

Geotechnics for Infrastructure through Case Studies

Failures, Investigation, Improvement and Monitoring

Dr. Arindam Dey

Professor

Geotechnical Engineering Division

Department of Civil Engineering

School of Interdisciplinary Studies and Sustainability (SiSAS)

IIT Guwahati

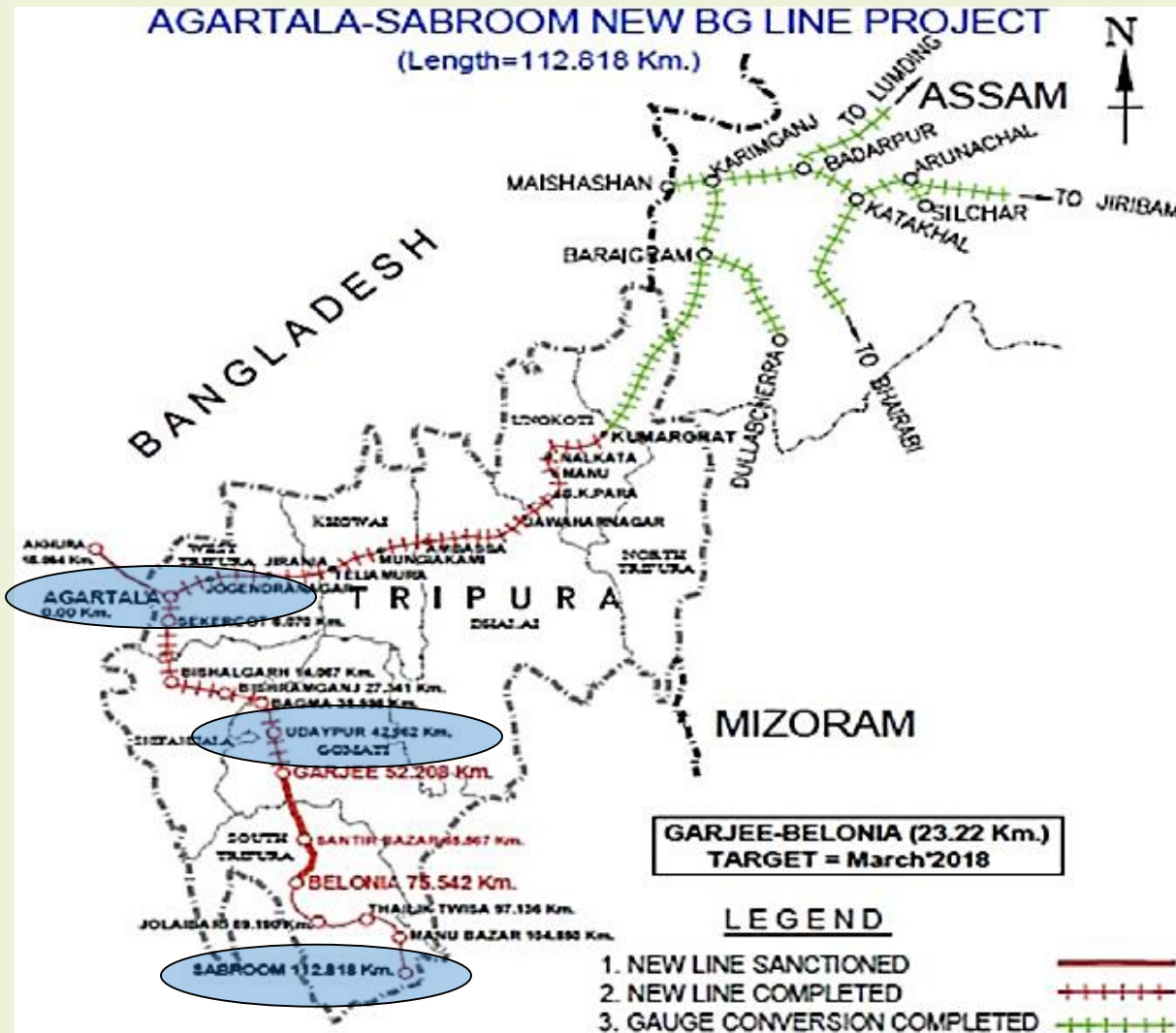


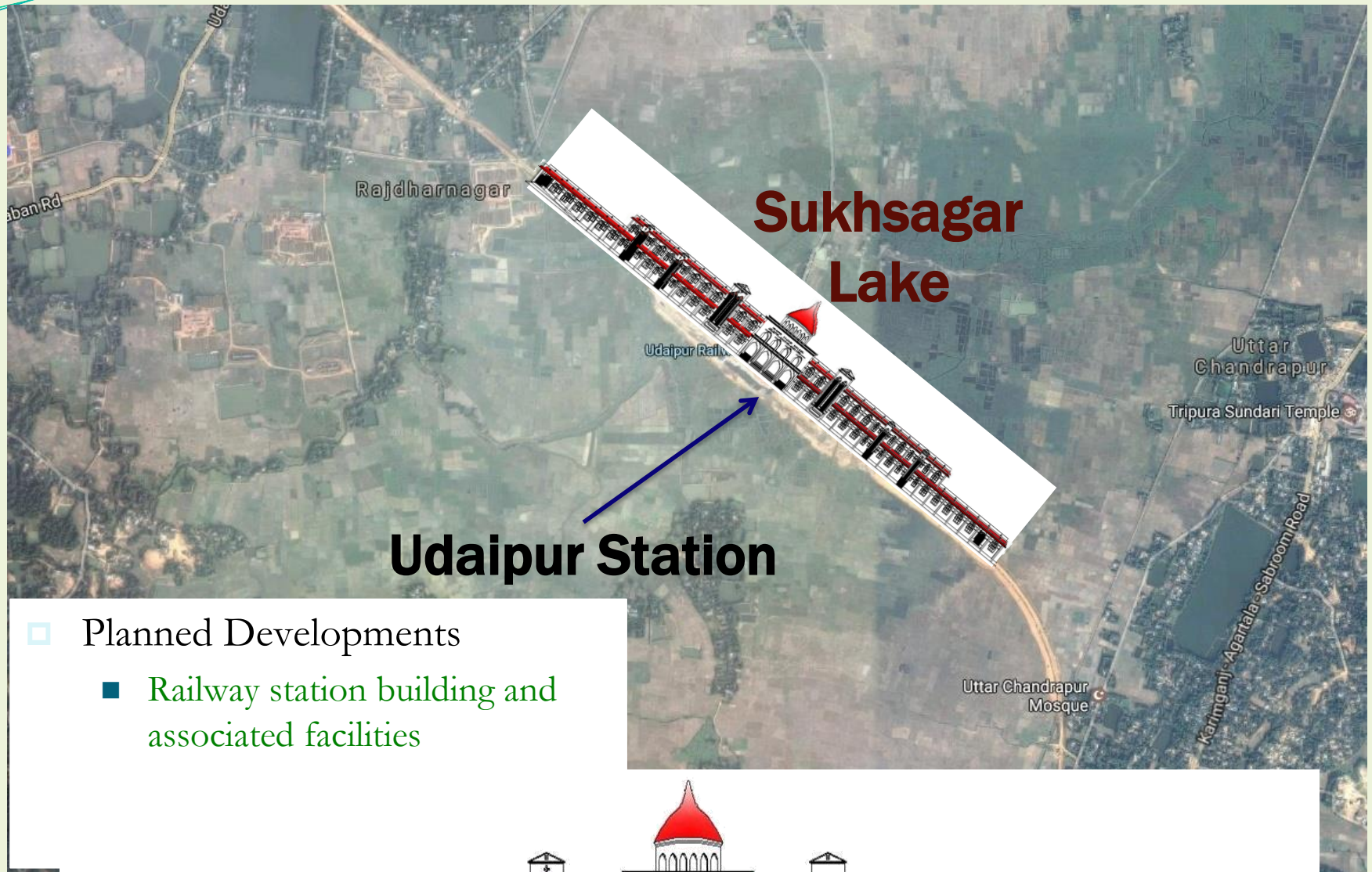
Heritage Railway Station at Udaipur, Agartala, Tripura **Construction in Very Difficult Subsoil**



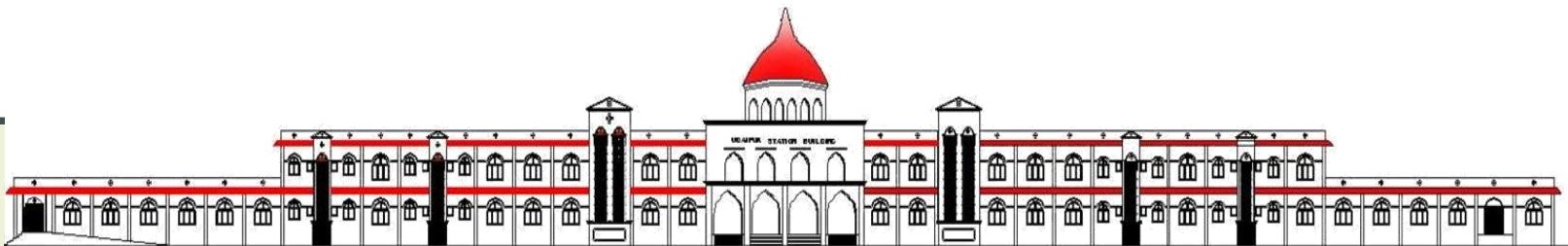
Geotechnical Investigations
Ground Improvement

Rail Links of Tripura (Proposed and Existing)





- Planned Developments
 - Railway station building and associated facilities



Project Walkthrough

- Udaipur railway station of Agartala-Sabroom New BG Line Project is situated between Km. 42.2 to 43.3 (KM. 0.00 at Agartala) in the state of Tripura.
- Station is situated in the Sukhsagar Lake of Udaipur.
 - **Water logged and marshy soil – 3 to 4 m above EGL during monsoons**
 - **Existence of soft soil (Silty Clay) up to 13.3-20 m depth at various locations.**
 - **Out of 13.3 m, top 8 m is mixed with decomposed trees & wooden logs.**
 - **Perennial problems with such soils**
 - Low shear strength
 - High compressibility
- The design and construction of embankments over soft soil has always been a challenging task for engineers
 - ❖ **Proper engineered attention required during initial planning stage with proper ground improvement techniques**

Problems Faced during Embankment Construction

- Desired height of embankment
 - ❖ **6.2 m**
- Embankment construction started in stages: Dec' 2010.
 - ❖ **September 2011**
 - First failure noticed at 3.0-3.5 m height:
 - ❖ **March 2012**
 - Large settlement of 5-5.2 m
 - Heaving up of ground until 30 m distance from the embankment
- Further construction stopped



