# Design of Remedial Measures at Lukhbir Slide on NH – 31A

*Prasad, P.S.*
*Senior Scientist, Geotechnical Engineering Division, CSIR – CRRI,*
*New Delhi - 110025, Delhi, India*
*Kumar, Kishor*
*Chief Scientist, Geotechnical Engineering Division, CSIR – CRRI,*
*New Delhi - 110025, Delhi, India*
*Negi, Indervir S.*
*Senior Project Fellow, Geotechnical Engineering Division, CSIR – CRRI,*
*New Delhi 110025, Delhi, India*
*Kathait , Anil*
*Project Fellow, Geotechnical Engineering Division, CSIR – CRRI,*
*New Delhi - 110025, Delhi, India*

**Abstract**

Lukhbir slide sandwiched between two major drains located at km 26.8 on National Highway, 31-A (NH-31A) is in active stage since 1968. It extents for about 400m along the road, 50-60m above the road & about 20-25m below the road. The prevention of landslide was important for uninterrupted & risk free traffic flow as well as for prevention of unwanted siltation to the dam being constructed on the Teesta flowing at the bottom of the slide toe. the lithology of the area includes the metamorphic rock, i.e. mainly mica schist, which is very fissile and breaks easily along its plane of schistosity. The rocks are in highly weathered conditions and in some locations they are found in the form of powder due to excess overburden pressure and availability of moisture. In addition, the slope has plentifully of seepage water which makes the slope more vulnerable to fail. As per Indian classification system the soil is classified as SW. The stability analysis and design of remedial measures of the uphill slope and downhill slope has been carried out by using GEO 5 software. The paper highlights the investigation of landslide & design of most suitable scheme of remedial measures which has been accepted and implemented by the users.

## 1. Introduction:

National Highway 31A links Gangtok to Sevoke on NH 31. NH 31A runs along the banks of the Teesta River and is the lifeline of Sikkim state. Lukhbir slide is located on Latitude: 27° 2'17.63"N and longitude: 88°25'35.71"E at km 26.8 on NH 31- A as shown in figure 1. This Landslide is active since 1968. Several agencies have already carried out studies on this landslide and suggested different schemes of remedial measures like benching of slopes, ceiling of cracks, retaining walls and Brest wall. The suggested measures have been implemented but none have been proved successful.

Road is considered as datum. From the road level to River is considered as downhill slope and from road level and above is considered as uphill slope. The damaged stretch of the road is around 400m. The road level is RL 230 and the HFL is RL 205. the Teesta dam which is being constructed in the mean vicinity of the slide due to which the water level will rise up to RL223. So the task of preventing the landslide for long term stabilization has become more important for traffic safety and uninterrupted traffic flow

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as well as for the safety of dam. The following paragraphs are a brief of the description of slide as well as the work carried out & its outcomes.

Figure 1 View of the Lukhbir Landslide

## 2. Brief Geological Description :

The rock type is a metamorphic rock, mica schist (figure 2 & 3). Schist is a very fissile rock and it breaks along its plane of schistosity. Flakes of mica schist break along its planes of schistosity which can be easily powdered by a bit rubbing. Though the planes are dipping away from the slope but the rock type itself is dangerous in its nature. It would not sustain any compact structure on its surface due to its fissile nature. It can be easily weathered to break along planes forming powdery soils or small blocks of rock, if weathering agents like water, wind etc., and over loading of slope is there. Since the rock is highly fragile, buildup of stress on its surface can cause the development of cracks very easily in the rock and once initiated cracks can further enlarge to cause fragmentation of the rocks into blocks along other surfaces other than the plane of schistosity also. The rock type is highly vulnerable to weathering and would easily give up at the action of weathering agents (i.e. air or water). In dry condition the rock breaks along fissile planes and in saturated condition it may be damp as muddy soil also.

Figure 2 condition of rocks on uphill slope

Figure 3 Condition of rocks on downhill slope

## 3. Drainage:

As observed in the field, the landslide area is sandwiched in between the two major drainages (figure 4). These two drainages are the main source of the water from uphill side during rainy days. The area comes under high rainfall the average annual rainfall observed approx 2000mm. The rain water flow with a very high velocity due to the high gradient and probably, due to good catchment characteristics. Almost whole slope is found damp, due to which the rocks weather continuously slide under the gravity and steepen the slope making it more vulnerable to failure.

