Example 31: Group of 9 isolated footings

1 Description of the problem

To verify the interaction of a group of footings, the settlement determined using the finite element method under the group of isolated footings from EWB (2003), Example 8.1, page 88, is compared with that obtained by *ELPLA*. This example is intended to show how the consideration of the stress overlap affects the result of the settlement calculation for a group of footings. Figure 78 shows the foundation plan of the group of 9 isolated footings. They are loaded vertically by supporting a frame structure. The columns transfer the loads of 800 [kN] and 1200 [kN from the superstructure to the footings. Outer columns 1, 2, 3 and 7, 8, 9 have the dimensions 50 x 50 [cm], while inner columns 4, 5, 6 have the dimensions75 x 50 [cm].

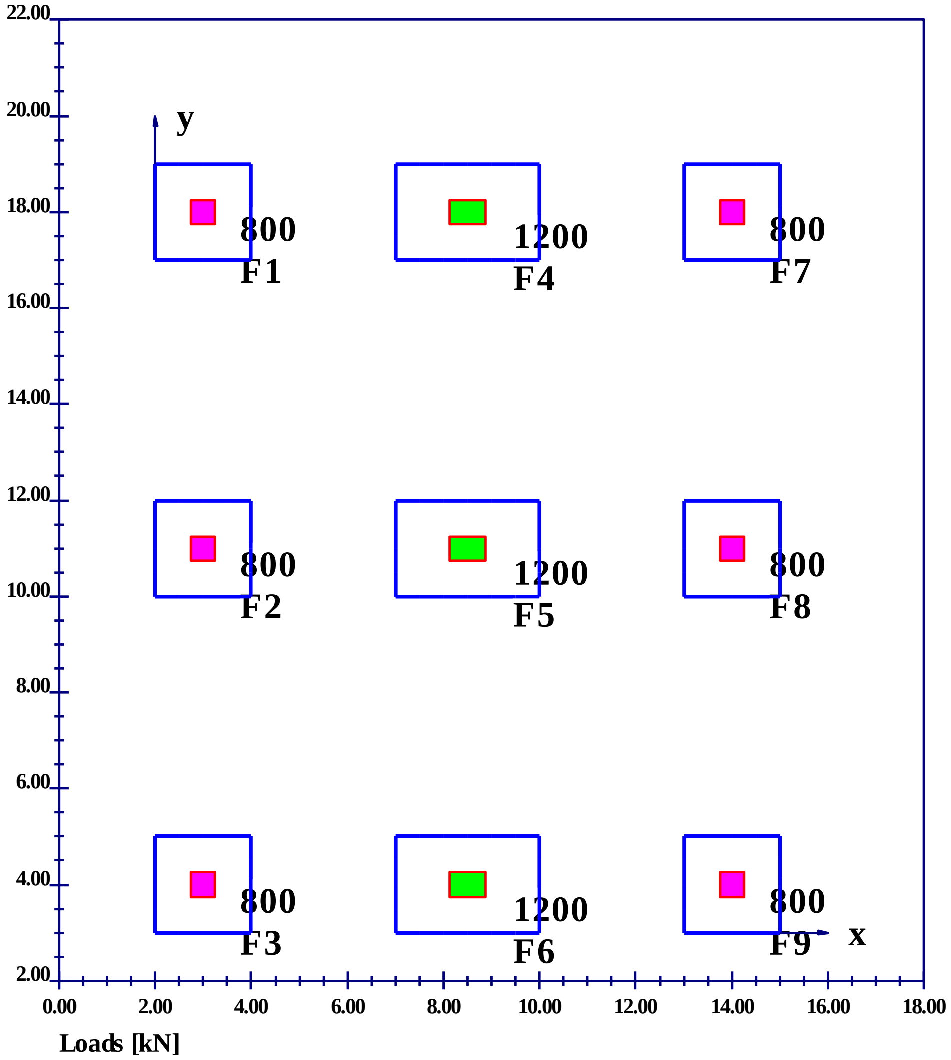


Figure 78 Foundation plan of the group of 9 isolated footings with loads [kN]

2 Loads

Each of the six square footings 1, 2, 3, 7, 8 and 9 is loaded with 800 [kN], while each of the three rectangular footings 4, 5 and 6 is loaded with 1200 [kN], as shown in Figure 78.

3 Soil properties

In the analysis, two different soil profiles are considered as:

Case 1: Isotropic elastic Half-Space soil medium with homogeneous stratification: silt
Case 2: Layered soil medium with two soil layers: silt and gravel

In this example, two limiting cases of the radius of influence are considered:

1) 2.00 [m] (no influence from neighboring footings)
2) 17.50 [m] (influence from all footings)

There are two layers of subsoil under the footings, as shown in Table 45 and Figure 79. The limit depth is not determined, as there is an incompressible layer at a depth of 10 m below the silt or gravel layer. The groundwater is at a depth of Tw = 10 [m] under the ground surface, while the foundation depth for all footings is Tf = 1.5 [m]. In order to be able to represent these dependencies as clearly as possible, the settlement calculation is limited to the initial load approach (Loading case).

Table 45 Soil properties and depth of the layers for the subsoil cases 1 and 2

Case No.	Layer No.	Soil type	Depth of the layer under the ground surface Tf [m]	Modulus of Compressibility for loading E_s [kN/m^2]	Unit weight of the soil γ_s [kN/m^3]
Case 1	1	Silt	4.7	8 000	17
	2	Silt	10	8 000	17
Case 2	1	Silt	4.7	8 000	17
	2	Gravel	10	120 000	19

