PILED FOUNDATION DESIGN & CONSTRUCTION

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Contents

Contents (Cont'd)

- Piling Supervision
- Pile Damage
- Piling Problems
- Typical Design and Construction Issues
- Myths in Piling
- Case Histories
- Conclusions

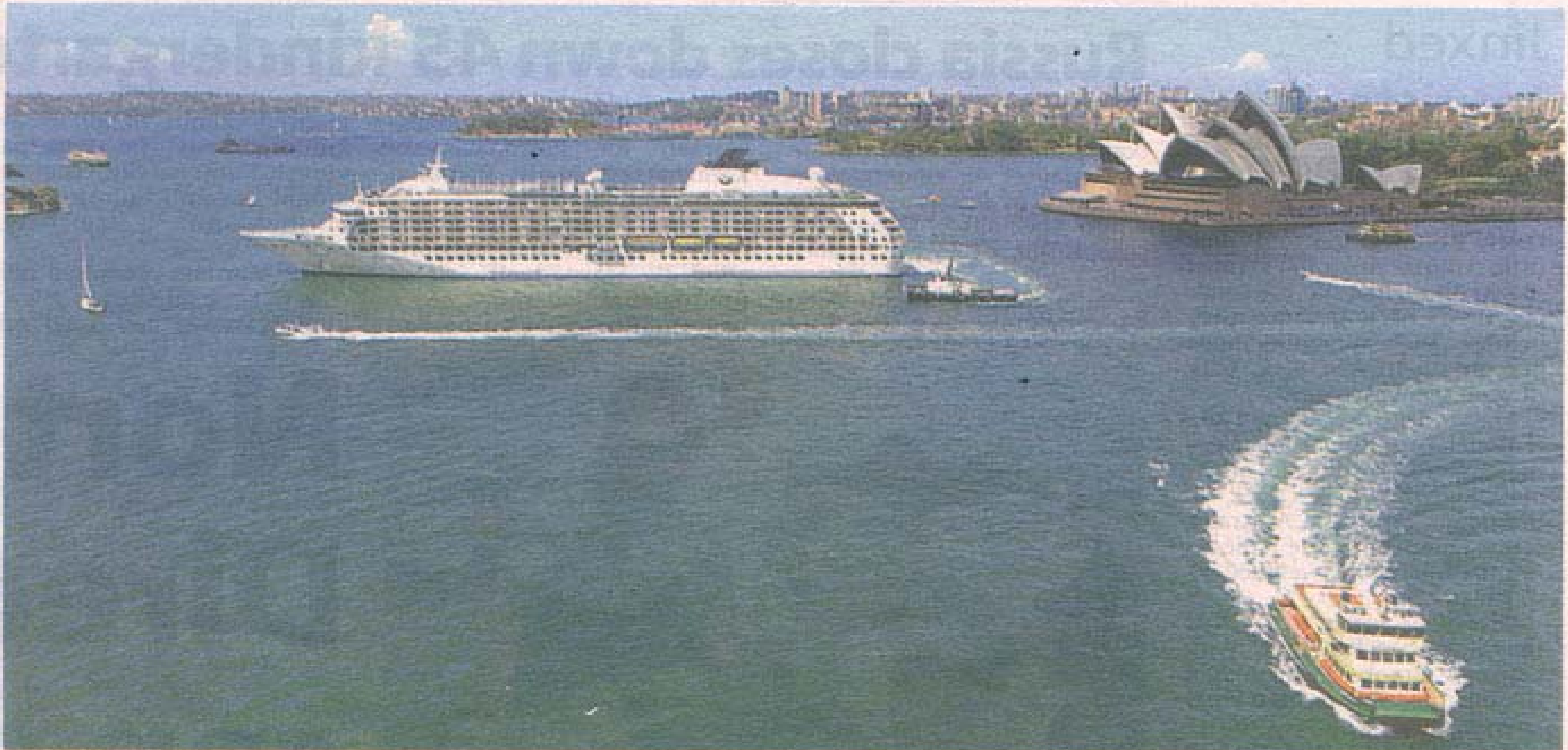
Overview

What is a Pile Foundation

It is a foundation system that transfers loads to a deeper and competent soil layer.

When To Use Pile Foundations

- Inadequate Bearing Capacity of Shallow Foundations
- To Prevent Uplift Forces
- To Reduce Excessive Settlement



PIROUETTE : The giant liner beginning a turn yesterday to give all apartment owners their share of the view of Sydney Opera House. The harbour came to a standstill as ferries and other passenger craft were forced to sit and wait for it to finish.
— *Reuterspic*

First floating condo turns for millionaires

SYDNEY: The world's first floating condominium, *The World*, brought Sydney Harbour to a standstill yesterday as it performed a graceful pirouette to ensure all its millionaire apartment owners had their fair share of the view.

The super-rich pay between A$2mil (RM4.7mil) and A$7mil (RM16.4mil) for an apartment aboard the white-hulled 44,500-tonne giant liner. Yet for the past two days half of them have been staring out at the bleak facade of the 1980s-built Overseas Passenger Terminal in Sydney Cove where it is moored.

The rest have been enjoying what is probably the finest view of the famous harbour and the Sydney Opera House.

But tugs and police boats turned the tables yesterday, gingerly shepherding the huge ship out into the harbour, turning it 180 degrees and edging it back to its moorings, in a 30-minute operation which was the first of its kind in Sydney.

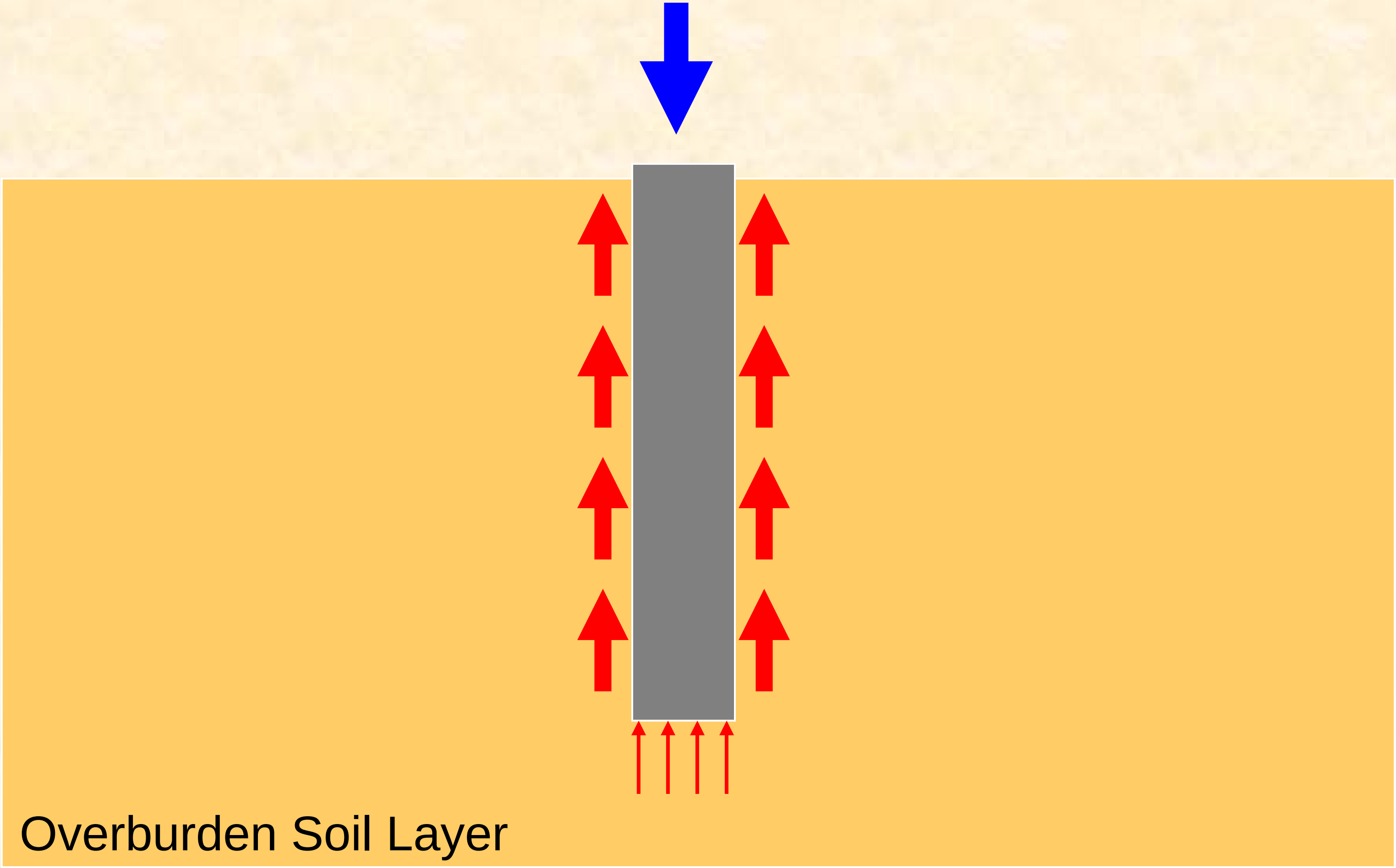
Extra charges for an apartment on *The World* range from A$100,000 (RM233,000) to A$340,000 (RM795,000) a year.
— Reuters

PILE CLASSIFICATION

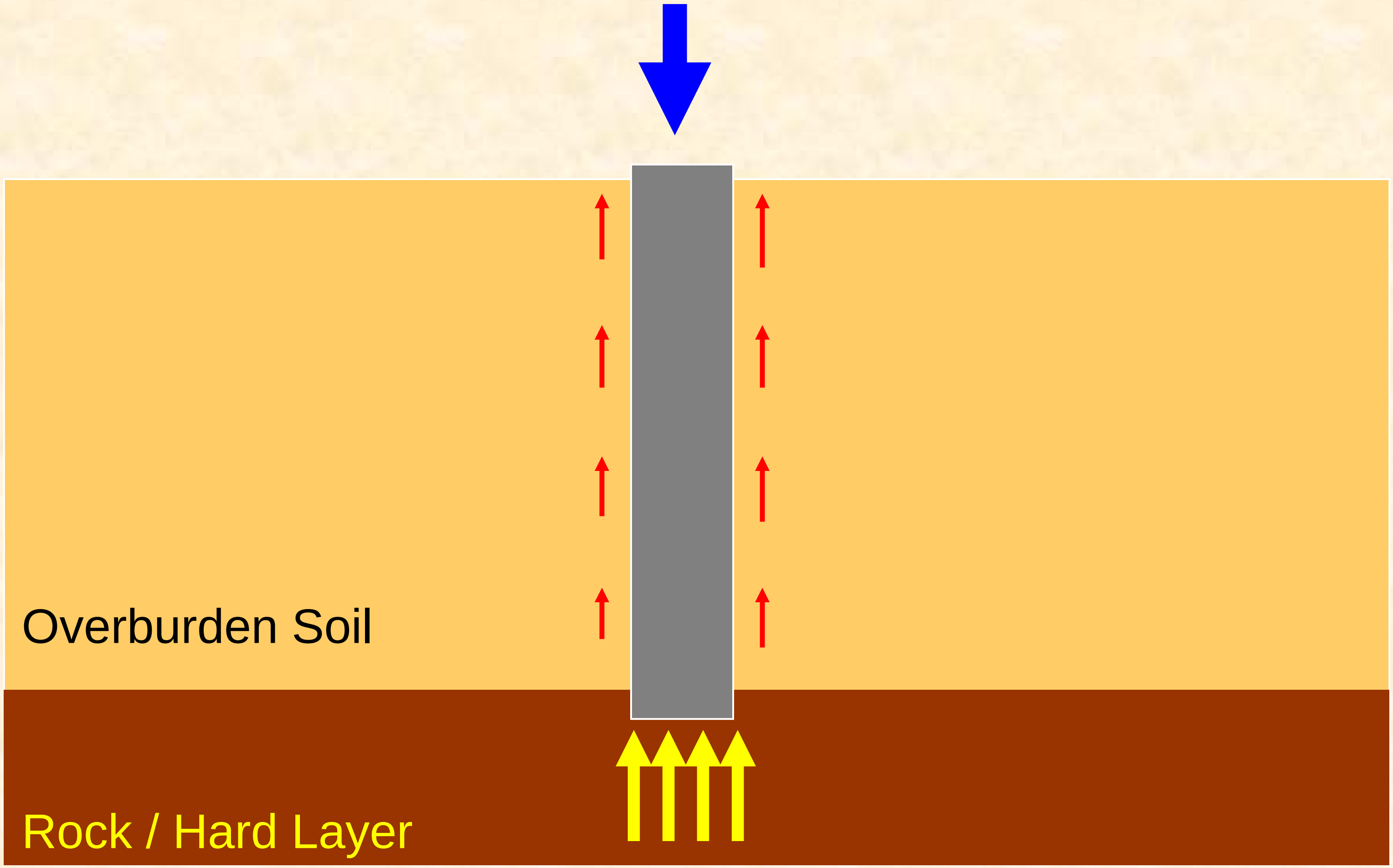
- **Friction Pile**
  - Load Bearing Resistance derived mainly from skin friction

- **End Bearing Pile**
  - Load Bearing Resistance derived mainly from base

Friction Pile



End Bearing Pile

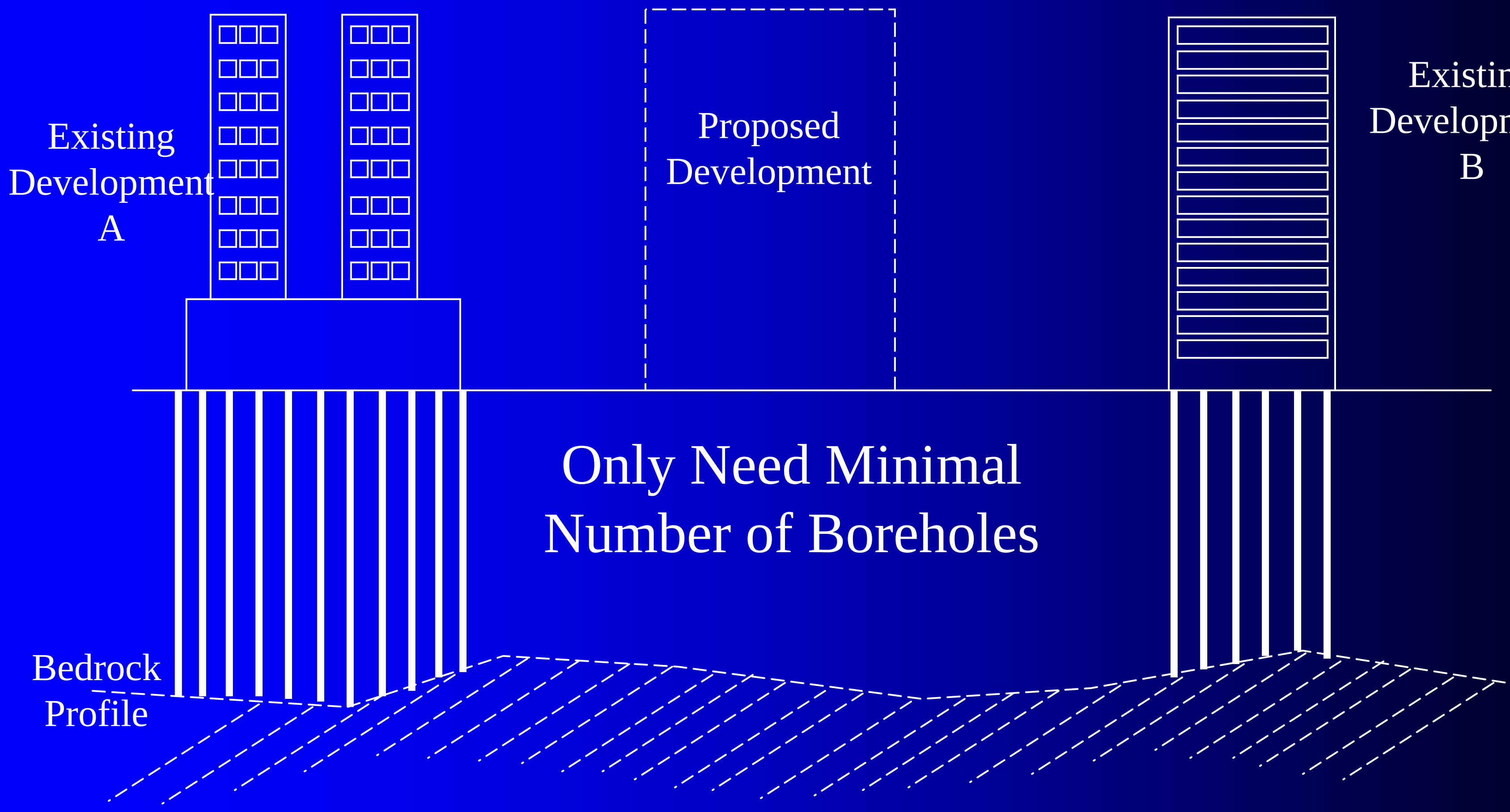


Preliminary Study

Preliminary Study

- Type & Requirements of Superstructure
- Proposed Platform Level (ie CUT or FILL)
- Geology of Area
- Previous Data or Case Histories
- Subsurface Investigation Planning
- Selection of Types & Size of Piles

Previous Data & Case Histories



Challenge The Norm Thru Innovation To Excel

SELECTION OF PILES

Factors Influencing Pile Selection

- Types of Piles Available in Market (see Fig. 1)
- Installation Method
- Contractual Requirements
- Ground Conditions (eg Limestone, etc)
- Site Conditions & Constraints (eg Accessibility)
- Type and Magnitude of Loading
- Development Program & Cost
- etc

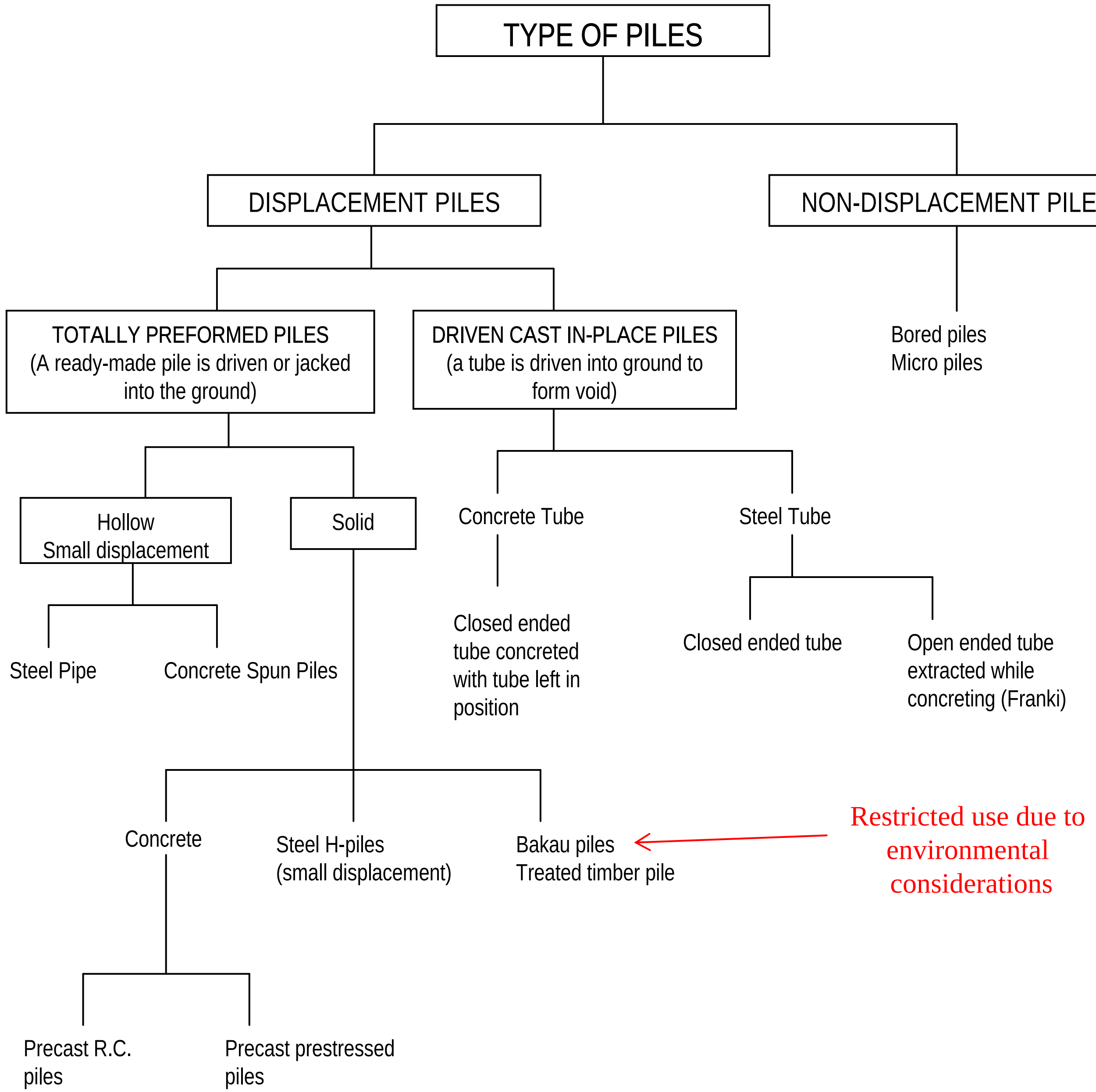


FIG 1: CLASSIFICATION OF PILES

DESIGN CONSIDERATIONS			TYPE OF PILE →	BAKAU PILES (PREFORMED PILES)	TIMPER PILES (PREFORMED PILES)	RC PILES (PREFORMED PILES)	PSC PILES (PREFORMED PILES)	SPUN PILES (PREFORMED PILES)	STEEL H PILES (PREFORMED PILES)	STEEL PIPE PILES (PREFORMED PILES)	JACKED PILES (PREFORMED PILES)	BORED PILES	MICROPILES	AUGERED PILES
SCALE OF LOAD (STRUCTURAL)		COMPRESSIVE LOAD PER COLUMN	<100 KN	✓	✓	✓	?	?	?	?	✓	x	?	✓
			100-300	✓	✓	✓	?	?	✓	✓	✓	x	✓	✓
			300-600	?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
			600-1100	x	?	✓	✓	✓	✓	✓	?	✓	✓	?
			1100-2000	x	?	✓	✓	✓	✓	✓	?	✓	✓	?
			2000-5000	x	x	✓	✓	✓	✓	✓	?	✓	✓	?
			5000-10000	x	x	✓	✓	✓	✓	✓	x	✓	✓	x
			>10000	x	x	?	✓	✓	✓	✓	x	✓	?	x
GEOTECHNICAL	BEARING TYPE	MAINLY END -BEARING (D=Anticipated depth of bearing)	<5m	?	?	?	?	?	?	?	x	✓	✓	?
			5-10m	✓	✓	✓	✓	✓	✓	✓	?	✓	✓	✓
			10-20m	?	?	✓	✓	✓	✓	✓	✓	✓	✓	✓
			20-30m	x	x	✓	✓	✓	✓	✓	✓	✓	✓	✓
			30-60m	x	x	✓	✓	✓	✓	✓	✓	✓	?	✓
		MAINLY FRICTION		✓	✓	✓	✓	✓	?	✓	✓	✓	?	✓
		PARTLY FRICTION + PARTLY END BEARING		✓	✓	✓	✓	✓	✓	✓	✓	✓	?	✓
	TYPE OF BEARING LAYER	LIMESTON FORMATION		?	?	?	?	?	✓	✓	✓	?	✓	✓
		WEATHERED ROCK / SOFT ROCK		x	x	✓	✓	✓	✓	✓	?	✓	✓	?
		ROCK (RQD > 70%)		x	x	?	?	?	✓	✓	?	✓	✓	?
		DENSE / VERY DENSE SAND		x	?	✓	✓	✓	✓	✓	✓	✓	✓	✓
	TYPE OF INTERMEDIATE LAYER	COHESIVE SOIL	SOFT SPT < 4	✓	✓	✓	✓	✓	✓	✓	✓	✓	?	✓
			M. STIFF SPT = 4 - 15	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
			V. STIFF SPT = 15 - 32	?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
			HARD SPT > 32	x	?	✓	✓	✓	✓	✓	✓	✓	✓	✓
		COHESIVELESS SOIL	LOOSE SPT < 10	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
			M. DENSE SPT = 10 - 30	?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
			DENSE SPT = 30 - 50	x	?	✓	✓	✓	✓	✓	✓	✓	✓	✓
			V. DENSE SPT > 50	x	x	✓	✓	✓	✓	✓	?	✓	✓	?
		SOIL WITH SOME BOULDERS / COBBLES (S=SIZE)	S < 100 mm	x	?	✓	✓	✓	✓	✓	✓	✓	✓	?
			100-1000mm	x	x	?	?	?	✓	✓	?	✓	✓	x
			1000-3000mm	x	x	?	?	?	?	?	?	?	✓	x
			>3000mm	x	x	?	?	?	?	?	?	?	✓	x
	GROUND WATER	ABOVE PILE CAP		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		BELOW PILE CAP		x	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ENVIRONMENT		NOISE + VIBRATION; COUNTER MEASURES REQUIRED		✓	✓	?	?	?	?	?	✓	✓	✓	✓
		PREVENTION OF EFFECTS ON ADJOINING STRUCTURES		?	?	?	?	?	?	?	✓	?	✓	✓
UNIT COST		(SUPPLY & INSTALL) RM/TON/M		0.5-2.5		0.3-2.0			1.0-3.5		1-2	0.5-2	1.5-3	1-2.5

LEGEND :	
▸	INDICATES THAT THE PILE TYPE IS SUITABLE
x	INDICATES THAT THE PILE TYPE IS NOT SUITABLE
?	INDICATES THAT THE USE OF PILE TYPE IS DOUBTFUL OR NOT COST EFFECTIVE UNLESS ADDITIONAL MEASURES TAKEN

FIG 2 : PILE SELECTION CHART

Site Visit and SI Planning

Site Visit

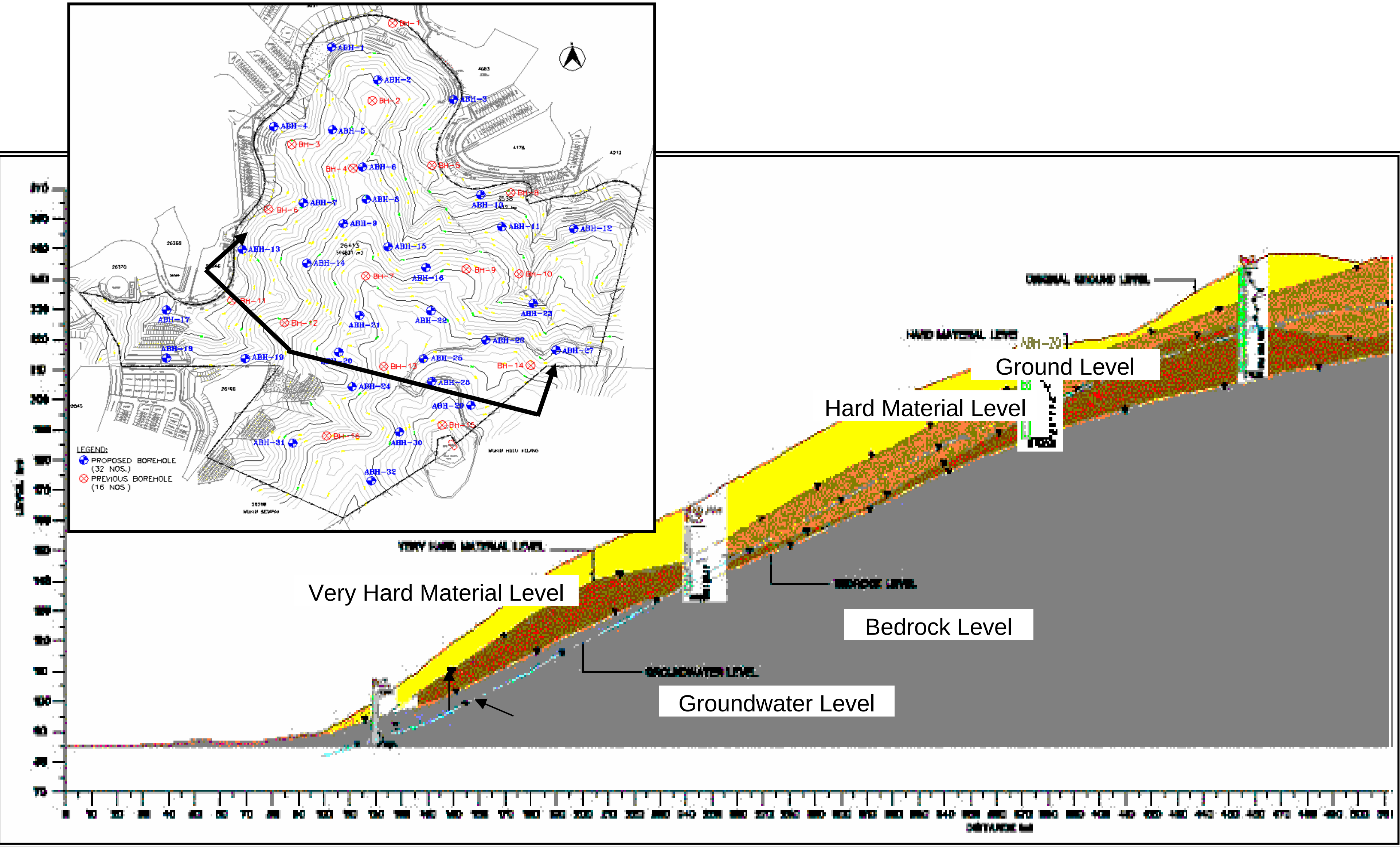
Things To Look For …

- Accessibility & Constraints of Site
- Adjacent Structures/Slopes, Rivers, Boulders, etc
- Adjacent Activities (eg excavation)
- Confirm Topography & Site Conditions
- Any Other Observations that may affect Design and Construction of Foundation

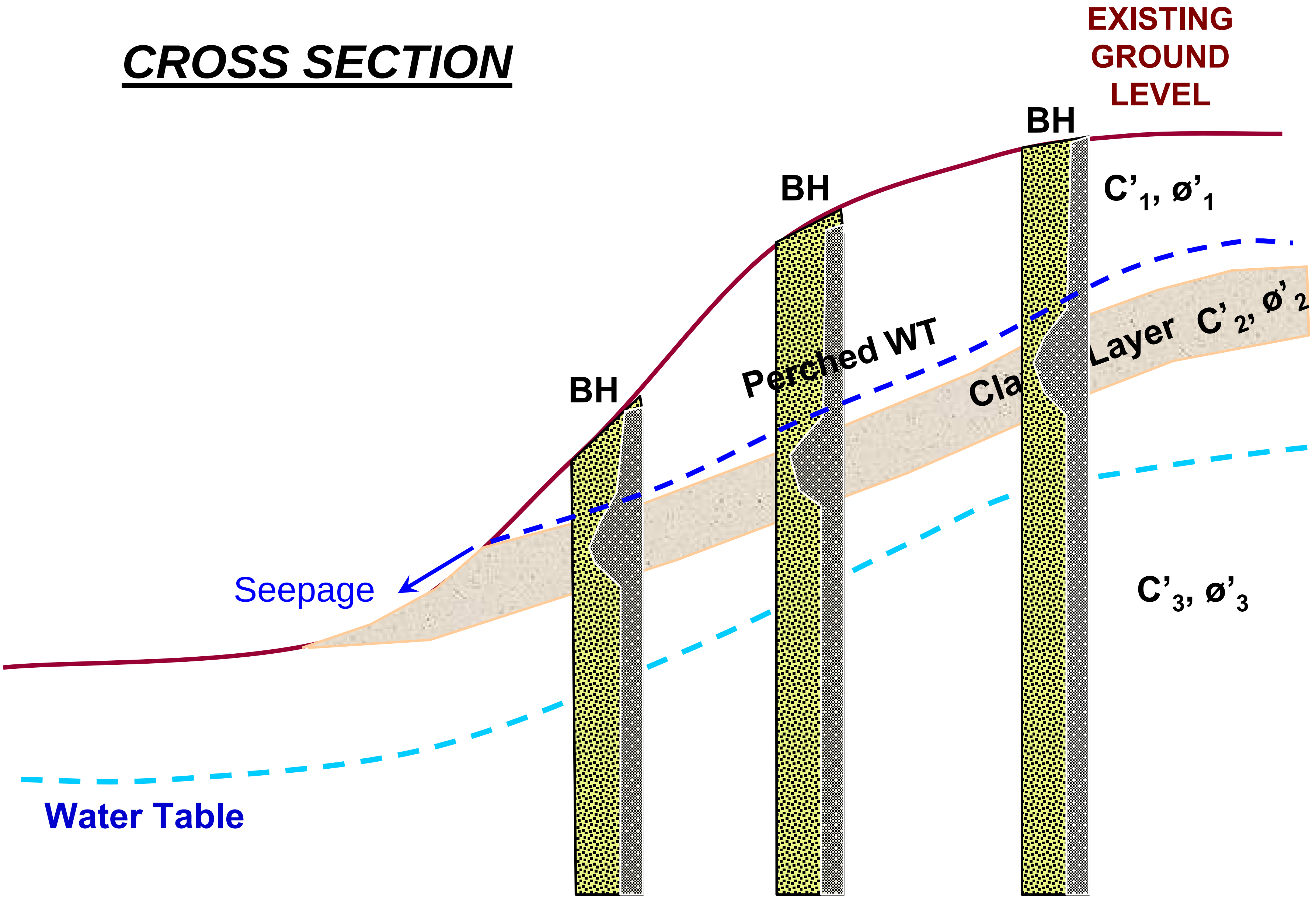
Subsurface Investigation (SI) Planning

- Provide Sufficient Boreholes to get Subsoil Profile
- Collect Rock Samples for Strength Tests (eg UCT)
- In-Situ Tests to get consistency of ground (eg SPT)
- Classification Tests to Determine Soil Type Profile
- Soil Strength Tests (eg CIU)
- Chemical Tests (eg Chlorine, Sulphate, etc)

Typical Cross-Section at Hill Site



CROSS SECTION



Placing Boreholes in Limestone Areas

- **Stage 1 : Preliminary S.I.**
  - Carry out geophysical survey (for large areas)

- **Stage 2: Detailed S.I.**
  - Boreholes at Critical Areas Interpreted from Stage 1

- **Stage 3: During Construction**
  - Rock Probing at Selected Columns to supplement Stage 2

Pile Design

PILE DESIGN

Allowable Pile Capacity is the minimum of :

1) Allowable Structural Capacity

2) Allowable Geotechnical Capacity
   a. Negative Skin Friction
   b. Settlement Control

PILE DESIGN

Structural consideration

- Not overstressed during handling, installation & in service for pile body, pile head, joint & shoe.
  - Dimension & alignment tolerances (common defects?)
  - Compute the allowable load in soft soil (<10kPa) over hard stratum (buckling load)
  - Durability assessment

