Lecture 27

NPTEL Course

GROUND IMPROVEMENT

Factors affecting the behaviour and performance of reinforced soil

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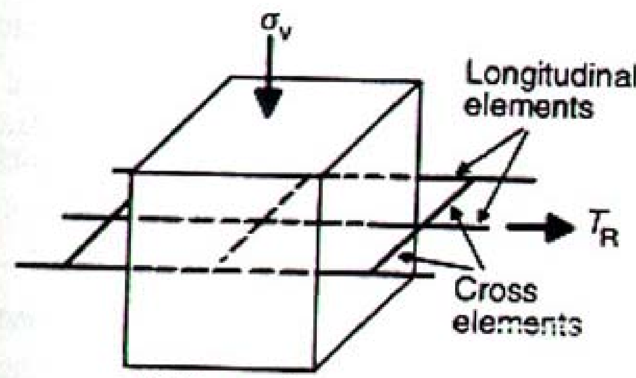
Factors affecting the Behaviour and Performance of Reinforced Soil

Reinforcement	**Reinforcement distribution**	**Soil**	**Soil state**	**Construction**
Forms(fibre, grid,anchor, bar, strip)	Location	Particle size	Density	Geometry of structure
Surface properties				Compaction
Dimensions	Orientation	Grading	Over Burden	Construction system
Strength		Mineral content	State of stress	Aesthetics
Stifness	Spacing	Index properties	Degree of saturation	Durability

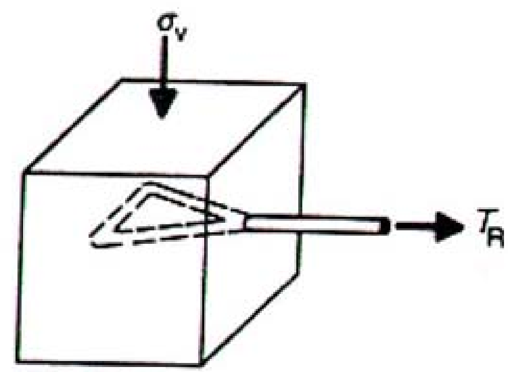
Reinforcement

- **Forms**: Steel strips, bars, geotextiles depend more on the interfacial friction between soil & reinforcement for the mobilization of tensile force, whereas anchors depend on the bond or pull out resistance, geogrids depend on interfacial friction, bonding besides the interlocking effect.
- **Surface properties**: Surface with roughened surfaces provides better friction properties.
- **Dimensions** : The dimensions of reinforcement such as length, diameter/thickness should be obtained to meet design requirements
- **Stiffness** stiff for flexible type of reinforcements

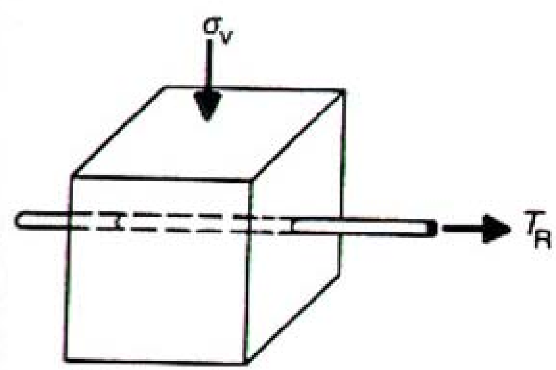
Forms of reinforcement



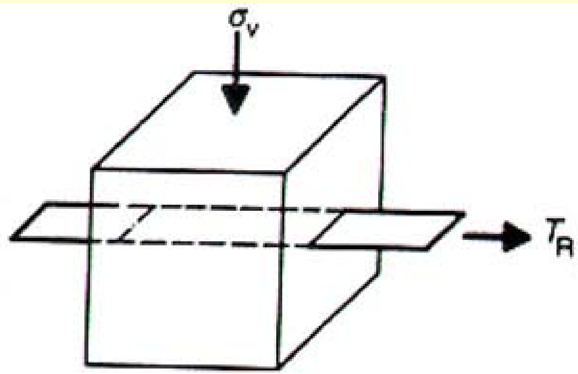
c) Grid or mesh



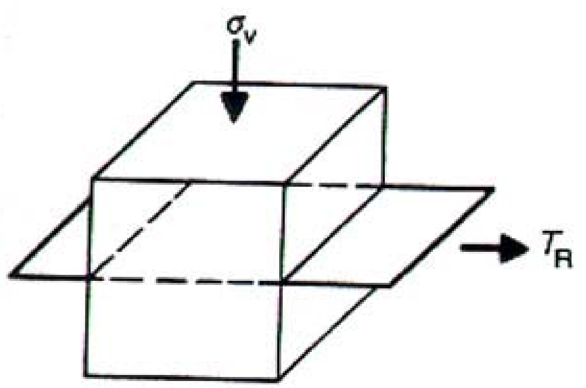
d) Anchor



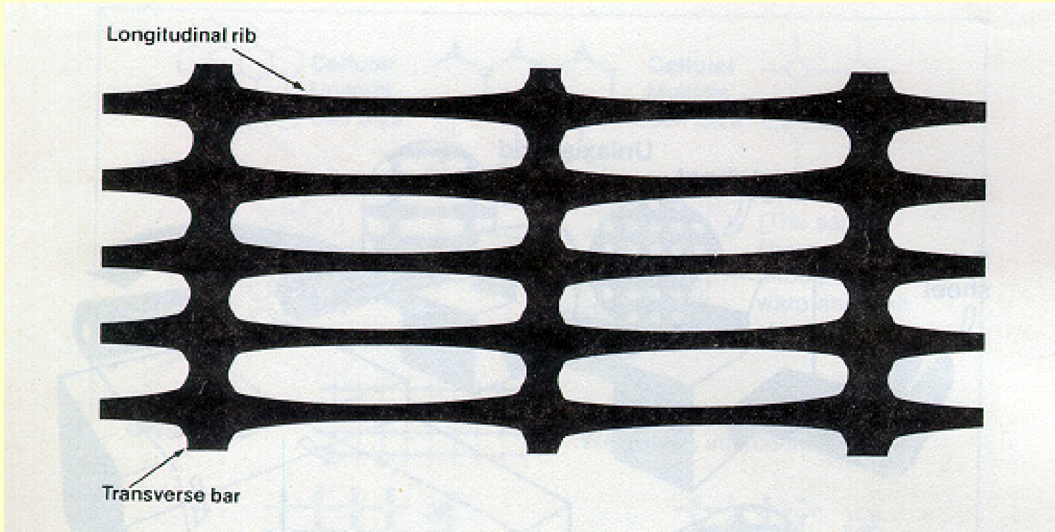
e) Bar or rod

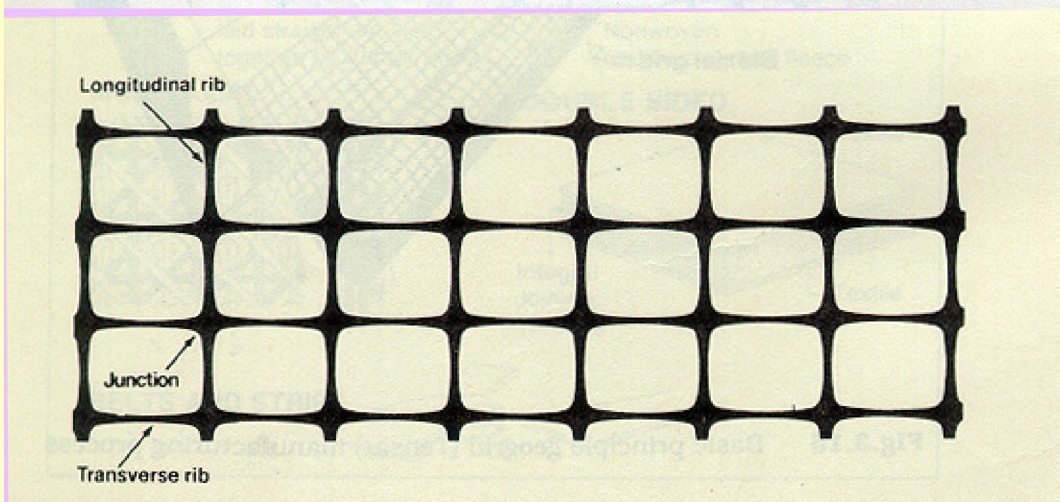


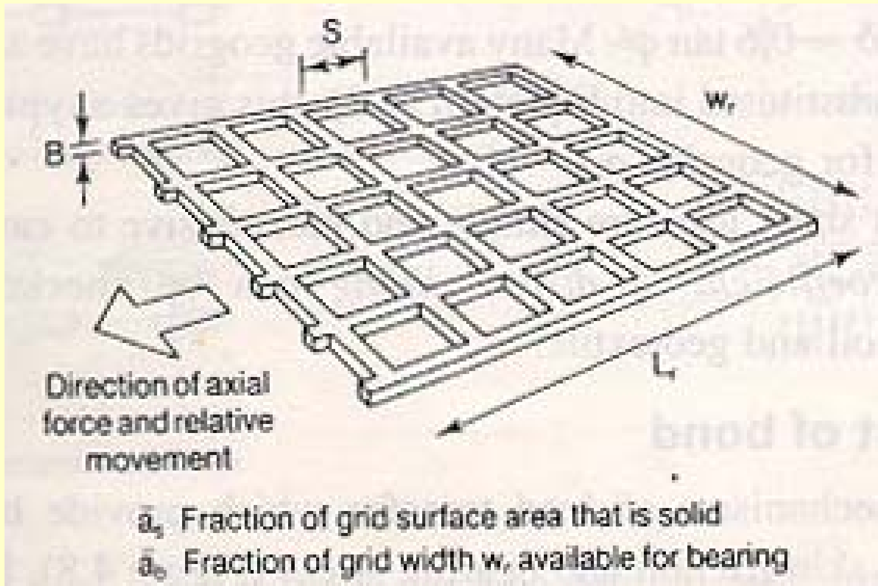
a) Strip or webbing

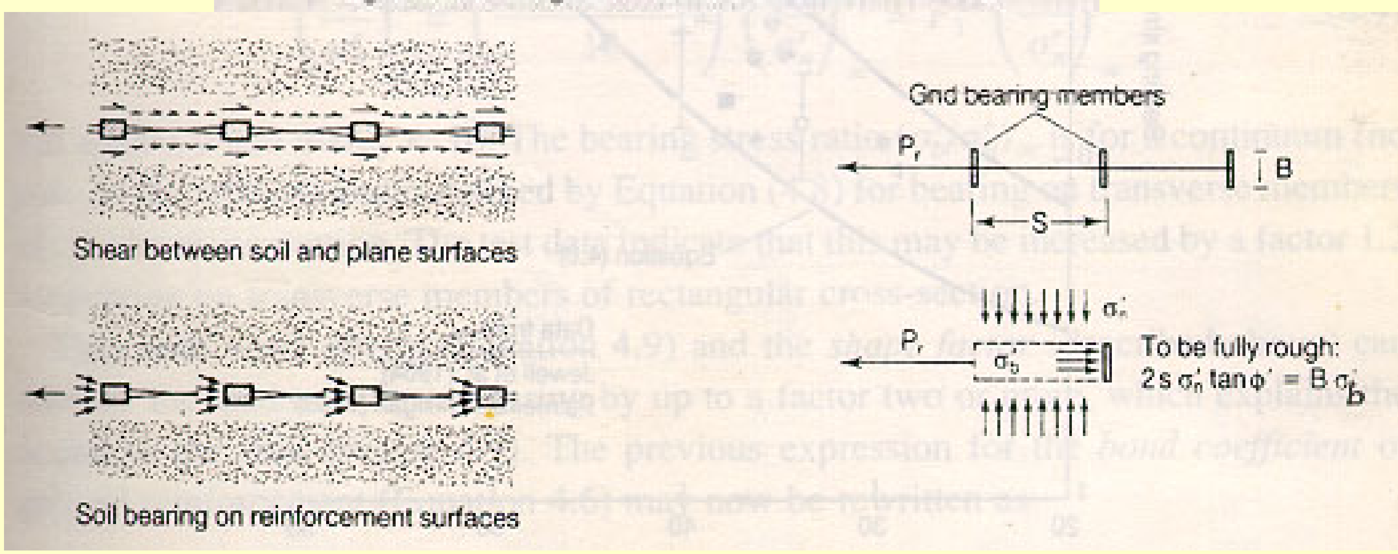


b) Sheet


Longitudinal rib
Transverse bar


Longitudinal rib
Junction
Transverse rib


S
B
w_r
L_r
Direction of axial force and relative movement
ā_s Fraction of grid surface area that is solid
ā_b Fraction of grid width w_r available for bearing


Shear between soil and plane surfaces
Soil bearing on reinforcement surfaces
Grid bearing members
P_r
B
S
σ'_n
σ'_b
To be fully rough:
2 s σ'_n tan φ' = B σ'_b

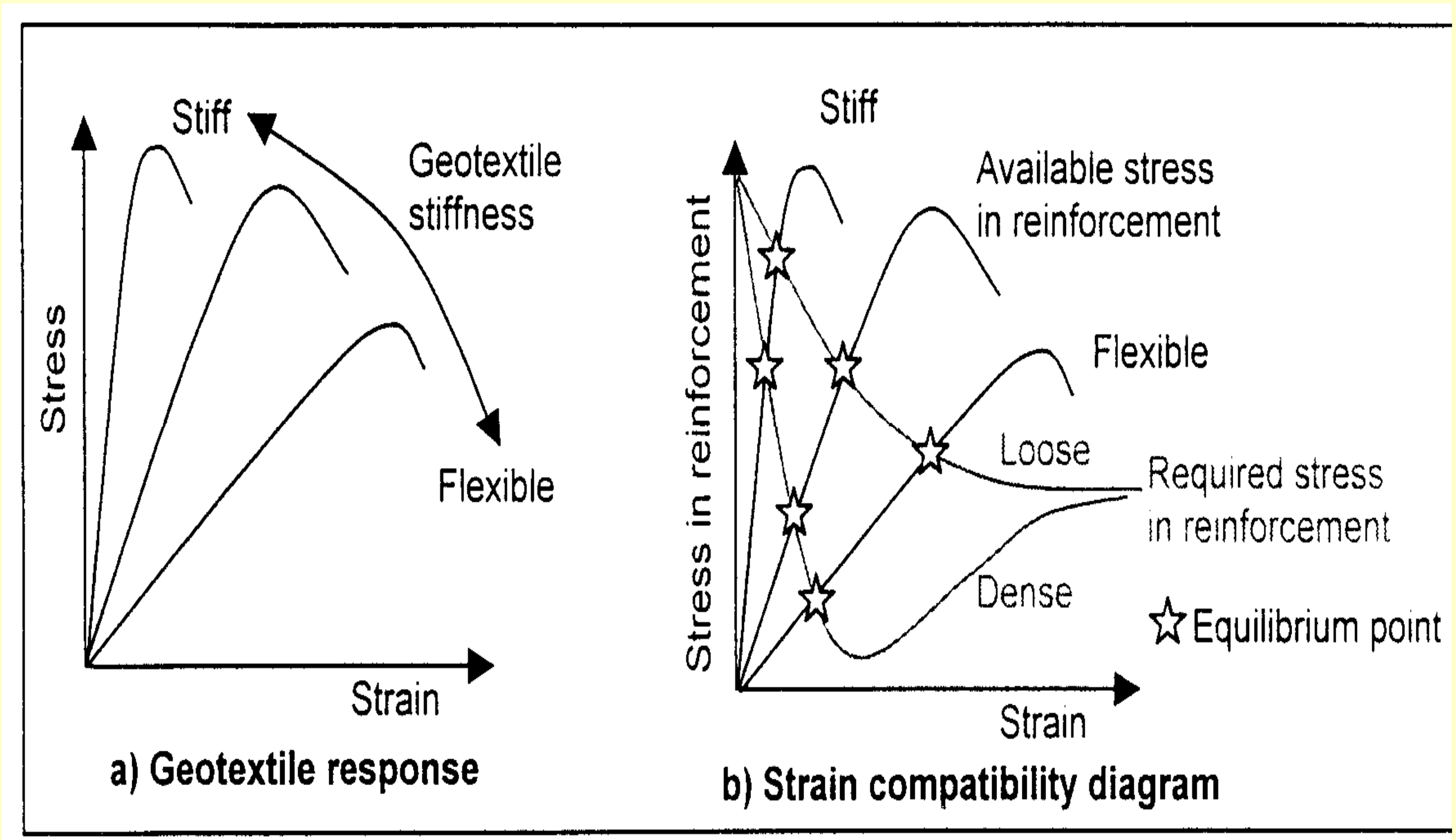
Dimensions

- Dimensions of the reinforcement are arrived at after ensuring the required strength and stiffness requirements from design considerations. Depending on the availability of the material, dimensions of the reinforcement such as length and diameter/thickness can be optimised. Many of the reinforcing materials and geosynthetic materials are available in standard dimensions and length and hence a proper choice considerably assists in reducing the wastage of the materials and the corresponding costs.

