Stress and Deformation Analysis--Simplified Method

6.2 Analysis of Settlement Induced by the Construction of Diaphragm Walls

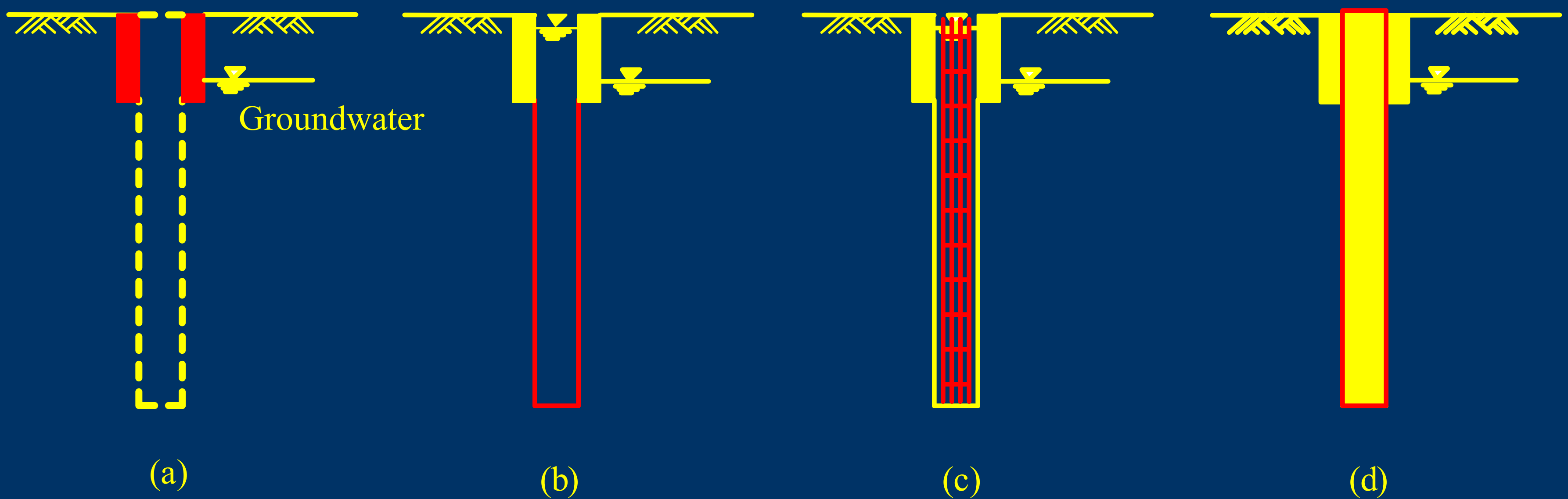


FIGURE 3.26 Construction procedure of a diaphragm wall panel
(a) construction of the guided wall (b) excavation of the trench
(c) placement of reinforcements (d) concrete casting

Excavation of the Trench：The depth of a guided trench is generally about 2~3 m, sometimes 5 m. And that no significant settlement occurs during this stage.

Trench：

The balanced state of the fluid pressure of single trench —

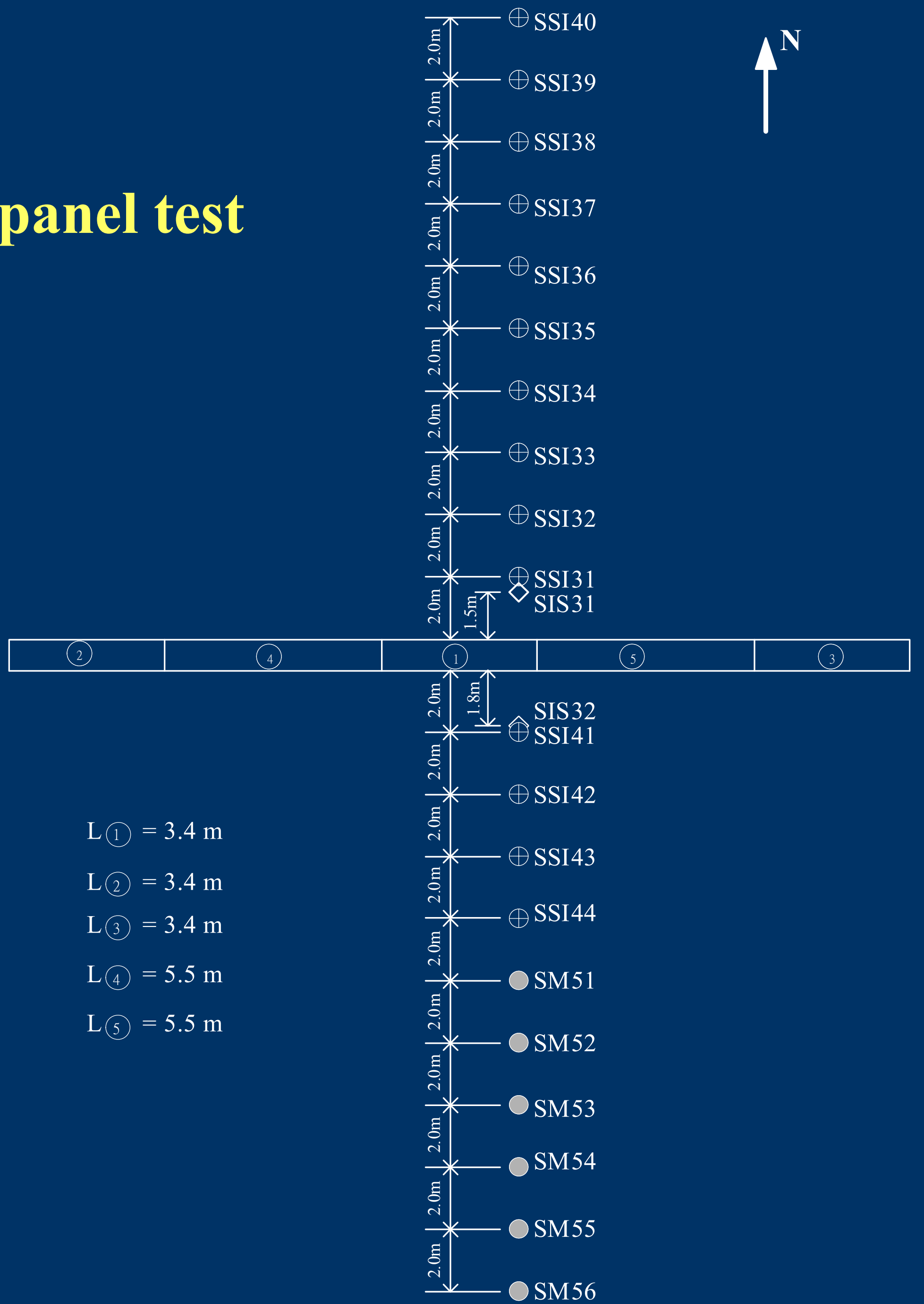
Concrete casting of single trench —

After the completion of a diaphragm wall of single trench —

After the completion of the diaphragm walls —

After the completion of the whole diaphragm wall —

Multiple wall panel test



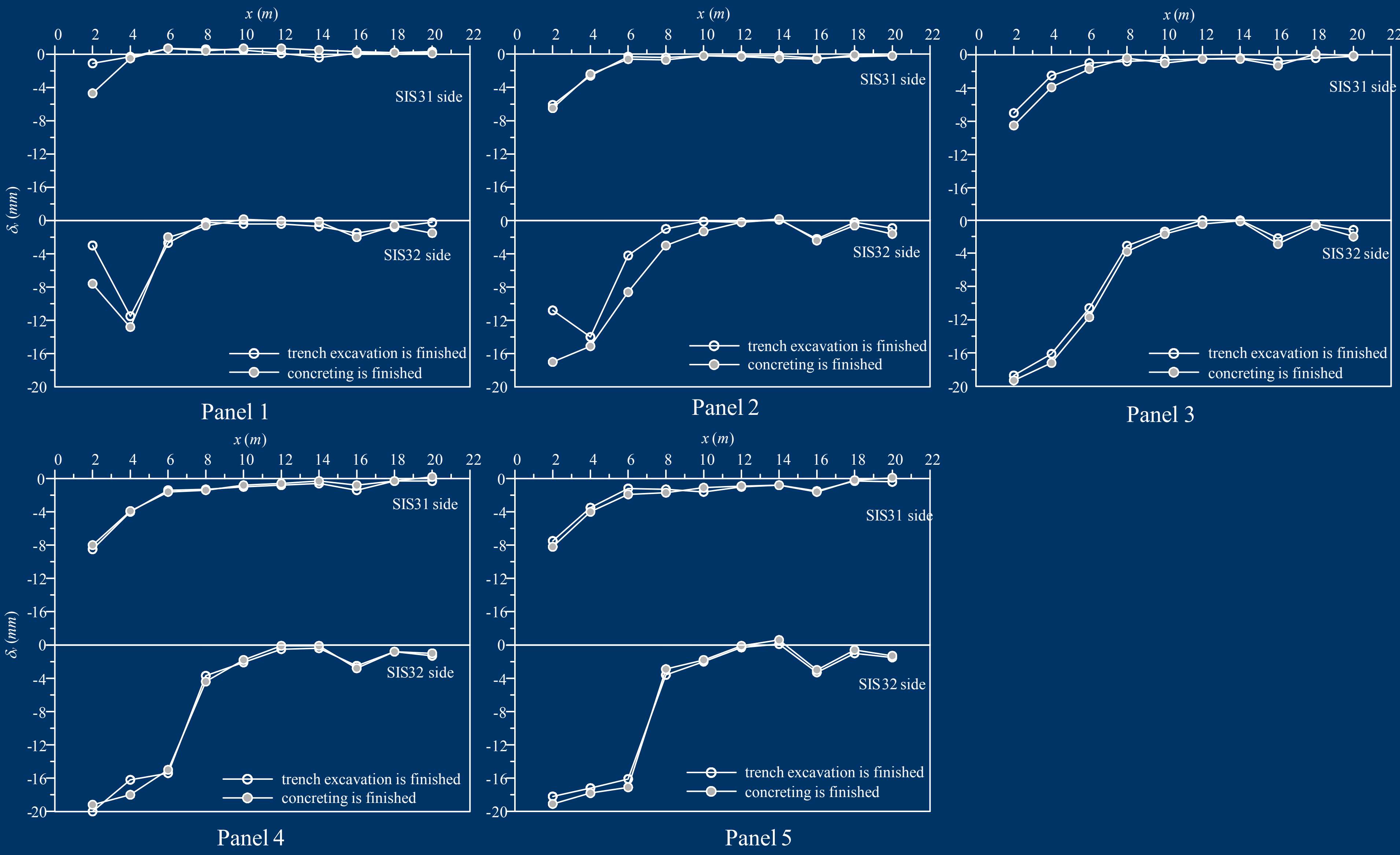
L① = 3.4 m

L② = 3.4 m

L③ = 3.4 m

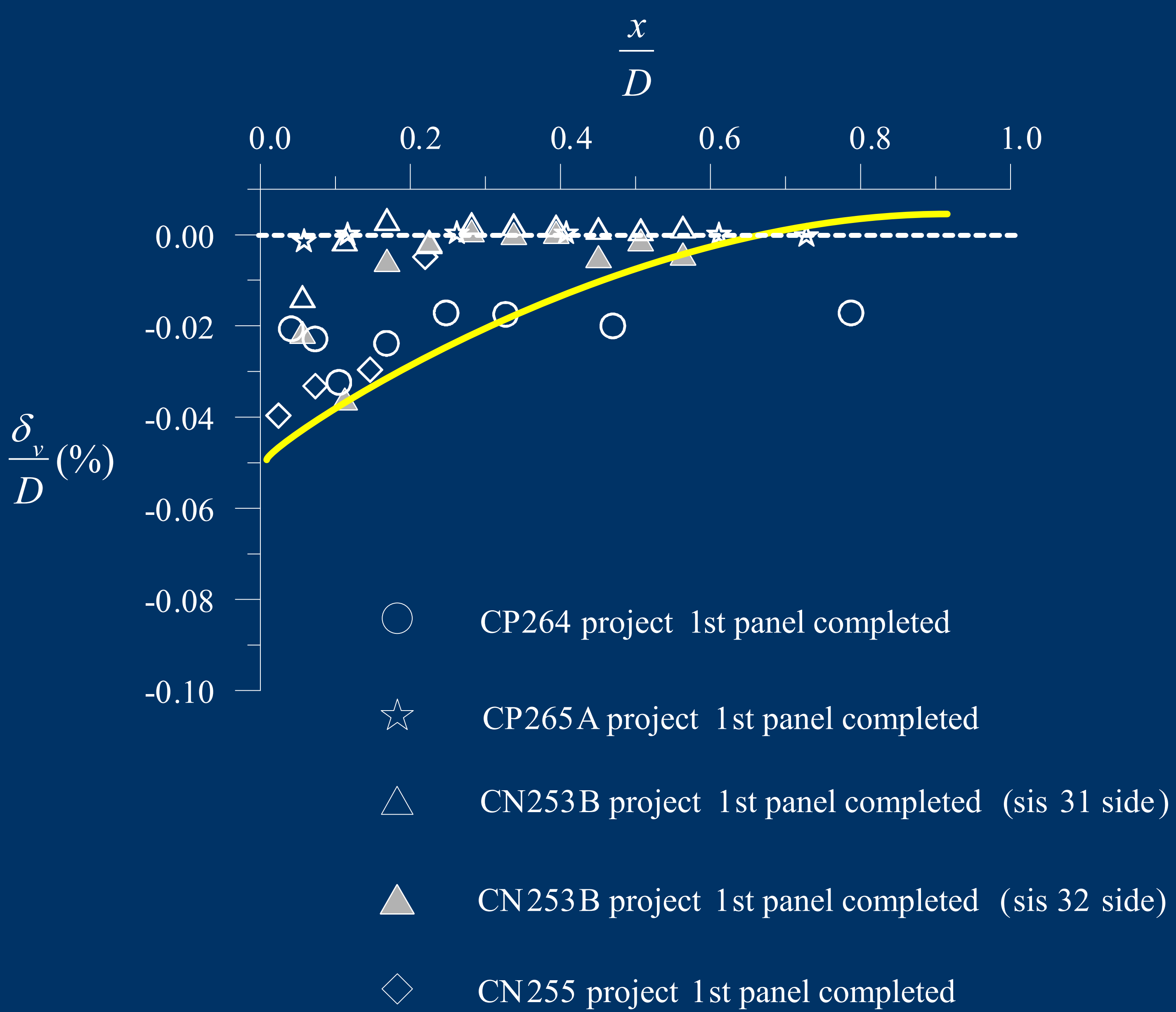
L④ = 5.5 m

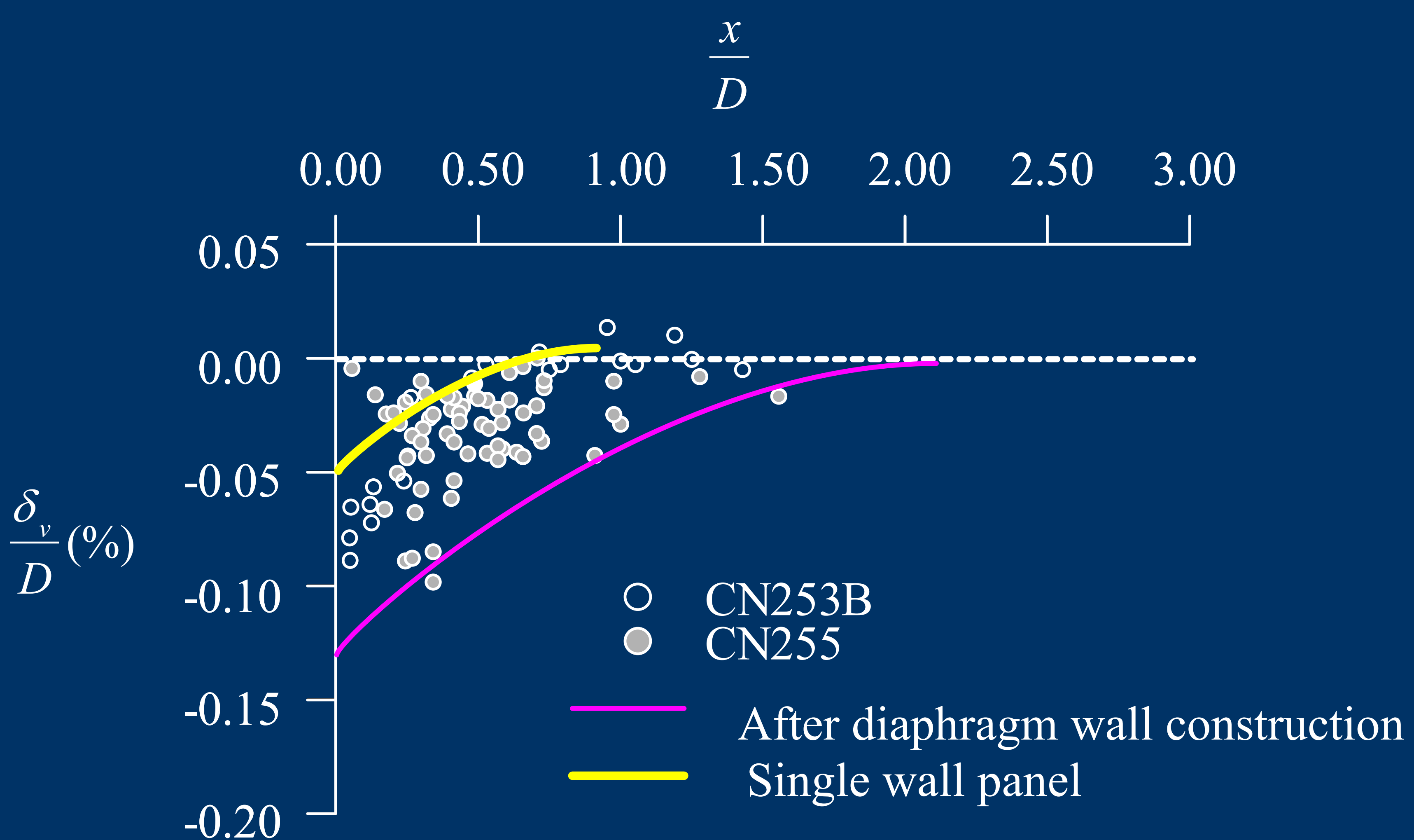
L⑤ = 5.5 m



x (m)
δ (mm)
SIS31 side
SIS32 side
trench excavation is finished
concreting is finished
Panel 1
Panel 2
Panel 3
Panel 4
Panel 5

Single wall panel





x/D
0.00
0.50
1.00
1.50
2.00
2.50
3.00
0.05
0.00
-0.05
-0.10
-0.15
-0.20
δv/D (%)
CN253B
CN255
After diaphragm wall construction
Single wall panel

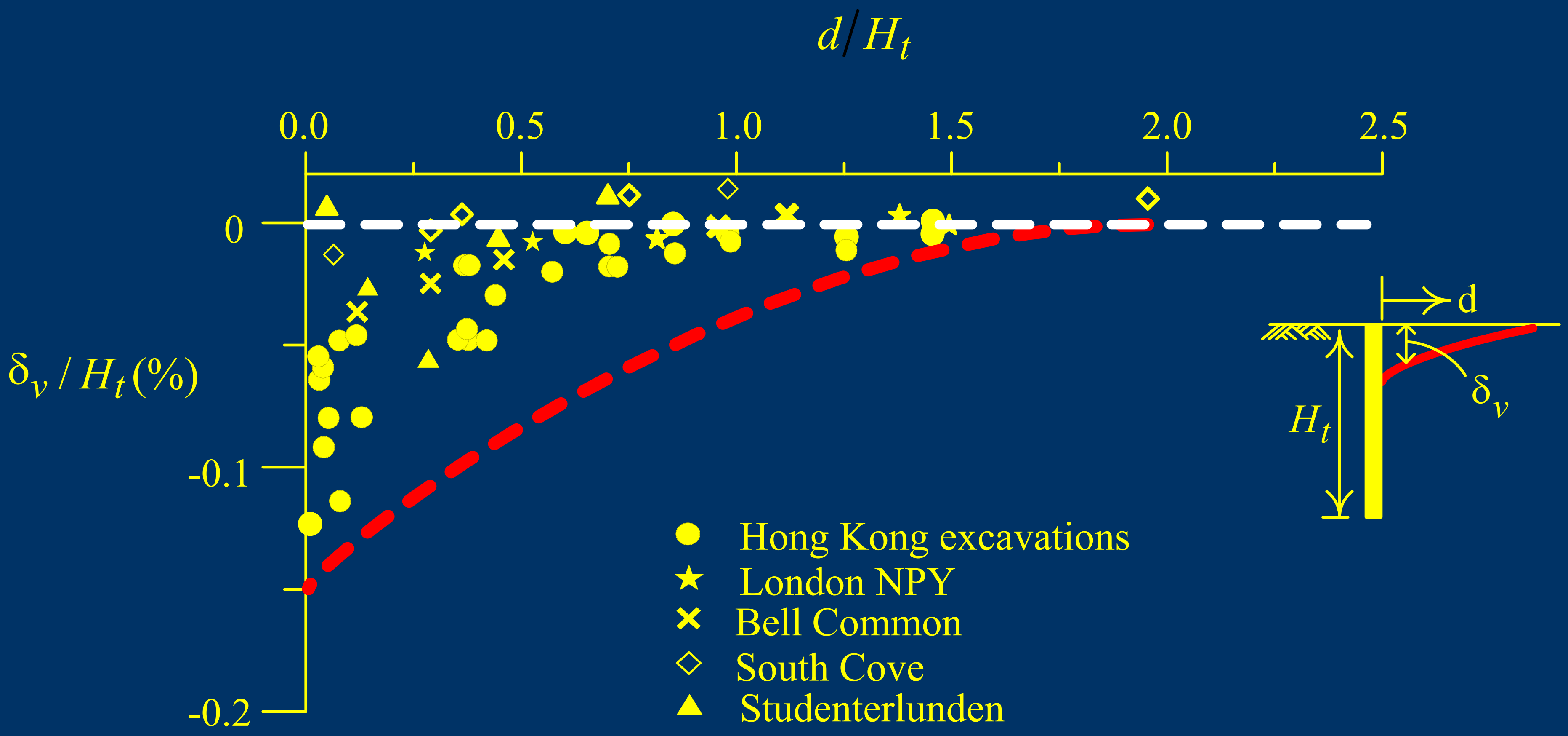


FIGURE 6.1 Envelope of ground surface settlements induced by trench excavations (Clough and O'Rourke, 1990)

