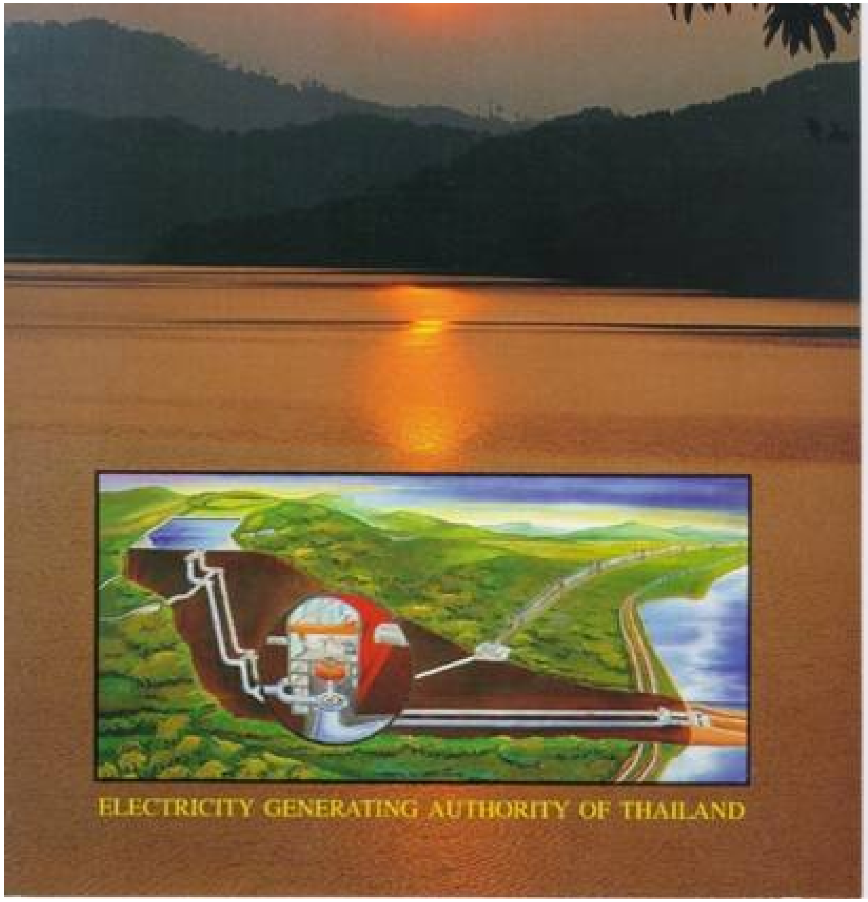
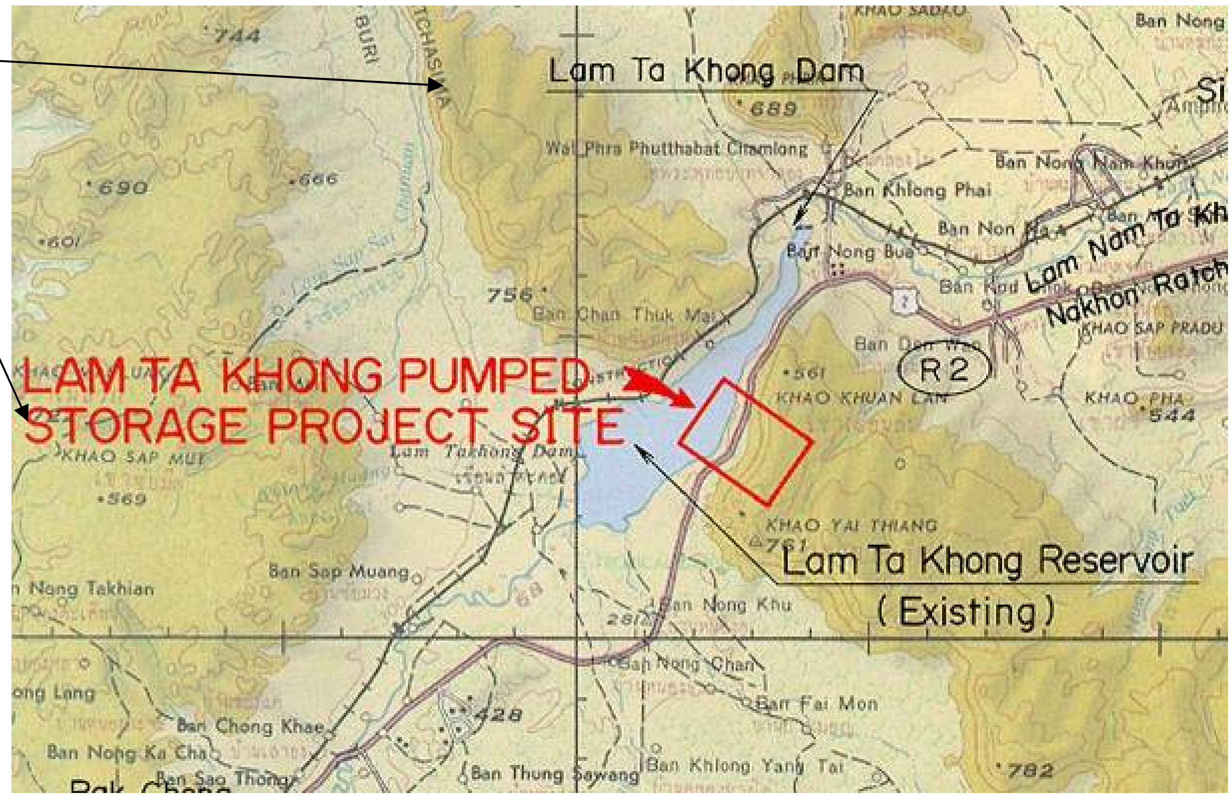
Performance of Asphalt Concrete-faced Rockfill Embankment at Lam Ta Khong Pumped Storage Project, Thailand

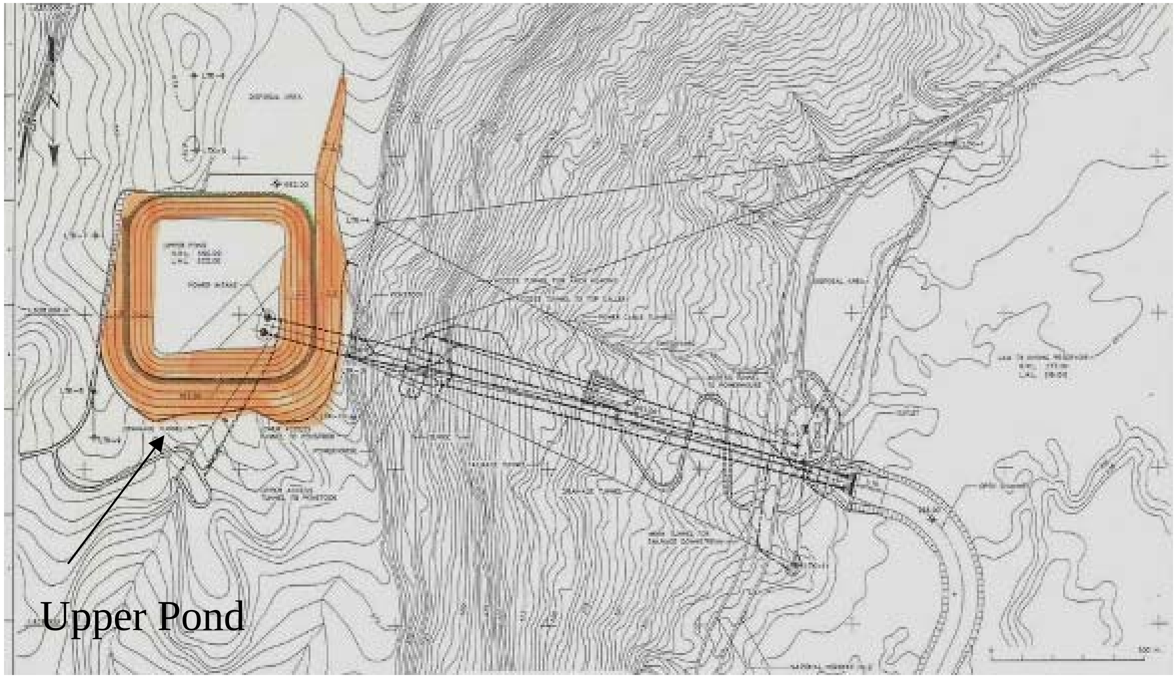


Features

- Owner: Electricity Generating Authority of Thailand (EGAT).
- A pumped storage scheme with a full installed capacity of 1000 MW (4@250 MW). Commission date of first two units were in 2000. For the other two it has been delayed.
- First underground powerhouse in Thailand
- Utilizing existing Lam Ta Khong reservoir as the lower pond.
- The Upper Pond was constructed by means of cut & fill method on the mountain top.
- Impervious faced rock fill dam was chosen to utilize sedimentary rocks from pond excavation. Poor quality rocks (siltstone and mudstone) were also used in the downstream zone of the embankment by adopting gentle embankment slope (1:2.5 V:H)
- Asphaltic concrete was adopted as the impervious lining in lieu of the commonly used concrete lining for reason of its higher flexibility and ductility and more durability that would be needed for dams of the pumped storage scheme. The entire upstream face of the embankment, cut slope and pond floor.
- The maximum embankment height is 50 m, the crest length is 2170 m, and the storage capacity of 10.3 million cu m.