Stiffness

- The longitudinal stiffness of the reinforcement governs the strain mobilization in the reinforced soil structure. The stress-strain characteristics of reinforcement are linear, whereas those of soil are non-linear. For a stable condition, the strain developed in the reinforced soil as a result of interaction between the soil and the reinforcement needs to be less than those mobilized in the soil alone. Assuming that tensile strain in the soil is the same as the strain in the soil (no slip) the maximum reinforcement can be estimated.

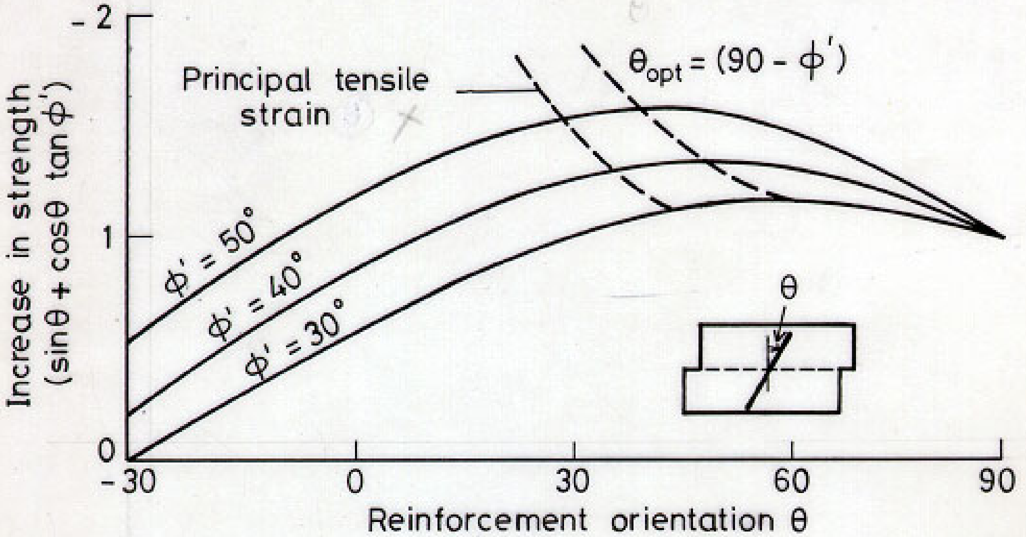
Strain compatibility



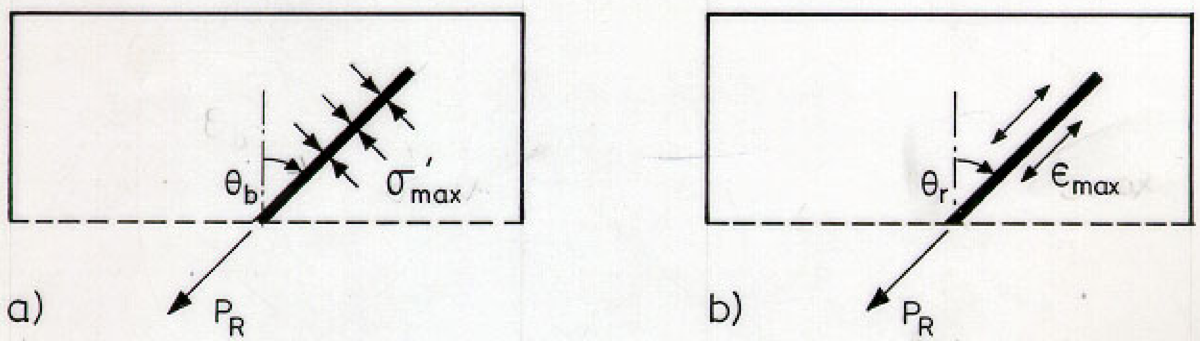
- It is useful to determine the magnitude of tensile strain that develops in the soil and the reinforcement to understand the equilibrium condition. This is useful to ensure that a) design values for the reinforcement and the soil resistance can realistically be mobilized together and b) equilibrium can be achieved with the acceptable deformation of the structure (Jewell, 1996).

Reinforcement Distribution

- Location, spacing &orientation of effect the behavior of reinforced soil.
- Reinforcement when placed in the direction of tensile strains induces increased stability.
- Optimum spacing should be chosen for the maximum shear strength.



Increase in strength (sinθ + cosθ tan φ')
Reinforcement orientation θ
- 2
1
0
- 30
0
30
60
90
Principal tensile strain
θopt = (90 - φ')
φ' = 50°
φ' = 40°
φ' = 30°
θ



θb
σ'max
a)
PR
θr
εmax
b)
PR

- Spacing of reinforcement is a function of forces that need to be resisted, compaction thickness etc.

Soil Properties- Cohesionless fill

Cohesionless fill made of well graded & non corrosive material is preferred. Following properties are required before selecting cohesionless soils & index properties shall be determined for cohesive soils.

1) Density 2) Grading 3) Uniformity Coefficient, C_u 4) pH value 5) Chloride ion content 6) SO_3 Content 7) Angle of internal friction 8) Coefficient of friction between fill & reinforcement.

Specifications for cohesionless fills

Sieve size	% passing
125	100
90	80 – 100
75	65 – 100
37.5	45-100
10	15-60
5	10 - 45
600 μm	0 – 25
63 μm	0 – 12

- Value of $C_u \geq 5$ is considered acceptable. Properties such as pH value, chloride ion, SO_3 content, resistivity and redox potential are associated with the durability of the reinforcing materials used and acceptable values for different reinforcing materials are given in BS 8006. The effective angle of internal friction of cohesionless soil (ϕ') should be $\geq 25^0$. Friction between the fill and reinforcing elements is an important property to characterize the interaction between the soil and reinforcements is usually measured from direct shear tests.

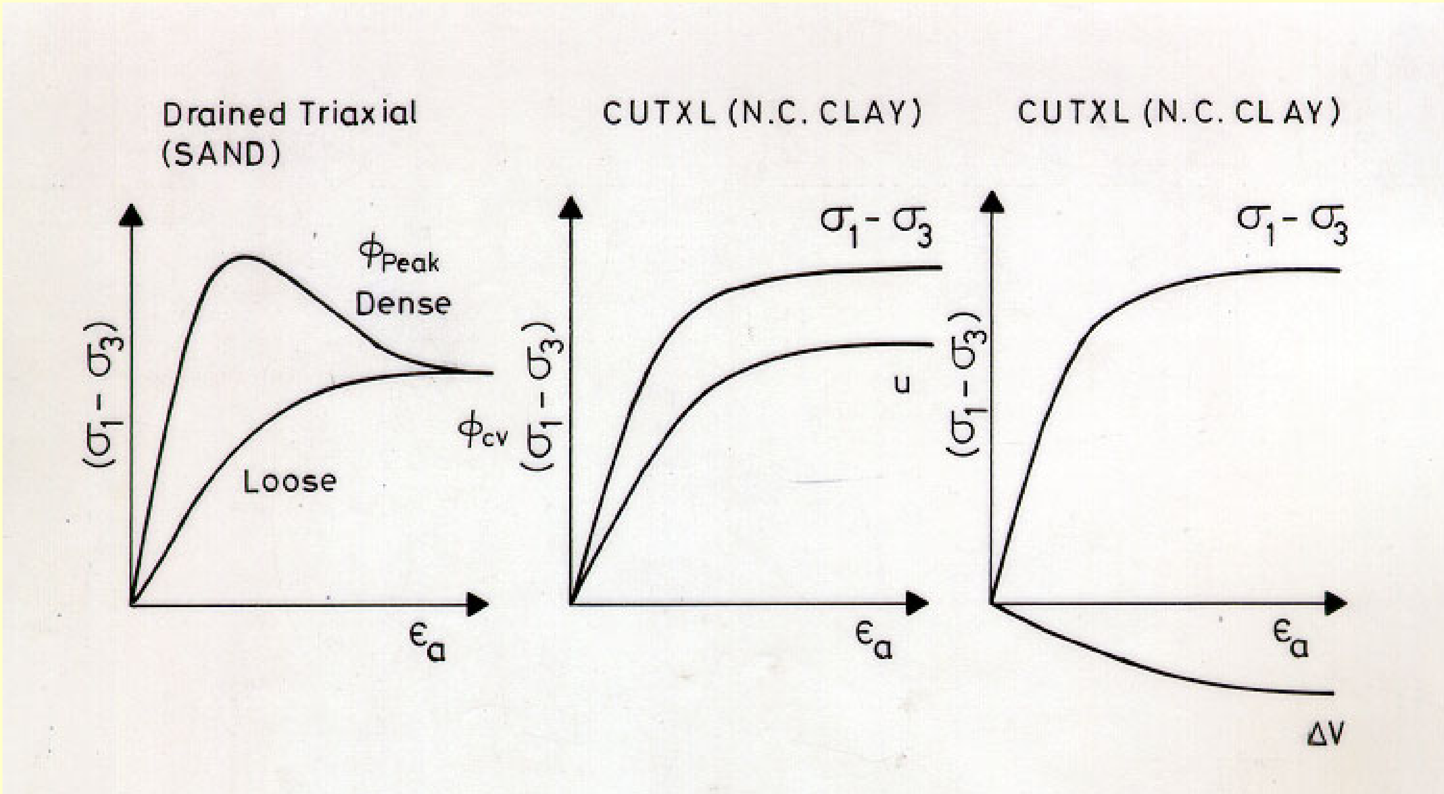
Cohesive frictional fill

The main advantage of cohesive frictional fill is better availability when compared with frictional fill. Cohesive frictional fill is specified in standards such as UK code of Practice for Reinforced Soil, BS 8006:2000. Knowledge of the material properties such as a) cohesion under effective stress conditions, b) adhesion between the fill and the reinforcing elements under effective stress conditions, c) liquid limit, d) plasticity index, e) consolidation parameters is required for the selection of cohesive frictional fill. Besides these properties, requirements such as grading, density, friction angle need to be satisfied similar to the case of cohesionless materials.

The select backfill is placed and compacted in layers. Heavy equipment should not come within 1.5 metres of the wall face. Compact close to the wall with hand operated vibrating plates or rollers. The degree of compaction required should not be less than 95 percent of the maximum dry density (Standard Compaction). The backfill should never be placed with a moisture content higher than Optimum Moisture Content.

Soil State

- Factors such as overburden, state of soil, drainage conditions & degree of saturation affect the response of reinforced soil structure.
- The state of stress in the reinforced soil needs to be assessed to know the earth pressure distribution behind the retaining wall.



Drained Triaxial
(SAND)
CUTXL (N.C. CLAY)
CUTXL (N.C. CLAY)
ϕ_{Peak}
Dense
Loose
ϕ_{cv}
$(\sigma_1 - \sigma_3)$
$\sigma_1 - \sigma_3$
u
ϵ_a
ΔV

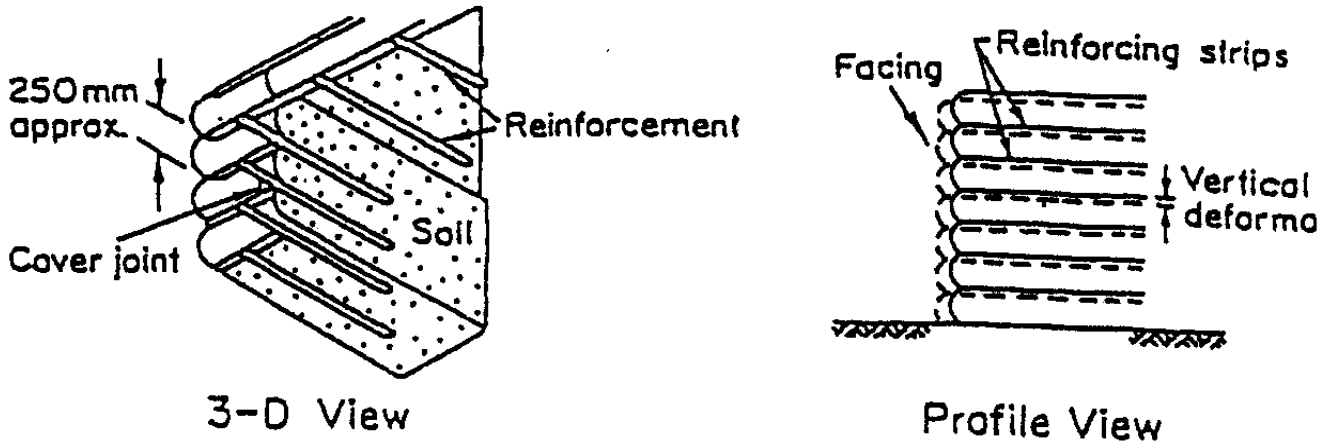
- Bolton (1986) proposed a simplified relationship between the peak friction angle and the residual or constant volume friction angle given by

$$\phi_p^{'} = \phi_{cs}^{'} + 0.8 \ \psi$$

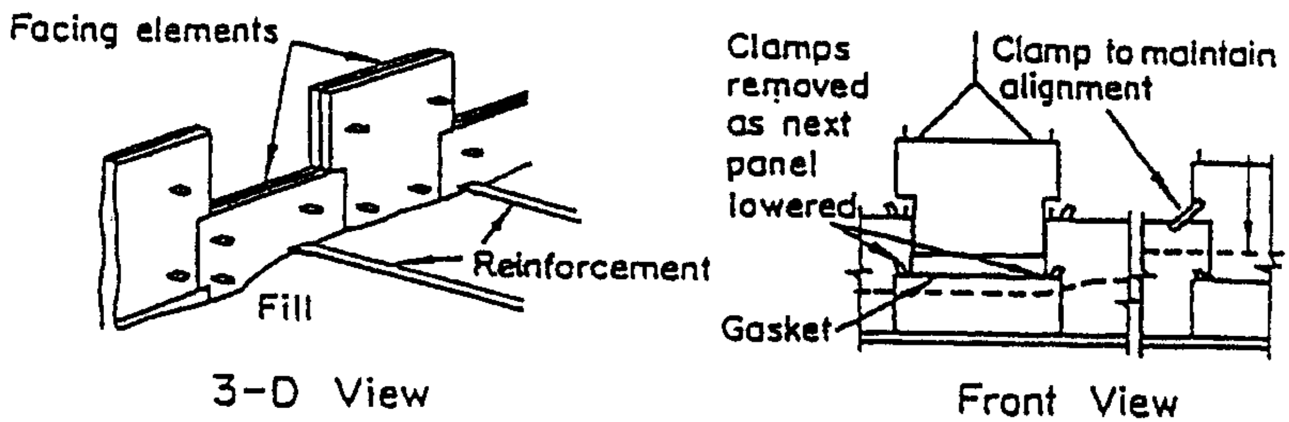
- where ψ in the angle of dilatancy which denotes the effect of compactions and the tendency for dilation. Higher angles of dilations denote higher normal stress on the reinforcement, which increases the pullout resistance of reinforcement.