09-10-2026

Construction Conclave 3.0

7

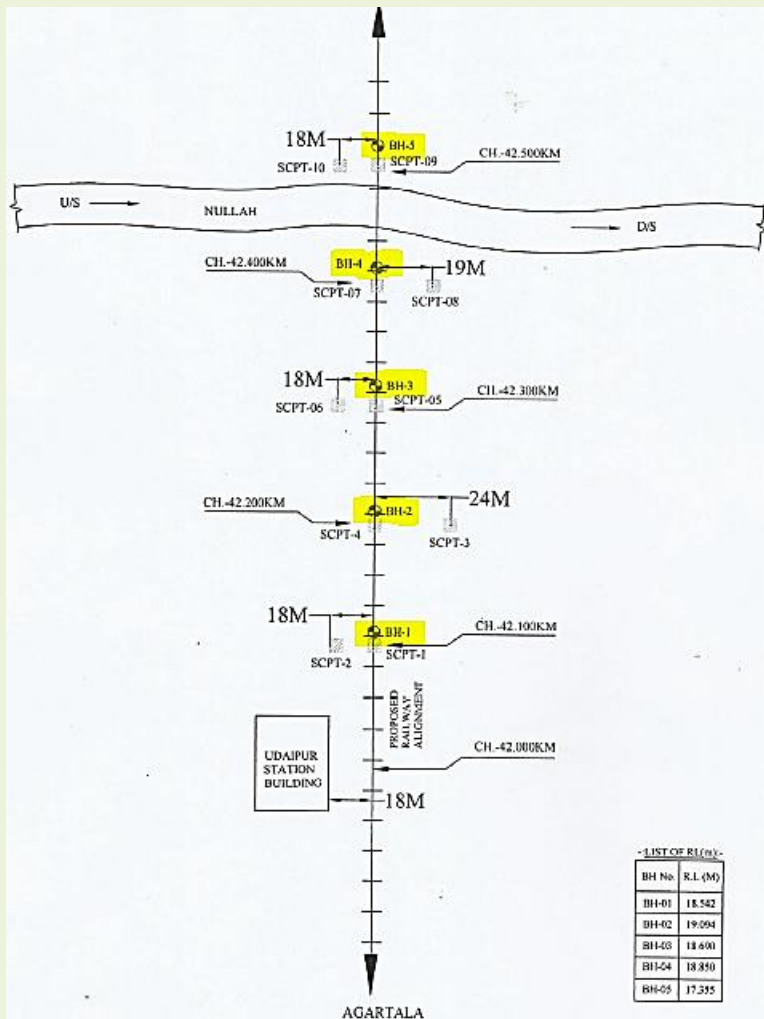




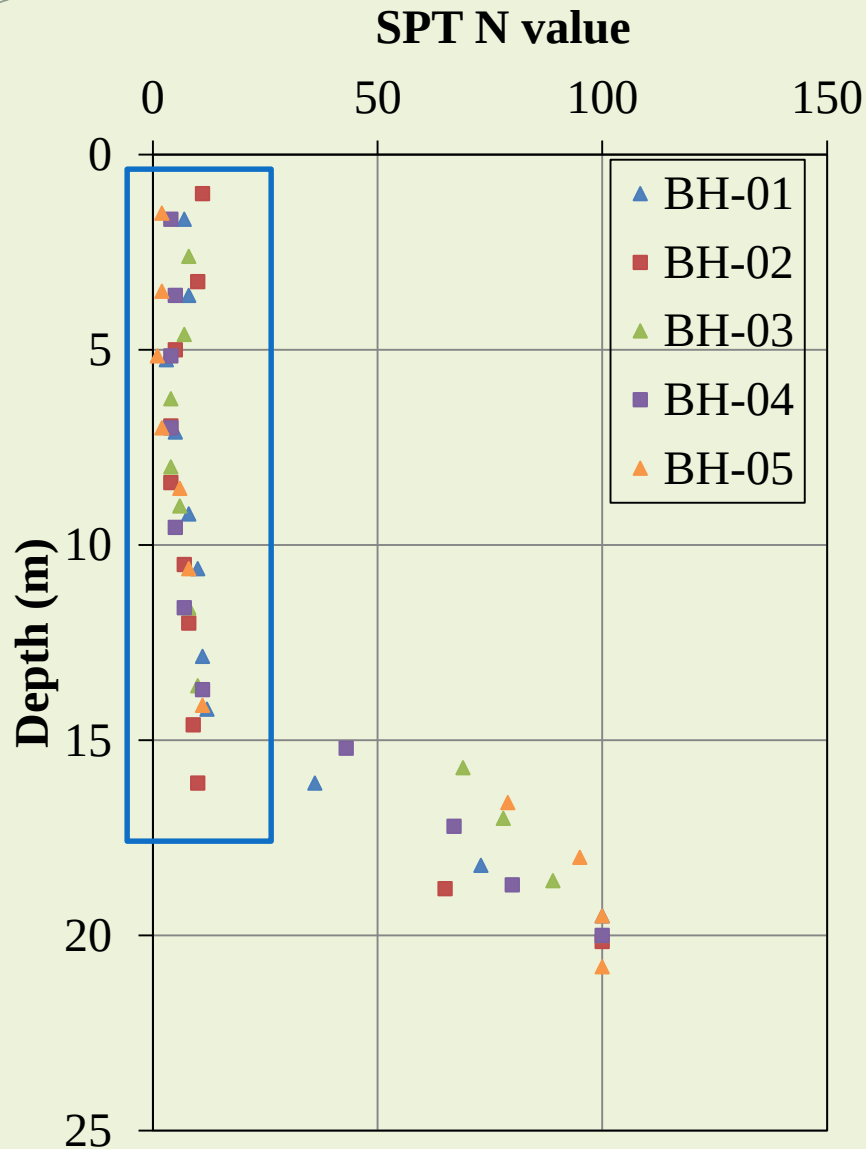
3-Stage Remedial Measures

- Ground improvement of the adjoining area by Pre-fabricated Vertical Drain (PVD) for accelerating consolidation of soft soil.
 - ❖ **Arresting long-term settlement**
- Sheet piling of adequate retaining capacity around the station building before stripping off the existing surrounding embankment for PVD installation.
 - ❖ **Preventing the movement of embankment soil**
- Retrofitting of the station building by providing additional pile raft system and Carbon Fibre Reinforced Polymer (CFRP).
 - ❖ **Distribution of building load and Strengthening the building**

Field Investigation



Bore Hole No.	Chainage (km)	G.L. (m)	Terminating Depth (m)	Standing Water Level (m)
BH-01	42.100	18.542	21.37	0.8
BH-02	42.200	19.094	21.87	2.5
BH-03	42.300	18.69	22.18	2.7
BH-04	42.400	18.85	21.48	2.8
BH-05	42.500	17.355	21.15	0.6

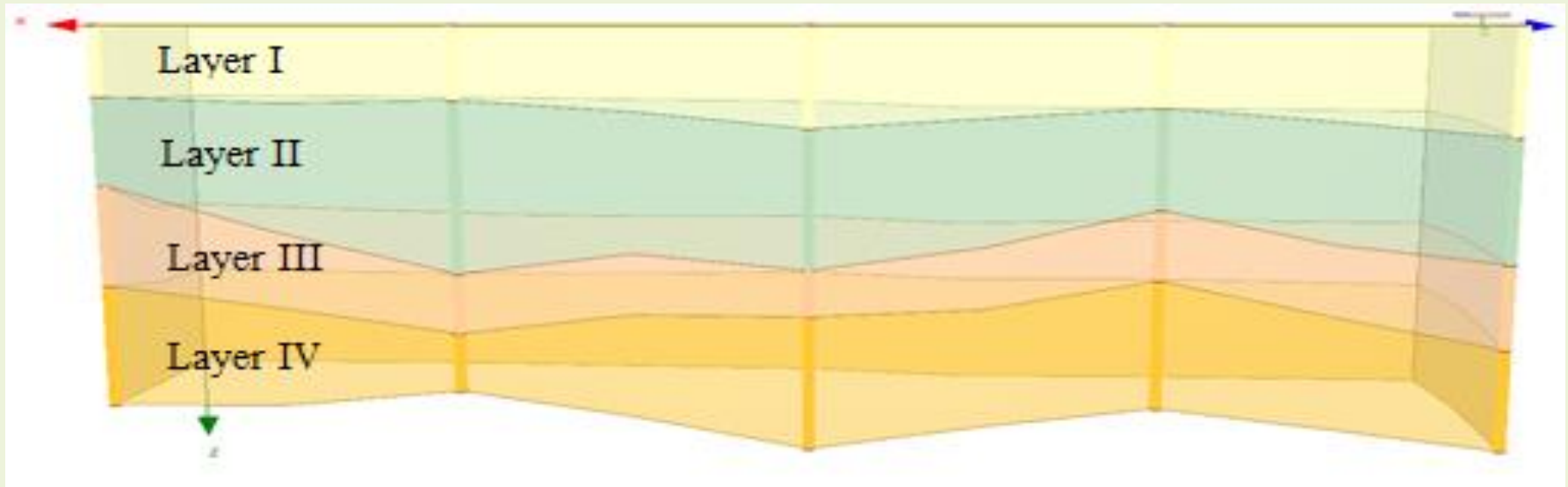


- Stratification of the subsoil

Stratum	SPT N-values	Depth (m)
Layer I	3 - 5	4
Layer II	5 - 10	5
Layer III	10 - 15	4
Layer IV	> 70	5

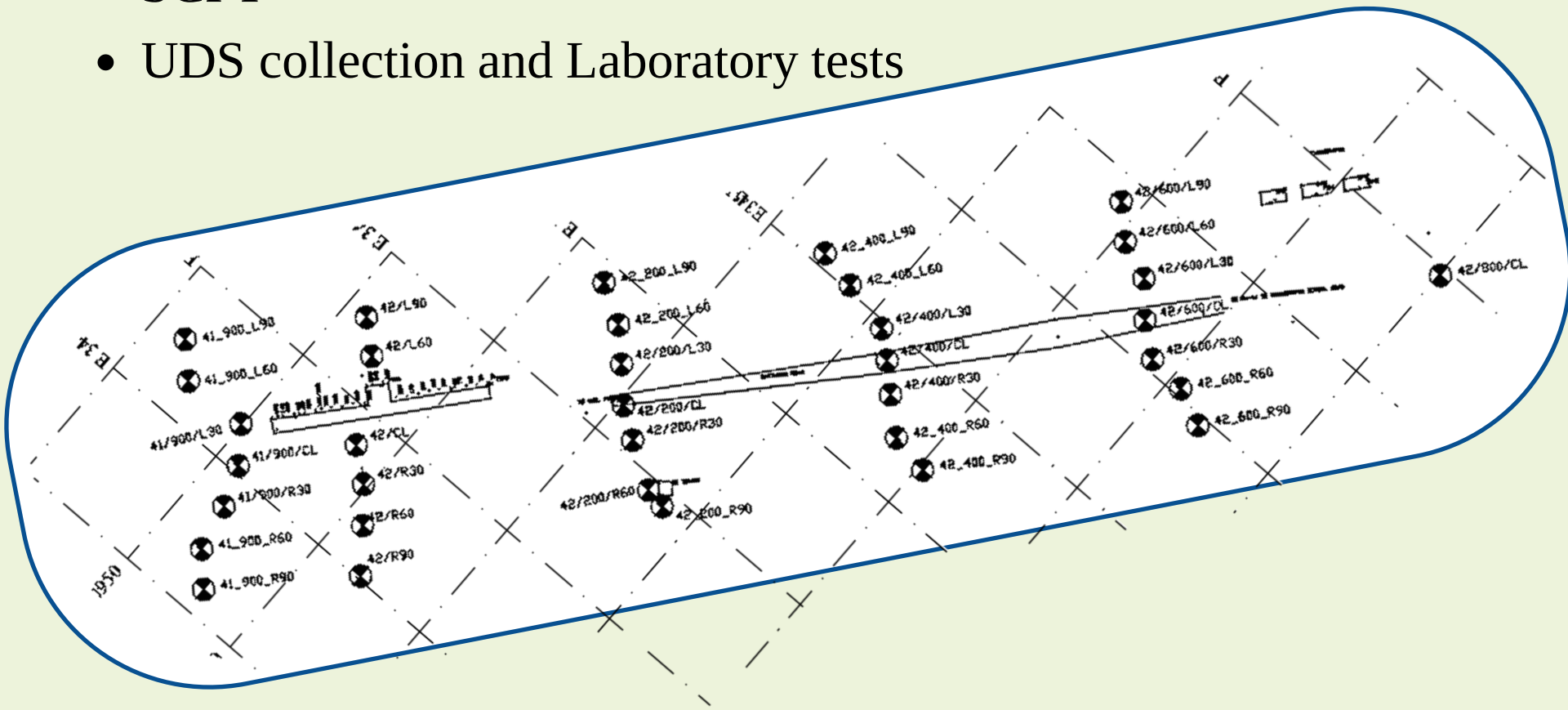
Tentative Subsurface Profiling

- From available bore log data of 5 boreholes, 4 different layers are identified.
- Depending on the SPT N-values, cohesion and physical appearance of the soil.