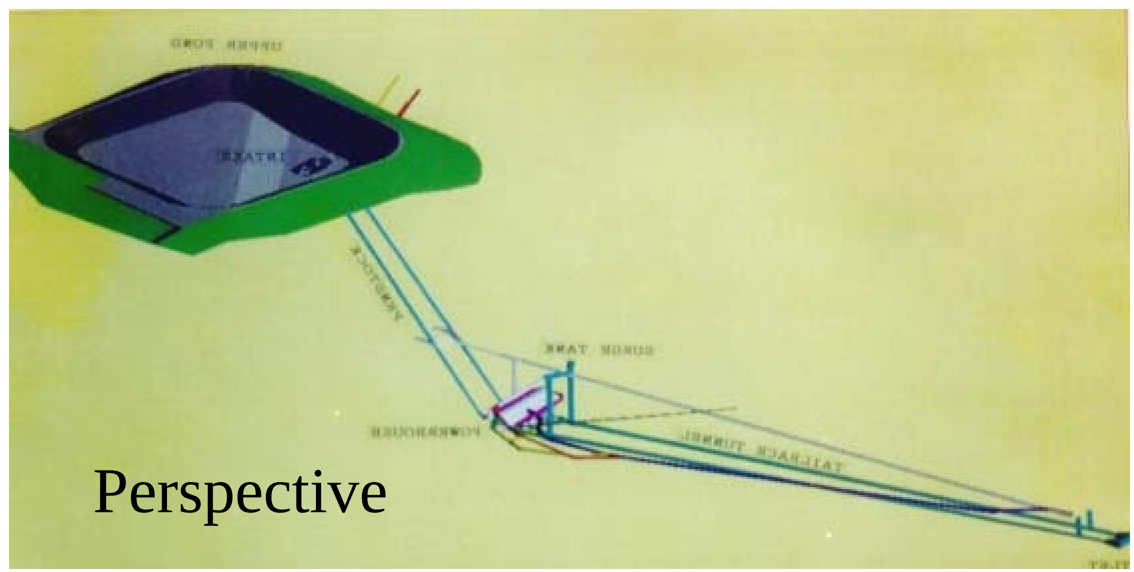
Project Location

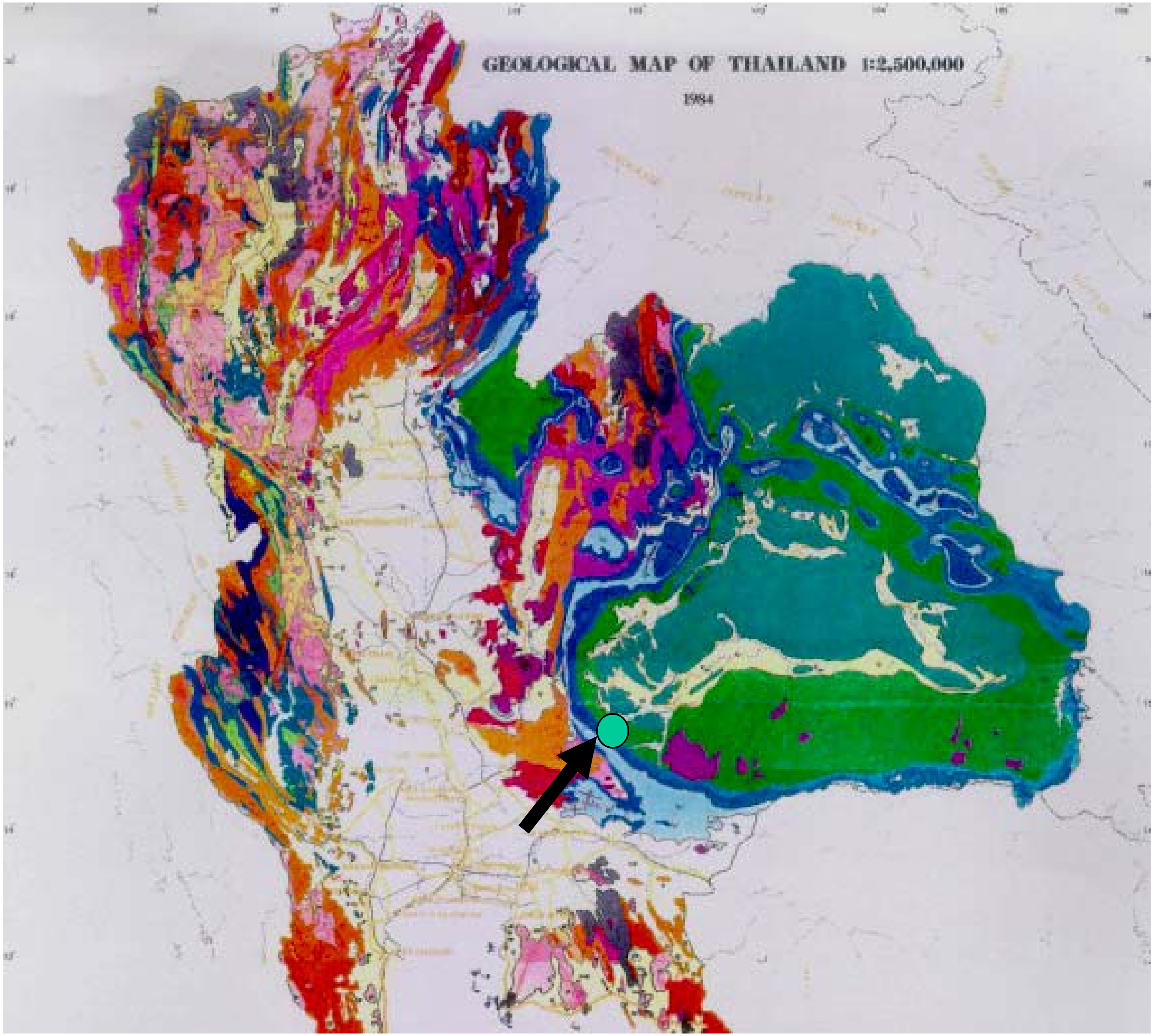




Site Layout

Cliff

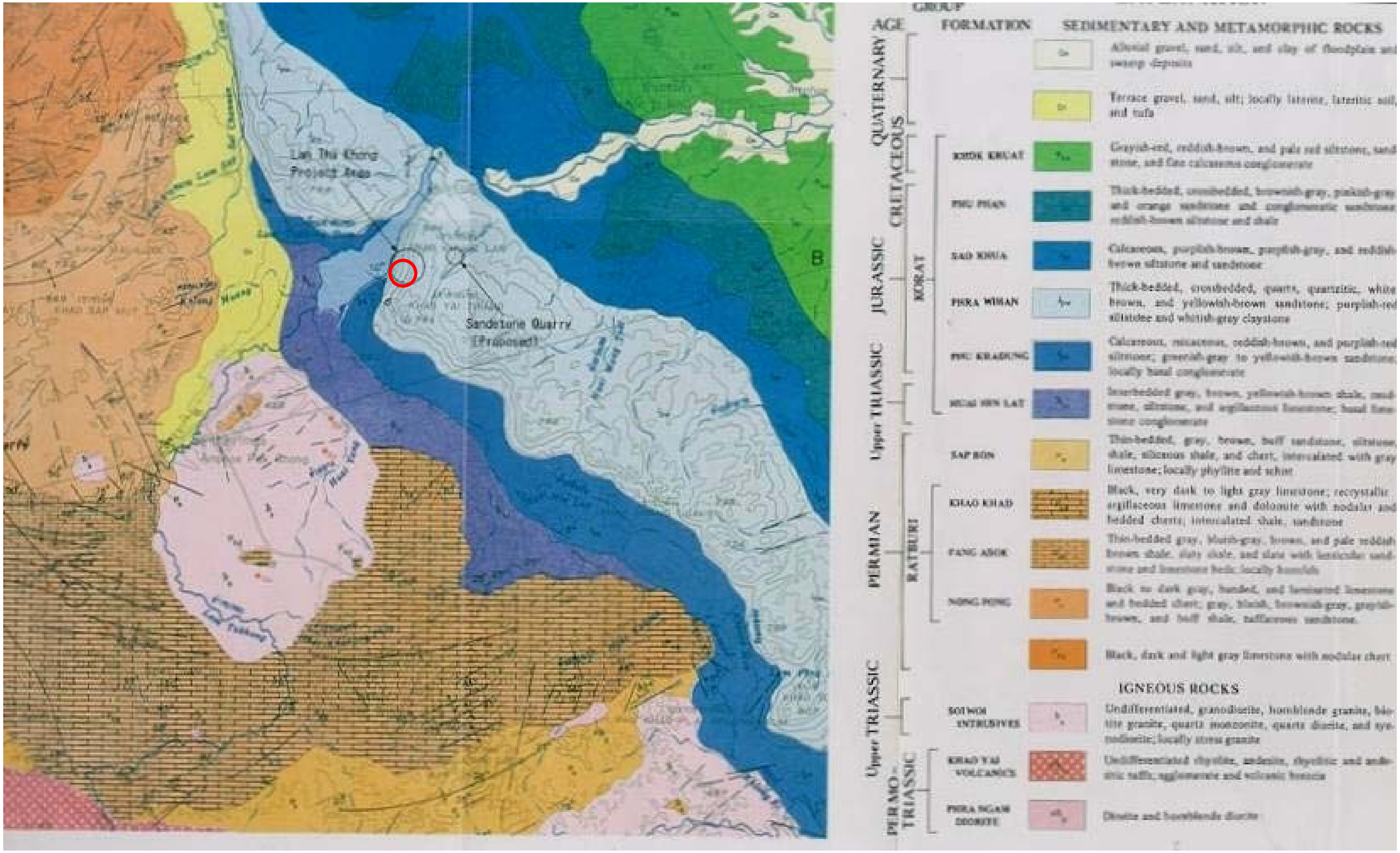




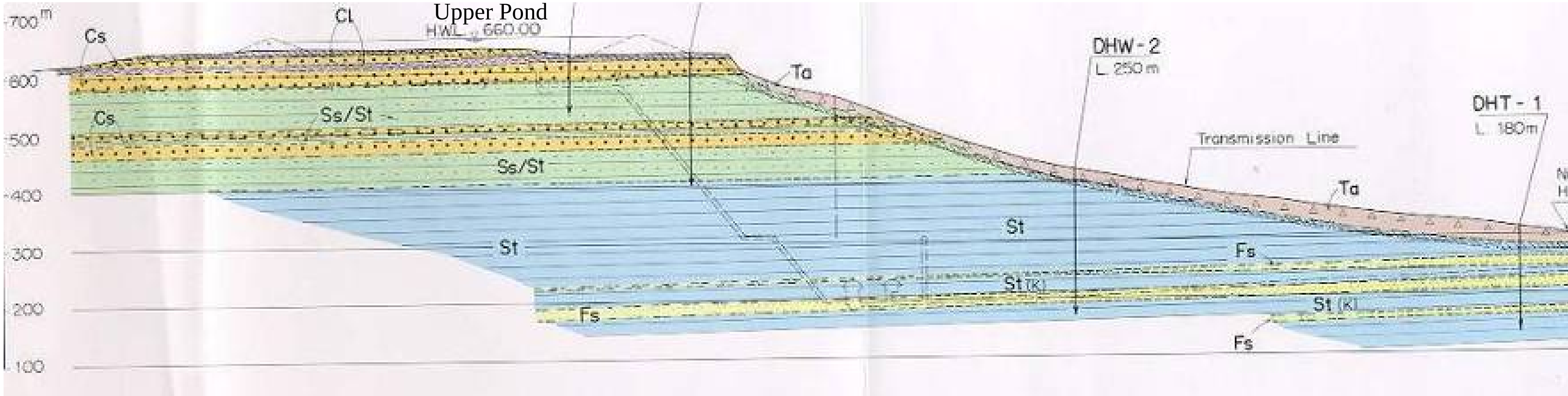
Khorat Rock Group:

Sedimentary rocks of Jurassic-Triassic ages

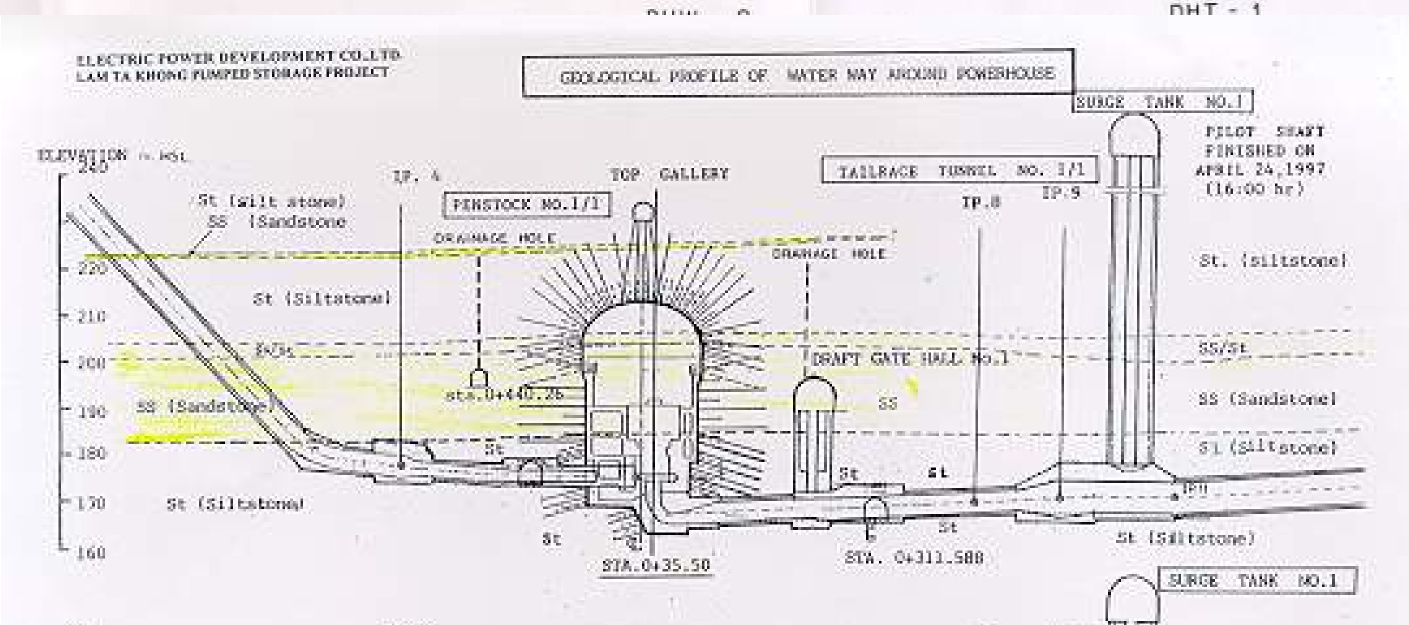
Geologic Map of Project Site



Bird Eye View of Work Site

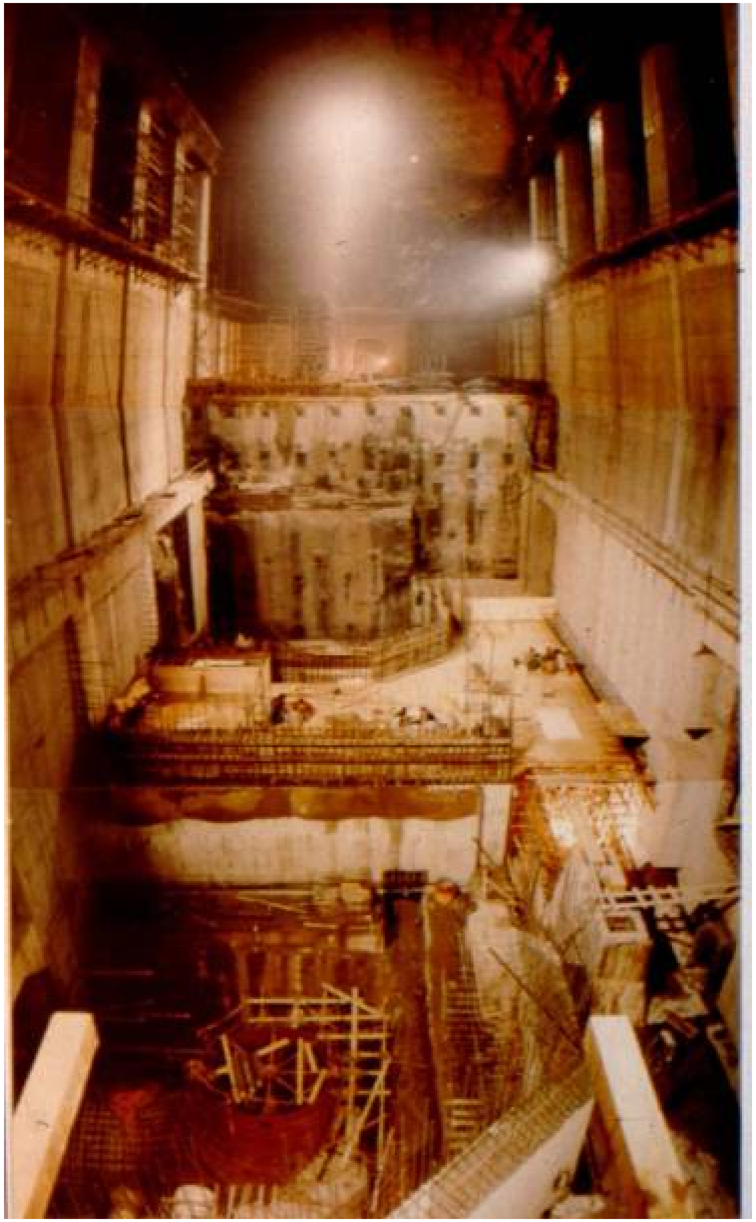


Geologic Profile



Sectional View of Underground Powerhouse Cavern

Underground Cavern

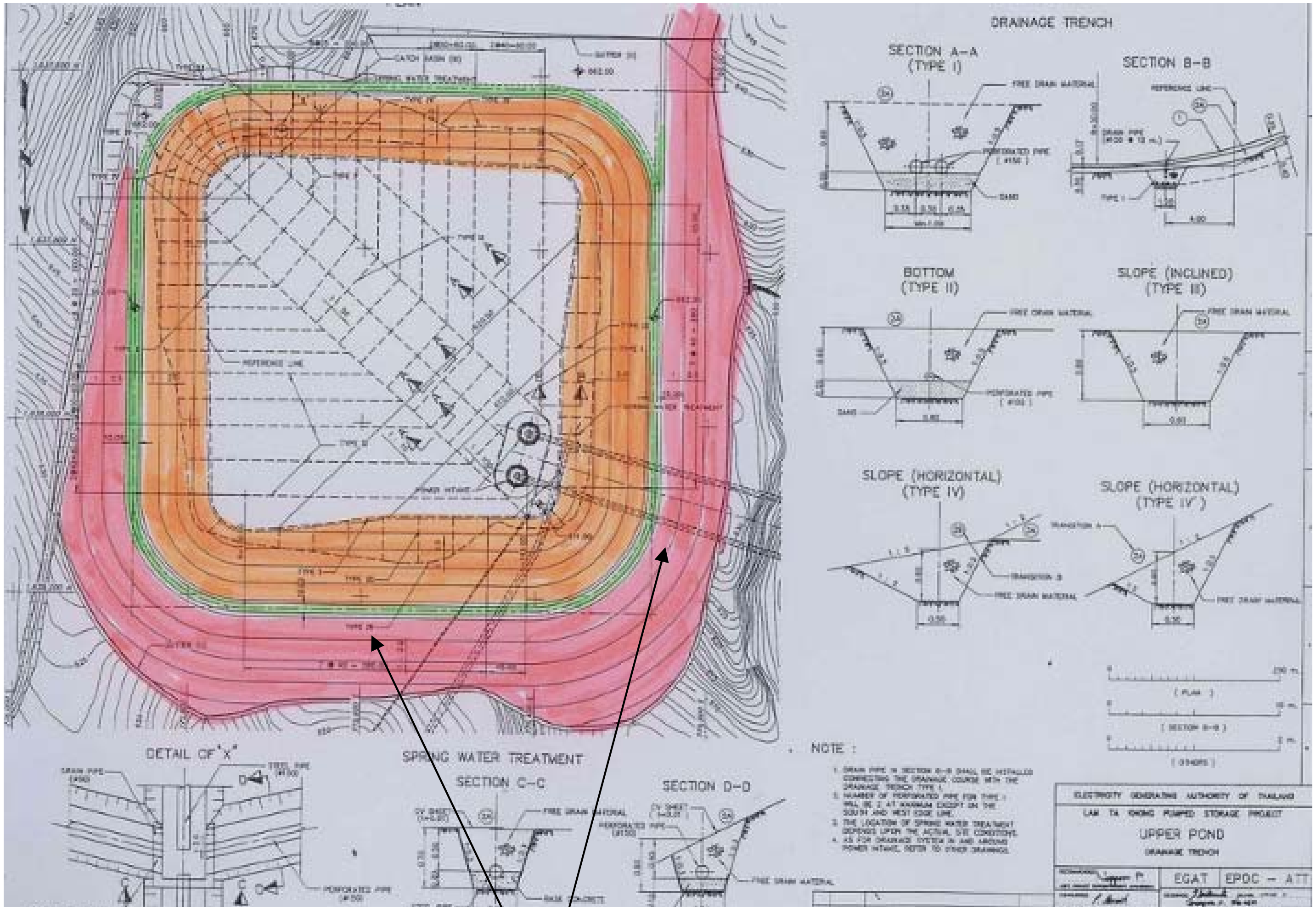


Cavern Supports

Heavy supports inform of closely spaced rock anchors and shotcrete for cavern roof in siltstone

