Lecture 22

NPTEL Course

GROUND IMPROVEMENT

USING MICROPILES

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Introduction

- Micropiles were conceived in Italy in the early 195Os, in response to the demand for innovative techniques for underpinning historic buildings and monuments that had sustained damage during World War II. A reliable method was required to support structural loads with minimal movement and for installation in access-restrictive environments with minimal disturbance to the existing structure. An Italian specialty contractor called Fondedile, and Dr. Fernando Lizzi developed the technique.
- The use of micropiles has grown significantly and have been used mainly as elements for foundation support to resist static and seismic loading conditions, and as in-situ reinforcements for slope and excavation stability.

- Piles are divided in two general types as
    a) Displacement piles
    b) Replacement piles

Displacement piles are members that are driven or vibrated into the ground, there by displacing the surrounding soil laterally during installation.

Replacement piles are placed or constructed with in a previously drilled borehole, thus replacing the excavated ground.

A Micropile is a small diameter (< 300mm), drilled and grouted pile that is typically reinforced.

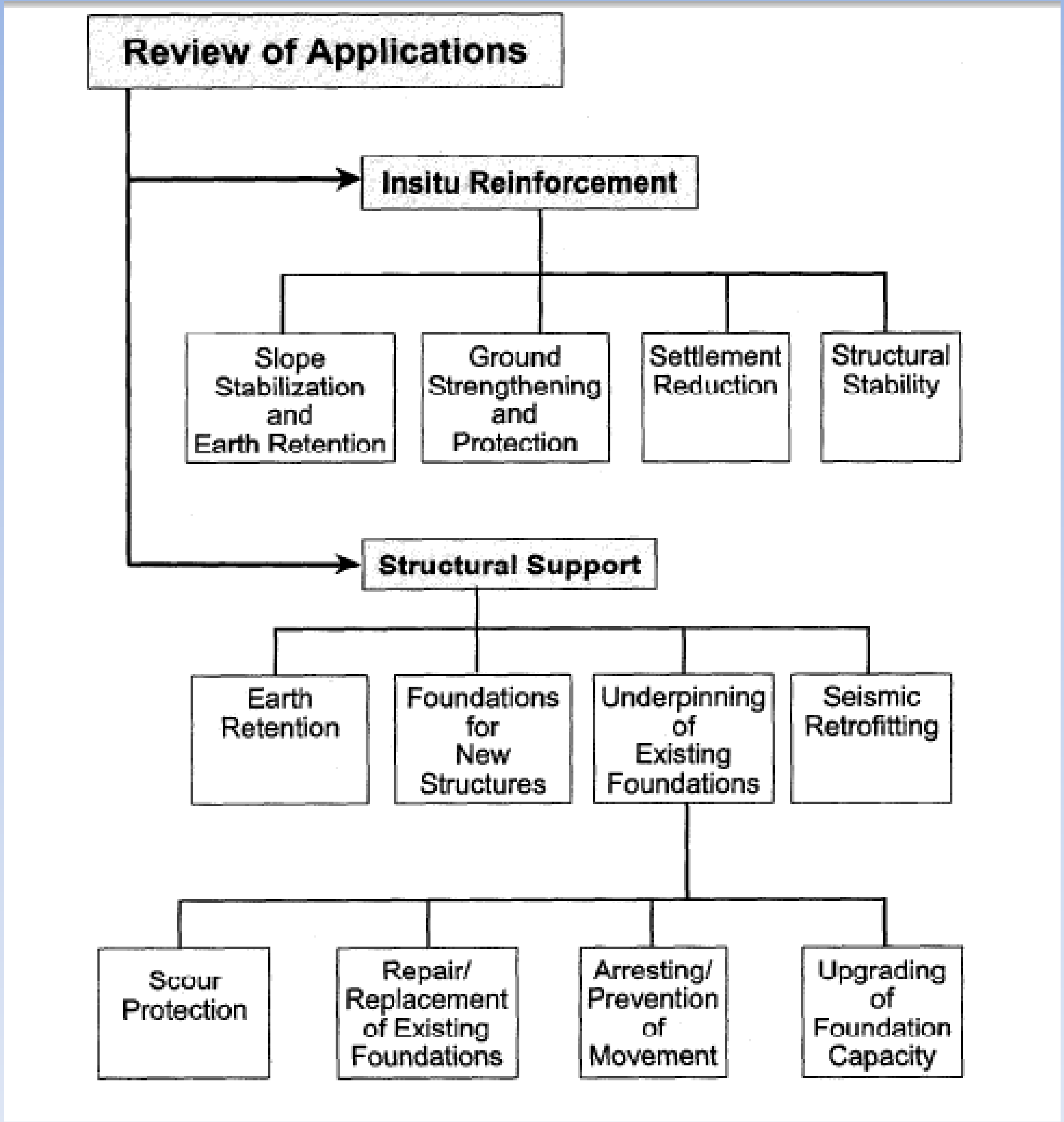
Classification of Micropiles

1) Based on Design Application

Case 1: Micropile elements, which are loaded directly & where the pile reinforcement resists the majority of the applied load.

Case 2: Micropile elements circumscribe and internally reinforce the soil to make a reinforced soil composite that resists the applied load.

Fig1(a): Drilled Micropiles under a building


Review of Applications
Insitu Reinforcement
Slope Stabilization and Earth Retention
Ground Strengthening and Protection
Settlement Reduction
Structural Stability
Structural Support
Earth Retention
Foundations for New Structures
Underpinning of Existing Foundations
Seismic Retrofitting
Scour Protection
Repair/ Replacement of Existing Foundations
Arresting/ Prevention of Movement
Upgrading of Foundation Capacity

Applications

- **For Structural support** (Case 1)

