Reduction of Landslide Risk in Sri Lanka

Part 4 - Mitigation of Landslide Risk by Multiple Measures- Case Histories from; Southern Expressway, Ginigathhena and Kahagolla

Time Capsule project of ISSMGE
Sri Lankan Geotechnical Society

Rectification of Slope Failures

If a slope has started to move, the means for stopping movement must be adapted to the processes which started the slide
- K Terzaghi , 1950

Landslide Remedial Measures

- Modification of slope Geometry
- Drainage
- Retaining Structures
- Internal Slope Reinforcement

Use of Structural Measures

In some sloping grounds further external support in the form of,

- Earth Retaining Structure or
- Internal Stabilizing Systems such as Soil nailing

would be necessary, in addition to the drainage measures.

This cut for a bypass road in the Southern expressway was supported by gravity wall at the toe in addition to surface drainage measures. With that the house at the crest could be saved.

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Construction of a Mass Concrete wall to support a cutting in the CKE – Approach to the underpass at A3.

The soil in the cut is a strong lateritic soils in an unsaturated state. It can remain stable under dry conditions but the wall was constructed and surface drainage was improved to ensure stability in all seasons

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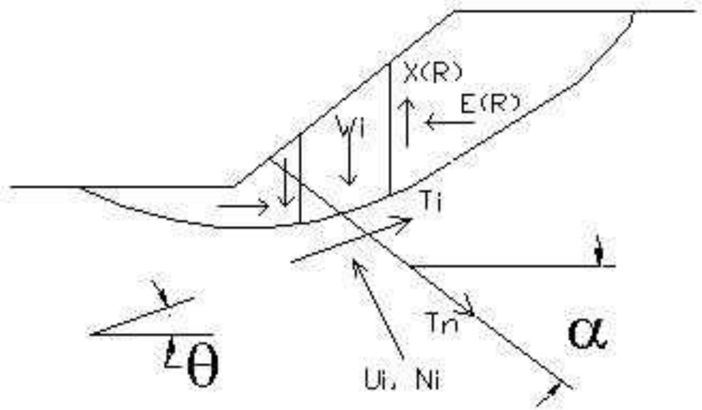
Gravity Walls with back batter Supporting an existing slope which is unstable during periods of heavy rain.
Drainage layer behind the wall and geotextile behind the drainage layer.

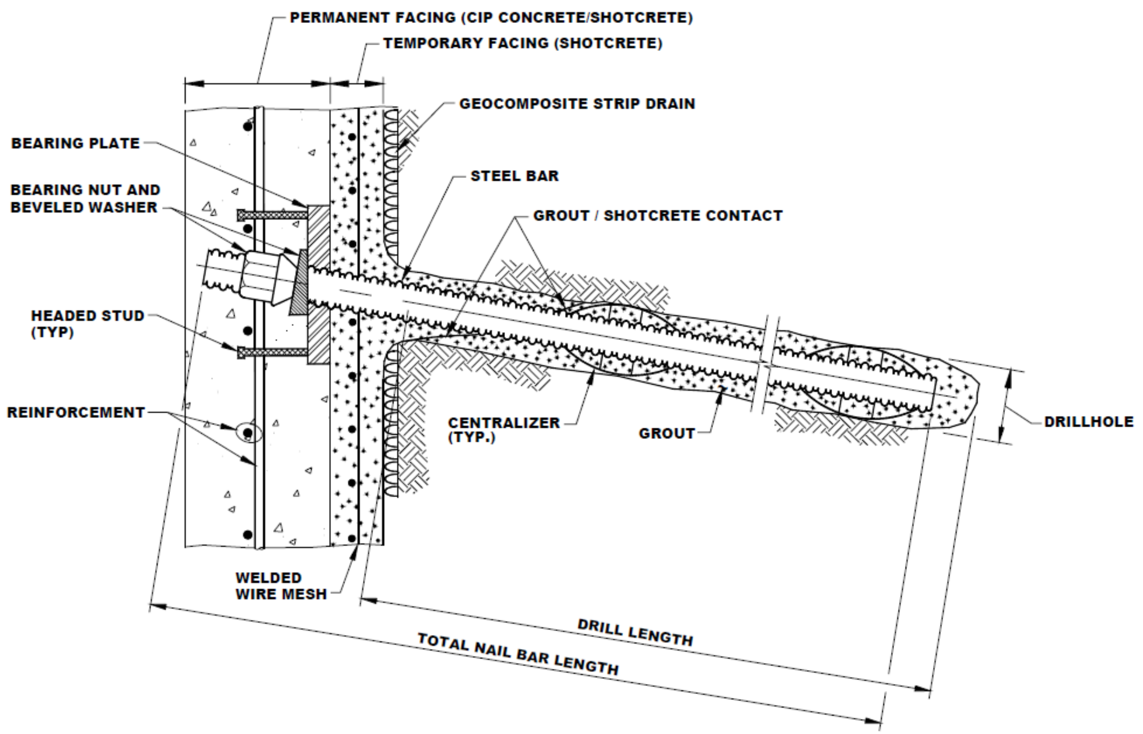
A surface drain was constructed behind the wall.

Internal Slope Reinforcement

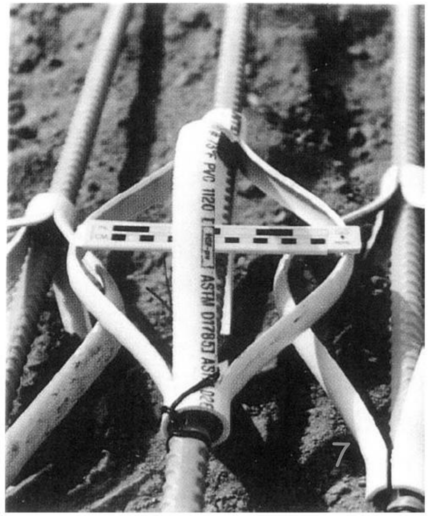
- Soil Nailing
- Anchors
  (pre-stressed)

Basic Mechanism





$$F = \frac{\sum\left\{\left[c'\Delta x_i + \left(w_i + Q_i - U_i\,\Delta x_i + T_N \sin\alpha\right)\tan\phi'\right]\left[{}^{1}\!/\!{}_{M_i(\theta)}\right]\right\}}{\sum\left[\left(w_i + Q_i\right)\sin\theta_i - T_{N,i}\cos\left(\theta_i + \alpha_i\right)\right]}$$



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Soil Nailing in the Southern Transport Development Project





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Drilling the hole, installing the nail and grouting, placement of reinforcement and shotcreting

Soil Nailing with a shotcrete facing

Improvement of surface drainage
A basin drain at the valley to collect all the water and direct that to a cascade drain

Nail heads are connected by beams.
In between, vegetation introduced by hydroseeding

Cut off drains at the crest of the slope

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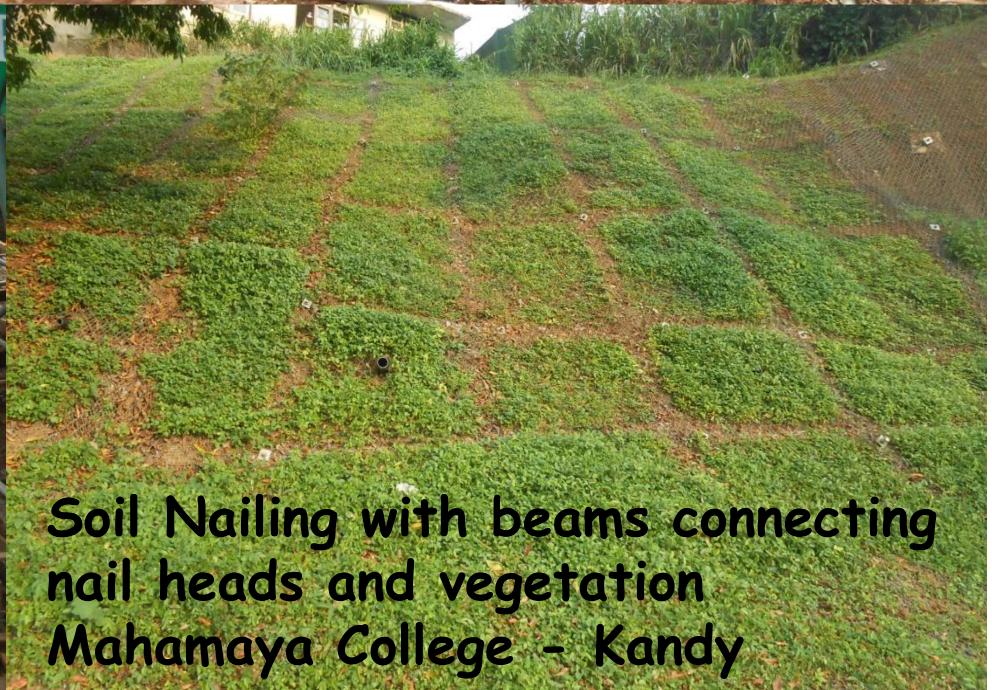
Portion of the slope covered with shotcrete as vegetation could not be established in the fractured rock with closely spaced joints.



Soil Nailing with beams connecting nail heads and vegetation
Mahamaya College - Kandy

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Current Trends

Surface protection that blends with the environment.

Isolated nail heads

- Vegetated facing is used for soil nailing in Kandy
- Mahiyangana road

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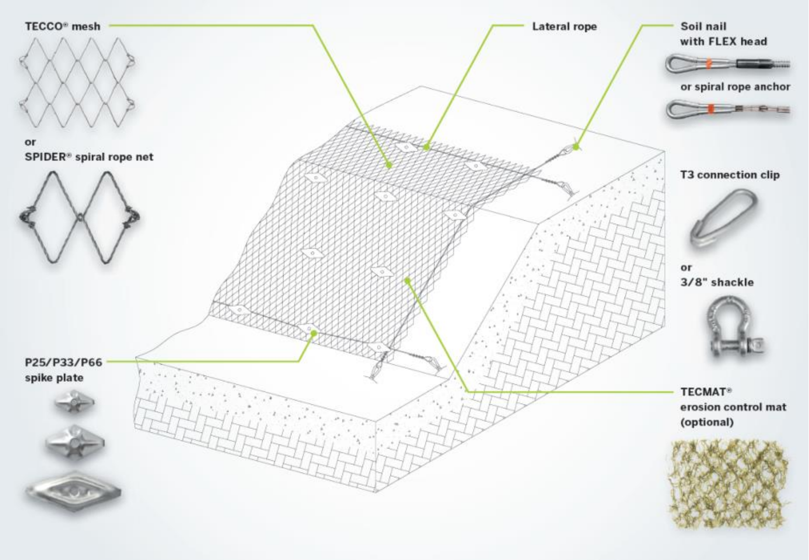
Protective net and coir mat introduced to provide surface cover by hydro seeding
Location 10 Kandy Mahiyangana Road

Nail heads connected with high tensile wire mesh and coir mesh for hydroseeding

Nail heads

Location 15 – Kandy Mahiyangana Road

Shotcreted facing



A commercial system, with spike plates replacing concrete nail heads and a net made of high tensile strength wire to combine nails and prevent local shallow failures

Erosion control mat will assist introduction of vegetation. Efficient installation process. Mesh can be pre tensioned to suit ground profile. Solution is both aesthetically pleasing and long lasting.

Initial tension cracks at 9AM

Landslide at Welipenna – Failure after adopting all drainage measures due to faulty surface drains- lack of maintenance

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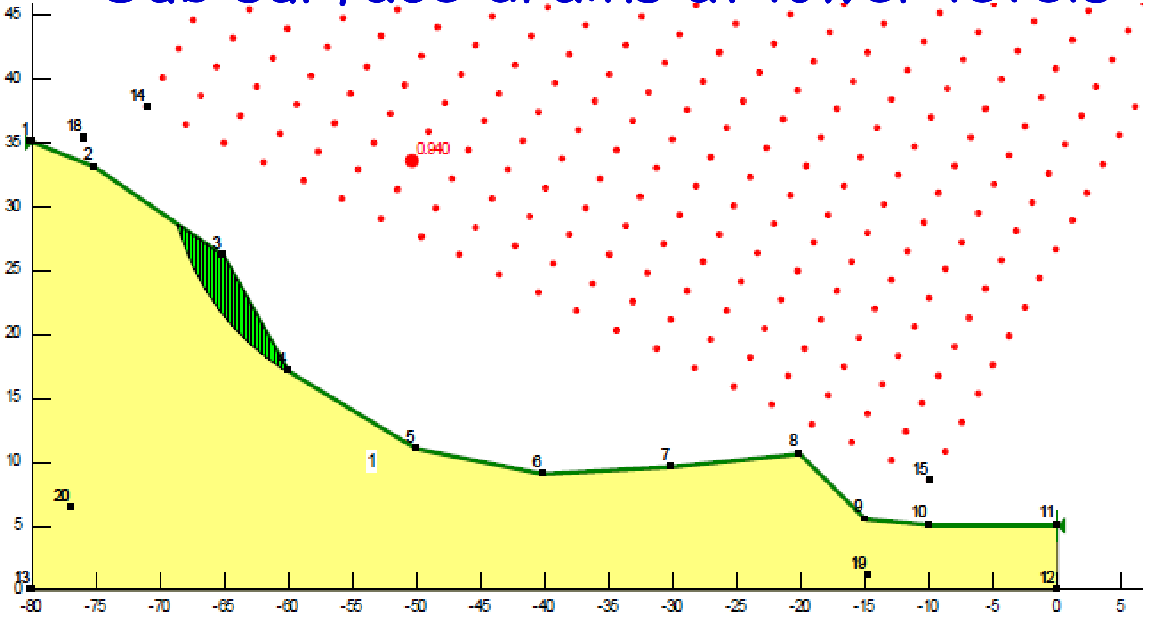
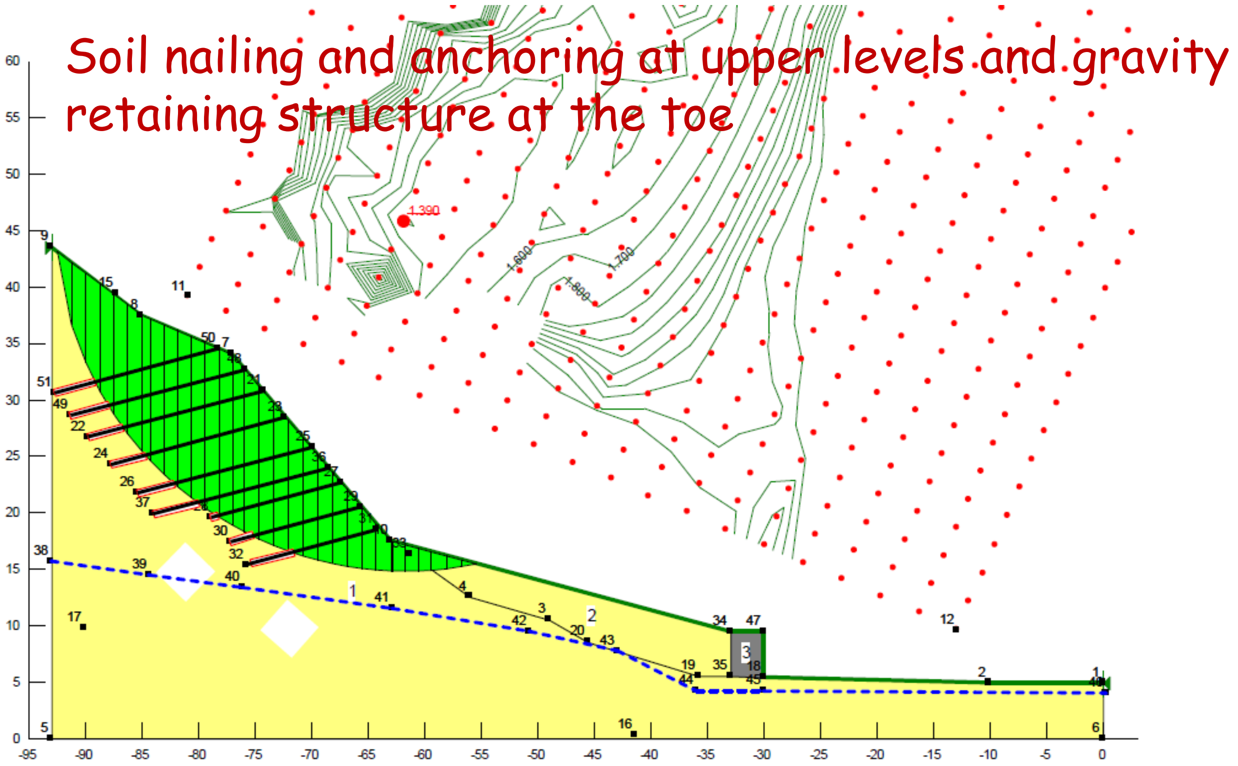
Scar left behind by the failure is unstable. Need to stabilize by multiple techniques