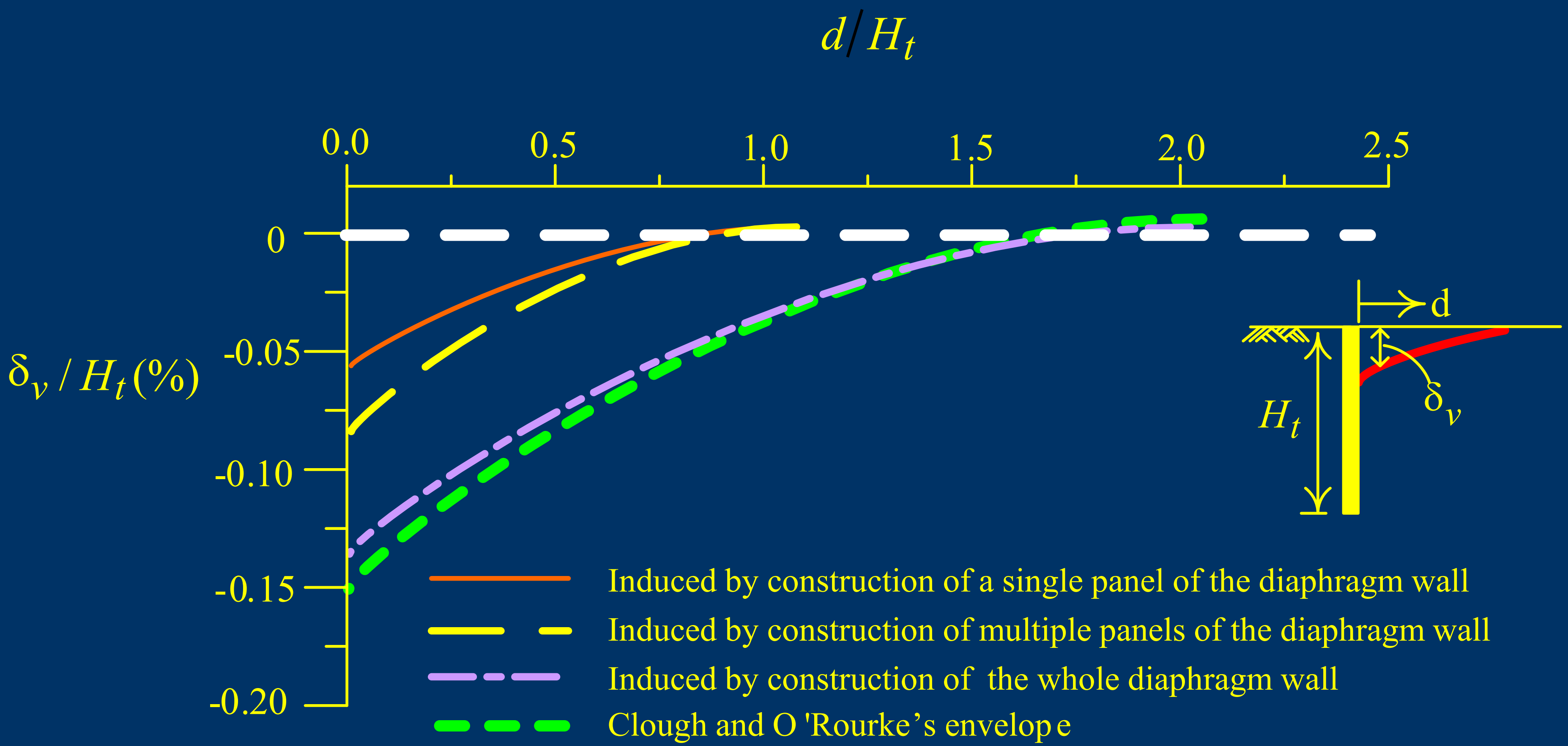


FIGURE 6.2 Envelopes of ground surface settlement induced by the diaphragm wall construction (Ou and Yang, 2000)

6.3 Characteristics of Wall Movement Induced by Excavation

The magnitude of wall movement＝F (unbalance forces, the stiffness of the retaining-strutting system, the excavation stability)

Unbalance forces＝F (excavation width, excavation depth……)

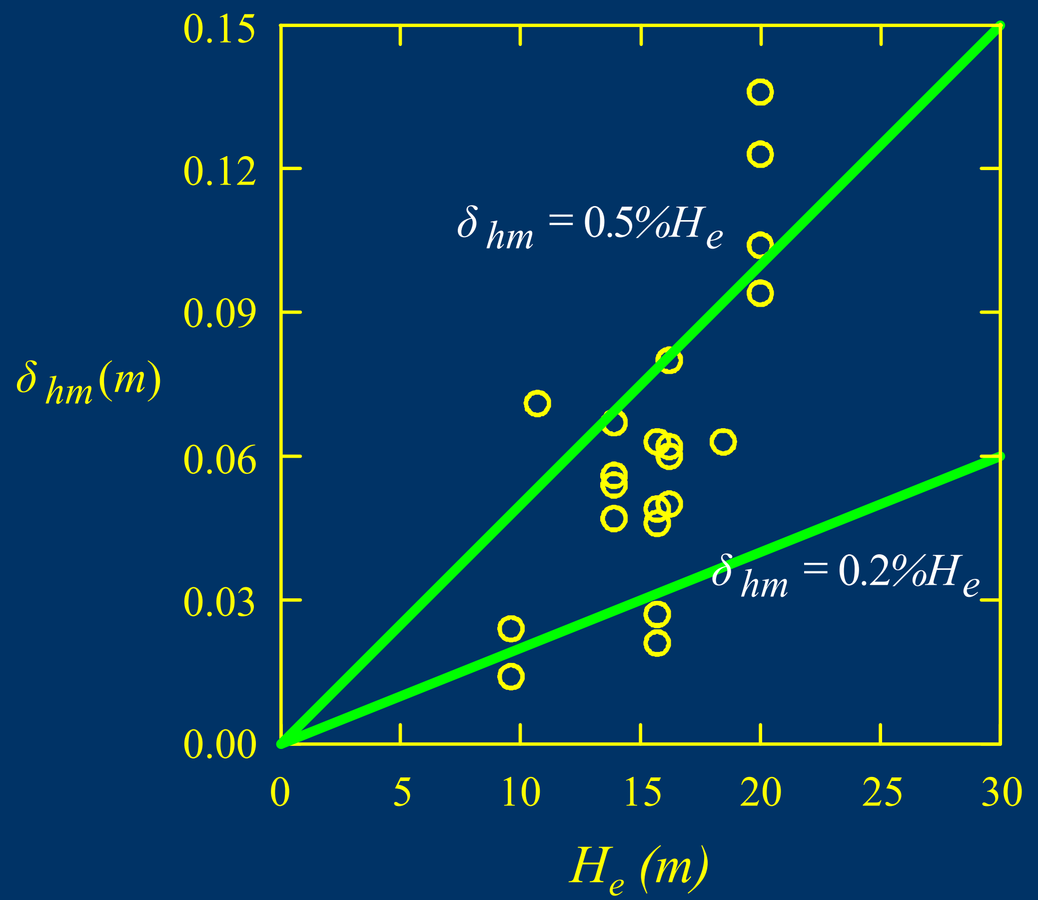
The stiffness of the retaining-strutting system＝F (stiffness of the retaining wall, strut spacing ……)

The excavation stability＝F (wall penetration depth, soil properties)

The relations of these factors with the deformation of a retaining wall can be inferred theoretically. for example, the thicker the retaining wall, the narrower and the shallower the excavation, the stronger the strut stiffness ,the larger the preload, and the greater the safety factor of stability, the smaller the wall deformation.

6.3 Characteristics of Wall Movement Induced by Excavation

6.3.3 Excavation Depth



$$\delta_{hm} = (0.2\% \sim 0.5\%)H_e \qquad (6.1)$$

FIGURE 6.4 Relationships between maximum wall deflections and excavation depths

6.3 Characteristics of Wall Movement Induced by Excavation

6.3.4 Wall Penetration Depth

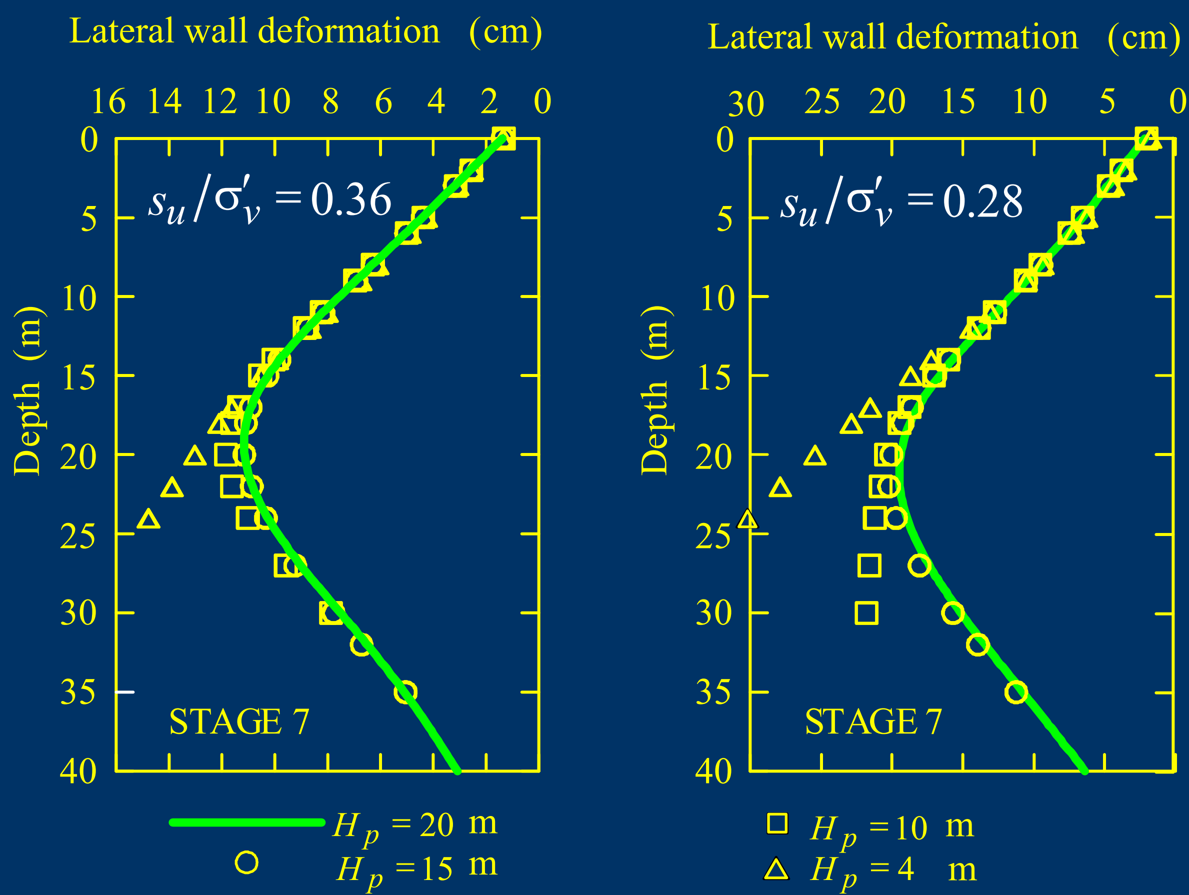


FIGURE 6.5 Relationships between penetration depths and wall deflections

6.3.6 Strut Stiffness

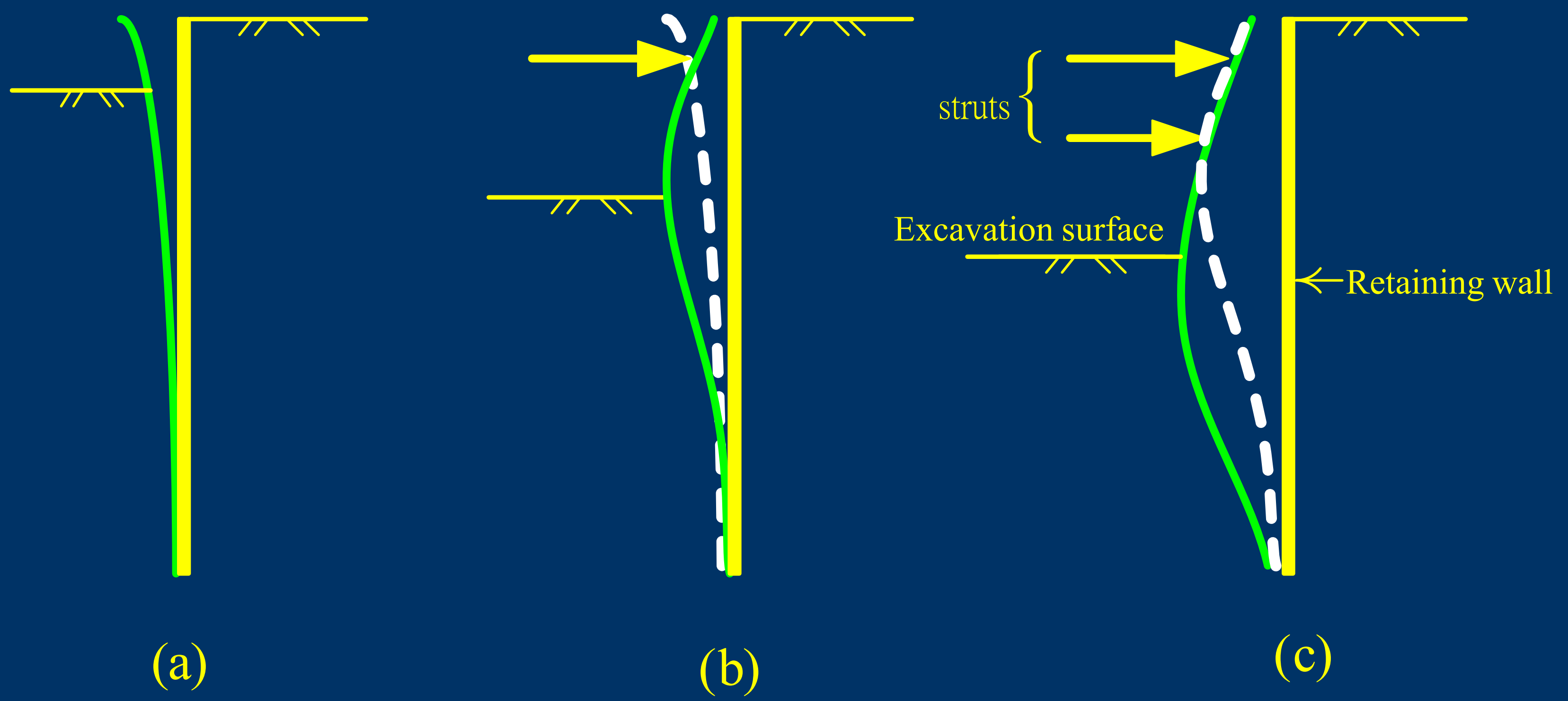


FIGURE 6.6 Relation between the shape of wall deformation and high strut stiffness
(a) first stage of excavation (b) second stage of excavation
(c) third stage of excavation

6.3 Characteristics of Wall Movement Induced by Excavation

6.3.6 Strut Stiffness

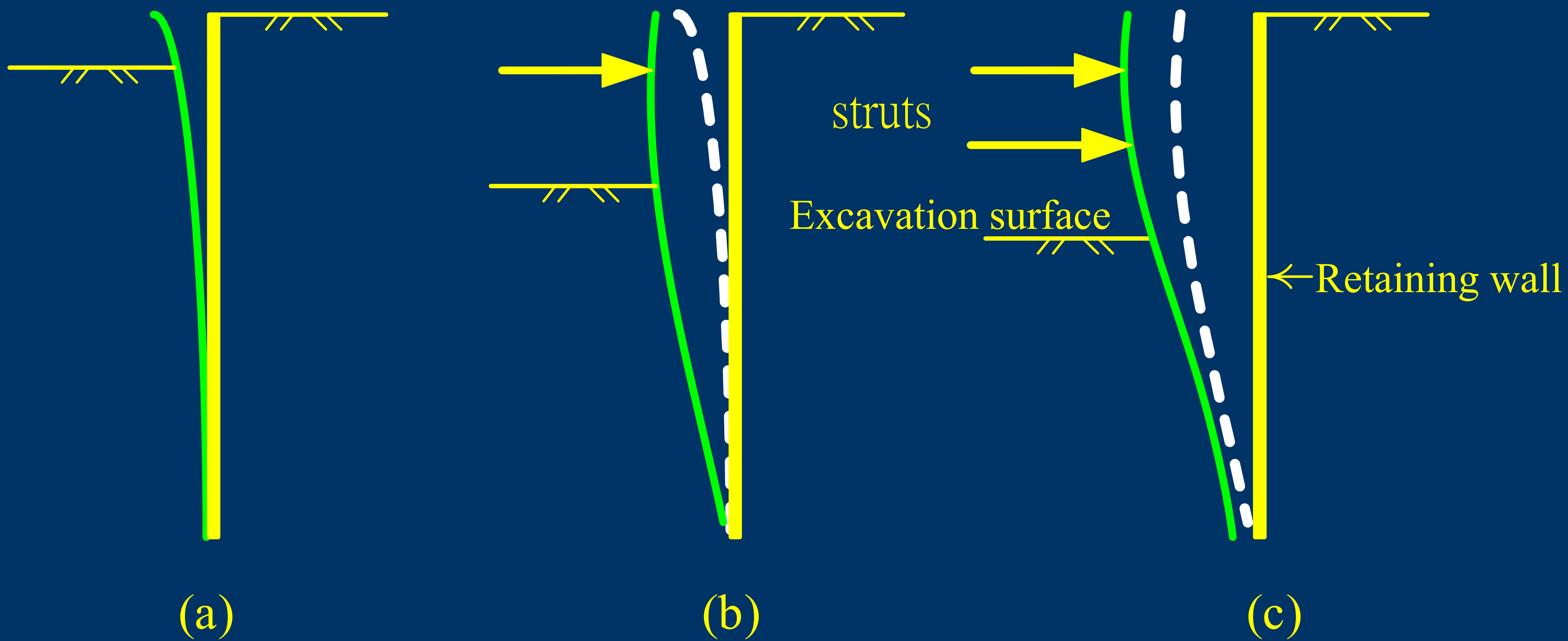
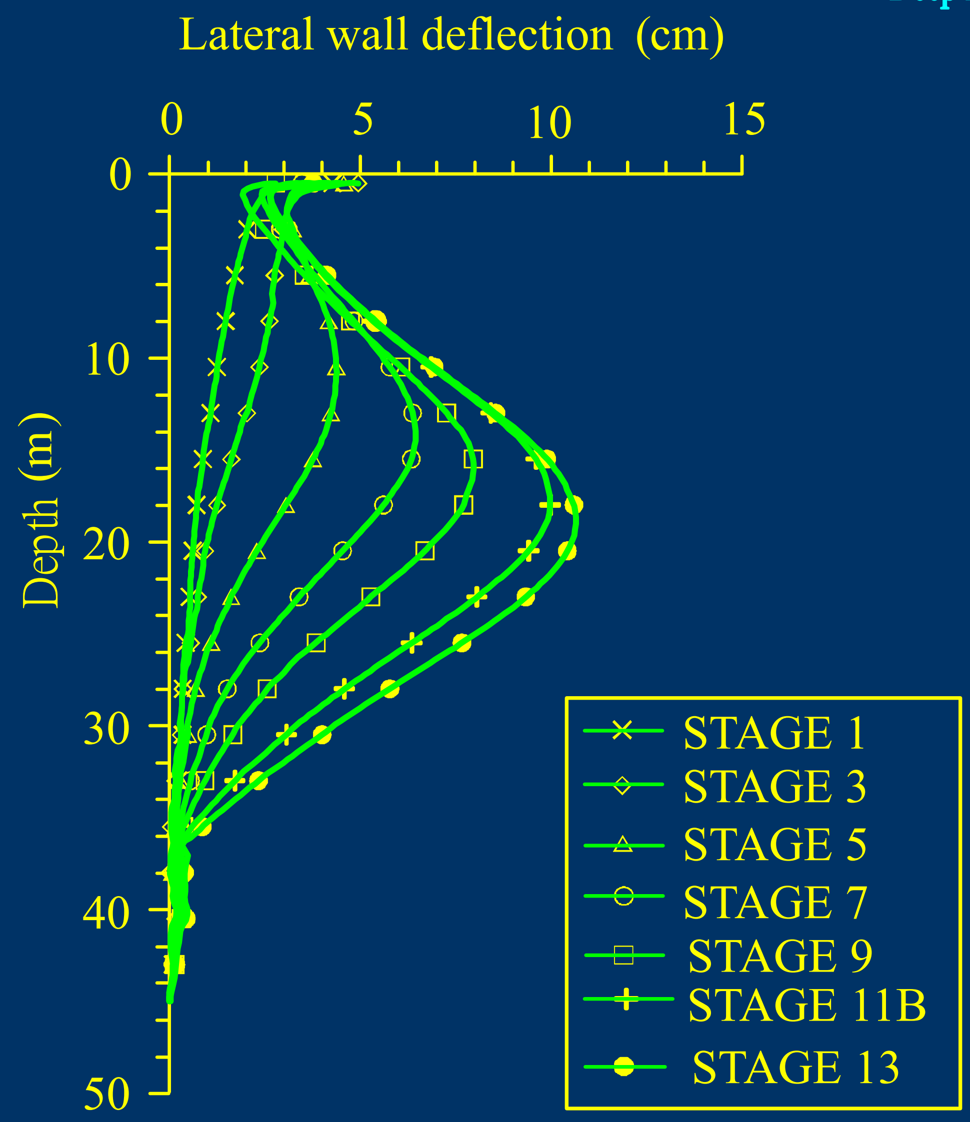