a) New Foundations

b) Under pinning of existing structures

c) Seismic retrofitting of existing structures

d) Scour protection

e) Earth retention

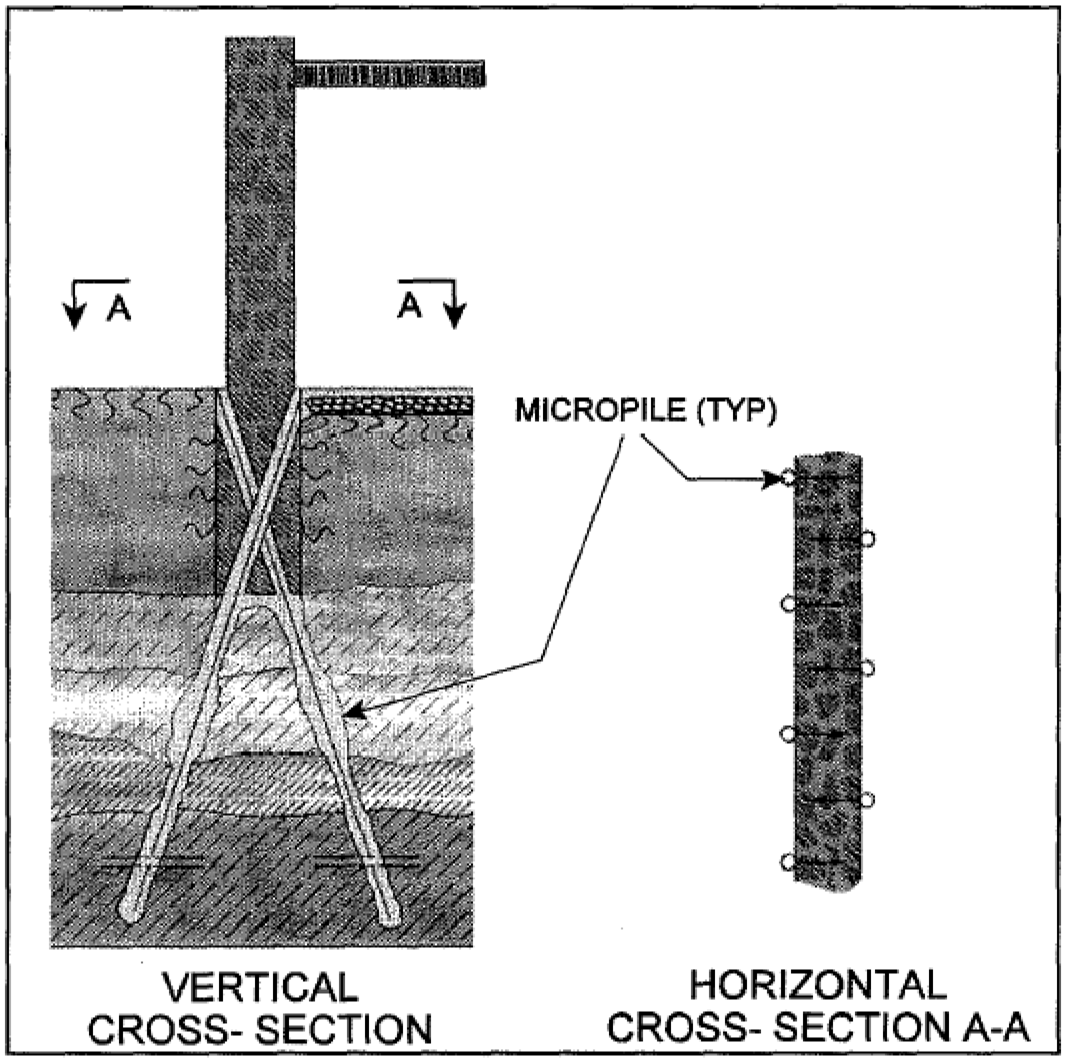
- **In situ Reinforcement** (Case 2)