Pile Capacity Design
Structural Capacity

- Concrete Pile

$$Q_{all} = 0.25 \times f_{cu} \times A_c$$

- Steel Pile

$$Q_{all} = 0.3 \times f_y \times A_s$$

- Prestressed Concrete Pile

$$Q_{all} = 0.25\,(f_{cu} - \text{Prestress after loss}) \times A_c$$

Q_{all} = Allowable pile capacity

f_{cu} = characteristic strength of concrete

f_s = yield strength of steel

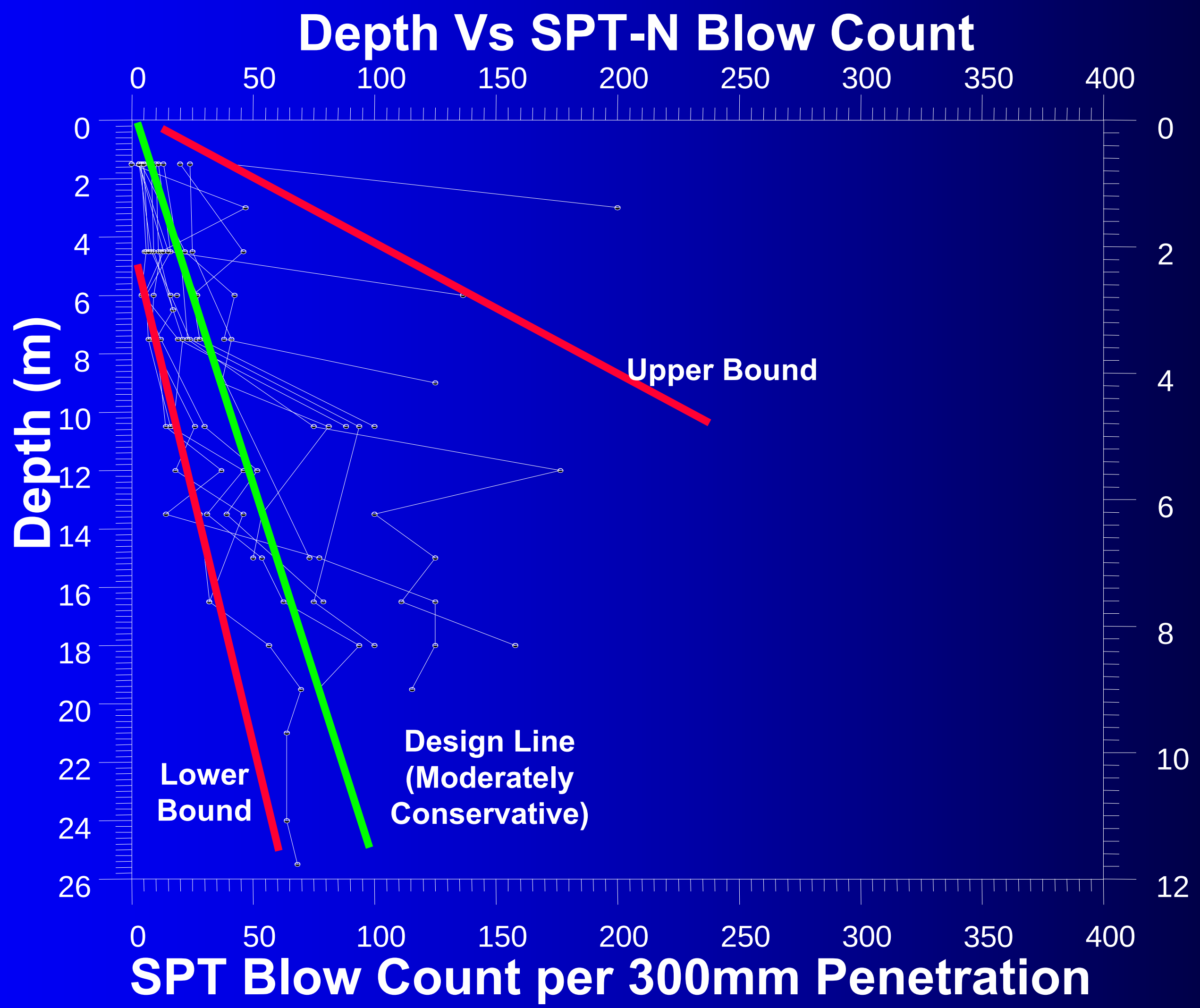
A_c = cross sectional area of concrete

A_s = cross sectional area of steel

Pile Capacity Design

Geotechnical Capacity

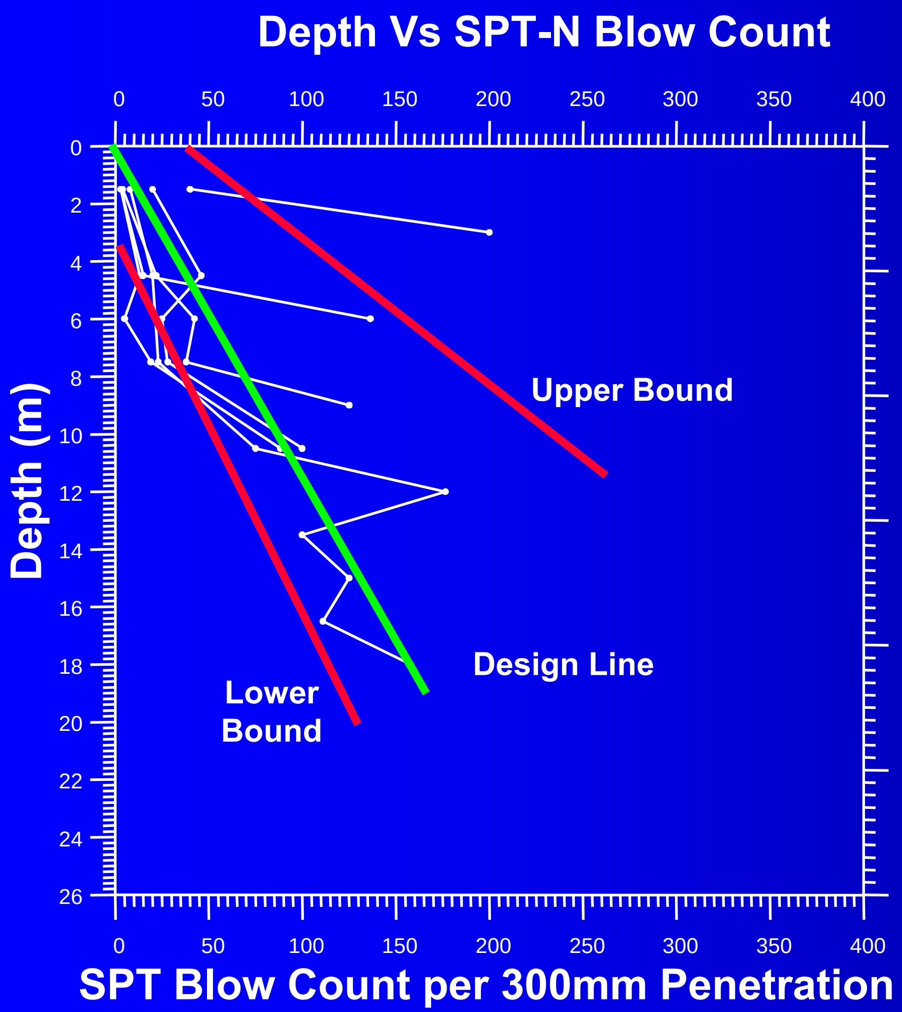
Collection of SI Data

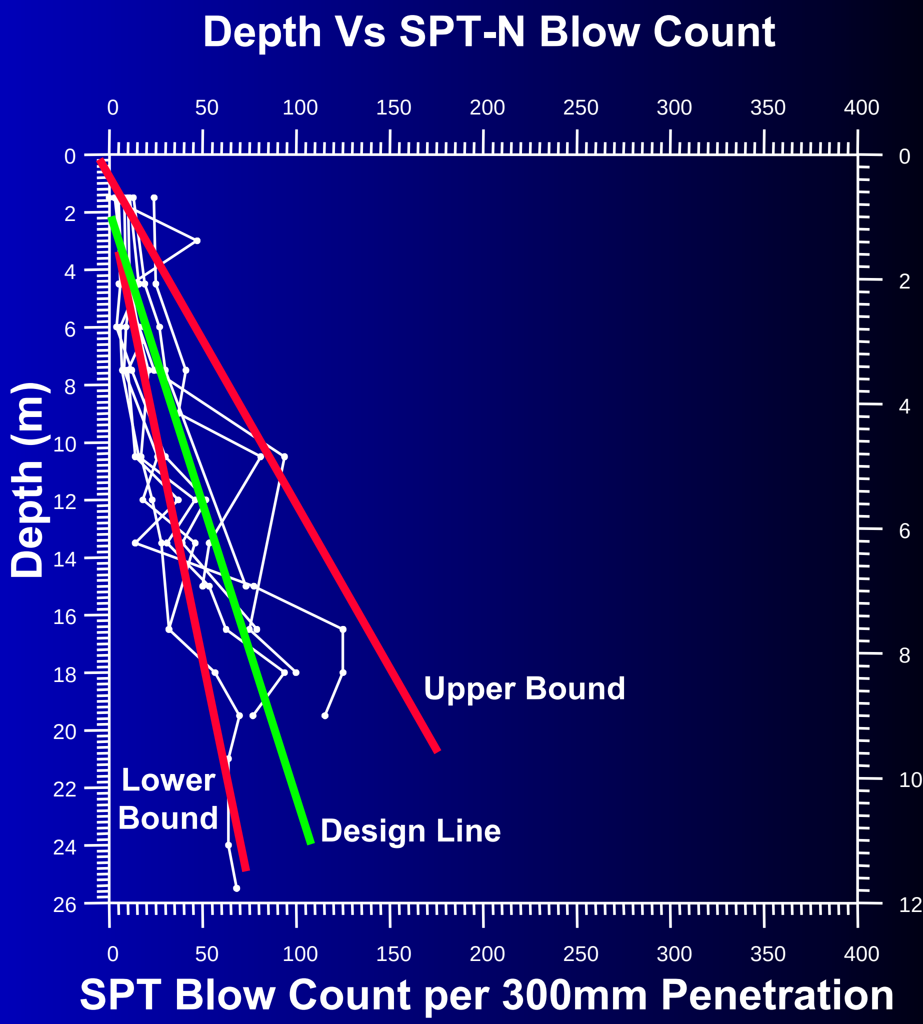


Pile Capacity Design

Geotechnical Capacity

Collection of SI Data





Moderately Conservative Design Parameters

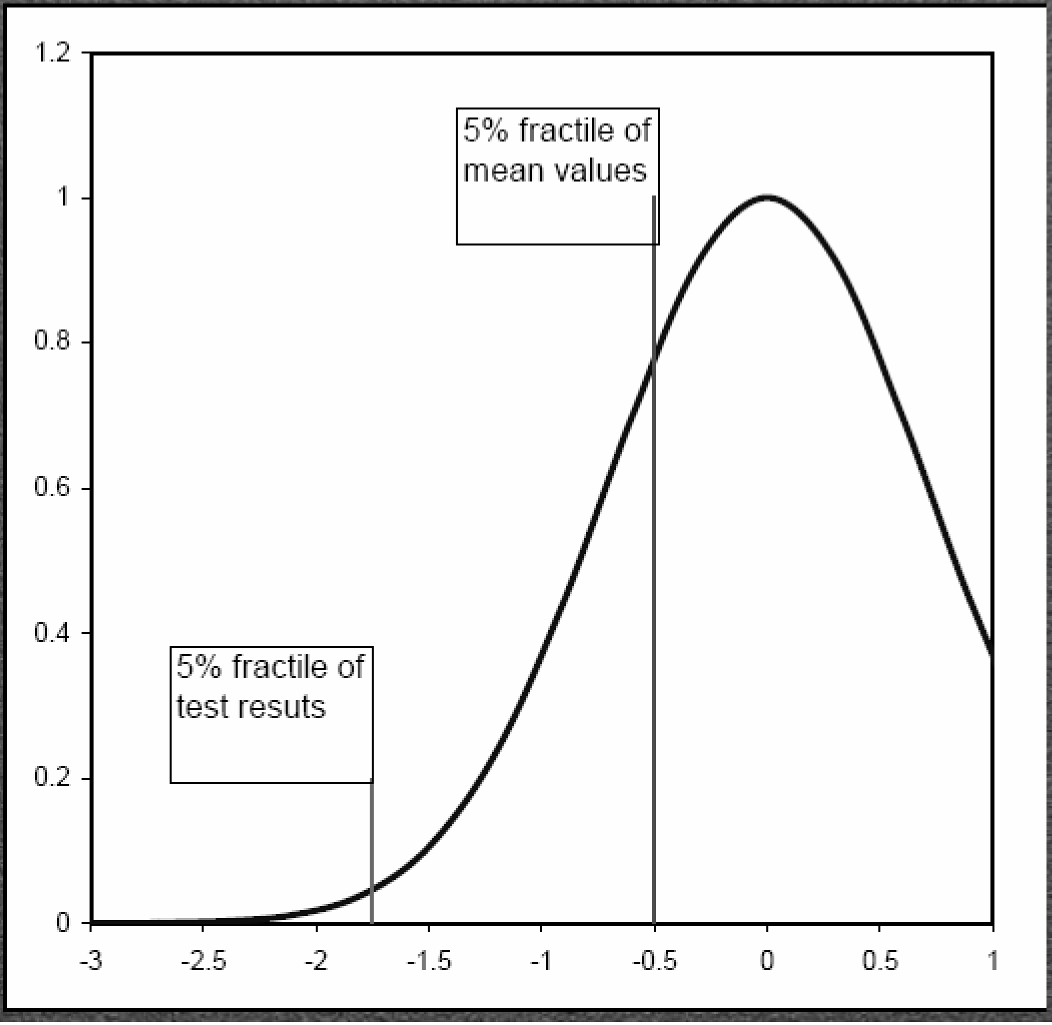
- **Eurocode 7 definition:**
  - Characteristic value of a geotechnical parameter shall be selected as a cautious estimate of the value affecting the occurrence of the limit state
  - In other words, moderately conservative

Moderately Conservative Design Parameters

- If at least 10 test results are available:
  - A value of **0.5D below the mean** of the test results provides a useful indication of the characteristic value

1. Contribution to Discussion Session 2.3, XIV ICSMFE, Hamburg, Balkema, Schneider H R (1997) – Definition and determination of characteristic soil properties. Discussion to ISSMFE Conference, Hamburg.
2. Extracted from Prof. Brian Simpson's Course Note (2-day Course on Eurocode 7 Geotechnical Design to EC7, 13-14 November 2007, PJ, Malaysia).

0.5 SD below the mean?



Extracted from Prof. Brian Simpson's Course Note (2-day Course on Eurocode 7 Geotechnical Design to EC7, 13-14 November 2007, PJ, Malaysia).

Pile Capacity Design
Geotechnical Capacity

- **Piles installed in a group may fail:**
  - Individually
  - As a block

Pile Capacity Design
Geotechnical Capacity

- **Piles fail individually**
  - When installed at large spacing

Pile Capacity Design
Geotechnical Capacity

- **Piles fail as a block**
  - When installed at close spacing

Pile Capacity Design

Single Pile Capacity

Pile Capacity Design
Factor of Safety (FOS)

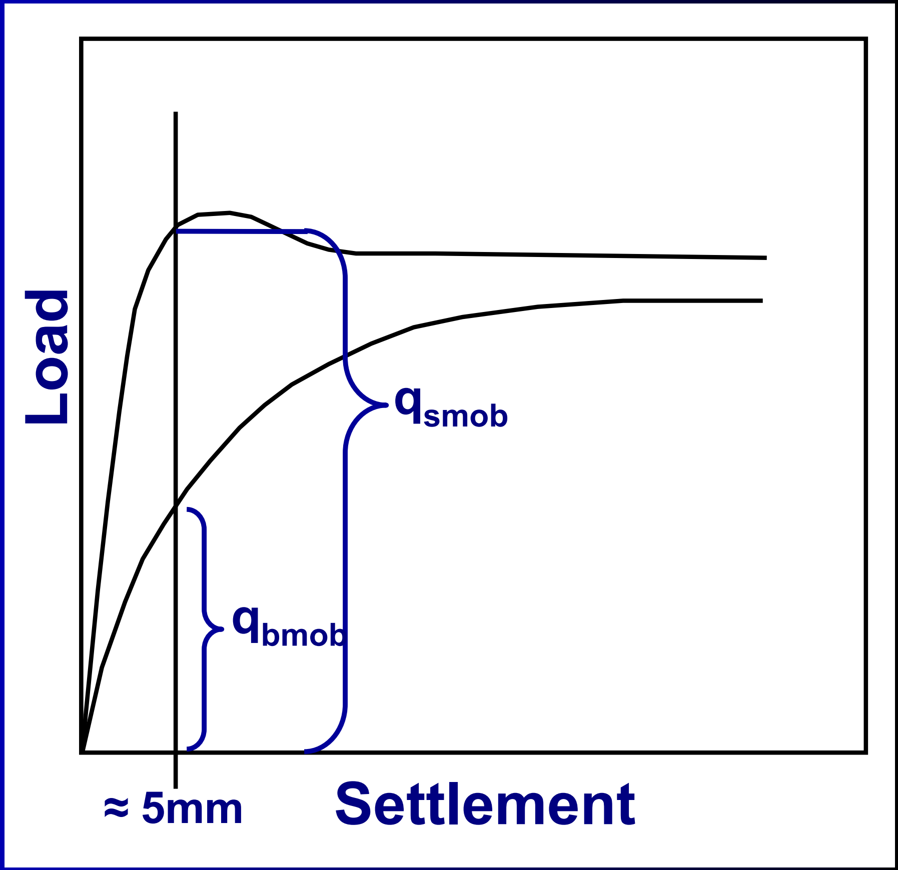
Factor of Safety (FOS) is required for

- Natural variations in soil strength & compressibility

Pile Capacity Design
Factor of Safety (FOS)

Factor of Safety is (FOS) required for

- Different degree of mobilisation for shaft & for tip



Pile Capacity Design
Factor of Safety (FOS)

Partial factors of safety for shaft & base capacities respectively

- For shaft, use 1.5 (typical)
- For base, use 3.0 (typical)
- $$Q_{all} = \frac{\Sigma Q_{su}}{1.5} + \frac{Q_{bu}}{3.0}$$

Pile Capacity Design
Factor of Safety (FOS)

Global factor of safety for total ultimate capacity

- **Use 2.0 (typical)**
- $$Q_{all} = \frac{\Sigma Q_{su} + Q_{bu}}{2.0}$$

Pile Capacity Design

Factor of Safety (FOS)

- **Calculate using BOTH approaches (Partial & Global)**
- **Choose the lower of the Q_{all} values**

Pile Capacity Design

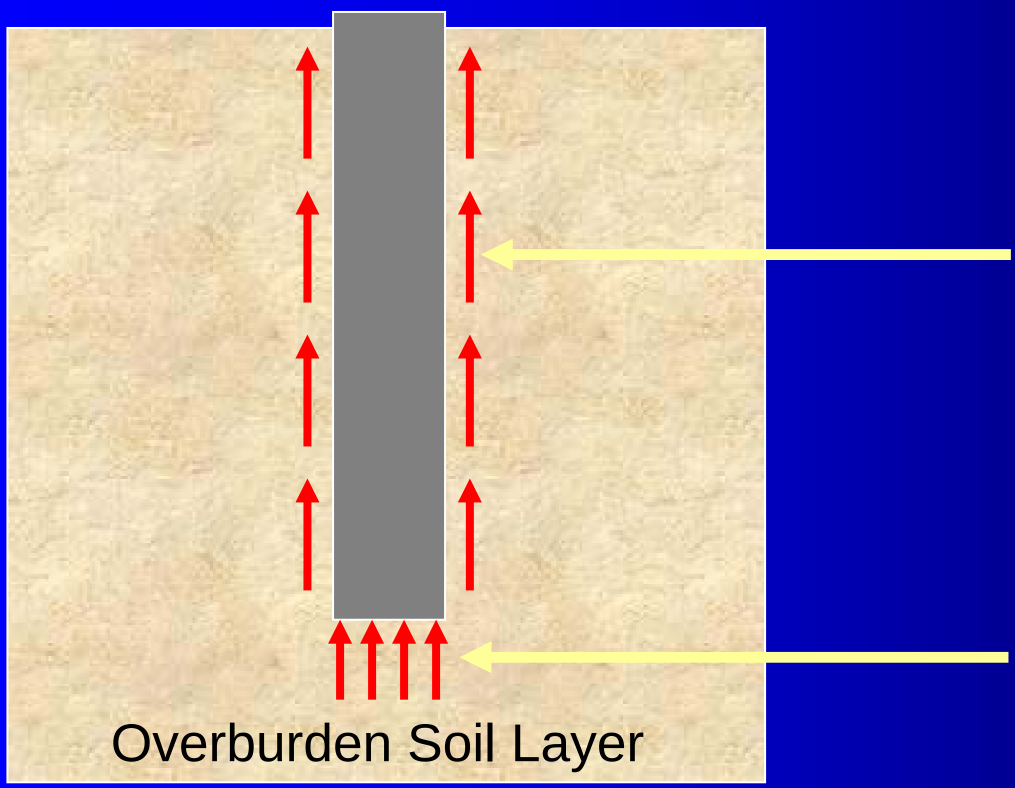
Single Pile Capacity

$$Q_u = Q_s + Q_b$$

Q_u = ultimate bearing capacity

Q_s = skin friction

Q_b = end bearing



Pile Capacity Design

Single Pile Capacity : In Cohesive Soil

Q_{su} Q_{bu}

$$Q_u = \alpha . s_{us} . A_s + s_{ub} . N_c . A_b$$

Q_u = Ultimate bearing capacity of the pile

a = adhesion factor (see next slide)

s_{us} = average undrained shear strength for shaft

A_s = surface area of shaft

s_{ub} = undrained shear strength at pile base

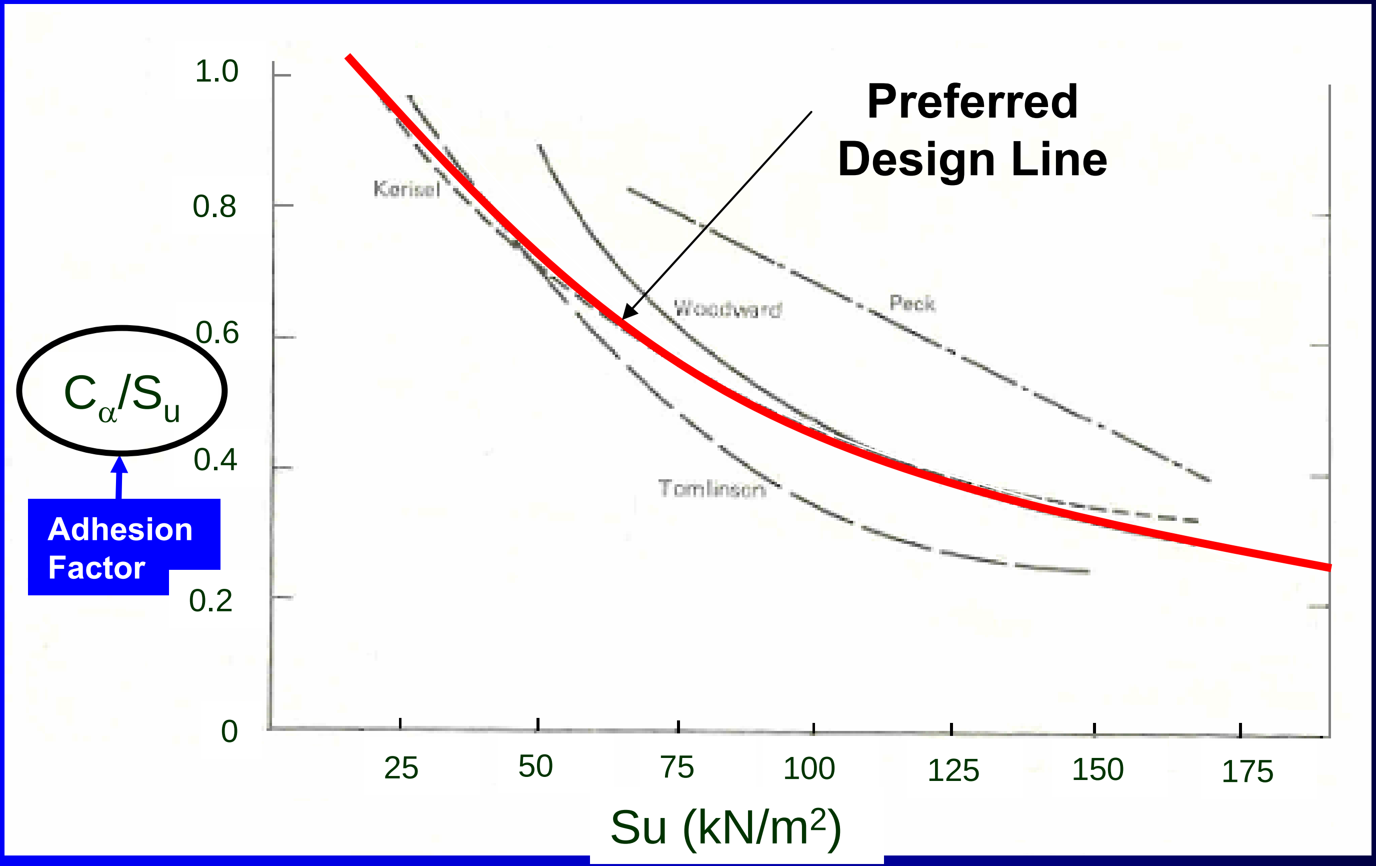
N_c = bearing capacity factor (taken as 9.0)

A_b = cross sectional area of pile base

Pile Capacity Design

Single Pile Capacity: In Cohesive Soil

Adhesion factor (α) – Shear strength (S_u) (McClelland, 1974)

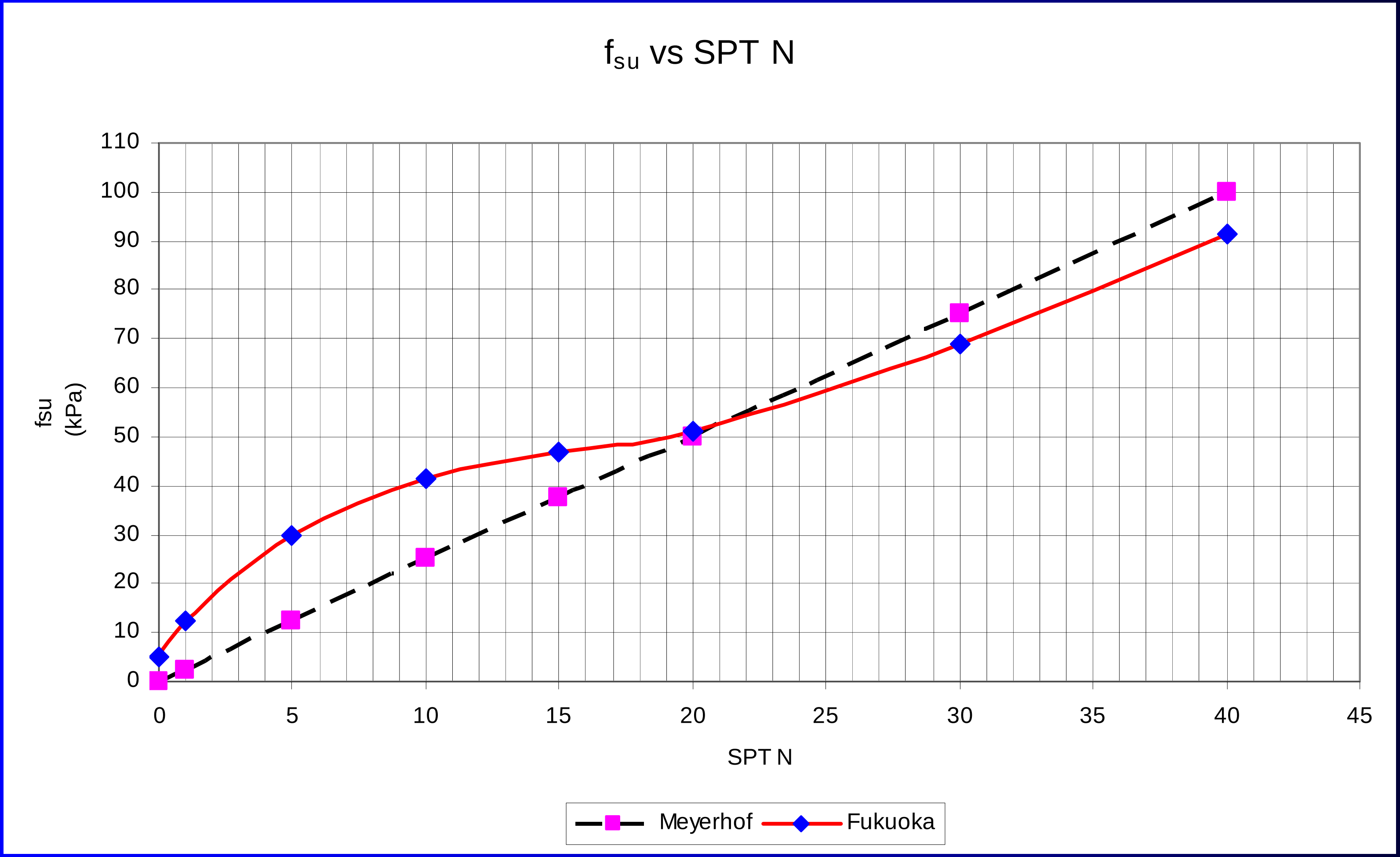


	Meyerhof	Fukuoka		
SPT N	f_{su}=2.5N (kPa)	s_u = (0.1+0.15N)*50 (kPa)	α	$f_{su}=\alpha.s_u$ (kPa)
0	0	5	1	5
1	2.5	12.5	1	12.5
5	12.5	42.5	0.7	29.75
10	25	80	0.52	41.6
15	37.5	117.5	0.4	47
20	50	155	0.33	51.15
30	75	230	0.3	69
40	100	305	0.3	91.5

Pile Capacity Design

Single Pile Capacity: In Cohesive Soil

Correlation Between SPT N and f_{su}



Pile Capacity Design

Single Pile Capacity: In Cohesive Soil

- Values of undrained shear strength, s_u can be obtained from the following:
  - ✓ Unconfined compressive test
  - ✓ Field vane shear test
  - ✓ Deduce based on Fukuoka's Plot (minimum s_u)
  - ✗ Deduce from SPT-N values based on Meyerhof

NOTE: Use only direct field data for shaft friction prediction instead of Meyerhof

Pile Capacity Design

Single Pile Capacity: In Cohesive Soil

Modified Meyerhof (1976):

- Ult. Shaft friction = $Q_{su} \cong 2.5N$ (kPa)
- Ult. Toe capacity = $Q_{bu} \cong 250N$ (kPa)

  or $9\ s_u$ (kPa)

(Beware of base cleaning for bored piles – ignore base capacity if doubtful)

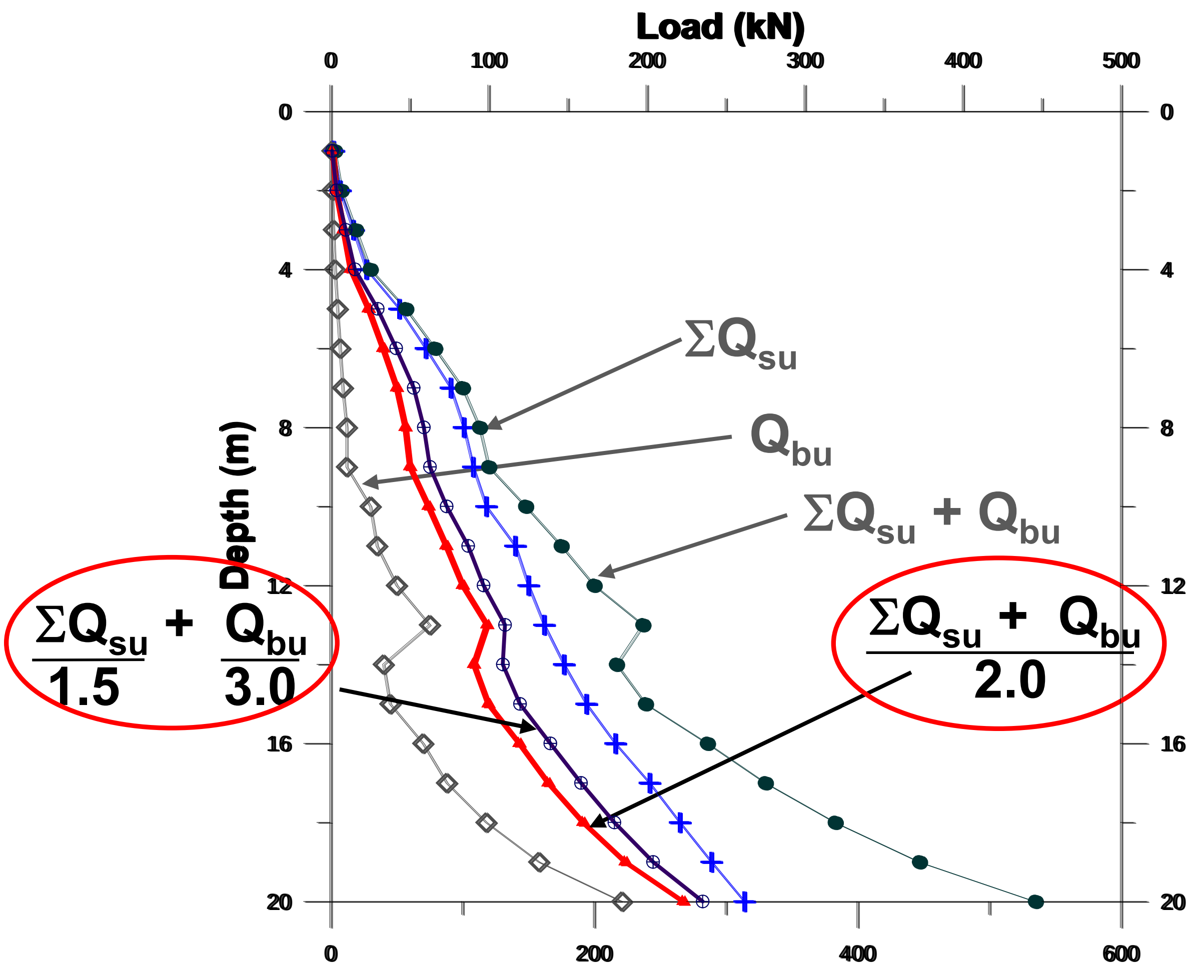
Pile Capacity Design

Single Pile Capacity: In Cohesionless Soil

Modified Meyerhof (1976):

- Ult. Shaft Friction = $Q_{su} \simeq 2.0N$ (kPa)
- Ult. Toe Capacity= $Q_{bu} \simeq 250N - 400N$ (kPa)

Pile Capacity Design



Pile Capacity Design

Single Pile Capacity: For Bored Piles

Semi-empirical Method (SPT-N)

Shaft : $f_{su} = K_{su} \times \text{SPT-N}$

Tip : $f_{bu} = K_{bu} \times \text{SPT-N}$

From Malaysian experience:

$K_{su} = 2.0$

K_{bu} = 7.0 to 60 (depending on workmanship)

Pile Capacity Design

Single Pile Capacity: For Bored Piles

- Base cleaning of bored piles
  - **Difficult and no practical means of verification during construction avaliable**

- Base resistance require **large movement** to mobilise

- **Base contribution in bored pile design <u>ignored</u> unless proper base cleaning can be assured and verified (or base grouting, etc.)**

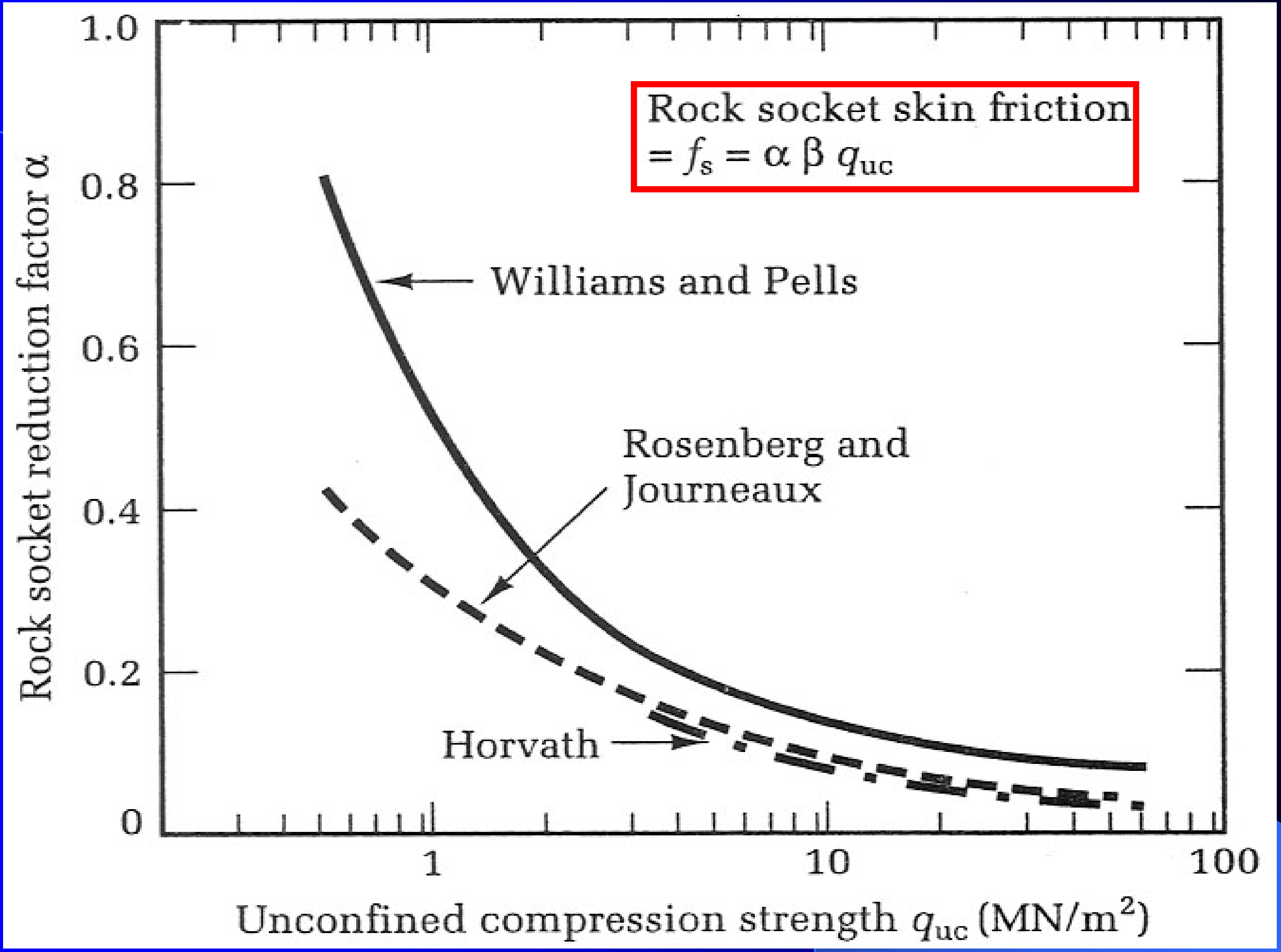
Rock Socket Design

Rock Socket Design Factors :

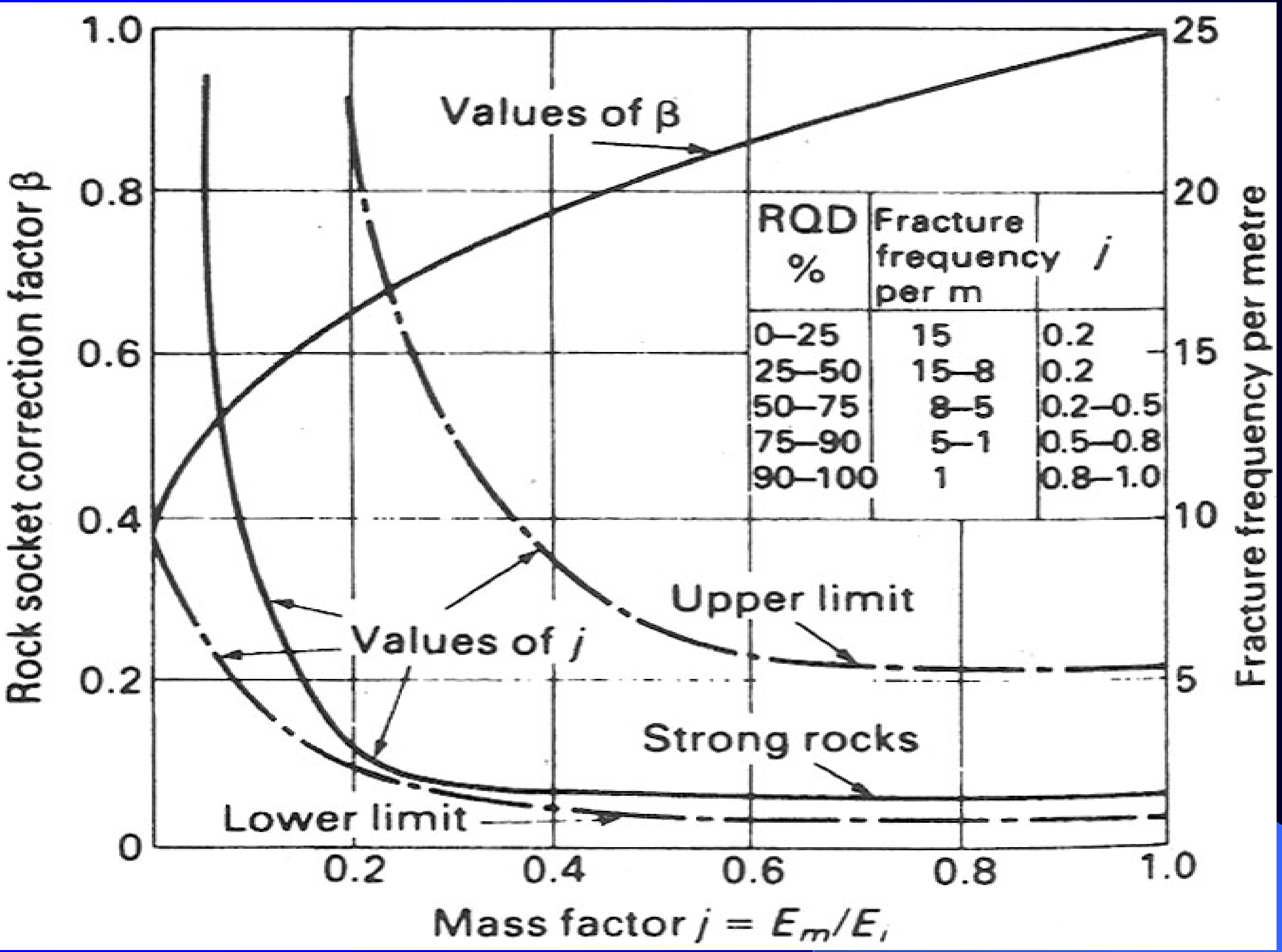
- Socket Roughness (*Shearing Dilation*)
- Intact Rock UCS, q_{uc}
- Confining Stiffness (*Rock mass fractures & Pile Diameter*)
- Socket Geometry Ratio

