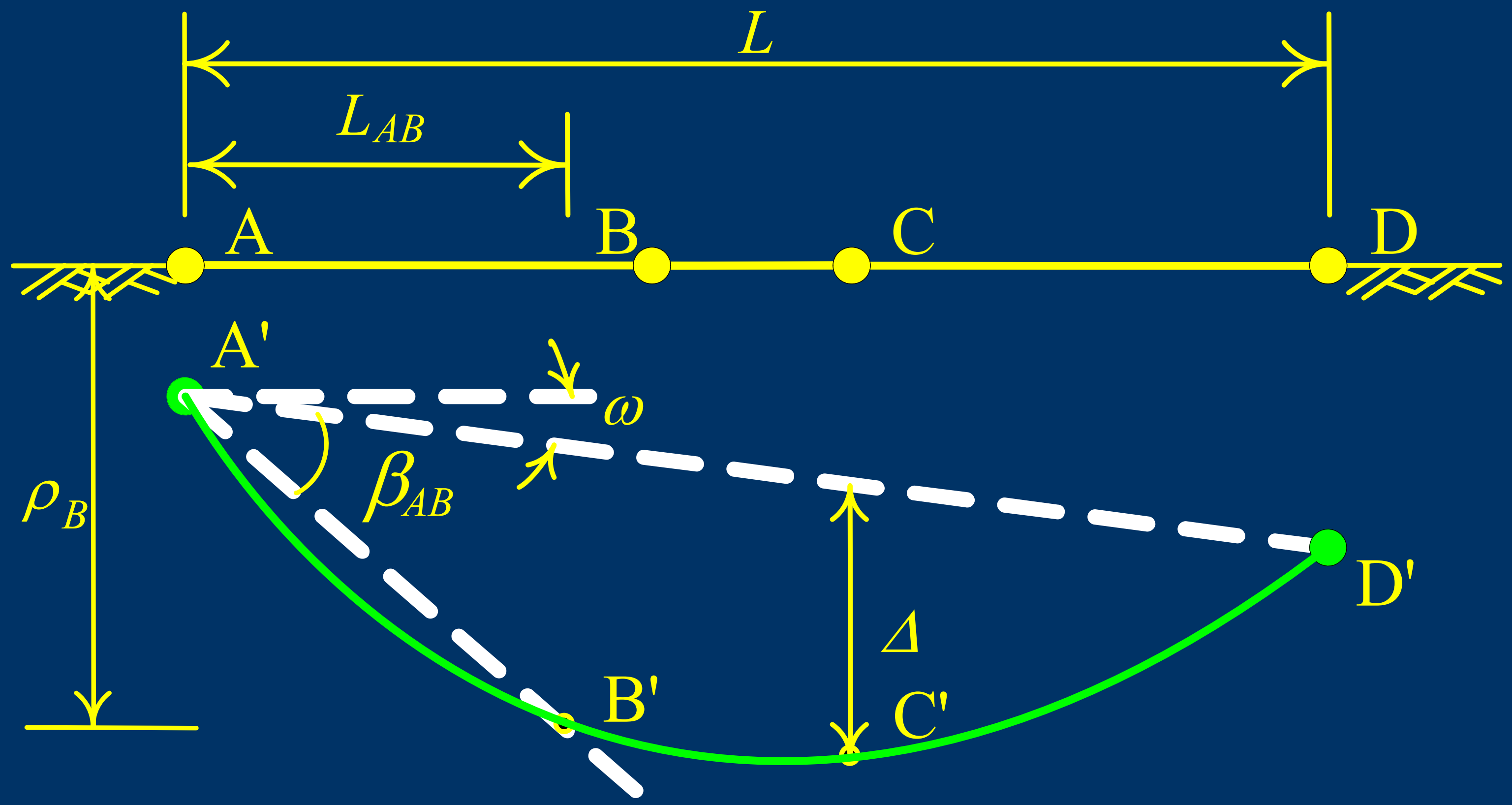
Excavation and Protection of Adjacent Buildings

1. Building Damage Estimation Procedure



ρ_i = total settlement at point *i*

δ_{ij} = differential settlement between points *i* and *j*

ω = rigid body rotation

Δ = relative deflection

Δ / L = deflection ratio

$\beta_{ij} = \delta_{ij} / L_{ij} - \omega$ = angular distortion between point *i* and *j*

L_{ij} = distance between referent points *i* and *j*

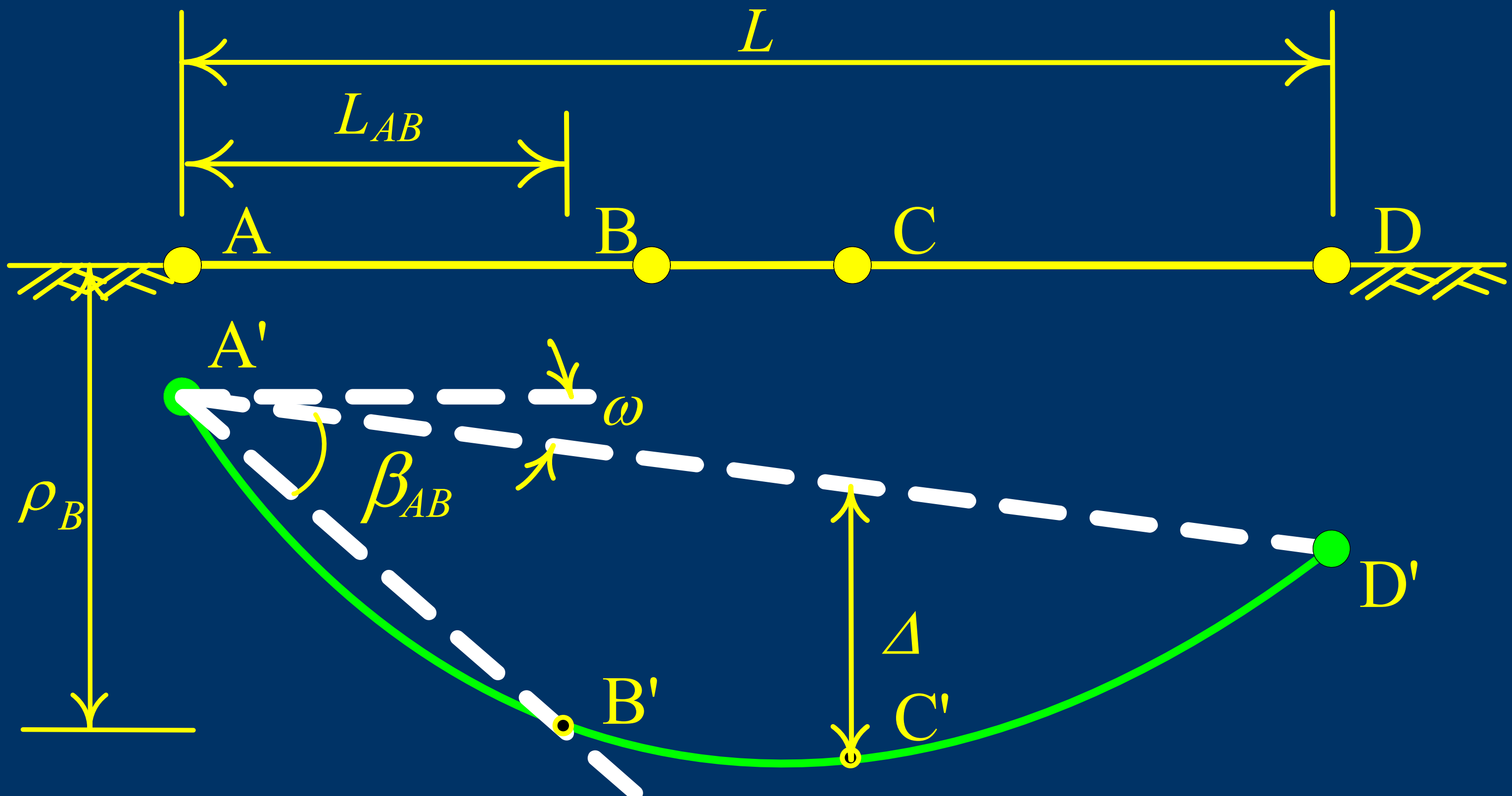


FIGURE 11.1 Parameters of settlements of buildings (b) settlement with rigid rotation

TABLE 11.1 Limiting values of angular distortion (Bjerrum, 1963)

Angular distortion	Type of damage
1/750	Dangerous to machinery sensitive to settlement
1/600	Dangerous to frames with diagonals
1/500	Safe limit to assure no cracking of buildings (factor of safety included)
1/300	First cracking of panel walls (factor of safety not included)
1/300	Difficulties with overhead cranes
1/250	Tilting with high rigid buildings become visible
1/150	Considerable cracking of panel and brick walls
1/150	Danger of structural damage to general buildings
1/150	Safe limit for flexible brick walls (factor of safety not included)

TABLE 11.2 Allowable angular distortion for RC framed or reinforced brick structures

Angular distortion	Behaviors of buildings
1/500	Non-structural damage (factor of safety included)
1/300	Non-structural damage, such as cracks, occur on panel walls
1/150	Structural damage

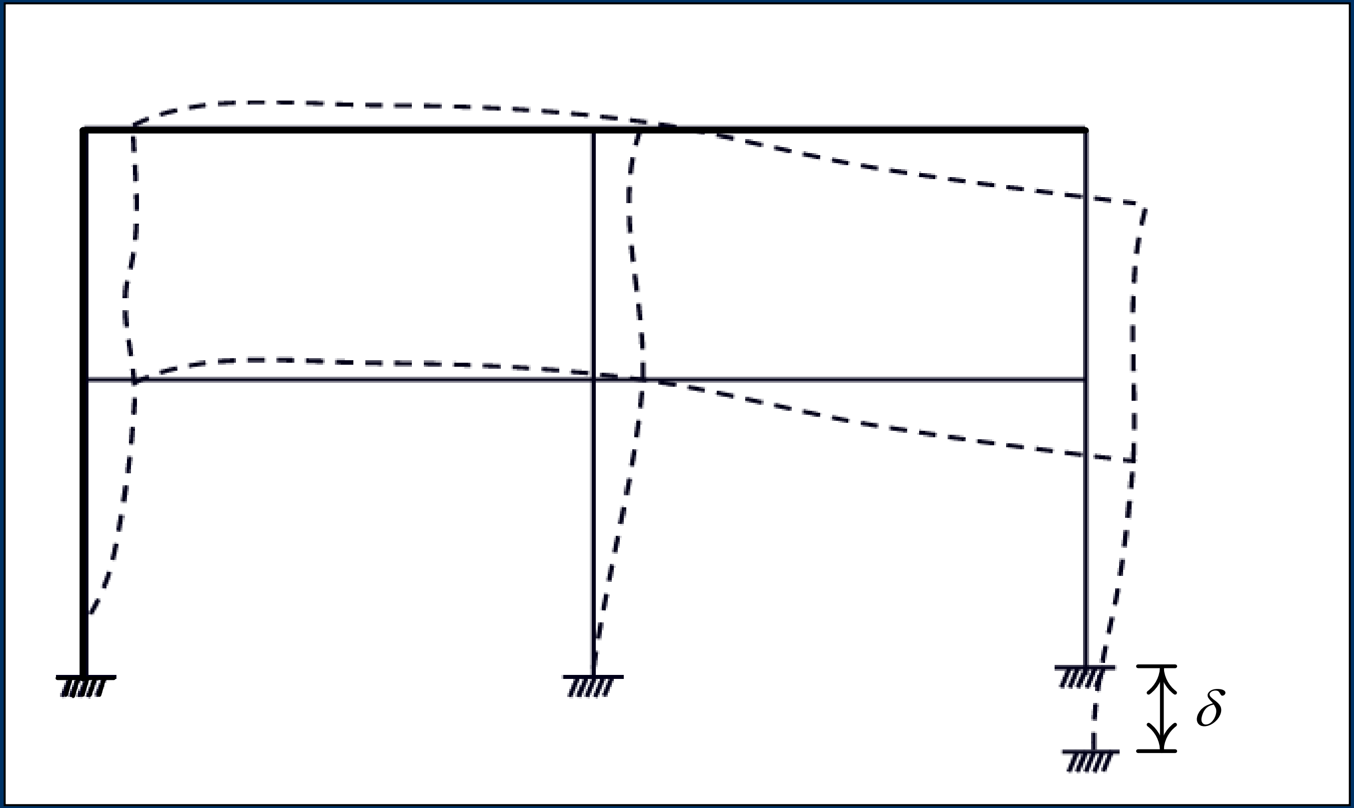


FIGURE 11.3 Differential settlement of a structure with individual footings

$$\frac{\delta_{ij}}{L_{ij}} \leq \frac{1}{300}$$

Assume that the typical distance between two columns is about 20 feet (6 meters). Thus, the above equation can be rewritten as

$$\delta_{ij} \leq (\frac{1}{300}) \times (20) \text{ ft} \approx \frac{3}{4} \text{ in} \approx 2.0 \text{ cm}$$

Since differential settlement is not easily measured by experience, the differential settlement in sandy soils is about 3/4 of the total settlement (including the required safety factor). Then,

$$\rho_i \approx \frac{4}{3}\delta_{ij} \approx 1 \text{ in} = 2.5 \text{ cm}$$

Terzaghi and Peck (1967) :

$$\delta_{\max} = 2.5 \text{ cm} \quad \delta_{diff} = 2.0 \text{ cm}$$

Skempton and MacDonald (1957):

$$\delta_{\max} = 5.0 \text{ cm} \quad \delta_{diff} = 3.0 \text{ cm}$$

JSA (1988) and TGS (2002):

$$\delta_{\max} = 3.0 \text{ cm} \quad \delta_{diff} = 2.0 \text{ cm}$$

TABLE 11.5 Allowable settlement of buildings recommended by TRTS

Type of foundation	Maximum settlement (mm)	Tilt angle	Angular distortion	Deflection ratio (hogging)	Deflection ratio (sagging)
RC raft foundation	45	1/500	1/500	0.0008	0.0012
RC individual footings	40	1/500	1/500	0.0006	0.0008
Brick individual footings	25	1/500	1/2500	0.0002	0.0004
Temporary buildings	40	1/500	1/500	0.0008	0.0012

Note: tilt angles are the measurement value on the tiltmeter, whose principle and application are discussed in Section 12.4.2, Chapter 12

Son and Cording (2005)

First Phase ---- estimation of free-field ground settlement

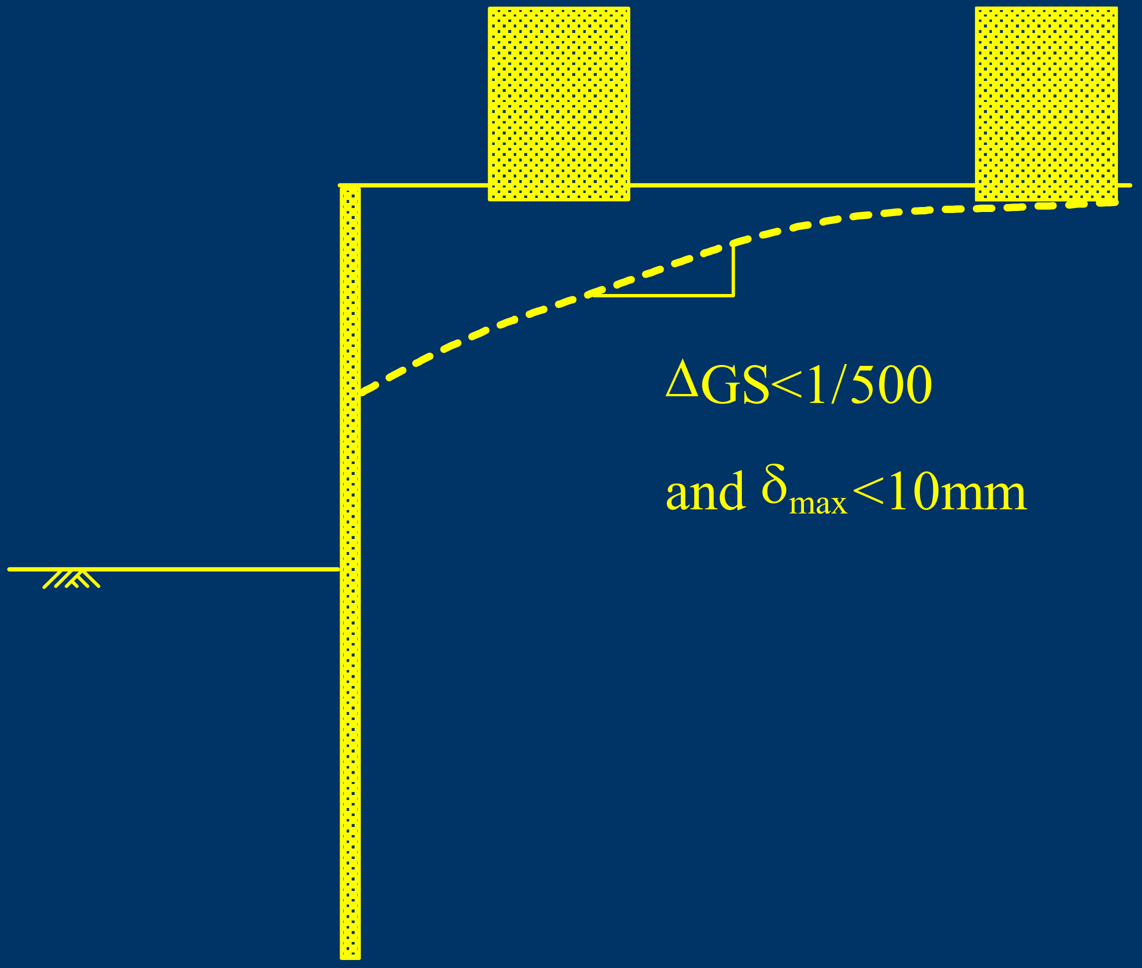
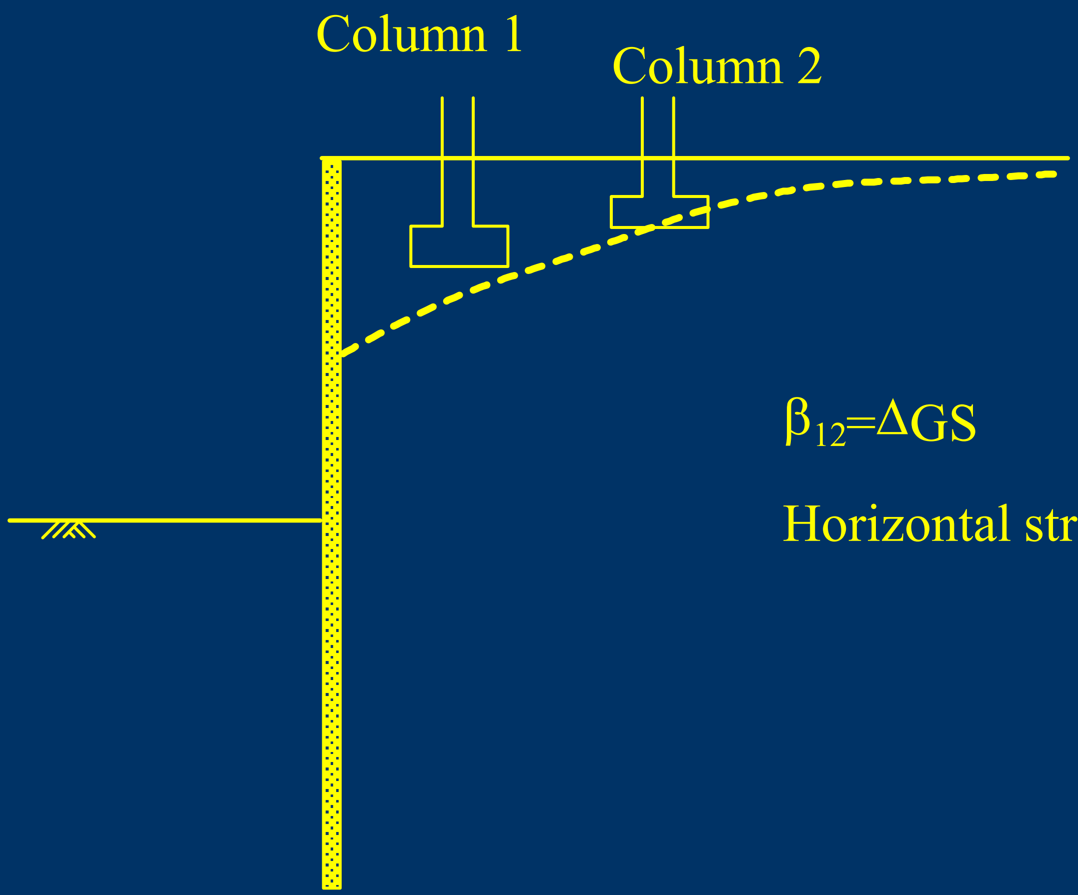


Table 6. Typical Values of Maximum Building Slope and Settlement for Damage Risk Assessment [after Rankin (1988)]

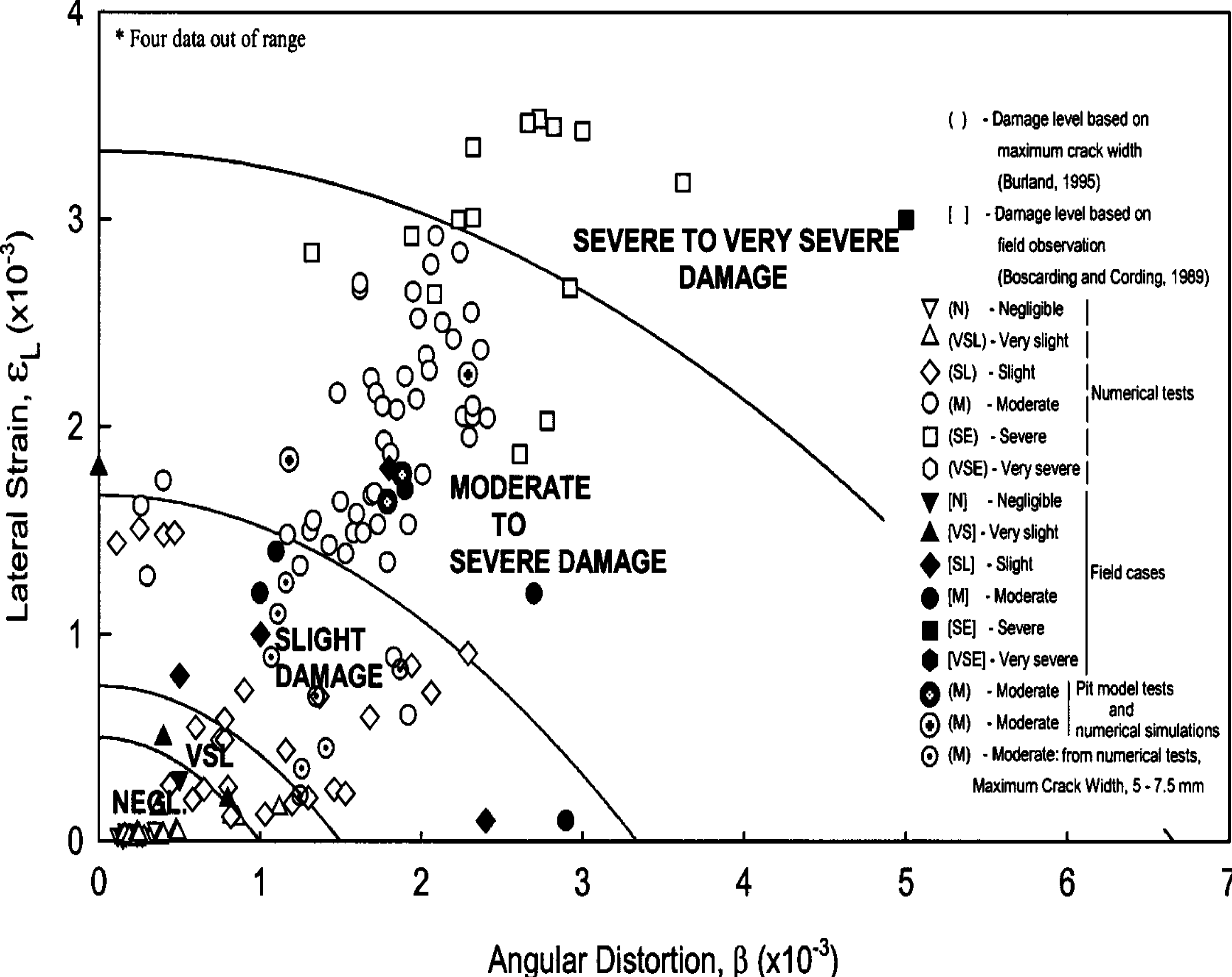
Risk category	Maximum slope of building	Maximum settlement of building (mm)	Description of risk
1	Less than 1/500	Less than 10	Negligible: superficial damage unlikely
2	1/500–1/200	10–50	Slight: possible superficial damage which is unlikely to have structural significance
3	1/200–1/50	50–75	Moderate: expected superficial damage and possible structural damage to buildings, possible damage to relatively rigid pipelines
4	Greater than 1/50	Greater than 75	High: expected structural damage to buildings. Expected damage to rigid pipelines, possible damage to other pipelines

