Numerical Analysis

Part I: Beam on Elastic Foundation Method

Part II: Finite Element Method

Part I: Beam on Elastic Foundation Method

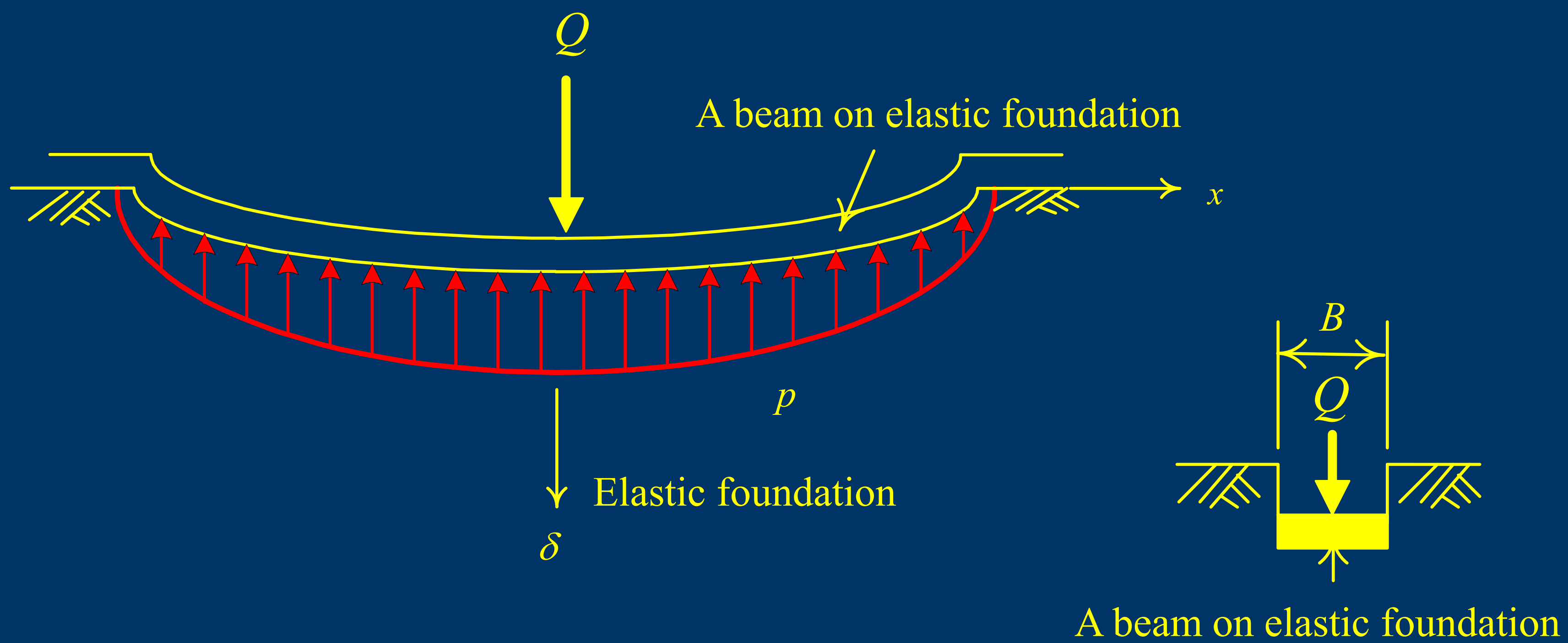


FIGURE 7.1 Winkler's model

Winkler's model：

$$k_s = \frac{p}{\delta} \tag{7.1}$$

k_s is called the coefficient of subgrade reaction, the modulus of subgrade reaction, or the soil spring constant, the unit of which is (force) $\times$(dimension)$^{-3}$.