Construction factors

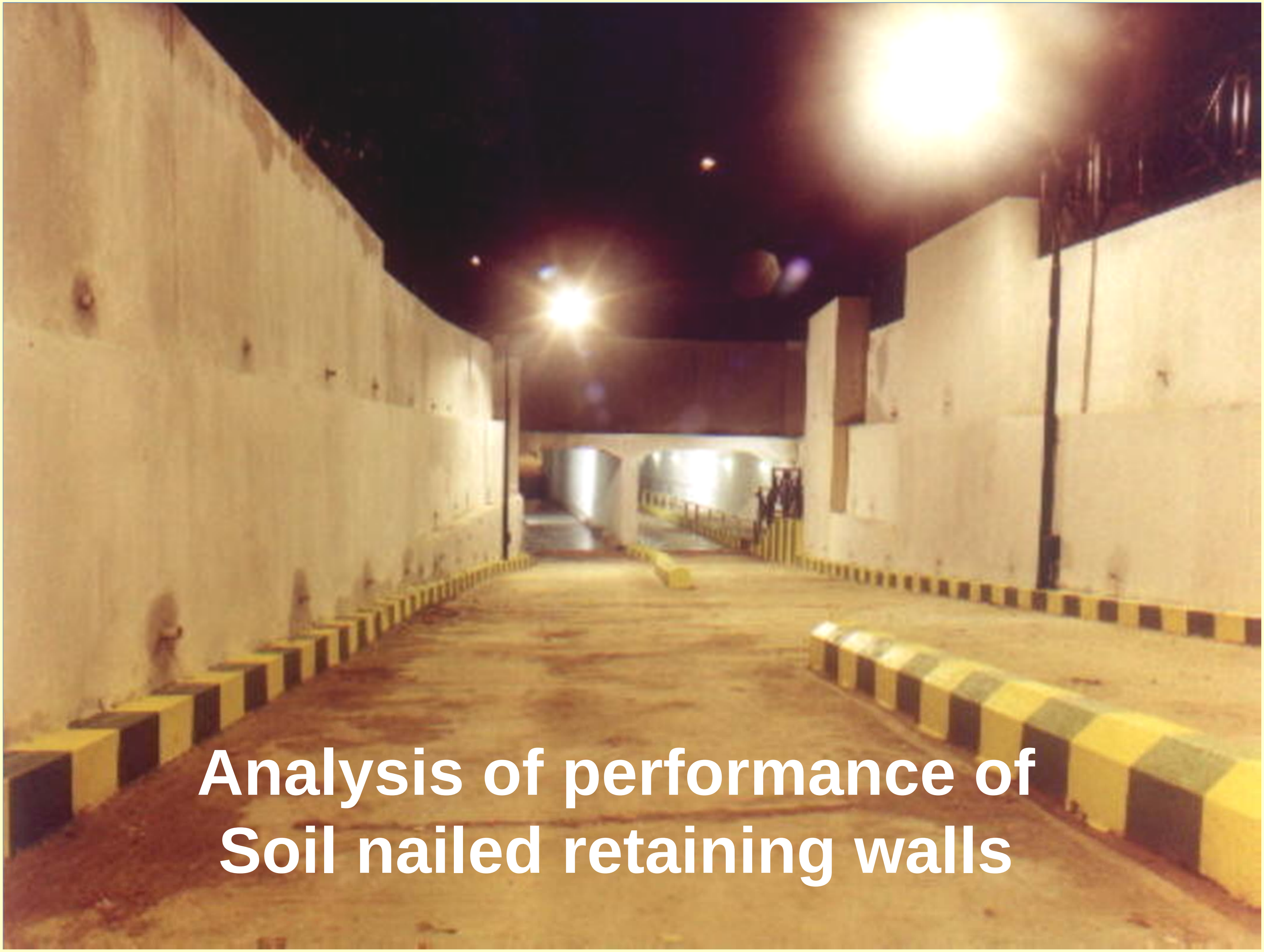
- Construction variables such as geometry of structure, compaction, construction system, aesthetics & the durability of reinforced elements affect the techniques such as earth pressure distribution, tensile forces mobilized & the deformation.
- The amount of compaction should be estimated so that the reinforcement members where the compaction stresses are predominant do not fail.

