CAUSES OF LANDSLIDES AND ITS CONSEQUENCES

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Landslide – Natural Hazard

- Landslides, though occur as localized event, are the major natural hazards which effect at least 15% of land area in India, covering more than 0.49 M km^2.
- In the seismically sensitive and geodynamically active Himalayan region, landslides occur very frequently and affect the population severely.
- There are some sensitive slopes through which construction is in progress and this activity is leading to uncontrolled slope movement and also affecting the areas in close vicinity.
- In such cases it is always better to avoid the active/potential slide zones and go for tunneling or viaduct.

Type of Slopes and Factors Causing Slope Failure

Slopes

Natural

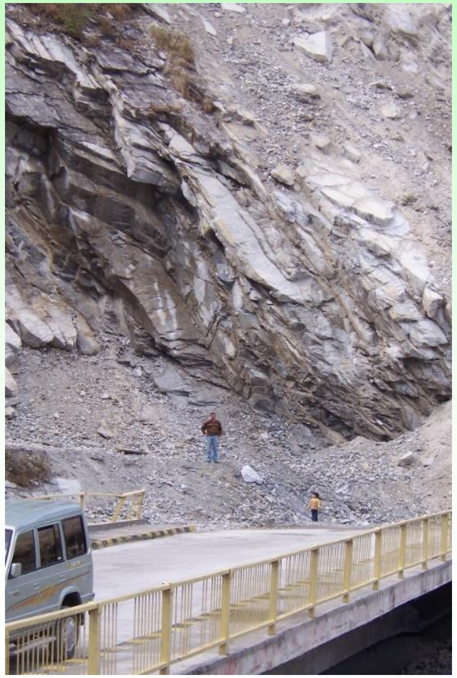
- Hill side and valleys
- Coastal and river cliffs

Man-made

- Cuttings and embankments for highways and rail roads
- Earth and ash pond dams
- Temporary excavations
- Waste heaps (landfill slopes)
- Landscaping for site development

Causes of slopes failure

⇨ Gravity
⇨ Seepage
⇨ Earthquake
⇨ Erosion
⇨ Geological features
⇨ Construction activities



Objectives

- To find out the impacts of landslide and its possibility of recurrence.
- To find out the most hazardous zones.
- How to minimize the damages of worst affected areas in the next rainy season?
- Suggesting precautionary measures for the construction of buildings, fields etc.
- Suggest mitigation measures for landslides.

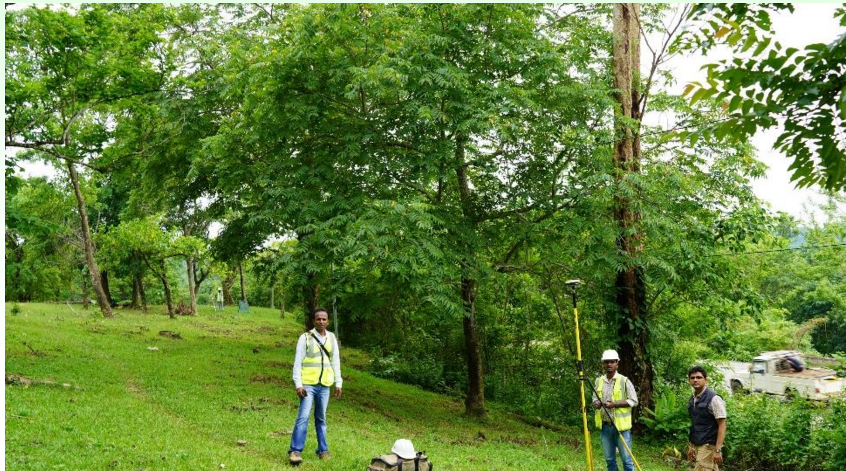
Geotechnical Investigations

- Surveying and contouring of the slide area on 1:1000 scale
- Geological and structural mapping on 1:1000 scale.
- Demarcation of lineaments/faults in the area by visual interpretation of IRS LISS II (FCC).
- Geophysical surveys to delineate depth of overburden mass occupying top of the hill.
- Exploratory drilling
- Geomechanical testing of overburden mass for stability analysis
- Slope stability analysis - Numerical Modelling
- Monitoring of slope movement by Automatic Target Recognition (ATR)
- Studies for biorestoration of overburden slopes

Survey…..DGPS

DGPS (Differential Global Positioning Systems) is used for Control Points Logging. Multifrequency GNSS (Global Navigational Satellite Systems) Receivers were used for logging readings at certain fixed locations. These locations are called Ground Control Points (GCPs).

These points were used as control points to rectify the LiDAR scanning data. In this study SP80, a new generation GNSS receivers were used to log the ground control points.



As a first step, the permanent DGPS Control points set up by the client were identified on the site and same were used as control points to commence the survey.