7.2 Basic Principles

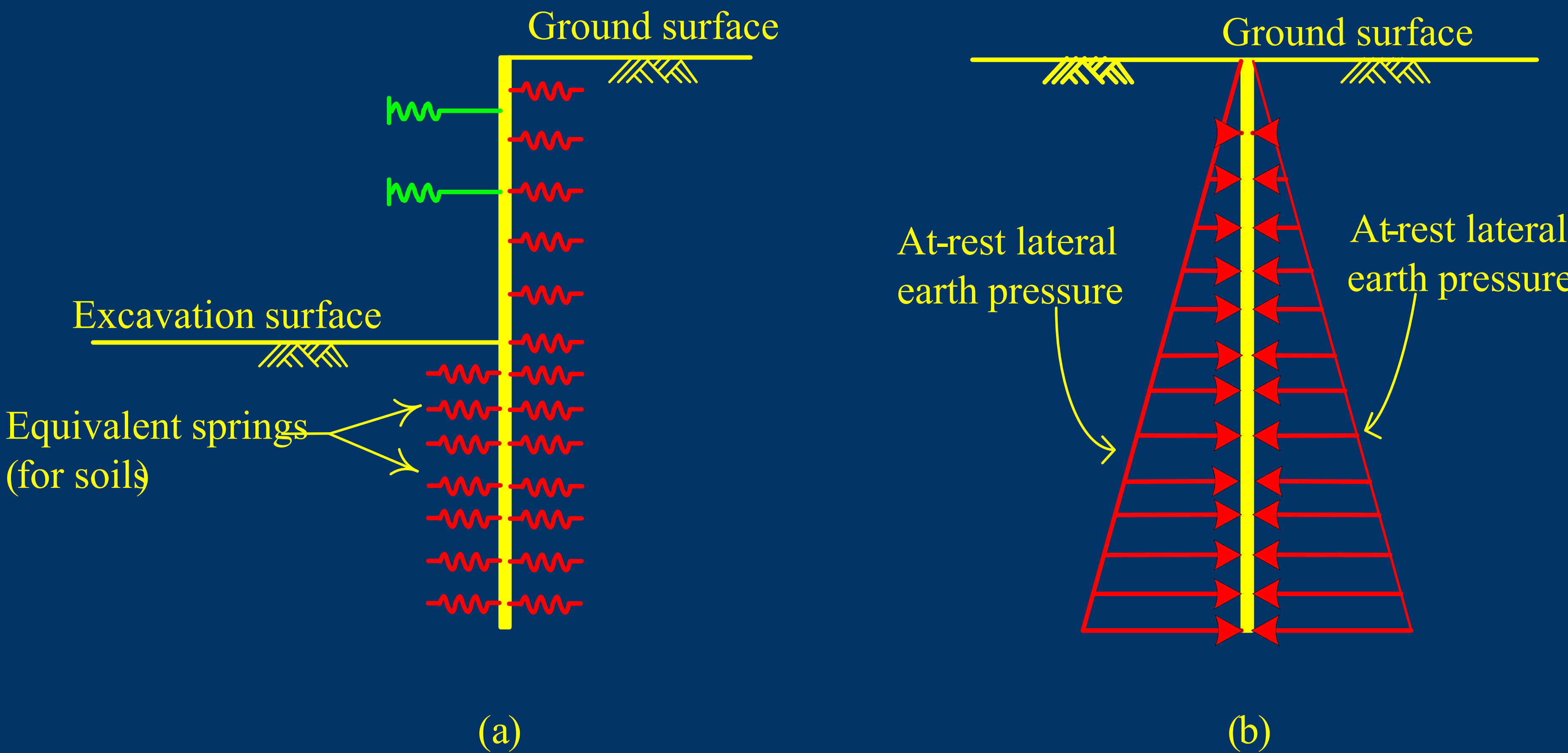


FIGURE 7.2 The beam on elastic foundation method
(a) springs placed at both sides of the continuous beam
(b) at rest earth pressure before excavation

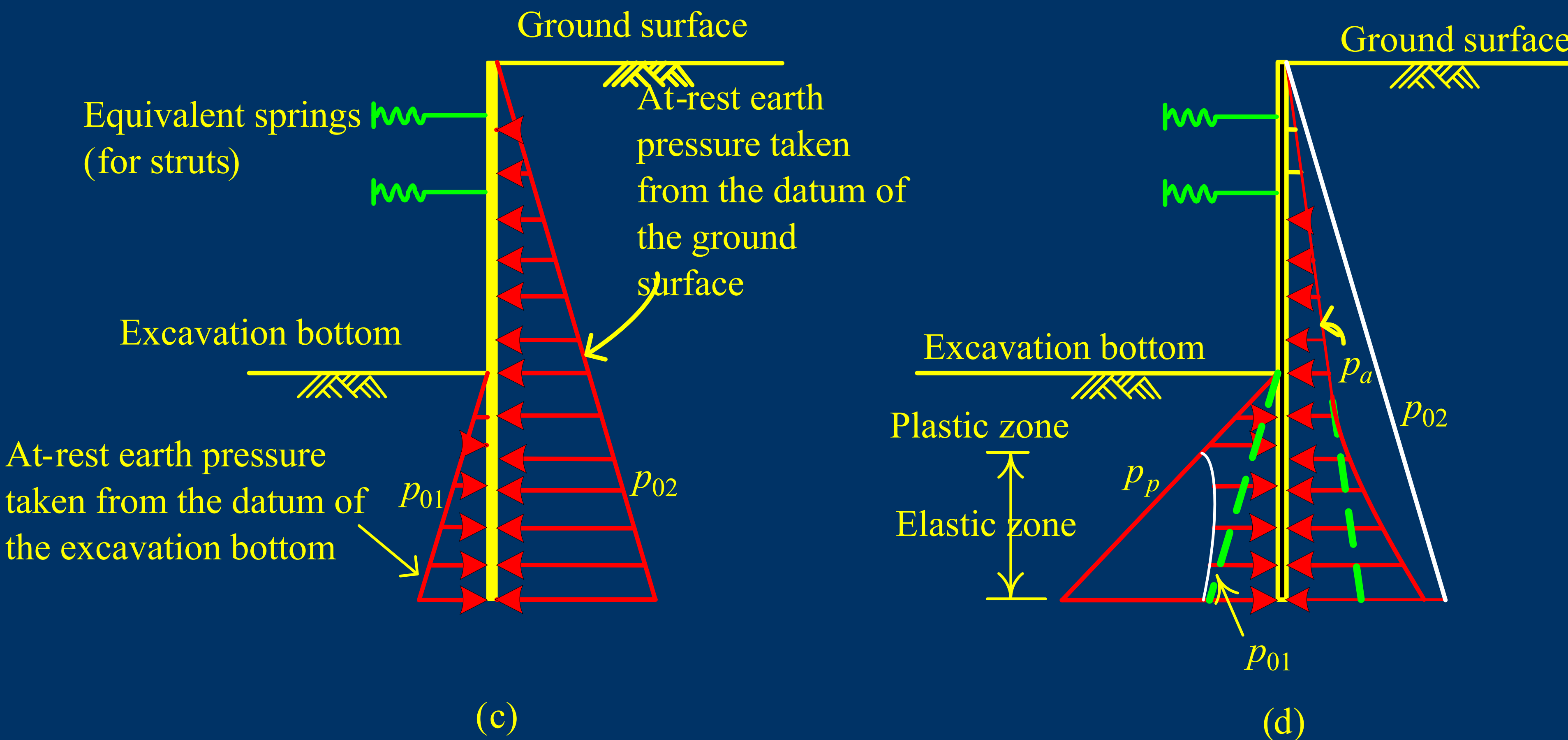


FIGURE 7.2 The beam on elastic foundation method
(c) distribution of earth pressures on both sides of the retaining wall before wall movement
(d) distribution of earth pressures on both sides of the wall after wall movement

Commercial Software:

RIDO (France)

FREW (British)

7.4 Distribution of Lateral Earth Pressure

P_a(Rankine)>P_a (actual earth pressure) > P_a(Coulomb)

P_p(Coulomb)>P_p (actual earth pressure) >P_p (Rankine)

$\delta=0$ ，Rankine's, Coulomb's, and Caquot- Kerisel's K_p are the same

$\delta < 0.5\phi'$, Caquot-Kerisel's K_p are close to Coulomb's.

