

Landslide Disaster and Hill Slope Instability Mitigation along National Highway Corridor for Safe and Sustainable Infrastructure Development in Indian Difficult Terrain



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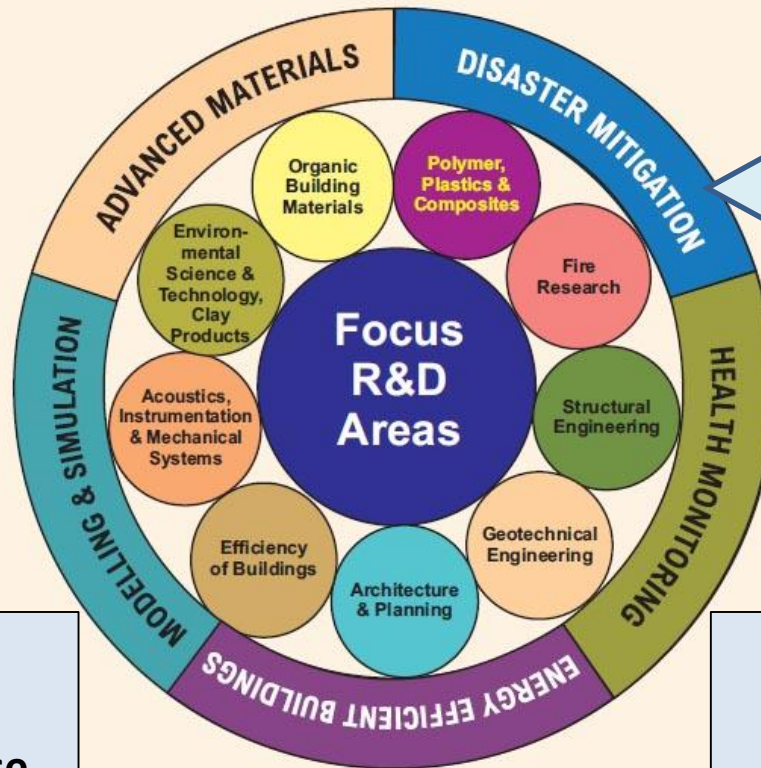
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CSIR-Central Building Research Institute, Roorkee, INDIA



CSIR - CENTRAL BUILDING RESEARCH INSTITUTE, ROORKEE



- Landslides
- Earthquakes
- Fires
- Cyclones

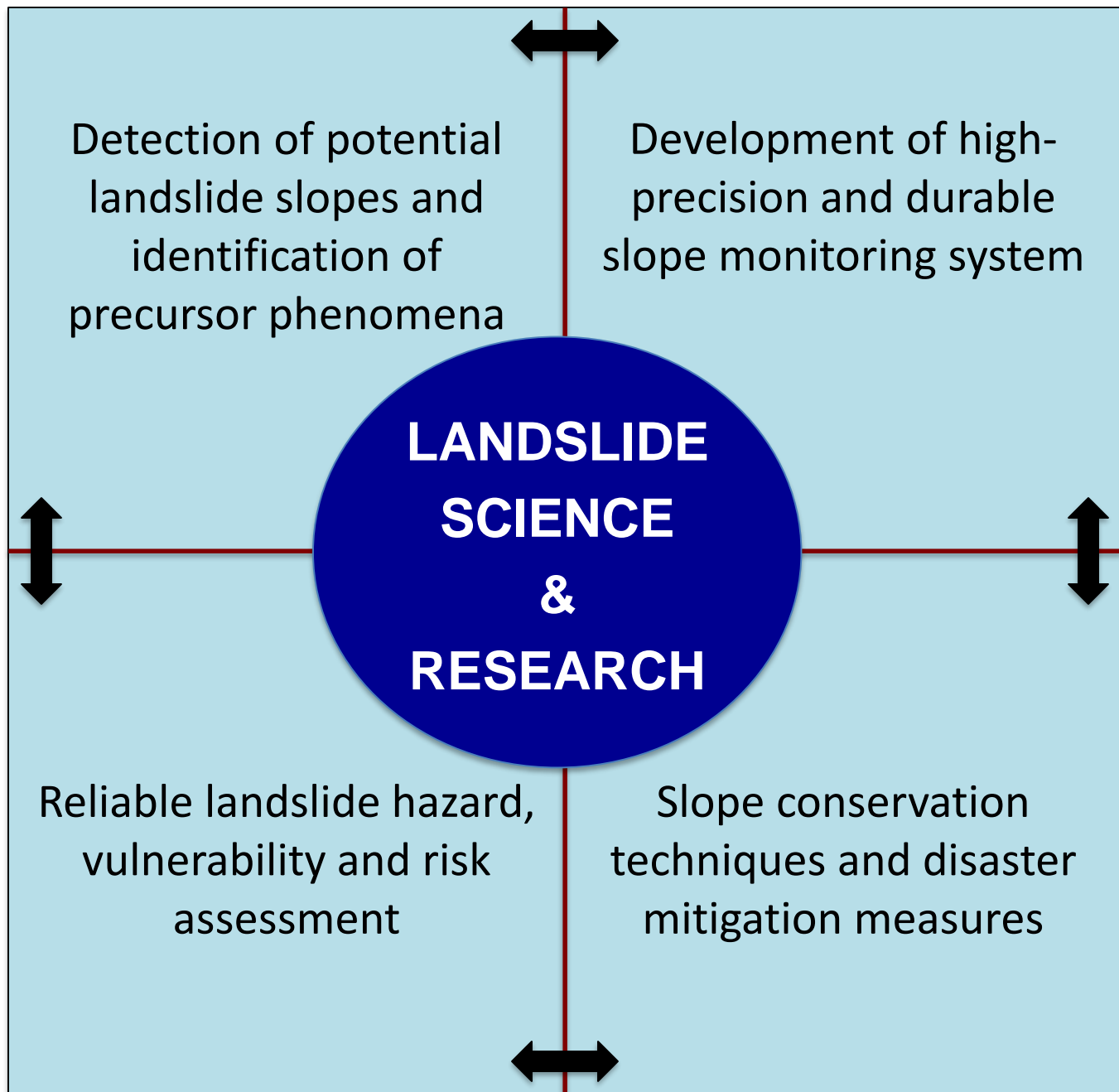
OUR VISION

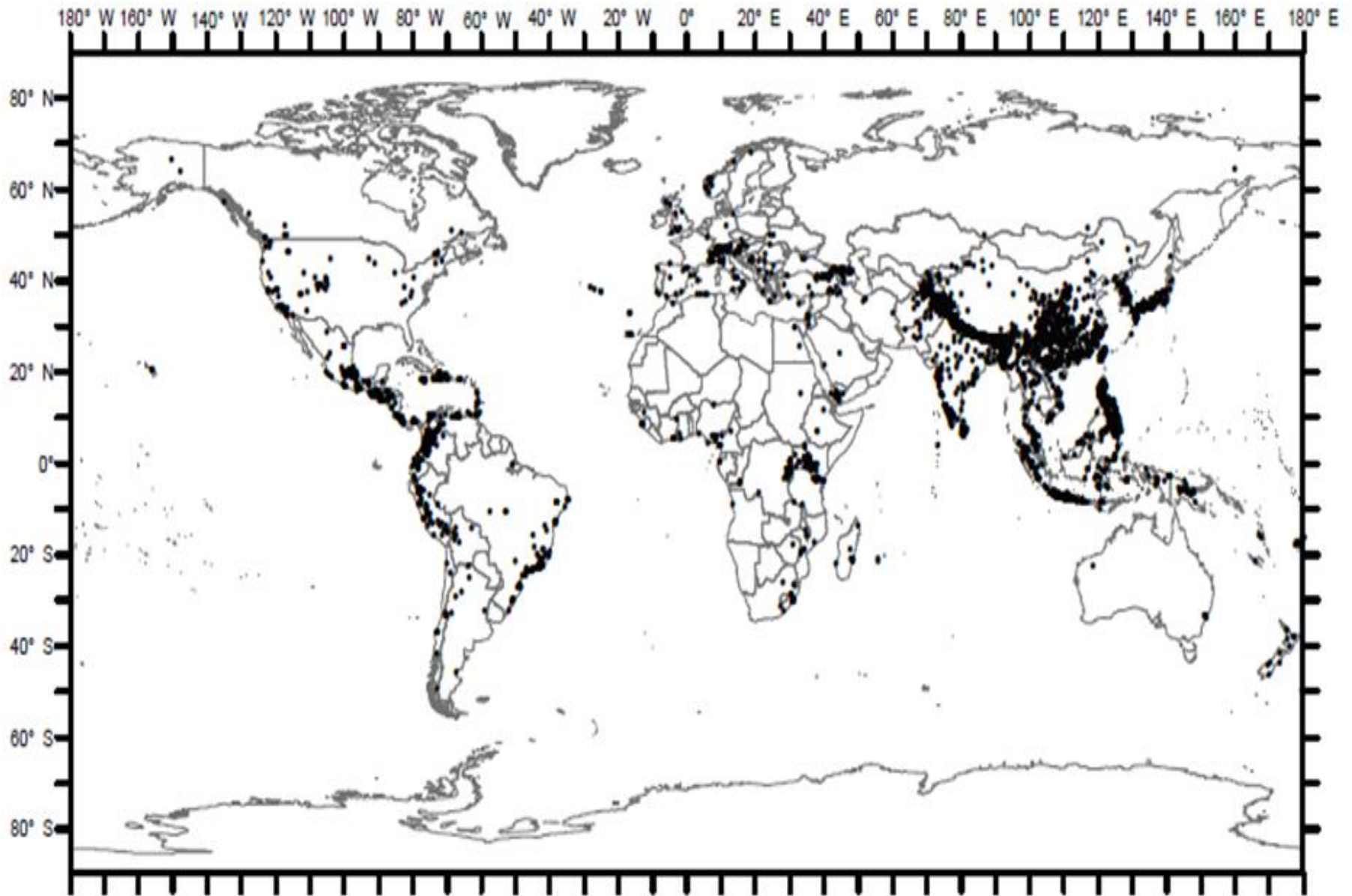
CSIR-CBRI to work as the world-class knowledge base for providing solutions to almost all area of Building construction / Habitat planning and construction including building materials, technology, fire engineering and **disaster mitigation**.

OUR MISSION

To carry out R&D on all aspects of building and housing and assist the building industry in solving problems of planning, designing, found at ions, materials and construction including **disaster mitigation** in all kinds of buildings.