Survey Control Points Provided by Client

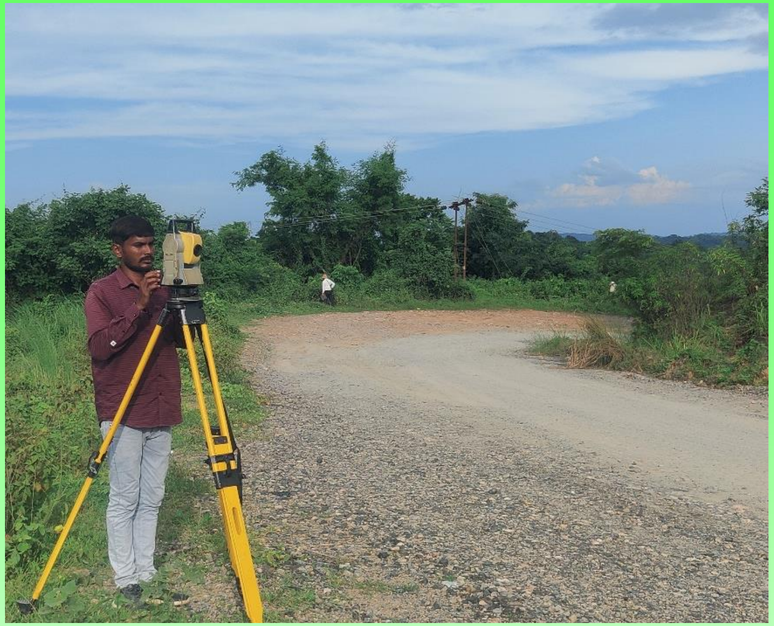
ID	Easting	Northing	Elevation (m)
DGPS31	220133.419	2813454.590	162.194
DGPS 32	220087.979	2813427.383	163.392

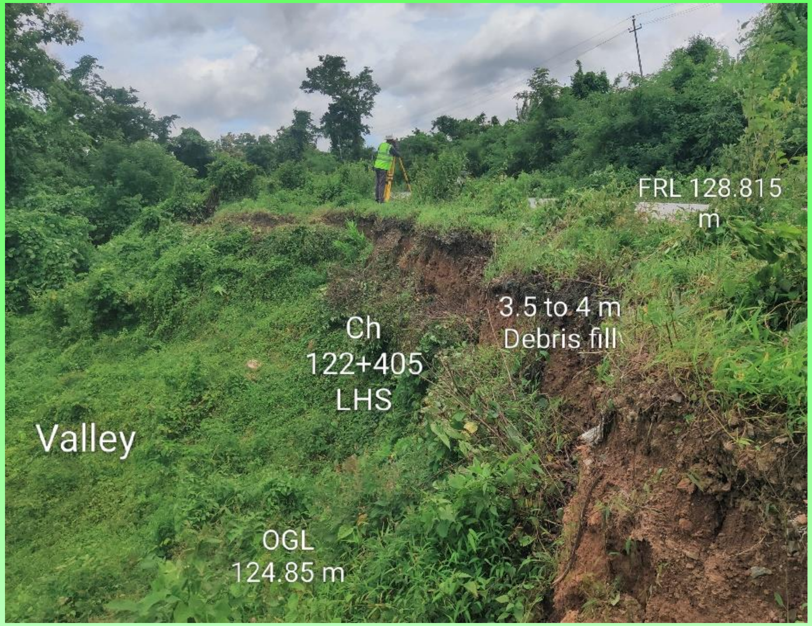
Survey….. LiDAR/3D laser Scanners

- The next step was to map the project area using LiDAR Scanner for recording the levels of the ground and to map all the physical features relevant to the project.
- The scanning was done using Faro Focus S350 scanner. The scanner was placed at several locations at the affected portions.
- The scanned data was downloaded into Scene – software for LiDAR data processing. The individual scans were registered using control points that were logged using the DGPS.
- The registered scans were used to generate point clouds of the surveyed features.
- The point cloud was then filtered to achieve a bare earth terrain data.
- The filtered data was then **used to extract contours of 1 m interval.**
- The scanned data was also used for **delineating other physical features** viz., roads, buildings, bridges, culverts, drains, etc.
- The processed topographic data was then used **for generating cross sections** across the affected sections of highway.