Figure 4 Major drains on uphill slope

## 4. Geotechnical properties of soil:

The soil samples collected from the field have been tested for the index as well as the engineering properties. Figure 5 shows the typical grain size distribution curve of the soil sample. The gravel content is 31%, sand content is 48%, silt content is 21%, and clay content is 0%. As per Indian Standard Classification the soil is classified as SW. The liquid limit value of the soil sample is 24 % and Pl value is zero (Non – Plastic). The direct shear test results conducted at average field dry density value (saturated, i.e., after soaking the sample for 24 hours) showed that cohesion, c' = 0 and angle of internal friction ($\phi$') = $25^0$ as indicated in figure 6.

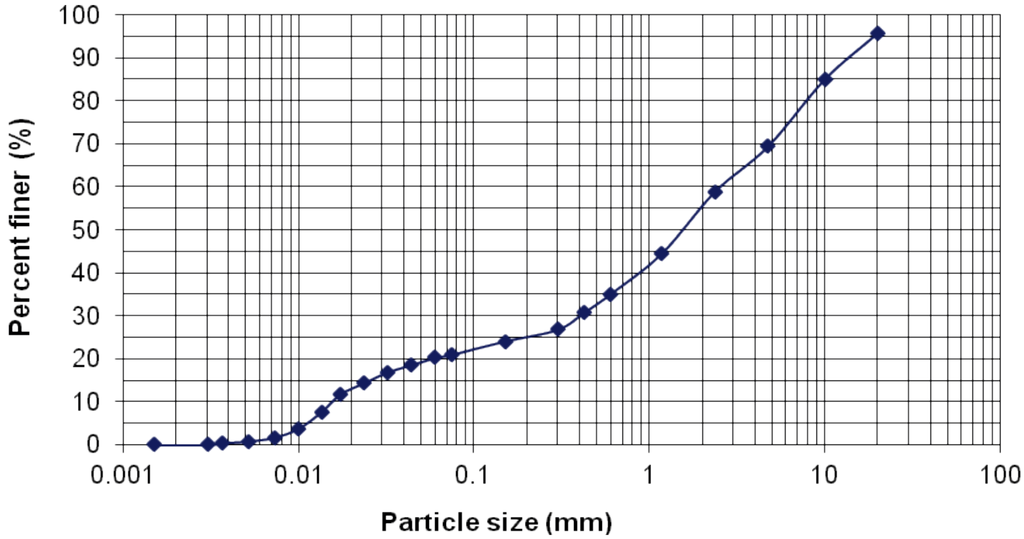



Figure 5 Grain Size Distribution Curve

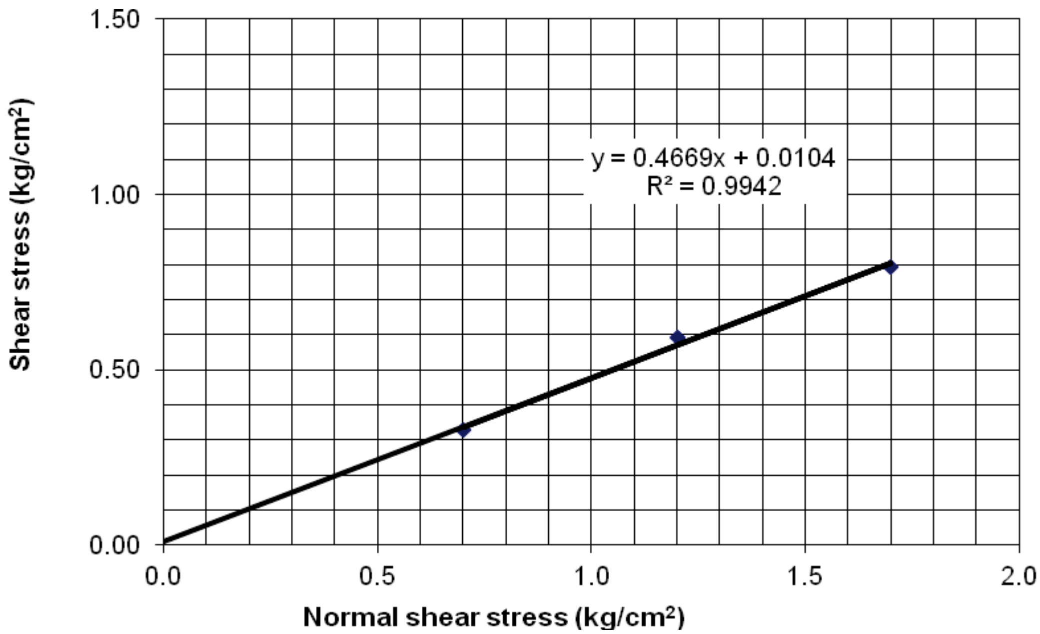



Figure 6 Shear Strength envelop of soil sample

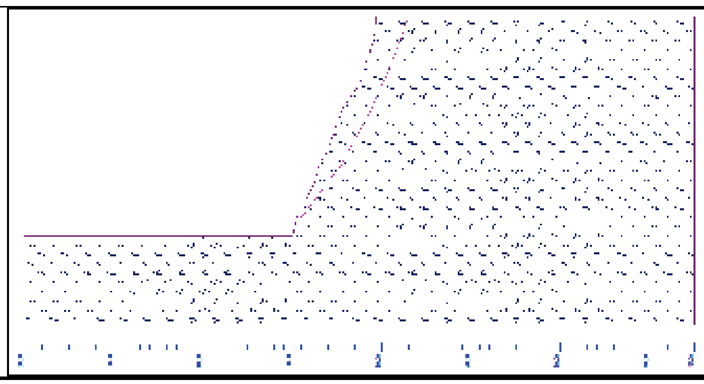
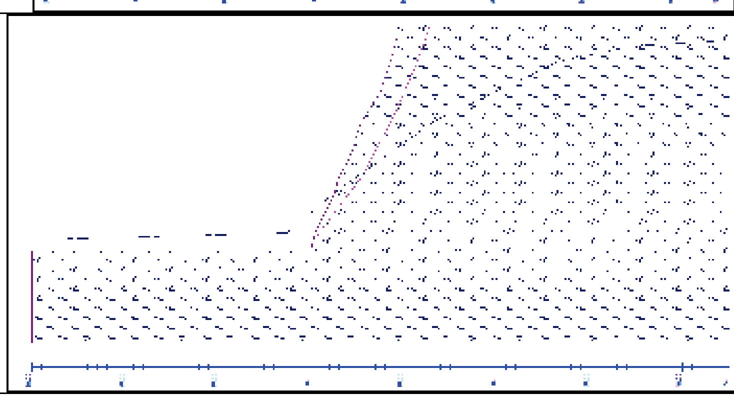
## 5. Slope Stability analysis:

The stability analysis of the slope was carried out using GEO 5 software. Since, the area comes under Zone V (Very high seismic zone), stability analysis has been considered with and without earth quake factors. The parameters considered in the stability analysis are given in table 1. The results of the stability analysis of downhill slope were presented in table 2. The Factor of safety of the present slope is just stable without considering earth quake forces and fails under the consideration of earthquake conditions.

Table 1
Parameters Considered for Stability

| **Problematic** slope | **Cohesion** (kPa) | **Angle of internal friction (ϕ)** | **Dry Density ($kN/m^3$)** |
|---|---|---|---|
| Soil/rock layerlayer | 27 | $23^0$ | 20 |
| Weathered mica schist(powdered form) | 0 | $25^0$ | 20 |

Table2
Stability analysis of downhill slope on landslide area

| **S.No** | **Downhill slope crossection** | **Factor of Safety** | |
|---|---|---|---|
| | | **Without EQ factors** | **With EQ factors** |