Socket Resistance, $f_s = \alpha \times \beta \times q_{uc}$

α - Factor *(after Tomlinson, 1995)*



β - Factor *(after Tomlinson, 1995)*

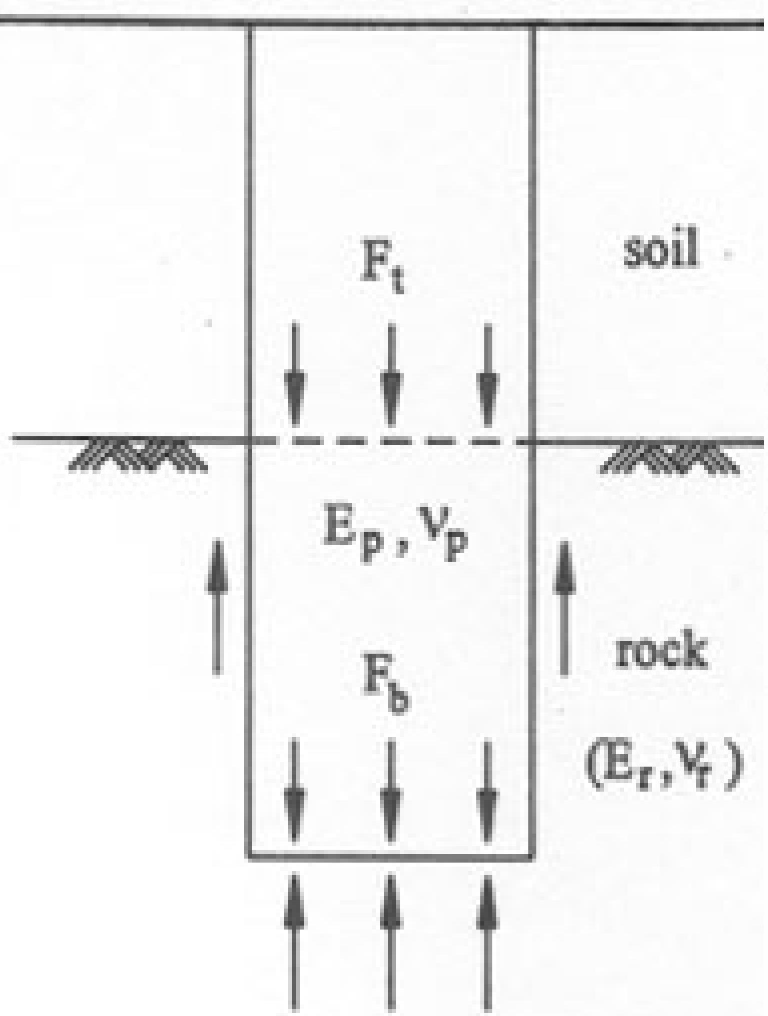


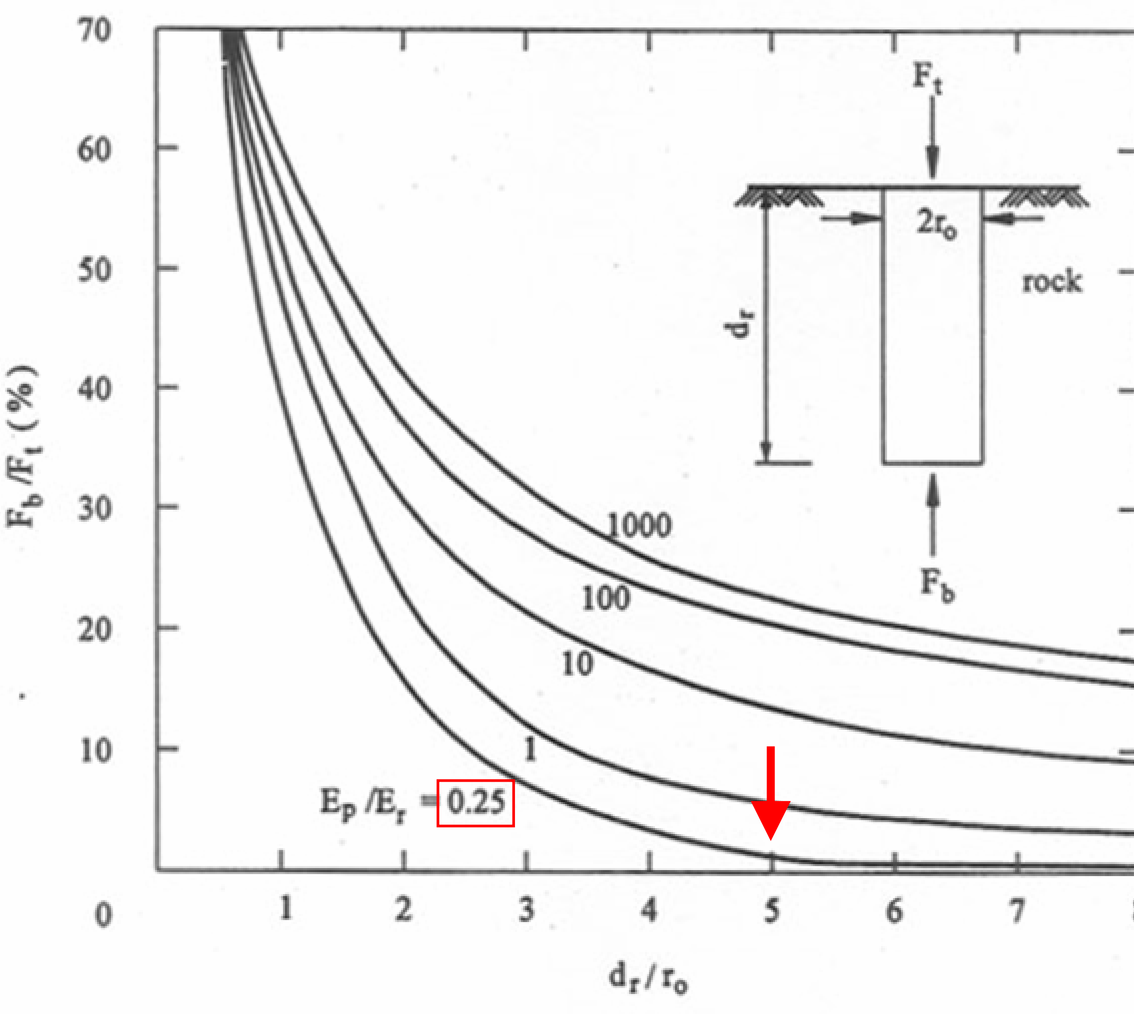
Point Load Test

(UCS of Intact Rock)

Load Transfer Profile of Rock Socket

(after Pells & Tuner, 1979)





Summary of Rock Socket Friction Design Values (updated from Tan & Chow, 2003)

Rock Formation	Working Rock Socket Friction*	Source
Limestone	300kPa for RQD < 30% 400kPa for RQD = 30 % 500kPa for RQD =40 % 600kPa for RQD =55 % 700kPa for RQD =70 % 800kPa for RQD > 85% The above design values are subject to 0.05x minimum of {q_{uc}, f_{cu}} whichever is smaller.	Authors
Sandstone	$0.10 \times q_{uc}$	Thorne (1977)
Shale	$0.05 \times q_{uc}$	Thorne (1977)
Granite	1000 – 1500kPa for q_{uc} > 30N/mm^2	Tan & Chow (2003)

Where:

RQD = Rock Quality Designation

quc = Unconfined Compressive Strength of rock

fcu = Concrete grade

End Bearing Design in Rock

Only designed when

- Dry Hole
- Base Cleaning & Inspection are possible

Pile Capacity Design
Block Capacity

Pile Capacity Design
Block Capacity:In Cohesive Soil

$$Q_u = 2D(B+L)\ s + 1.3(s_b.N_c.B.L)$$

Where

Q_u= ultimate bearing capacity of pile group

D = depth of pile below pile cap level

B = width of pile group

L = length of pile group

$\underline{s}$ = average cohesion of clay around group

s_b = cohesion of clay beneath group

N_c= bearing capacity factor = 9.0

(Refer to Text by Tomlinson, 1995)

Pile Capacity Design

Block Capacity: In Cohesionless Soil

No risk of group failure

if FOS of individual pile is adequate

Pile Capacity Design
Block Capacity: On Rock

No risk of block failure

if the piles are properly seated in the rock formation

Pile Capacity Design

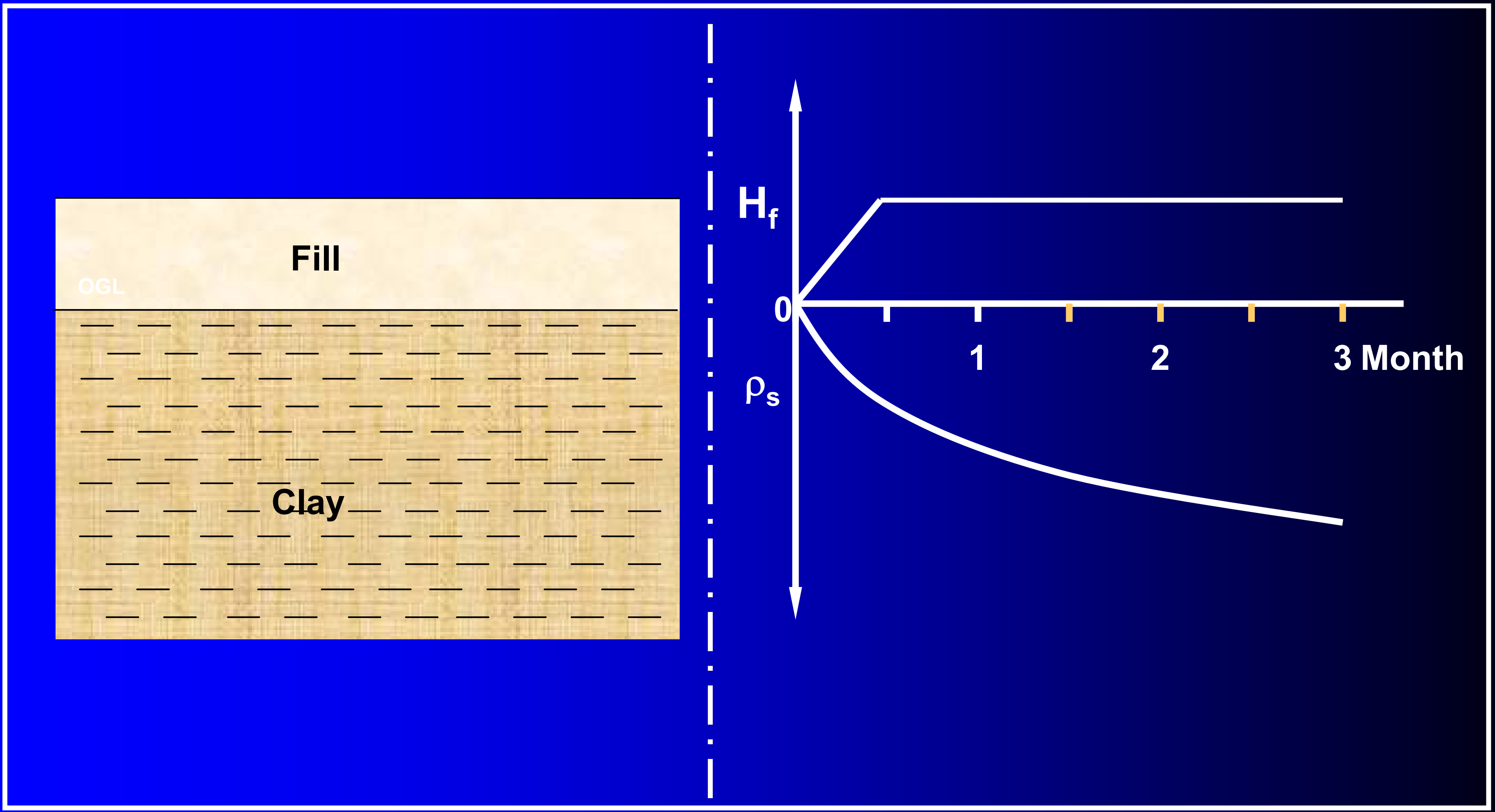
Negative Skin Friction (NSF)

Pile Capacity Design
Negative Skin Friction

- Compressible soil layer consolidates with time due to:
  - Surcharge of fill
  - Lowering of groundwater table

Pile Capacity Design

Negative Skin Friction



Pile Capacity Design
Negative Skin Friction

Pile to length (floating pile)

- Pile settles with consolidating soil → **NO NSF**

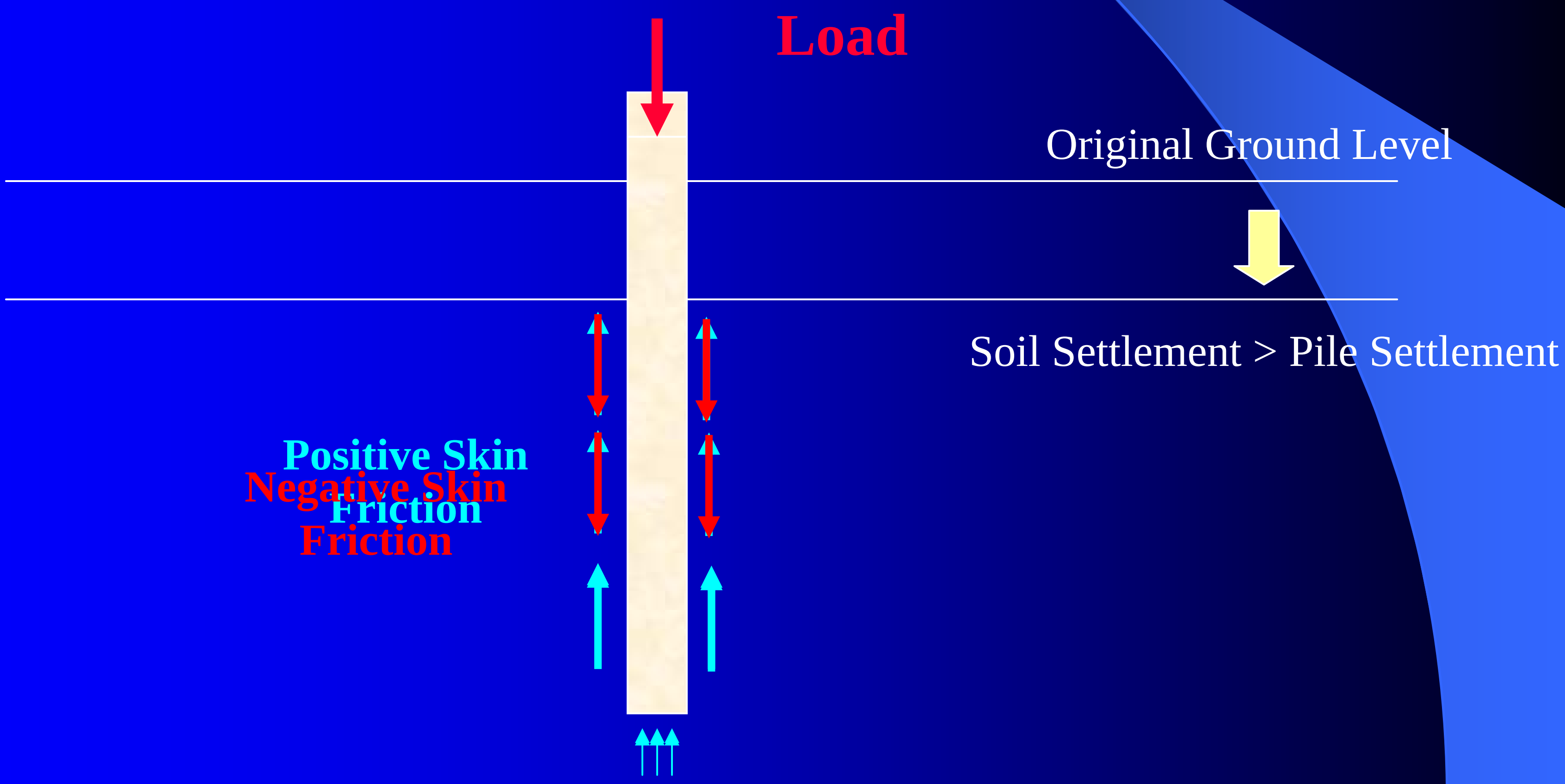
Pile Capacity Design
Negative Skin Friction

Pile to set at hard stratum (end-bearing pile)

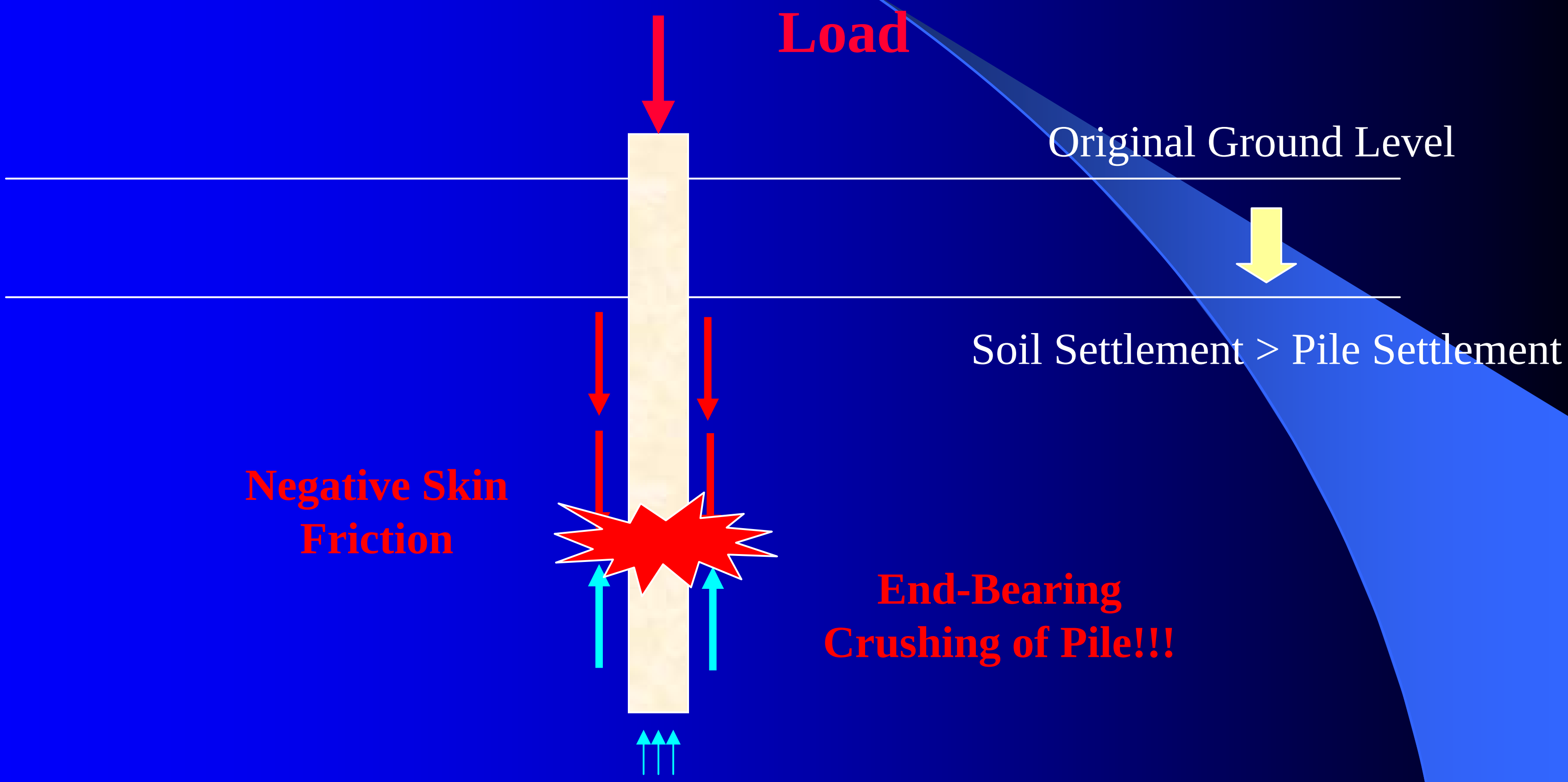
- Consolidation causes **downdrag** forces on piles as soil settles more than the pile

Design Considerations

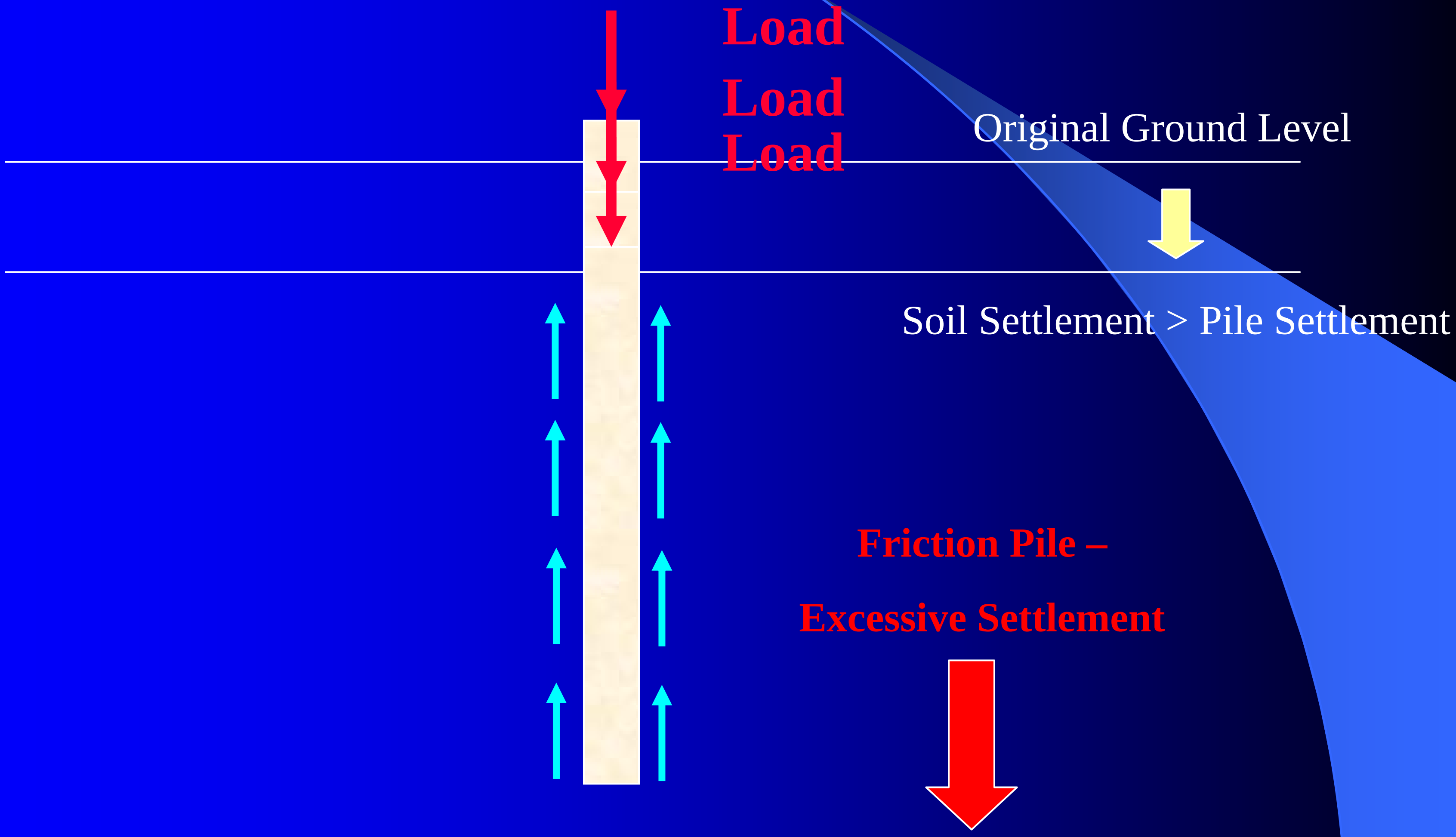
- Skin Friction



Negative Skin Friction



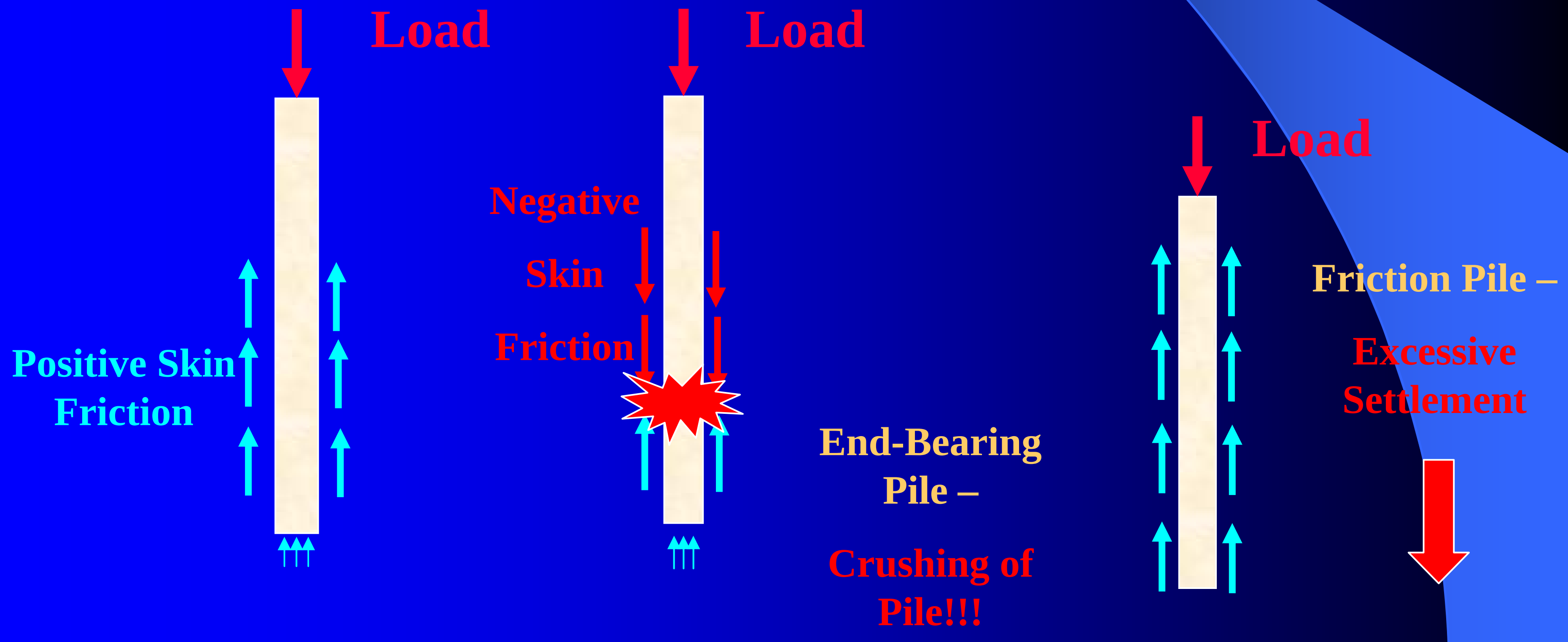
Negative Skin Friction



Negative Skin Friction

Pile Settlement > Soil Settlement

Soil Settlement > Pile Settlement

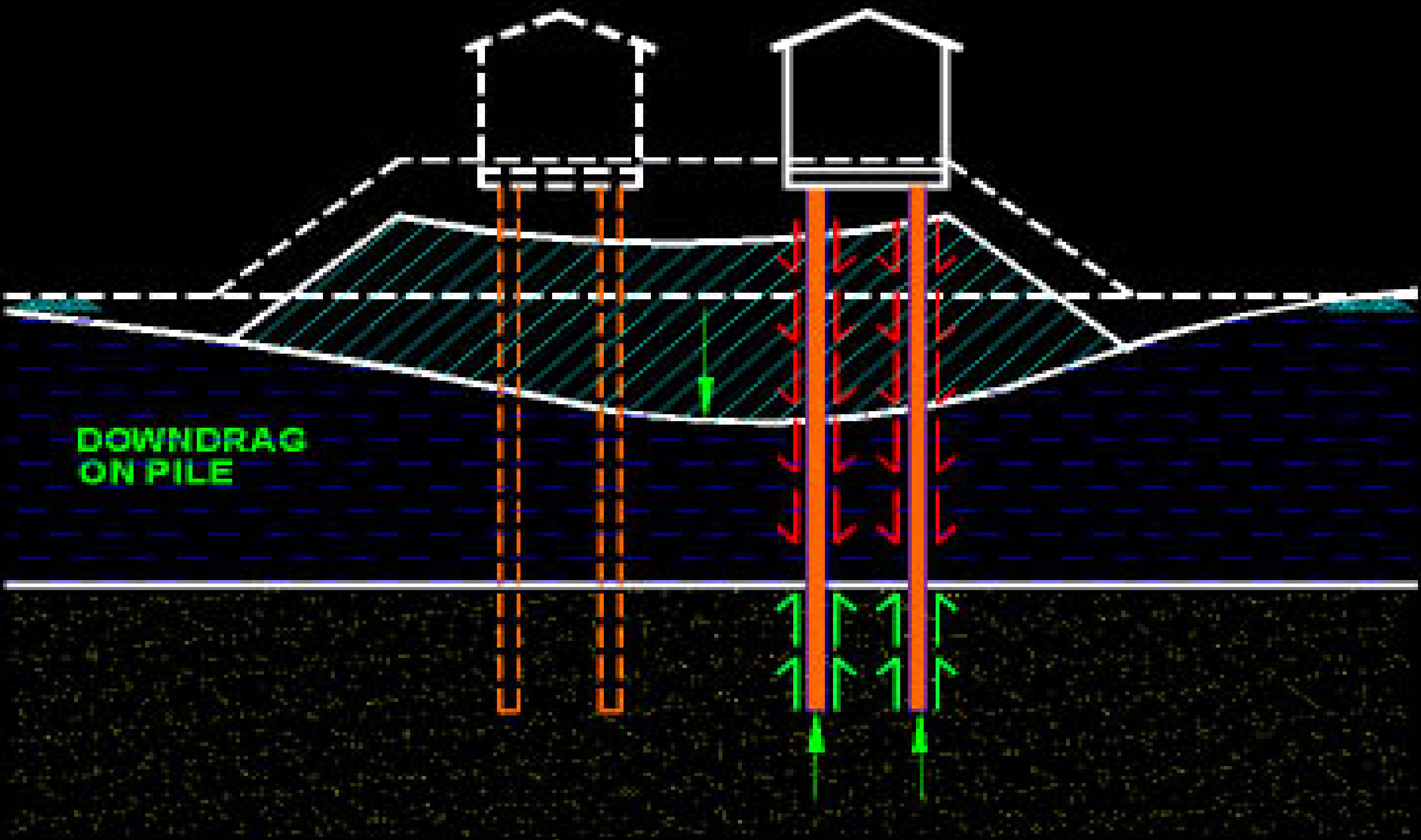


Pile Capacity Design
Negative Skin Friction

WARNING:

- No free fill by the contractor to avoid NSF

Effect of NSF …



Reduction of Pile Carrying Capacity

Effect of NSF …

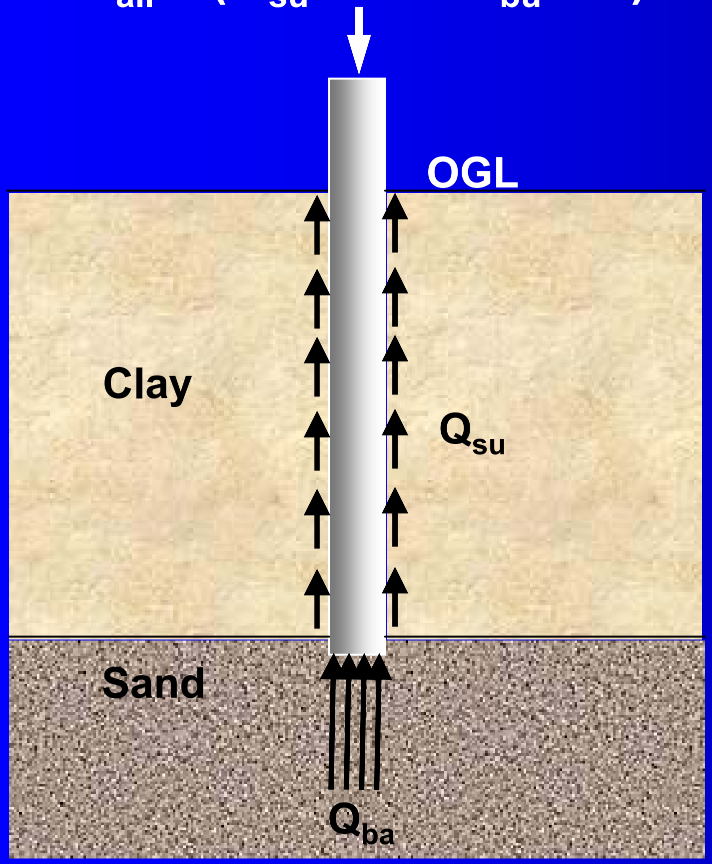
NSF Preventive Measures

- Avoid Filling
- Carry Out Surcharging
- Sleeve the Pile Shaft
- Slip Coating
- Reserve Structural Capacity for NSF
- Allow for Larger Settlements

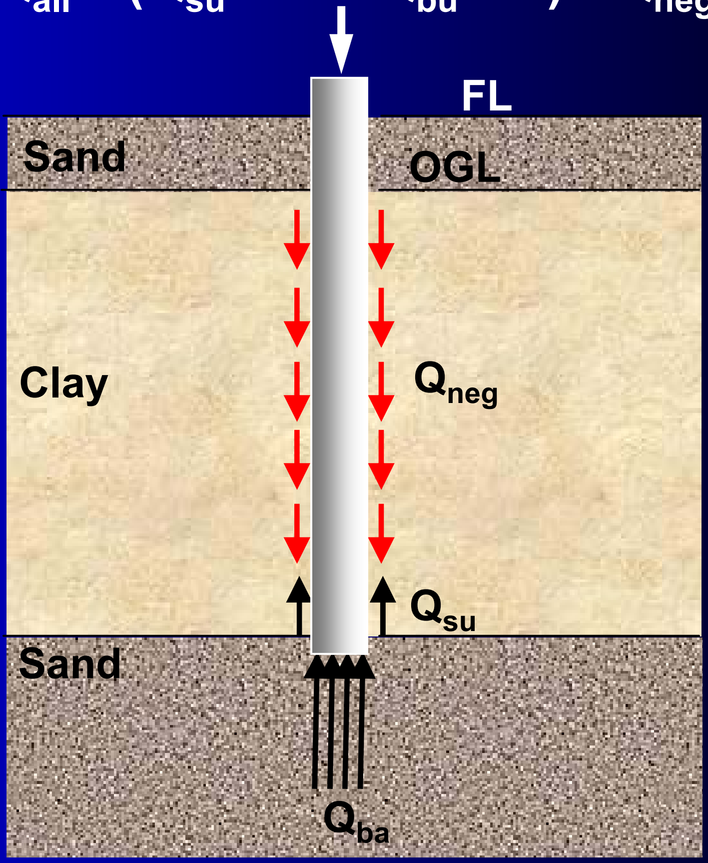
Pile Capacity Design

Negative Skin Friction

$$Q_{all} = (Q_{su}/1.5 + Q_{bu}/3.0)$$



$$Q_{all} = (Q_{su}/1.5 + Q_{bu}/3.0) - Q_{neg}$$

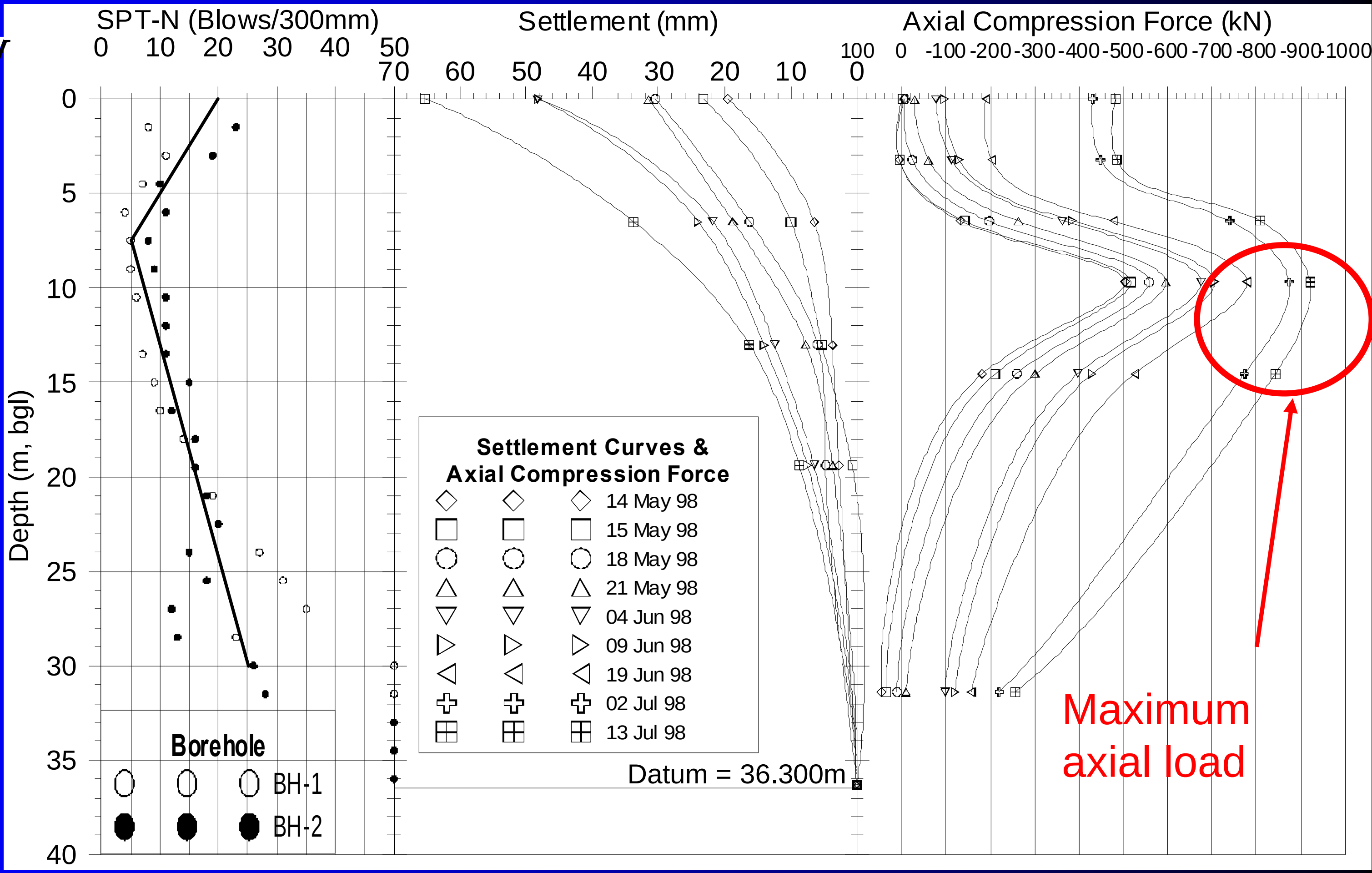


Pile Capacity Design

Negative Skin Friction

Increased Pile Axial Load

Check: maximum axial load < structural pile capacity



Pile Capacity Design

Factor of Safety (FOS)