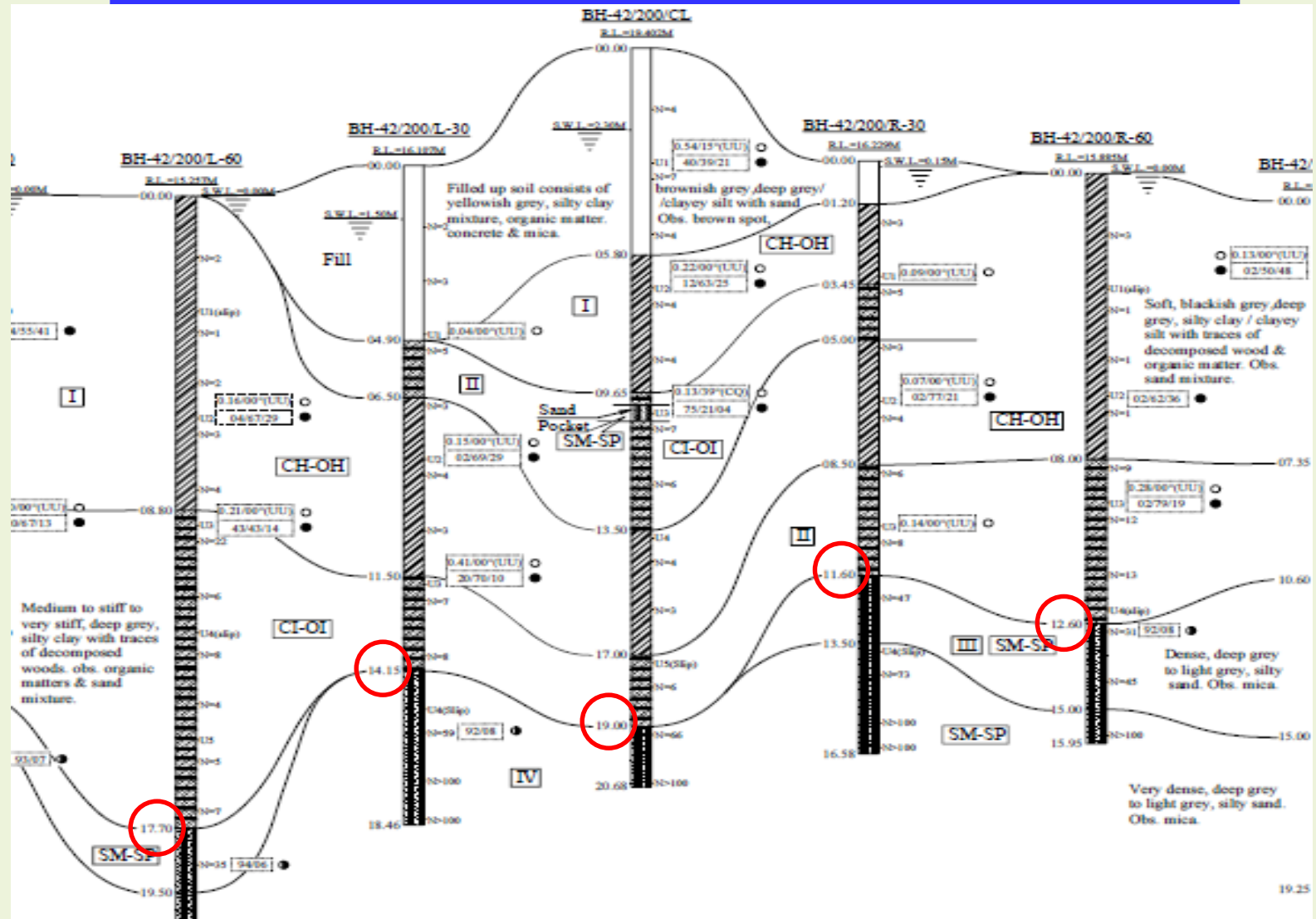


Investigations for Forensic Analysis

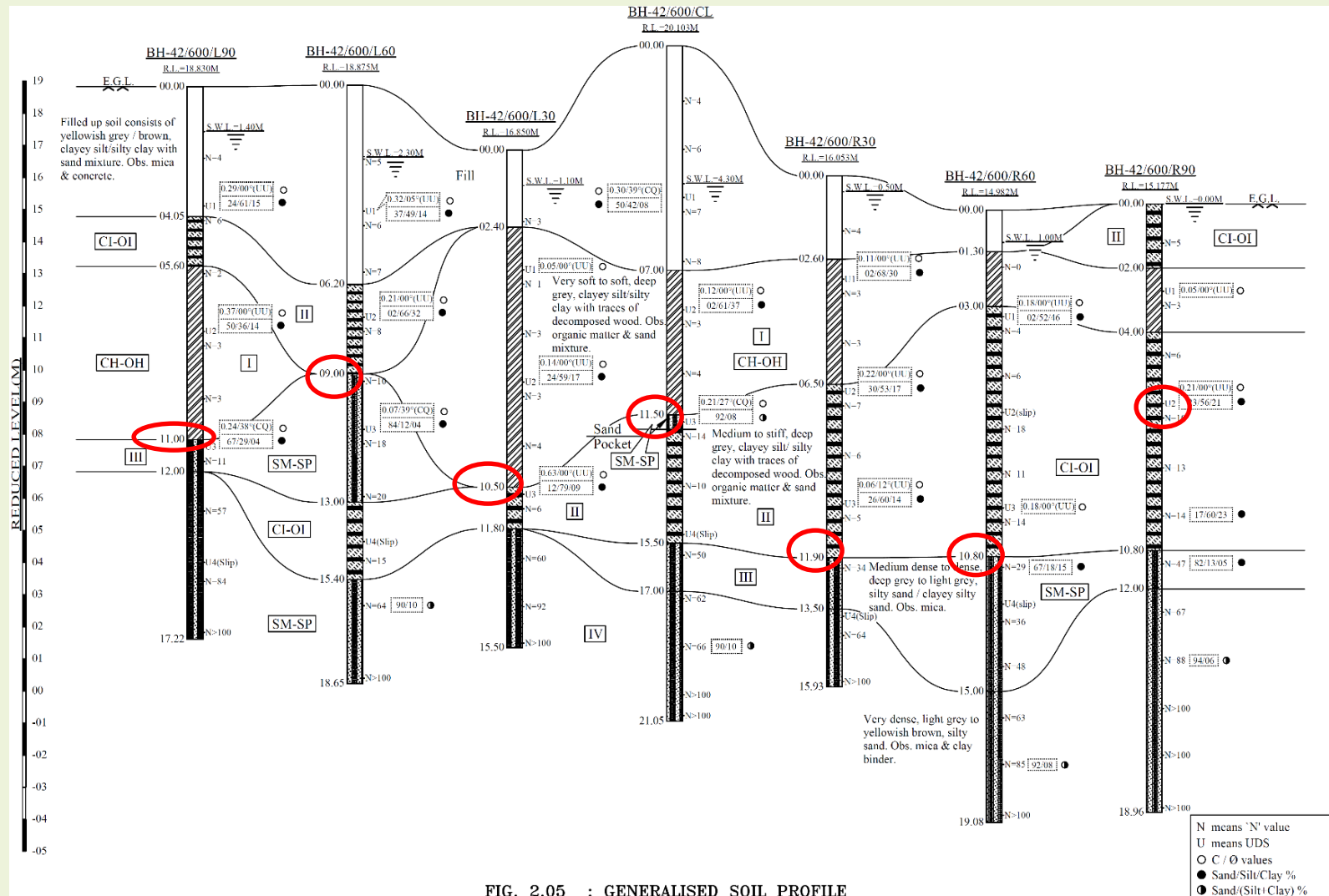
- New Borelogs in adjacent areas (outer embankment area)
- SPT
- SCPT
- UDS collection and Laboratory tests



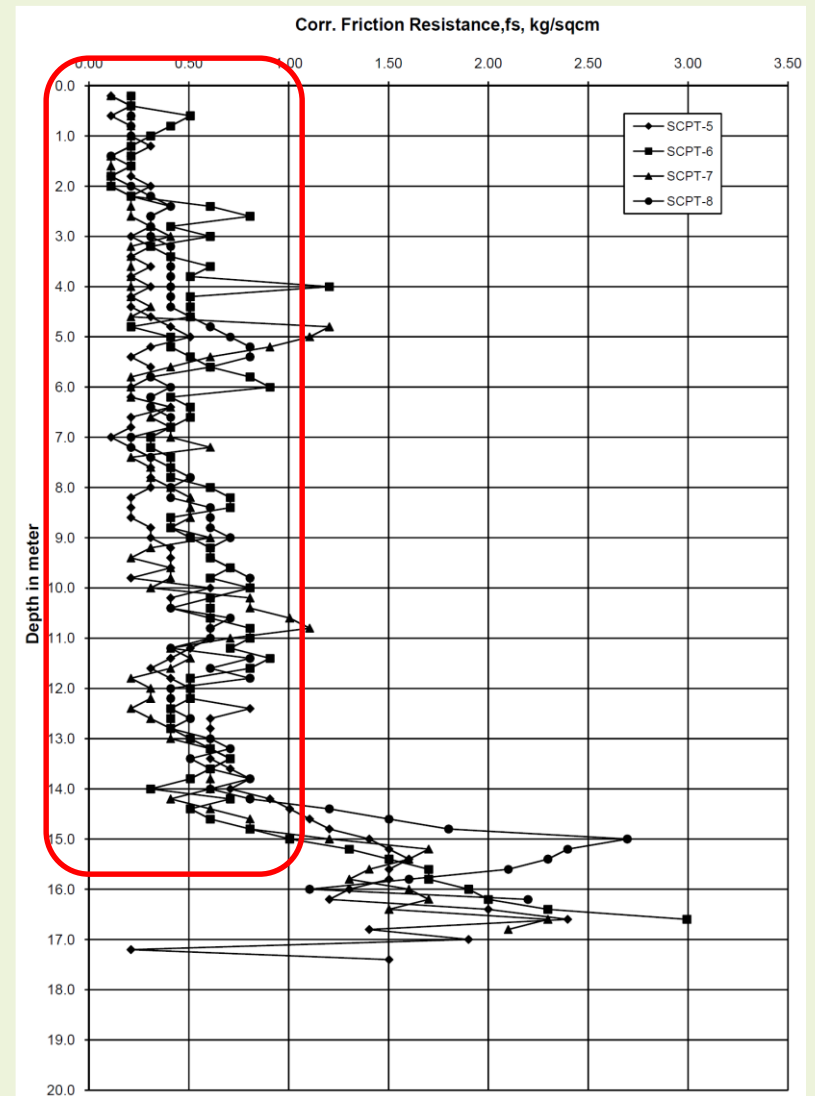
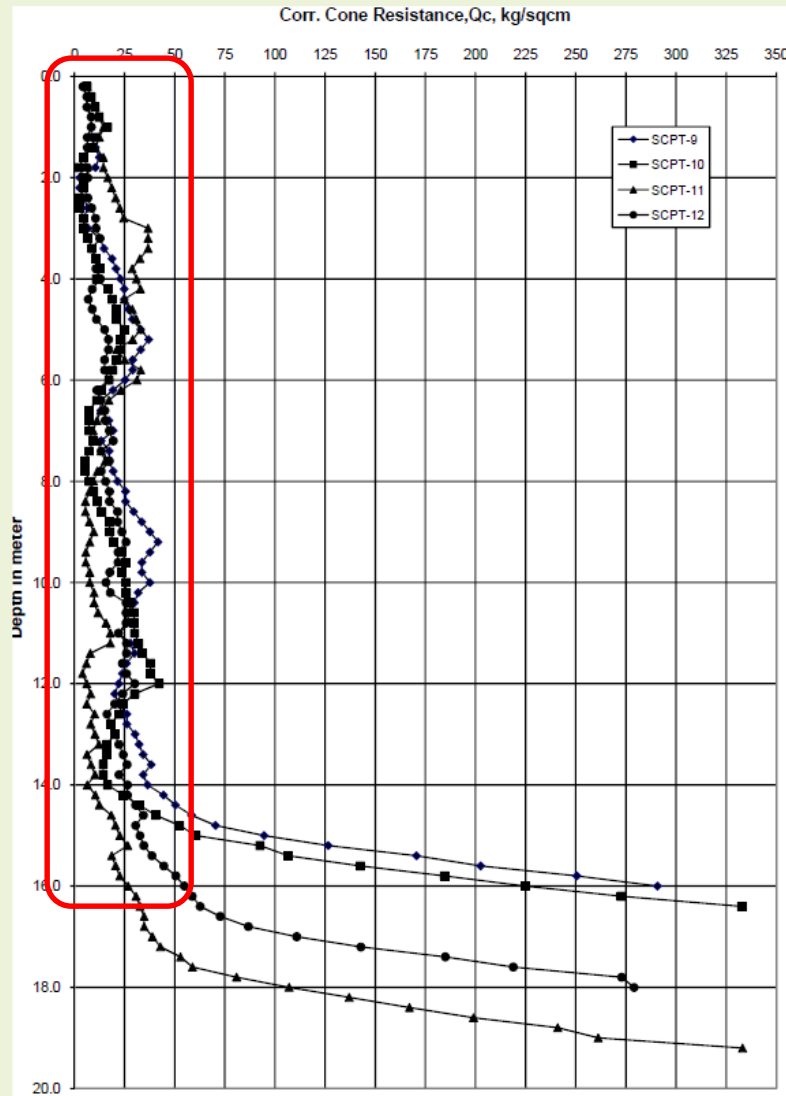
Boreholes at the outer side of embankment



Boreholes at the outer side of embankment



Typical SCPT results

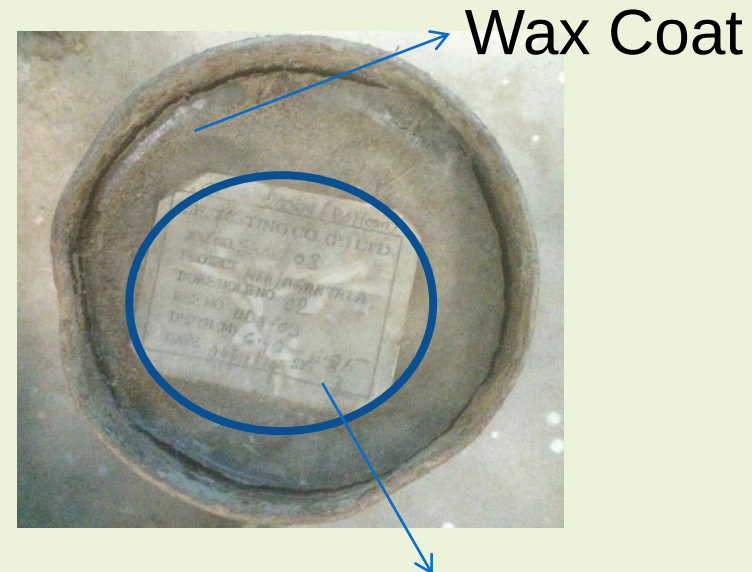


Laboratory tests on Undisturbed Soil

- ❖ Proper identification and classification of the sub-soil deposits is required.
- ❖ Undisturbed samples of 100 mm dia. were collected by means of pushing Shelby tubes.
- ❖ Index and Engineering properties of the soil were found out.