a) Slope Stabilization

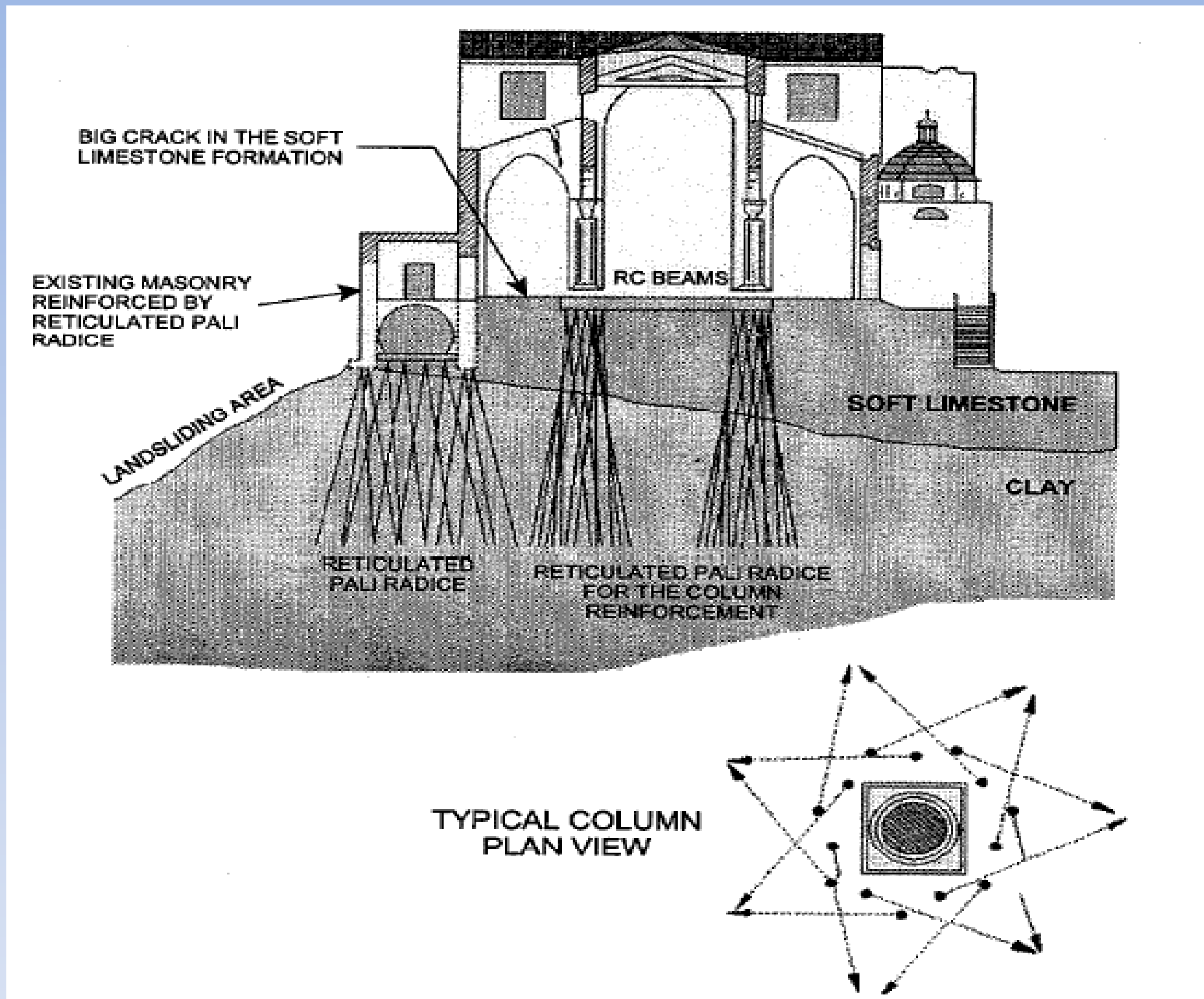
b) Earth retention

c) Ground strengthening and protection

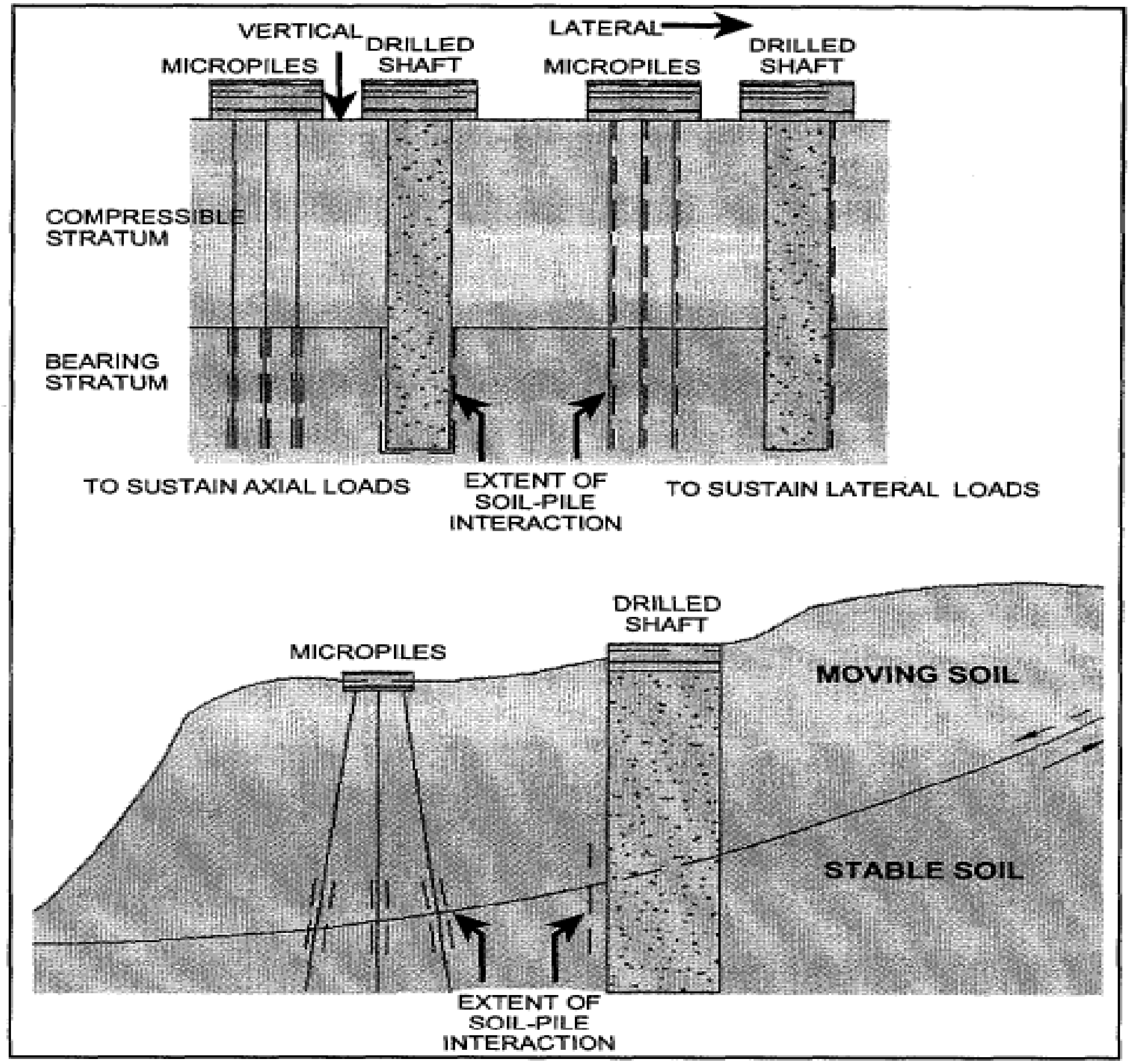
d) Settlement reduction



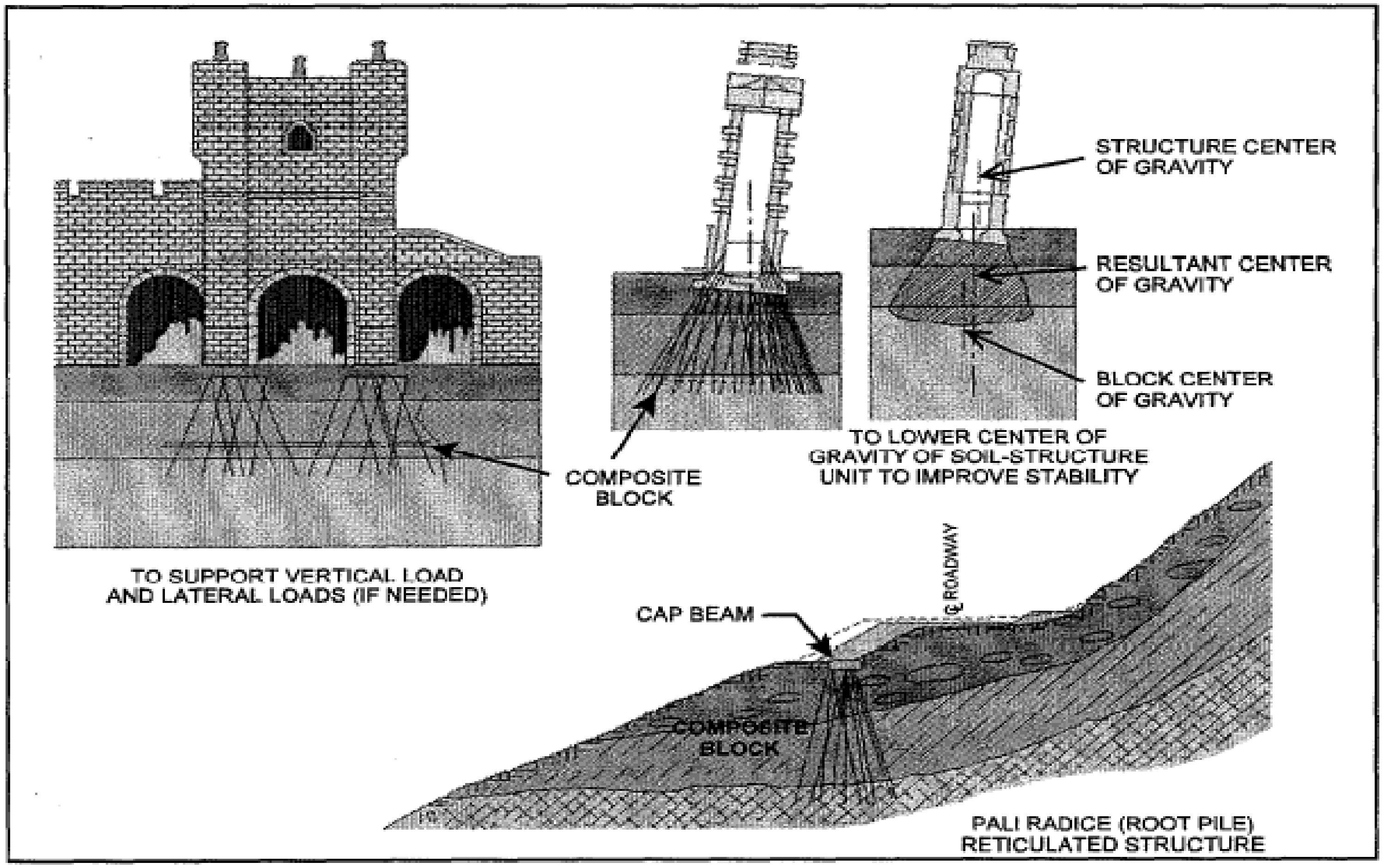
Classical arrangement of root piles for underpinning