Survey….. Total Station

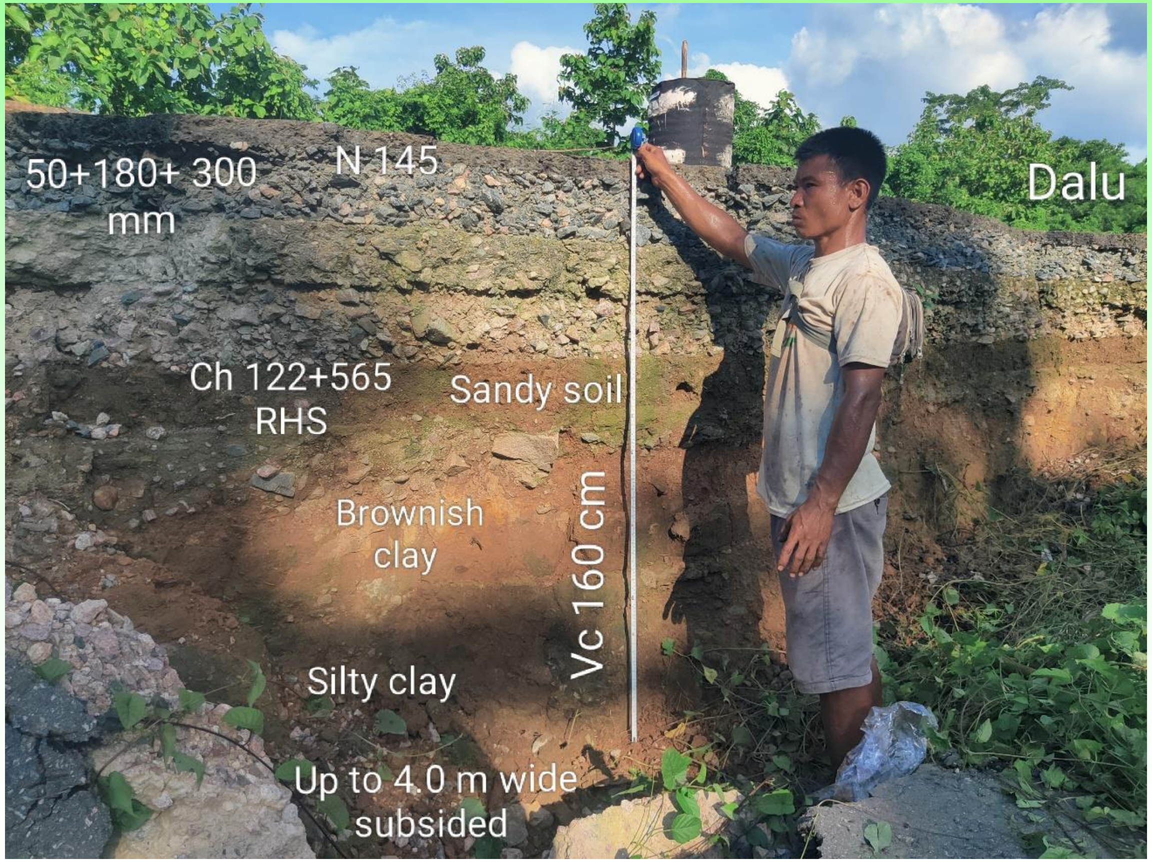
- Total Station survey equipment was used for recording positions and dimensions of cracks.
- The extents of the cracks recorded by Total Stations were helpful for filling up data formats devised by the geologist.
- The field observations being carried out required in situ results related to cracks, subsidence extent and displacement of structures from their original positions.
- The field assistant would place the target prism on the feature to be mapped viz., road edge, crack, culvert etc., and the operator would record that position using the Total Station.
- The chainages marked on permanent features by the client were used as reference for the chainages.