Second Phase --- estimation of horizontal strain



$\beta_{12}=\Delta GS$

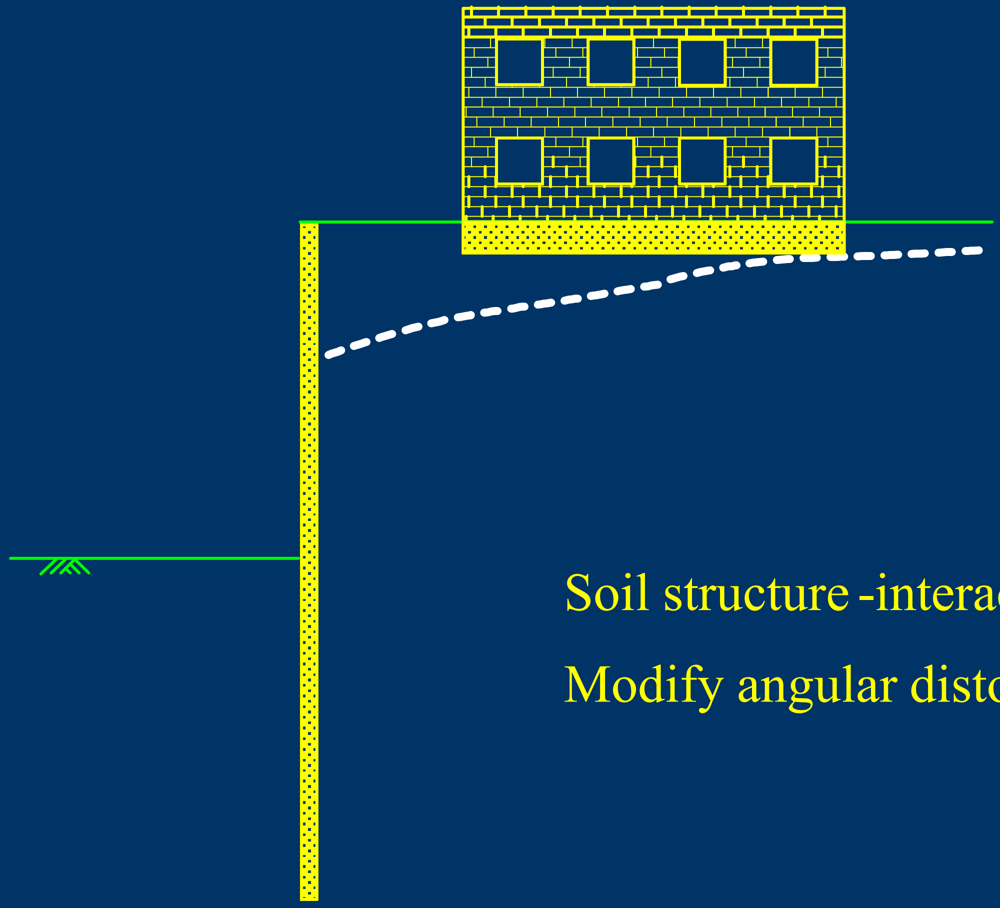
Horizontal strain of the building



* Four data out of range
SEVERE TO VERY SEVERE DAMAGE
MODERATE TO SEVERE DAMAGE
SLIGHT DAMAGE
VSL
NEGL.
( ) - Damage level based on maximum crack width (Burland, 1995)
[ ] - Damage level based on field observation (Boscarding and Cording, 1989)
(N) - Negligible
(VSL) - Very slight
(SL) - Slight
(M) - Moderate
(SE) - Severe
(VSE) - Very severe
Numerical tests
[N] - Negligible
[VS] - Very slight
[SL] - Slight
[M] - Moderate
[SE] - Severe
[VSE] - Very severe
Field cases
(M) - Moderate
(M) - Moderate
Pit model tests and numerical simulations
(M) - Moderate: from numerical tests, Maximum Crack Width, 5 - 7.5 mm
Lateral Strain, ε_L ($\times 10^{-3}$)
Angular Distortion, β ($\times 10^{-3}$)
0
1
2
3
4
5
6
7

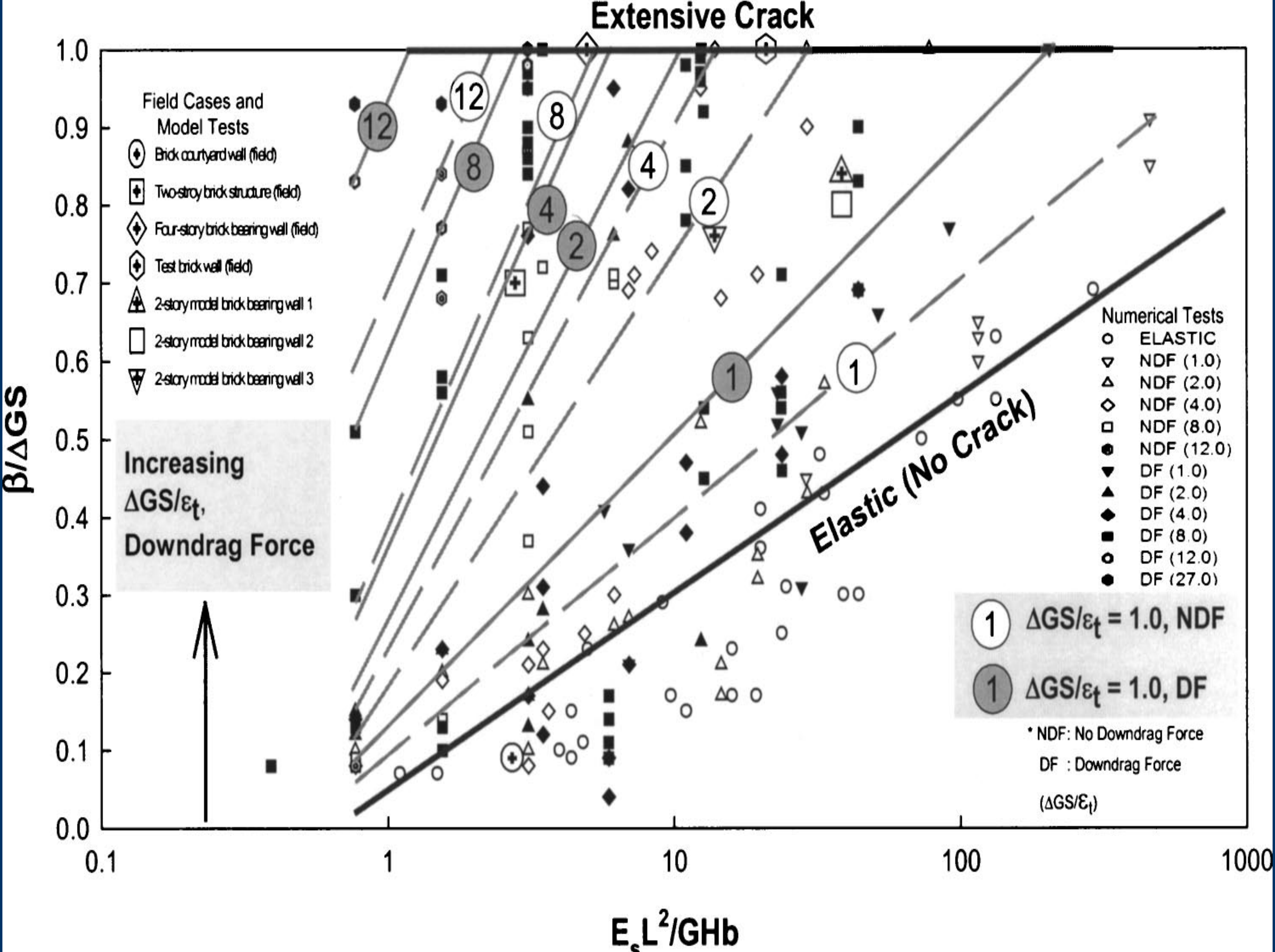
1. Use the free-field ground movement and assume that a structure conforms with the free-field ground movement.
2. Determine the change in ground slope between adjacent sections based on column spacing, footing spacing, etc. Assume that the change in ground slope is equal to angular distortion.
3. Determine the horizontal free-field ground movement strain between adjacent sections based on column spacing, footing spacing, cross-wall spacing, or ground movement gradient.
4. If calculated shear distortions are high throughout the height of the structure, or if major pre-existing vertical joints or weaknesses are present in the structure, determine the bending (lateral) strain at the top of a building unit, using the height of the building unit and the radius of a curvature of ground movement.
5. Using the angular distortion and lateral strains, determine the damage level (Fig. 8).
6. If it is unacceptable, proceed to the final estimation phase.

Final Phase --- consider the soil-structure interaction

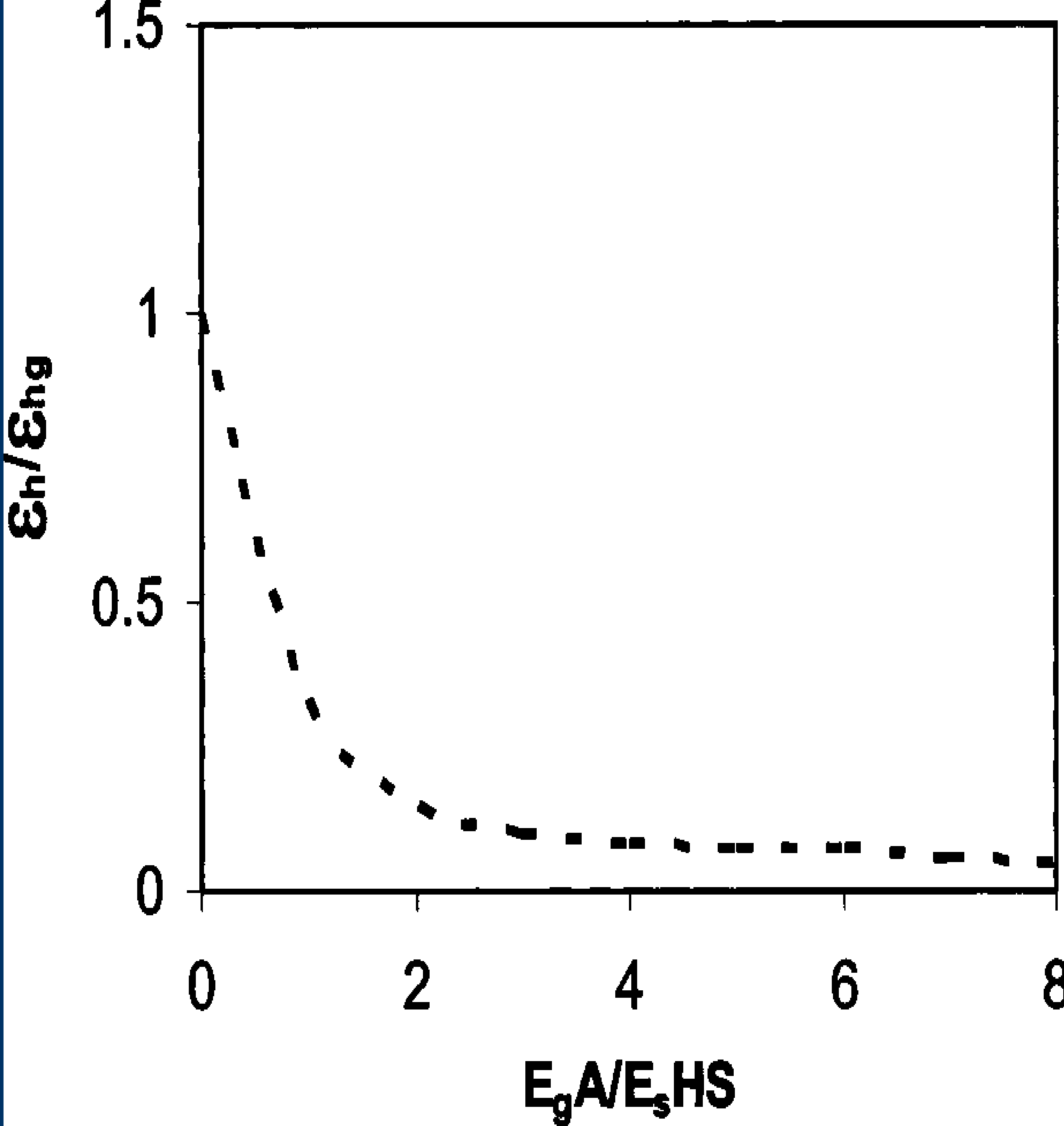


Soil structure -interaction

Modify angular distortion , horizontal strain

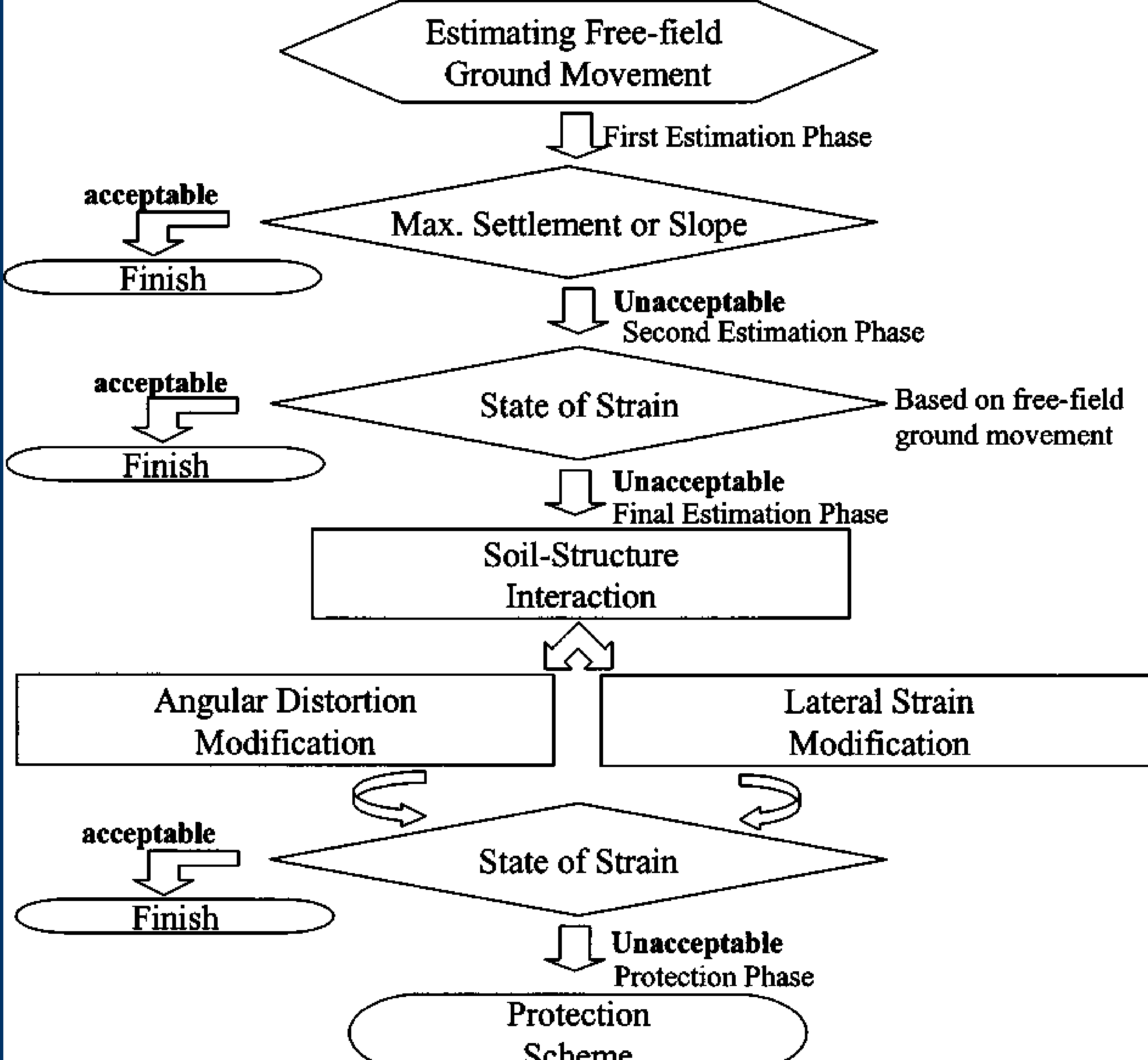


Extensive Crack
Field Cases and Model Tests
Brick courtyard wall (field)
Two-stroy brick structure (field)
Four-story brick bearing wall (field)
Test brick wall (field)
2-story model brick bearing wall 1
2-story model brick bearing wall 2
2-story model brick bearing wall 3
Increasing ΔGS/εt, Downdrag Force
Numerical Tests
ELASTIC
NDF (1.0)
NDF (2.0)
NDF (4.0)
NDF (8.0)
NDF (12.0)
DF (1.0)
DF (2.0)
DF (4.0)
DF (8.0)
DF (12.0)
DF (27.0)
Elastic (No Crack)
ΔGS/εt = 1.0, NDF
ΔGS/εt = 1.0, DF
* NDF: No Downdrag Force
DF : Downdrag Force
(ΔGS/εt)
β/ΔGS
EsL2/GHb
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0.1
1
10
100
1000



1.5
1
0.5
0
εh/εhg
0
2
4
6
8
EgA/EsHS

1. Use the change in ground slope of the free-field settlement determined at Step 1 of the “Second Estimation Phase.”
2. Determine the relative stiffness between soil and structure.
3. Find the normalized angular distortion Then determine an angular distortion (i.e, soil-structure interaction).
4. From the lateral strains obtained at Step 2 of the “Second Phase,” determine a lateral strain considering factors of influence such as the effects of a grade beam; an interface between soil and building, shear cracks; pre-existing cracks at the top of a building.
5. Find a damage level from the generalized state of strain damage criterion using the angular distortion and the lateral strain (Fig. 8).
6. If this is unacceptable, determine appropriate protection measures



Estimating Free-field Ground Movement
First Estimation Phase
acceptable
Max. Settlement or Slope
Finish
Unacceptable
Second Estimation Phase
acceptable
State of Strain
Based on free-field ground movement
Finish
Unacceptable
Final Estimation Phase
Soil-Structure Interaction
Angular Distortion Modification
Lateral Strain Modification
acceptable
State of Strain
Finish
Unacceptable
Protection Phase
Protection Scheme

2. Take Advantage of Corner Effect

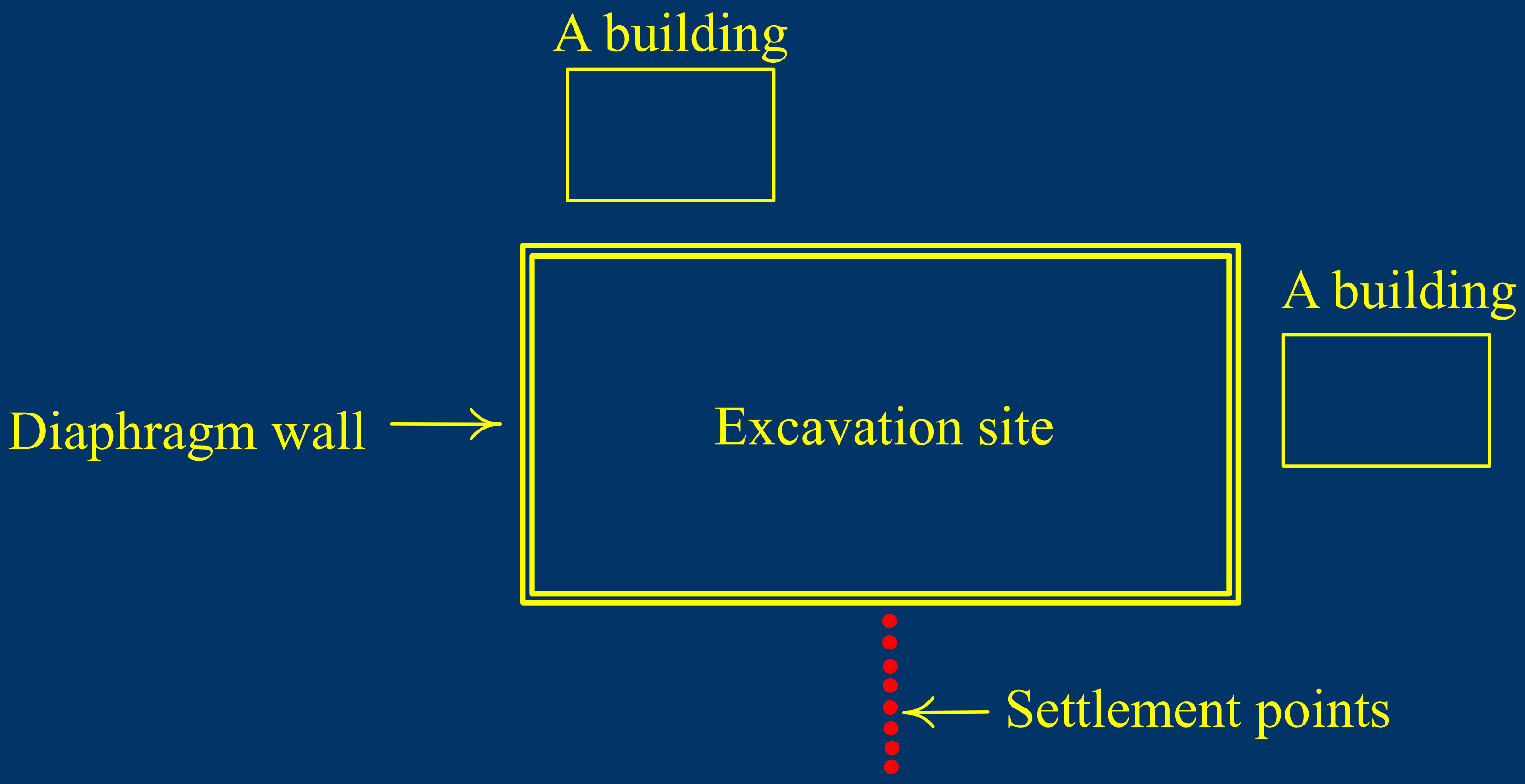


FIGURE 11.10 Buildings located at corners or along the shorter side of an excavation