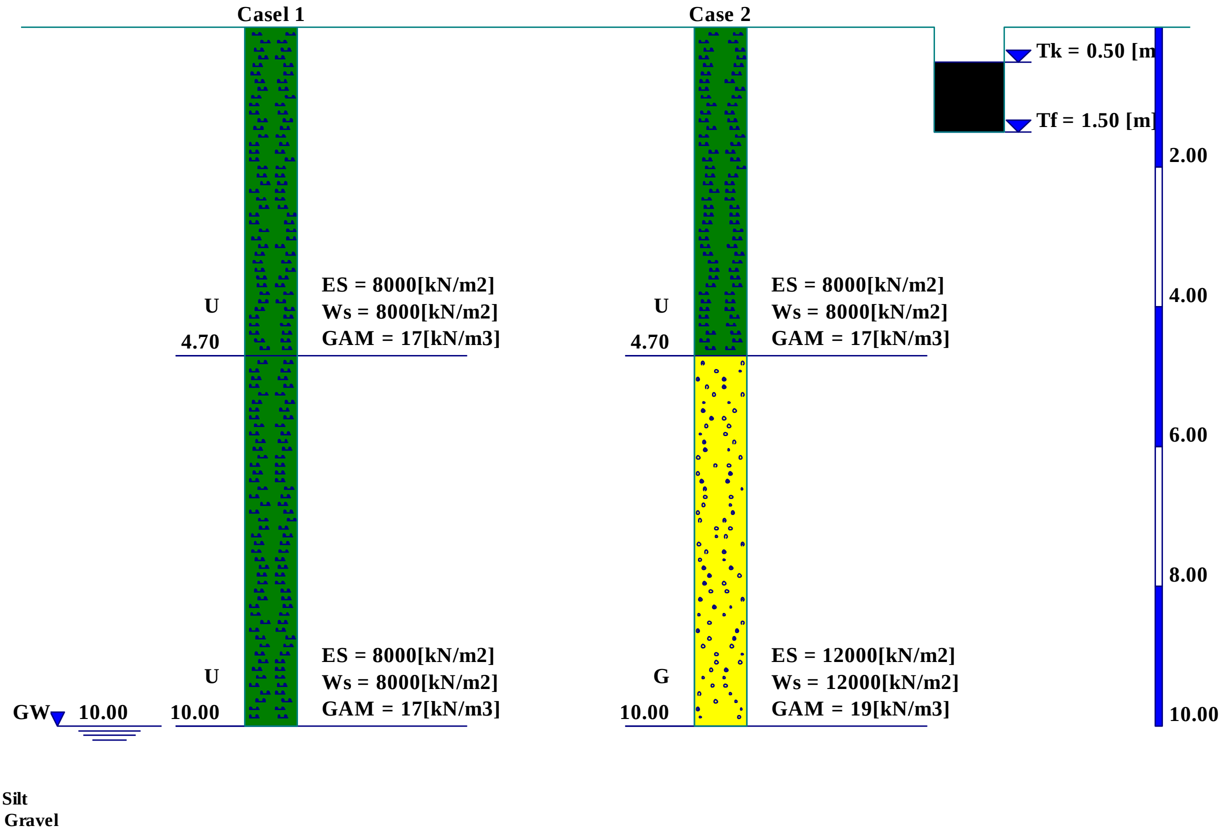


Figure 79 Soil layers of cases 1 and 2

4 Slab thickness and material properties of the concrete

The 9 isolated footings are represented by plate finite elements. The thickness of the footing (d = 1 [m]) is used as the element thickness. Concrete grade is B 35, while steel grade is BST 500. The behavior of the material is assumed homogeneous and isotropic with no non-linear properties. The material properties of the slab are:

Modulus of Elasticity	E_b	$= 3.4 \times 10^7$	[kN/m^2]
Poisson's ratio	ν_b	= 0.2	[-]
Unit weight of the slab material	γ_b	= 0.0	[kN/m^3]

The weight of the concrete is neglected in this example.

5 Analyzing by *ELPLA*

5.1 Choosing the calculation method

In this example, the modulus of compressibility method for the elastic plate (Method 7) was chosen to analysis the group of 9 isolated footings. The calculation of the group of 9 isolated footings can be carried out for the entire group of 9 isolated footings using one FE-Net. The group of 9 isolated footings is divided into 225 square elements with a side length of 0.5 [m] (Figure 80).

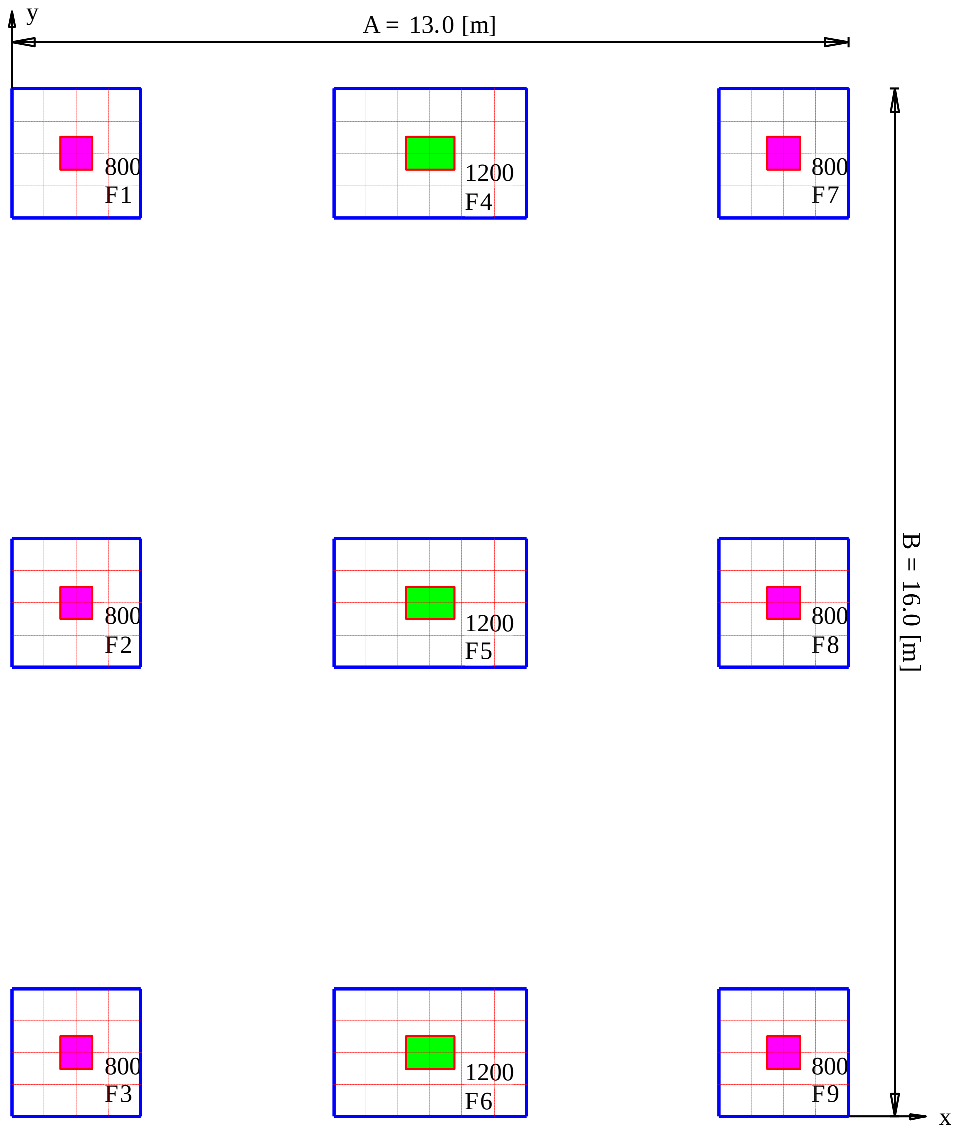


Figure 80 FE-Net for the entire group of 9 isolated footings with loads [kN]]

5.2 Limit distance between the nodes for calculating the flexibility coefficients

In the case of large systems, this can drastically reduce the computing time. In the following, two different radii of influence are considered as borderline cases in order to illustrate the effect. In a variant, it is chosen to be very small at 2.00 [m] in order to exclude any influence from neighboring footings. In a second, the radius of influence is increased to 17.5 [m] in order to take into account the influence of the remaining eight footings for each footing. It should be noted that too small a radius of influence has a negative effect on the quality of the results.

