

Reduction of Landslide Risk in Sri Lanka

Part 3 - Mitigation of Landslide Risk by
Drainage Measures- Case Histories from;
Southern Expressway, Watawala and
Budulusirigama

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

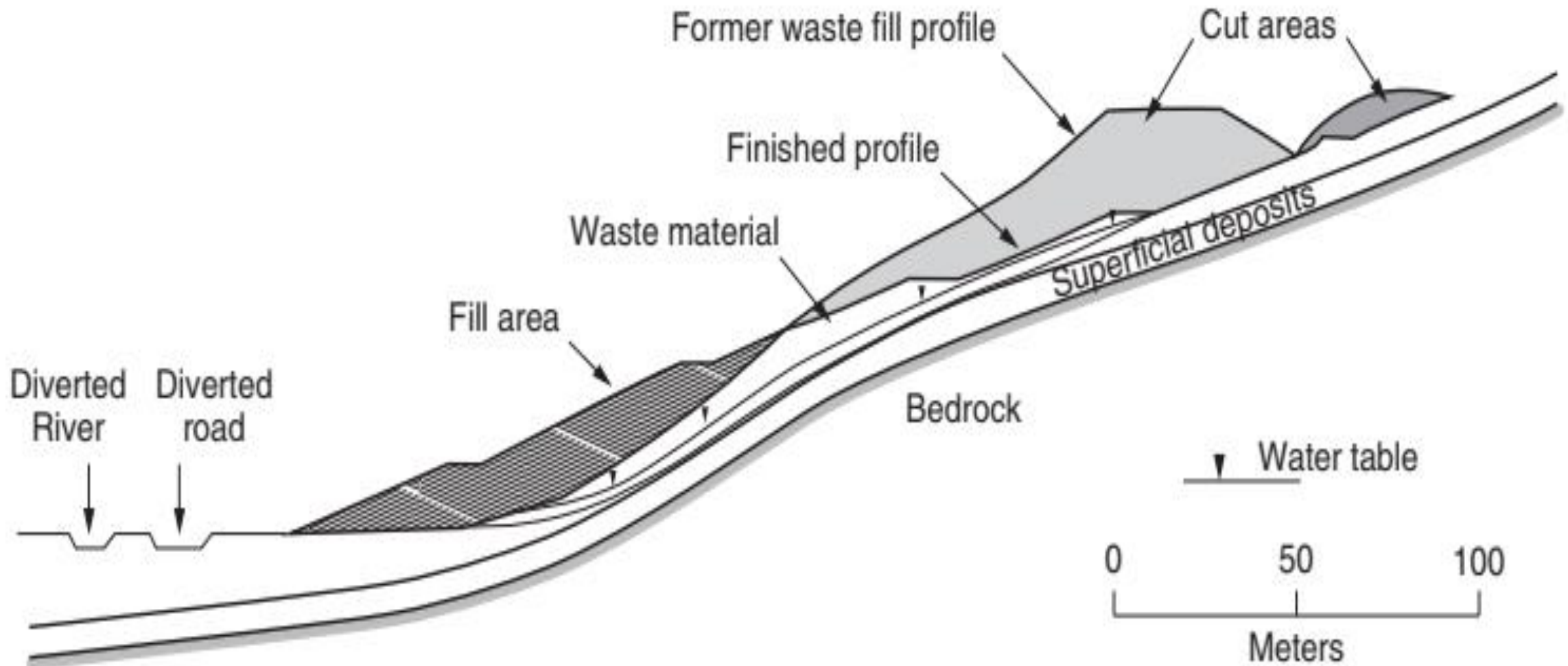
- K Terzaghi , 1950

Landslide Remedial Measures

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

Modification of Slope Geometry

- Removing material from the area driving the landslide
- Adding material to the area maintaining stability
- Reducing general slope angle



**Slope Stabilization by cut and Fill
(Modification of the slope geometry)**

The results of the infiltration analyses illustrated that making the Slope flatter may not necessarily ensure the stability during long duration rainfalls.

Hence, Our attempt should be to;

Reduce infiltration, minimize the loss of matric suction and reduce the pore water pressure built up

This can be achieved by

- Improving Surface drainage
- Providing sub surface drainage

Stabilization by Drainage

Surface drainage should be enhanced by the construction of Cut off drains, berm drains.

Shallow or deep trench drains filled with free draining geo-materials.

Appropriate Vegetation or artificial Slope Cover such as shotcrete could minimize infiltration and prevent erosion as well.

Infiltration into relict joints should be prevented by sealing.

Vertical wells with gravity drains or pumping

Sub surface drains may be required in some situations.

Surface Drainage Measures in Southern Expressway

Cutoff Drains



Berm Drains



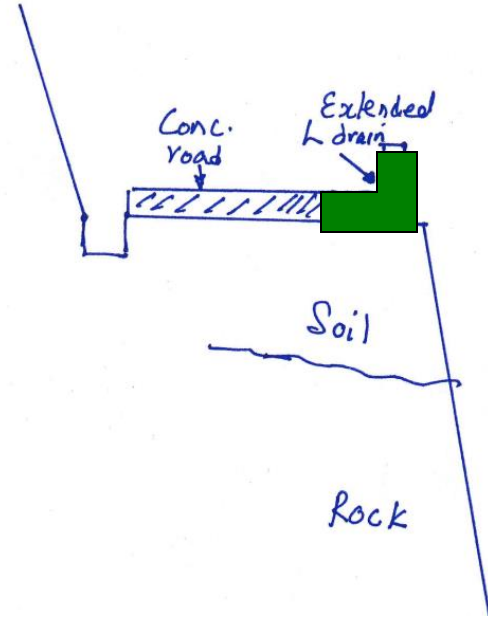
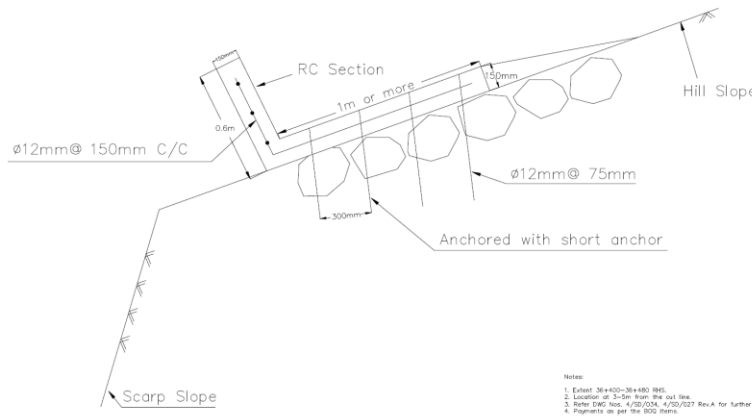








Present Situation



Cut off drain at the crest of the slope

- Has to be done with minimum cutting to prevent disturbance to the boulders at the crest



Different forms of surface protective measures are used



Vegetation will;

- Prevent surface erosion
- Enhance the cohesion at shallow levels through closely binding root system
- Provide some reinforcing action through deeper system of roots
- Foliage intercept rainfall, causing absorptive and evaporative losses reducing infiltration
- Roots extract moisture which is lost to atmosphere by transpiration - reduce pore water pressure

Based on the level of weathering and the nature of the soil different techniques will have to be used in introduction of vegetation to a slope.