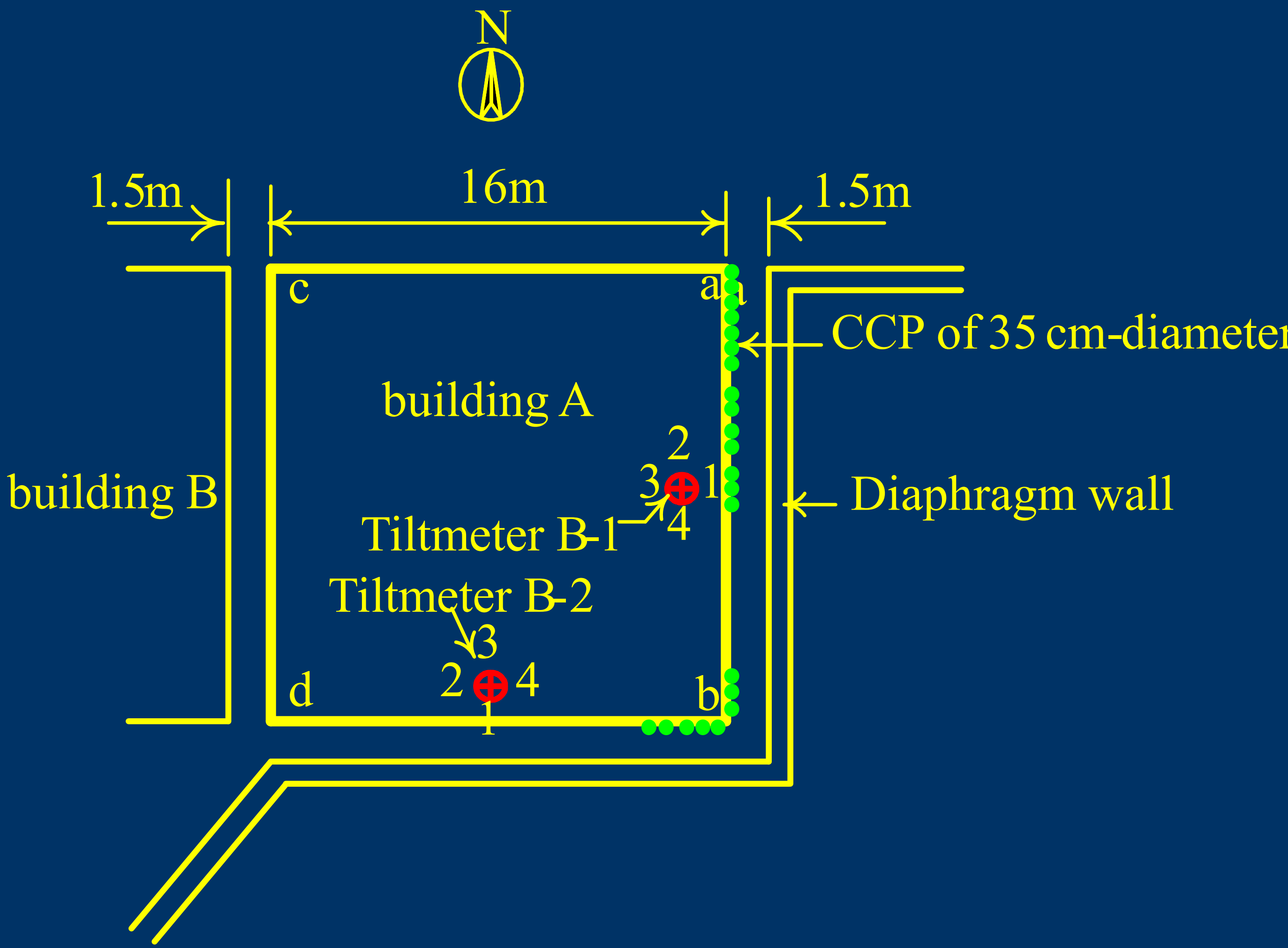


FIG. 11.11 Arrangement of grouting at the building in the vicinity of the TNEC excavation (a) plan

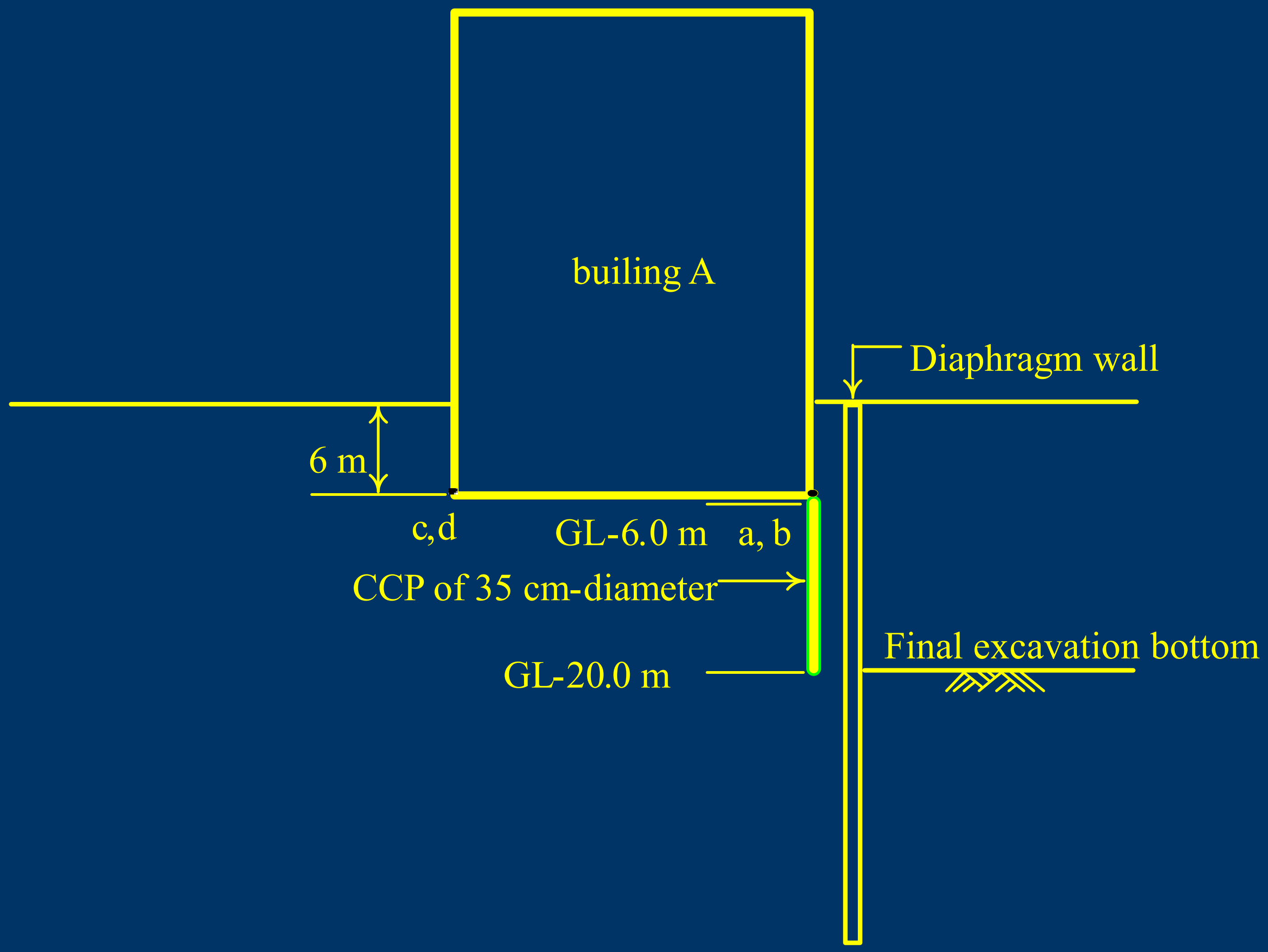


FIG. 11.11 Arrangement of grouting at the building in the vicinity of the TNEC excavation (b) profile

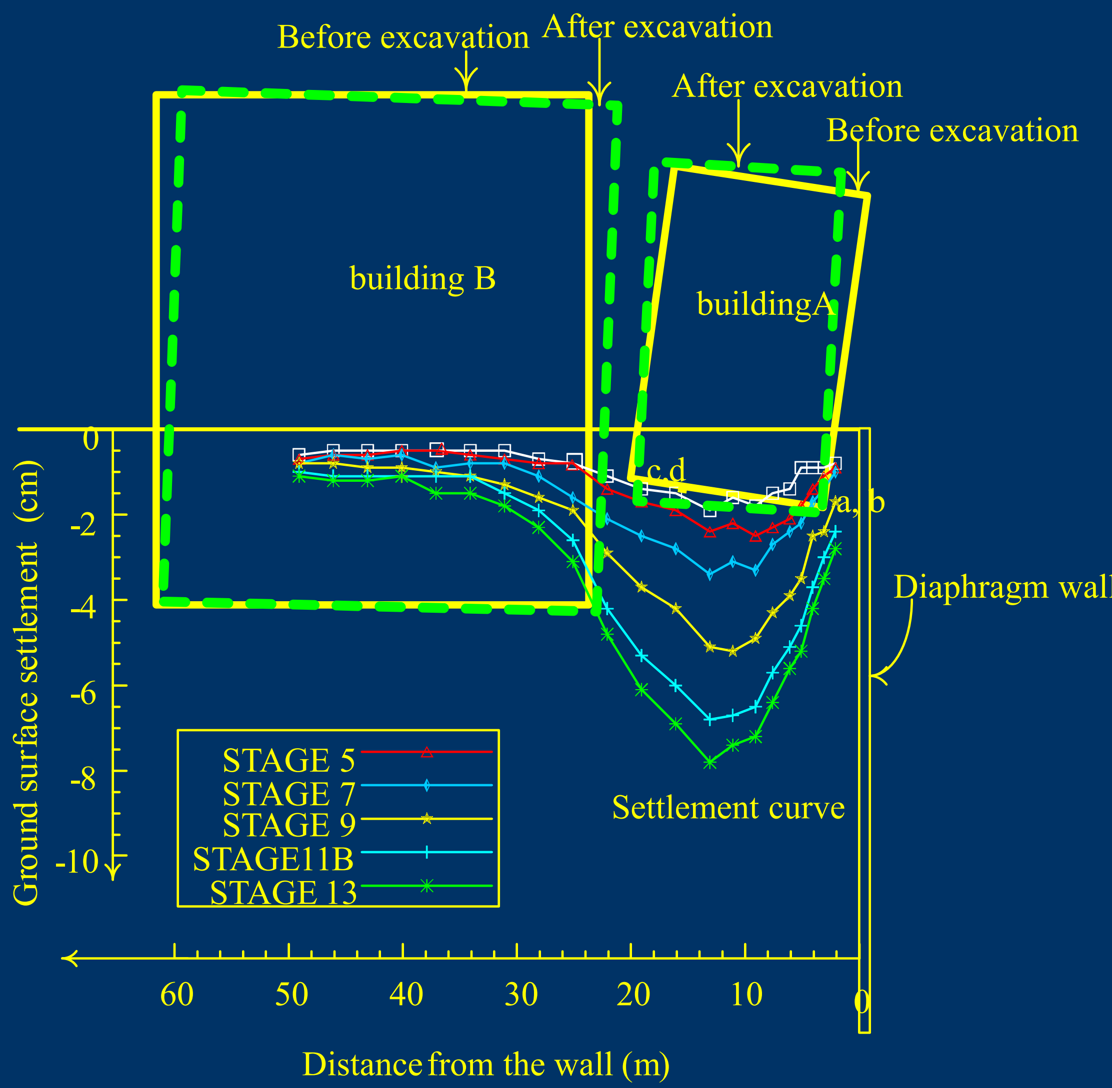


FIGURE 11.12 Slanting conditions of the buildings after excavation for the TNEC excavation

3. Strengthen the-Strut-Retaining System

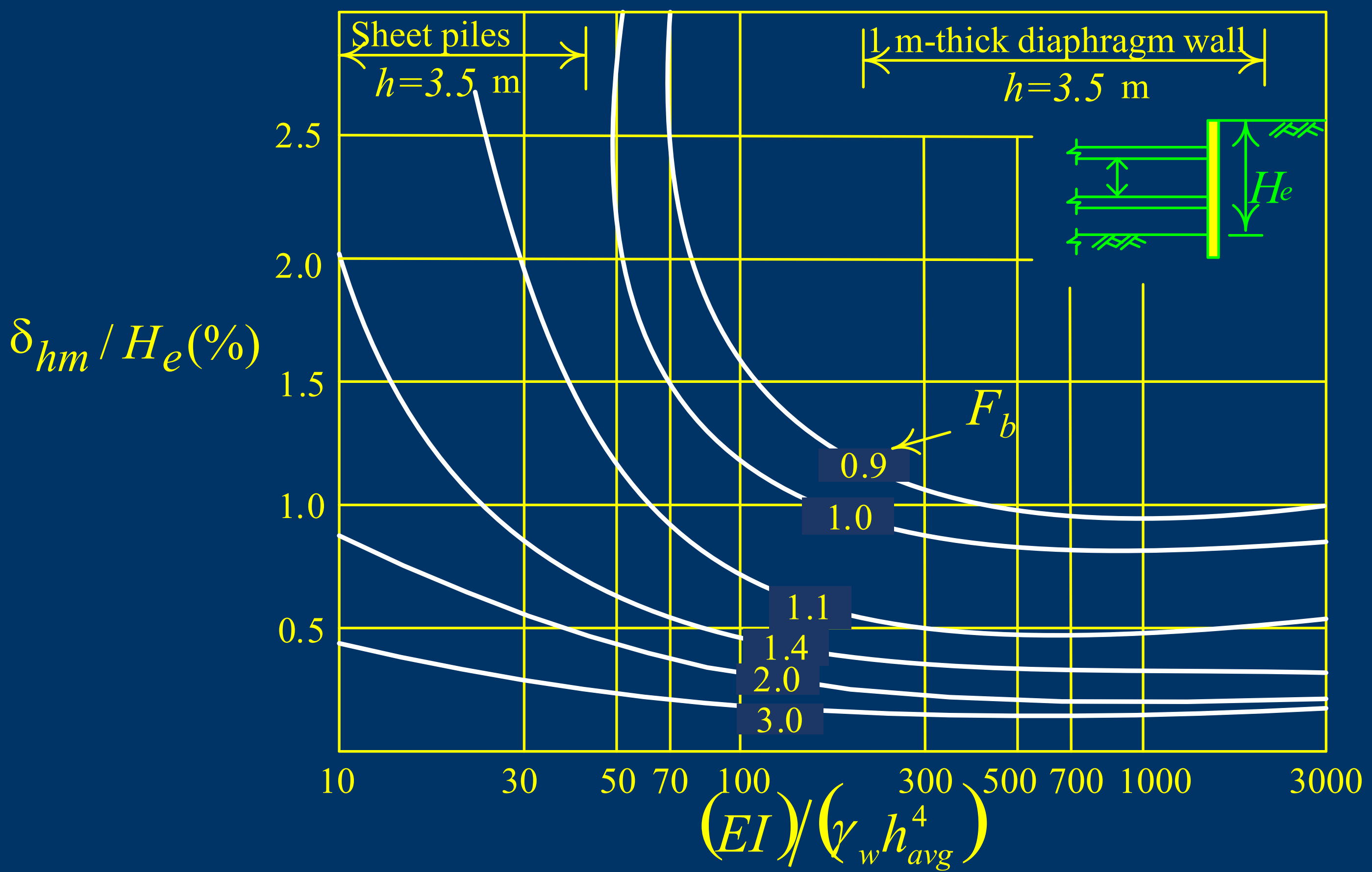
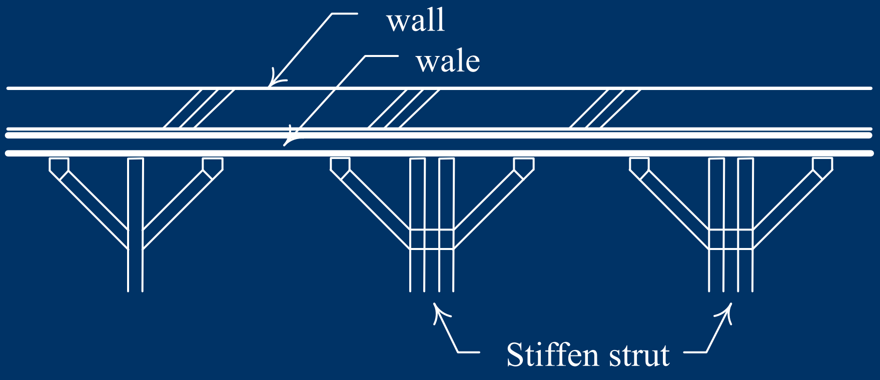
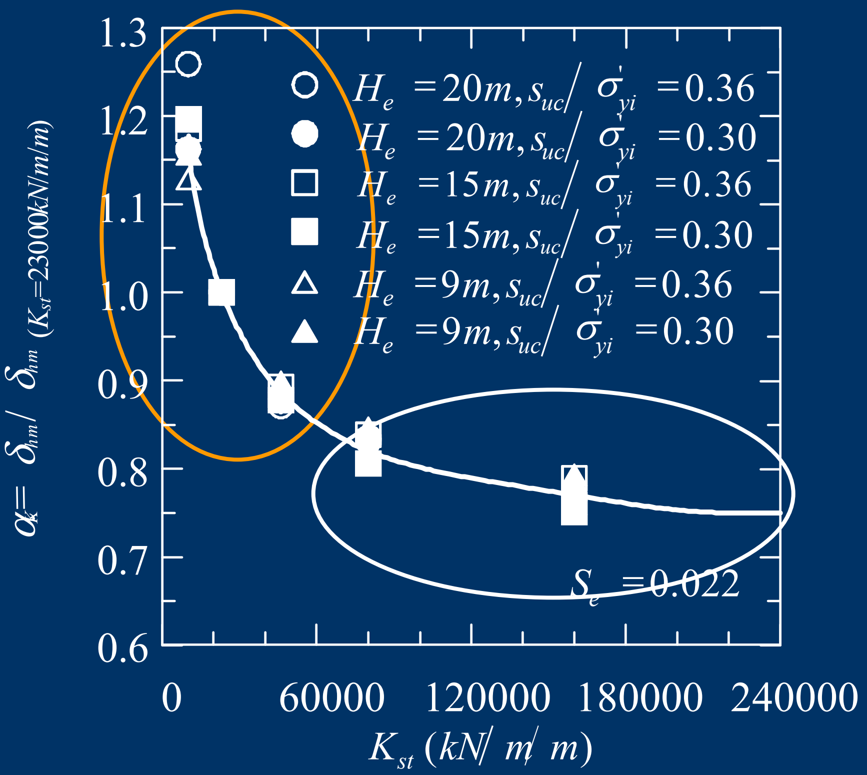


FIGURE 6.3 Relationships between the maximum deflections of walls, stiffness of strutting systems, and factors of safety against basal heave

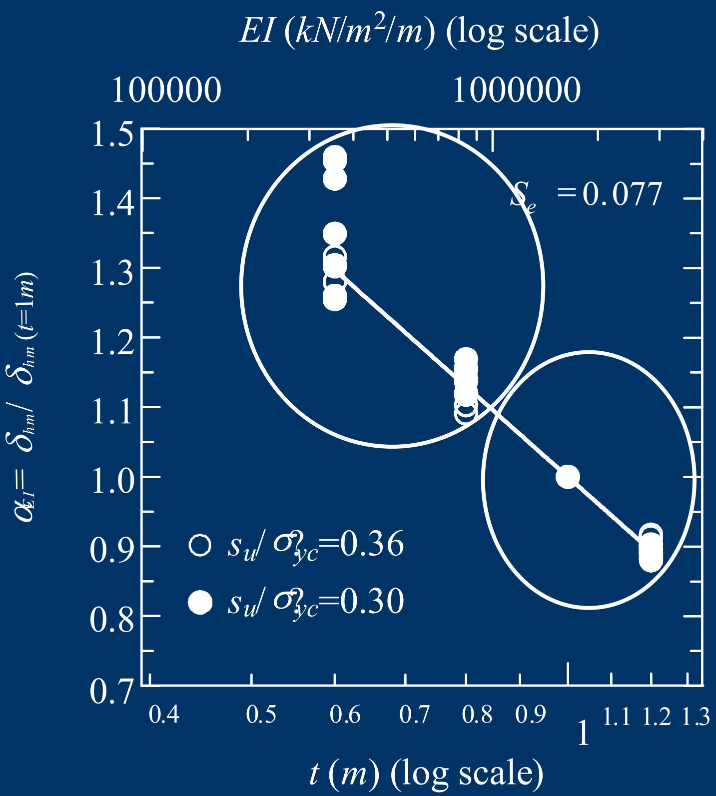
- Increase strut stiffness
  - Size or strut numbers
- Increase wall stiffness
  - Wall thickness
- Reduce vertical spacing of struts



- Increase strut stiffness

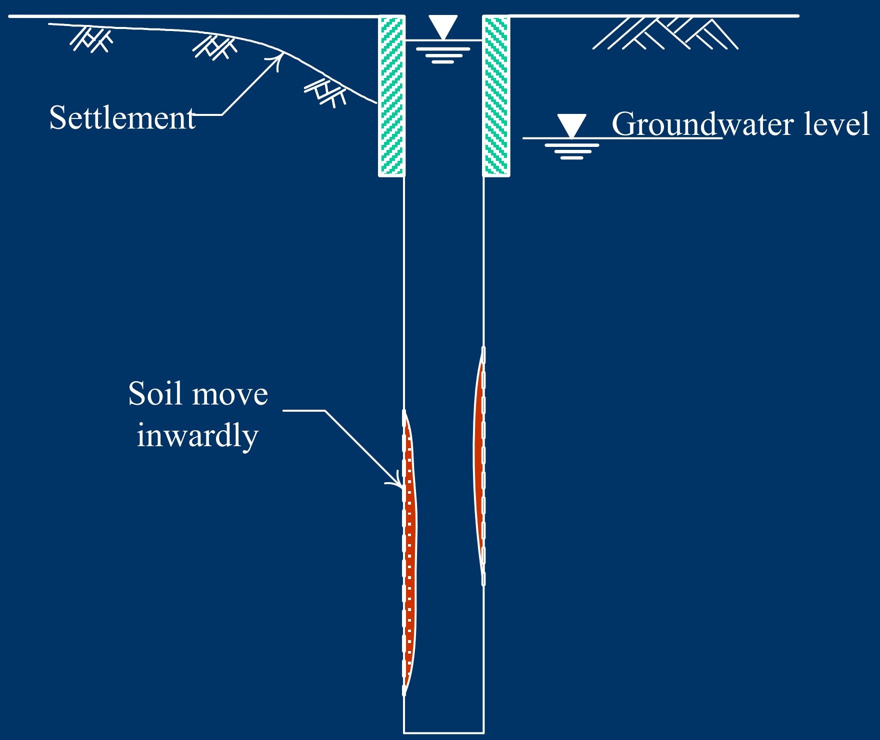


- Increase wall stiffness



- Increase wall stiffness
  - When wall thickness is too large,
    - For example, over 1.5 m
  - Required long construction time for trench excavation, steel cage placement and concrete casting

