Example 4.5 Analysis of a swimming pool

1 Description of the problem

A swimming pool is supposed to be constructed at a river. The existing ground around the pool has to be increased up to a meter. The pool has dimensions of 25 [m] × 10 [m] and maximum water depth of 1.20 [m] as shown in Figure 4.32. The foundation level is 1.45 [m] under the ground surface. Slab and walls are reinforced concrete of concrete grade B 25 with thickness of 25 [cm] for slab and 20 [cm] for walls. It is divided into two independent parts through a joint at the pool middle.

The filling material around the pool is non-cohesive soil (Figures 4.33 and 4.34). The filling is supposed to be carried out after finishing the pool.

In this example, it is required to study the following:

i) Influence of the joint on the settlements, contact pressures and internal forces of the pool slab and the pool walls in case of the pool is completely filled by water

ii) Influence of the ground rising by additional filling soil material at the southern part of the pool on the settlement

2 Soil properties

The subsoil under the swimming pool is defined by five boring logs B1 to B5 up to 15 [m] under the ground surface. The subsoil consists of four soil layers of fill, silt with organic admixture, silt clayey and gravel, which are not horizontally stratified as shown in Figure 4.33 and Table 4.8. *Poisson*'s ratio for the soil is ν_s = 0.3 [-]. Ground water level is 3.80 [m] under the ground surface.

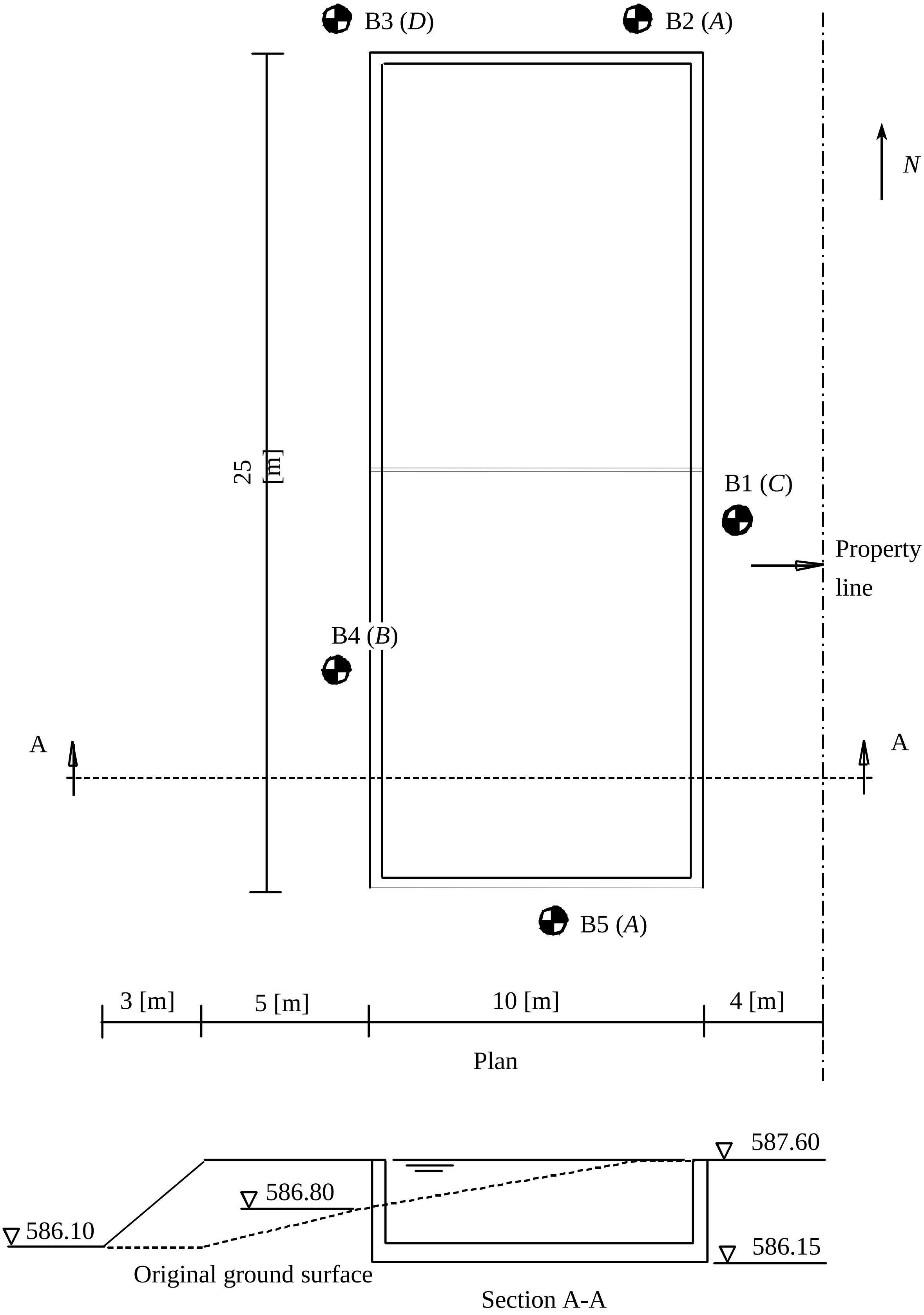

Figure 4.32 Details of the swimming pool

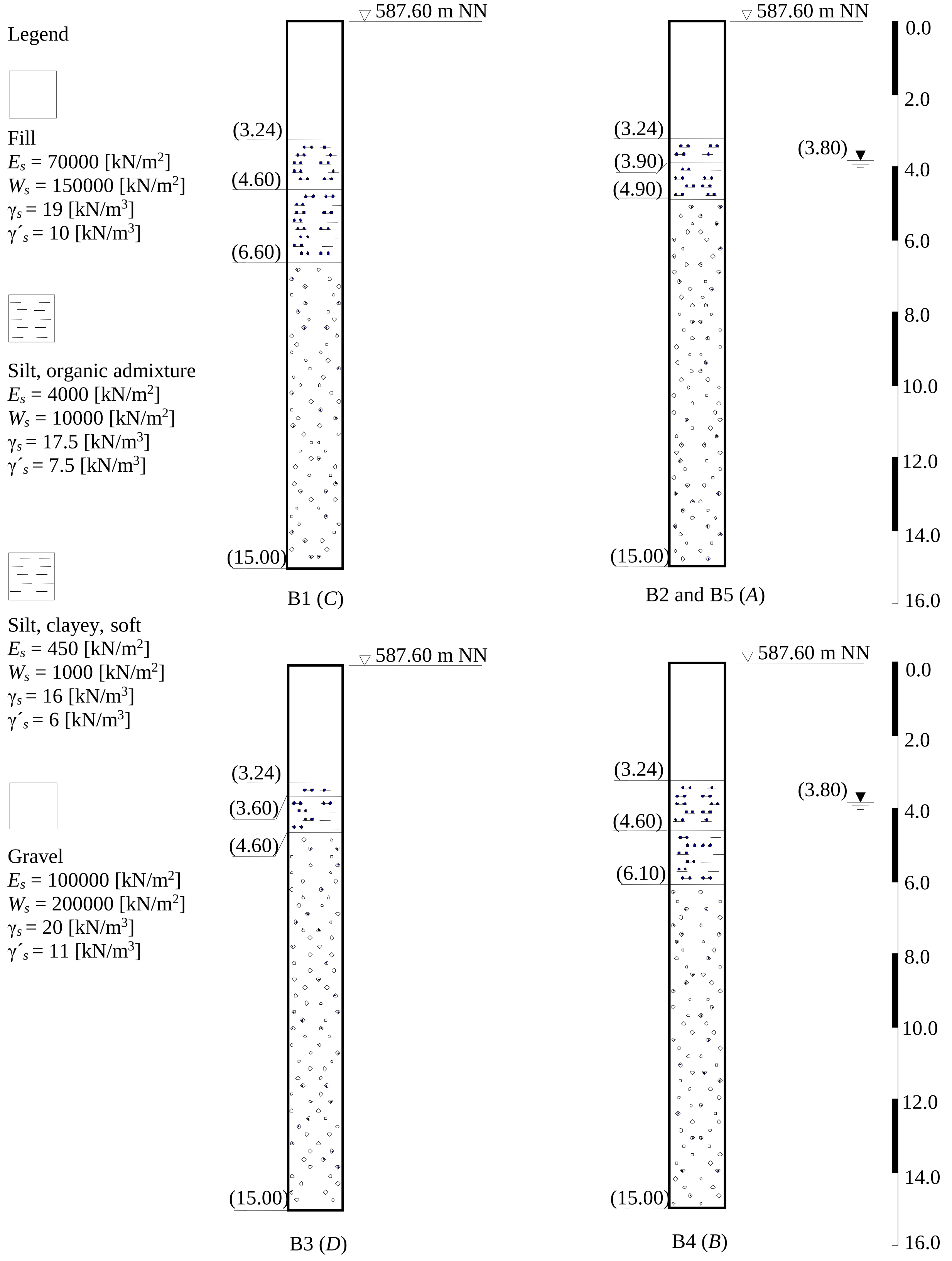

Figure 4.33 Boring logs B1 to B5 with soil properties

Table 4.8 Soil properties

Layer No.	Type of soil	Modulus of compressibility of the soil for		Unit weight of the soil	
		Loading E_s	Reloading W_s	above *GW* γ_s	under *GW* γ'_s
1	Fill	70000	150000	19	10
2	Silt, organic admixture	4000	10000	17.5	7.5
3	Silt, clayey, soft	450	1000	16	6
4	Gravel	100000	200000	20	11

3 Raft material and properties

The material of the raft and walls is reinforced concrete of grade B 25. It has the following properties:

Young's modulus E_b $= 3 \times 10^7$ [kN/m²]
Shear modulus G_b $= 1.3 \times 10^7$ [kN/m²]
Unit weight γ_b $= 25$ [kN/m³]
Poisson's ratio ν_b $= 0.25$ [-]

4 Stiffness of edge walls

The rigidity of the edge walls (thickness B = 0.2 [m], height H = 1.2 [m]) is simulated through beam elements along the raft edge with the following data:

Moment of inertia I

$$I = B \times \frac{H^3}{12}$$

$$= 0.2 \times \frac{1.2^3}{12} = 0.0288 \qquad [\mathrm{m}^4]$$

Torsional inertia J

$$J = H \times B^3 \times \left(\frac{1}{3} - 0.21\right) \frac{B}{H} \left\{1 - \frac{B^4}{12 \times H^4}\right\}$$

$$= 1.2 \times 0.2^3 \times \left(\frac{1}{3} - 0.21\right) \frac{0.2}{1.2} \left\{1 - \frac{0.2^4}{12 \times 1.2^4}\right\}$$

$$= 0.0286 \qquad [\mathrm{m}^4]$$

5 Determination of settlements, contact pressures and internal forces

5.1 Studying the influence of the joint

Four cases concerning the influence of the joint are considered as follows:

Case 1 Analysis without interaction (Figure 4.34)
The two rafts are constructed side by side separately without interaction between them through the soil

Case 2 Analysis with interaction but without shearing forces (Figures 4.34)
The two rafts are constructed side by side separately with interaction only through the soil. The zero distance between the two rafts is represented by concrete elements of 1 [cm] wide and 0 [cm] thickness

Case 3 Analysis with interaction and with shearing forces (Figure 4.36)
The two rafts are connected through hinged joint. The hinged joint is represented by elements of 1 [cm] wide and 2 [cm] thickness

Case 4 Analysis without joint (Figure 4.35)
Rather than two rafts, one raft is constructed

5.2 Studying the influence of surrounding loading

To study the influence of the surrounding loading on the swimming pool due to the filling soil material, the weight of the filling is represented by four loaded areas according to its weight intensity as shown in Figure 4.38 and Table 4.9. The loaded areas are subdivided into four independent nets. The analysis of these loaded areas is carried out firstly to obtain the contact pressures under them. Due to these computed contact pressures, the settlement will occur under the swimming pool.