$\delta \geq 0.5\phi'$, Coulomb's K_p are significantly larger than Caquot-Kerisel's.

7.5 Estimation of Coefficient of Subgrade Reaction

Vesic derived the coefficient of subgrade reaction

$$k = 0.65 \times \sqrt[12]{\frac{E_s B^4}{E_b I}} \frac{E_s}{B(1 - \nu_s^2)} \qquad (7.20)$$

$$k_s \approx \frac{E_s}{B(1 - \nu_s^2)} \qquad (7.21)$$

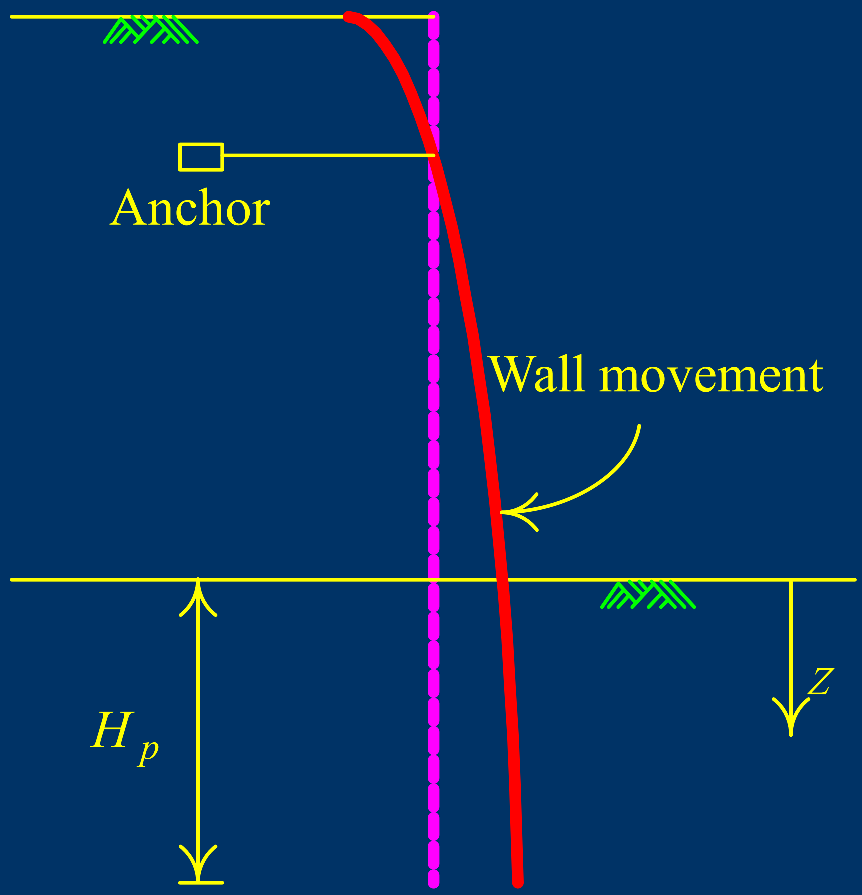


FIGURE 7.11 Deflection of a free earth support wall

Terzaghi:

The coefficients of subgrade reaction as behave as a free earth support in sandy soils

$$k_h = \ell_h \frac{z}{H_p} \qquad (7.22)$$

The coefficients of subgrade reaction as behave as a free earth support in stiff clays

$$k_h = k_{h1} \frac{1}{H_p} \qquad (7.21)$$

Some engineering substitute the excavation width for *B* to estimate the coefficient of horizontal subgrade reaction for excavation

