# Elachi Khola Landslide Complex, East District, Sikkim - A case study on the text book type landslides

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**Abstract**

Elachi Khola Landslide in East District, Sikkim is a composite slide. The terrain is represented by phyllites and quartzites of Daling Group. Beside rock outcrops, the slope is covered with slope wash material and old slide debris. The activity of the slide continued since 1984, affecting about 300m of road length. The devastations are erosion of road bench due to flow of debris from the rock slide, subsidence/creeping in eastern portion of the road bench, shooting boulders from a perennial nala and rock cum debris slide. The main causative factor for rock slide is wedge failure where rock bolting, shotcreting, surface and subsurface drainage have been suggested. The sinking zone is a result of erosion/ piping of finer particles from the old slide debris through sub surface flow. Trench drains filled up with filter material, benches and retaining walls are required to contain this slope. Small boulders and pebbles roll down with high velocity due to steep gradient of a perennial nala, where boulder catcher in form of chain link wire has been suggested. Steep slope cut for the road bench has resulted the rock cum debris slide. Benching, retaining walls and bolting to stitch the wedges have been recommended.

## 1. Introduction:

Elachi Khola Landslide is a composite one having rock slide, sinking/subsidence/slow creeping zone, rock cum debris slide and boulder shooting zone. It is located 6.5km from Singtam on Singtam Dikchu Road. Singtam is situated about 30km from Gangtok on NH-31A connecting Siliguri.

## 2. Regional Geomorphological and Geological Setup:

### 2.1 Geomorphology:

The Elachi Khola, originates at EL 1000m and meets the trunk stream Tista River at the left bank at EL 360m. Parallel drainage of the area is indicated by structurally controlled drainage pattern, mainly along the master joints. In this stretch the southerly flowing Tista takes a turn towards SE with a few meandering kinks. Northeasterly to easterly trending ridge line is seen passing across the Tista River. Though the trend of the ridge line on either side is same yet there is a gap of about 700m between the left and right banks. Therefore, there is a possibility of a fault along the Tista River.

### 2.2 Geology:

Darjeeling District of West Bengal and entire Sikkim lie in Eastern Himalaya. Rocks of this terrain are characterized by intense folding, shearing and thrusting. The rocks show an inversion of stratigraphic succession due to a number of thrust sheets. As a result unmetamorphosed Siwaliks are overlain by Gondwanas along Main Boundary Thrust (MBT), similarly the low grade metamorphosed Daling Group (phyllite-quartzite) is overlain by high grade schists and gneisses of Darjeeling Group along Main Central Thrust (MCT). Buxa Group of rocks occur as window within Gondwanas. Besides, a number of other thrusts and faults have also sliced the rocks. The contact between the underlying Gondwanas (Younger) with overlying Buxa / Daling (Older) is also a thrust. Stratigraphically, the study area falls within Daling Group comprising quartzite-phyllite and its variants like phyllitic quartzite, quartzitic phyllite etc.

## 3. Geomorphology and Geology of the Site:

### 3.1 Geomorphology :

Elachi Khola slide is located on the western slope of the NE-SW to E-W trending ridge. The average slope of the area is 20°. At the site, Elachi Khola flows towards SW and a number of tributaries meet the Khola above and below the Singtam-Dikchu road bench (fig.- I). To the west, a perennial nala is present, characterized by several rapids and a waterfall just above the road bench. This nala flows southerly to meet the Elachi Khola below the road bench. The gradient of this nala is generally high and varies from 20° to sub-vertical at the waterfall. Presence of a dry nala just west of this perennial nala indicates that its course has been shifted. Further west there is another dry nala at about 50m from this nala. To the east of Elachi Khola a small perennial nala initiates from about 30m above the road bench, mainly fed by ground seepage meets Elachi Khola below the road bench.

### 3.2 Geology :

The site lies in Lesser Himalaya and represents Daling Group of rocks of Precambrian Age. The litho units mainly comprise quartzite, phyllite and quartz-sericite schist permeated with quartz veins. The rocks have a prominent planer fabric beside foliation and it is better manifested in phyllites as axial plane crenulations / fracture cleavage. Another planer fabric is also developed due to broad warping. The rock has been affected by four sets of master (major) joints and three sets of random joints.