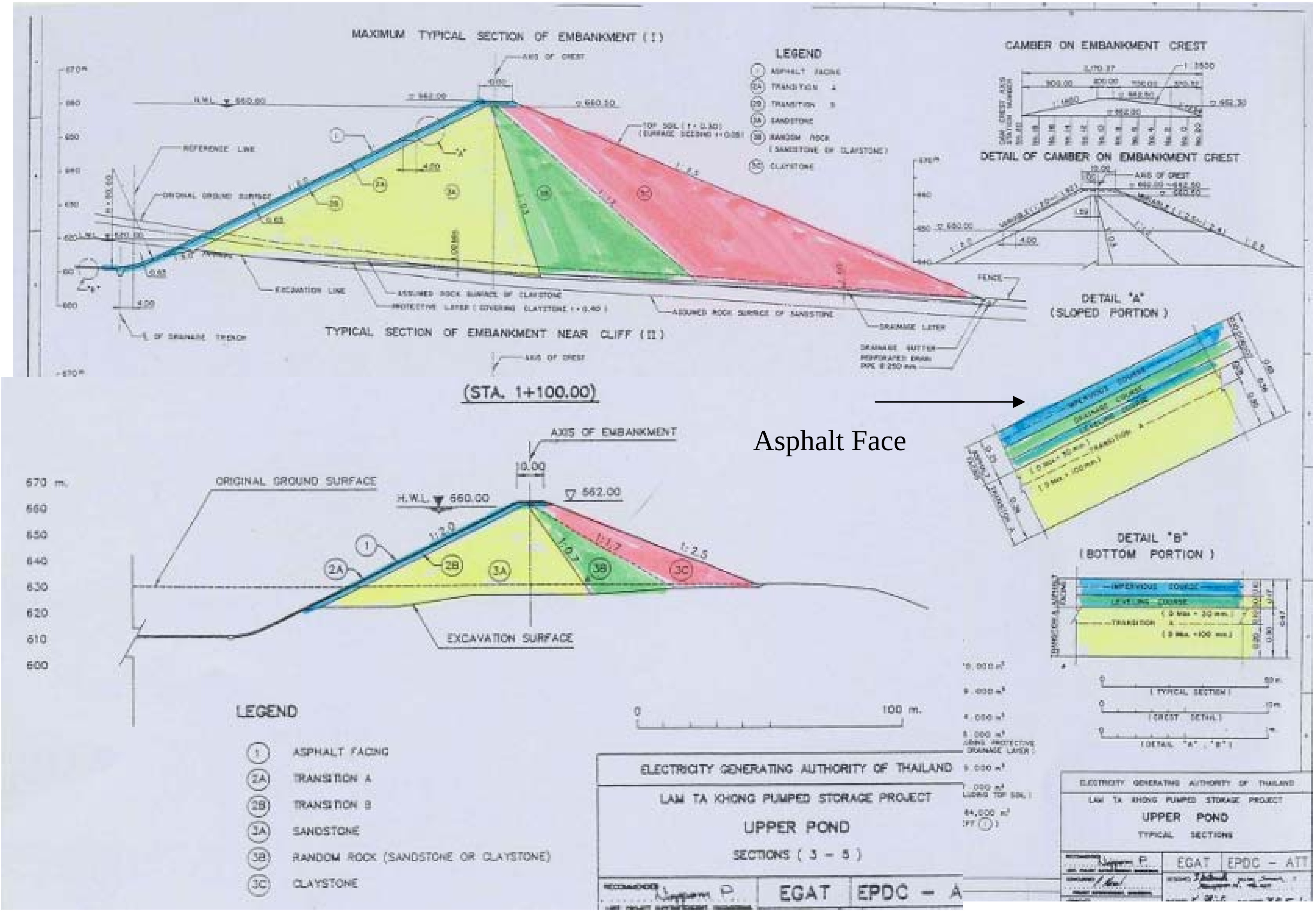
UPPER POND

Upper Pond Layout and Sub Drain System

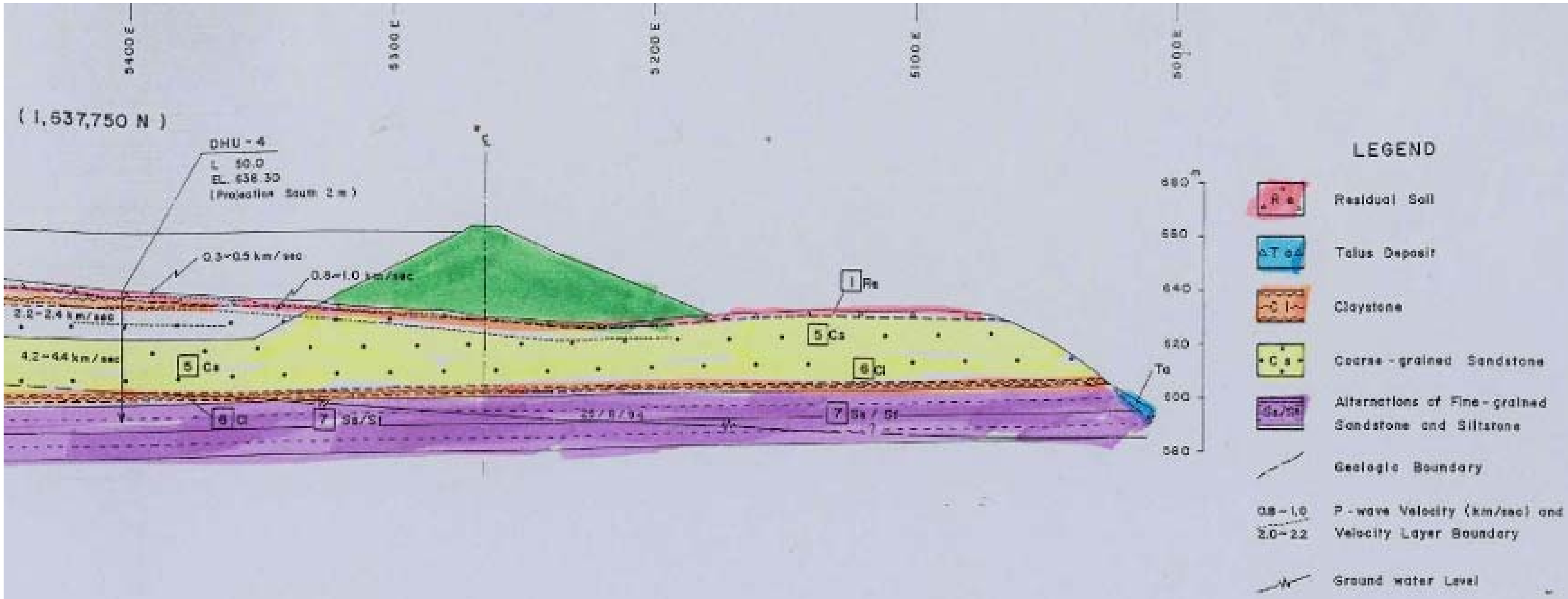


Upper Pond Embankment

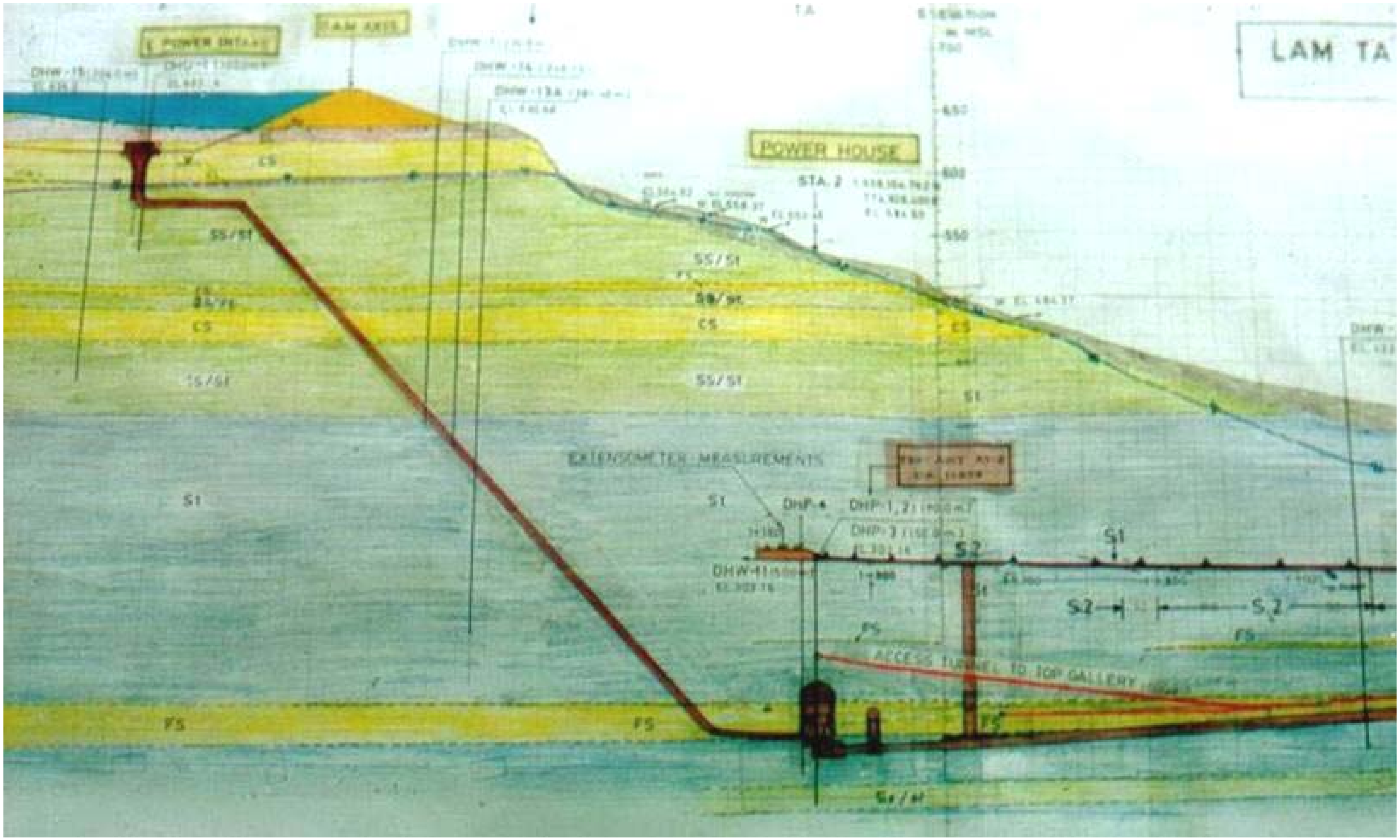
Zoning of Rock Fill Embankment



Condition of Rock Foundation underneath Rock fill embankment on cliff side

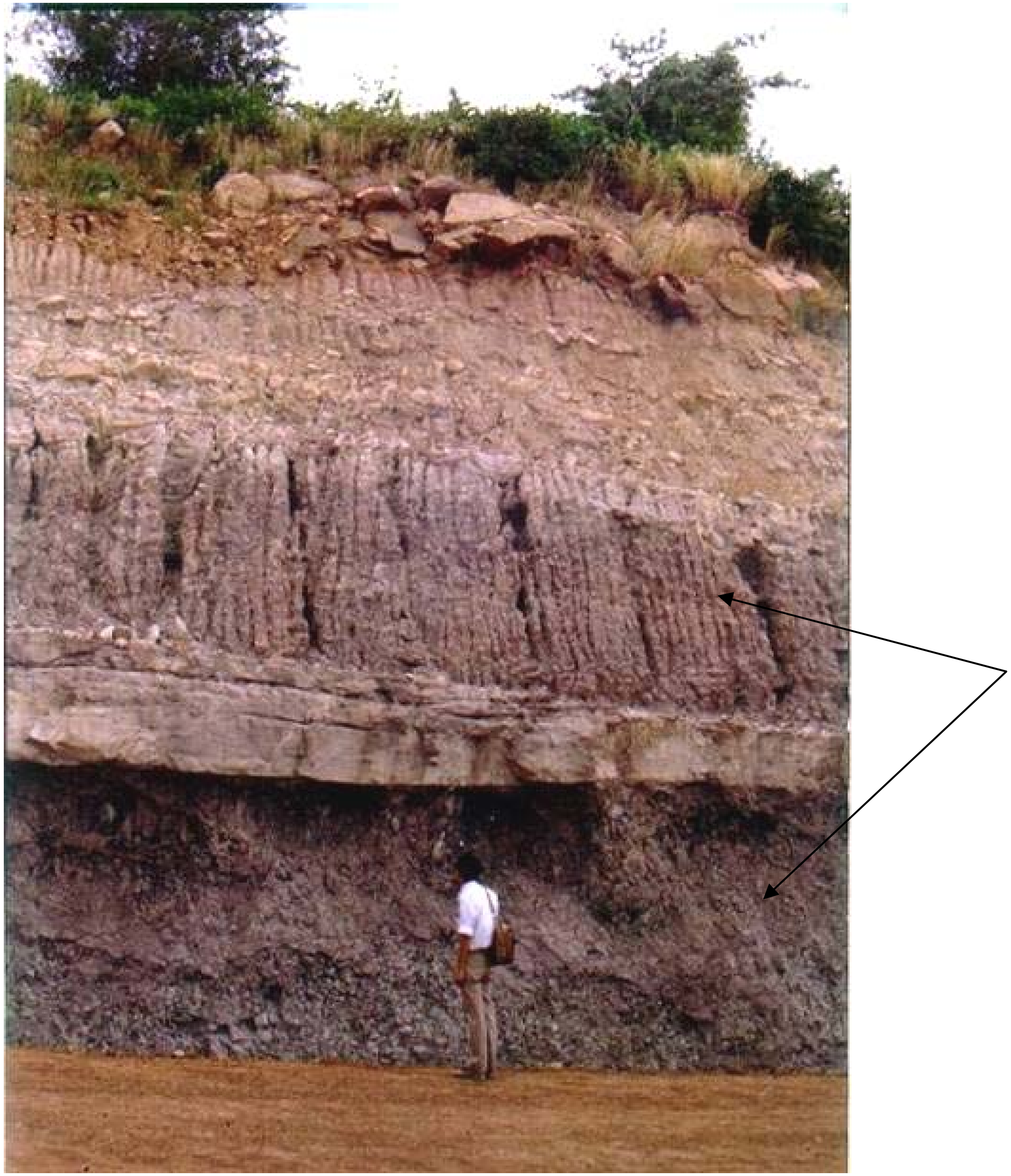


Sectional Profile



POWER INTAKE
DAM AXIS
LAM TA
POWER HOUSE
STA. 2
650
600
550
CS
SS/St
FS
St
EXTENSOMETER MEASUREMENTS
DHP-4
DHP-1,2
DHP-3
DHW-11
S2
S1
ACCESS TUNNEL TO TOP GALLERY

General condition of outcrop of sandstone beds
Near vertical orthogonal jointed

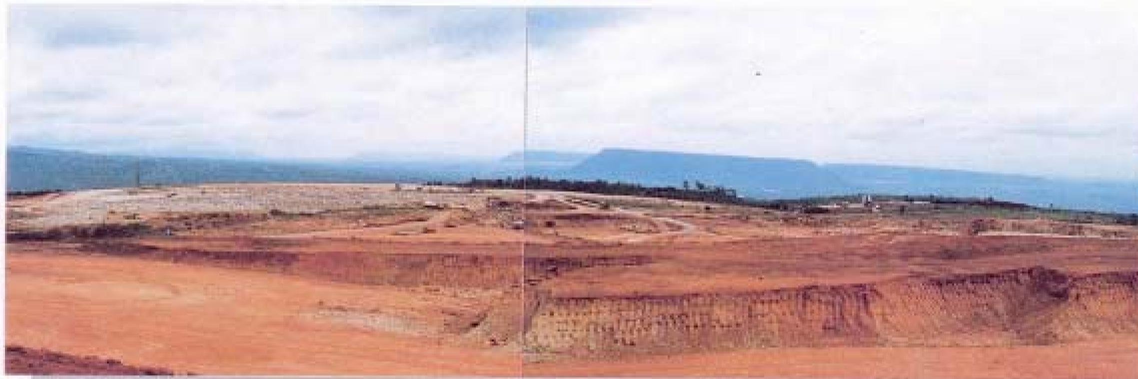


Condition of outcrop of siltstone beds and their slaking condition after exposure to atmosphere

Slaking of siltstone left unattended in core boxes

Claystone in the
Upper Pond area

Construction of Upper Pond



ก่อสร้างอ่างพักน้ำ บริเวณเขายายเที่ยง

Excavation by blasting of rock beds
(sandstone, siltstone and claystone)

Excavation and embanking: Balancing materials

Rockfill Embankment: Controlled compaction

Rock fill embankment at completion of filling

Paving of asphaltic concrete lining on embankment slope face

Paving equipment and procedures.