Table 4.9 Properties of the loaded area

Loaded area No.	Dimensions [m]			Load	Foundation level	Origin coordinate	
	L	B	h	$p = \gamma\, h$ [kN/m^2]	t_f [m]	x [m]	y [m]
1	3	35	0.75	19 × 0.75 = 14.25	1.5	-3	-6
2	5	35	1.15	19 × 1.15 = 21.85	1.15	-3	-3
3	8	5	0.40	19 × 0.40 = 7.6	0.4	27	2
4	8	5	0.40	19 × 0.4 = 7.6	0.4	-3	2

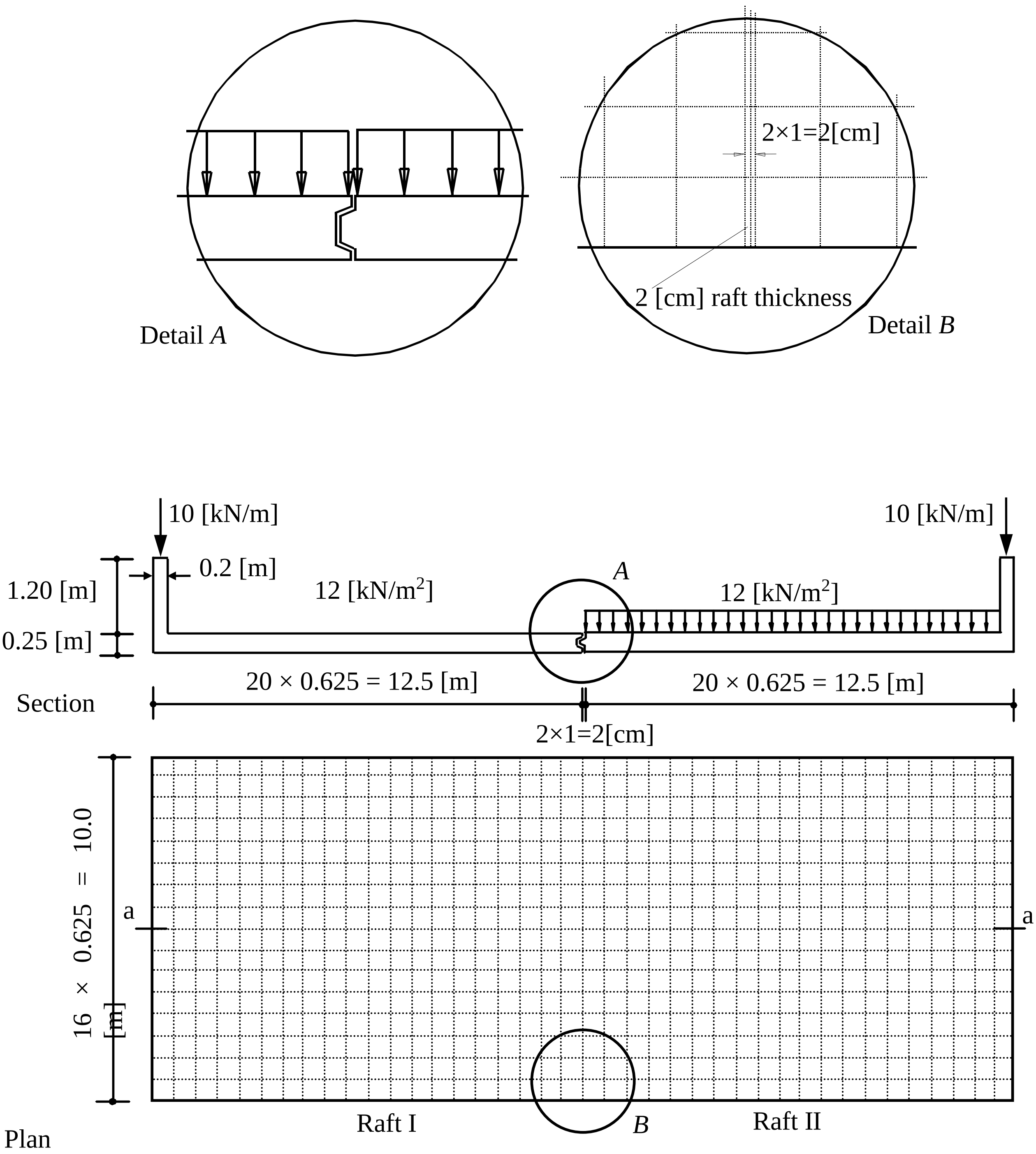

Figure 4.34 Rafts I and II are connected by a hinged joint (case 3)

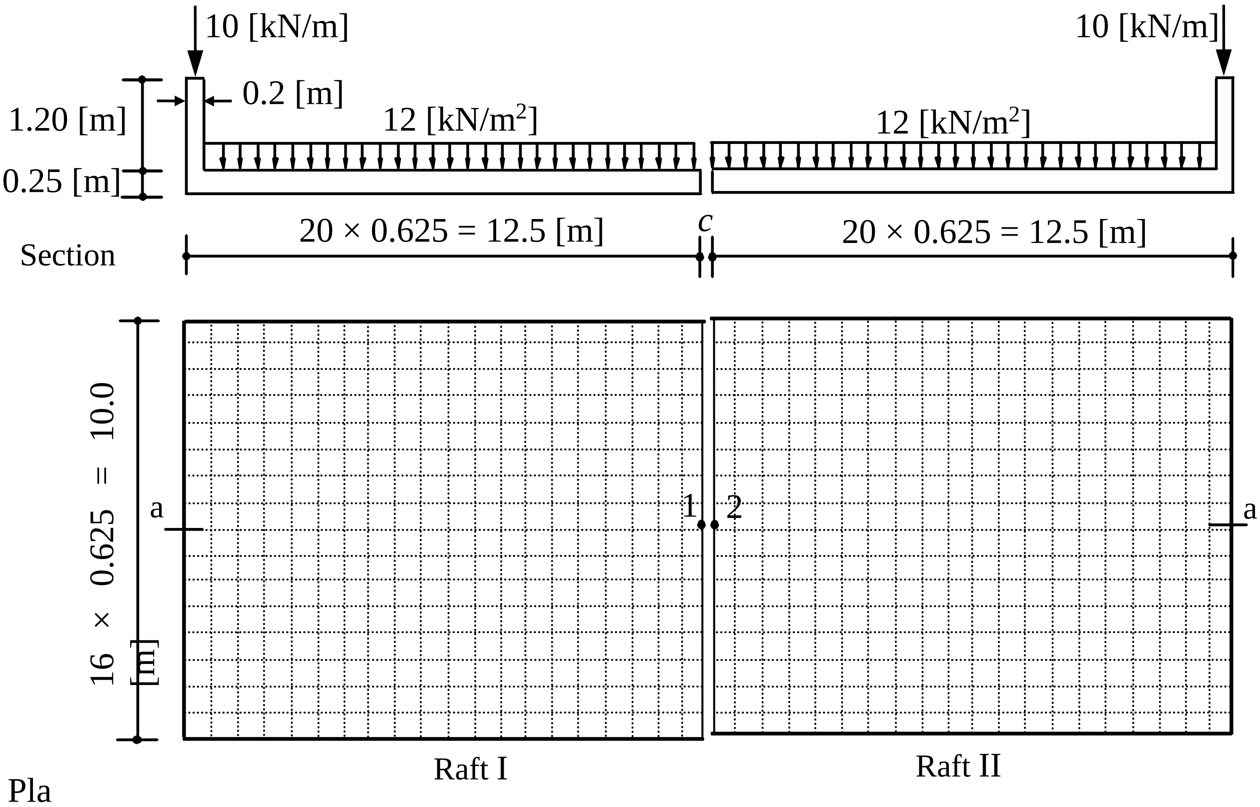

Figure 4.35 Rafts I and II are constructed side by side (cases 1 and 2)

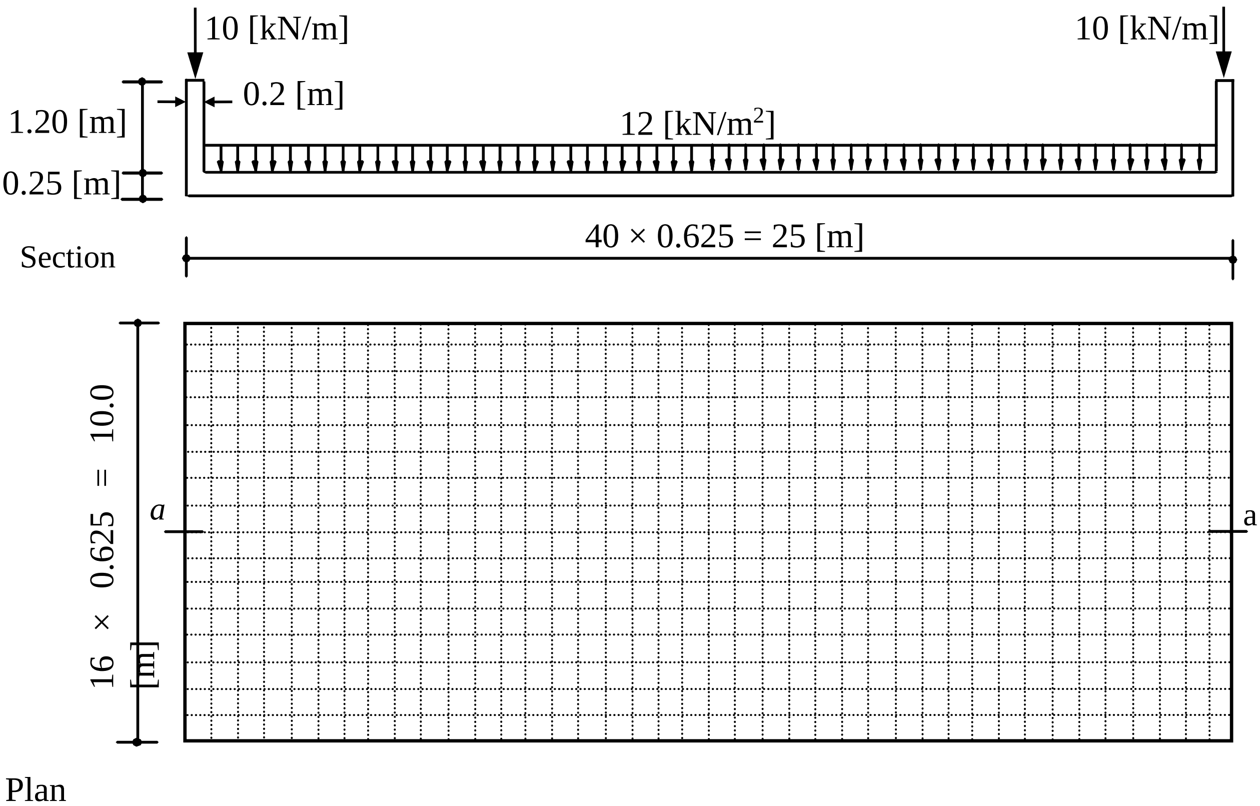

Figure 4.36 Rather than rafts I and II, only one raft is constructed (case 4)

6 Analysis
6.1 General

The rafts are subdivided into 640 square finite elements, each element has a side of 0.625 [m] as shown in Figures 4.34 to 4.36. The analysis of rafts in case 2 (analysis with interaction but without shearing forces) is carried out by using a net for the two rafts. The free distances between the rafts are carried out by inserting appropriate two very small elements between rafts. Each element has 1 [cm] width and 0.0 [cm] thickness. The very small widths of the elements keep the distance between the rafts nearly zero, while the zero thickness of the elements eliminates the raft rigidity at the joint.