- Turfing
- Hydro seeding

Slope Surface Protection Using Vegetation

Hydro seeding protected
by coir mat





Turfing



Hydro seeding protected by coir mat



Hydro seeding protected by straw mat

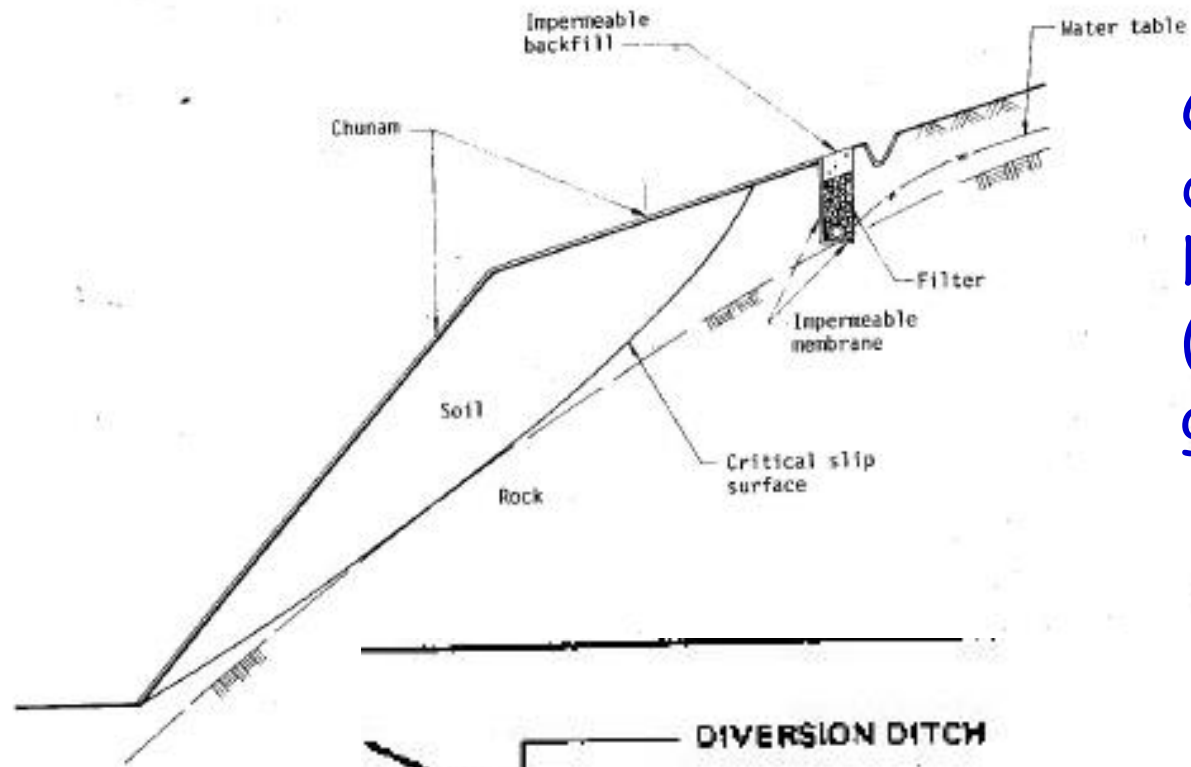


Vegetation growing up

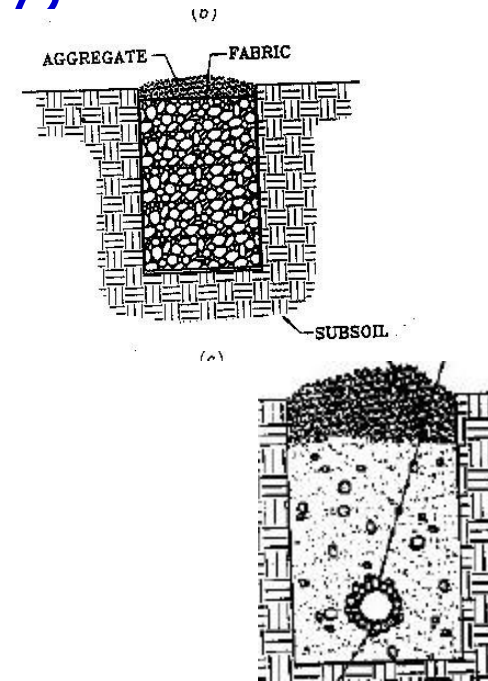
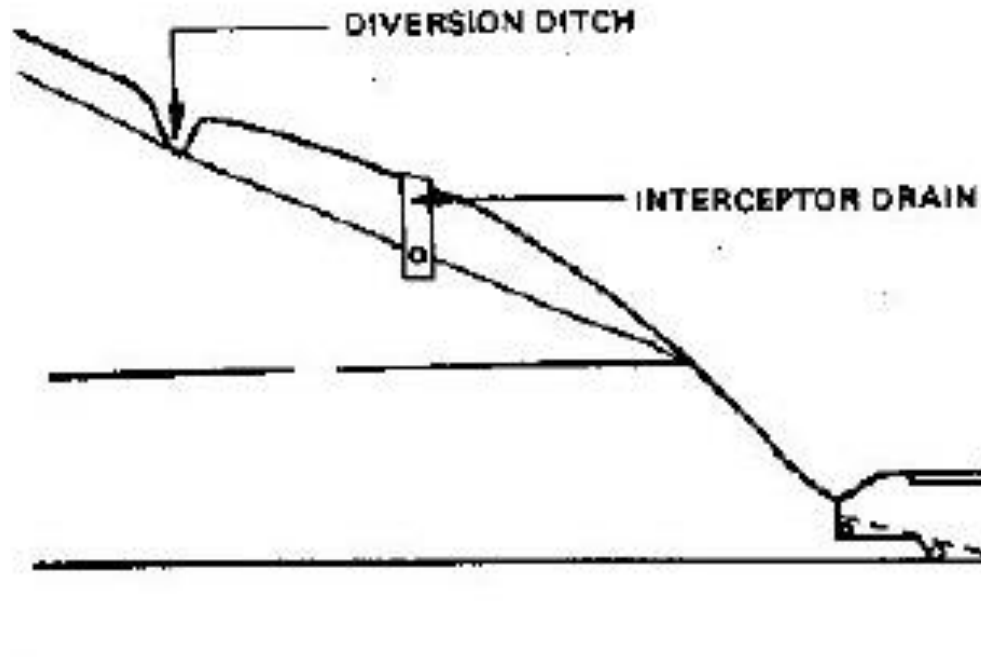
Sub Surface Drainage

Some Slopes may require sub surface drainage in addition to the surface drainage measures to maintain stability

Sub surface drainage facilitate the movement of water already gone into the soil and accelerates the pore water pressure dissipation.



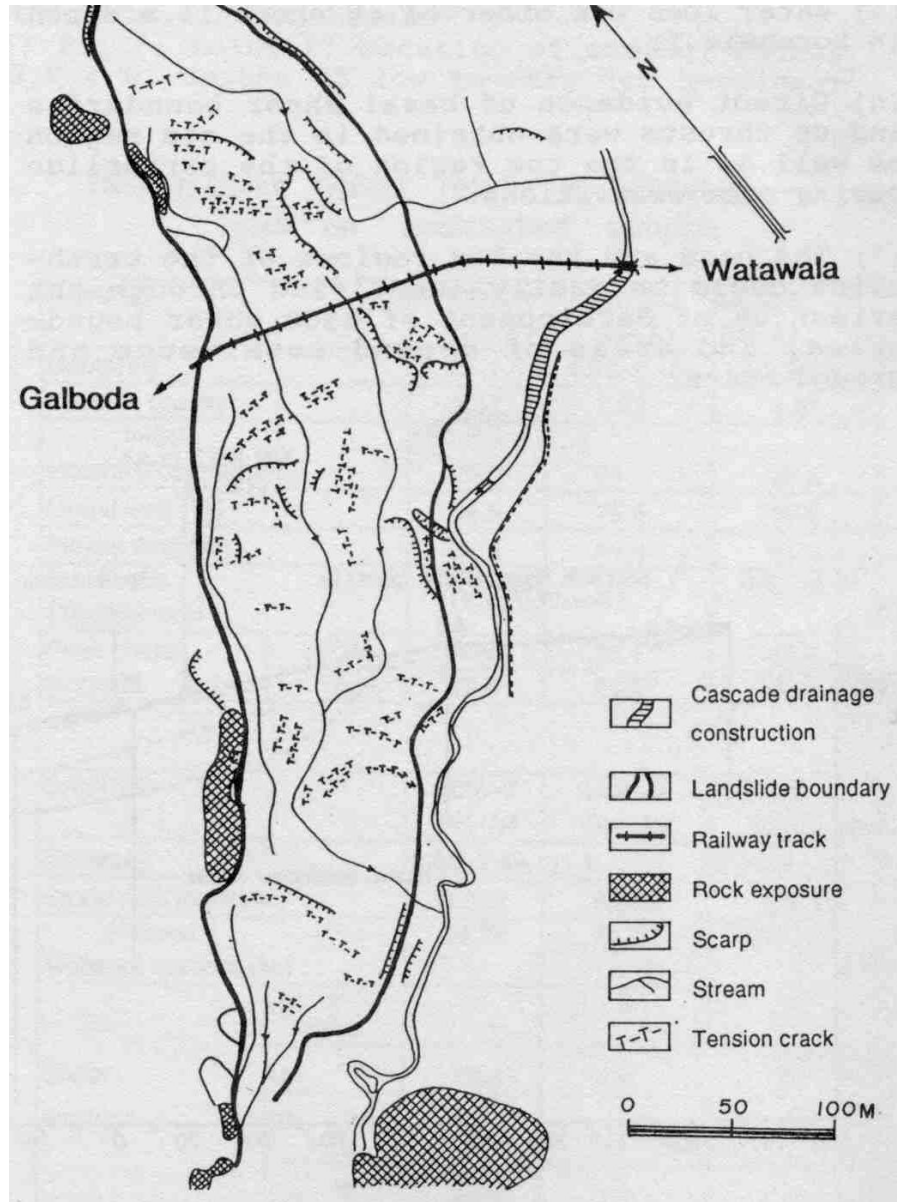
Combination of trench drains and sub horizontal drains. (water flow under gravity)