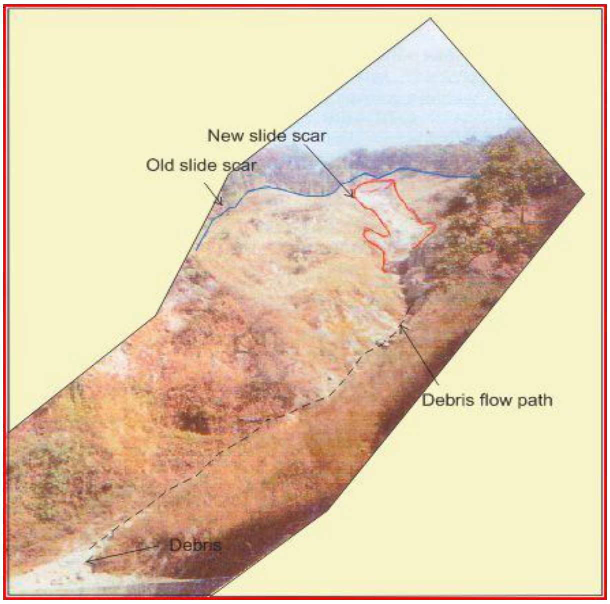
Besides the rock outcrops, the surface is either covered by old slide debris or slope wash materials. The debris is a heterogeneous material derived from old slide debris of the above mentioned rocks. It consists of huge boulders to cobble size rock fragments mixed in a sandy to clayey matrix. The slope wash material is mainly pale brownish sandy soil with rock fragments.

## 4. Geotechnical Assessment of the landslides :

The devastations of this composite landslide has been recorded as (a) erosion of road bench due to flow of debris from the major rock slide, (b) sinking/subsidence in one portion of the road bench, (c) shooting boulders from a perennial nala and (d) rock cum debris slide affecting the road bench of the study area. The landslide complex can be divided into four zones depending upon the nature of hazard as well as mass movement/wasting; they are (1) the main rock slide located at the central portion, (2) the sinking/subsidence/soil creeping zone located east of the main rock slide zone, (3) rock cum debris slide located west of the main rock slide zone and (4) boulder shooting zone from the perennial nala located west of Elachi Khola i.e., between rock cum debris and rock slide zones. About 300m road length has been affected by this composite landslide.

### 4.1 Main Rock Slide :

The main rock slide is located at the central portion of the area (figures 1 & 2). The rock slide initiated in 1984 and its activity continued since then (picture 1). The slide probably activated in an old slide scar. Tall vertical trees are found to occur beyond the rim of the old slide scar. The area between old and new scars is covered with grass and shrubs as big trees are not supported in rocky slope due to removal of soil cover during old slide event. The upper limit of old slide scar reached upto EL 840m i.e. about 310m above the road bench. The crown of new slide reaches upto EL 825m i.e. 295m above the road bench. The surface of the old as well as new slide scar is entirely rocky consisting of phyllites, quartzites and quartz-sericite schist.




Picture 1 Main Rock slide

The present slide activation zone is in between 245m and 295m above the road Bench (EL 775-825m) and debris comes down through a curvilinear and zig-zag path on and below the road bench. This zig-zag and curvilinear path has resulted due to protruded competent rock mass (e.g. quartzite) present along the debris flow path, which represents the locus of the head ward movement of the present slide. Due to the debris flow, erosion of the rock outcrops has resulted in development of some small rock slides on both sides of the debris flow path.

The slope of this debris path varies from 20° to sub-vertical and in the active slide zone and the slope at the head region varies from 50°- 55°. The rocks have been dissected by a number of joint sets, viz., foliation joints, valley-ward (southerly) dipping joints and some random joints. Variations have been observed in the dips of foliation and other joints. The attitudes of structural data are given in Table-1.

Table 1
Structural data (Planer/ linear)

| | |
|---|---|
| Variation of attitude of foliation /foliation joint | |
| | F' - N45°W - S45°E/25°NE<br>F" - N70°W - S70°E/35°NE<br>F"' - N86°E - S86°W /52°NW |
| Attitude of master joints sets | |
| | 1. -N80°E - S80°W/52°SE (valley ward)<br>2. -N80°E - S80°W /60°NW<br>3. -N75°W - S75°E/75°SW ( valley ward)<br>4. -N38°E - S38°W/85°SE (valley ward) |
| Attitude of random joint sets | |
| | 5. -N20°E - S20°W/83°SE<br>6. -N20°W - S20°E/45°SW<br>7. –N - S/75°W |
| Fold/ warp axis 24° | N67° E (plunge) |

The intersections of joints forming wedges (derived from analysis of joint data through stereo plots) are given in table 2.

Table 2
Intersection of Joints

| Intersection of joint planes | Attitude of joint planes | Intersection Lineation |
|---|---|---|
| $I_{23}$ | N75°W-S75°E/75° SW N80°E-S80°W/52°SEly | 38° S63°E |
| $I_{24}$ | N80°E-S80°W/52°SE & N38°E-S38°W/85°SE | 44° S34°W |
| $I_{25}$ | N80°E-S80°W/52°SE & N20°E-S20°W/83°SE | 52° S12°W |
| $I_{26}$ | N80°E-S80°W/52°SE & N20°W-S20°E/45°SW | 41° S41°W |
| $I_{27}$ | N80°E-S80°W/52°SE & N-S/75°W | 50° S18°W |
| $I_{46}$ | N38°E-S38°W/85°SE & N20°W-S20°E/45°SW | 39° S34°W |
| $I_{56}$ | N20°E-S20°W/83°SE & N20°W-S20°E/45°SW | 31° SI6°W |
| $I_{57}$ | N20°E-S20°W/83°SE & N-S/75°W | 42° S14°W |
| $I_{67}$ | N20°W-S20°E/45°SW & N-S/75°W | 25° S7°W |