Without Negative Skin Friction:

$$\text{Allowable working load} = \frac{Q_{ult}}{FOS}$$

With Negative Skin Friction:

$$\text{Allowable working load} = \frac{Q_{ult}}{FOS} - (Q_{neg} + \text{etc})$$

Pile Capacity Design

Static Pile Load Test (Piles with NSF)

- Specified Working Load (SWL) = Specified foundation load at pile head
- Design Verification Load (DVL) = SWL + 2 Q_{neg}
- Proof Load: will not normally exceed

  DVL + SWL

Pile Settlement Design

Pile Settlement Design
In Cohesive Soil

- Design for *total* settlement & *differential* settlement for design tolerance
- In certain cases, *total* settlement not an issue
- *Differential* settlement can cause damage to structures

Pile Settlement Design
In Cohesive Soil

Pile Group Settlement in Clay

=

Immediate / Elastic Settlement + Consolidation Settlement

Pile Settlement Design
In Cohesive Soil

IMMEDIATE SETTLEMENT

$$p_i = \frac{\mu_1 \mu_0 q_n B}{E_u}$$

by Janbu, Bjerrum and Kjaernsli (1956)

Where

p_i = average immediate settlement

$q_{n=}$ pressure at base of equivalent raft

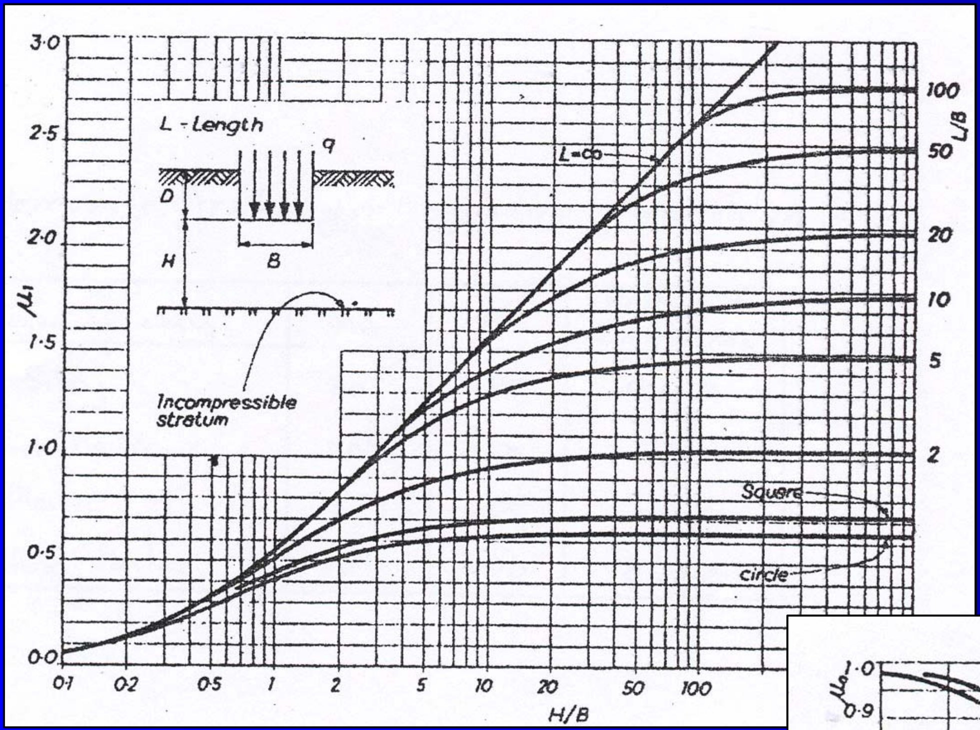
B = width of the equivalent raft

E_u= deformation modulus

$\mu_{1,}\ \mu_0$= influence factors for pile group width, B at depth D below ground surface

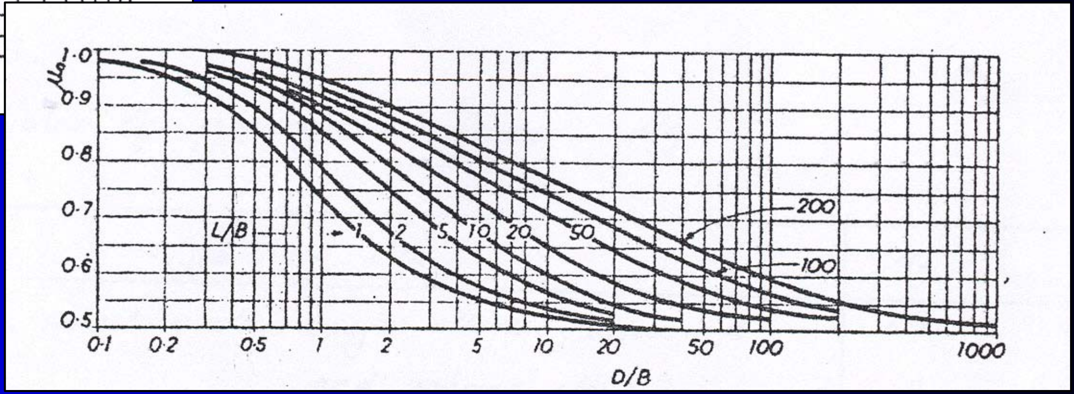
Pile Settlement Design
In Cohesive Soil

IMMEDIATE SETTLEMENT



μ_1

μ_0



Influence factors (after Janbu, Bjerrum and Kjaernsli, 1956)

Pile Settlement Design
In Cohesive Soil

CONSOLIDATION SETTLEMENT

As per footing (references given later)

Pile Settlement Design
On Rock

No risk of excessive settlement

Pile Installation Methods

PILE INSTALLATION METHODS

- Diesel / Hydraulic / Drop Hammer Driving
- Jacked-In
- Prebore Then Drive
- Prebore Then Jacked In
- Cast-In-Situ Pile

Diesel Drop Hammer Driving

Hydraulic Hammer Driving

Jacked-In Piling

Jacked-In Piling (Cont'd)

Cast-In-Situ Piles (Micropiles)

THE MICROPILE INSTALLATION PROCESS

1. Setting casing and drilling of bore hole over pile position.
2. Lowering the Down the Hole hammer for hard material drilling after ensuring hole is truly vertical.
3. Installation of the micropile structural member by lowering the steel bars into the drilled hole.
4. Checking to ensure drilled hole formed is washed and cleaned before grouting.
5. Tremie grouting in progress.
6. Four bar micropile system ready to be incorporated into the pile cap.

Types of Piles

TYPES OF PILES

- Treated Timber Piles
- Bakau Piles
- R.C. Square Piles
- Pre-Stressed Concrete Spun Piles
- Steel Piles
- Boredpiles
- Micropiles
- Caisson Piles

R.C. Square Piles

- Size : 150mm to 400mm
- Lengths : 3m, 6m, 9m and 12m
- Structural Capacity : 25Ton to 185Ton
- Material : Grade 40MPa Concrete
- Joints: Welded
- Installation Method :
  - Drop Hammer
  - Jack-In

RC Square Piles

Pile Marking

Pile Lifting

Pile Fitting to Piling Machine

Pile Positioning

Pile Joining

Considerations in Using RC Square Piles …

- Pile Quality
- Pile Handling Stresses
- Driving Stresses
- Tensile Stresses
- Lateral Loads
- Jointing

Pre-stressed Concrete Spun Piles

- Size : 250mm to 1000mm
- Lengths : 6m, 9m and 12m (Typical)
- Structural Capacity : 45Ton to 520Ton
- Material : Grade 60MPa & 80MPa Concrete
- Joints: Welded
- Installation Method :
  - Drop Hammer
  - Jack-In

Spun Piles

Spun Piles vs RC Square Piles

Spun Piles have …

- **Better Bending Resistance**
- **Higher Axial Capacity**
- **Better Manufacturing Quality**
- **Able to Sustain Higher Driving Stresses**
- **Higher Tensile Capacity**
- **Easier to Check Integrity of Pile**
- **Similar cost as RC Square Piles**

Steel H Piles

- Size : 200mm to 400m
- Lengths : 6m and 12m
- Structural Capacity : 40Ton to 1,000Ton
- Material : 250N/mm^2 to 410N/mm^2 Steel
- Joints: Welded
- Installation Method :
  - Hydraulic Hammer
  - Jack-In

Steel H Piles

Steel H Piles (Cont'd)

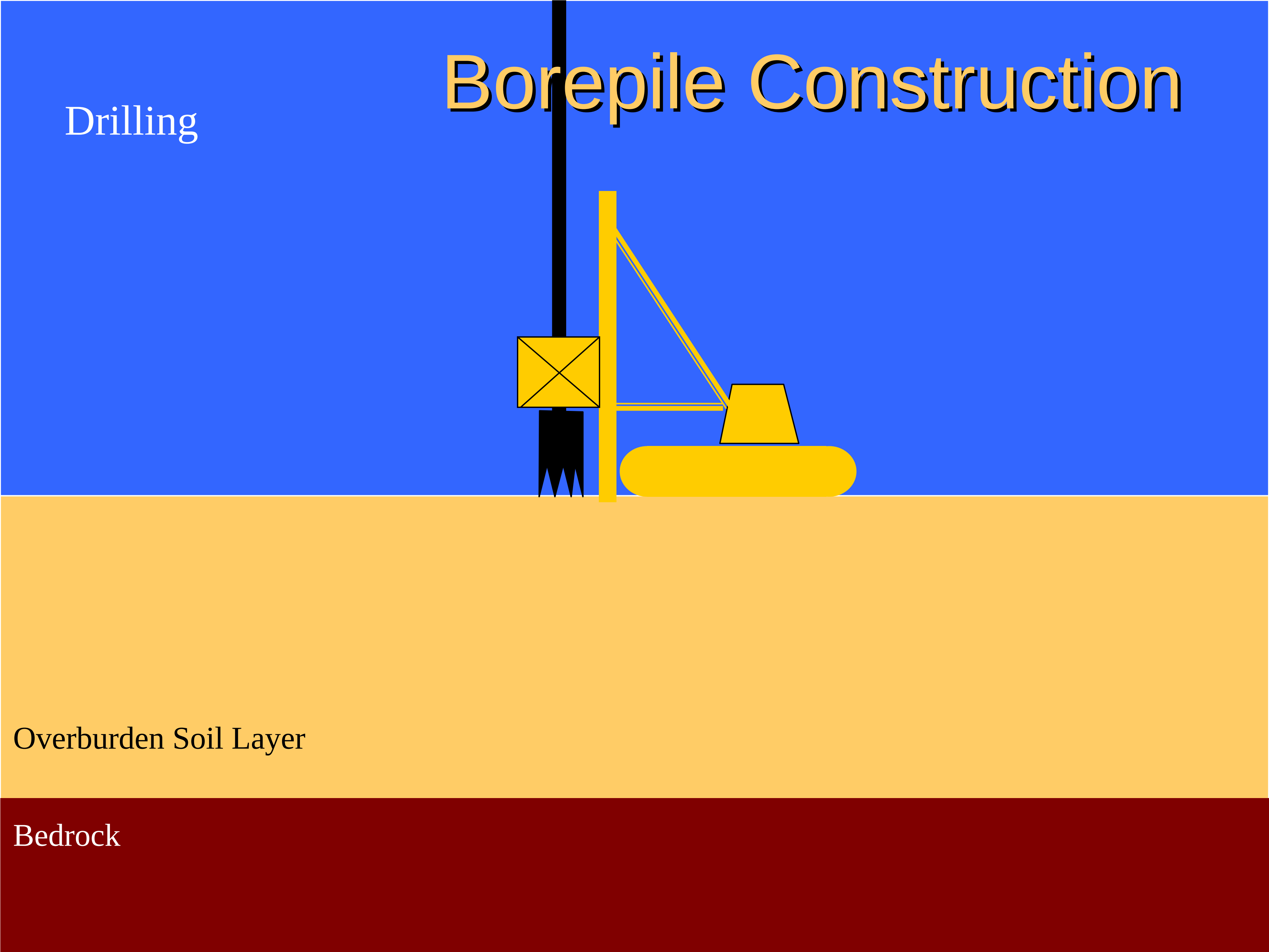
Steel H Piles Notes…

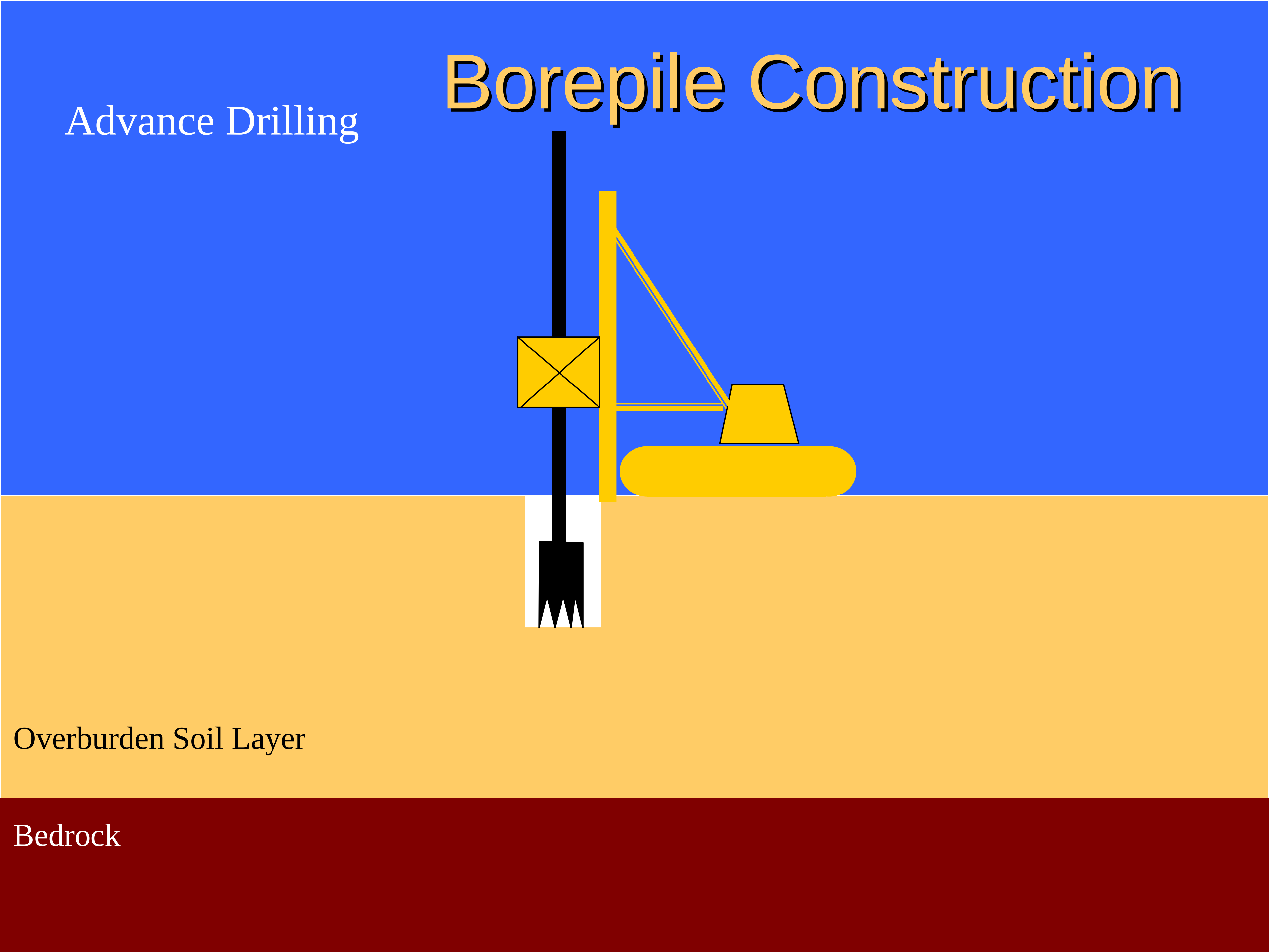
- Corrosion Rate
- Fatigue
- OverDriving

OverDriving of Steel Piles

Large Diameter Cast-In-Situ Piles (Bored Piles)

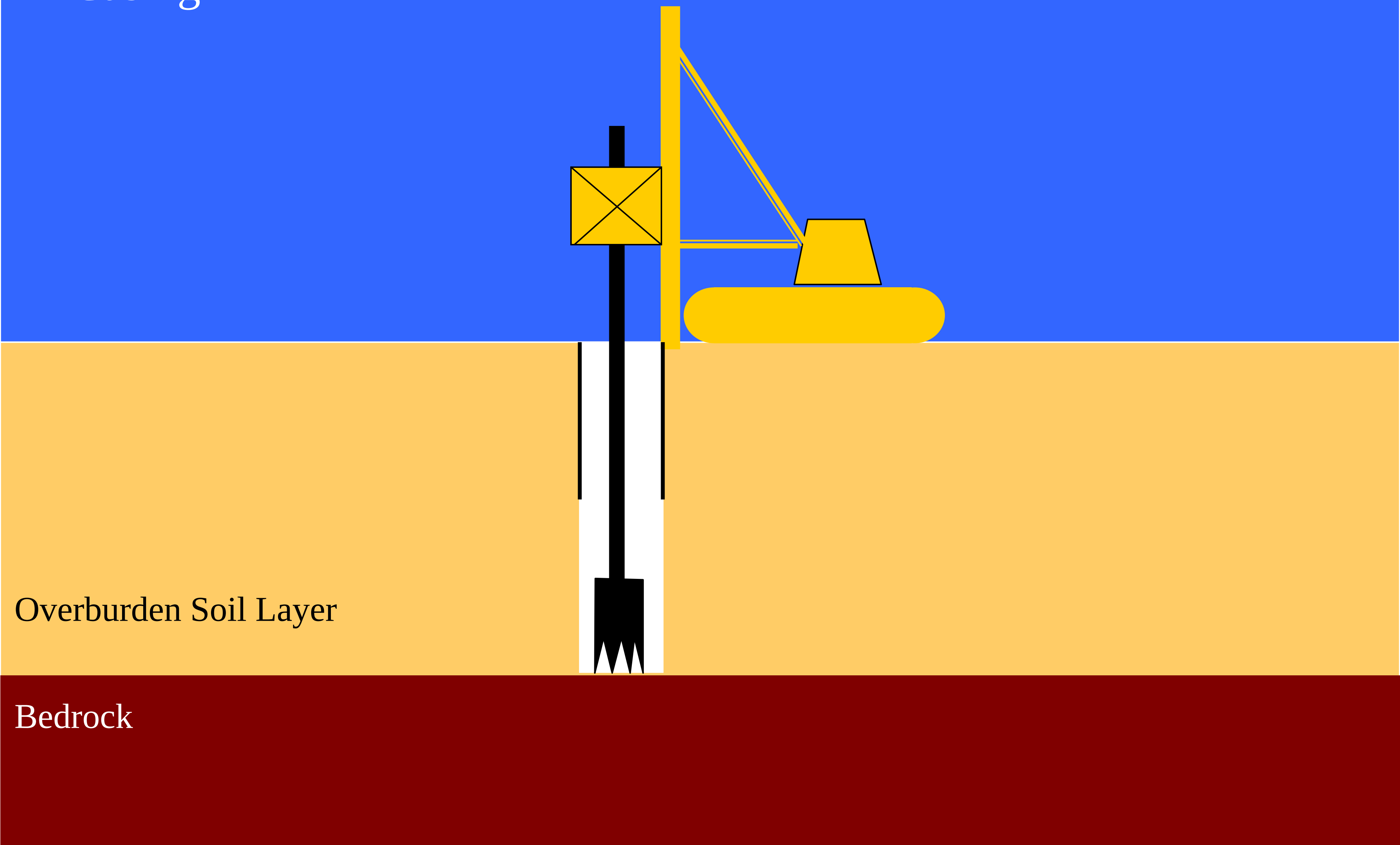
- Size : 450mm to 2m
  (Up to 3.0m for special case)
- Lengths : Varies
- Structural Capacity : 80Ton to 2,300Tons
- Concrete Grade : 20MPa to 35MPa (Tremie)
- Joints : None
- Installation Method : Drill then Cast-In-Situ

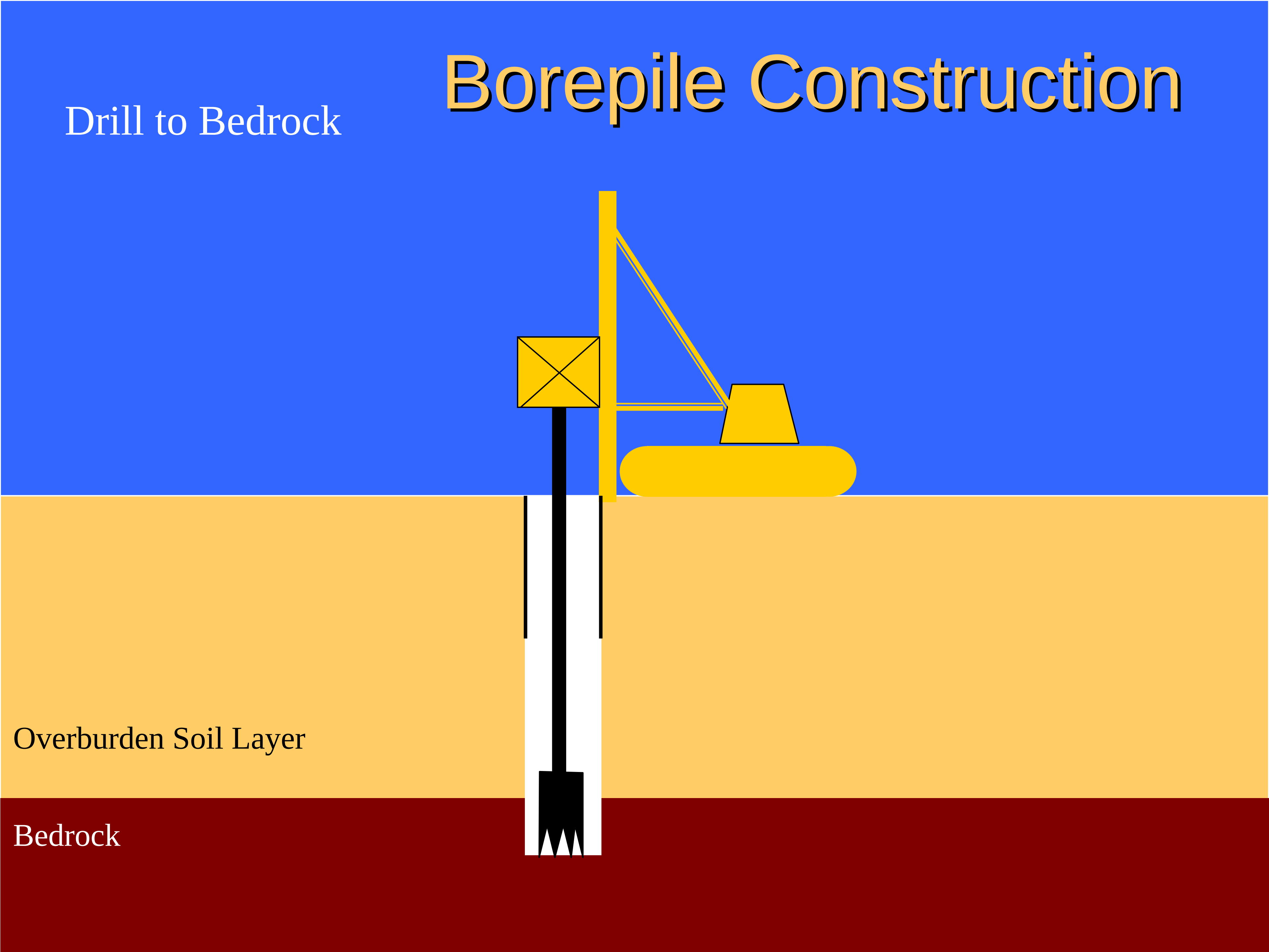

Borepile Construction
Drilling
Overburden Soil Layer
Bedrock

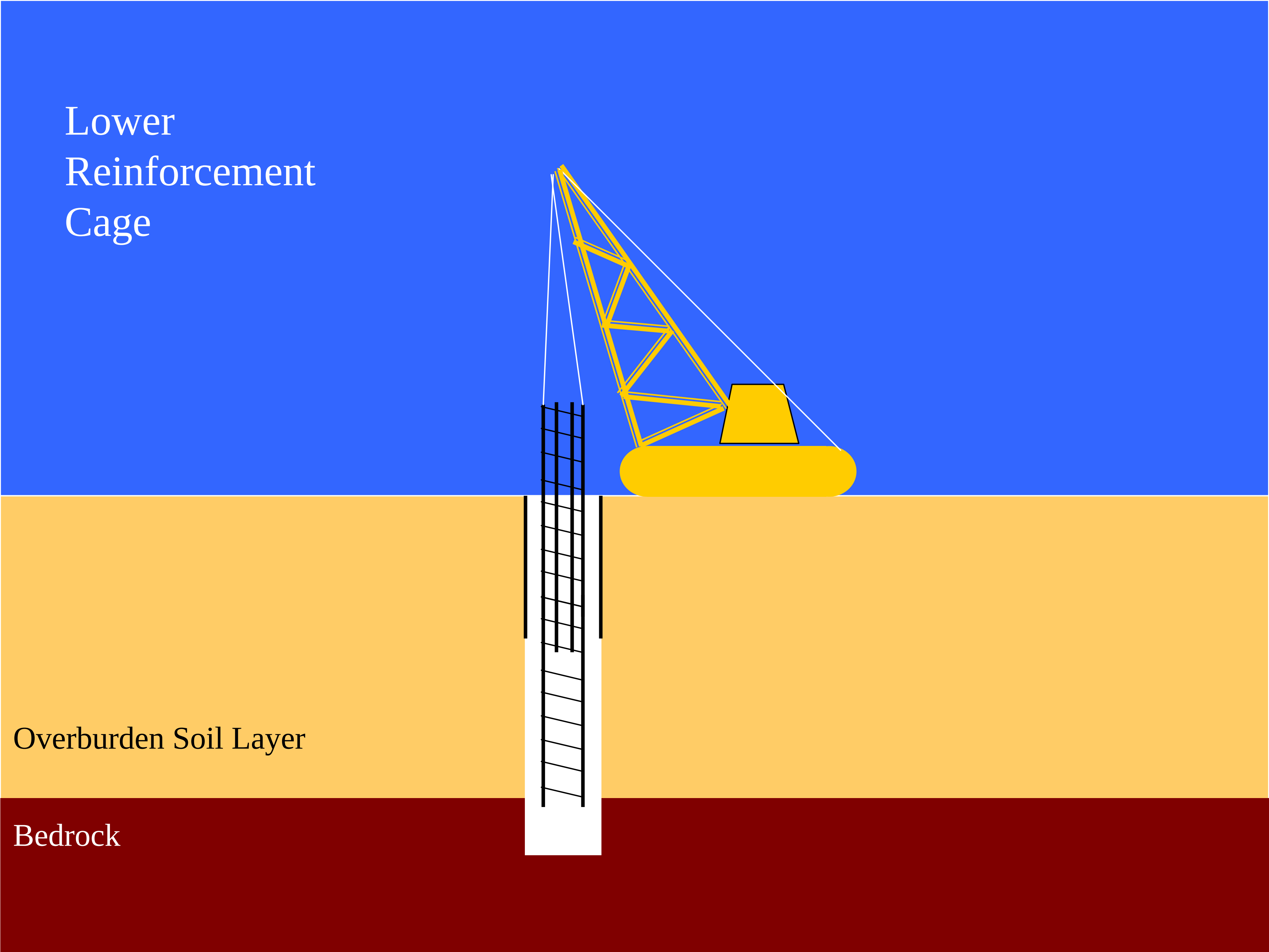

Borepile Construction
Advance Drilling
Overburden Soil Layer
Bedrock

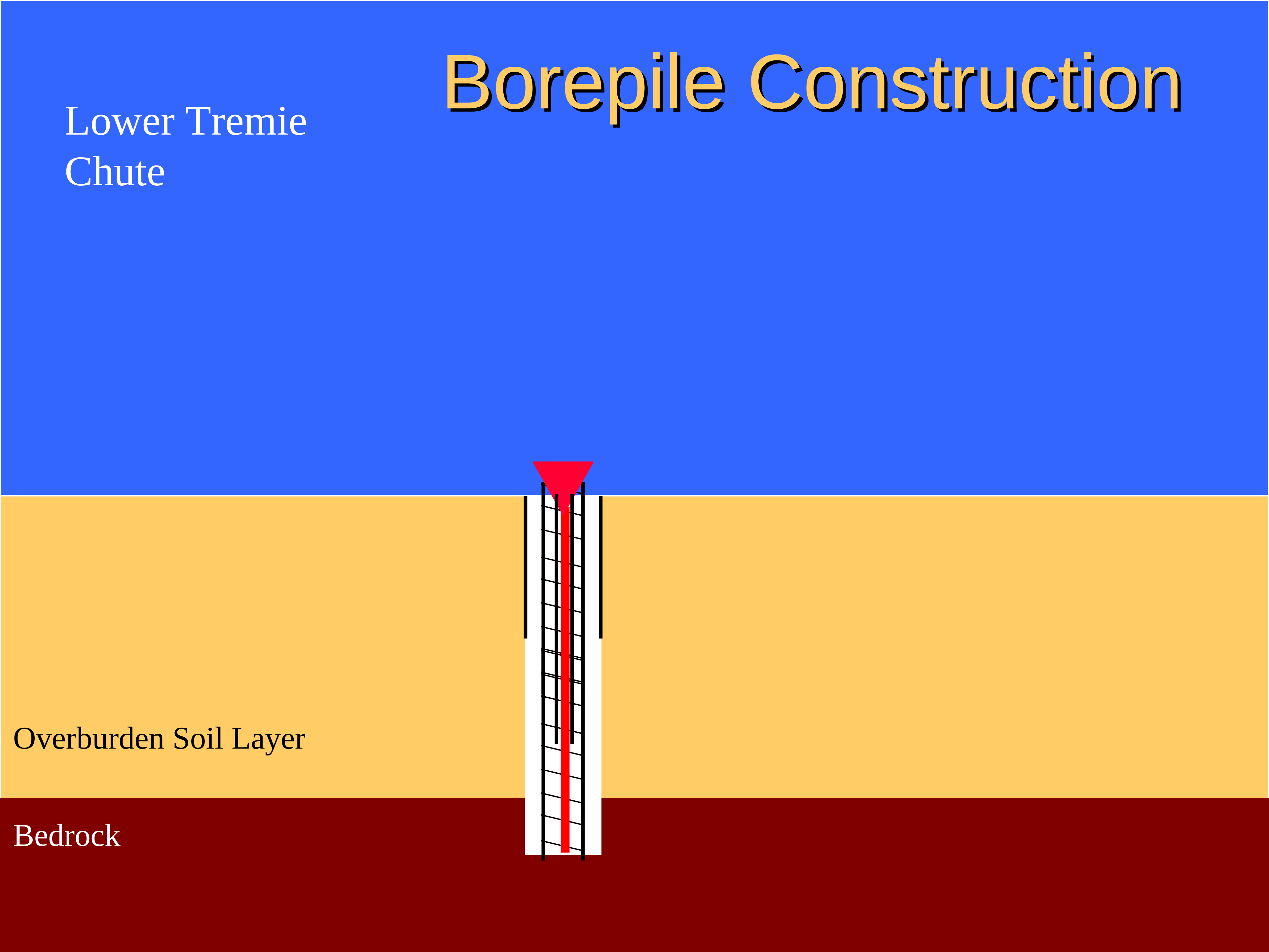
Borepile Construction

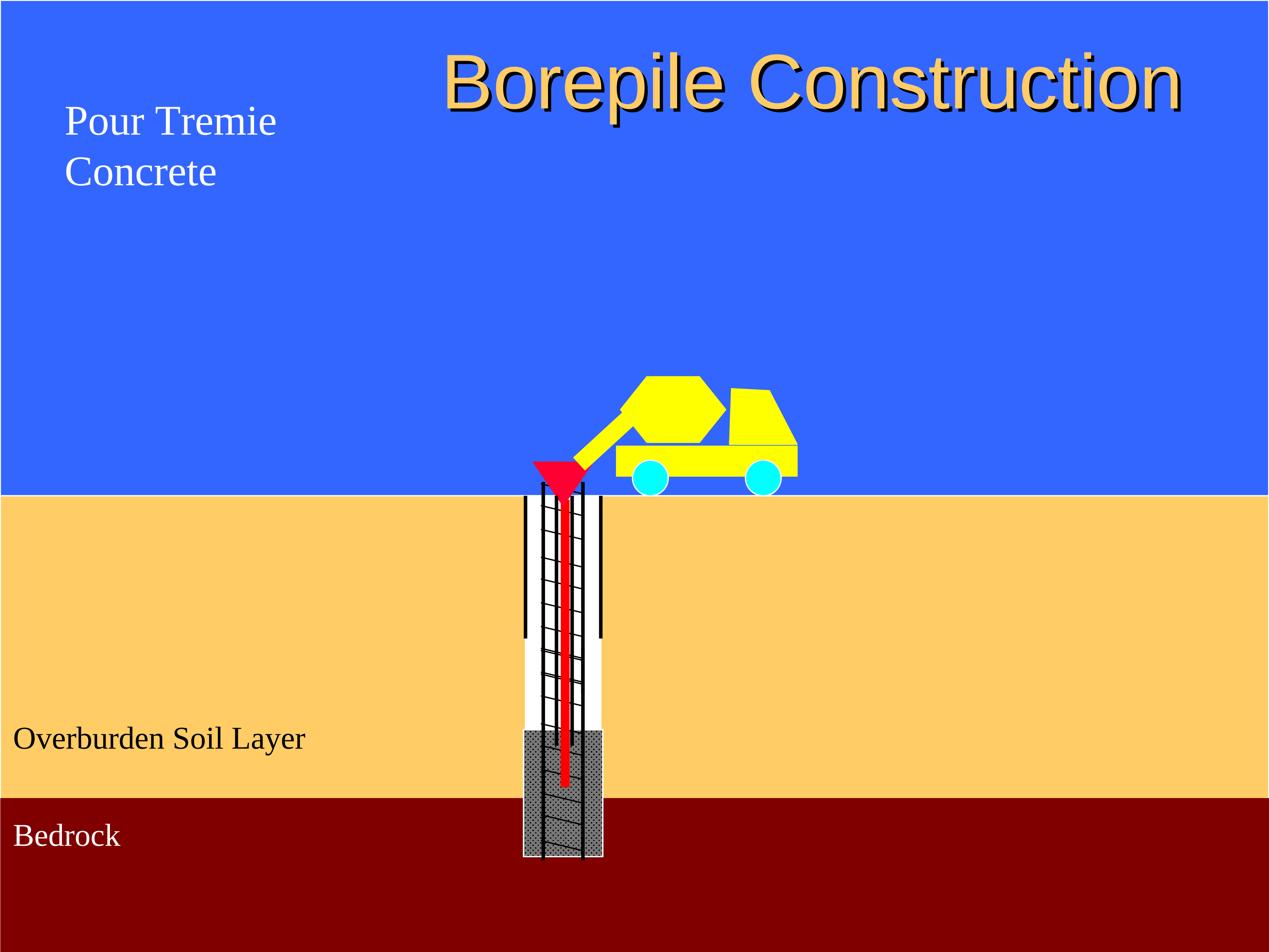
Drilling & Advance Casing

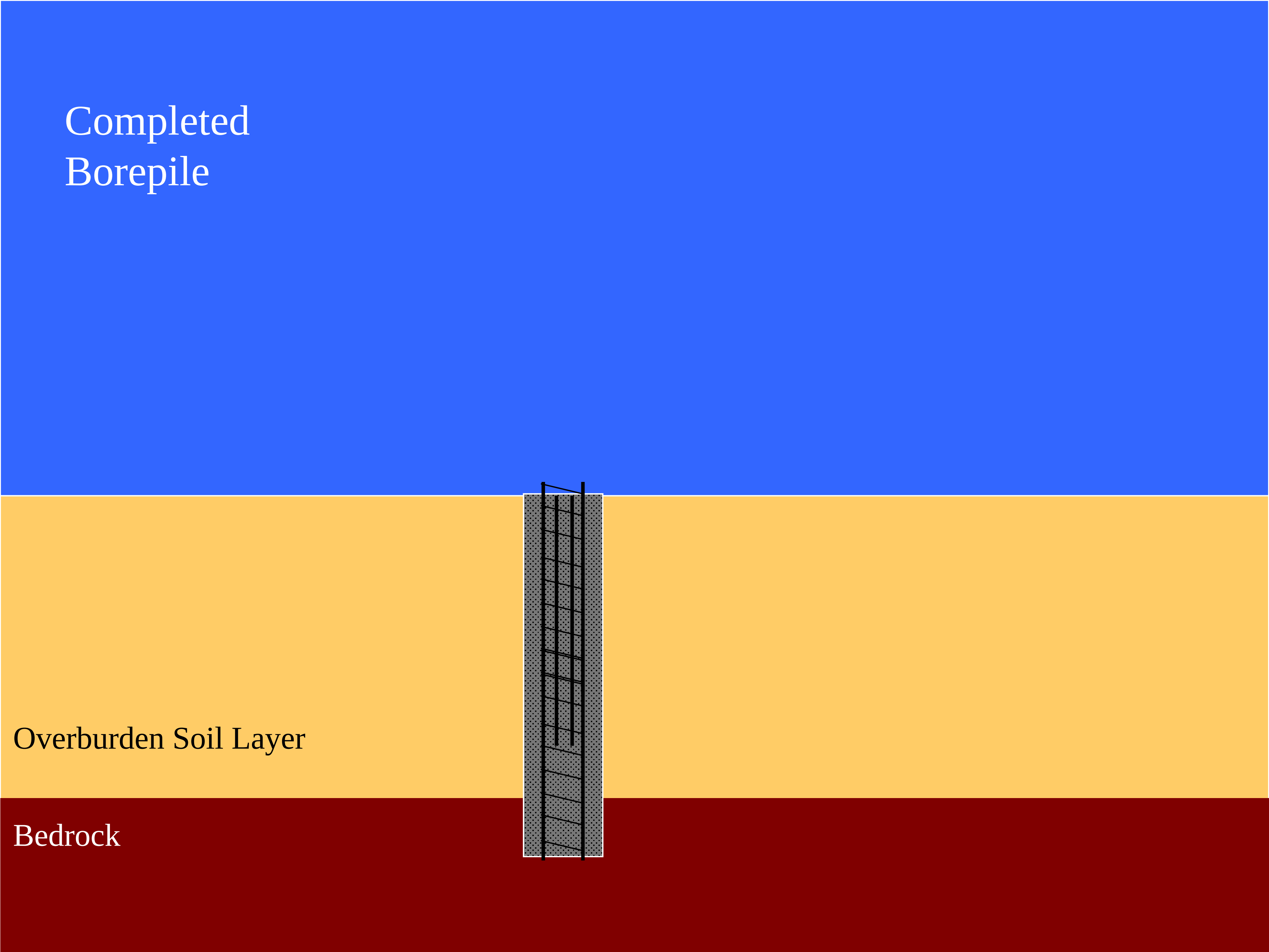



Borepile Construction
Drill to Bedrock
Overburden Soil Layer
Bedrock


Lower
Reinforcement
Cage
Overburden Soil Layer
Bedrock


Borepile Construction
Lower Tremie
Chute
Overburden Soil Layer
Bedrock


Borepile Construction
Pour Tremie
Concrete
Overburden Soil Layer
Bedrock


Completed
Borepile
Overburden Soil Layer
Bedrock

BORED PILING MACHINE


Rock Reamer
Rock Auger
Cleaning Bucket


Rock Chisel
Harden Steel

DRILLING EQUIPMENT

BENTONITE PLANT

Drilling

Lower Reinforcement

Place Tremie Concrete

Completed Boredpile

Borepile Cosiderations…

- Borepile Base Difficult to Clean
- Bulging / Necking
- Collapse of Sidewall
- Dispute on Level of Weathered Rock

Micropiles

- Size : 100mm to 350mm Diameter
- Lengths : Varies
- Structural Capacity : 20Ton to 250Ton
- Material : Grade 25MPa to 35MPa Grout

  N80 API Pipe as Reinforcement
- Joints: None
- Installation Method :
  - Drill then Cast-In-Situ
  - Percussion Then Cast-In-Situ

Cast-In-Situ Piles (Micropiles)

TYPES OF PILE SHOES

- Flat Ended Shoe
- Oslo Point
- Cast-Iron Pointed Tip
- Cross Fin Shoe
- H-Section

Cross Fin Shoe

Oslo Point Shoe

Cast Iron Tip Shoe

H-Section Shoe

Piling Supervision

Uniform Building By Law (UBBL)1984

4. (1) A local authority may if it is of the view that any plan, drawing or calculation is beyond the competence of such qualified person submitting the same, return such plan, drawing or calculation. — Return of plan

(2) A local authority shall accept any returned plan, drawing or calculation if the same were re-submitted together with a certificate from the relevant competent authority responsible for registering such qualified person, certifying that such plan, drawing or calculation is within the competence of such qualified person submitting the same.