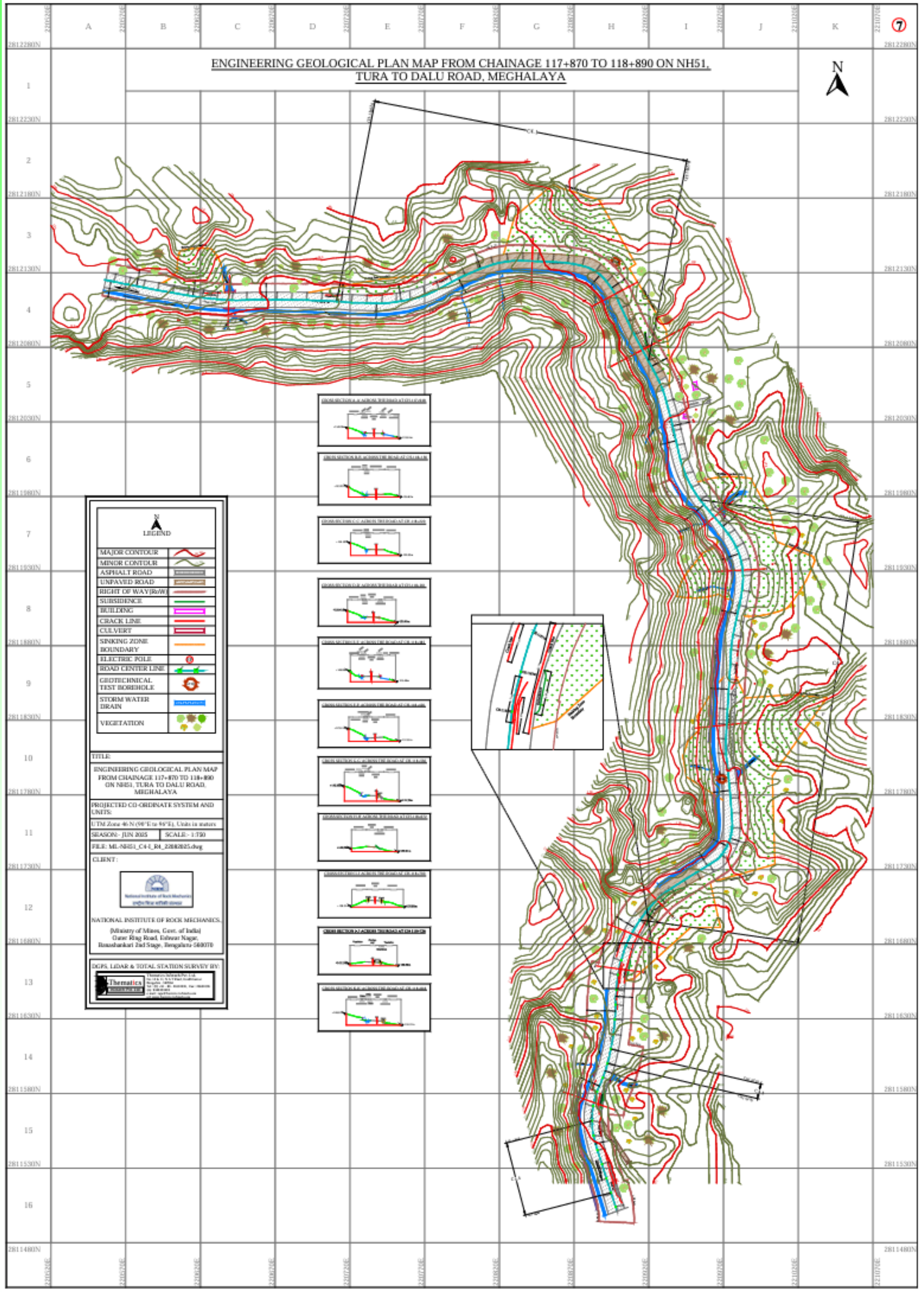


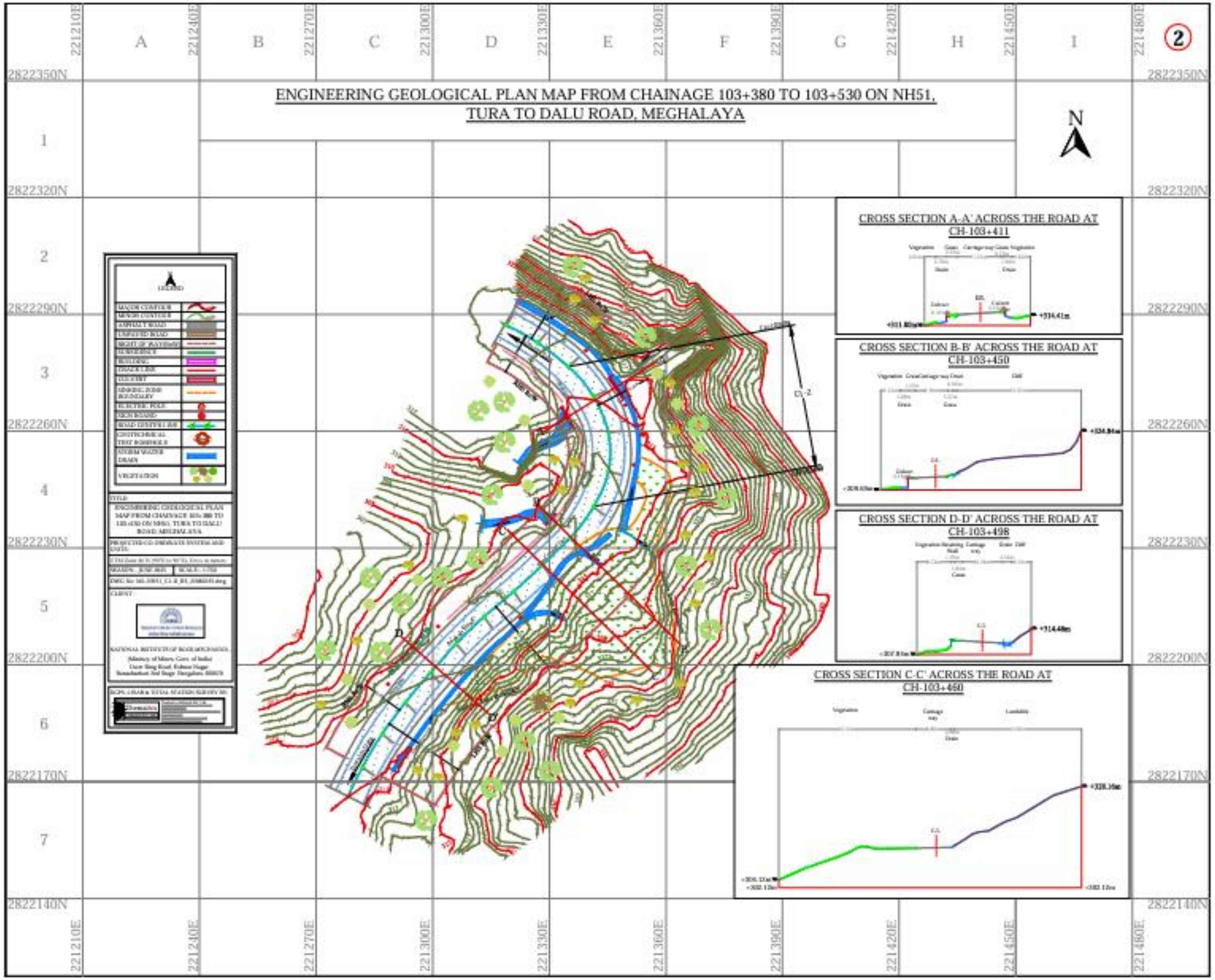
SZ-08 (3) (Ch. 115+730 to 115+780 km)		
Sr. No.	Parameter/factor	Description
1.	Sink/landslide	Sunk
2.	Type of movement	Sinking
3.	Activity	Active
4.	History	Since the construction of road as per local communication
5.	Type of material	Unconsolidated loose soil material (clay rich material)
6.	Crown elevation	159.70 m
7.	Toe elevation	158.68 m
8.	Orientation of the flow direction	N 290°
9.	Weathering grade	Residual soil (W-VI)
10.	Spring (location and elevation)	No
11.	Causative factor (Internal/External factors, including filling/cutting of road)	Geological conditions and high rainfall intensity
12.	Landuse / Landcover	Barren and forest land
13.	Source of water (Stream)	No
14.	Influence of house-hold drainage in the sink/landslide	No
15.	Geology of the area	The area is cover with grey shale formations
16.	Road drainage	Temporary drain on LHS
17.	Specific characteristics of the site	Cracks observed in the on LHS, RHS and middle part of the road Crack length: >20 m, Width: 20 cm Vertical displacement: 30 cm
18.	Type of Road	Paved road
19.	Details of retaining structure if any	No
20.	Road restriction	No