Watawala Landslide - Night train gone down the slope



Watawala Landslide



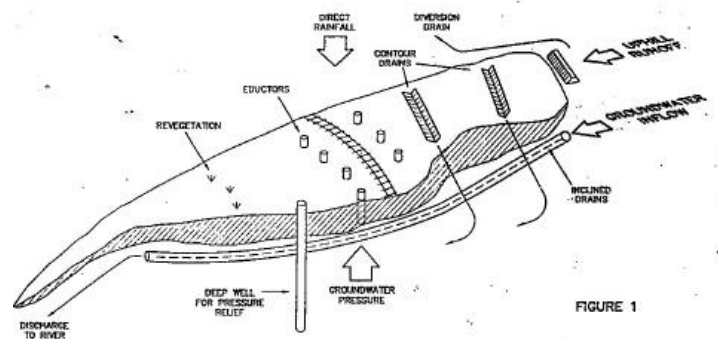
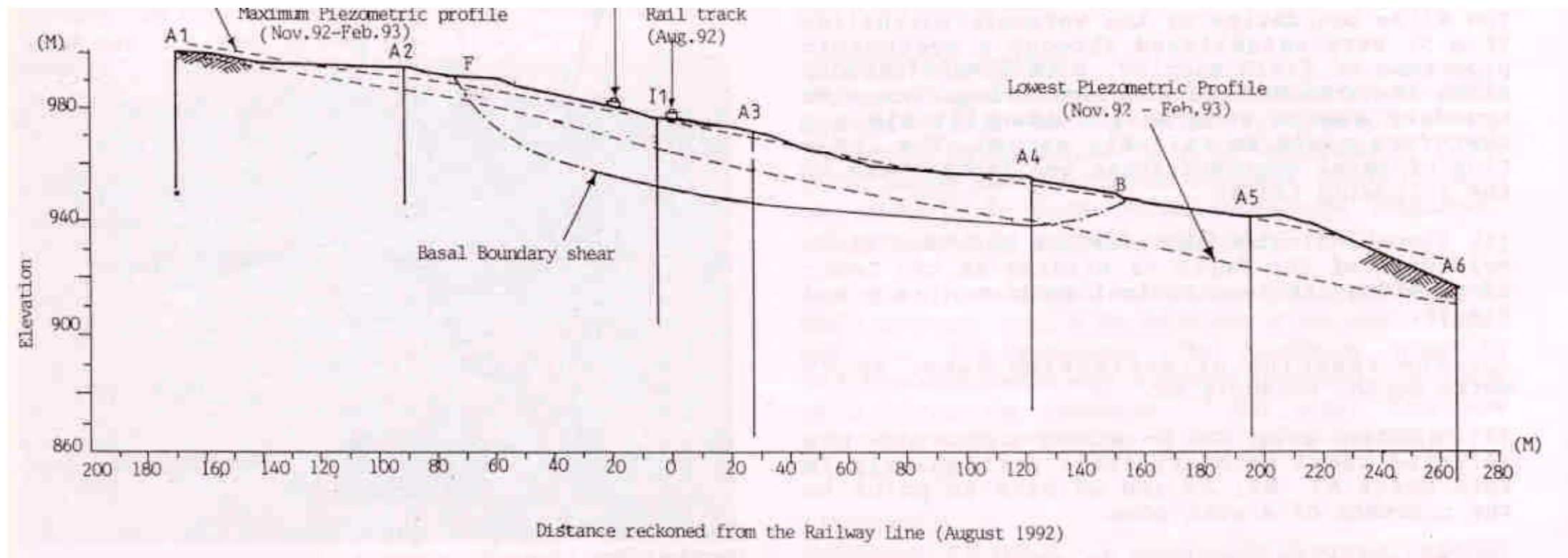
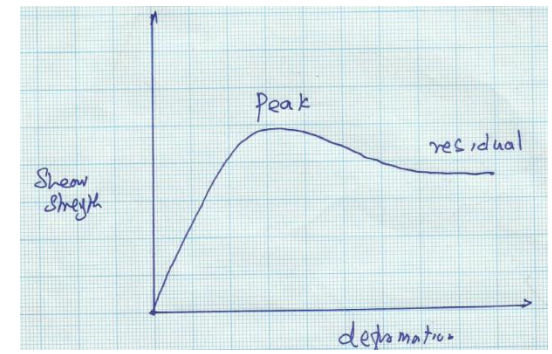
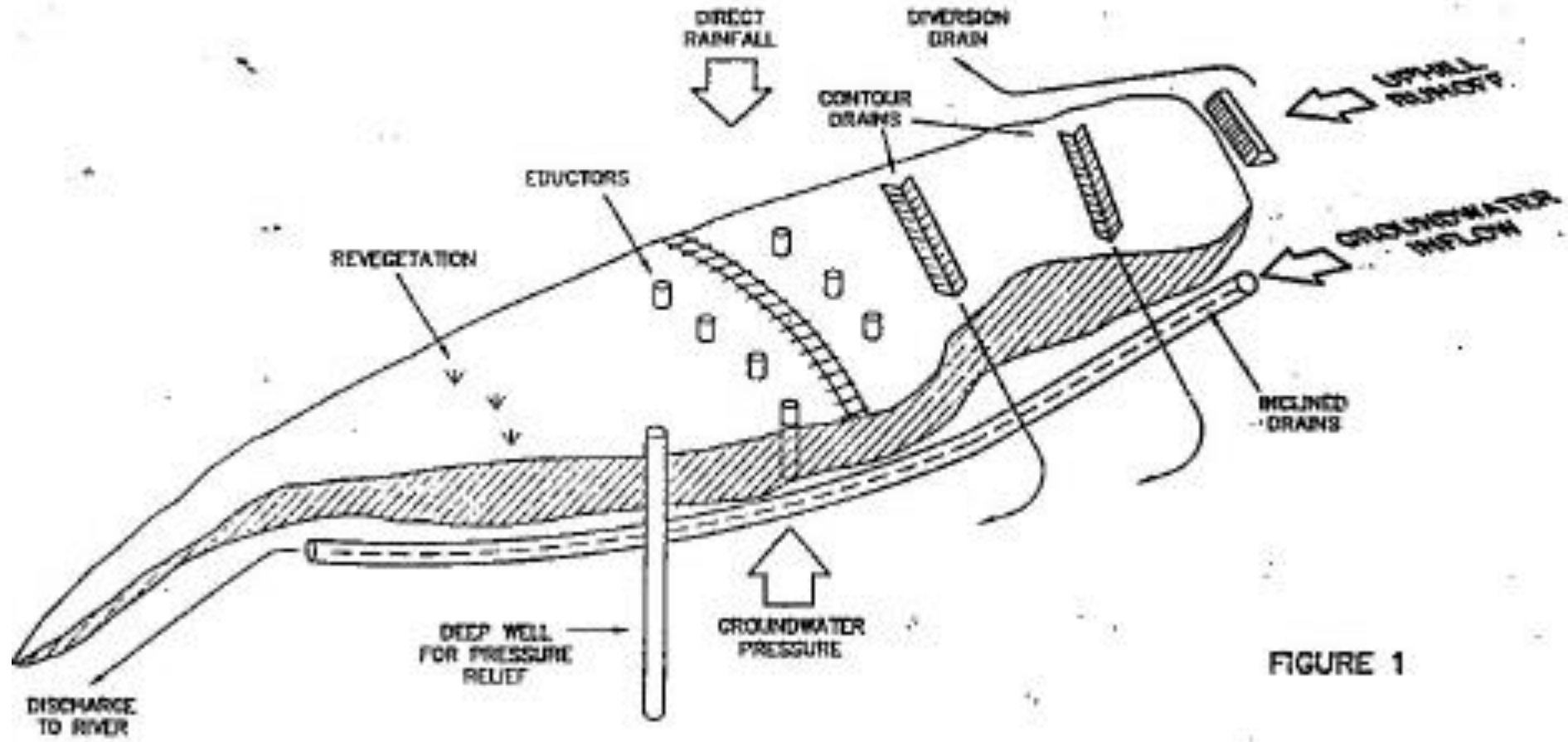


FIGURE 1



The Identified Slip Surface of the Watawala Landslide

Stabilization of Watawala Landslide



Stabilisation of Watawala Landslide

Surface Drainage Measures



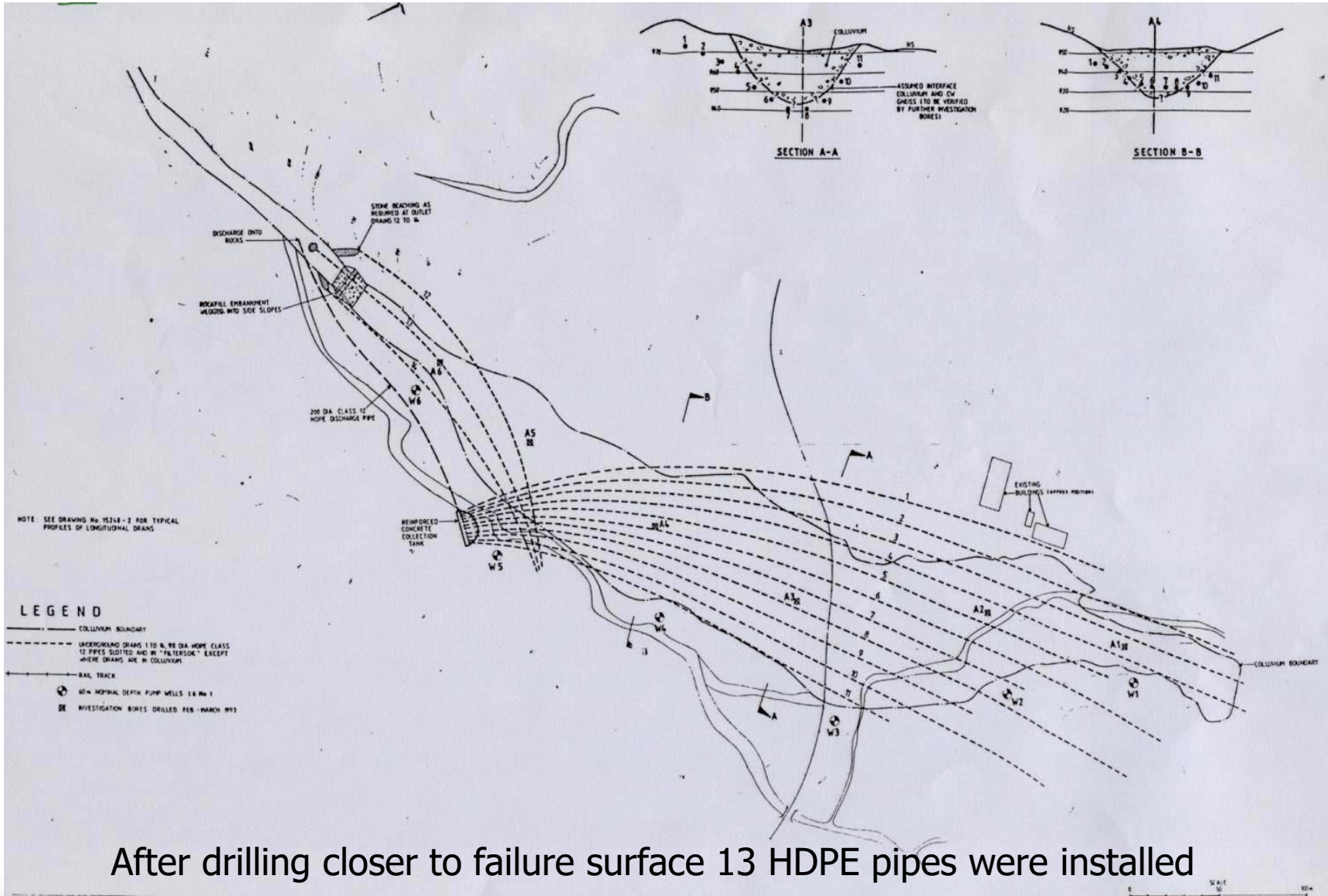
Improvement of surface drainage - this will minimise infiltration