AREAS OF EXPERTISE





The location of fatal landslide (non-seismically triggered) events from 2004 to 2016. Individual landslide events shown by a black dot. (Source: Froude and Petley, 2018)

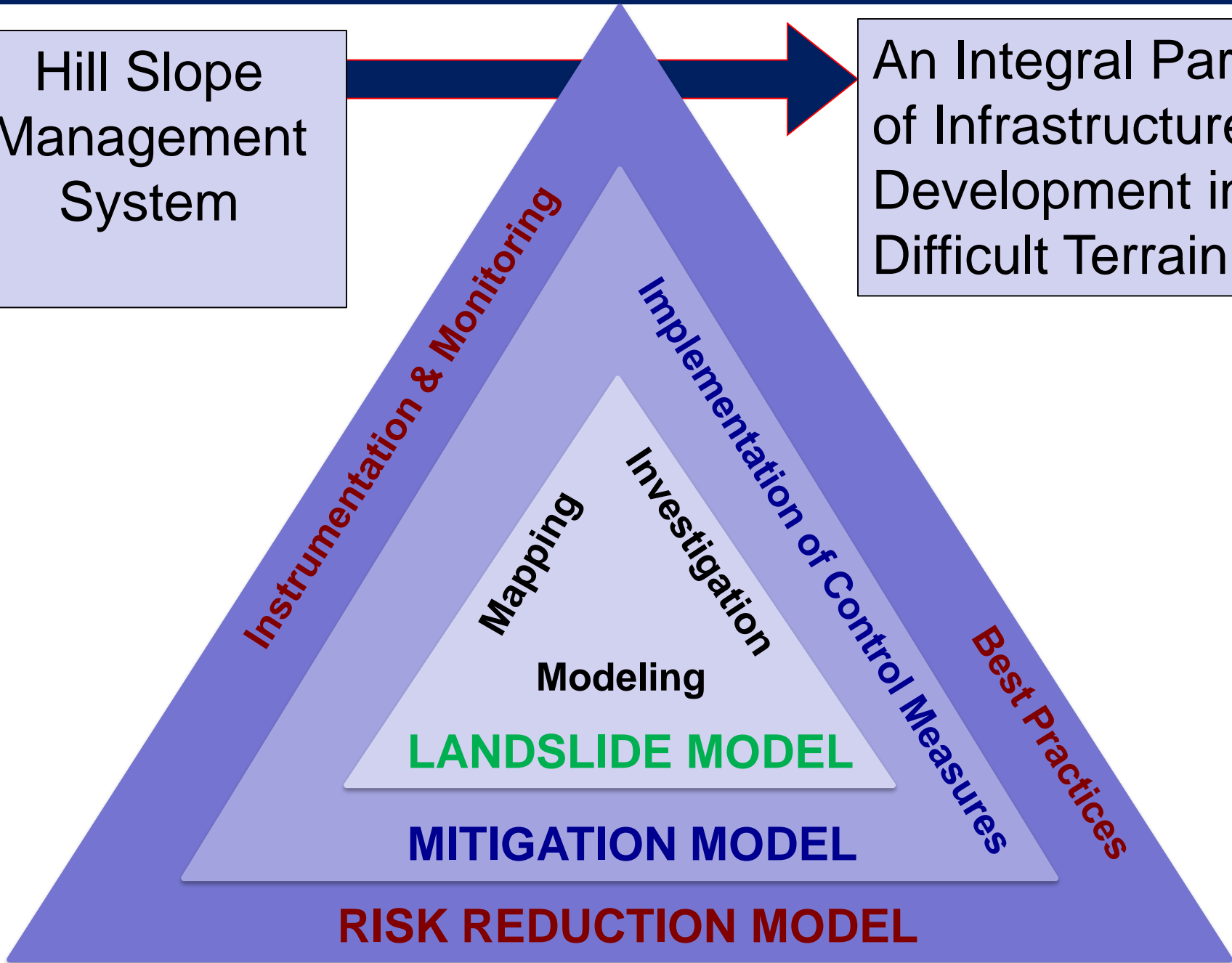
In context to India, the following conclusions are drawn from the study conducted by Froude and Petley (2018):

- Majority of landslides (non-seismic fatal events) during the year 2004–2016, were **triggered by rainfall** (79%) of which **India contributes 16%** in the global dataset.
- By country, India contributes the most about **28% in construction-triggered landslide** events and about **12% in landslide events triggered by mining**. Further, it is observed that the fatal landslides triggered by illegal mining practices have occurred in 32 countries of which India ranks 15th in the list.
- Road network in India has nearly tripled in length in last 24 years (Govt. of India, 2016) leading to **30% of the landslide events due to construction activities along the roads**.
- Hill cutting is another problem that is slowly on the rise in the country.

LANDSLIDE DISASTER RISK REDUCTION

Hill Slope
Management
System

An Integral Part
of Infrastructure
Development in
Difficult Terrain



PURPOSE OF LANDSLIDE SITE INVESTIGATION

Determination of nature of soil and its stratification

Determination of depth and nature of bedrock

Determination of position of water table

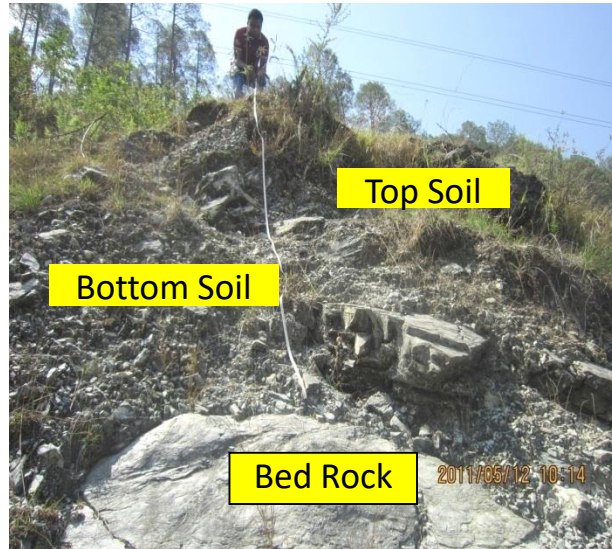
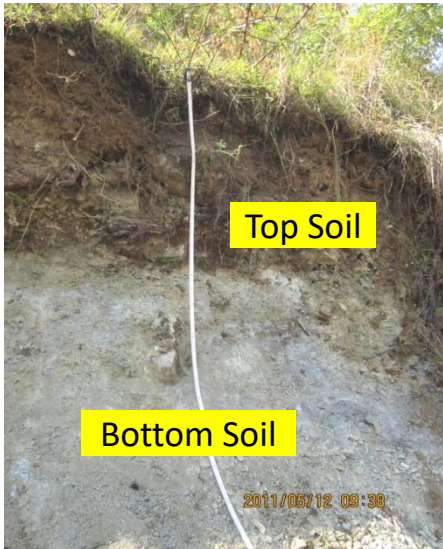
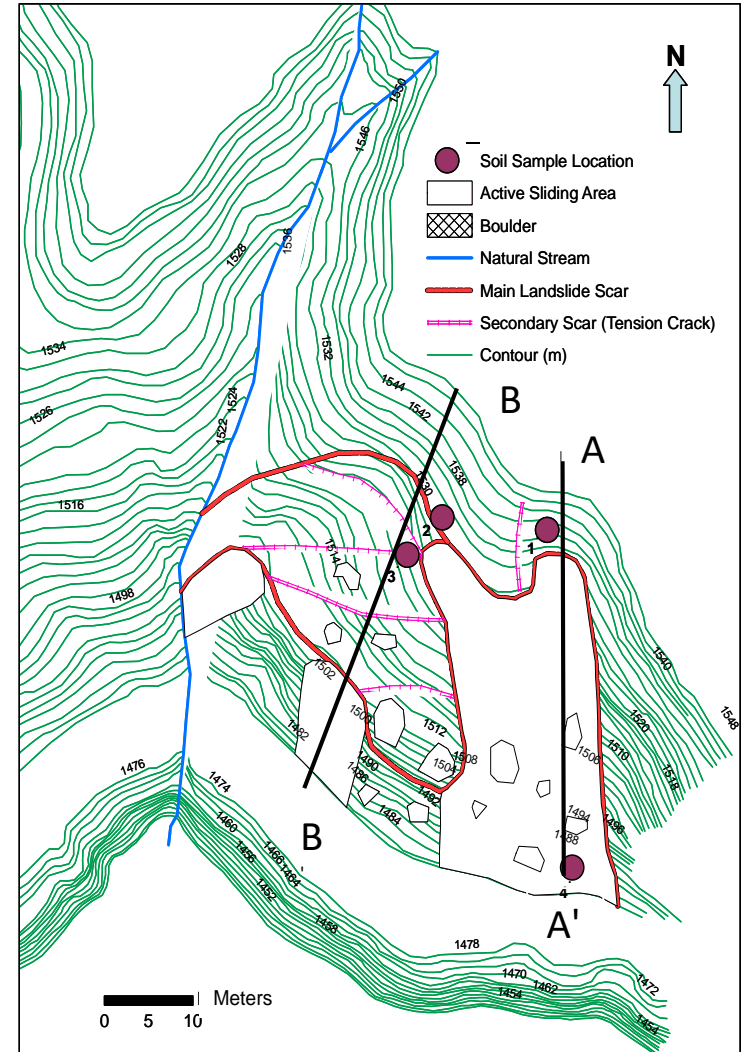
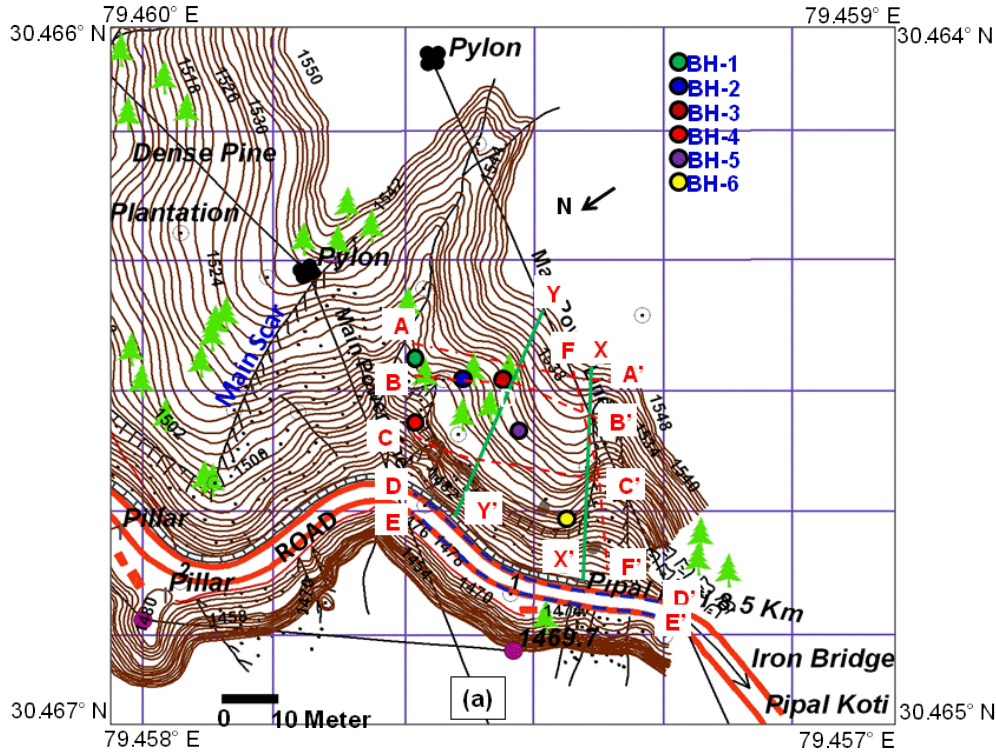
Obtaining disturbed and undisturbed samples of soil

Performing in-situ field tests

Observing drainage conditions from and into site

Assessment of any special construction problems

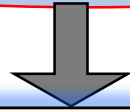
LANDSLIDE SURFACE MAPPING



- Total Station
- Robotic Smart Station
- Distomat

LANDSLIDE SUB-SURFACE MAPPING: Geotechnical Investigation

Non-destructive



Seismic method

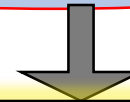
Electrical resistivity method

Magnetic method

Gravity method

- Resistivity Imaging
- GPR
- Engineering Seismograph

Destructive



Standard penetration test (SPT)

Static cone penetration test (SCPT)

Dynamic cone penetration test (DCPT)