The main causative factor of the slide is failure of wedges formed by intersection of major joint sets. The failure is aggravated by percolation of water through joints as evidenced from openness of the joints, stained joint planes and presence of few seepage points in this zone. Weathering along the joints especially in phyllite indicates percolation/flow of water. Consequently, the shearing resistance of the rockmass along joints reduced during saturation resulting in failures. It is also found that the spacing of foliation joint is very close in phyllite in comparison to those in quartzite and quartz-sericite schist. As a result, the wedges of quartzite and quartz-sericite schist are larger than those in phyllite.

The joint data has been analysed through stereo plots. The intersections of different joints have been shown in fig.- V and vulnerable wedges in respect to slope in fig.- VI. The angle of internal friction of the rock has been assumed as 30°. During determination of vulnerable wedges the average slope of the slide face has been taken as 54° S20°W. It is found that nine intersections plunging towards the slope closely fall within the vulnerable area. An average plane containing most of the vulnerable joint intersections has been worked out. The pole of this average plane indicates the inclination and direction (40° N21°W) of rock bolts, suitable to stitch the joints to prevent wedge failure.

## 5. **Sinking Zone**:

The sinking zone is located east of the rock slide zone, i.e., towards Singtam side (figures 1 & 4 and picture 2). Elachi Khola flows along the northern boundary of the sinking zone. A perennial nala fed by ground seepage marks the southern boundary of this zone. Further south, rock is exposed at the edge of the road bench. Gradual sinking/subsidence and creep movement of the ground including the road bench is a common phenomenon at this site especially during rainy season and has left the imprints of successive damages on the retaining structures both above and below the road bench.


Picture 2 Sinking zone showing subsidence gap (60cm) between the retaining walls and concrete causeway and subsidence of old retaining walls.

Though the area is covered with old slide debris for considerable distance towards Singtam, but the most affected zone is about 60m wide along the road bench. This is because the rocks are exposed south of the sinking zone, form the toe support of the overlying debris preventing subsidence/ sinking. The slope of the sinking zone is gentle (10°-25°); however, higher slope (35°- 40°) is present at the lower reaches i.e from road bench to 45m in the upslope direction. At the gentler slope, step cultivation is observed. The old slide debris consists of varying sizes of boulders including exotic blocks in a sandy to silty clayey matrix. Probably concentrations of these huge boulders have made the slope steeper near the road bench. A few 1-2 m thick shear zones (N70°W-S70°E/85°SW) have been observed on the road cutting slope at the rock outcrops beyond the southern boundary of the sinking zone. As the attitudes of these shear zone are tentatively matching with the scar of the old slide, there are chances of presence of a major shear zone in the debris laden sinking zone. The old slide debris may have resulted due to sliding along the above major shear zone. A number of seepage points have been observed above the road bench. It indicates presence of impervious soil at a shallow level as rock is not expected upto a considerable depth. Three soil samples have been collected; these pertain to disturbed washed out samples (E1) derived through the seepages, the sample E2 is from the sinking zone away from the seepage points and sample E3 from the seepage points. The samples E2 and E3 are taken from 10-30cm depths. The determined physical properties of the samples are given in Tables – 3 & 4. The washed out sample (E1) represents the transported material from the old debris through seepages. It contains mainly silt (59%) with about 4% clay belonging to ML group, indicating low compressibility clay. The E2 and E3 represent the debris material and belong to GW group. Whereas, E2 comprises mainly sand (89%), with little amount of silt (10.5%) and negligible clay (0.5%) indicating very high permeability, E3 contains mainly gravel and sand (~86%). However, finer fraction of E3 represents MI group of soil containing silt (~15%) and clay (~0.7%). It indicates intermediate plasticity silt and high permeability. It is anticipated that finer particles like silt and clay fractions from E2 and E3 are removed through piping along with seepage water. Owing to removal of finer particles from the top layer of soil it has a higher permeability. The clay present in the sample is about 0.5% and devoid of swelling nature. Thus, it is not likely that sinking/subsidence has resulted from the swelling of clay present in the old slide debris and due to piping of finer particles (silt and clay) caused by sub surface flow during super saturation.