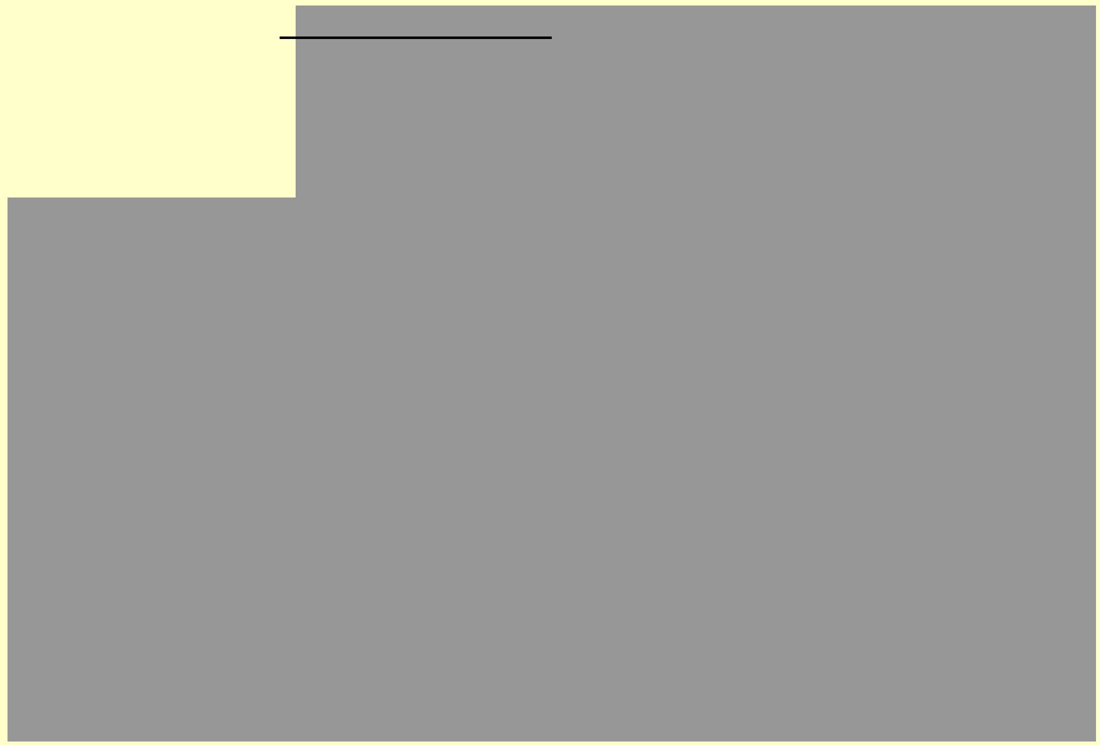


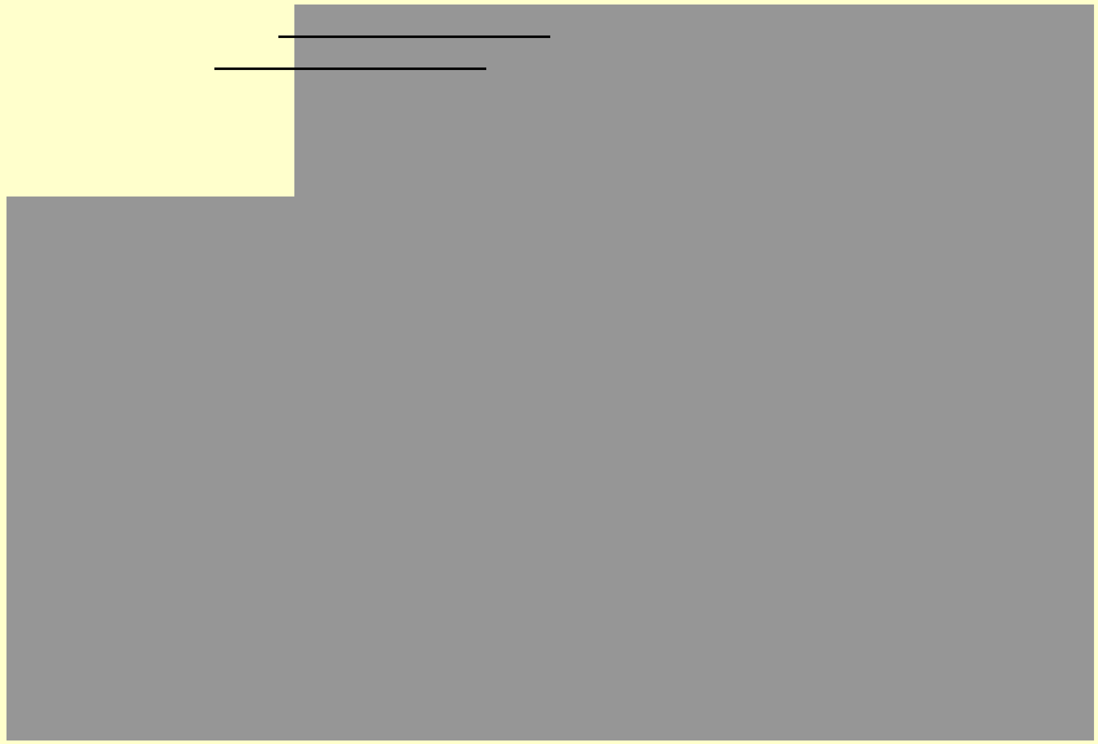
a) Concertina Method

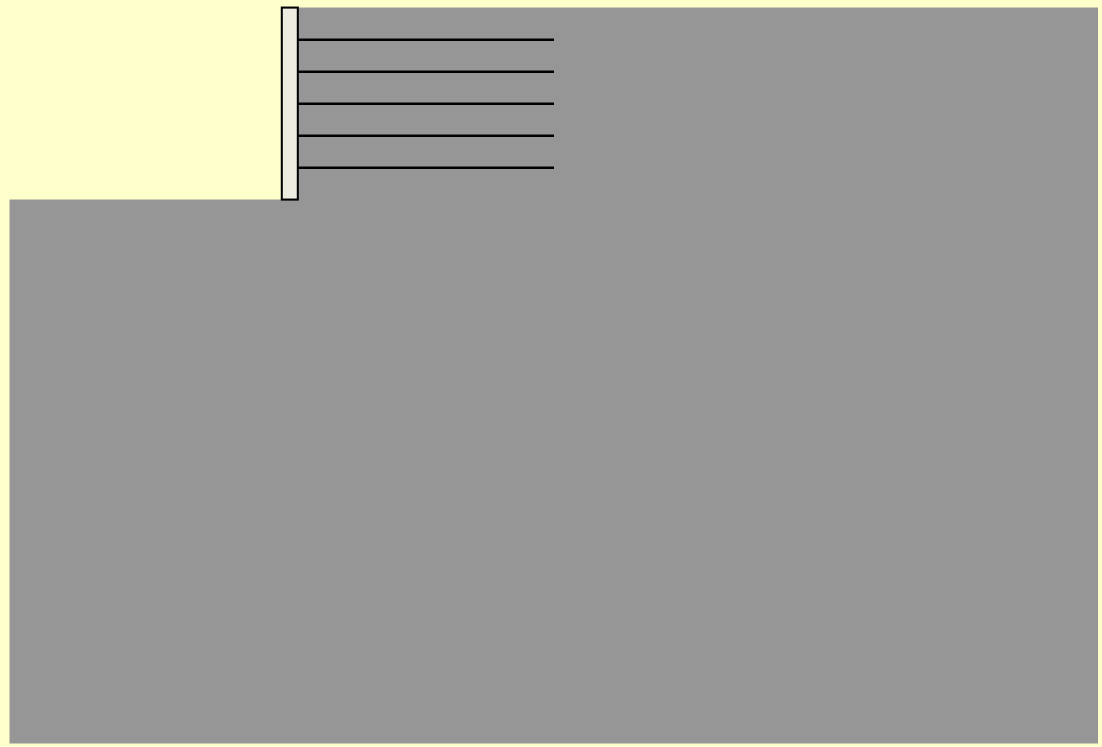


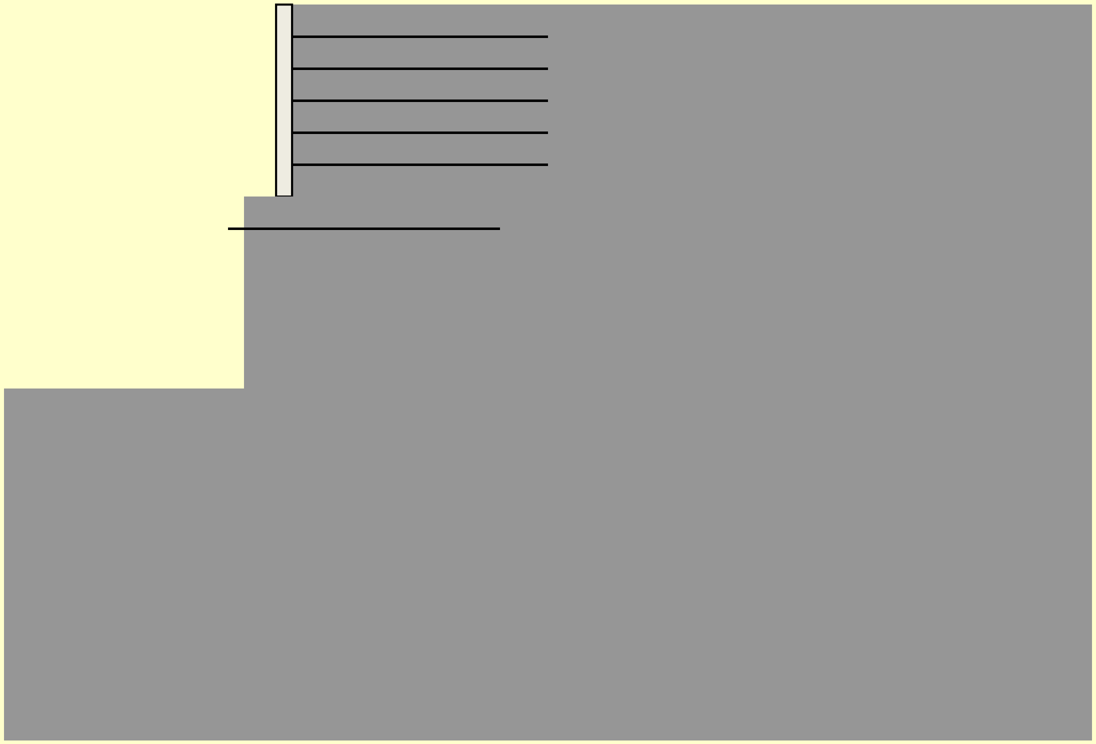
b) Telescope Method

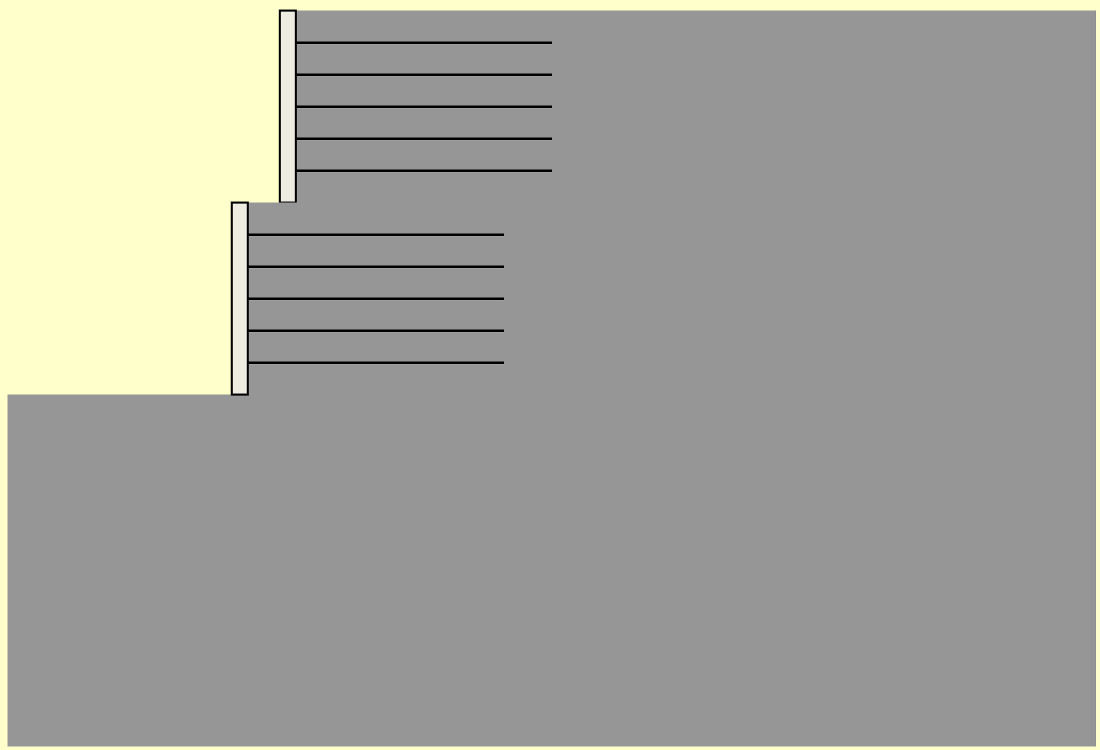

Analysis of performance of
Soil nailed retaining walls

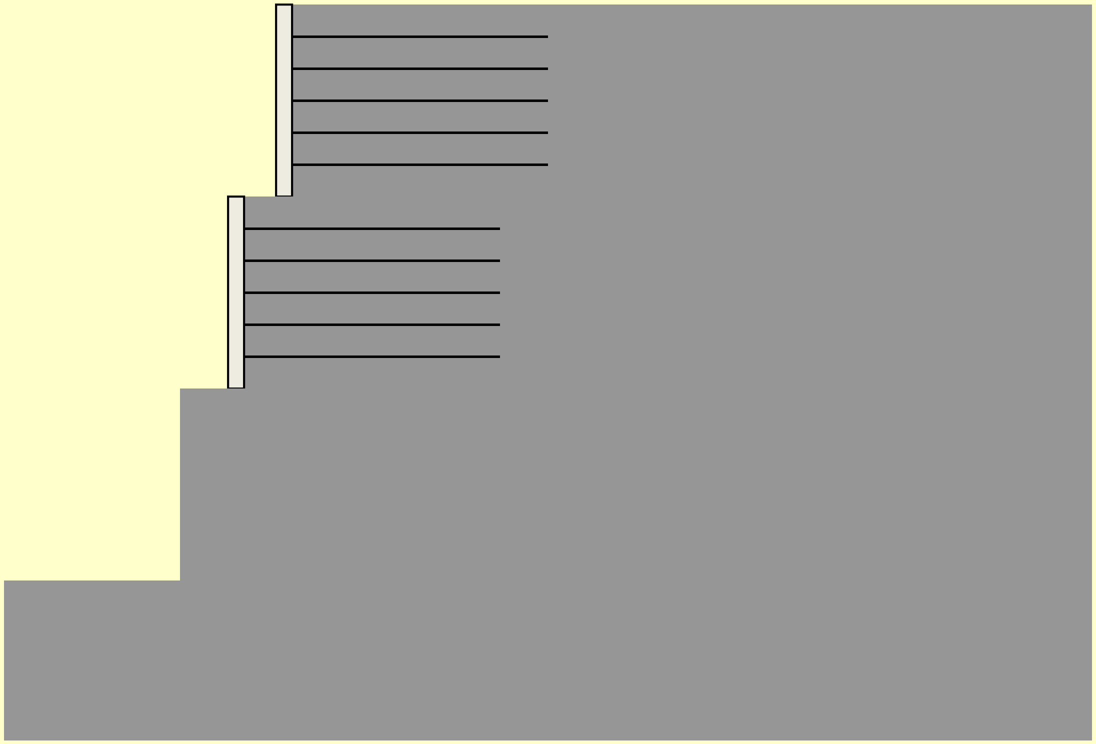


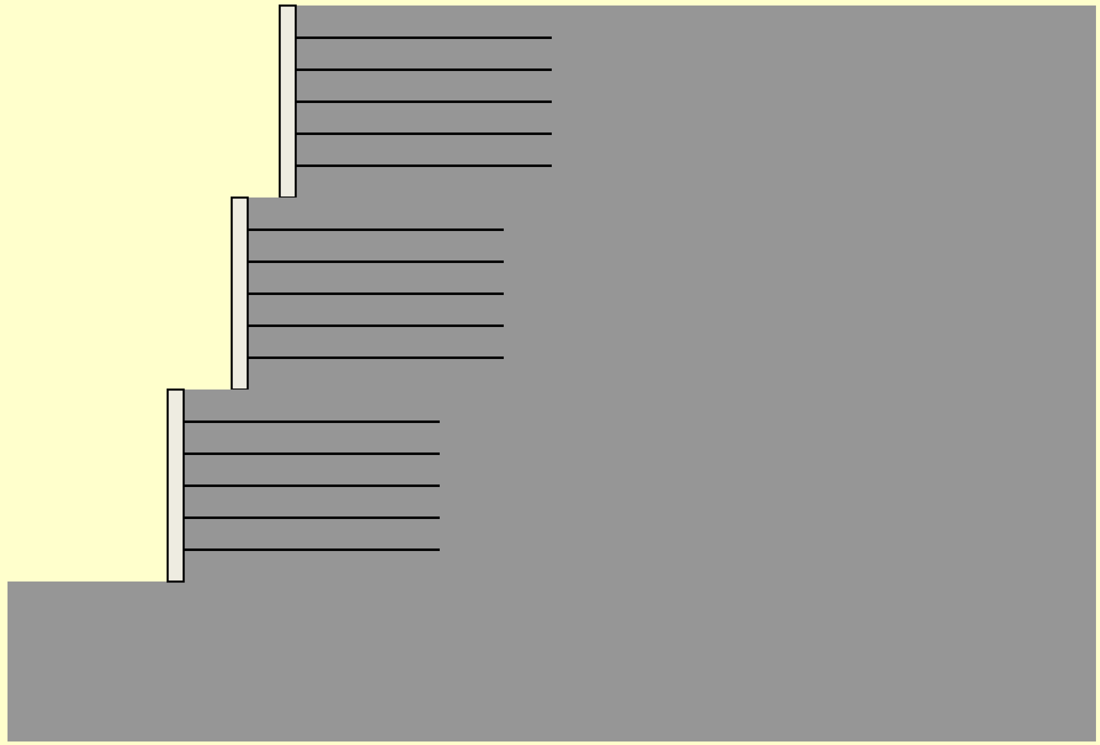


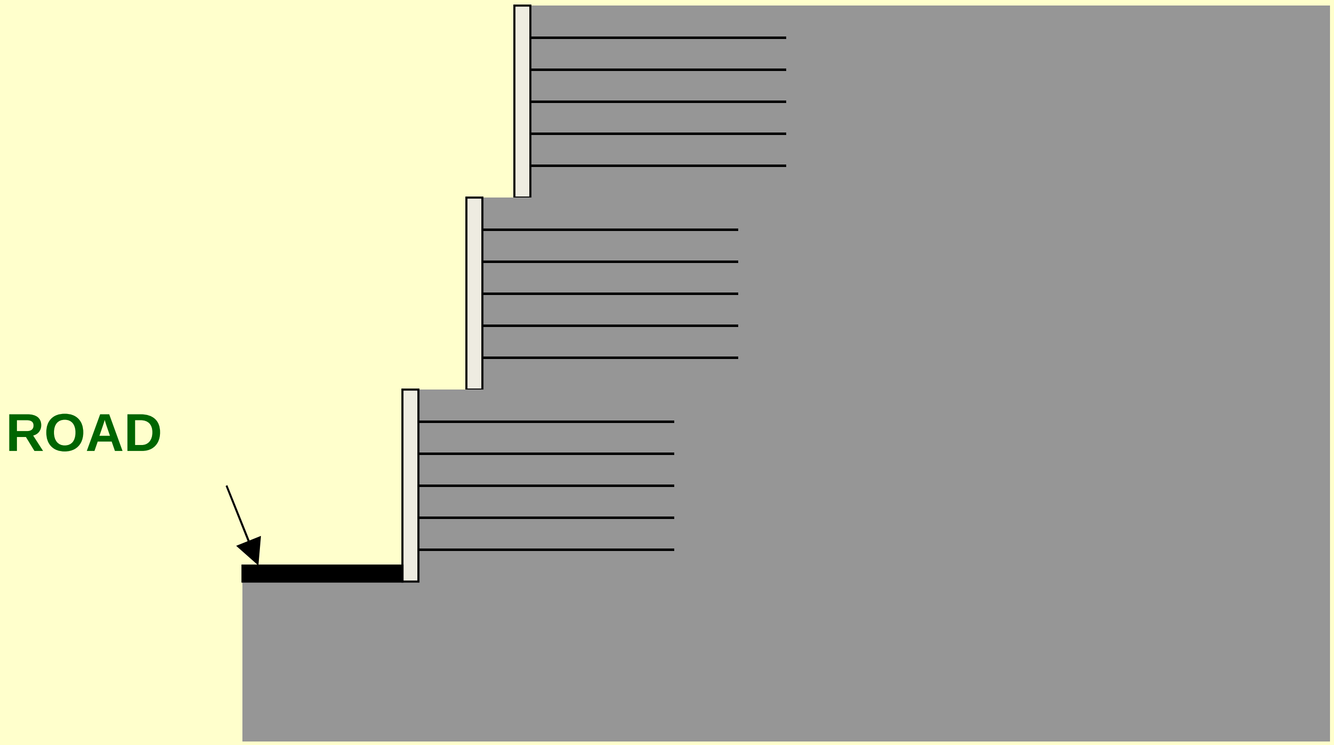


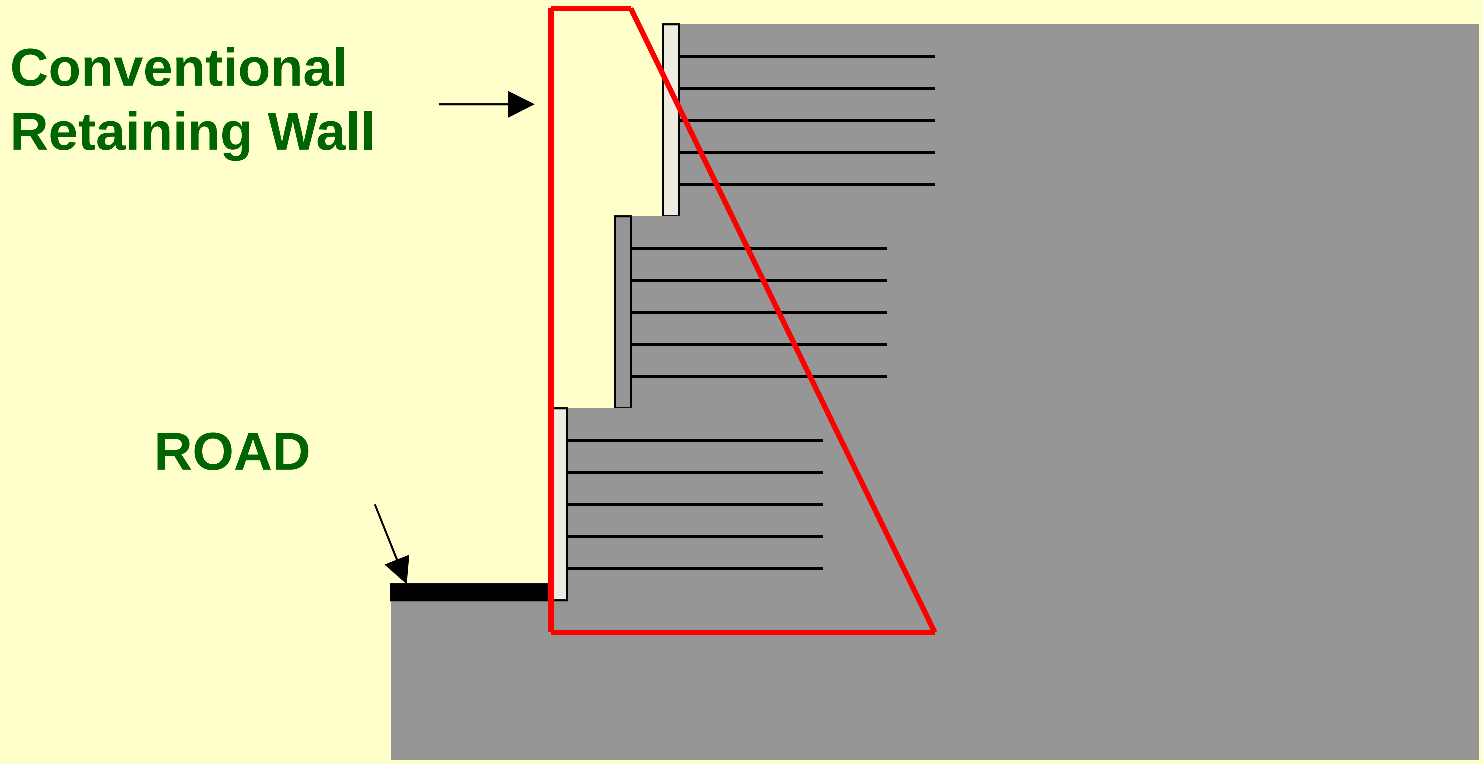








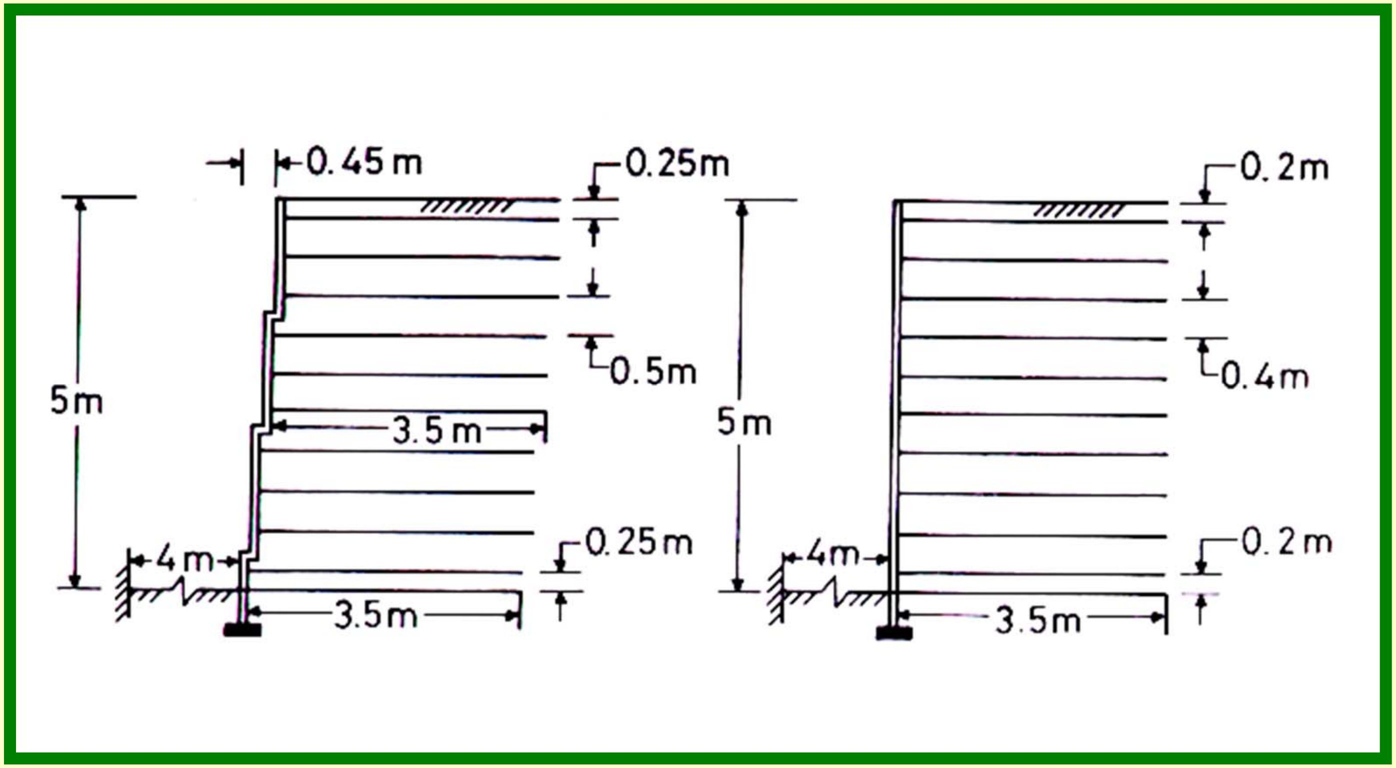

ROAD



Conventional
Retaining Wall
ROAD

GEOMETRY AND DESIGN

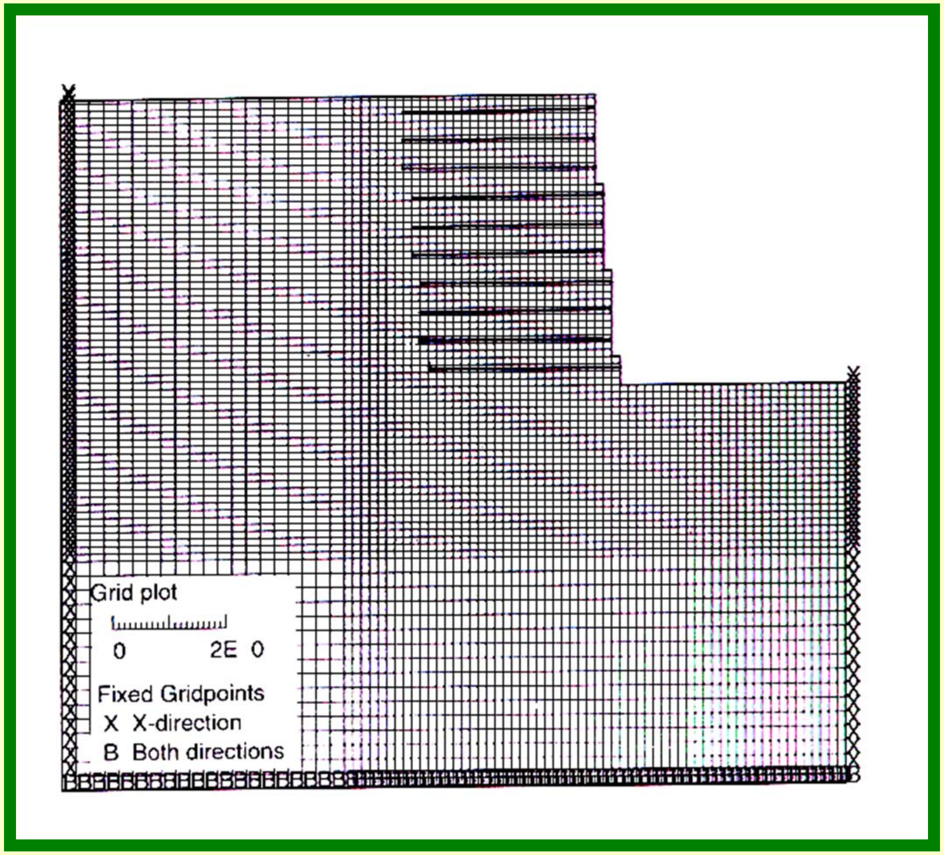
Geometry



Design

Walls were designed with coherent gravity method

Discretisation



Soil - Mohr Coulomb model

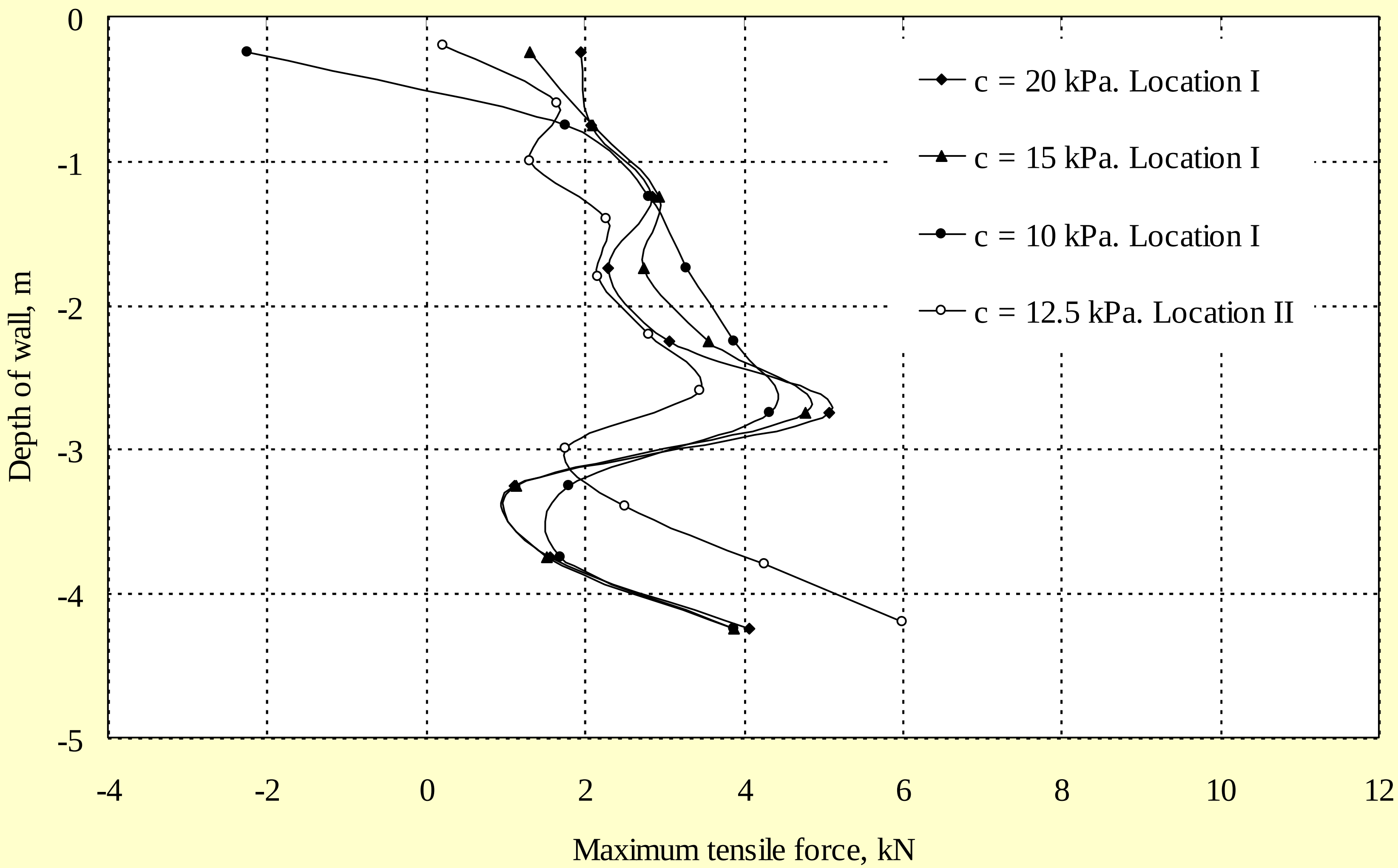
Nails - Elastic-pile elements

Parameters adopted	Value used
Cohesion (c)	10 to 20 kPa
Angle of internal friction (ϕ)	25^0
Unit weight (γ)	18 kN/m^3