In situ direct shear test

Vane shear test

In situ density test

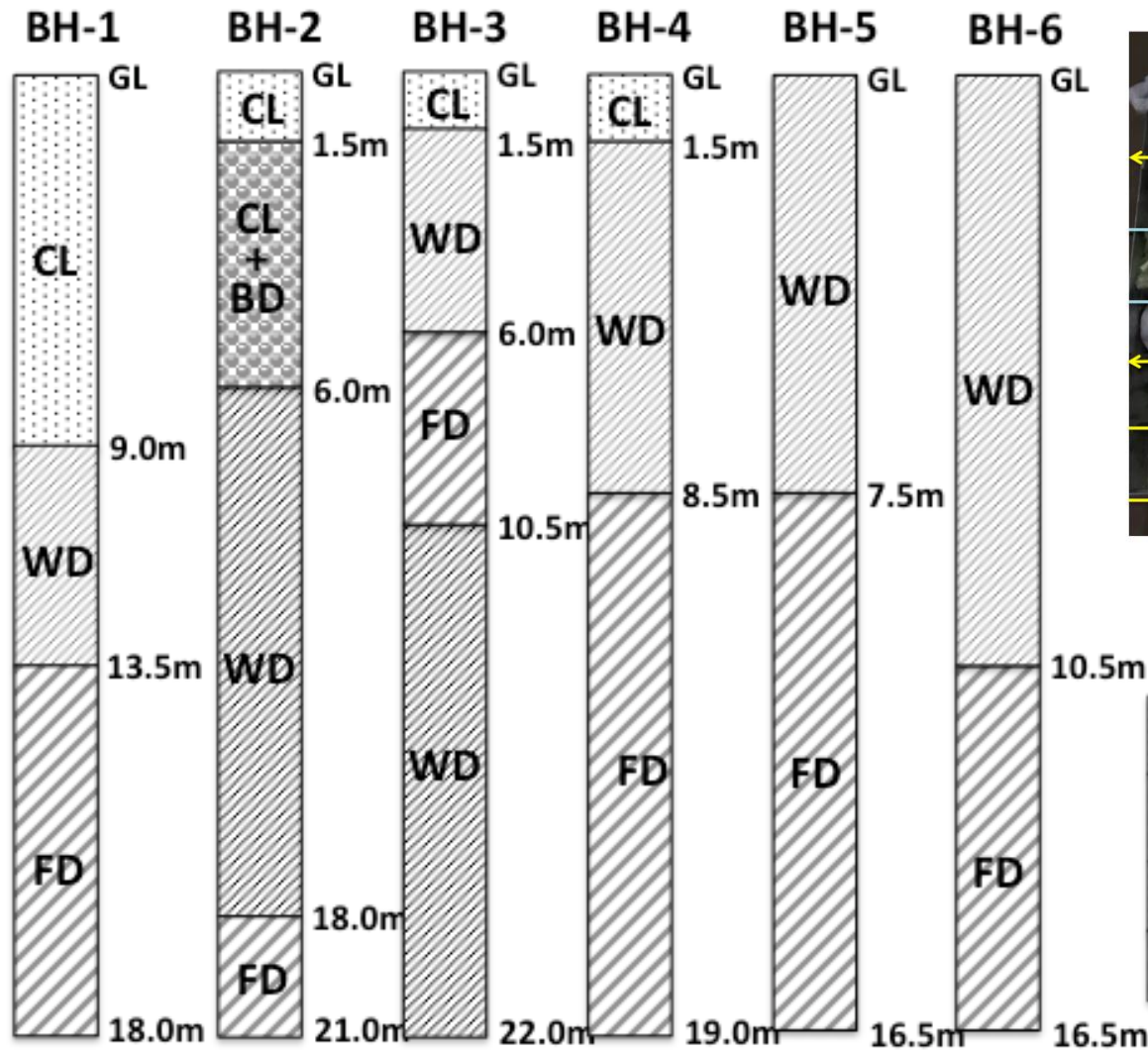
In situ permeability test

Laboratory test

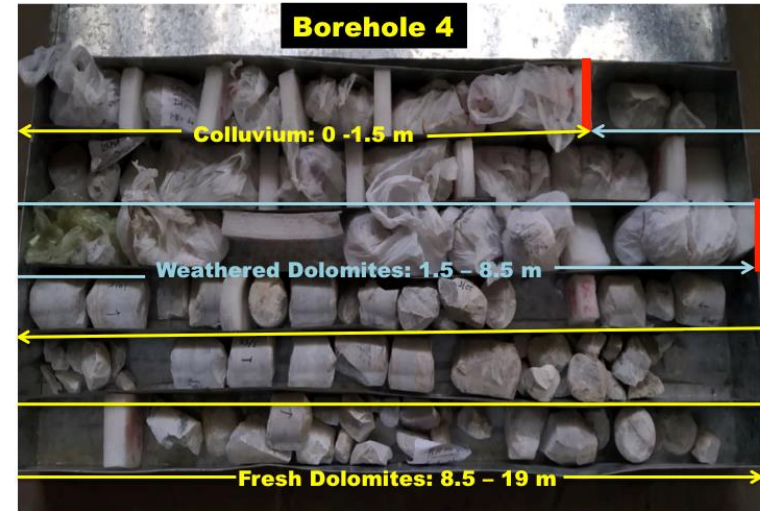
- Specific Gravity
- Moisture Content
- Grain-size Analysis
- Consistency Limits (LL, PL, SL)
- Compaction Test
- Permeability Test
- Direct Shear Test
- Triaxial Test (UU, CU, CD)



Drilling and Borehole Logging



(a)



(b)



- CL Colluvium (CL)
- CL + BD Colluvium with Boulder (CL+BD)
- WD Weathered Dolomites (WD)
- FD Fresh Dolomites (FD)

Not to Scale

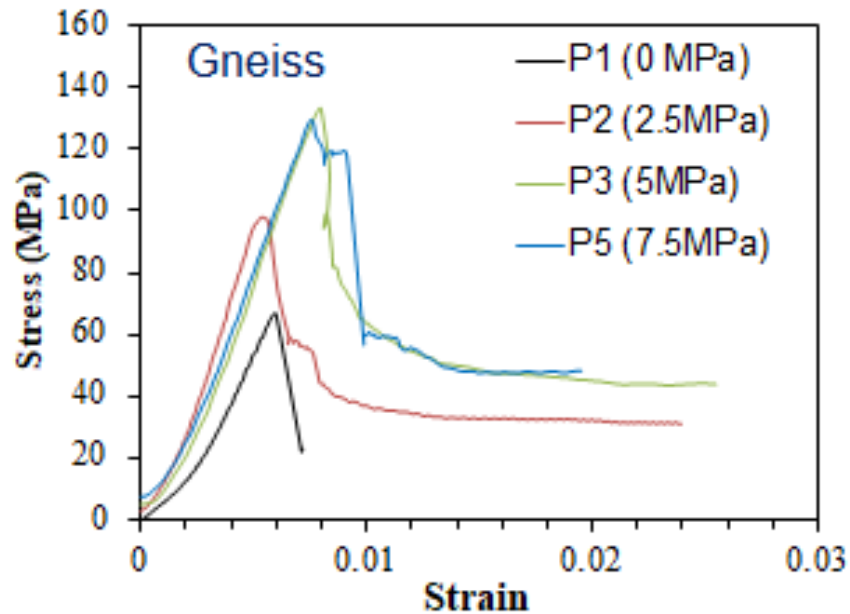
Rock Mass Characterization

Field data

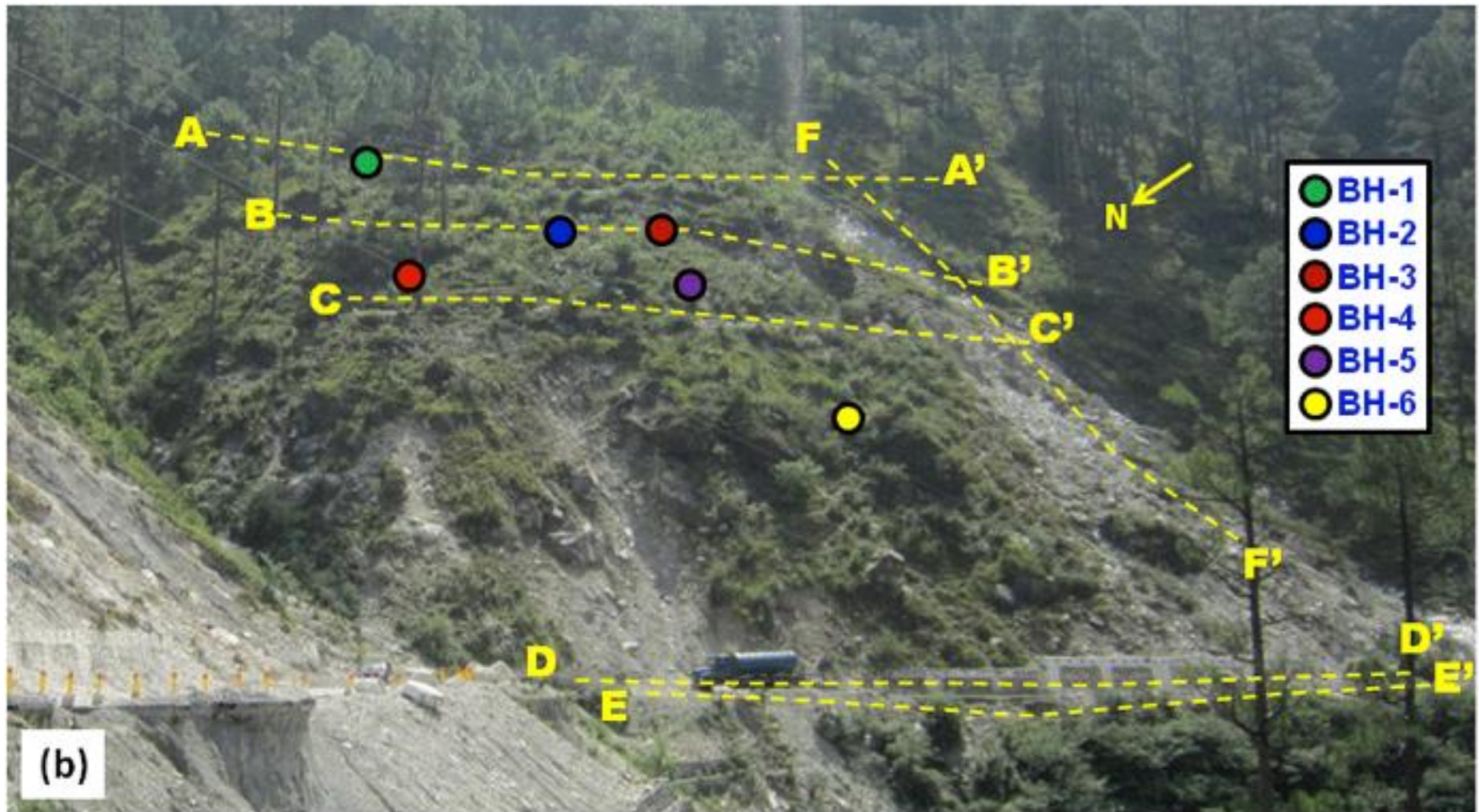
- ✓ Joint attributes (dip, dip direction)
- ✓ Joint shear strength properties (JRC, JCS)
- ✓ Joint condition details (roughness, weathering, infilling)
- ✓ Rock mass characterization (GSI, RMR)