To simulate a hinged joint between rafts in case 3 (analysis with interaction and with shearing forces), two very small elements are inserted between the rafts. Each element has 1 [cm] width and 2 [cm] thickness. The very small widths of the elements keep the distance between the rafts nearly zero, while the small thickness of the elements makes the raft rigidity at the joint very small. These boundary conditions allow interacting of only the vertical forces between rafts. Moments at hinged connection will be eliminated due to the very small rigidity of connection elements. For all cases of analyses, the horizontal forces due to water pressure or earth pressure are neglected.

6.2 Choice of the calculation method for studying the influence of the joint

A primary analysis was carried out by the modulus of compressibility method (method 7). It was found that this method maybe causes numerical problems; these problems also occur when applying the modulus of compressibility method using iteration (method 6). The numerical problems were due to the light loads distributed uniformly on the pool in addition to stiff edges as a result to edge walls. Consequently, negative contact pressures occur by applying the modulus of compressibility method. Therefore, all analyses of the pool were carried out by Modification of modulus of subgrade reaction by iteration (method 4). The iteration process of the method is repeated till the difference between the results of the step i and those of the step of i +1 are nearly the same. In this example 20 steps were sufficient for the analysis.

6.3 Choice of the calculation method for studying the influence of the surrounding loading

The loads from filling around the swimming pool (21.85 [kN/m^2]) are higher than those acting on the swimming pool itself (12 [kN/m^2]). Therefore, it is expected great settlements on the swimming pool due to the filling. In this case, negative contact pressures will be expected on the swimming pool.

6.4 Consideration of the irregularity of the subsoil material on the behavior of the swimming pool

The available information about the subsoil under the swimming pool is five boring logs B1 to B5. Each boring has four layers as shown in Figure 4.33 and Table 4.8. Arrangement of boring locations is shown in Figure 4.37. In order to carry out the analysis of the swimming pool taking into account the irregularity of the subsoil, the whole foundation area is subdivided into triangle zones as shown in Figure 4.37. Then, the flexibility coefficients are determined by Interpolation method.

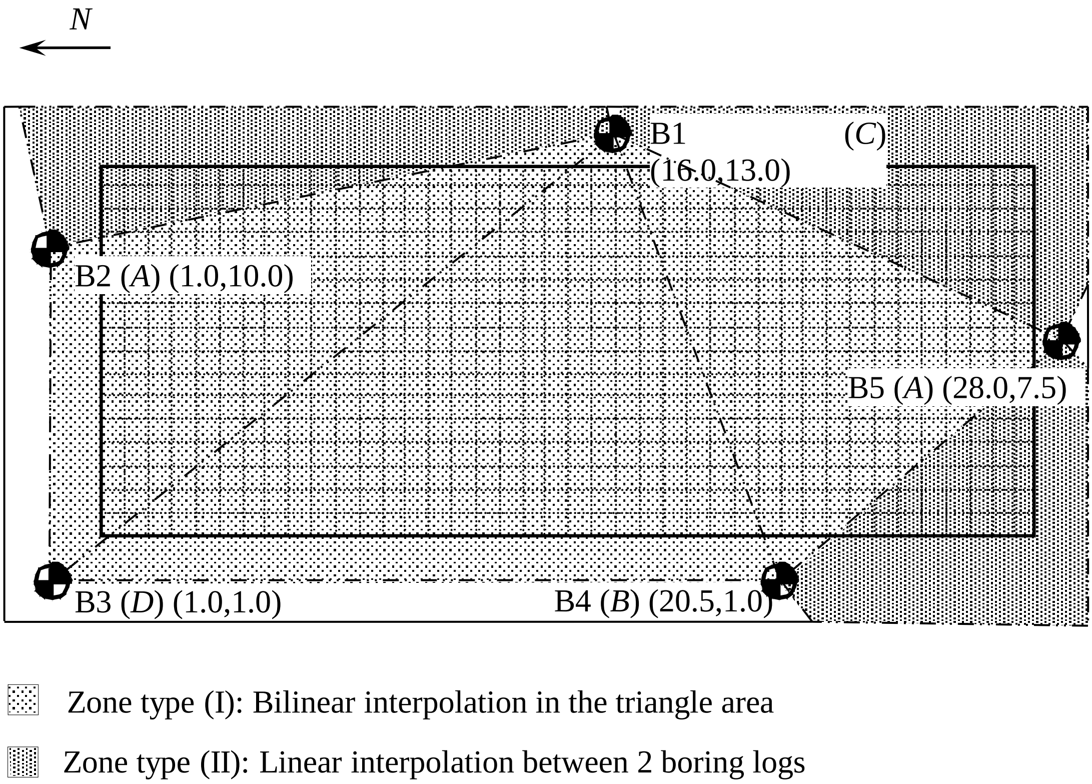

Figure 4.37 Locations of boring logs B1 to B5 with interpolation zones

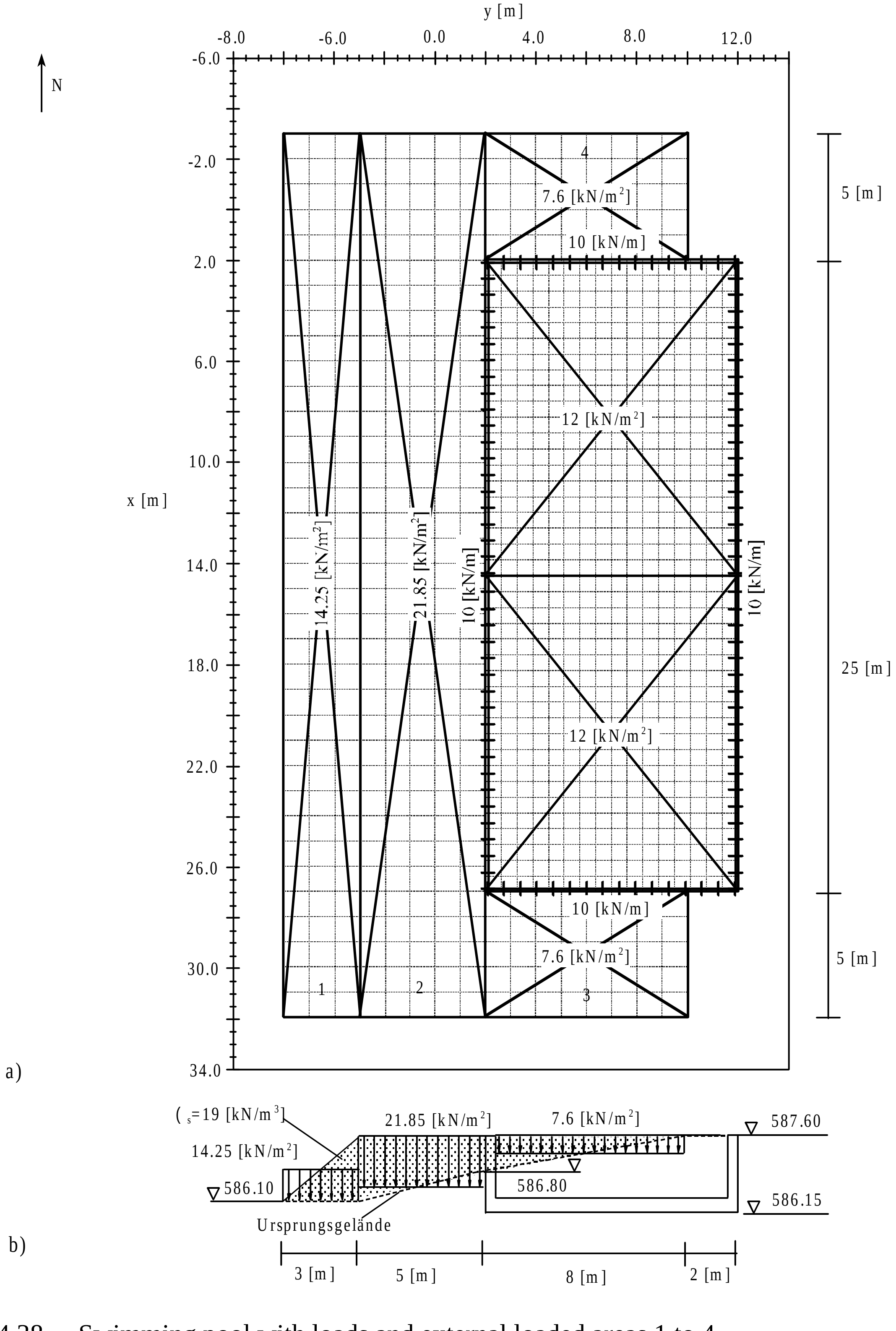

Figure 4.38 Swimming pool with loads and external loaded areas 1 to 4

7 Results and discussion

7.1 Studying the influence of the joint

Figures 4.39 to 4.50 show the contour lines of settlements, isometric view of contact pressures, circular diagrams of moments for the four cases of analysis while Figure 4.51 shows settlements, contact pressures and moments at the middle section a-a. Figures 4.52 to 4.59 show the internal forces in the edge walls.

In general, it can be noticed from those figures that:

Settlements

- Settlements at the edges (points 1 and 2) of the rafts with joints (cases 2 and 3) are greater than that without interaction (case 1) and without joint (case 4), Figure 4.51a

- Settlements for rafts with joints (cases 2 and 3) are nearly similar (Figures 4.40, 4.41 and 4.51a)

- If hinged joint between rafts is used (case 3), there will be continuation of settlement under the rafts (Figure 4.51a)

- A continuation of settlement under the rafts with free joint (case 2) is also found, this related to the loads on both rafts are equal (Figure 4.51a)

- The analysis of rafts with interaction showed that both rafts would lean toward each other (Figures 4.40 and 4.41)

Contact pressures

- If hinged joint between rafts is used (case 3), there will be continuation of contact pressure under the rafts at the joint (Figures 4.45 and 4.51b)

- Slight differences in contact pressures at the edges (points 1 and 2) of the rafts with free joint (case 2) occur (Figure 4.44)

Moments

- Moments for rafts without interaction (case 1) and for the raft without joint (case 4) are much greater than that for rafts with joints (cases 2 and 3), Figures 4.47 to 4.50 and Figure 4.51c

- For rafts with joints (cases 2 and 3), the positions of maximum moments are shifted to the center of the rafts (Figure 4.51c)

- It is clear from Figure 4.51c for rafts with joints (cases 2 and 3) that the moment at the joints for the two rafts tends to zero

Internal forces in walls

- Moments will be minimum if a raft with joint is used (cases 2 and 3), Figures 4.53 and 4.54. Moments and shear forces for rafts without interaction (case 1) is unreal (Figures 4.52 and 4.56)

- For the raft without joint (case 4) a positive maximum moment at the position of connection is to be found (Figures 4.55), while for rafts with joints the moments are equal to zero at that position due to joints (Figures 4.53 and 4.54)

- Moments and shear forces for the rafts with joints (cases 2 and 3) are nearly similar (Figures 4.53, 4.54, 4.57 and 4.58)

Finally, it can be concluded that:

- Considerable differences will be expected in the results, if the analysis is carried out for rafts without and with interaction

- The results for the rafts with free joint (case 2) and with hinged joint (case 3) are nearly similar in this example

- If rafts with free joint (case 2) have equal loads, only slight differences will be expected at the position of joint connection. Therefore, both of the two types of joints (hinged or free) may be used in this example

- Although the rafts with joints (cases 2 and 3) lead to higher settlements than that without joints (case 4), but give less internal forces

- The suitable foundation system may be used in this example is the rafts with joints (case 2 or 3)

7.2 Studying the influence of surrounding loading

Figure 4.60 shows contour lines of the settlement under the swimming pool due to the surrounding loading only. As it is expected, the settlement at the edge of the swimming pool near the surrounding loading is about 2.5 [cm] greater than that due to the swimming pool itself (Figures 4.39 to 4.42) by application of the four cases of analysis concerning the joint. Figures 4.61 to 4.64 show the contour lines of settlement under the swimming pool due to both loads from filling and swimming pool itself. These figures show that the direction of the settlements is changed toward the surrounding loading. To overcome extreme results concerning the internal forces on the swimming pool in this case, it is recommended that most of the filling must be carried out before constructing the swimming pool.