Modulus of elasticity (E_S)	20 MPa
Poisson's ratio (ν)	0.3
Nail Properties:	
Diameter (d)	0.02 m
Length (L)	3.5 m
Spacing of nails (S_v x S_h)	0.5m x 0.5m for location I and
	0.4m x 0.4m for location II
Modulus of elasticity (E)	2×10^{11} N/m^2
RCC Facing:	
Thickness (t)	0.1 m
Modulus of elasticity (E_C)	2×10^{10} N/m^2
Cross-sectional area (A)	0.1 m^2 /m length
Moment of inertia (I)	8.334×10^{-5} m^4/m length

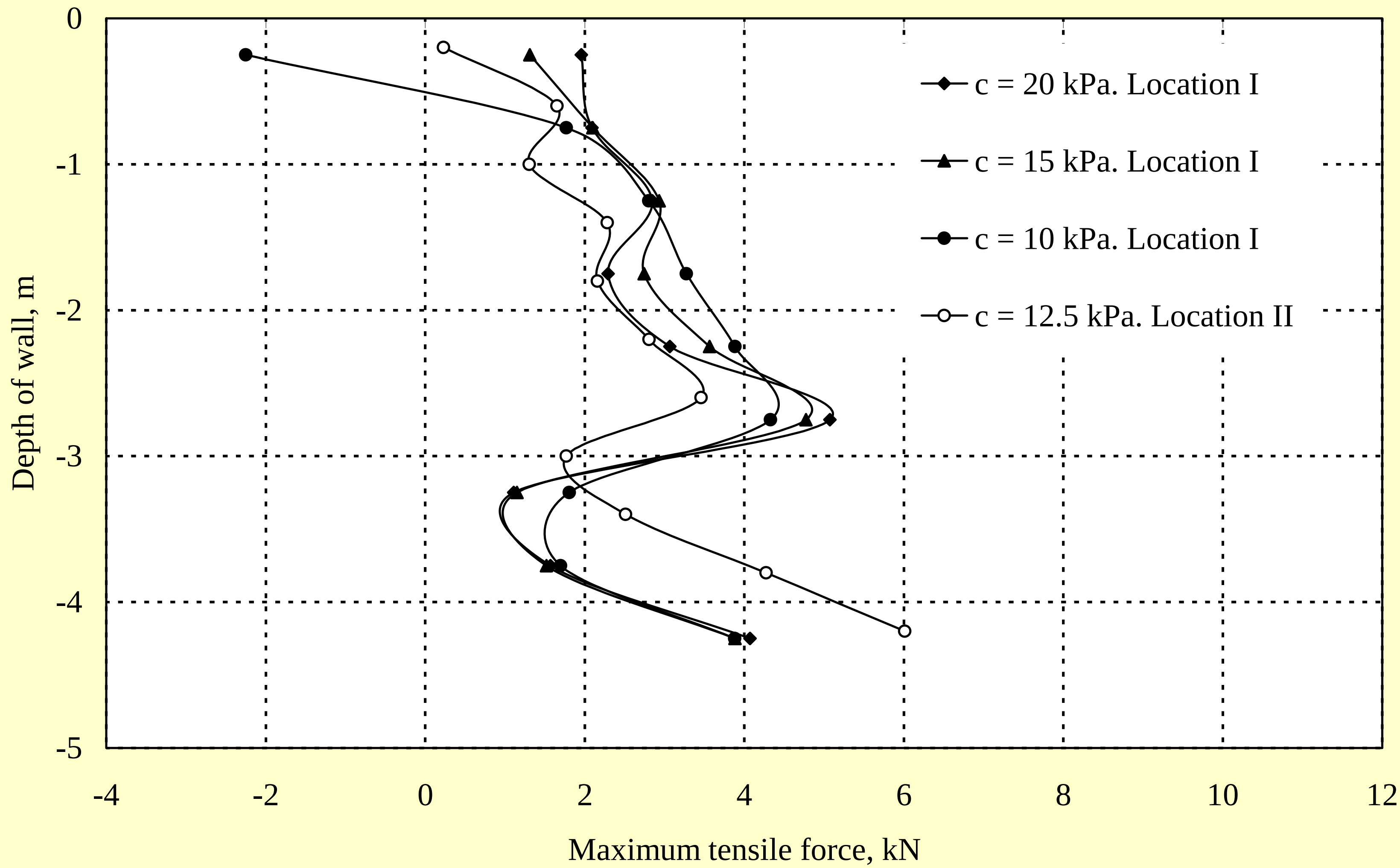
STABILITY AND DEFORMATION ANALYSIS

The results are presented in terms of behaviour of

- Forces mobilized in reinforcement
- Horizontal deformations in soil nailed structure
- Critical depth of excavation



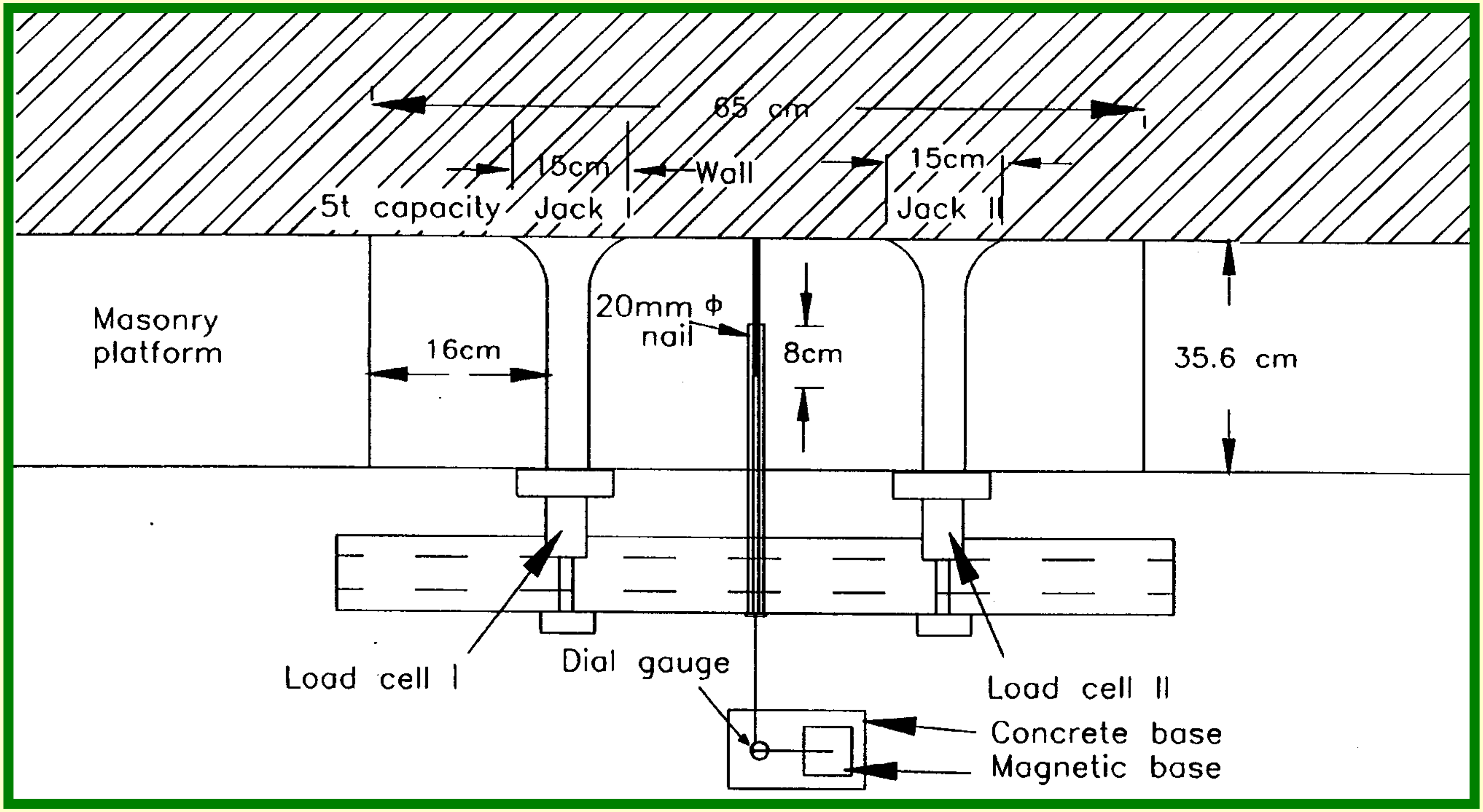
Variation of maximum tensile force in nails with depth of wall


c = 20 kPa. Location I
c = 15 kPa. Location I
c = 10 kPa. Location I
c = 12.5 kPa. Location II
Depth of wall, m
0
-1
-2
-3
-4
-5
-4
-2
0
2
4
6
8
10
12
Maximum tensile force, kN

