Example 5: Immediate settlement under a circular tank on layered subsoil

1 Description of the problem

To verify the immediate settlement under a circular loaded area calculated by *ELPLA*, the immediate settlement at the center of a tank calculated by *Das* (1983), Example 6.2, page 354, is compared with that obtained by *ELPLA*.

A circular tank of 3.0 [m] diameter is considered as shown in Figure 5. The base of the tank is assumed to be flexible and having a uniform contact pressure of q = 100 [kN/m^2]. A sand layer 9.0 [m] thick is located under the tank. The modulus of elasticity of the sand is E_s = 21000 [kN/m^2] while *Poisson's* ratio of the sand is ν_s = 0.3 [-]. It is required to determine the immediate settlement at the center of the tank for two cases:

- Considering the underlying soil as one layer of 9.0 [m] thickness
- Dividing the underlying soil into three layers of equal thickness of 3.0 [m]

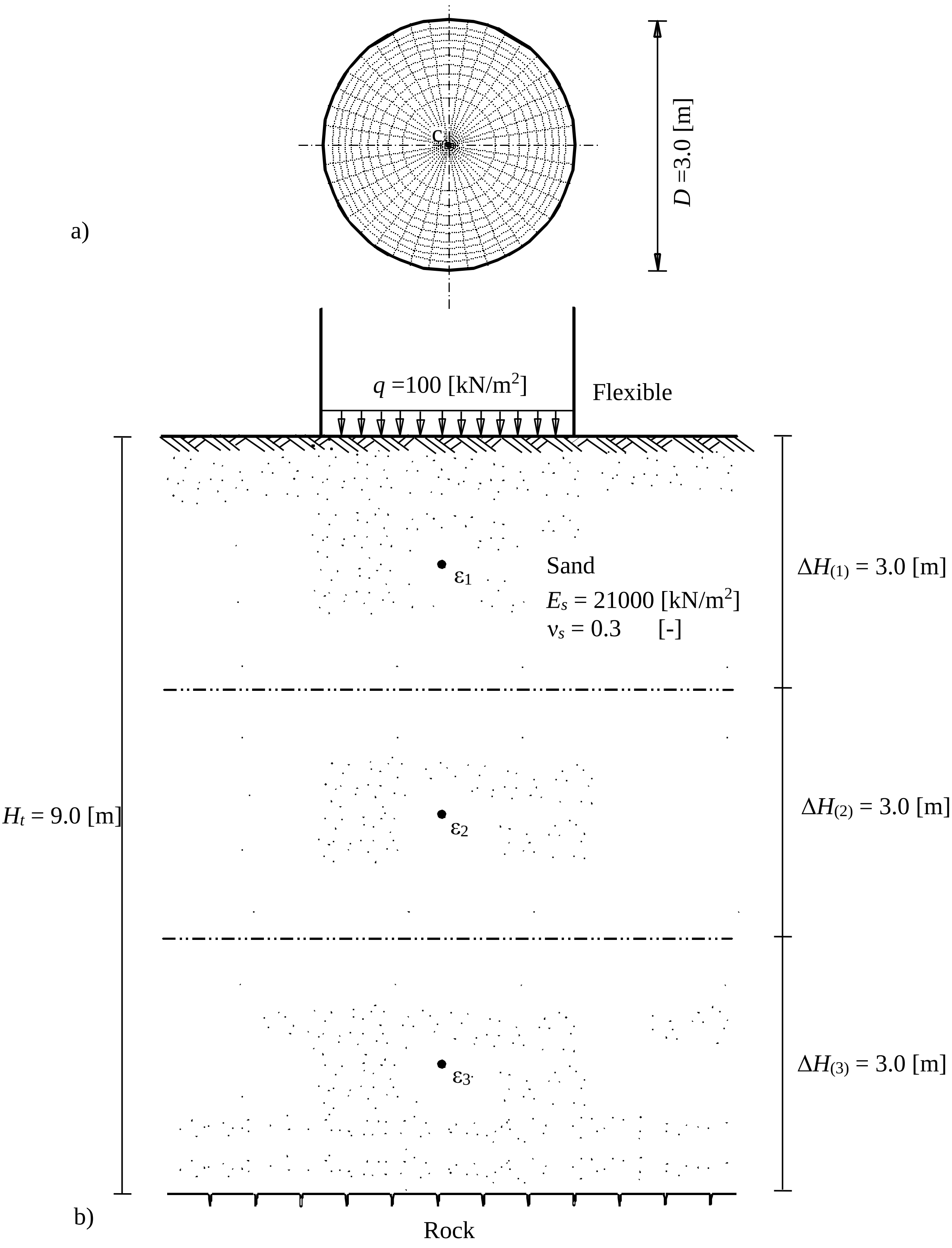

Figure 5 a) Plan of the tank with dimensions and FE-Net

b) Cross section through the soil under the tank

2 Hand calculation of the immediate settlement

According to *Das* (1983), the immediate settlement at the center of the tank can be obtained by hand calculation as follows:

a) Considering the underlying soil as one layer of 9.0 [m] thickness

The vertical deflection s_e [m] under the center of a circular loaded area at a depth z [m] from the surface can be obtained from

$$s_e = q \frac{1 + ny_s}{E_s} r \left[\frac{z}{r} I_1 + \left(1 - ny_s\right) I_2\right] \qquad (6)$$

where:

I_1, I_2 Coefficients for vertical deflection (which is a function of z/r and s/r) according to *Ahlvin/ Ulery* (1962) [-]
ν_s *Poisson's* ratio of the soil [-]
E_s Modulus of elasticity of the soil [kN/m^2]
r Radius of the circular area [m]
q Load intensity [kN/m^2]
s Distance from the center of the circular area [m]

Settlement at the surface $s_{e\,(z=0)}$

At surface z/r = 0 and s/r = 0. Then, I_1 = 1 and I_2 = 2

$$s_{e(z=0)} = 100 \frac{1 + 0.3}{21000} 1.5 \left[0 + \left(1 - 0.3\right) 2\right] = 0.013 \text{ [m]}$$

Settlement at depth z = 9.0 [m] from the surface $s_{e\,(z=9)}$

For z/r = 9/1.5 = 6 and s/r = 0. Then, I_1 = 0.01361 and I_2 = 0.16554

$$s_{e(z=9)} = 100 \frac{1 + 0.3}{21000} 1.5 \left[\frac{9}{1.5} 0.0136 + \left(1 - 0.3\right) 0.16554\right] = 0.00183 \text{ [m]}$$

The immediate settlement s_e is given by

$$s_e = s_{e(z=0)} - s_{e(z=9)} = 0.0130 - 0.00183 = 0.01117 \text{ [m]}$$

b) Dividing the underlying soil into three layers of equal thickness of 3.0 [m]

Another general method for estimation of immediate settlement is to divide the underlying soil into *n* layers of finite thickness $\Delta H_{(i)}$. If the strain $\varepsilon_{z(i)}$ at the middle of each layer can be calculated, the total immediate settlement s_e [m] can be obtained as

$$s_e = \sum_{i=1}^{i=n} \Delta H_{(i)}\ \varepsilon_{z(1)} \qquad (7)$$

The strain ε_z at the middle of the layer is given by

$$\varepsilon_z = q\,\frac{1 + ny_s}{E_s}\left[\left(1 - 2ny_s\right)A^` + B^`\right] \qquad (8)$$

where:

A', B' Coefficients for vertical deflection (which is a function of z/r and s/r) according to *Ahlvin/ Ulery* (1962)

Layer (1)

For z/r = 1.5/1.5 = 1 and s/r = 0. Then, A' = 0.29289 and B' = 0.35355

Layer (2)

For z/r = 4.5/1.5 = 3 and s/r = 0. Then, A' = 0.05132 and B' = 0.09487

Layer (3)

For z/r = 7.5/1.5 = 5 and s/r = 0. Then, A' = 0.01942 and B' = 0.03772

The final stages in the calculation are listed in Table 5.

Table 5 Final stages in the calculation of immediate settlement s_e

Layer No.	Layer thickness $\Delta H_{(i)}$ [m]	Strain at the center of the layer $\varepsilon_{z(i)}$ [-]	Immediate settlement $s_{e(i)}$ [m]
1	3.0	0.00291	0.00873
2	3.0	0.00071	0.00213
3	3.0	0.00028	0.00084
Total immediate settlement $s_e = \sum$			0.0117

3 Immediate settlement by *ELPLA*

The tank rests on a layer of sand. However, in *ELPLA*, it will be sufficiently accurate to consider the sand layer as a whole but the immediate settlement is to be calculated twice. The first calculation by considering the underlying soil as one layer of 9.0 [m] thickness and the second calculation by dividing the underlying soil into three layers of equal thickness of 3.0 [m]. The contact pressure of the tank in this example is known where the tank base is considered to be flexible. Therefore, the available method "Flexible foundation 9" in *ELPLA* is used here to determine the immediate settlement of the sand layer. The immediate settlements obtained by *ELPLA* under the center of the tank in both cases of calculations are compared with those obtained by hand calculation in Table 6.

Table 6 Comparison of immediate settlements s_e [cm] obtained by *ELPLA* and *Das* (1983)

Calculation	s_e [cm]	
	Das (1983)	*ELPLA*
Considering the underlying soil as one layer	1.117	1.115
Dividing the underlying soil into three layers	1.170	1.115

Table 6 shows that results of the immediate settlements obtained by *ELPLA* and those obtained by *Das* (1983) for both cases are in good agreement.