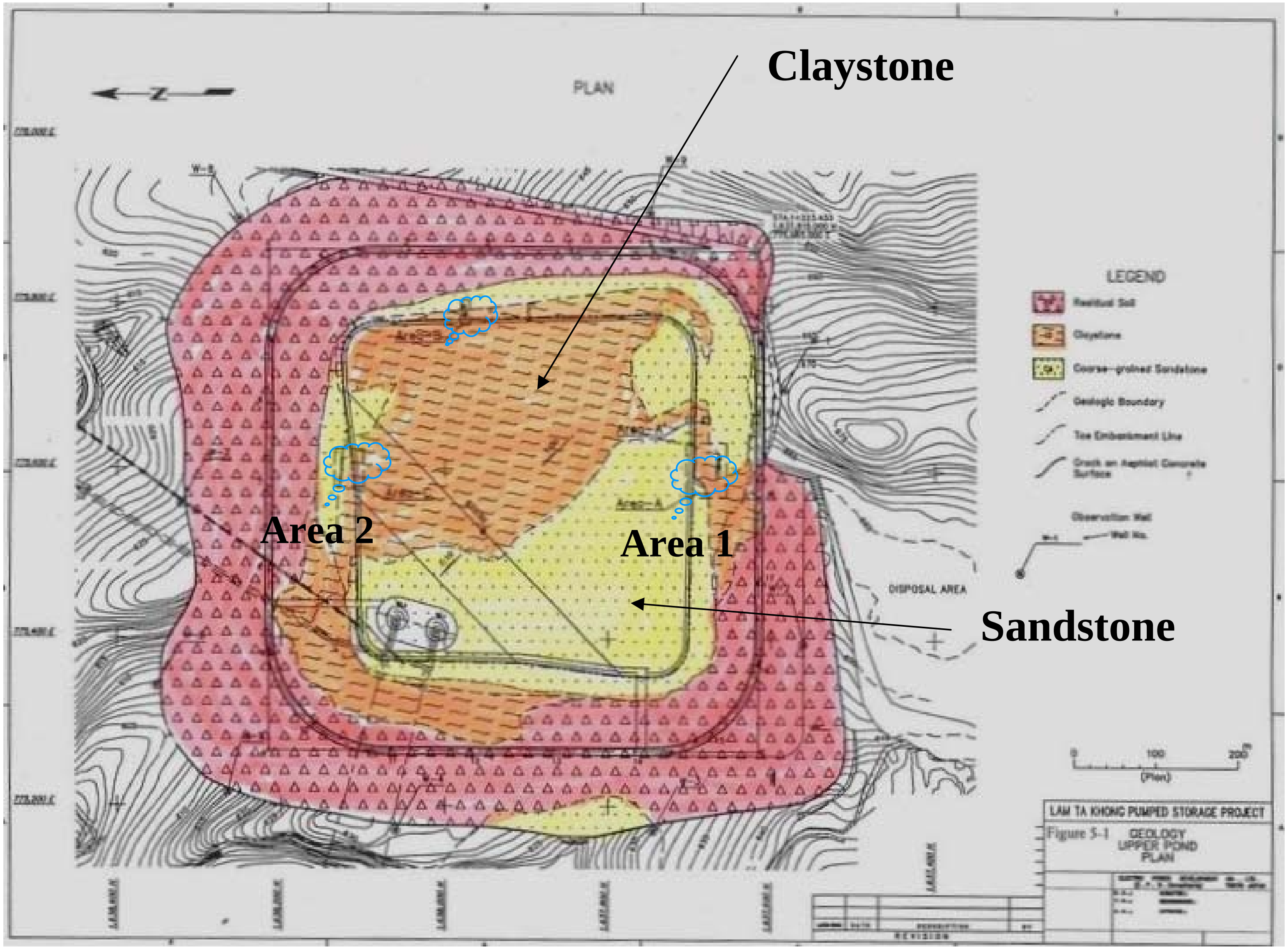
Cases of Unsatisfactory Performances

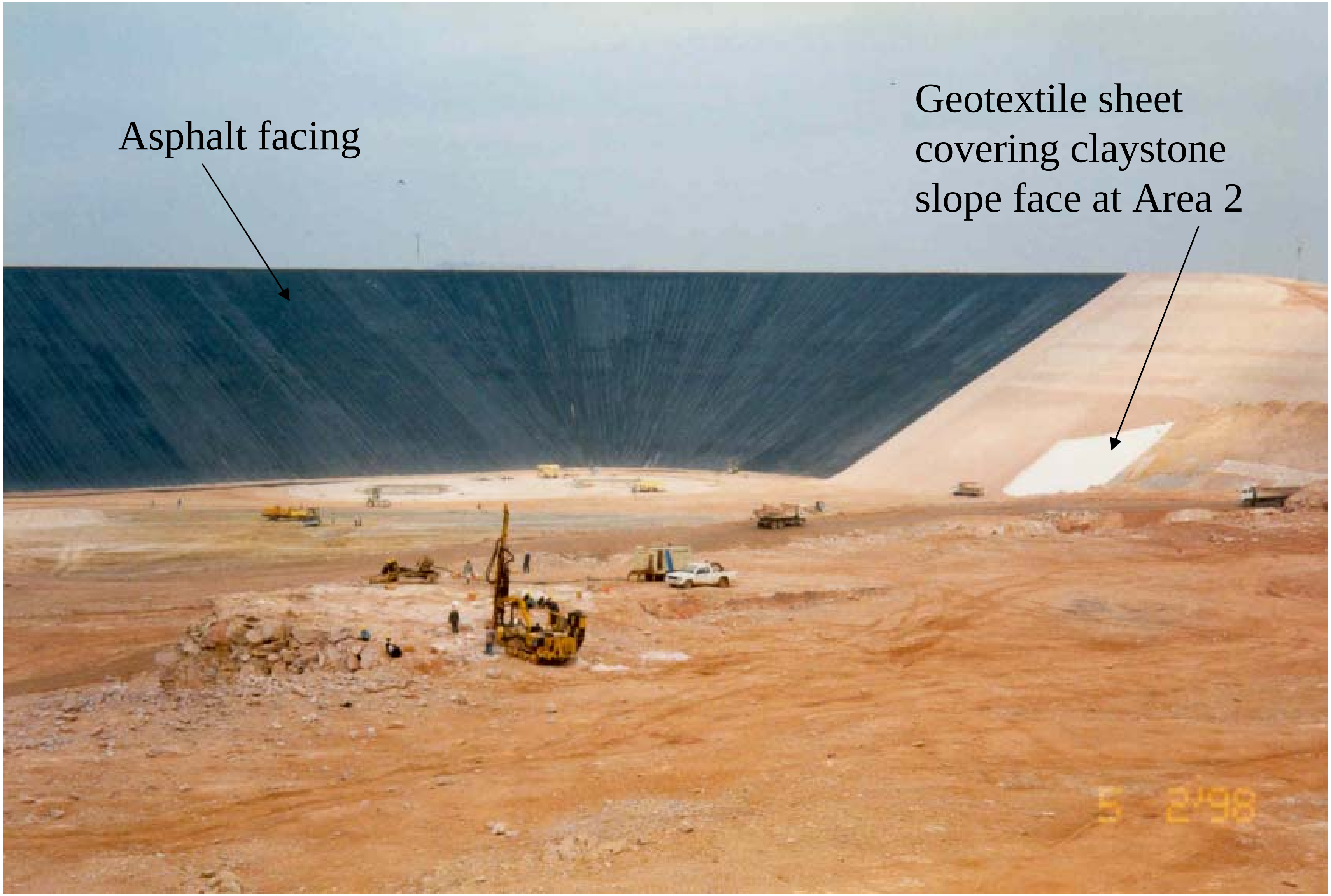
- Cracks and bulge of asphalt lining on cut slope due to the slippage of lining layer over weak rock.
- Rupture of asphalt lining in pond floor due to piping of bedding material and leading severe leakage of the pond
- Excessive and continuous settlement and lateral displacement of rock fill embankment resulting pronounced cracking of dam crest.

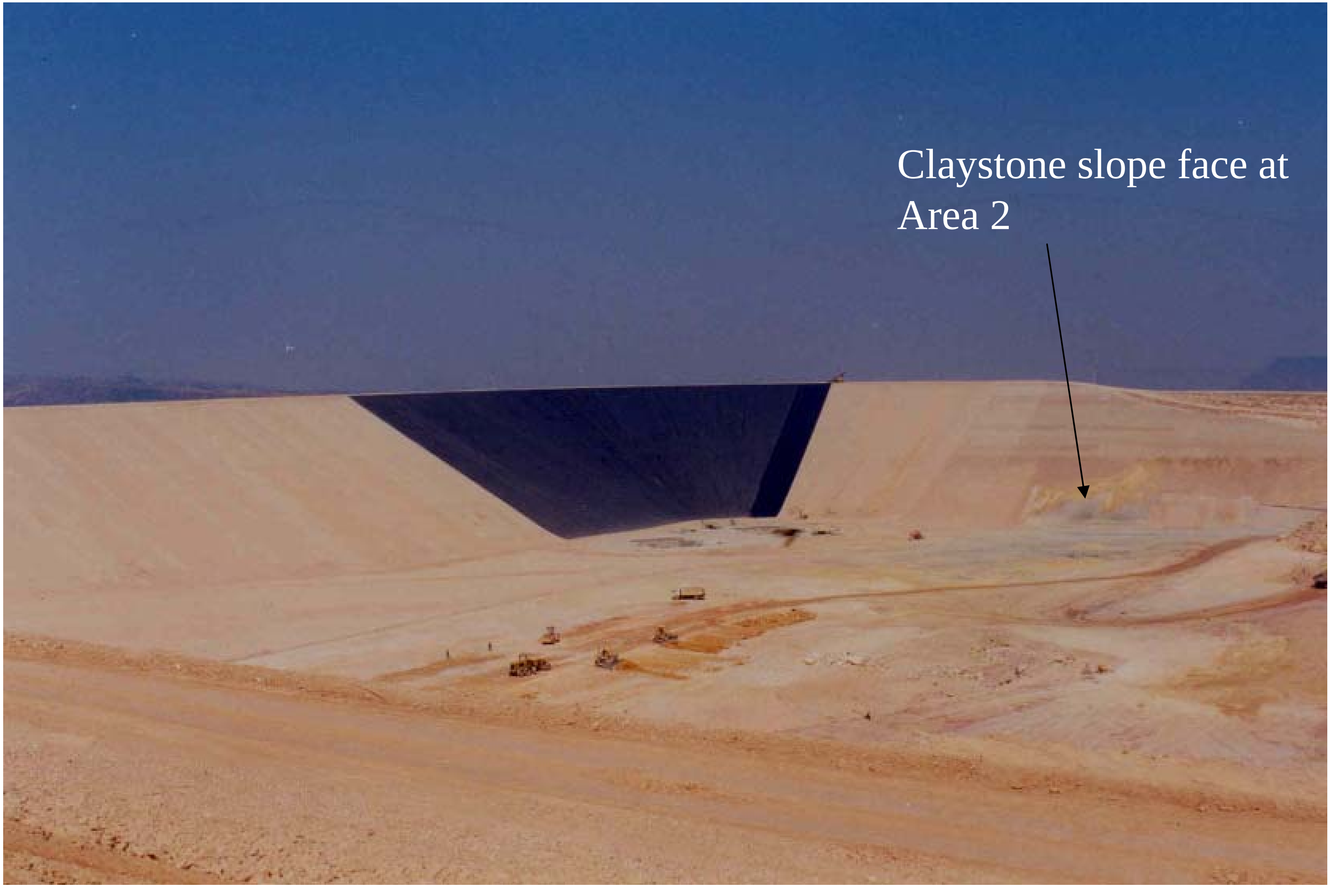
Cracks and bulge of asphalt lining on cut slope due to the slippage of lining layer over weak rock.

- Increased leakage rate was detected during the trial pond filling up to about a half full.
- The inspection after emptying the reservoir revealed cracks, bulges and heaves of asphalt facing near toe of slope at three areas of cut slope.
- All three areas were located in zones of claystone where a special treatment using geotextile covering was adopted underneath the facing layers to avoid a problem of deterioration and piping of claystone in contact with water.
- Inspection trenches were excavated to investigate the cause of the failure.