Table3
Test Report of Soil Samples

| Sample | LL | PL | PI | Soil Group | Saturated moisture content (%) | Permeability (cm/sec) | Shear parameters (under saturated moisture content, consolidated and undrained condition) | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | C(kg/cm$^2$) | φ |
| E1 | 27 | 24 | 3 | ML | n.d. | nd. | | |
| E2 | n.d. | n.d. | n.d. | GW | 14.01 | $5.23*10^{-5}$ | 0.190 | $29^0$ |
| E3 | 37 | 31 | 6 | MI | n.d. | n.d. | | |

n.d.- not determined; LL- liquid limit; PL- plastic limit; PI- plasticity index; ML- low compressibility clay; MI- intermediate plasticity silt; GW- gravel & sand

Table 4
Grain Size Analysis of Soil Samples (wt %)

| S. No | +5.00 cm | +3.5 cm | +1.5 cm | +4.0mm | +2.0 mm | +1.4 mm | +1.0 mm | +0.71mm | +0.5 mm | +0.35 mm | +0.25 mm | +0.17 mm | +0.12 mm | +0.09 mm | +0.063 mm | silt | clay |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| E1 | 0.00 | 0.00 | 0.00 | 0.00 | 4.43 | 1.46 | 0.66 | 2.56 | 3.09 | 1.68 | 5.51 | 9.35 | 0.04 | 0.28 | 8.84 | 58.60 | 3.53 |
| E2 | 0.00 | 42.70 | 10.27 | 5.82 | 8.57 | 4.30 | 1.21 | 2.12 | 1.74 | 0.80 | 2.11 | 5.40 | 0.00 | 0.18 | 3.70 | 10.58 | 0.50 |
| E3 | 38.19 | 8.21 | 15.74 | 6.27 | 5.56 | 1.89 | 0.51 | 0.71 | 0.67 | 0.36 | 0.94 | 1.96 | 0.00 | 0.14 | 3.49 | 14.64 | 0.73 |

## 6. **Boulder Shooting Zone**:

There is a nala with a small waterfall at the western side of the main rock slide (figure I and picture 3). Due to high discharge of the perennial nala during monsoon, boulders from the nala bed roll down on the road bench. Generally, the nala has a steep gradient; at few places, gentle gradients are also observed, e.g., just above the waterfall.


Picture 3 Rock cum debris and Boulder shooting along waterfalls

The nala bed is rocky with thin veneer of nala deposit (pebbles and boulders) for a considerable distance in the upslope direction at least upto the crown of the rock slide zone (EL 840m). The nala indicates a shift in course as evidenced from presence of a dry abundant nala located just west of it, caused possibly by erosion along weak zones/joints during excessive discharge. During the monsoon it is observed that pebbles and boulders roll down from the nala course with high velocities.

## 7. Rock Cum Debris Slide:

It is located to the west of the boulder shooting nala and affected about 35 m road length. The slide has initiated from the uphill slope cut face of the road bench. The height of the slide scar varies from 30-60m from the road bench, i.e., EL 560-590m (figures 1 & 3 and picture 3). At this site, rock is present below a cap of 1- 2.5m thick slope wash material. The slide initiated in slope wash material due to steep slope cuts for the road bench. The rock mass has also a tendency to slide down along unfavorably oriented valley-ward dipping joints. Steep cut slope and weathering of rock coupled with percolation of rain water are the main causes of slide.

## 8. Remedial Measures :

### 8.1 Rock slide:

Failure of wedges formed by vulnerable joints is the main factor of slides and slope failure. Protection is required at the crown portion (245m – 290m above the road bench) from where major sliding is taking place. Owing to failure of smaller wedges wire mesh shotcrete appears to be effective. However, rock bolting in the quartzitic rock is required where larger wedges are being formed. The angle and direction of the rock bolts as worked out earlier is 40° N20°W. Surface and seepage water also play an important role for activating the slide by reducing the shear resistance along the joints and by eroding the softer/weathered rock mass (phyllite) present at the active slide zone as well as along the debris flow path. Contour drains above the crown of the slide are required to drain out the surface flow and to minimize the percolation/ infiltration. Draining out of subsurface water is also required to reduce pore water pressure and to prevent erosion of finer particles. For this purpose perforated pipes filled up with filter material are to be inserted into the rock mass for about 3m depth with an inclination of 15° with the horizontal considering the smaller size of wedges. To prevent erosion along the debris flow path a concrete chute is preferred.

### 8.2 Sinking Zone:

Prima-facie, the cause of sinking/subsidence of debris material is removal i.e., piping of finer particles through sub-surface flow. Prevention of migration/removal of finer particles as well as subsidence could be checked by providing a series of contour trench drains in the sinking zone filled up with filter material. The seepage water may be channelized from these drains to both Elachi Khola and the nala fed by seepages located to the north and south of the sinking zone respectively (fig.- III). Besides, a few benches may be provided with sausage breast walls to ease out the slope.

