Example 4: Immediate settlement under a rectangular loaded area on layered subsoil

1 Description of the problem

To verify the mathematical model of *ELPLA* for computing the immediate (elastic) settlement under a rectangular loaded area on layered subsoil, the immediate settlement of saturated clay layers under a rectangular loaded area calculated by *Graig* (1978), Example 6.4, page 175, is compared with that obtained by *ELPLA*.

Janbu/ Bjerrum/ Kjaernsli (1956) presented a solution for the average settlement under an area carrying a uniform pressure q [kN/m^2] on the surface of a limited soil layer using dimensionless factors. Factors are determined for *Poisson's* ratio equal to ν_s = 0.5 [-]. The average vertical settlement s_a [m] is given by

$$s_a = my_0 \; my_1 \frac{qB}{E_s} \qquad (5)$$

where:

μ_0, μ_1 Coefficients for vertical displacement according to *Janbu/ Bjerrum/ Kjaernsli* (1956)
E_s undrained modulus of the soil [kN/m^2]
B lesser side of a rectangular area [m]
q Load intensity [kN/m^2]

Eq. 5 can be used to estimate the immediate (elastic) settlement of loaded areas on saturated clays; such settlement occurs under undrained conditions. The principle of superposition can be used in cases of a number of soil layers each having a different undrained modulus E_s.

A foundation 4 [m] × 2 [m], carrying a uniform pressure of q = 150 [kN/m^2], is located at a depth of d_f = 1.0 [m] in a layer of clay 5.0 [m] thick for which the undrained modulus of the layer E_s is 40 [MN/m^2]. The layer is underlain by a second clay layer 8.0 [m] thick for which the undrained modulus of the layer E_s is 75 [MN/m^2]. A hard stratum lies below the second layer. A plan of the foundation with dimensions and FE-Net as well as a cross section through the soil under the foundation are presented in Figure 4. It is required to determine the average immediate settlement under the foundation.