| 1 |  | 1.04 | 0.89 |
| 2 |  | 1.03 | 0.92 |

## 6. Remedial Measures:

Many methods can be used to correct landslides as flattening of slopes, lowering of ground water table, providing vegetation cover on slopes, retaining structures, reinforced earth, grouting , improved surface drainage preventing rockslides, bolting and shotcreting etc. depending upon site constraints and likely solution on case to case basis.

**Measures for Downhill slope:**

In the present situation the measures have been suggested for downhill as well as uphill location as separate schemes described below.

**Protection of Toe:**

Going through the history of the landslide it is learned that the initial triggering factor was the intense toe erosion particularly during the high flood instances. Due to this reason repeated damage/subsidence of the highway had been occurring. With frequent damage of highway, to restore the same, instead of strengthening downhill side slope the uphill slope was cut. This practice was repeated almost every time the road was damaged. As a result the uphill slope had become active and continues to be same till date. The focus on preventing the slope uphill side has therefore become a priority and no attention was paid to the need of toe protection. The gradual cutting of the toe may become a cause of concern in years to come. It is therefore required to think holistically to undertake all the measures in view of the long term stability of slope instead of very short term approach.

River Teesta takes a turn (meandering) at the base of the slide resulting in direct impact of the water particularly during the monsoon season (figure 7). It is proposed to protect the toe from the onslaught of high velocity river Teesta. Some river training protection measures are required along the river like construction of spurs or placing concrete blocks in the curved portion to reduce thrust on the slope. Deflecting spurs can solve the problem of toe erosion effectively since they are designed to deflect the water coming on to the toe of the slope.