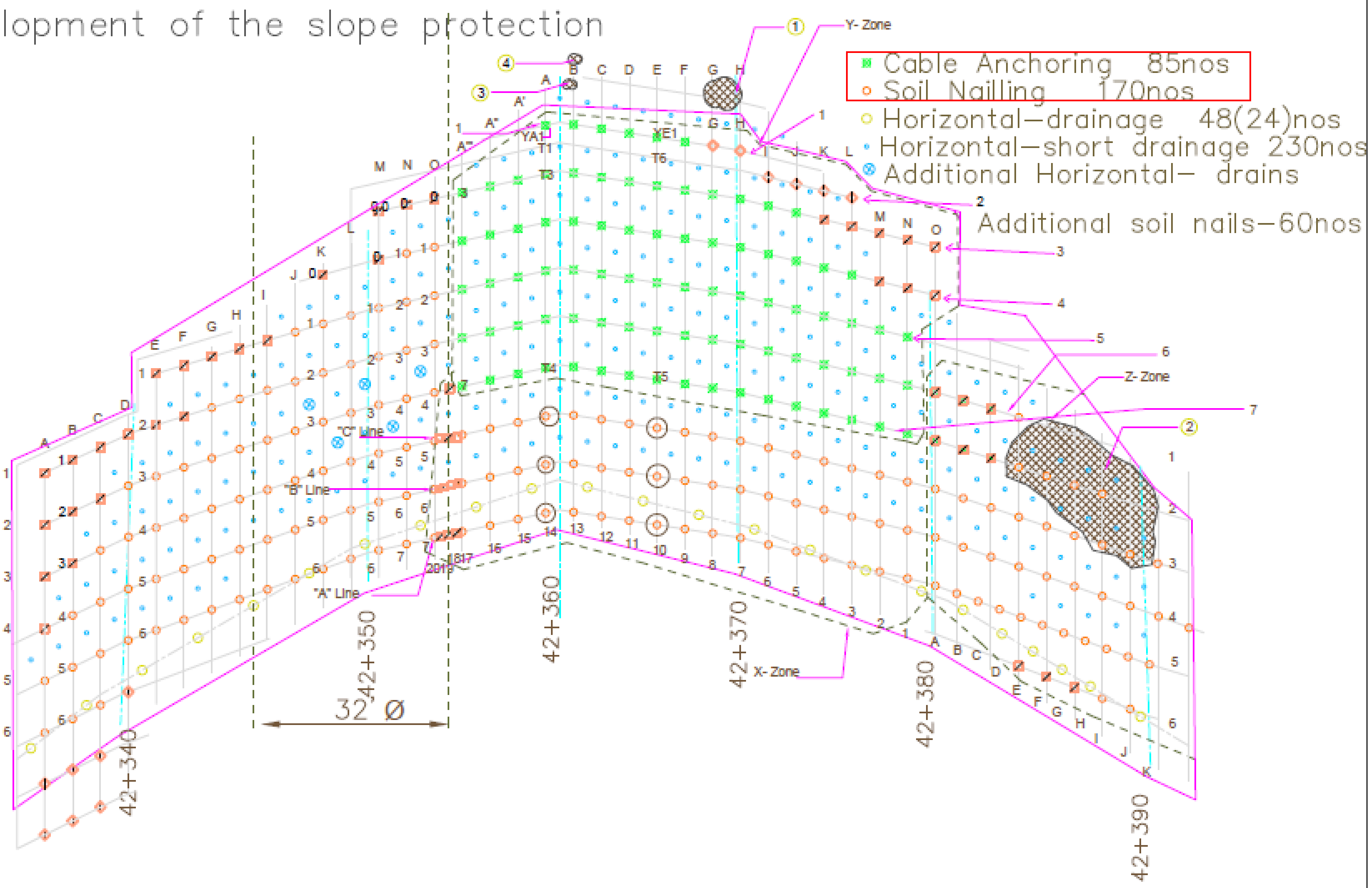
- Soil nailing and anchoring at upper level
- Gravity retaining structure at the toe
- Surface drainage –berm drains and cascade drains
- Sub surface drains at lower levels

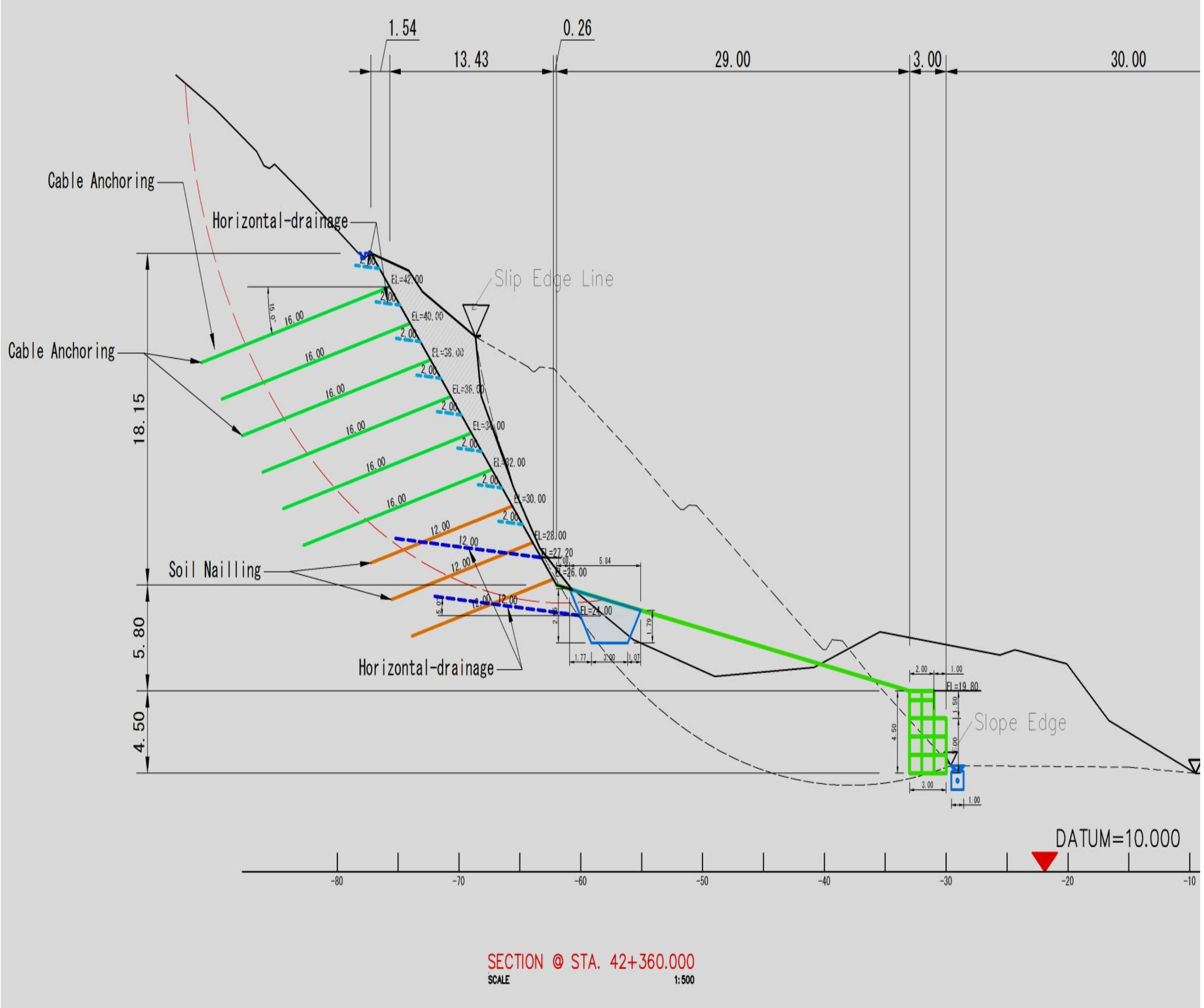




Soil nailing and anchoring at upper levels and gravity retaining structure at the toe

Development of the slope protection





1.54
0.26
13.43
29.00
3.00
30.00
Cable Anchoring
Horizontal-drainage
Slip Edge Line
Cable Anchoring
18.15
Soil Nailling
5.80
Horizontal-drainage
4.50
Slope Edge
DATUM=10.000
-80
-70
-60
-50
-40
-30
-20
-10
SECTION @ STA. 42+360.000
SCALE 1:500

Final Tensioning of the Cable Anchor – Note that a precast concrete bearing plate and a steel plate are placed

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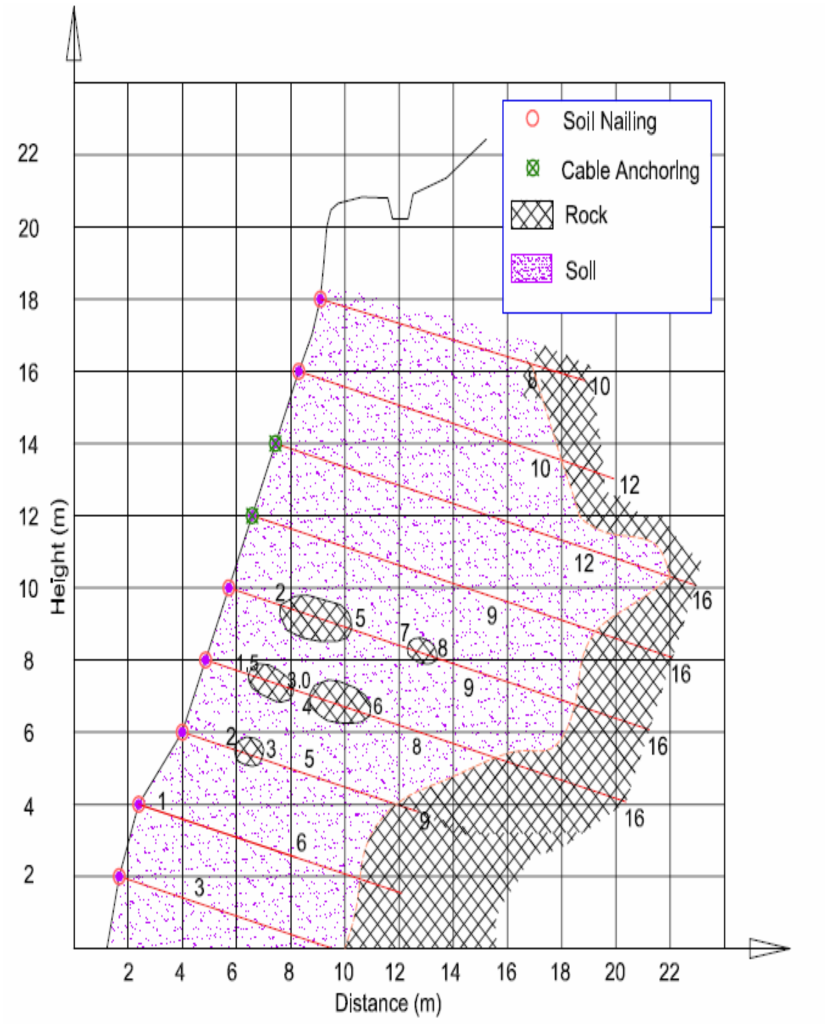
Field observations during drilling and grouting



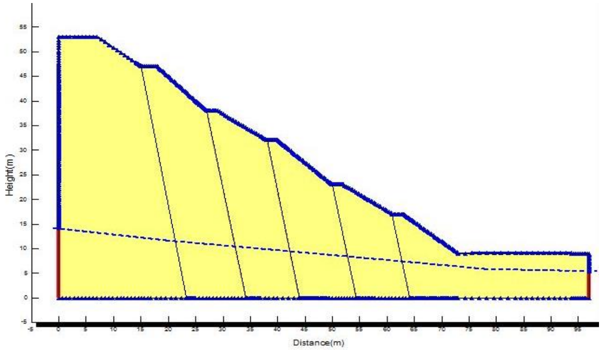
Boudinage Structures were encountered during the drilling for nailing and cable anchors

Typical drilling records indicating

boudinage structures

Pattern of relict joints identified during drilling

- **Construction sequence**
  Drilling for sub horizontal drains should be done only after the grouting of nailed holes



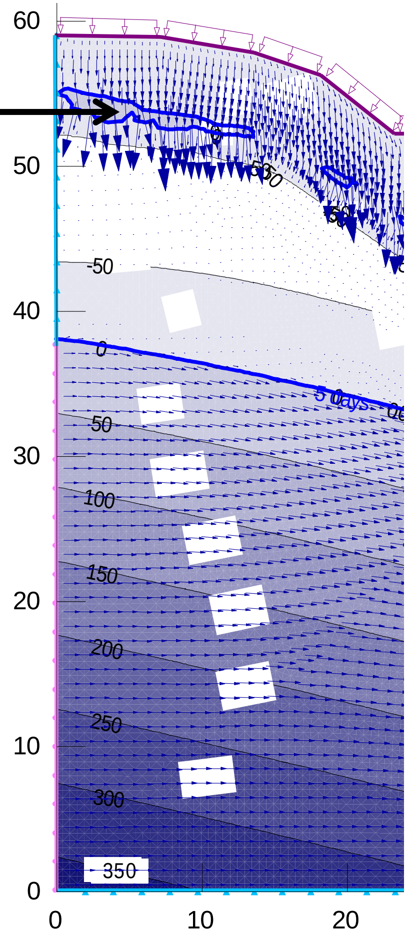
- Water gushed out during the drilling due to high pressure built up(worker covered in mud)
- During the grouting of boreholes after placement of nails, the grout was coming out from non grouted holes.
- The volume of grout used was much greater than the volume of holes which indicates that the systems of joints are interconnected.

Infiltration through relict joints is much higher than the infiltration through soil slope. (Idirimanna and Kulathilaka 2020)

It reveals with following diagrams. (The arrow size represents the intensity of the infiltration)