FIGURE 6.7 Relation between the shape of wall deformation and low strut stiffness
(a) first stage of excavation (b) second stage of excavation
(c) third stage of excavation



(a)

FIGURE 6.8 Lateral wall deflections and ground surface settlements of the TNEC excavation
(a) lateral wall deflections

6.3.8 Strut Preload

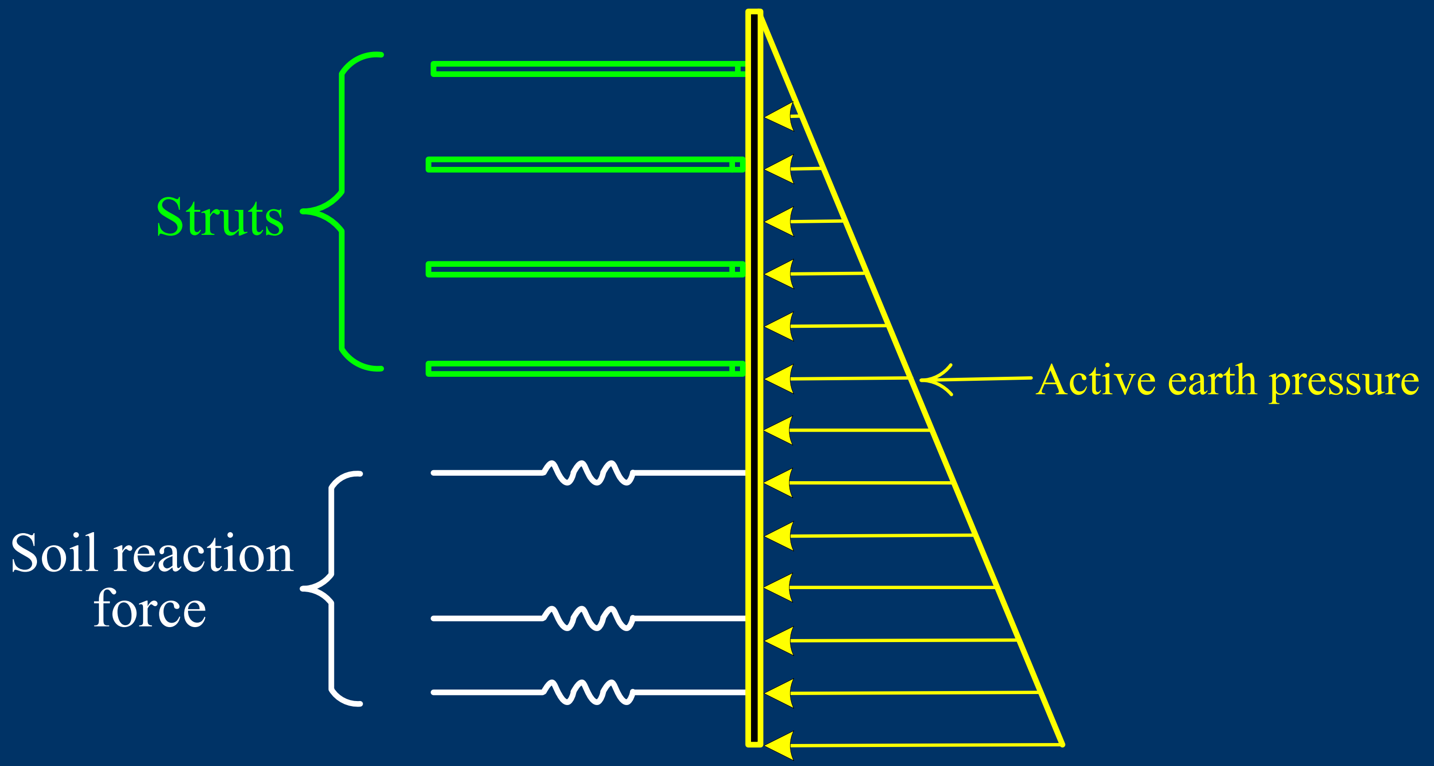


FIGURE 6.9 Relationship between earth pressures, strut loads, and reactions of soil

6.4 Characteristics of Ground Movement Induced by Excavation

6.4.1 Shapes and Types of ground Surface Settlement

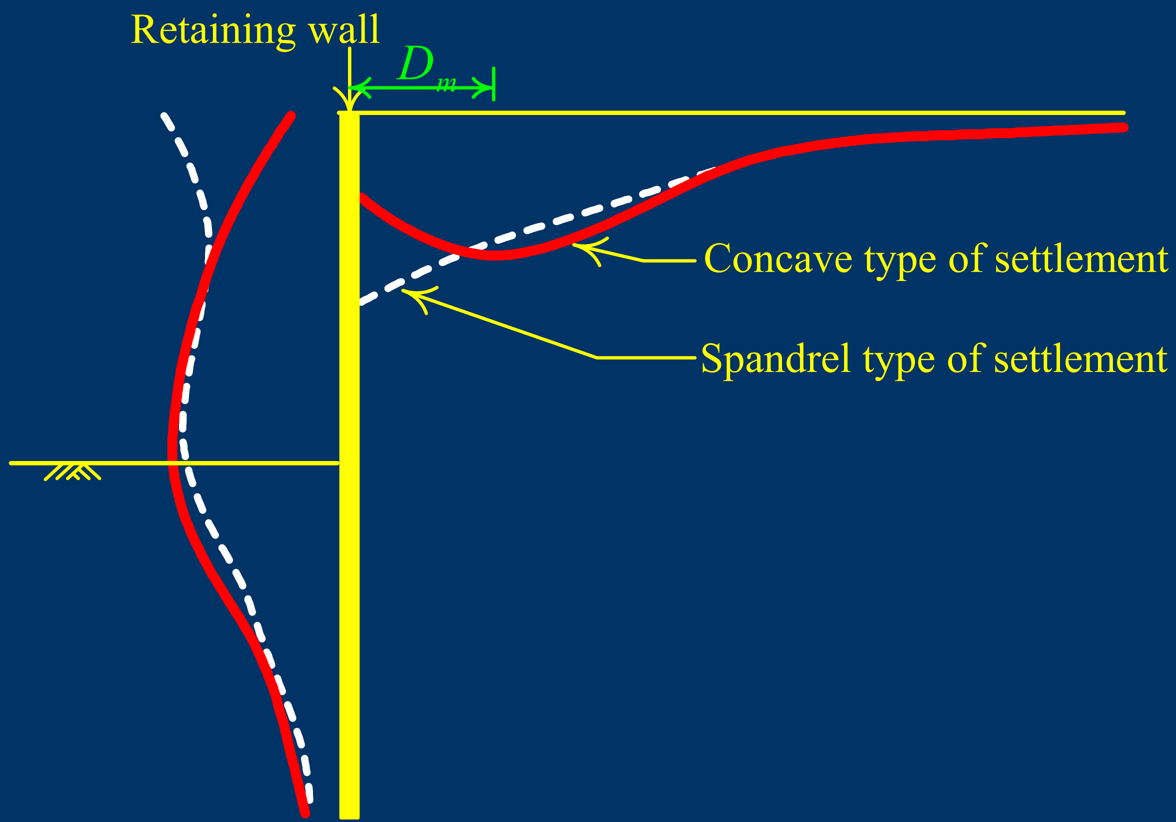


FIGURE 6.10 Types of ground surface settlements

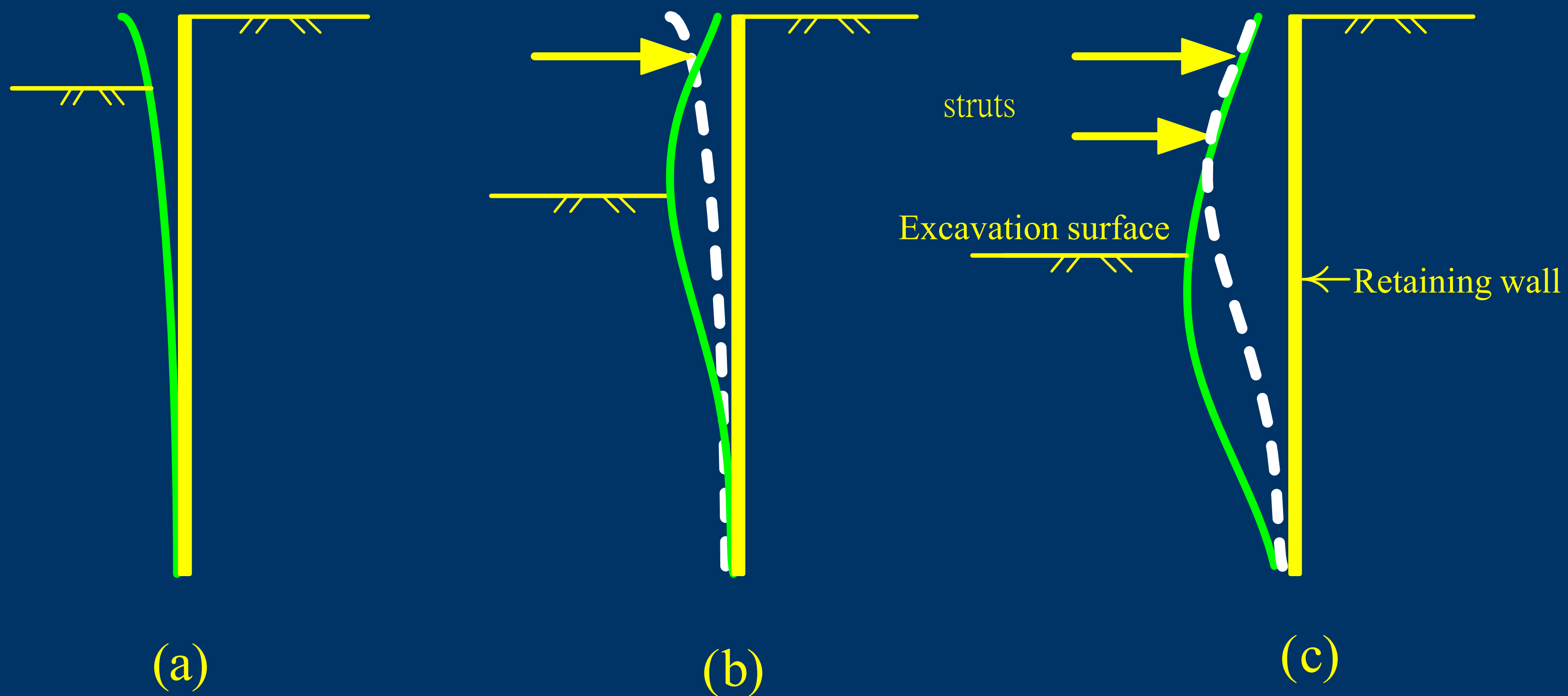


FIGURE 6.6 Relation between the shape of wall deformation and high strut stiffness
(a) first stage of excavation
(b) second stage of excavation
(c) third stage of excavation

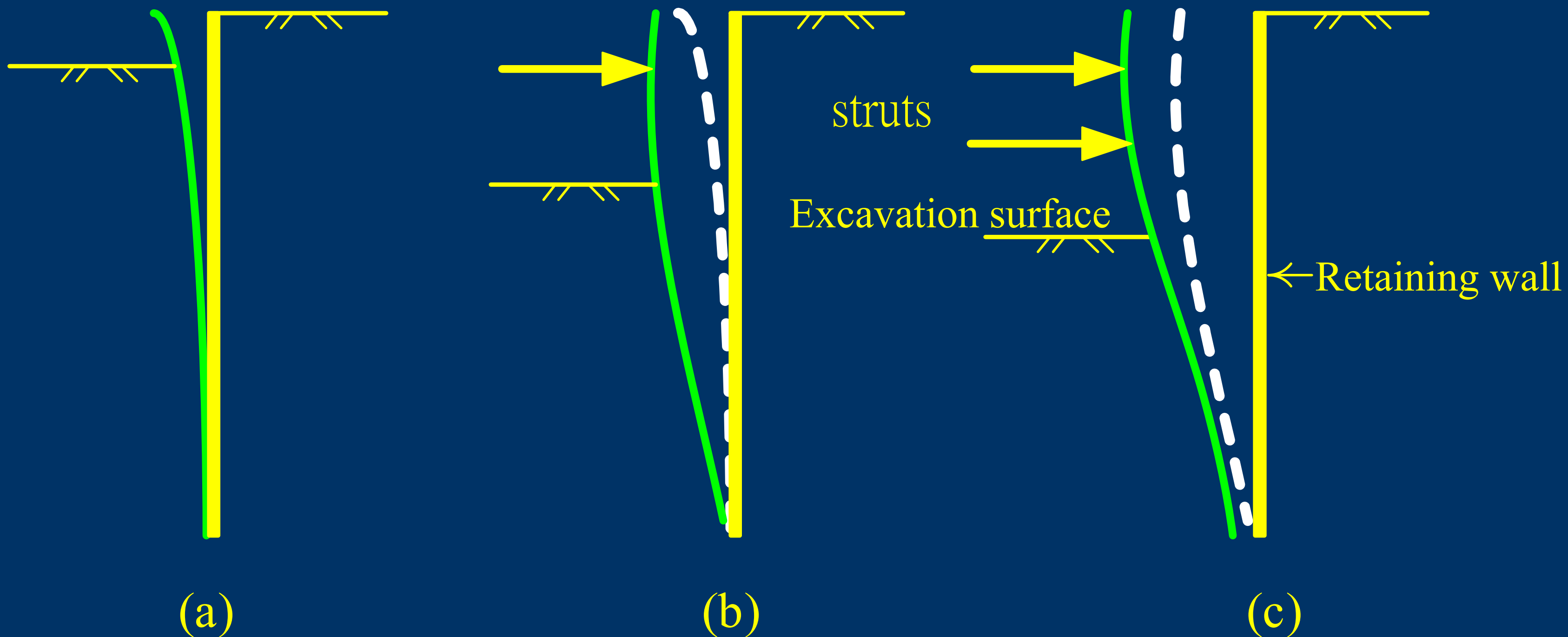
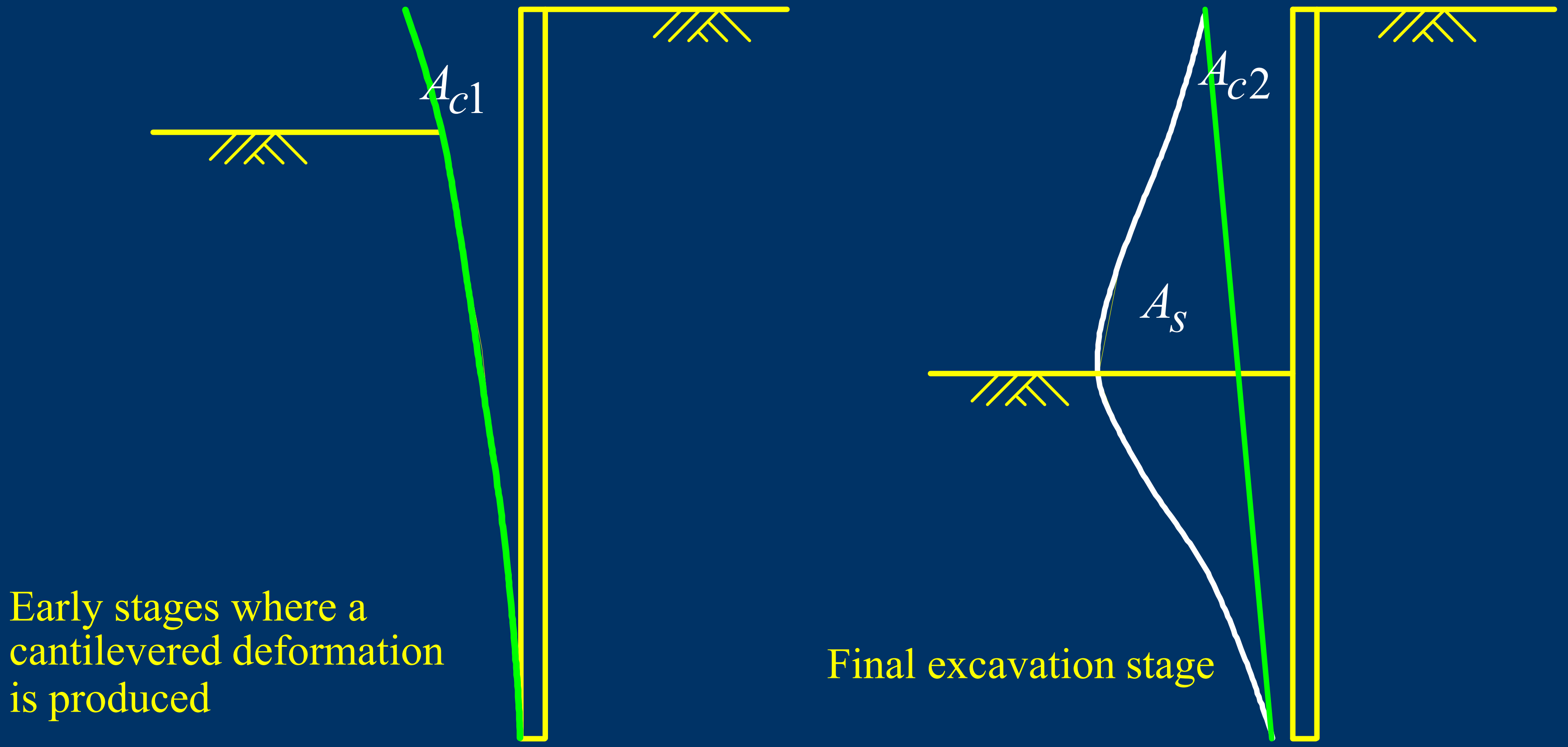


FIGURE 6.7 Relation between the shape of wall deformation and low strut stiffness
(a) first stage of excavation
(b) second stage of excavation
(c) third stage of excavation



$$A_c = \max(A_{c1}, A_{c2})$$

FIGURE 6.11 Definitions of the area of the deep inward part and the cantilevered part of wall deformation

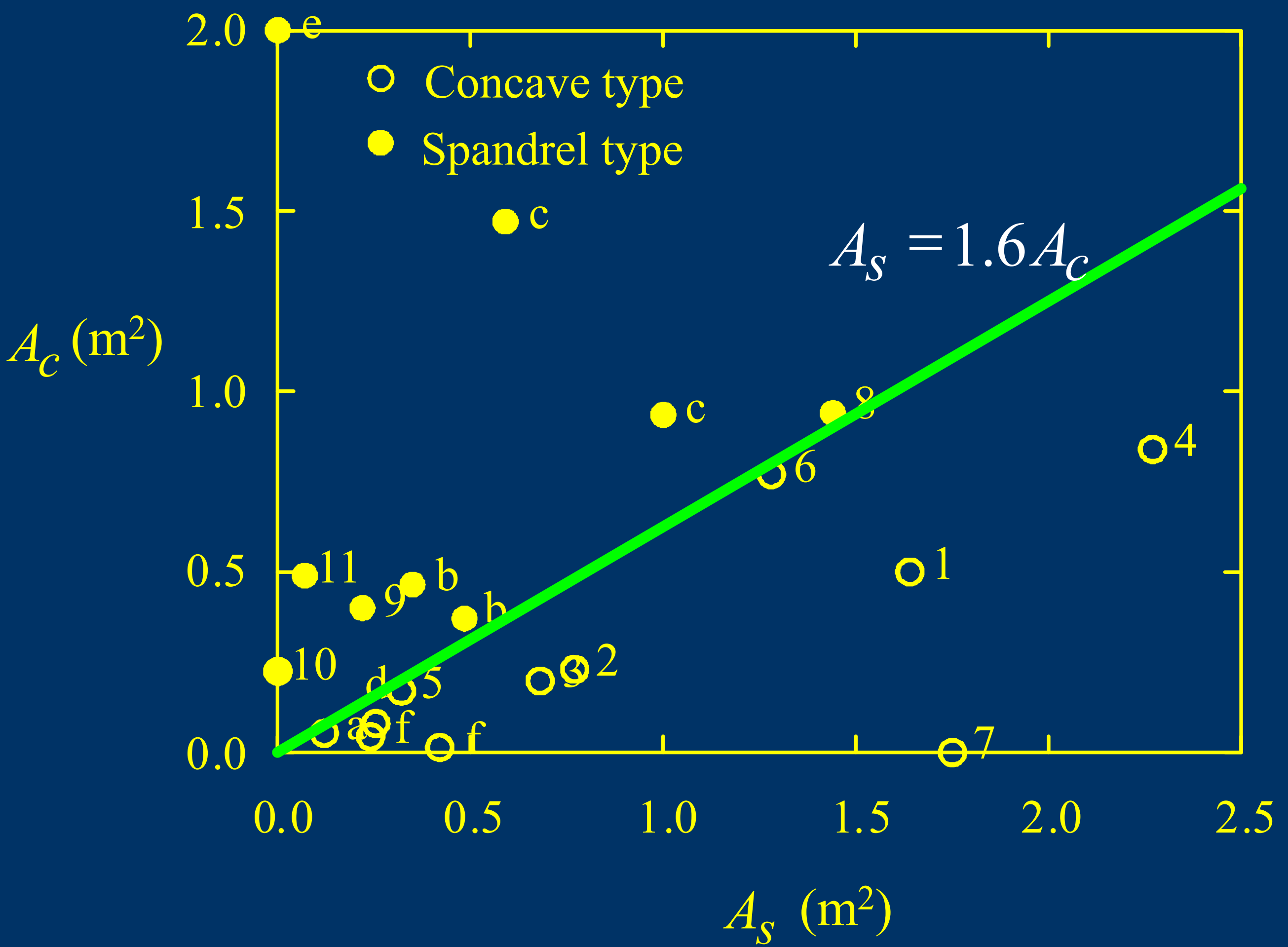


FIGURE 6.12 Relationship between the type of ground surface settlement and shapes of lateral wall deflection (English alphabets labels refer to excavation cases from other countries while Arabic numbers labels to cases from Taiwan)