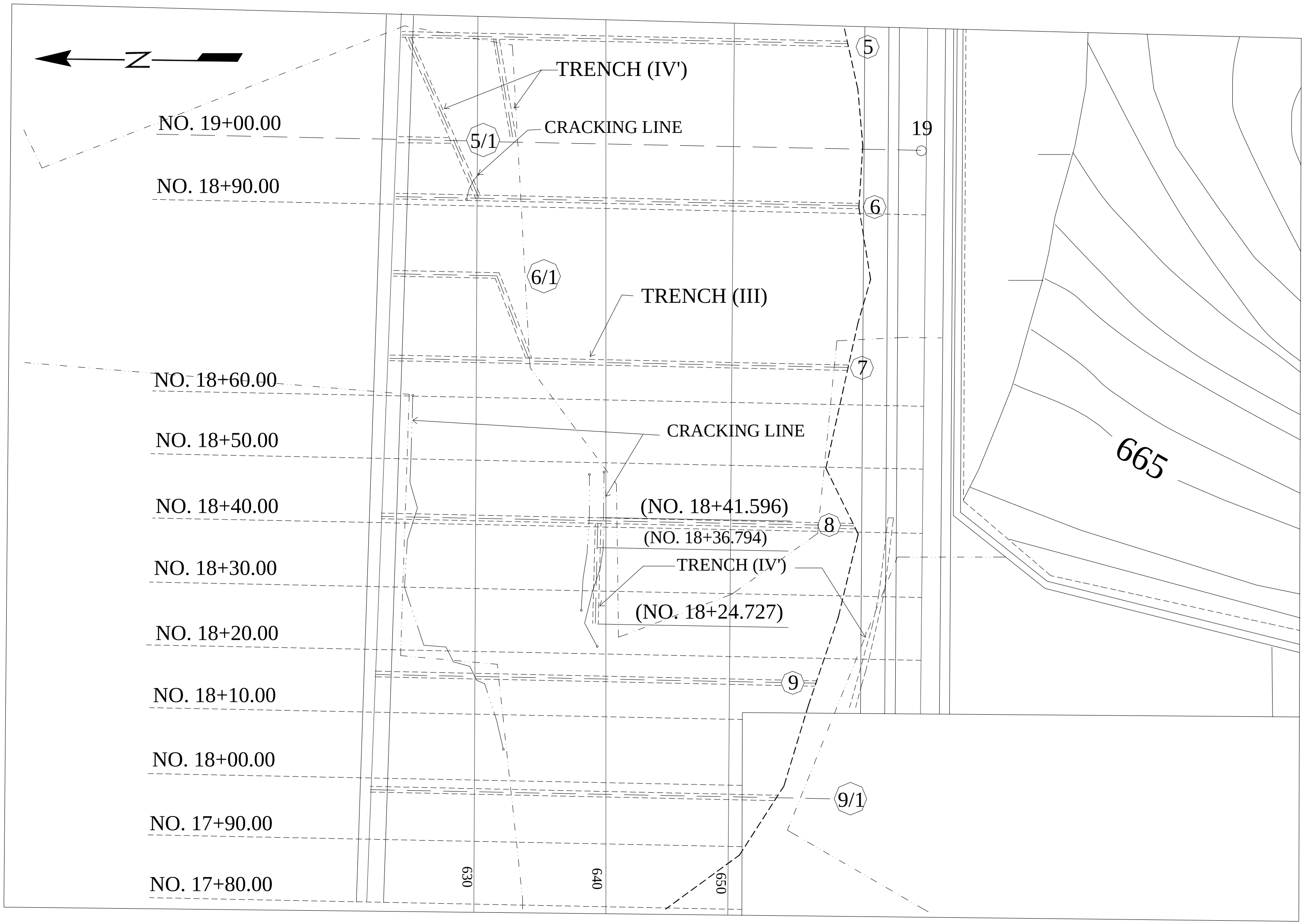
Locations where slippage and cracks of the asphalt facing on cut slope occurred.



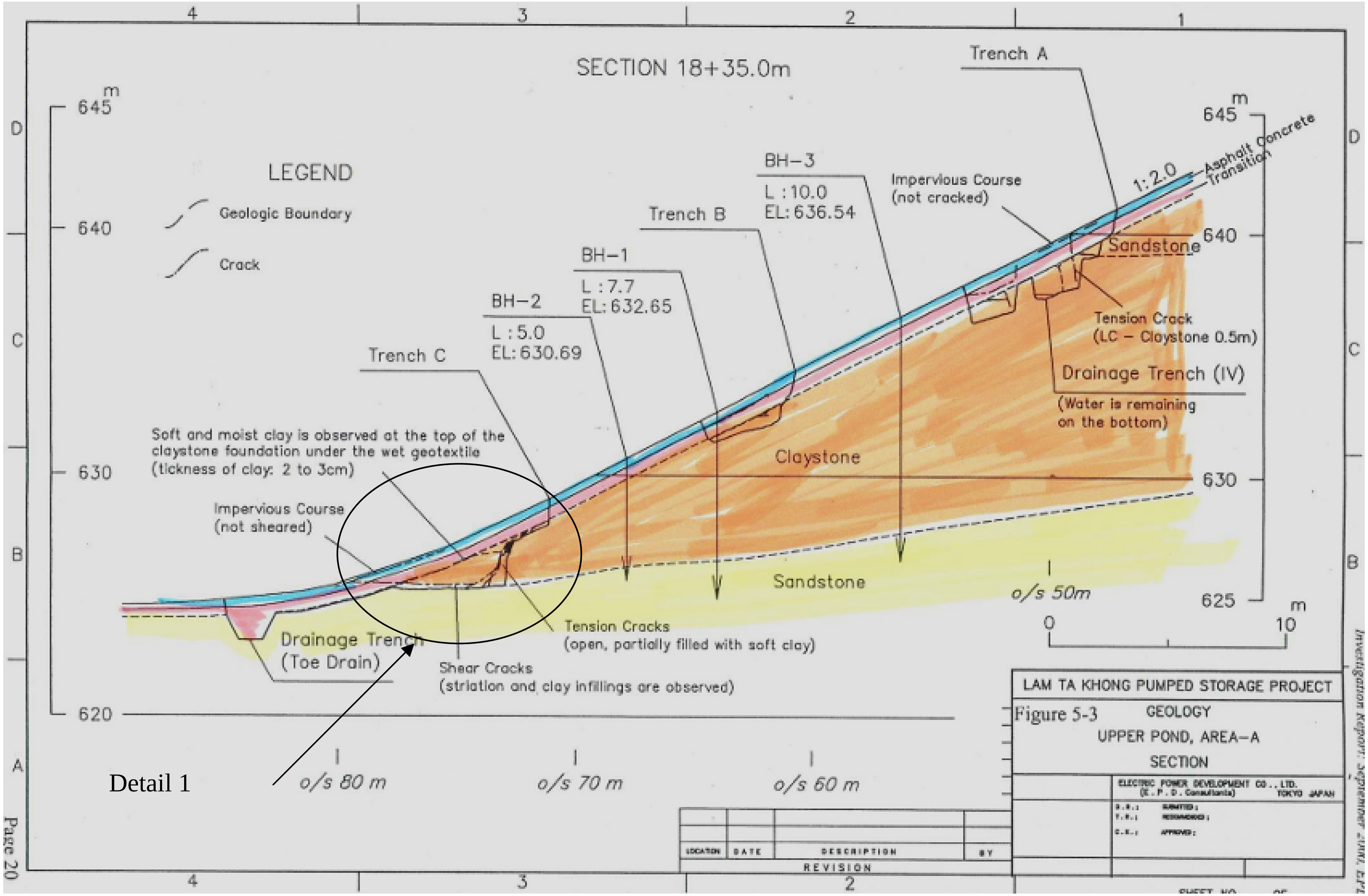

Asphalt facing
Geotextile sheet
covering claystone
slope face at Area 2
5 2'98


Claystone slope face at
Area 2

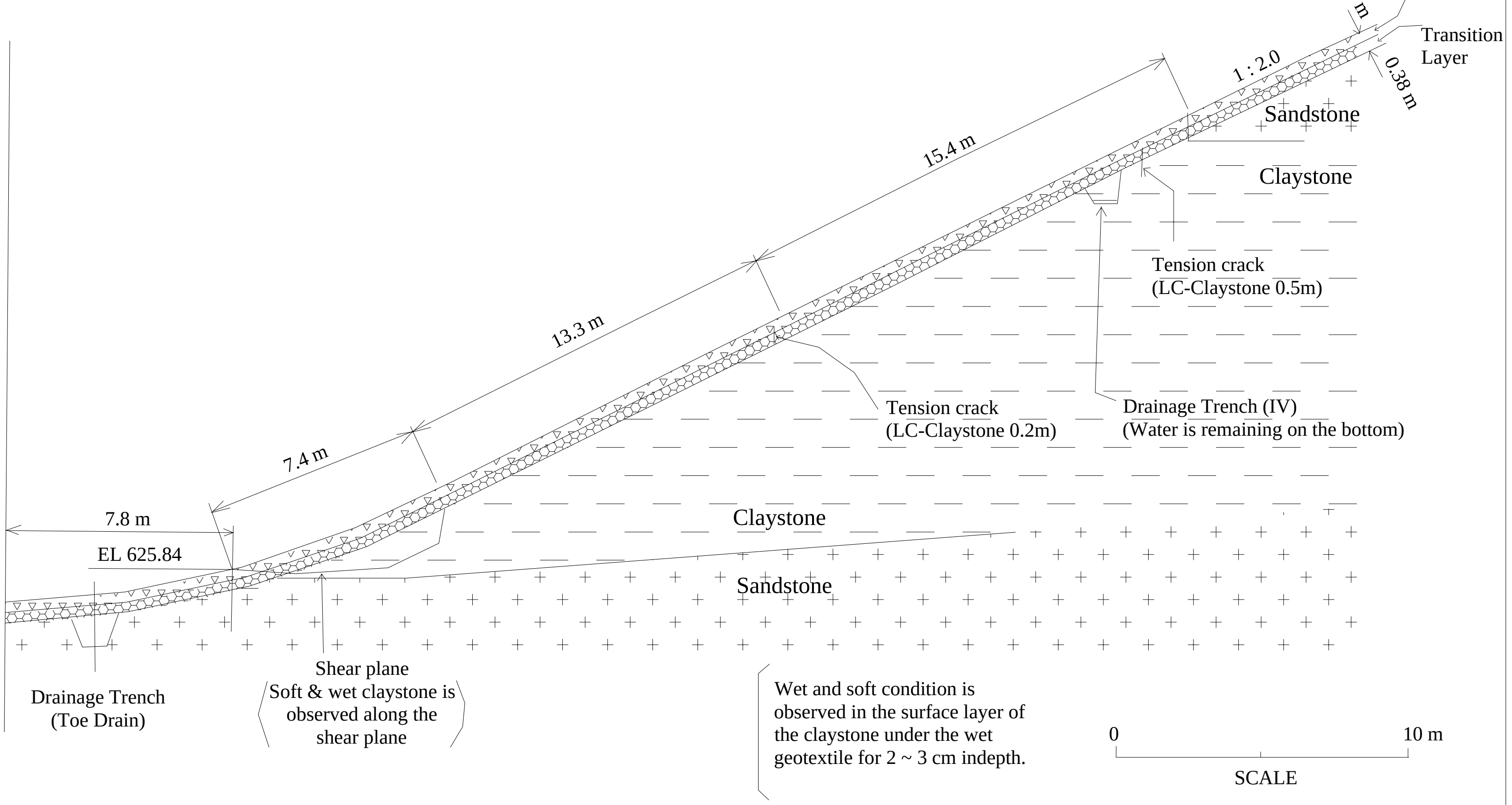
Map of Cracks in Area 1 (South Slope)