5.3 Determination of the deformations on the surface

To determine the deformations on the surface area, the group of 9 isolated footings and the surface area are divided into two independent FE-Nets, as shown in Figure 81. Two independent names are chosen to define the data of the group of 9 foundations and the surface. The subsoil data are similar for the two projects. The original coordinates of the group of 9 isolated foundations are (x_o, y_o) = (2.0, 3.0), but for the surface area (0.0, 0.0).

The calculation of the group of 9 isolated footings is carried out first in order to obtain the contact pressures under footings. Due to these contact pressures, settlement occurs not only under the group of 9 isolated footings, but also on the outside under the surface area. Then the settlements of the outer areas are determined.

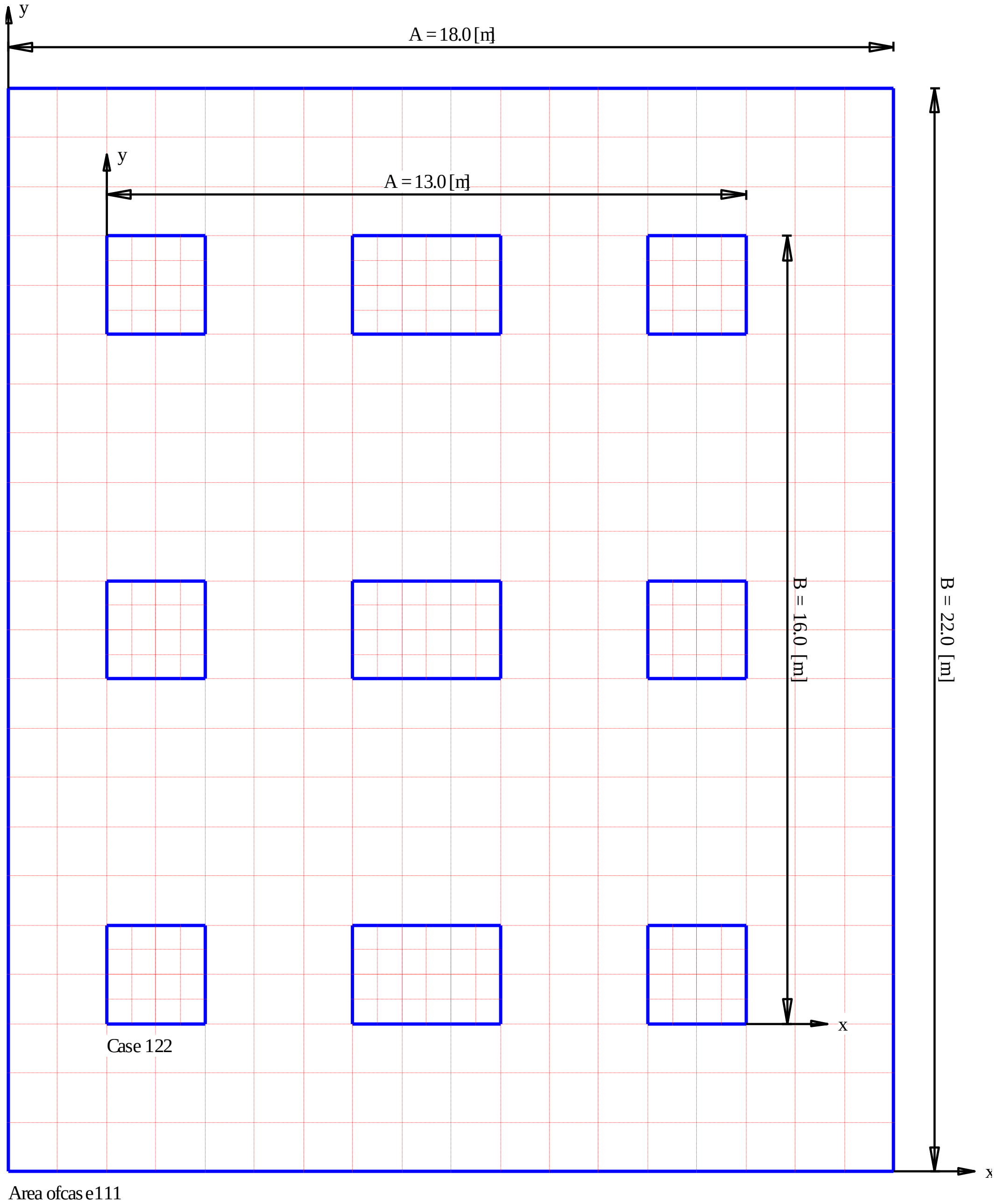


Figure 81 Discretization of the group of 9 footings and the surface

5.4 System variants

The group of 9 isolated footings without a superstructure are combined with the two soil profiles and the influence radii in four system variants.

Table 46 Overview of system variants

Soil profil	Influence radius [m]	System number
1	2.0	111
1	17.5	112
2	2.0	121
2	17.5	122

6 Comparison of results

Results for determining the interaction of the group of 9 isolated footings with the different calculation assumptions are presented in tabular form by manual calculation from EWB (2003) and *ELPLA*. Table 47 and from Figure 82 to Figure 89 show that the settlement has practically no difference.