Figure 7 Downhill slope damaged due to river meandering

**Remedial Measures on Down Hill Slope:**

For stabilizing the downhill slope the following alternative options of remedial measures were designed.

Option 1. Design of 10m high cantilever wall with cladding

Option 2. Design of cladding with anchors on downhill slope

Therefore the following paragraphs belong to only the implemented remedial measures.

**Option 1: Design of 10m high cantilever wall with cladding**

10m high cantilever retaining wall as shown in figure 8 is designed and it is safe. Remaining slope is covered with RCC cladding as shown in figure 9. and the results are as follows.

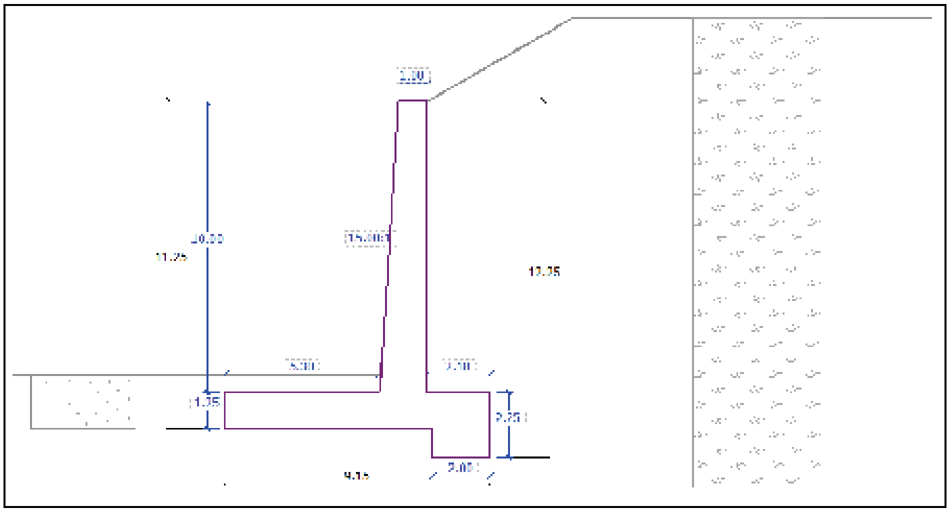


Figure 8 Cross section of 10m high retaining wall

**Verification of complete wall**

**Check for overturning stability**

| | | | |
|---|---|---|---|
| Resisting moment | $M_{res}$ | = | 8125.75 kNm/m |
| Overturning moment | $M_{ovr}$ | = | 1843.82 kNm/m |

Safety factor = 4.41 > 1.50
Wall for overturning is SATISFACTORY

**Check for slip**

| | | | |
|---|---|---|---|
| Resisting horizontal force | $H_{res}$ | = | 745.13 kN/m |
| Active horizontal force | $H_{act}$ | = | 380.07 kN/m |

Safety factor = 1.96 > 1.50
Wall for slip is SATISFACTORY

**Forces acting at the centre of footing bottom**

| | | | |
|---|---|---|---|
| Overall moment | M | = | -626.14 kNm/m |
| Normal force | N | = | 1229.36 kN/m |
| Shear force | Q | = | 374.79 kN/m |

Overall check - WALL is SATISFACTORY

**Bearing capacity of foundation soil check**

**Eccentricity verification**

| | | | |
|---|---|---|---|
| Max. eccentricity of normal force | $e$ | = | 0.0 mm |
| Maximum allowable eccentricity | $e_{alw}$ | = | 3036.4 mm |