Undisturbed sample cores
obtained from the site location



Bore hole
details

Index Tests



a) Dry Sieve analysis, b) Hydrometer Analysis, c) Liquid Limit, d) Specific gravity by gravity bottles and e) Plastic Limit

Index Properties

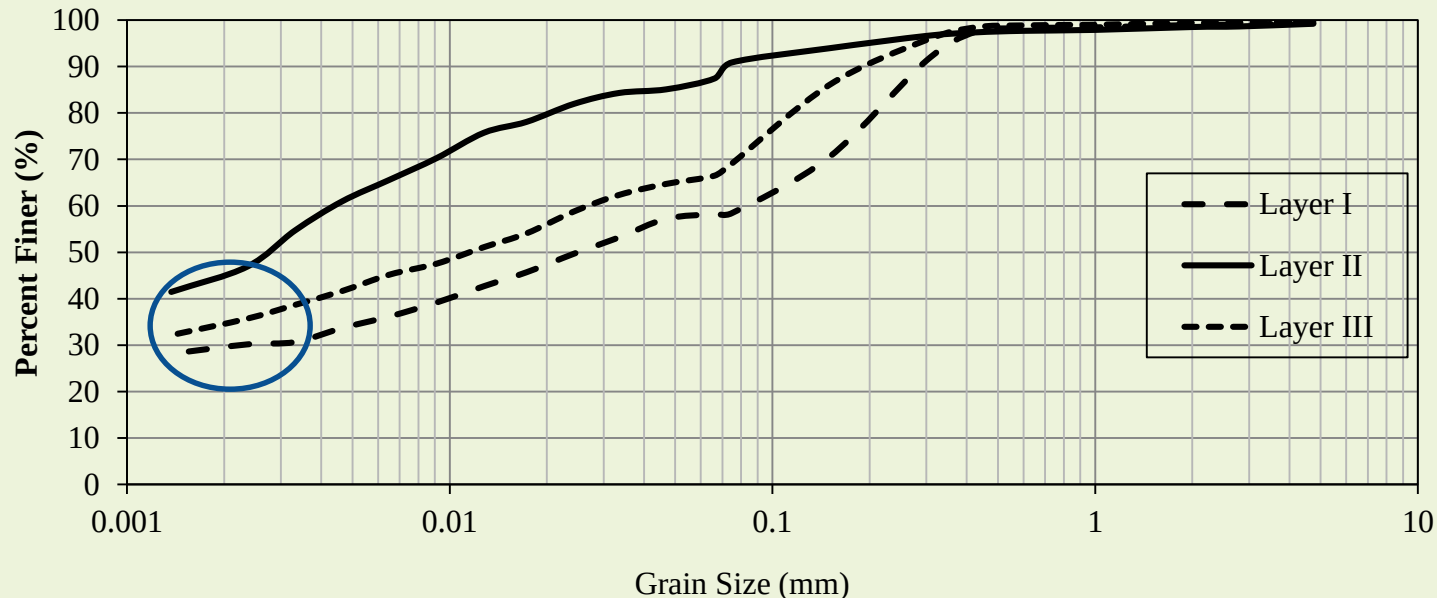
- Summary of index properties and classification of cohesive soil samples

Bore Hole	Sample Number	Depth (m)	Natural Moisture content, %	Specific Gravity	Liquid Limit	Plastic Limit
BH 01	UDS-02	1.65-2.10	28.57	2.511	42.6	-
BH 03	UDS-01	2.00-2.45	26.58	2.601	-	20
BH 01	UDS-04	5.25-5.70	82.52	1.398	55.2	19.04
BH 04	UDS-06	9.55-10.00	23.54	2.335	42.4	20.8
BH 03	UDS-04	6.25-6.70	40.29	2.725	47.6	-
BH 05	UDS-04	5.15-5.60	80	2.257	48.8	-

Particle size Distribution

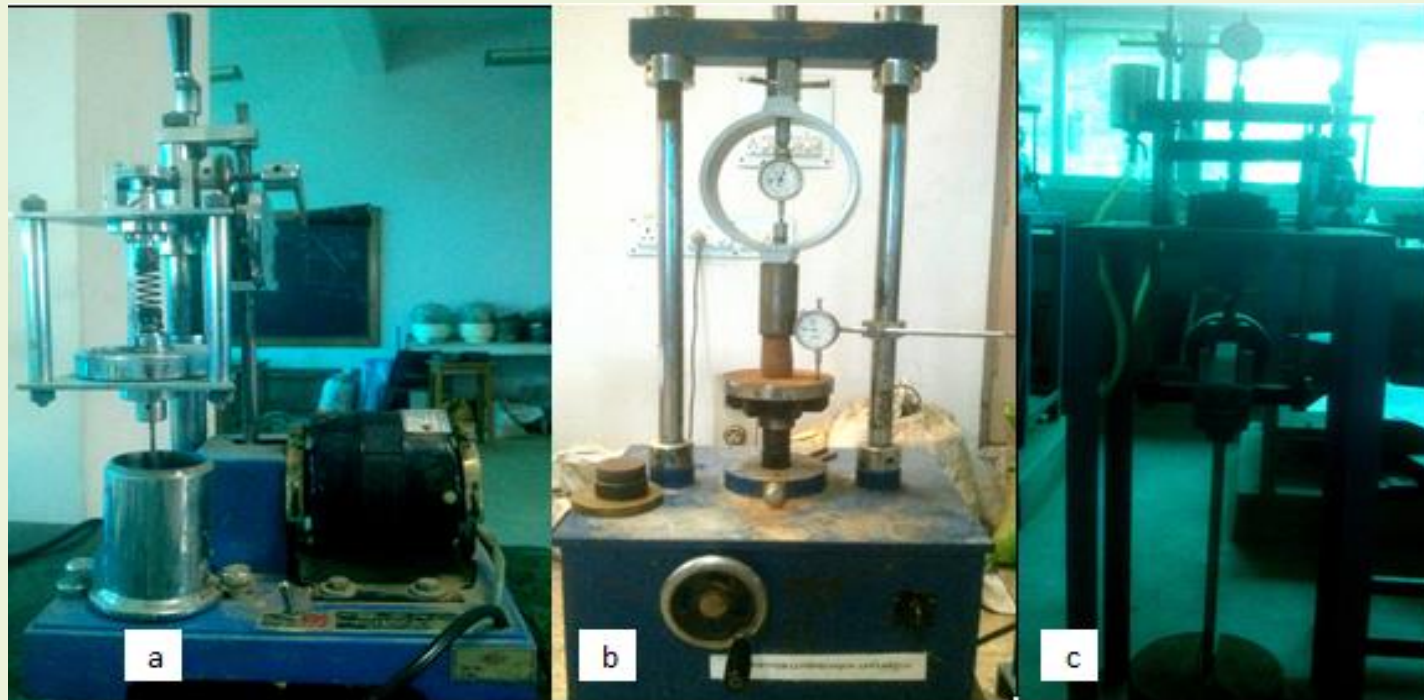
Particle size	Layer I (%)	Layer II (%)	Layer III (%)
Coarse sand (4.75mm-2mm)	0.5	2	0
Medium sand (2mm-0.425mm)	1.5	0	2
Fine sand (0.425m-0.075mm)	40	7	30
Silt (0. 075mm-0.002mm)	28	47	34
Clay (<0.002mm)	30	44	34

Both wet sieve and hydrometer analysis are conducted to complete particle size distribution of the sub-soil



Engineering Properties of soil

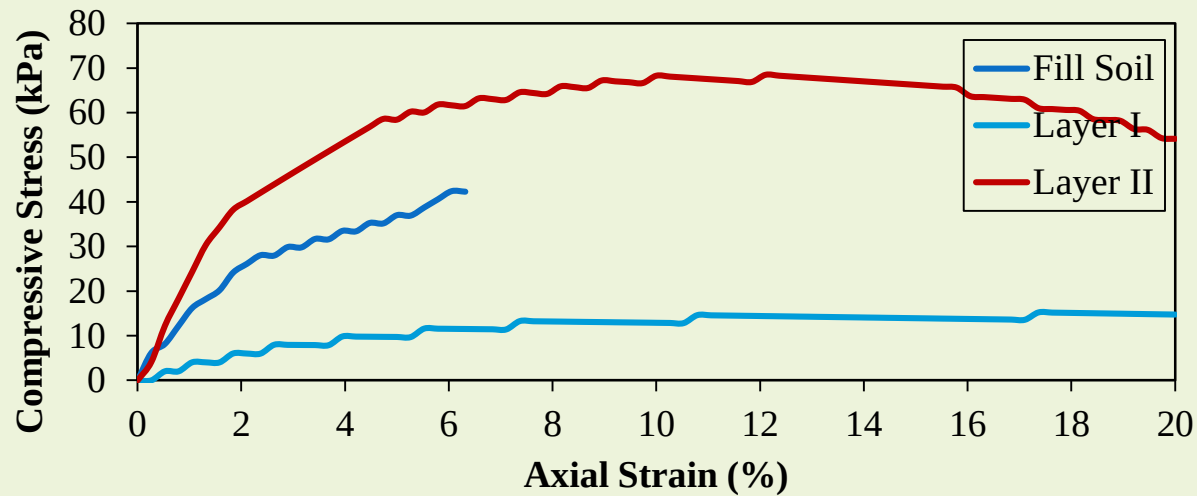
- ❖ Undrained shear strength of the soil is found out from Unconfined Compression test (UCS) and laboratory Vane shear test.
- ❖ Compressibility and Permeability Parameters are found out from Oedometer test.



a) Vane Shear test b) Uniaxial compression test and c) Oedometer Test



Modes of failure



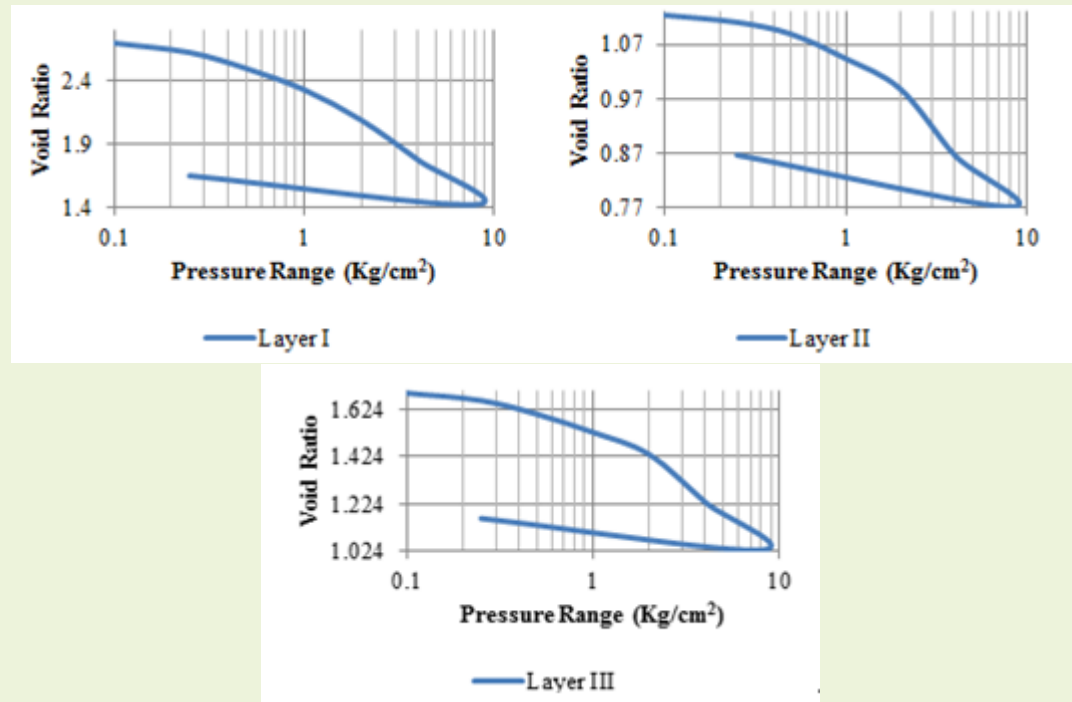
Stress strain response of different layers
under unconfined compression