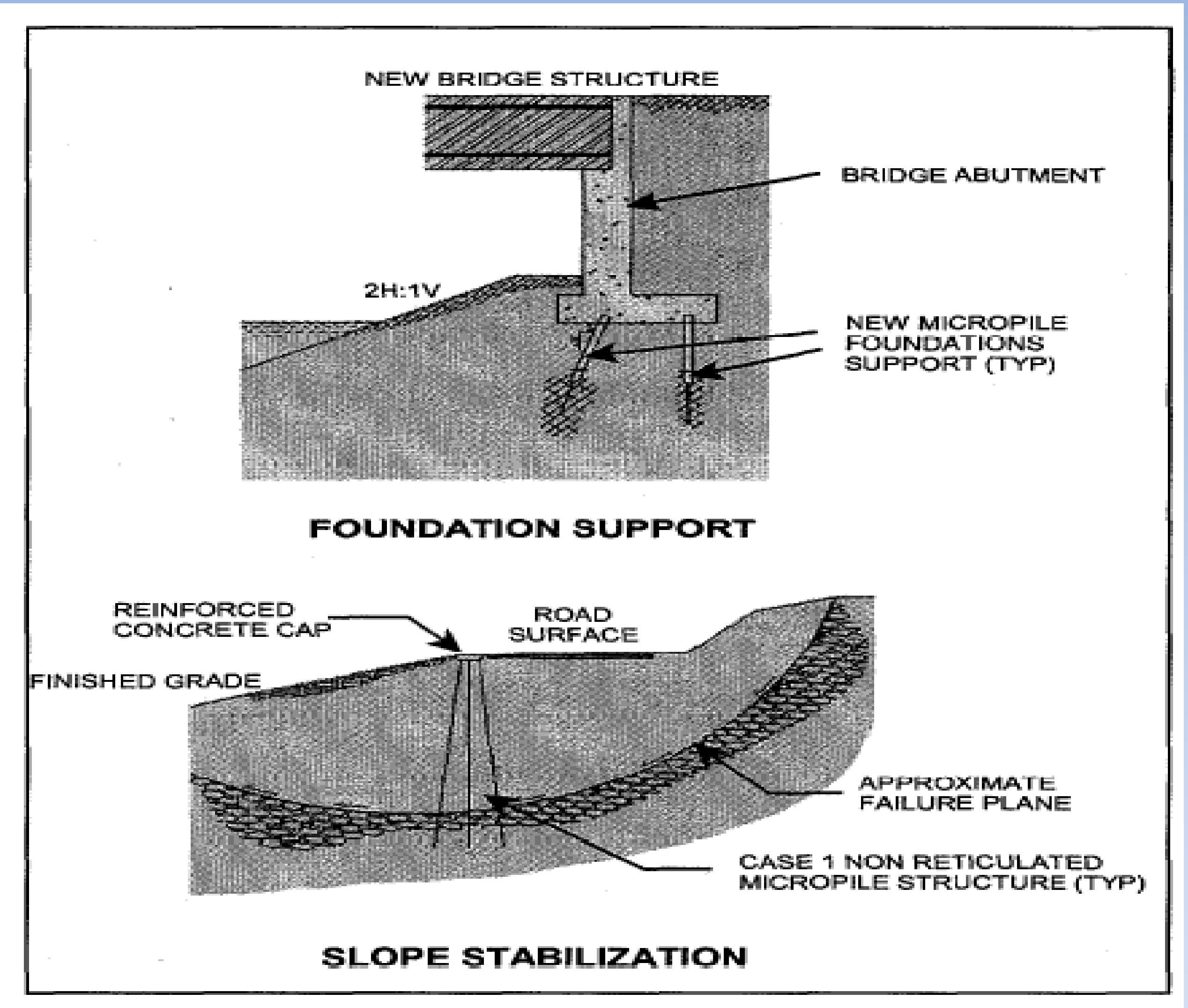
Typical network of Reticulated Micropiles



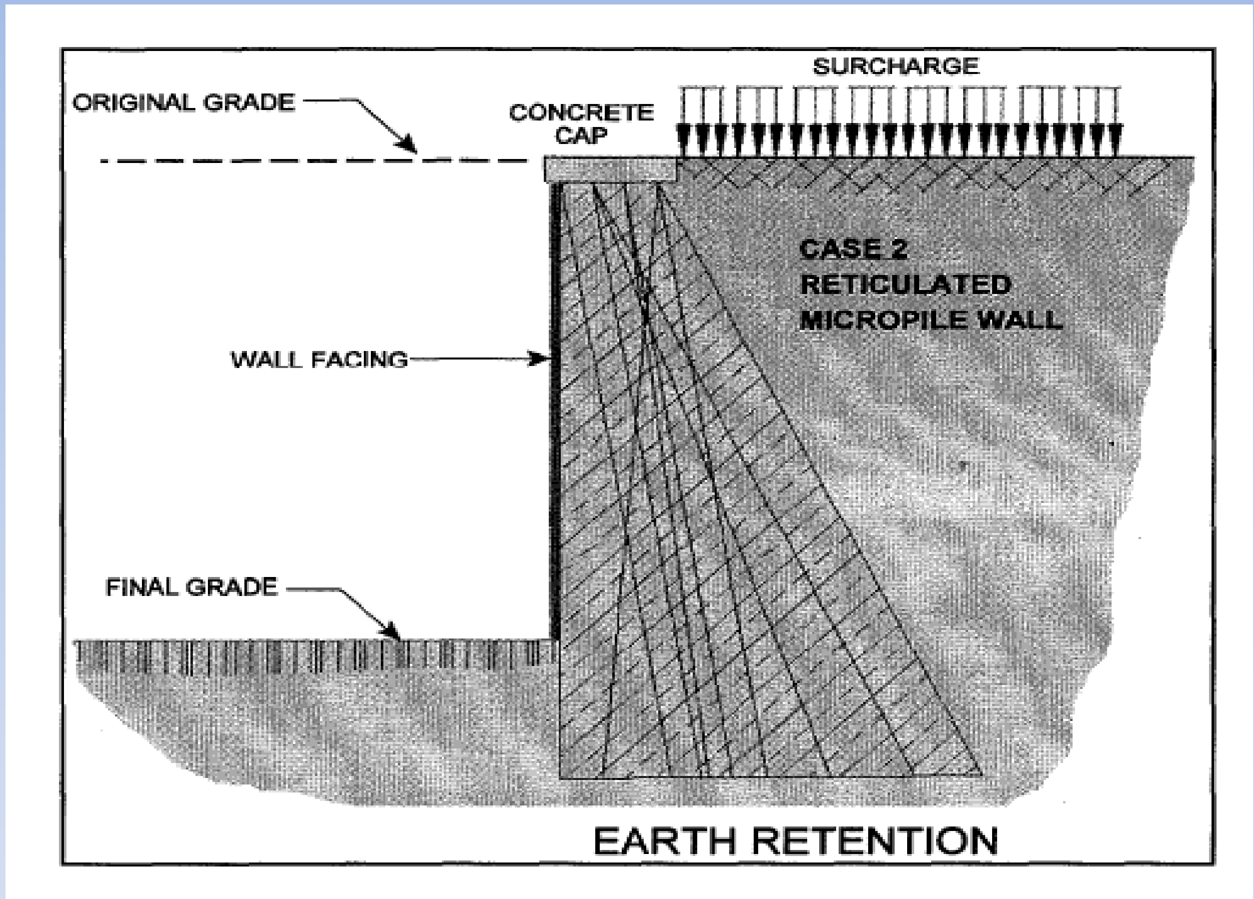
CASE 1 Micropiles (Directly Loaded)



CASE 2 Micropiles-Reticulated Pile Network with Reinforced Soil Mass Loaded or Engaged



CASE1 Micropile arrangements



CASE 2 Micropile arrangements

2) Based on Construction type

- The method of grouting is generally the most sensitive construction control over grout/ground bond capacity. Grout-to-grout capacity varies with the grouting method.

a) Type A: Gravity Grout

b) Type B: Pressure through Casing

c) Type C: Single Global Post Grout

d) Type D: Multiple Repeatable Post Grout

- **Type A**: Here the grout is placed under gravity head only using sand-cement motors or neat cement.
- **Type B**: In this type neat cement grout is placed in to the hole as the temporary steel casing is with drawn. Injection pressures varies from 0.5 to 1.0 MPa. The pressure is limited to avoid fracturing of the surrounding ground.