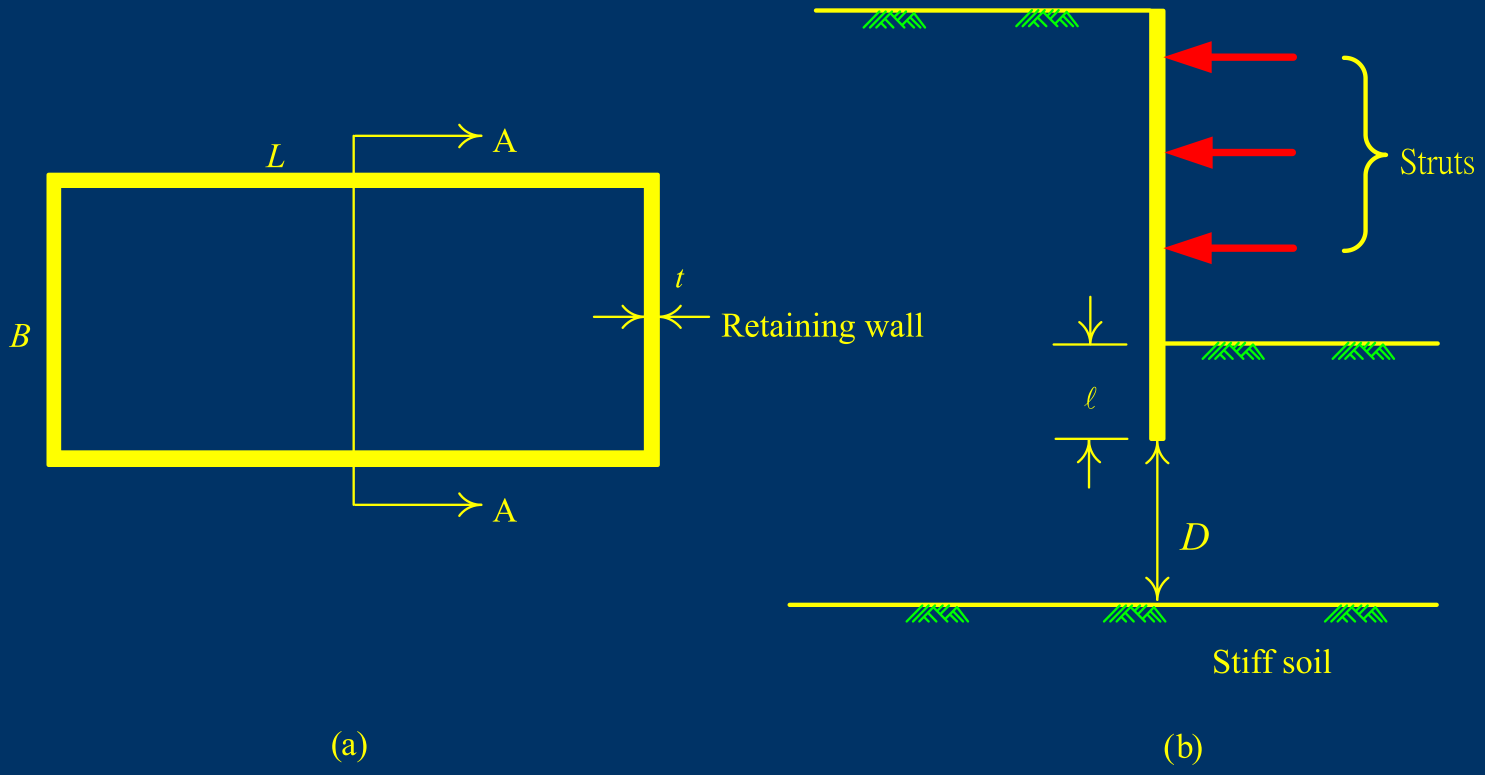


FIGURE 7.10 Excavation with the retaining wall ℓ deep into ground
(a) plan
(b) profile at the A-A section

back analyses for many excavation histories and proposed the following empirical formula to estimate k_h by

For clay $$k_h = (40 \sim 50)\, s_u \qquad (7.24)$$

For sand $$k_h = (700 \sim 1000)\, N \qquad (7.25)$$

k_h = coefficient of subgrade reaction. The unit is kN/m^3
s_u = undrained shear strength of soils. The unit is kN/m^2
N = SPT value

7.6 Estimation of Structural Parameters

- Soldier piles

The nominal Young's modulus for soldier piles is $2.04 \times 10^6 \ \mathrm{kg/cm^2}$

Theoretically, the stiffness (*EI*) does not need reduction in analysis. Considering the repeated use of soldier piles, which decreases their stiffness as a result, therefore, the nominal Young's modulus is usually reduced by 20%.

- Sheet piles

The nominal Young's modulus for sheetpiles is also $2.04 \times 10^6 \ kg/cm^2$

Considering the repeated use of sheetpiles, the stiffness can be assumed to be 80% of the nominal Young's modulus value in analysis.

- Diaphragm walls

According to the ACI Code, the Young's modulus for concrete can be estimated using the equation：$E = 15{,}000\sqrt{f_c'}\ \mathrm{kg/cm^2}$

where f_c' is the 28th-day compressive strength of concrete.

Considering the possibility of bending moment-induced cracking in concrete and the reduction of the sectional modulus accordingly, the stiffness (EI) is usually reduced by 20~40% in analysis.