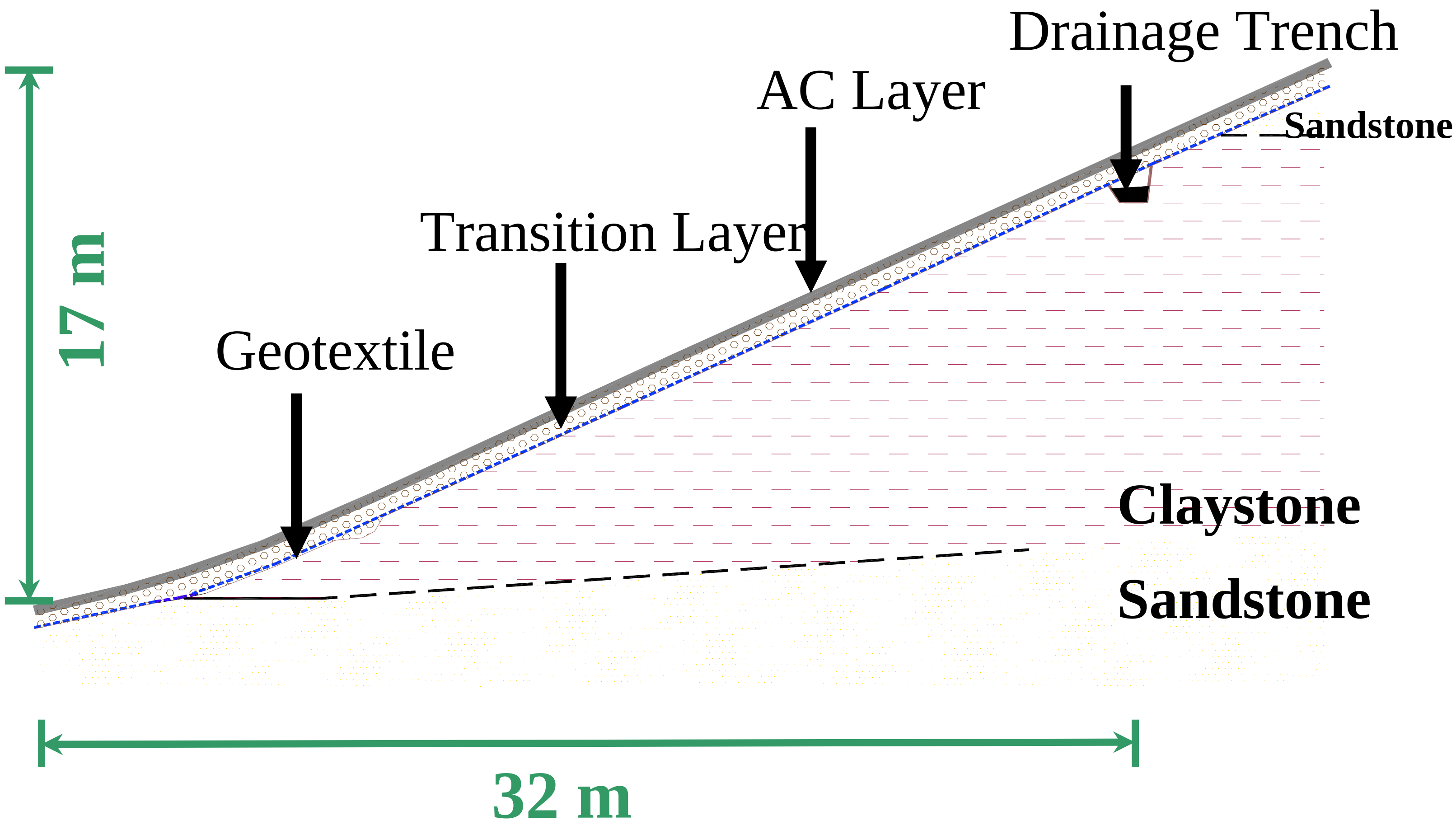


Section along Inspection Trench in Area 1



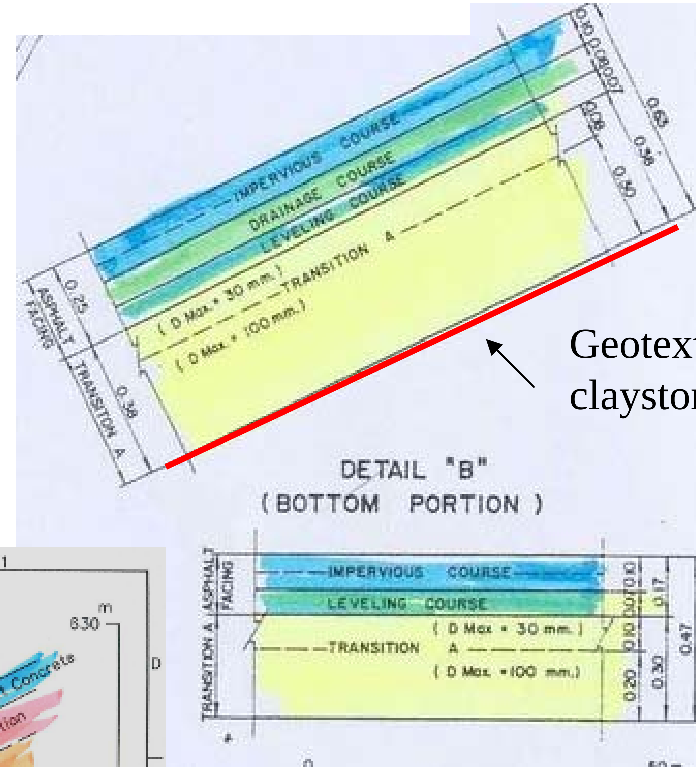
Cross Section of Area - A



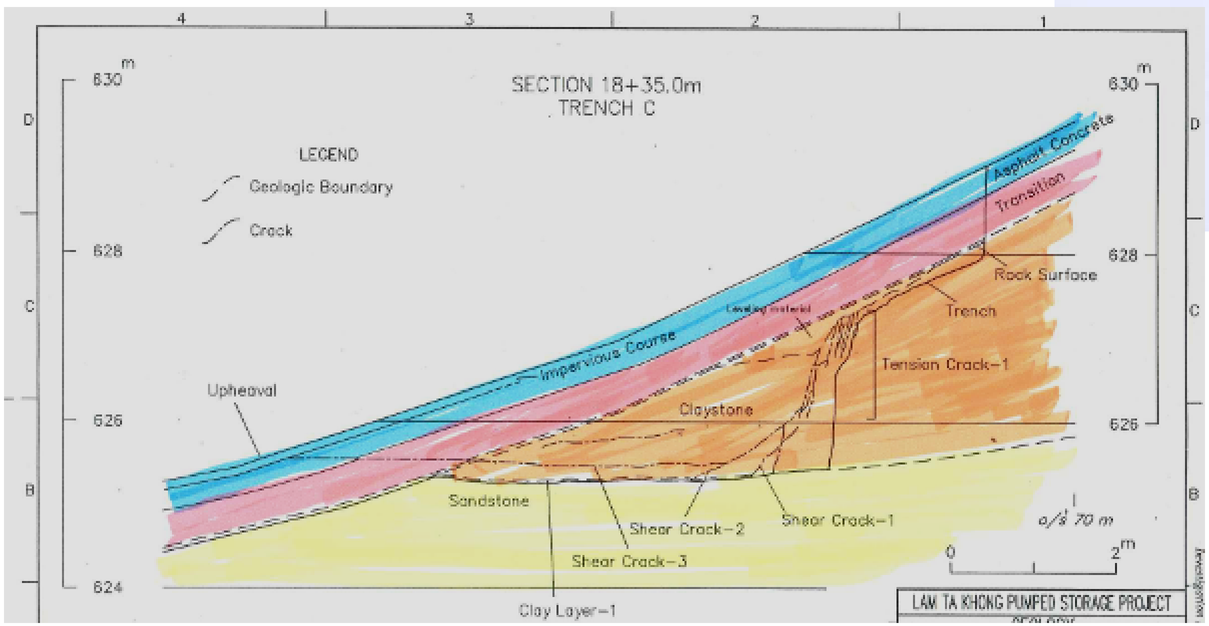


Drainage Trench
AC Layer
Sandstone
Transition Layer
17 m
Geotextile
Claystone
Sandstone
32 m

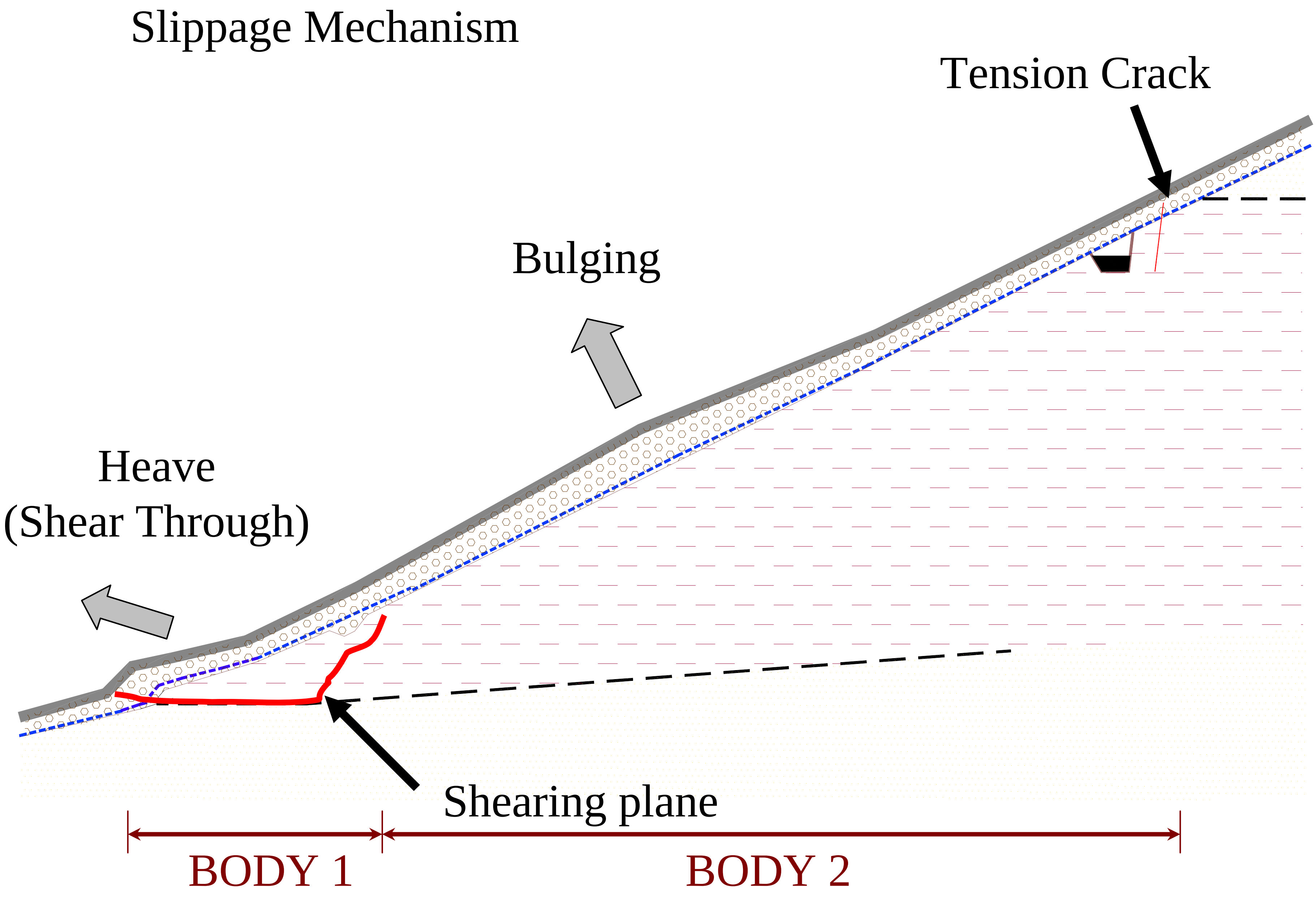
Asphalt Facing Layers Design



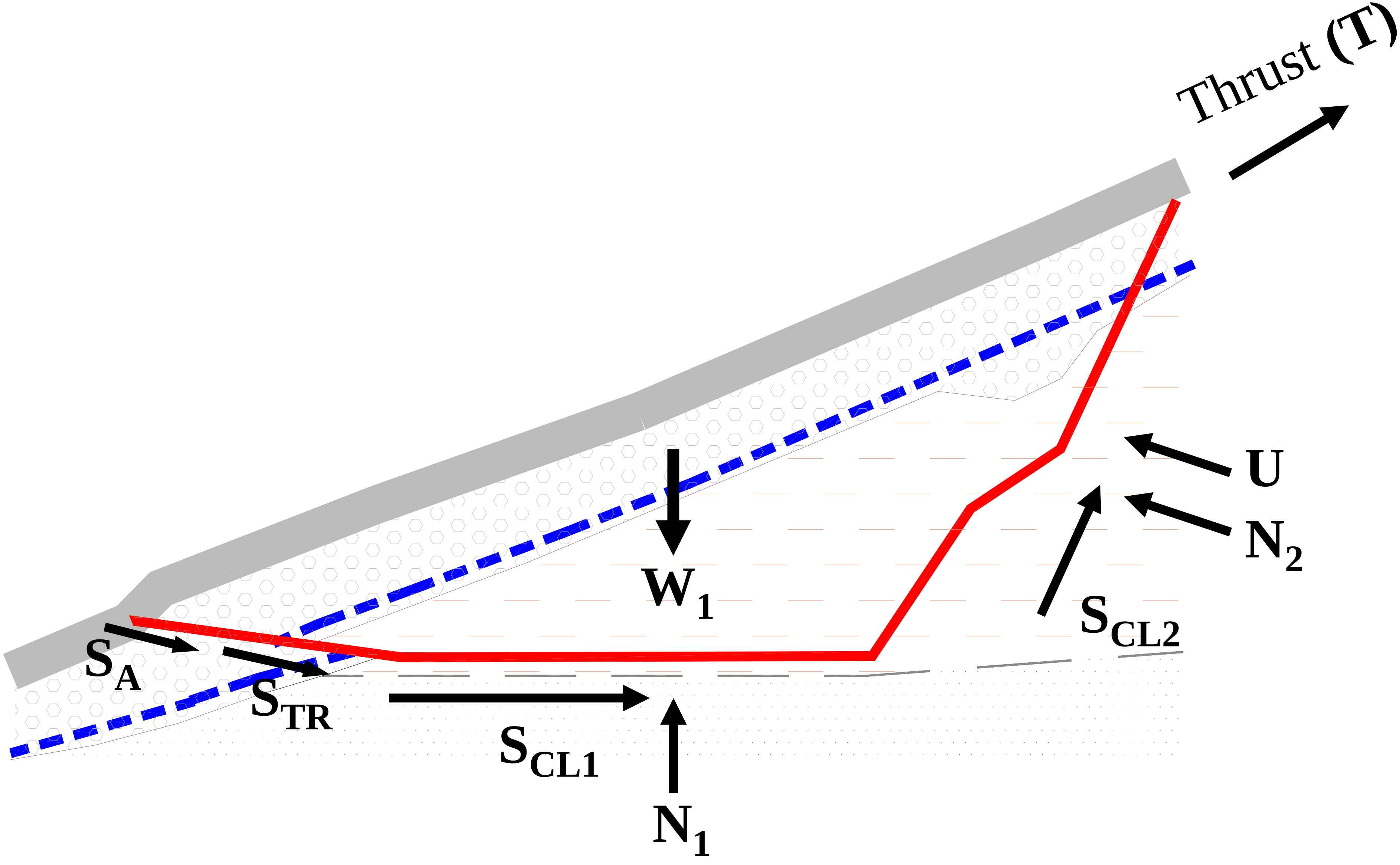
Geotextile over claystone



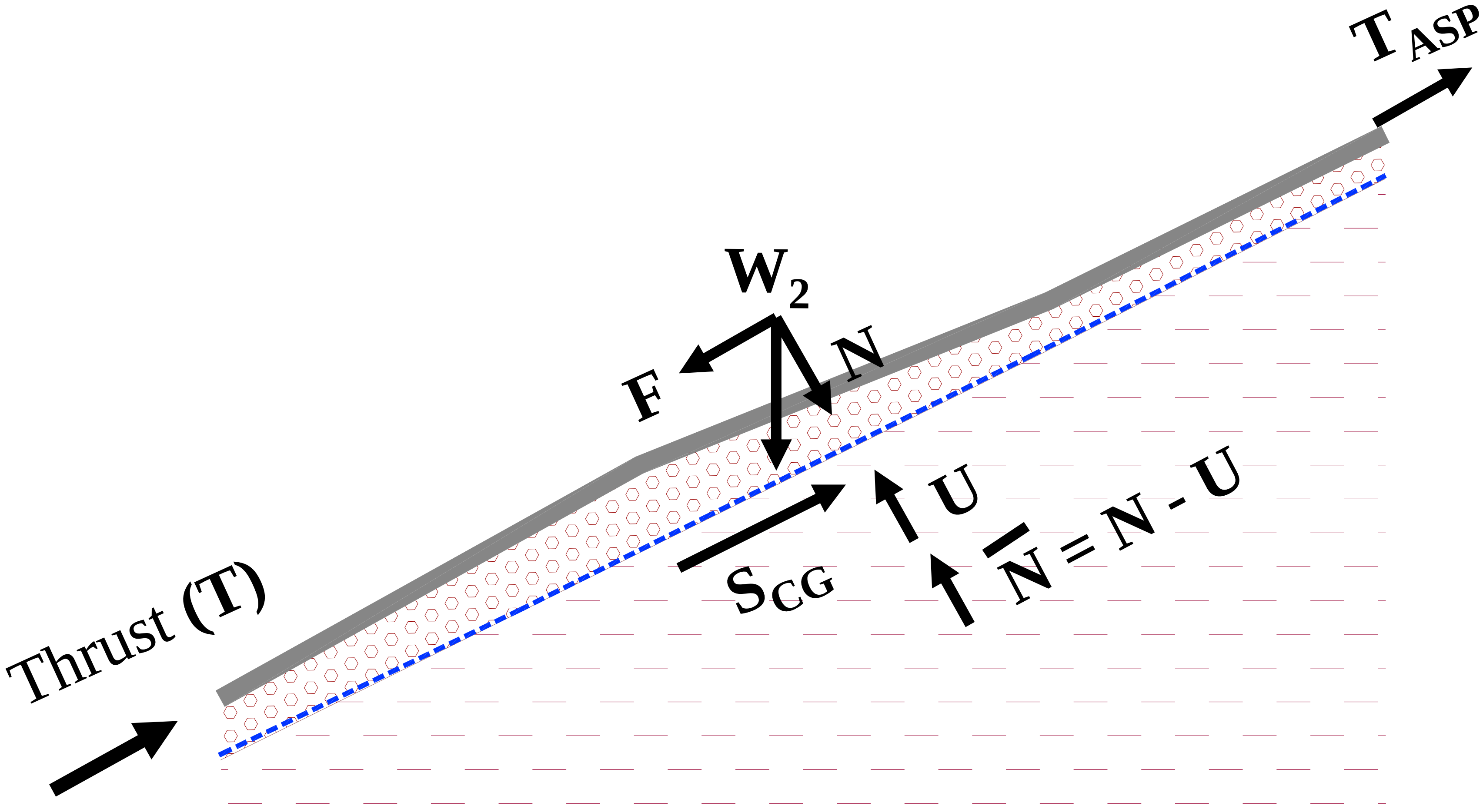
Detail 1



Slippage Mechanism
Tension Crack
Bulging
Heave
(Shear Through)
Shearing plane
BODY 1
BODY 2



(BODY 1)



(BODY 2)

Shear Strength of Claystones

Summary of Direct Shear Test on Claystone

Upper Pond, Lam Ta Khong Pumped Storage Project

Sample A: Brown to cherry red laminated claystone.(Depth 0.50 - 0.80 m)

Average water content (%) = 11.41 (10.03 - 12.47)

