Example 4.4 Interaction of two square rafts constructed side by side

1 Description of the problem

Settlement joints are usually used in the foundation when the intensity of loads on it differs considerably from area to another. In such case, the foundation may be divided corresponding to its load intensity to avoid cracks. A settlement joint is constructed by making a complete separated joint in the foundation or a hinged joint. If the foundation has a separated joint, each part will settle independently but it will be interaction between parts of the foundation through the subsoil. In the other case of hinged joint, there will be transmission of shearing forces between connection parts.

This example is carried out to examine the interaction of two rafts considering settlement joint. Consider two equal square rafts I and II which will be constructed side by side. Each raft has a side of 12 [m] and 0.5 [m] thickness. Raft I is subjected to a uniform load of 400 [kN/m^2], while raft II carries a uniform load of 200 [kN/m^2].

2 Soil properties

The rafts rest on a soil layer of thickness 10 [m], overlying a rigid base. The soil has the following parameters:

Modulus of compressibility for loading	E_s	= 10 000	[kN/m^2]
Modulus of compressibility for reloading	W_s	= 30 000	[kN/m^2]
Unit weight	γ_s	= 18	[kN/m^3]
Poisson's ratio	ν_s	= 0.3	[-]

3 Raft material

The raft material has the following parameters:

Young's modulus	E_b	= 2 × 10^7	[kN/m^2]
Unit weight	γ_b	= 25	[kN/m^3]
Poisson's ratio	ν_b	= 0.25	[-]

Four cases concerning the influence of neighboring structures are considered as follows:

Case 1: Rafts I and II are constructed side by side at the same time. This case is examined for different distances *c* between the two rafts (Figure 4.17), where *c* = 0.0 [m], 0.01 [m], 0.1 [m], 1.0 [m] and 10 [m]

Case 2: Raft I is constructed at first, then later the raft II. This case is examined for different distances *c* between the two rafts (Figure 4.17), where *c* = 0.0 [m], 0.01 [cm], 0.1 [m], 1.0 [m] and 10 [m]

Case 3: Rather than rafts I and II, only one raft is constructed (Figure 4.18)

Case 4: Rafts I and II are connected by a hinged joint (Figure 4.19)

4 Analysis

The rafts are subdivided into square finite elements, each element has a side of 1.5 [m] as shown in Figures 4.17 to 4.19.

The analysis of rafts in case 1 can be carried out through one of the following two ways:

- Iteration by using two independent nets, one for raft I and the other for the second raft II

- Without iteration by using a net for the two rafts. The free distances between the rafts are carried out by inserting appropriate two elements between rafts. Then the boundary nodes of these elements are eliminated as considered in this example

To carry out the analysis of rafts in case 2, two independent file names define the data of the two rafts are chosen. The data are quite similar for the two rafts except the loads and the origin coordinates. The origin coordinates are chosen (x_o, y_o) = (0.0, 0.0) for raft I and (x_o, y_o) = (12.0+c, 0.0) for raft II. Raft II is analyzed first to obtain the contact pressures and then raft I to consider the influence of neighboring raft II.

To simulate a hinged joint between rafts in case 4 two very small elements are inserted between the rafts. Each element has 1 [cm] width and 5 [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 only the vertical forces between rafts. Moments at hinged connection will be eliminated due to the very small rigidity of connection elements.