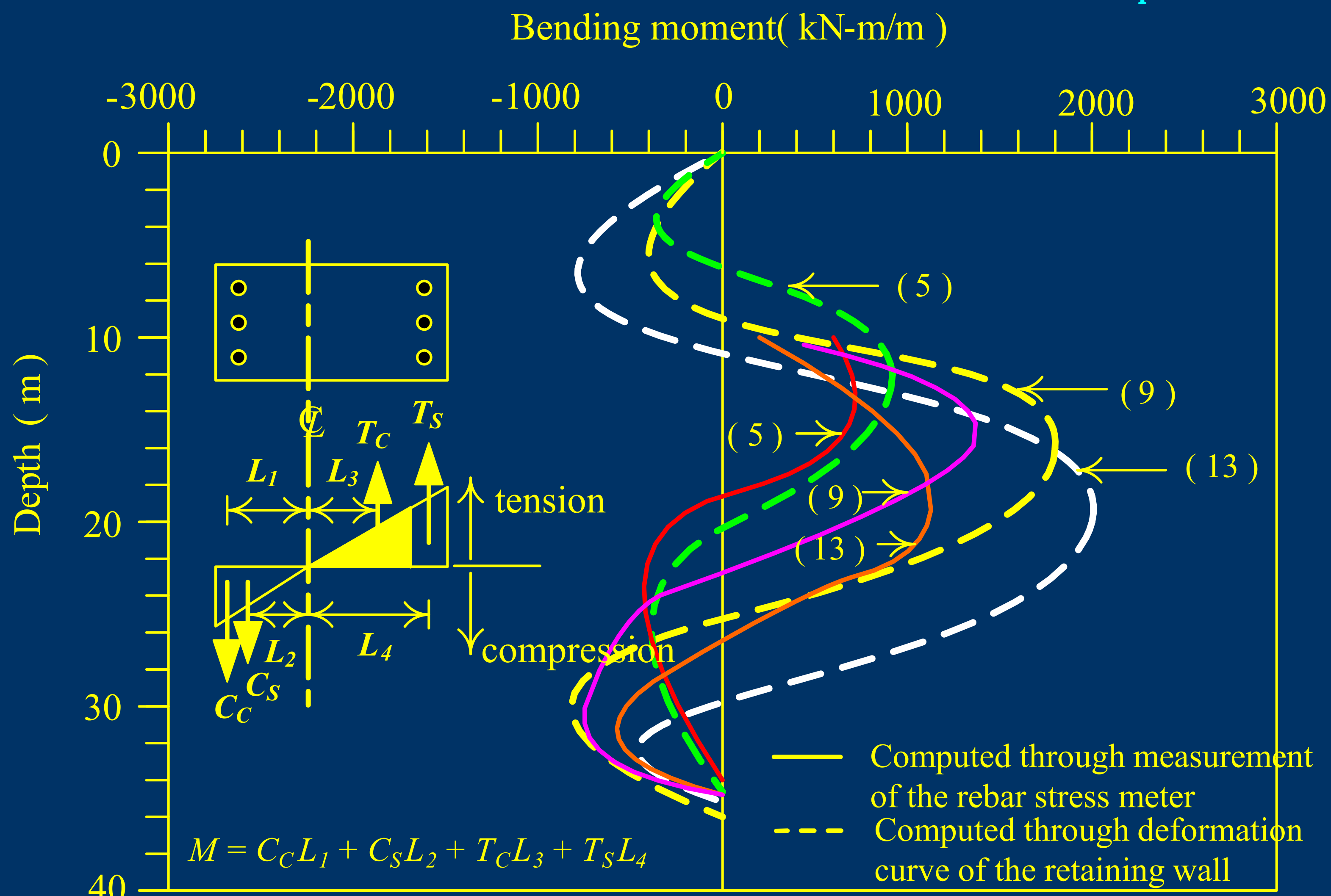


FIGURE 7.13 Variations of bending moments of the diaphragm wall in the TNEC excavation

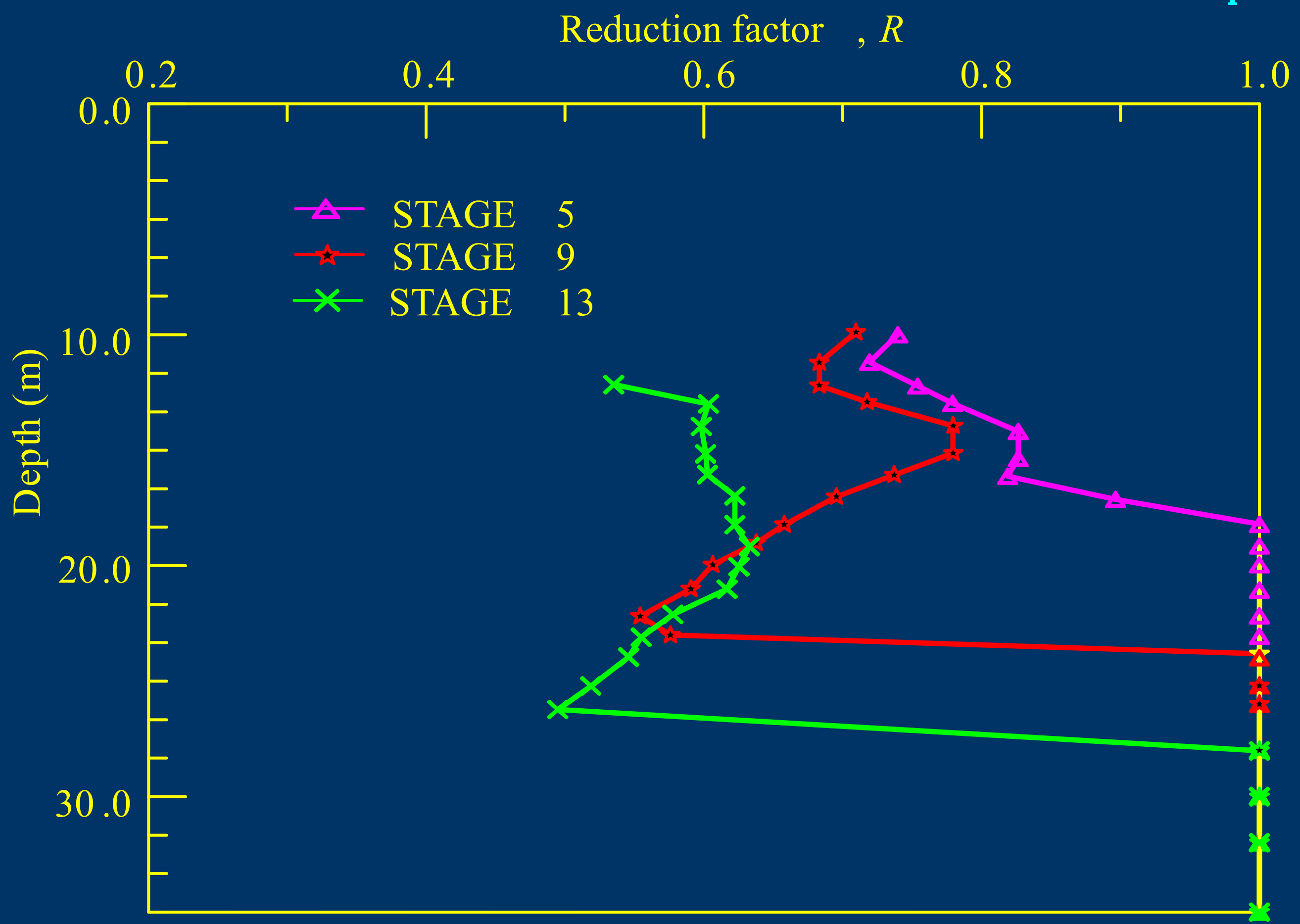


FIGURE 7.14 Reduction factors of bending moments for the diaphragm wall in the TNEC excavation

- Column piles

Column piles can be distinguished into packed-in-place (PIP) piles, reinforced concrete piles, and mixed piles. Reinforced concrete piles can further be classified into reverse circulation drill piles and all casing piles. The value of f_c' for PIP piles is about 170 kg/cm^2 and that for reinforced concrete piles and all casing piles is about 280 kg/cm^2.