Undrained Shear Strength

Bore Hole	Sample Number	Depth (m)	UCS		Vane Shear		Consistency
			Moisture Content, %	c_u (kPa)	Moisture Content, %	c_u (kPa)	
BH 01	UDS-02	1.65-2.10	28.57	26.48	30.21	34.3	Soft
BH 01	UDS-04	5.25-5.70	75.23	12.17	82.52	7.775	Very Soft
BH 01	UDS-10	16.10-16.55	-	7.03	-	-	Very Soft
BH 03	UDS-01	2.00-2.45	26.58	55.69		16.01	Very Soft
BH 03	UDS-04	6.25-6.70	30.92	28.61	40.29	44.36	Medium
BH 04	UDS-04	5.15-5.60	-	-	21.58	105.2	Stiff
BH 04	UDS-06	9.55-10.00	27.67	41.87	23.54	53.97	Medium
BH 05	UDS-02	1.50-1.95	15.16	54.11	20.36	25.61	Stiff
BH 05	UDS-04	5.15-5.60	-	-	80	14.17	Soft
BH 05	UDS-08	12.5-12.6	34.54	22.5	24.4	54.88	Soft

Distribution of undrained shear strength is very erratic (mostly soft) – conducive of large differential settlements

- Typical void ratio against effective stress for different layers of the soil are drawn from the readings of consolidation test.
- C_c and C_v values are calculated from the graphs.



Borehole	Depth (m)	Moisture Content, w%	Initial Void Ratio, e_0	C_c	C_v (cm²/sec)	k_v (cm/sec)
UDS-04	10.65-11.10	40.8	1.126	0.365	0.000576	1.57×10^{-08}
UDS-03	9.0-9.45	61	1.702	0.664	0.001369	5.05×10^{-08}
UDS-03	10.0-10.45	87.9	2.719	1.079	0.000838	6.04×10^{-08}

Subsoil Parameters

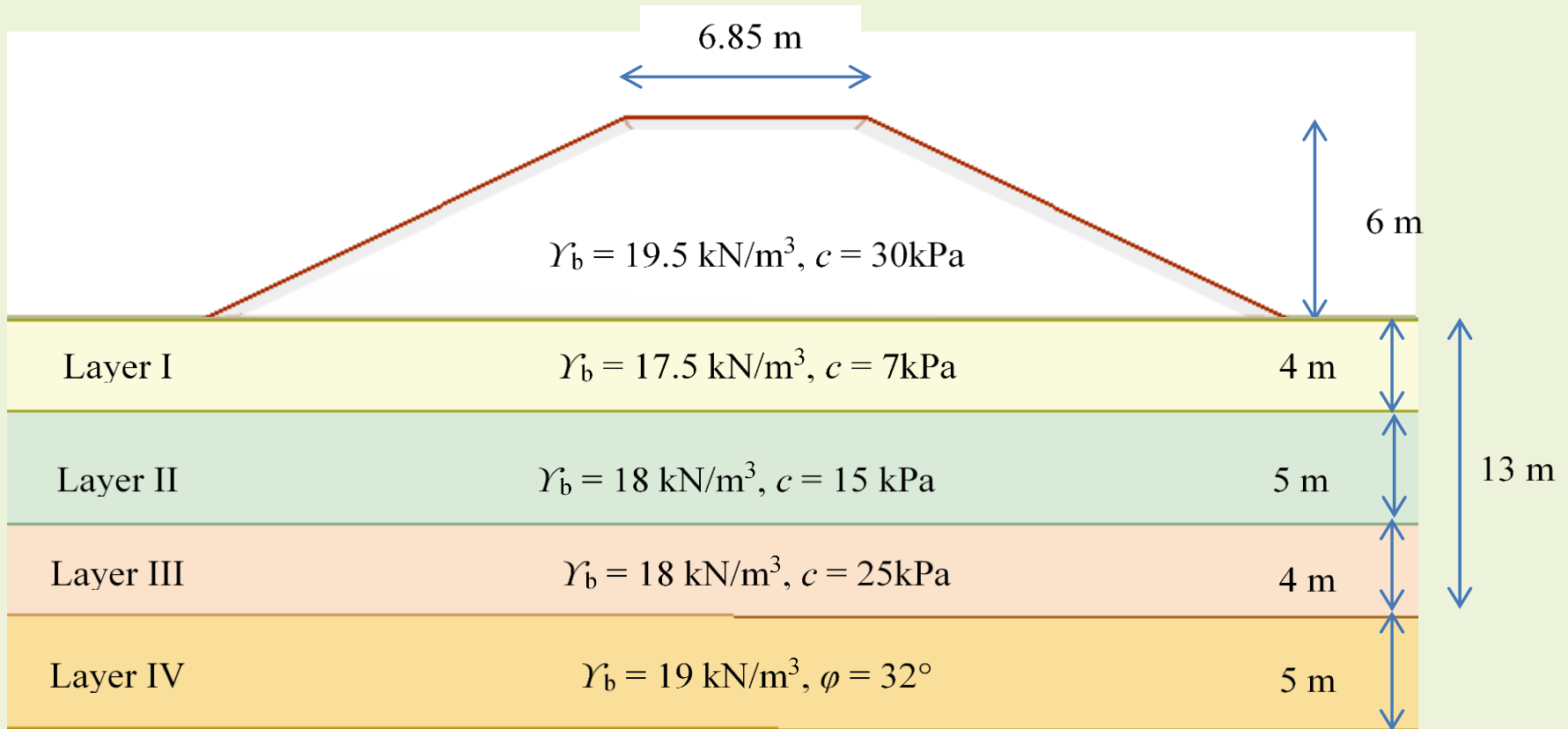
Stratum	Fill	Layer I	Layer II	Layer III	Layer IV
Unit Weight (kN/m ³)	19.5	17.5	18	18	19
Specific Gravity	2.45	2.2	2.34	-	-
Cohesion (kPa)	30	7	15	25	0
Angle of Internal Friction, ϕ°	-	-	-	-	32-35
Natural Moisture content	24%	48%	23.54%	34.54%	-
Liquid Limit	42%	50%	42.40%	-	-
Plastic Limit	20%	19%	20.80%	-	-
Plasticity Index	22%	31%	21.60%	-	-
Compression Index, C_c	-	1.079	0.365	0.664	-
Coefficient of Consolidation, C_v (cm ² /sec)	-	0.000838	0.000576	0.001369	-
Permeability (cm/sec), k_v	-	8.76×10^{-9}	1.57×10^{-8}	5.05×10^{-8}	-
Initial void ratio, e_0	-	2.719	1.126	1.702	-

Sub-soil Profile with properties

- The ultimate soil profile with parameters found out from the laboratory tests.
- These properties will be used in modeling in Settle3D software.

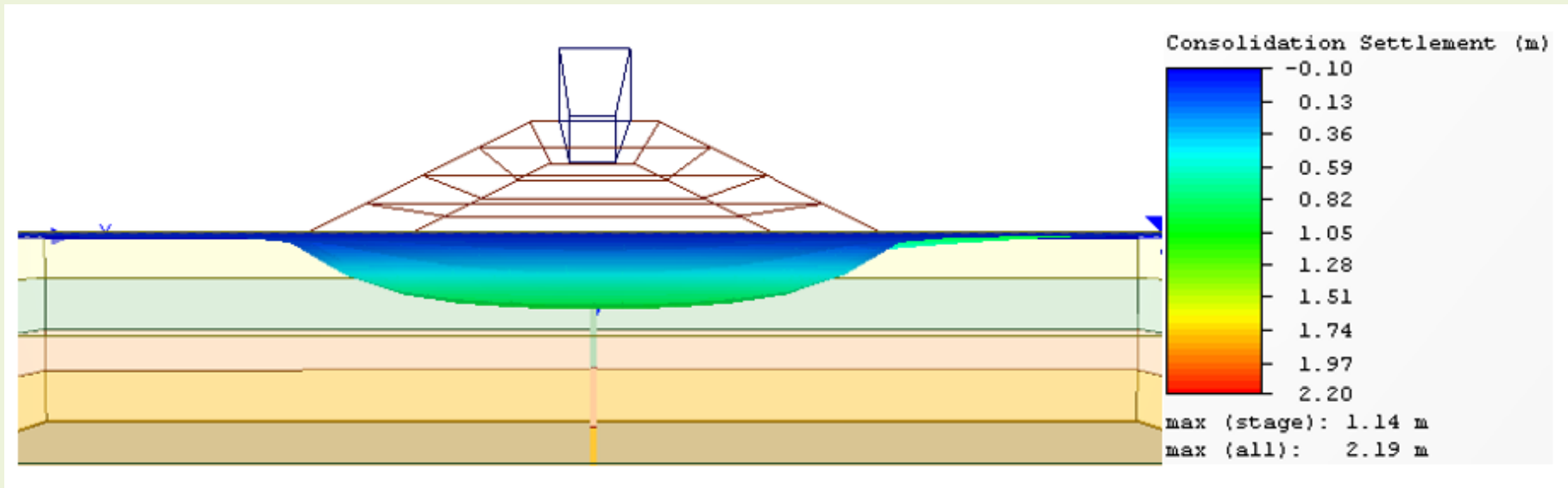
Layer I	$\gamma_b = 17.5 \text{ kN/m}^3, C = 7 \text{ kPa}$	4 m	13 m
Layer II	$\gamma_b = 18 \text{ kN/m}^3, C = 15 \text{ kPa}$	5 m	
Layer III	$\gamma_b = 18 \text{ kN/m}^3, C = 25 \text{ kPa}$	4 m	
Layer IV	$\gamma_b = 19 \text{ kN/m}^3, \phi = 32^\circ\text{-}35^\circ$	5 m	

Railway Embankment Resting on Soft Soil



Analysis of Embankment stability

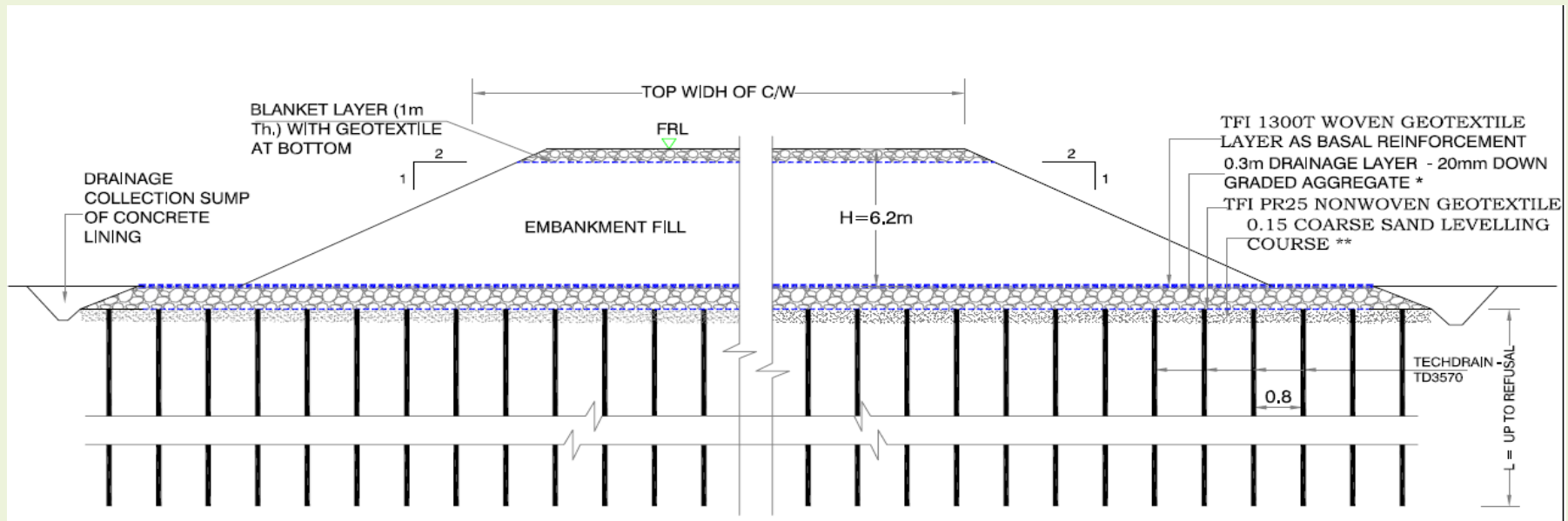
- Using SETTLE3D software (Rocscience 2014)
 - ❖ The primary consolidation settlement of 0.505 m, 0.755 m, and 0.951 m after 3.14 m, 4.64 m, and 6 m embankment heights were