Eductors to pump out sub surface water

- Need to use electrical power-not a feasible continuous solution in the long term

Sub surface Drainage by Directional Drilling



After drilling closer to failure surface 13 HDPE pipes were installed



A typical HDPE pipe that could withstand a large strain (up to 800%). As such it will not break due to deformations in the soil. Pipes are with perforated section

Directionally controlled borings were done with a computer controlled drilling machine following the profile of the failure surface and the drains were installed.

(This is a technique used in the oil industry and used for slope stabilization for the first time)



Outlets of the directional Drains

Pore water entering the pipe through the perforated segments can escape quickly under gravity. Thus there would be rapid pore pressure dissipation

1995



Directional drains at present (2012) -





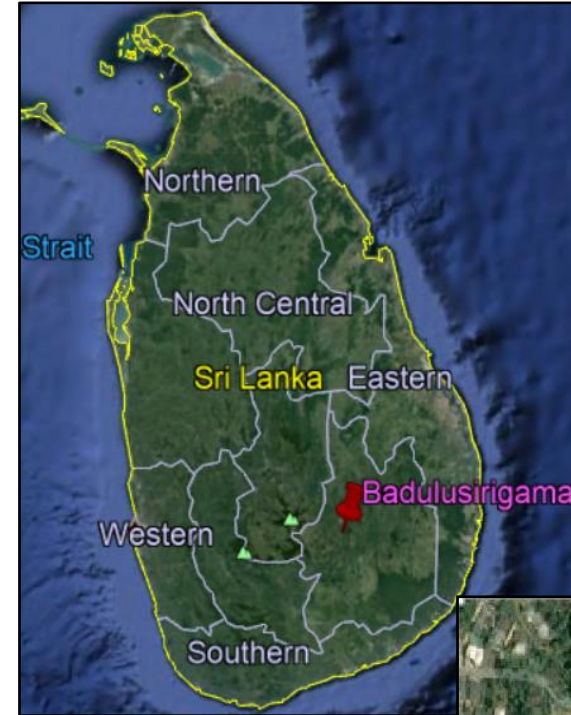
Pumping wells

Railway Track at present (2012)



Badulusirigama Landslide

- Badulusirigama landslide is a slow moving landslide which is activated during heavy rainfall events.
- The landslide was rectified in 2016
- Long subsurface drains network arranged in fan-like groups were used in rectification.
- Rectification of Badulusirigama landslide is remarkable due to the usage of longer subsurface drains of about 40 - 60 m in length as opposed to typically applied lengths of 15 to 30 m as well as common parallel orientation.
- Badulusirigama landslide is also equipped with a good monitoring instrumentation system.



Location of Badulusirigama in Google Map



Location of the landslide (Balasuriya and Nishikawa, 2016)

Site Investigation Programme at Badulusirigama Landslide

1. Geomorphological survey

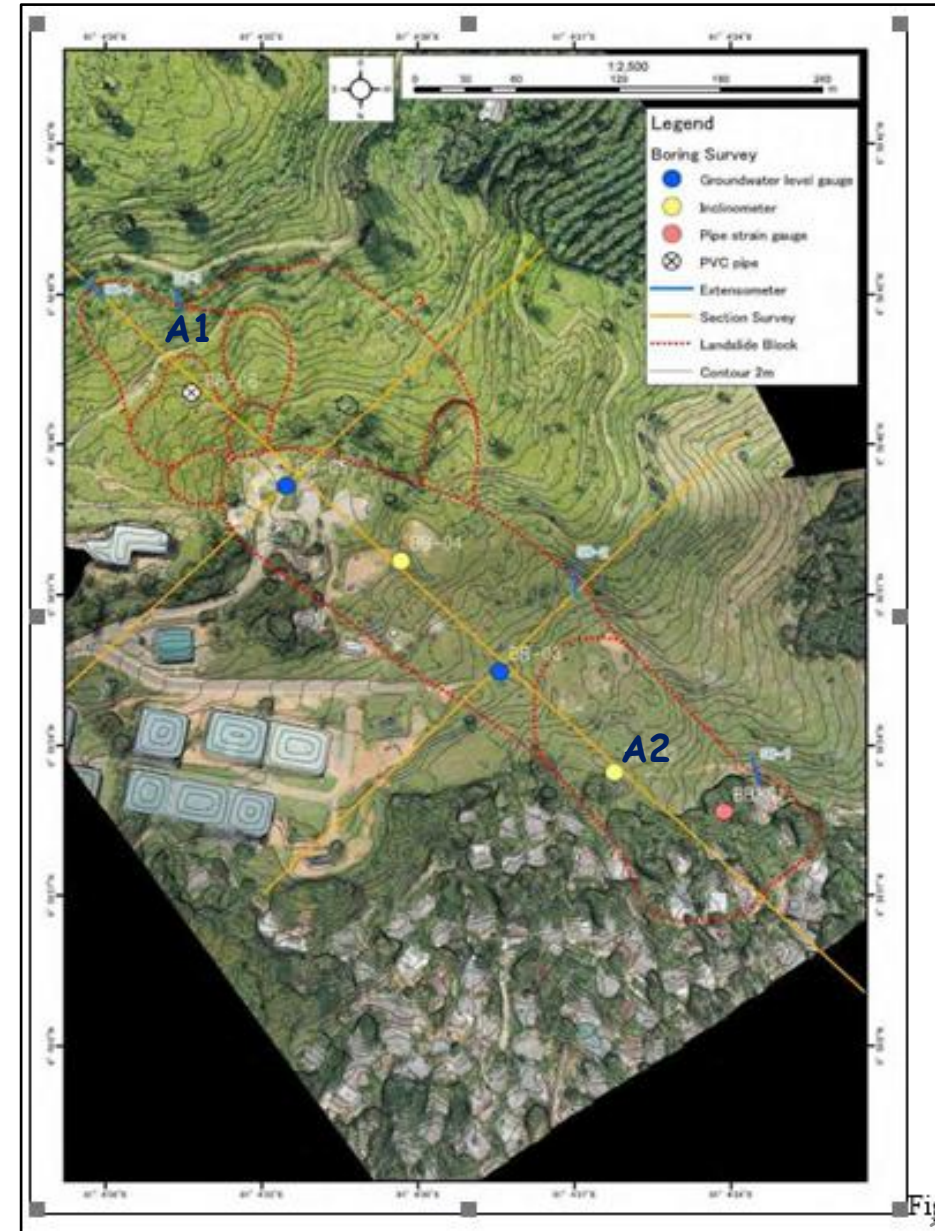
- ✓ Topographic survey
- ✓ Cross sectional survey
- ✓ Unmanned Aerial Vehicle (UAV) analysis.

2. Borehole survey

- ✓ Five boreholes
- ✓ To identify subsurface conditions
- ✓ To identify the location of the slip surface.