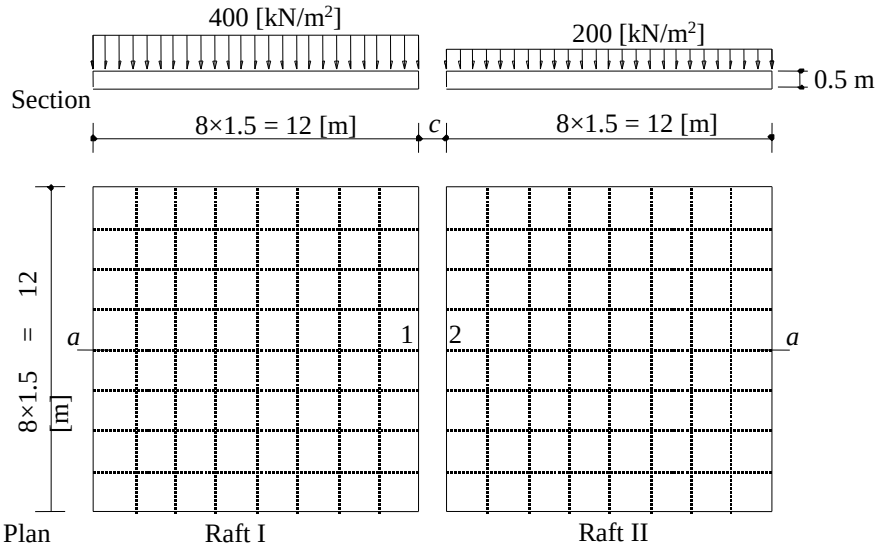

Figure 4.17 Rafts I and II are constructed side by side (cases 1 and 2)

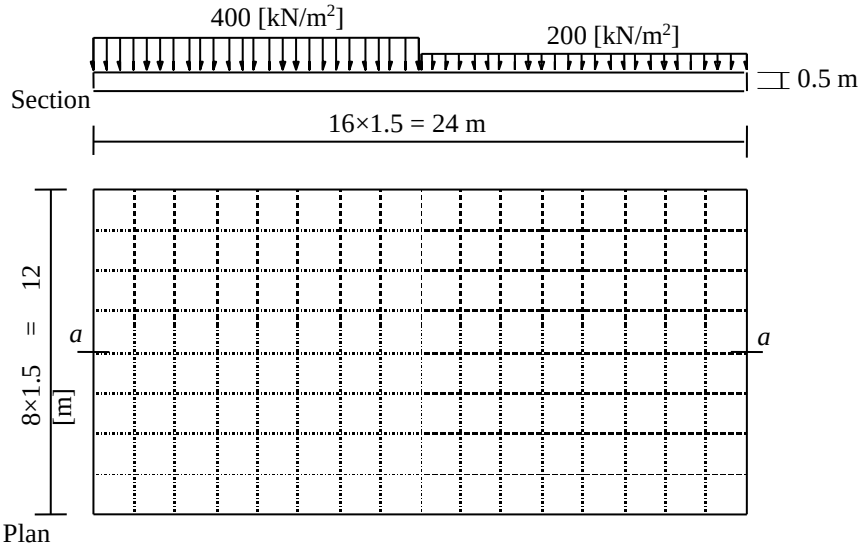

Figure 4.18 Only one raft is constructed (case 3)