Table 47 Maximum vertical settlements of the isolated footings [mm] from *EWB* (2003) and *ELPLA*

Footing	Variant							
	111		112		121		122	
	EWB	*ELPLA*	*EWB*	*ELPLA*	*EWB*	*ELPLA*	*EWB*	*ELPLA*
1	34.20	33.40	42.39	44.16	31.39	30.98	34.54	38.30
2	34.16	33.93	44.31	46.27	31.36	31.54	34.85	39.10
4	38.29	38.50	51.17	52.69	34.98	35.28	40.44	44.80
5	38.26	38.41	53.77	55.01	34.95	35.42	40.86	46.34

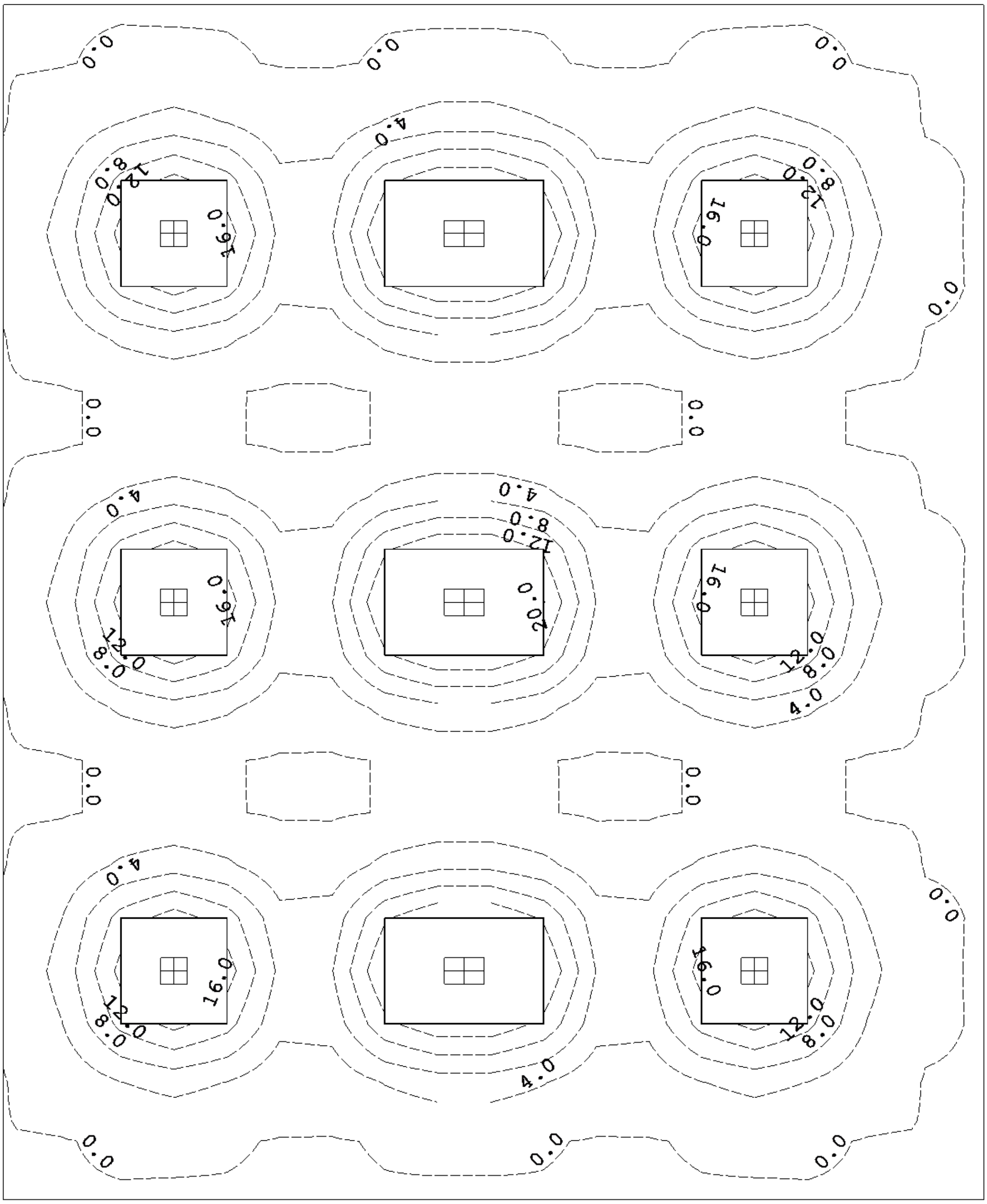


Figure 82 Settlement contour lines [mm] of system variant 111 according to Table 42 (*EWB*)