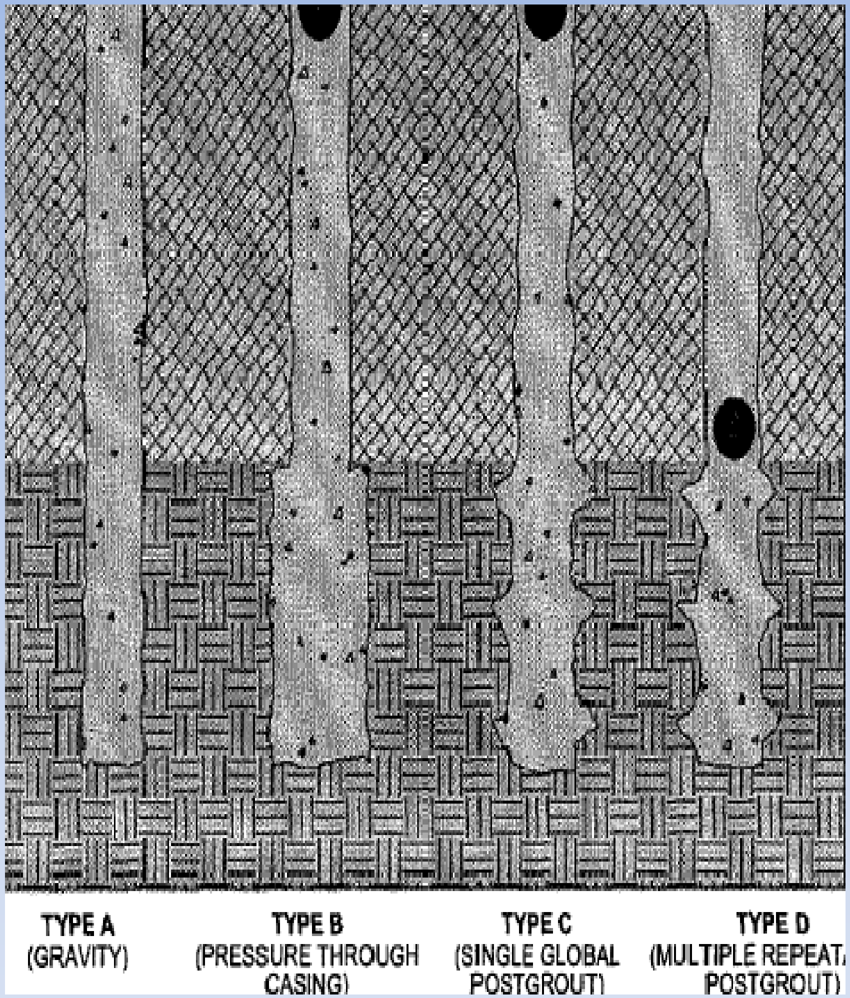


Fig1(b): Micropile classification based on type of grouting.

- **Type C**: This is done in two step process:

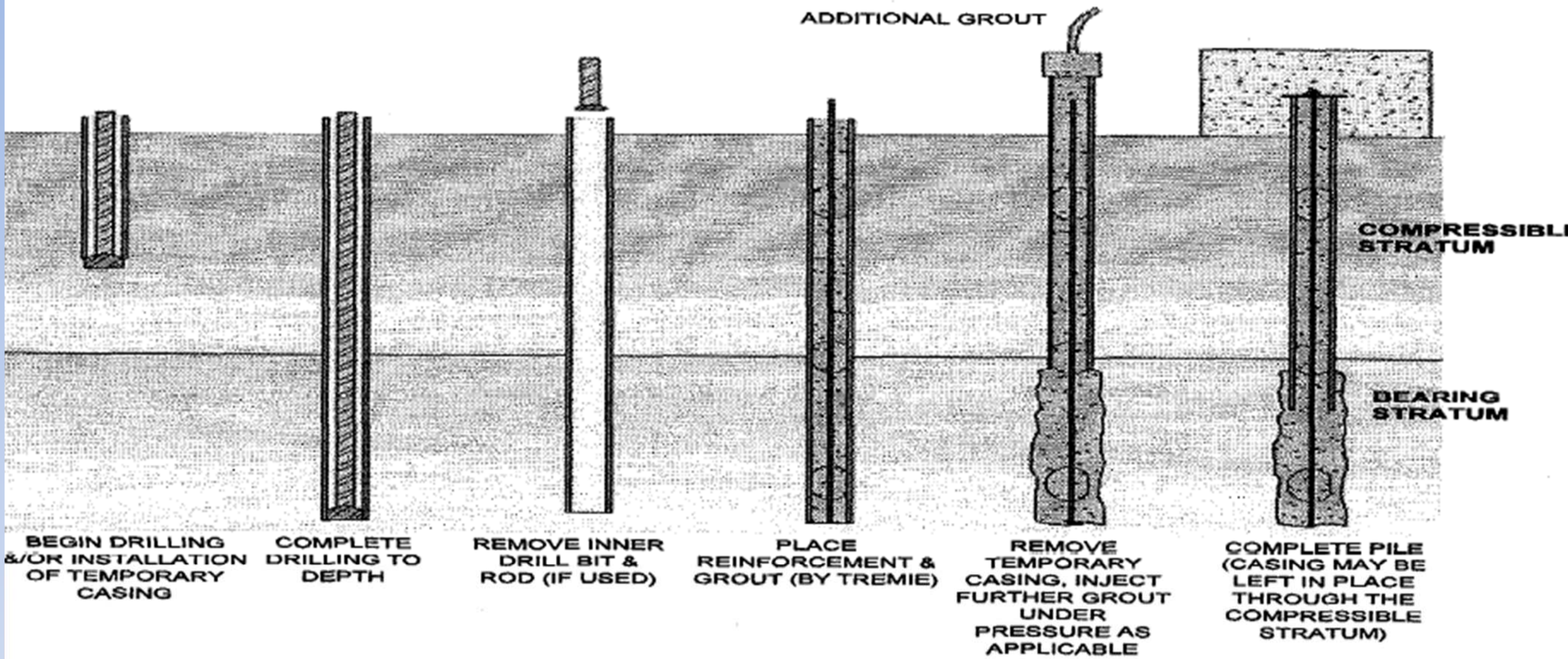
1) As of Type A

2) Prior to hardening of the primary grout, similar grout is injected one time via a sleeve grout pipe at pressure of at least 1.0MPa.

- **Type D**: This is done in two step process of grouting similar to Type C with modifications to step 2 where the pressure is injected at a pressure of 2.0 to 8.0 MPa:

Advantages of Micropiles

- Micropiles are often used to underpin the existing structure where need of minimal vibration or noise is of prime importance.
- Micropiles can be easily laid where low head room is a constraint.
- Micropiles can be easily installed at any angle below the horizontal using the same equipment used for ground anchors and grouting projects.
- Offer a practical and cost-effective solution to costly alternative pile systems as well as a solution to job sites with difficult access.
- Do not require large access road or drilling platforms



Micropile Construction sequence using casing

Outline of Design steps

1) Review available project information
2) Review geotechnical data
3) Geotechnical design
4) Pile structural design
5) Combined geotechnical & structural design considerations
6) Additional micro pile system considerations

Determination of Geotechnical bond capacity

Allowable geotechnical bond axial load capacity, $P_{G\text{-}allowable}$ can be determined by the following equation;

$$\mathbf{P_{G\text{-}allowable} = \alpha_{bond\ strength}\ 3.14^{x} \varphi_{bond}{}^{x} Bond\ length/S.F}$$

- $\alpha_{bond\ nominal\ strength}$ = Grout to ground bond capacity of pile from Table 1(a).
- $P_{G\text{-}allowable}$ = Allowable geotechnical bond axial load