3. Geophysical survey

- ✓ Seismic refraction surveys
- ✓ Resistivity surveys



Selected investigation locations and survey lines (JICA Report, September 2015)

Geotechnical model of the Badulusirigama Landslide

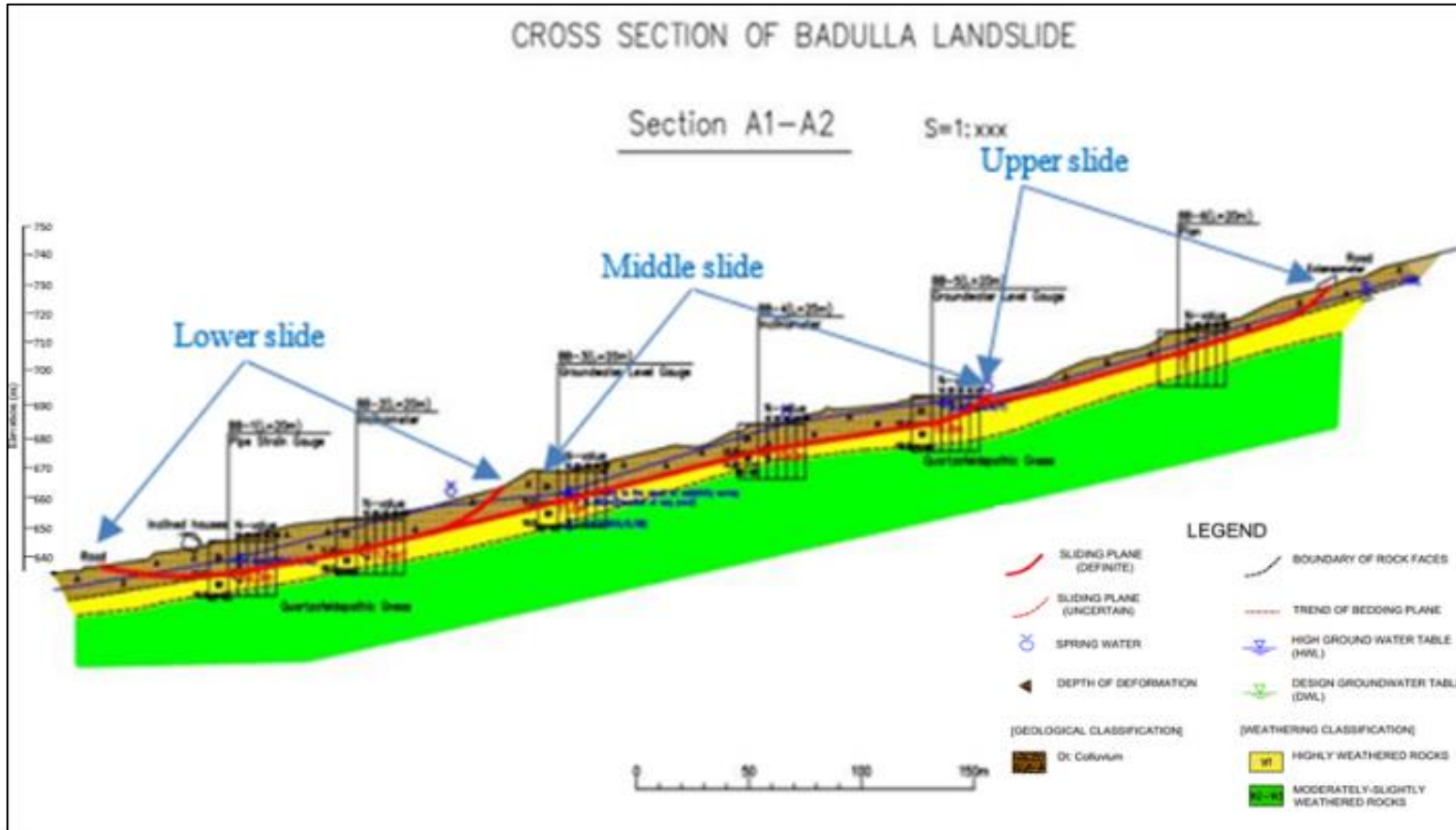
- Mechanical and hydrological parameters for subsoil layers were determined based on the field SPT correlations available in the literature as well as experience gained from similar studies conducted in the past.

Parameter Layer	Density		Effective Cohesion (kPa)	Effective Friction angle (deg)	Elastic modulus (kPa)	Poisson's ratio	Void ratio	Saturated permeability (mday ⁻¹)
	Bulk (kNm ⁻³)	Saturated (kNm ⁻³)						
Colluvium	15	16	2	22	12000	0.3	0.8	0.86
Completely to highly weathered rock	16	17	6	32	30000	0.3	0.5	8.6E-2
Moderately weathered rock	20	20	20	40	150000	0.2	0.2	8.6E-10

Identification of the Slip surface

Assembling the borehole investigation data with the geophysical survey data obtained and tension cracks observed on the ground surface, the sliding plane had been established

- ❖ The sliding mass was divided into three slides namely:
 1. Upper slide
 2. Middle slide
 3. Lower slide
- ❖ Extensometers at the toe of the slope had indicated compression displacements which denoted that the slide was rotational in nature



Potential slip surfaces defined based on the field investigations (JICA Report, September 2015)

Adopted mitigation measures

Surface Drainage Measures

- The surface drainage ditches have been designed in align with natural channels to eliminate the infiltration and spring flow.
- The total length of the surface drainage ditches are 861 m.



Surface drainage measures (JICA Report, September 2015)

Subsurface Drains

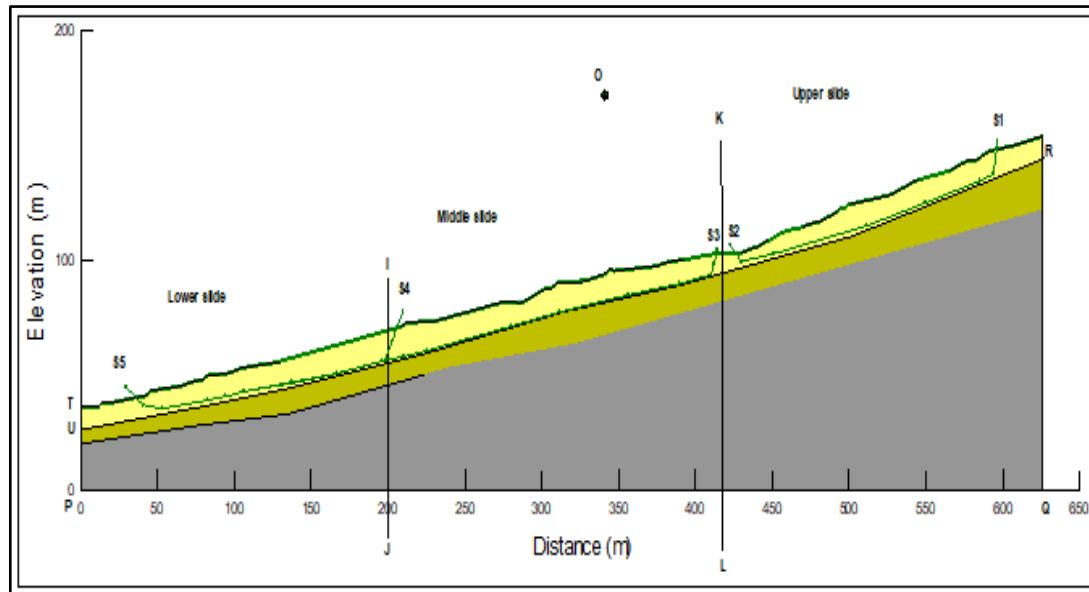


Numerical modelling of Badulusirigama Landslide

(kankanamge and Kulathilaka-2021)

Two dimensional plane strain analysis (2D model): Limit Equilibrium approach

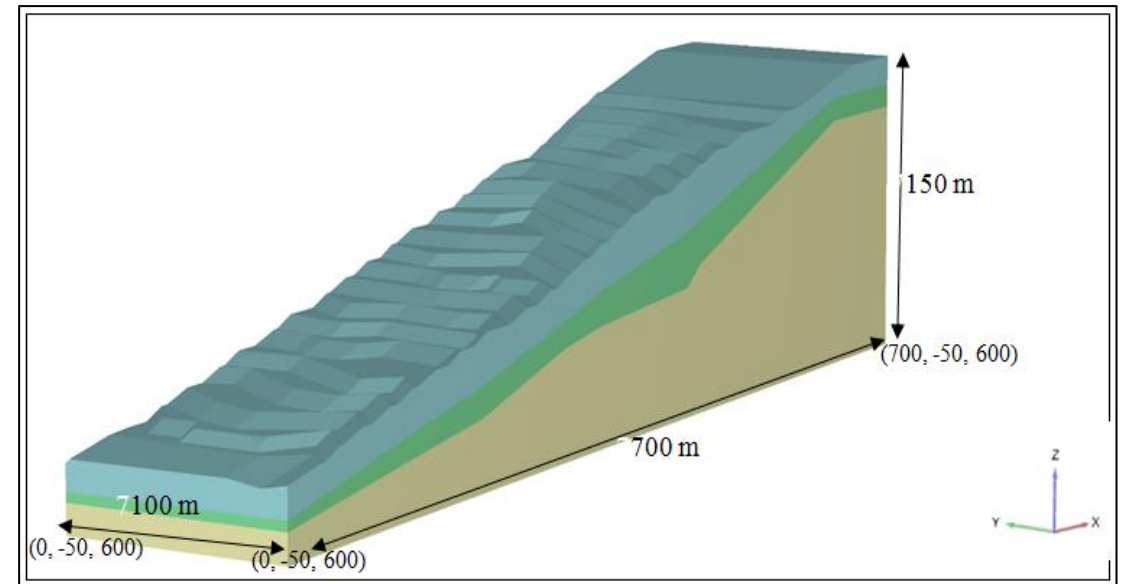
- Using GeoStudio 2012 software package



Assumed failure surface based on site investigation data

Three dimensional finite element model (3D model)