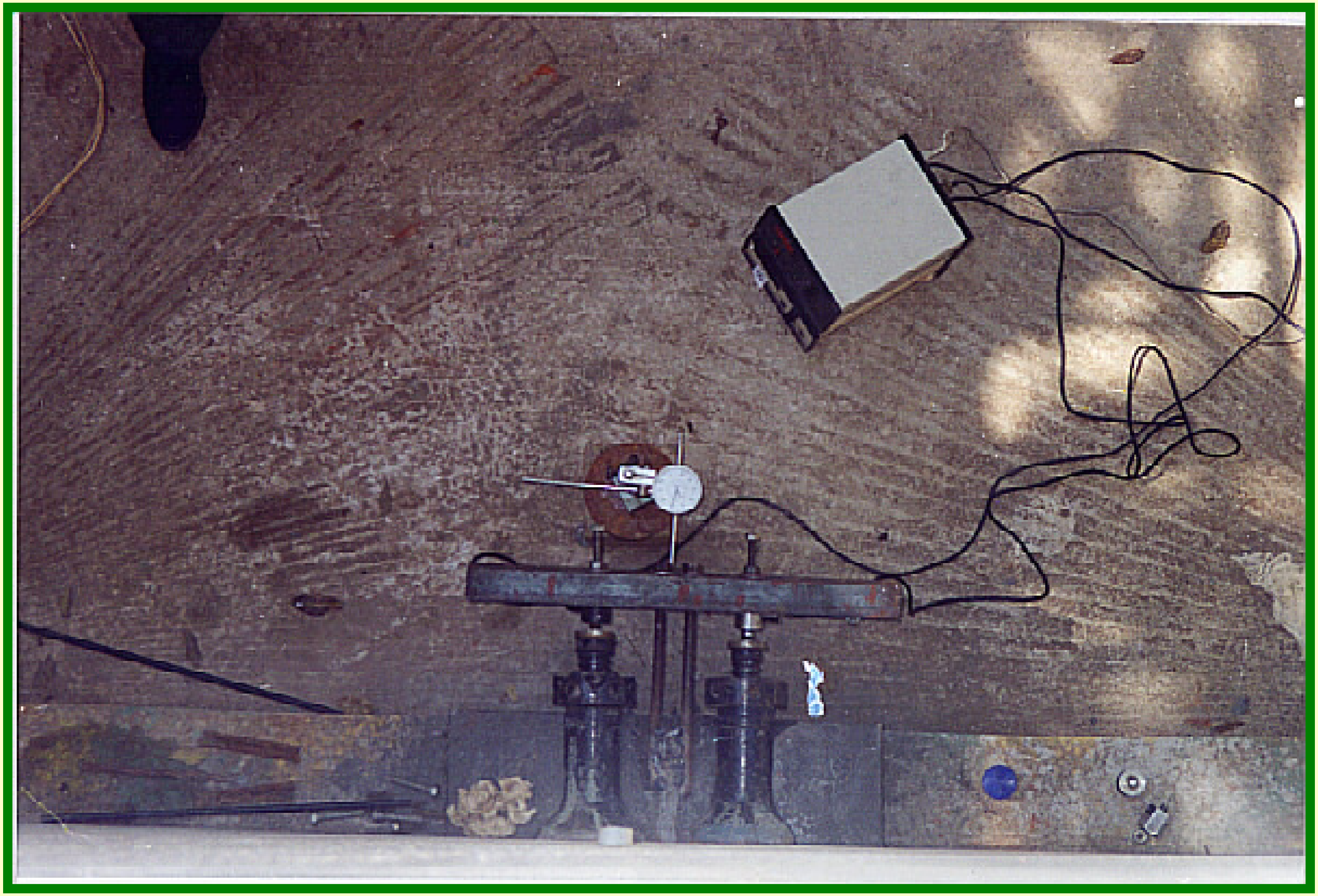
Summary of critical depths of excavation

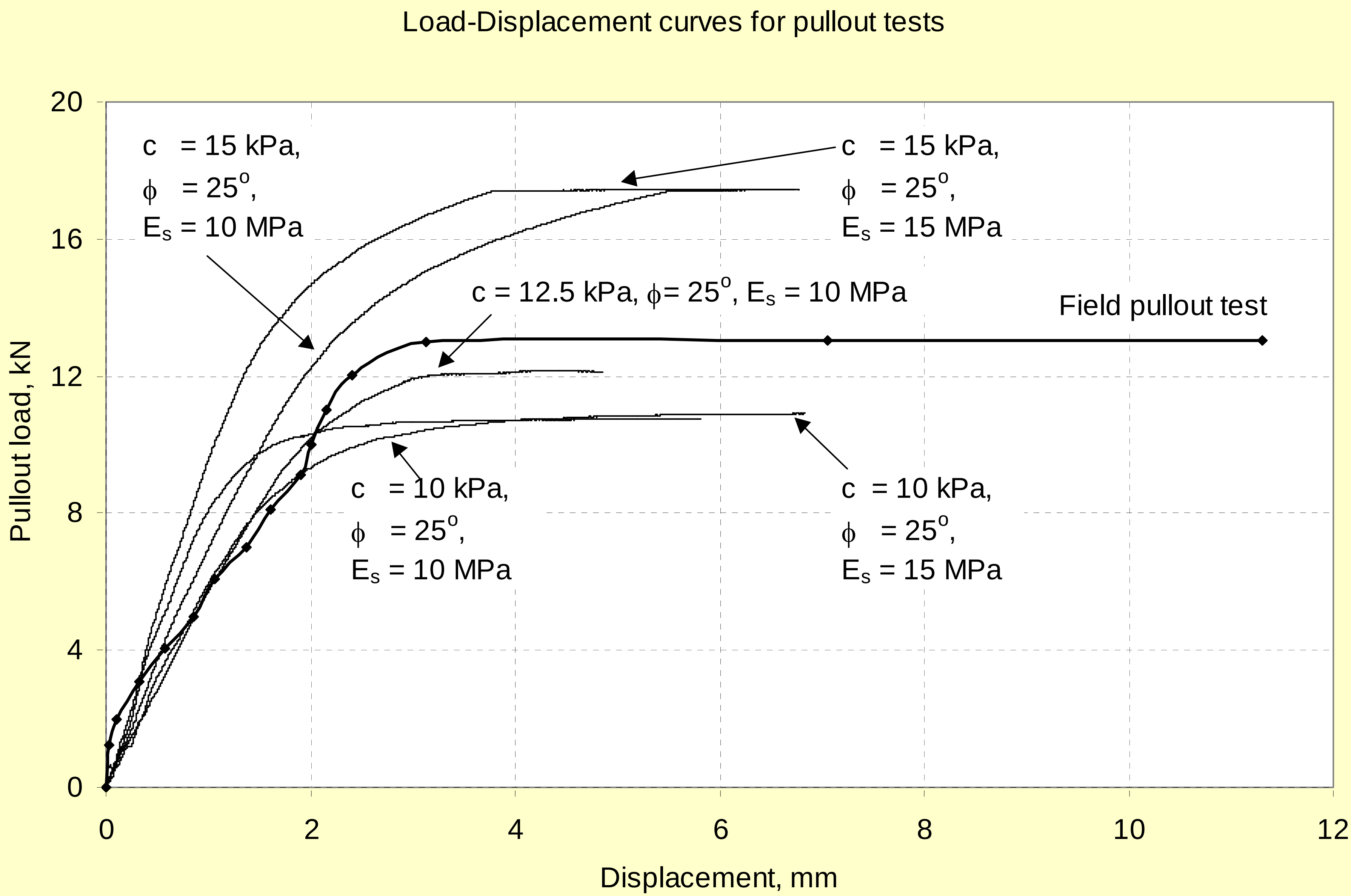
Cohesion (kPa)	Critical depths of excavation (m)		Location of maximum horizontal deformation	Critical Depth improvement factor
	Without nailing	With nailing*		
10	2.5	5.0	3.81 m depth	2.00
15	4.0	7.0	5.31 m depth	1.75
20	5.0	10.0	7.90 m depth	2.00

(* The critical depths of excavation are arrived based on the maximum horizontal deformation exceeding 1%).

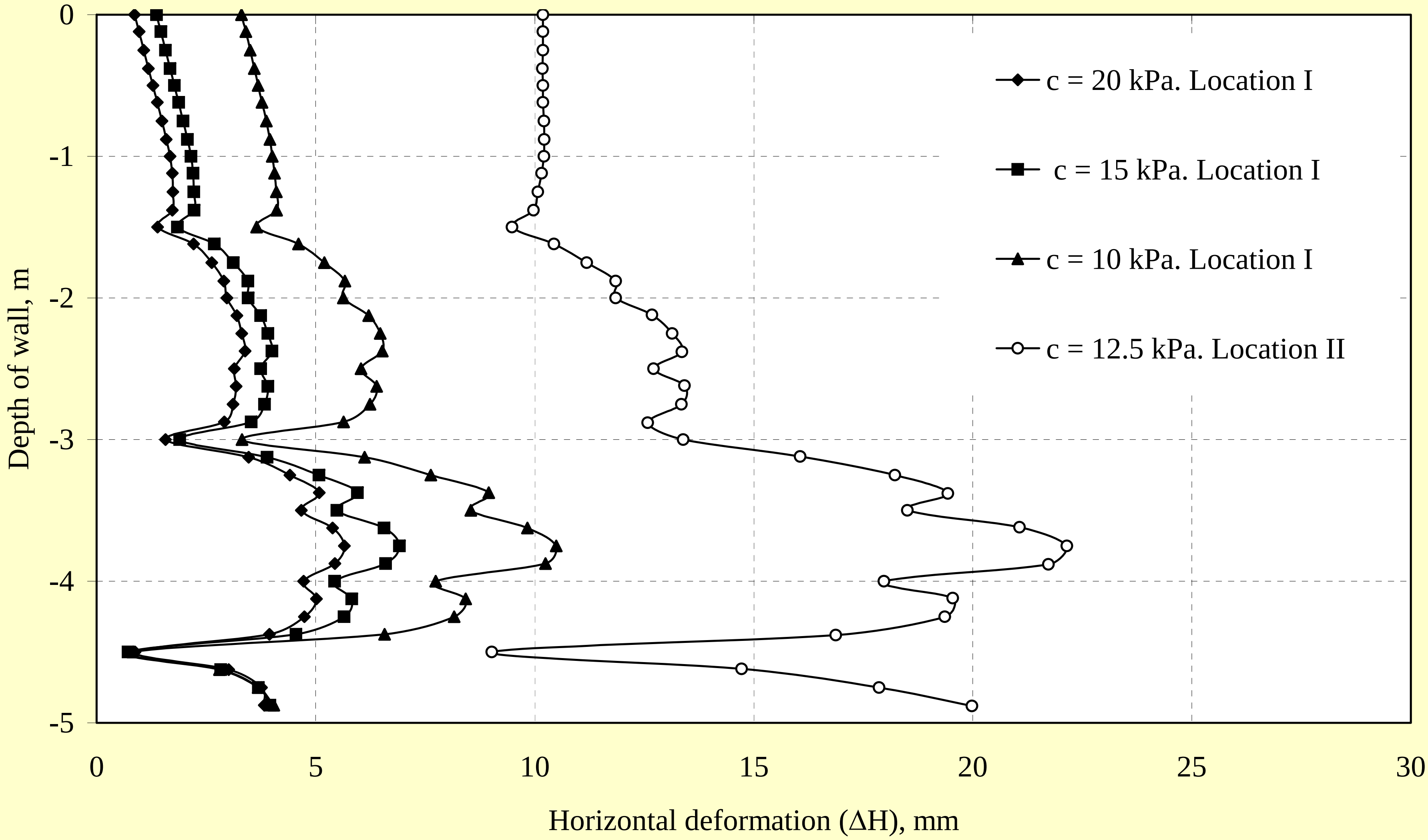


FIELD PULL-OUT TEST SETUP





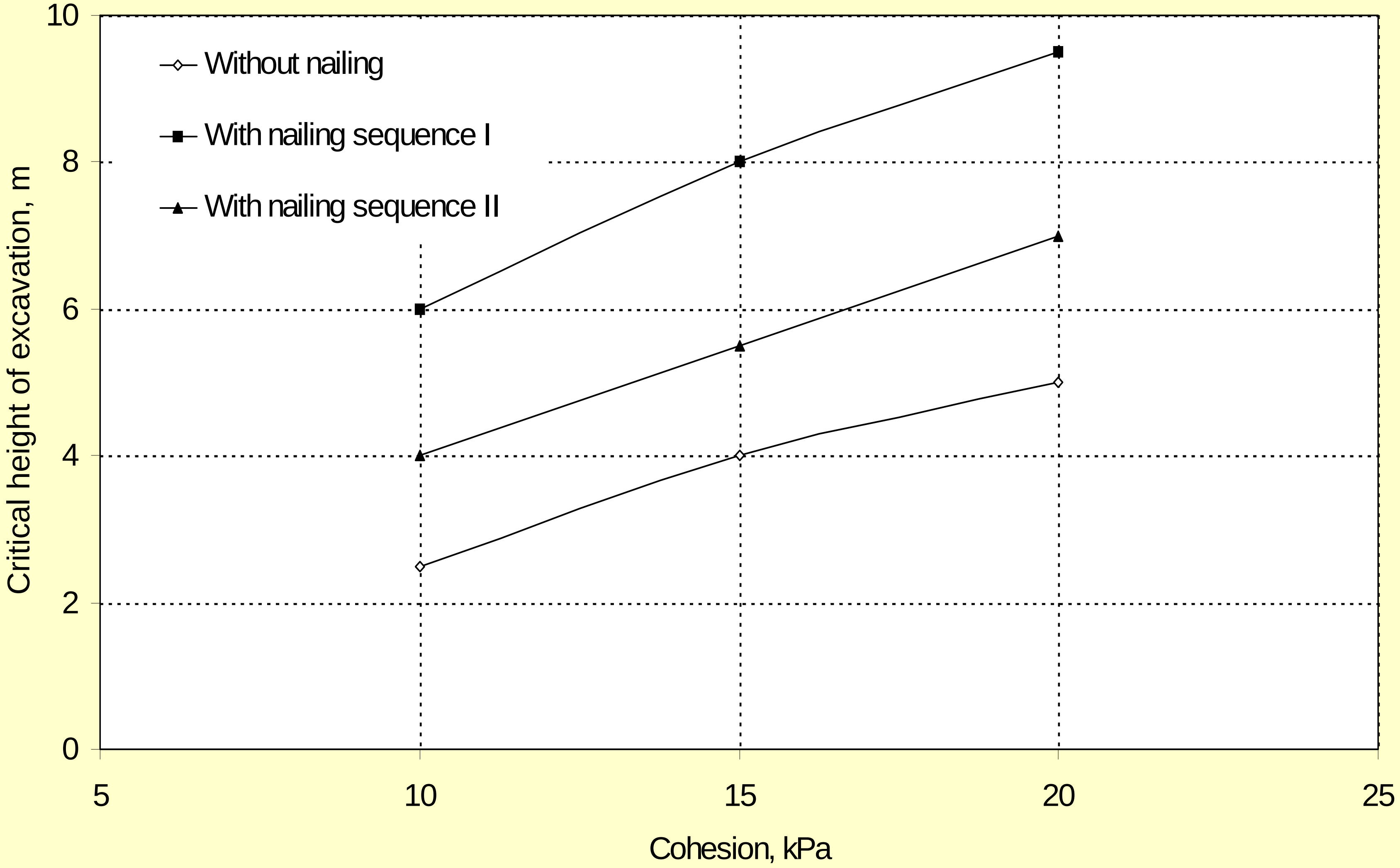
Load-Displacement curves for pullout tests
c = 15 kPa,
ϕ = 25o,
Es = 10 MPa
c = 15 kPa,
ϕ = 25o,
Es = 15 MPa
c = 12.5 kPa, ϕ= 25o, Es = 10 MPa
Field pullout test
c = 10 kPa,
ϕ = 25o,
Es = 10 MPa
c = 10 kPa,
ϕ = 25o,
Es = 15 MPa
Pullout load, kN
Displacement, mm
0
4
8
12
16
20
0
2
4
6
8
10
12