In analysis, it can be reduced by 30%~50%, which depends on the construction quality of the column pile. We can assign different reduction factors at different depths of the column pile, which is similar to the approach for diaphragm walls.

The values of f_c' for mixed piled is about 5 kg/cm^2. With rather low strength, the stiffness of mixed piles can be ignored and we can only consider the stiffness of the H steel (or W section) within mixed piles.

- Struts or floor slabs

$$k = \frac{AE}{L} \qquad (7.26)$$

A= cross-sectional area of a strut or floor slab
E= Young's modulus
L= length of the strut or floor slab, usually half of the excavation width

According to experience,

the stiffness of a floor slab is about 80% of the nominal value

the stiffness of a steel strut is 50%~70% of the nominal value

7.7 Analysis Methods for Excavations

7.7.1 Direct Analysis and Back Analysis

Direct analysis：

Input the soil parameters obtained from soil tests into the computer program and the thus derived results represent the behaviors of the excavation, which is called direct analysis.

The soil parameters obtained from soil tests sometimes have to be adjusted. If the adjustment procedure has a certain regularity, reproducibility and consistency and is also applicable to any soil and construction conditions, the method is also called the direct analysis method.

Back analysis：

Peck designated it as the observational method.

(1) take measurement data as an object to back analysis.

(2) uses the observations at the initial stages as an object to back analyze the parameters, which are then used for the prediction of behaviors at the final or critical construction stage.

7.7.2 Drained Analysis, Undrained Analysis, and Partially Drained Analysis

Drained analysis：

In analysis, the excess porewater pressure has been all dissipated (i.e., $u_e = 0$)

The required parameters in analysis are effective parameters, i.e., c' and ϕ'.

Undrained analysis：

In analysis, the excess porewater is not dissipated ($u_e \neq 0$) and no volume change

No volume change can be observed when the soils are in the saturated state. The parameter to be used in analysis would be s_u and $\phi = 0$.

The undrained analysis for unsaturated clay adopts the test result of the triaxial UU tests where c_T and ϕ_T are directly adopted.

Partially drained behavior：

Reason：

The clay is neither totally drained nor completely undrained.

Analysis method：

(1) install a piezometer to measure the porewater pressure at a construction stage. Then use the equation $\sigma' = \sigma - u$, assuming the total stress unchanged, to derive the effective stress of the soils. Given the effective stress of soils, according to the normalized behavior of soils (s_u / σ'_v = constant), the undrained shear strength of the soils can then be obtained. Then carry out an undrained analysis of the excavation for each stage to obtain the partially drained behavior of soils.

(2) obtained the undrained shear strengths for each stage by way of laboratory or in-situ shear strength tests first, which are then used for undrained analysis to analyze the partially drained behavior.

7.8 Computation of Ground Surface Settlement

The beam on elastic foundation method can only yield the deformation of a retaining wall but is not capable of producing the ground settlement.

Peck's method：don't need to estimate the lateral deformation of the retaining wall before analysis. Didn't classify the spandrel and concave types.

Bowles's method： need to estimate the lateral deformation of the retaining wall before analysis. Can only predict the spandrel type.

Clough and O'Rourke's method： need to estimate the maximum lateral deformation of the retaining wall before analysis. Can predict the spandrel and concave types.

Ou and Hsieh's method：need to estimate the lateral deformation of the retaining wall before analysis. Can predict the spandrel and concave types.

Elucidate the procedure of prediction using Ou and Hsieh's method ：

1. Predict the lateral wall deformation using the beam on elastic foundation method.

2. The lateral wall deformation know, compute the areas of the cantilevered part (A_c) and the deep inward movement (A_s). Determine the type of ground surface settlement with the help of Figure 6.12.

3. Estimate the maximum ground surface settlement (δ_{vm}) according to its relation with the maximum lateral wall deformation (δ_{hm}), as shown in Figure 6.14.

4. According to the settlement type determined in step 2, compute the ground surface settlements in different positions behind the retaining wall using Figure 6.26.

7.9 Limitation of the Beam on Elastic Foundation Method

The beam on elastic foundation method is an analysis method based on the plane strain condition.

3-D analysis：using the concept of plane strain ratio (*PSR*)