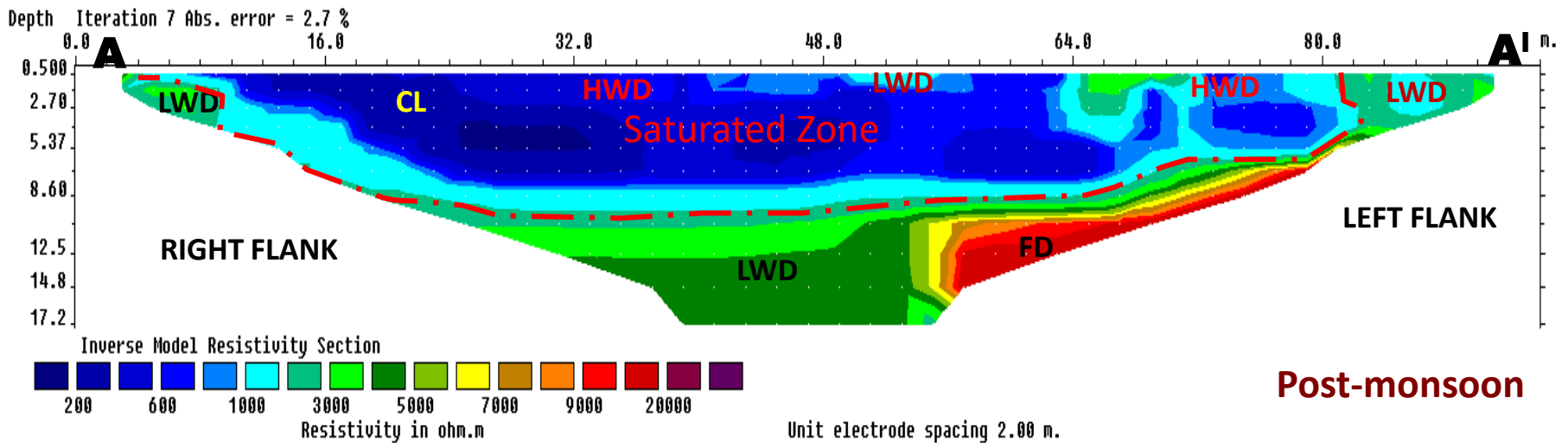
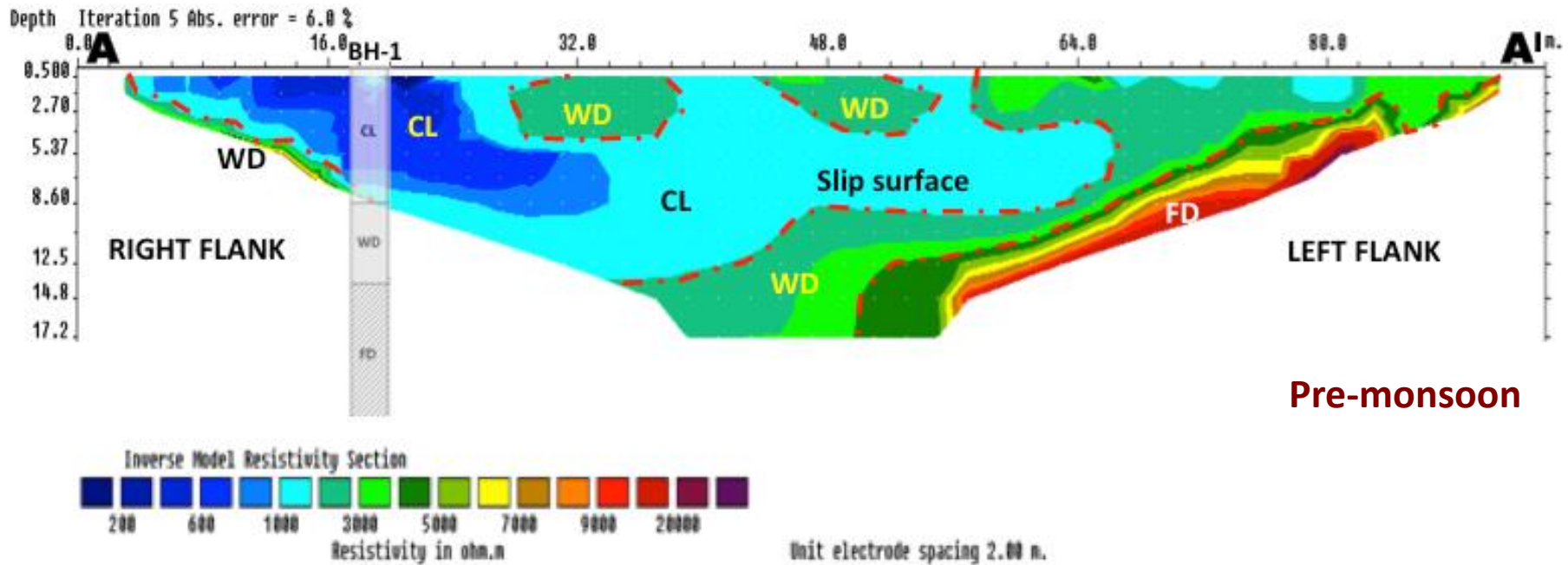
Laboratory testing of Intact Rock

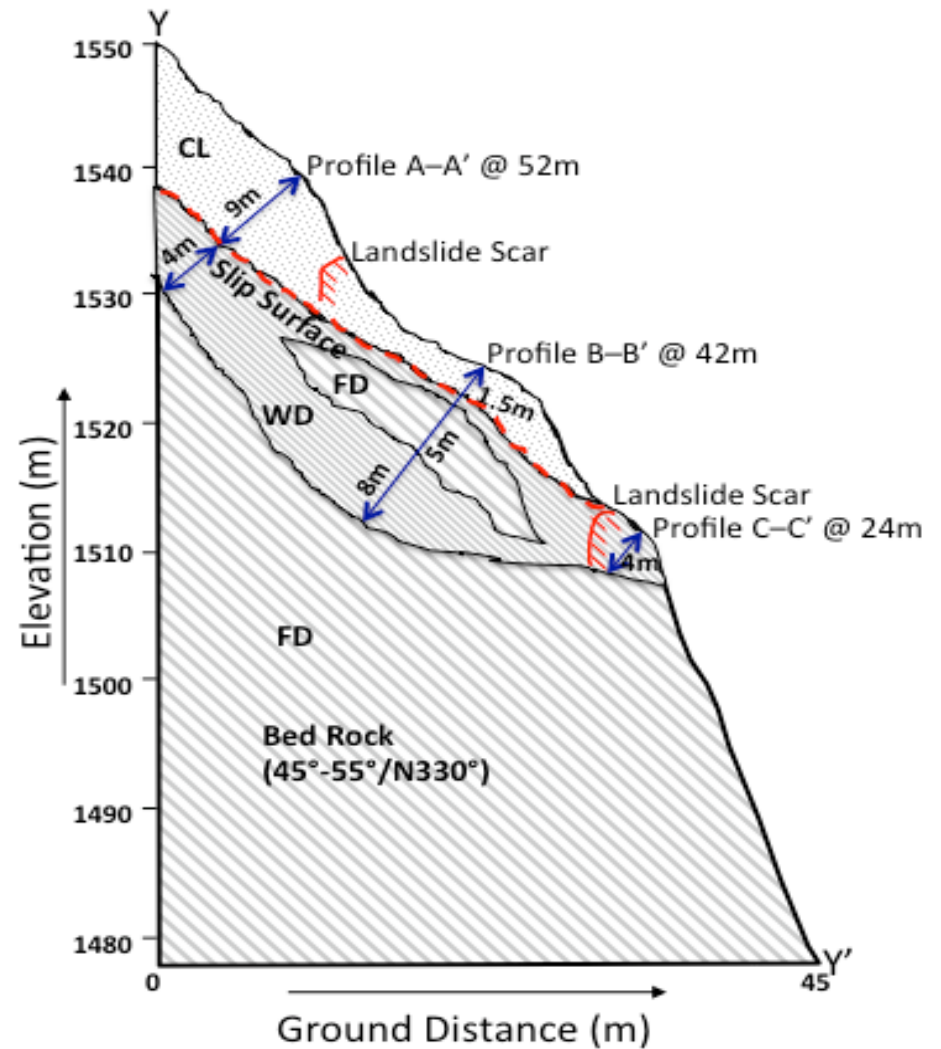
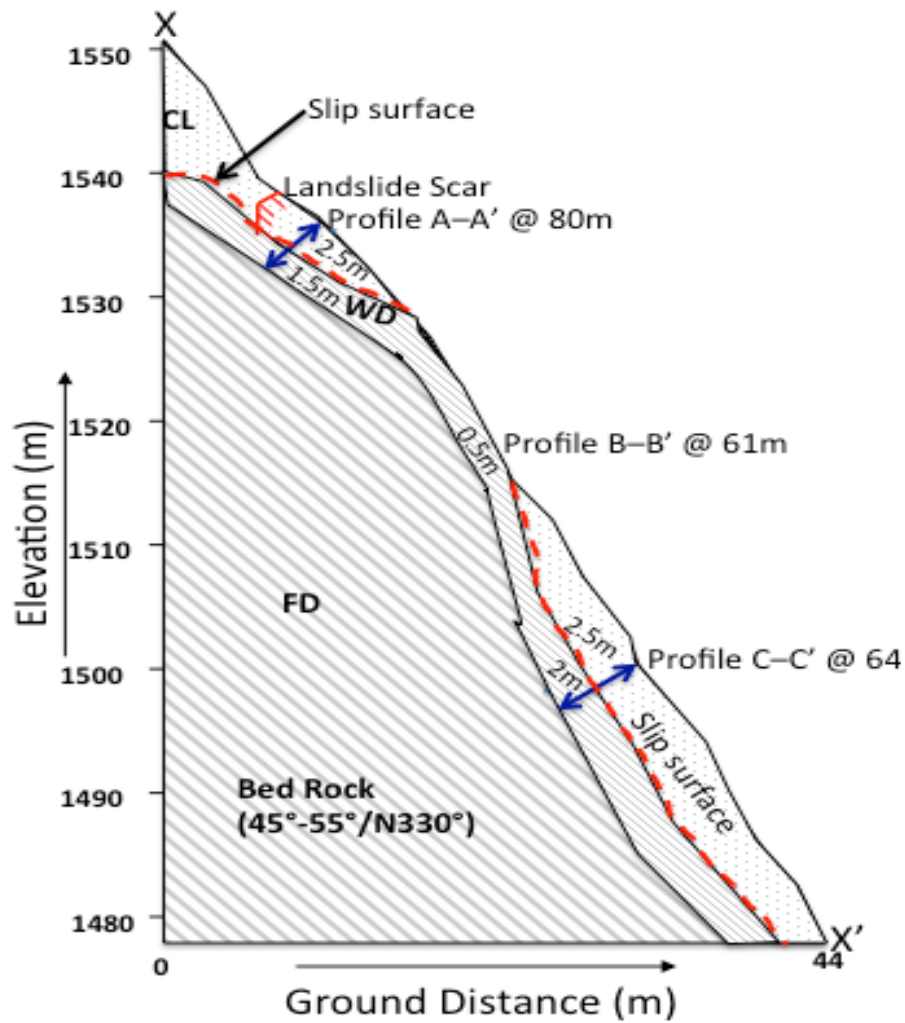


Electrical Resistivity Tomography (ERT)



