study area are sandstone, siltstone and shales and their admixtures in various proportions. The general trend of rock formations is N-S with 40° dip due west. The rocks are intersected by two sets of joints besides a bedding plane joints. Five litho-units have been delineated in the slide area (Table 5.1). The lithological map of the study area has been prepared and is shown in Fig. 5.8. The details of the rock types and bed thickness are as follows:

**Table 5.1: Details of the litho-units in the study area**

<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Lithology</th>
<th>Thickness (in m)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.</td>
<td>Silty-shale</td>
<td>3.6</td>
<td>Brown coloured, medium bedded, fine grained,</td>
</tr>
<tr>
<td>4.</td>
<td>Sandstone</td>
<td>5.0</td>
<td>Thickly bedded, brown coloured and fined grained. Spacing of bedding planes and joint sets are nearly 2m.</td>
</tr>
<tr>
<td>3.</td>
<td>Intraformational</td>
<td>0.5</td>
<td>Grey coloured, hard, and bioturbated conglomerate</td>
</tr>
<tr>
<td>2.</td>
<td>Shale</td>
<td>5.5</td>
<td>Deep grey coloured, thinly bedded and crumpled, very fine grained, and smooth, occasionally clayey and micro-cross laminated</td>
</tr>
<tr>
<td>1.</td>
<td>Sandstone-Shale</td>
<td>22.5</td>
<td>Sandstone is brown coloured, fine grained, silty alternations and rippled. Shale is grey coloured, micaceous and laminated.</td>
</tr>
</tbody>
</table>
Fig. 5.8: Lithological Map of the Sairang landslide area near 27.4 km post on Aizawl - Silchar Road
5.1.5 STRUCTURAL MAP OF SAIRANG LANDSLIDE AREA

Structural map of Sairang landslide area has been prepared (Fig. 5.9). Attitude of bedding planes and joints sets are shown in this map.

Fig. 5.9: Structural map of the Sairang landslide area Near 27.4 km post on Aizawl – Silchar Road
FACTOR OF SAFETY

Factor of safety was calculated using the following formula:

\[
\text{Factor of Safety (FS)} = \frac{CA + W \cos \alpha \tan \phi}{W \sin \alpha}
\]

Where

- \( C \) = Cohesive strength,
- \( A \) = Total area of failure surface,
- \( W \) = Total weight of the failed mass
- \( \alpha \) = Angle of failure plane
- \( \phi \) = Angle of friction of the failure surface

Sample-1: Sandstone (Sairang)

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (h)</td>
<td>22.5 m</td>
</tr>
<tr>
<td>Total area of failure surface (A)</td>
<td>101.25 m²</td>
</tr>
<tr>
<td>Average density of rock mass (D)</td>
<td>2500 Kg/m²</td>
</tr>
<tr>
<td>Total weight of slided mass (W)</td>
<td>253125 x 10² Kg</td>
</tr>
<tr>
<td>Cohesion strength of failure plane (C)</td>
<td>5 x 10⁵ Pa</td>
</tr>
<tr>
<td>Angle of friction of the failure (( \alpha ))</td>
<td>46°</td>
</tr>
<tr>
<td>Angle of friction of the failure plane (( \phi ))</td>
<td>12°</td>
</tr>
<tr>
<td>( \cos \alpha )</td>
<td>0.695</td>
</tr>
<tr>
<td>( \tan \phi )</td>
<td>0.213</td>
</tr>
<tr>
<td>( \sin \alpha )</td>
<td>0.719</td>
</tr>
</tbody>
</table>

By putting above values in the equation, we get

\[
FS = \frac{5 \times 10^5 \times 101.25 + 253125 \times 10^2 \times 0.695 \times 0.213}{253125 \times 10^2 \times 0.719}
\]

\[
FS = \frac{11241407.8125}{18199687.50}
\]

FS = 0.62
Sample-2: Shale (Sairang)