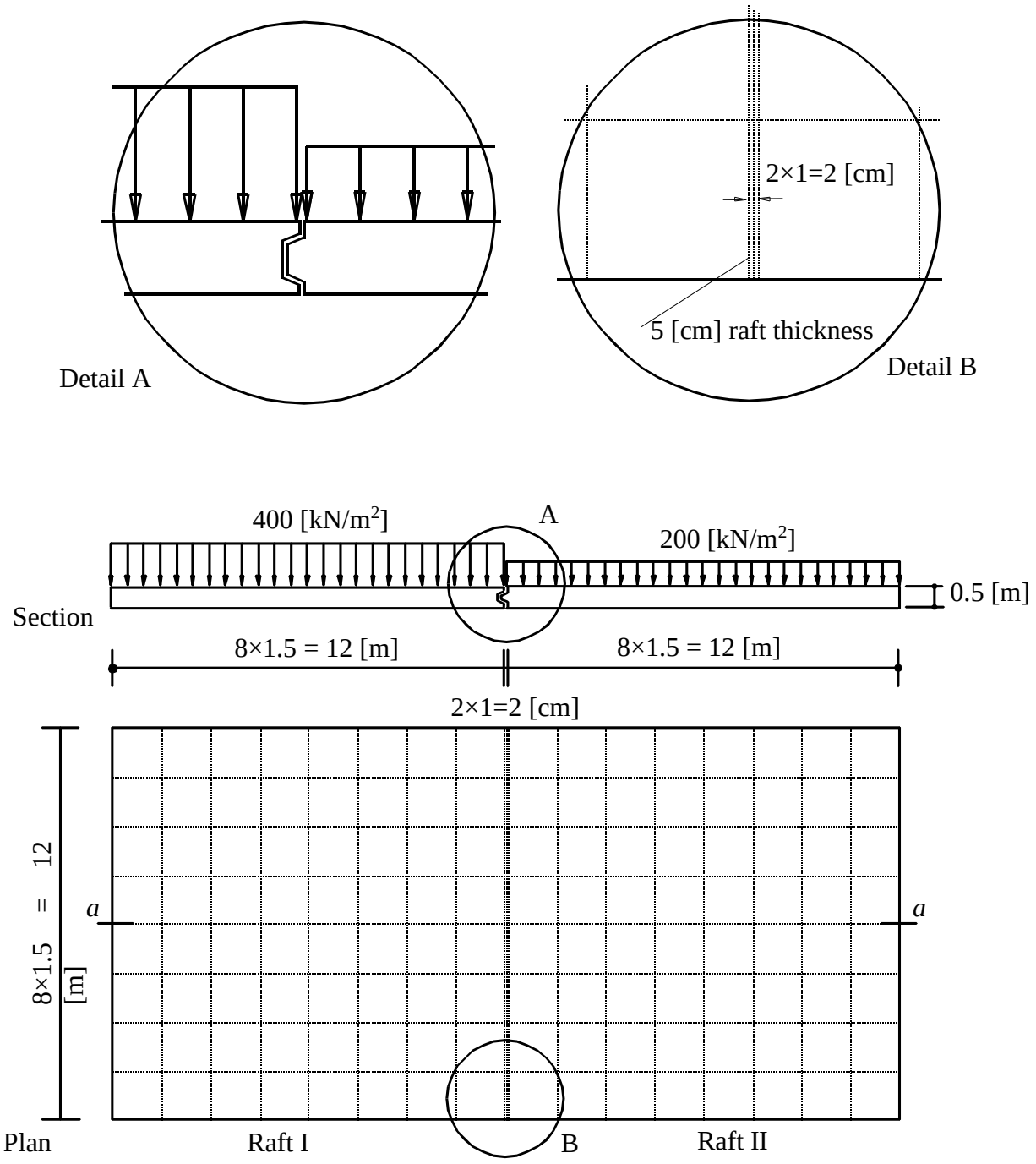

Figure 4.19 Rafts I and II are connected by a hinged joint (case 4)

5 Results and discussion

Figures 4.20 to 4.31 show the distribution of settlement, contact pressure, moment and shearing force at middle section a-a for the four cases of analyses. Tables 4.6 and 4.7 show the joint width c between the two rafts, settlements (s_1, s_2), contact pressures (q_1, q_2) at edges of the rafts (points 1 and 2) and the differences (Δs, Δq) for cases 1 and 2.

Table 4.6 Settlements s_1 and s_2 at edges of rafts I and II and differences Δs

Joint width c [m]	Rafts I and II are constructed side by side at the same time (case 1)			Raft I is constructed at first, then later raft II (case 2)		
	s_1 [cm]	s_2 [cm]	$\Delta s=s_1-s_2$ [cm]	s_1 [cm]	s_2 [cm]	$\Delta s=s_1-s_2$ [cm]
0.00	15.05	14.71	0.34	17.87	6.35	11.52
0.01	15.12	14.54	0.58	17.08	6.35	10.73
0.10	15.30	13.70	1.60	17.24	6.35	10.89
1.00	14.73	10.29	4.44	15.29	6.35	8.94
10.0	13.00	6.16	6.84	12.99	6.35	6.64
∞	13.10	6.35	6.75	13.10	6.35	6.75

Table 4.7 Contact pressures q_1 and q_2 at edges of rafts I and II and differences Δq