Total unit weight (kN/m^3) = 21.59

Sample Type	Peak Stress		Residual Stress		Remarks
	Frictional Angle (degree)	Cohesion (MPa)	Frictional Angle (degree)	Cohesion (MPa)	
Core	22.78	0.31	22.28	0.0736	Quick test (2-3 hours)
Pre-cut surface	23.76	-	20.12	-	Quick test (30-45 min.),
Soaked pre-cut surface	15.60	-	14.46	-	Residual Stress taken at 8-10 mm displ.
Pre-cut surface with geotextile	18.65	-	16.26	-	

Sample B: Yellowish brown claystone. (Depth 0.00 - 0.25)

Average water content (%) = 11.86 (11.65 - 12.08)

Total unit weight (kN/m^3) = 22.41

Sample Type	Peak Stress		Residual Stress		Remarks
	Frictional Angle (degree)	Cohesion (MPa)	Frictional Angle (degree)	Cohesion (MPa)	
Core	15.30	0.2443	14.20	0.658	Quick test (2-3 hours)
Pre-cut surface	23.56	-	21.64	-	Quick test (30-45 min.),
Soaked pre-cut surface	26.76	-	25.50	-	Residual Stress taken at 8-10 mm displ.
Pre-cut surface with geotextile	11.09	0.0125	23.14	0.0049	Strain hardening behaviour

Lam Ta Khong Claystones

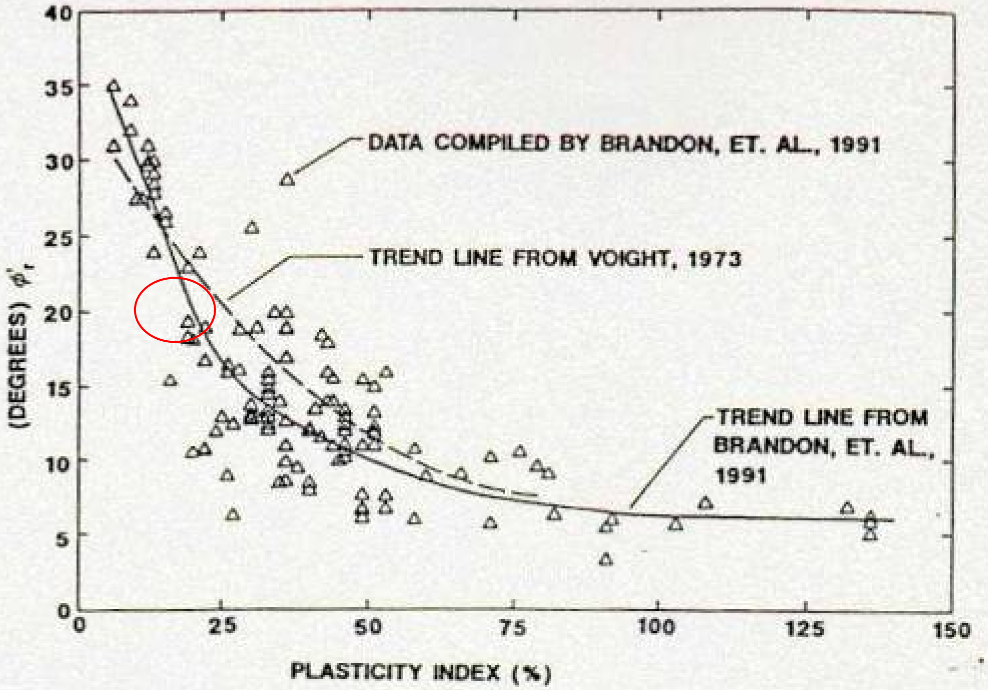
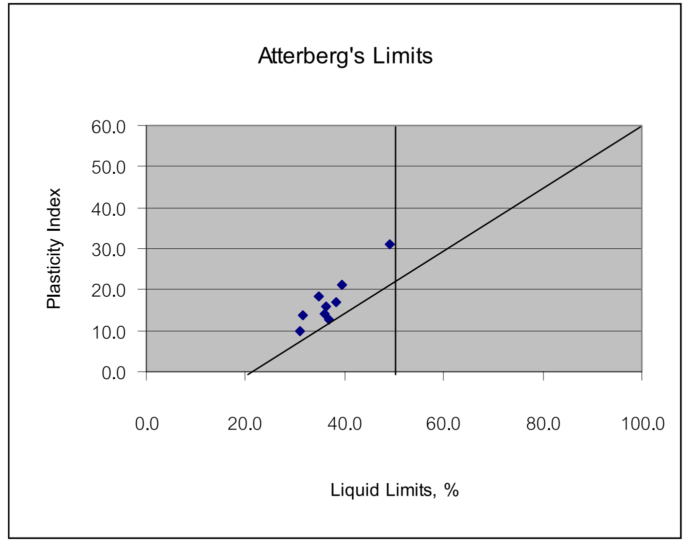


Figure 1.32 Plasticity index residual friction angle relationship (Voight, 1973, and Brandon et al., 1991).



Laboratory Test Results on Asphalt Facing

<u>Uniaxial Compression test (UCS) on asphalt</u>

Upper Pond, Lam Ta Khong Pumped Storage Project

Diameter (mm) = 54.50

X-section area (sq.m)= 0.002334

Sample No.	Axial Stress (MPa)	Remarks
At temperature 50 degree celsius		
South 1	0.50	Quick test (within 2-3 min.)
South 2	0.42	
East 1	0.36	
East 2	0.38	
At room temperature (~26 degree celsius)		
South 3	1.59	Quick test (within 2-3 min.)
South 4	1.41	
East 3	1.11	
East 4	1.15	

Laboratory Test Results on Asphalt Facing

<u>Direct Shear Test of Asphaltic Concrete Lining</u>

Diameter (mm) = 54.50

X-section area (sq.m) = 0.002334

Sample No.	Normal Load (MPa)	Shear Stress (MPa)	Loading Rate (mm/sec)	Remarks
At temperature 40 degree celsius				
South 5	0.018	**0.175**	0.009	Slow test (3 - 4 hours to shear 10 mm) Test was performed using the Wykeham Ferrance shearbox as used for soil test.
South 6	0.018	**0.100**	0.001	
South 7	0.018	**0.115**	0.001	
South 8	0.018	**0.120**	0.001	
At room temperature (~26 degree celsius)				
South 9	0.018	**0.107**	0.001	
South 10	0.018	**0.119**	0.001	
At temperature 40 degree celsius				
South 11	0.018	**0.130**	0.030	Very quick test, (~5 min to shear 10 mm displ.) Initial temp.was 59^{0}C before test and final temp was ~40^{0}C after test.
South 12	0.018	**0.197**	0.030	
South 13	0.018	**0.127**	0.030	
South 14	0.018	**0.144**	0.030	

Remedial Measures

- Thickening asphalt lining in toe areas of slopes in the damaged zones to serve as buttress and improved shear resistance.
- Avoided using geotextile sheet as the separator over claystone (Geotextile sheet created planar sliding surface between claystone and transition layer).

Rupture of asphalt lining in pond floor leading to severe leakage

- This incident occurred after the repair of the asphalt facing damages from slippages on slopes in claystone area.
- Severe leakage through the drainage tunnel at the pond floor was experienced during a trial pond filling almost to the full supply level.
- Upon emptying the pond, severe deformation, depression and cracking were spotted on the asphalt floor lining near the intake shaft of the penstocks.
- Voids were created below the asphalt lining at the location resulting in severe subsidence and cracking of the asphalt layer from heavy water pressure above it.
- The area was underlain by claystone bed which was not protected from slaking and deterioration during construction. However, it also extended in the zone underlain by sandstone bed.
- Leveling layer made with mixture of sandstone and weathered materials over claystone bed had low resistance to piping from leakage water underneath the asphalt lining.
- Inspection excavation revealed severe piping condition of the transition layer.

Rupture of asphalt lining in pond floor

Depression and rupture of asphalt lining in pond floor

Rupture of asphalt lining in pond floor


Damaged area
5 2'98

Damaged area

Bedding layer in the damaged area showing piped out condition of fines between sandstone fragments

Highly jointed sandstone bed created difficulty in preparation of smooth surface to start placement of a good transition (levelling) layer for asphalt lining. Levelling of the surface by filling with fines over the rough and angular surfaces resulted in unstable layer against piping.

Remedial Measures

- It was judged that the condition and extent of the problem was so severe beyond repair using the original design concept having the asphalt lining as the reservoir sealing. Similar piping could progressively occur in any areas below the pond floor owing to false design the under drainage system that did not match with the foundation rock condition.
- It was then decided to adopt the relining of the entire pond floor and slope face with a layer of high strength geomembrane sheet which was expected to give a functional duration for 10-15 years before replacement.

Relining the reservoir with a high strength geomembrane sheet

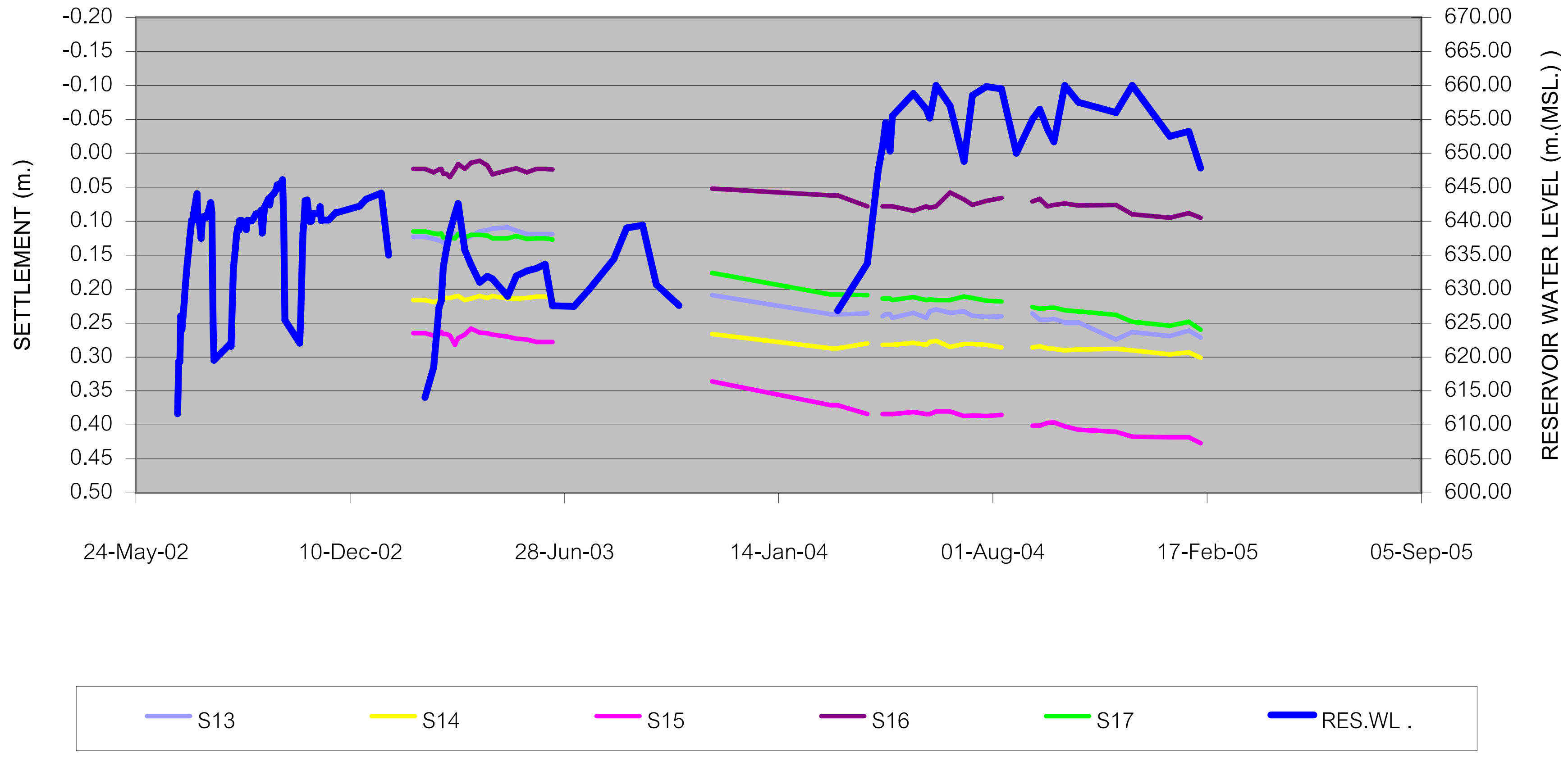
Settlement and cracking problems of dam crest.

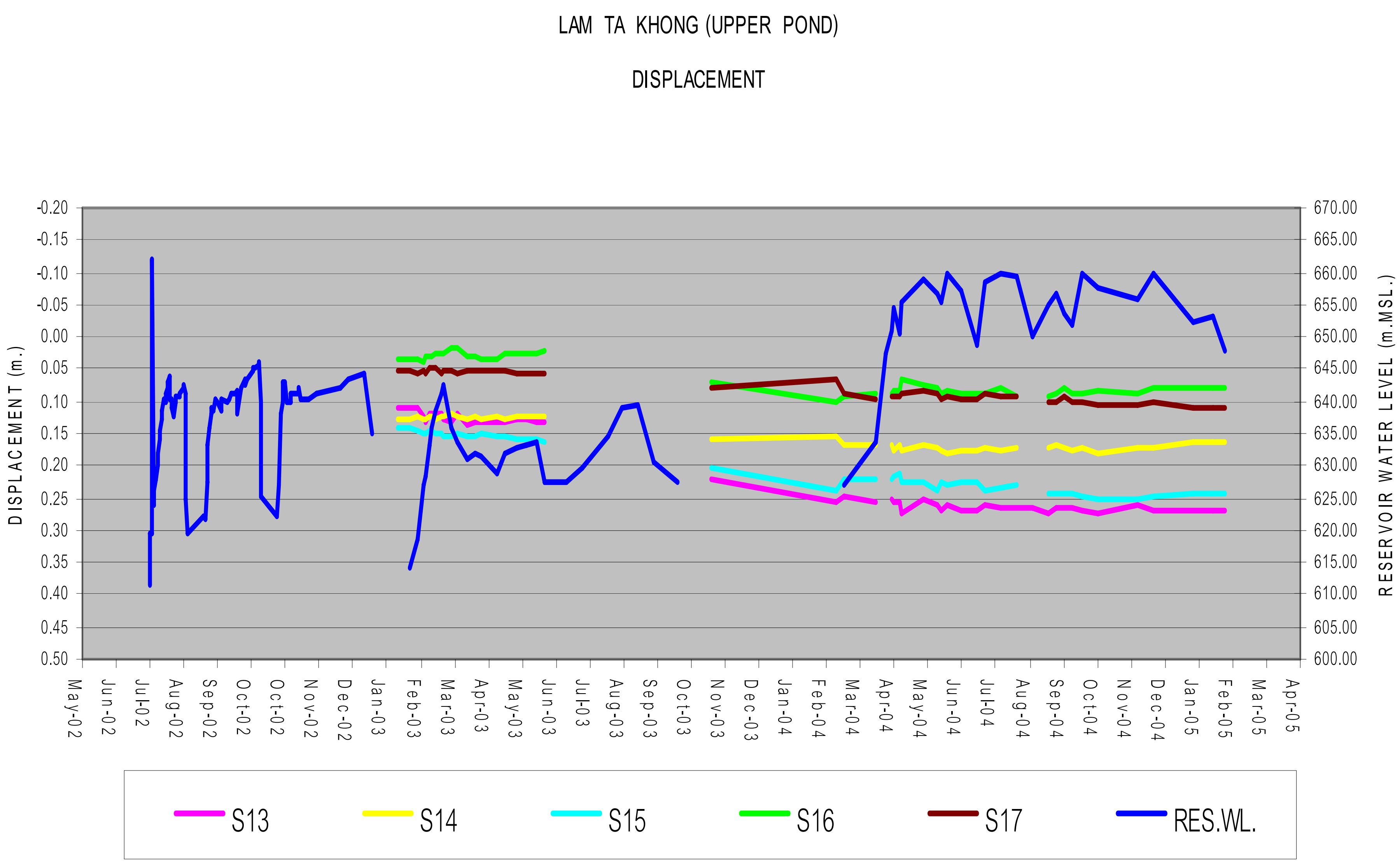
- Pronounced progressive cracking and settlement of dam crests occurred on west and north rock fill embankment over the years.
- The problem was more pronounced on the cliff side embankment (west embankment). Cracks occurred along the crest as well as on the bench of the downstream slope.
- Possible causes of the problem were investigated including high compressibility or low strength of the rock fill materials, and planar sliding along claystone bed being pushed by the embankment toward the cliff face.
- Up to present the exact cause has not been determined but it is likely that the problem is attributed to the progressive deterioration in the strength and compressibility properties of claystones and siltstones used in zone 3C of the embankment. The Zone 3C was not heavily compacted.