- Large wall thickness
  - Collapse and creep near the trench
  - Large ground settlement during wall installation



4. Ground Improvement

The location of improvement：

inside or outside the excavation zone？

Chemical Grouting Method

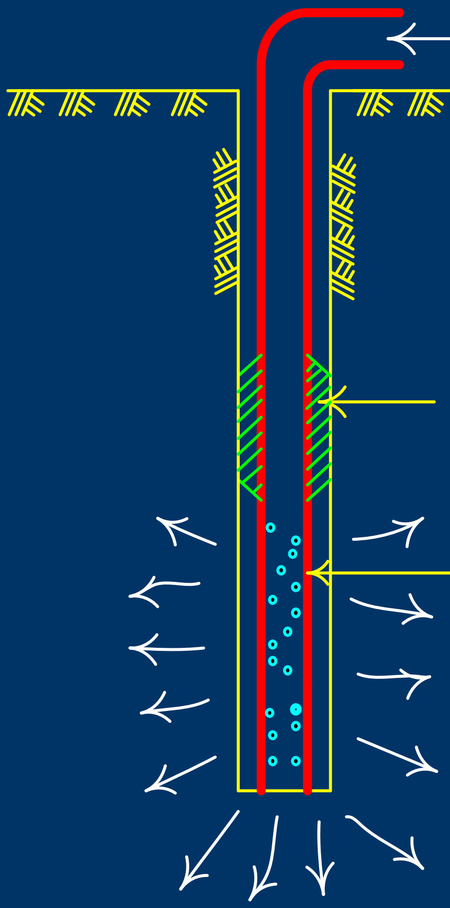


FIGURE 11.4 Schematic diagram of chemical grouting (Single packer method)

Jet Grouting Method

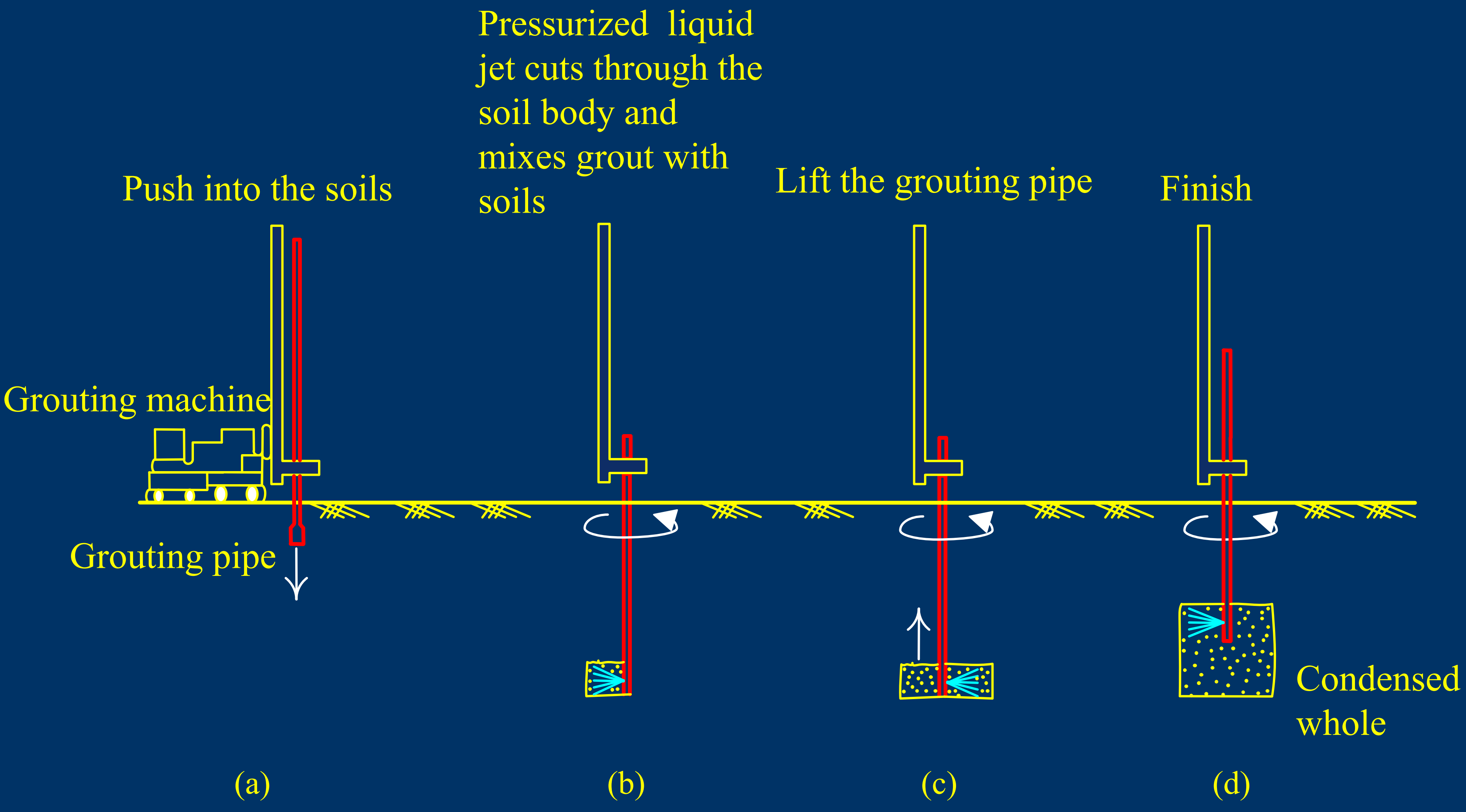
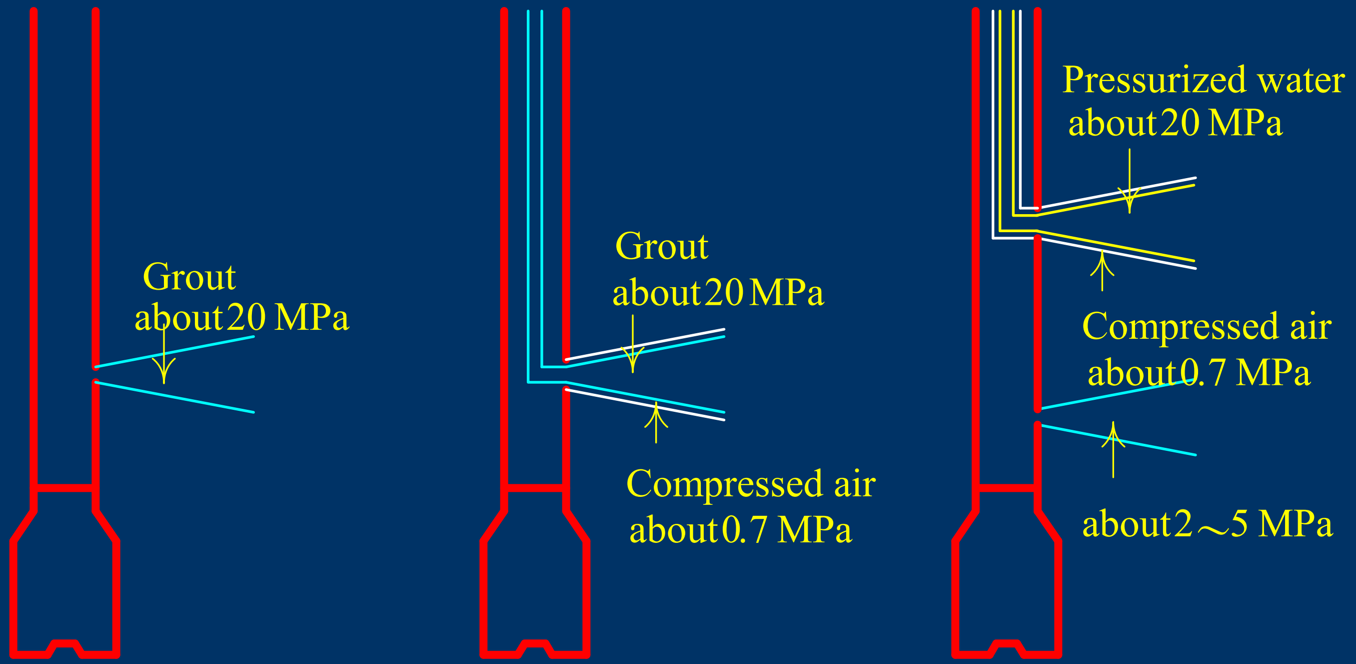


FIGURE 11.5 Procedure of the jet grouting method



(a) single tube method (b) double tube method (c) triple tube method

Deep Mixing Method (DMM method)

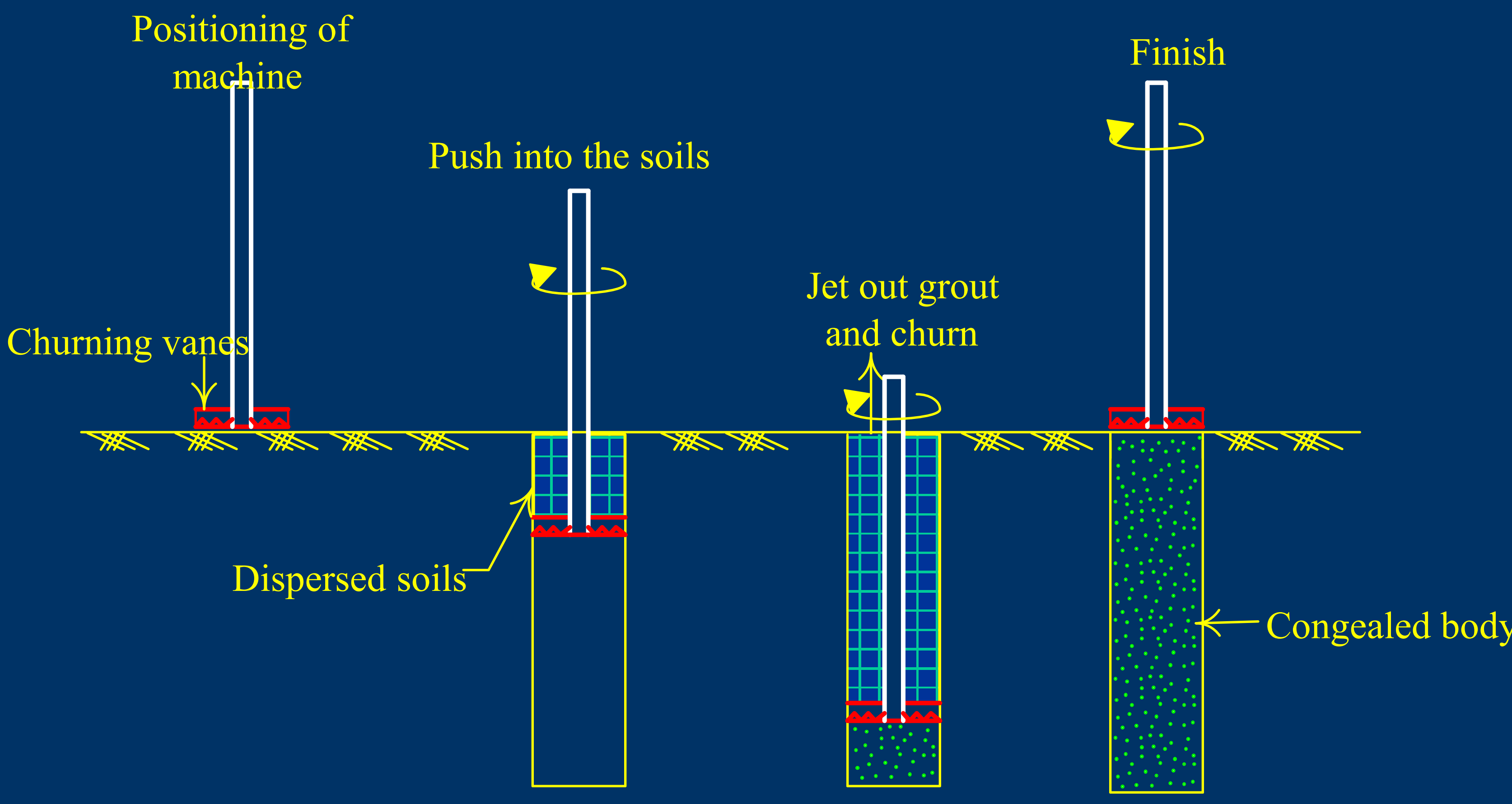


FIGURE 11.7 Procedure of the deep mixing method

The arrangements of these types are elucidated as follows

(1) Block type

Within a specific area, improve the soils fully. Replace the soil bodies within the area completely or have them completely combined with chemical into treated soils.

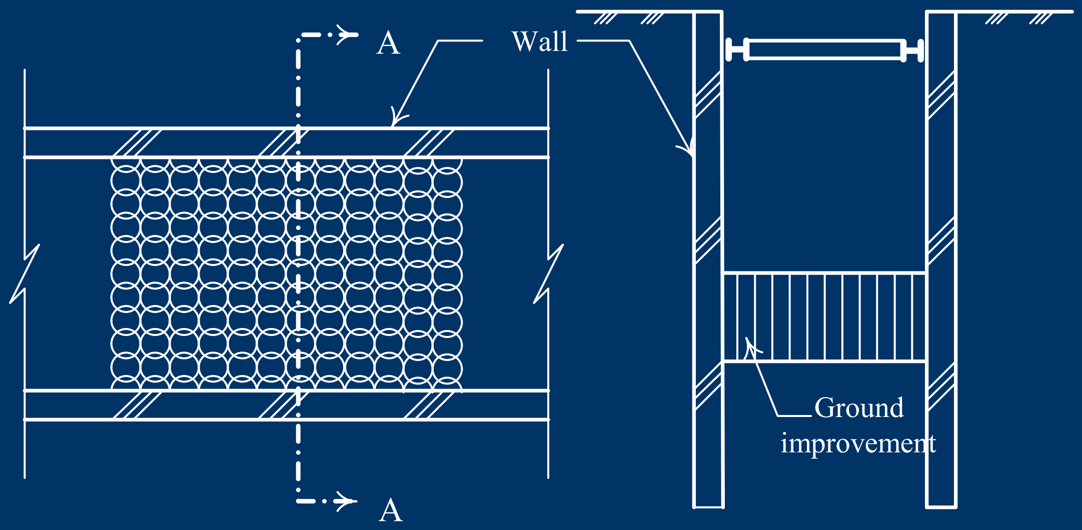
(2) Column type

The pattern of the improved soils is similar to that of piles. The columns of improved soils do not connect with each other.

(3) Wall type

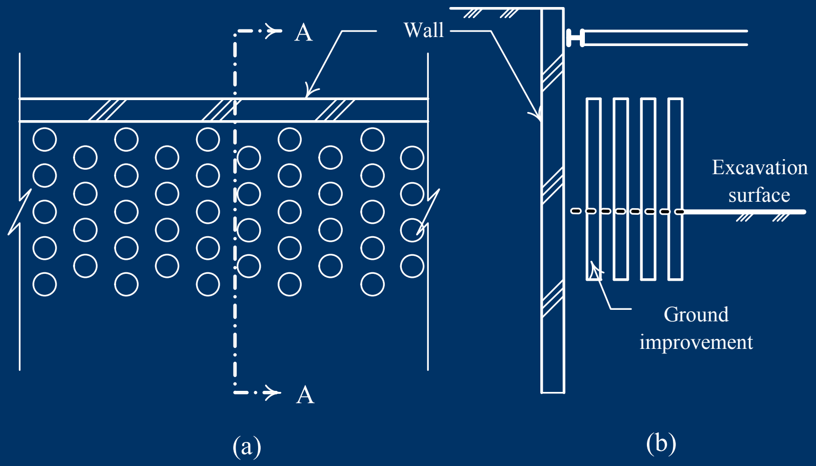
Connect the columns of improved soils into a wall shape, which joins the retaining wall and forms a counterfort-like wall. The wall can only increase the soil strength in front of the retaining wall. It is not able to raise the moment-resistance stiffness of the wall.

- Arrangement
  - Block type

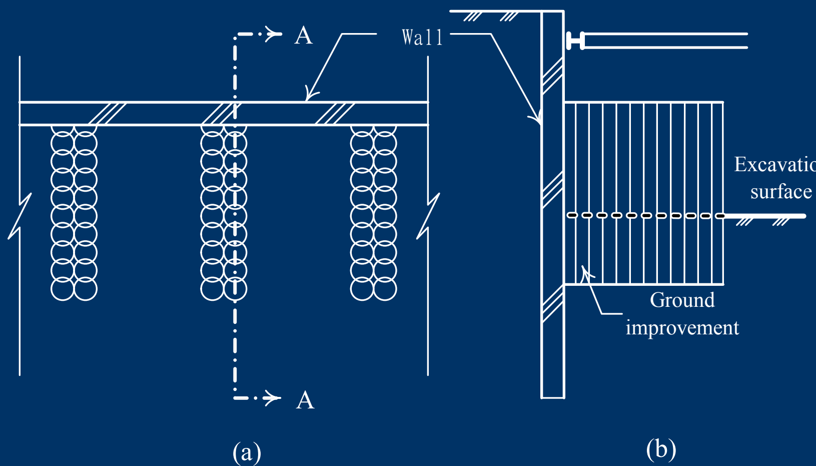


(a) (b)

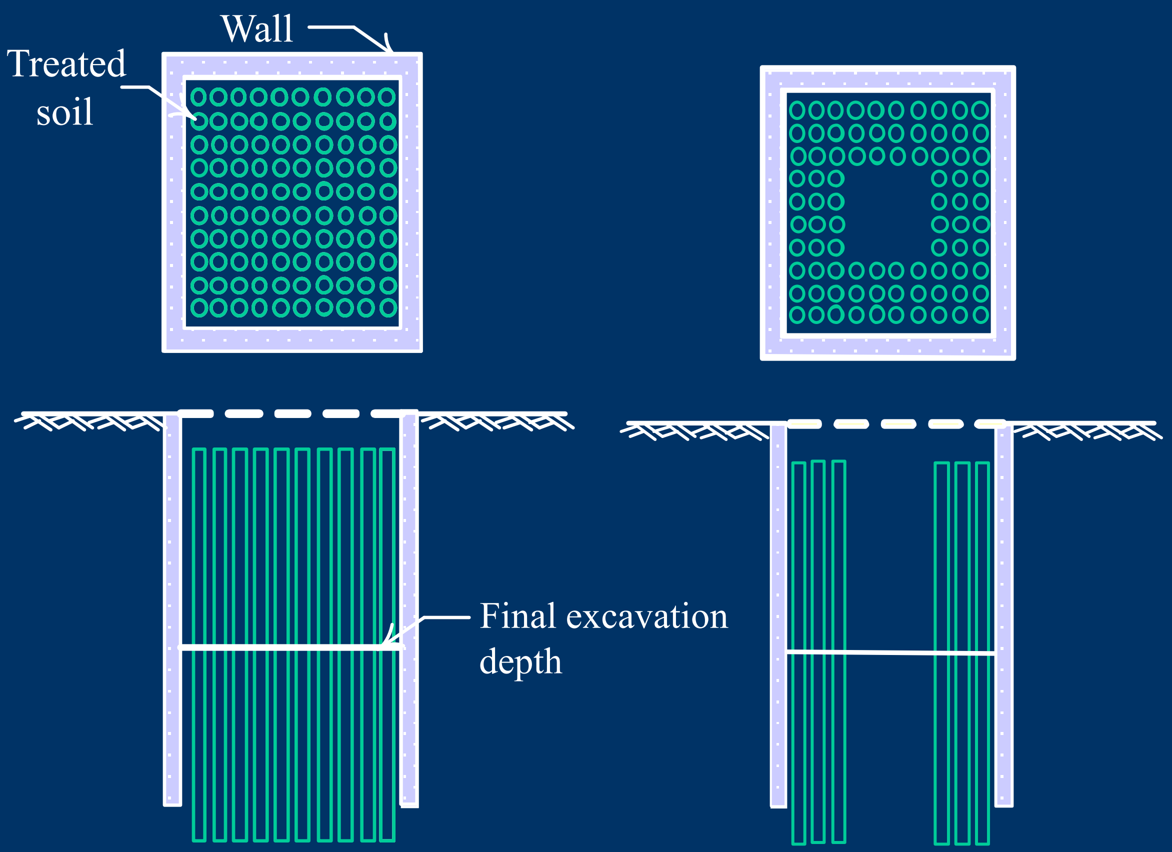
- Arrangement
  - Column type



  - Wall type

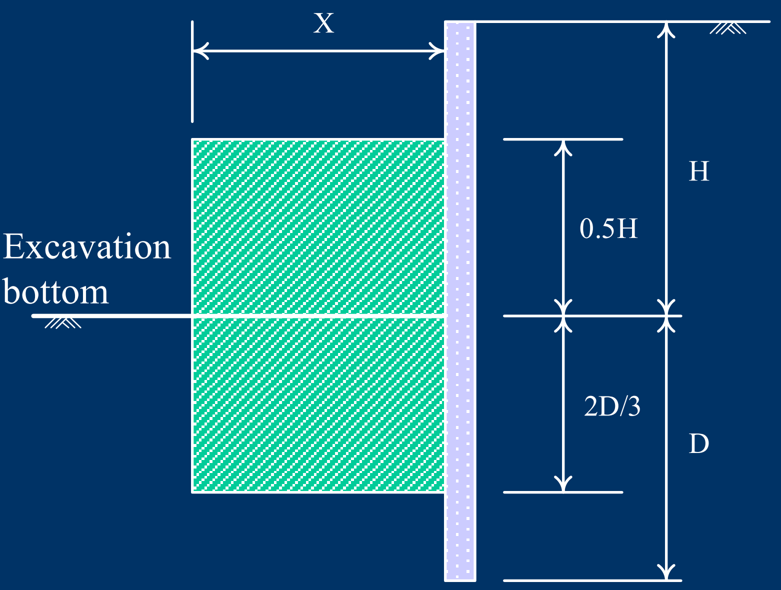


- Improvement zone

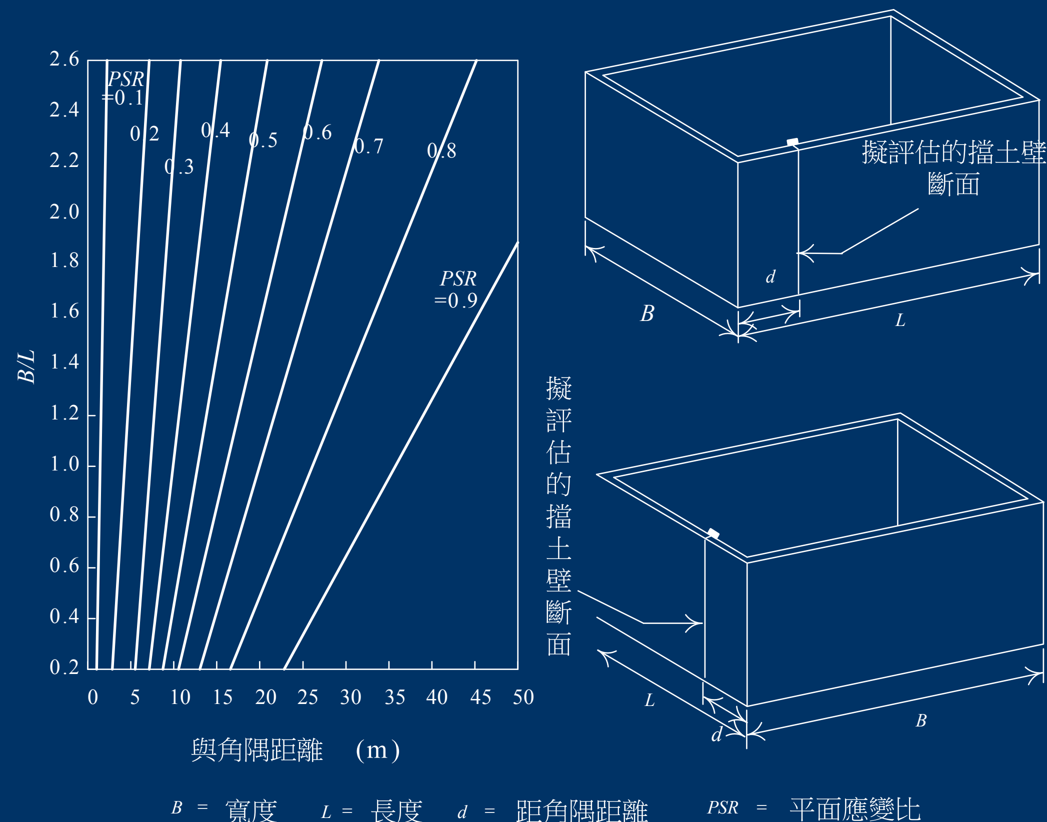


Full improvement Partial improvement

- Improvement depth
  - Improve in the zone of 0.5H to 2D/3， we can obtain the result similar to that to the wall bottom