Eccentricity of the normal force is SATISFACTORY

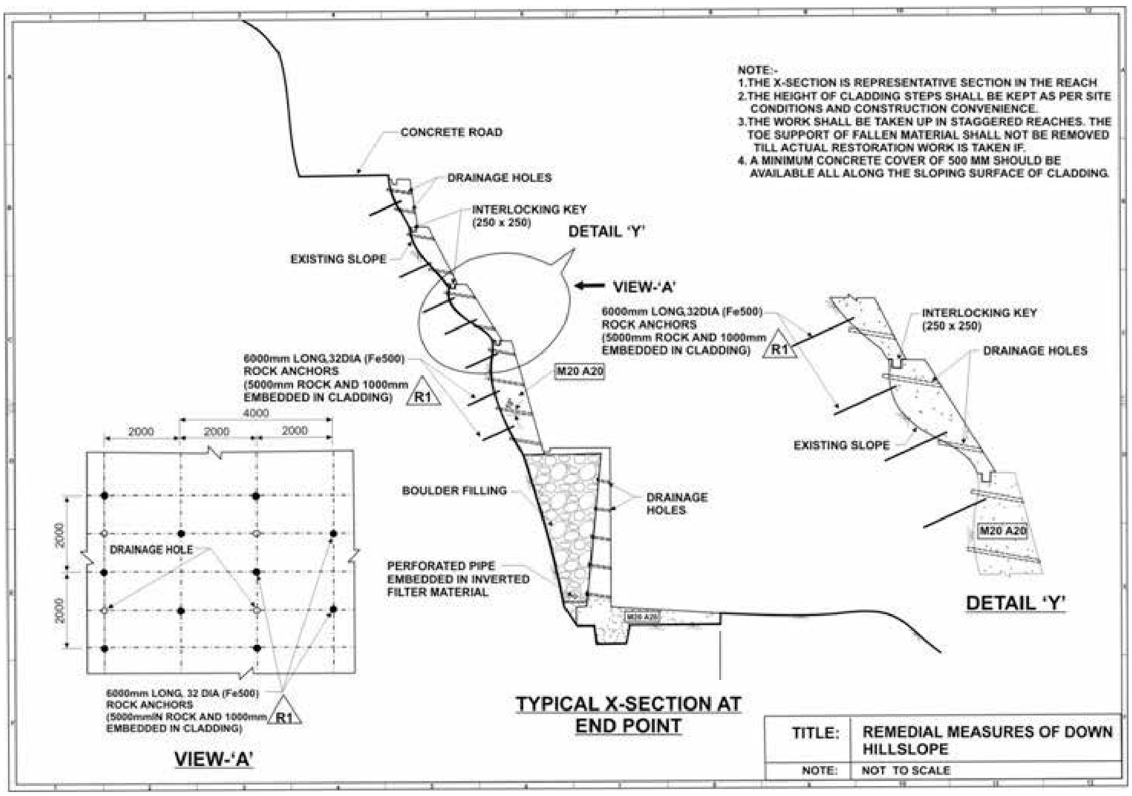



Figure 9 Remedial measures on Downhill slope

**Footing bottom bearing capacity verification**

| | | | |
|---|---|---|---|
| Max. stress at footing bottom | □ | = | 133.61 kPa |
| Bearing capacity of foundation soil | $R_d$ | = | 300.00 kPa |

Safety factor = 2.25 > 1.50
Bearing capacity of foundation soil is SATISFACTORY

Overall verification - bearing capacity of found. Soil is SATISFACTORY

**Option 2: Design of cladding with anchors on downhill slope:**

The slope was designed with cladding from river bed level to top of the road levels. However, the slope stabilized with cladding alone was not found safe as shown in figure and description below. To stabilize the slope with cladding an option of cladding with anchors was opted. The slope stabilized with cladding and anchors was found safer as shown in figure 10, and the results are as follows.