5. Where under these By-laws any plan, drawing or calculation in relation to any building is required to be submitted by qualified person, no erection or continued erection of that building shall take place unless that qualified person or any person duly authorised by him undertakes the supervision of the erection and the setting out, where applicable, of that building. — Supervision of work.

6. (1) All plans submitted shall be signed by the qualified person and by the owner or his agent and shall bear the full address of the owner. — Plans to be signed.

(2) The local authority may, if satisfied that the owner of the premises has refused to or has failed to execute any work which is required under the Act to be executed by him, direct the owner of the premises in writing to execute such work.

7. (1) The qualified person submitting the plans shall be responsible for the proper execution of the works and shall continue to be so responsible until the completion of the works unless— — Withdrawal or change of qualified person.

PILING SUPERVISION

- Ensure That Piles Are Stacked Properly
- Ensure that Piles are Vertical During Driving
- Keep Proper Piling Records
- Ensure Correct Pile Types and Sizes are Used
- Ensure that Pile Joints are Properly Welded with NO GAPS
- Ensure Use of Correct Hammer Weights and Drop Heights

PILING SUPERVISION (Cont'd)

- Ensure that Proper Types of Pile Shoes are Used.
- Check Pile Quality
- Ensure that the Piles are Driven to the Required Lengths
- Monitor Pile Driving


20 8 '98

FAILURE OF PILING SUPERVISION

Failing to Provide Proper Supervision

WILL Result in

Higher Instances of Pile Damage

& Wastage

Pile Damage

Driven concrete piles are vulnerable to damages by overdriving.

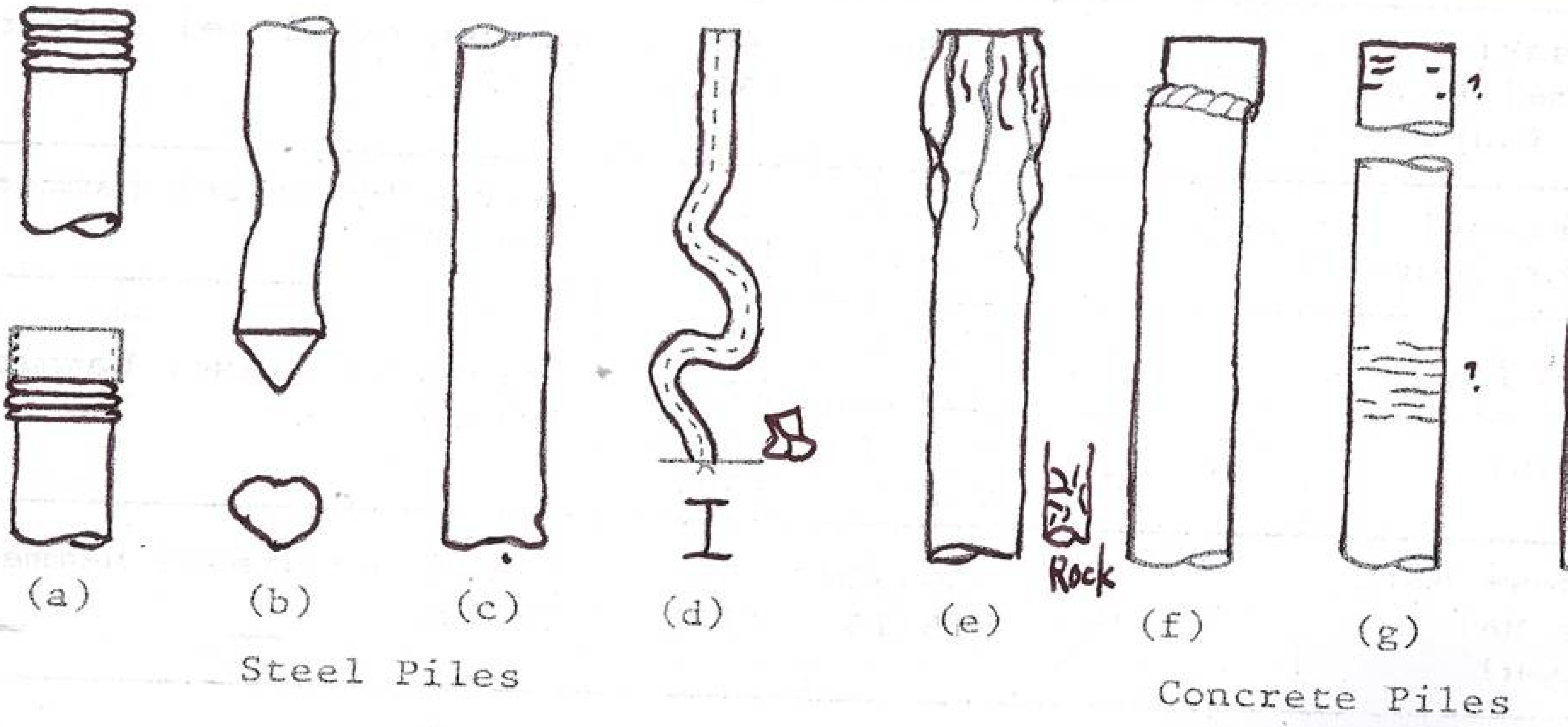


Fig. 1 Examples of Pile Damages by overdri

Damage to Timber Pile

Damage To RC Pile Toe

Damage to RC Pile Head

Damage to RC Piles

Damage to RC Piles – cont’d

Damage to Steel Piles

Damaged Steel Pipe Piles

Piling Problems

Piling Problems – Soft Ground

Piling Problems – Soft Ground

Ground heave due to pressure relief at base & surcharge near excavation

Pile tilts & moves/walks

Piling Problems – Soft Ground

Piling in Kuala Lumpur Limestone

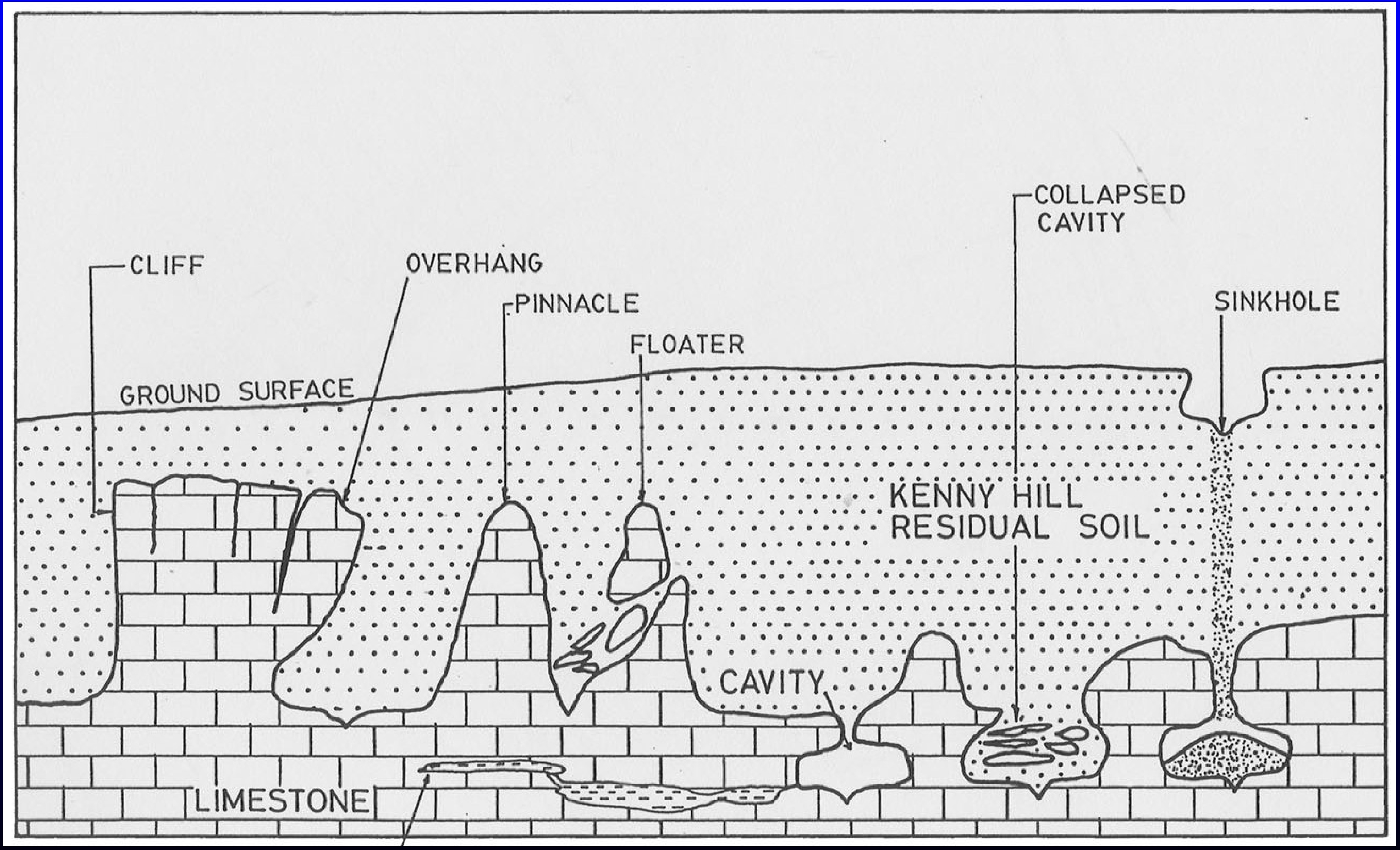
Important Points to Note:

- Highly Irregular Bedrock Profile
- Presence of Cavities & Solution Channels
- Very Soft Soil Immediately Above Limestone Bedrock

Results in …

- High Rates of Pile Damage
- High Bending Stresses

Piling Problems in Typical Limestone Bedrock



Piling Problems – Undetected Problems

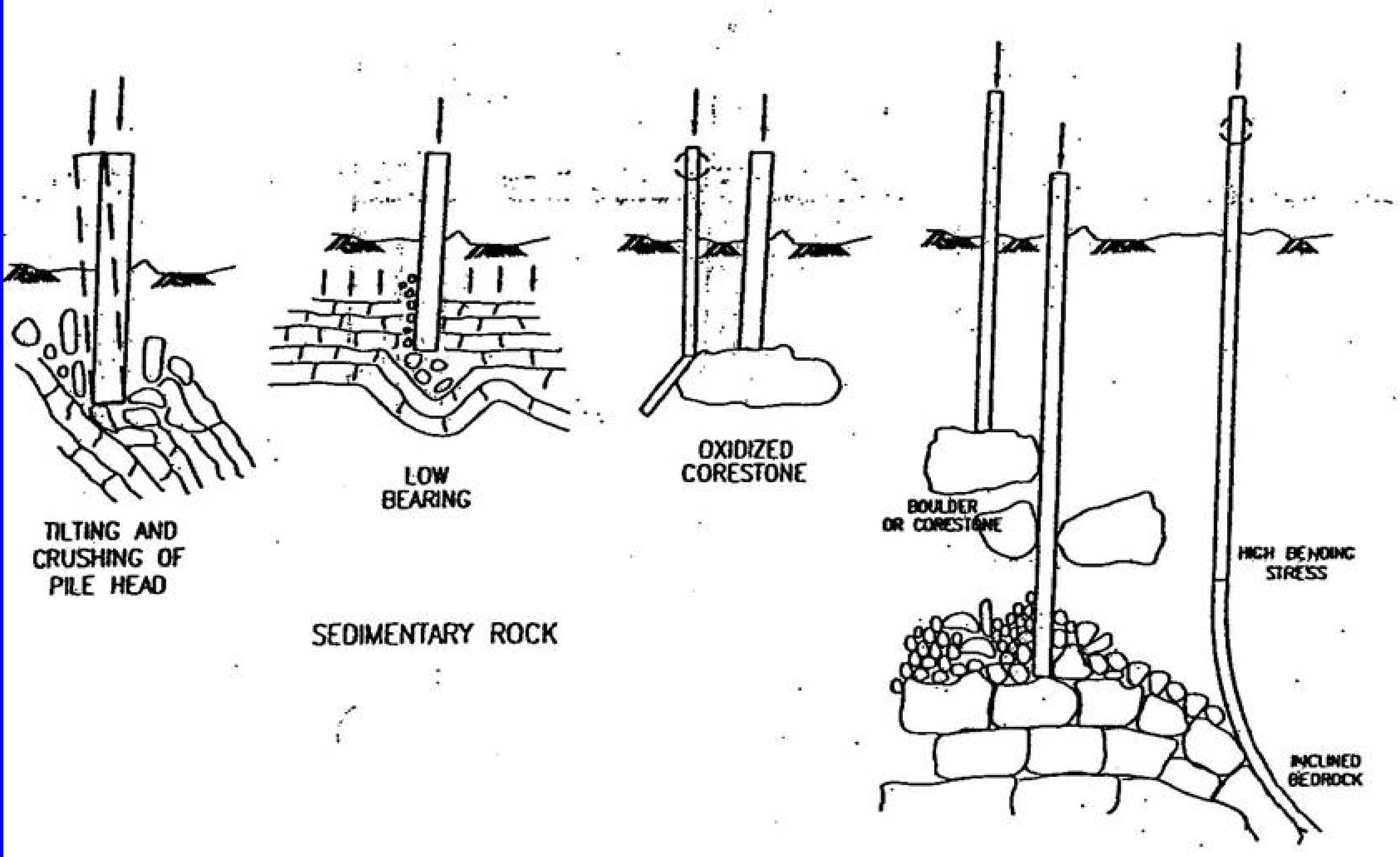


FIG 5: PILING PROBLEMS

Piling Problems – Coastal Alluvium

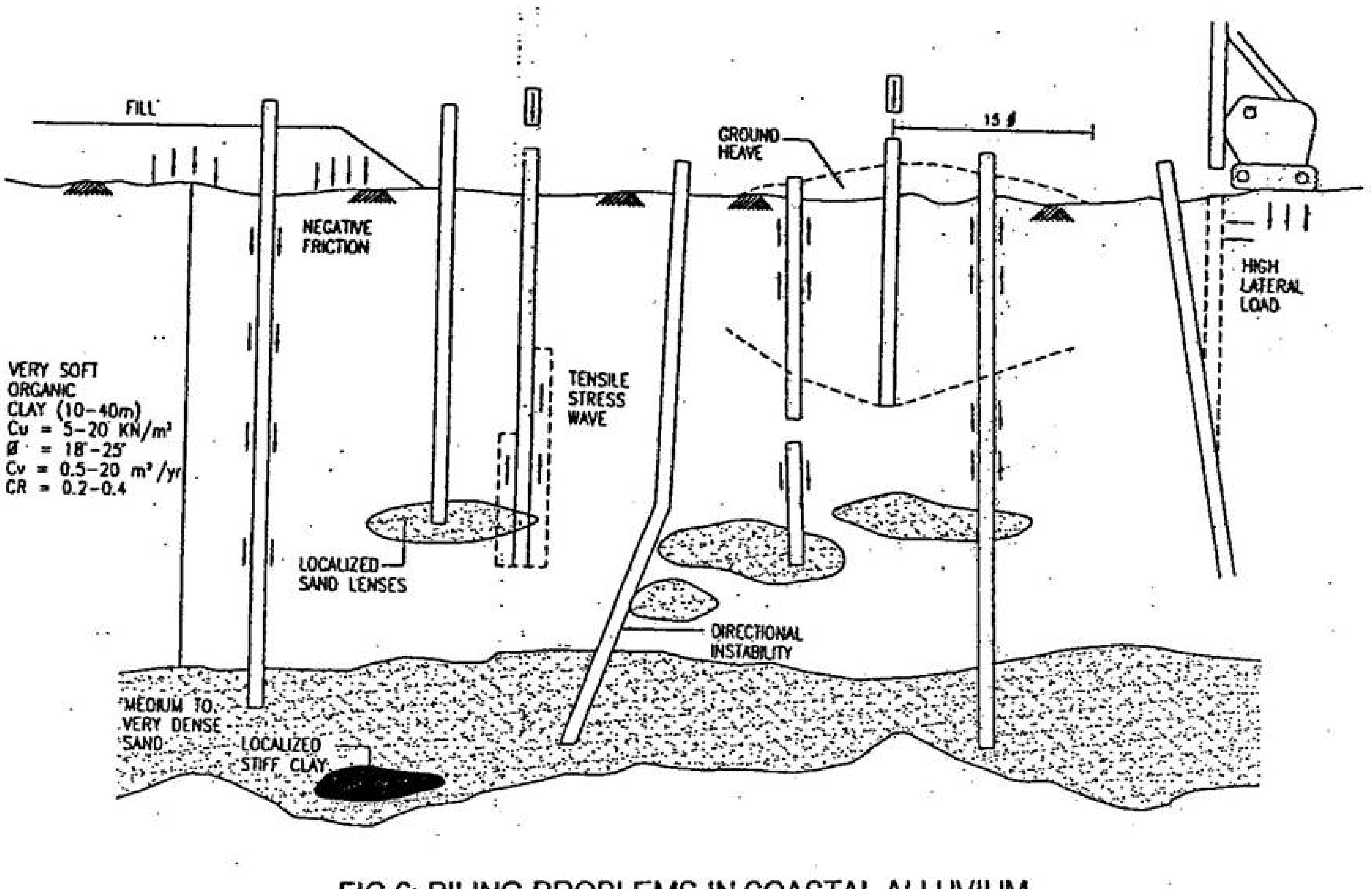


FIG 6: PILING PROBLEMS IN COASTAL ALLUVIUM

Piling Problems – Defective Piles

Seriously damaged pile due to severe driving stress in soft ground (tension)

Defect due to poor workmanship of pile casting

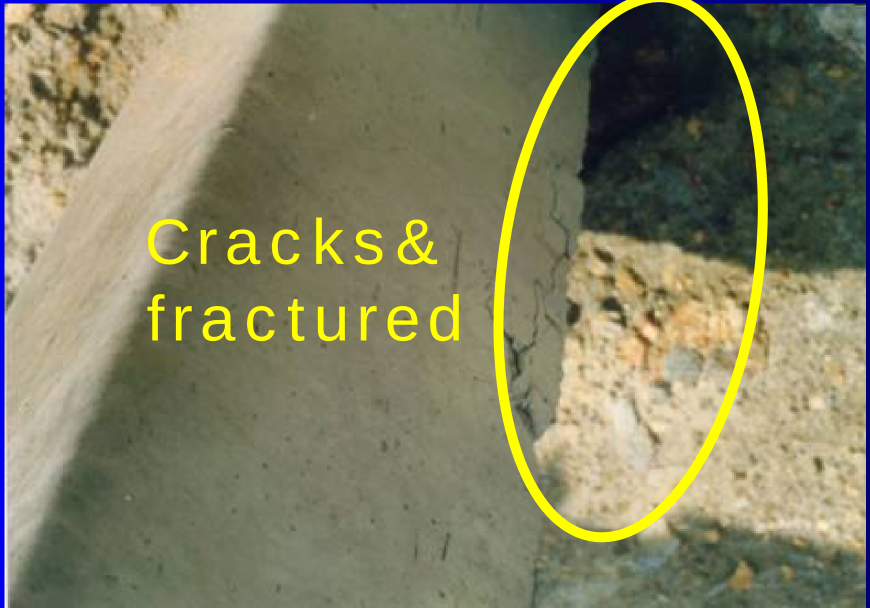
Piling Problems – Defective Piles

Defective pile shoe

Problems of defective pile head & overdriving!

Piling Problems – Defective Piles

Non-
chamfered
corners



Piling Problems – Defective Piles

Pile head defect due to hard driving or and poor workmanship

Piling Problem - Micropiles

Sinkholes caused by installation method- dewatering?

Piling in Fill Ground

Important Points to Note:

- High Consolidation Settlements If Original Ground is Soft
- Uneven Settlement Due to Uneven Fill Thickness
- Collapse Settlement of Fill Layer If Not Compacted Properly

Results in …

- Negative Skin Friction (NSF) & Crushing of Pile Due to High Compressive Stresses
- Uneven Settlements

Typical Design and Construction Issues #1

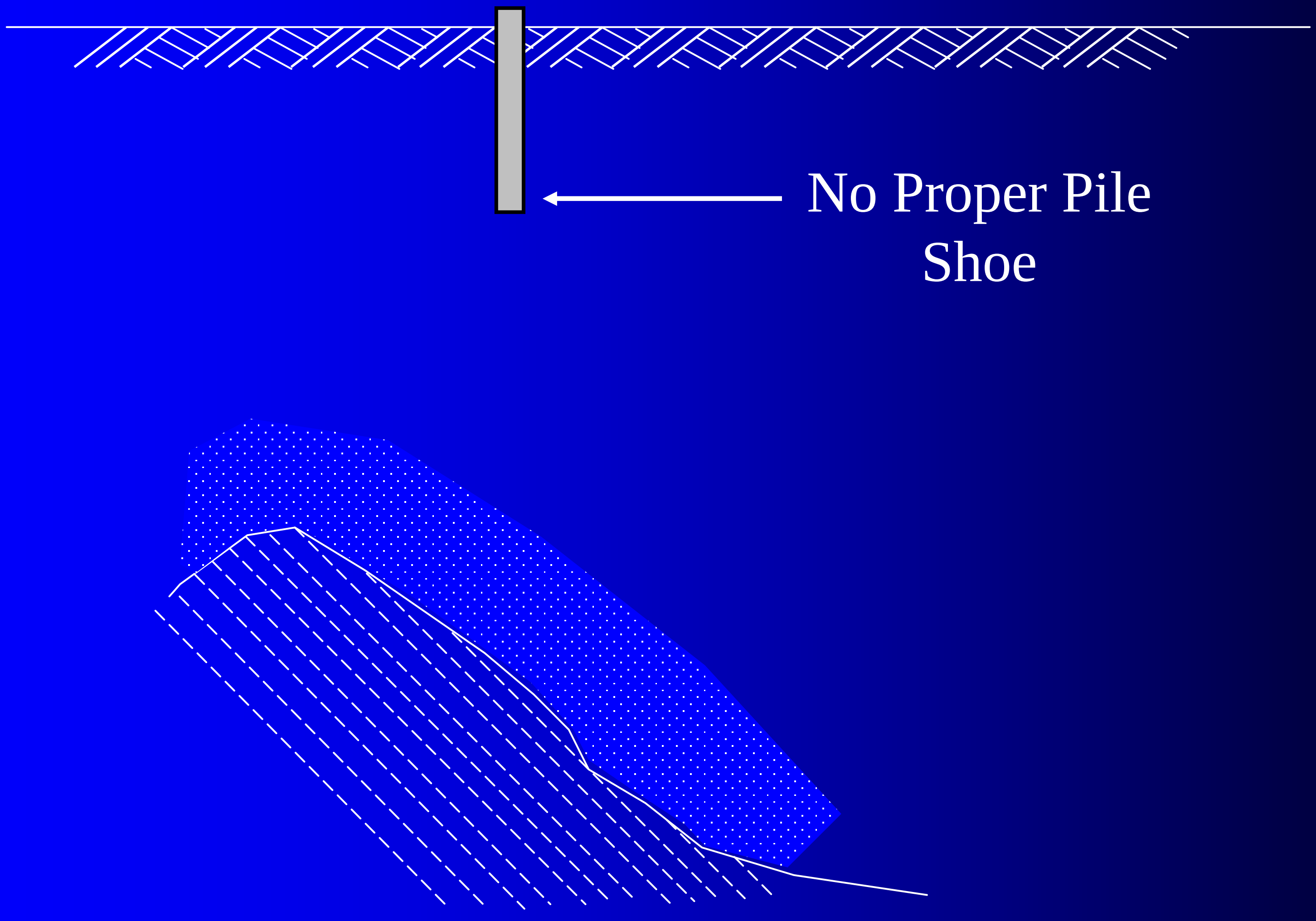
Issue #1

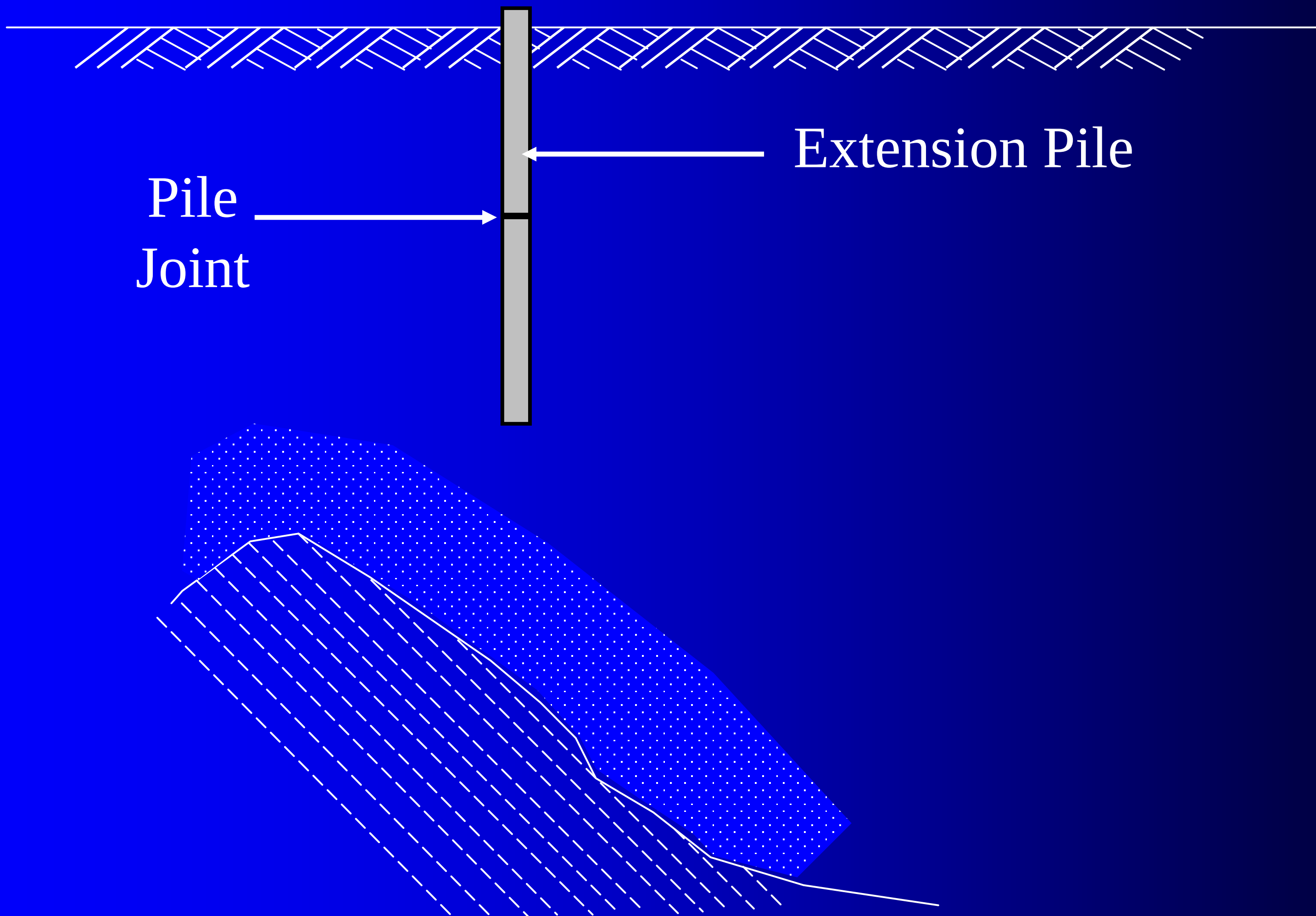
Pile Toe Slippage Due to Steep Incline Bedrock

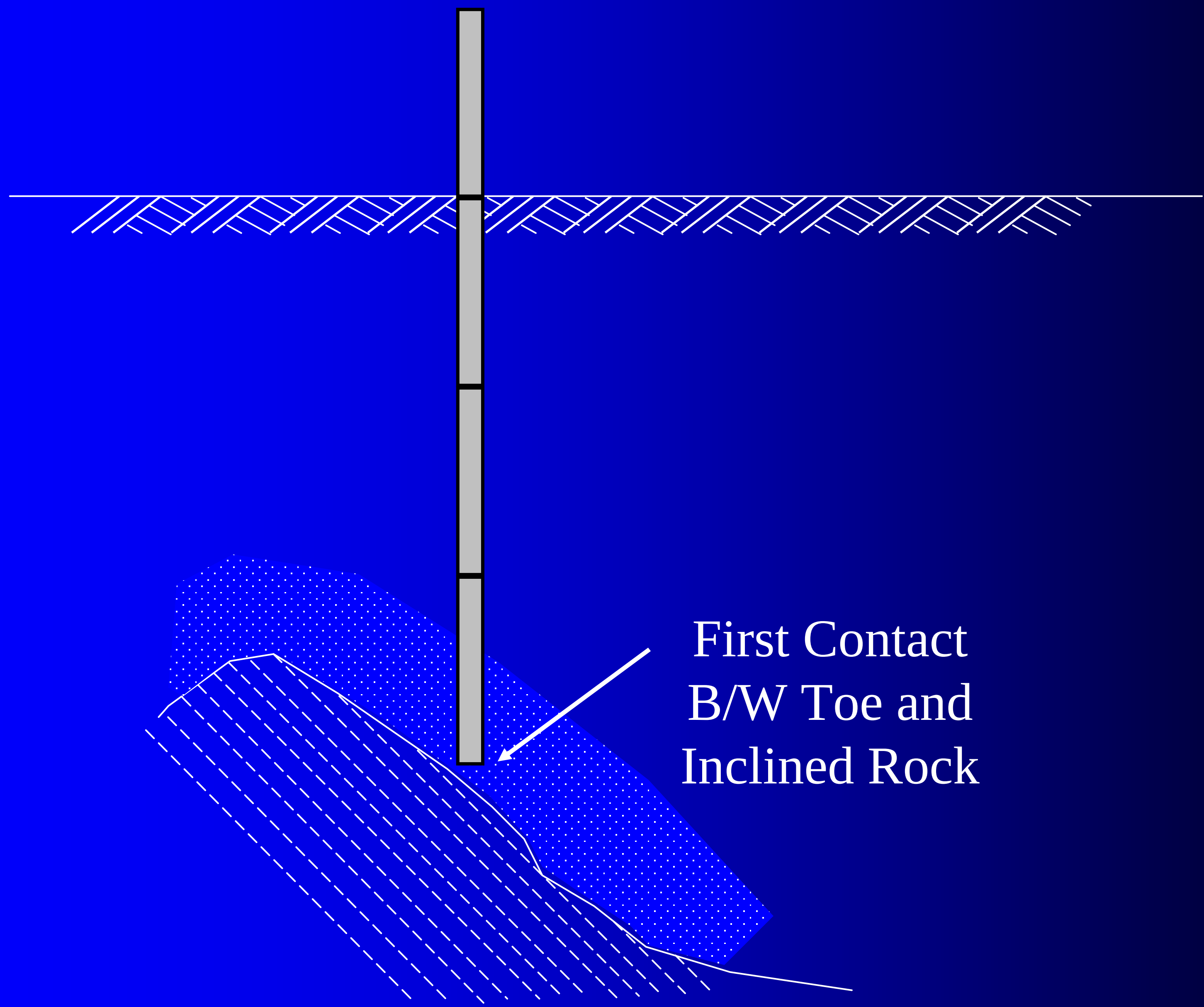
Solution #1

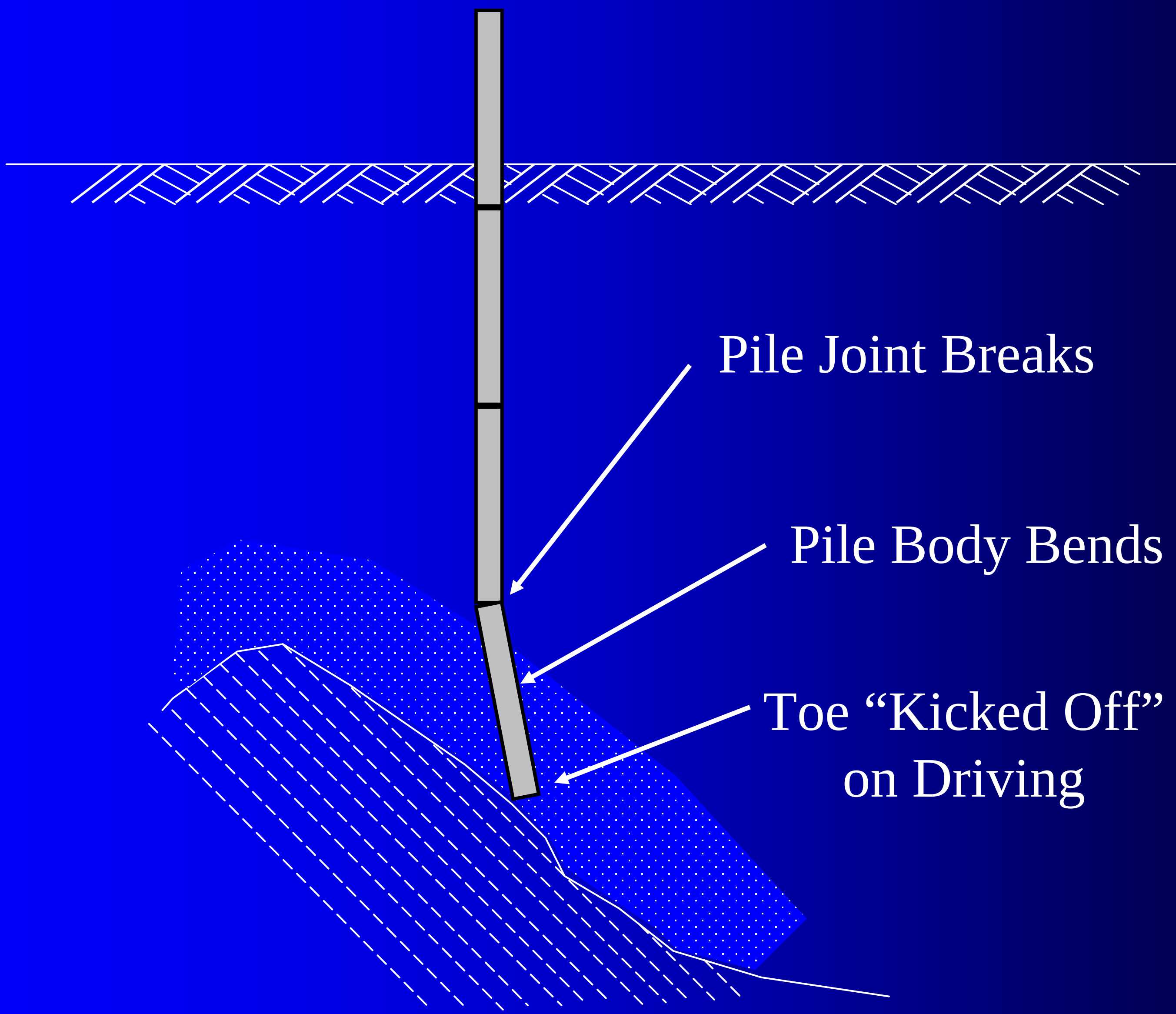
Use Oslo Point Shoe To Minimize Pile Damage