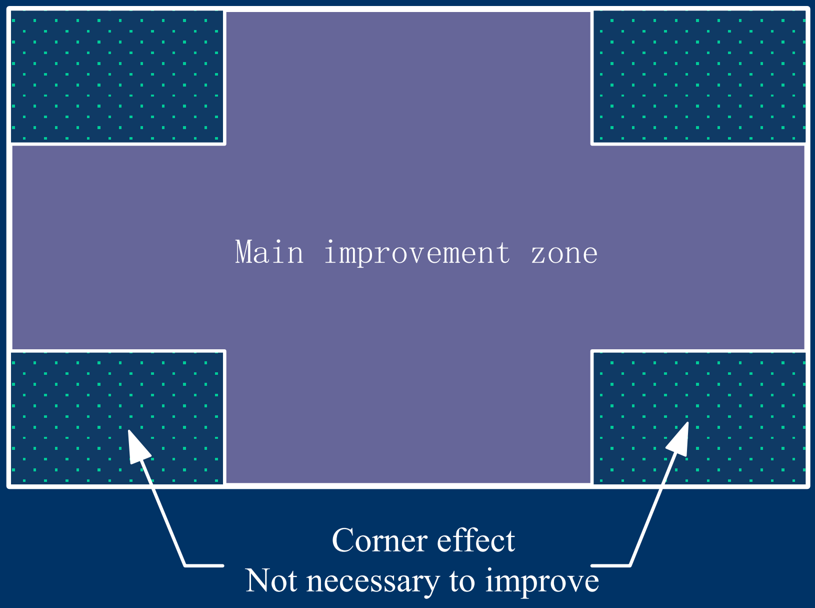


- Improvement zone
  - Whole zone
    - Consider corner effect
    - Ou,et al.1996

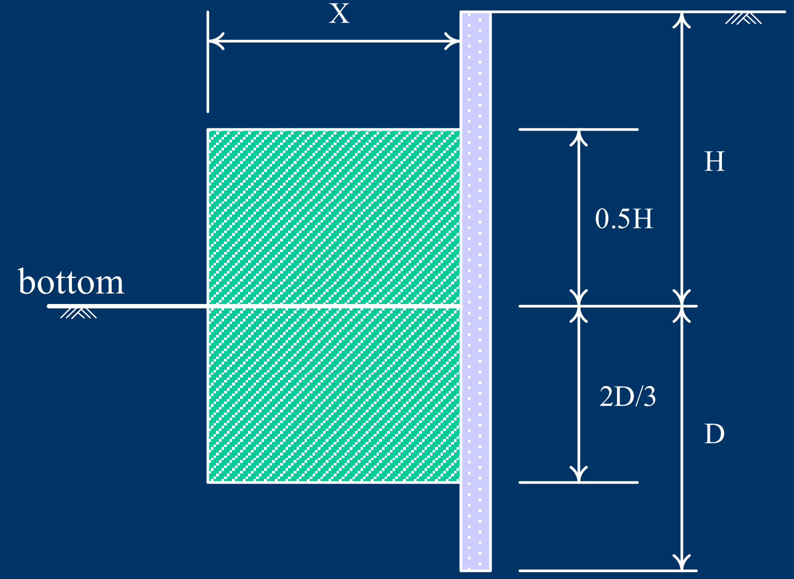


(a) (b)

- Improvement zone (Whole zone)



- Improvement zone (partial zone)
  - Ground settlement increase with the increasing improvement distance



To ensure ground improvement capable of property protection, improvement should be analyzed in terms of the strength of the treated soil, its diameter, span depth, location, and range. The soils within the area can be viewed as a composite material in analysis.

When the composite soil body bears vertical load：

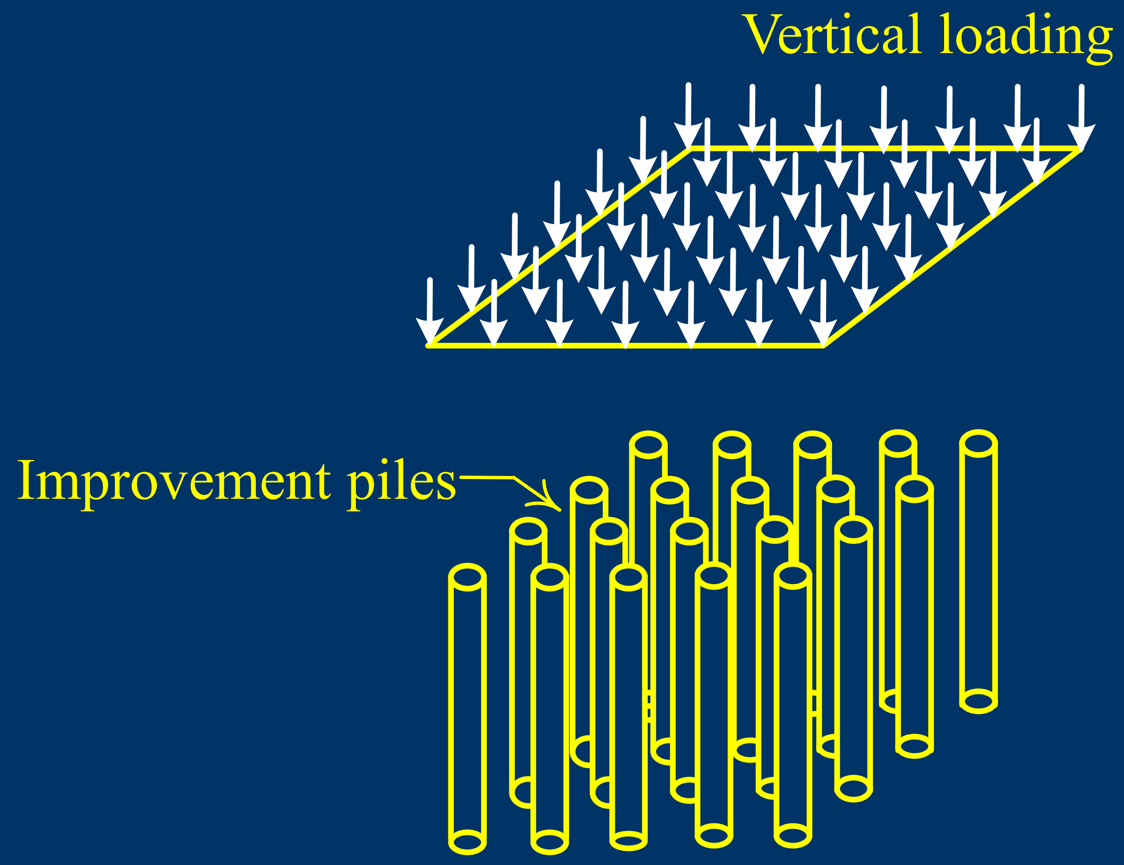


FIGURE 11.15 Composite soil bodies subjected to vertical loading

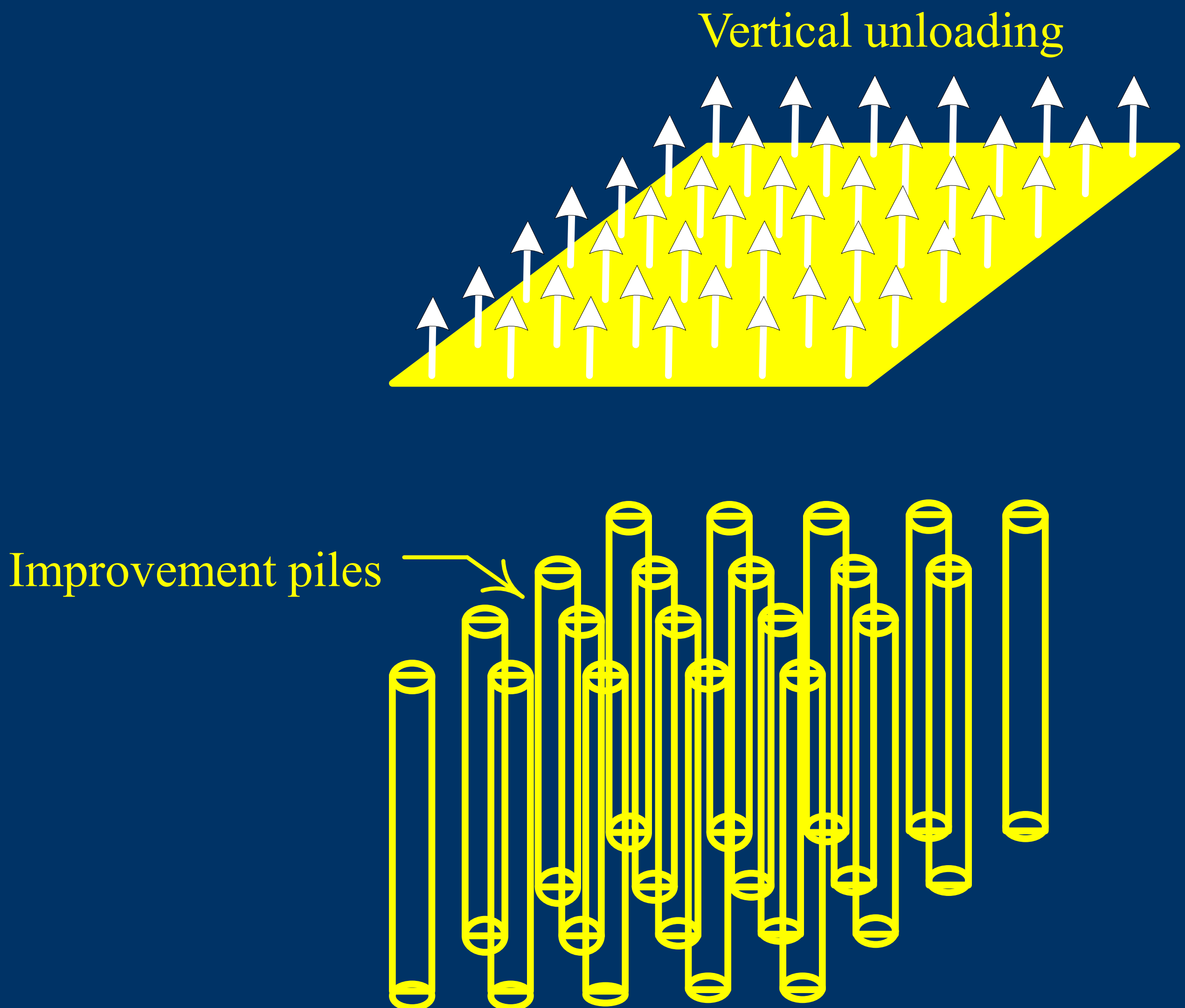


FIGURE 11.16 Composite soil bodies subjected to vertical unloading

According to the principle of force equilibrium, the strength of the composite soil subject to vertical loading can be written as

$$\tau_{eq} = \tau_t I_r + \tau_s (1 - I_r) \qquad (11.4)$$

τ_t = shear strength of the treated soil

τ_s = shear strength of the untreated soil

I_r = improvement ratio, that is, the area of the treated soil divided by the total area

The strength of the composite soil subject to vertical unloading can be written as

$$\tau_{eq} = \alpha \tau_t I_r + \tau_s (1 - I_r) \qquad (11.5)$$

α = modification factor, around 0.2-0.25, which is about equal to the ratio of tensile strength to compressive strength of the treated material

$$P_{eq} = P_g I_r^m + P_c(1 - I_r^m) \quad (1)$$

where P_{eq} = the equivalent soil parameter for the composite ground such as E_{ui}, S_u, ν, etc.; P_g = the parameter of the treated soil; P_c = the parameter of the untreated soil; I_r = the improvement ratio, which is defined as the ratio of treated soil area to the total area; and m = an equivalent parameter index. For the case without soil improvement, the improvement ratio $I_r = 0$ and $P_{eq} = P_c$; for the case where in-situ soils are completely replaced by the treated soil, $I_r = 100\%$ and $P_{eq} = P_g$.

Ou et al. (1996)--ASCE

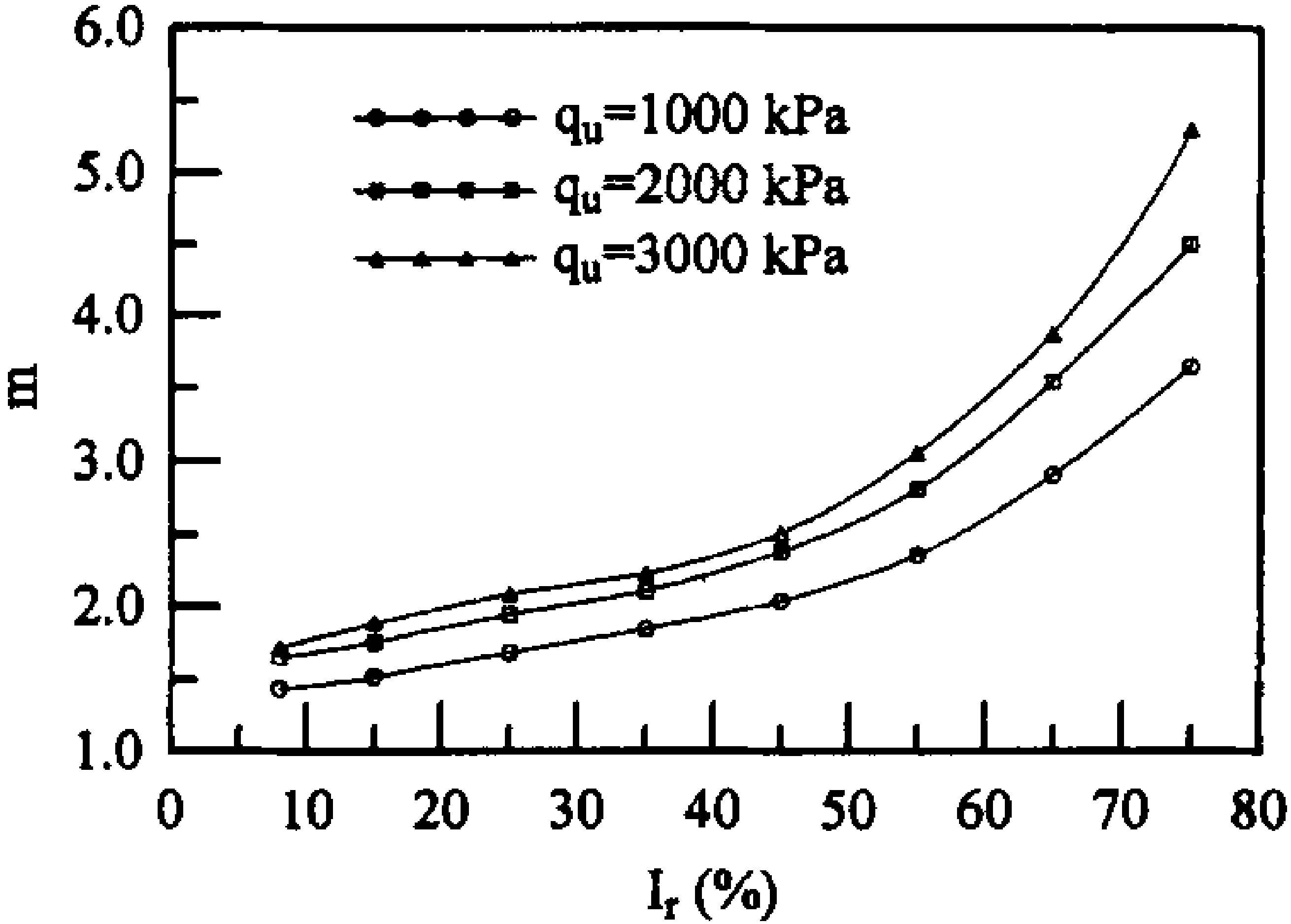


FIG. 7. q_u-m-I_r Relationship

5. Cross Walls

The arrangement of cross walls is schematically shown in Figure 11.26.

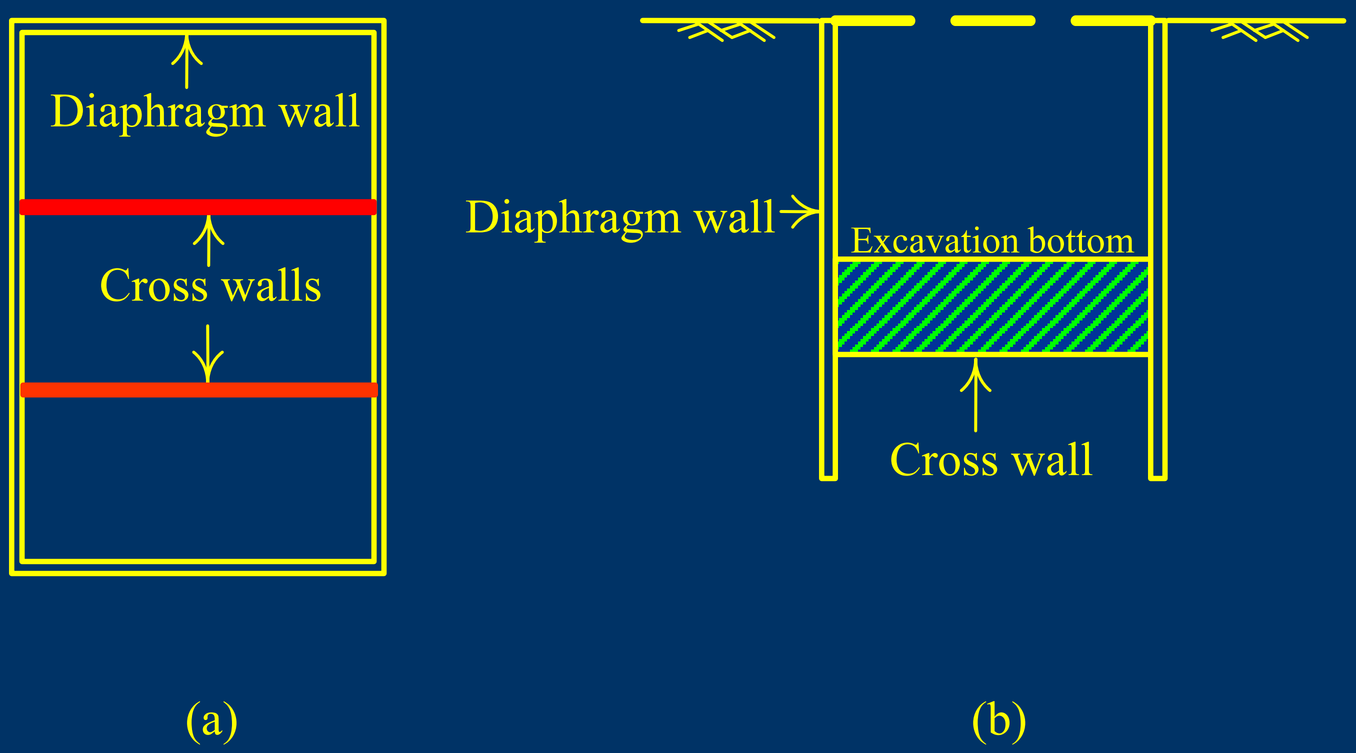


FIGURE 11.26 Configuration of cross walls (a) plan (b) profile

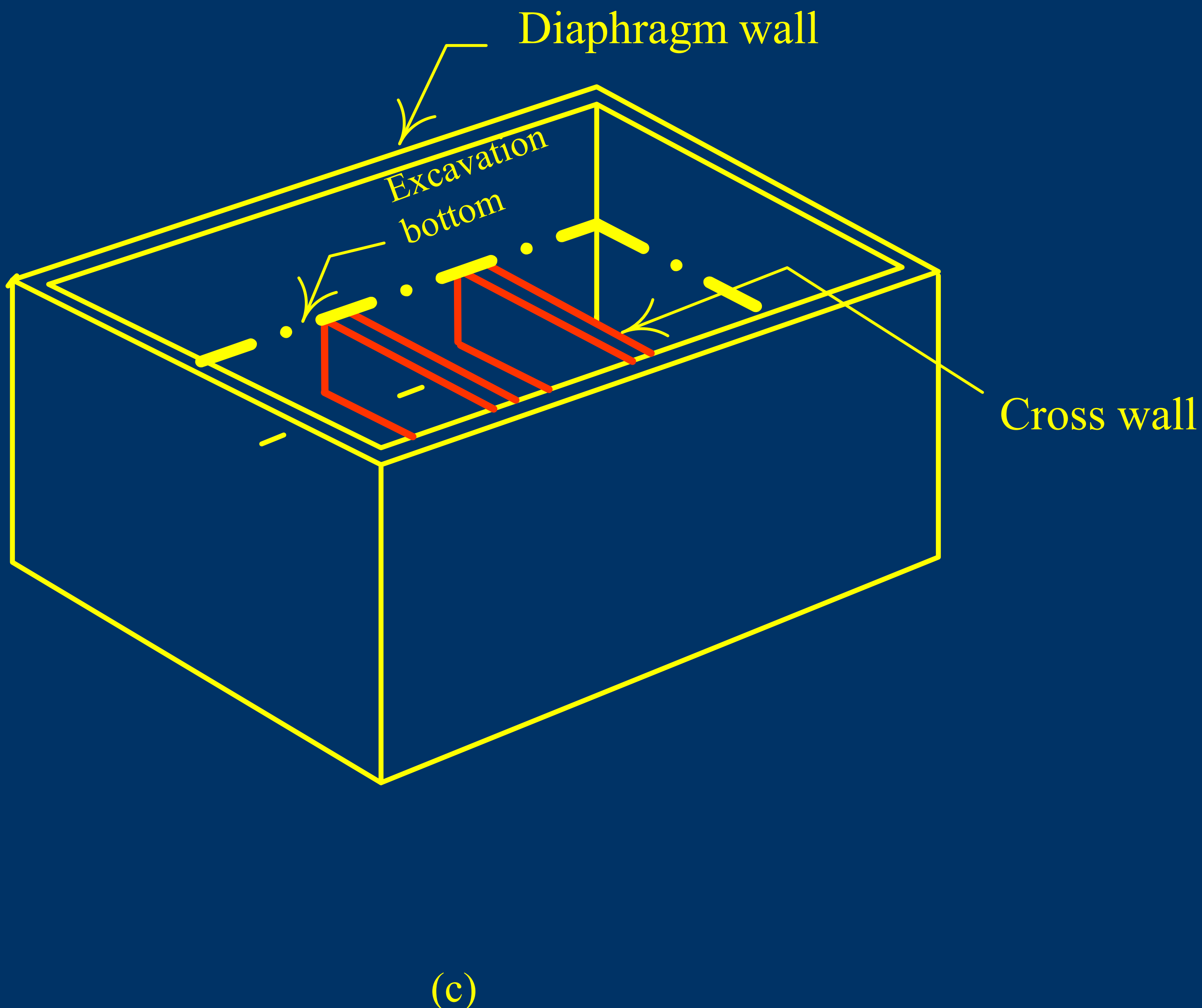


FIGURE 11.26 Configuration of cross walls (c) three dimensional view

Construction methods ：

(1) It can be constructed using ground improvement techniques (such as jet grouting or deep mixing). The unconfined compression strengths of treated soils are usually between 10~20 kg/ cm^2

(2) To obtain a better construction quality or compressive strength, the cross wall can also be constructed by unreinforced diaphragm walls (the concrete diaphragm wall can achieve 280 kg/cm^2 with a minimum of 100 kg/cm^2).