Pre- and Post-monsoon ERT of Landslide

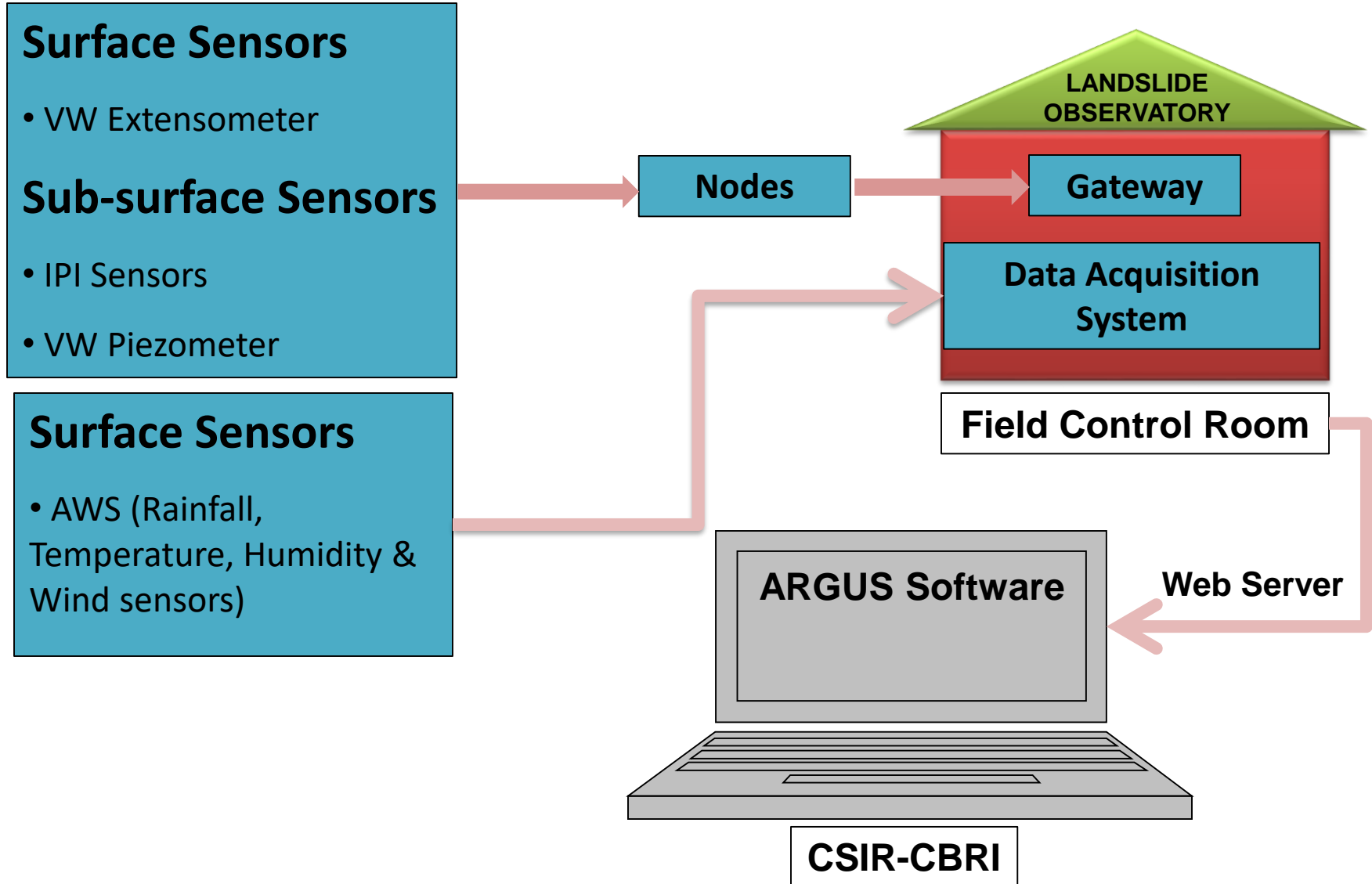




Numerical Modeling: Material Model & Properties

	1 st Case	2 nd Case
Top Soil	<p>Material model: Mohr-Coulomb</p> $\tau = c + \sigma_n \tan\phi$ <p>Elastic properties (Griffiths 1998): Elastic modulus (E) = 105 kN/m² Poisson's ratio (ν) = 0.3</p>	<p>Material model: Mohr-Coulomb</p> $\tau = c + \sigma_n \tan\phi$ <p>Elastic properties (Griffiths 1998): Elastic modulus (E) = 105 kN/m² Poisson's ratio (ν) = 0.3</p>
Bottom Soil	<p>Material model- Generalized Hoek-Brown</p> $\sigma_1 = \sigma_3 + \sigma_{ci} \left((m_b * \sigma_3 / \sigma_{ci}) + s \right) a$ $m_b = m_i \exp\left(\frac{GSI - 100}{28 - 14D}\right)$ $s = \exp\left(\frac{GSI - 100}{9 - 3D}\right)$ $a = 1/2 + 1/6 + \left(e^{\frac{-GSI}{15}} - e^{\frac{-20}{3}} \right)$ <p>D=0 (Natural Slope)</p> <p>Strength and elastic properties: GSI = 15, UCS (σ_{ci}) = 3 MPa, m_i = 9, E = 0.4 GPa and ν = 0.3 (Marinos-Hoek,2000 & Cai et.al., 2003)</p>	<p>Material model: Mohr-Coulomb</p> $\tau = c + \sigma_n \tan\phi$ <p>Elastic properties (Griffiths 1998): Elastic modulus (E) = 105 kN/m² Poisson's ratio (ν) = 0.3</p>
Bed Rock	<p>Material model- Generalized Hoek-Brown</p> $\sigma_1 = \sigma_3 + \sigma_{ci} \left((m_b * \sigma_3 / \sigma_{ci}) + s \right) a$ <p>Strength and elastic properties: GSI = 60, UCS (σ_{ci}) = 90 MPa, m_i = 9, E = 10.7 GPa and ν = 0.25 (Marinos-Hoek,2000 & Cai et.al., 2003)</p>	<p>Material model- Generalized Hoek-Brown</p> $\sigma_1 = \sigma_3 + \sigma_{ci} \left((m_b * \sigma_3 / \sigma_{ci}) + s \right) a$

Wireless Landslide Instrumentation & Real Time Monitoring System

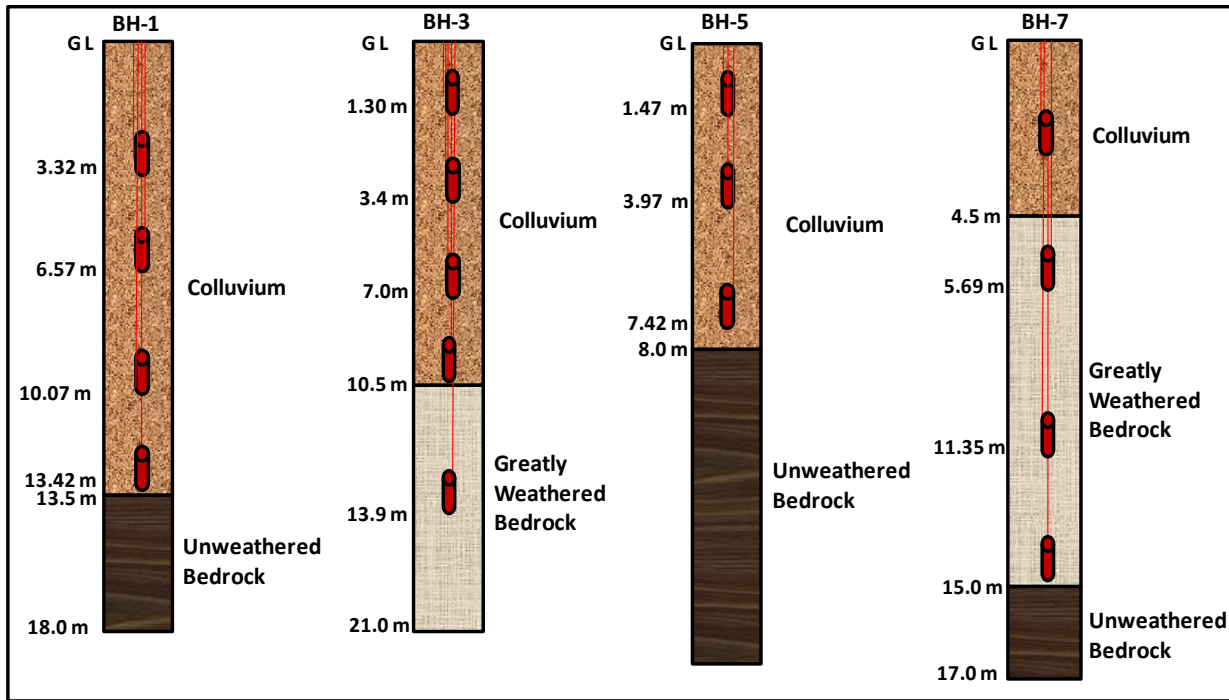


LANDSLIDE OBSERVATORY

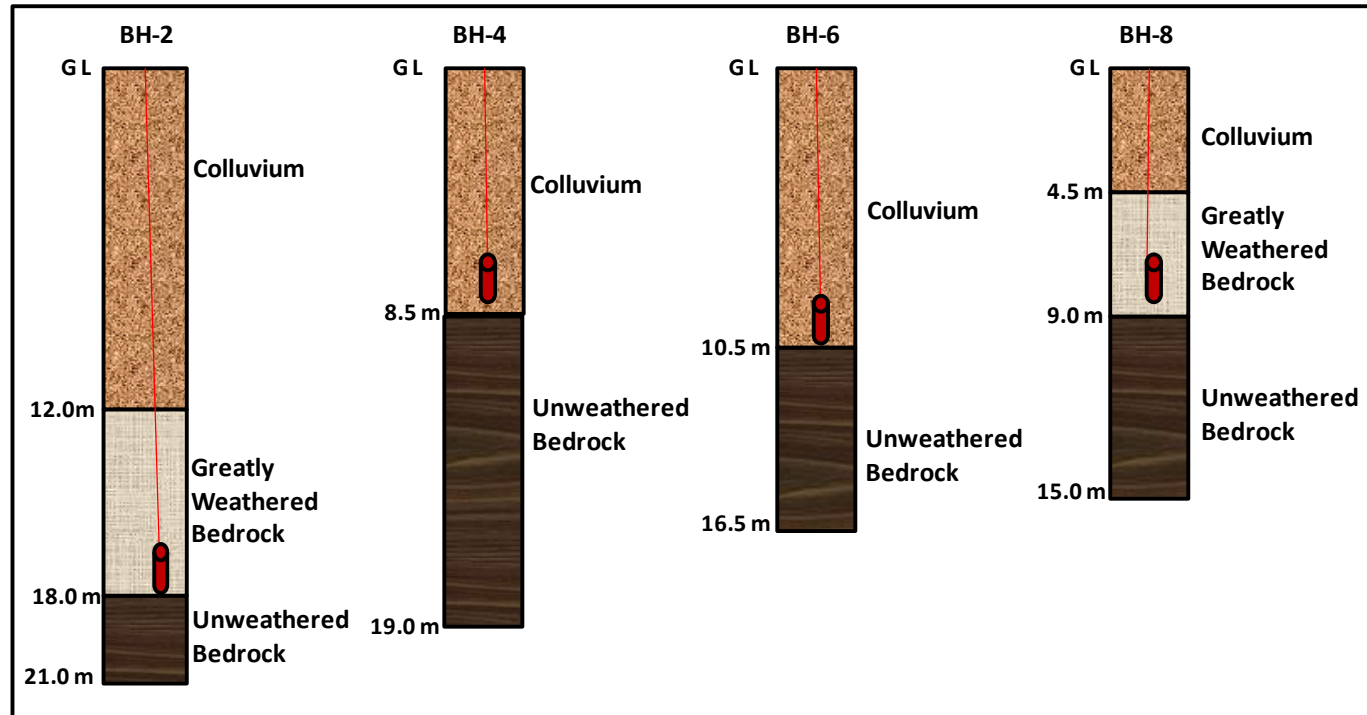
Pakhi Landslide (Pipalkoti)