Fig. 21: Longitudinal open cracks (up to 25 cm wide) with vertical displacement (up to 30 cm) mapped along right edge of the pavement near Ch 115+867 km

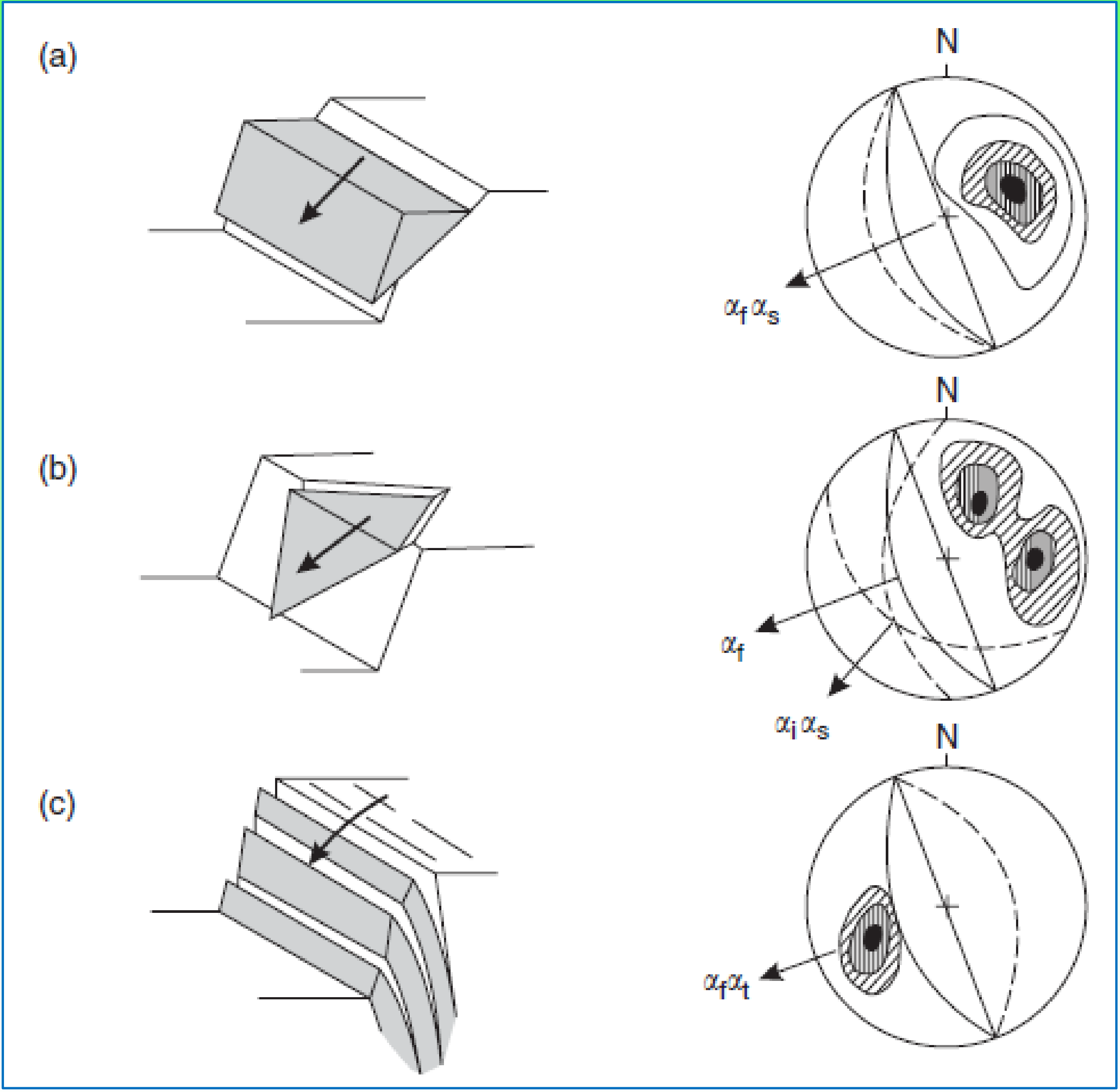


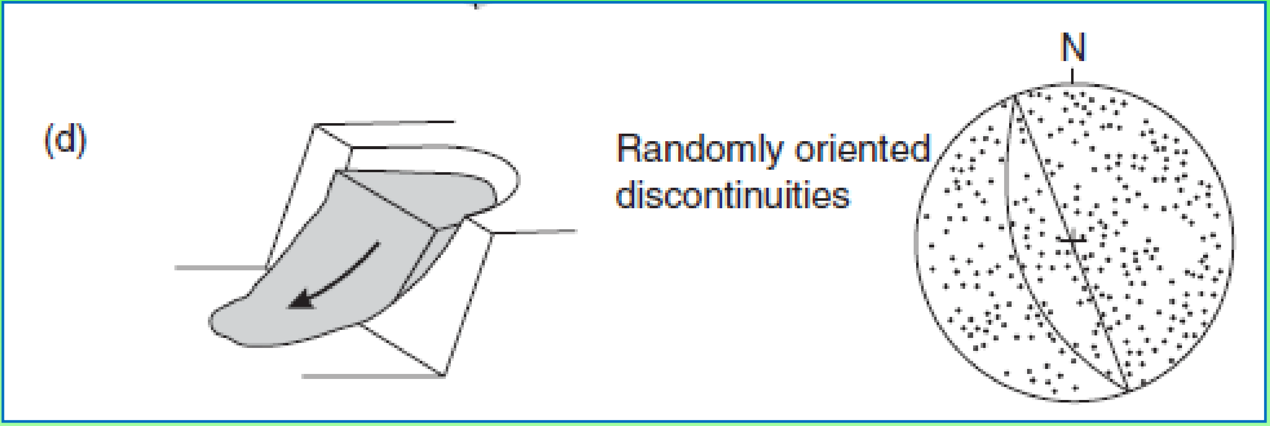
Engineering Geological Plan Map

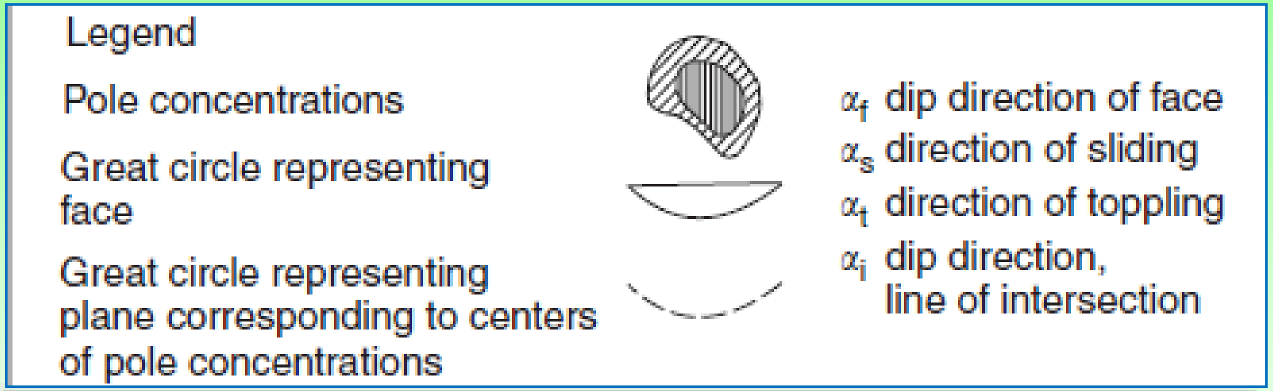




Kinematic Analysis







Main types of block failures in slopes, and structural geology conditions likely to cause these failures: (a) **plane failure** in rock containing persistent joints dipping out of the slope face, and striking parallel to the face; (b) **wedge failure** on two intersecting discontinuities; (c) **toppling failure** in strong rock containing discontinuities dipping steeply into the face; and (d) **circular failure** in rock fill, very weak rock or closely fractured rock with randomly oriented discontinuities.