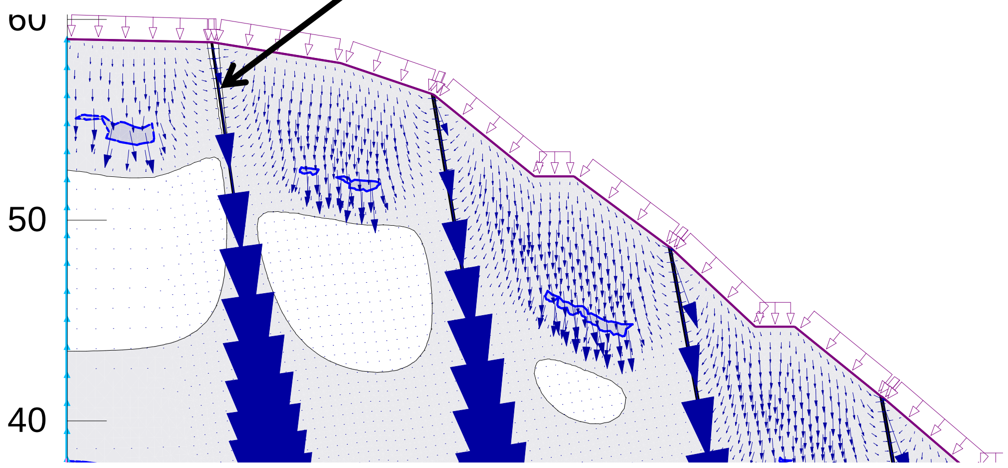
Without relict joints

Development of perched water table

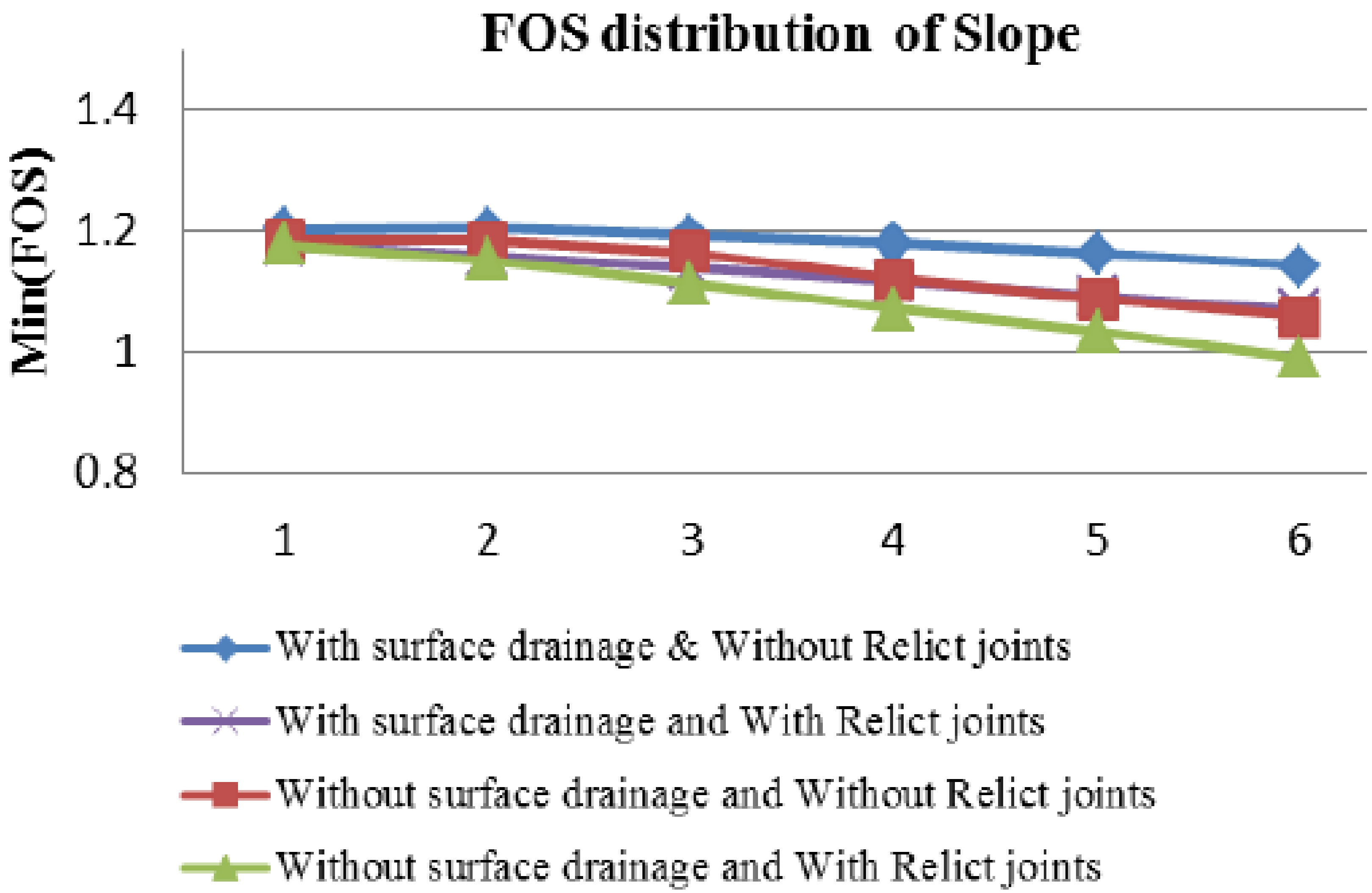


With relict joints

Water infiltration through relict joints



Reduction of FOS of the Slope with rainfall under different conditions



After completion of rectification work

Rectification of Ginigathhena Landslide

Excavation at the toe to widen the road reactivated the landslide Propagated further with the subsequent rainfall

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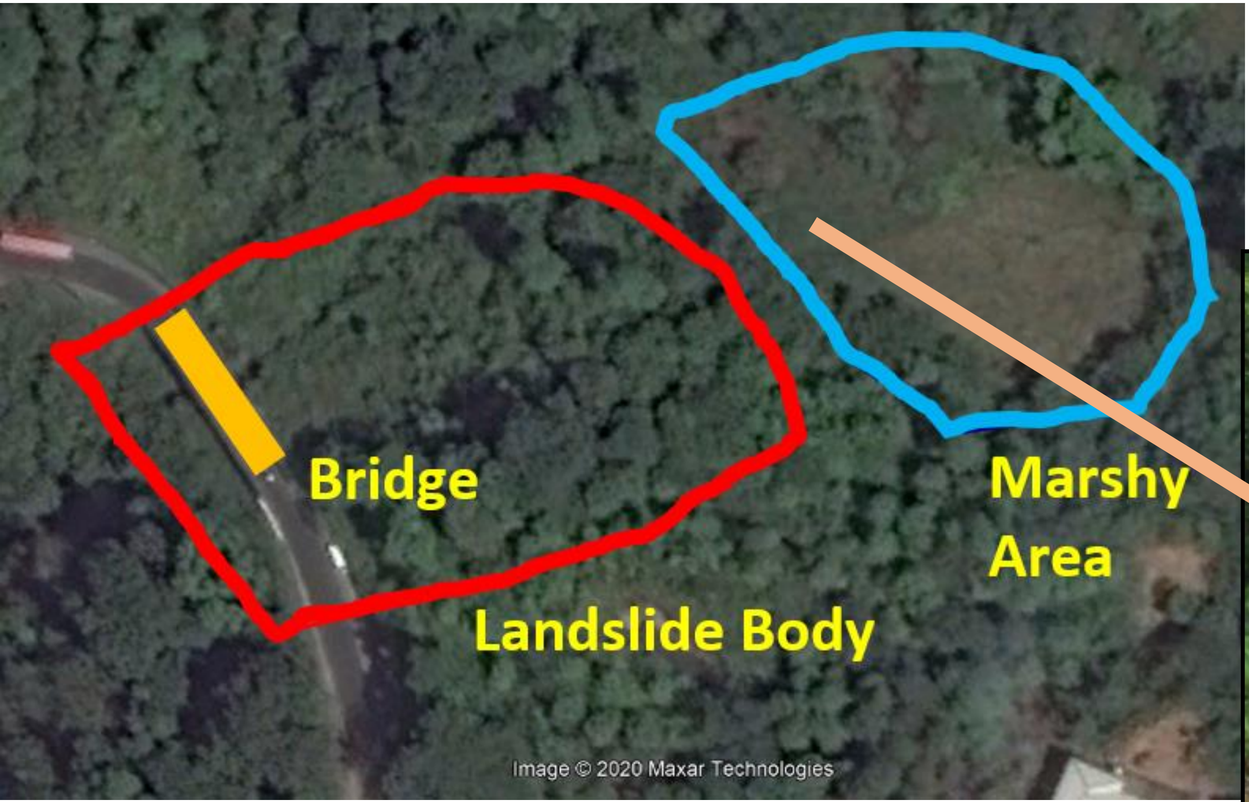
Ginigathhena Landslide