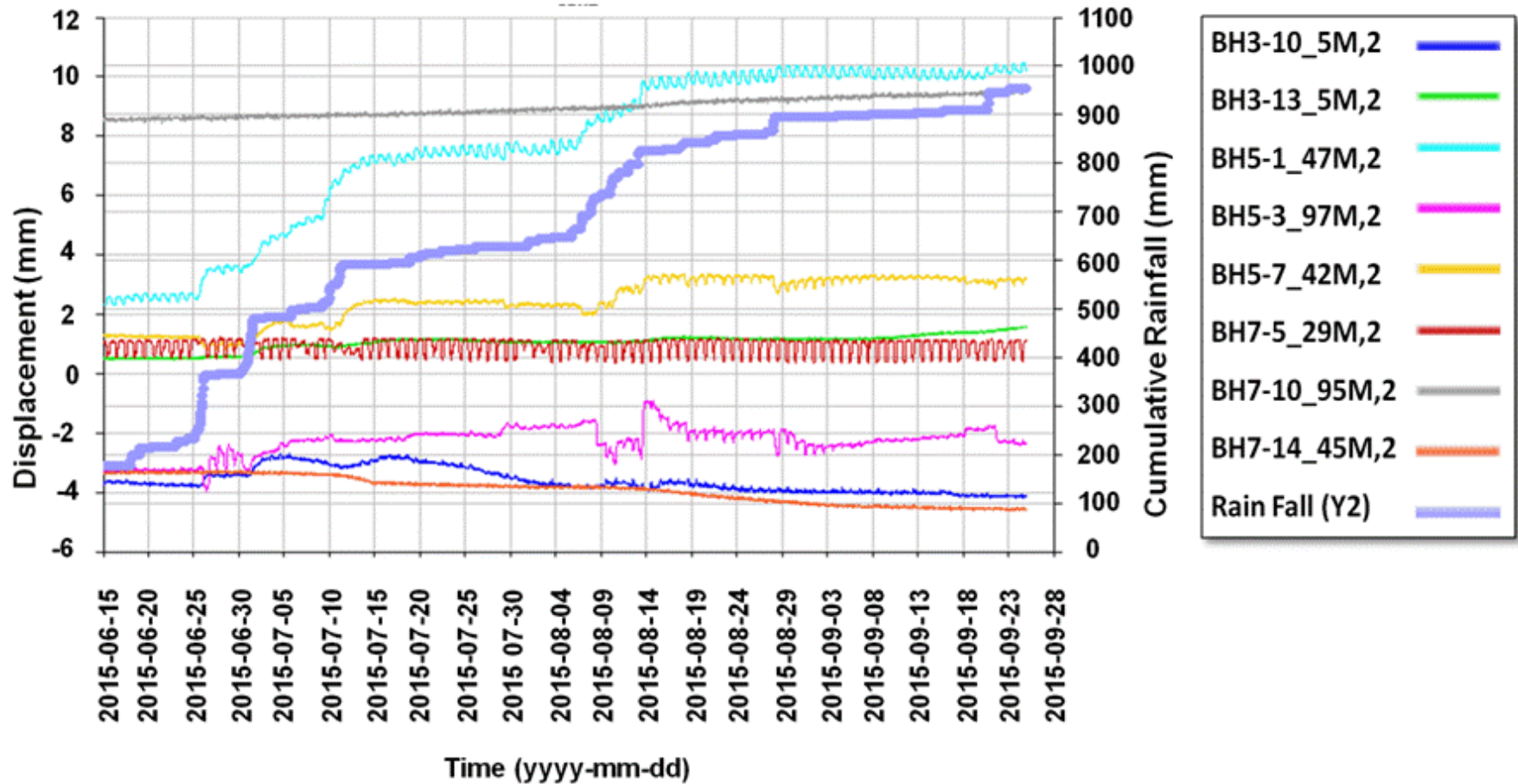
IPI Sensors



VWP Sensors

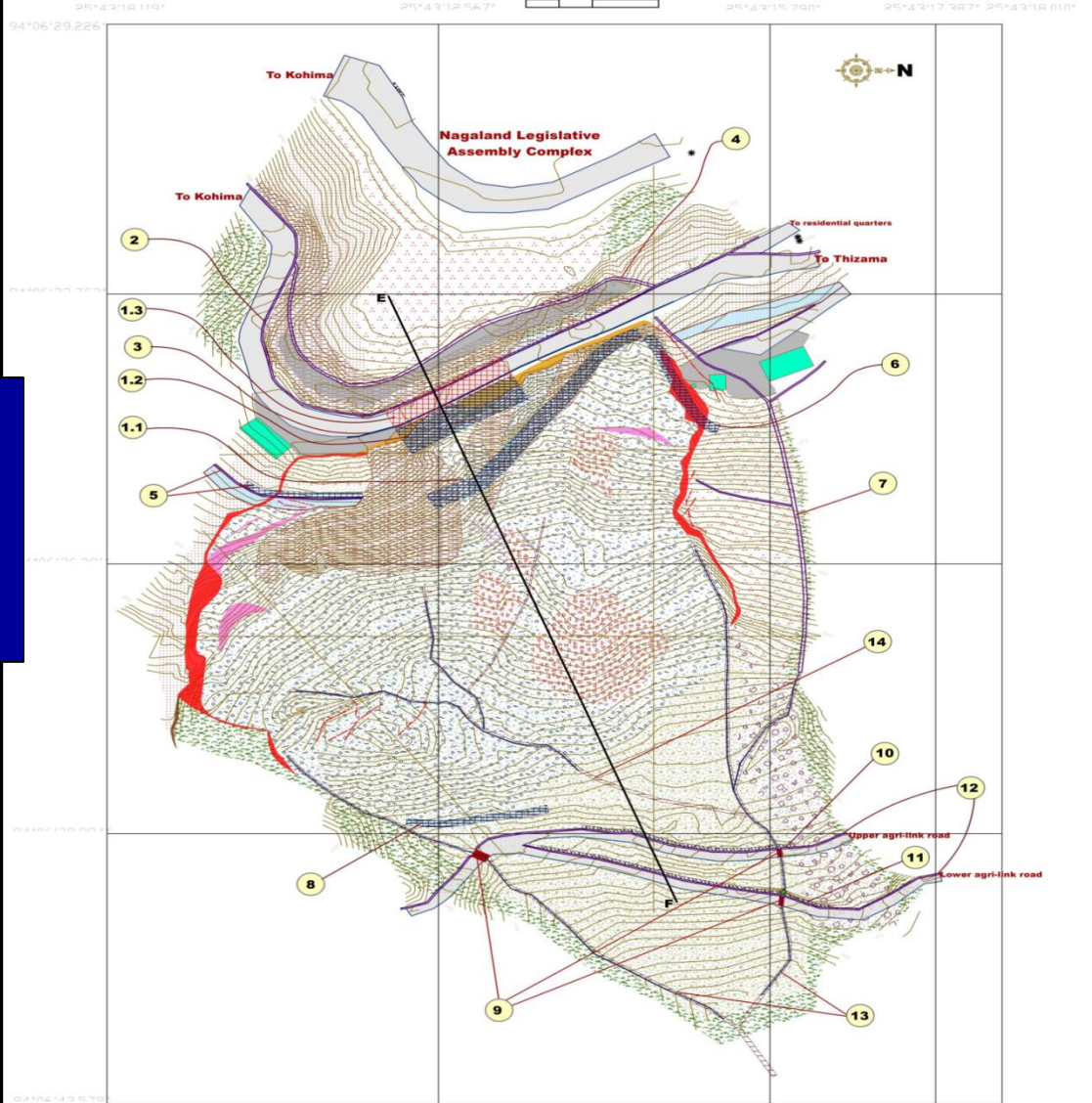


Cumulative displacement (mm) as observed from IPI sensors (B-axis) in boreholes during monsoon period



Geological Map of the Landslide on the eastern downslope of the Nagaland Legislative Assembly Complex, Kohima showing the recommended remedial measures

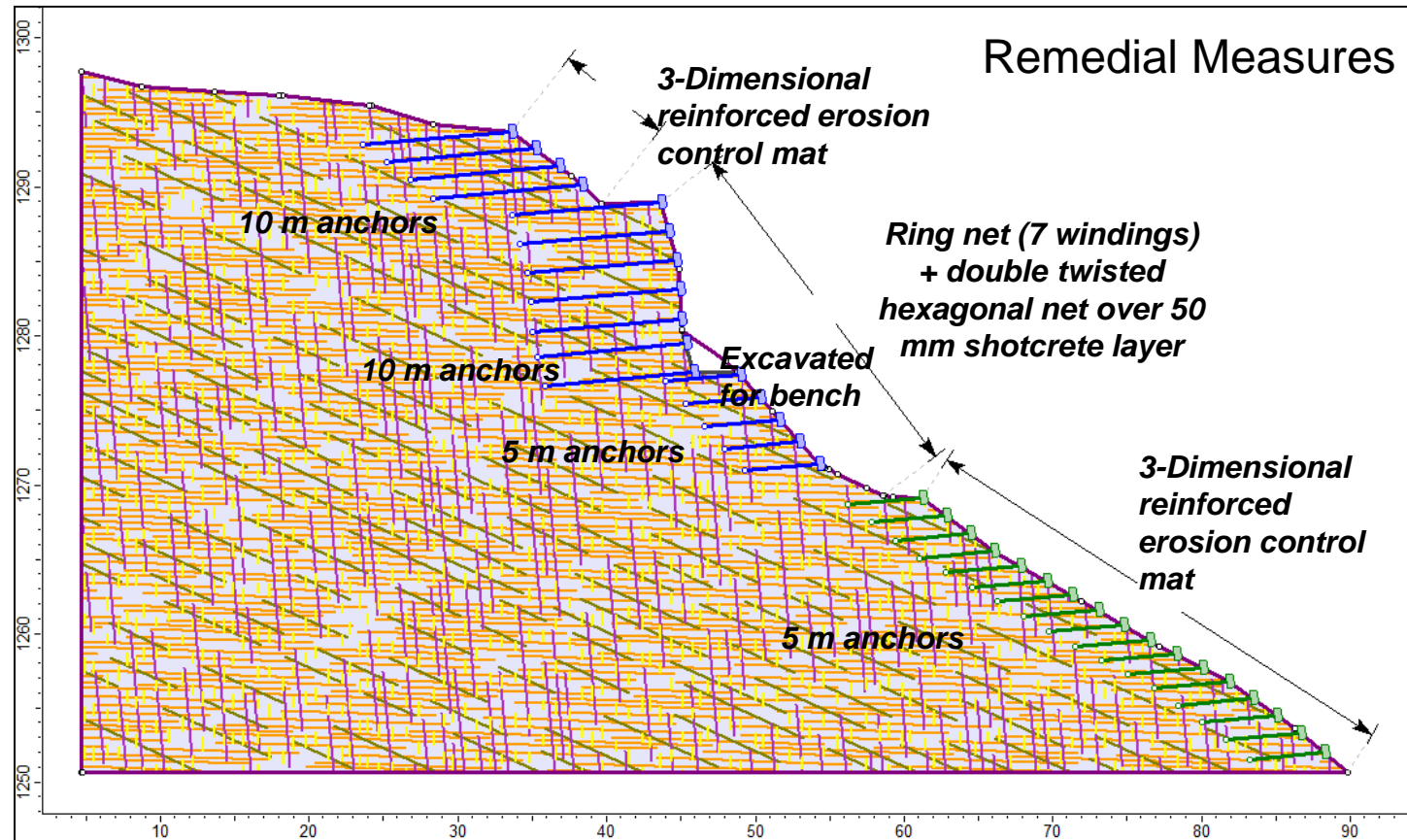
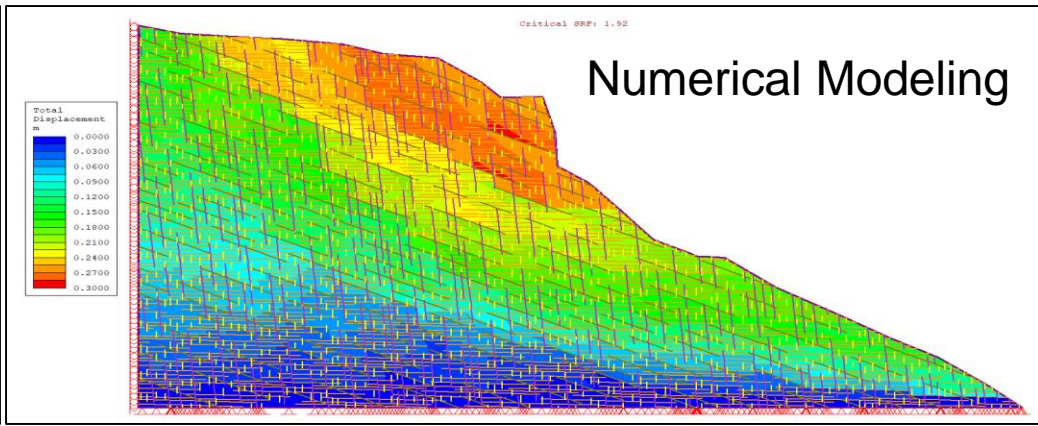
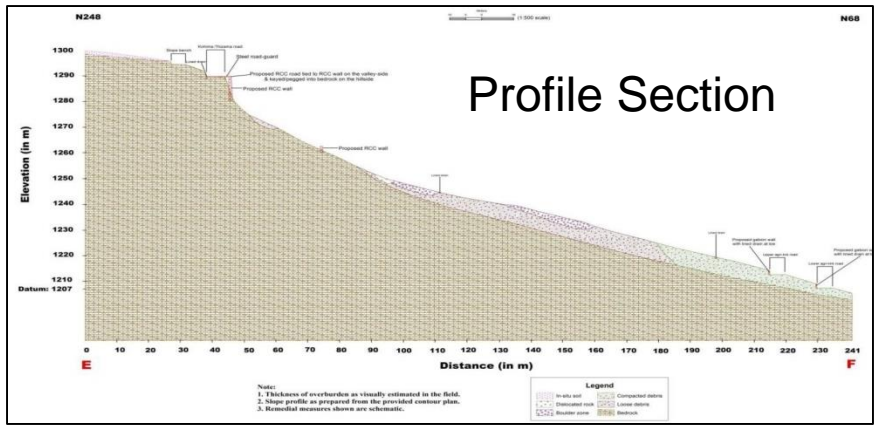
Meters
20 10 0 20



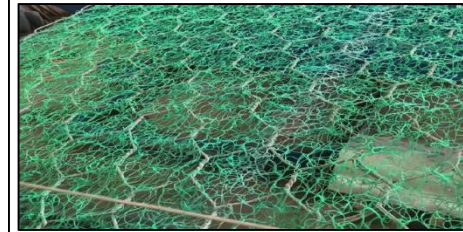
Nagaland Legislative Assembly Complex Landslide, Kohima