6.4 Characteristics of Ground Movement Induced by Excavation

6.4.2 Influence Zones of Settlement

The influence zones includes：

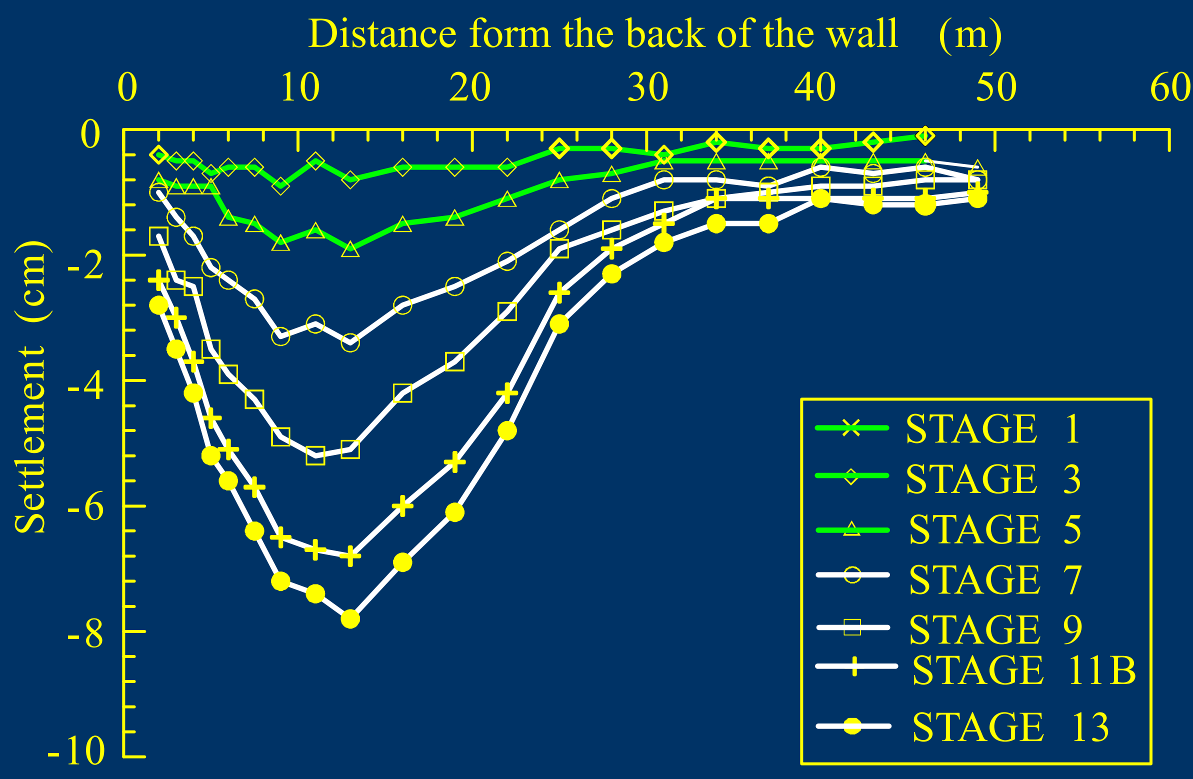
Primary Influence Zone, *PIZ*—

Secondary Influence Zone, *SIZ*—

6.4 Characteristics of Ground Movement Induced by Excavation

6.4.2 Influence Zones of Settlement

The characteristics of influence zone (take the TNEC excavation for example)

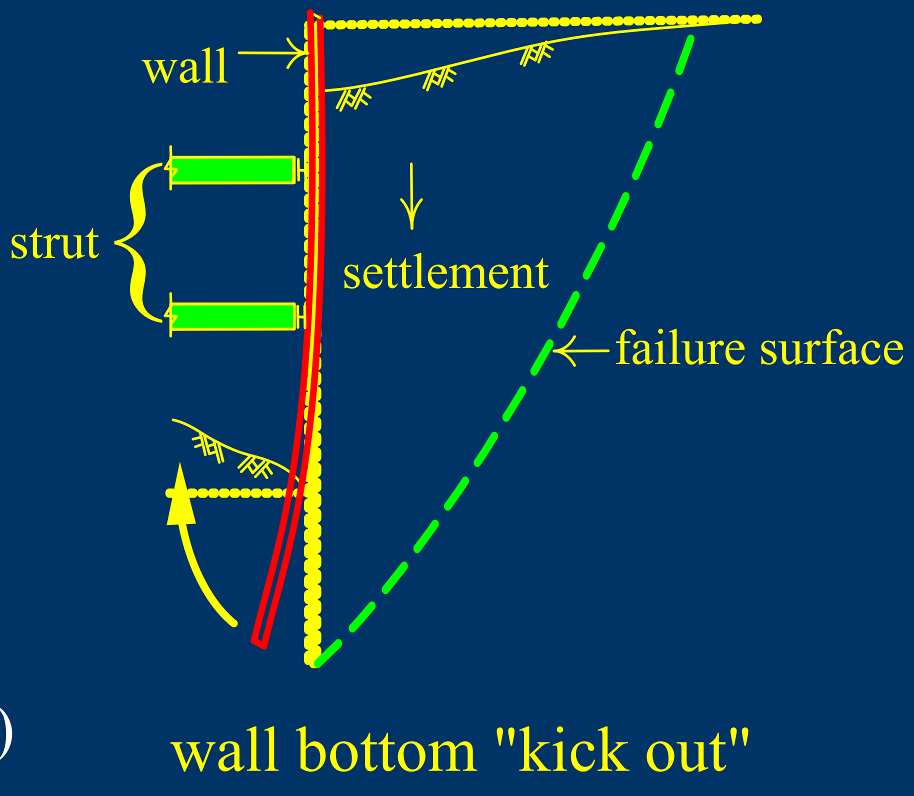


(b)

FIGURE 6.8 Lateral wall deflections and ground surface settlements of the TNEC excavation (b) ground surface settlements

6.4 Characteristics of Ground Movement Induced by Excavation

6.4.2 Influence Zones of Settlement



(a)

Consider from push-in:

$$PIZ_1 = \min(2H_e, H_g) \qquad (6.3)$$

FIGURE 5.1 Overall shear failure modes (a) push-in

6.4 Characteristics of Ground Movement Induced by Excavation

6.4.2 Influence Zones of Settlement

Consider from basal heave：

$$PIZ_2 = \min(H_f, B) \quad (6.4)$$

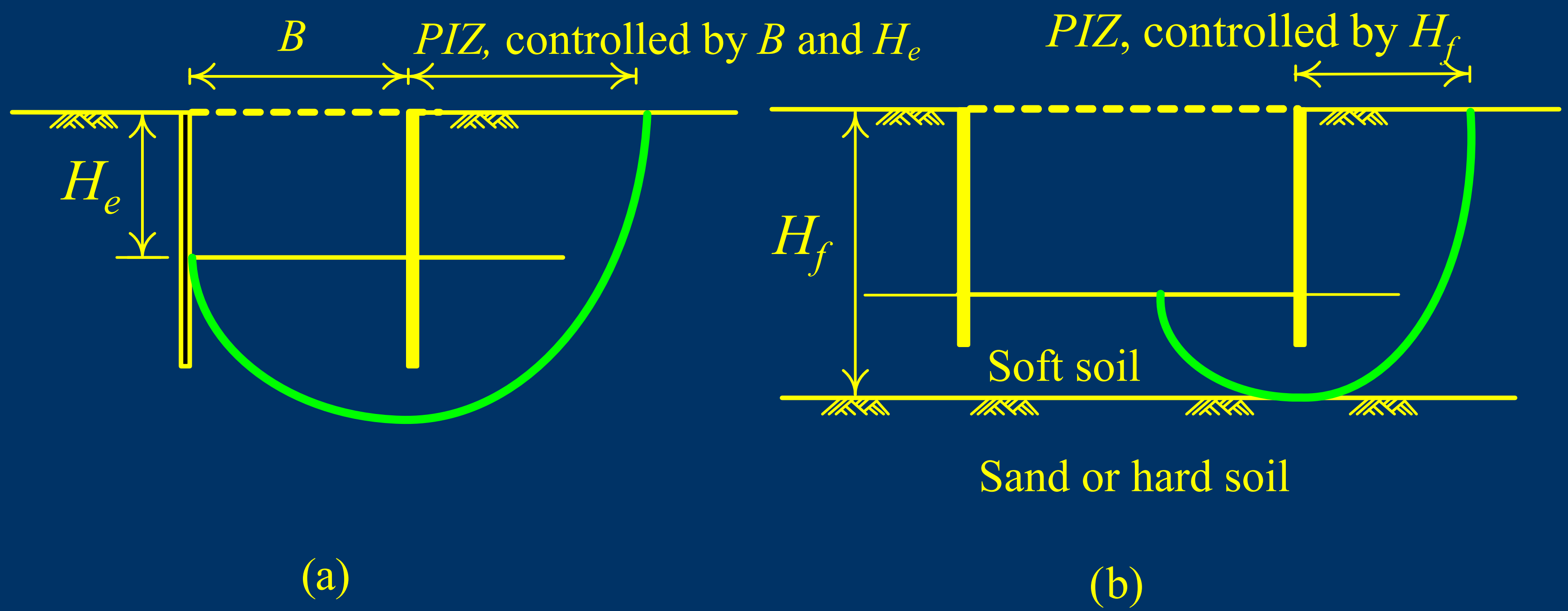


FIGURE 6.13 Primary influence zone produced by potential basal heave failure surfaces

The primary influence zone is the larger of PIZ_1 and PIZ_2 :

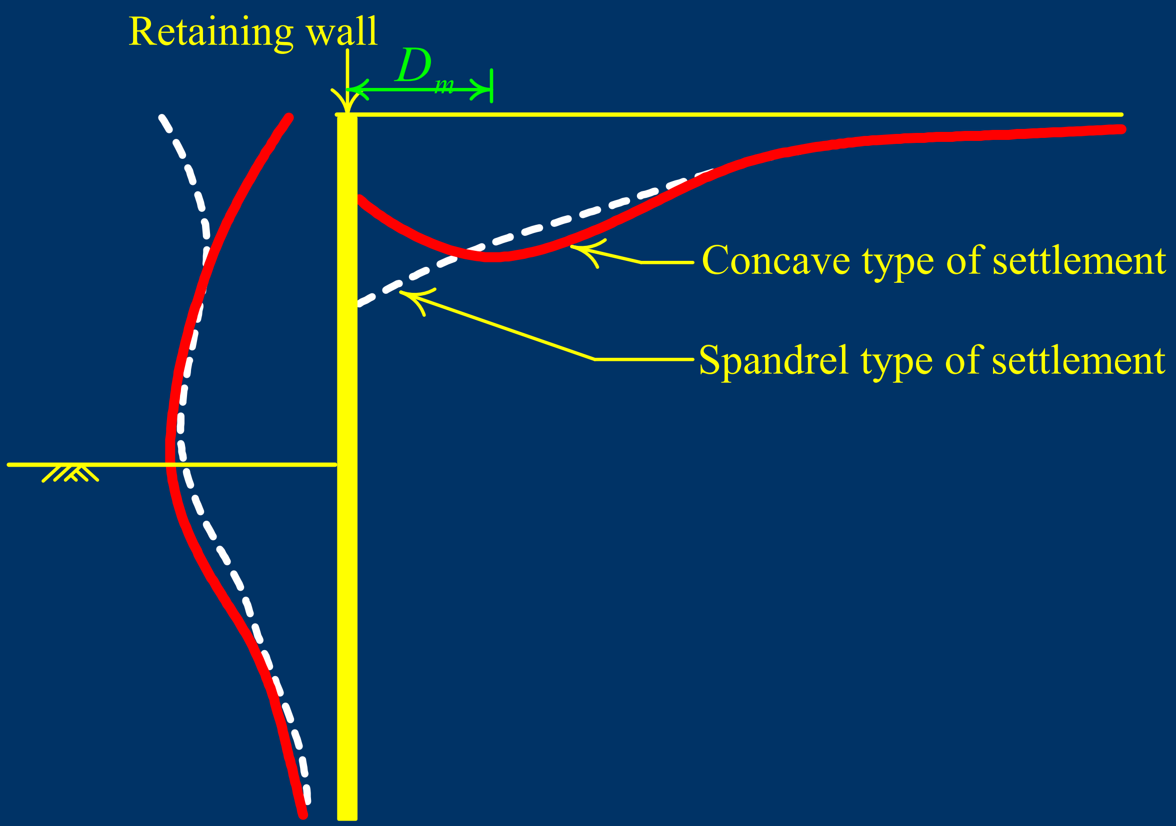
$$PIZ = \max(PIZ_1, PIZ_2) \tag{6.5}$$

6.4 Characteristics of Ground Movement Induced by Excavation

6.4.3 Locations of the Maximum Settlement

The location of the maximum settlement of the cantilevered type：

$$D_m = PIZ/3$$



6.4 Characteristics of Ground Movement Induced by Excavation

6.4.4 Magnitude of the Maximum Settlement

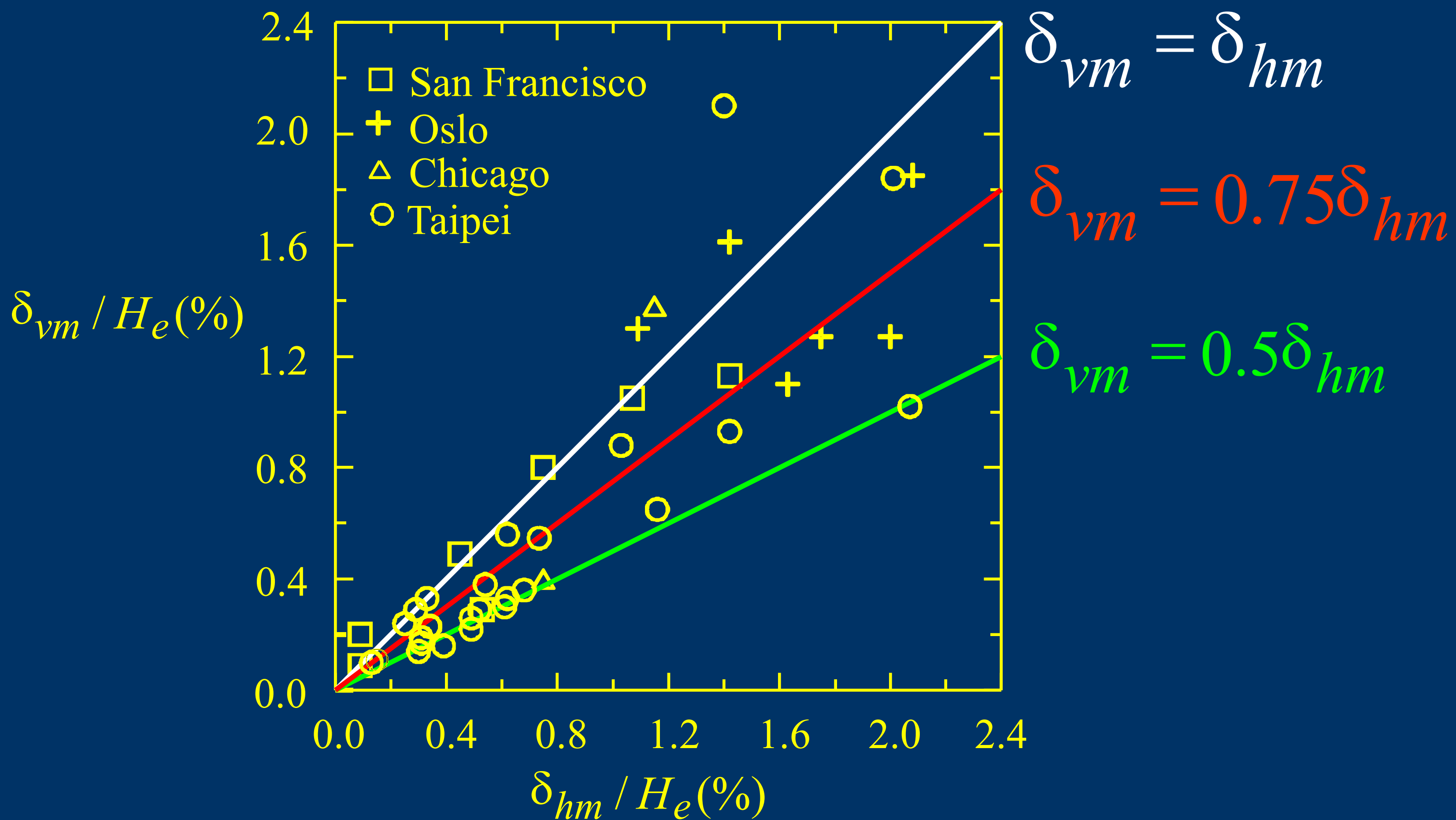


FIGURE 6.14 Maximum ground surface settlement and lateral wall deflection

6.4 Characteristics of Ground Movement Induced by Excavation

6.4.5 Relationships between Ground Surface Settlements and Soil Movements

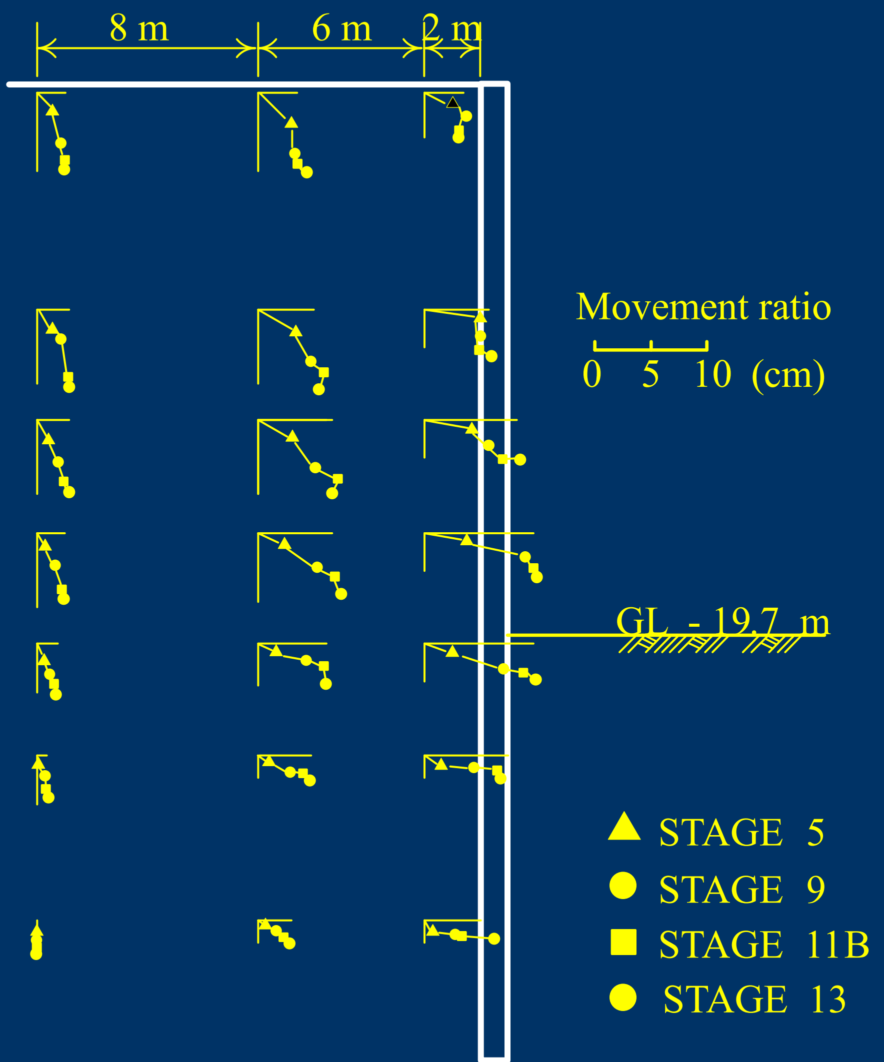


FIGURE 6.15 Displacement vectors at points in soil outside of the TNEC excavation zone