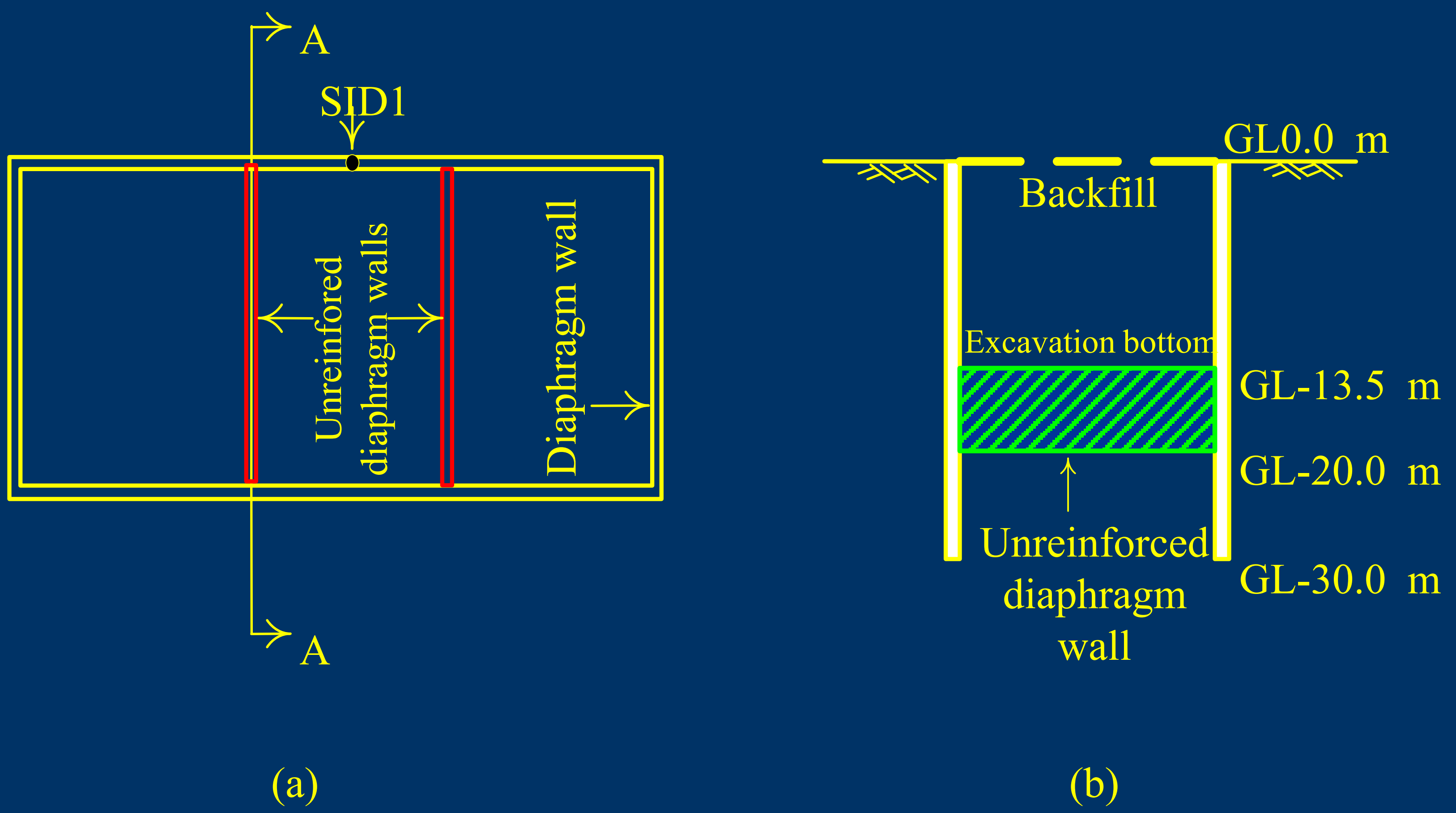


FIGURE 11.27 Cross walls in excavations (a) plan (b) profile

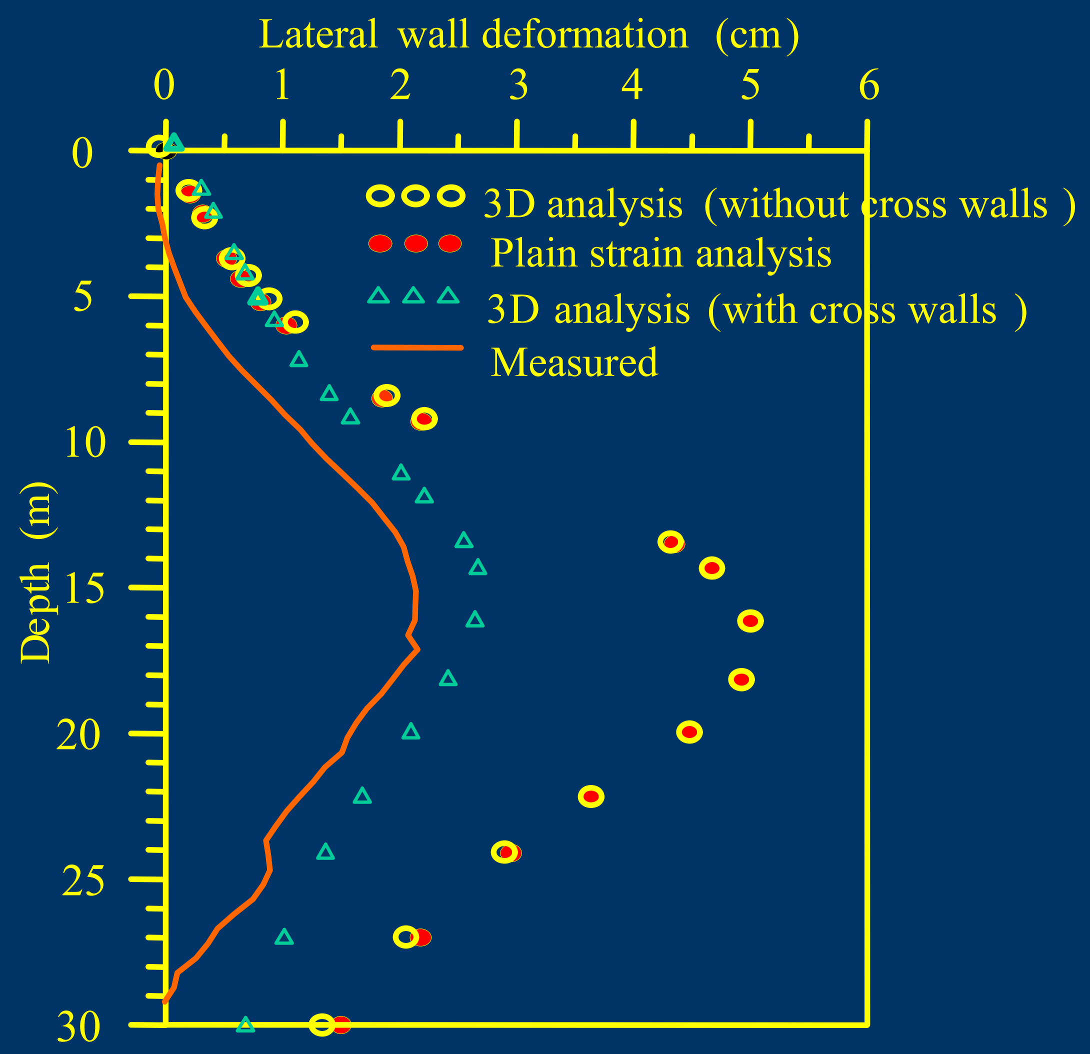
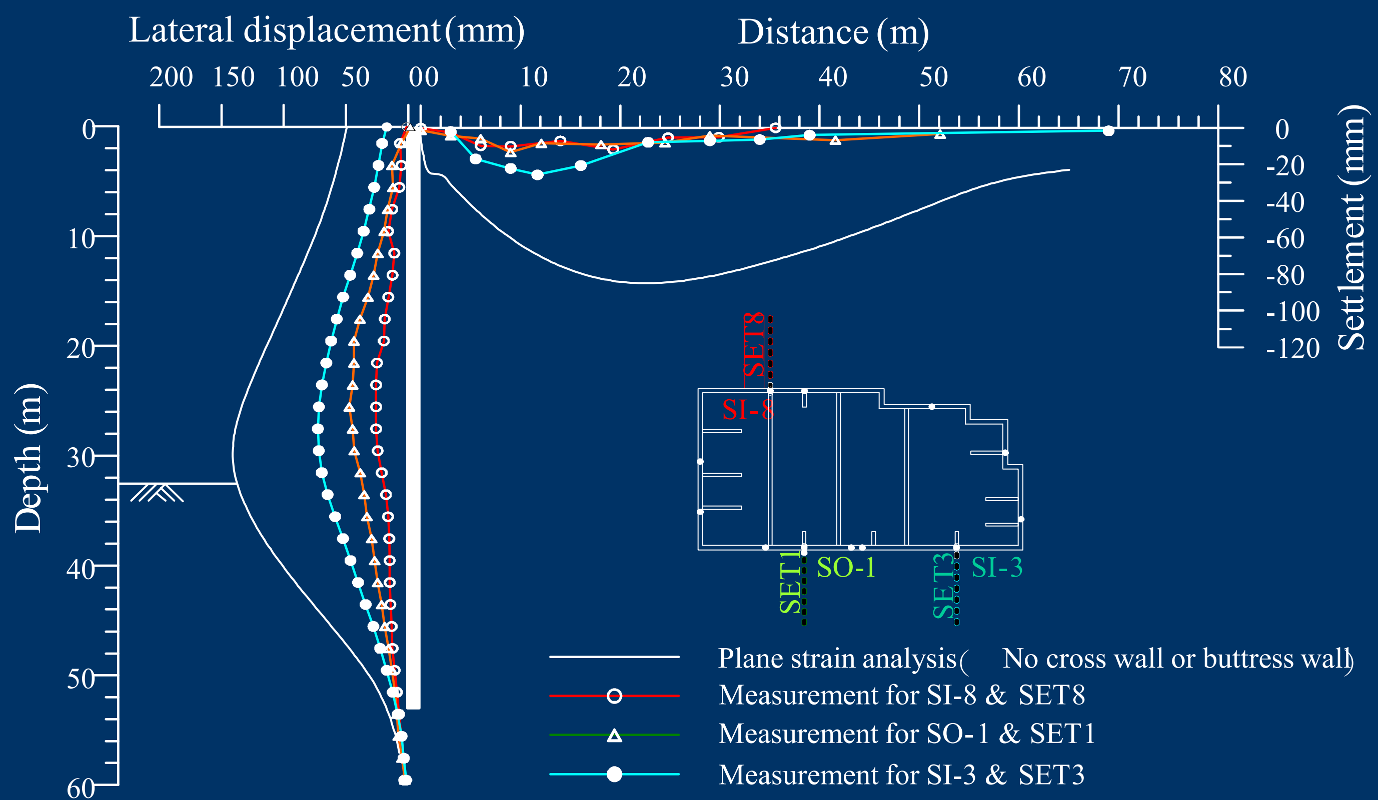
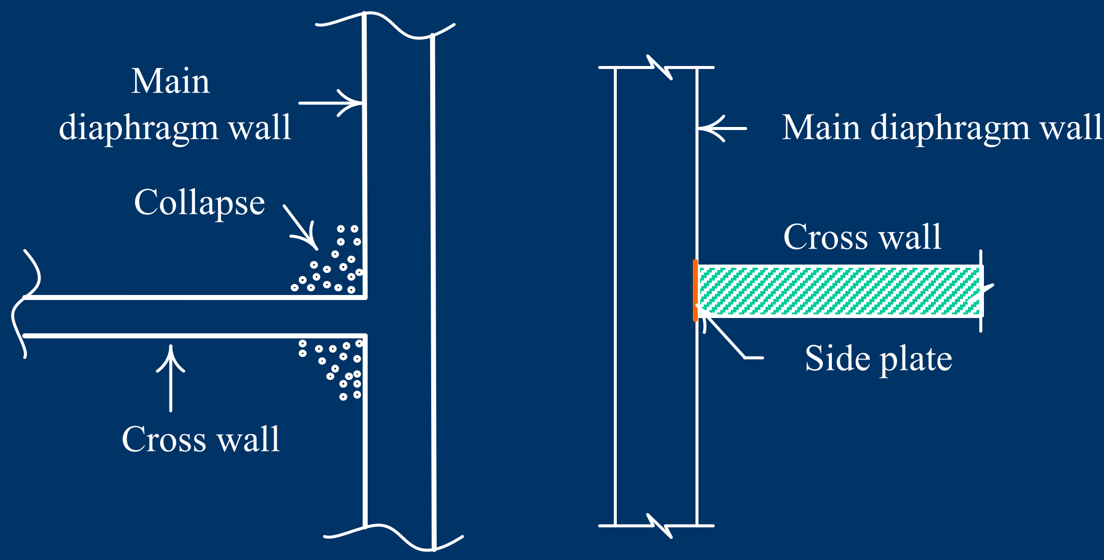


FIG. 11.28 Measured and computed lateral deformations of the diaphragm wall with cross walls

- Taipei case history





Main
diaphragm wall
Collapse
Cross wall
Main diaphragm wall
Cross wall
Side plate

(a) (b)

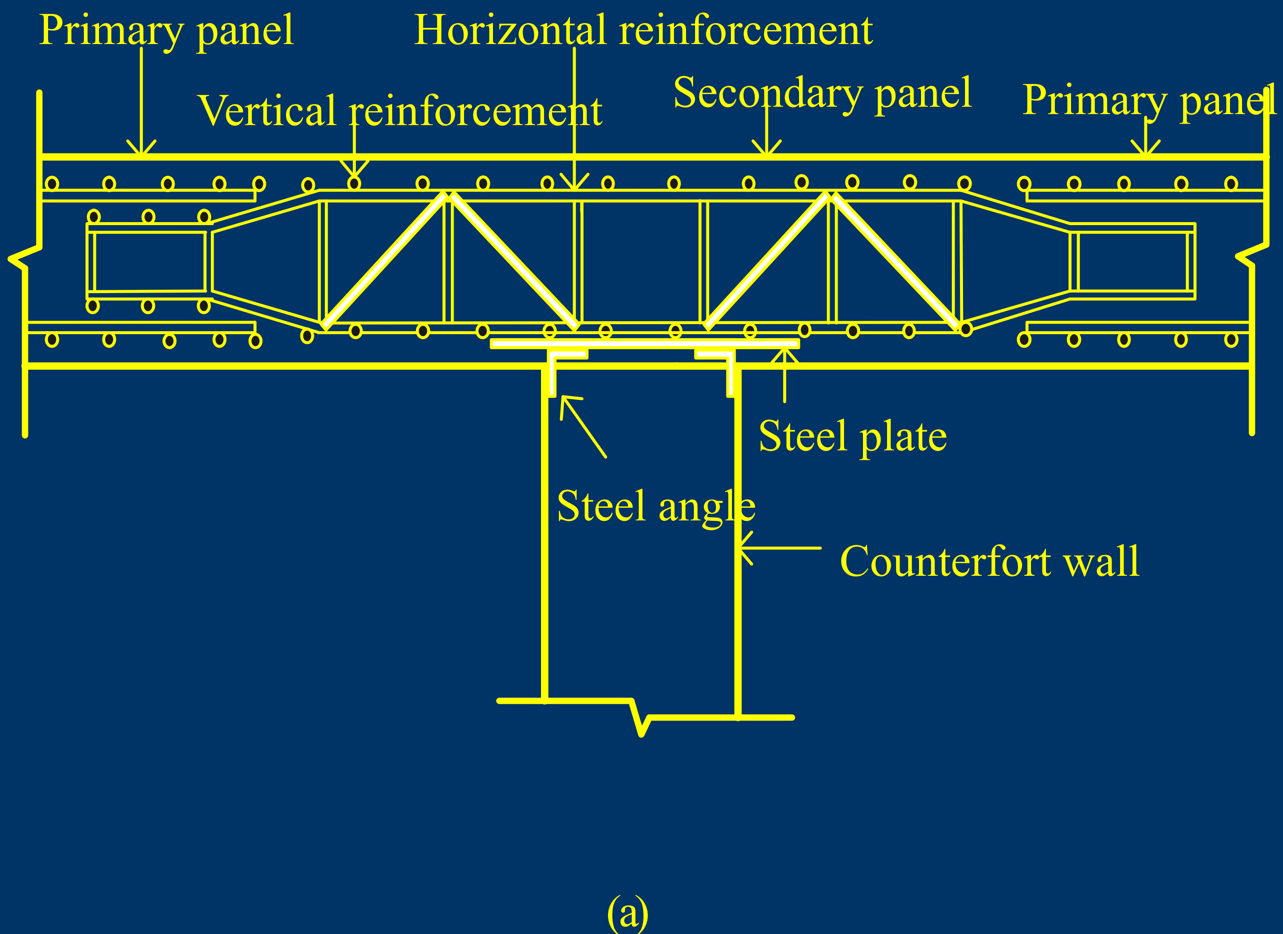
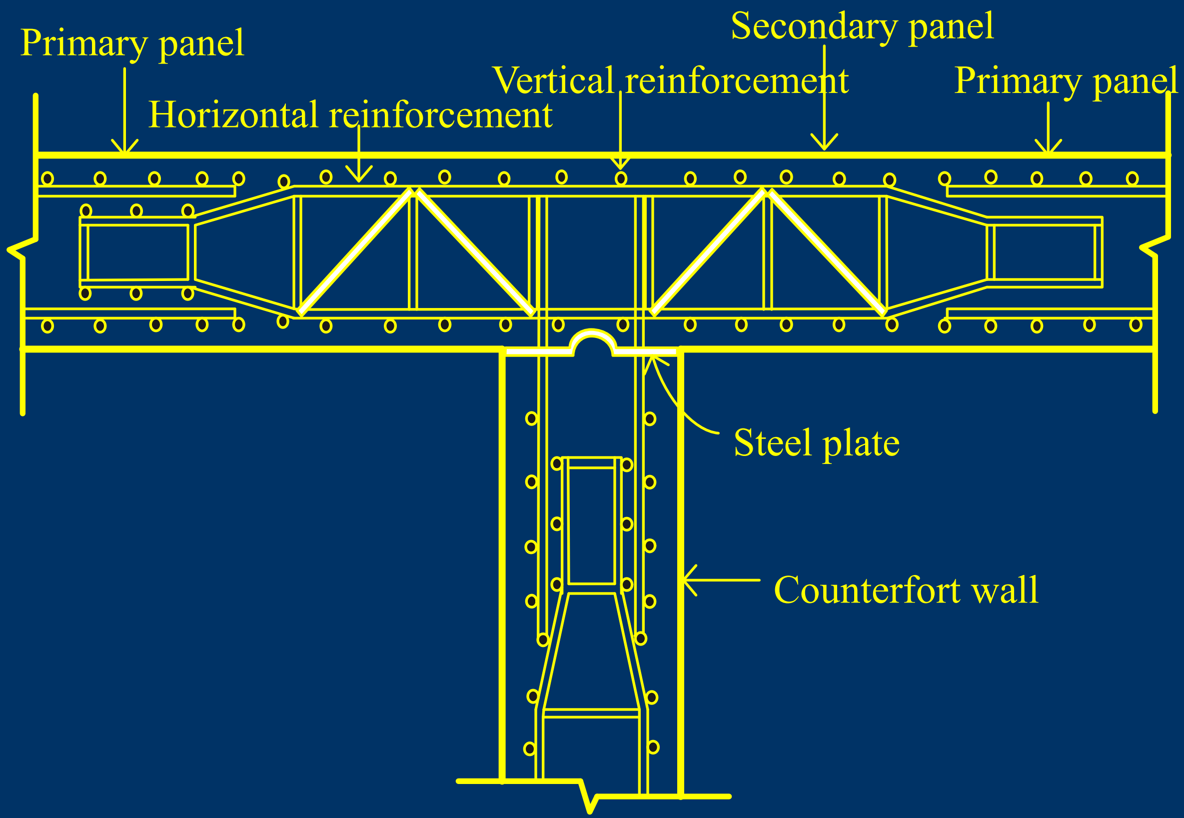
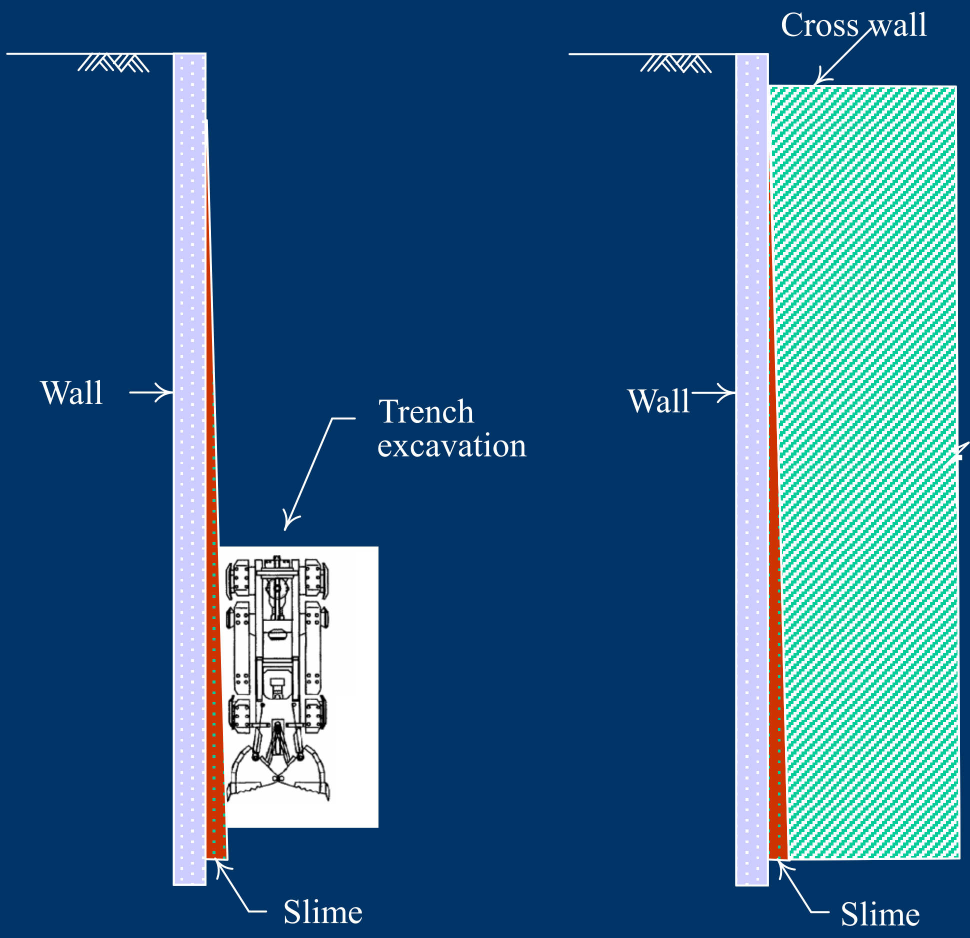