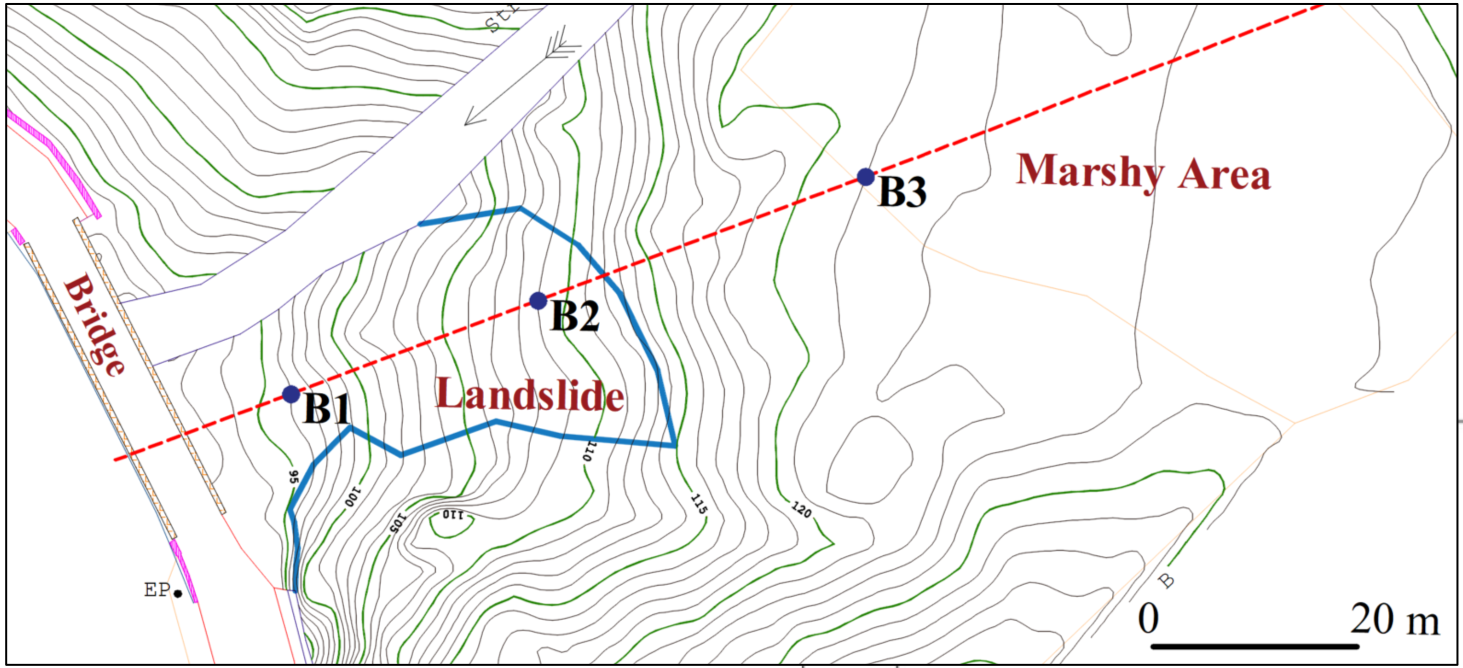


Area Map

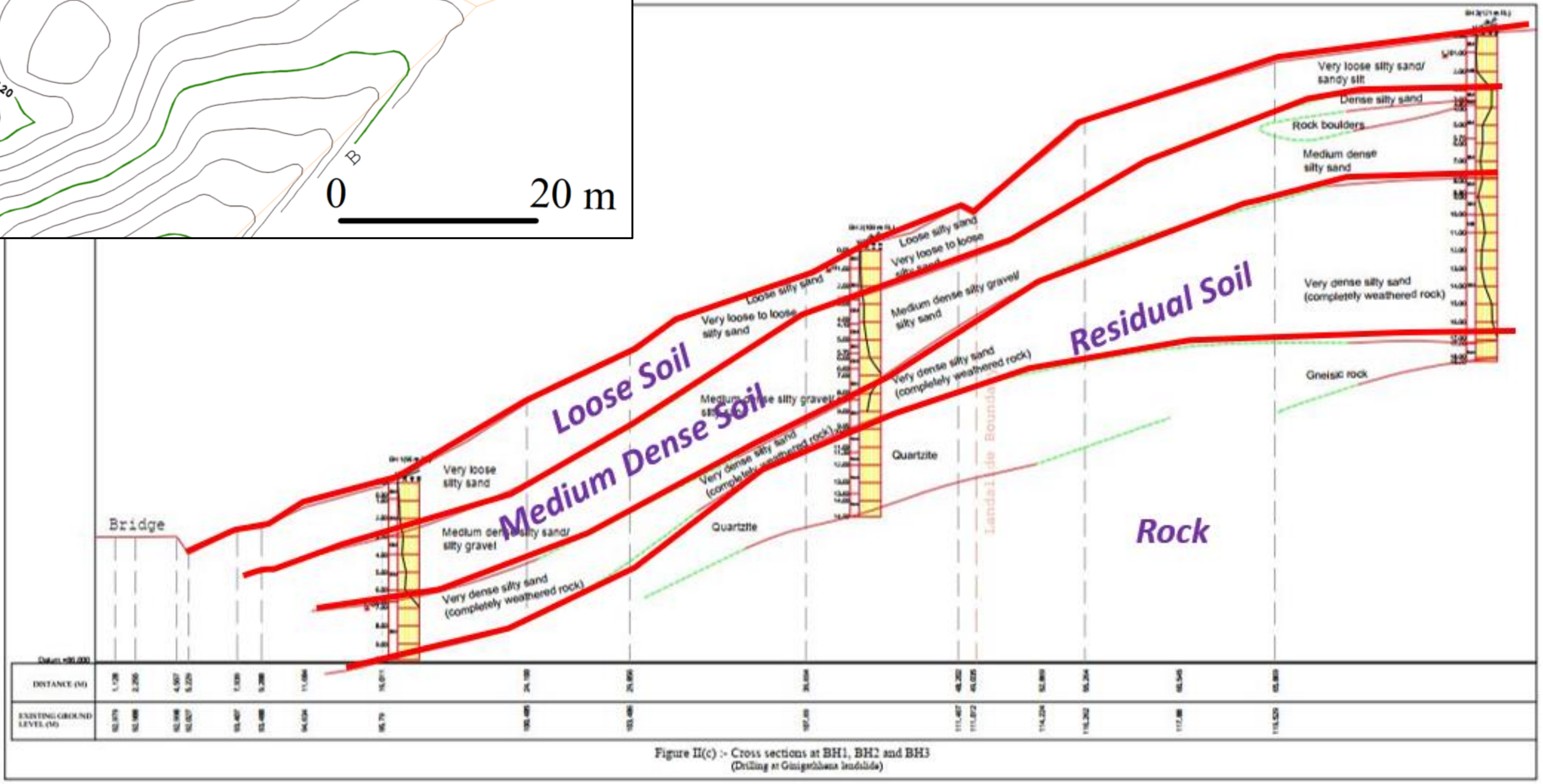
Marshy Area

Investigation

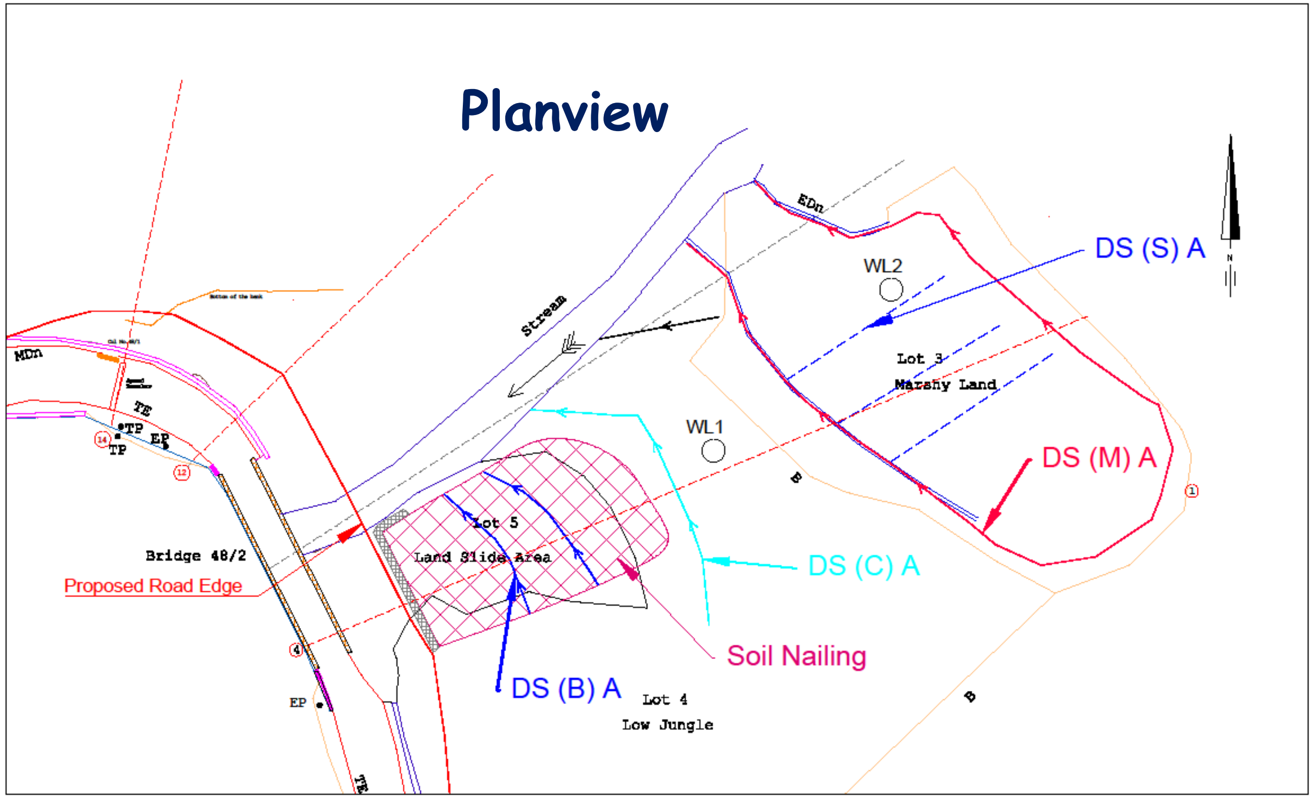
Contour Map



Subsoil Profile



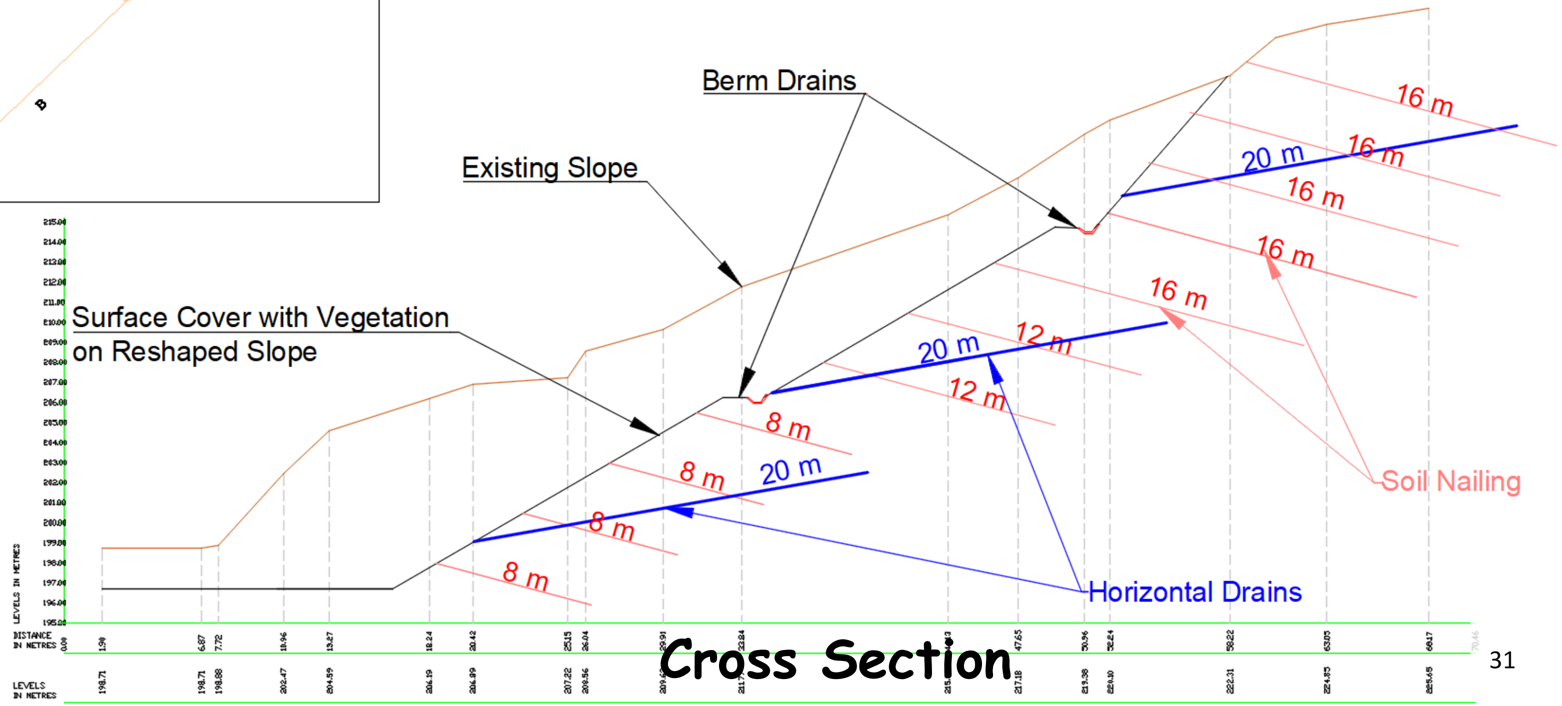
Mitiaation Measures



Legend
Cutoff Drains – DS (M) A
DS (C) A
Berm Drains – DS (B) A
Trench Drains – DS (S) A

- 5 * 16 m nails
- 2 * 12 m nails
- 4 * 8 m nails

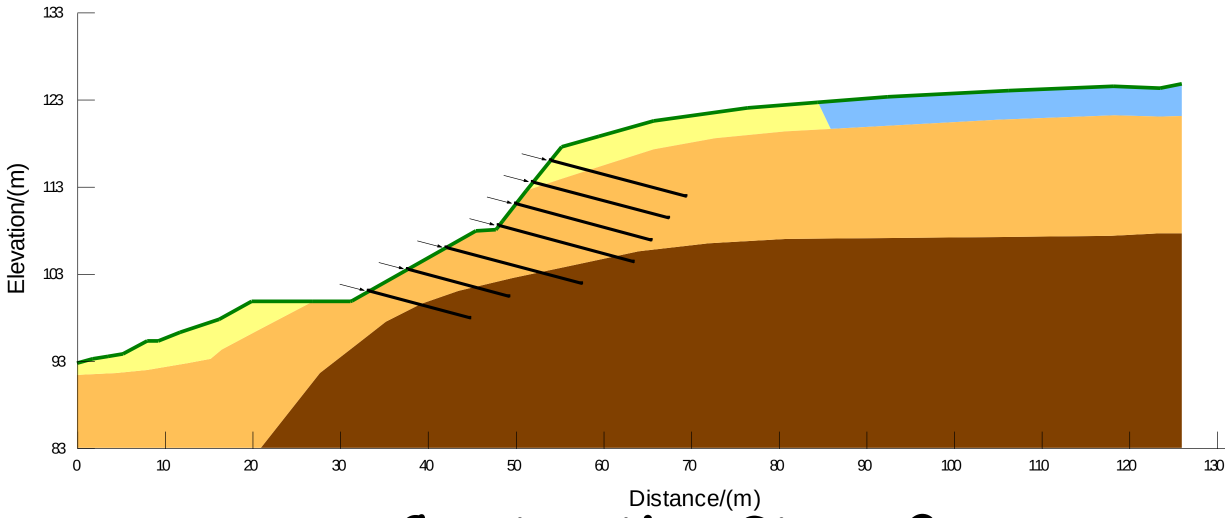
2.0 m × 2.5 m grid



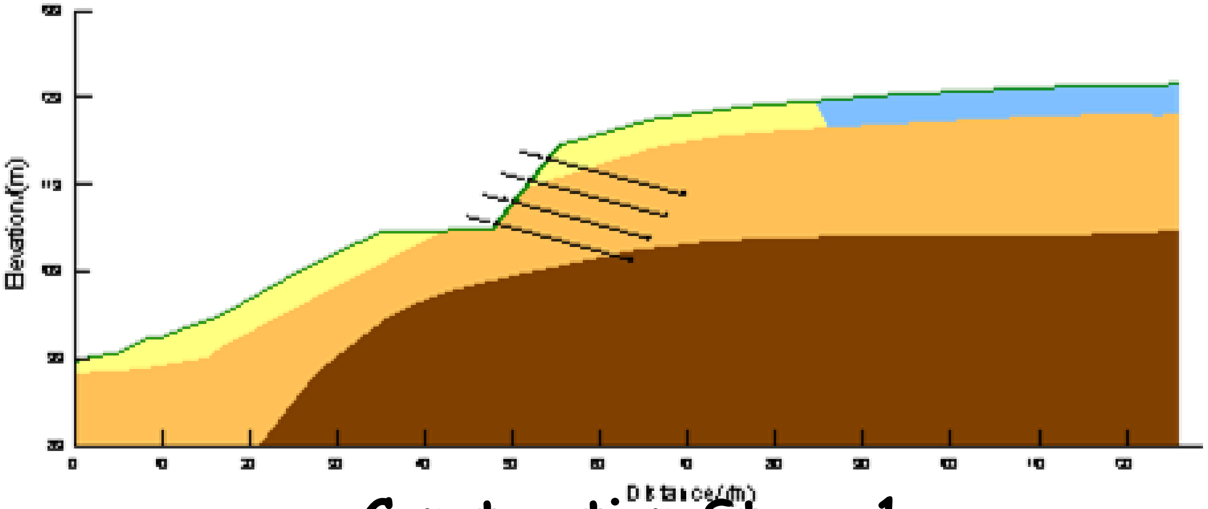
Cross Section

Construction Stages

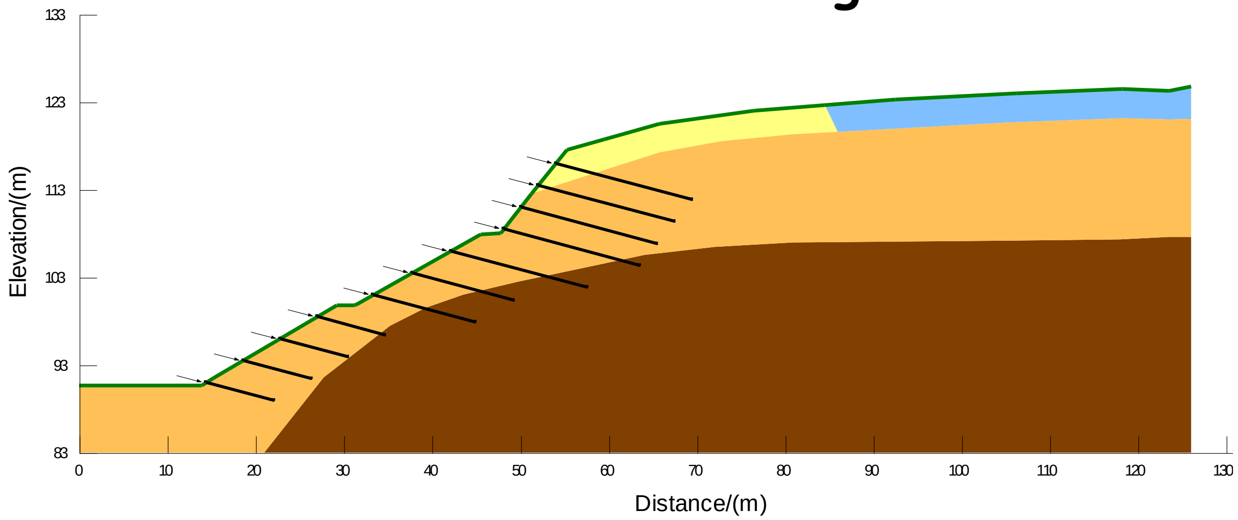
- Slope excavation was done in three construction stages
- Stability of each stage was evaluated for different combinations of mitigation measures



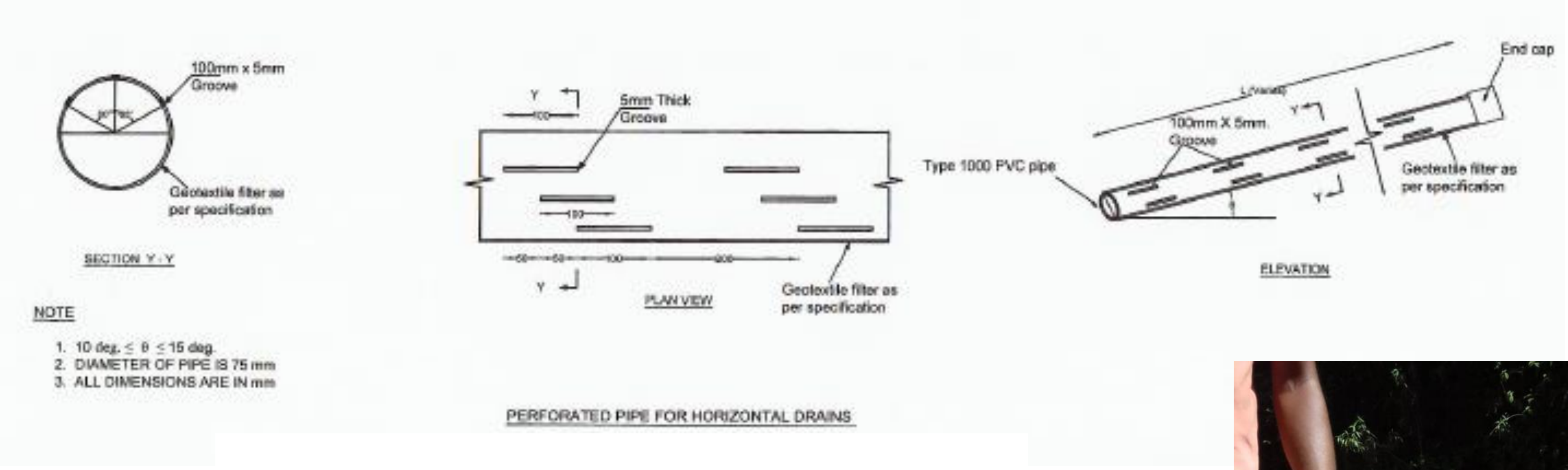
Construction Stage 2

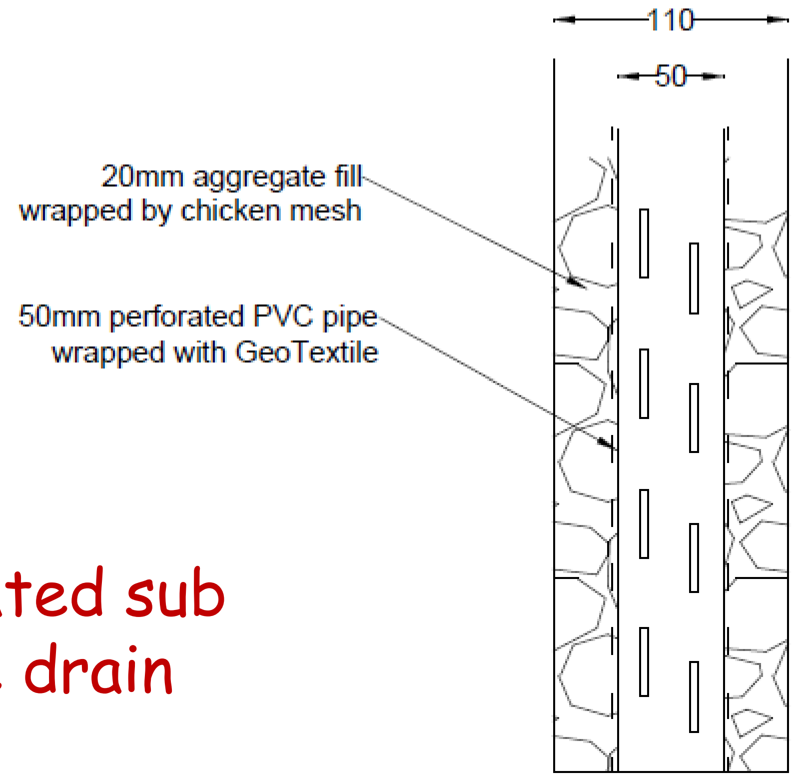


Construction Stage 1

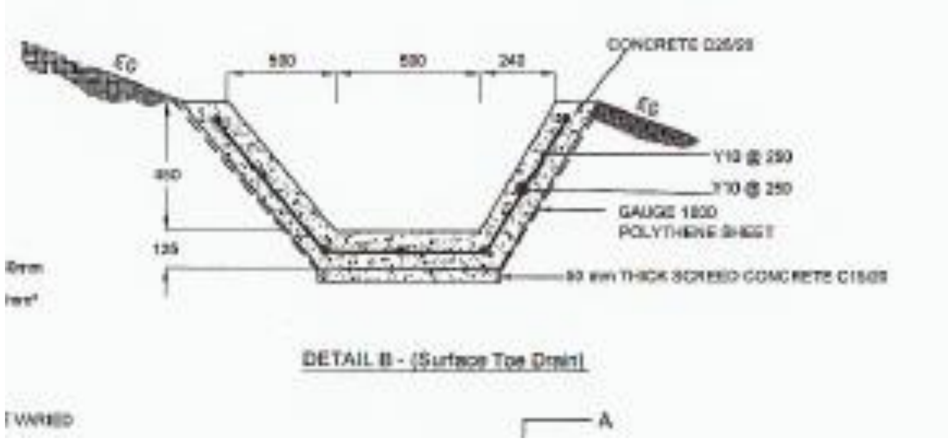


Construction Stage 3

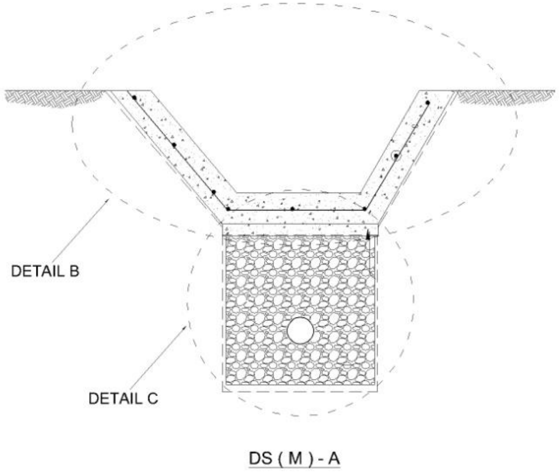




Perforated sub surface drain



Surface drains and Trench drains



Ginigathhena -Rectification

Nail heads connected by beams and vegetation introduced in between with the by hydroseeding protected by coir geotextiles. (at Ginigathhena)