6.6 Time Dependent Movement

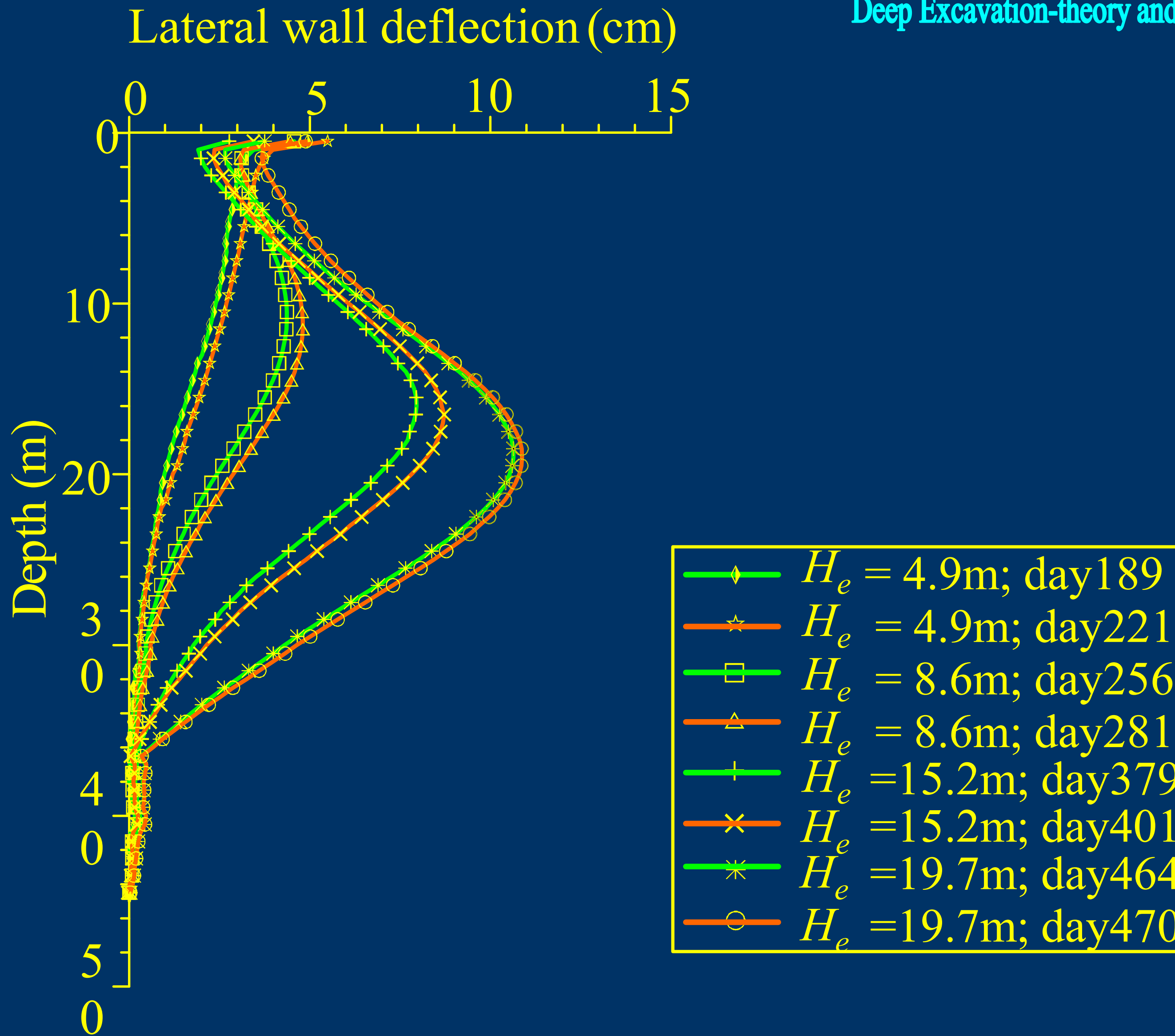
Bottom-up excavation method：about 1~2 weeks.

Top-down construction method：cast floor slabs, each stage took a waiting period of 30~60 days (TNEC).

During the waiting periods, the lateral displacement of the retaining wall, the ground surface settlement, and the movement of the excavation bottom all increased.

Consolidation？

Creep？



(a)

FIGURE 6.20 Time-dependent lateral wall deflection and ground surface settlement of the TNEC excavation (a) wall deflection

Mana and Clough's study point out that the deflection rate of walls about 0.3～30mm/day

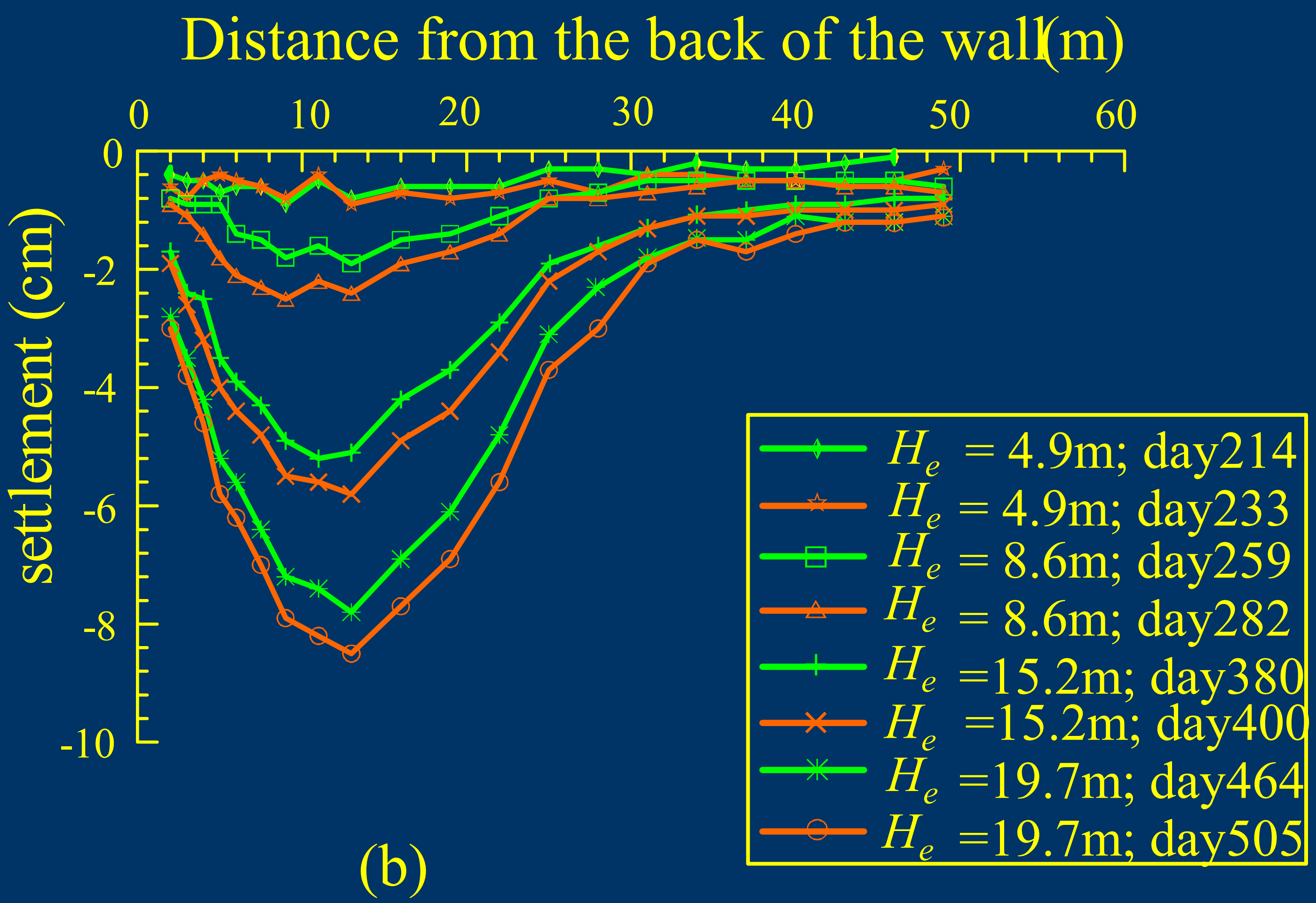
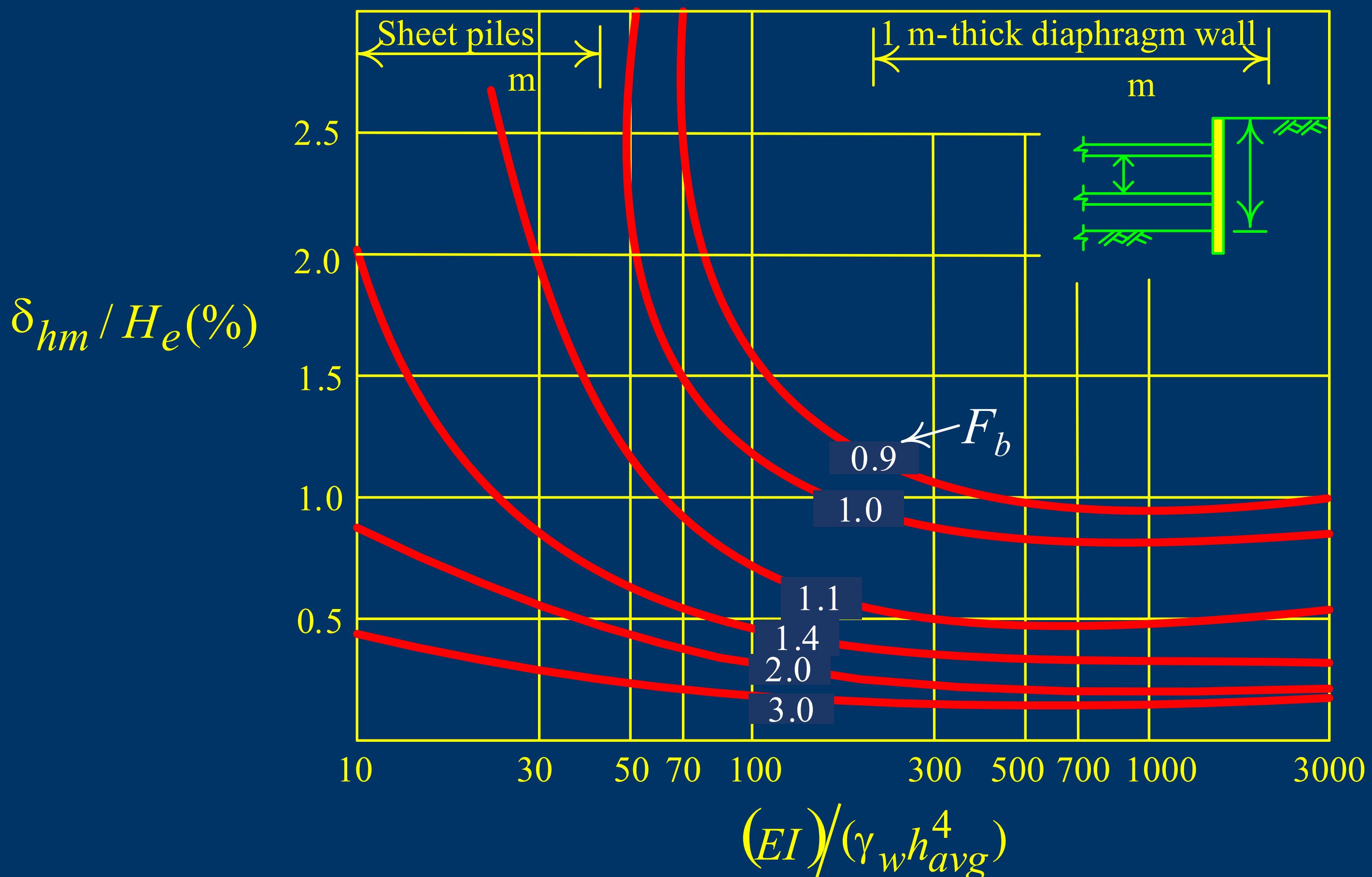


FIGURE 6.20 Time-dependent lateral wall deflection and ground surface settlement of the TNEC excavation
(b) ground surface settlement

6.7 Analysis of Wall Deformations Induced by Excavation



$$\delta_{hm} = (0.2\% \sim 0.5\%) H_e$$

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

6.8 Analysis of Ground Surface Settlements Induced by Excavation

6.8.1 Peck's Method

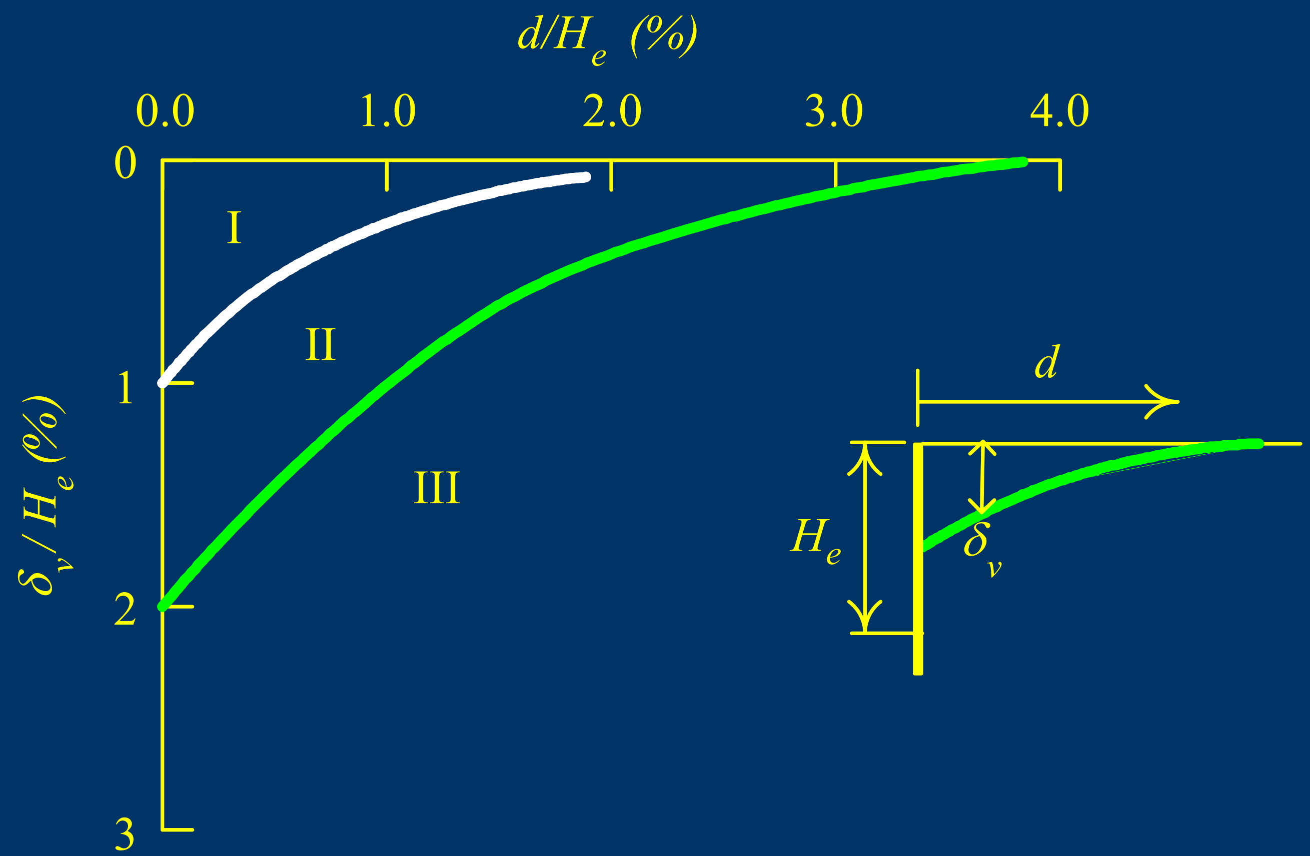
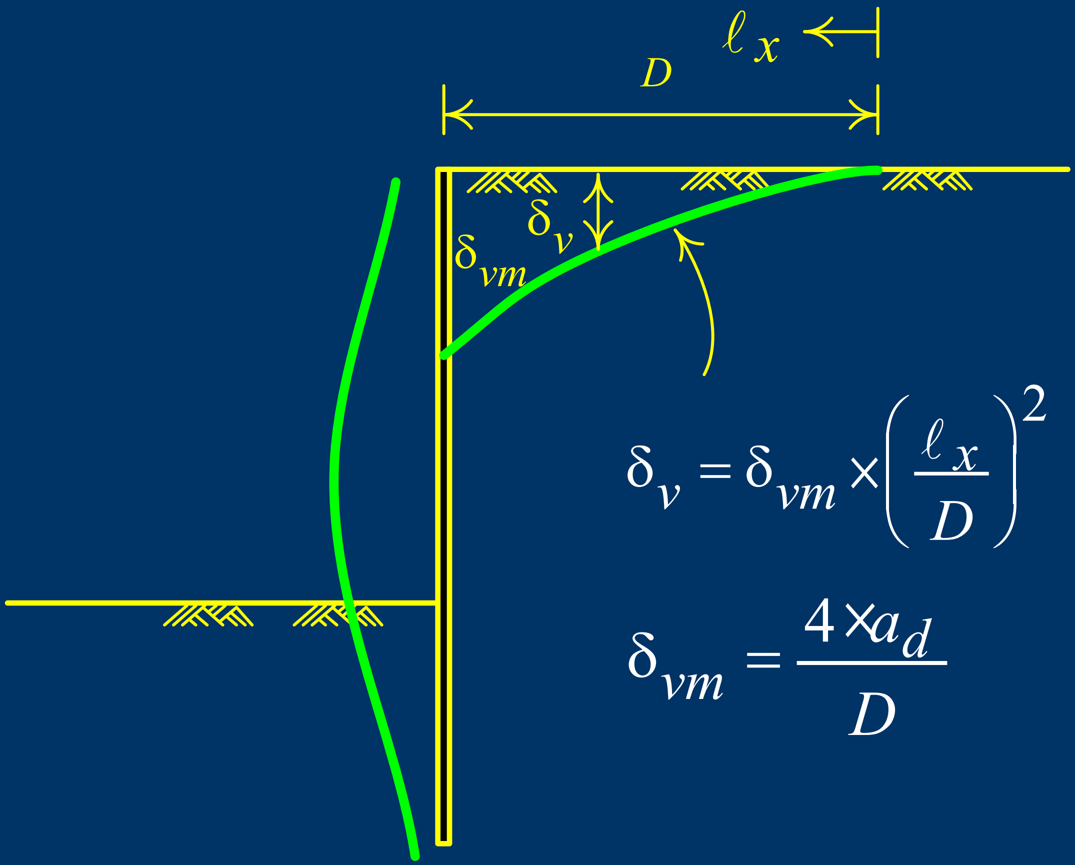


FIGURE 6.23 Peck's method (1969) for estimating ground surface settlement

6.8 Analysis of Ground Surface Settlements Induced by Excavation

6.8.2 Bowles' Method



$$\delta_v = \delta_{vm} \times \left(\frac{\ell_x}{D} \right)^2$$

$$\delta_{vm} = \frac{4 \times a_d}{D}$$

$$D = (H_e + H_d)\tan(45^\circ - \frac{\phi}{2})$$

Theoretically, excavating in undrained saturated soft soils, the area of lateral wall displacement should be about that of ground surface settlement.