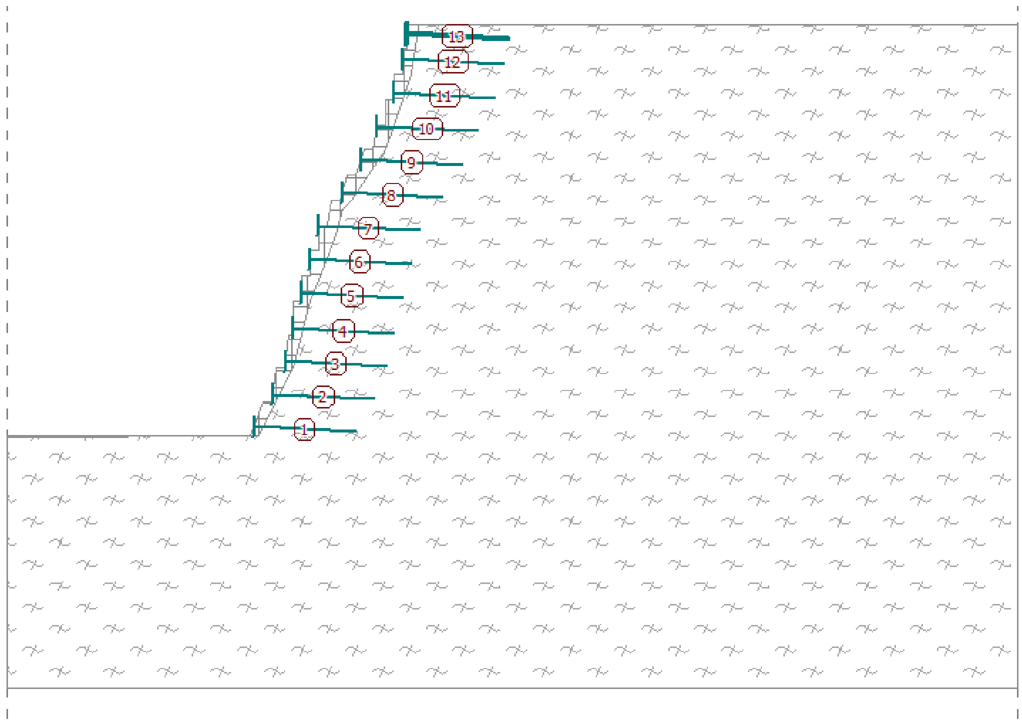



Figure 10 Slope stabilised with cladding and anchors

**Slope stability verification (Bishop)**

Sum of active forces : $F_a =$ 3618.36 kN/m
Sum of passive forces : $F_p =$ 11597.30 kN/m
Sliding moment : $M_a =$ 95741.82 kNm/m
Resisting moment : $M_p =$ 306864.68 kNm/m

Factor of safety = 3.21 > 1.50
Slope stability ACCEPTABLE

**Slope stability verification (Fellenius / Petterson)**

Sum of active forces : $F_a =$ 3618.36 kN/m
Sum of passive forces : $F_p =$ 10588.19 kN/m
Sliding moment : $M_a =$ 95741.82 kNm/m
Resisting moment : $M_p =$ 280163.51 kNm/m

Factor of safety = 2.93 > 1.50
Slope stability ACCEPTABLE
**Remedial measures for Uphill Slope:**

**Drainage measures:**

In view of the observed situation & the information available about the actual catchment characteristics the following is proposed.

1. The two major visible drainages are required to be properly treated so that water drains without endangering the slope. It is proposed to construct stepped chutes all along the slope through highway & draining into the river.
2. To prevent the water coming onto the slope above the crown of the landslide, it is proposed to construct a catch water drain at an appropriate place, depending on the topography. The catch water drain should be connected with the chutes on both side of the slide with proper gradient so that water from the catch water drain flows into the chutes of both sides.

**Stability measures for uphill slope:**

Uphill slope is almost vertical up to 10m and afterwards it is sloppy having an average of $45^0$-$50^0$. The rock is highly weathered and with high damping due to excessive water on the slope. It is therefore required to tackle the stability as well as the drainage issue so that effective long term stability of the slope can be sustained. The measures are designed as per figure 11 & description below.