Legend (Remedial Measures)

	RCC road (raft foundation)		Stream training
	Culvert		Road guard-wall
	Lined drains		
	Gabion wall		
	Retaining wall (RCC/Concrete)		



Ring net

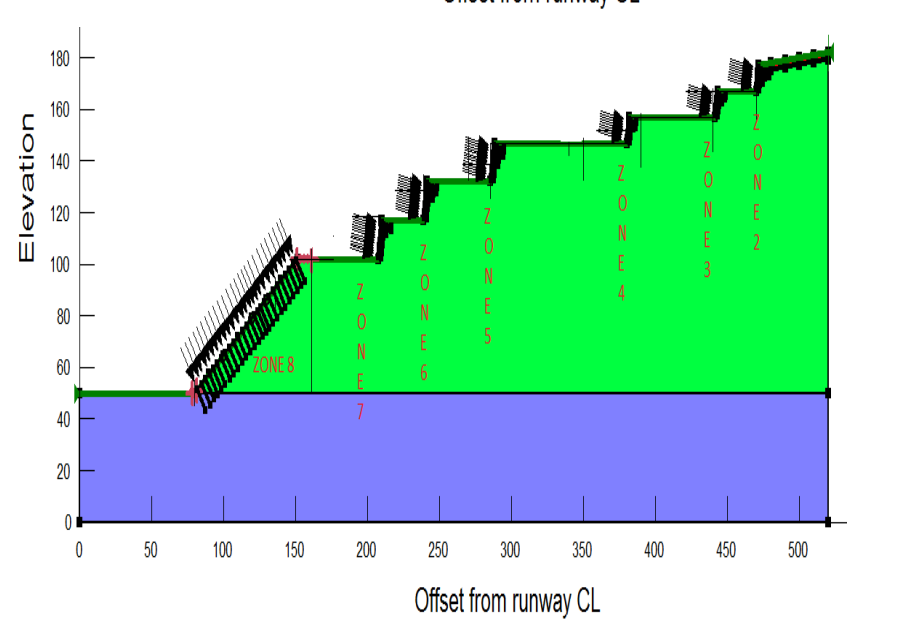
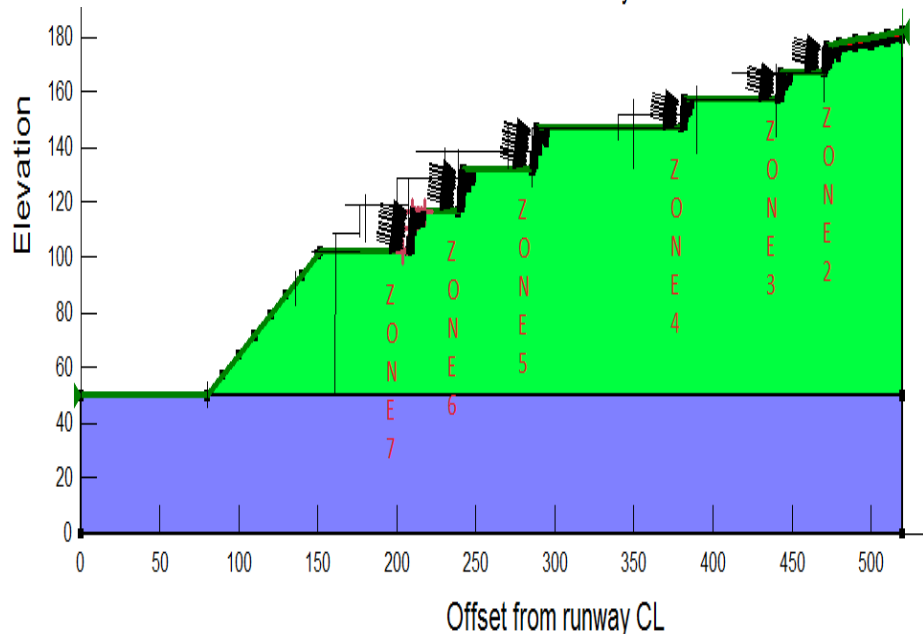
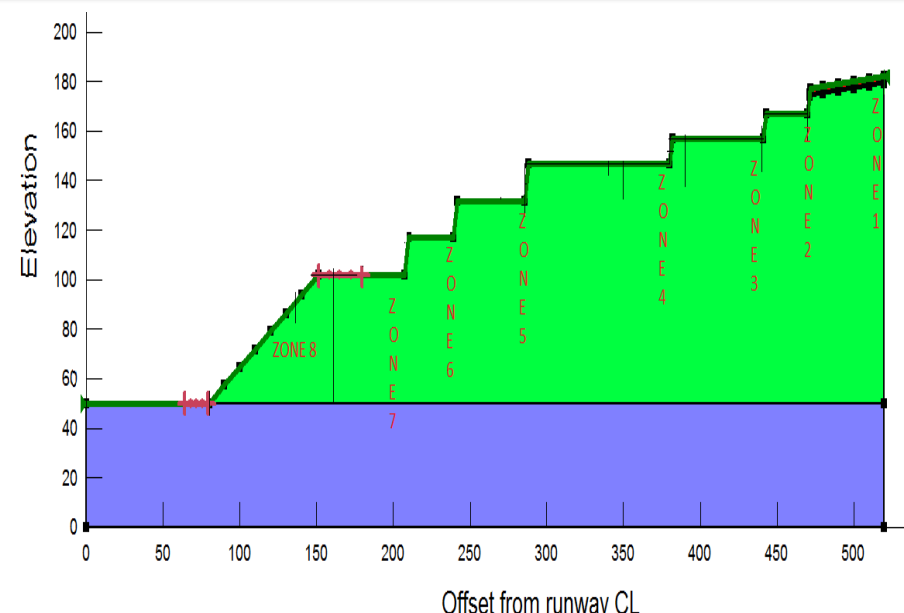
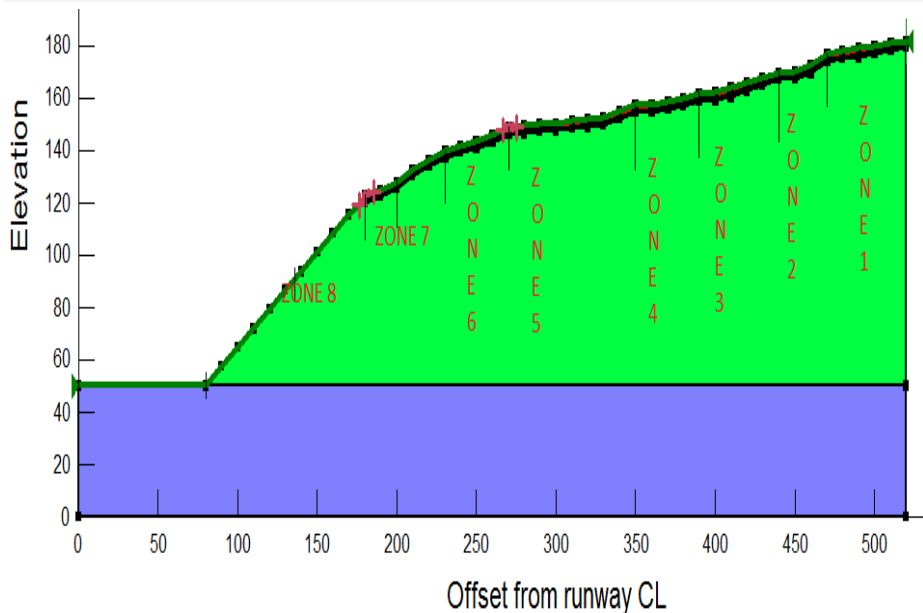


3-Dimensional reinforced erosion control mat

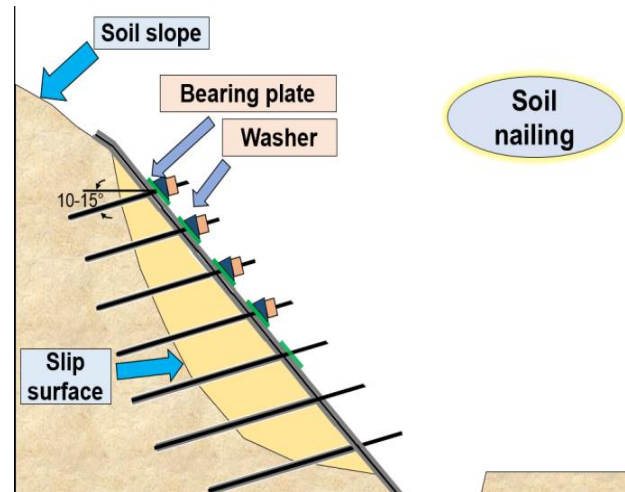
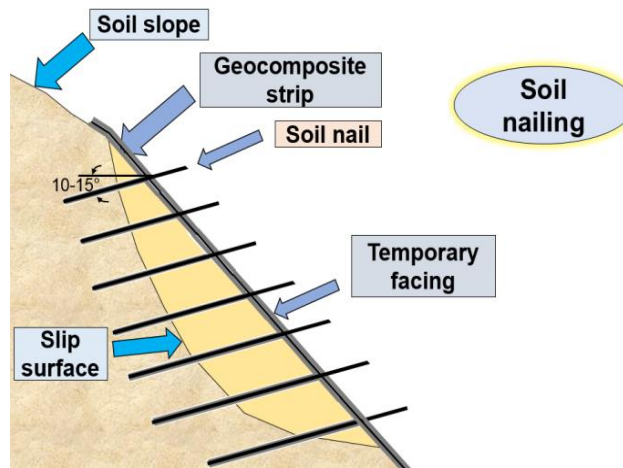
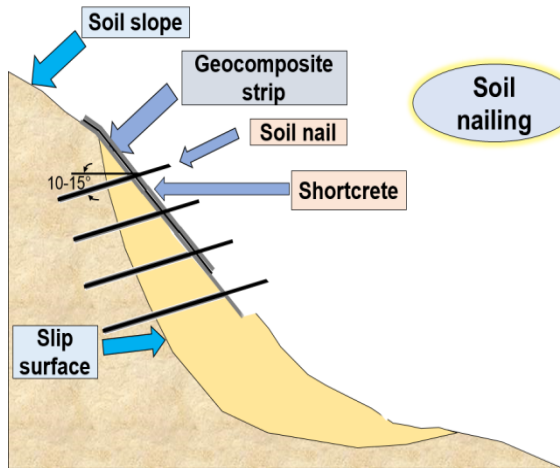
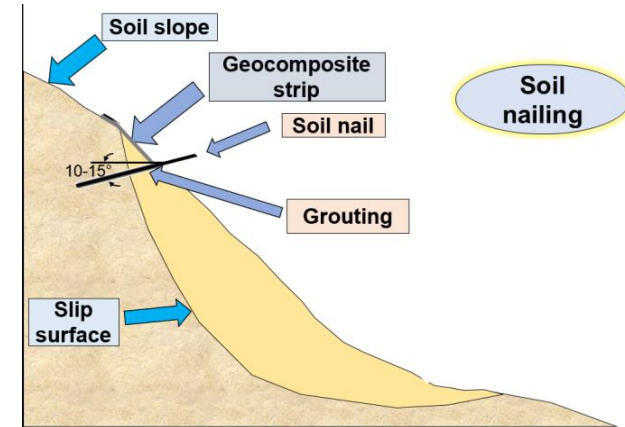
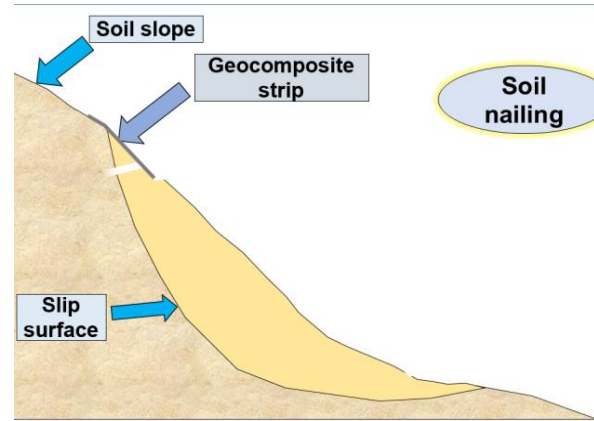
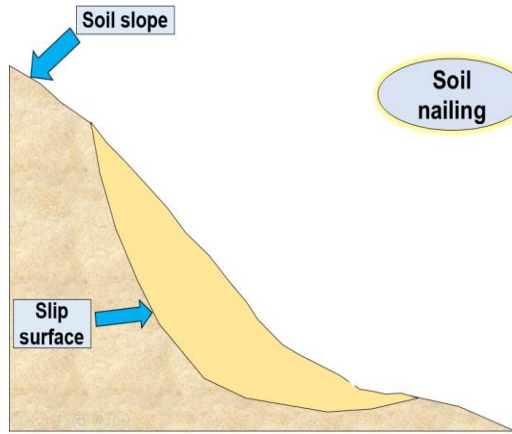
SLOPE STABILITY ASSESSMENT AND REMEDIAL MEASURE FOR PAKYONG AIRPORT, SIKKIM