0
-1
-2
-3
-4
-5
Depth of wall, m
0
5
10
15
20
25
30
Horizontal deformation (ΔH), mm
c = 20 kPa. Location I
c = 15 kPa. Location I
c = 10 kPa. Location I
c = 12.5 kPa. Location II

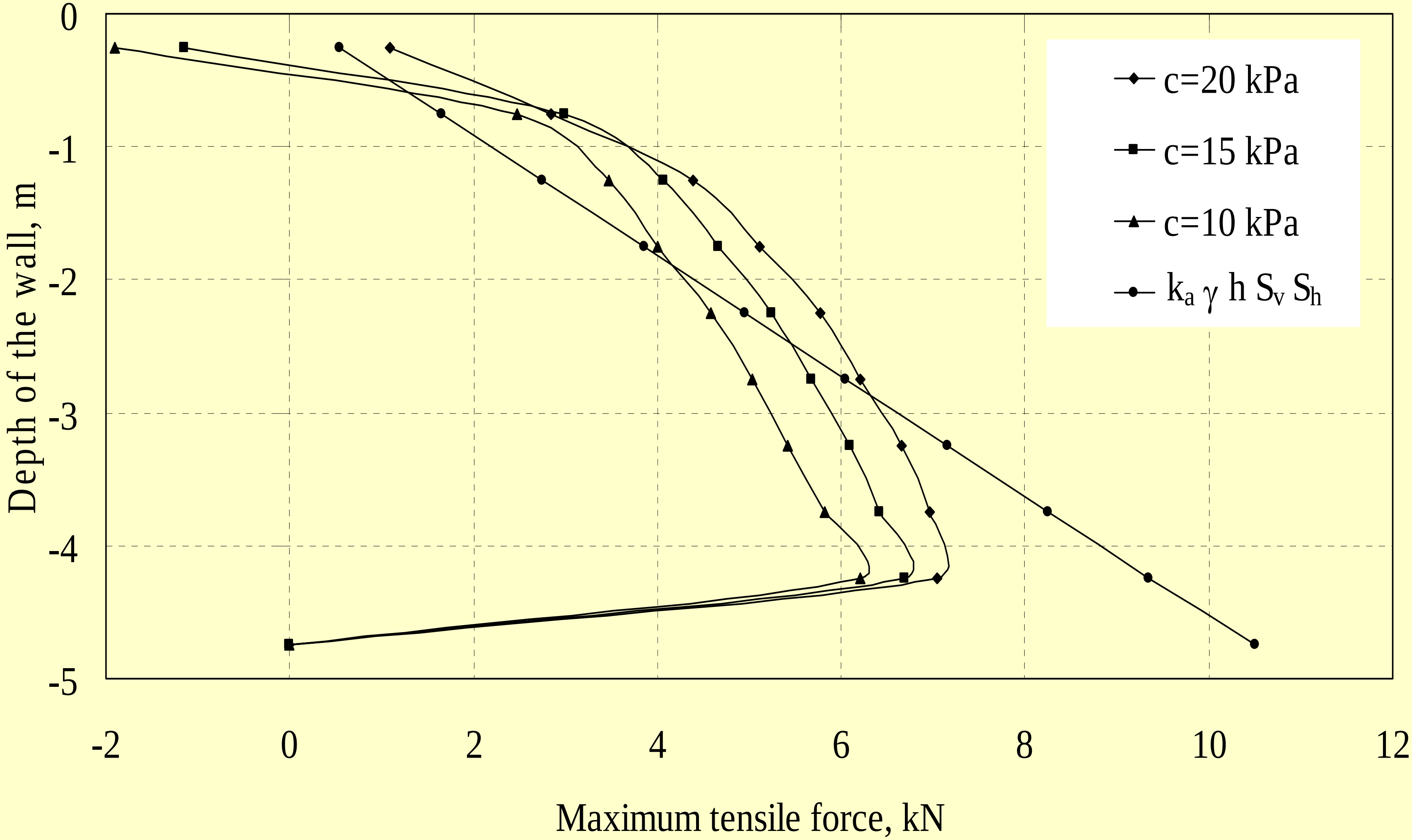
INFLUENCE OF CONSTRUCTION PRACTICES

- **Effect of sequence of construction**
- **Effect of type of facing**
- **Effect of connection between nails and facing**
- **Effect of stiffness of facing**
- **Effect of inclination of facing**

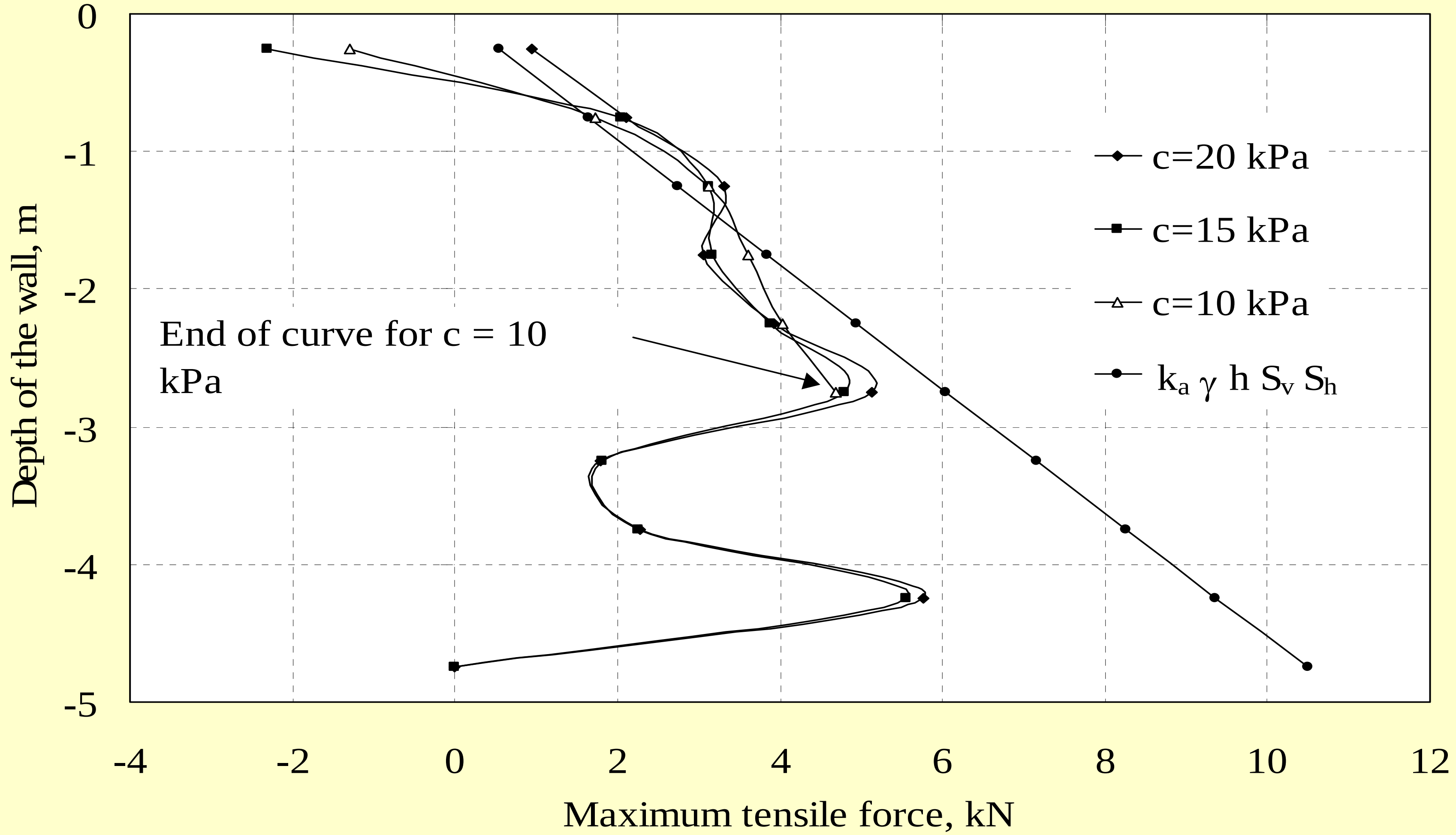
--In terms of critical height of excavation, forces developed in the nails and horizontal deformation pattern



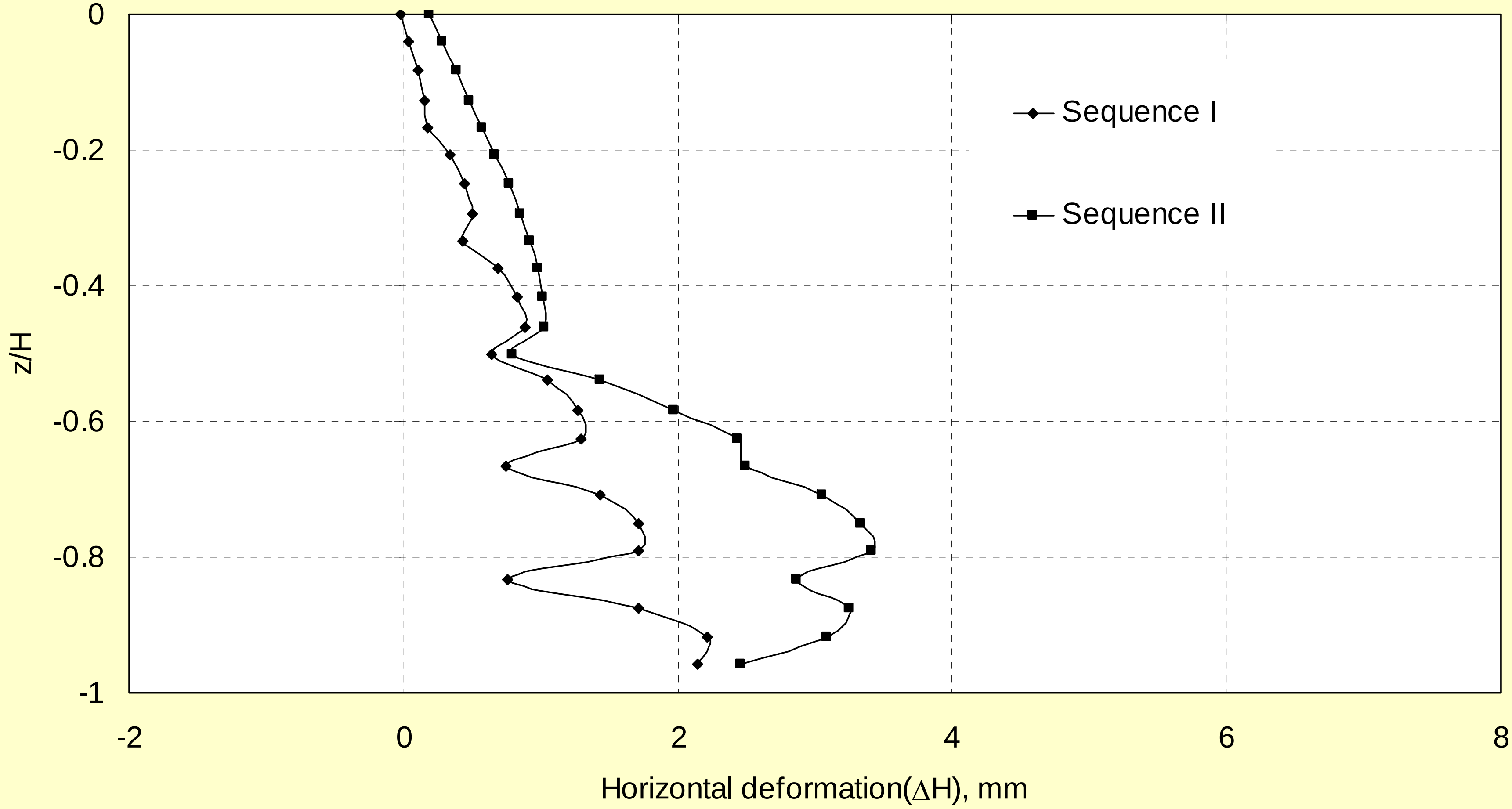
Effect of sequence of construction



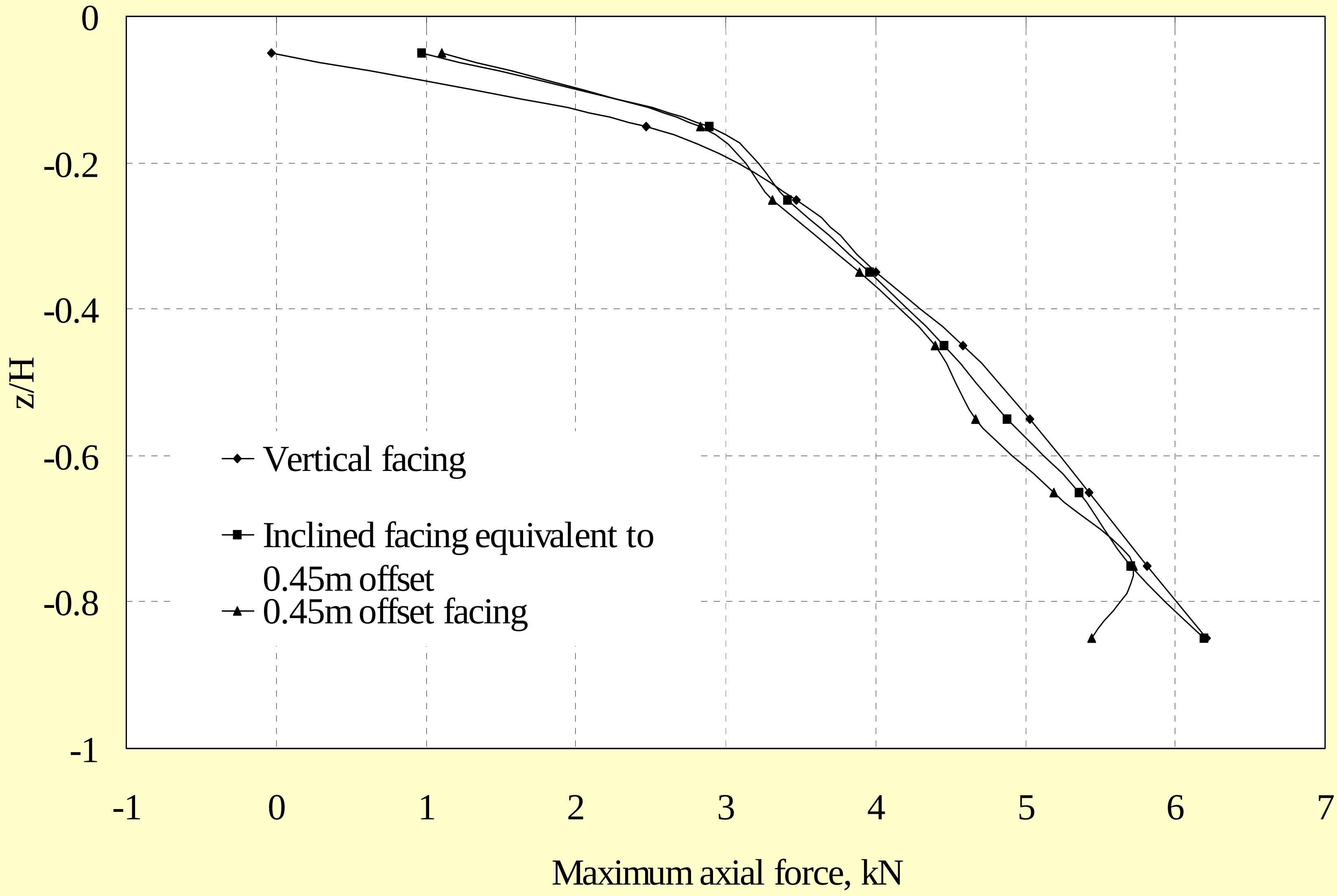
Effect of sequence on distribution of maximum tensile force