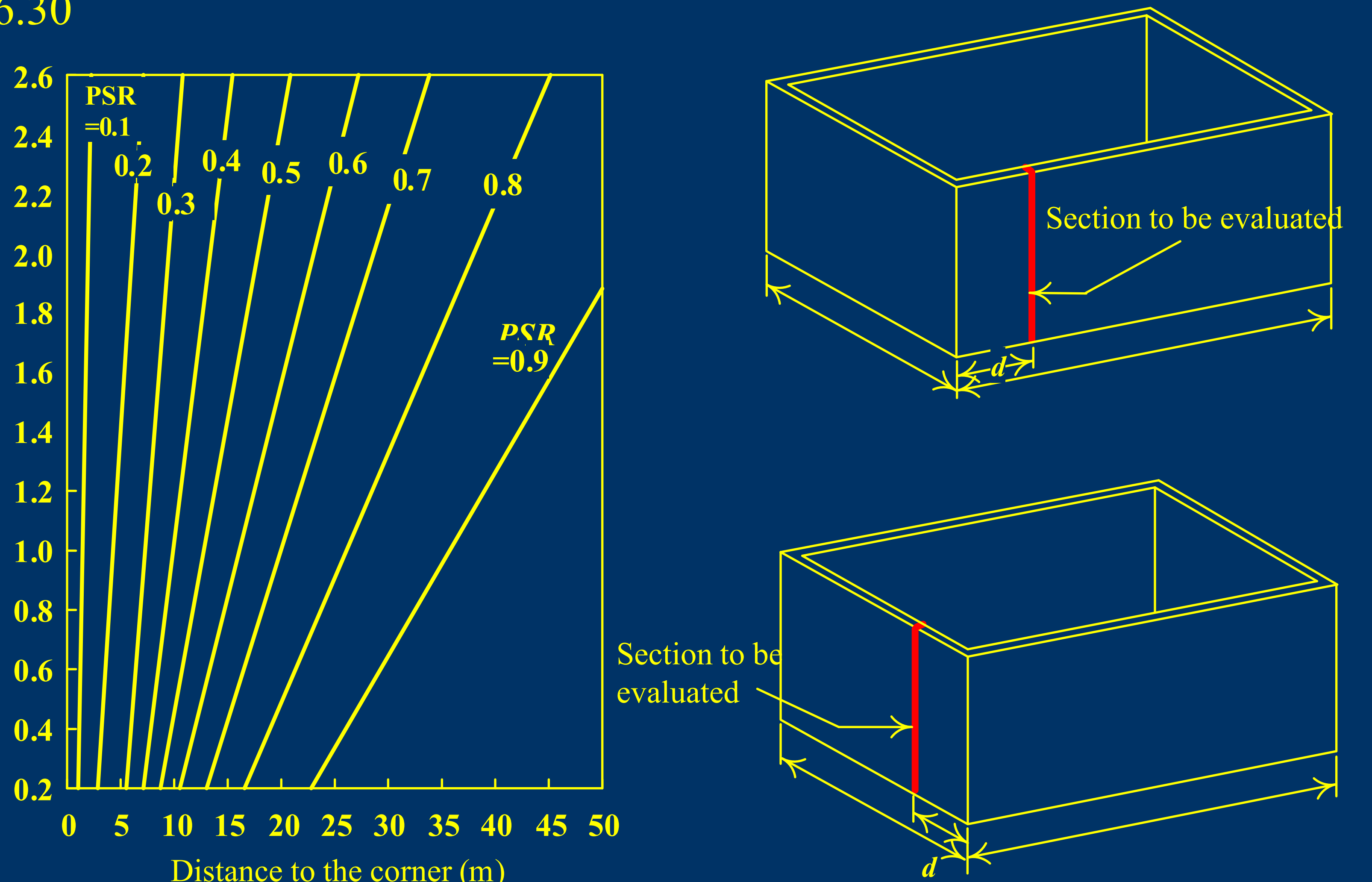
$$PSR = \frac{\delta_{hm,d}}{\delta_{hm,ps}} \quad (6.12)$$