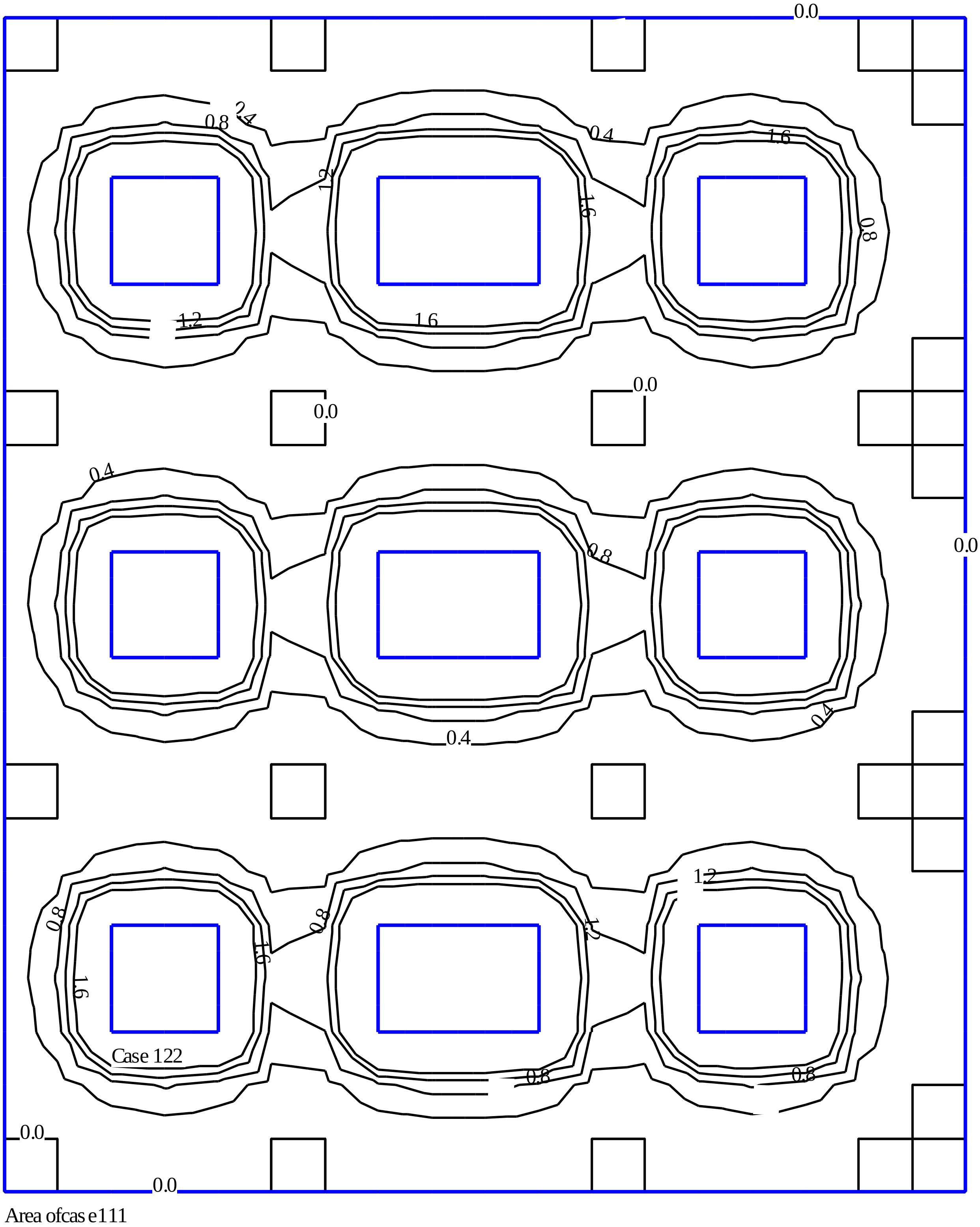


Figure 83 Settlement contour lines [cm] of system variant 111 according to Table 42 (*ELPLA*)

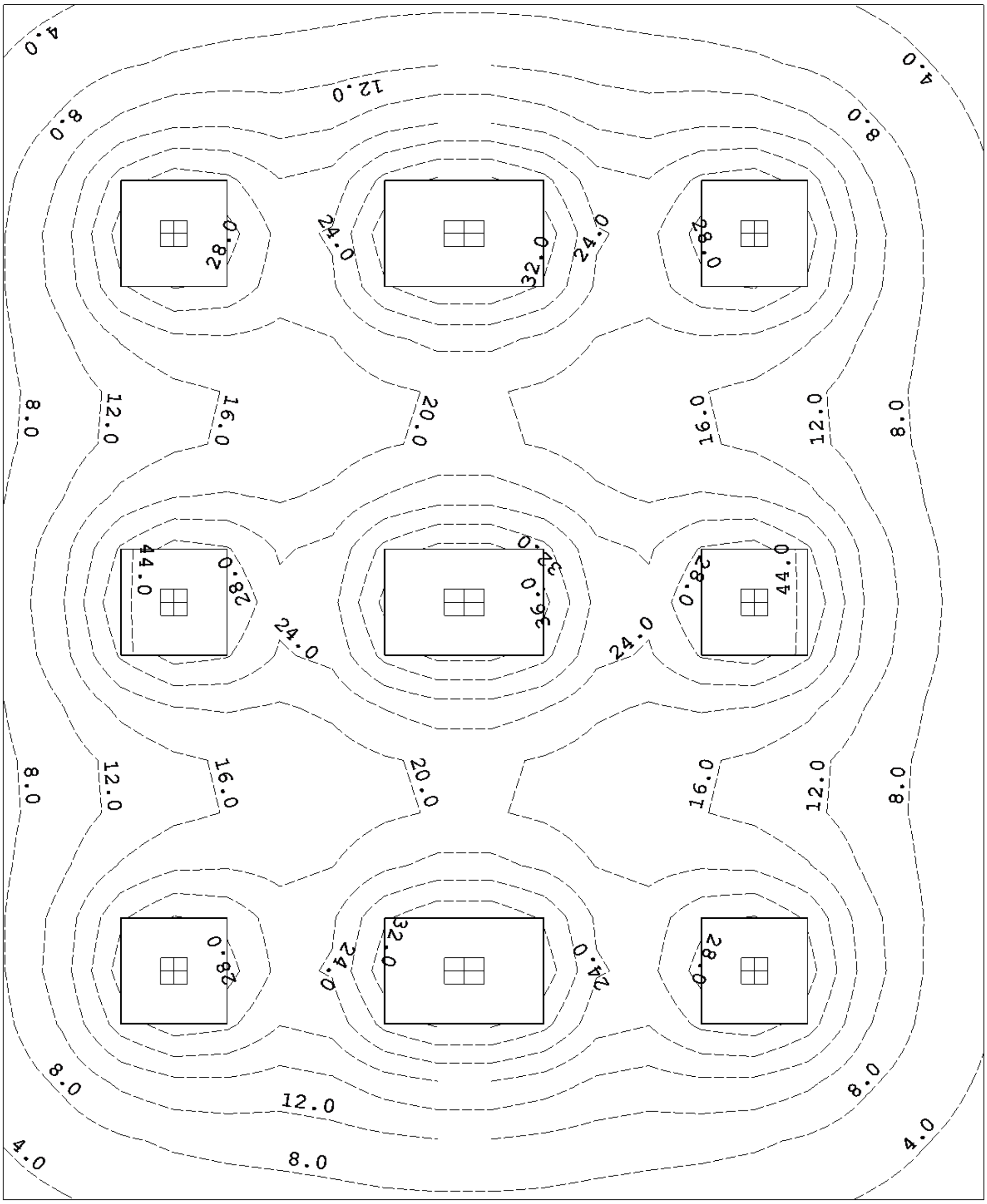
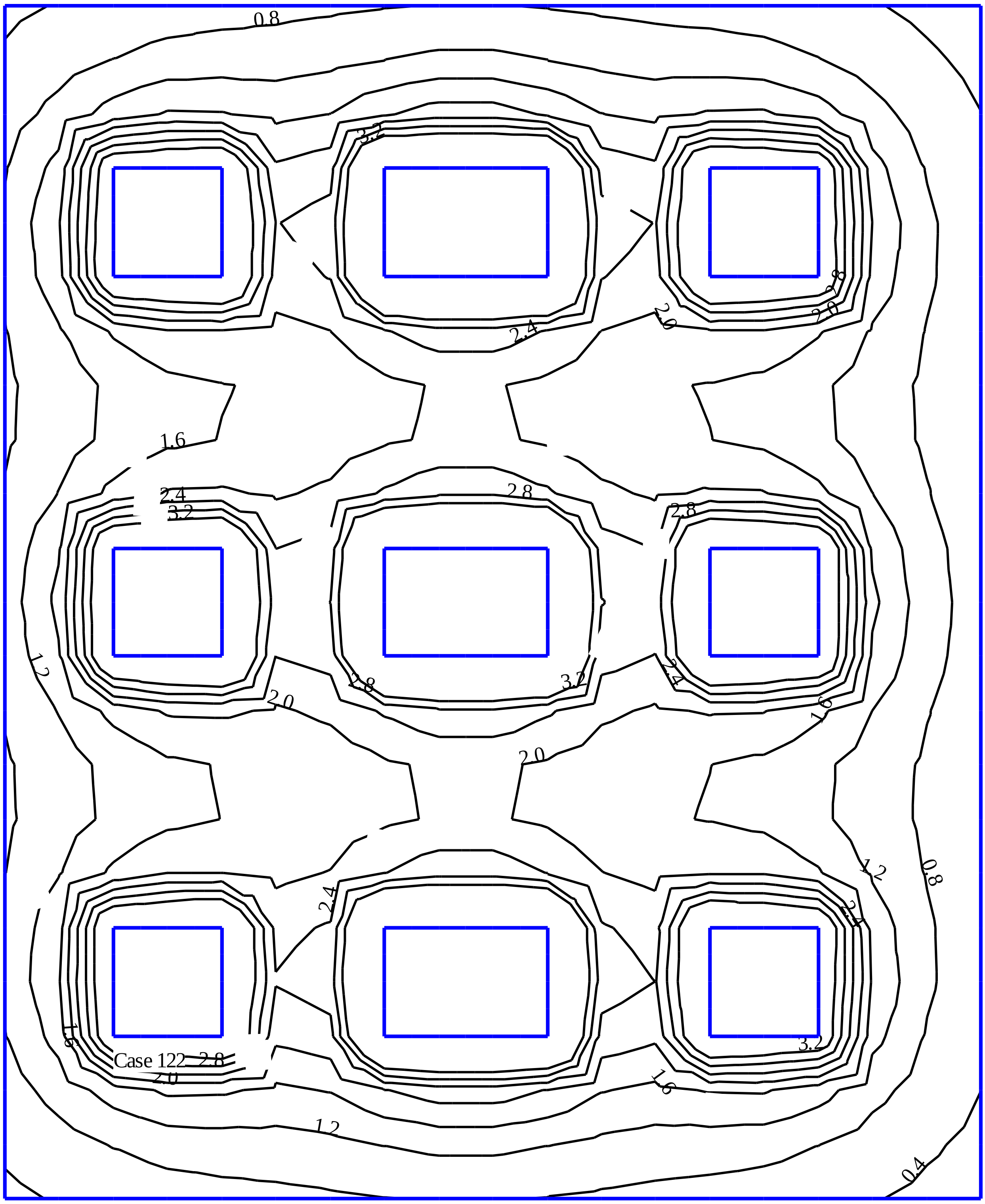