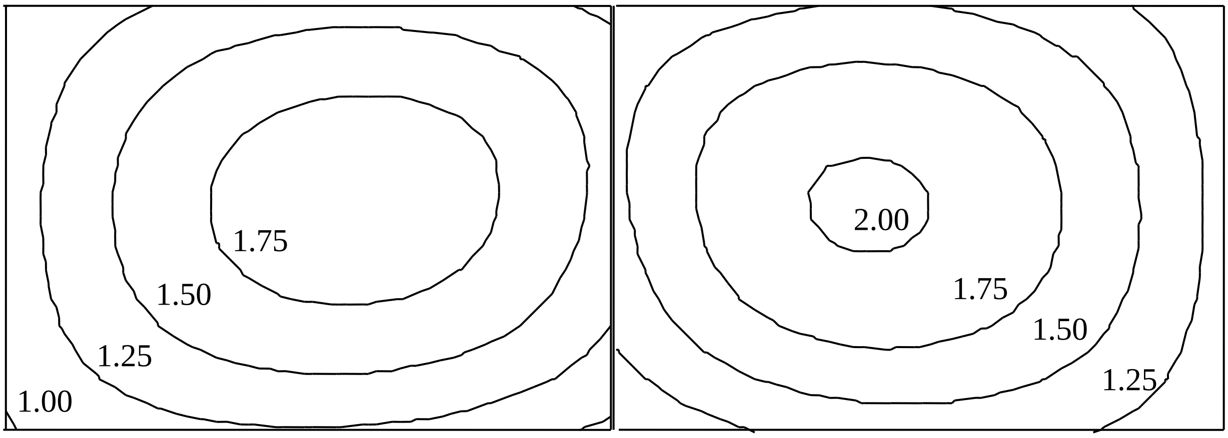

Figure 4.39 Contour lines of settlements *s* [cm]
Analysis without interaction (case 1)

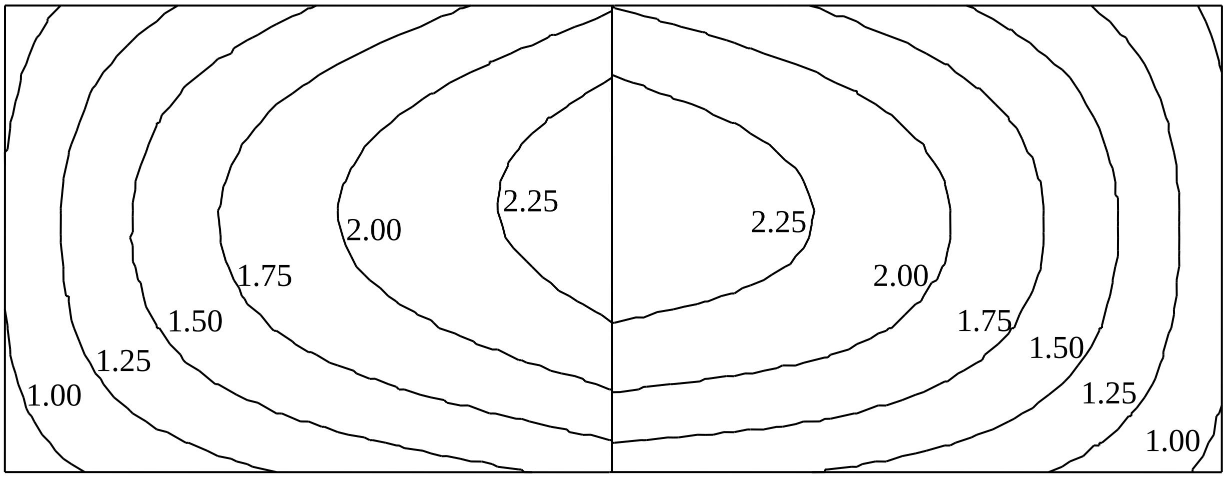

Figure 4.40 Contour lines of settlements *s* [cm]
Analysis with interaction and without shearing forces (case 2)

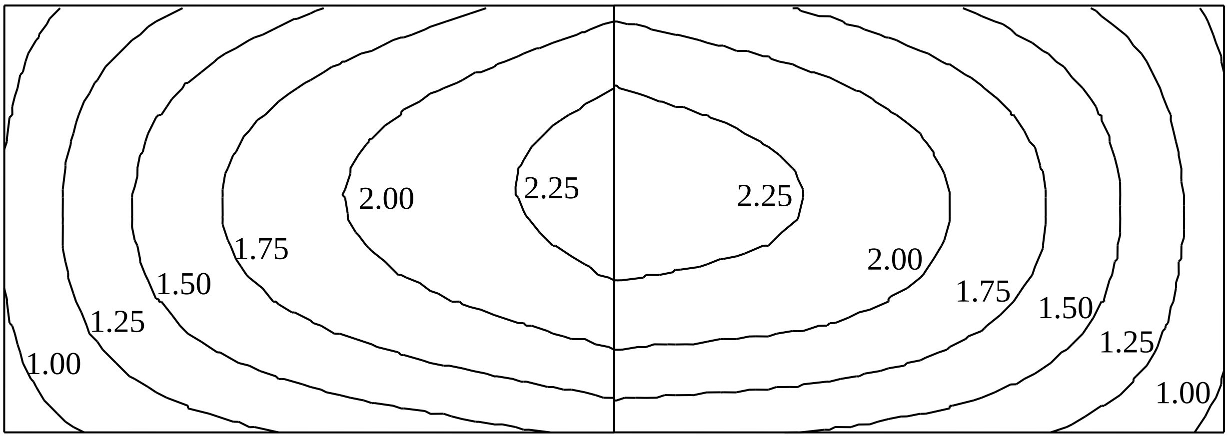

Figure 4.41 Contour lines of settlements *s* [cm]
Analysis with interaction and with shearing forces (case 3)

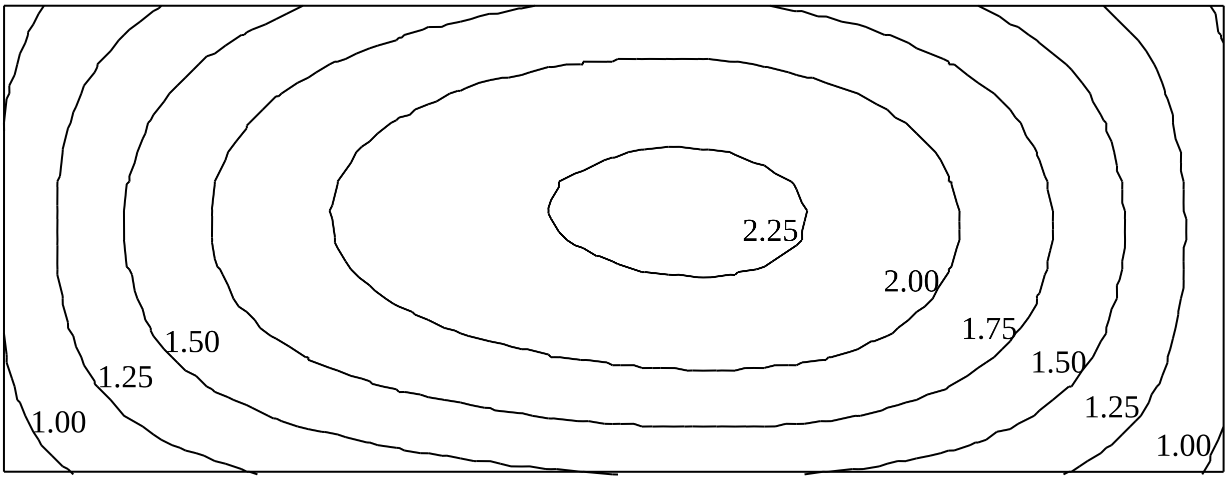

Figure 4.42 Contour lines of settlements *s* [cm]
Analysis without joint (case 4)

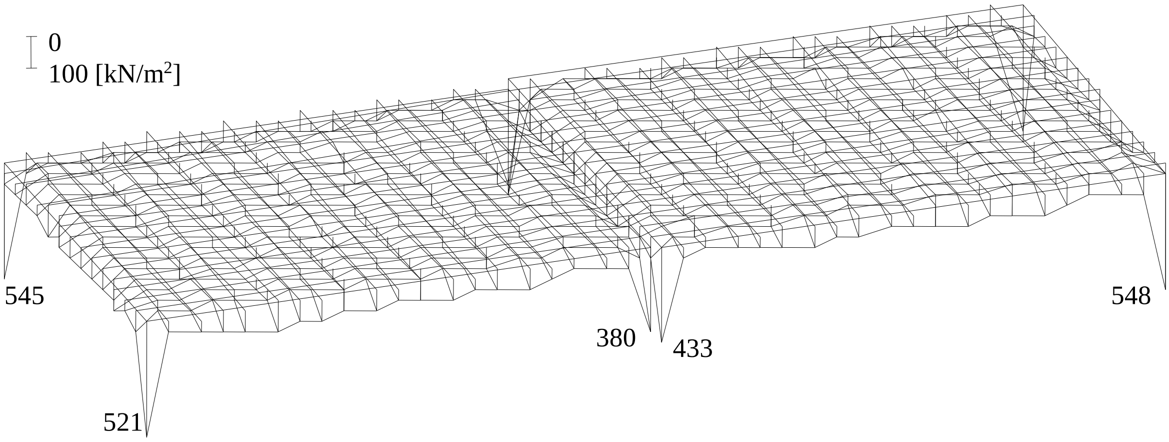

Figure 4.43 Isometric view of contact pressures q [kN/m^2]
Analysis without interaction (case 1)