- Using PLAXIS 3D 2017 software



No assumptions of failure surface. Instead C-Phi reduction technique addresses for deformation and change in stresses

Numerical modelling of the Badulusirigama landslide

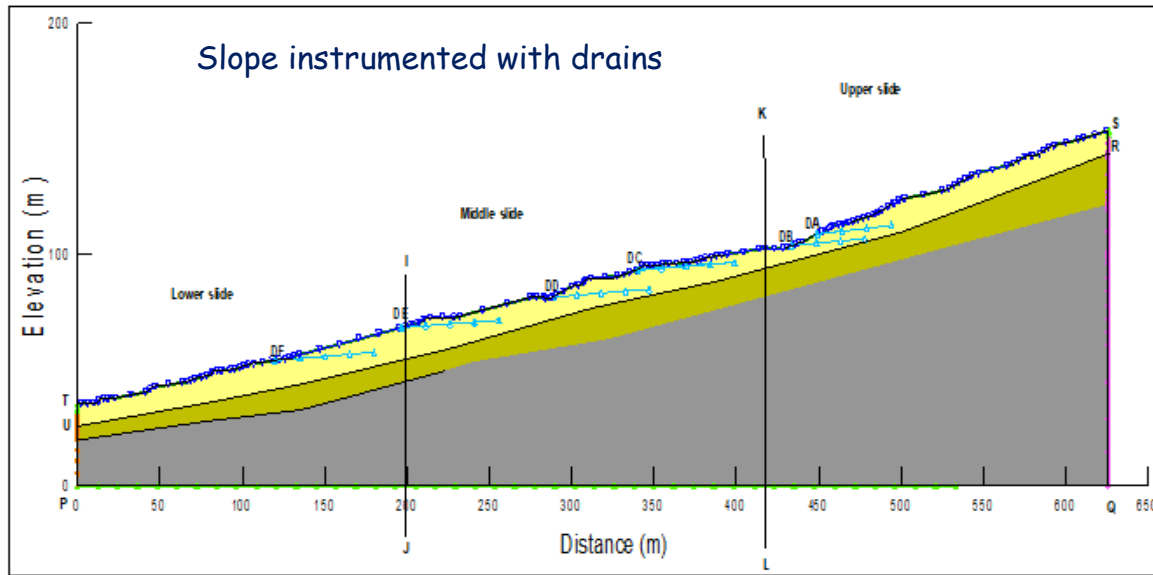
Two dimensional plane strain analysis with limit equilibrium approach

- The most critical cross section was identified using the site investigation data.
- Slip surfaces were fully specified (using the option available in the GEO SLOPE software) as per the data obtained from the site investigations and monitoring program
- Factor of safety of the respective slip surfaces, subjected to different conditions, were determined using the Spencer method which is valid for both circular and non-circular slip surfaces and accounts for both force and moment equilibrium

Three dimensional finite element analysis

- A real-scale 3D model of the slope was developed in PLAXIS 3D software using the site investigation and survey data
- The model represents the surface irregularities existing in the site
- Factor of safety of the slip surface was determined using the strength reduction approach available in the software

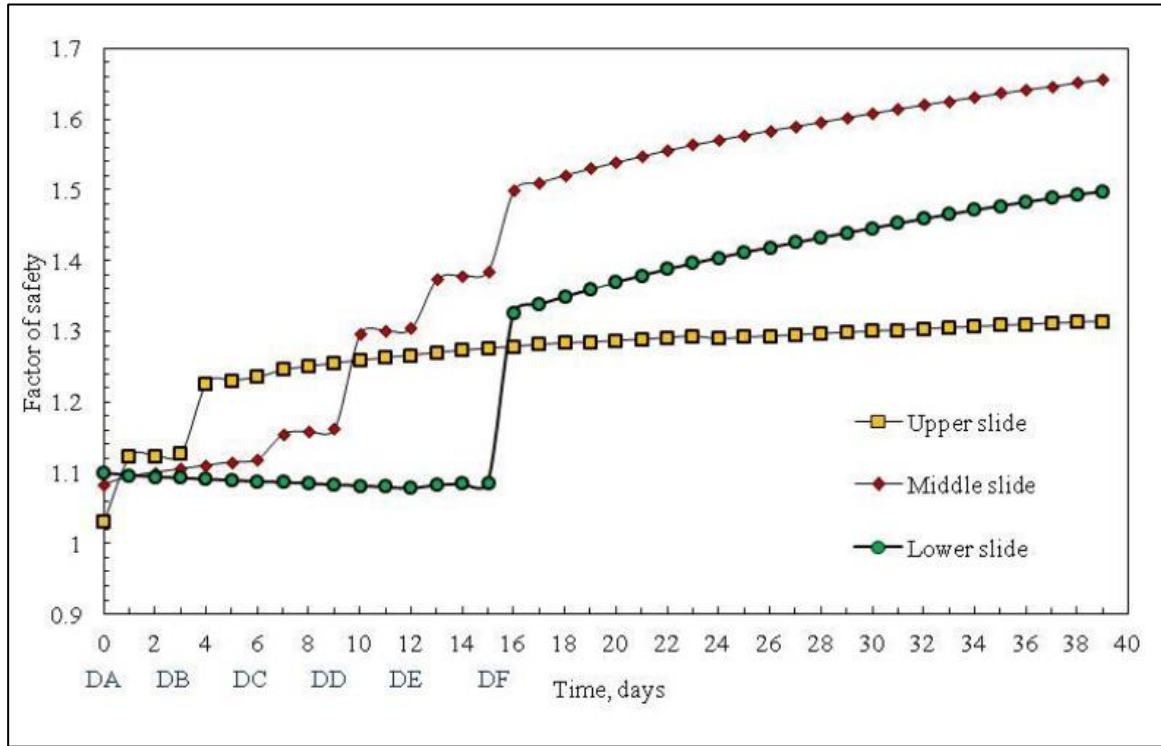
2D analysis : Summary of the analysis cases conducted



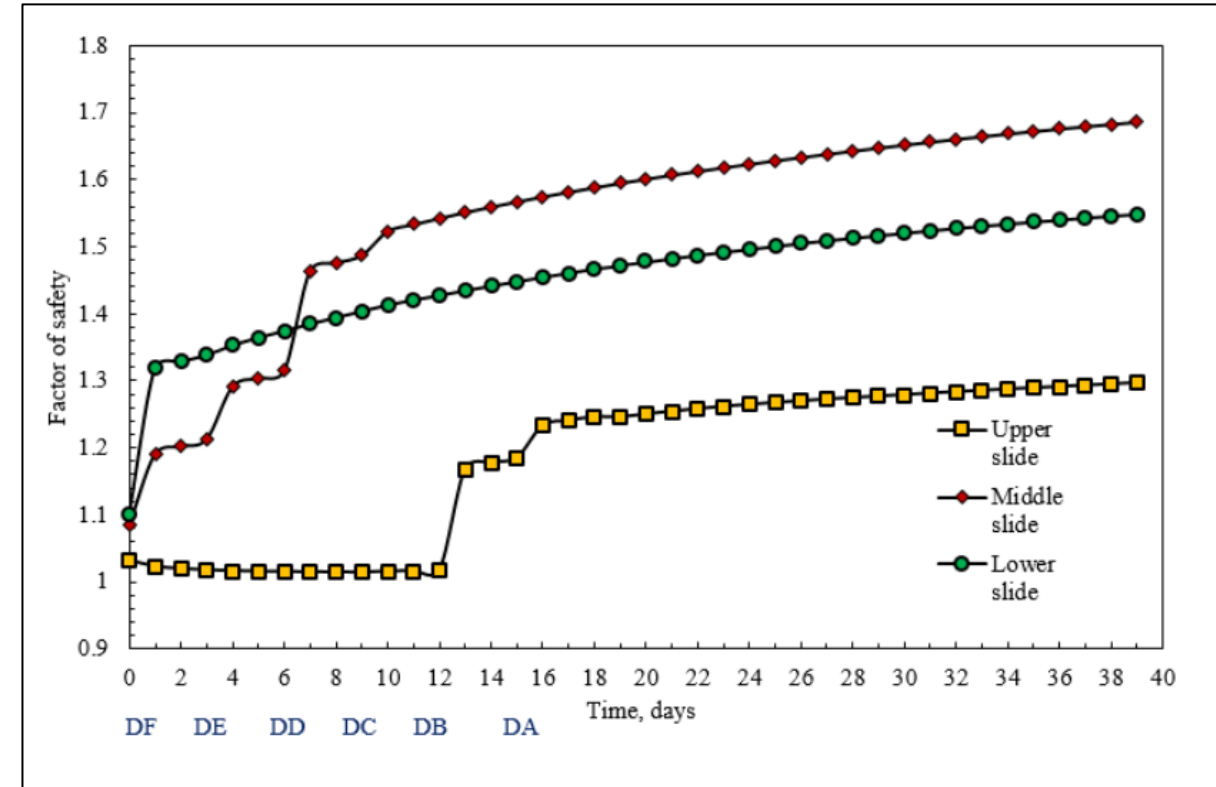
- Improvement of FoS with the construction of drains was assessed under three different construction sequences.
- Analyses were carried out for all four slip surfaces. (upper, middle, lower and a possible composite slip)