FIGURE 11.20 Types of counterfort walls (a) unreinforced



(b)

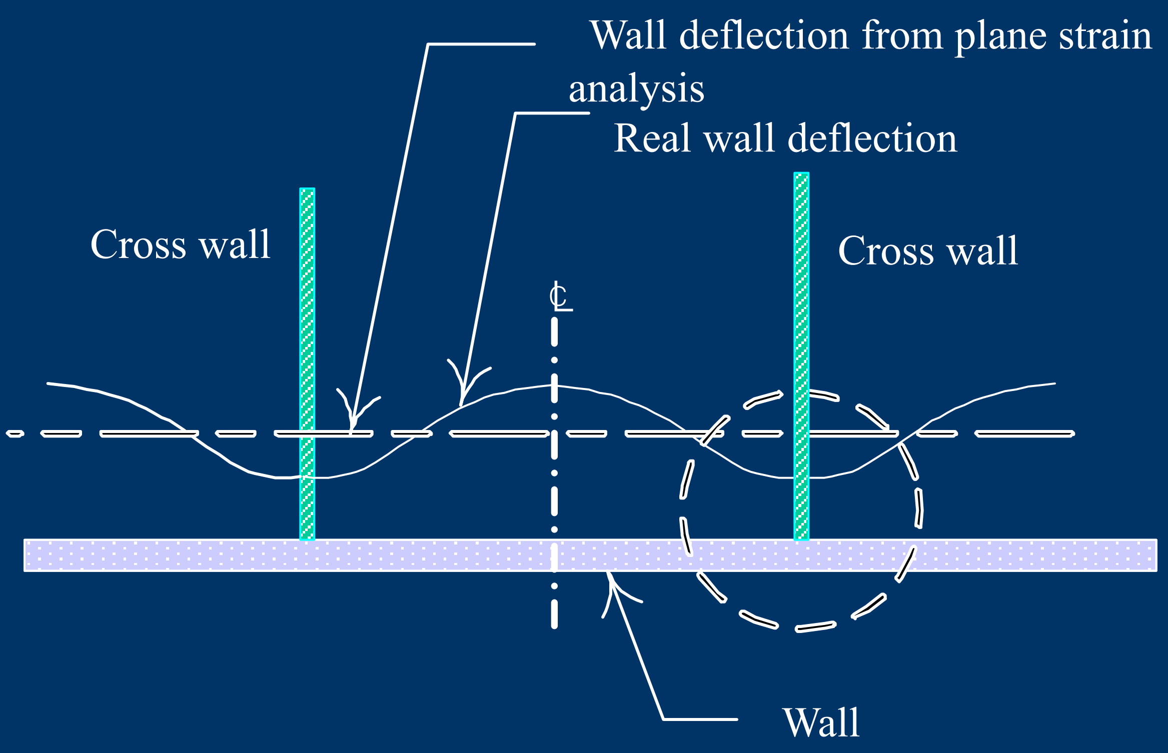
FIGURE 11.20 Types of counterfort walls (b) reinforced


Wall
Trench
excavation
Slime
Cross wall
Wall
Slime

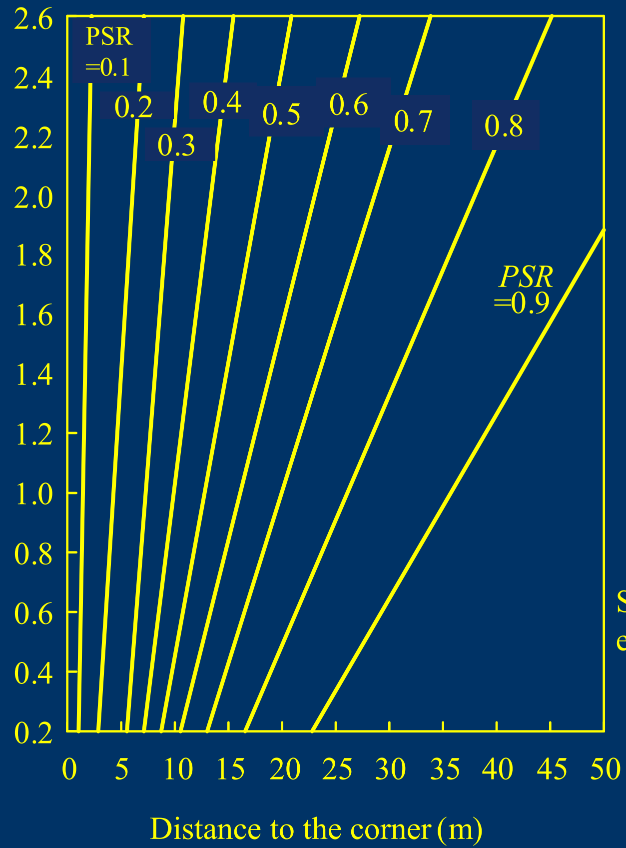
Cross wall-analysis method

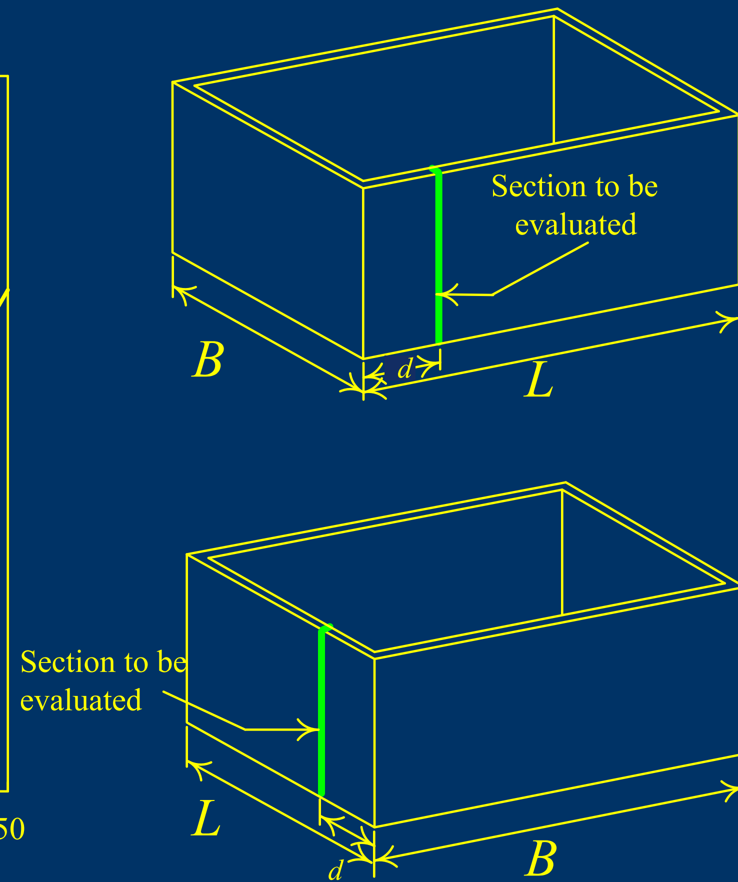
- Design: depth of the cross wall and space between the walls
- Its behavior is three dimensional
- Thee dimensional finite element analysis

- Plane strain analysis



- Plane strain analysis coupled with the concept of corner effect





B=Width *L*= Length *d*=Distance to the corner *PSR*=Plane strain ratio

(a) (b)

5. Counterfort wall or Buttress Wall

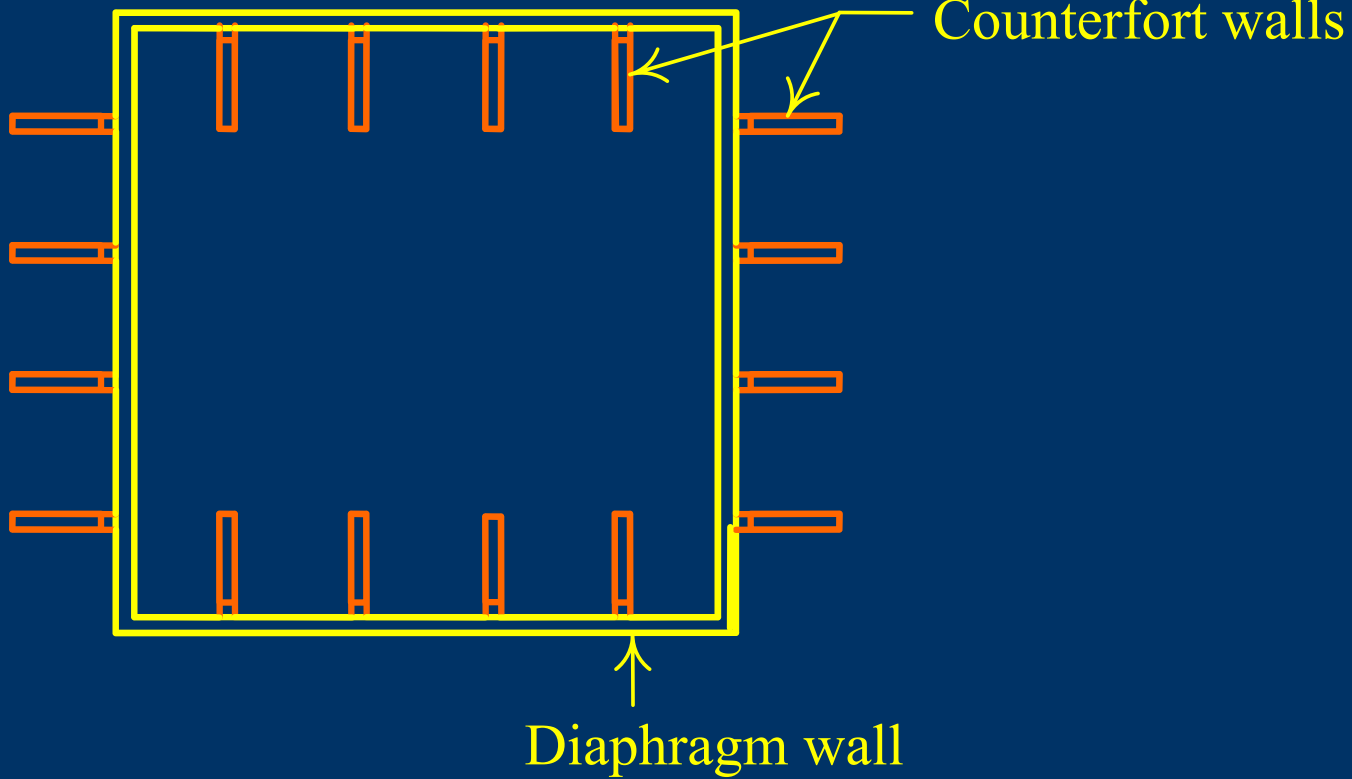
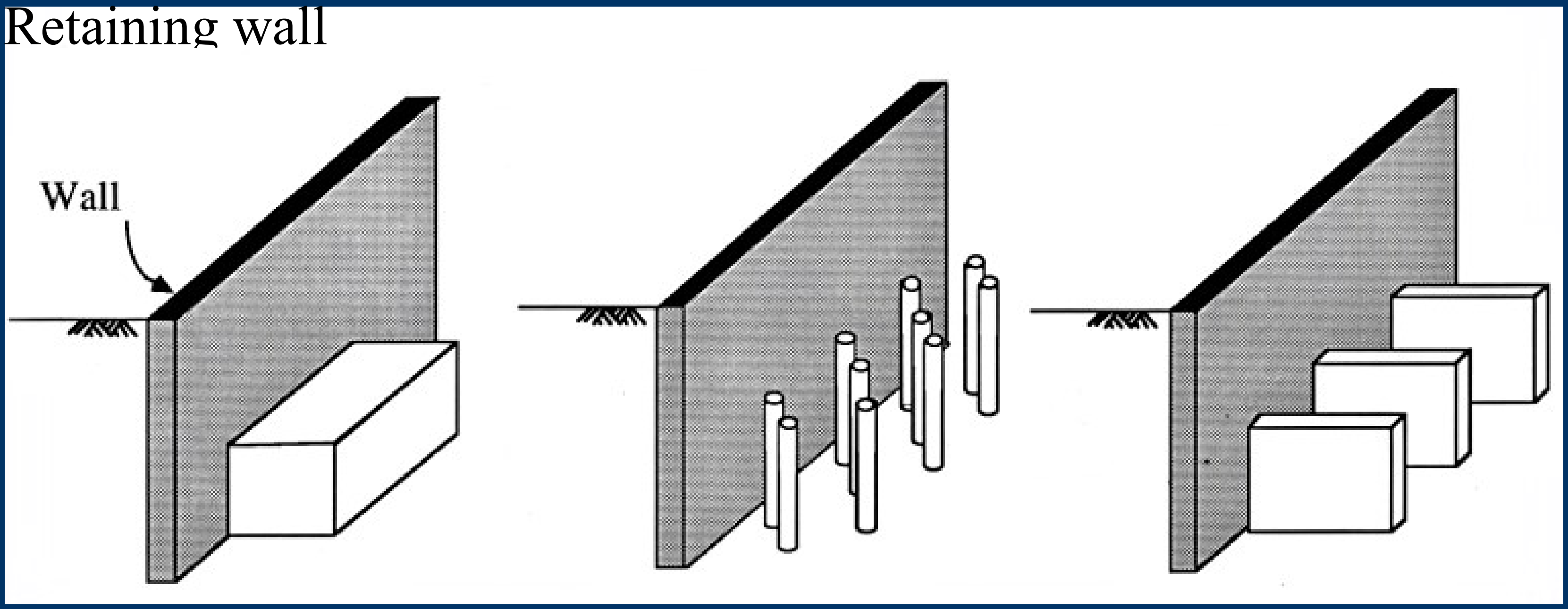


FIGURE 11.18 Locations of counterfort walls

6. Buttress Walls (Counterfort walls)

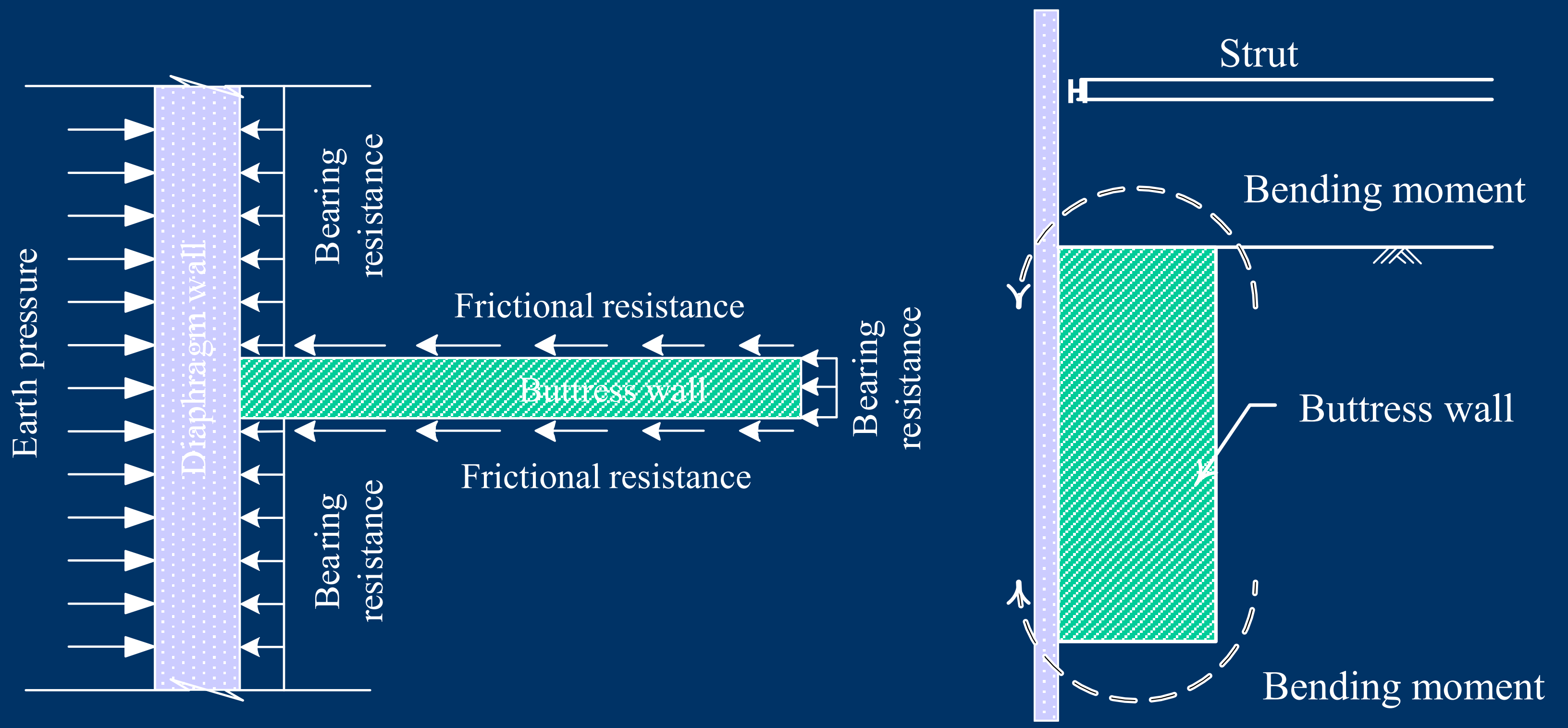


(a) (b) (c)

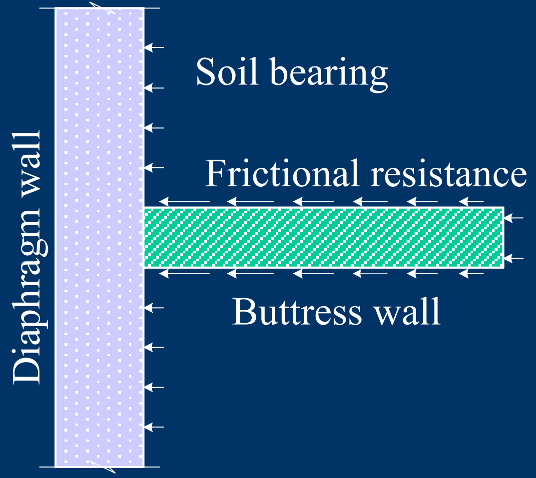
FIGURE 11.13 Typical arrangement of soil improvement in excavations

(a) block type (b) column type (c) wall type

Buttress wall---principles



- Buttress wall and diaphragm wall are not formed a unity
  - When wall defects, the buttress is pushed forward
  - When length of buttress wall increases, side frictional resistance increases