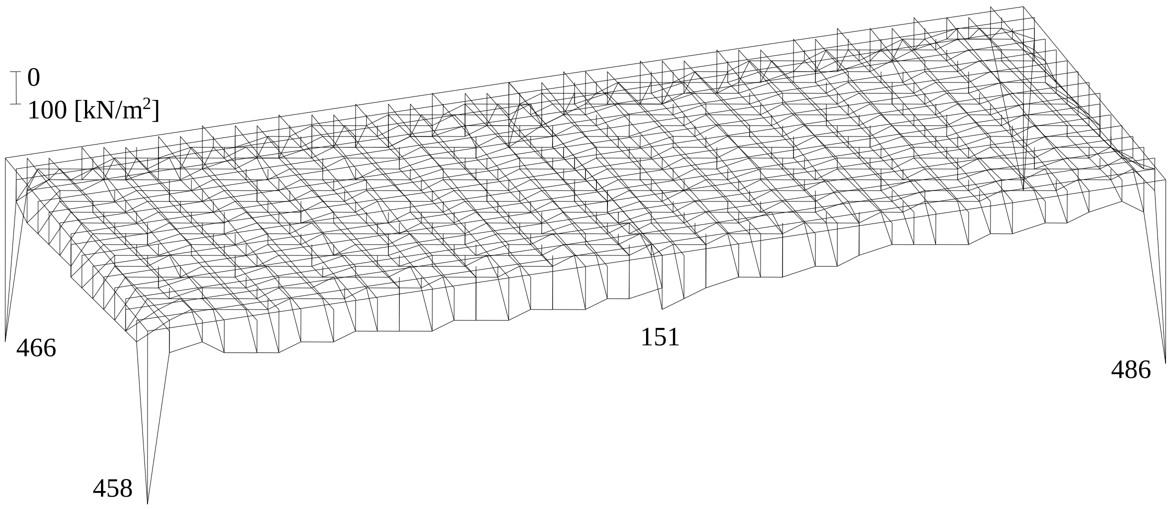

Figure 4.44 Isometric view of contact pressures q [kN/m^2]
Analysis with interaction and without shearing forces (case 2)

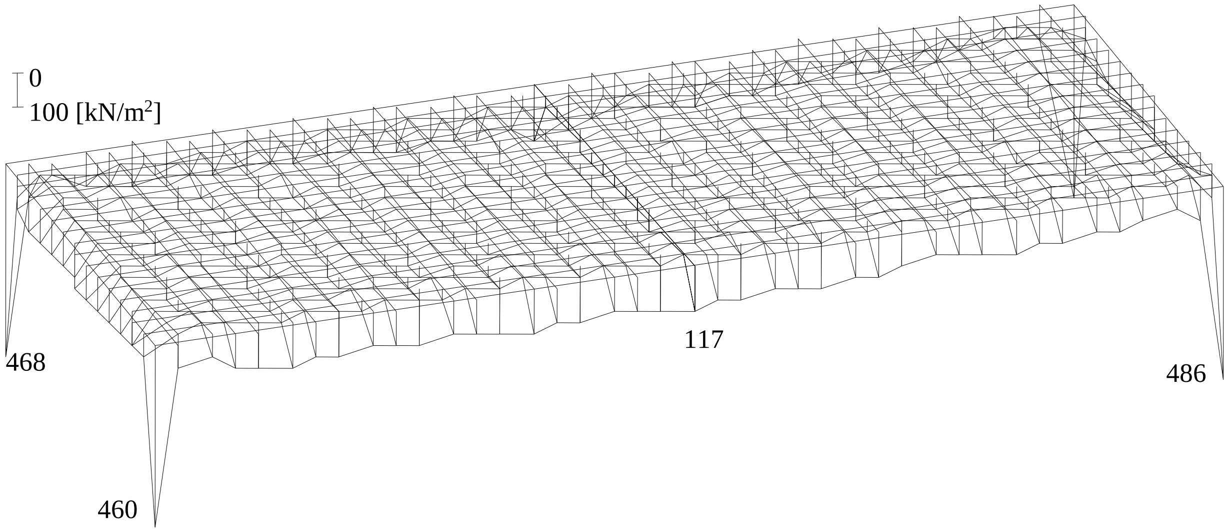

Figure 4.45 Isometric view of contact pressures q [kN/m^2]
Analysis with interaction and with shearing forces (case 3)

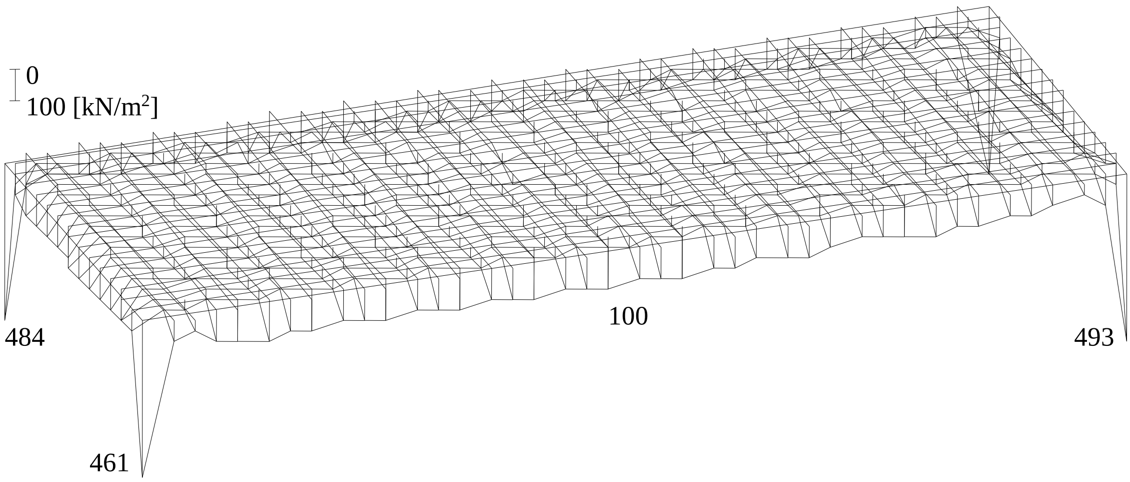

Figure 4.46 Isometric view of contact pressures q [kN/m^2]
Analysis without joint (case 4)

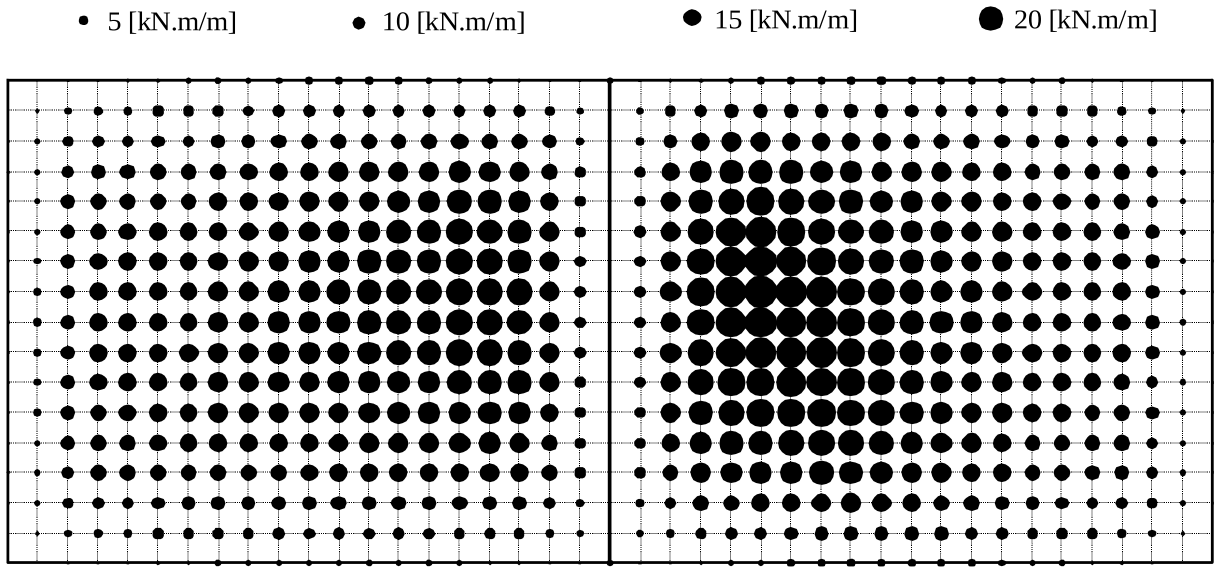

Figure 4.47 Circular diagrams of moments m_x [kN.m/m]
Analysis without interaction (case 1)

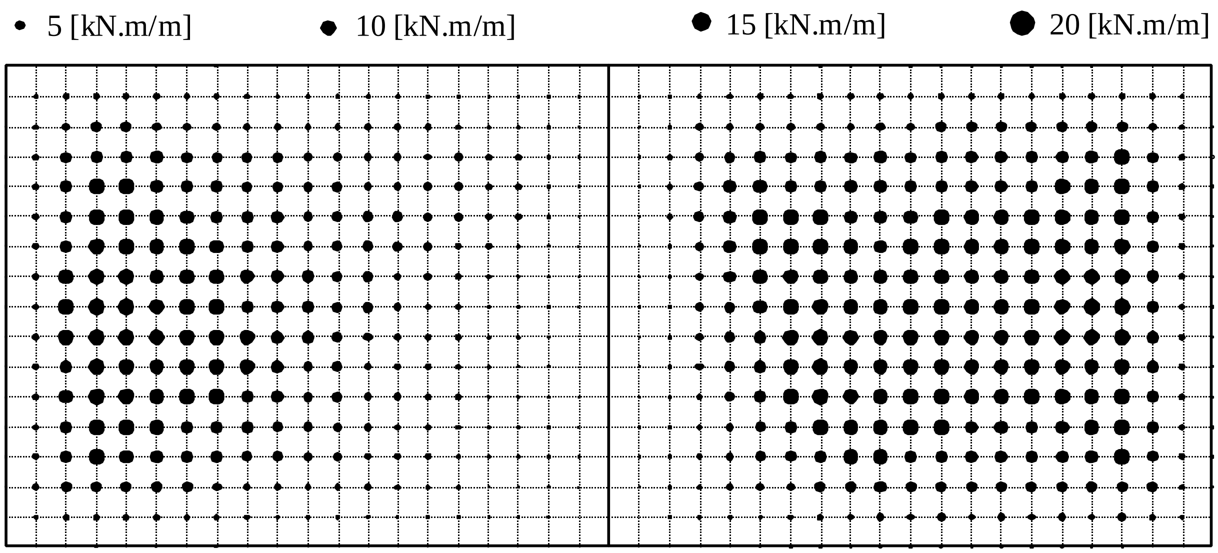

Figure 4.48 Circular diagrams of moments m_x [kN.m/m]
Analysis with interaction and without shearing forces (case 2)