Day of installation of drains	Case 1 all six drains simultaneously	Case 2 top - down construction of drains	Case 3 bottom - up construction of drains
At the start	All drains	A	F
After 03 days	-	A,B	F,E
After 06 days	-	A,B,C	F,E,D
After 09 days	-	A,B,CD	F,E,D,C
After 12 days	-	A,B,C,D,E	F,E,D,CB
After 15 days	-	A,B,C,D,E,F	F,E,D,C,B,A

2D analysis : Improvement of stability of three identified failure surface during rectification

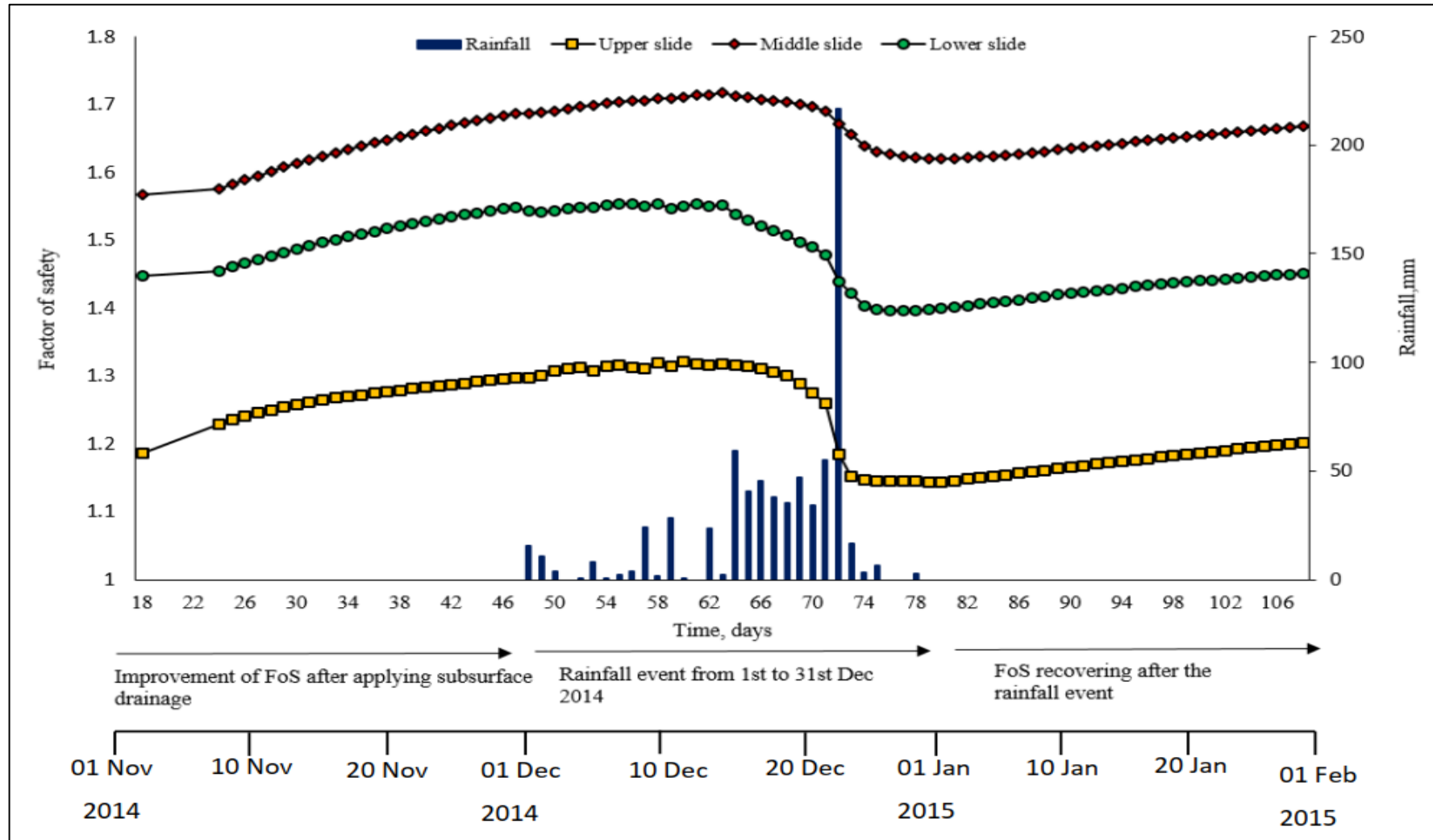


Variation of factor of safety under top down construction sequence



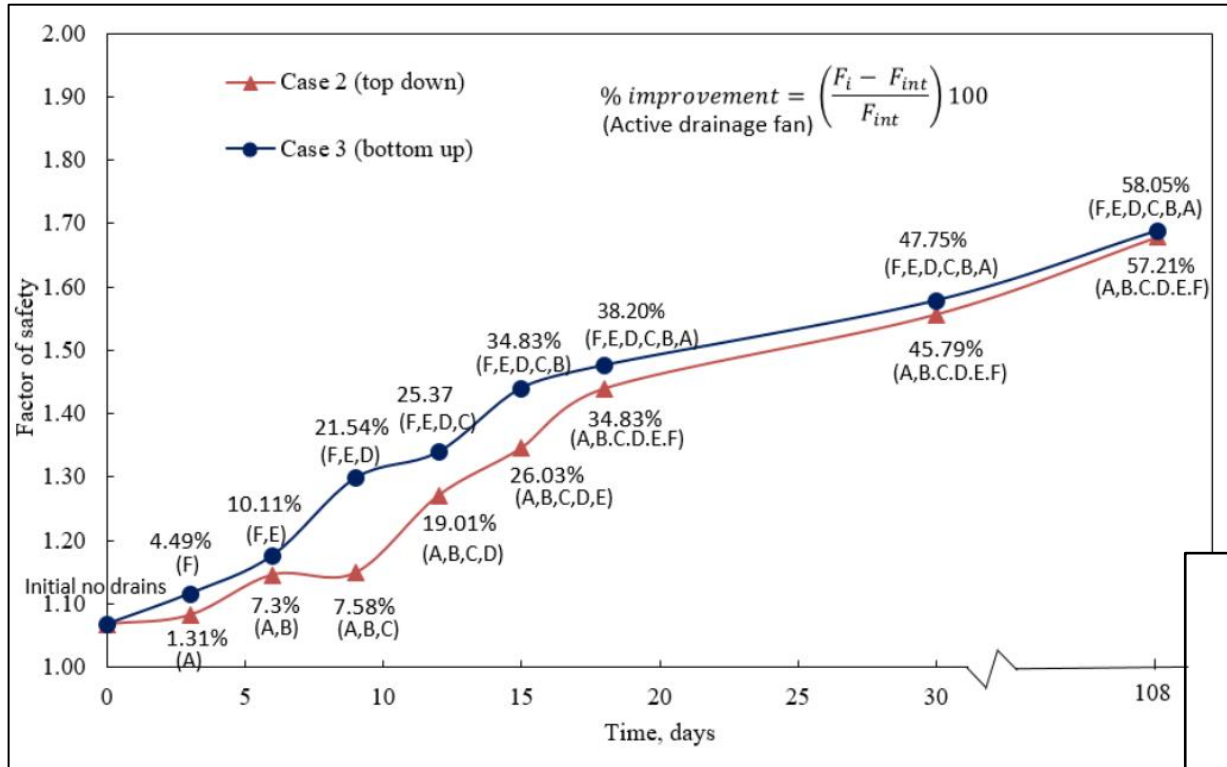
Variation of factor of safety under bottom up construction sequence

2D analysis : Variation of factor of safety of the upper , middle and lower slides during a critical rainfall event after drainage improvement



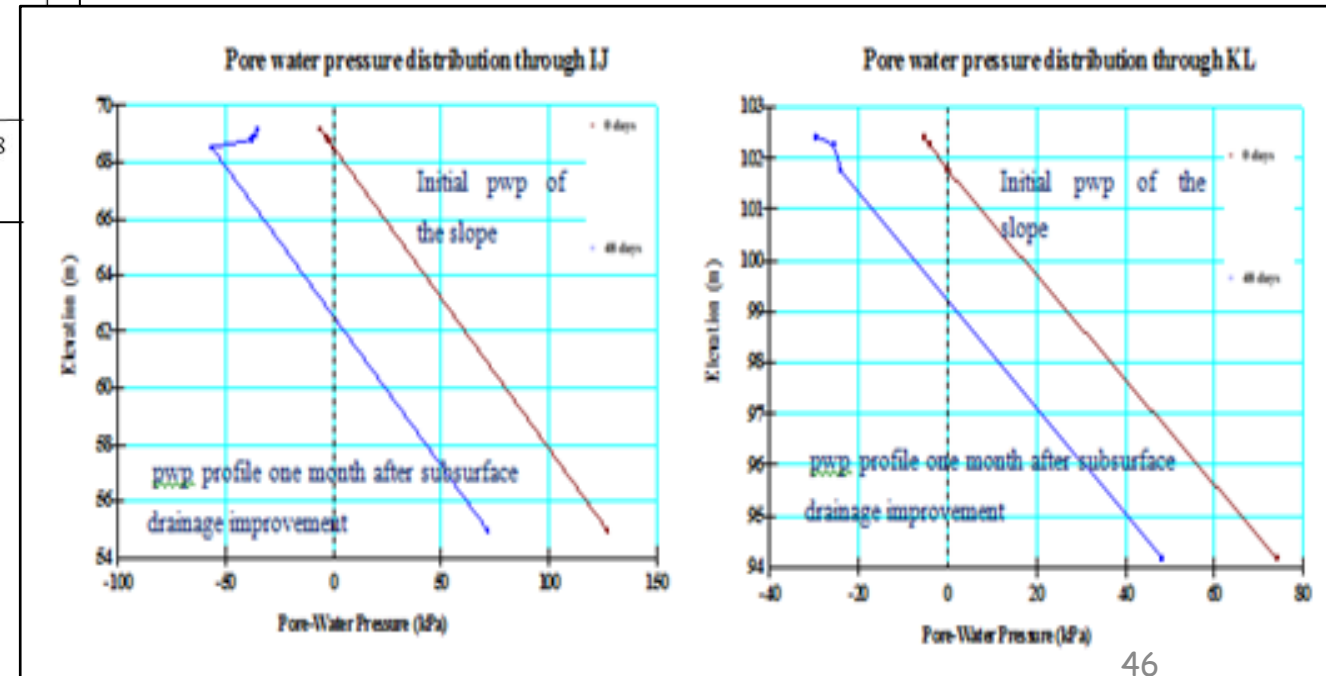
Variation of factor of safety of three rectified slides during a critical rainfall event