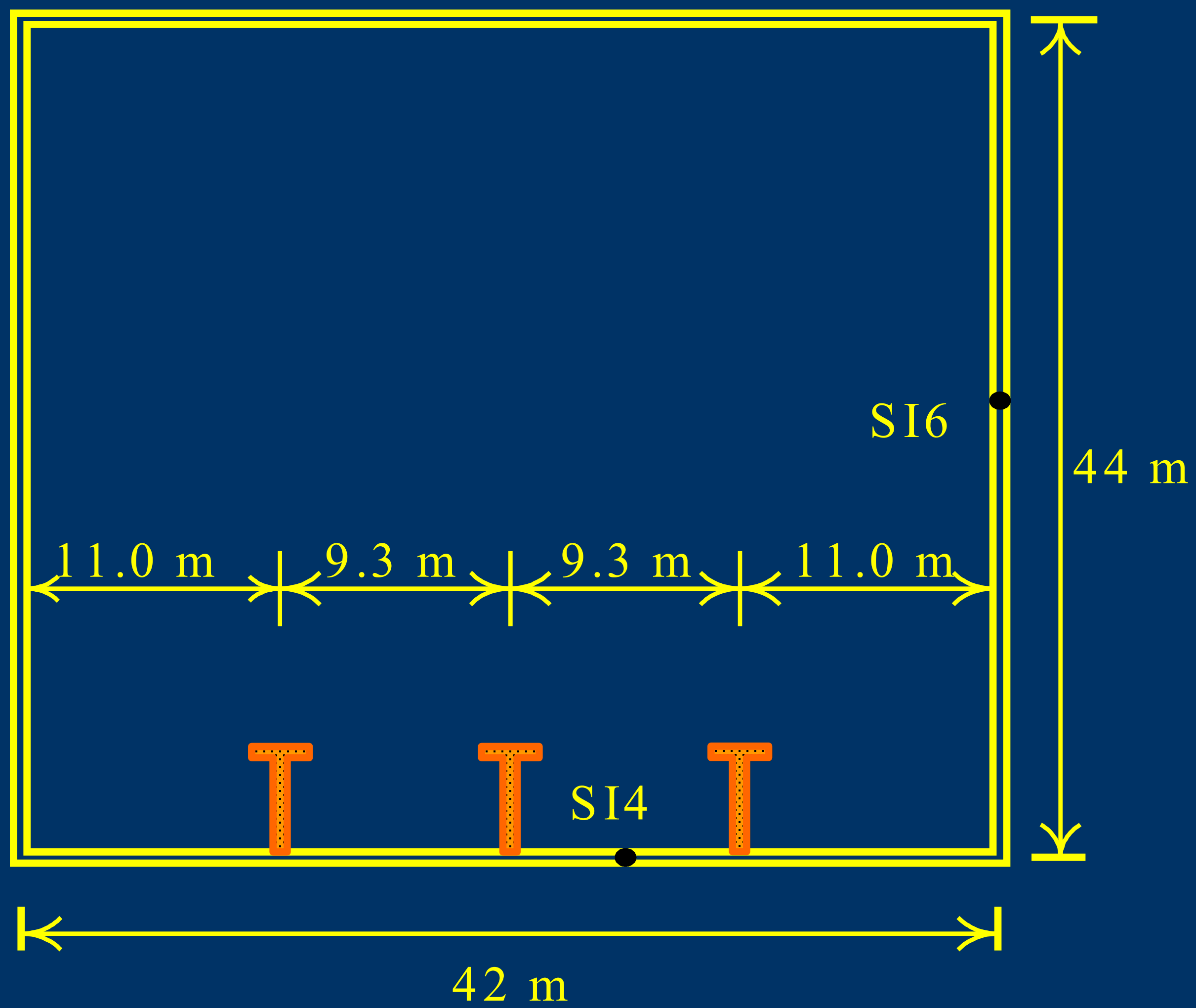


FIGURE 11.21 Plan of an excavation with T-counterfort walls

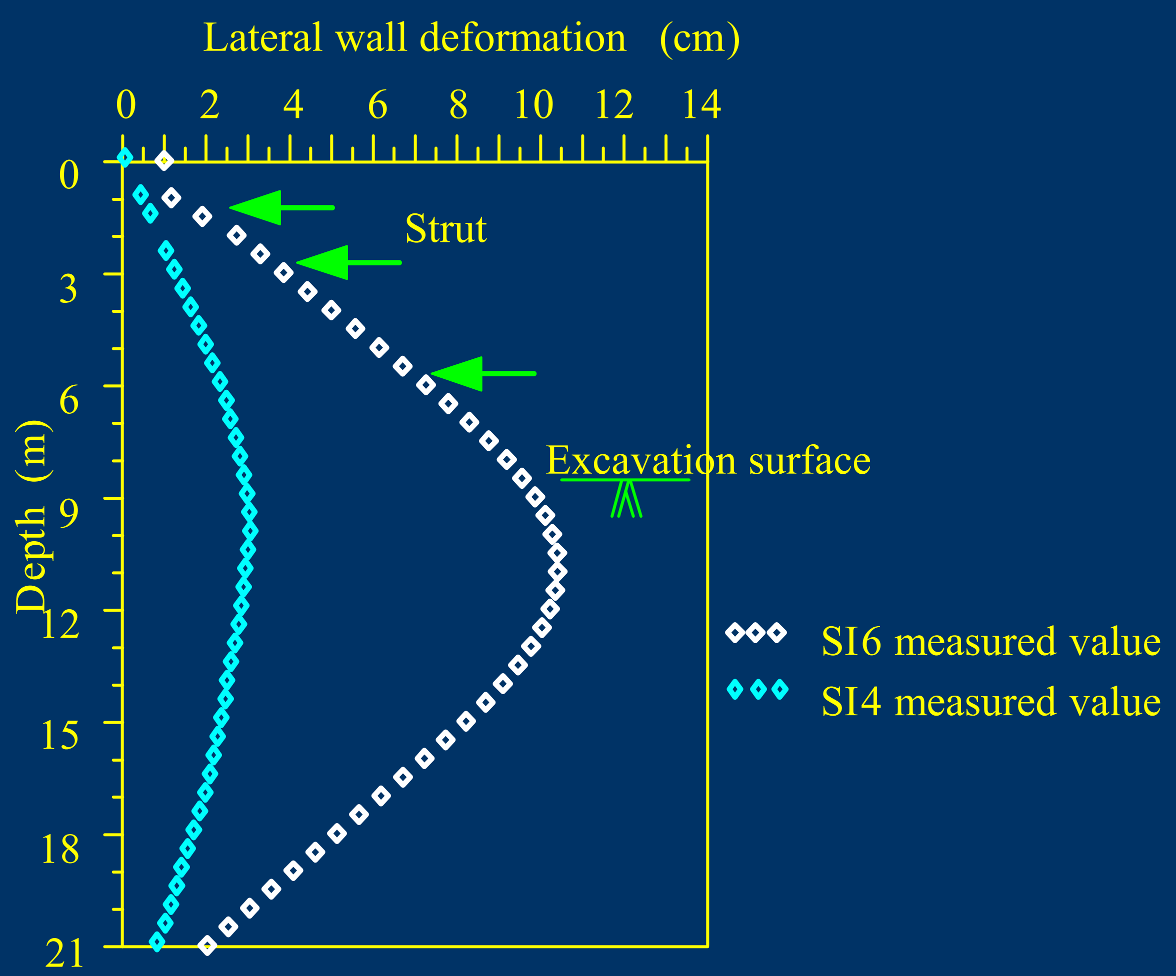


FIGURE 11.22 Measurements of lateral deformation of the wall at S14 and S16

Parametric Studies：

Conclusions：

(1) The deformation behaviors of the counterfort-diaphragm wall can be successfully analyzed or predicted using the three dimensional finite element method.

(2) The deformation behavior of the counterfort-diaphragm wall has much to do with whether it penetrates into the hard soil stratum (sandy or gravelly soils) or not. In other words, it relates to whether the wall bottom is effectively restrained or not.

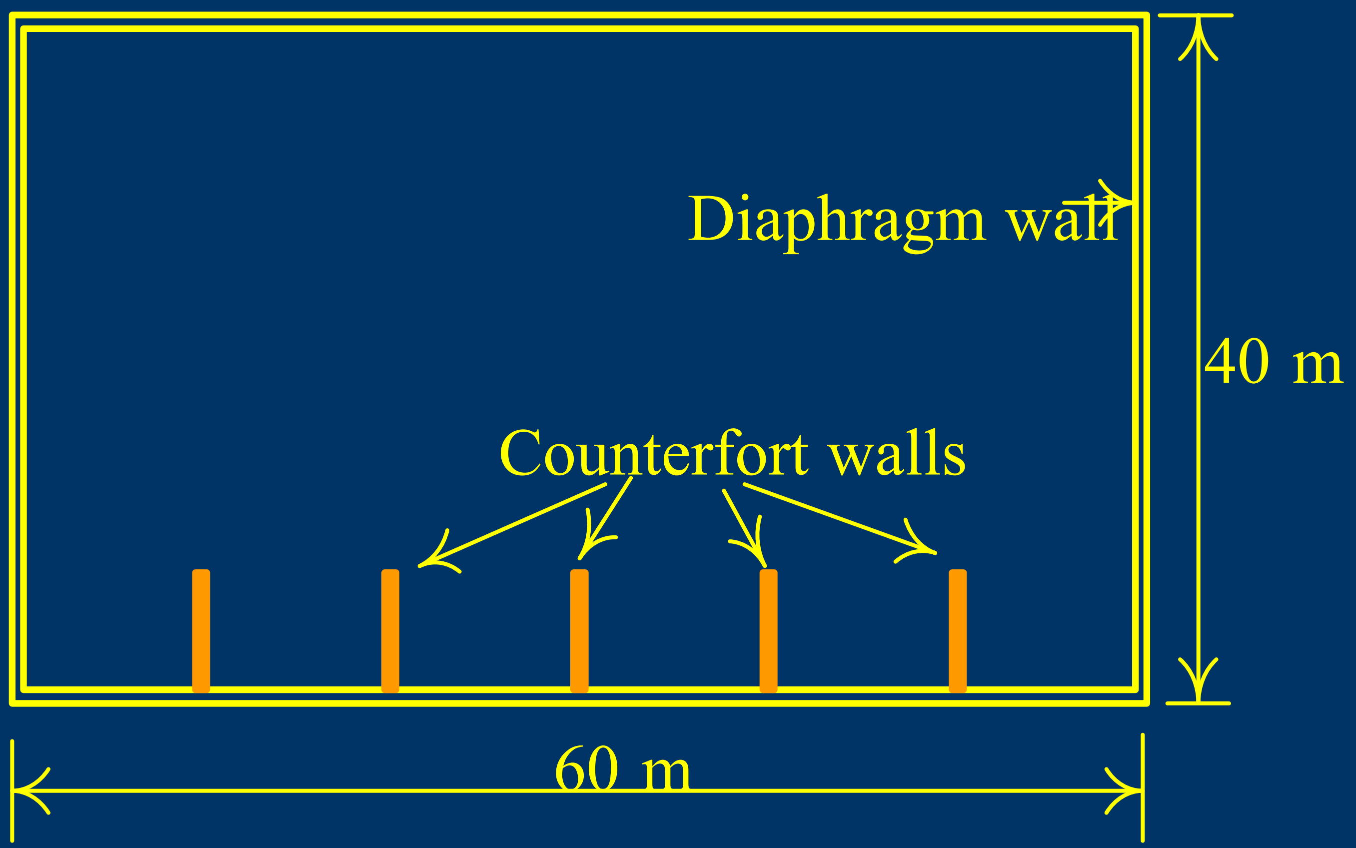


FIGURE 11.23 Arrangement of counterfort walls in a hypothetical excavation

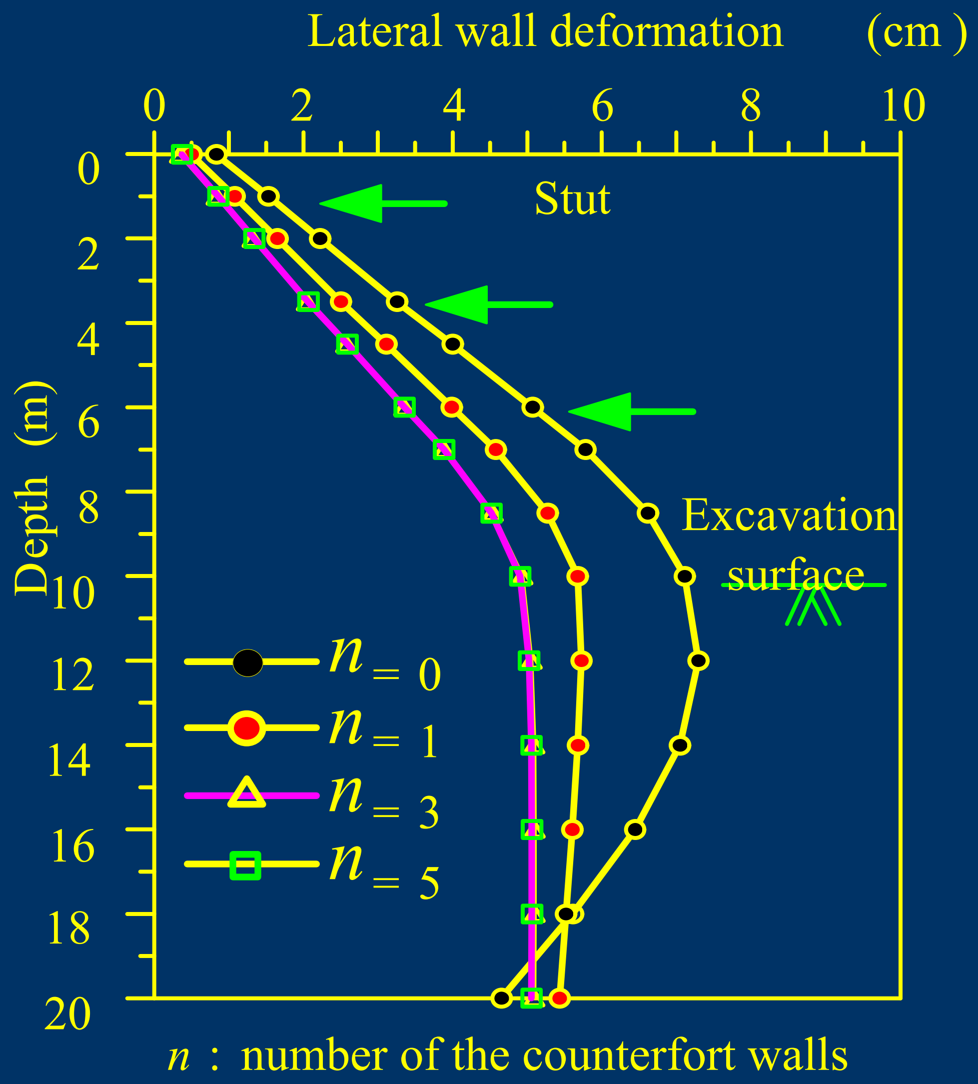


FIGURE 11.24 Relation between the deformation of a diaphragm wall and the number of counterfort walls (note: counterfort walls not penetrated into hard soils)

(3) The counterfort wall can only restrain the wall deformation at the part where it is placed. If the deformation of the whole diaphragm wall, i.e., along the excavation border, is to be reduced, several counterfort walls have to be placed evenly along the excavation border.

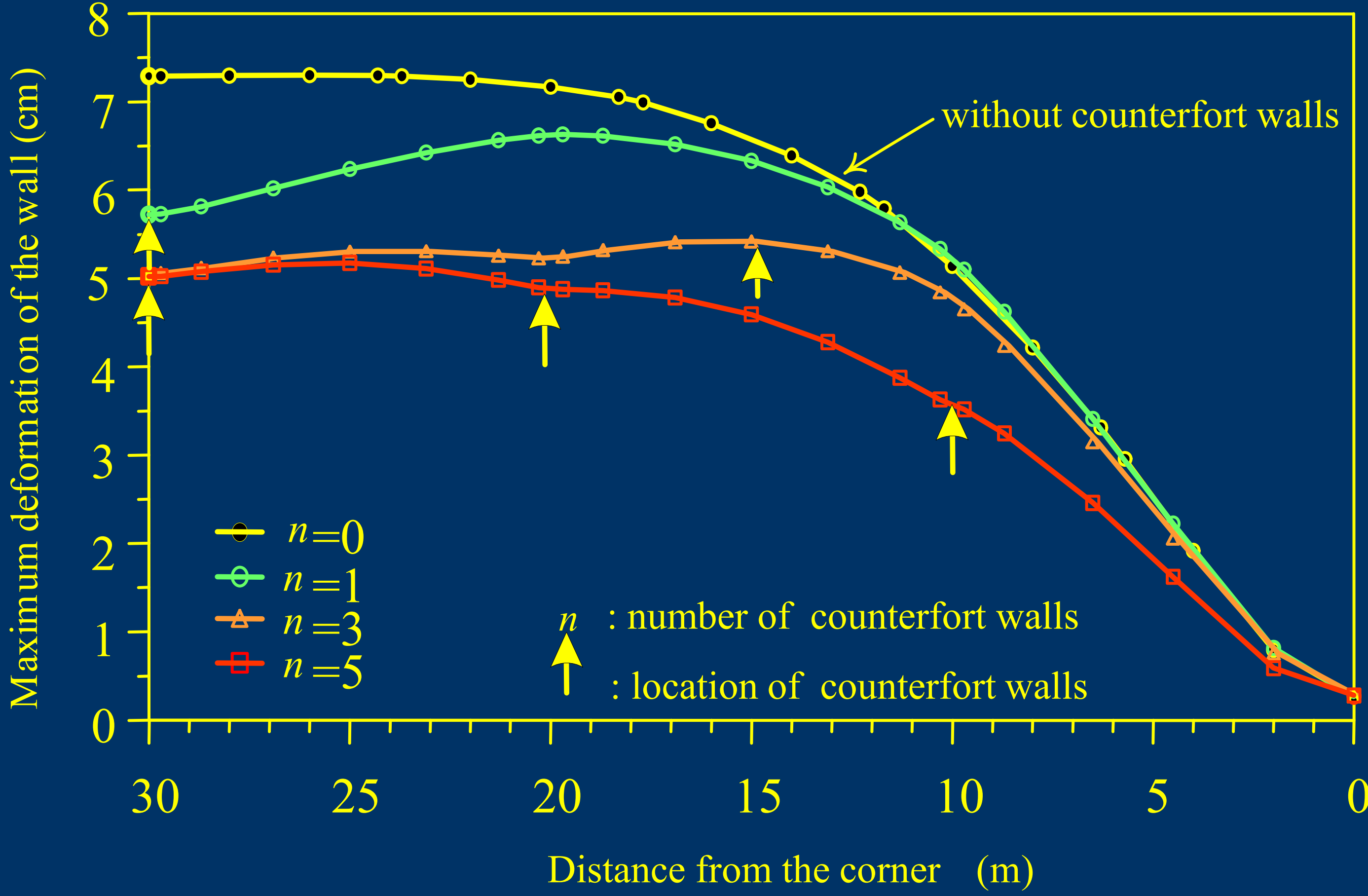


FIGURE 11.25 Influence of the number of counterfort walls on the maximum wall deformation in different positions

7. Micro Piles

Micro piles are also called soil nails. In practice,

The diameter of a micro pile varies from 10 cm to 30 cm. The reinforcements can be steel bars, steel rails, H steels, or even steel cages. The construction process of micro piles is as follows. First, bore to the designed depth with casings or by other drilling measures and then place reinforcements into the bores. Inject cement mortar into bores under a certain pressure. Pull out the casing little by little and add more mortar.

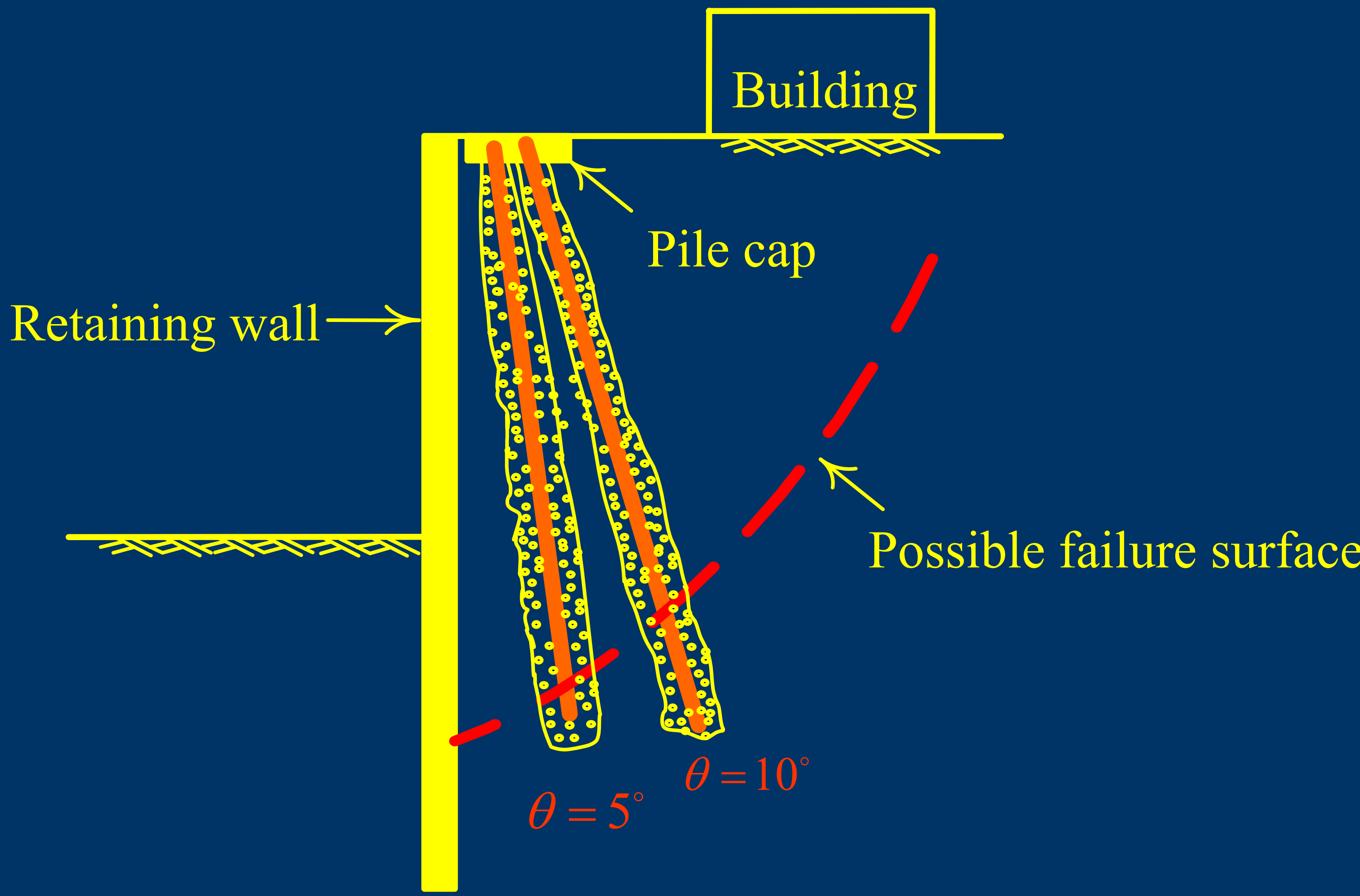


FIGURE 11.29 Mechanism of micro piles to protect buildings

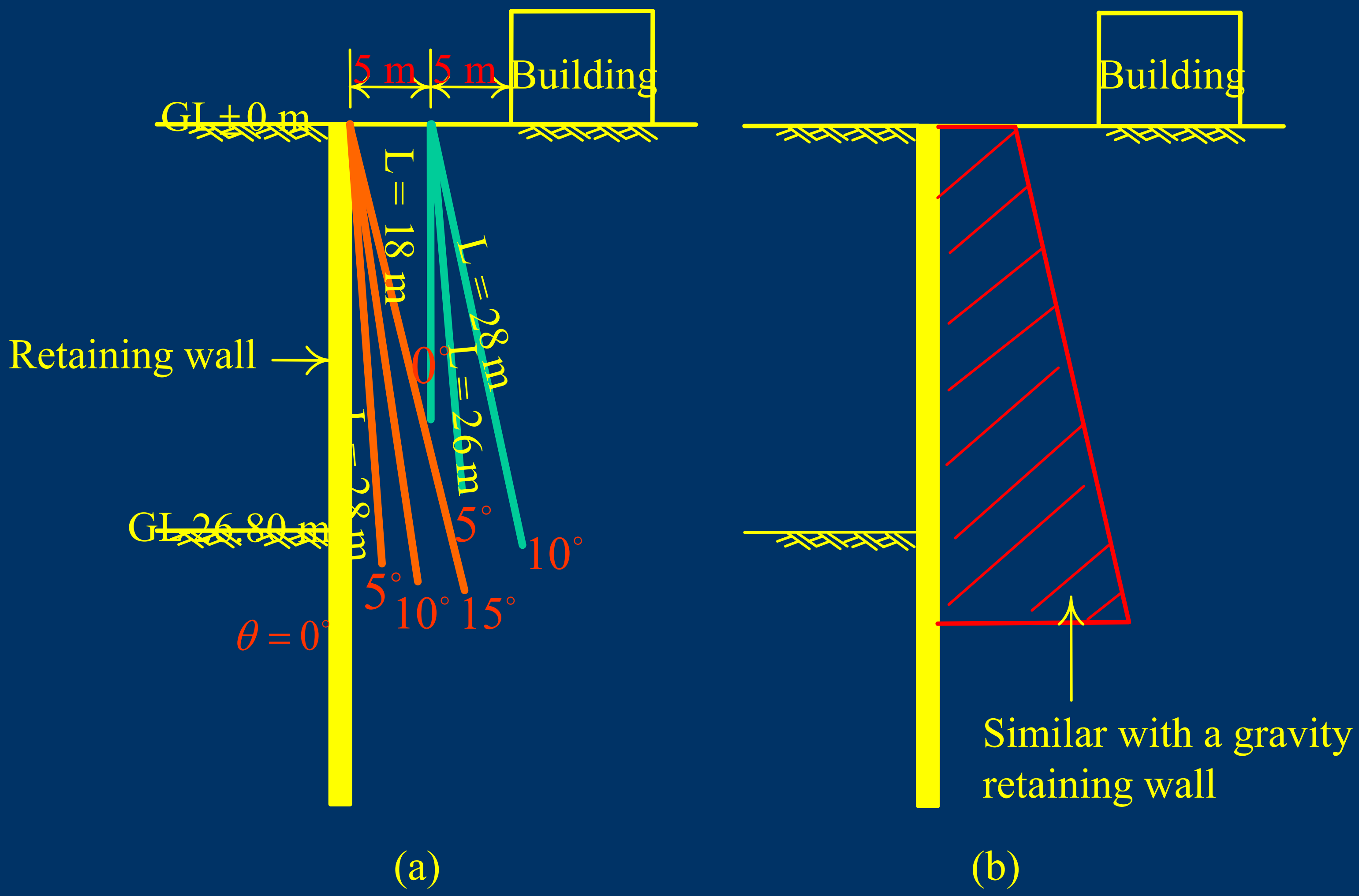


FIG. 11.30 Mechanism of micro piles to protect buildings
(a) arrangement of micro piles (b) serving as a gravity retaining wall