Figure 84 Settlement contour lines [mm] of system variant 112 according to Table 42 (*EWB*)



Area of case 112

Figure 85 Settlement contour lines [cm] of system variant 112 according to Table 42 (*ELPLA*)

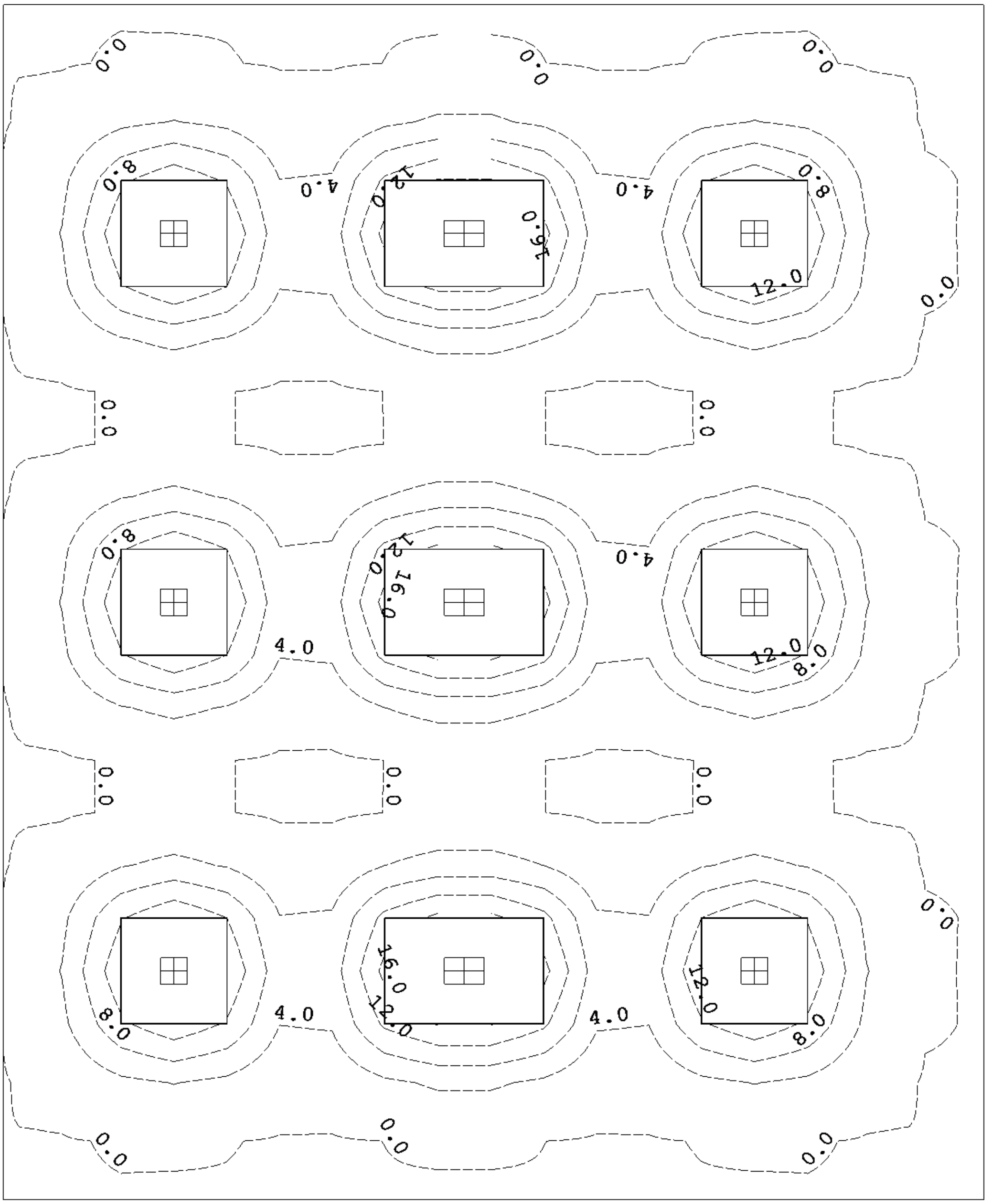


Figure 86 Settlement contour lines [mm] of system variant 121 according to Table 42 (*EWB*)