δ_{vm} should equal $3a_d / D$

FIGURE 6.24 Bowles' method for estimating ground surface settlement

6.8 Analysis of Ground Surface Settlements Induced by Excavation

6.8.3 Clough and O'Rourke's Method

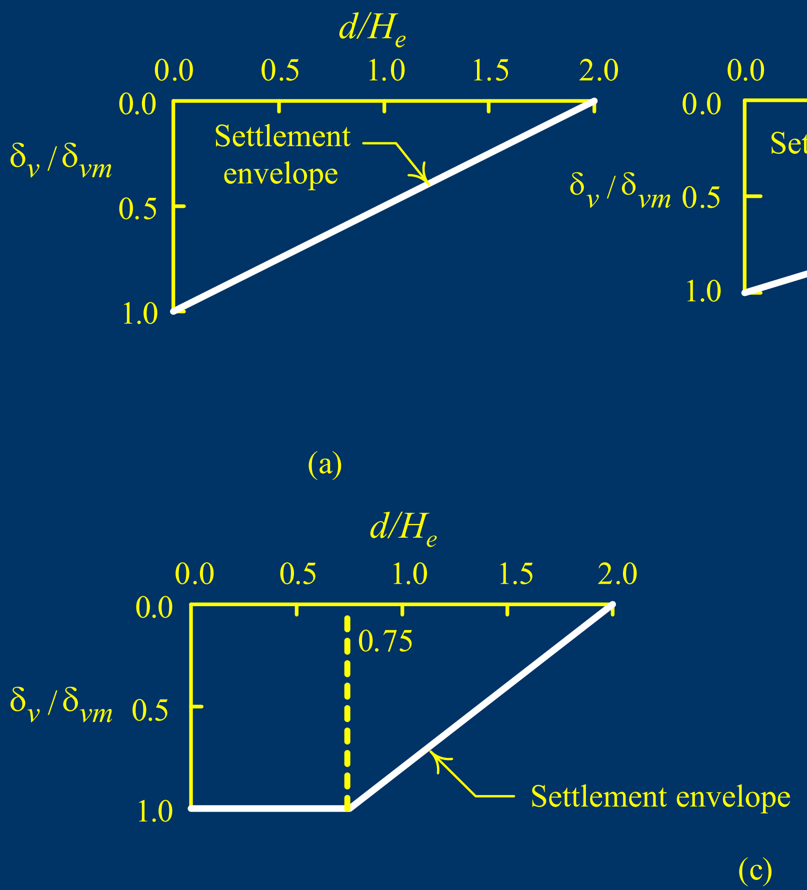


FIG. 6.25 Clough and O'Rourke's method (1990) for estimating ground surface settlement (a) sand (b) stiff to very stiff clay (c) soft to medium soft clay

6.8 Analysis of Ground Surface Settlements Induced by Excavation

6.8.4 Ou and Hsieh's Method

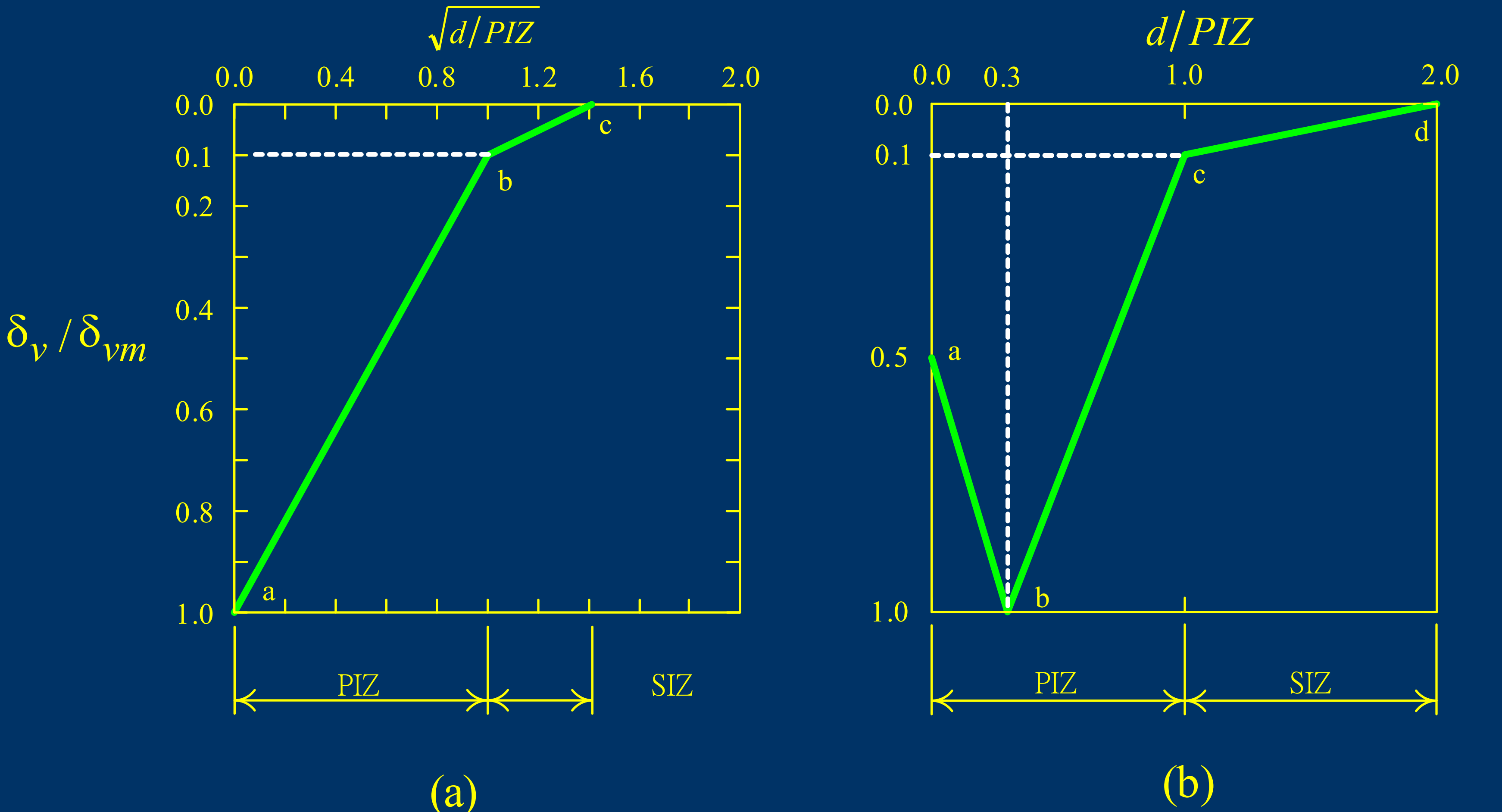


FIGURE 6.26 Ou and Hsieh's method (2000) for estimating ground surface settlement

Predicted procedure：

1. Estimate the value of δ_{hm}

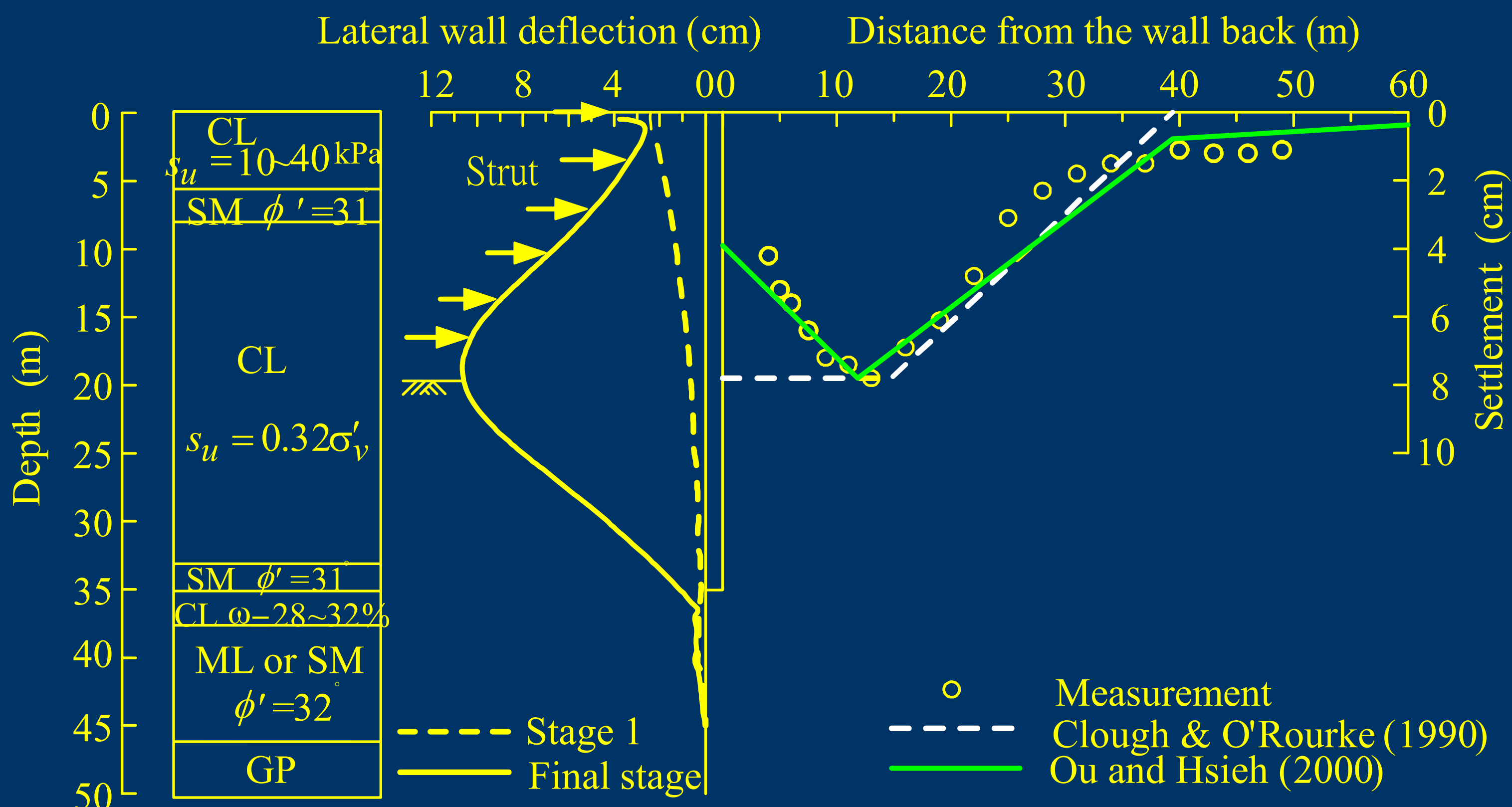
2. Determine the type of ground surface settlement

3. Estimate the value of δ_{vm}

4. Compute various settlements occurring in different positions in back of the wall

6.8 Analysis of Ground Surface Settlements Induced by Excavation

6.8.5 Comparison of the Various Analysis Methods

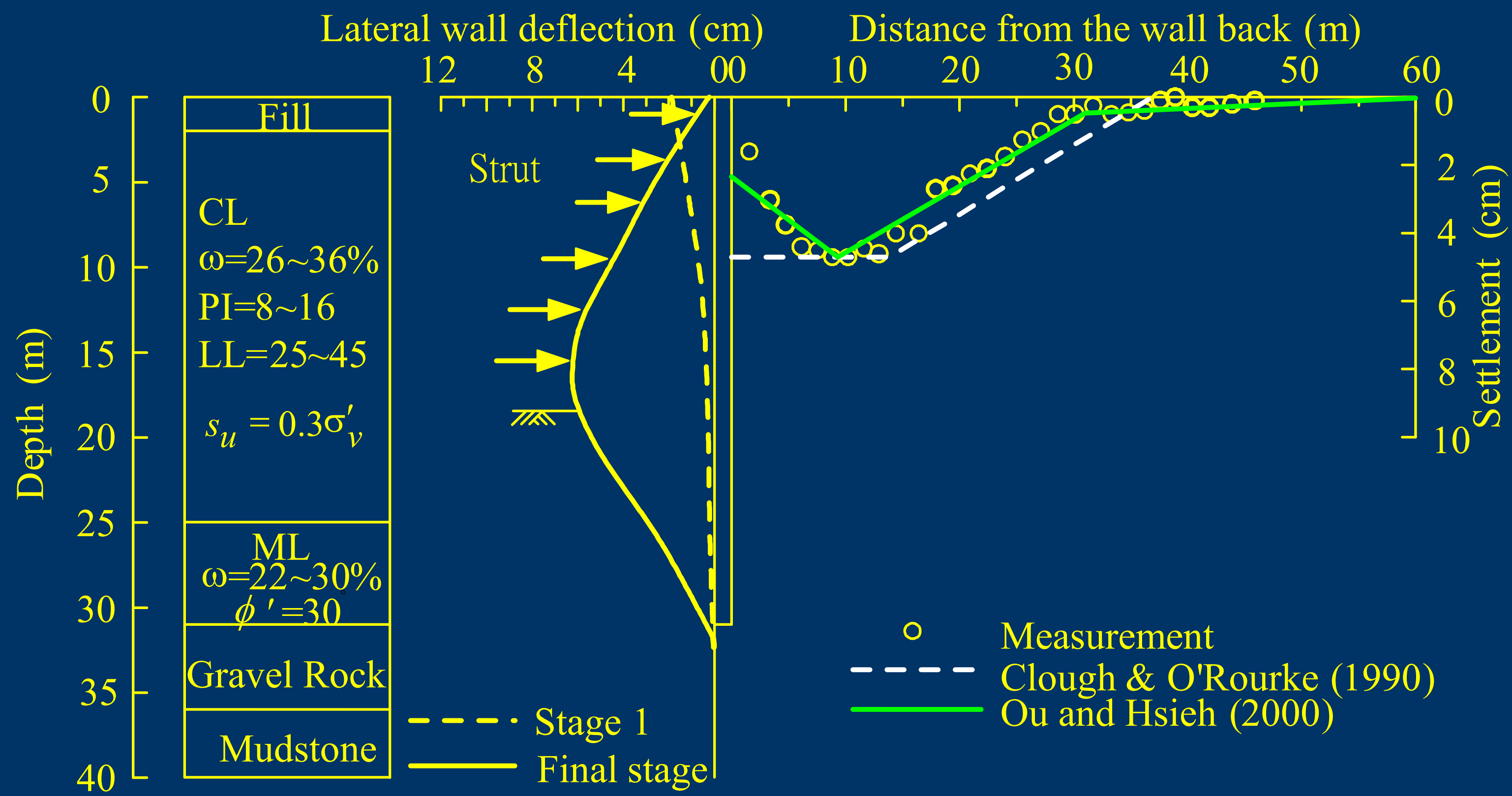


(a)

FIGURE 6.27 Comparisons of predicted and observed ground surface settlements
(a) Case I: the excavation of TNEC

6.8 Analysis of Ground Surface Settlements Induced by Excavation

6.8.5 Comparison of the Various Analysis Methods

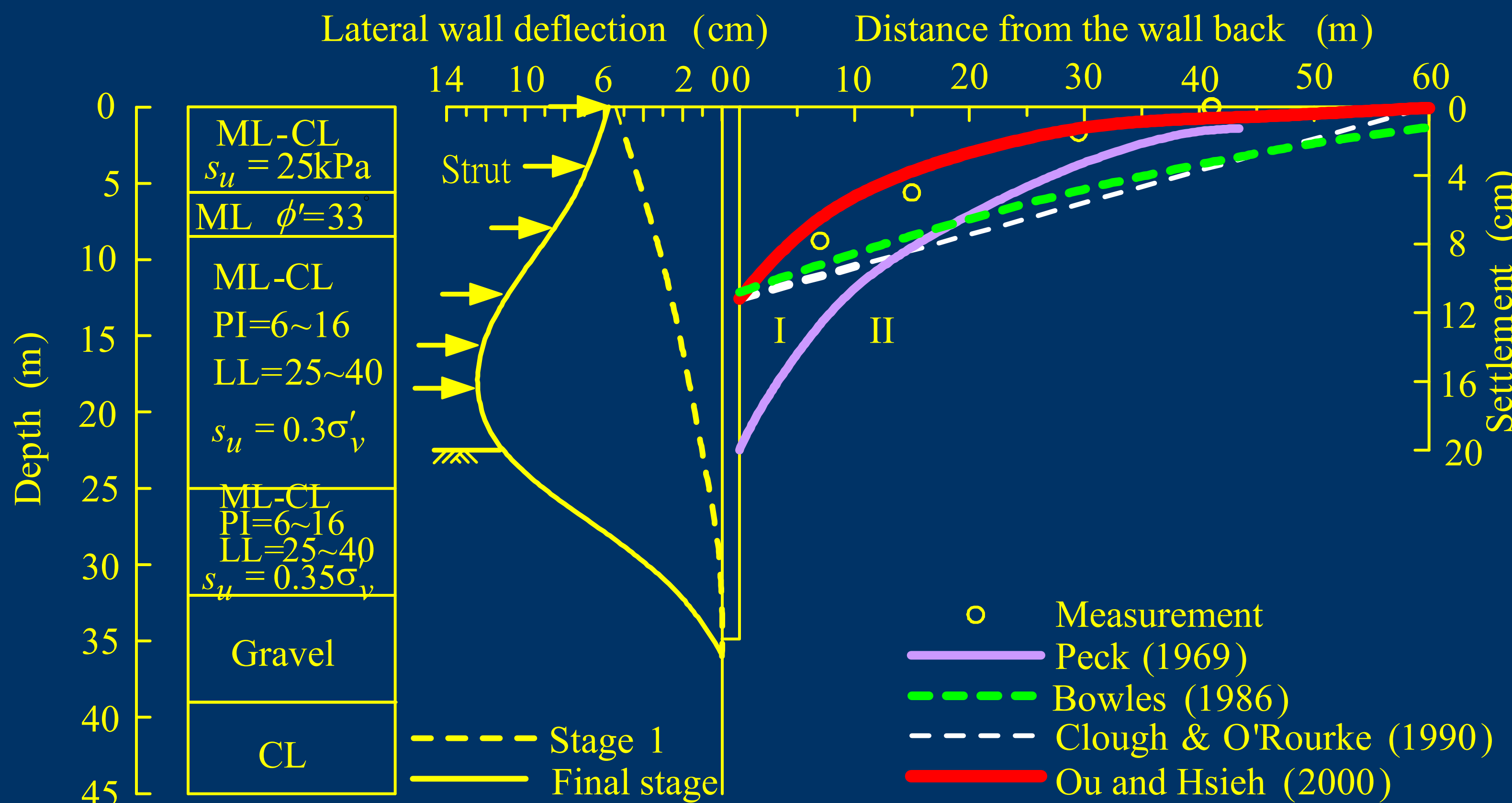


(b)

FIGURE 6.27 Comparisons of predicted and observed ground surface settlements
(b) Case II: the excavation of a building

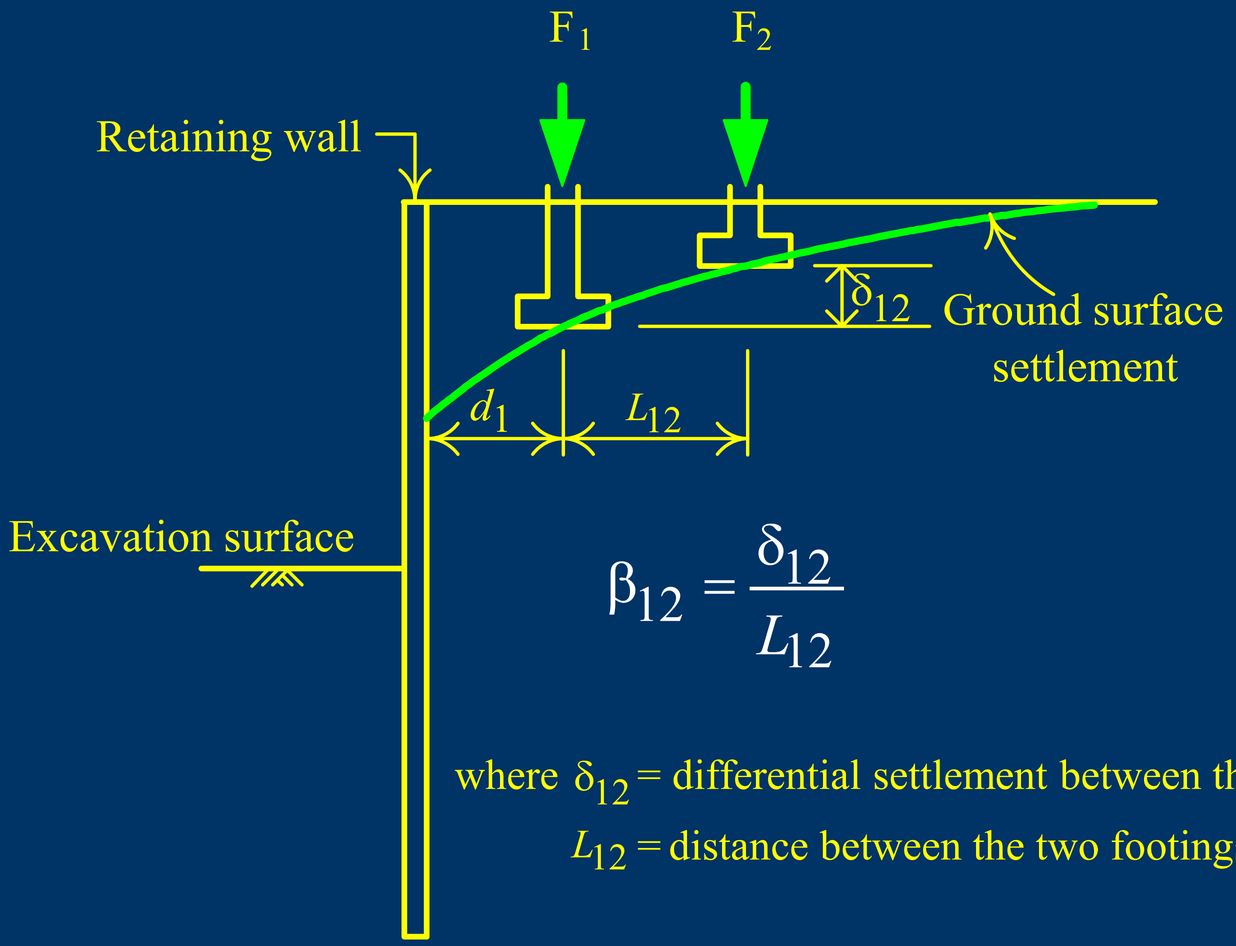
6.8 Analysis of Ground Surface Settlements Induced by Excavation

6.8.5 Comparison of the Various Analysis Methods



(c)

FIGURE 6.27 Comparisons of predicted and observed ground surface settlements (c) Case III: the excavation of a building



$$\beta_{12} = \frac{\delta_{12}}{L_{12}}$$

where δ_{12} = differential settlement between the two footings

L_{12} = distance between the two footings

FIGURE 6.28 Angular distortions of footings near an excavation

TABLE 6.1 Comparisons of the predicted and observed angular distortions at the final excavation stage of the case

Case	Observation & prediction method	d_1 / H_e			
		0.0	0.5	1.0	1.5
Case I	Observation Clough and O'Rourke **Ou and Hsieh**	1/200 0 **1/300**	1/5000 1/7350 **1/4100**	1/300 1/320 **1/400**	1/750 1/320 **1/400**
Case II	Observation Clough and O'Rourke **Ou and Hsieh**	1/150 0 **1/390**	1/870 1/6800 **1/540**	1/660 1/530 **1/520**	1/1400 1/530 **1/750**
Case III	Observation Clough and O'Rourke Bowles **Ou and Hsieh**	1/180 1/540 1/430 **1/125**	1/370 1/540 1/485 **1/390**	1/450 1/540 1/555 **1/530**	1/820 1/540 1/660 **1/1100**