Severe Cracking and Settlement of Dam Crest

LAM TA KHONG (UPPER POND)

SETTLEMENT (Start of Pond Filling 26 June 2002)




LAM TA KHONG (UPPER POND)
DISPLACEMENT
DISPLACEMENT (m.)
RESERVOIR WATER LEVEL (m.MSL.)
-0.20
-0.15
-0.10
-0.05
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
670.00
665.00
660.00
655.00
650.00
645.00
640.00
635.00
630.00
625.00
620.00
615.00
610.00
605.00
600.00
May-02
Jun-02
Jul-02
Aug-02
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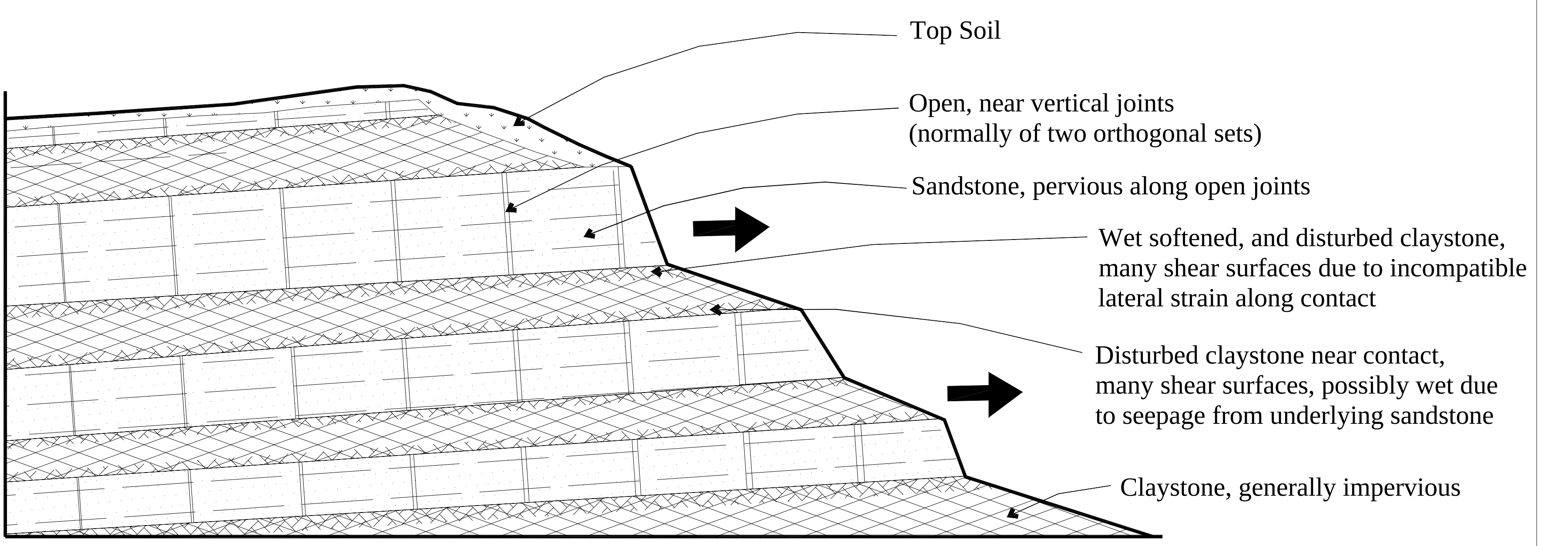
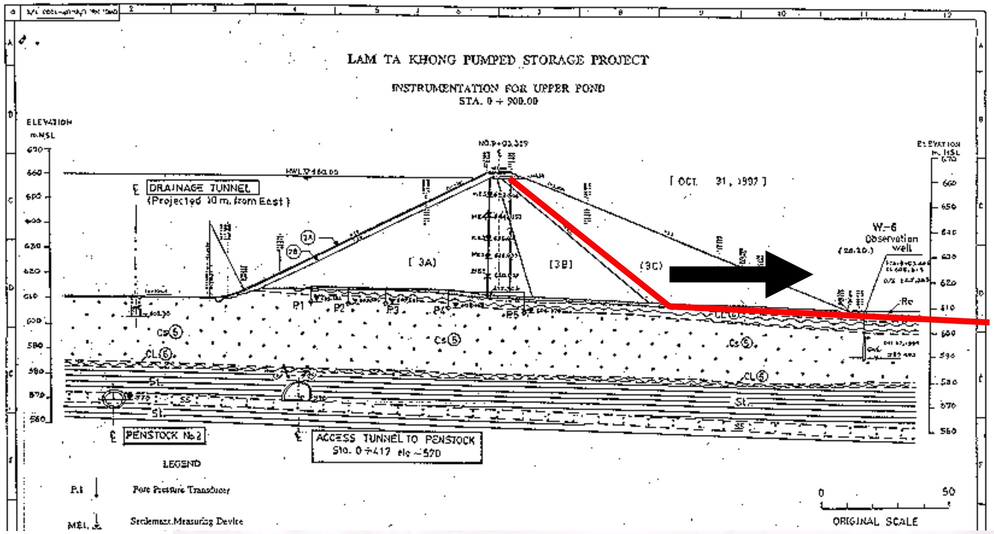
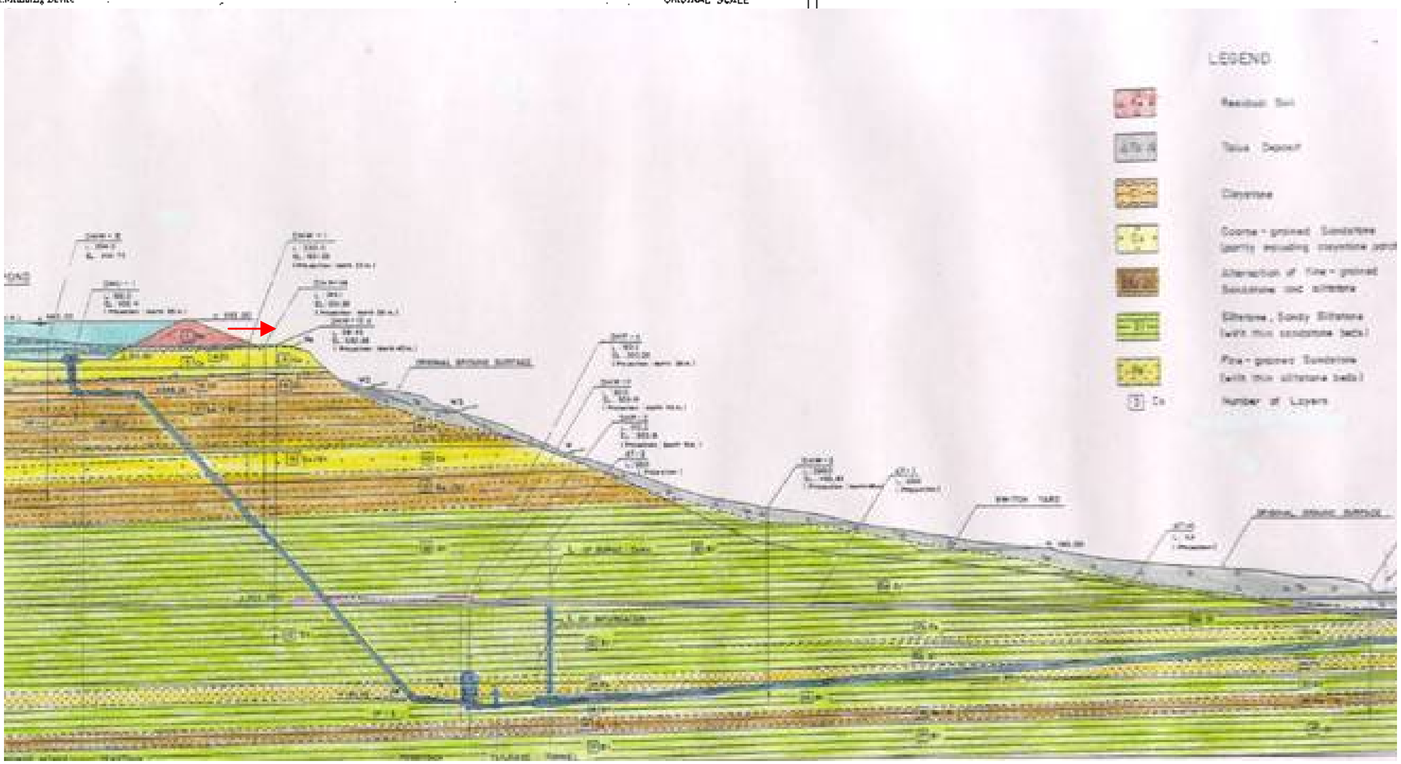
Oct-04
Nov-04
Dec-04
Jan-05
Feb-05
Mar-05
Apr-05
S13
S14
S15
S16
S17
RES.WL.

Weak zone of siltstone or claystone beds at along contact with harder sandstone beds.

SCHEMATIC DEPICTING DIFFERENT JOINT CONDITIONS IN THE NEAR HORIZONTAL ALTERNATING BEDS OF SANDSTONE (COMPETENT ROCK) AND CLAYSTONE (INCOMPETENT ROCK) IN THE VICINITY OF A VALLEY WALL



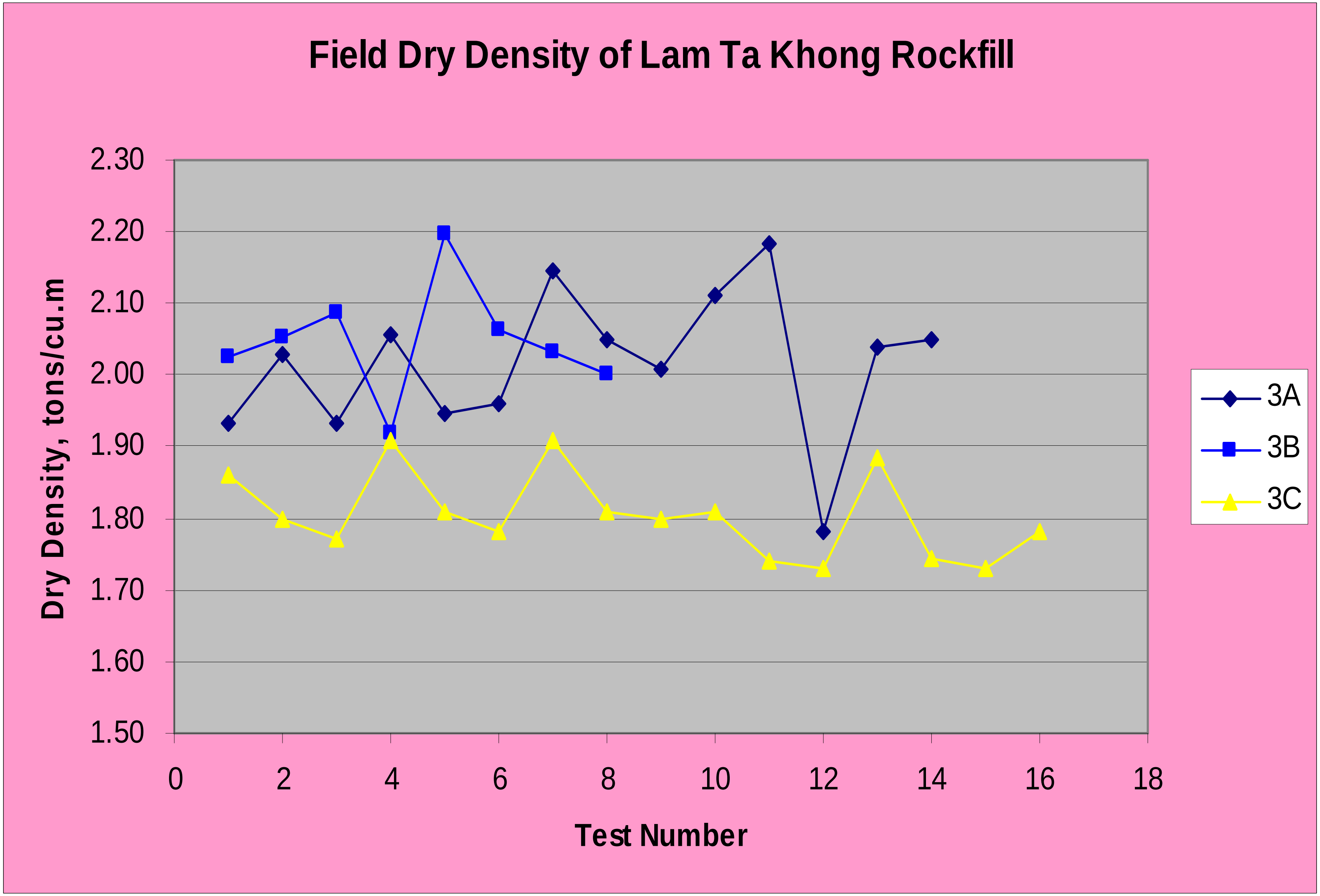




Potential sliding of rock fill embankment along claystone bed at base toward the cliff face.

West Side Embankment

Cause of the problem: Possibly time-dependent troubled properties of Zone 3C Materials



Field Dry Density of Lam Ta Khong Rockfill
Dry Density, tons/cu.m
2.30
2.20
2.10
2.00
1.90
1.80
1.70
1.60
1.50
0
2
4
6
8
10
12
14
16
18
Test Number
3A
3B
3C

Conclusions

- Unsatisfactory performance of the Asphalt Faced Rock Fill Embankment and Cut Slopes of Lam Ta Khong Pumped Storage Project was attributed to the adverse properties of weak sedimentary rocks (claystone and siltstone) at the project site which were underestimated during the design and construction.
- Ironically, the design and construction works were constantly reviewed and endorsed by world renounced authority in rock fill dam.
- Lessons learnt from the project was valuable to dam and rock engineering community but it was too unfortunate to the owner of the project who have not yet had confidence to continue with the commissioning of the remaining two power generating units.