Pile Breakage on Inclined Rock Surface

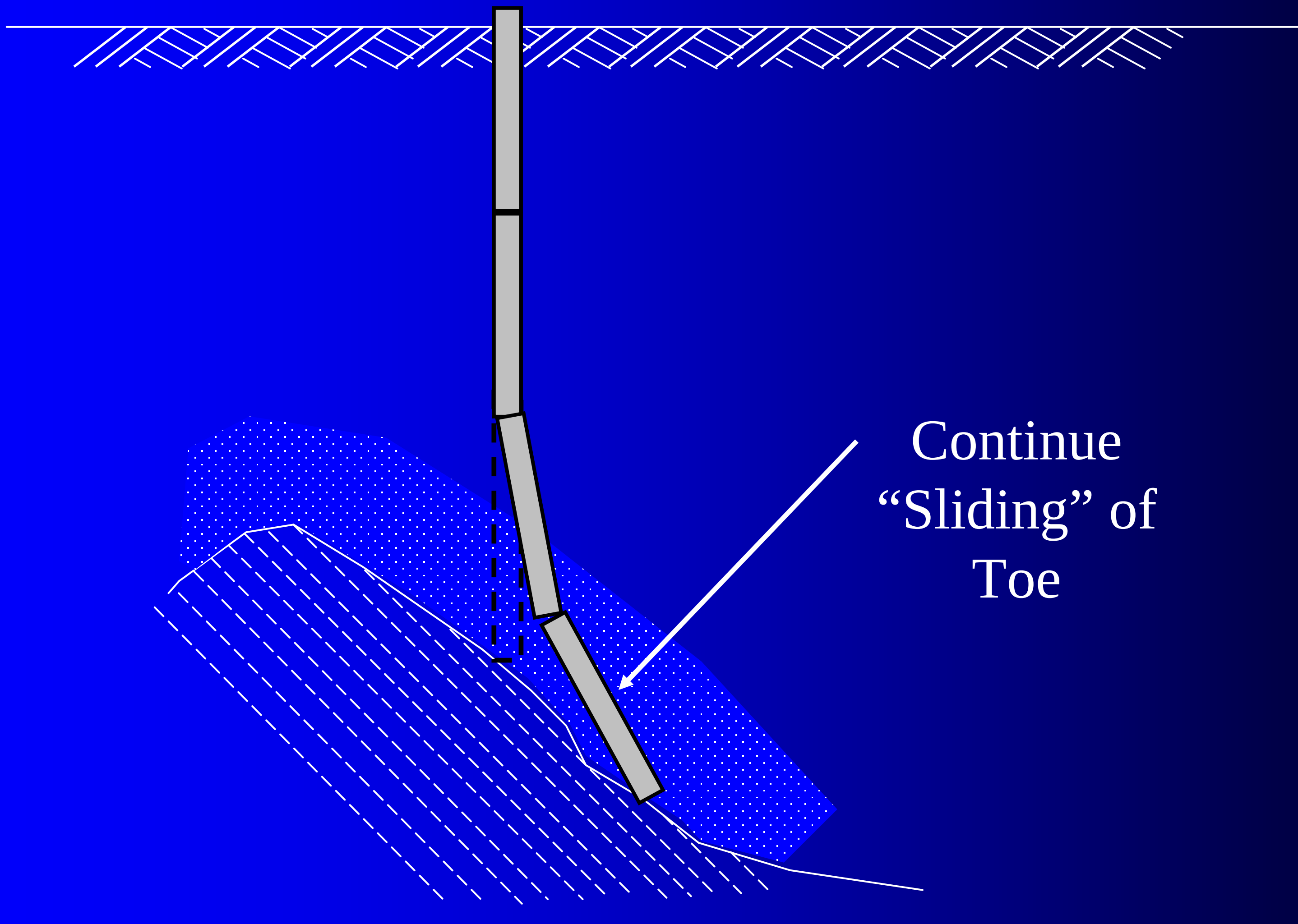



Extension Pile
Pile
Joint


First Contact
B/W Toe and
Inclined Rock


Pile Joint Breaks
Pile Body Bends
Toe “Kicked Off”
on Driving

Pile Breakage on Inclined Rock Surface



Use Oslo Point Shoe to Minimize Damage

Design and Construction Issues #2

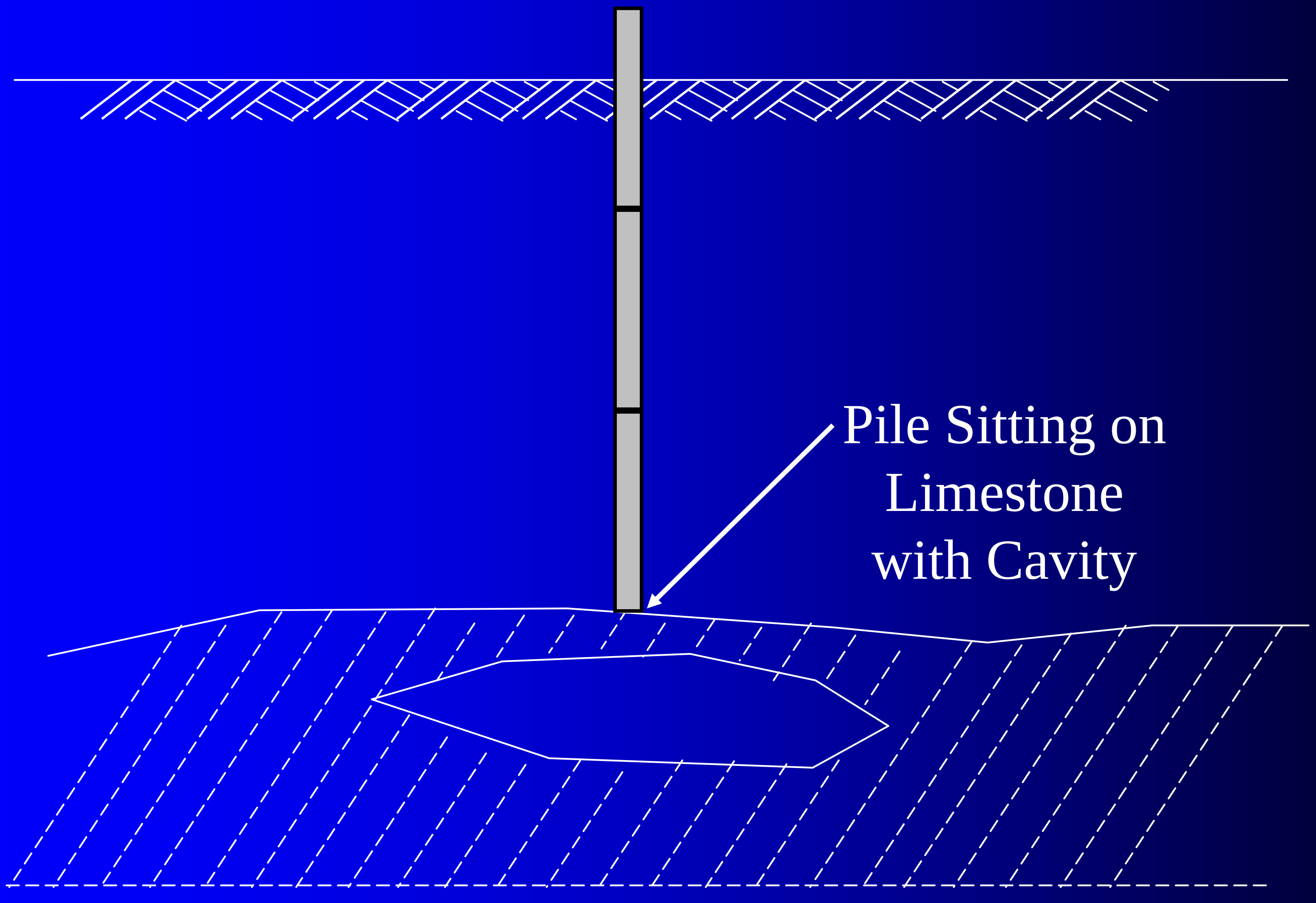
Issue #2

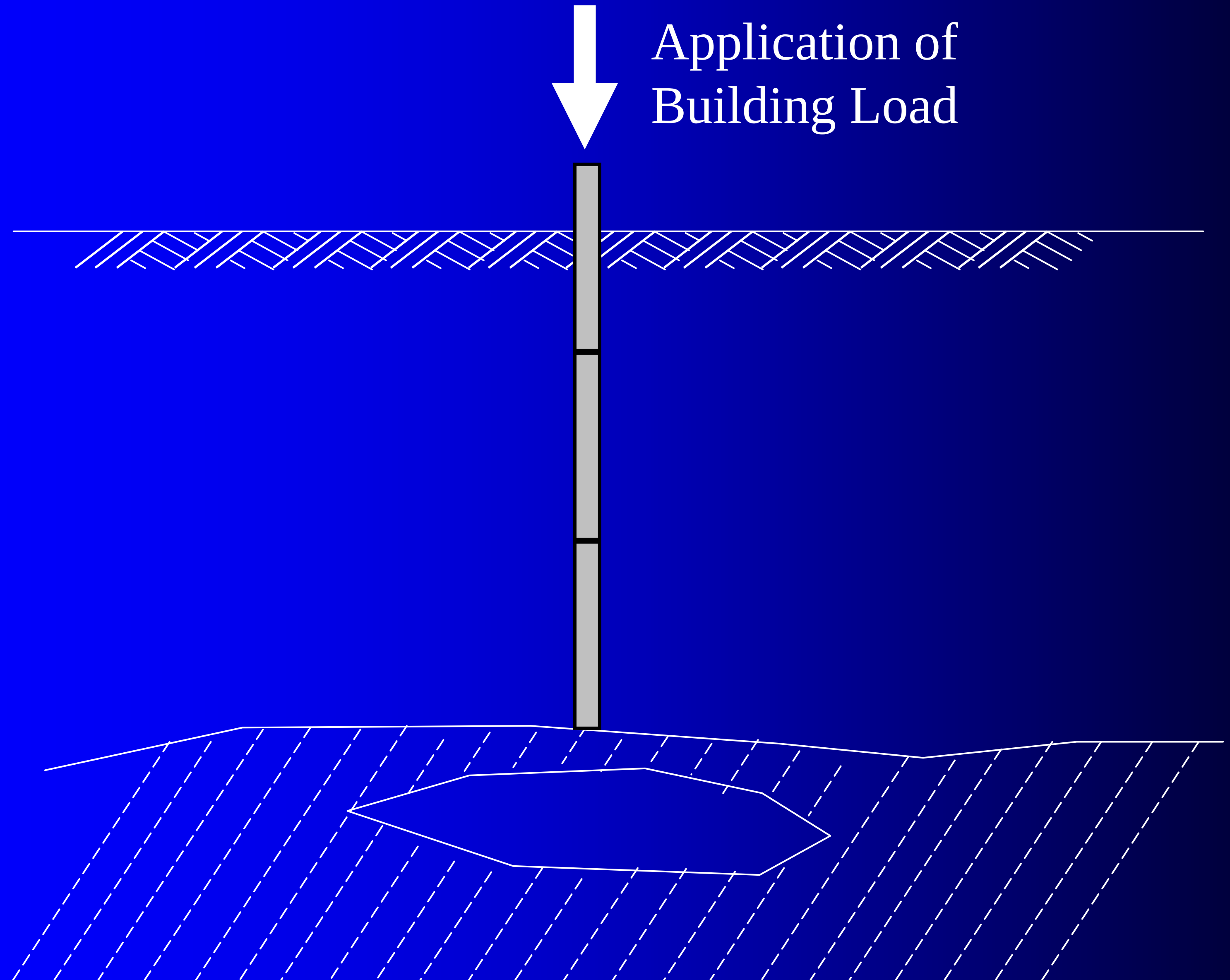
Presence of Cavity

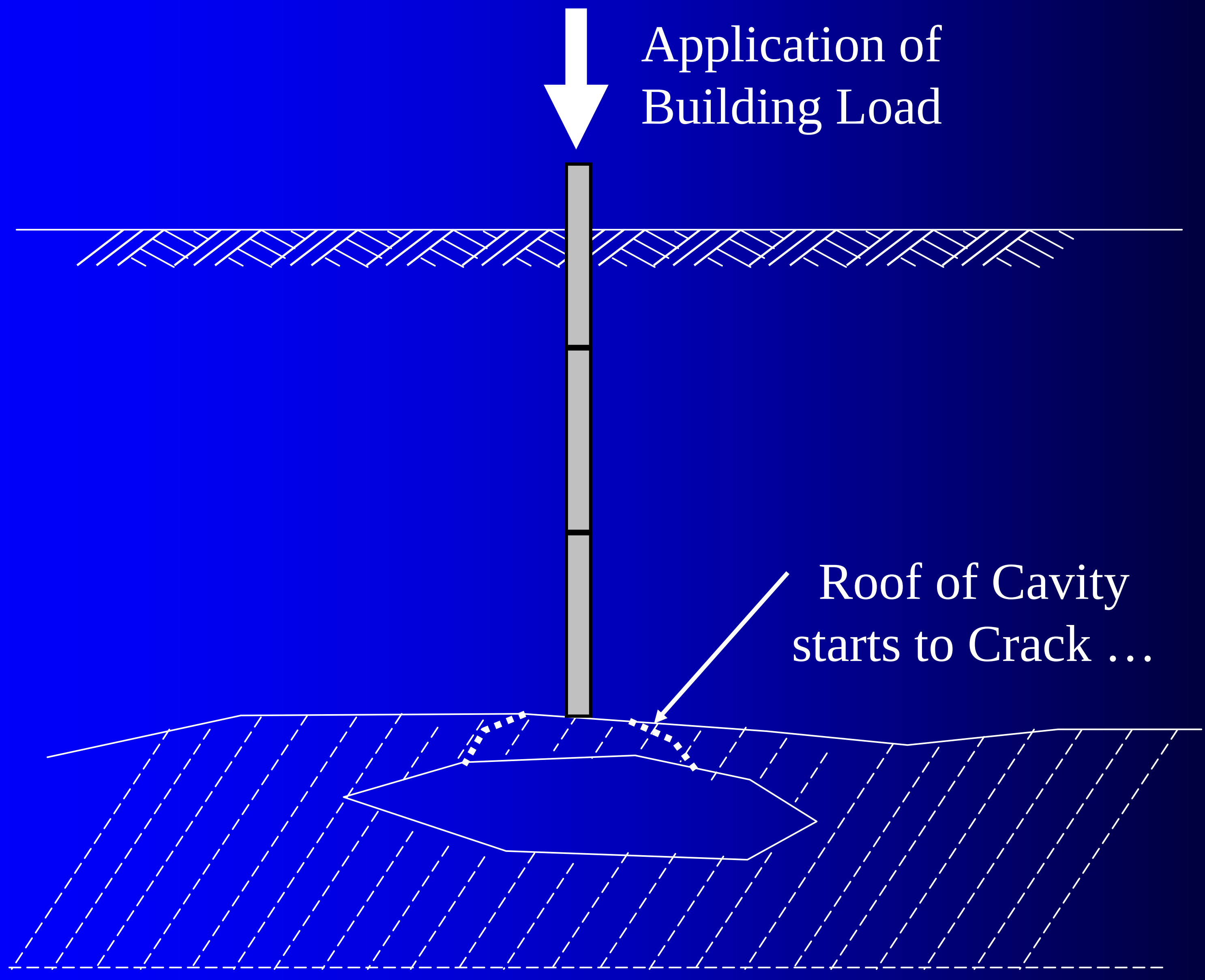
Solution #2

Detect Cavities through Cavity Probing then perform Compaction Grouting

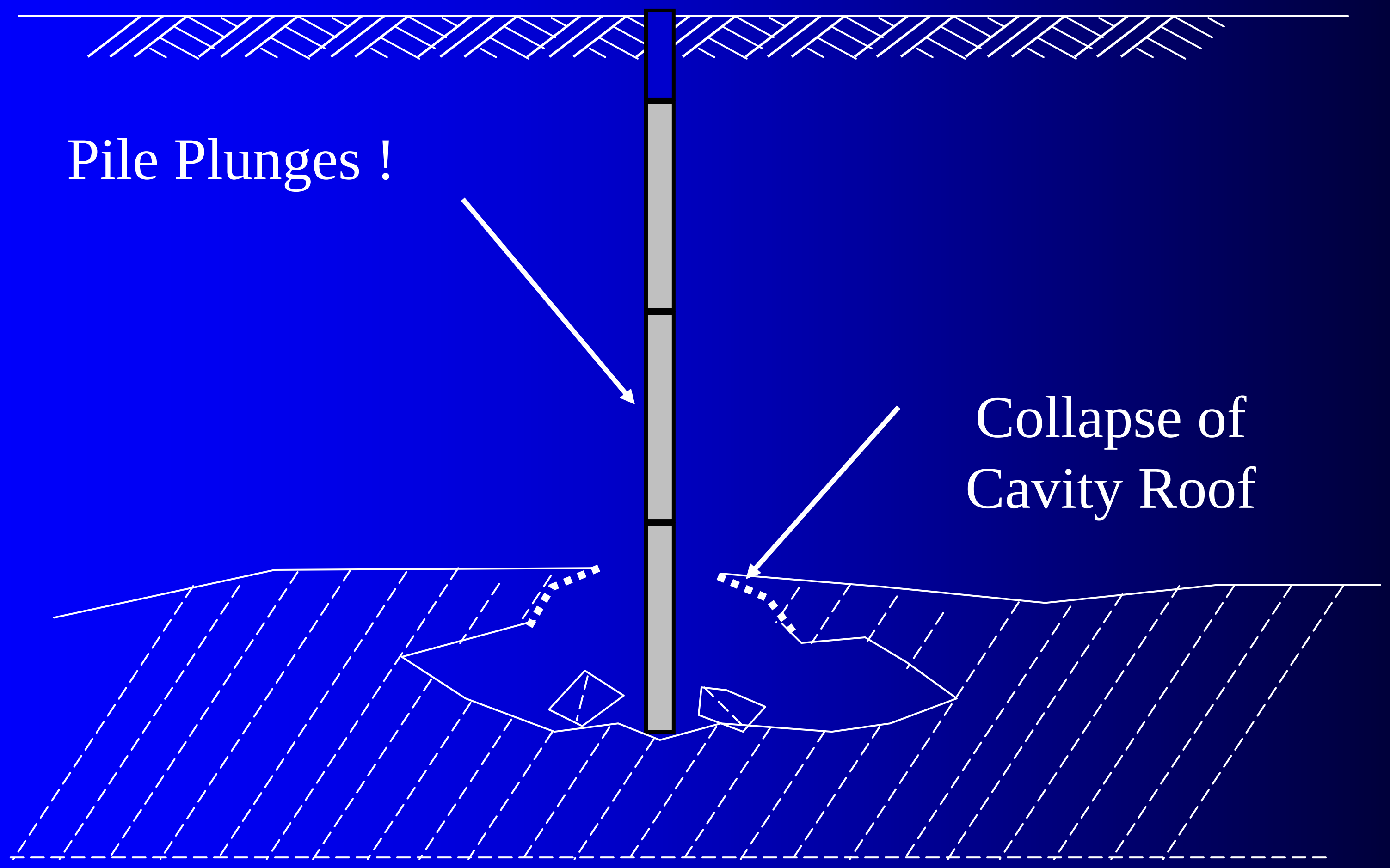
Presence of Cavity




Application of
Building Load


Application of
Building Load
Roof of Cavity
starts to Crack …

Building Collapse



Design and Construction Issues #3

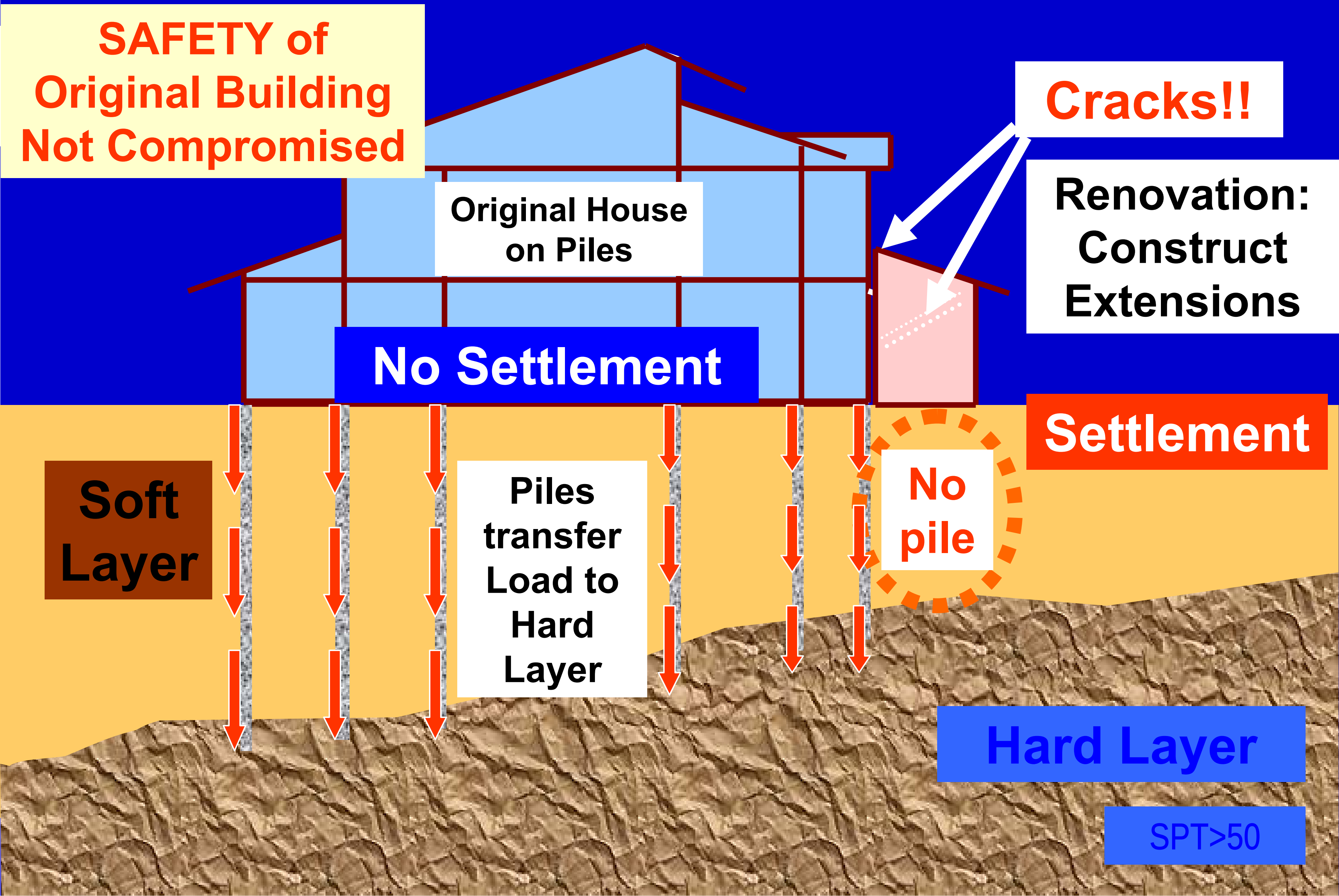
Issue #3

Differential Settlement

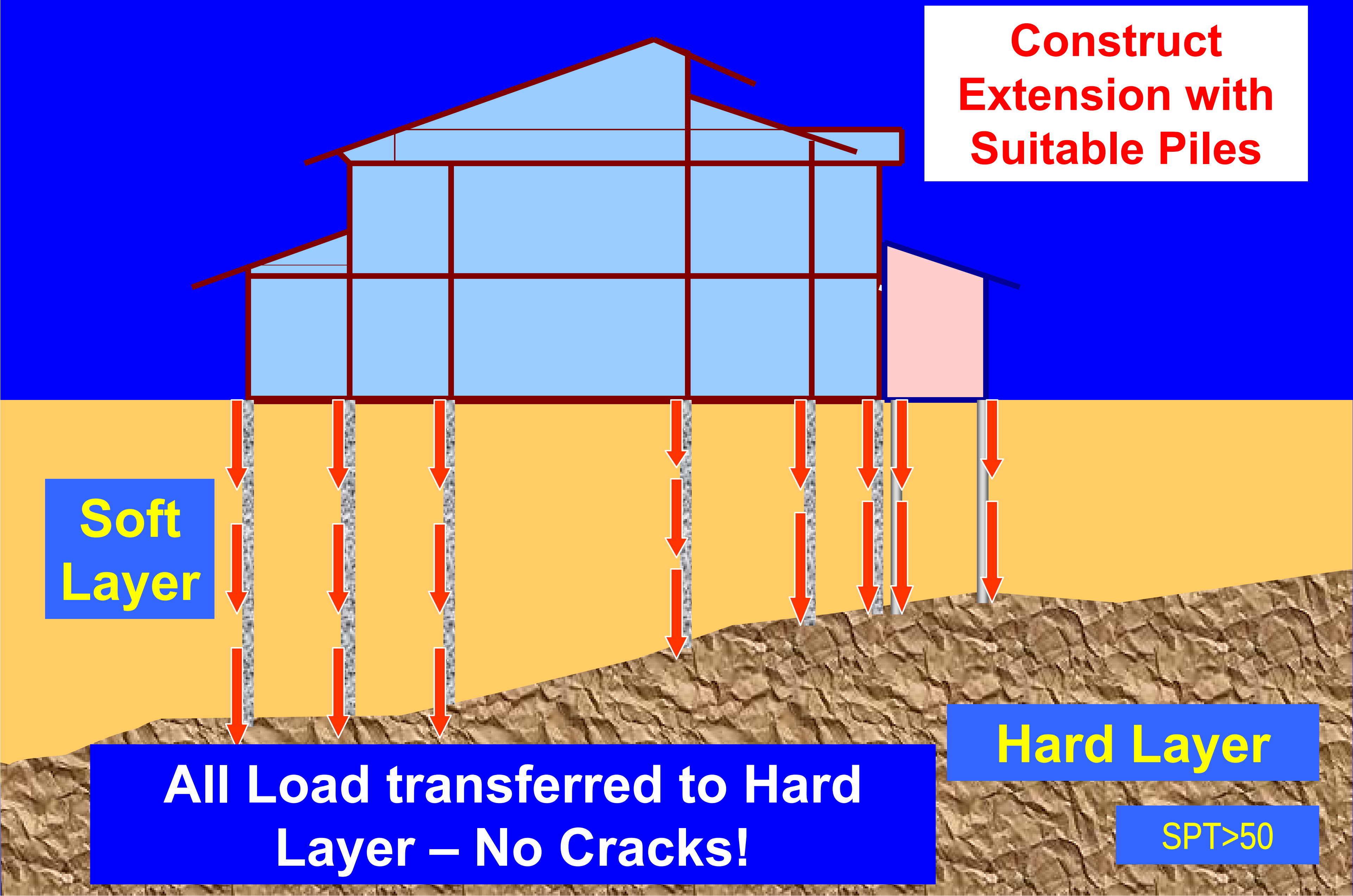
Solution #3

Carry out analyses to check the settlement compatibility if different piling system is adopted

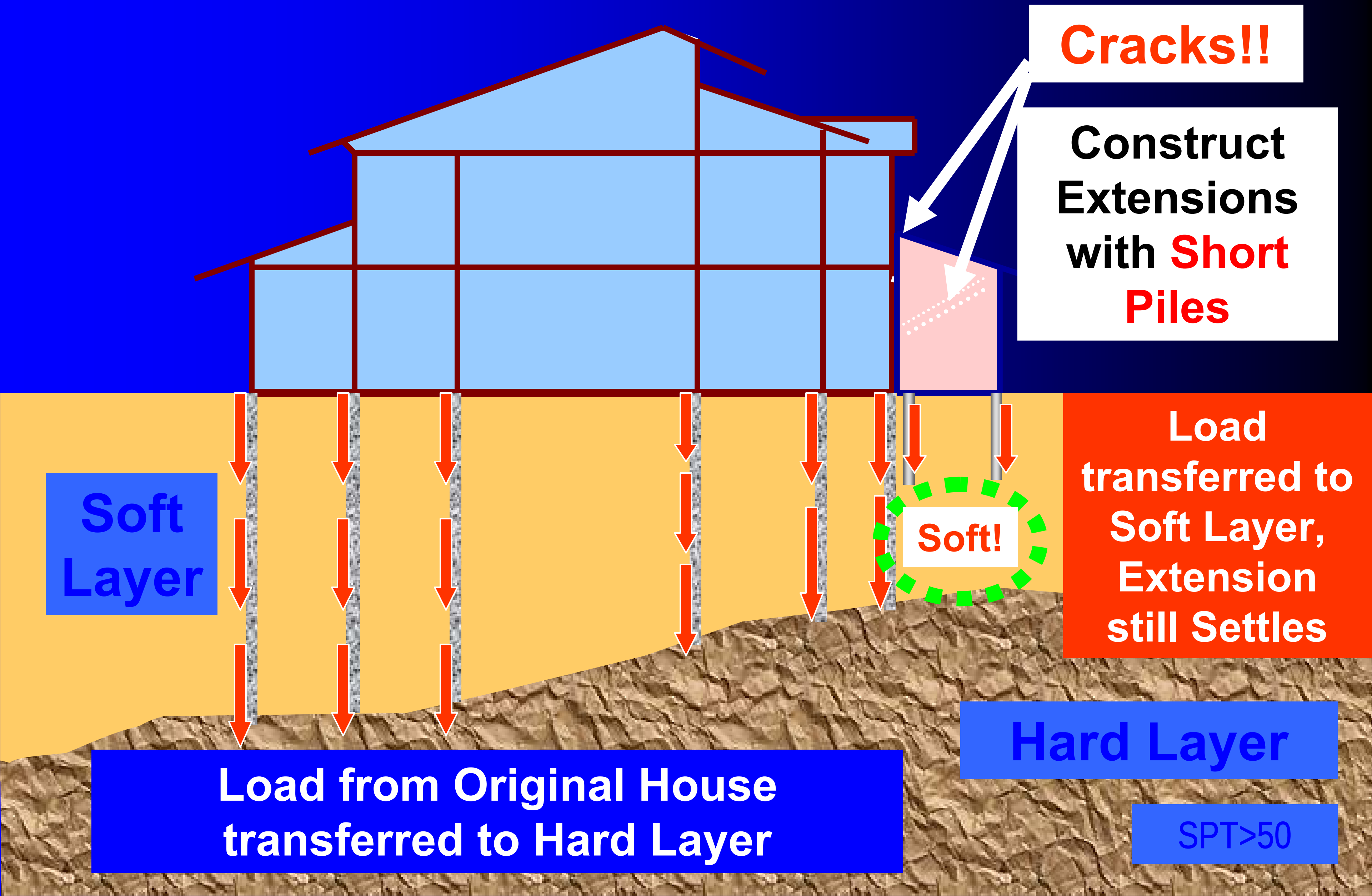
Differential Settlement of Foundation



Eliminate Differential Settlement



Problem of Short Piles



Cracks at Extension

Typical Design and Construction Issues #4

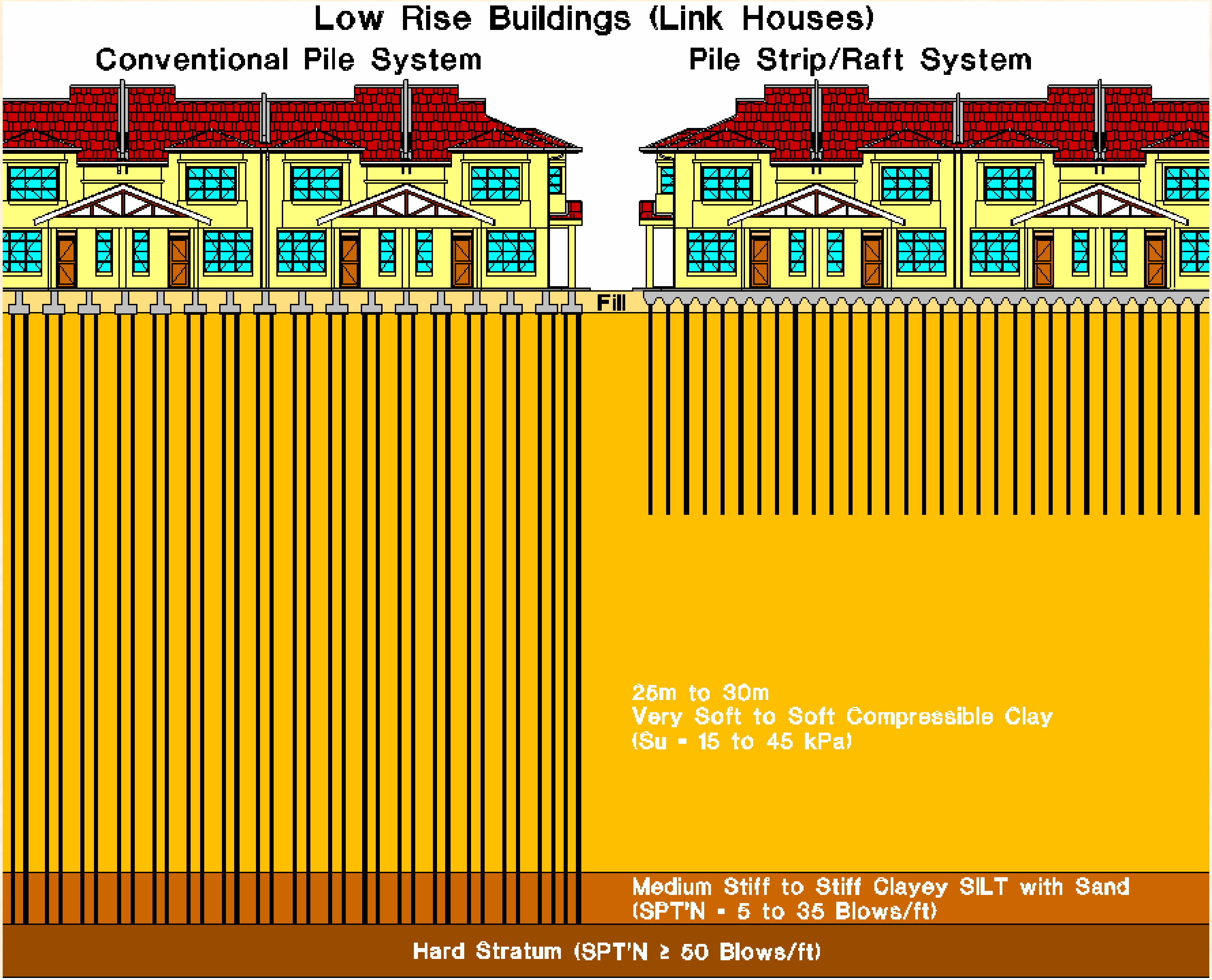
Issue #4

Costly conventional piling design – piled to set to deep layer in soft ground

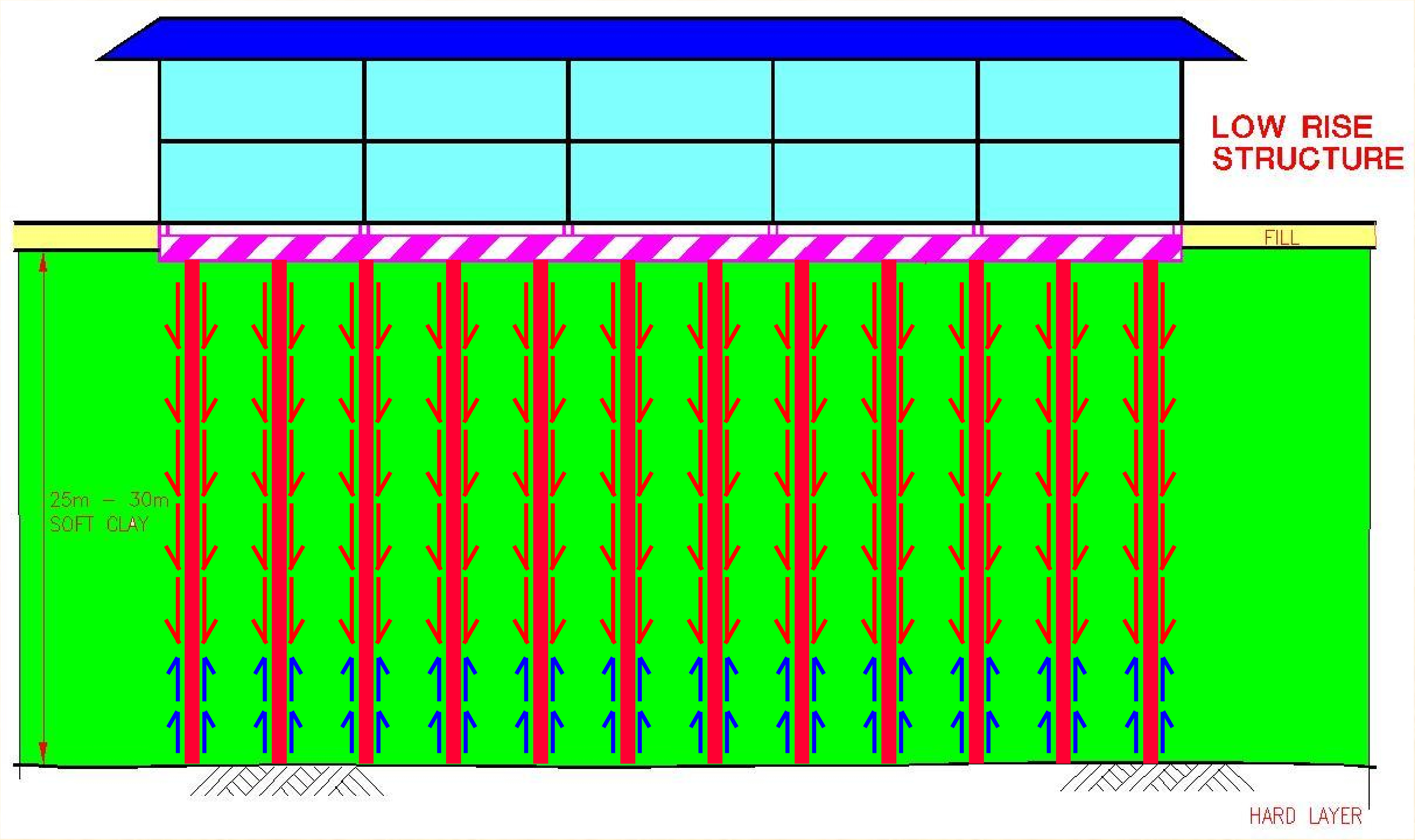
Solution #4

-Strip footings / Raft

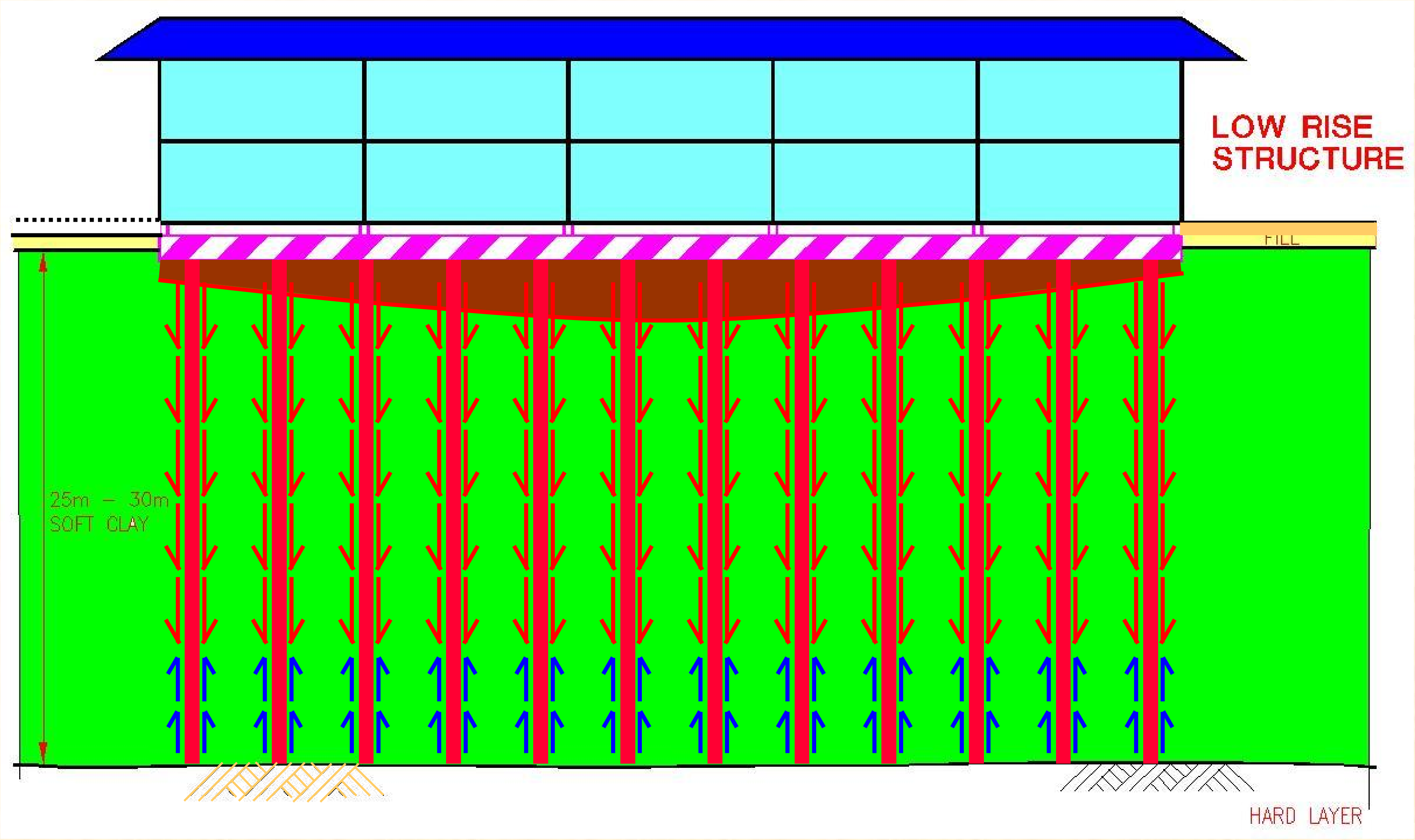
-Floating Piles


Low Rise Buildings (Link Houses)
Conventional Pile System
Pile Strip/Raft System
Fill
25m to 30m
Very Soft to Soft Compressible Clay
(Su = 15 to 45 kPa)
Medium Stiff to Stiff Clayey SILT with Sand
(SPT'N = 5 to 35 Blows/ft)
Hard Stratum (SPT'N ≥ 50 Blows/ft)