6.9 Three Dimensional Excavation Behavior

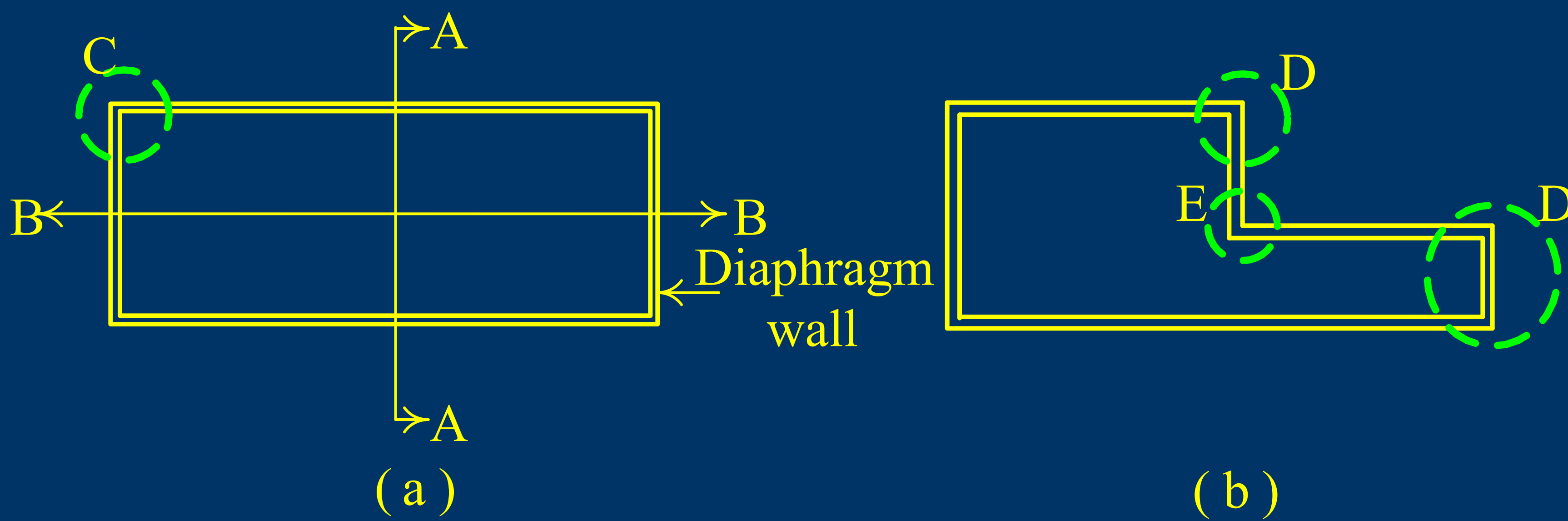
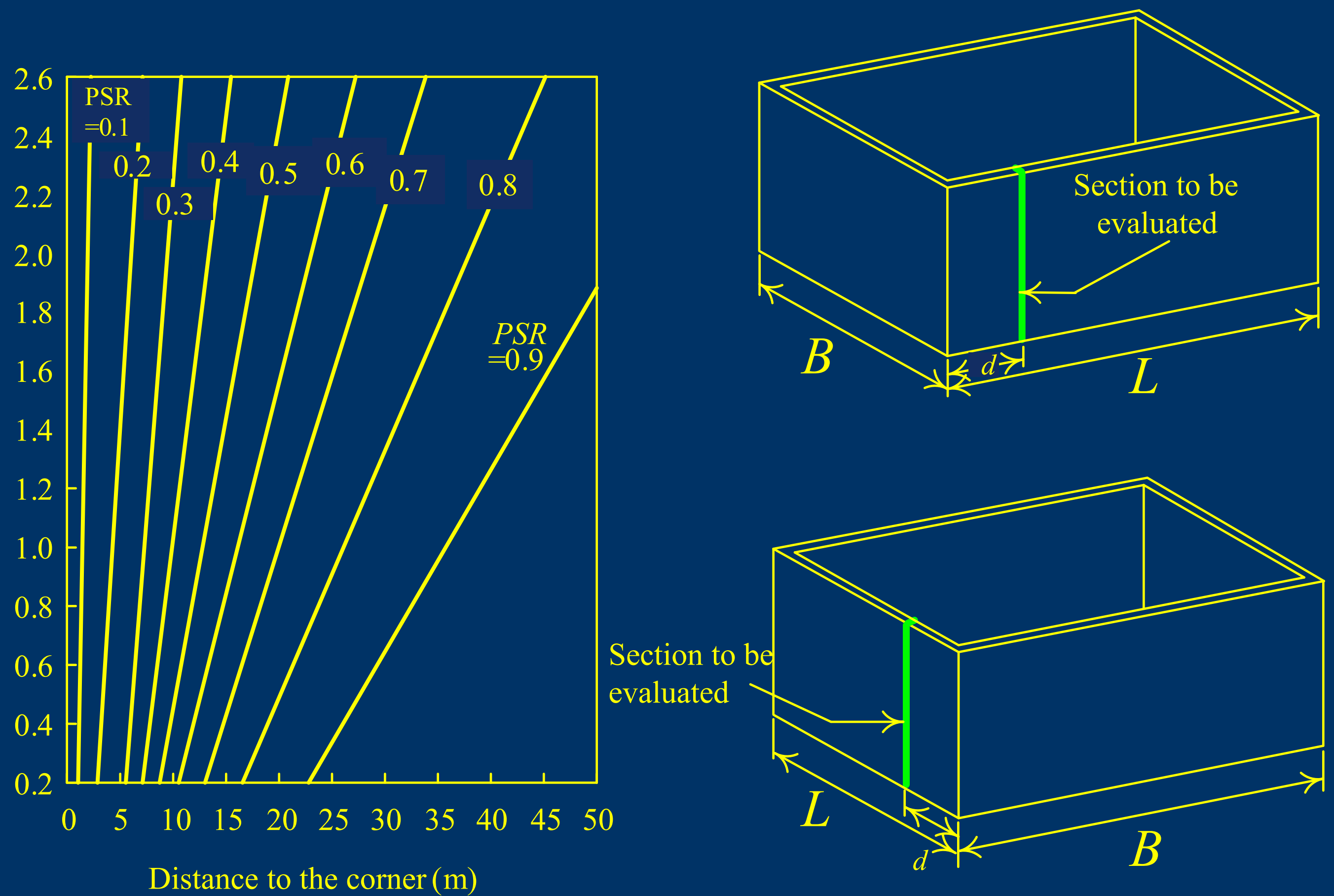


FIGURE 6.29 Zones of plane strain behavior and three-dimensional behavior in excavations (a) rectangular excavation (b) irregular excavation

$$PSR = \frac{\delta_{hm,d}}{\delta_{hm,ps}} \qquad (6.12)$$

Maximum wall deflection at the distance of *d* from the corner：

$$\delta_{hm,d} = \mathrm{PSR} \times \delta_{hm,ps}$$



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

(a) (b)

FIGURE 6.30 Relationship between the plane strain ratio and the aspect ratio of an excavation
(a) *PSR*, the length-width ratio, and the distance from the corner
(b) symbol explanation

6.10 Stress Analysis

6.10.1 Struts--the Apparent Earth Pressure Method

6.10.2 Cantilevered Walls--the Simplified Gross Pressure Method

6.10.3 Strutted Walls--the Assumed Support Method

6.10.1 Struts--the Apparent Earth Pressure Method

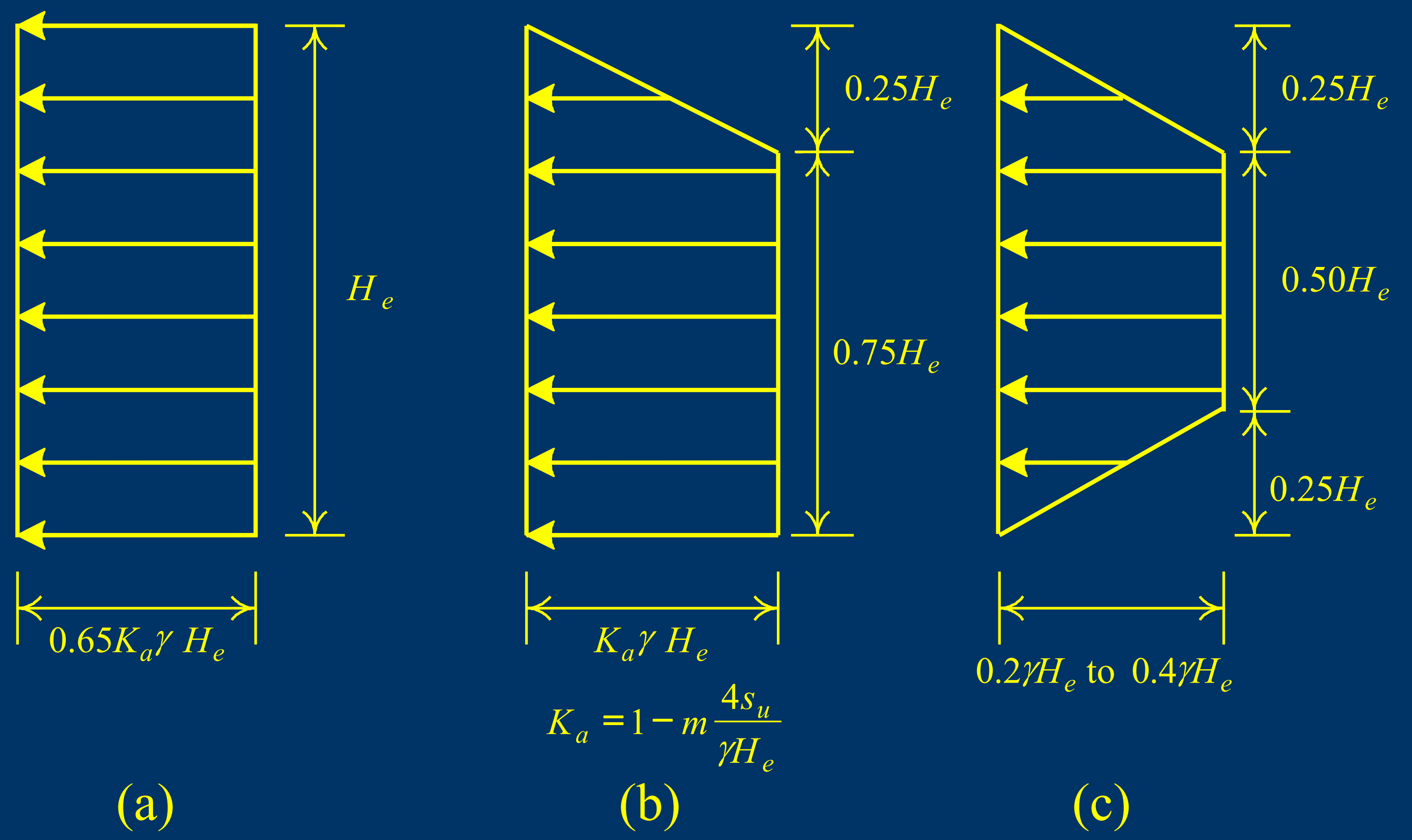


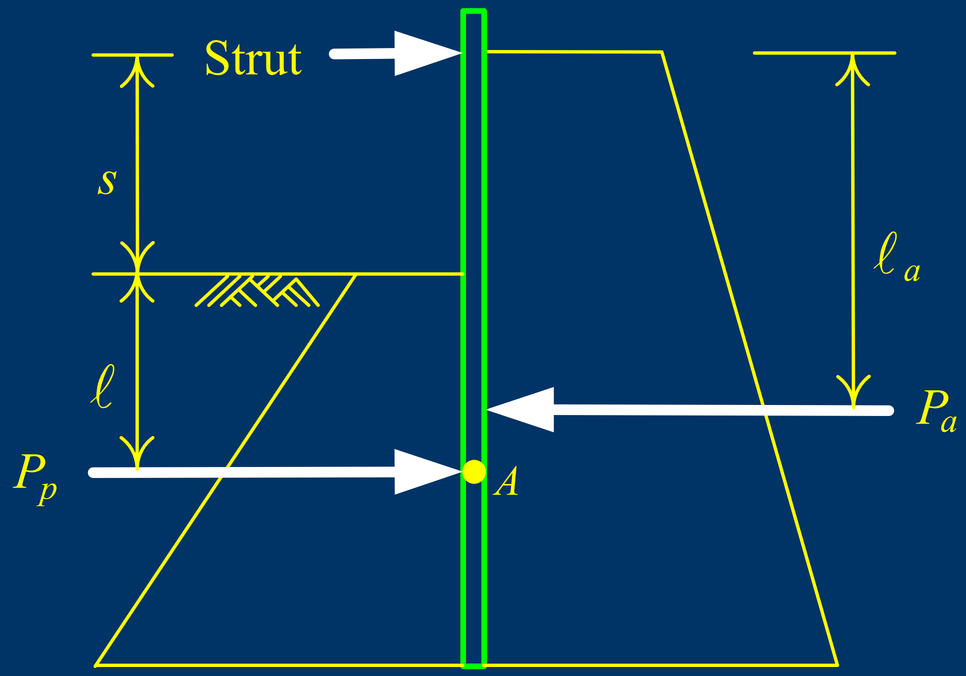
FIGURE 6.32 Peck's apparent earth pressure diagram
(a) sand
(b) soft to medium soft clay $(\gamma H_e/s_u > 4)$
(c) stiff clay $(\gamma H_e/s_u \leq 4)$

6.10 Stress Analysis

6.10.3 Strutted Walls--the Assumed Support Method

（2）Location of the assumed support

1.Location of the assumed support (ℓ) equal to



$$\ell = \frac{P_a \ell_a}{P_p} - s \qquad (6.20)$$

A is the location of the assumed support

FIGURE 6.35 Determination of the location of the assumed support by way of the moment equilibrium of earth pressures below the lowest level of struts

（2）Location of the assumed support

	Sandy Soils	Clayey Soils	The locations of the assumed supports
Dense soils	$N>50$	$N>15$	$\ell = 0 \sim 0.5$ m
Medium dense soils	$10 \leq N \leq 50$	$4 \leq N \leq 15$	$\ell = 1.0 \sim 2.0$ m
Soft soils	$N<10$	$N<4$	$\ell = 3.0 \sim 4.0$ m

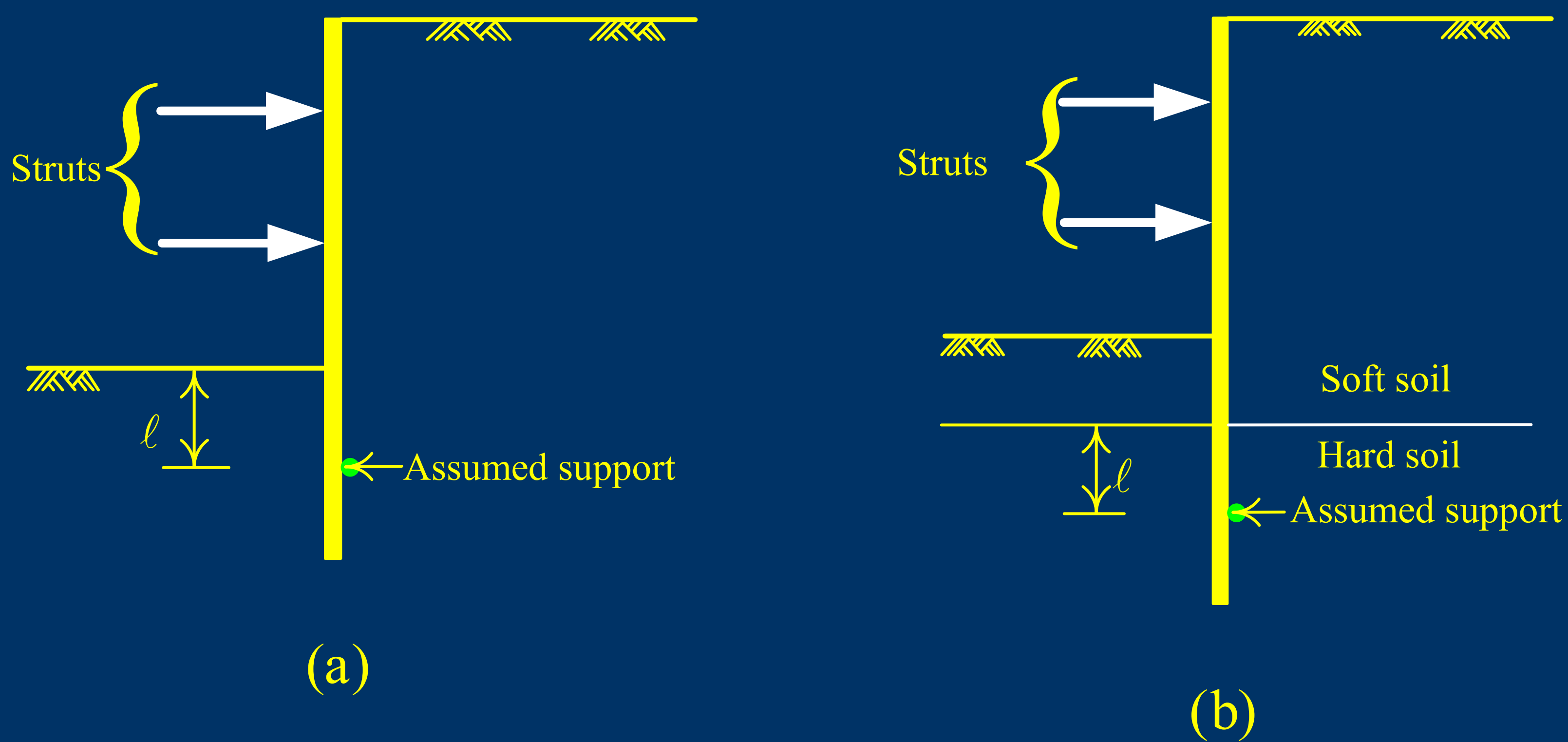


FIGURE 6.36 Locations of the assumed support
(a) homogeneous soil
(b) soft clay above a stiff layer

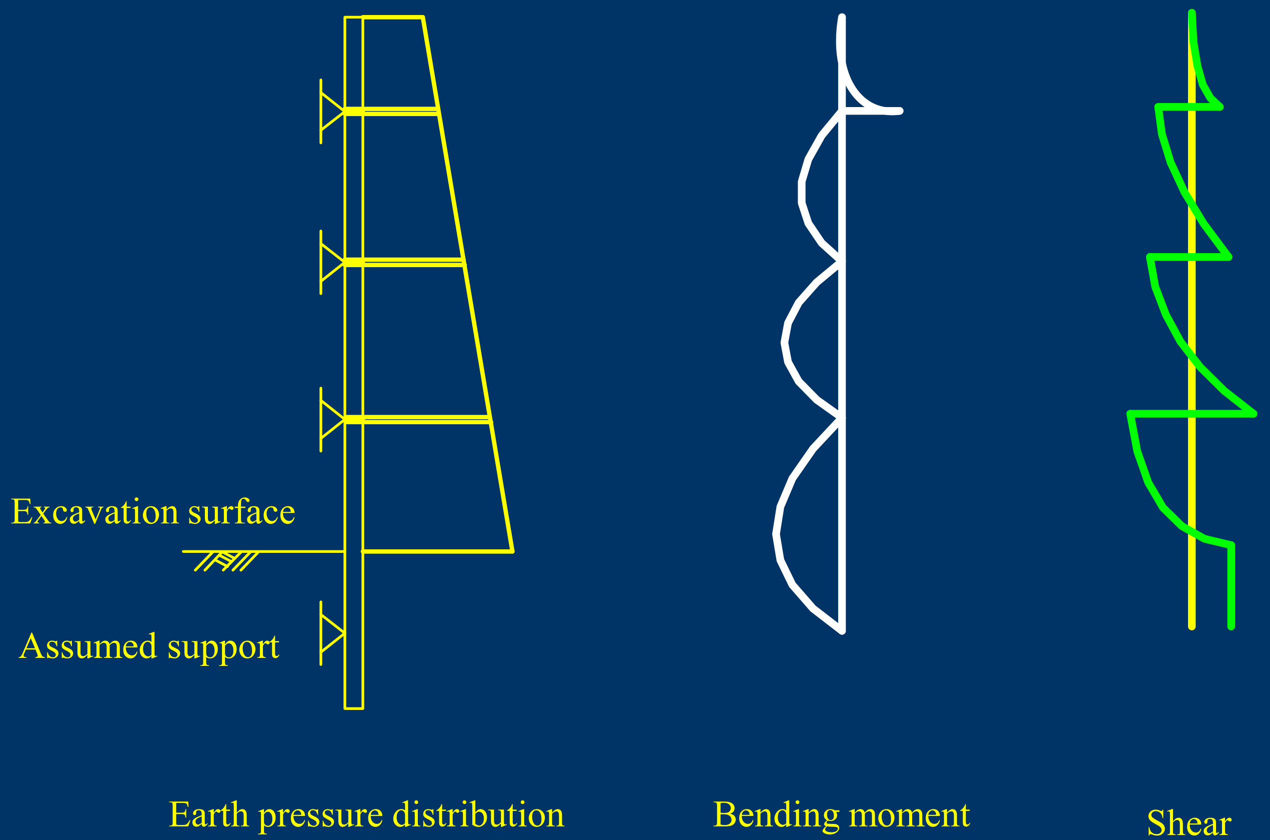


FIGURE 6.37 One-stage loading simply supported beam method (the simply supported beam model)