Height (h) : 5.5 m
Total area of failure surface (A) : 27.5 m²
Average density of rock mass : 2170 Kg/m²
Total weight of slipped mass (W) : 4774 x 10³
Cohesion strength of failure plane (C) : 2.5 x 10⁵
Angle of friction of the failure (α) : 28°
Angle of friction of the failure plane (Φ) : 11°
Cos α : 0.883
Tan α : 0.194
Sin α : 0.469

FS = \frac{2.5 \times 10^5 \times 27.5 + 4774 \times 10^3 \times 0.883 \times 0.194}{4774 \times 10^2 \times 0.469}

FS = \frac{1995496.998}{2239006.000}

FS = 0.89

Factor of safety for sandstone is 0.62, which is less than that of Shale i.e. 0.89. This can be understood by the several factors. Among which most conspicuous one is the fact that slope height at the sandstone horizon (22.5 m) is considerably higher than height at shale horizon (5.5m). Despite the fact that average cohesion of sandstone horizon which is 5 x 105 Pa, is double than that of shale horizon, the slope at sandstone site is more vulnerable than Shale site.

5.1.6 KINEMATIC STUDY OF ROCK DISCONTINUITIES

Analysis of slope stability is a complex and cumbersome exercise because there are many rock discontinuities in a rock mass such as bedding planes, joint planes and fissures. Majority of the slip surfaces of the landslides are influenced by the orientation, spacing and nature of the surfaces of the rock discontinuities, and their relation to the slope. The shear strength of rock mass and its deformability are also influenced by the pattern, geometry and extent of development of rock discontinuities.
The rock mass strength is affected by spacing of the rock discontinuities to the extent that even strong intact rock can be reduced to the weak ones if intersected by closely spaced several joint sets.

Orientation and frequency of rock discontinuities jointly influence the response of a rock mass to the slope failure. Closely spaced joint planes tend to cause massive block failure. Kinematic analysis of joint plane is therefore necessary in order to understand their influence in the overall instability of slope. Though, kinematic analysis of rock discontinuities does not provide the numerical measure of the degree of instability of the slope, it provides the information whether or not the stability of slope is feasible. The two primary factors that help determine the influence of orientation of joint planes on the stability of slopes are:

i) Whether joint or joint intersection cut the slope at angle less than the angle of natural or manmade slope, and if so

ii) Whether the dip angles of the joints or the angle of plunge of the joints Intersections exceed the angle of friction along the joint surface.

The methodology of the kinematic analysis of rock discontinuities involves:

i) Measurement of attitude of maximum numbers of rock discontinuities

ii) Plotting of the readings of the stereonet

iii) Determination of main discontinuity sets, and

iv) Determination of possible mode of failure

About 75 readings of joint sets from the Sairang landslide site were recorded with the help of Brunton Compass. These were plotted in the Stereonet using GEOrient software. Three joint sets have been identified from the contour diagrams of (Figs 5.10, 5.11 and 5.12) of these joint poles. These joint sets were plotted in the stereonet along with the slope angles. Three wedges in the stereoplot of Sairang landslide (Fig. 5.13) have been identified. Rose diagram of joint sets has also been prepared to show the frequency of occurrence of joints (Fig. 5.14). The attitudes of joint sets and of the wedges are as follows (Table 5.2):
Table 5.2: Attitudes of joint sets and wedges

<table>
<thead>
<tr>
<th>Orientation of Joint sets</th>
<th>Orientation of Wedges</th>
</tr>
</thead>
<tbody>
<tr>
<td>J1=S0</td>
<td>W1 : 15°/210°</td>
</tr>
<tr>
<td>J2</td>
<td>W2 : 50°/070°</td>
</tr>
<tr>
<td>J3</td>
<td>W3 : 20°/330°</td>
</tr>
<tr>
<td>Slope</td>
<td>50°/270°</td>
</tr>
</tbody>
</table>

The spacings of J2 and J3 at Sairang is 1.6m and 1m respectively. The joint openings of J2 and J3 are 3-5 mm and 2-3mm respectively. The joint surfaces of J2 and J3 are rough and rippled respectively. The stereo plot indicates planar failure because it is along the prevalent and continuous joint set (J1) dipping towards the slope. Moreover, the strike of this joint set is near parallel to the dip of the slope face and dip is less than the dip of the slope. Thus, joint set J1 (=S0) is most critical for the stability of the slope. W1 is formed by the intersection of J1 and J2, W2 by the intersection of J2 and J3 and W3 by J1 and J3.