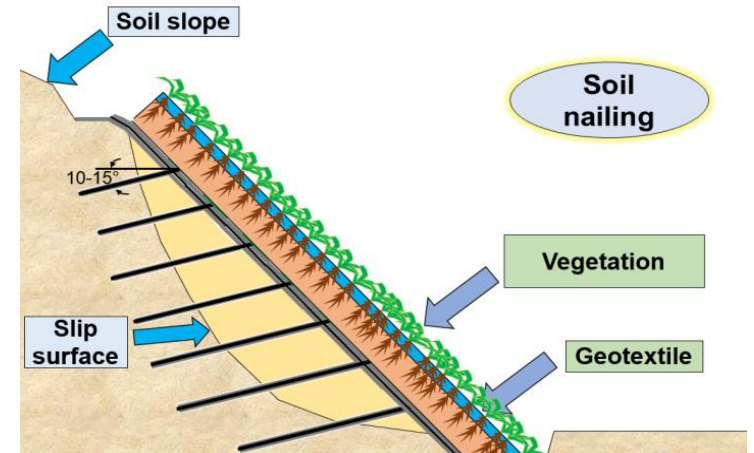
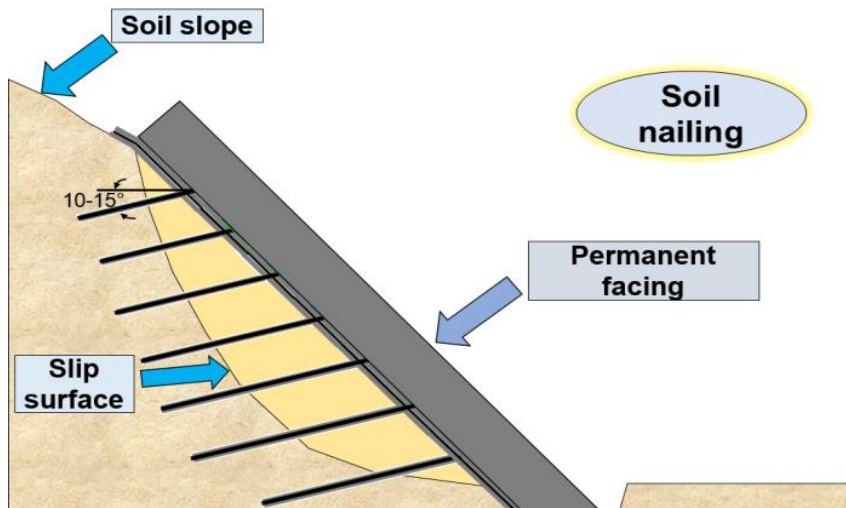
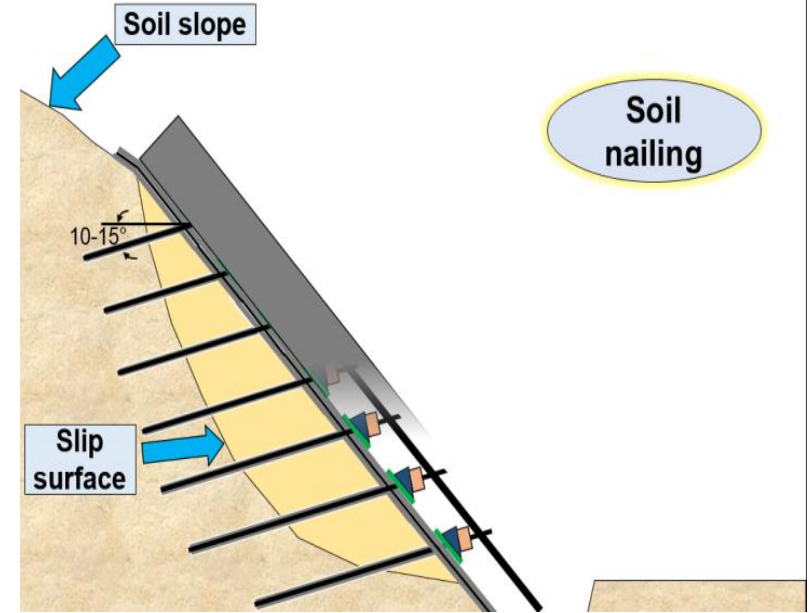
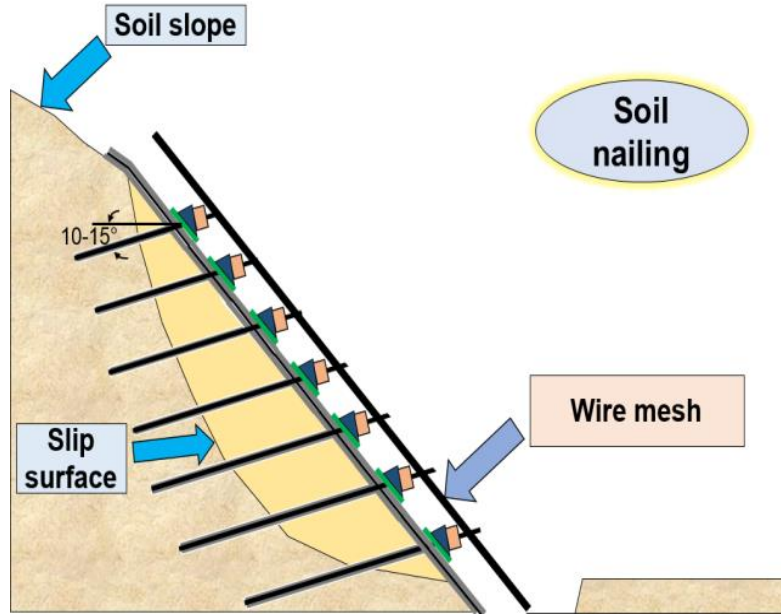
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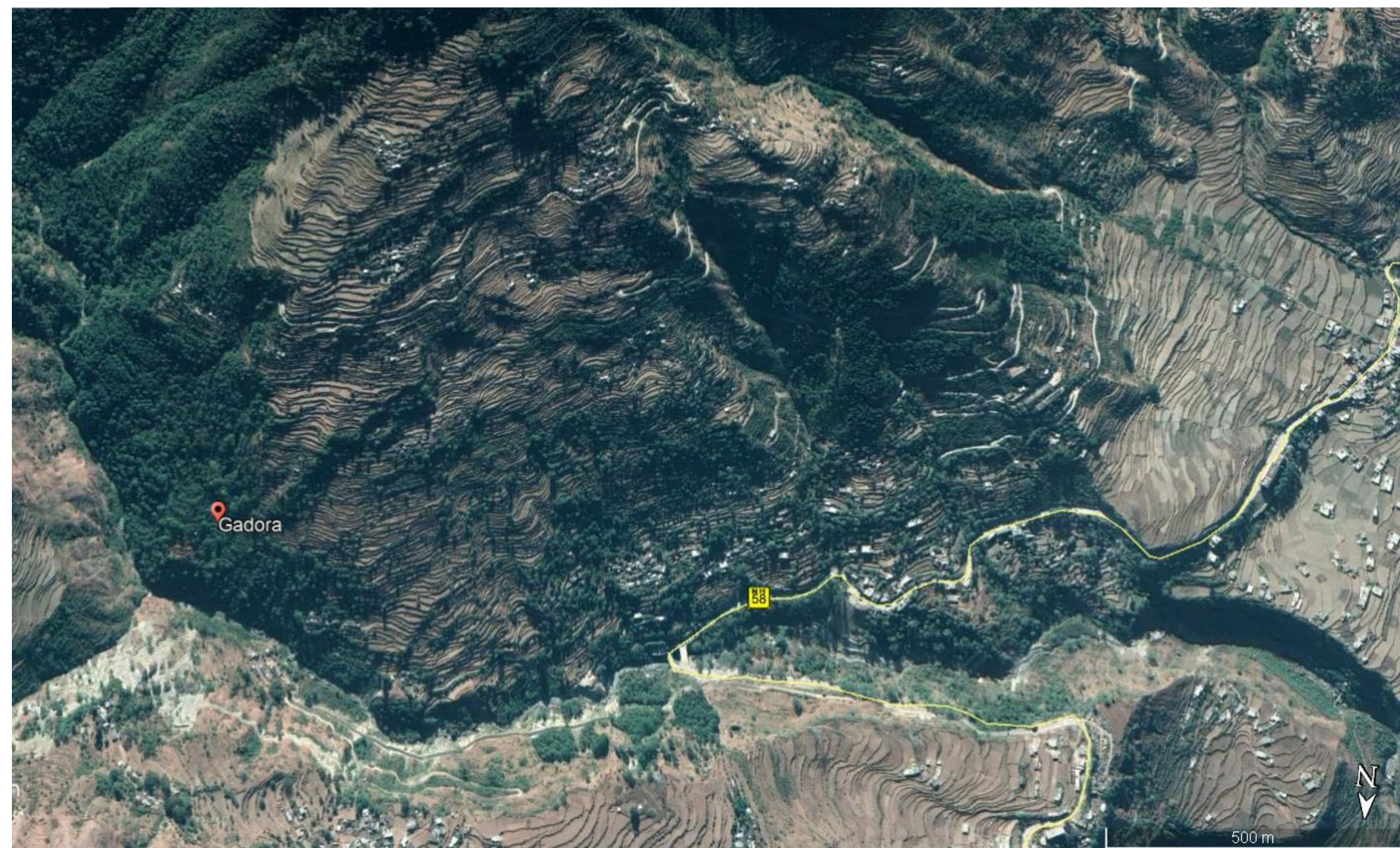
SLOPE STABILITY ASSESSMENT AND REMEDIAL MEASURE FOR PAKYONG AIRPORT, SIKKIM



SLOPE STABILITY ASSESSMENT AND REMEDIAL MEASURE FOR PAKYONG AIRPORT, SIKKIM



Gadora Village Subsidence Zone along NH-07 under Chardham Pariyojna



Gadora Village Subsidence Zone

- Old landslide accumulated debris
- Multiple transverse and longitudinal cracks witnessed
- Colluvial soil deposit/debris overburden above in-situ rock
- Terrace cultivation infers localized aquifer/water charged area.
- Water seepage on slope
- Loaded with building infrastructure
- Subsidence zone (creep movement)

Gadora Village Subsidence Zone



Gadora Village Subsidence Zone



Possible Remedies (Gadora Village Subsidence Zone)

- **Planning and Design of remedial measures**
 - **Multi-level measures – starting from valley side through road level up to crown of the landslide**
 - **Retaining structures – Road & Valley side**
 - ✓ **RCC retaining wall/Piling/Gabion wall**
 - **Terracing on slope with soil nailing/retaining structures**
 - **Drainage measures –**
 - **Catch water drain/collection drain**
 - **Drainage well/Inclined radial sub-surface drain (pressure relief)**

Pagal Nala (Tangni) Landslide along NH-07 under Chardham Pariyojna



- Uncontrollable Landslide
- Bridge is the only option to avoid the landslide

Congratulations NHIDCL for Right Decision

Pagal Nala (Tangni) Landslide



Loose Rock Boulders at Landslide Source Area

THANK YOU