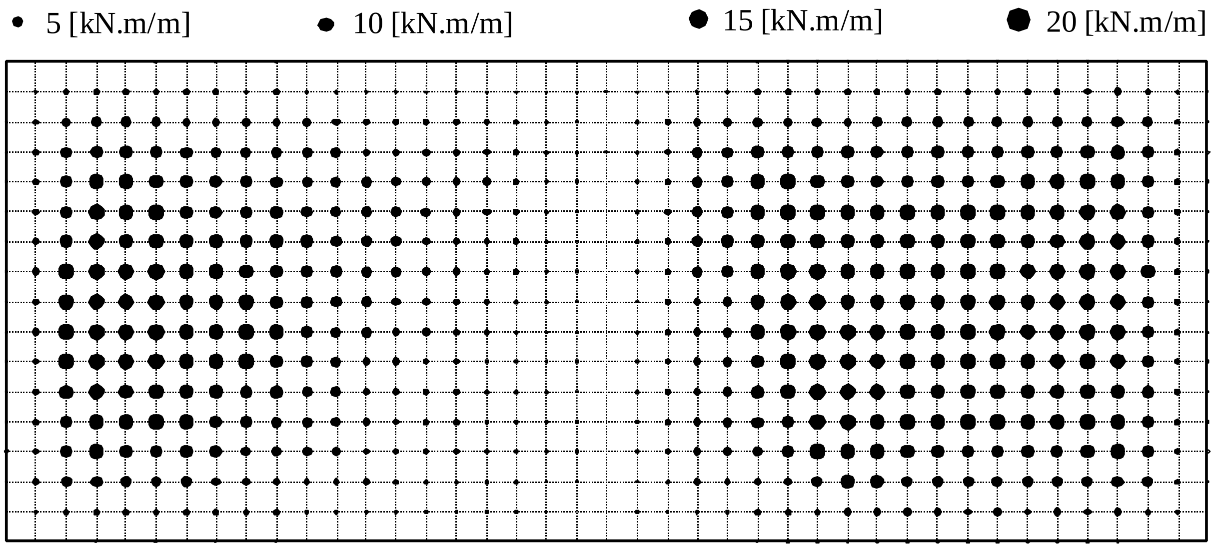

Figure 4.49 Circular diagrams of moments m_x [kN.m/m]
Analysis with interaction and with shearing forces (case 3)

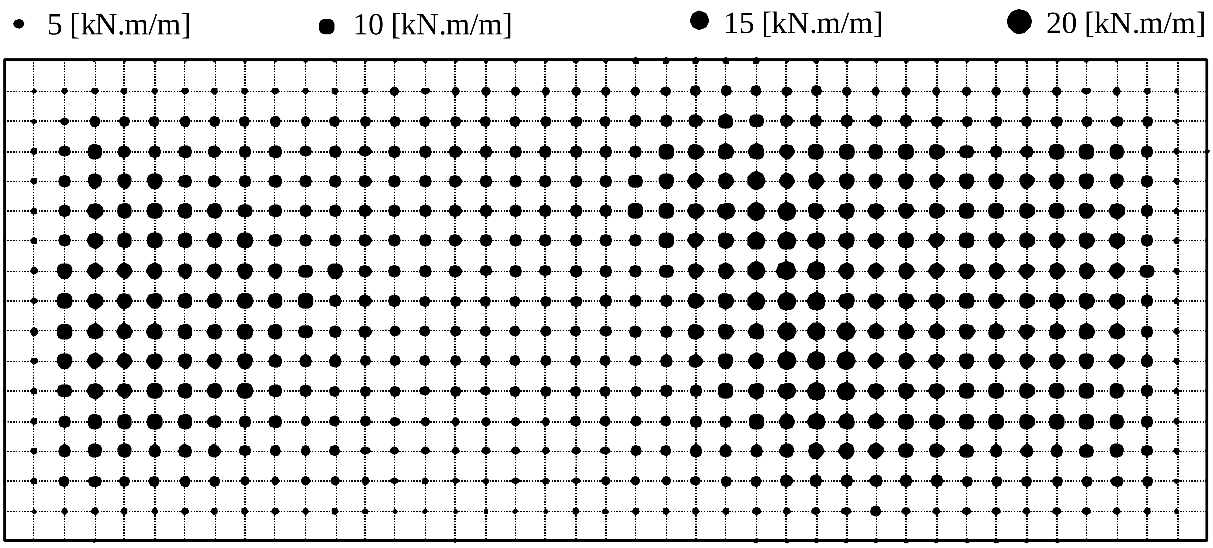

Figure 4.50 Circular diagrams of moments m_x [kN.m/m]
Analysis without joint (case 4)

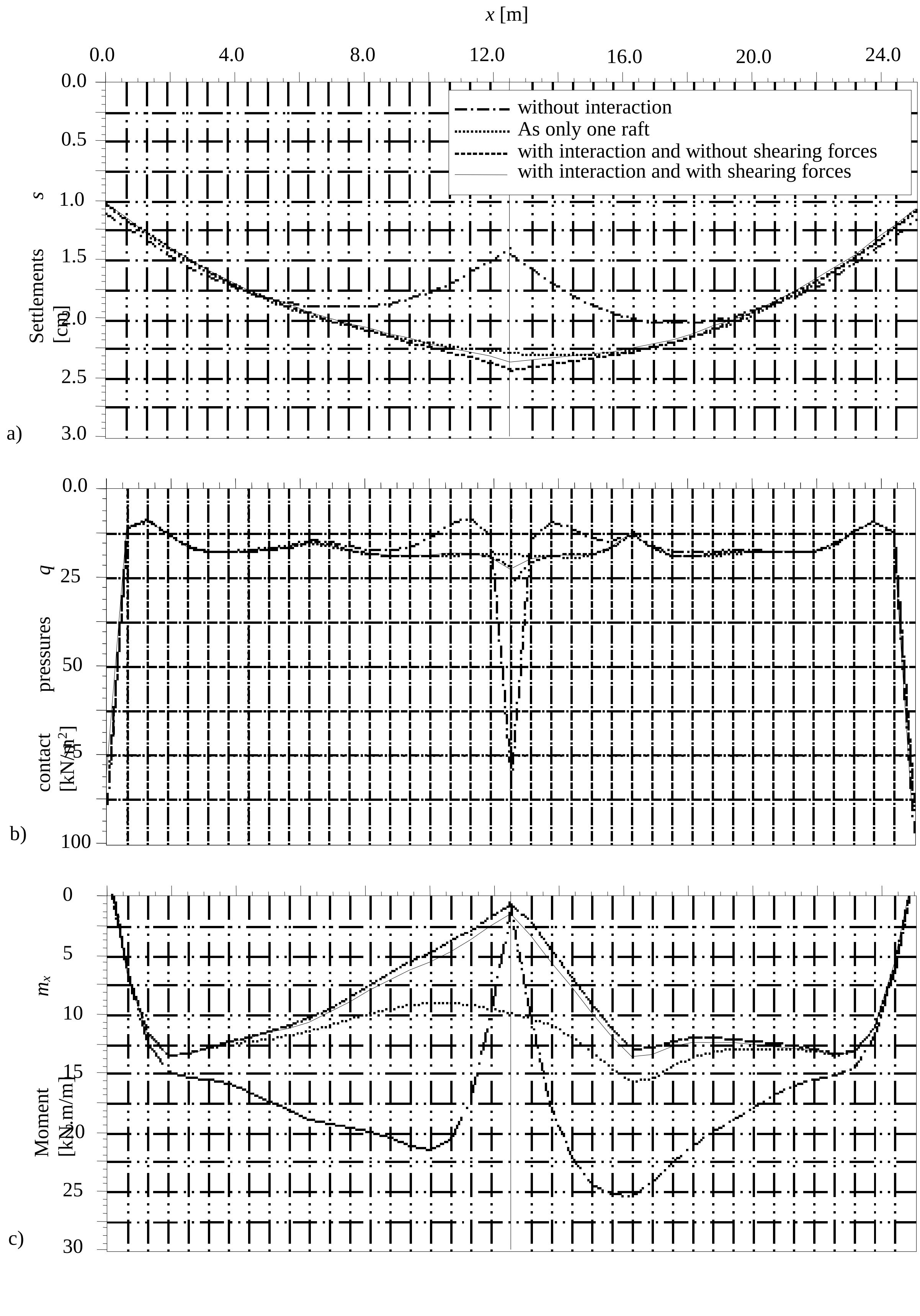

Figure 4.51 Settlements, contact pressures and moments at middle section of rafts I and II

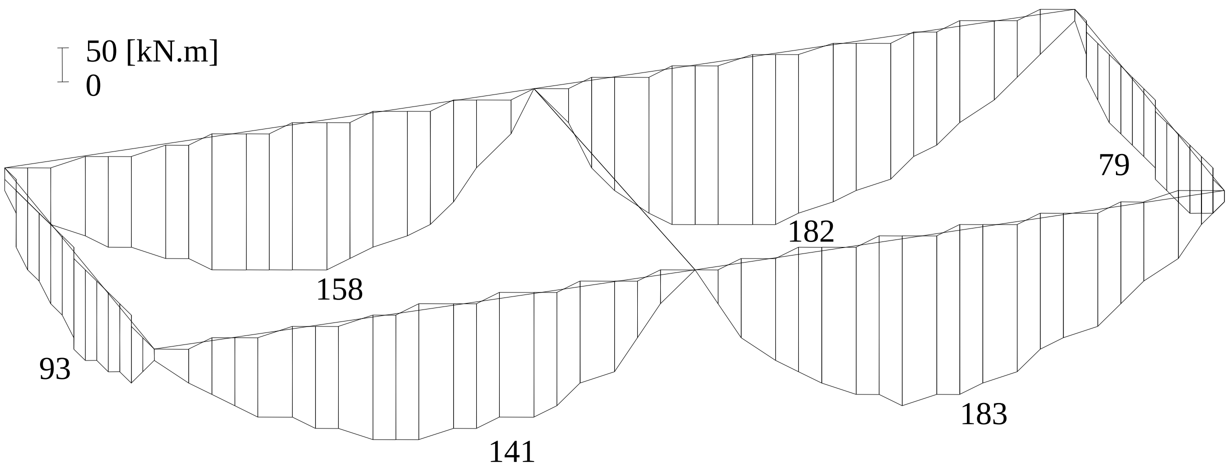

Figure 4.52 Beam-bending moments M_b [kN.m] at edge walls of the swimming pool
Analysis without interaction (case 1)

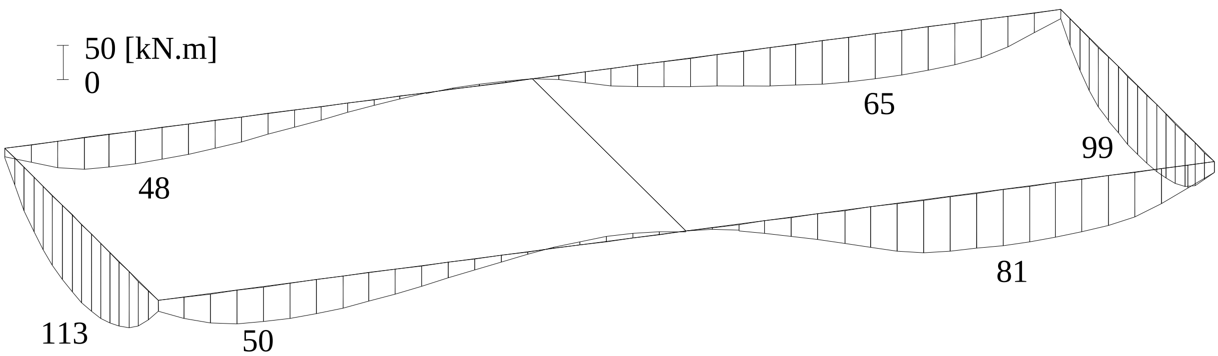

Figure 4.53 Beam-bending moments M_b [kN.m] at edge walls of the swimming pool
Analysis with interaction and without shearing forces (case 2)