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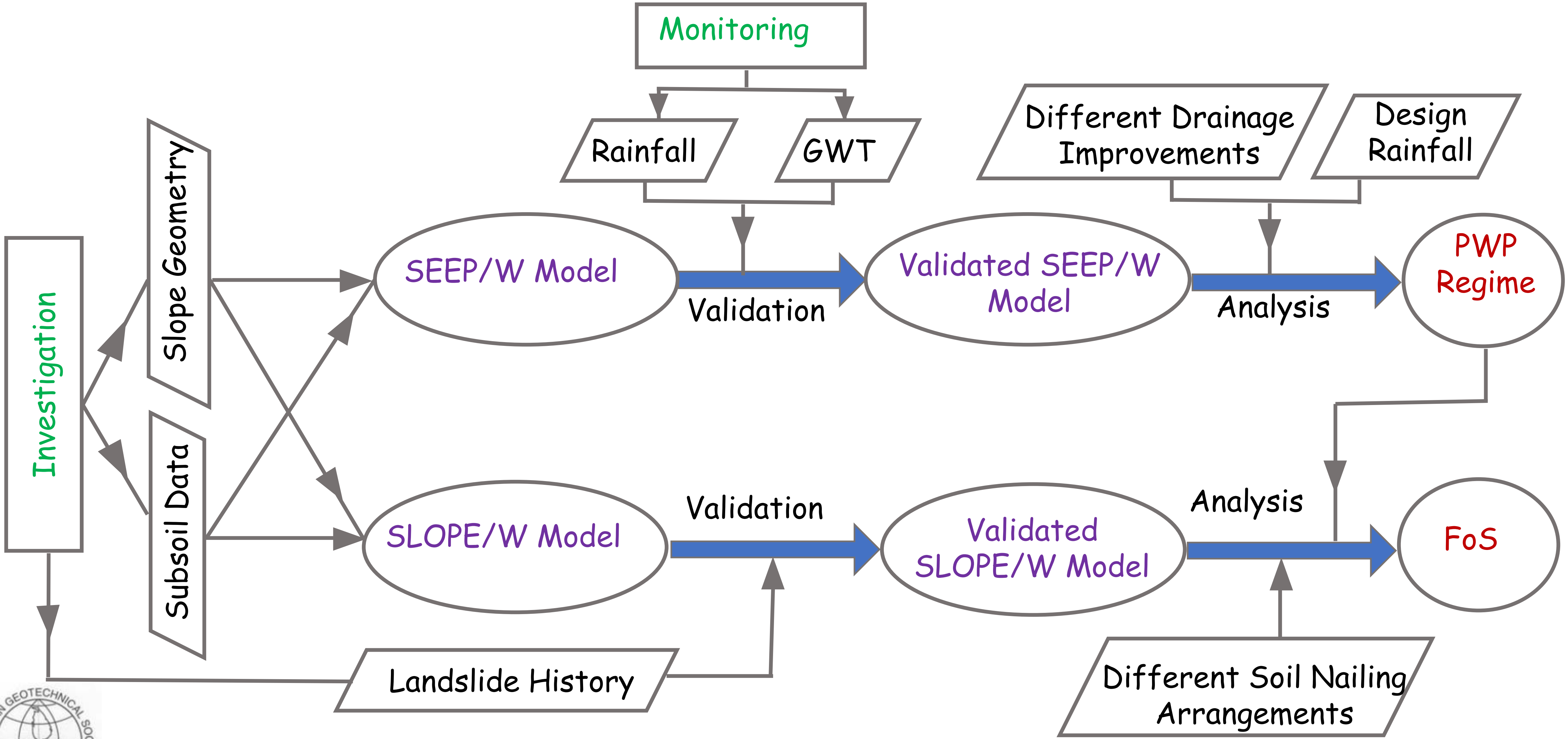
Research studies conducted subsequently
(Mihira Lakruwan and Kulathilaka(2020)

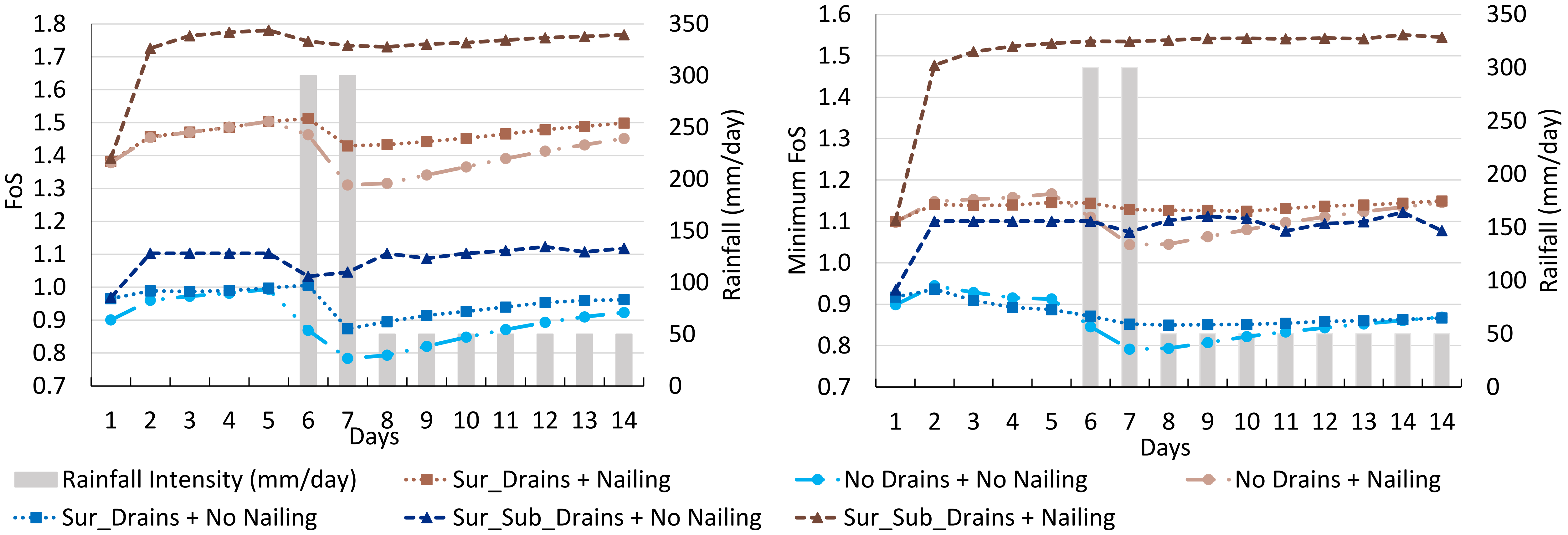
- Evaluation of the effectiveness of different mitigation measures and their combinations under a critical rainfall event
- Assessment of the effect of different drainage improvement measures on soil nailing
- Study the importance of stage construction and following a top-down approach in soil nailing application

Methodology Adopted



Results

FoS of Construction Stages 1 & 2

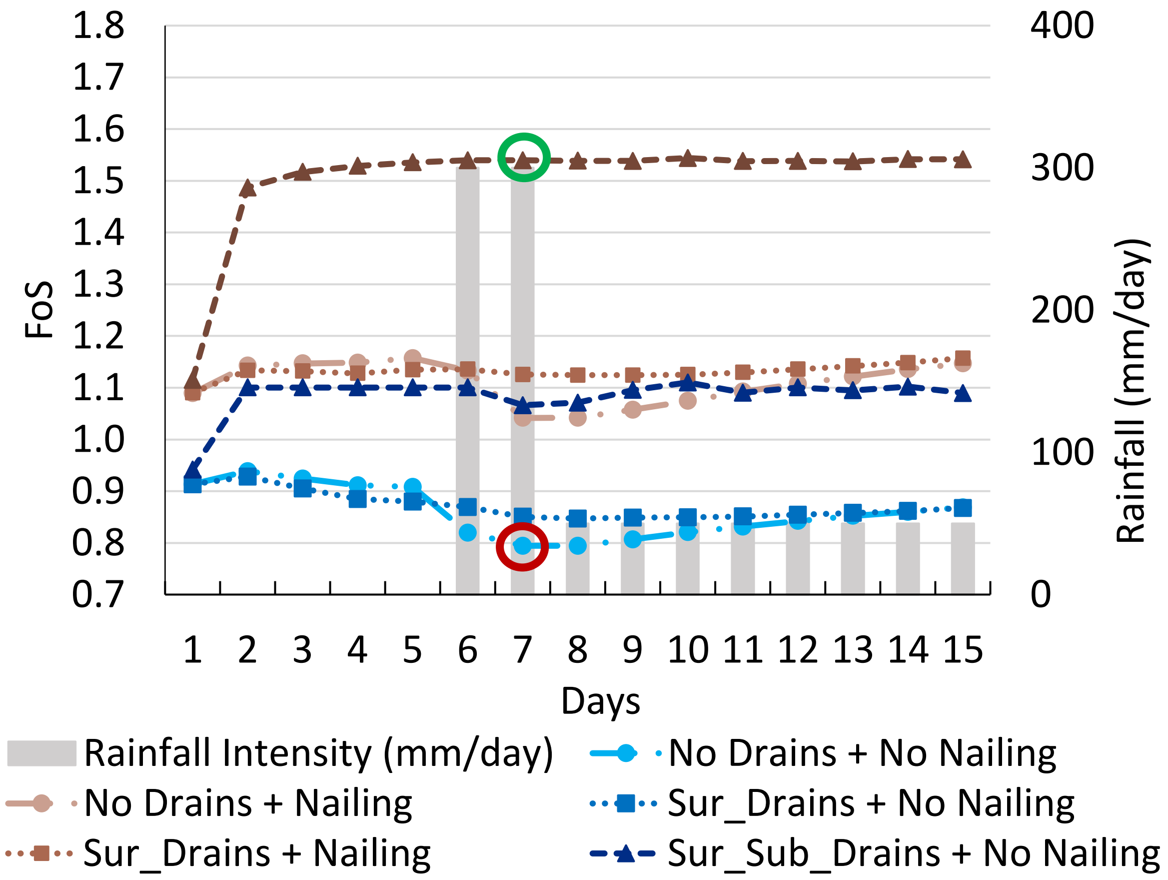


Daily FoS Variation of Stage 1

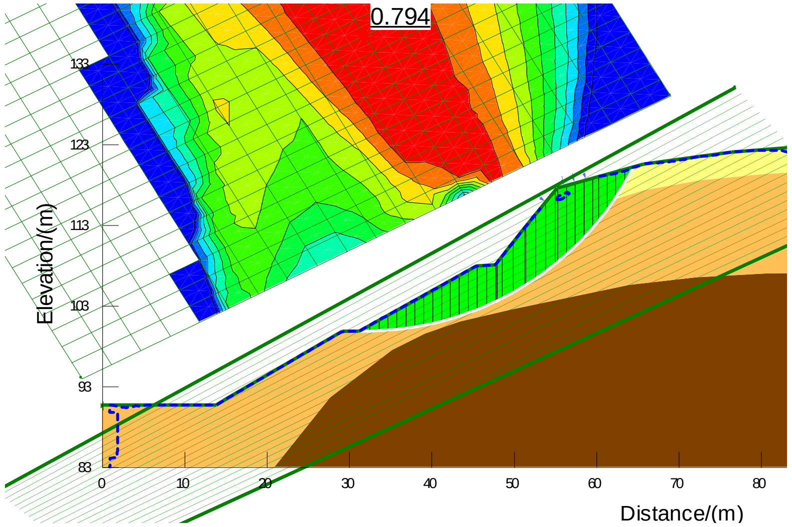
Daily FoS Variation of Stage 2

Results

FoS of Construction Stage 3



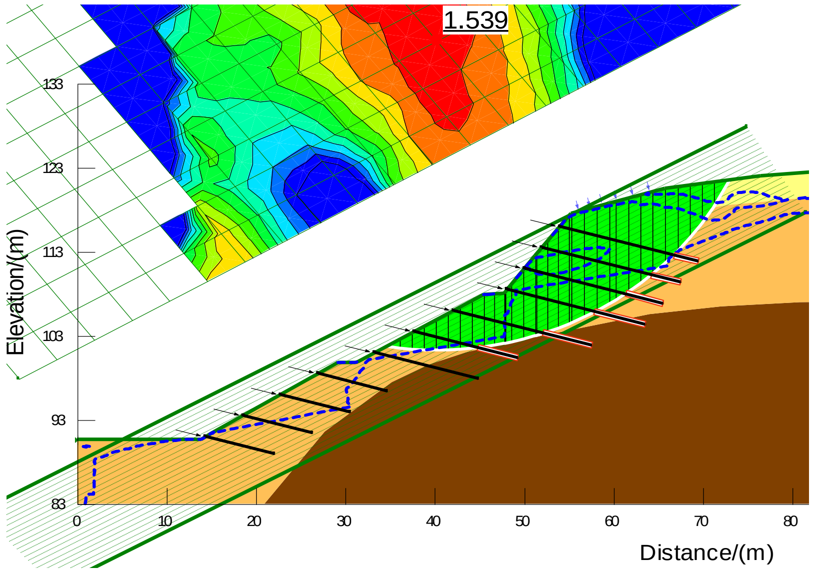
Daily FoS Variation of Stage 3



No Drains + No Nailing (FoS = 0.794)

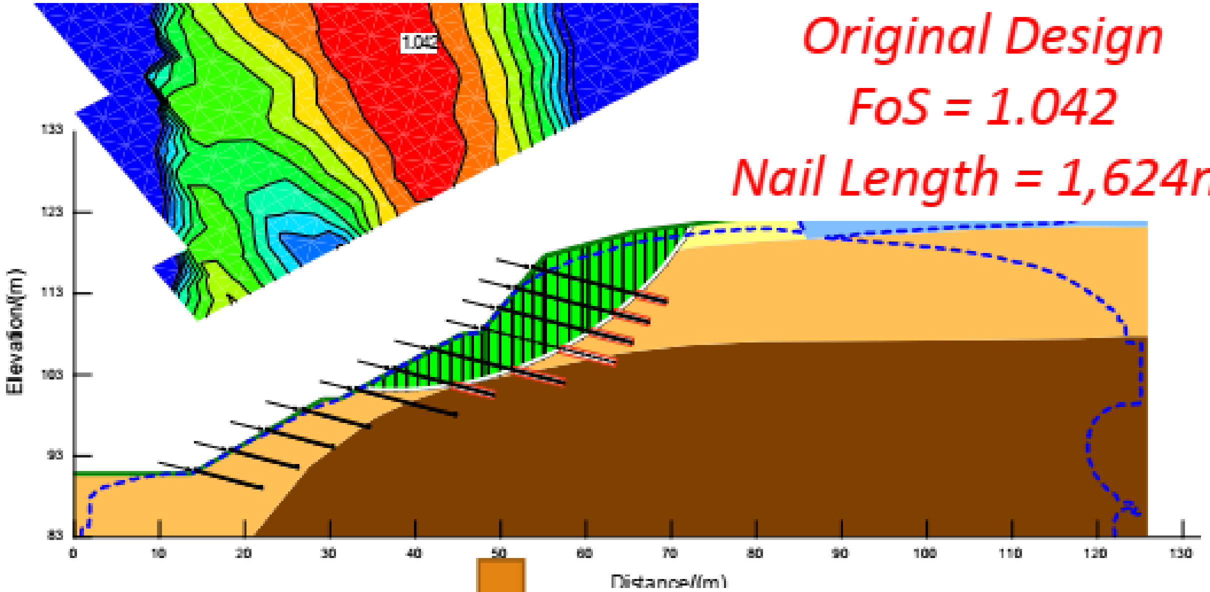
Slip Surface - No Drains + No Nailing

Surface & Subsurface Drains + Nailing (FoS = 1.539)