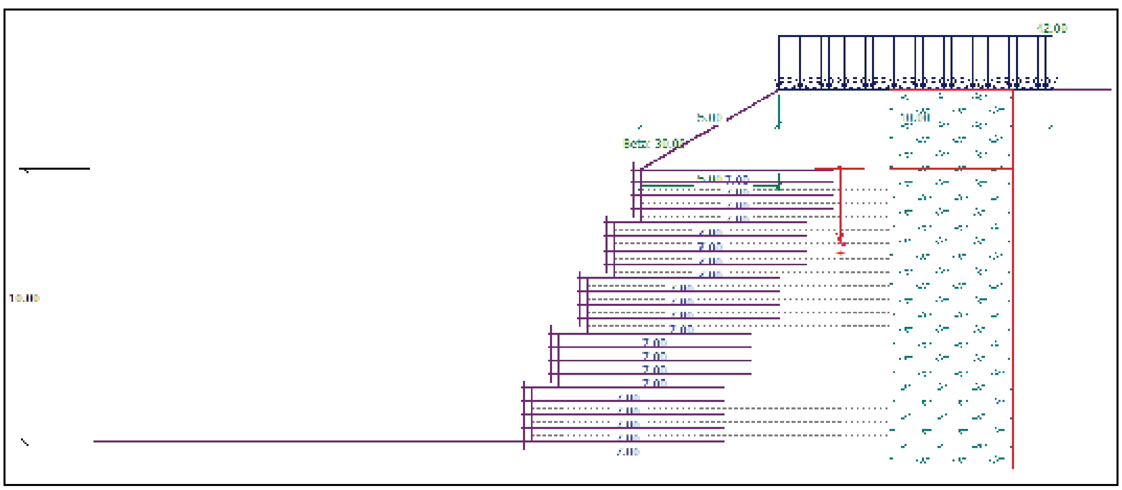


Figure 11 Soil nailing on uphill slope

**Soil Nailing:**

The slope is very steep and the angle varies from $80^0$ to $90^0$. Most of the steeper slopes are more prone to sliding & required treatment as suggested here. Since the working space on the slope is less, crown of the affected slope is near to existing road, it is, required to stabilize the mass in such a way that there is minimum disturbance with optimum effects. In the existing slope conditions conventional slope protection methods may either be inapplicable or may prove to be very costly mainly due to the restriction of space. The shear strength characteristics of overburden material can be improved by adopting soil nailing technique. This in turn would lead to enhanced stability of the slope.

There are two different types of soil nail, sometimes referred to as flexible nails and stiff nails. Flexible nails are generally drilled and grouted and orientated to mobilize tension. Steel nails should have properties that tend to ductile rather than brittle. This is particularly relevant, as at the ultimate condition the nail must retain its ability to carry tensile forces whilst deformed. Yield stresses in excess of 500 N/sq mm should be avoided. The other advantage of using low yield stress is that corrosion will be more uniform and the tendency to pit will be less. The use of stainless steel is not generally recommended unless soil conditions are highly aggressive.

In this project nailing process proposed should be done by driving. If not possible then the surface should be treated with grouted nails. For installing the grouted nails wash boring should not be allowed.

**Facing elements:** The purpose of facing element is to protect the soil nailed surface from damage due to direct rain falling on it and subsequent erosion due to run-off. Use of pre-cast concrete panels, wire mesh with shotcrete, fibre reinforced shotcrete are common for constructing facing element. In this project, the surface of the slope was protected by a layer of cement mortar applied on a wire mesh on to the slope. The design parameters and stability are presented in table 3.

**Design parameters:**

Table 3
Soil Nail design parameters

| **Parameter** | **Value** |
|---|---|
| Internal angle of friction of overburden soil | $23^0$ |
| Cohesion (C) of soil | 27.0 kPa |
| Density of soil | 20.00 kN/m$^3$ |
| Concrete cover thickness | 0.10 m |
| Grade of concrete | M 20 |
| Longitudinal steel | Fe415 |
| Vertical spacing of nails | 0.5 m c/c |
| Horizontal spacing of nails | 0.5 m |
| Inclination of nails from horizontal | 0.00 to 10 degr. |
| Length of nails | 7 m |
| Diameter of nail | 32 mm |
| Bearing capacity of single nail | 60 kN/m |
| Surcharge | 0 kPa |

Internal stability – straight slip surface

**Plane slip surface after optimization:**

| | | |
|---|---|---|
| Slip surface angle | = | $34^0$ |
| Origin of slip surface at a depth of | = | 10.00 M |

**Verification:**

| | | |
|---|---|---|
| Gravity force | = | 2845.27 kN/m |
| Overall force carried by nails behind slip surf. | = | 462.44 kN/m |
| Forces on slip surf. driving (grav.force) | = | 1591.05 kN/m |
| Forces on slip surf. driving (pressure) | = | 0.00 kN/m |
| Forces on slip surf. resist. (soil) | = | 1575.83 kN/m |
| Forces on slip surf. resist. (nails) | = | 383.38 kN/m |

Resisting force = 1959.21 kN/m > 1591.05 kN/m = shear force.

Stability of slip surface is SATISFACTORY

**Internal stability – broken slip surface**

**Broken slip surface after optimization:**

| | | |
|---|---|---|
| Slip surface angle | = | 16.00 ° |
| Origin of slip surface at a depth of | = | 10.00 m |

**Verification:**

| | | |
|---|---|---|
| Gravity force | = | 1239.44 kN/m |
| Overall force carried by nails behind slip surf. | = | 160.97 kN/m |
| Forces on slip surf. driving (grav.force) | = | 341.64 kN/m |
| Forces on slip surf. driving (pressure) | = | 455.96 kN/m |
| Forces on slip surf. resist. (soil) | = | 656.48 kN/m |
| Forces on slip surf. resist. (nails) | = | 154.73 kN/m |

Resisting force = 811.21 kN/m > 797.59 kN/m = shear force.

Stability of slip surface is SATISFACTORY

***Horizontal drain***

Horizontal drains serve to introduce additional drainage channels into the hillslope to facilitate drainage of the subsoil. These consist of making boreholes at a negative gradient of $5^0$ to $10^0$ to the horizontal and then introducing slotted PVC pipes of 5 cm diameter into the pre-drilled holes. Water draining from each row of the drains should be collected and eventually discharged into a suitable surface drainage point.