BH-1 (Ch. 115+449) Description and Physico-Mechanical Properties

Geotechnical Parameters of BH-1 (Ch. 115+449)

Depth (m)		Test on Rock Specimen								Shear Strength Parameters		SPT	Soil Classification	Grain Size Analysis			Index Property					
From	To	Core Recovery %	RQD %	Density (gm/cc)	Specific gravity	Point load Index kN/m²	U.C.S (MPa)	Porosity (%)	Modulus of Elasticity (GPa)	Cohesion (KPa)	Angle of Friction (Degree)	N-Value (Corrected)		Gravel (%)	Sand (%)	Silt & Clay (%)	Bulk Density (gm/cc)	Dry Density (gm/cc)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Specific Gravity
0.00	0.50	Brownish grey gravely clay								-	-	-	-	26	9	65	2.12	1.94	-	-	-	2.69
1.50	1.95	Brownish grey silty clay								30	6.0	65	CL-CI	-	10	90	1.98	1.68	48	15	33	2.69
3.00	3.45									29	6.5	83		-	33	67	2.11	1.84	41	14	27	2.70
4.50	4.86	Brownish grey gravely clay								30	6.8	69		32	41	27	2.08	1.95	40	14	26	2.70
4.86	6.00	Nil	-	2.48	2.59	0.21	-	2.0	-	Greyish very dense stiff clay		-	-	-	-	-	-	-	-	-	-	-
6.00	6.20	Brownish grey silty clay-								31	4.3	N>100	CL	1	1	98	2.19	1.85	49	17	32	2.68
6.20	7.50	52	-	2.49	2.60	0.18	-	2.1	-	Greyish very dense stiff clay		-	-	-	-	-	-	-	-	-	-	-
7.50	7.65	Brownish grey silty clay								29	3.5	N>100	CL	-	7	93	2.18	1.94	50	17	33	2.68
7.65	8.50	34	-	2.50	2.60	0.14	-	2.2	-	Greyish very dense stiff clay		-	-	-	-	-	-	-	-	-	-	-
8.50	10.0	71	49	2.48	2.60	0.17	-	-	-			-	-	-	-	-	-	-	-	-	-	-

Note: Depth of water table: 1.80 m; RQD = Rock quality designation; UCS = Uniaxial compressive strength; SPT = Standard penetration test; CL = Clay of low plasticity; CI = Clay of intermediate plasticity

Electrical Resistivity Surveys Report

Profile – 1 (Ch. 115+449 to 115+536): The resistivity section shows three main zones. The shallow layer (0–3 m) has low resistivity (1.6–16.6 Ohm.m), likely indicating clay or water-saturated soil. The middle layer (3–10 m) has moderate resistivity (16.6–78.8 Ohm.m), suggesting Medium – Stiff consistency clay. The deeper layer (below 10 m) shows high resistivity (above 172 Ohm.m), which likely represents dry, compact material.

Profile – 2 (Ch. 115+329 to 115+449): In this section, shallow zone (0–3 m depth) shows low resistivity (11.7–38 Ohm.m), likely representing clayey or water-saturated soils. Between 3 m and 12 m, medium resistivity values (38–83.7 Ohm.m) suggest medium – Stiff consistency Clay. Below this, high resistivity zones (up to 184 Ohm.m, especially around 50–70 m) may indicate dry compact layers.

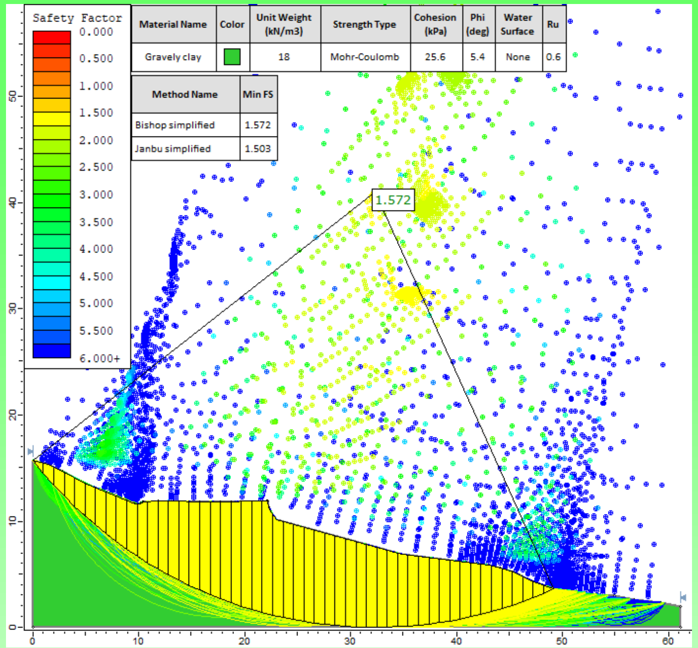
Major Contributing Factors

Due to the nature of foundation soil, embankment settlement/subsidence is going on. The following factors may contribute to the development of these cracks:

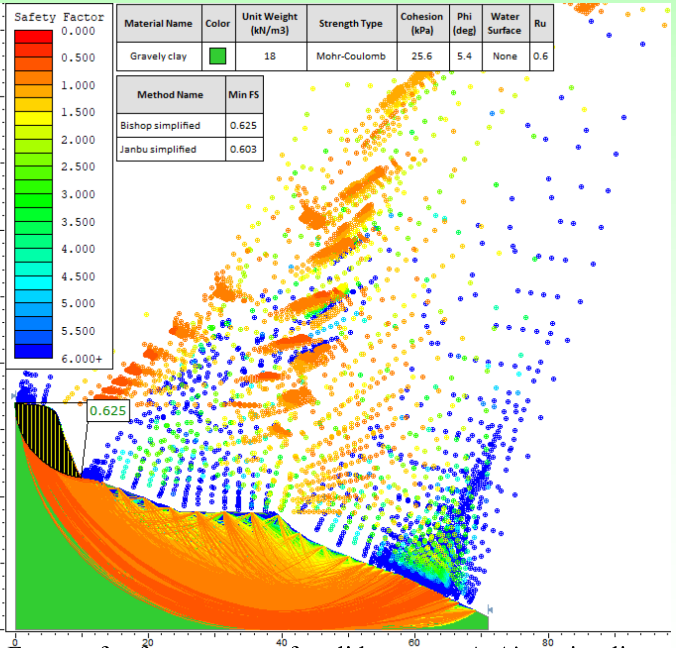
- Lack of literal support from the shoulders.
- Inadequate surface drainage, especially during flooding conditions.
- Shrinkage due to drying out of the surrounding earth, generally caused by roots of trees or bushes close to the pavement edge. Highly expansive soil is particularly prone to shrinkage when moisture dries out.
- Settlement or yielding of the underlying material.
- Inadequate pavement thickness, inadequate pavement width forcing traffic to be too close to the edge of the pavement and non-provision of extra width of pavement on curves.

Slope Stability Analysis

- The slope stability and landslide analysis are carried out using Slide2 software.
- Slide2 is a 2D slope stability analysis developed by RocScience Inc., widely used in the field of geotechnical engineering.
- For sinking zones/landslides stability analysis has been carried out using the Limit Equilibrium Method (LIM) which is the most common approach for analysing slope stability.
- To develop a model for slope stability, it is essential to define the problems geometry and boundary conditions.
- The input parameters required to analyses slope stability are unit weight, cohesion, angle of internal friction, and pore water pressure ratio (Ru) for static case, however, in the dynamic case, one additional parameter namely, coefficient of horizontal seismic acceleration is required along with other input parameters of static case.
- Detailed limit equilibrium analysis was conducted to assess the stability of landslide-prone areas and zones affected by ground subsidence or sinking.



Factor of safety contours for slide area at B-B'-section line (Cluster-5) at Ch. 124+840 km



Factor of safety contours for slide area at A-A'-section line (Cluster-5) at Ch. 125+227 km

Option for strengthening of slopes

Natural Slopes

- Regrading
- Drainage
- Soil Nailing
- Vegetation
- **Retaining Wall Gabions**

Man made Slopes

- Soil hardening
- Buttressing
- **Retaining Walls Gabions**
- Reticulated Micro Piles
- **Reinforced Slopes**

How to Avoid Active/Potential Slide Zones




Madhyamaheshwar – August 1998
Human Losses: 103, Animal Losses: 558
Total Losses: Rs. 17 Crore

Uttarkashi – 24 September 2003
Human Losses: Nil; Animal Losses: Nil
Total Losses: Crores of Rupees

Thick debris in Higher Himalayan valleys provide space for agricultural fields & hence settlements are mostly clustered around these valleys

Flow Chart for Management of Landslide Disaster

(after Naithani & Nawani, 2023)

Establishment of Control Room

Formation of a Group

[Comprising Bureaucrats, Subject Experts (Engineering Geologist/Engineer), Doctors, Volunteers, Persons from Electricity and Water Supply Departments]

↓

Setup a Base Camp & Godown near to the Affected Area

↓

Dividing the People into following Four Groups

↓

Subject Expert

1. Visit the affected areas
2. Find out the causes of losses / failure
3. Demarcate the hazard prone areas
4. Communicate to Bureaucrats if evacuation is needed immediately
5. Suggest short- and long-term mitigation measures
6. Suggest suitable sites for the construction within the villages
7. Risk assessment analysis

Bureaucrats (from District Administration) & Volunteers (from NGOs)

1. To assist people in returning to their pre-disaster level of functioning
2. Coordination among all the people who are in the group
3. Local people should be educated about the ill effects of landslides and should be involved in the rehabilitation activities.
4. Not allowed national / international funding agencies to distribute the goods to villagers.
5. Ensure that community should participataspects.

Health Department (Doctors etc.)

1. Setup the temporary camp in the affected villages.
2. To minimize the emotional & psychological impact of disaster by means of treatment & support.
3. Psychotherapists or psychiatrists should view all people touched by disaster.
4. Identify people at risk for long term mental health problems related to the disaster until the pre-disaster mental health level is achieved.

Persons from Essential Services

1. Chocked drains should be cleared.
2. Implement short term mitigation measures suggested by experts.

Photo Courtesy – Dr. N. Juyal

Thank you

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