![Data description: Plots of the poles of J1 joint set from Sairang area](image)

Fig. 5.10: Plots of the poles of J1 joint set from Sairang area.
Fig. 5.11: Plots of the poles of J2 joint set from Sairang area.

Fig. 5.12: Plots of the poles of J3 joint set from Sairang area.
Fig. 5.13: Synoptic diagram showing plots of J2, J3, slope angle, W1, W2.

Fig. 5.14: Rose diagram from the plots of the joints (J1, J2, J3) of Sairang landslide area.
5.1.7 CAUSES OF LANDSLIDE

After carefully studying the slide, it is inferred that the present slide was due to the following causes:

1. Presence of bedding shears and clay pockets/beds with swelling and shrinkage properties. This in conjunction with the poor shear strength of the slope forming material both in natural moisture content caused frequent slope failure at this locality. Further, decrease in the shear strength of overburden and bed rocks during rainy season due to water saturation also contributed significantly to the frequent failure of slope at this point.

2. Frequent lithological variations lead to frequent change in the stability conditions. Factor of safety worked out at two points in two litho-units (i.e. sandstone and shale) is 0.62 and 0.89 respectively.

3. Steep hill slope at the crown part of the slide led to failure at the crown. This lead to sliding of soil debris and even bed rock as the thickness of the soil is thin at the crown.

4. Removal of shaley horizons by scouring action during heavy rains. This loosens the blocks of sandstones (formed by intersections of joint planes and bedding plane) that slid down the slope.

5. The stereo plot of joint sets indicates planar failure because it is along the prevalent and continuous joint set (J1) dipping towards the slope. Moreover, the strike of this joint set is near parallel to the dip of the slope face and dip is less than the dip of the slope. Thus, joint set J1 (=S0) is most critical for the stability of the slope.

6. Slope forming materials are not self draining and thereby a hydrostatic pressure is developed that is detrimental to the slope stability.
5.1.8 REMEDIAL MEASURES

1. Provision for suitably lined catch water drains of adequate capacity sloping towards hill with chute for channeling surface water flow from slide zone. There should be provision for deep drains to minimize saturation of debris material.

2. Lining of nala that is formed at the middle of the slide zone to keep free flowing condition, to prevent toe erosion and also to prevent water percolation through debris.

3. Sealing/filling of ground fractures/cracks with clayey material in order to prevent percolation of water and depth of zone saturation of slope material. This in turn will prevent reduction in the shearing strength of slope material.

4. Checking of toe erosion by providing suitably designed breast and retaining structures as a guard against toe erosion.

5. Provision of boulder crate to prevent toe erosion.

6. Provision of wooden piles at suitable intervals to check debris flow.

7. Aforestation in the slide mass using fast growing trees and grasses.
5.2 SOUTH HLIMEN LANDSLIDE

5.2.1 INTRODUCTION

South Hlimen landslide occurred on the fateful morning of 9th August, 1992 involving complete collapse of a stone quarry of 300m length and 250m thickness. Due to this disastrous incident, several people reportedly lost their lives including the villagers and labourers. The place of incident is about 4.2 km south of Aizawl town in a village named South Hlimen (23° 41' & 92° 43'). This quarry is considered as one of the best in the state due to its hard and compact nature of sandstones (Plate 5.2). Thus there is tremendous pressure on this quarry to increase the production to cope up the rapid urbanization of the Aizawl city and surrounding areas. After the first incident, this area has slided several times.