PSR = plane strain ratio

$\delta_{hm,d}$ = maximum wall deflection at the distance of d from the corner

$\delta_{hm,ps}$ = maximum wall deflection under the plane strain condition

FIGURE 6.30



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

(a) **(b)**

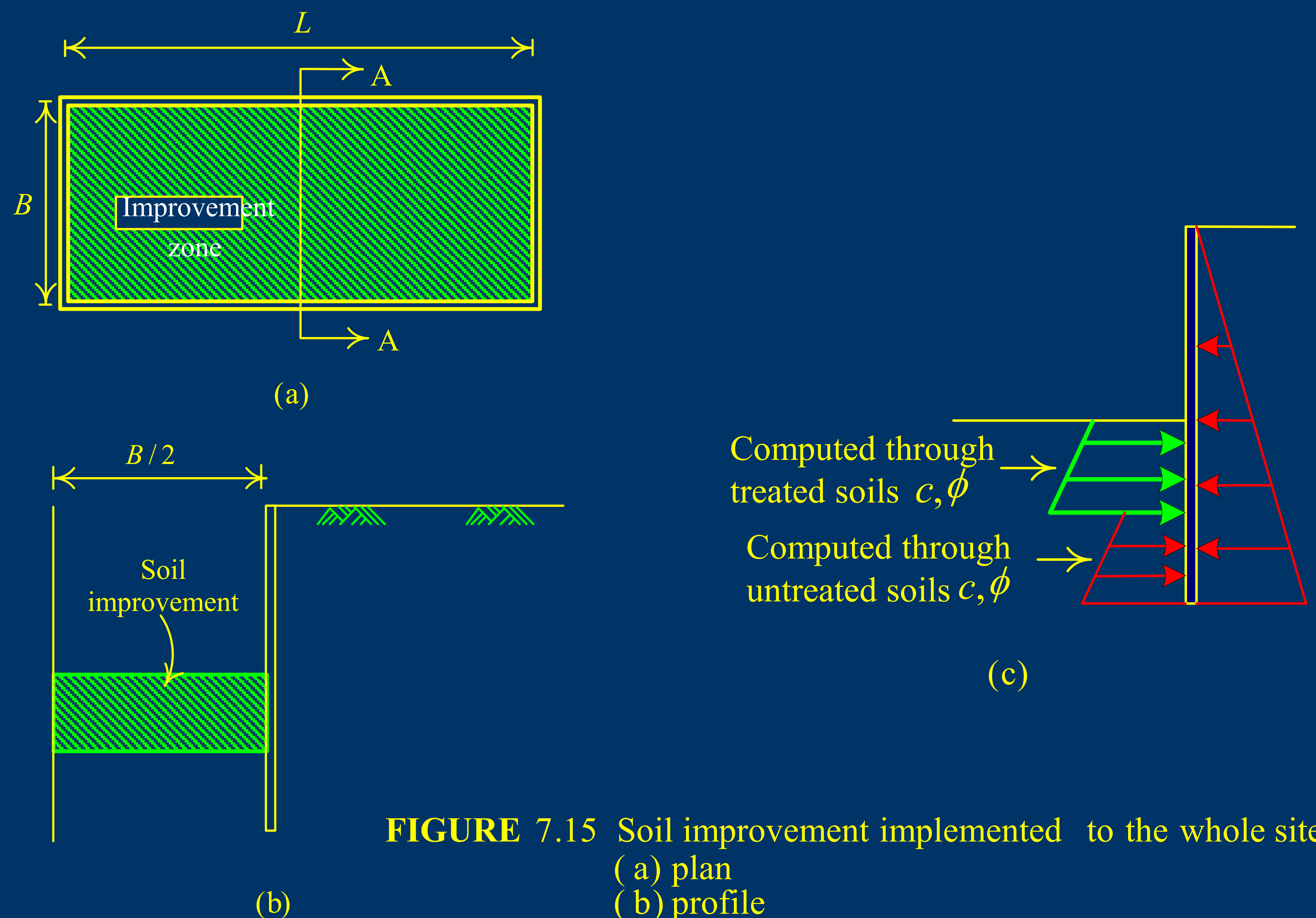


FIGURE 7.15 Soil improvement implemented to the whole site
(a) plan
(b) profile
(c) distribution of earth pressure

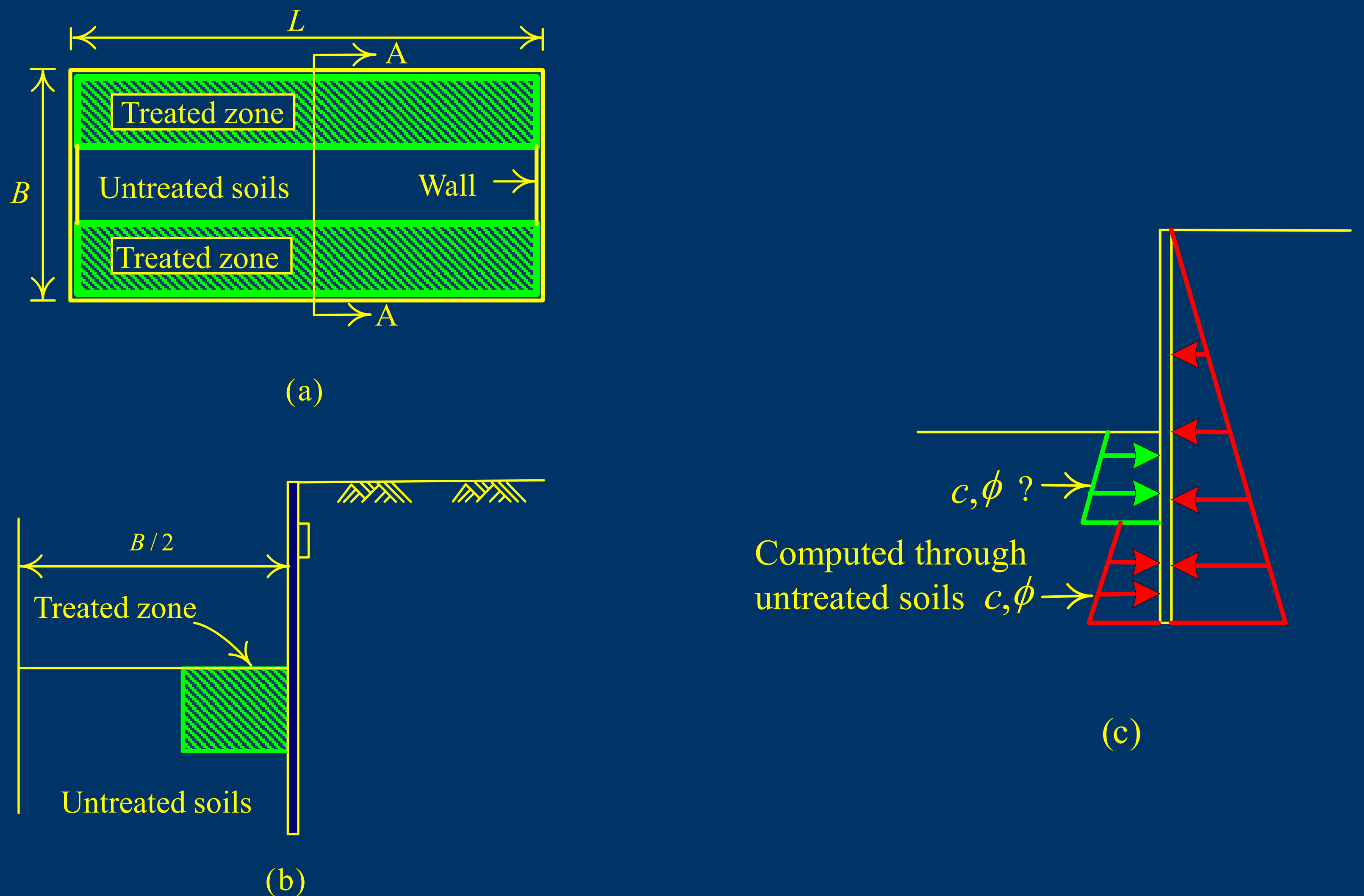


FIGURE 7.16 Soil improvement implemented to a part of the excavation zone (a) plan (b) profile (c) distribution of earth pressure