***Compaction of loose fill***

Loose debris slopes are often the cause of surface mudflows. It is important that at critical locations, loose debris on the slope is appropriately compacted. This may be done by choice of suitable vibrators. Once the slopes are compact, they should be vegetated. And when the vegetation takes growth, one is reasonably sure of preventing surface mud flows.

The remedial measures designed & proposed on uphill slope and downhill slope are shown in figure 12.

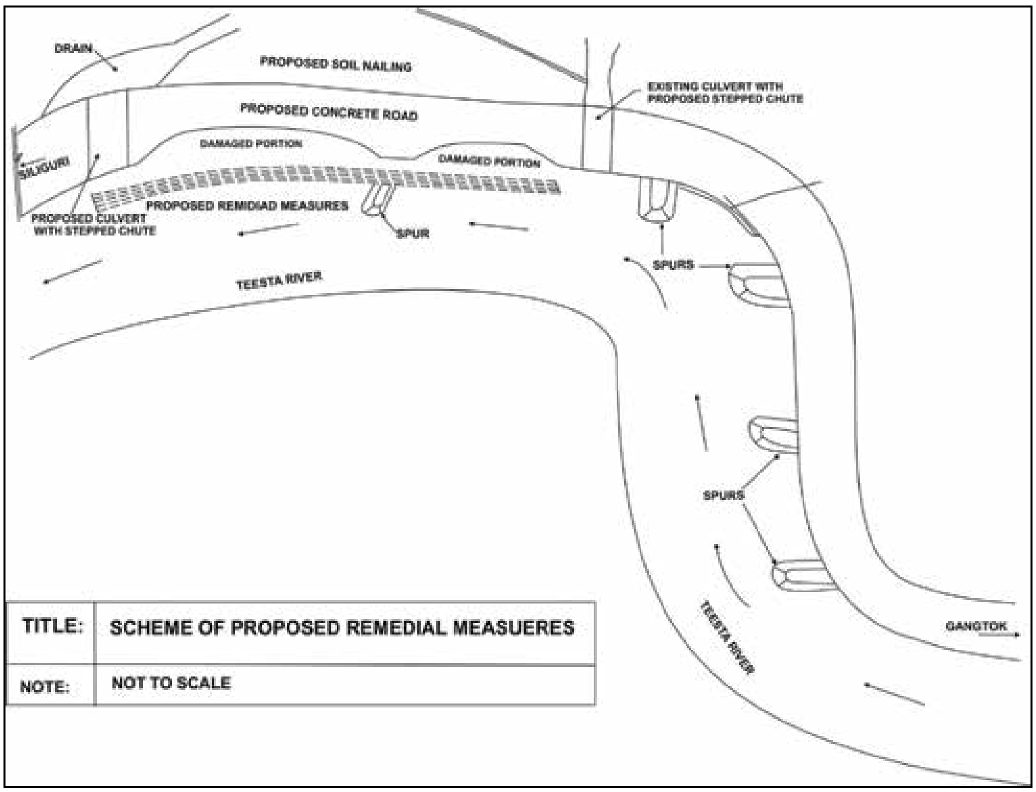



Figure 12 Scheme of remedial measures on entire slide portion

## 7. Conclusions:

Based on the field geological, geomorphological and geotechnical investigations of the landslide area the following general concluding points emerged.

- Although enormous construction work have already been undertaken for restoration of the hill road yet the area requires further implementation of additional remedial measures at several deteriorated failure prone locations specially in the up & down hill slope region to achieve improved stability condition of the overall slide area.
- Catch water drains, horizontal drains and stepped chutes were suggested for improving the existing drainage system.

- For overall stability of the slope, the uphill slope was stabilized with soil nailing, shotcrete & stepped chutes. The downhill slope was stabilized with 10m high cantilever wall with cladding & claddings with anchors were proposed.
- Regular monitoring of the slide is important. The development of tension cracks and monitoring the growth of these cracks would serve to be the indicator of the effectiveness of stabilisation measures. It was suggested to adopt suitable instrumentation like piezometer, settlement plates & inclinometer for this slide at the crown portion, top of uphill side of the and also at the downhill slope near to toe of the embankment. Water table, development of cracks and the subsurface/surface movements can be monitored. These will be helpful in early warning.

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1. CRRI (2013) Report on "Design of Remedial Measures at Lukhbir Slide on NH – 31A", CSIR – Central Road Research Institute, New Delhi.