5.2.2 GEOLOGICAL DESCRIPTION

Geologically, the area belongs to Upper Bhuban unit of Bhuban Formation (Surma Group) of Miocene age. The rock types exposed in the area are thickly bedded sandstones with alternate thinly bedded shales. The sandstones of the quarry are gray to brown in colour, fine to medium grained, compact, micaceous, relatively hard with cementing material of varying composition, viz., calcareous, arenaceous, ferruginous etc. The shales are also gray to brown in colour, micaceous, thinly laminated and occasionally clayey. At the quarry site, the rock formations trend roughly N-S with 45° dip due west and are traversed by F-W tending vertical joint planes. The bedding and joint planes are lacking aspirates on their surfaces, thereby resulting into relatively smooth planes of structural discontinuities. The vegetation and the overburden at the quarry site are practically negligible. A road passes through the middle of the hill slope.

5.2.3 SLOPE STABILITY PROBLEM

Slope stability problem in the quarry of the South Hlimen arises mainly due to the blocky nature of the sandstones. In fact, the huge blocks of sandstones have been formed as a result of two intersecting planes of structural discontinuities, viz., roughly N-S tending bedding joint planes (275°/45°) and F-W trending vertical joint planes.
With the continuous removal of the toe material, the natural support for the uphill blocks was loosing strength and thus the stability got disturbed and ultimately these were subjected to free fall along the bedding planes. Moreover, tropical climate and heavy rainfall had further reduced the cohesive strength of the joint planes. Shaly intercalations between the sandstone beds might have provided active slippage surfaces to the failure. Additionally, the explosive are being used to speedup the excavation operation. As a result of excessive blasting, a number of minor and major cracks have developed. These also facilitated the fall of huge sandstone boulders.

5.2.4 REMARKS

Slope failure at South Hilm ton Quarry site is an eye opener because quarry operation in the state is not taken seriously. Quarrying activity in the State is undertaken in the most haphazard manner without properly surveying the area. Most of the quarries in the state are located along the road sides and excavation of stones starts form the base of the hill upward. In order to have safe quarrying and to minimize landslides and its consequences, the following points may be recommended:

- The area is properly surveyed, before allotting it to Miners.
- Quarry lease should not be granted along the road sides in order to avoid road blockade and to provide stability to the roadcut face of the hills.
- Good deposits of stones should be located deep within the jungles away from human settlement.
- Explosives should be used within permissible limit.
- Quarry operations should start form top towards bottom making benches.
Plate 5.2a: Northern part of South Hlimen Landslide

Plate 5.2b: Southern part of South Hlimen Landslide
5.3 BAWNGKAWN LANDSLIDE

5.3.1 INTRODUCTION

The slide area (Lat 23° 45' 30" N & Long 92° 44' E) is located at about 5.5 kms from Aizawl town (about 700 m from Bawngkawn police point) on the Aizawl – Lunglei road (NH 54) (Plate. 5.3 a-b). The area belongs to western aspect of the NW-SE trending hill range in Bawngkawn locality and forms a part of the Survey of India Topsheet nos. 84 A/9 & A/10. A road passes through the middle of the hill face and a nallah runs from the left flank of the area. The vegetation in the area is scarce.

The dimensions of the slides are: length – 250 m, height – 150 m and width – 25 m. The material involved in the sliding is debris and small and large blocks of rocks. The supply of the material is from four to five metre thick overburden and 150 m hill face composed of highly weathered and joined sandstones intercalated with thin layers of shales and siltstone alternation.

5.3.2 GEOLOGY OF THE AREA

The dominant rock types exposed in the area are sandstones, shales and siltstone-shale alternations. These form the sandstone-shale Unit of Middle Bhutan Formation (Tiwari & Kumar, 1995). The sandstones are thickly bedded, grey to brown coloured, medium to coarse grained, relatively hard, feldspathic & micaceous in nature, occasionally silty, bioturbated and intercalated with thin layers of shales. The shales are also grey to brown coloured, thinly laminated, micaceous and occasionally clayey. The siltstone-shale alternations are very thinly laminated and often exhibit micro-cross laminations. Layers of clay are noticed along the discontinuities which might be the weathered product of feldspathic sandstones.