"Conventional" Foundation for Low Rise Buildings



Foundation for Low Rise Buildings (Soil Settlement)



Settling Platform Detached from Building

Conceptual Design of FOUNDATION SYSTEM

1. **Low Rise Buildings :-**

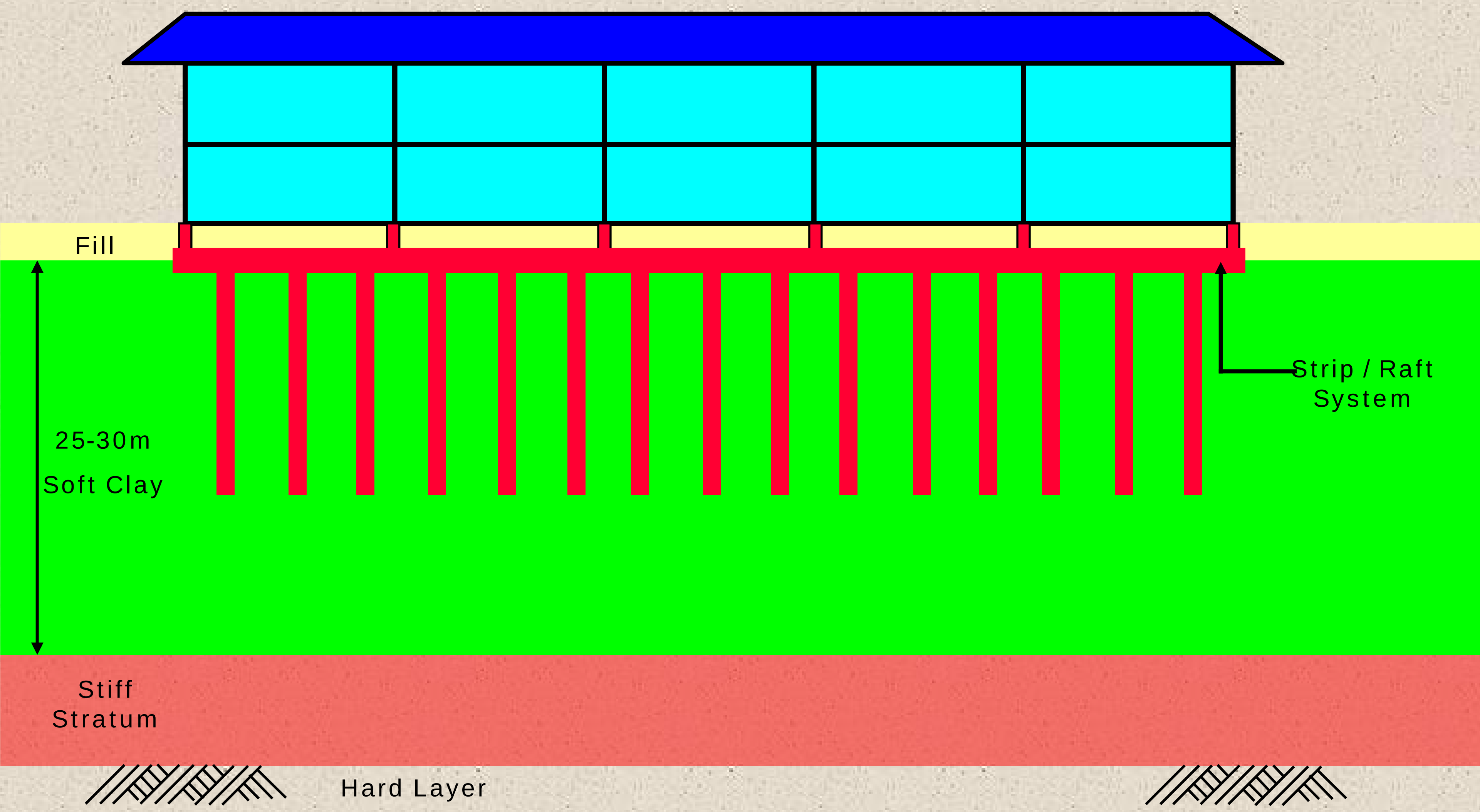
   (Double-Storey Houses)

   = Strip Footings or Raft or Combination.

2. **Medium Rise Buildings :-**

   = Floating Piles System.

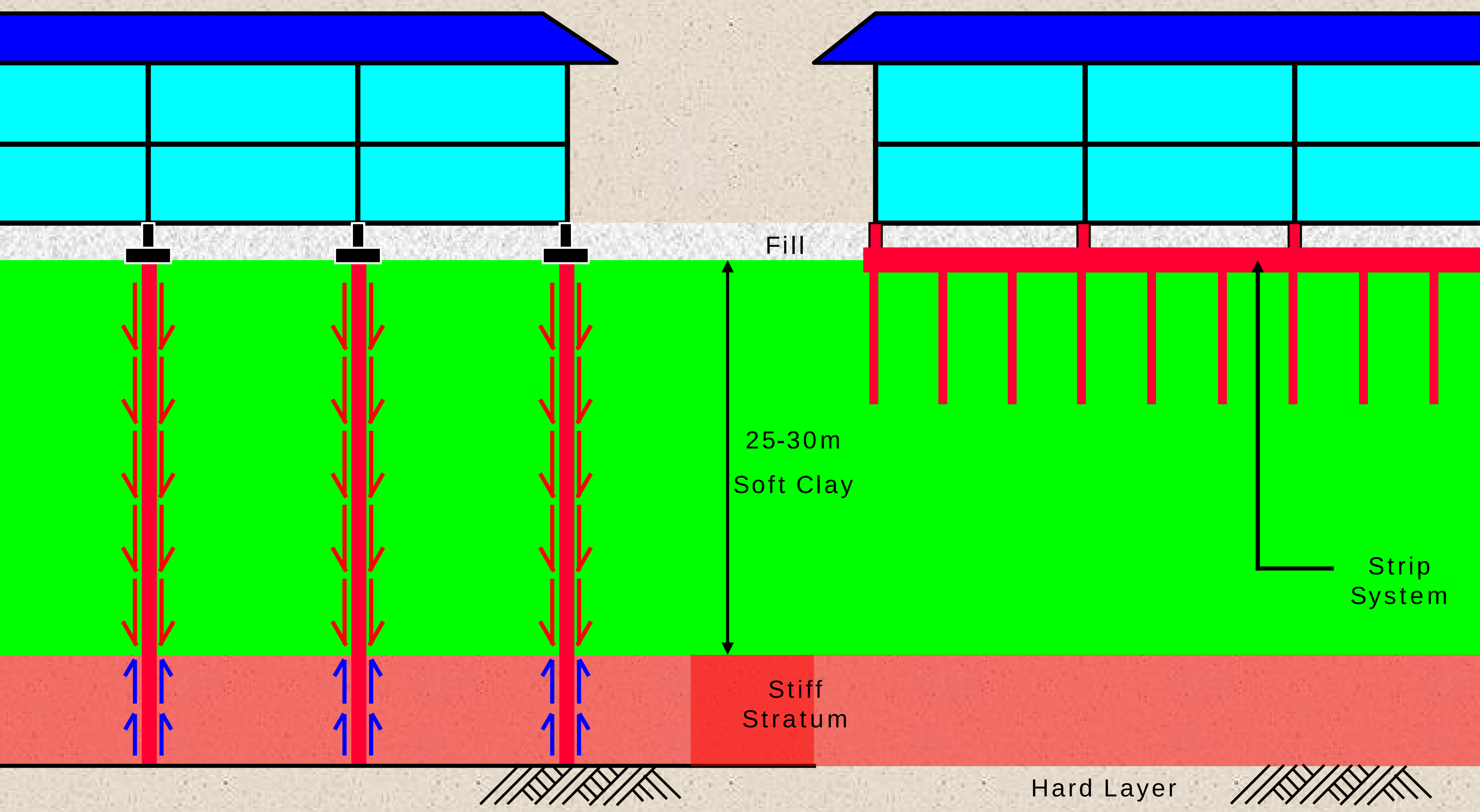
Low Rise Buildings on Piled Raft/Strips



Comparison

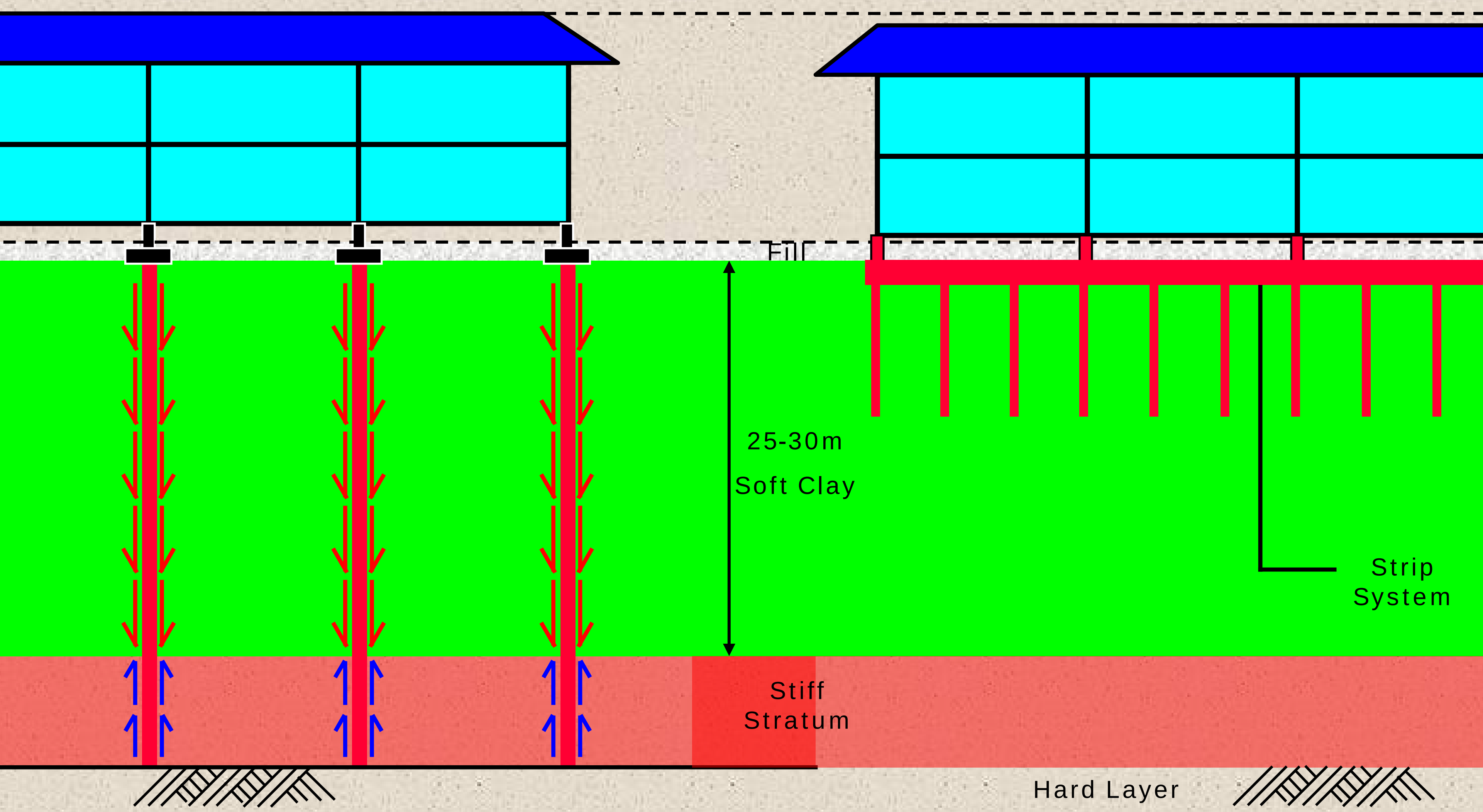
Building on Piles

Building on Piled Strips



Comparison (after settlement)

Building on Piles | **Building on Piled Strips**



Advantages of Floating Piles System

1. **Cost Effective.**

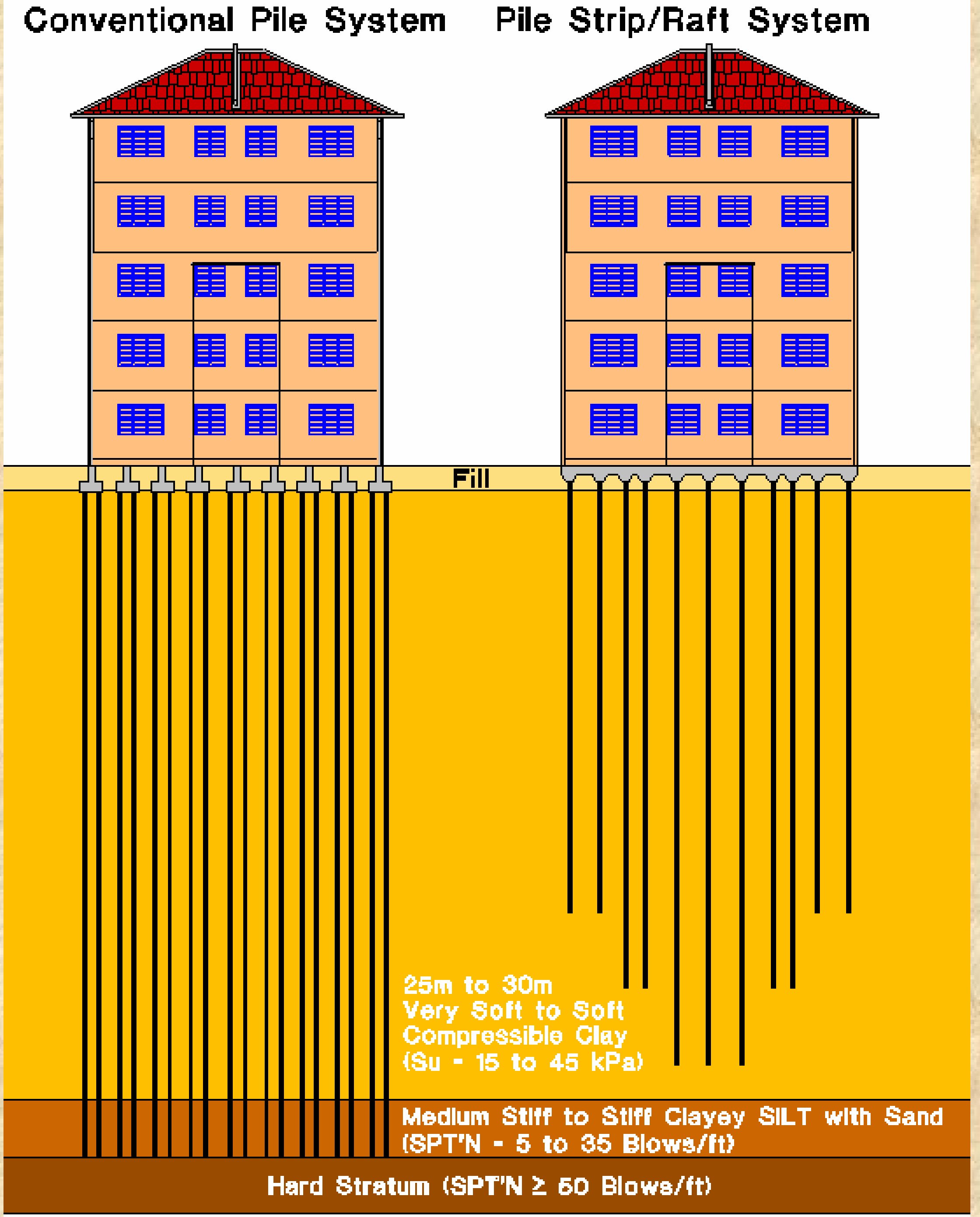
2. **No Downdrag problems on the Piles.**

3. **Insignificant Differential Settlement between Buildings and Platform.**

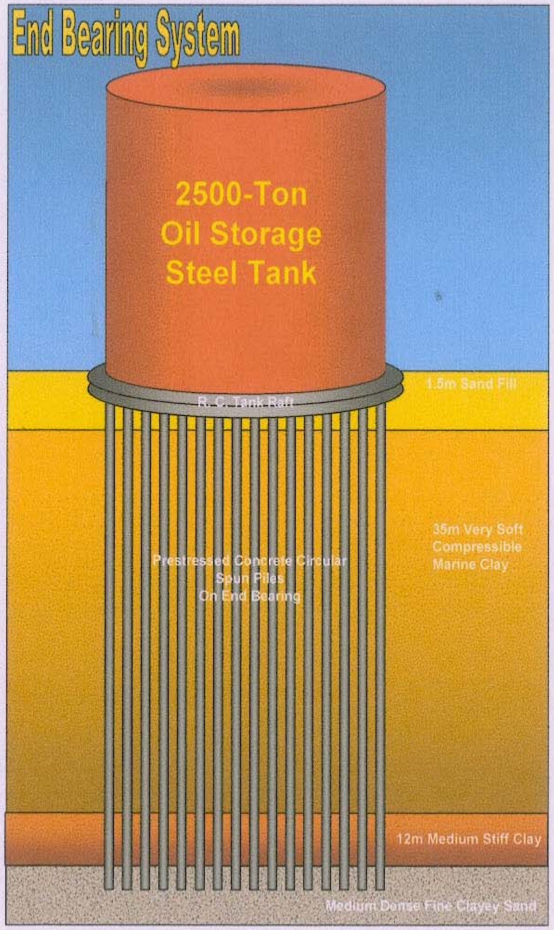
Bandar Botanic

Bandar Botanic at Night

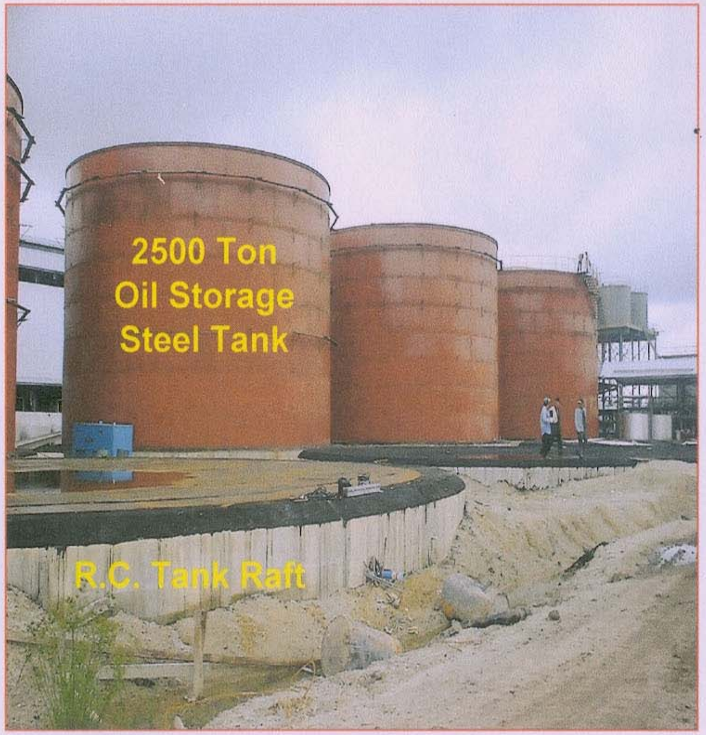
Medium Rise Buildings



Soft Ground Engineering



Adopted



Completed Tank Structure

Typical Design and Construction Issues #5

Issue #5

Load test results far below predicted pile capacity

Solution #5

-Modifications to test set-up

-Change of pile installation method

-Adequate soil plug to prevent toe softening

Testing Set-up Using Reaction Piles

Testing Set-up

- Long reaction piles at close spacing used
- Case histories:
  - Load tests using reaction piles give **ERRATIC** results
  - Reference: Weele (1993)

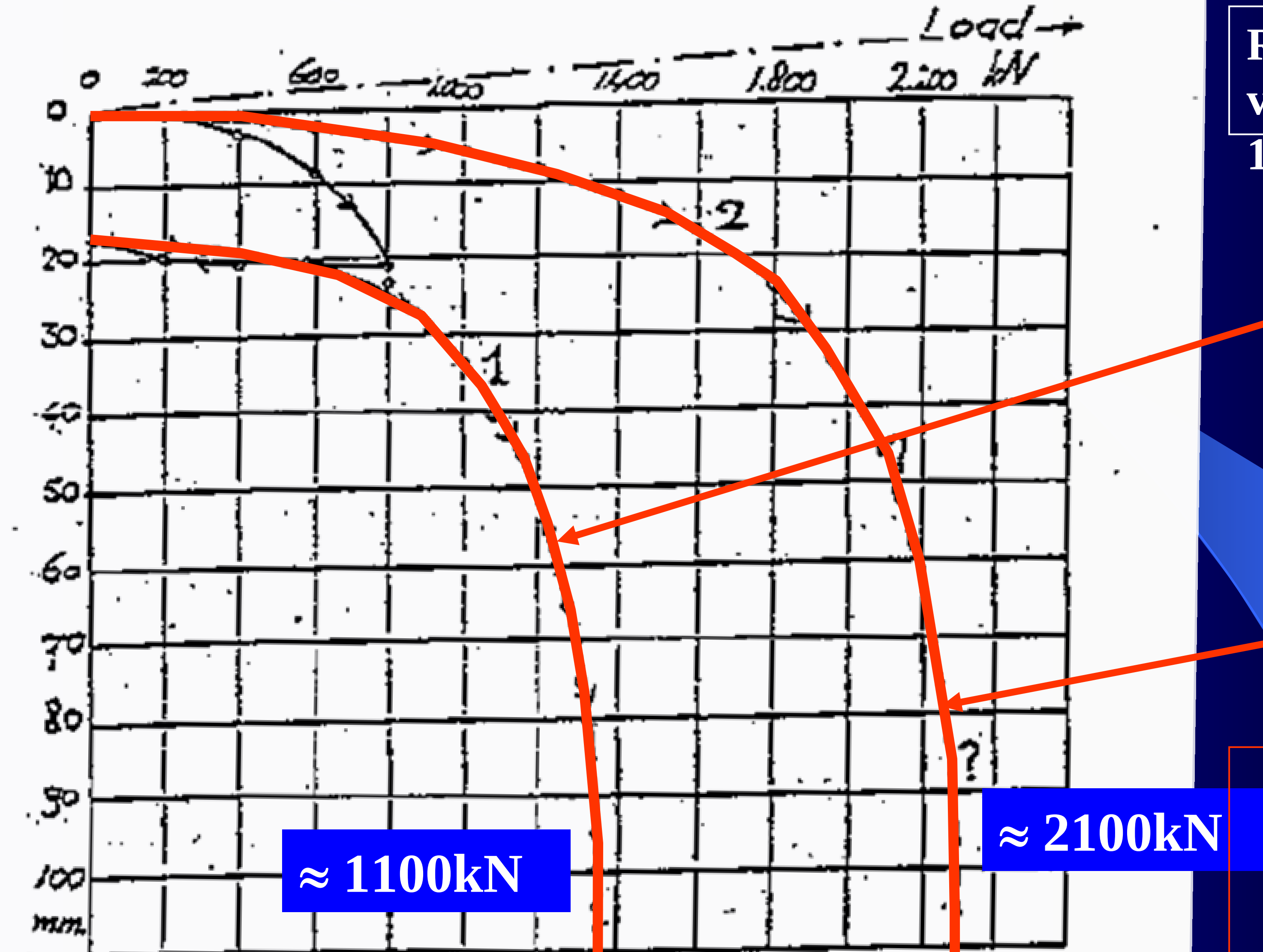


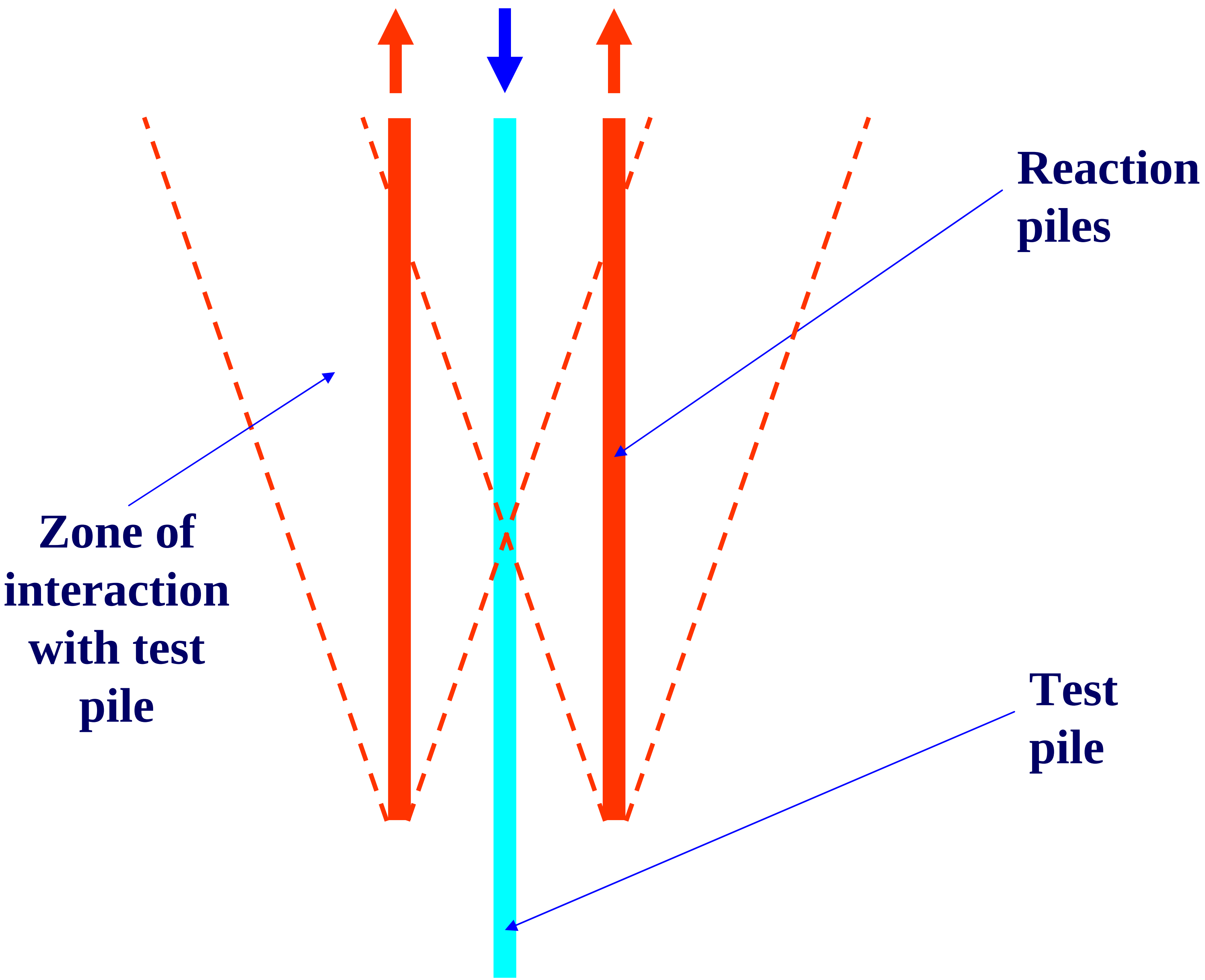
Fig. 1 The result of 2 load tests on the same pile. Test 1 with anchorpiles; test 2 with dead weight.

Ref: A.F. van Weele, 1993

Tested using anchor piles

Tested using kentledge

Approx. 2 times smaller using reaction piles!