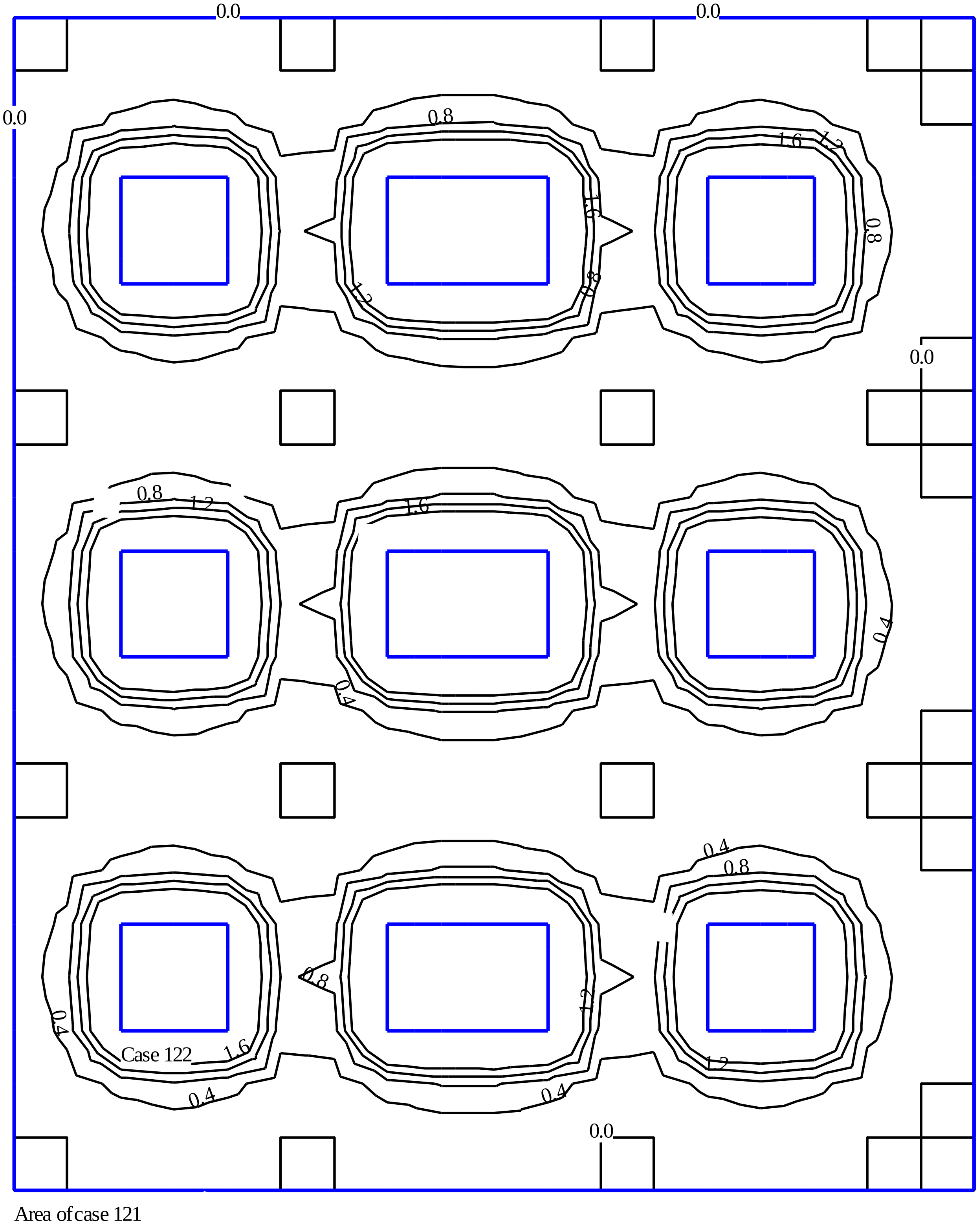


Figure 87 Settlement contour lines [cm] of system variant 121 according to Table 42 (*ELPLA*)