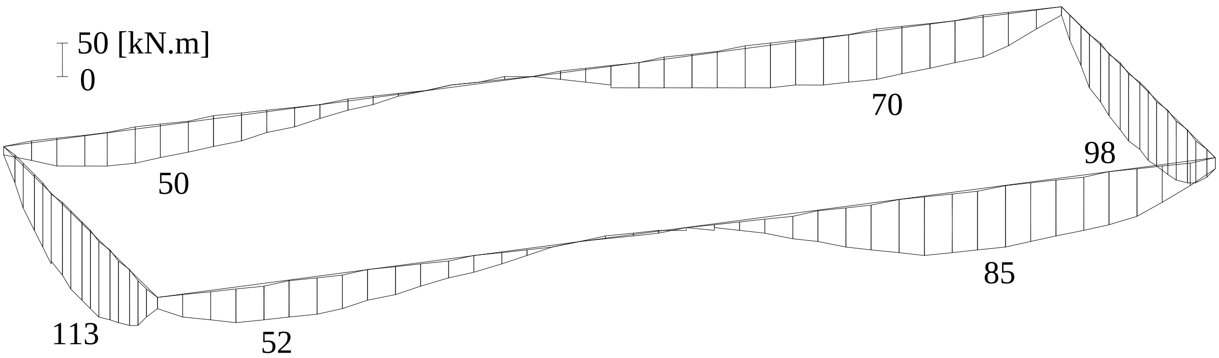

Figure 4.54 Beam-bending moments M_b [kN.m] at edge walls of the swimming pool
Analysis with interaction and with shearing forces (case 3)

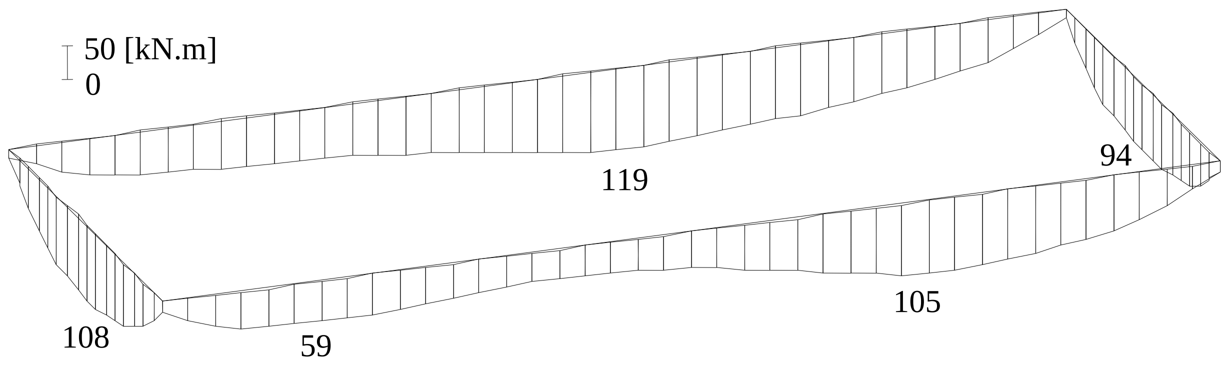

Figure 4.55 Beam-bending moments M_b [kN.m] at edge walls of the swimming pool
Analysis without joint (case 4)

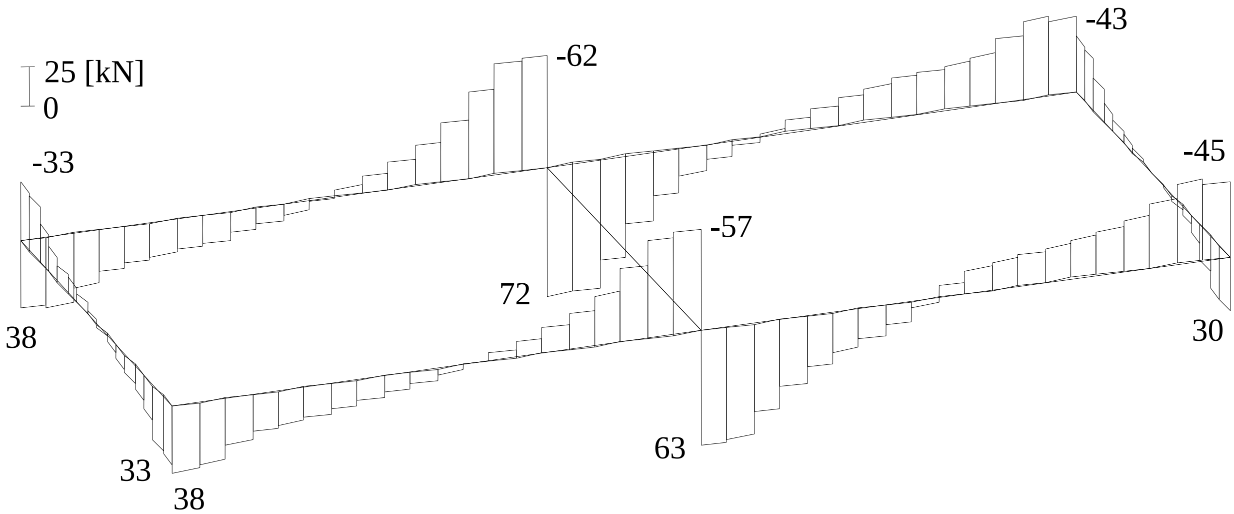

Figure 4.56 Beam-Shearing forces Q_s [kN] at edge walls of the swimming pool
Analysis without interaction (case 1)

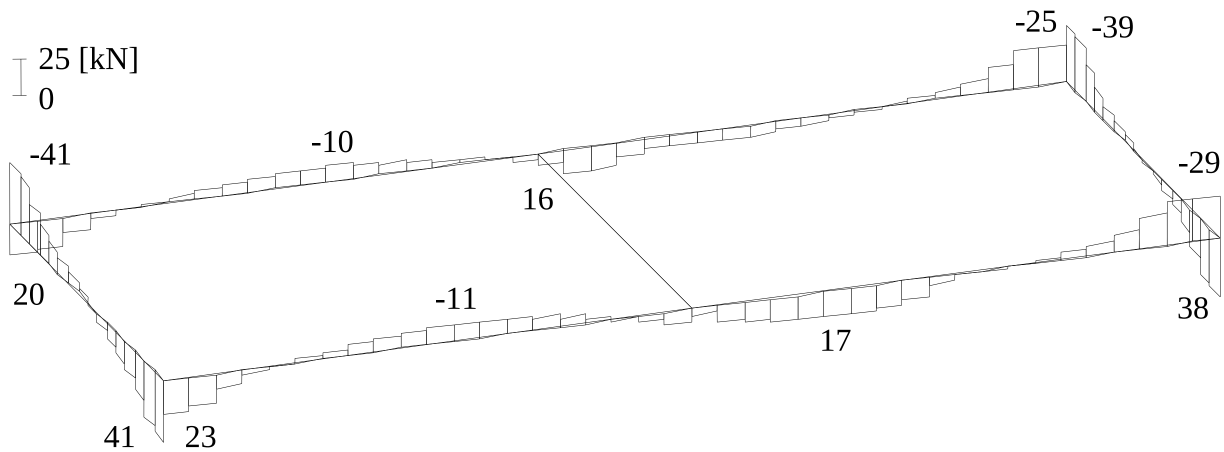

Figure 4.57 Beam-Shearing forces Q_s [kN] at edge walls of the swimming pool
Analysis with interaction and without shearing forces (case 2)

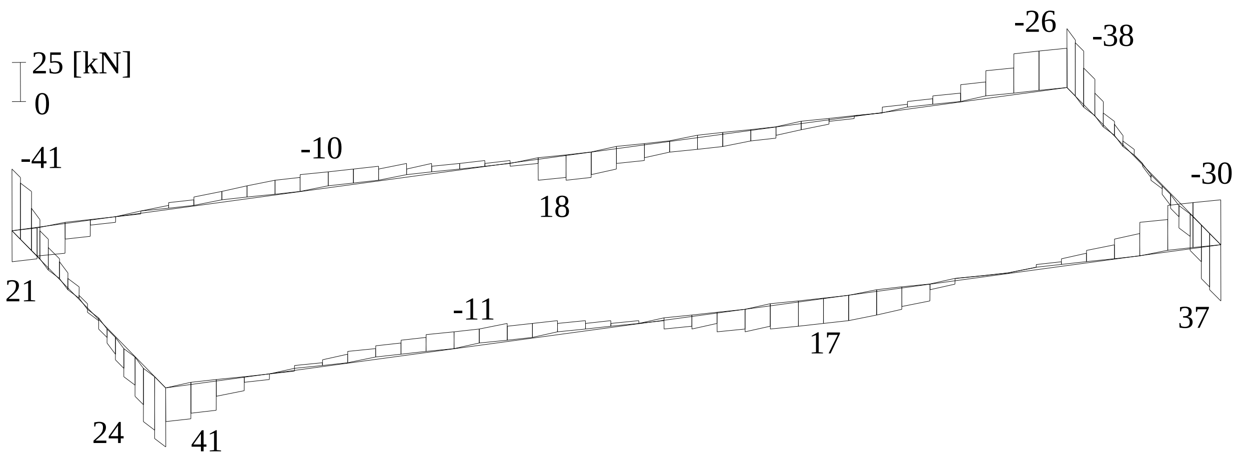

Figure 4.58 Beam-Shearing forces Q_s [kN] at edge walls of the swimming pool
Analysis with interaction and with shearing forces (case 3)

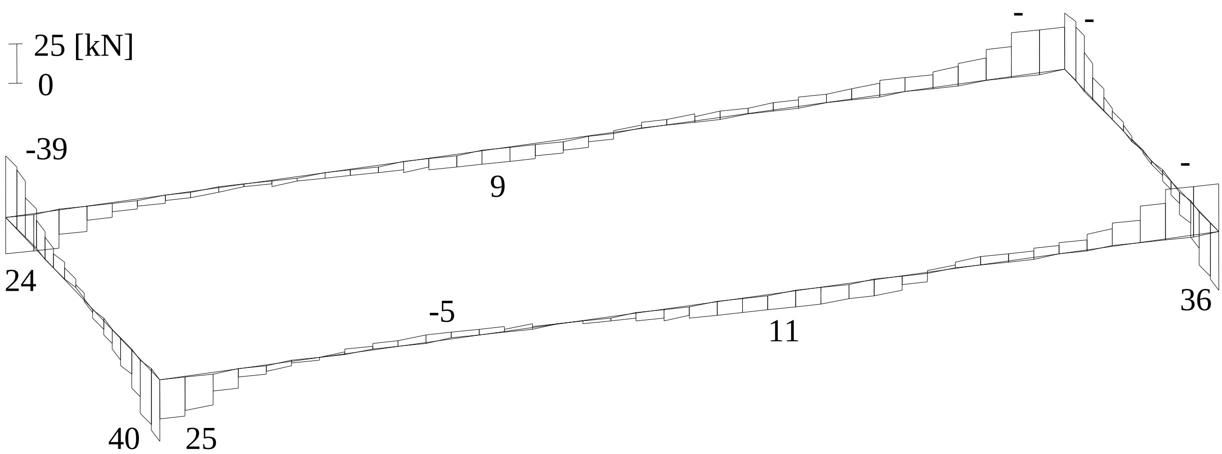

Figure 4.59 Beam-Shearing forces Q_s [kN] at edge walls of the swimming pool
Analysis without joint (case 4)