## 9. Boulder Shooting Zone:

The size of boulders is small and there is a slope break at the nala bed just above the waterfall/road bench. A boulder catcher at the gentle slope portion (above the waterfall) may be an effective remedy. Owing to small size of boulders, a wire mesh/ chain link wire net (as used in the gabions/sausage walls) may be provided across the nala as fencing, fixing it with two RCC pillars to be constructed from the rocky banks of the nala. The wire mesh/ chain link wire net may be used as double ply to strengthen the same; it requires time to time cleaning. An RCC cause-way at the waterfall site on the road may be constructed to prevent degradation of the road bench due to incessant flow of water.

## 10. Rock Cum Debris slide:

One bench with a breast wall at about 3m below the crown of the slide is proposed near the contact of the slope wash material and rock mass to prevent sliding of the former. The height of the rocky zone is less where, wire mesh shotcrete with drainage holes and a few rock bolts would be required to prevent the rockslide.

## 11. Conclusions:

Elachi Khola landslide is a composite slide causing mass wasting in form of rock slide, subsidence, boulder shooting problems, rock cum debris slide etc. affecting about 300m length of Singtam- Dikchu road, since 1984. The terrain belongs to Daling Group of rocks comprising mainly phyllite and quartzite. The slope is covered with old slide debris and slope wash material beside rock outcrops.

Four types of slope instabilities have been recorded. They are (a) Main rock-slide (b) Sinking zone (c) Boulder shooting zone and (d) Rock cum debris slide. The main rockslide occurs within an old slide scar. The causative factor is failure of wedges formed by intersection of different joints. The sinking/ subsidence has been recorded within old slide debris material. Removal of finer particles is the main causative factor for the subsidence interpreted from surface geology supported by laboratory tests. The boulder-shooting zone is restricted to a steep gradient perennial nala along which small boulders come down during high discharge in the monsoon. The rock cum debris slide has resulted due to sliding of slope wash material and wedge failure of rock from the steep cut slope of the road bench.

Shotcrete, rock bolting, draining of subsurface water through perforated pipes, contour and chute drains have been suggested to contain the rock slide. A series of trench drains filled up with filter material for preventing removal of finer particles, beside benches, breast and retaining walls in form of gabions are required as protective measures to stabilize the sinking/subsidence. In regard of boulder shooting zone a boulder catcher is suggested. Benches, retaining walls, stitching of unfavorable wedges through rock bolts have been suggested for rock cum debris slide,