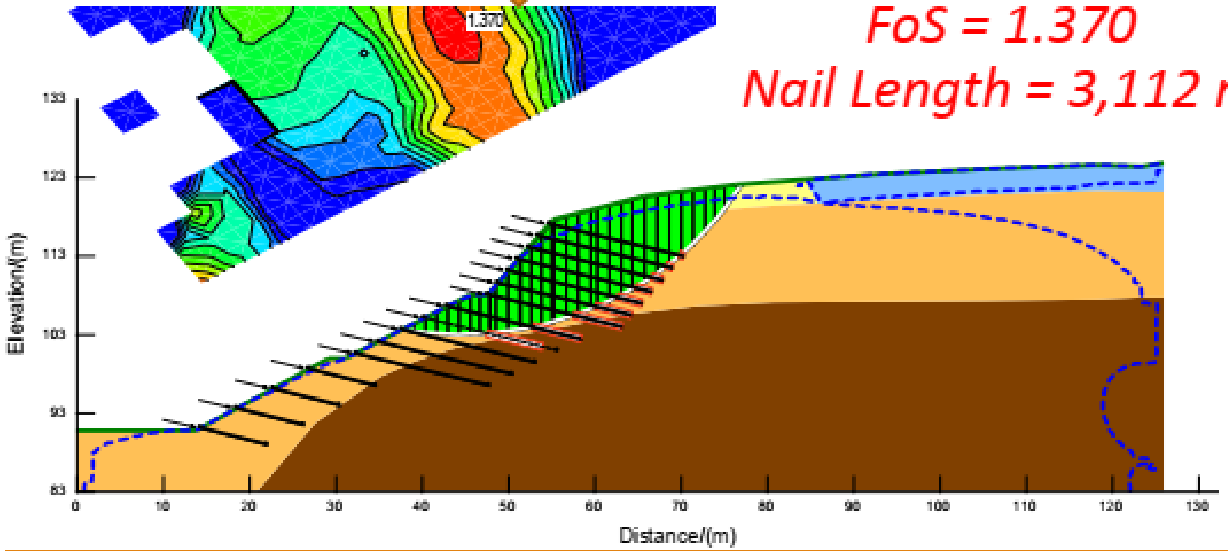


Slip Surface – Surface & Subsurface Drains + Nailing

If no drainage measures were adopted



Original Design
FoS = 1.042
Nail Length = 1,624m



New Design
FoS = 1.370
Nail Length = 3,112 m

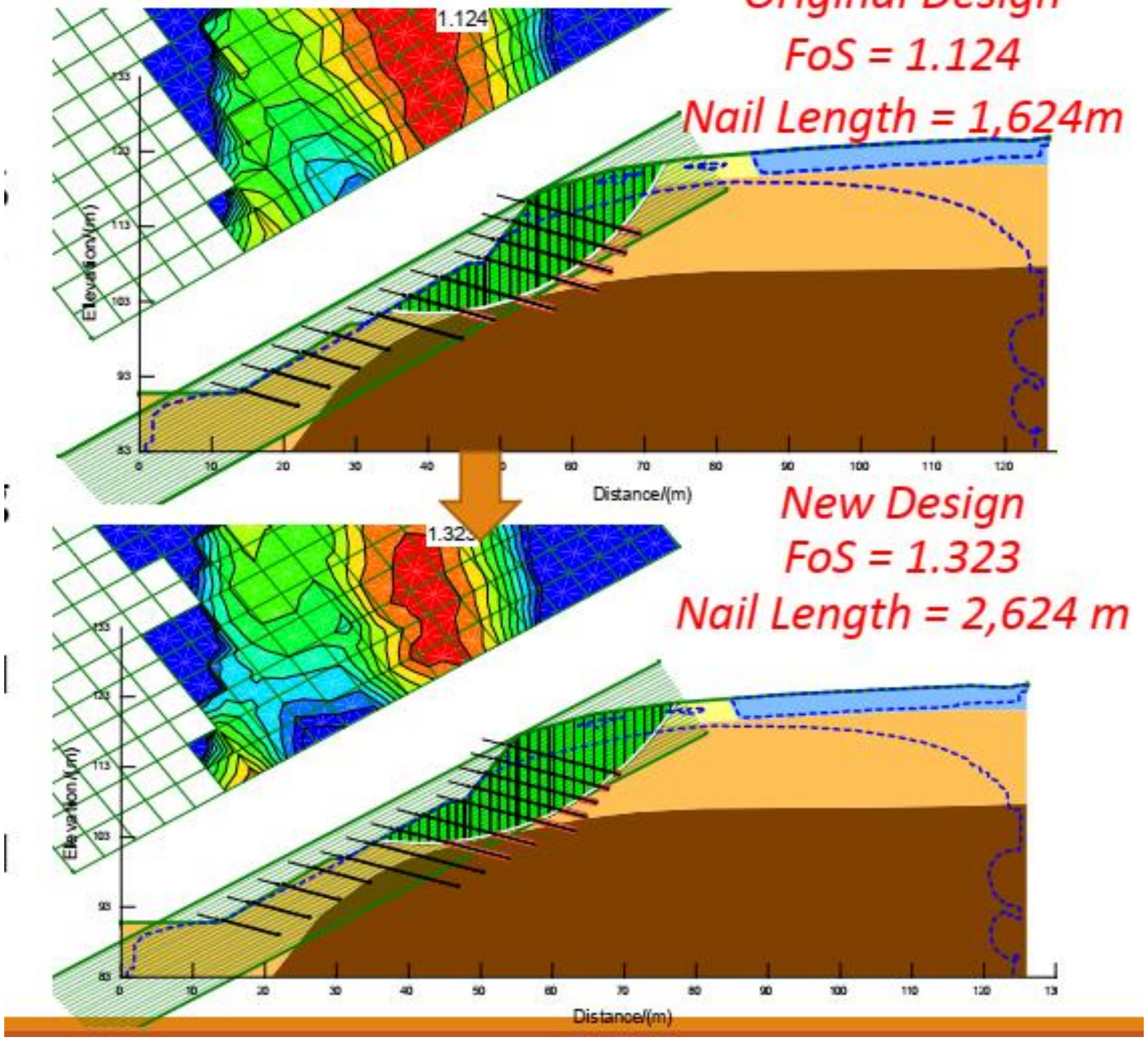
Extra nails needed

If only surface drainage measures were adopted

Original Design

FoS = 1.124

Nail Length = 1,624m



New Design

FoS = 1.323

Nail Length = 2,624 m

Extra nails needed

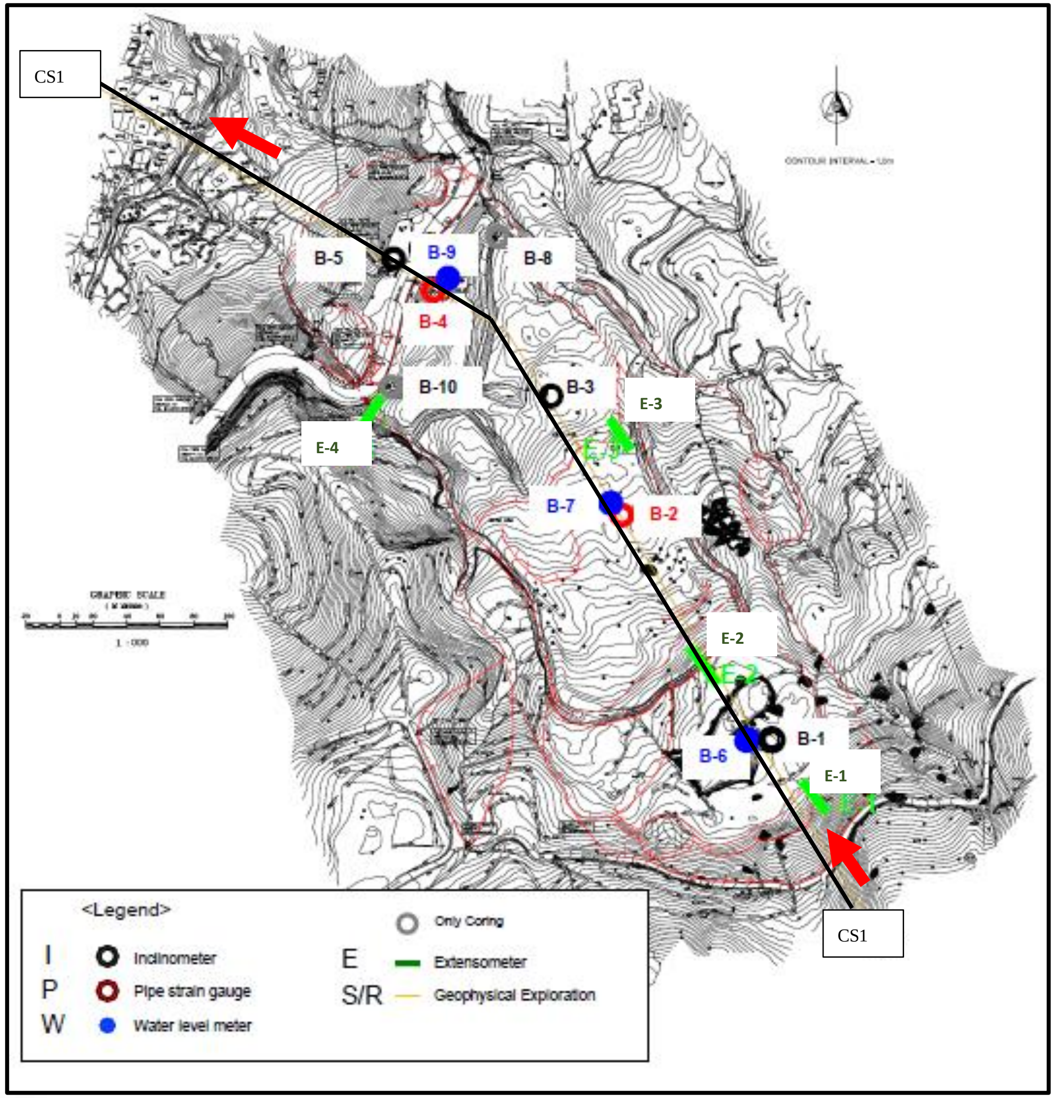
Findings

- Ancient landslide at Ginigathhena was reactivated due to toe excavation for road widening and it was stabilized using extensive mitigation measures
- Surface & subsurface drainage could enhance the slope stability to some extent
- Soil nailing is mandatory to achieve the stability requirements and necessary widening of the road
- Stage construction following top-down approach and adopting correct sequence is important in soil nailing applications to prevent failures during construction
- Drainage measures helped to economize the nailing design and overcome potential construction problems during soil nailing

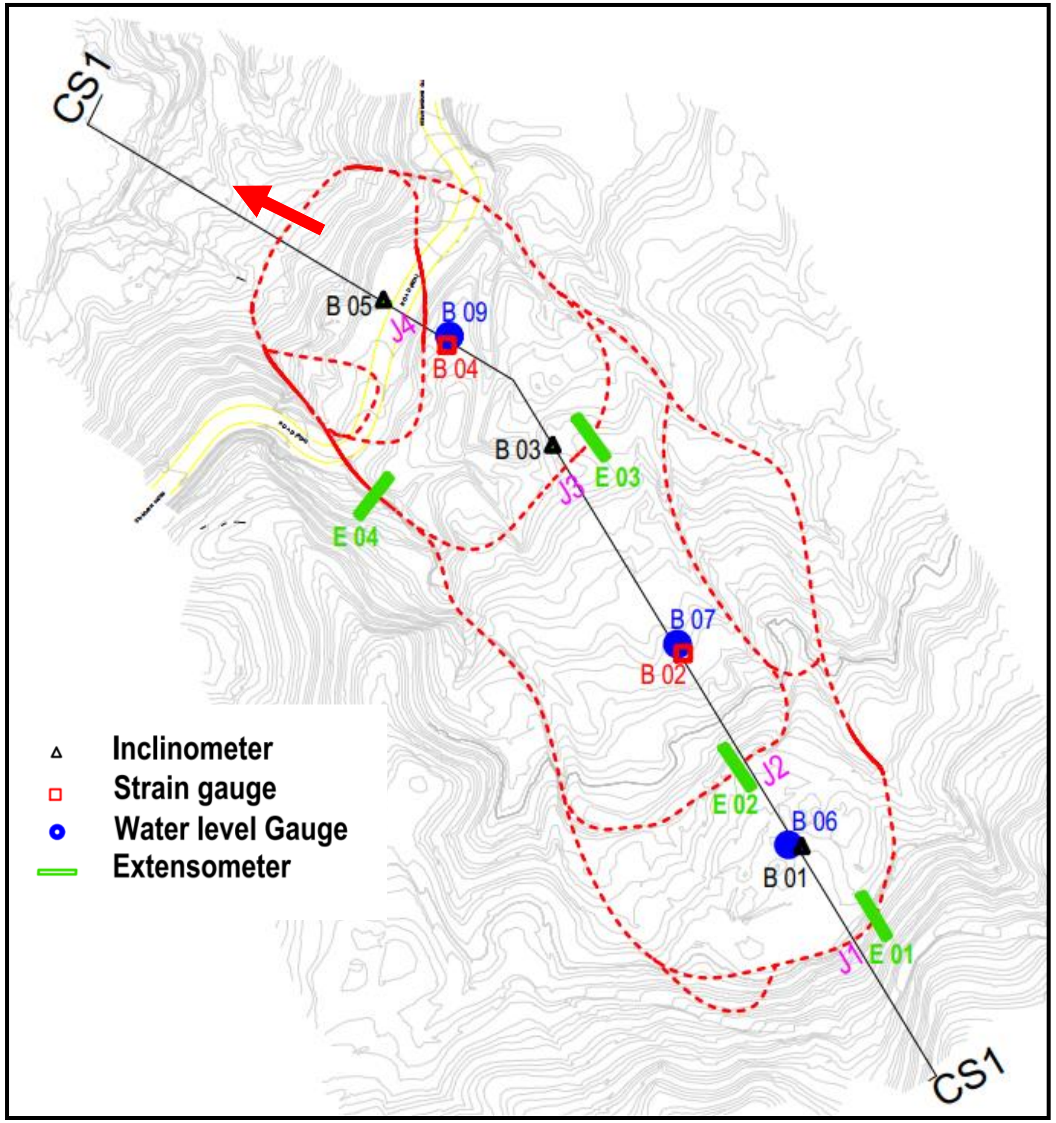
Slope After Completion of all Rectification