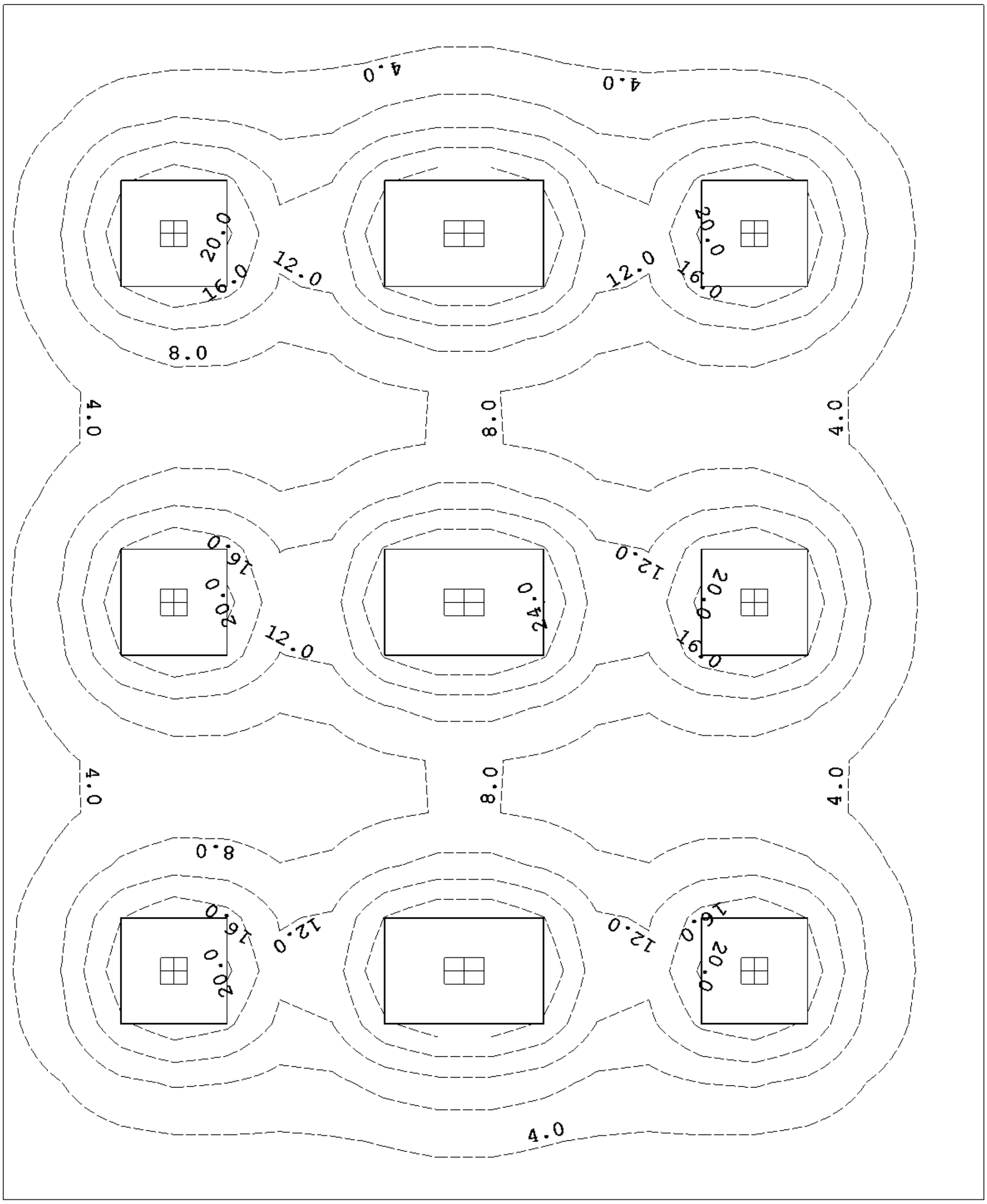


Figure 88   Settlement contour lines [mm] of system variant 122 according to Table 42 (*EWB*)

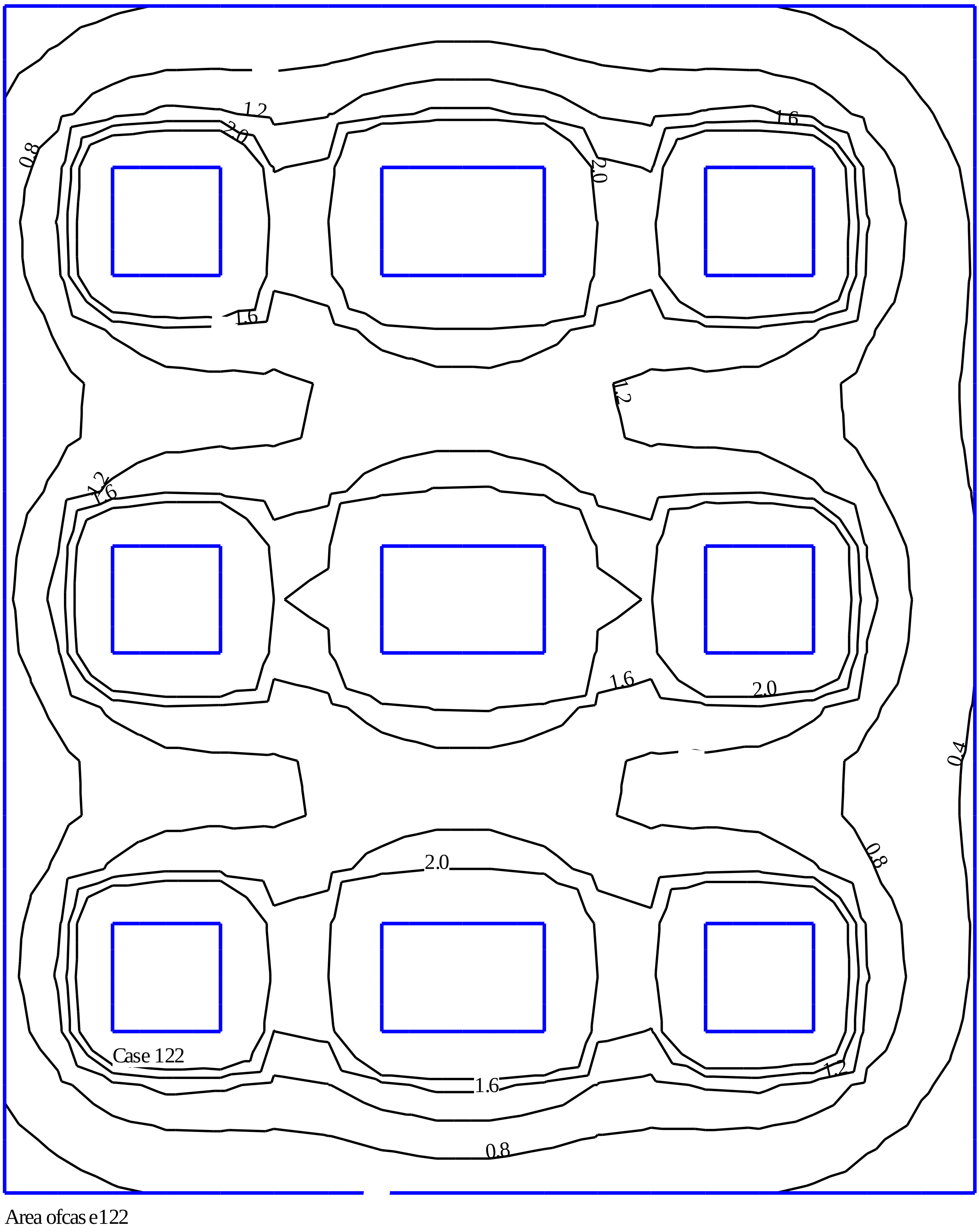


Figure 89 Settlement contour lines [cm] of system variant 122 according to Table 42 (*ELPLA*)

7 Discussion of results

7.1 System variant 111 according to Table 8.1.2

Without considering the stress overlap under footings and with a superstructure without rigidity, the edge footings 1, 2, 3 and 7, 8, 9 have the same settlement s = ~ 34 mm, the middle footings 4, 5, 6 have the same settlement s = ~ 38 mm. The differences in settlement are solely due to different footing sizes, since the mean soil stresses are the same.

7.2 System variant 112 according to Table 8.1.2

Taking into account the stress overlap and otherwise the same superstructure without rigidity as in variant 111, the settlement of the footings is the same on all sides of the main mirror axes. The corner footings 1, 3, 7, 9 have settlements s = ~ 42 mm. The square edge footings 2, 8 have settlements s = ~ 44 mm. The rectangular edge foundations 4, 6 have settlements s = ~ 51 mm and the central footing 5 has settlement of 53 mm. The increase in soil stresses caused by the stress overlap leads to greater settlement according to the number and distance of the adjacent footings.

7.3 System variant 121 according to Table 8.1.2

This variant, corresponding to variant 111, has the same settlement behavior; only the settlements are 3 to 4 mm lower because of the lower, stiffer layer.

7.4 System variant 122 according to Table 8.1.2

This variant, corresponding to variant 112, has the same settlement behavior; only the settlements are 8 to 13 mm lower due to the greater influence of the lower, stiffer layer on the effect of the stress overlap. The influence of the lesser effect of the stress overlap with a greater distance can be clearly seen.