5.3.3 STRUCTURE OF THE AREA

The slide area forms a part of eastern limb of approximately N-S trending Aizawl antiline which is asymmetrical and doubly plunging. The eastern limb of the antiline dips 20° to 50° while western one 23° to 68°. Variation in the strike of beds in the slide area may be attributed to local warping in the limb of the antiline. The
limb is also offset by a NW-SE trending Chitelui fault (Tiwari & Kumar, 1995). Landslide is located in the eastern side of this fault in the close vicinity. Drag folds in the incompetent shale layers and occurrence of slickenside towards the left flank of slided area confirm the presence of this fault. Moreover a shear zone of about 5 m thickness has also been recorded in the same flank which is evidenced by the sheared nature of shale. Further the shale has also acquired slaty character indicating metadiagenesis of the sediments.

5.3.4 ANALYSIS OF THE ROCK DISCONTINUITIES

The area in and around landslide is intercepted by three sets of joints viz, bedding joint (J1=SO), strike joint (J2) and oblique joint (J3) (Table 5.3). These joint sets divide the rock beds into blocks of varying dimensions. The failure mode in the area is determined on the basis of graphical analysis of joints observed in the site. About 50 readings for each joint are recorded; poles are plotted on the stereonet and contoured to get maximas of the pole concentrations. The general orientation of the joints sets is as follows:

Table 5.3: General orientation of the joint sets in Bawngkawn landslide

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Strike</th>
<th>Dip Amount &amp; Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>J1</td>
<td>N 312°</td>
<td>30° NE</td>
</tr>
<tr>
<td>J2</td>
<td>N 310°</td>
<td>68° SW</td>
</tr>
<tr>
<td>J3</td>
<td>N 70°</td>
<td>72° SE</td>
</tr>
</tbody>
</table>

The stereo plot of these joint sets indicate planar failure because it is along the prevalent and continuous joint set (J2) dipping towards the slope (Romana, 1985). Moreover, the strike of this joint set is near parallel to slope face and dip is less than the dip of the slope. Thus, joint set J2 is most critical for the stability of the slope. On the basis of field and laboratory investigations, the following causes are assigned to failure in the present area:

1. The problem of instability in the area stems from the intersection of three sets of joints dividing the rock beds into blocks of varying dimensions. The critical joint set (J2) provides a continuous plane for failure and dips
towards the slope at a lower angle. Along this plane soil debris and rock blocks rapidly fall down the slope due to gravity pull.

2. The area enjoys humid and tropical climate. The feldspathic sandstones were subjected to weathering and decomposition due to percolation of surface water along the planes of discontinuities. This resulted in the formation of clayey bands along such planes. These clay bands and thinly laminated shaly intercalations were responsible for increasing pore water pressure and in turn reducing the shear strength of the rocks.

3. The area is an old landslide site and there was a huge accumulation of soil debris. Several houses were constructed subsequently over the debris before it could stabilize. This exerted load pressure and enormous amount of soil debris fell down followed by rock blocks.

4. Rocks excavation and repeated blasting were frequently carried out to accommodate a petrol pump along the road side in the left flank of the slided area. This facilitated erosion and widening of discontinuity planes.

5.3.5 REMEDIAL MEASURES

Landslide in the high relief, high rain fall, geologically young & incompetent, tectonically disturbed and high seismic zone area of Mizoram can not be avoided totally. However its frequency of occurrence and adverse effects can be minimized to a fair extent by adopting certain remedial measures. The following measures are suggested to mitigate the problem of instability in the area under study.

1. Removal of slided debris to reduce the dead load.

2. Improvement of drainage by providing catch water drains at the crown, toe and two sides of the slided area for channelizing the rain water.

3. As a road passes through slided area, adequate support, ie retaining walls, should be provided on both sides of the road. A few rows of trees may be planted behind the retaining walls.

4. Further construction should be avoided in and around the slided area and quarrying should be discouraged in its vicinity.
Plate 5.3a: Eastern view of Bawngkawn landslide

Plate 5.3b: Western view of Bawngkawn landslide