Rectification of Landslide at Kahagolla

Kahagolla Landslide Instrumentation at the site



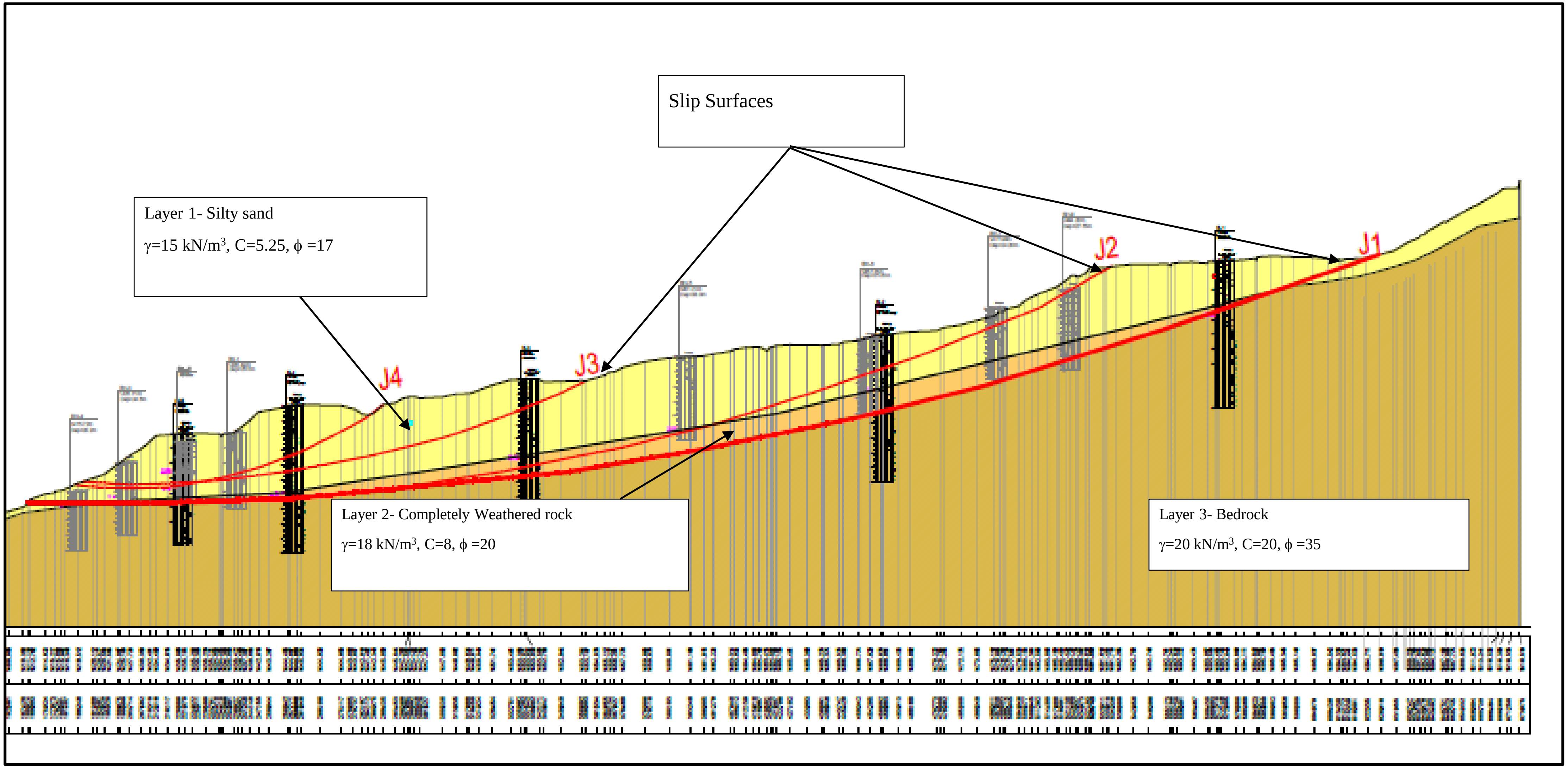
Plan View



J1, J2, J3, J4- Identified blocks/Slip surfaces

Kahagolla Landslide

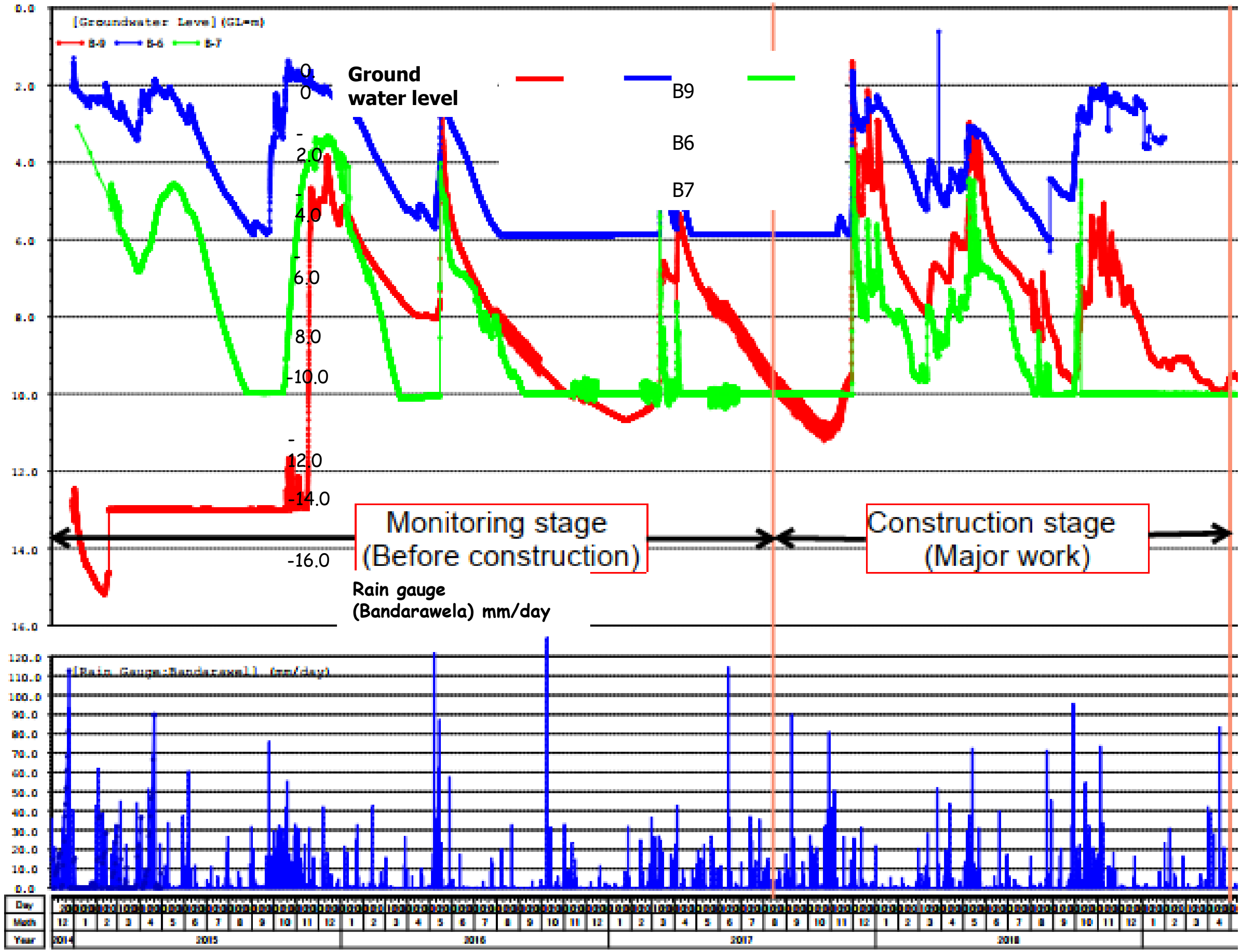
Idealization of subsoil profile

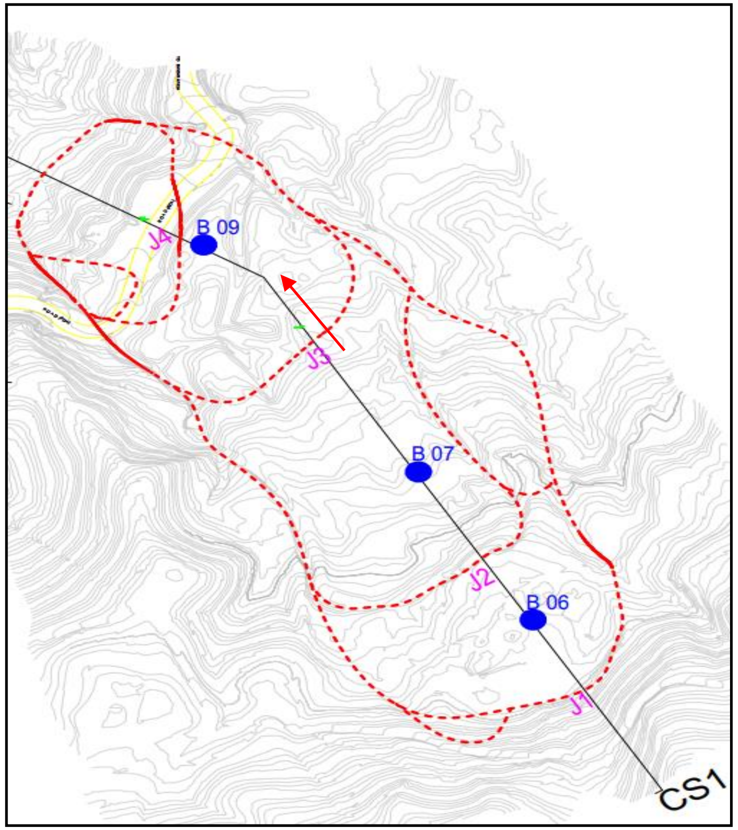


Layer properties in longitudinal cross section

Kahagolla Landslide – Monitoring Data

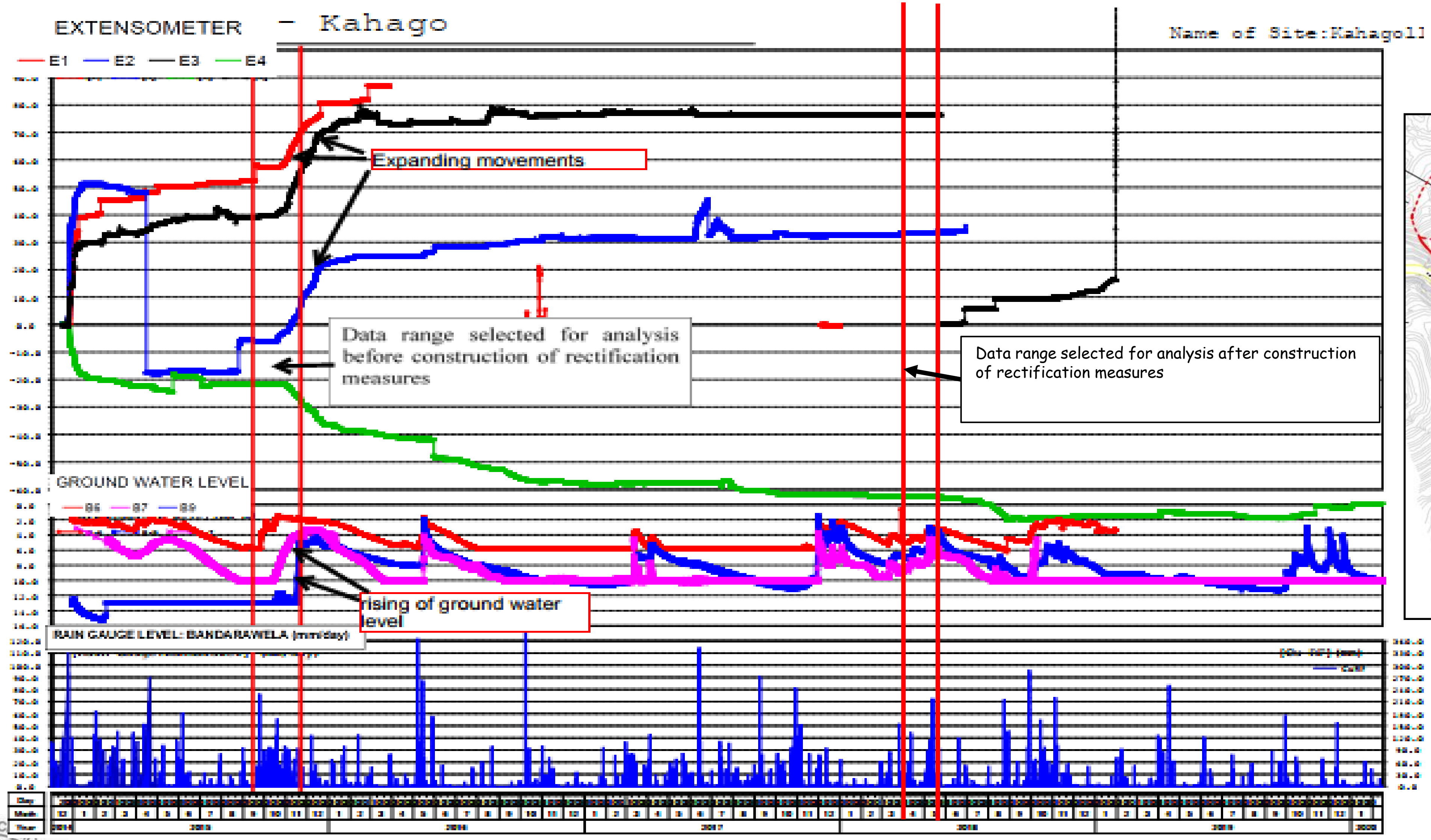
Response of the measured GWL to rainfall