Table:1(a): Summary of typical $\alpha_{bond\ nominal\ strength}$ (kPa)values (Grout-to-ground bond) for micropile design

Soil/Rock Description	Type A	Type B	Type C	Type D
Silt&clay(some sand) (Soft, medium plastic)	35-70	35-95	50-120	50-145
Silt&clay(some sand) (Stiff, dense to very dense)	50-120	70-190	95-190	95-190
sand (some silt) (fine, loose medium dense)	70-145	70-190	95-190	95-240
sand (some silt,gravel) (fine coarse,medium -very dense)	95-215	120-360	145-360	145-385
gravel(some sand) (medium-very dense)	95-265	120-360	145-360	145-385
Glacial till(silt, sand gravel) (medium very dense cemented)	95-190	95-310	120-310	120-335

Determination of Geotechnical end bearing capacity

- The design is done similar to end bearing drilled shafts or driven piles or may be based on previous load test experience of similar projects.

$$Q_a = Q_u / F.S$$

Q_a= Allowable bearing capacity, Q_u= Ultimate bearing capacity and Safety factor=2.5

Group effect of axially loaded Micro piles

- For driven piles no individual pile capacity reduction for group considerations with the exception of friction piles in cohesive soils.
- For driven piles an efficiency factor of 0.70 shall be applied for piles with center to center spacing of less than 3.0 times the pile diameter.

Micropile structural design

- Pile cased length structural capacity

  For Strain compatibility between casing & bar the Yield stress of steel is taken as follows:

$F_{y\text{-steel}} = \text{min. of } F_{y\text{-bar}} \;\&\; F_{y\text{-casing}}$

Where, $F_{y\text{-steel}}$ = Yield stress of steel

$F_{y\text{-bar}}$ = Yield stress of bar

$F_{y\text{-casing}}$ = Yield stress of casing

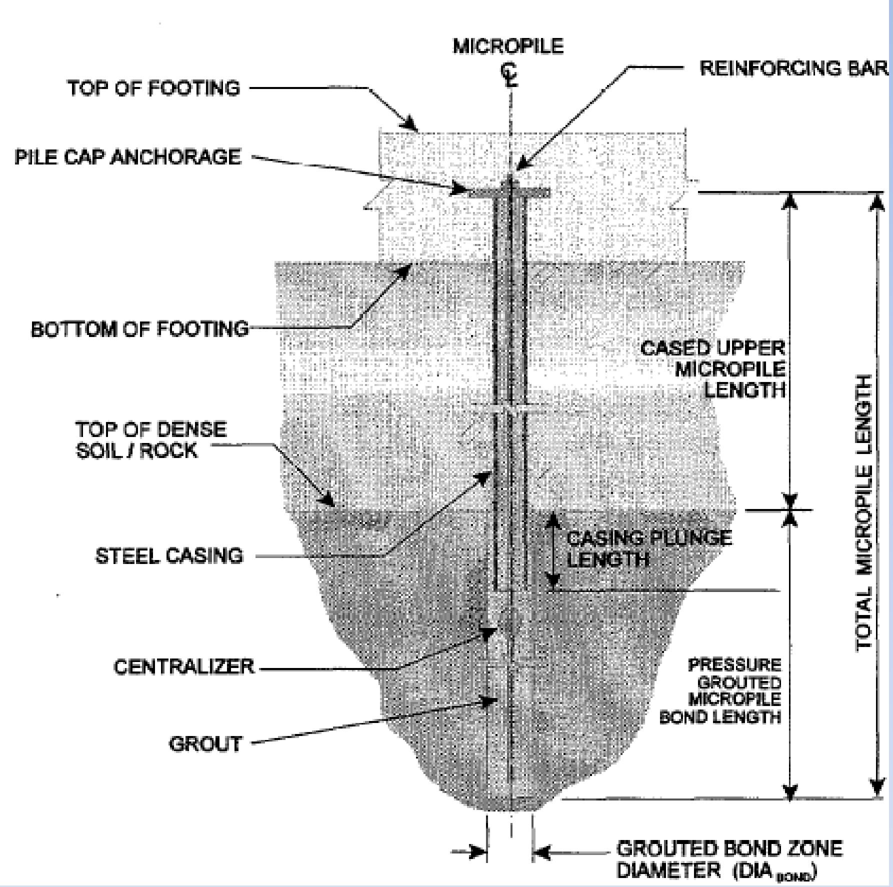


Fig2(a): Details of a composite reinforced micropile

Pile cased length structural capacity

- Nominal allowable tensile strength can be determined by the following equation:

$P_{t\text{-}allowable}=0.55f_{y\text{-}steel}\,[A_{bar}+A_{casing}]$

Compression-allowable load

$$P_{c\text{-}allowable}=0.4f'_{c\text{-}grout}\,A_{grout}+0.47\,f_{y\text{-}steel}\,[A_{bar}+A_{casing}]$$

Where, $P_{t\text{-}allowable}$ = Allowable structural tensile strength

$P_{c\text{-}allowable}$ = Allowable compressive strength

A_{grout} = Area of grout; A_{bar} = Area of reinforcement

A_{casing} = Casing area

Pile un-cased length structural capacity

The tensile & compressive allowable loads for the uncased bond length is given below:

Cased bond length(plunge length) allowable load=$P_{transfer\ allowable}$ is given by

$P_{transfer\ allowable} = \alpha_{bond\ nominal}$ /(S.F)strength*3.14*dia_{bond}*plunge length

Tension allowable load

$P_{t-allowable}$=0.55*F_{y-bar} A_{bar}+$P_{transfer\ allowable}$

Compression allowable load

$P_{c-allowable}$=0.4f'$_{c-grout}$ A_{grout}+0.47 F_{y-bar} A_{bar}+$P_{transfer\ allowable}$

Prediction of anticipated structural axial displacements

When pile designs require displacement criteria, such as earth quake analysis, it may be necessary to predict pile stiffness and deflection limits during designs & confirm through load tests:

For an anchor or micropile, the elastic displacement can be approximated by the following eq:

$$\Delta_{Elastic} = PL/AE$$

Where, $\Delta_{Elastic}$ = Elastic component of total displacement,

P= Applied Load, L= Elastic length and AE= Stiffness of the section

Design Example

- Design micro piles for an embankment with top width of 4.0m width and 2m high with 1:2 slope on both sides with unit weight of embankment fill of 17 kN/m^3 on a soft soil to improve the bearing capacity in a uniform deposit of medium clay with unconfined compressive strength of 100 kN/m^2. Consider the dia. of micro pile as 0.1m with a minimum spacing of 3 times center to center.

Given,

Unconfined compressive strength of soil, q_u=100 kPa

$$c_u = q_u/2 = 50 \text{ kPa}$$

Point load capacity of single pile is given by

$$Q_{pu} = c_u * N_c * A_p$$
$$= 50*9*0.785*0.1^2$$
$$= 3.53 \text{ kN}$$

Skin friction resistance of single pile

$$Q_f = \alpha * c_u * A_s$$
$$= 0.9*50*3.14*0.1*10 = 141.3 \text{ kN}$$

Ultimate capacity of single pile Q_u = 3.53+141.3 = 145 kN.

Total load from the embankment (including 20 kPa of surcharge)= (4+4+4)17+20x4= 284 kN per metre length of the embankment

Ultimate load capacity of the pile group of 3 piles spaced at 0.3m = 435 kN.

FS= 435/284 = 1.53. Hence configuration of micro piles with the above ultimate capacity is appropriate.