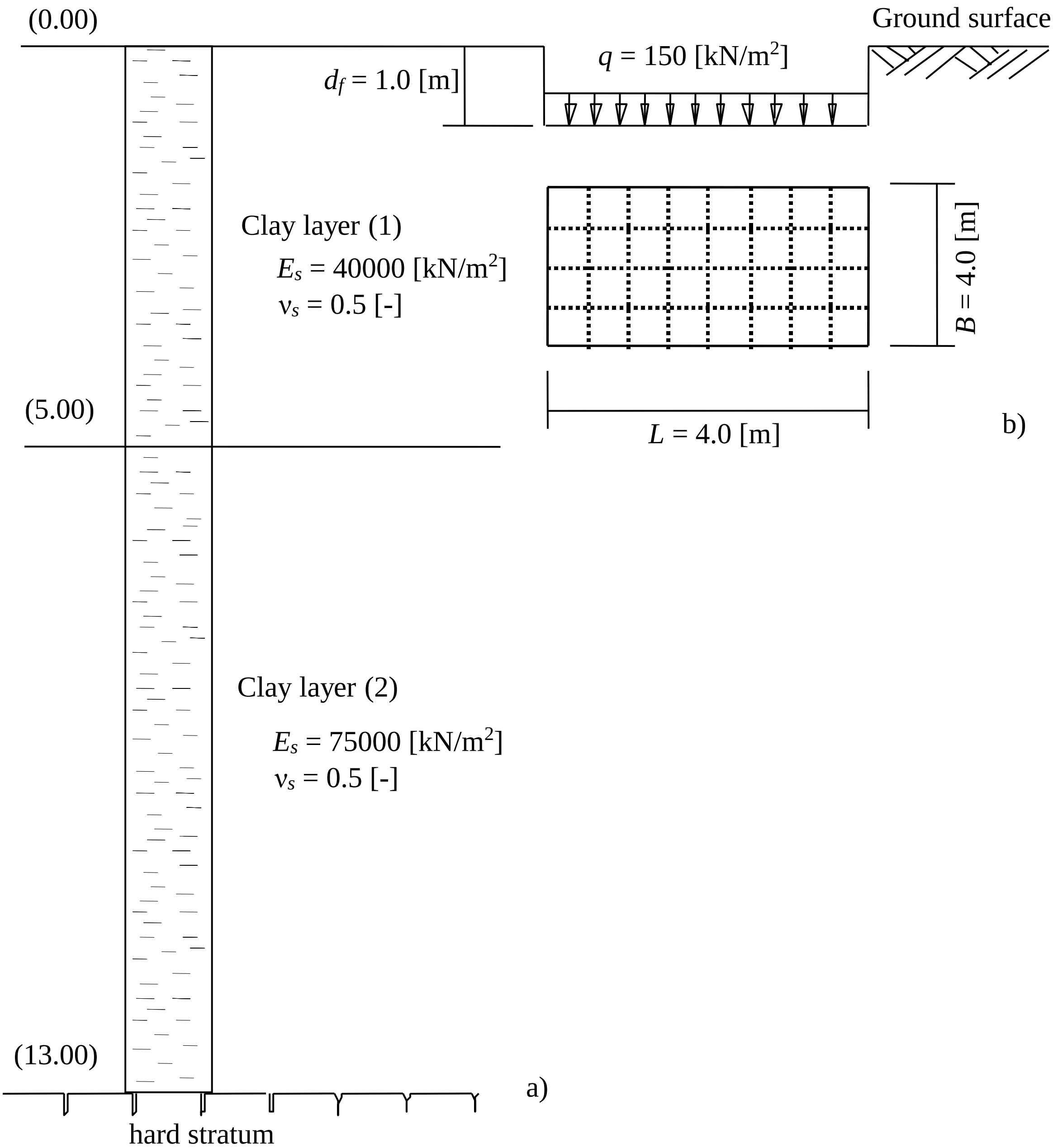

Figure 4 a) Cross section through the soil under the foundation

b) Plan of the foundation with dimensions and FE-Net

2 Hand calculation of the immediate settlement

According to *Graig* (1978), the average immediate settlement under the foundation can be obtained by hand calculation as follows:

Determination of the coefficient μ_0

$$\frac{d_f}{B} = \frac{1}{2} = 0.5[-] \text{ and } \frac{L}{B} = \frac{4}{2} = 2\,[-]$$

From charts of *Janbu/ Bjerrum/ Kjaernsli* (1956)

$$my_0 = 0.9 \text{ [-]}$$

a) Considering the upper clay layer, with E_s = 40 [MN/m^2] and thickness H = 4.0 [m]

$$\frac{H}{B} = \frac{4}{2} = 2 \text{ [-] and } \frac{L}{B} = \frac{4}{2} = 2 \text{ [-]}$$

then my_1 = 0.7 [-]

Hence from Eq. 5

$$s_{a1} = 0.9 \times 0.7 \times \frac{150 \times 2}{40000} = 0.0047 \text{ [m]} = 0.47 \text{ [cm]}$$

b) Considering the two layers combined, with E_s = 75 [MN/m^2] and thickness H = 12.0 [m]

$$\frac{H}{B} = \frac{12}{2} = 6 \text{ [-] and } \frac{L}{B} = \frac{4}{2} = 2 \text{ [-]}$$

then my_1 = 0.9 [-]

Hence from Eq. 5

$$s_{a2} = 0.9 \times 0.9 \times \frac{150 \times 2}{75000} = 0.0032 \text{ [m]} = 0.32 \text{ [cm]}$$

c) Considering the upper layer, with E_s = 75 [MN/m^2] and thickness H = 4.0 [m]

$$\frac{H}{B} = \frac{4}{2} = 2 \text{ [-] and } \frac{L}{B} = \frac{4}{2} = 2 \text{ [-]}$$

then my_1 = 0.7 [-]

Hence from Eq. 5

$$s_{a3} = 0.9 \times 0.7 \times \frac{150 \times 2}{75000} = 0.0025 \text{ [m]} = 0.25 \text{ [cm]}$$

Hence, using the principle of superposition, the average immediate settlement s_a of the foundation is given by

$$s_a = s_{a1} + s_{a2} - s_{a3} = 0.47 + 0.32 - 0.25 = 0.54 \text{ [cm]}$$

For rectangular flexible foundation the average settlement s_a is equal to 0.85. Then, the central immediate settlement s_c of the foundation is given by

$$s_c = \frac{1}{0.85} s_a = \frac{0.54}{0.85} = 0.64 \text{ [cm]}$$

Christian/ Carrier (1978) carried out a critical evaluation of the factors μ_0 and μ_1 of *Janbu/ Bjerrum/ Kjaernsli* (1956). The results are presented in a graphical form. The interpolated values of μ_0 and μ_1 from these graphs are given in Table 4. The average settlement s_c according to this table is s_c = 0.60 [cm].

Table 4 Factors μ_0 and μ_1 according to *Christian/ Carrier* (1978)

Variation of μ_0 with d_f/B

d_f/B	μ_0
0	1.0
2	0.9
4	0.88
6	0.875
8	0.87
10	0.865
12	0.863
14	0.860
16	0.856
18	0.854
20	0.850

Variation of μ_1 with L/B

H/B	Circle	L/B				
		1	2	5	10	∞
1	0.36	0.36	0.36	0.36	0.36	0.36
2	0.47	0.53	0.63	0.64	0.64	0.64
4	0.58	0.63	0.82	0.94	0.94	0.94
6	0.61	0.67	0.88	1.08	1.14	1.16
8	0.62	0.68	0.90	1.13	1.22	1.26
10	0.63	0.70	0.92	1.18	1.30	1.42
20	0.64	0.71	0.93	1.26	1.47	1.74
30	0.66	0.73	0.95	1.29	1.54	1.8
						4

3 Immediate settlement by *ELPLA*

The available method "Flexible foundation 9" in *ELPLA* is used to determine the immediate settlement under the center of the foundation. A net of equal square elements is chosen. Each element has a side of 0.5 [m] as shown in Figure 4b. The immediate settlement obtained by *ELPLA* under the center of the raft is s_c = 0.65 [cm] and nearly equal to that obtained by hand calculation.