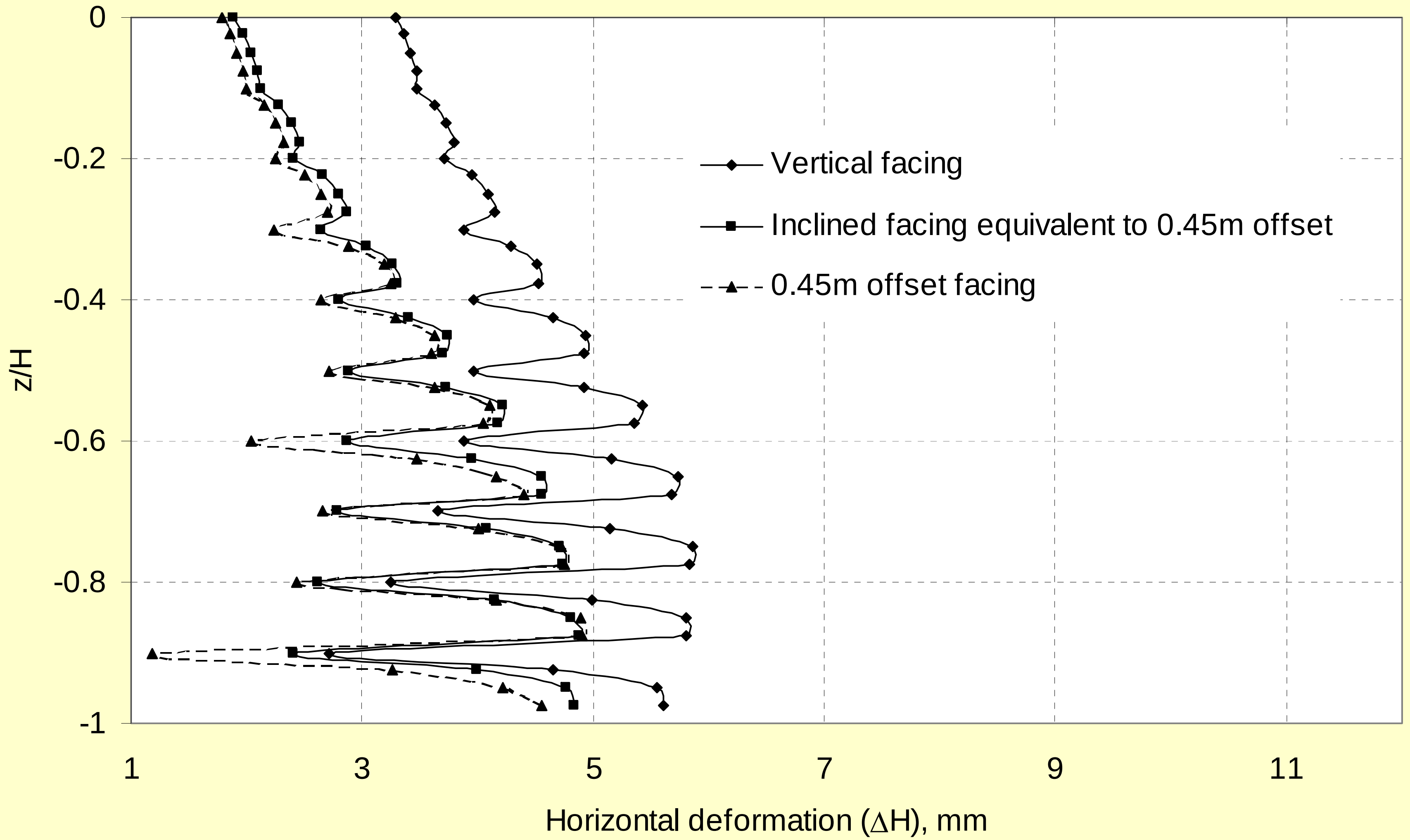
Variation of maximum tensile force in nails with depth for sequence II



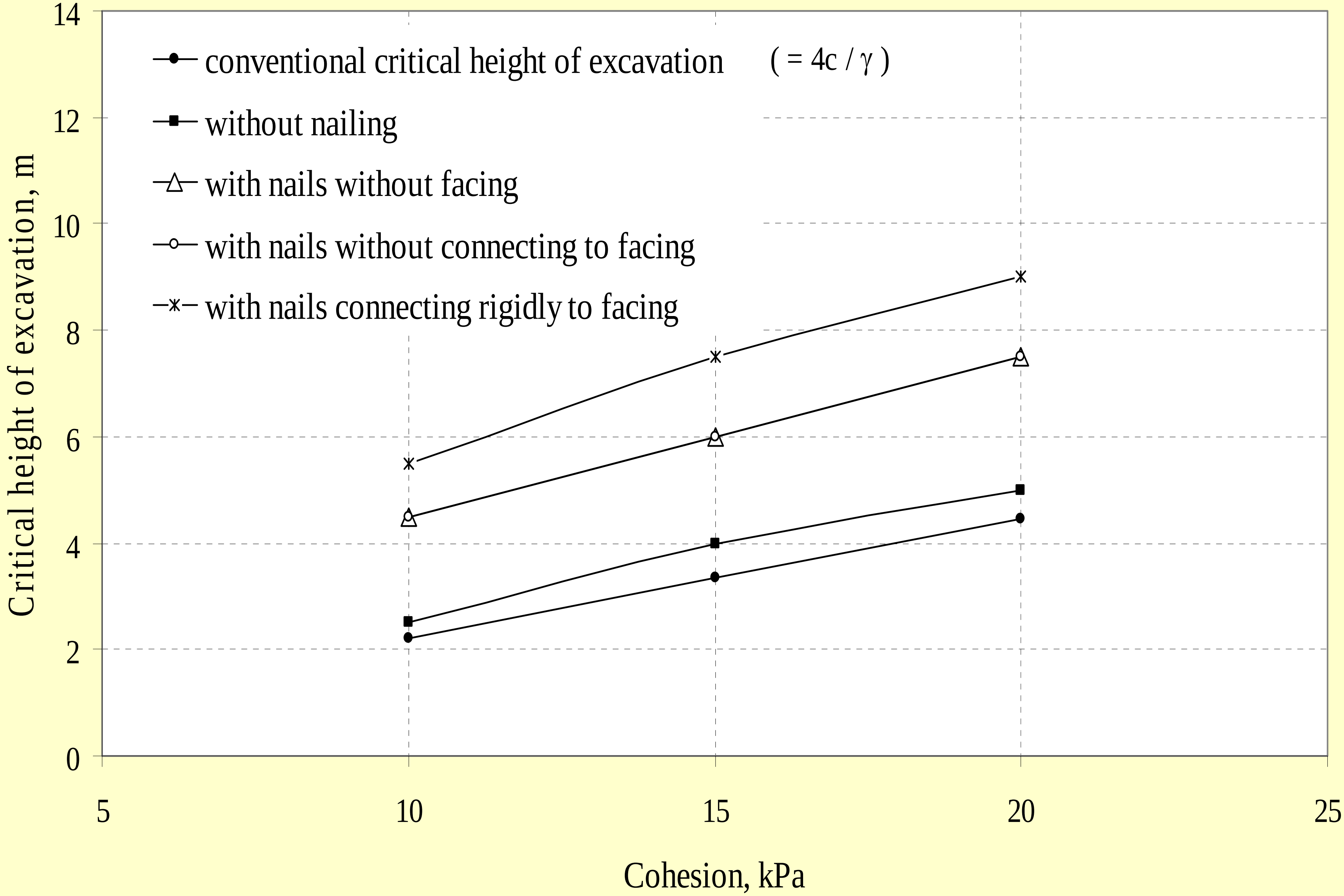
Variation of horizontal deformation of soil for sequences I and II (c = 10 kPa)

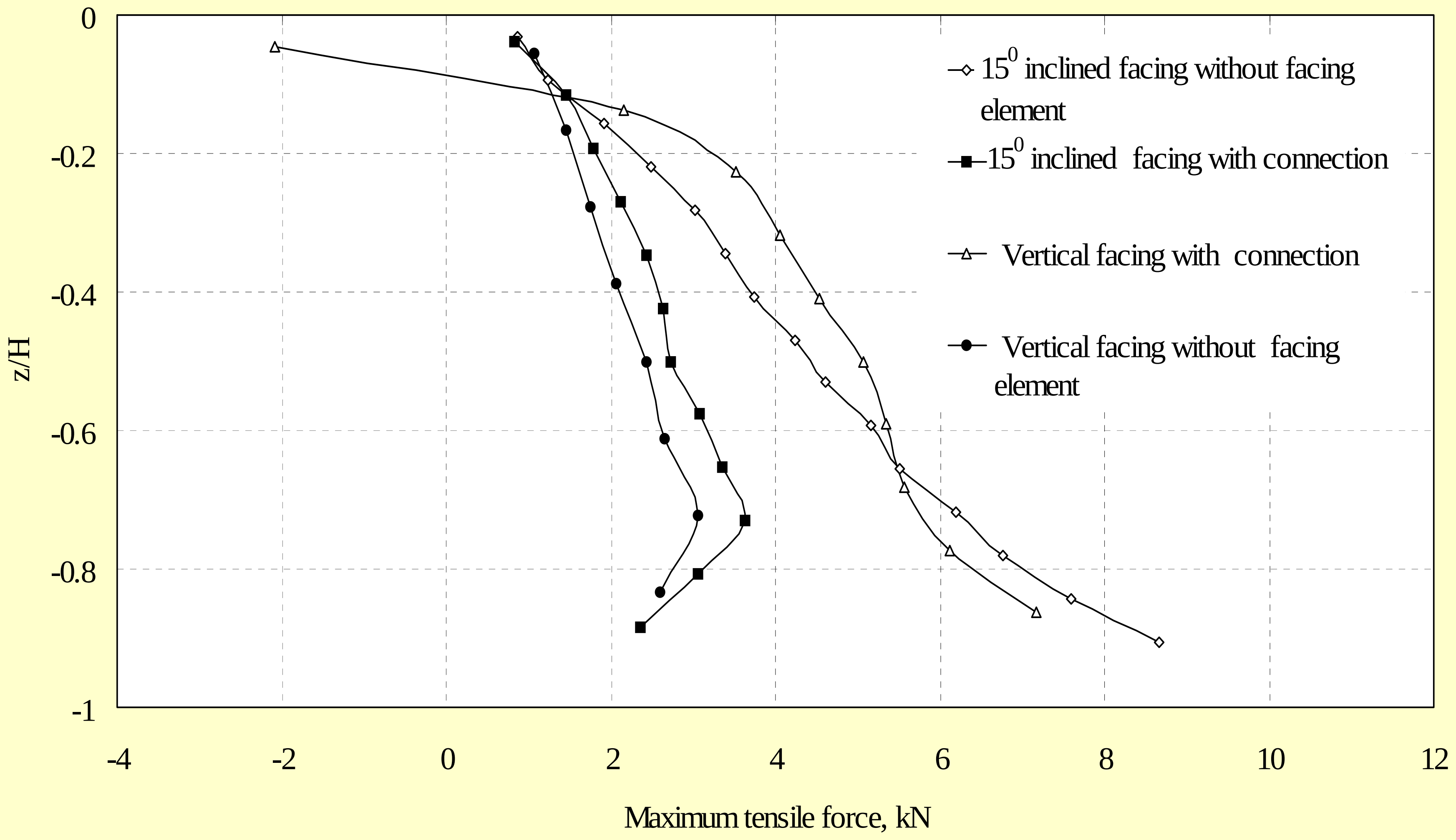


Effect of inclination in terms of tensile force

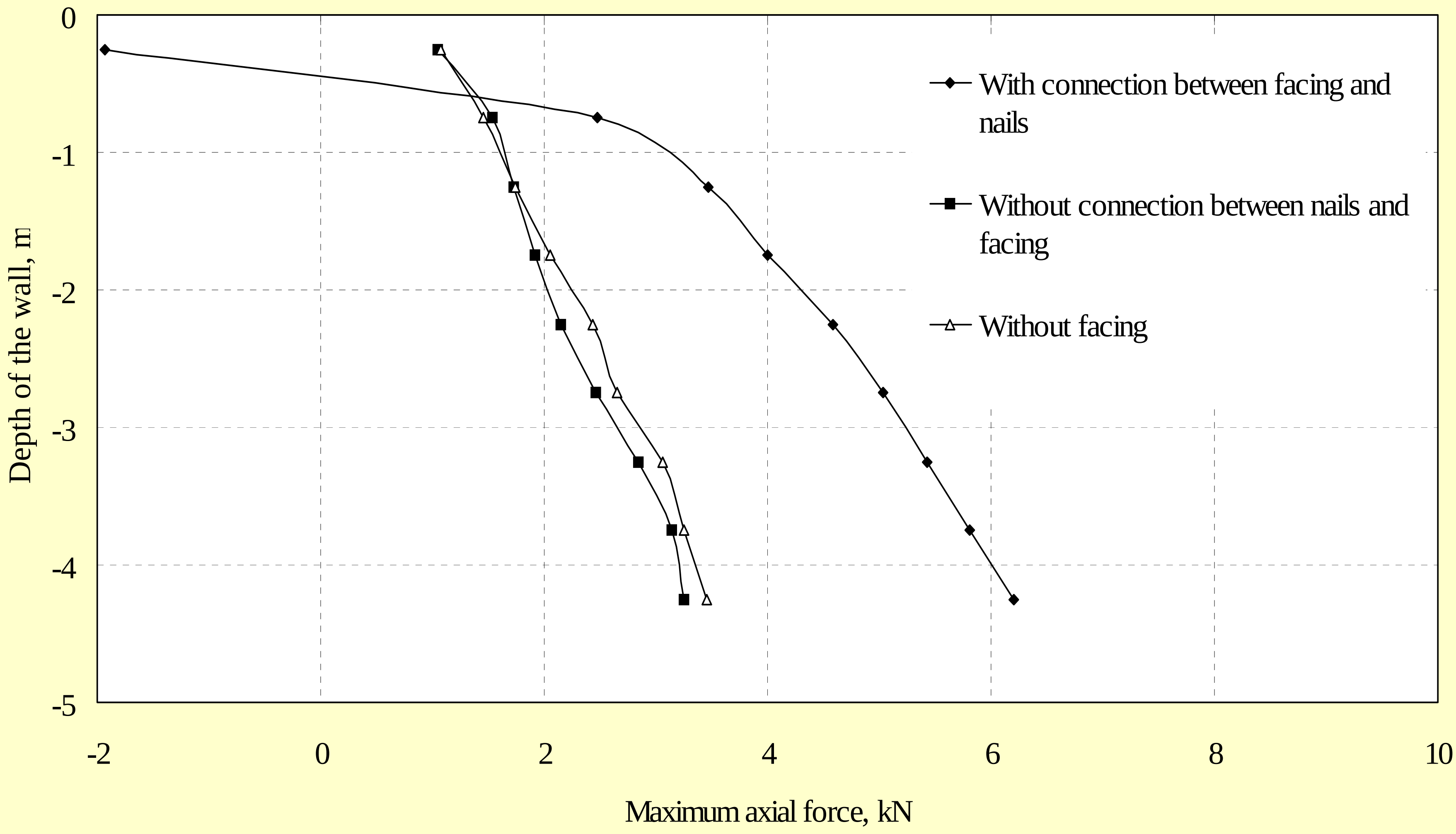


Effect of inclination in terms of horizontal deformation


conventional critical height of excavation (= 4c / γ)
without nailing
with nails without facing
with nails without connecting to facing
with nails connecting rigidly to facing
Critical height of excavation, m
Cohesion, kPa
0
2
4
6
8
10
12
14
5
10
15
20
25



Effect of connection



Effect of connection

CONCLUDING REMARKS

Sequence I type of construction is advantageous over sequence II in terms of critical height of excavation and deformation behaviour.

Offset facing resulting in lesser horizontal deformation and is advantageous over vertical facing.

Rigid connection between nails and facing significantly improves the overall performance of soil nailed mass with regard to both stability and deformation, when compared to nails without connection to the facing. Similar results are obtained for inclined facing.

The thickness of the facing do not have significant influence and a minimum thickness of 75mm for the present case is in order.