Determination of Allowable Structural and Geotechnical Pile Loads:

Pile cased length allowable load:

Material dimensions & properties

Casing - Use 120 mm outside diameter x 10 mm wall thickness

Pile casing inside diameter Id_{casing}= 120 mm - 2 x 10 mm = 100 mm

Pile casing steel area= 3454mm^2

- Yield strength of casing $F_{y\text{-}casing}$ =240 kPa

  •Use reinforcing bar of yield strength of 415MPa of 25mmφ

- Grout compressive strength =30 MPa

- For strain compatibility between casing and rebar, use for steel yield stress:

- $F_{y\,–steel}$= the minimum of $F_{y\text{-}steel}$ and $F_{y\text{-}casing}$= 240 MPa

- Nominal allowable tensile strength can be determined by the following equation:

$$P_{t\text{-}allowable} = 0.55 f_{y\text{-}steel} \, [A_{bar} + A_{casing}]$$
$$= 0.55*240*3944$$
$$= 520.608 \text{ kN}$$

Compression-allowable load

$$P_{c\text{-}allowable} = 0.4 f'_{c\text{-}grout} \, A_{grout} + 0.47 \, f_{y\text{-}steel} \, [A_{bar} + A_{casing}]$$
$$= 530.55 \text{ kN}$$

Allowable Geotechnical Bond Load

- From Table 1(a) select an ultimate unit grout-to-ground bond strength

$$\alpha_{\text{bond nominal strength}} = 190 \text{ kPa.}$$

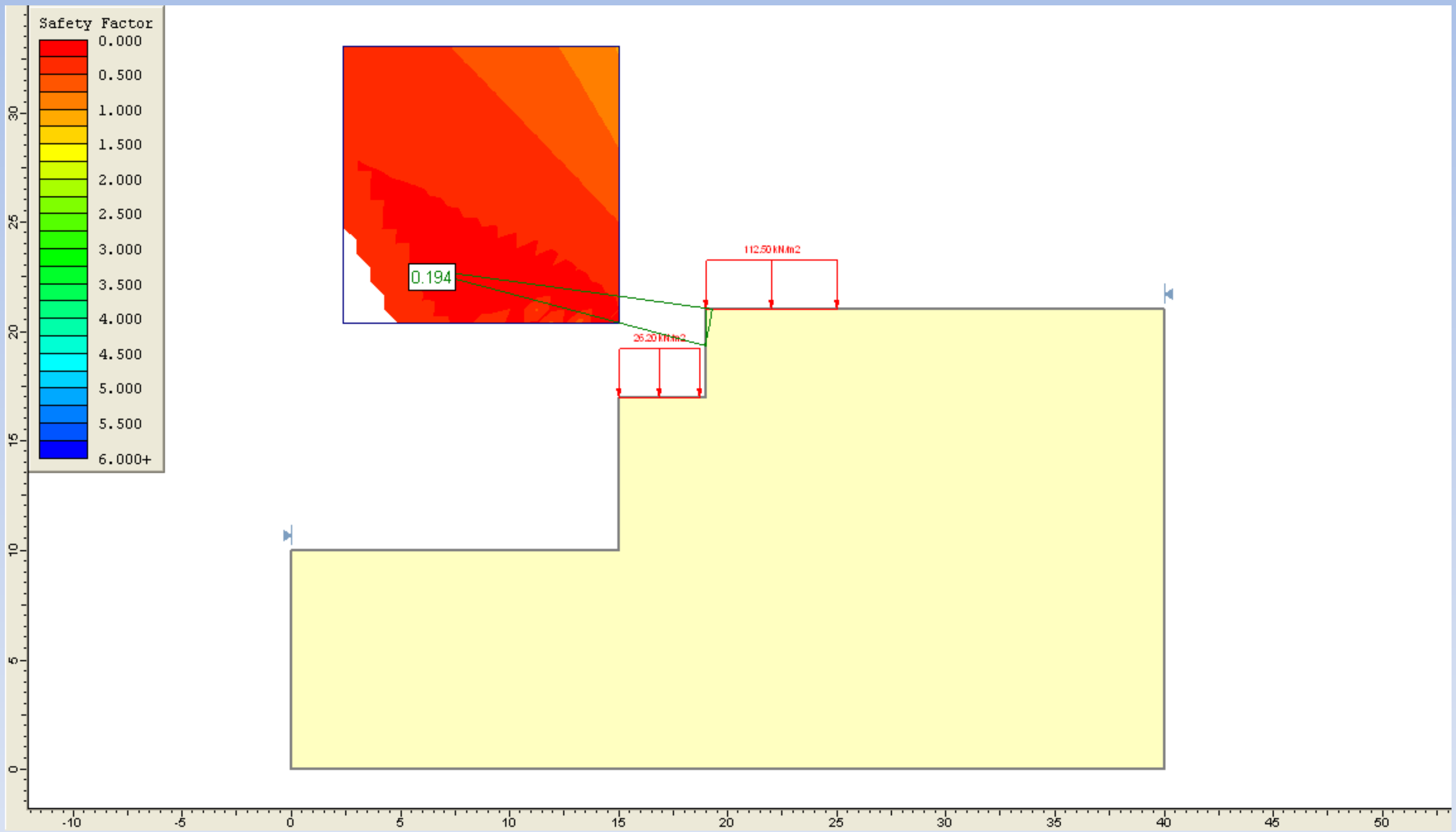
Allowable geotechnical bond axial load capacity, $P_{G\text{-allowable}}$ can be determined by the following equation;

$$\mathbf{P_{G\text{-allowable}} = \alpha_{bond\ strength}\ {}^{x}3.14^{x}\varphi_{bond}{}^{x}bond\ length/S.F}$$