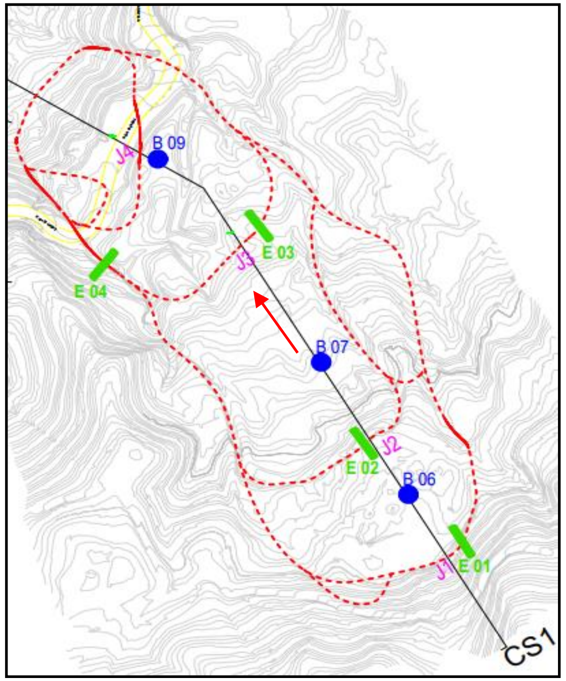




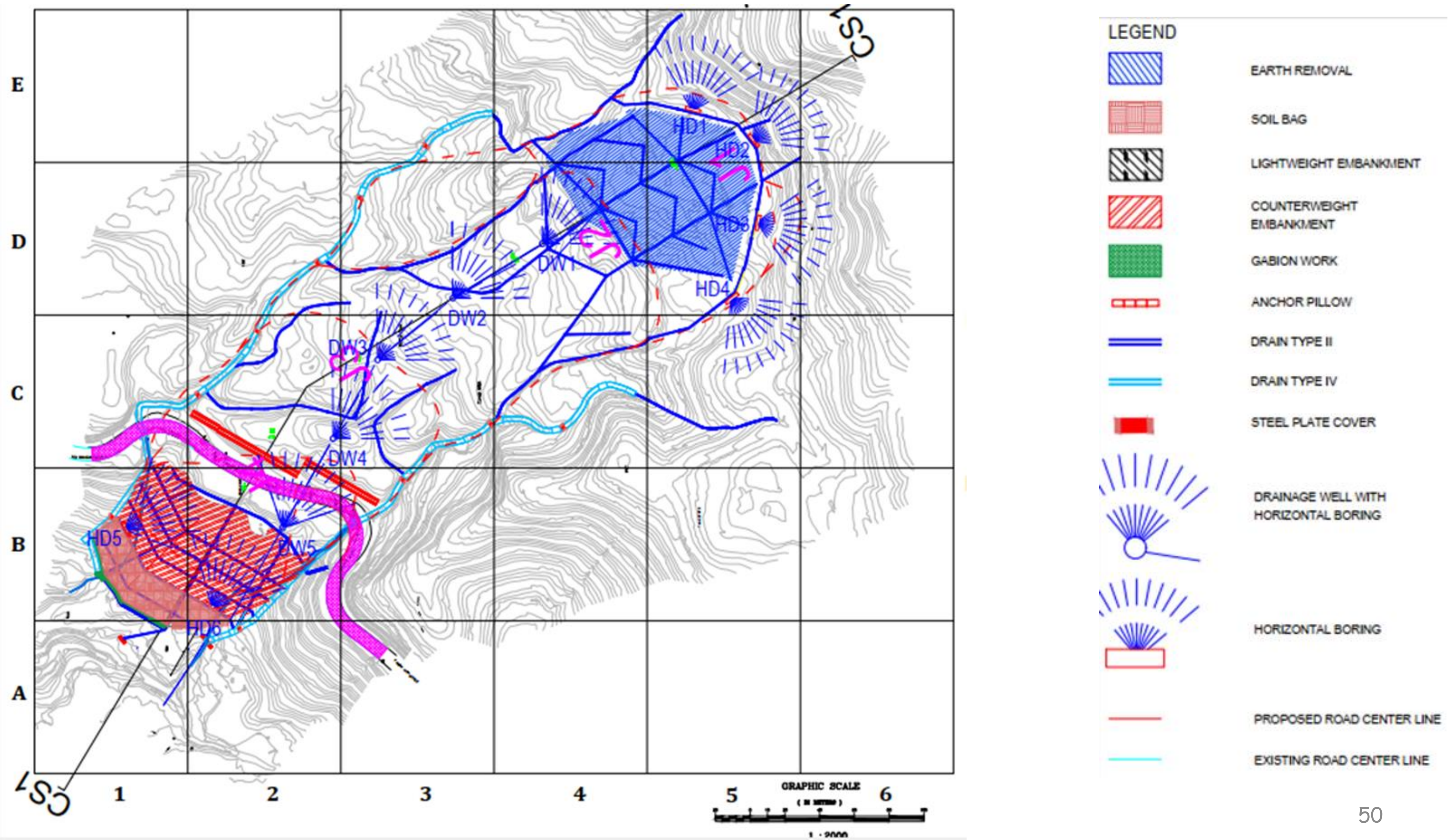
Kahagolla Landslide – Monitoring Data

Response of the extensometers to rainfall

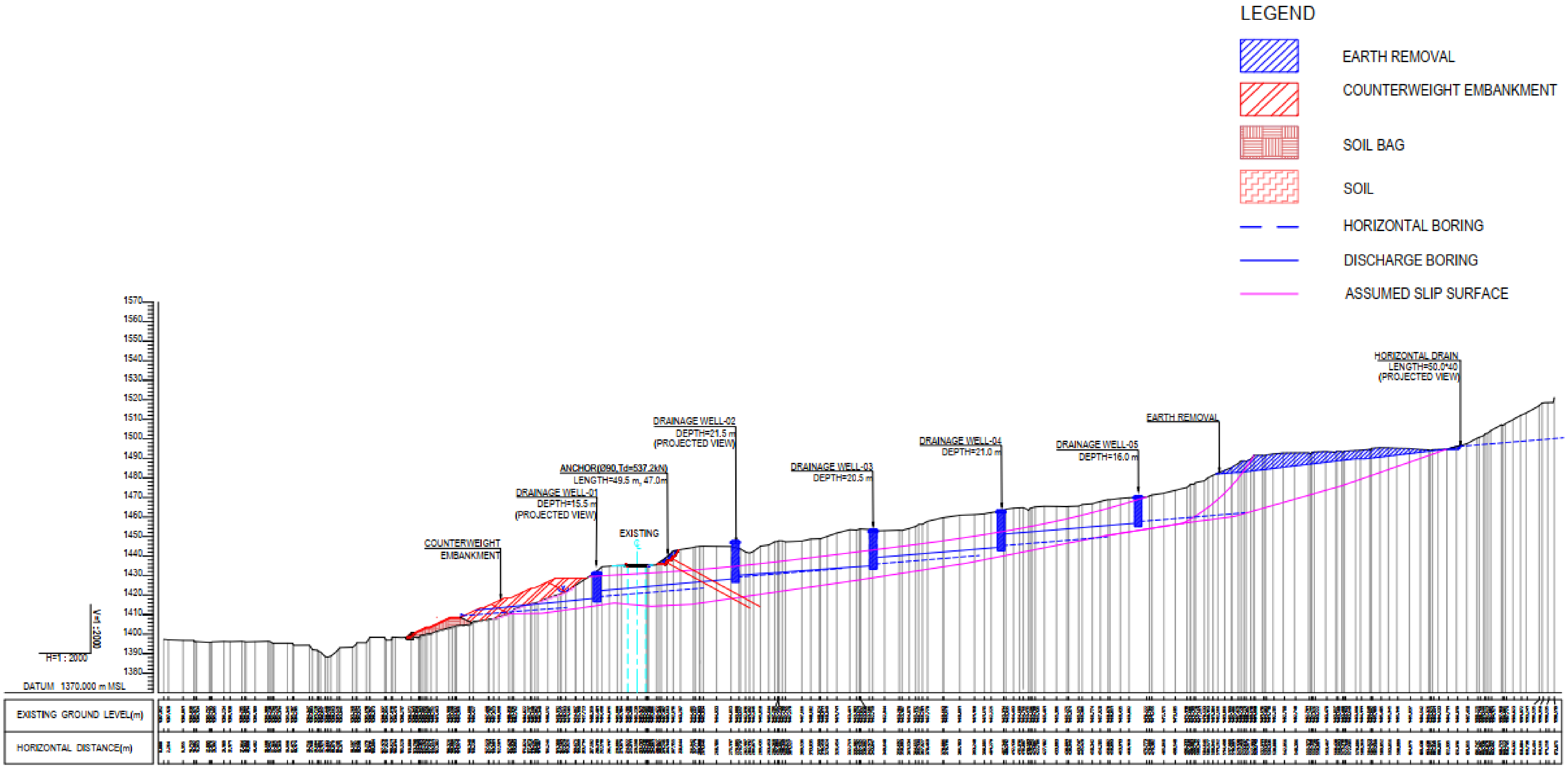


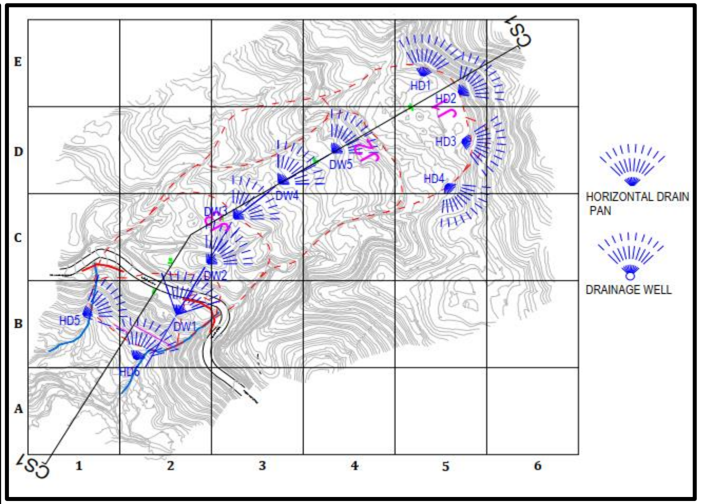


Rectification measures Applied-plan view



Countermeasures applied - Sectional view





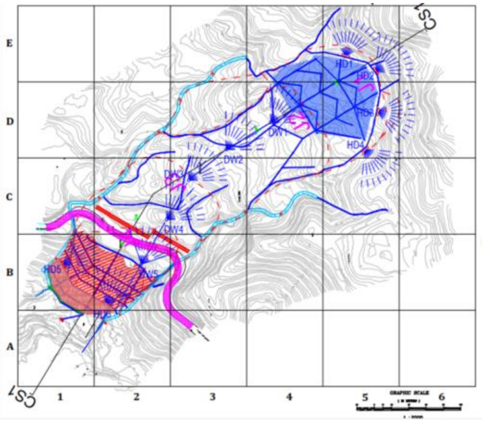
Drainage wells

Surface drains

Sub Horizontal drains

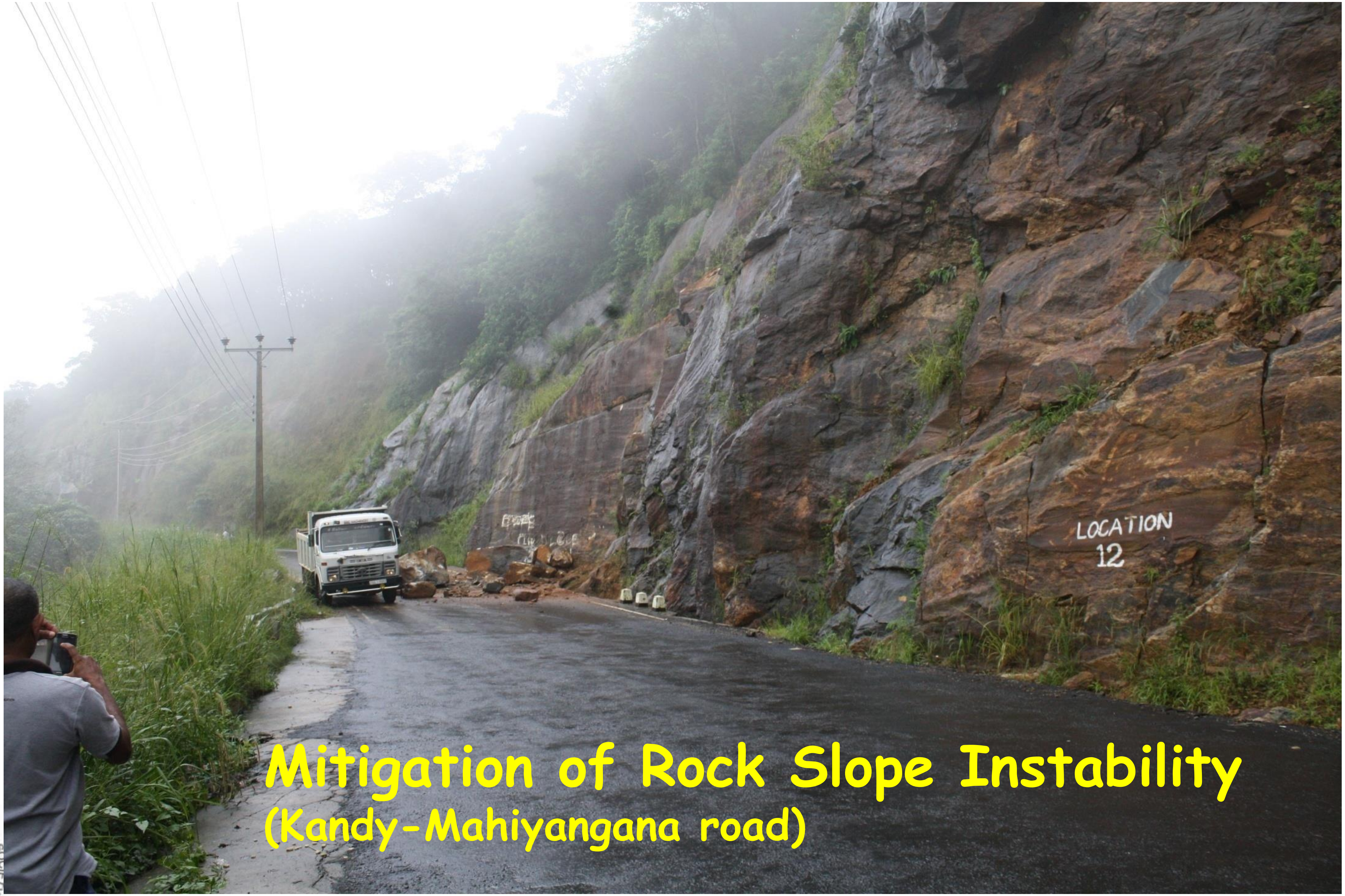
Countermeasures Applied - After completion of construction

Counterweight embankment



Ground anchors (134 nos.)

Earth removal and slope protection



Mitigation of Rock Slope Instability
(Kandy-Mahiyangana road)

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A major rock slides in Kandy – Mahiyangana Road

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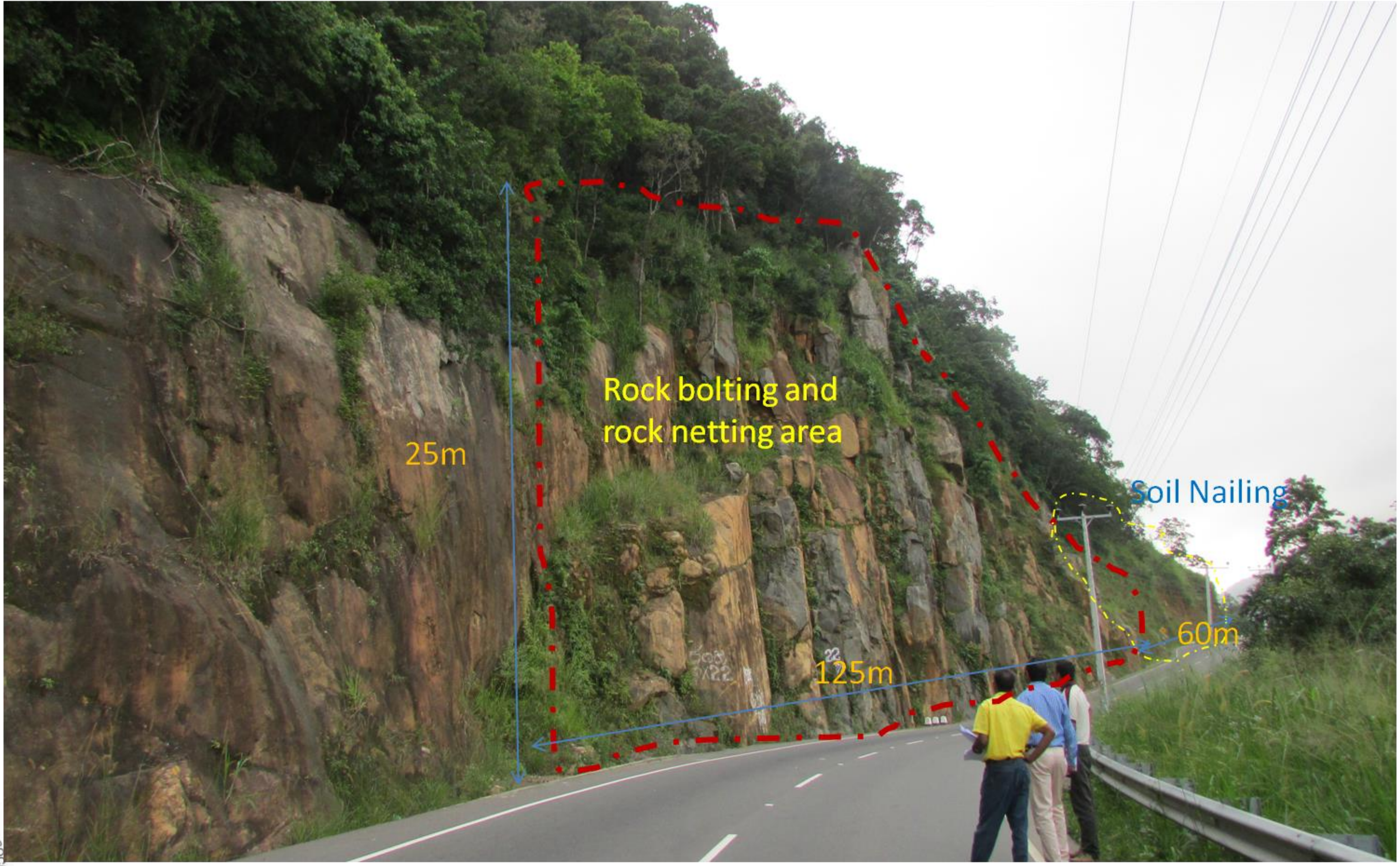
Rock bolting and
rock netting area
25m
Soil Nailing
60m
125m

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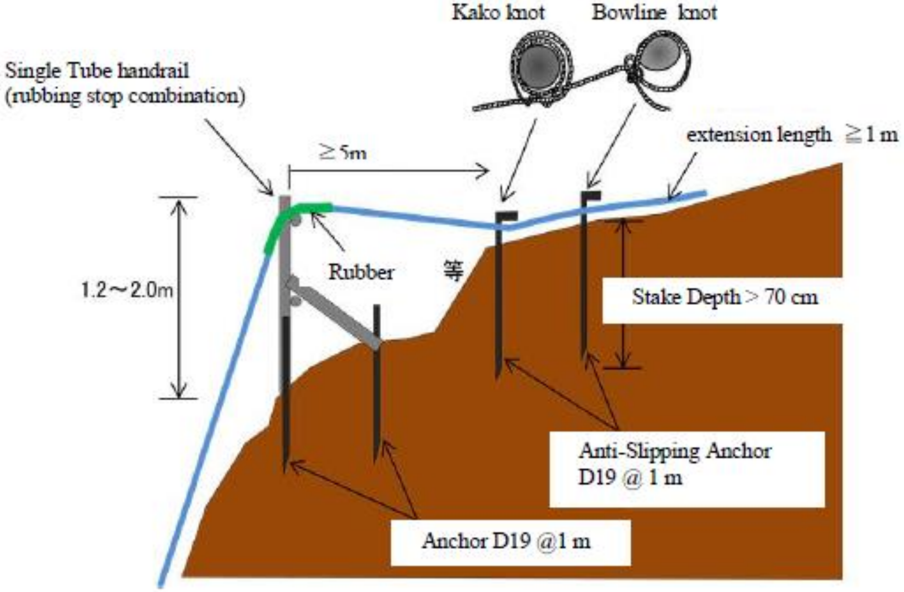
Rock Netting to prevent Rockfalls

Curtain Netting to retain falling rock pieces
Kandy – Mahiyangana Road



After completion

Rock Fence to catch Falling rockfalls- Kandy - Mahiyangana Road

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Concluding Comments

- Sloping grounds in Sri Lanka are made of; residual soils, rocks at different levels of weathering and colluvial soils from previous landslides. Groundwater table is generally low during the dry periods and slopes remain stable due to prevailing matric suction. With rainwater infiltrations these slopes will be unstable and failures would occur.

- The challenge offered by the rain induced landslides is well taken by the Sri Lankan Geotechnical Engineers and good progress is made on the reduction of the risk. Deficiencies in the process are identified and continuous efforts are made to improve.

- The scope of the landslide hazard zonation project is being widened to include the flow paths and depositional areas and to incorporate the triggering rainfalls. The number of automatic rain gauges in the country are increased to cover all relevant areas. Recent landslides are being studied to identify the rainfall that triggered the landslides that were located in different zones in the current susceptibility maps.

- Designs for mitigation of the risk of landslides and rectification of the landslides that have already taken place are done at the design unit of the NBRO. The design team includes graduate Civil Engineers with years of experience. They are guided by Geotechnical Engineers with postgraduate and professional qualification. University academics of relevant fields are also involved.
- Engineering geologists and geologists with wide experience are also a part of the team. Visiting the potential sites, comprehending the geological conditions, planning the necessary geological, geophysical and geotechnical investigations, installation of monitoring equipment are done with detailed discussions among the team members. The designs are finally verified with site visits.

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- Institutions such as Norwegian geotechnical Institute (NGI) have provided great assistance through many collaborative studies. NGI experts have assisted with training NBRO staff on aspects such as; flow path modelling, design of rectification measures. They have also provided drones to conduct the surveys necessary to obtain the 3D terrain models to establish the slope topography in lands which are not accessible for conducting conventional topographic surveys. They have provided necessary training for the NBRO Engineers in this context. Other modern techniques such as Ground Penetration Radar (GPR) and Cross borehole logging have also been introduced.

- Japan International Collaborative Agency (JICA) has also provided technical assistance and trained NBRO professionals in work related to landside risk reduction.

- A large number of projects were done within the last two decades for the reduction of landslide risk in the country by mitigating the instability in critical slopes and landslides along infrastructure facilities such as; roads, railways , schools and hospitals.
- These projects were funded by Sri Lankan government and through loans obtained from different international agencies. Around 150 sites were rectified at a cost of 13 Billion Rupees over the last decade.
- Local contractors were involved in a great majority of these projects and enhancement of technology and capacity building could be witnessed over the years.

- There are further plans to introduce global monitoring of the susceptible site and rectified slope with techniques of; Terrestrial photogrammetry, Digital Photographs with Drones , LiDAR survey InSAR satellite techniques etc.
- Many government organizations such as: Road Development Authority, Disaster Management Center, Department of Metrology, Department of Education, Department of Health and the Civil Engineering community in the country have collaborated with NBRO over the years in this national effort to reduce the risk of landslides in the country.
- The efforts to reduce the risk of landslides in the country will continue with the incorporation of the emerging new technologies.

Thank You