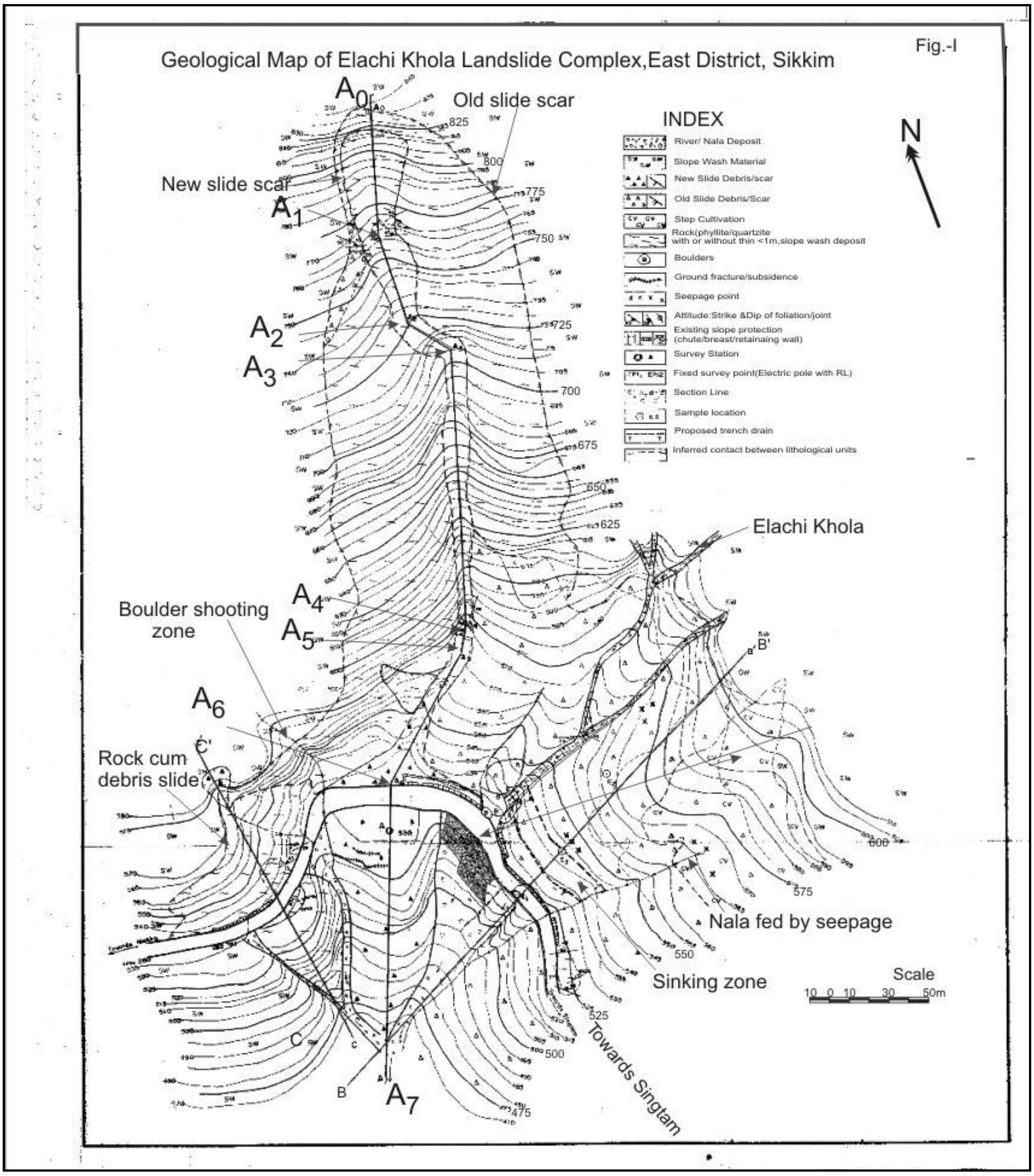



Figure 1 Geological Map of Elachi Khola Landslide Complex, East District, Sikkim

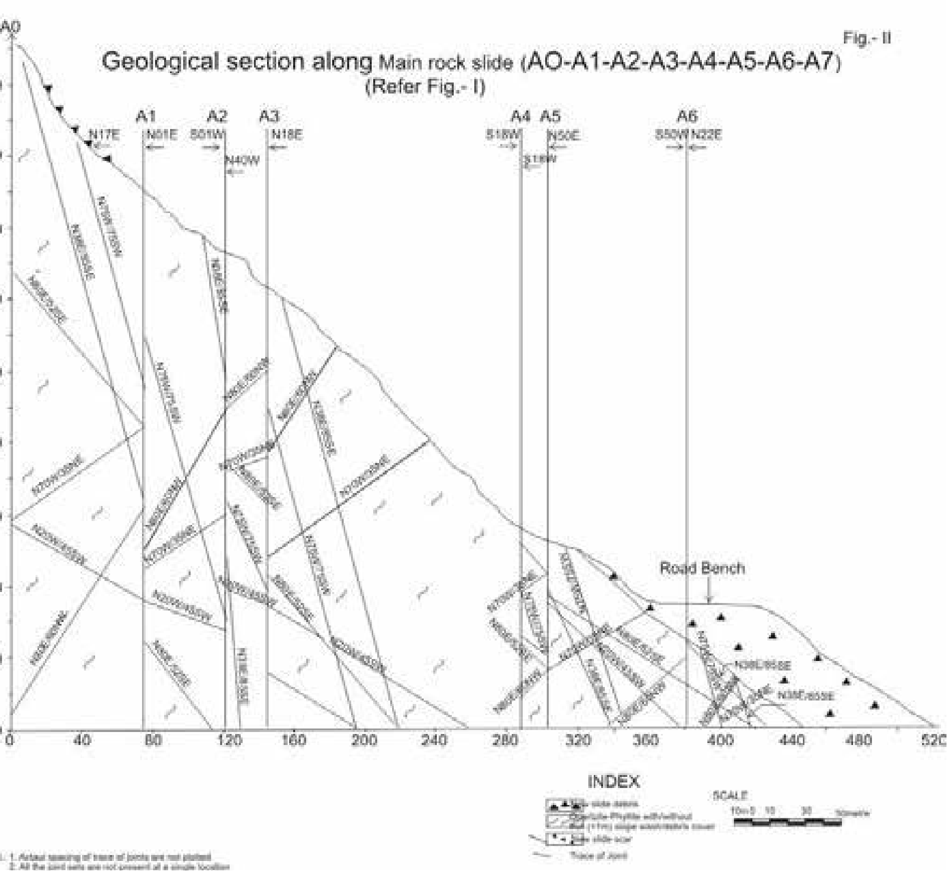



Figure 2 Geological Section along main rock slide (A0-A1-A2-A3-A4-A5-A6-A7)