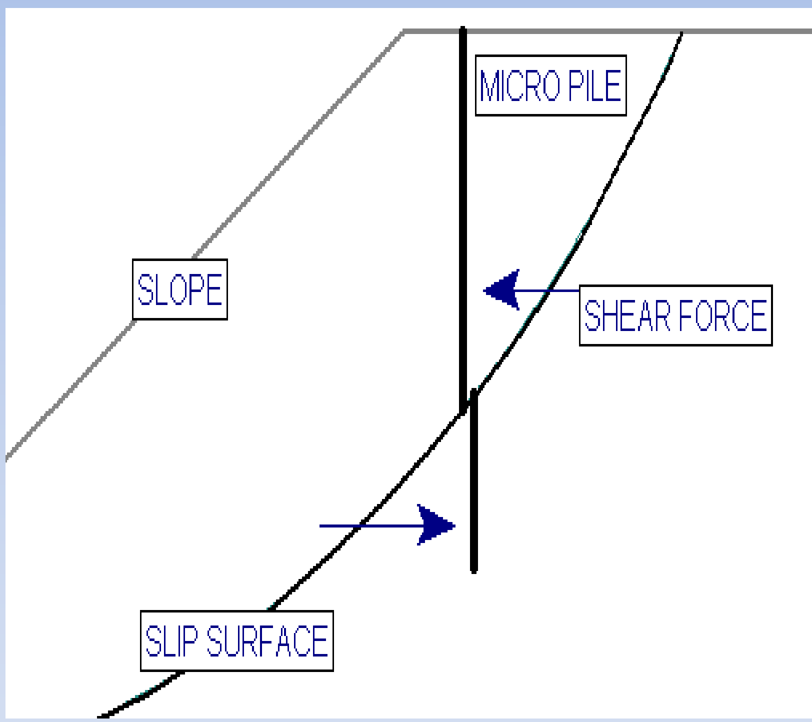
$$\mathbf{=190*3.14*0.1*10/2.5}$$

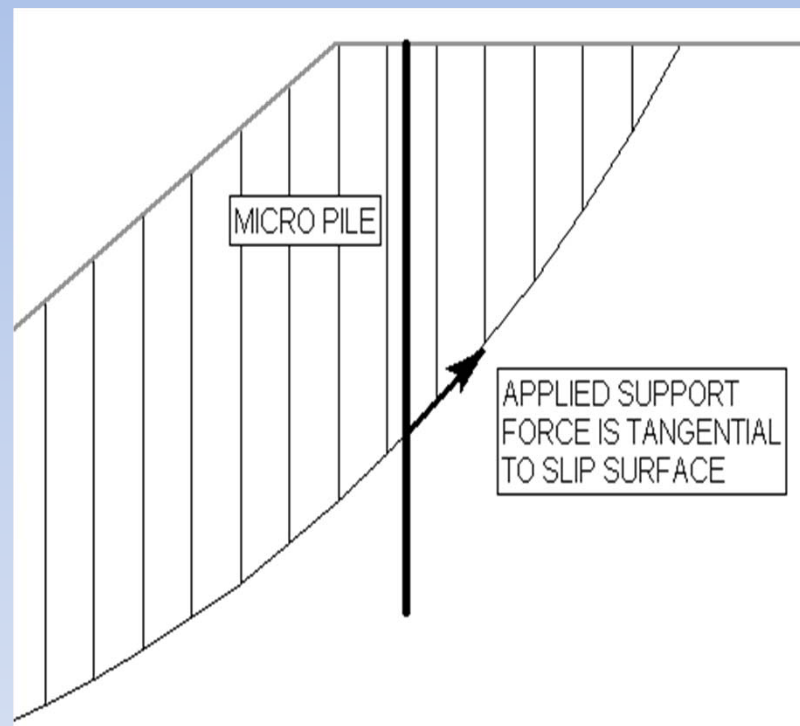
$$\mathbf{=238.64\ kN}$$

Results of the analysis without excavation support



Mechanism


MICRO PILE
SLOPE
SHEAR FORCE
SLIP SURFACE

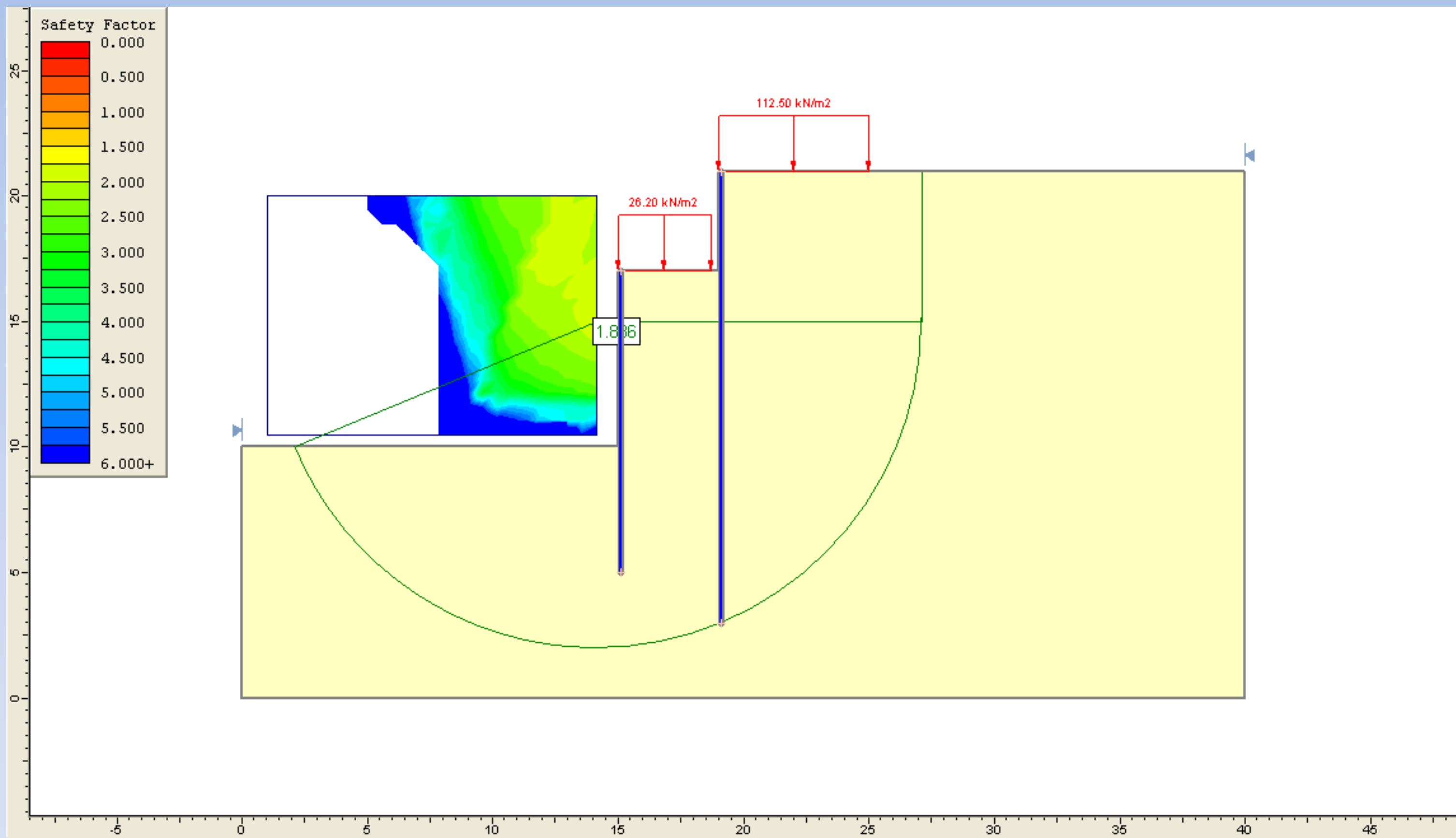

MICRO PILE
APPLIED SUPPORT
FORCE IS TANGENTIAL
TO SLIP SURFACE

Micropiles(steel pipes of 125mm dia with 6mm thickness are considered as micro piles.

Shear resistance = 0.4 f_y A_s = $0.4x250x0.785(125^2-113^2)/1000$ =224.2 kN.

Horizontal component of shear resistance provides resistance for induced shear forces due to excavating and loading. Hence it is suggested to provide two rows of 125 mm outer dia., 6.5 mm thick in staggered direction at 250 mm centre to centre for a length of 3.5m from the centre line of railway track on both sides.

This configuration results in higher factors of safety as shown in the Fig.3 (1.836 based on Bishop's method)



Safety Factor
0.000
0.500
1.000
1.500
2.000
2.500
3.000
3.500
4.000
4.500
5.000
5.500
6.000+
112.50 kN/m2
26.20 kN/m2

Use of micro piles as retention system

Concluding remarks

Use of Micro piles is versatile in situ ground improvement technique and has been used very effectively in many stability problems.
In many cases, micro piles are loaded tested following typical codes of practice (FHWA, pile load tests of Indian Standards etc). to measure the vertical and lateral capacities of the piles which are required in the validation of the design configuration and redesign if required.

References

MICROPILE DESIGN AND CONSTRUCTION GUIDELINES (2000) US Department of Transportation, Federal Highway Administration, Priority Technologies Program