2D analysis : Stability improvement of the composite failure surface during rectification

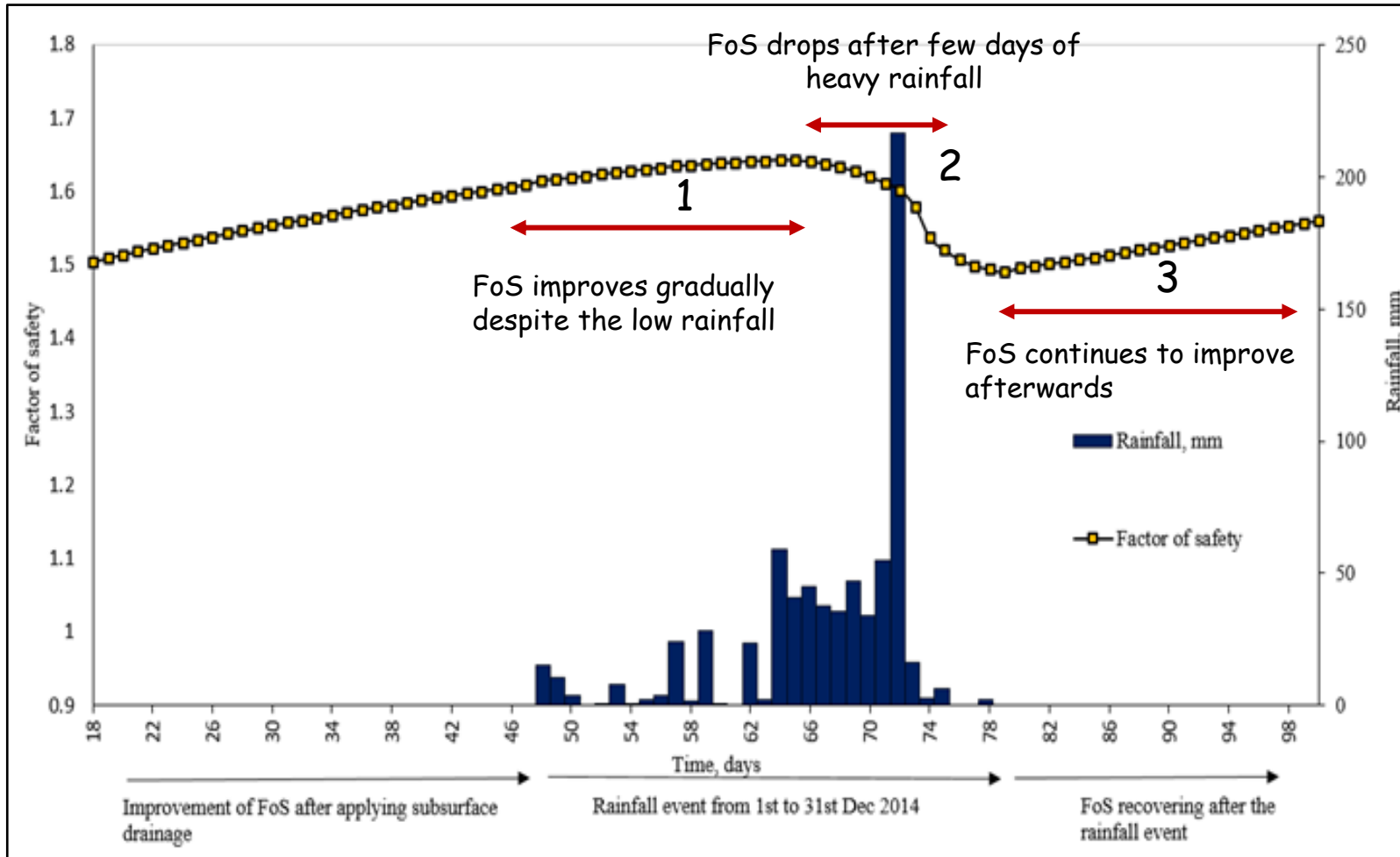


Factor of safety improvement for two different cases

Variation of the pore water pressure profile before and after subsurface drainage improvements: (a) Section IJ, (b) Section KL



2D analysis : Stability of composite failure surface during a critical rainfall event after drainage improvement



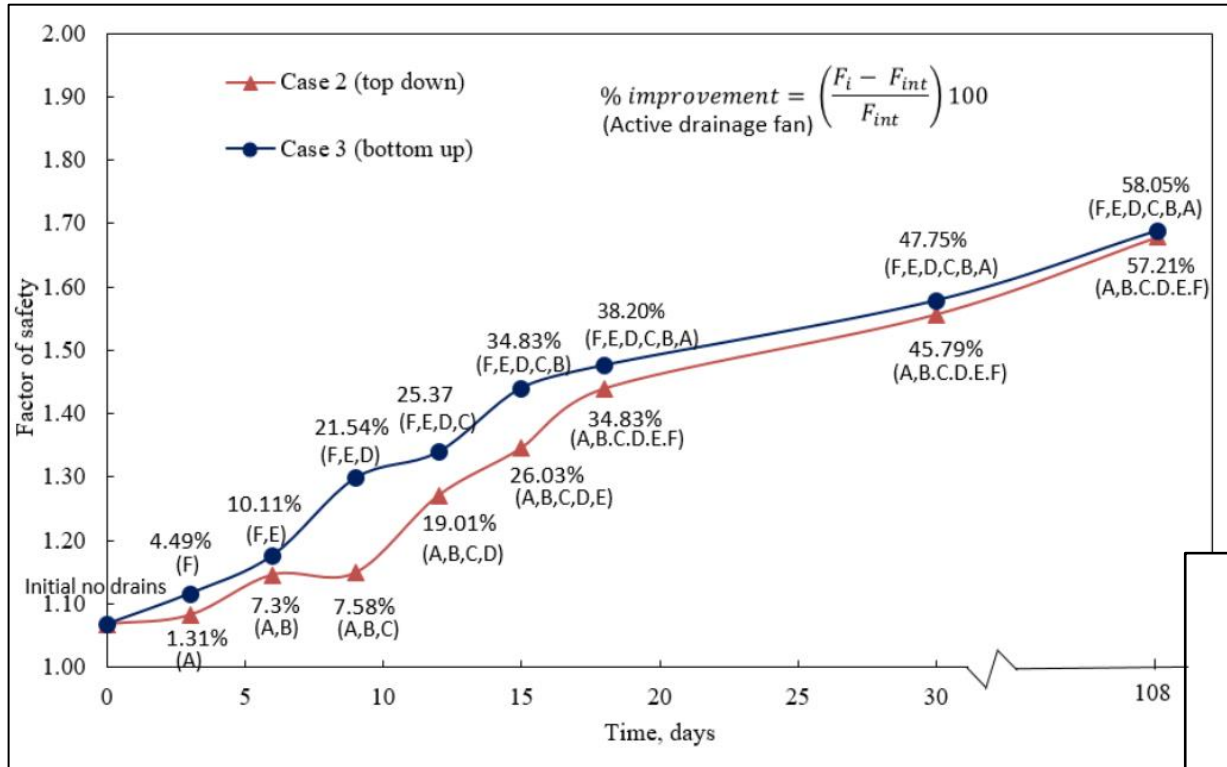
1. During the drain out of initial high ground water table conditions, some residual flow channels are already established. The light infiltration during this period is easily drained through these residual flow channels.
2. When larger infiltration occurs the capacity of residual flow channels are exceeded. Therefore, the water accumulate in the soil body and occupy the remaining void spaces. This results in reduction of FoS.
3. Once the rainfall event is over FoS continues to improve as expected.

Variation of Factor of safety with the daily rainfall

Thank You



2D analysis : Stability improvement of the composite failure surface during rectification



Factor of safety improvement for two different cases

Variation of the pore water pressure profile before and after subsurface drainage improvements: (a) Section IJ, (b) Section KL