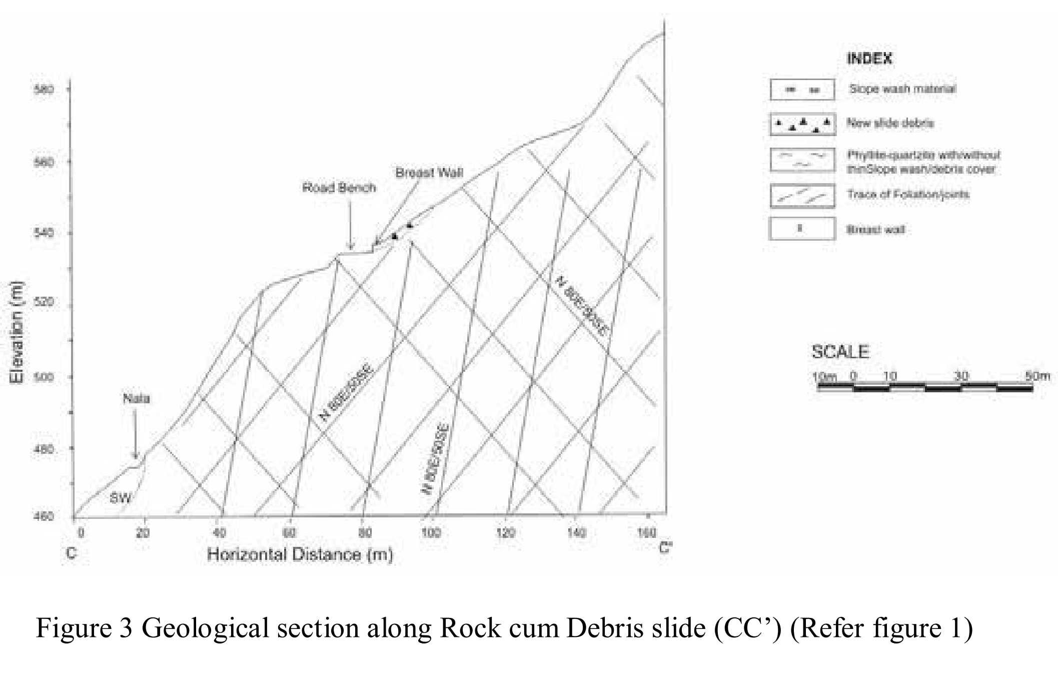



Figure 3 Geological section along Rock cum Debris slide (CC') (Refer figure 1)

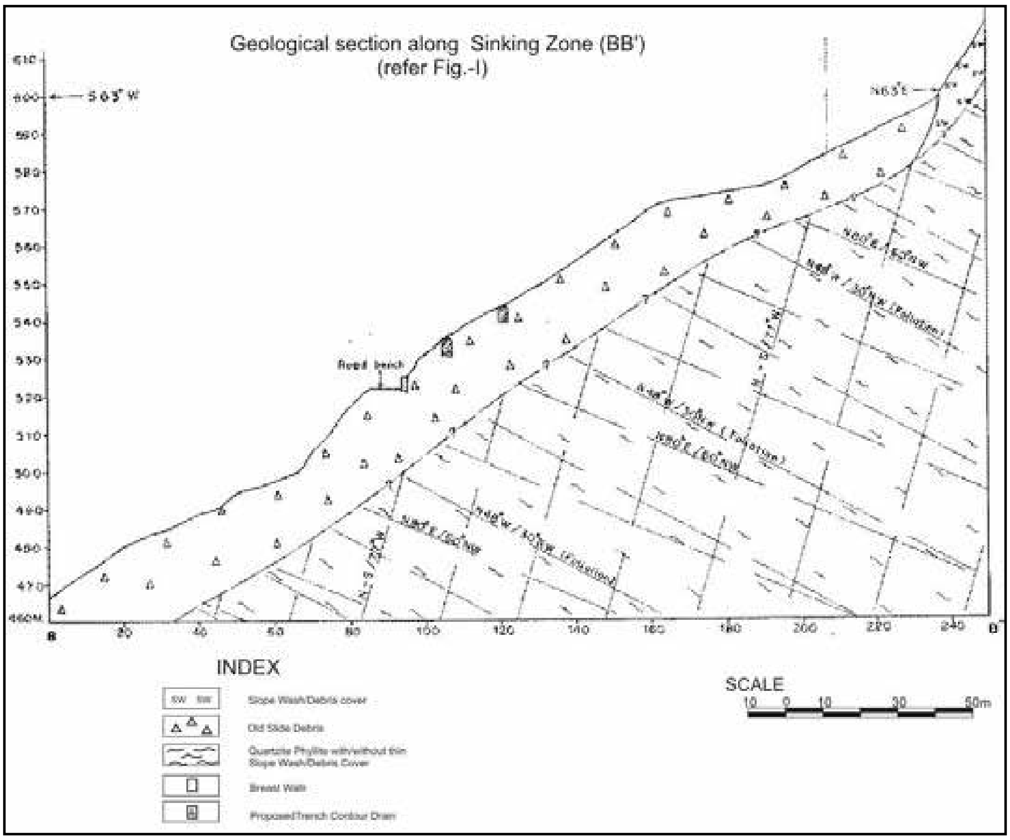



Figure 4 Geological Section along Sinking Zone (BB') (Refer figure 1)