Reaction piles
Zone of interaction with test pile
Test pile

Testing Set-up

- Latest version of ASTM D1143
- Published April 2007

ASTM INTERNATIONAL

Designation: D 1143/D 1143M – 07

Standard Test Methods for Deep Foundations Under Static Axial Compressive Load[1]

This standard is issued under the fixed designation D 1143/D 1143M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

Testing Set-up

- **ASTM D1143**
  - **Clear distance of at least 5 times the maximum diameter**
  - **Caution on factors influencing results:**
    - **“Possible interaction ……….from anchor piles……..”**

Drilling to the Casing Tip to Form "Bored Pile"

Drilling to Form “Bored Pile”

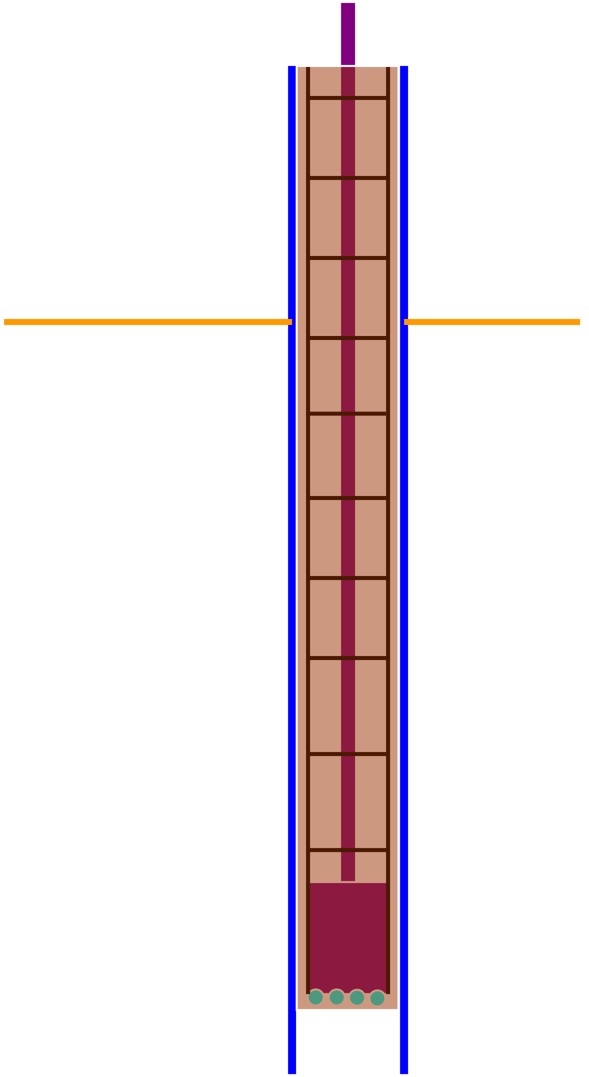
- Disturbance to soil at tip and surrounding the pile
- Potential **hydraulic/basal heave failure** resulting in lower soil strength
- Effect more severe for longer pile

Construction of "Bored Pile"

1. Install Permanent Steel Casing to Pile Toe

2. Removal of Soil within Steel Casing to Toe of Casing

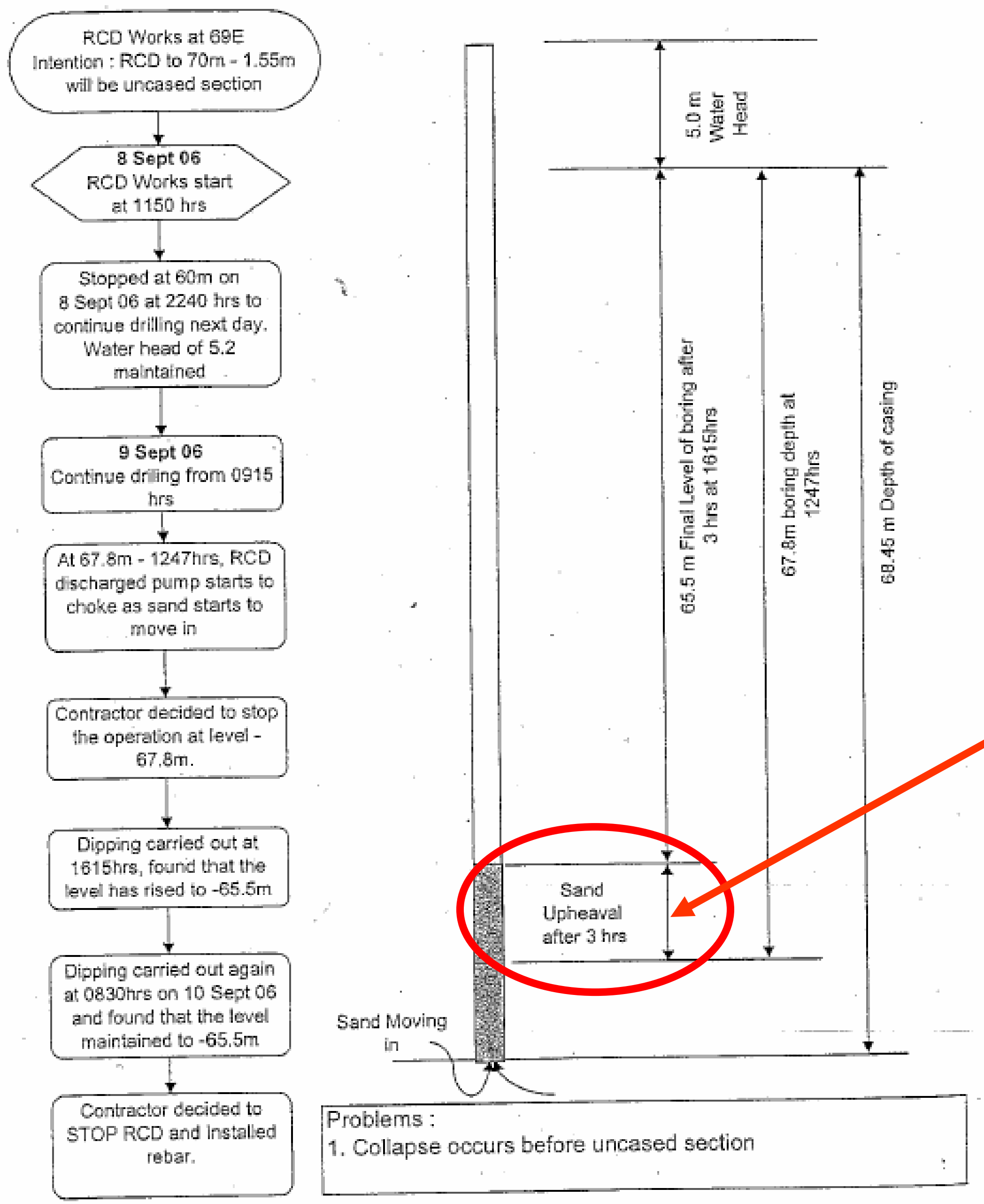
3. Installation of Reinforcement and Concreting



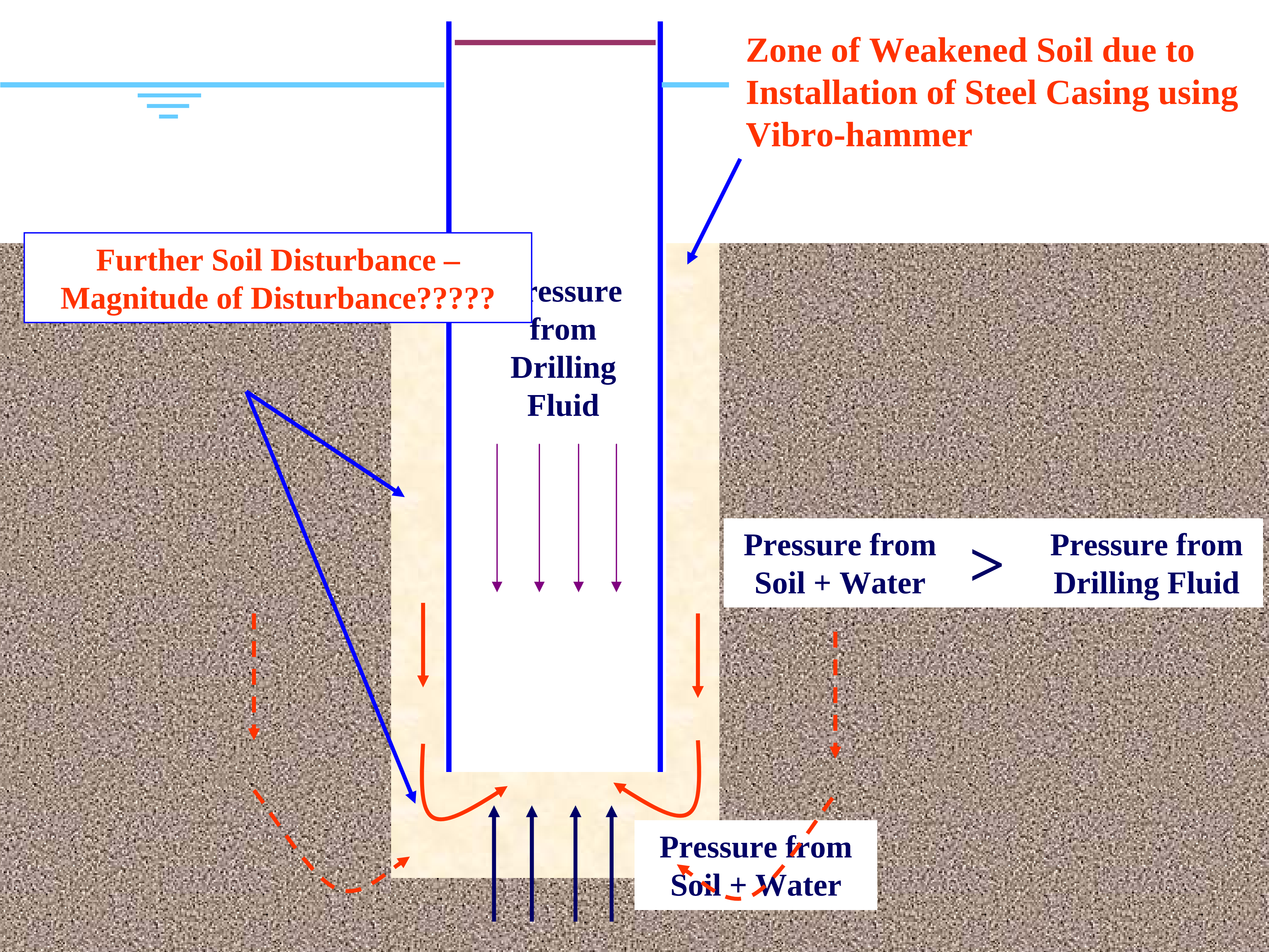
Drilling to Form "Bored Pile"

- Pile behaviour **COMPLICATED!**
  - Influenced by steel casing which behave like **DRIVEN PILE**
  - Influenced by soil removal which behave like **BORED PILE**

RCD Works for Test Pile 69E
(8 - 9 Sept 06)



SAND UPHEAVAL AFTER 3 HRS



Zone of Weakened Soil due to Installation of Steel Casing using Vibro-hammer
Further Soil Disturbance – Magnitude of Disturbance?????
ressure from Drilling Fluid
Pressure from Soil + Water
>
Pressure from Drilling Fluid
Pressure from Soil + Water

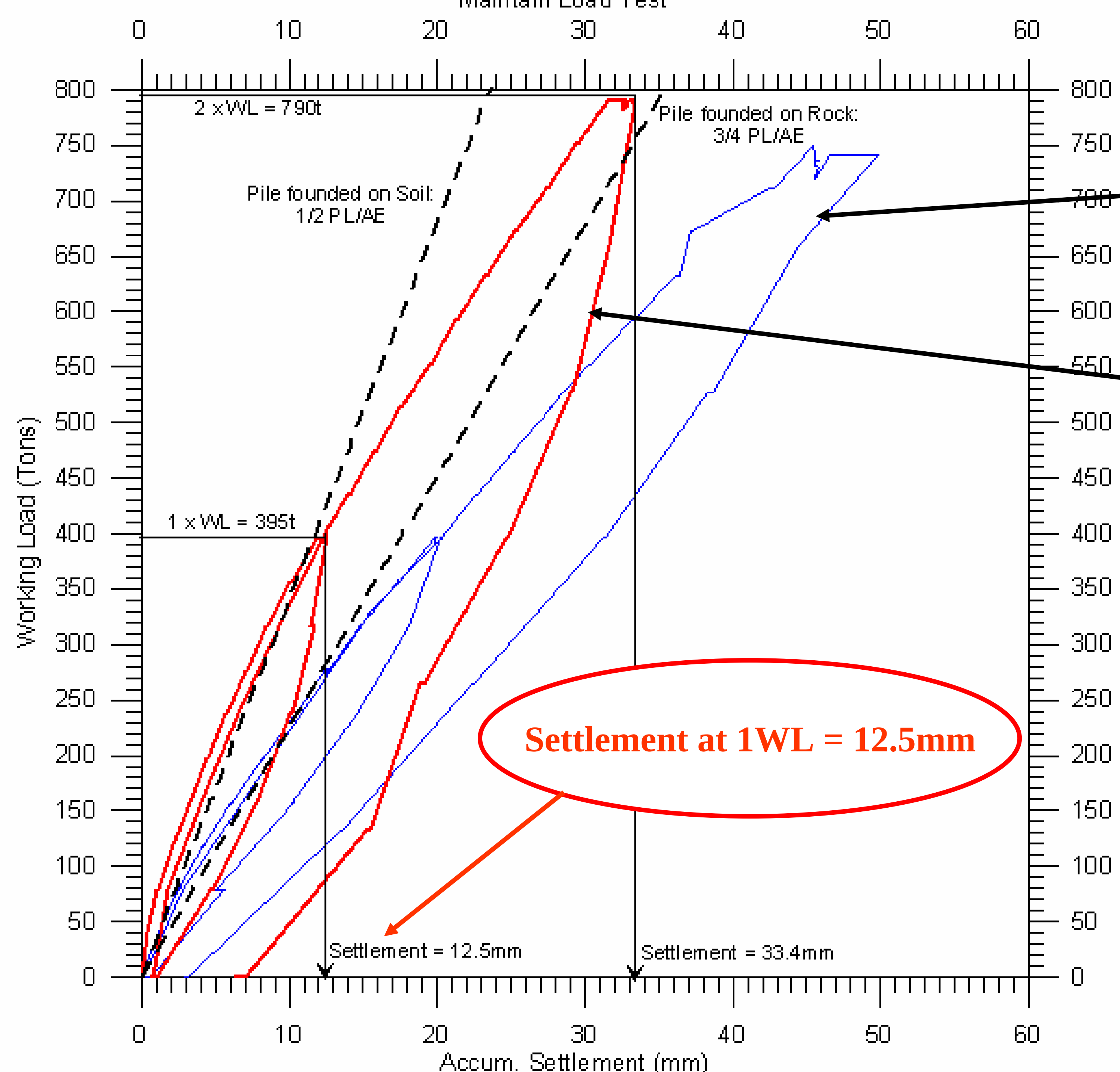
- **Probable causes of erratic and unpredictable pile capacities:**
  - Testing set-up using reaction piles
  - Drilling to the casing tip to form “bored pile”

Original Load Test

– 1^{st} Load Test – Failed at **90% of WL**
  - After 32 days

– 2^{nd} Load Test – Failed at **110% of WL**
  - After 94 days

- **Recommendations:**
  - Open-ended spun pile or steel pipe pile with adequate soil plug
  - Use of impact hammer instead of vibro-hammer
  - Trial piles for correlation between static load test and high strain dynamic load test



Result for Empty Casing

Result for Concreted Pile

Pile performs satisfactorily within acceptable settlement limits!!!

Load Test Results at P52W

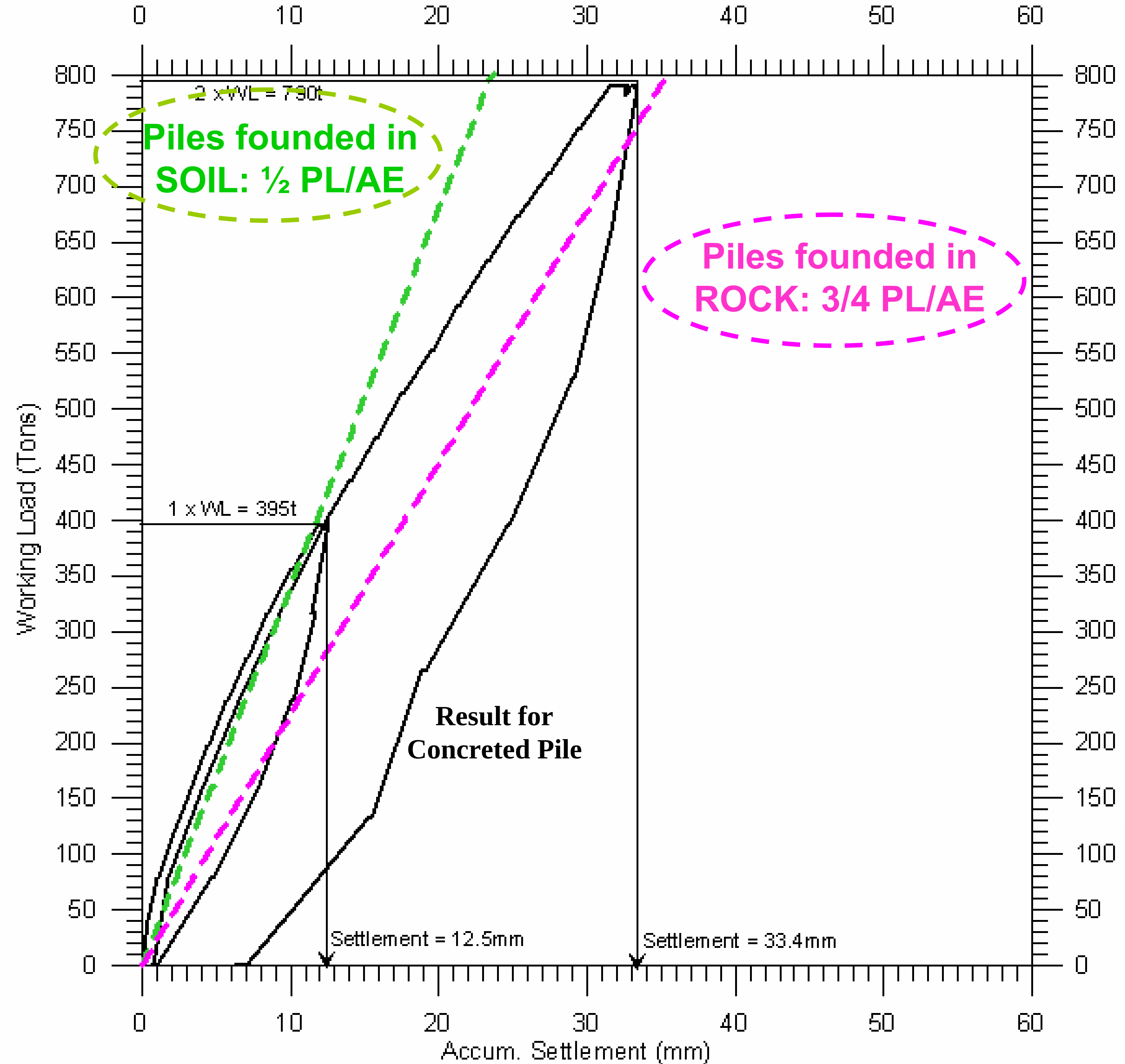
- **Result for Empty Casing**
  - 1xWL: pile settlement= 20mm (residual settlement= 1mm)
  - 1.9xWL: pile settlement= 50mm (residual settlement= 3mm)
- **Result for Cast Pile**
  - 1xWL: pile settlement= 12.5mm (residual settlement= 1mm)
  - 2xWL: pile settlement= 33.4mm (residual settlement= 7mm)

The Pile is Stiffer after Concreting !!

Larger Residual Settlement due to Disturbance from RCD work !!

Load Test Results at P52W

- Research by Ng et al., 2001:
  - Elastic compression of large diameter bored piles:
    - **½ PL/AE - Piles founded in soil**
    - **¾ PL/AE - Piles founded in rocks**



Settlement is in accordance to prediction!!

ELASTIC COMPRESSION OF PILE

- Depends on:
  - E – Elastic Modulus of Pile Material
  - A – Cross-sectional Area of Pile
  - L – Pile Length

Elastic Compression = f (PL / AE)

Therefore, after concreting of pile:

- A increased significantly (composite E due to steel and concrete reduced slightly)
- Elastic compression will reduce

Pile Settlement Criteria

- Pile settlement criteria depends on
  - Pile Size
  - Pile Material (e.g. steel, concrete, etc.)
  - Pile Length

- **Unrealistic to adopt same settlement criteria (e.g. 12mm) for all piles (regardless of length, size, etc.)**

Myths in Piling

MYTHS IN PILING #1

Myth:

Dynamic Formulae such as Hiley's Formula Tells us the Capacity of the Pile

Truth:

Pile Capacity can only be verified by using:

(i) Maintained (Static) Load Tests

(ii)Pile Dynamic Analyser (PDA) Tests

MYTHS IN PILING #2

Myth:

Pile Achieves Capacity When It is Set.

Truth:

Pile May Only "Set" on Intermediate Hard Layer BUT May Still Not Achieve Required Capacity within Allowable Settlement.

MYTHS IN PILING #3

Myth:

Pile settlement at 2 times working load must be less than certain magnitude (e.g. 38mm)

Truth:

Pile designed to Factor of Safety of 2.0. Therefore, at 2 times working load:

Pile expected to fail unless capacity under-predicted significantly

Pile Capacity Design
Factor of Safety (FOS)

Global factor of safety for total ultimate capacity

- Use 2.0 (typical)
- $$Q_{all} = \frac{\Sigma Q_{su} + Q_{bu}}{2.0}$$

CASE HISTORIES

- Case 1: Structural distortion & distresses
- Case 2: Distresses at houses

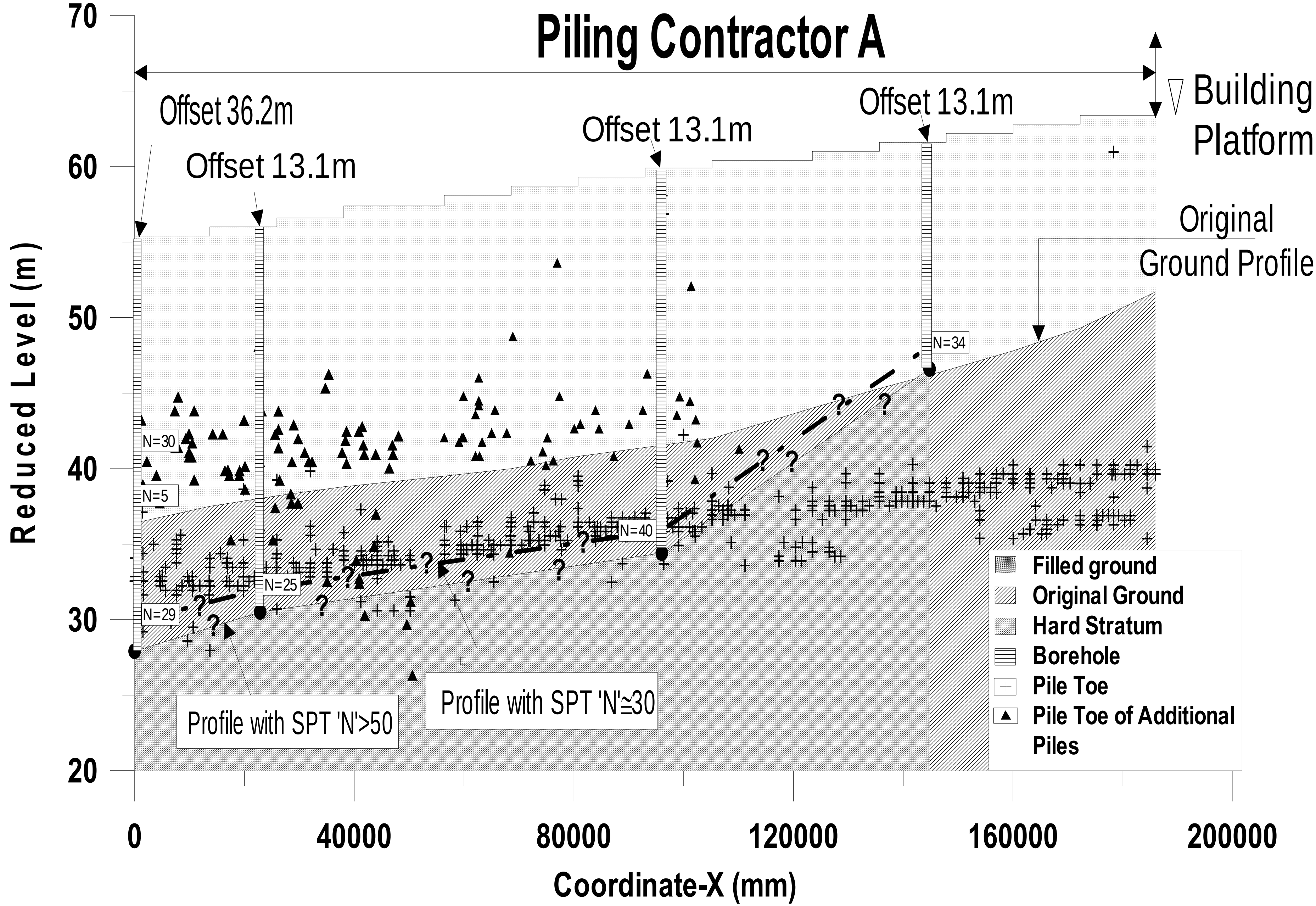
CASE HISTORY 1

Distortion & Distresses on 40 Single/ 70 Double Storey Houses

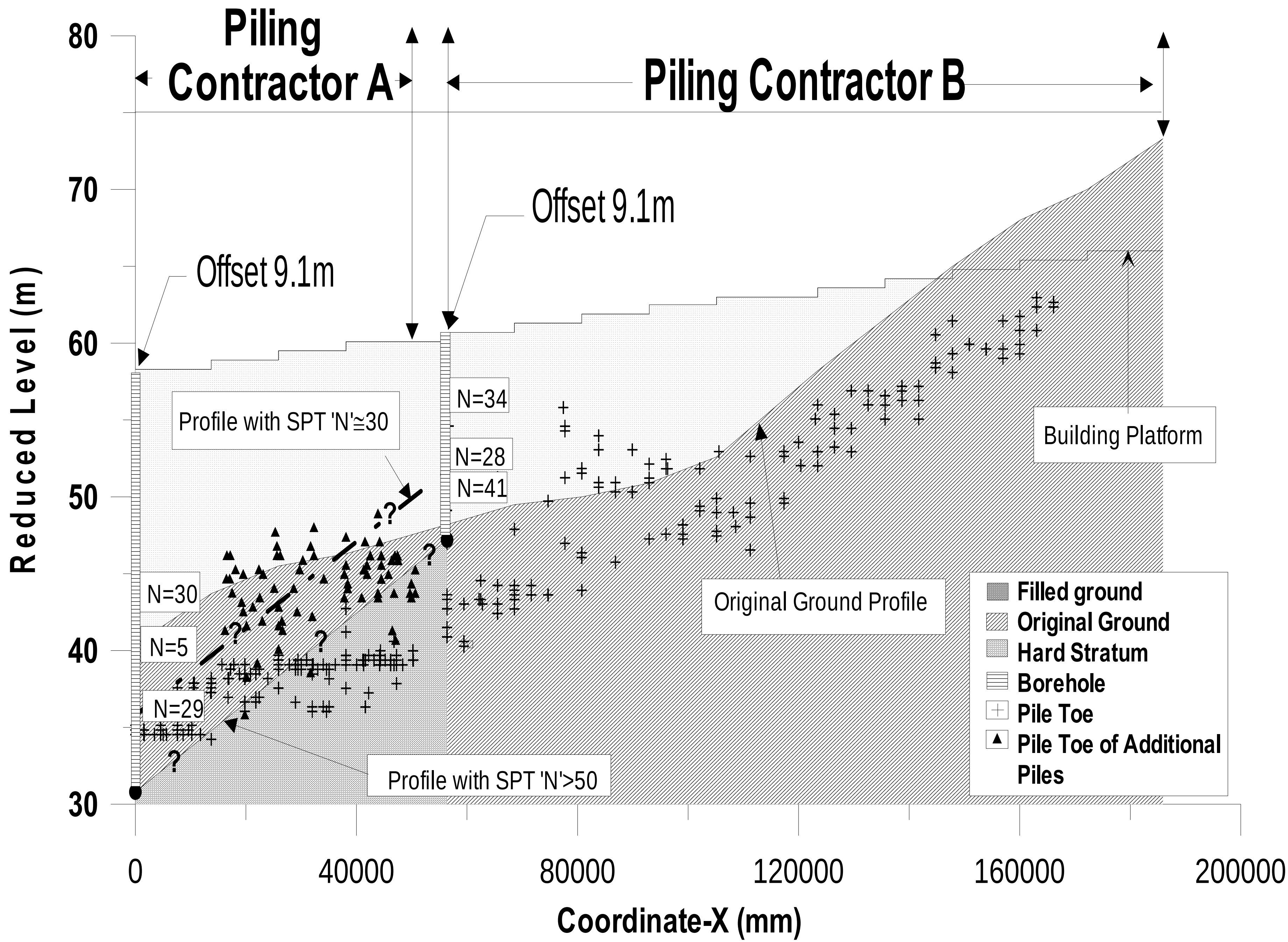
- Max. 20m Bouldery Fill on Undulating Terrain
- Platform Settlement
- Short Piling Problems
- Downdrag on Piles

Distresses on Structures


Void



Piling Contractor A
Building Platform
Offset 36.2m
Offset 13.1m
Offset 13.1m
Offset 13.1m
Original Ground Profile
N=30
N=5
N=29
N=25
N=40
N=34
Profile with SPT 'N'>50
Profile with SPT 'N'≅30
Filled ground
Original Ground
Hard Stratum
Borehole
Pile Toe
Pile Toe of Additional Piles
Reduced Level (m)
Coordinate-X (mm)
70
60
50
40
30
20
0
40000
80000
120000
160000
200000



Piling Contractor A
Piling Contractor B
Offset 9.1m
Offset 9.1m
Profile with SPT 'N'≅30
N=34
N=28
N=41
N=30
N=5
N=29
Building Platform
Original Ground Profile
Profile with SPT 'N'>50
Filled ground
Original Ground
Hard Stratum
Borehole
Pile Toe
Pile Toe of Additional Piles
Reduced Level (m)
Coordinate-X (mm)
80
70
60
50
40
30
0
40000
80000
120000
160000
200000

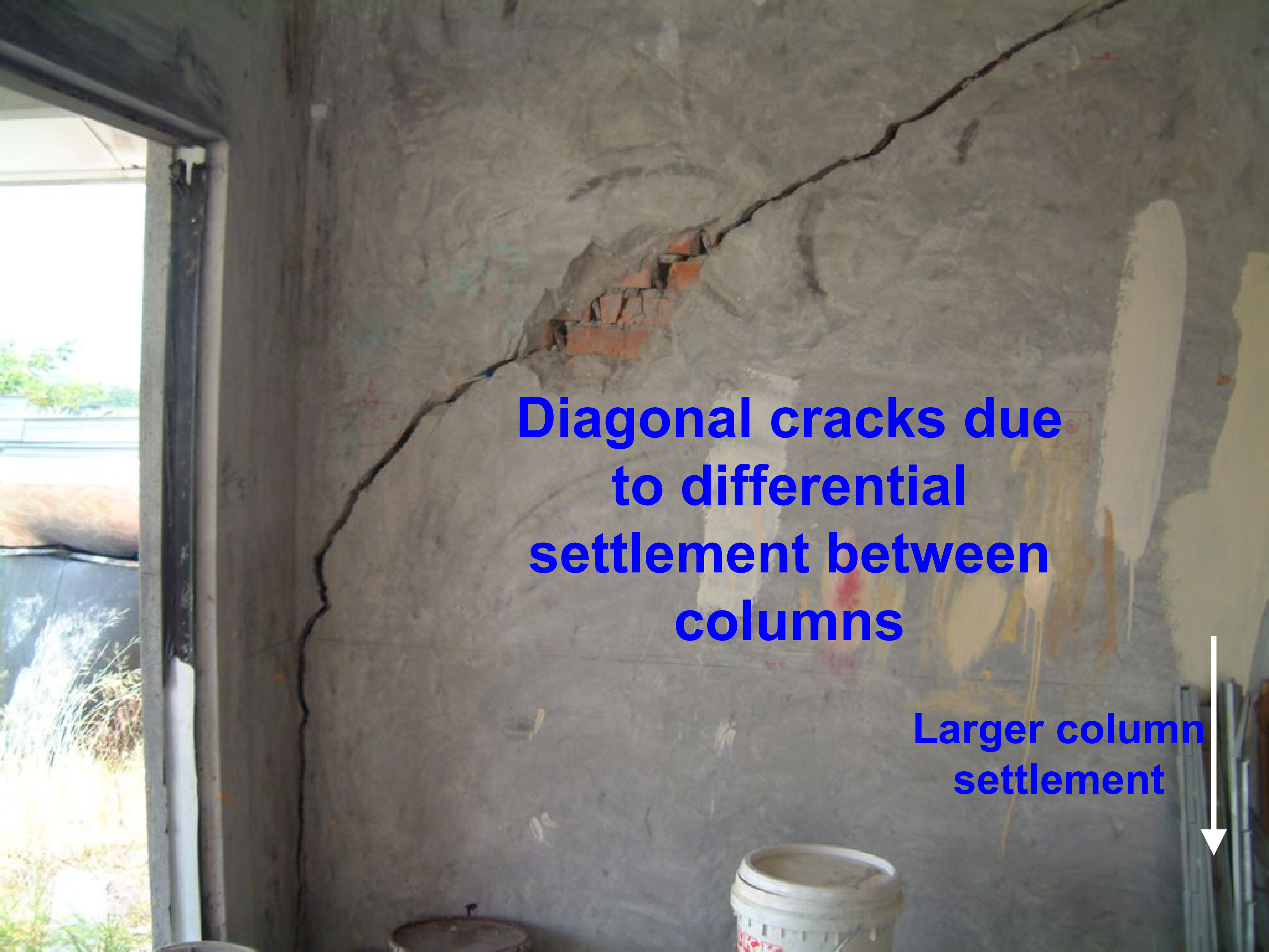
Prevention Measures

- Design:
  - Consider downdrag in foundation design
  - Alternative strip system
- Construction:
  - Proper QA/QC
  - Supervision

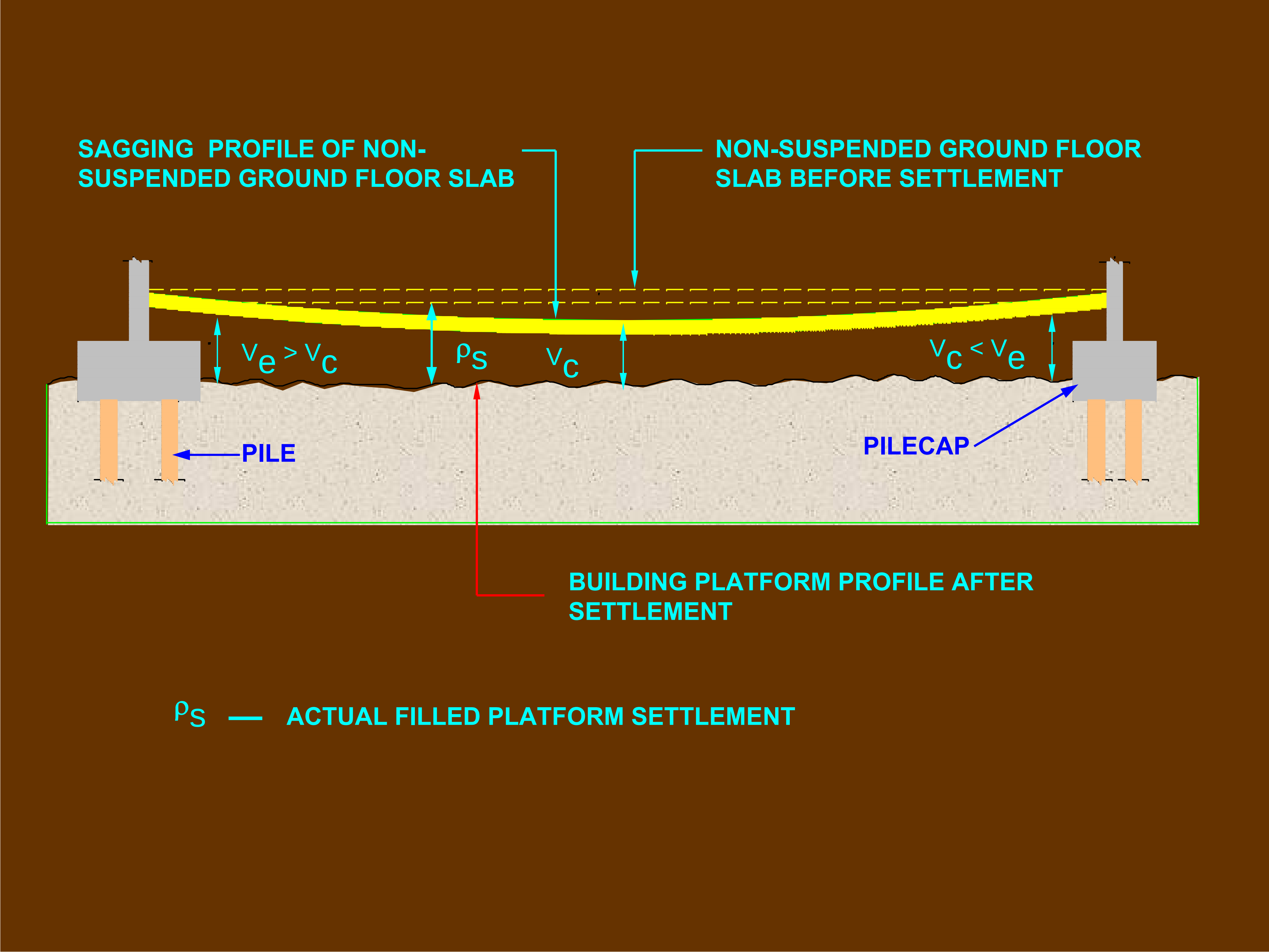
CASE HISTORY 2

Distresses on 12 Double Storey Houses & 42 Townhouses

- Filled ground: platform settlement
- Design problem: non-suspended floor with semi-suspended detailing
- Bad earthwork & layout design
- Short piling problem

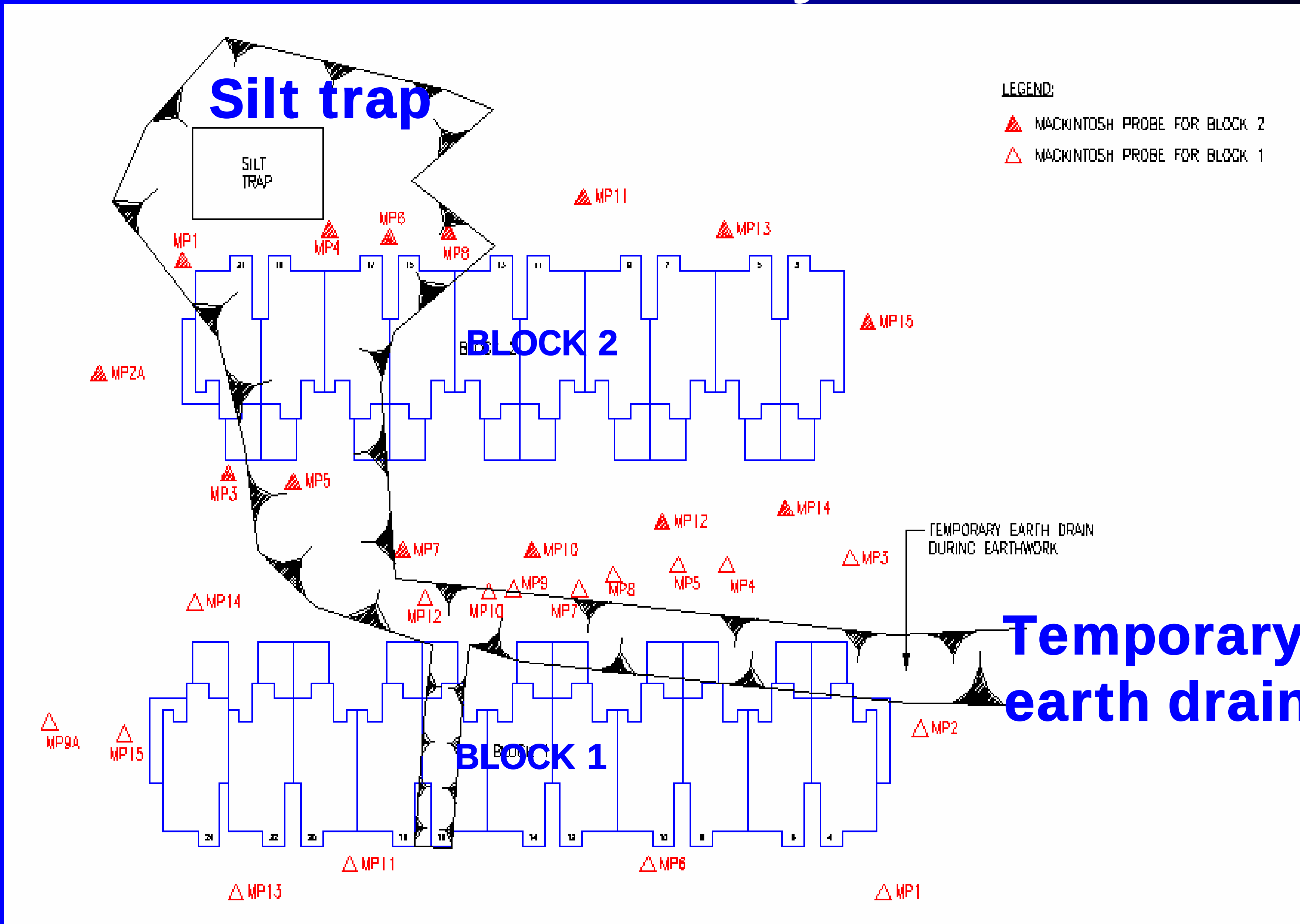

Diagonal cracks due to differential settlement between columns
Larger column settlement


Sagging
Ground
Floor Slab


SAGGING PROFILE OF NON-SUSPENDED GROUND FLOOR SLAB
NON-SUSPENDED GROUND FLOOR SLAB BEFORE SETTLEMENT
$v_e > v_c$
ρ_s
v_c
$v_c < v_e$
PILE
PILECAP
BUILDING PLATFORM PROFILE AFTER SETTLEMENT
ρ_s — ACTUAL FILLED PLATFORM SETTLEMENT


Distorted Car Porch Roof

Poor Earthwork Layout



Prevention Measures

- Planning:
  - Proper building layout planning to suit terrain (eg. uniform fill thickness)
  - Sufficient SI
- Design:
  - Consider filled platform settlement
  - Earthwork layout
- Construction:
  - Supervision on earthwork & piling

SUMMARY

- Importance of Preliminary Study
- Understanding the Site Geology
- Carry out Proper Subsurface Investigation that Suits the Terrain & Subsoil
- Selection of Suitable Pile
- Pile Design Concepts

SUMMARY

- Importance of Piling Supervision
- Typical Piling Problems Encountered
- Present Some Case Histories

CHALLENGING THE NORM

WITH TEAMWORK WE SHALL EXCEL TO HIGHER HORIZON

FERRARI 'S PITSTOP WAS COMPLETED BY 15 MECHANICS (FUEL AND TYRES) IN 6.0 SECONDS FLAT.

54 PEOPLE TOOK PART IN THIS CONCERTED ACROBATIC JUMP.

GEOTECHNICS

Thank You for Your Attention