- Numerical study confirms large deformations observed in the field
- Warrants for ground improvement

Restoration of embankment

- Prefabricated vertical drains (PVDs) or sand piles with preloading
 - ❖ Owing to the time constraint of the project and unavailability of stone aggregate nearby to the site



Typical Schematic of Railway Embankment on PVD











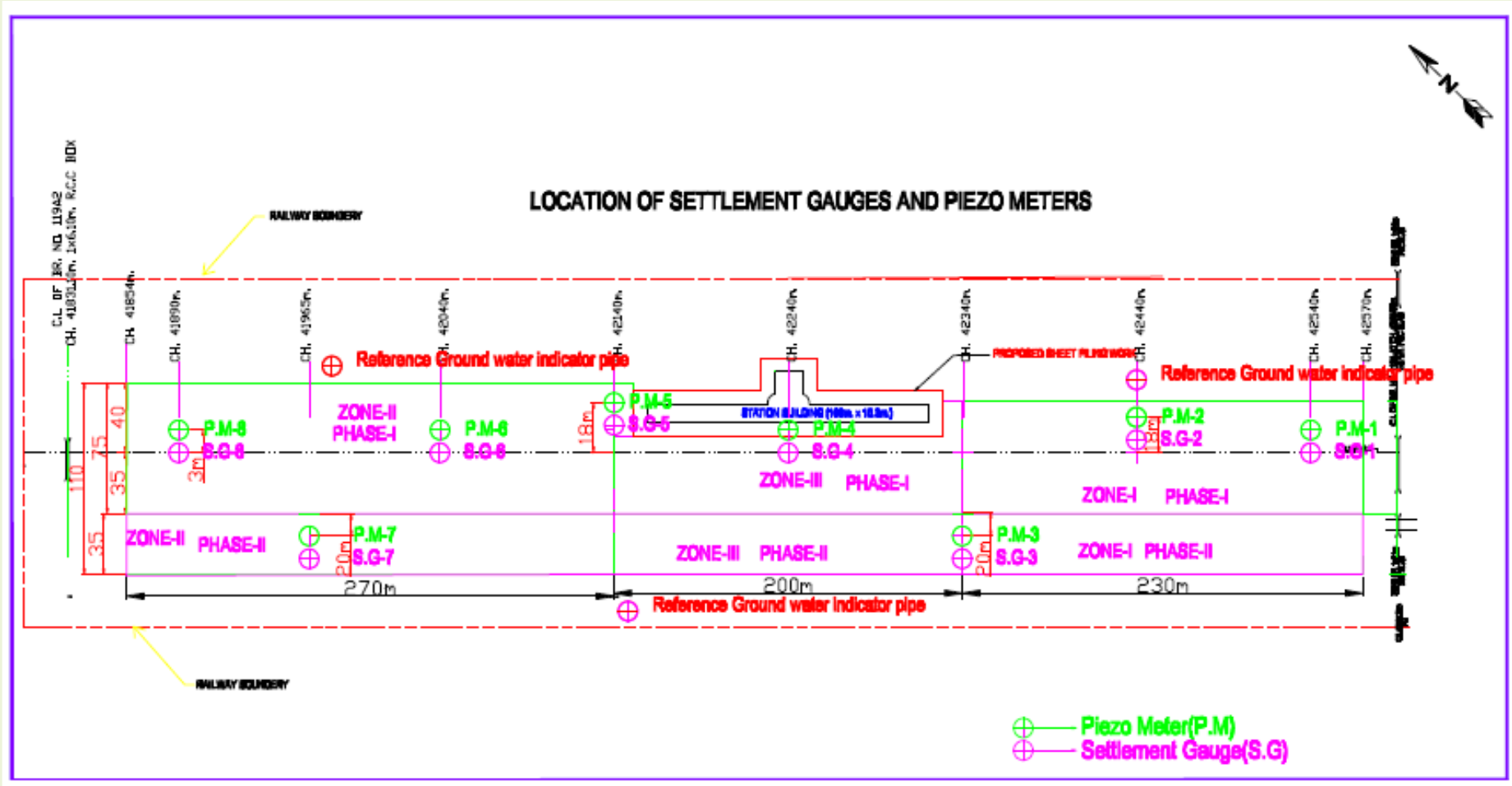




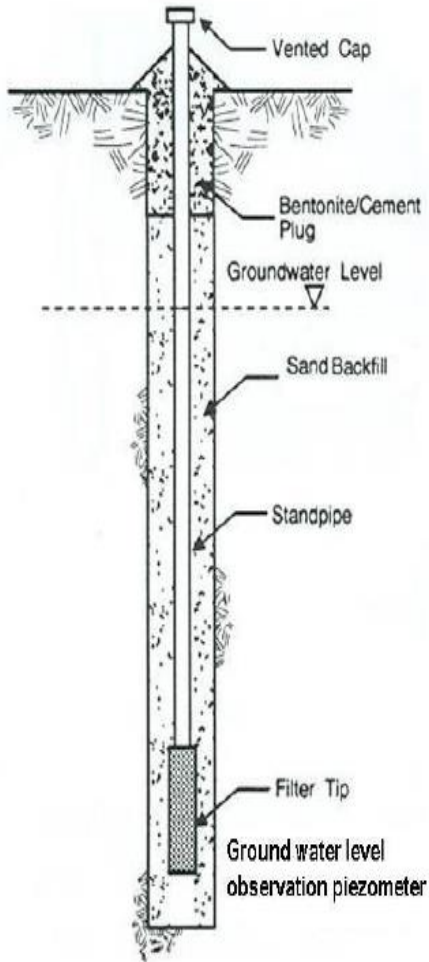
a) Laying of Coarse sand, b) Laying of Non-Woven Geo-textile, c) Laying of Granular Blanket.
d) Laying of Woven Geo-textile, e & f) Stage construction of embankment.



Instrumentation



Piezometers & Settlement Gauges



Construction Plan for Embankment at Udaipur

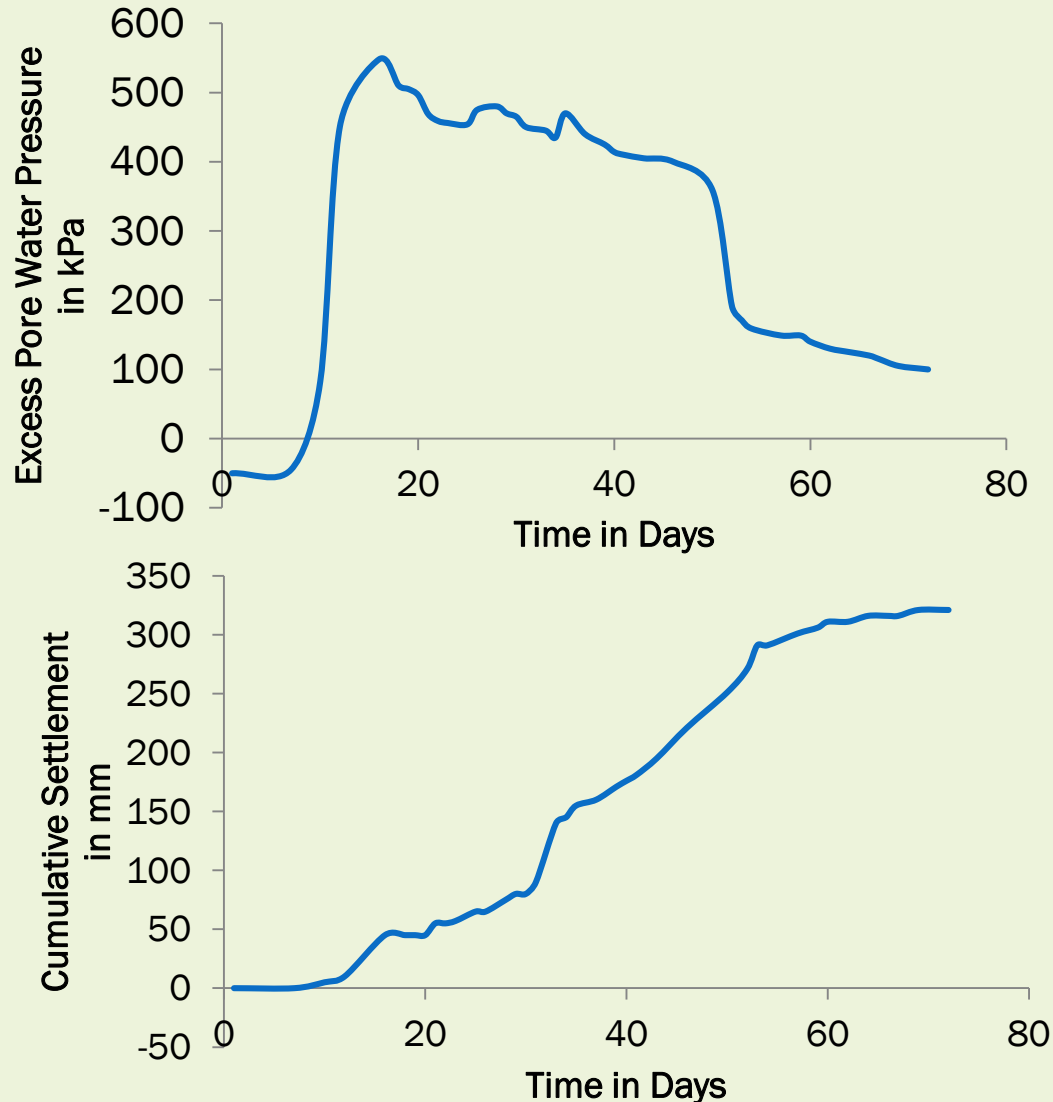
Height of embankment, m	P_0 , kPa $[H/2 \times 6.53]$	δP , kPa $[(\Delta h \times 19) + 24]$	No of Days	Settlement due to load with time, mm	Cumulative Settlement, mm	Time* period, days	U_h	Cumulative settlement, m (achievable)	U
0	43.26	0.00	0	0.00	0.00	0	0.00	0.00	0
0.5	43.26	33.50	20	0.488	0.488	20	0.45	0.22	17.75
1	43.26	43.00	20	0.099	0.587	40	0.70	0.42	33.71
1.5	43.26	52.50	20	0.089	0.676	60	0.84	0.56	45.37
2	43.26	62.00	20	0.081	0.756	80	0.91	0.69	55.67
2.5	43.26	71.50	20	0.074	0.831	100	0.95	0.79	63.76
6.2	43.26	141.80		0.407	1.238	**			

Considering 20 days of time period after execution of each stage of 0.5m height.