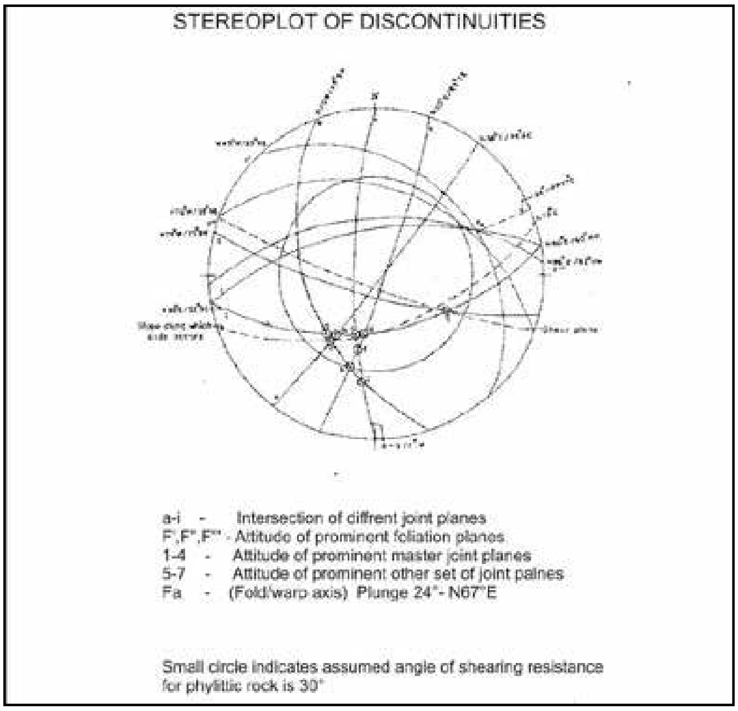



Figure 5 Stereo Plot of discontinuities

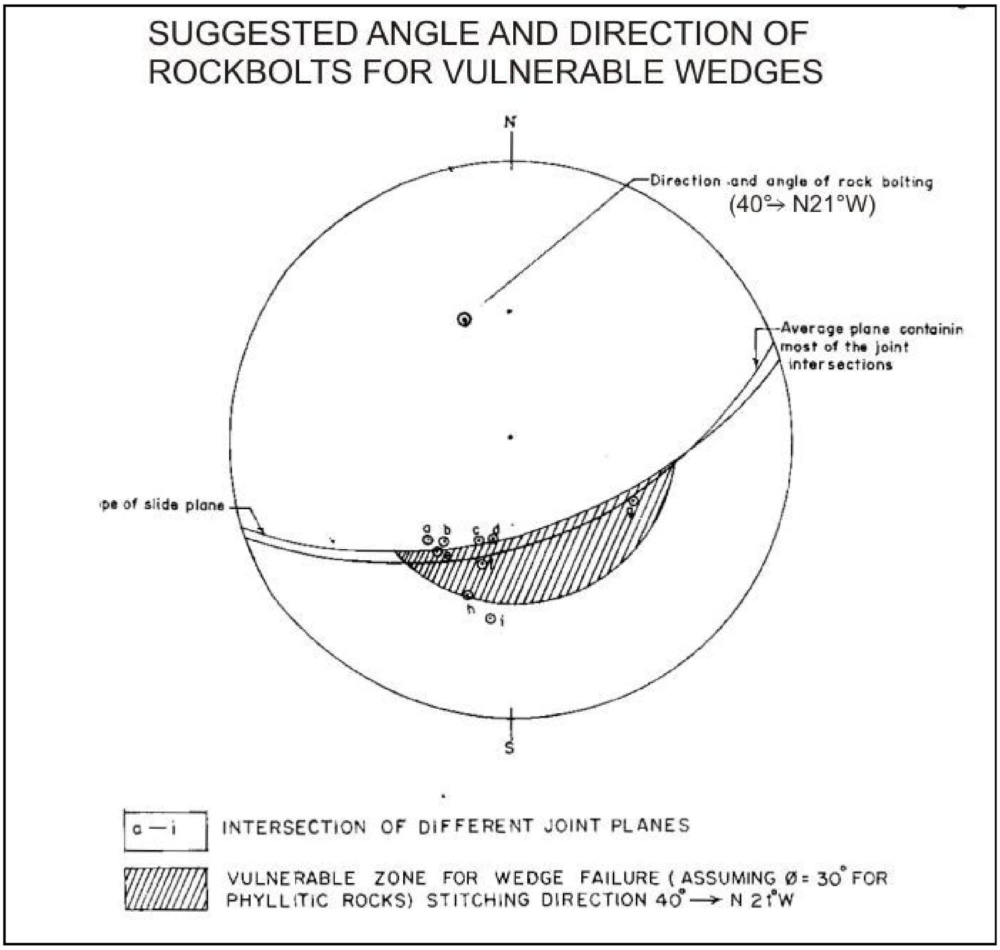



Figure 6 Suggested Angle and Direction of Rock bolts and Vulnerable Wedges

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