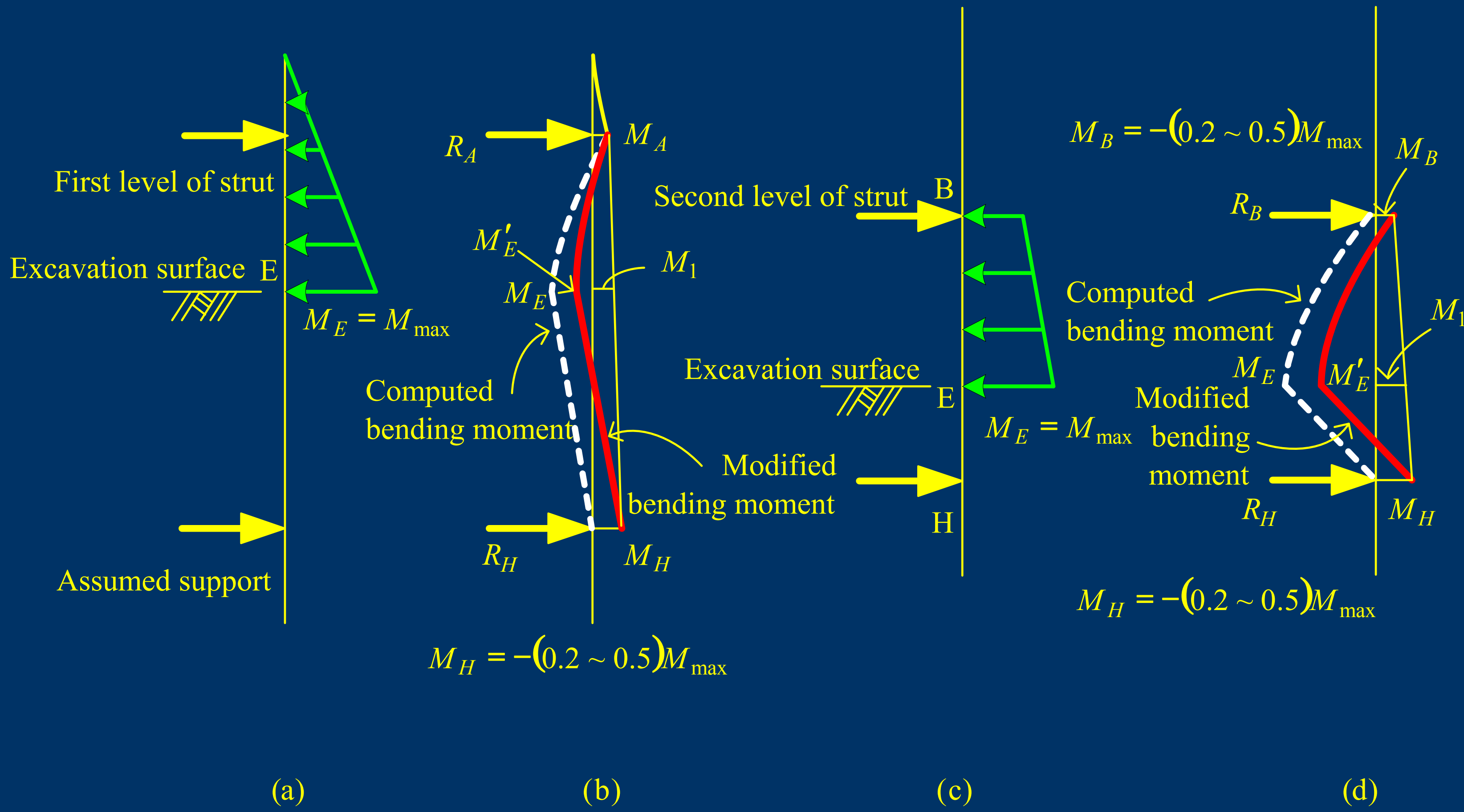


FIGURE 6.38 Phased loading assumed supported method
(a) earth pressure distribution at the second excavation stage
(b) computation of bending moment at the second excavation stage
(c) earth pressure distribution at the third excavation stage
(d) computation of bending moment at the third excavation stage

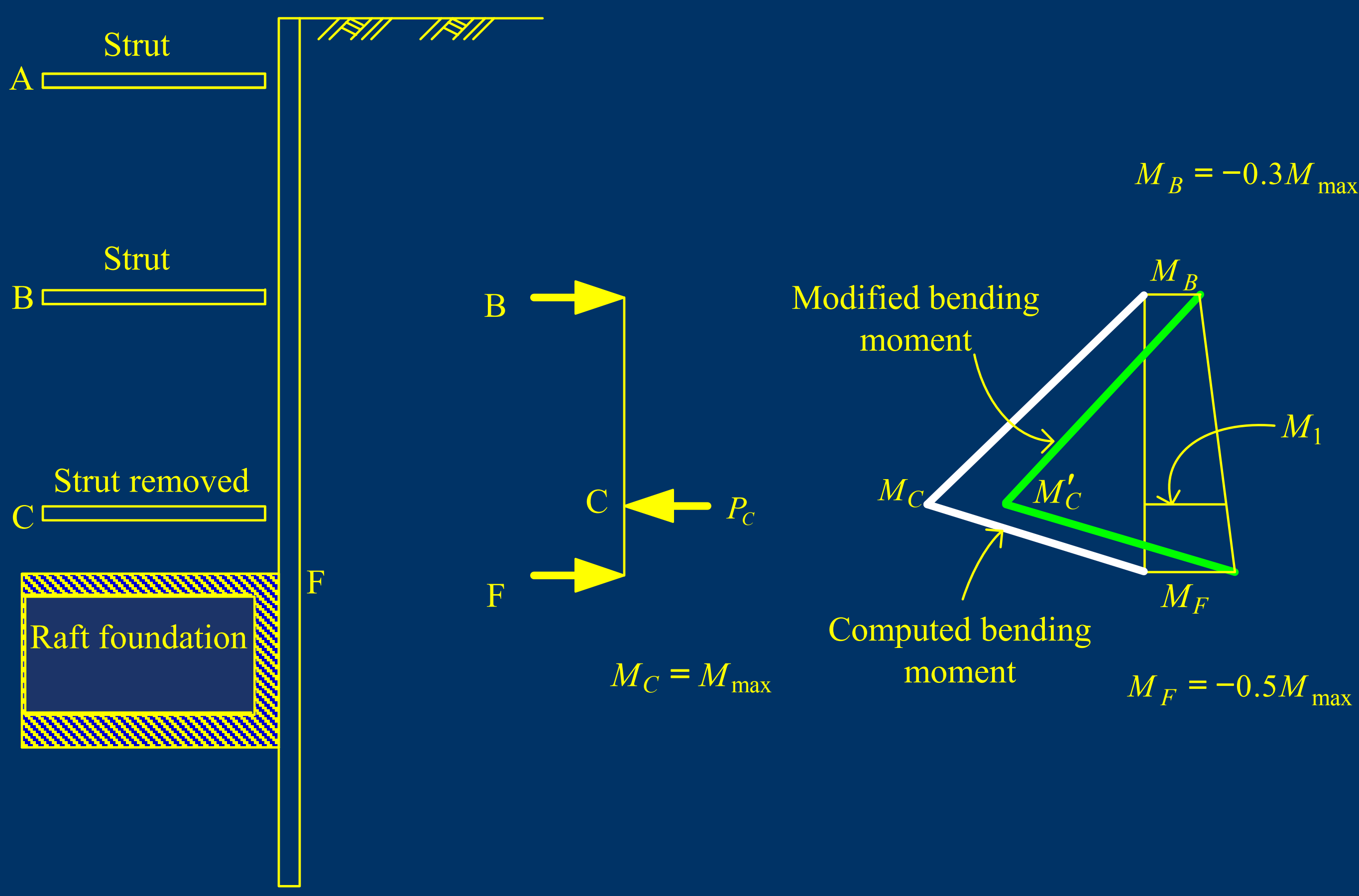


FIGURE 6.39 Phased loading assumed support at the stage of strut demolition

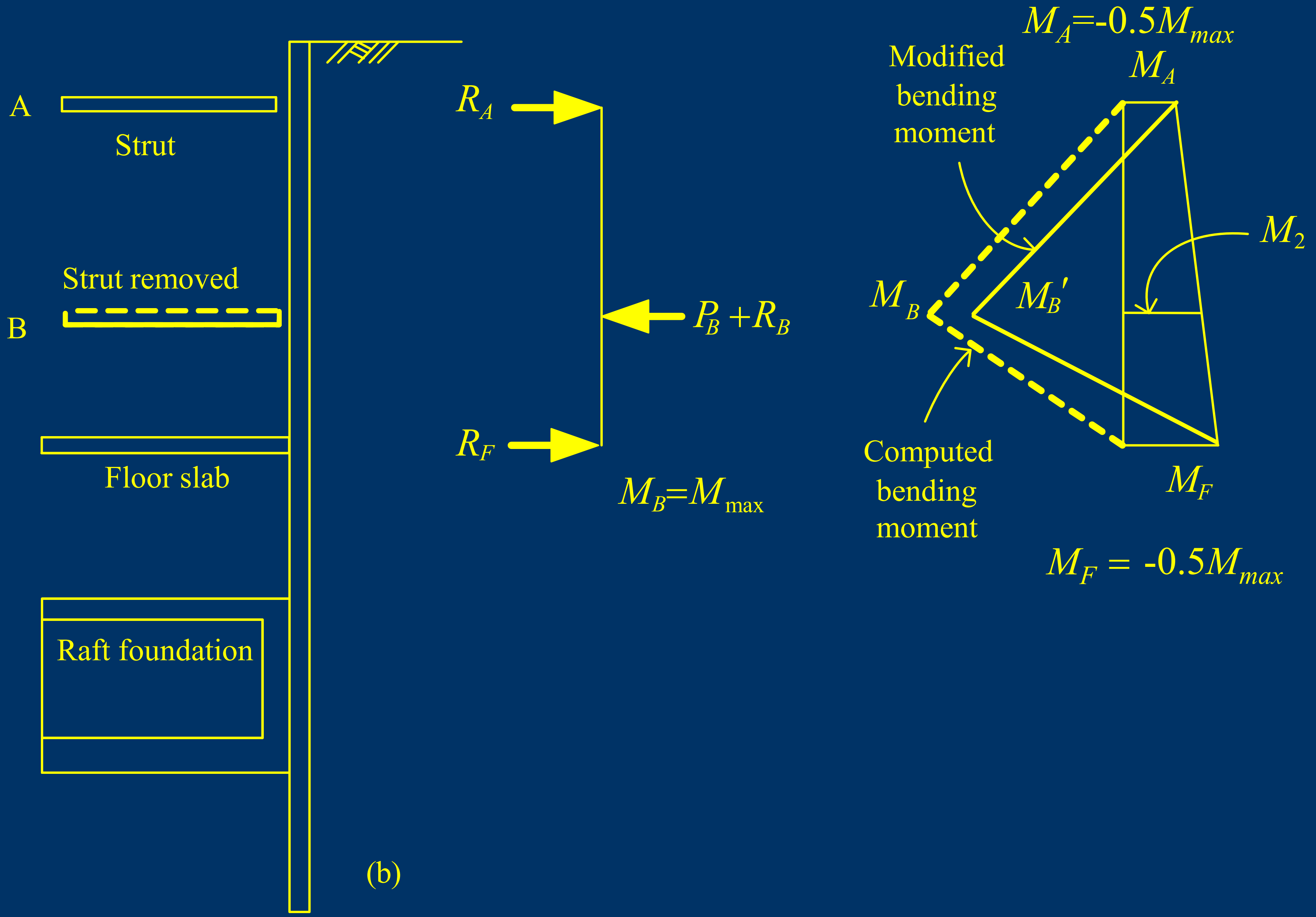


FIGURE 6.39 Phased loading assumed support at the stage of strut demolition (R_B, R_R, R_A, R_F are reaction forces due to demolition of the struts, P_C, P_B are strut loads at the final stage of excavation and can be computed using the apparent earth pressure diagram)

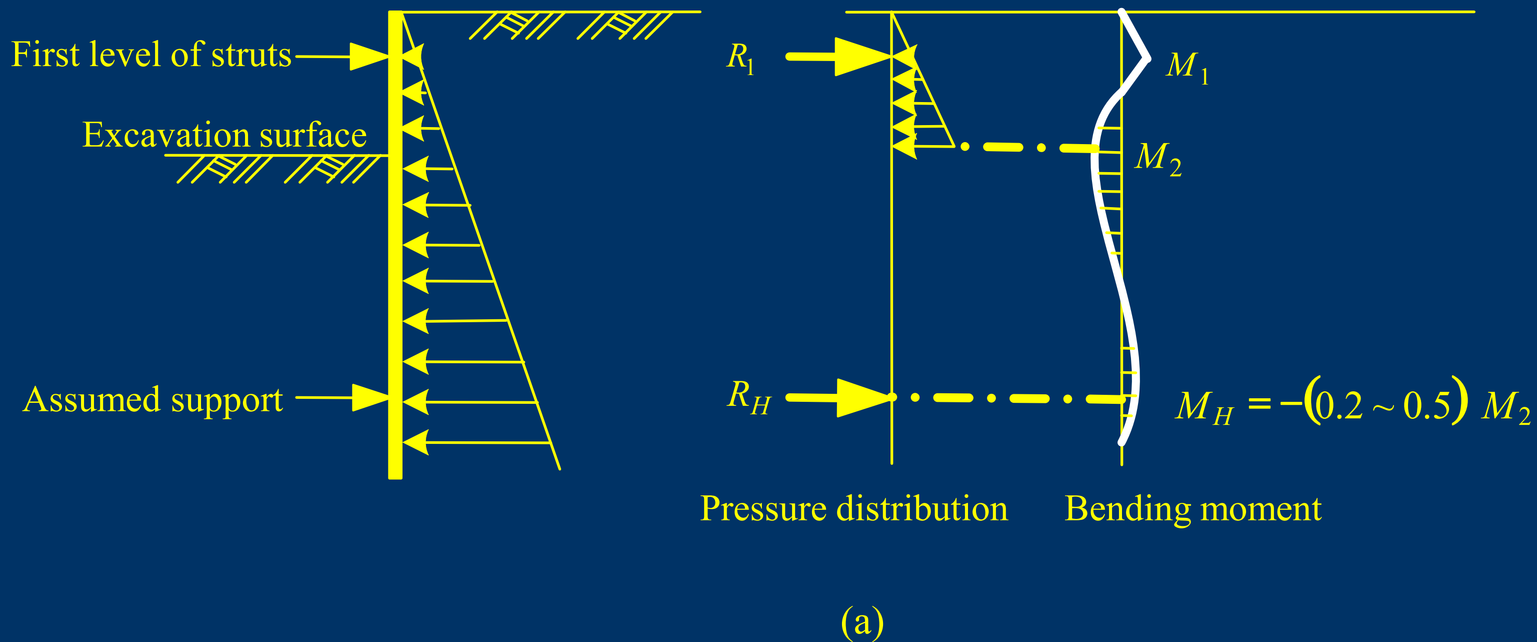


FIGURE 6.40 Computing procedure for the assumed supported method

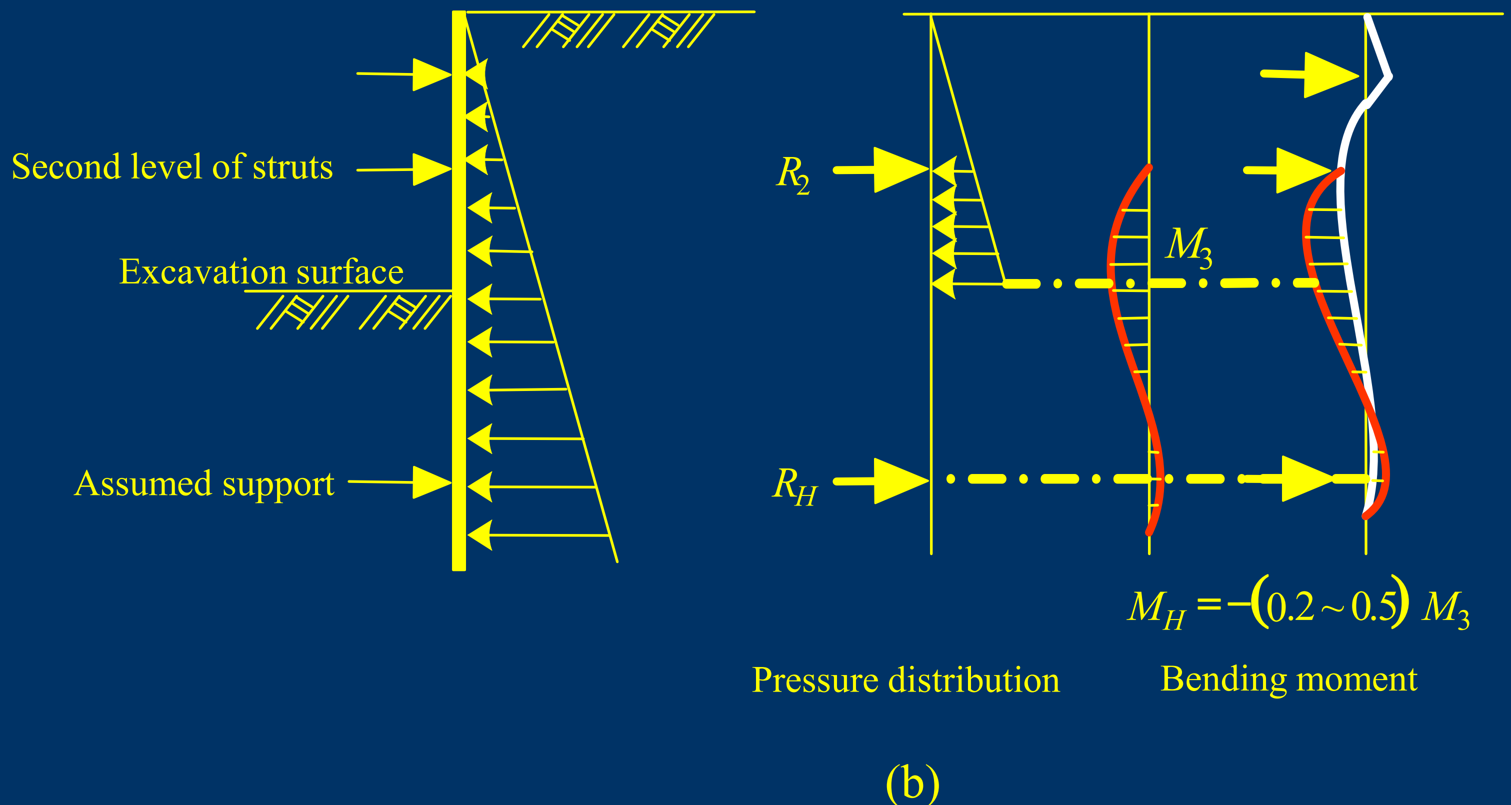


FIGURE 6.40 Computing procedure for the assumed supported method

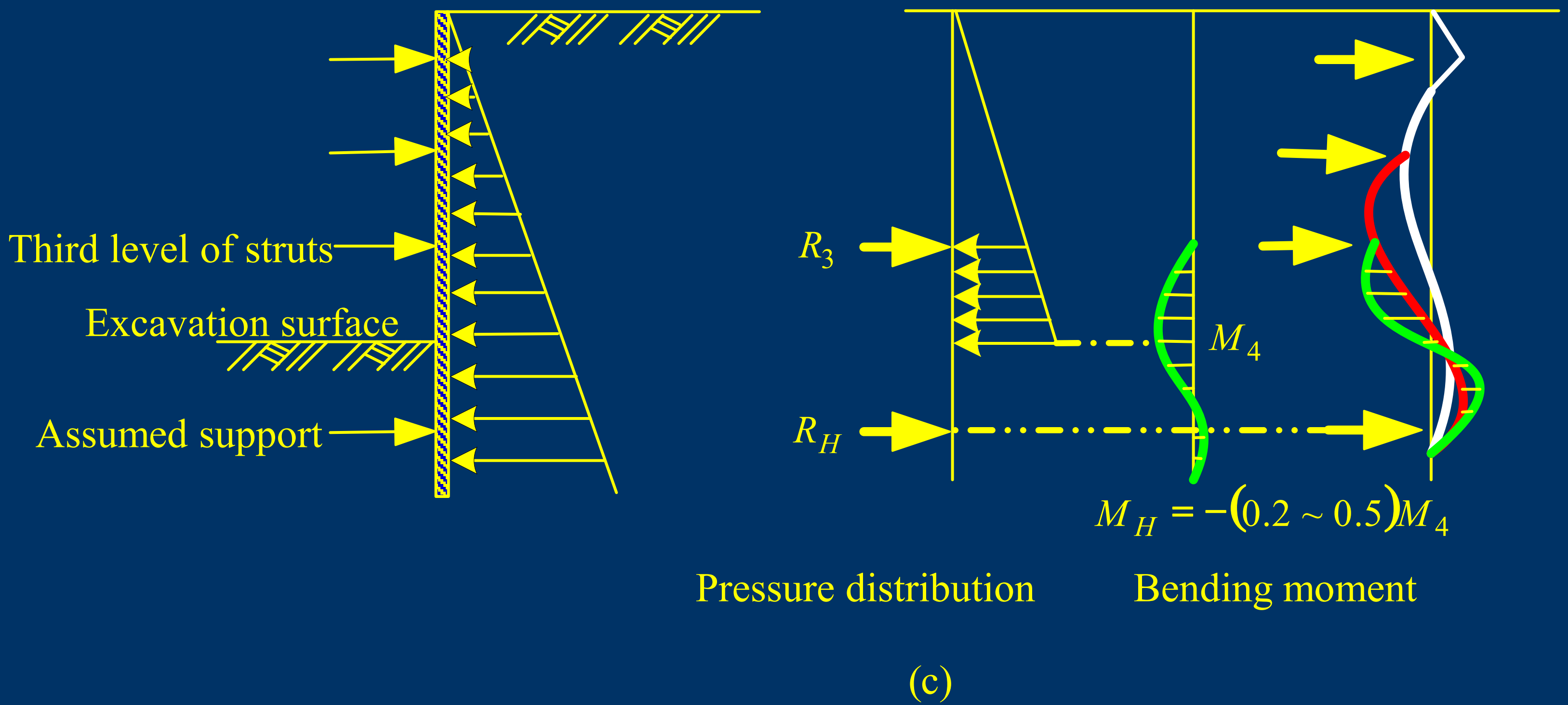


FIGURE 6.40 Computing procedure for the assumed supported method