Height of embankment (m)	No of Days	Corresponding degree of consolidation	Initial Cohesion (kPa)	Increased pressure δP [due to DL (kPa)]	Gain in Cohesion value	Final Cohesion, kPa	Bearing Capacity of soil, in kN/m ²
0	0	0	4	0	0	4	20.6
0.5	20	45	4	9.5	0.75	4.75	24.4
1	20	71	4	19	2.38	6.38	32.8
1.5	20	83	4	28.5	4.18	8.18	42
2	20	91	4	38	6.11	10.11	51.9
2.5	20	95	4	47.5	7.97	11.97	61.5

**Suzuki and Yasuhara,
Soils and
Foundations, 2007**

Record of Pore Water Pressure, Settlement & N-Value



N-Value Before & After Installation of PVDs (Ch: 42.44)			
Depth from OGL	Description of the Soil	Old Bank (May 2014)	New Bank (11 Jan 2016)
2	Soft , deep, grey clayey soil	4	9
3		4	15
4.5	Medium, deep, grey clayey silty soil		16
6		4	11
7	Medium, deep, grey clay silty sand soil	7	16
9		6	25
11	Medium dense silty sand	4	28
12.5		3	29
14.5	Medium to dense sandy soil	6	36
16		66	72
17.5	Very dense sandy soil	100	100
N-Value After 51 days of PVD installation			

Retrofitting of Railway Station Building

USE OF MODERN RETROFITTING TECHNIQUES IN UDAIPUR STATION BUILDING OF AGARTALA-SABROOM NEW LINE PROJECT OF N.F.RAILWAY

By: Harpal Singh, Chief Engineer/Con-8/Maligaon,

B.N.Bhaskar, Deputy Chief Engineer/Con/Agartala,

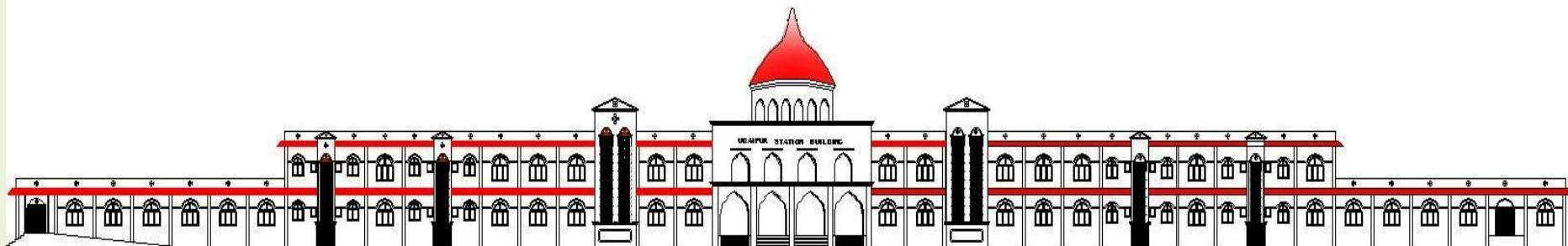
Koteswar Ponnala, Asstt. Executive Engineer/Udaipur



The Institution of Permanent Way Engineers (India)

<http://ipweindia.org.in/index.php/books-publications/technical-papers/10-publications>

<https://drive.google.com/file/d/1b4Xu7lIM6ZykaMArHBwnlIFzDZOqLLaH/view?usp=sharing>



Agartala-Udaipur Section,
First Engine Rolling upto Udaipur,
on 15.03.2016



Footplate inspection
of Agartala-Udaipur Section
by GM/Con/NFR on 17.03.2016



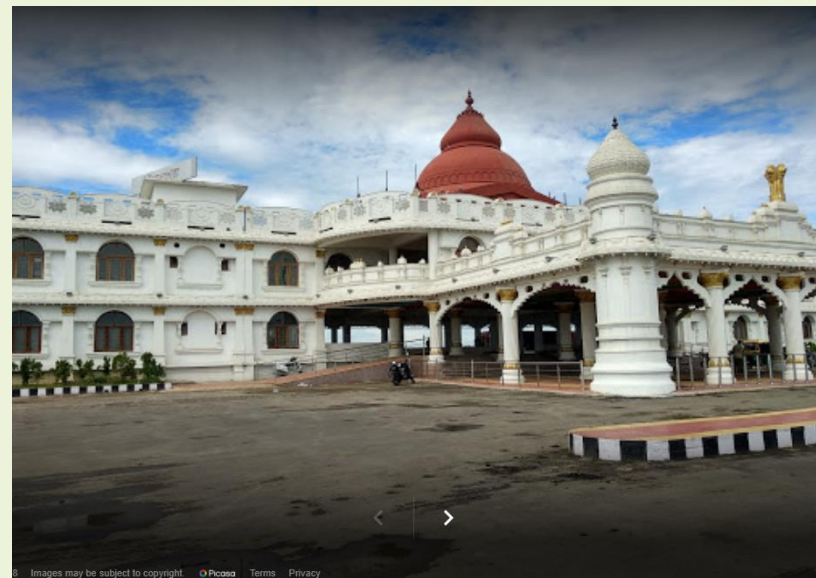


09-10-2026

Construction Conclave 3.0

Heritage Railway Station, Udaipur, Agartala

- Application of preloading and PVD for developing of railway yard in a ditch marshland





Project Team

- North-East Frontier Railway (NFR) Officials and Team
- CE Testing Kolkata
- Techfab India, Mumbai
- Dhirendra Group of Companies, R&M, Mumbai

Dr. Murali Krishna
IIT Tirupati



Dr. Kaustubh Dasgupta
IIT Guwahati

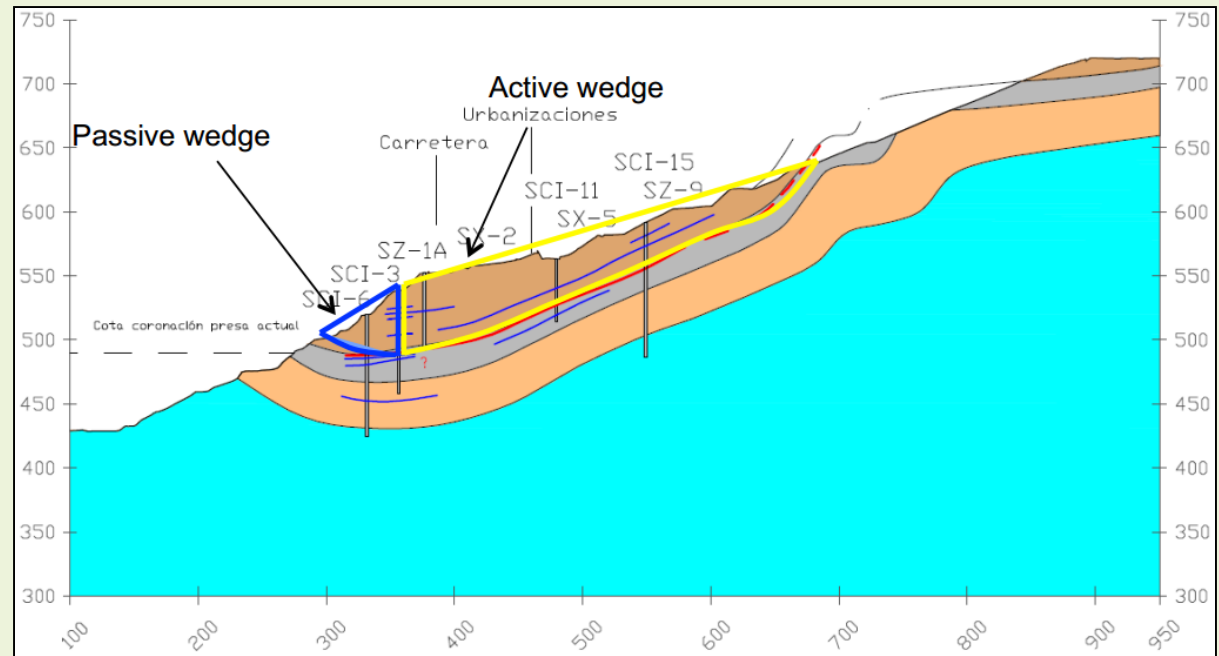


Monitoring

Very Important but Mostly Neglected

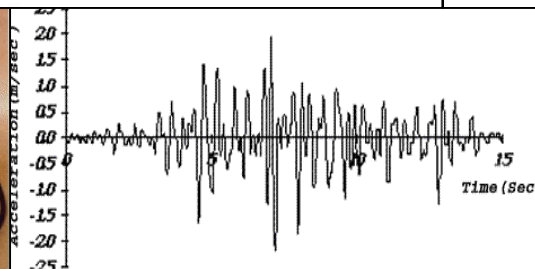
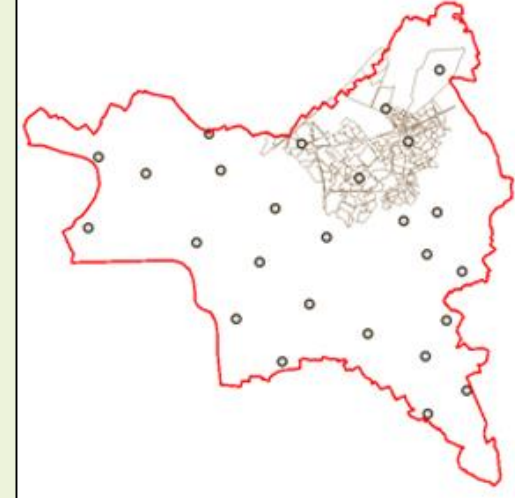
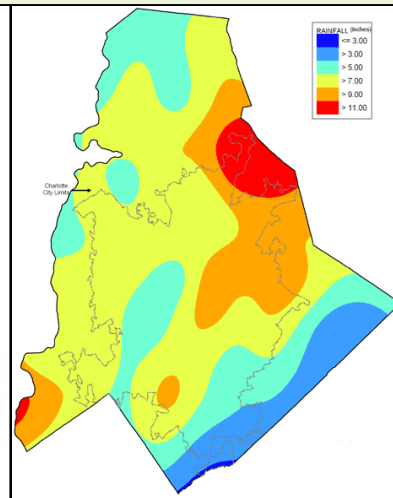
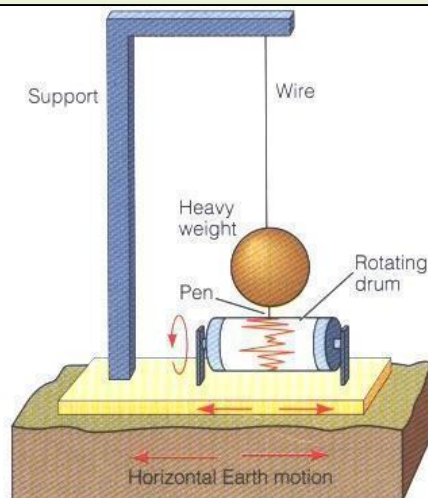
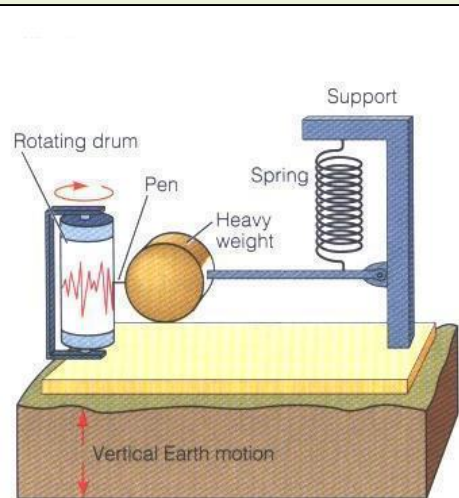
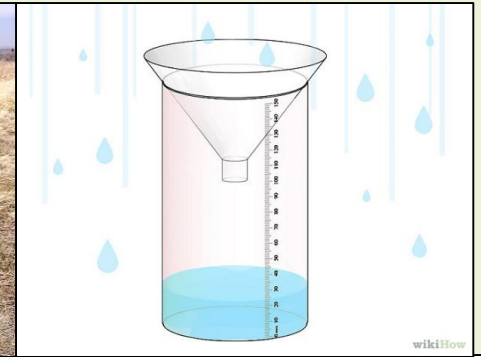
Continuous/Frequent/Intermittent Monitoring

- Ground water monitoring
 - ❖ **Piezometers and In-situ Tensiometers**



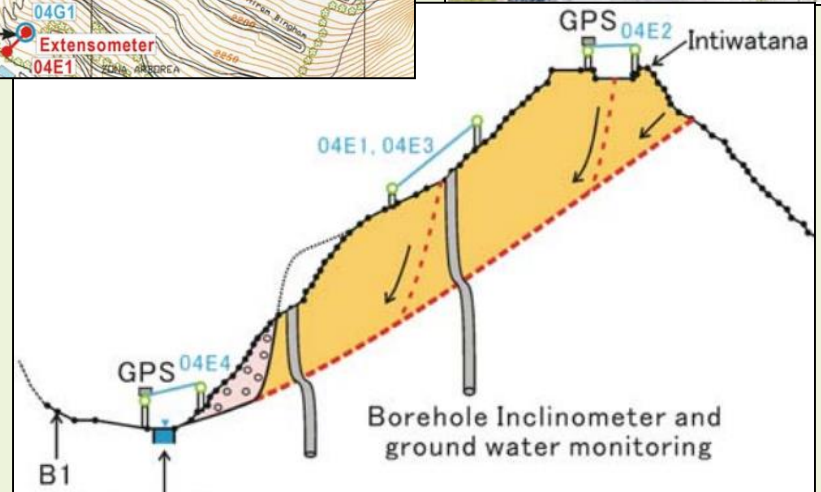
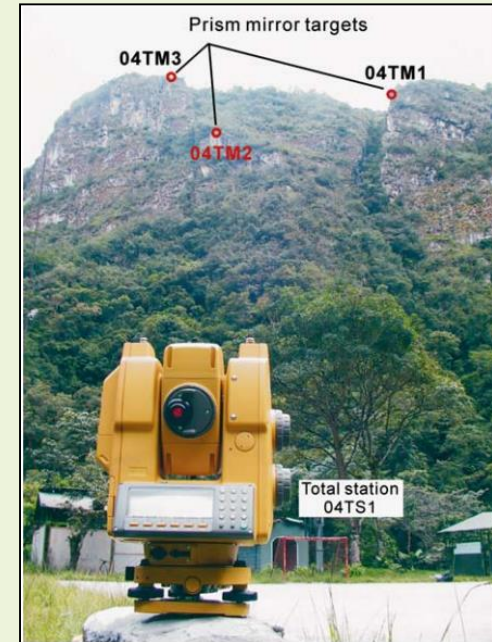
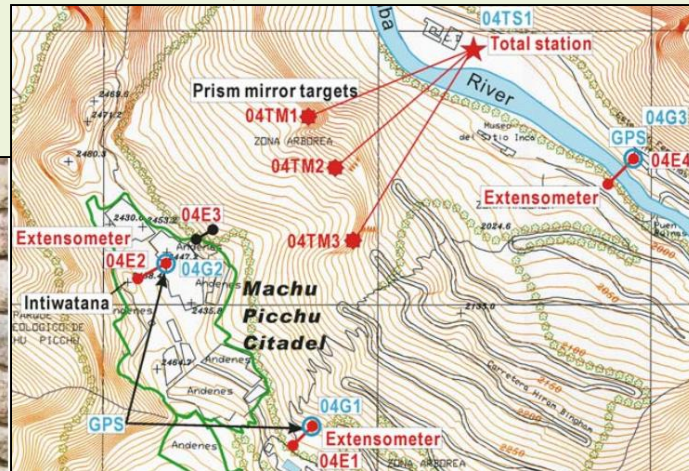
Investigation of Natural Triggering Events