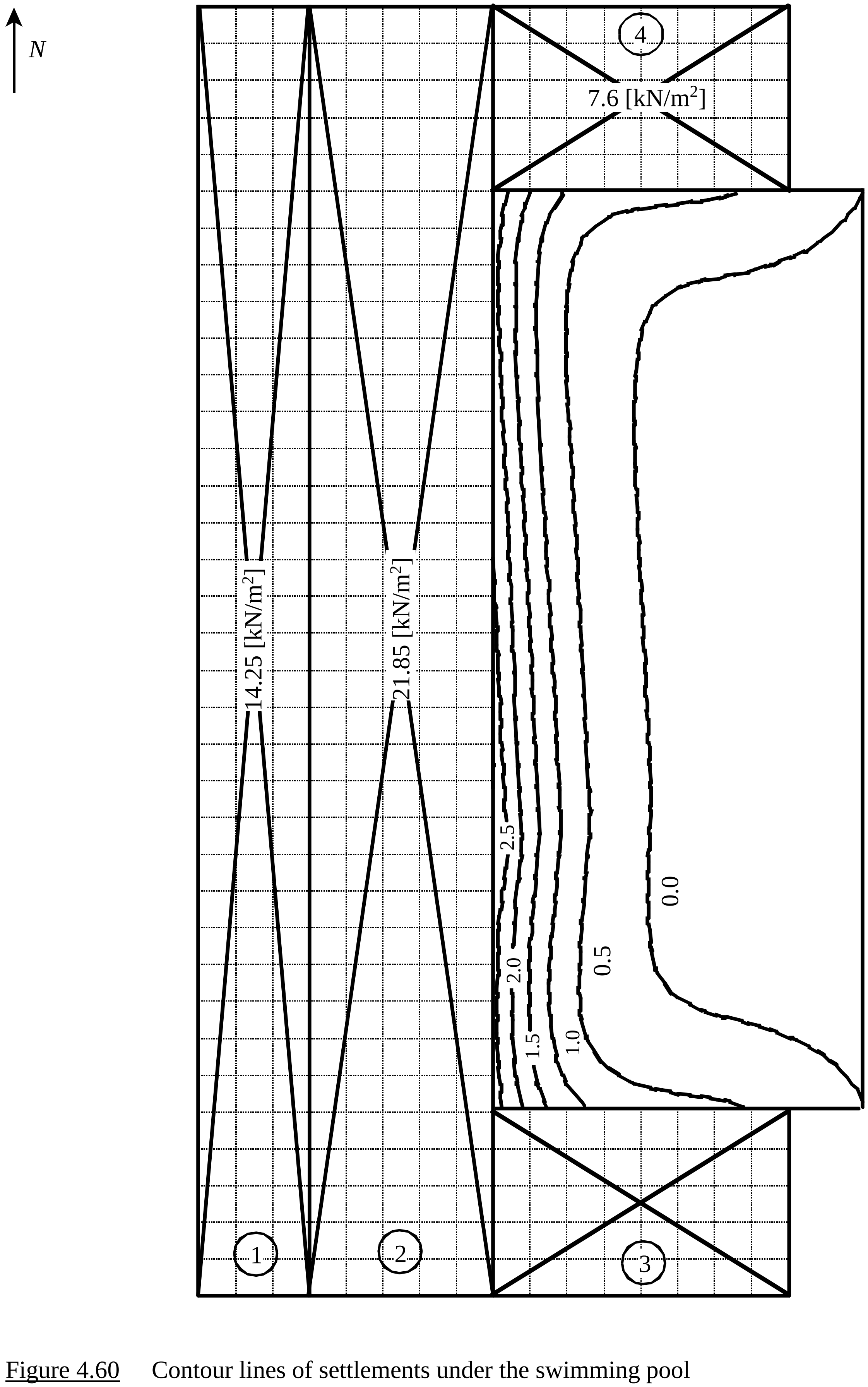

Figure 4.60 Contour lines of settlements under the swimming pool due to the filling around it

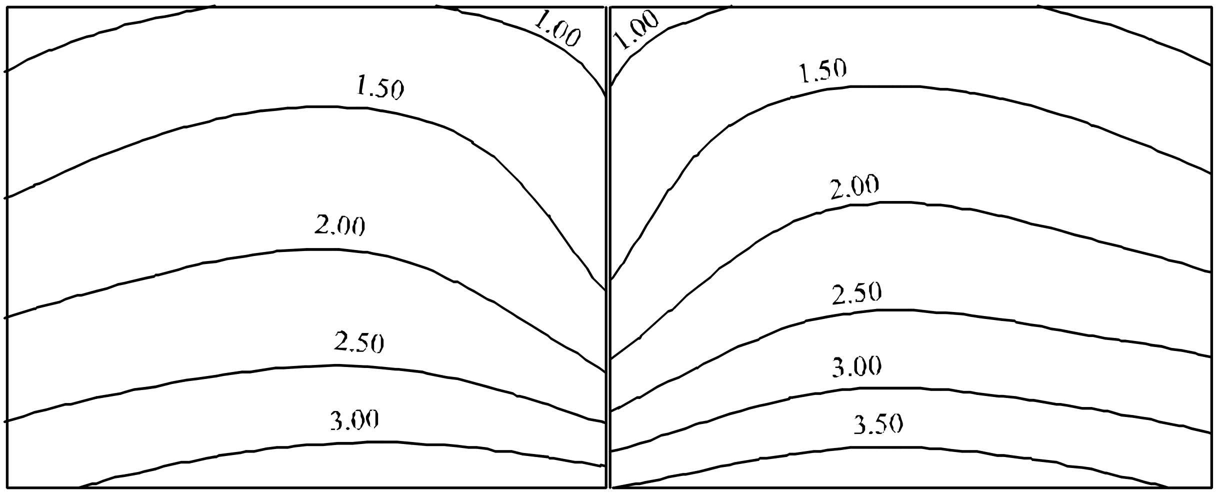

Figure 4.61 Contour lines of settlements *s* [cm]
Analysis without interaction (case 1)
With influence of surrounding loading

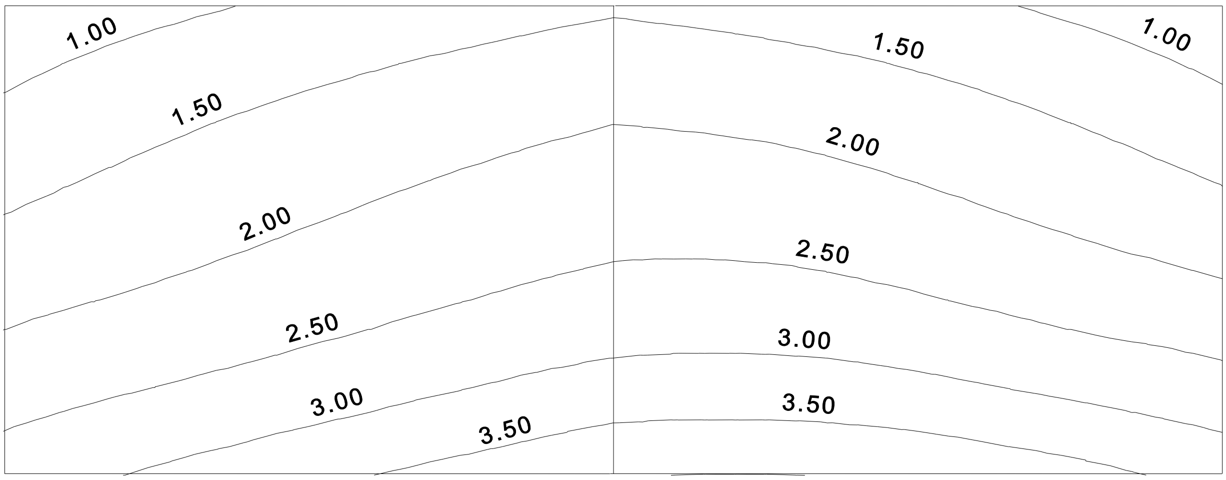

Figure 4.62 Contour lines of settlements *s* [cm]
Analysis with interaction and without shearing forces (case 2)
With influence of surrounding loading

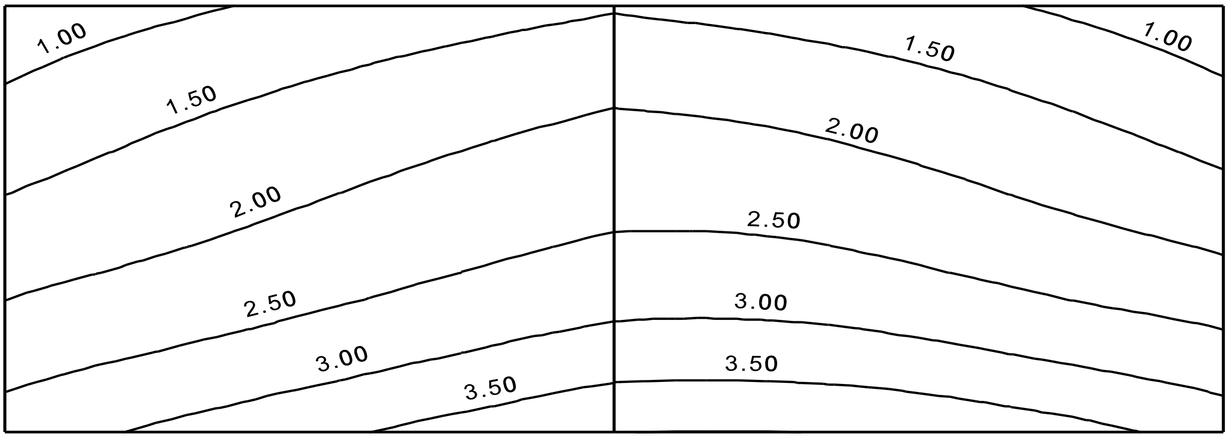

Figure 4.63 Contour lines of settlements *s* [cm]
Analysis with interaction and with shearing forces (case 3)
With influence of surrounding loading

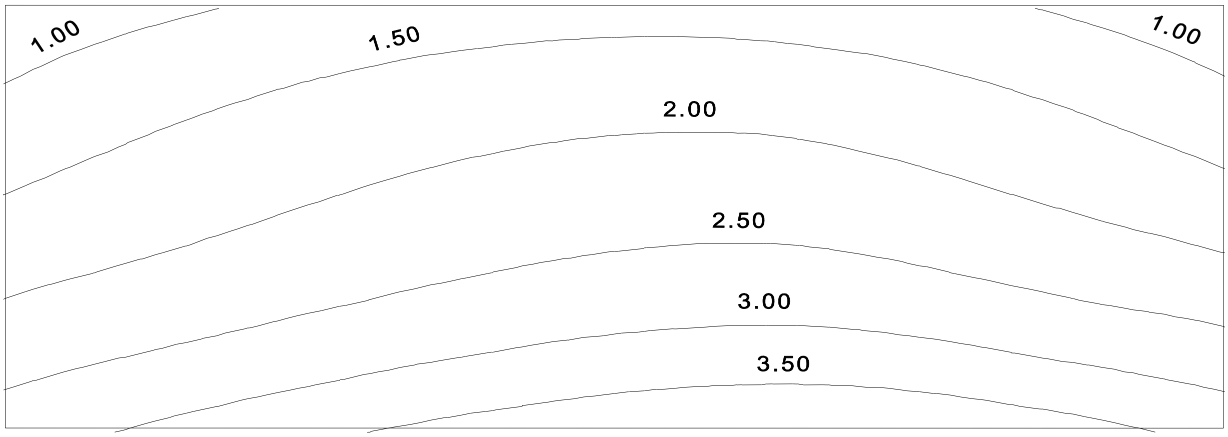

Figure 4.64 Contour lines of settlements *s* [cm]
Analysis without joint (case 4)
With influence of surrounding loading