- Rainfall event monitoring
 - ❖ **Strategically located Rain Gauges**
- Seismic event monitoring
 - ❖ **Accelerographs**



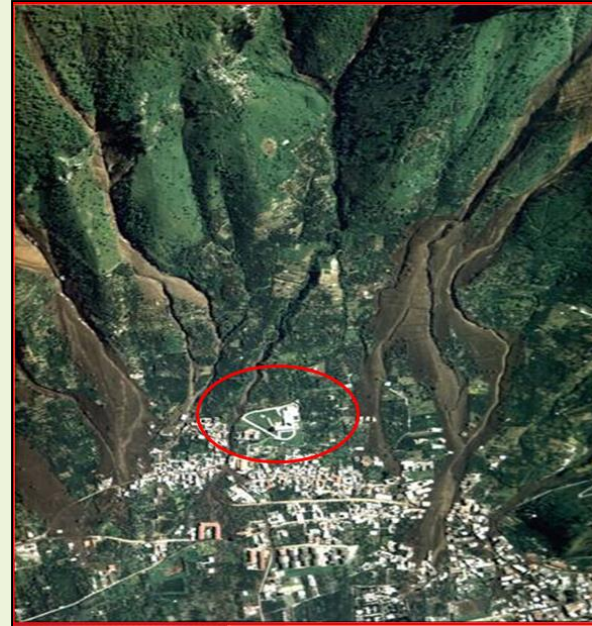
Continuous/Frequent/Intermittent Monitoring

- Mass Movement monitoring
 - ❖ Electronic Distance Measurement (EDM)
 - ❖ Inclinometers, Extensometers, and Strain Meters
 - ❖ Ground tiltmeters



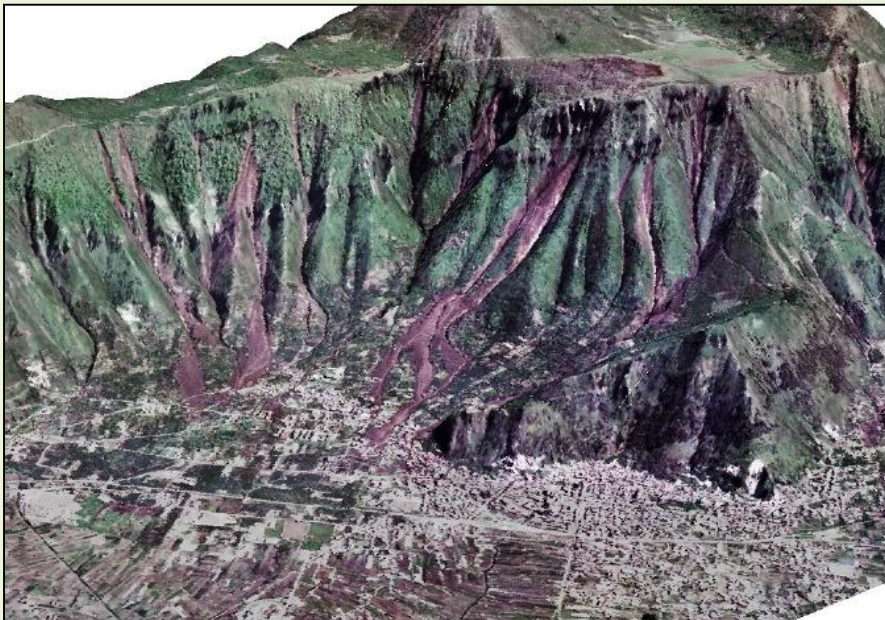
Ariel/Geodetic Surveys

- LIDAR Technique
 - ❖ Velocity of soil movements
 - ❖ Type of movements
 - Rotational, Translational, Cascading
 - ❖ Extent of damage

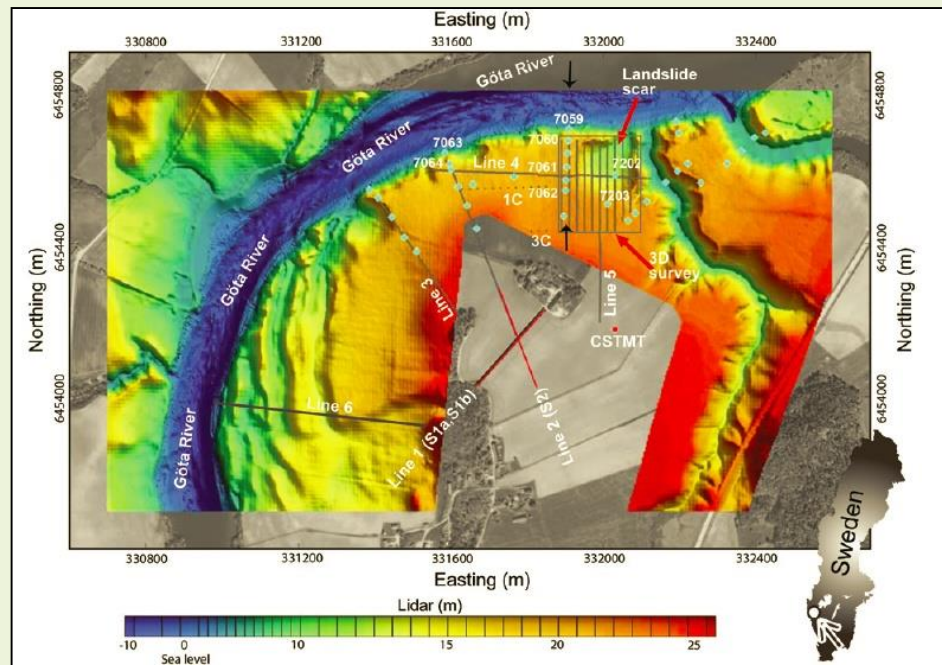


Observing that it was not damaged by the flowslides, the Authorities argued that it was not an element at risk.

The white triangle was an hospital (under construction at the time of flowslides)

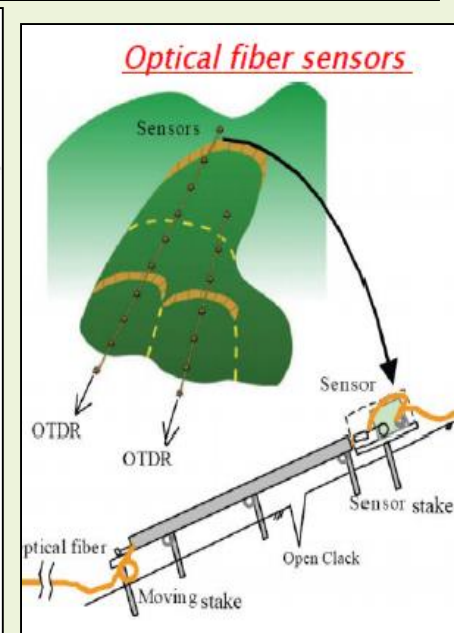
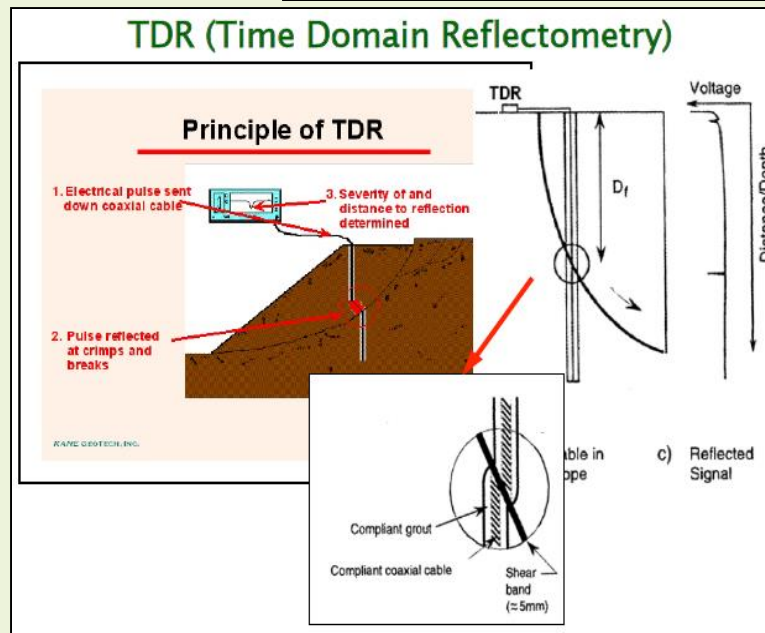
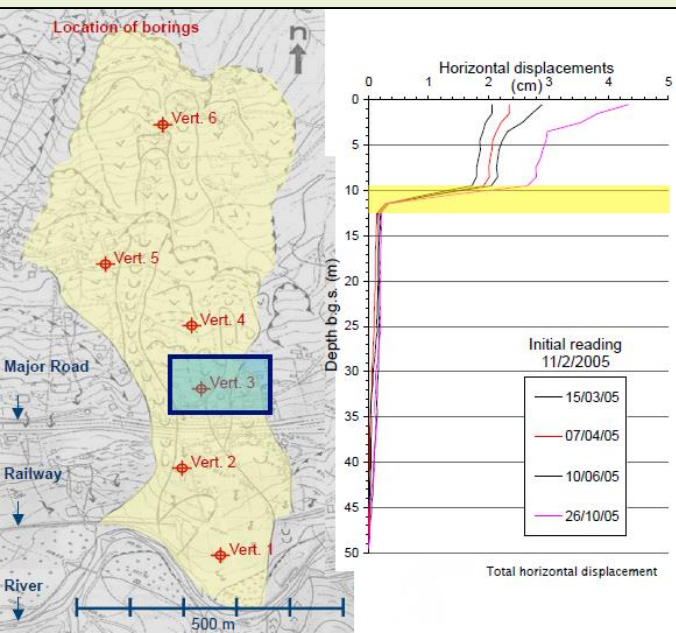
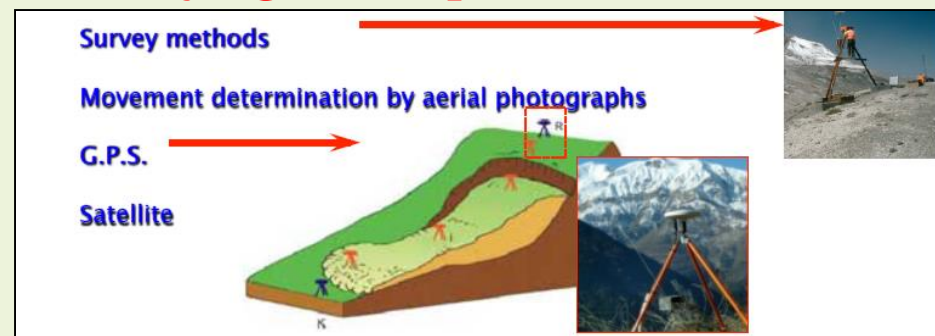


Pizzo d'Alvano (southern Italy)



Continuous/Frequent/Intermittent Monitoring

- Mass Movement monitoring
 - ❖ Ariel photographs and Advanced surveying techniques using GPS and Satellite images
 - ❖ Time domain reflectometry
 - Use of Optical fiber sensors





Thank You for Patient Hearing



<http://www.iitg.ac.in/arindam.dey/homepage/index.html#>

https://www.researchgate.net/profile/Arindam_Dey11