Joint width c [m]	Rafts I and II are constructed side by side at the same time (case 1)			Raft I is constructed at first, then later the raft II (case 2)		
	q_1 [kN/m^2]	q_2 [kN/m^2]	$\Delta q=q_1-q_2$ [kN/m^2]	q_1 [kN/m^2]	q_2 [kN/m^2]	$\Delta q=q_1-q_2$ [kN/m^2]
0.00	669	-133	802	444	368	76
0.01	664	-119	783	529	368	161
0.10	644	-53	697	495	368	127
1.00	653	160	493	616	368	248
10.0	733	367	366	733	368	365
∞	733	365	368	733	368	365

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

Timeout of the construction process

- Considerable differences will be expected in the results, if the analysis is carried out for system of rafts (case 1) or for construction of a new raft II beside an existing old one I (case 2)

- If the two rafts are constructed side by side at the same time, both rafts will lean toward each other (Figure 4.21)

- If raft I is constructed first and then raft II, there will be an additional pressure under raft I will cause an inclination of raft I in the direction of raft II (Figure 4.25)

Settlement differences at the joint

- For system of rafts (case 1), the settlement difference between rafts is relatively small at the joint for joint width c = 0.0 [cm]. The more settlement difference is for farther distance between rafts. In contrast, for the raft I with neighboring raft II (case 2) because of the pressure overlap from the neighboring raft II, the greater settlement difference is for the smaller joint width c (Figures 4.21, 4.25 and Table 4.6). This phenomenon occurs because the behavior of contact pressures of raft II has great influence on the settlement distribution of the raft I. Figures 4.20 and 4.24 show the contact pressure distribution for cases 1 and 2. The contact pressure of raft II for case 1 decrease by decreasing the width joint c, while for case 2 is independence from joint width c

- Settlements at the edge of the raft I due to influence of neighboring raft II (case 2) are greater than those due to system of rafts (case 1)

- Settlements from case 1 for joint width c = 0.0 [cm] and from cases 3 and 4 are quite similar (Figures 4.21 and 4.29)

- If hinged joint between rafts is used (case 4), there will be continuation of settlement under the rafts (Figure 4.29)

Contact pressures

- For system of rafts (case 1) the contact pressure distribution under the raft I is almost independent of the joint width due to the heavy load of the raft I. On the other hand, for the raft II strong dependence on the joint width is to be found because the strong edge contact pressure of the raft I, which affects on the raft II (Figure 4.23 and Table 4.7)

- Contact pressures at the edge of the raft I, if the raft I is constructed first and then the raft II (case 2), decreases by decreasing the width joint c (Figure 4.25)

- Contact pressures from case 3 (rafts as one unit) and 4 (rafts with hinged joint) are nearly similar (Figure 4.28)

Moments

- For system of rafts (case 1) the maximum moments for the raft I decrease by decreasing the joint width *c*, while for the raft II the sign of moment is changed from positive to negative in some places. The greater negative moment for raft II is for the smaller joint width *c* (Figure 4.22)

- For case 2, if the raft I is constructed first and then the raft II, the maximum moments of raft I decrease by decreasing the joint width *c*. The positions of maximum moments are also shifted to the opposite direction of raft II (Figure 4.26)

- It is clear from Figure 4.30 for rafts connected with hinged joint (case 4) that, the moment at the hinged joint for the two rafts is zero. Figure 4.30 shows for case 3 that a positive moment is to be found at the connection position. Raft II for both cases 3 and 4 has a negative moment beside a positive moment

Shearing forces

- The change in shearing forces for the raft I in case 1 is less than that in case 2 (Figures 4.23 and 4.27), while for the raft II in case 1 the singe of shearing force is changed from negative to positive at the edge of the raft. The greater positive shearing force for raft II is for the smaller joint width *c* (Figure 4.23)

- For both cases 3 and 4 a positive shearing force at the connection is to be found (Figur 4.31). Maximum shearing force is for hinged connection

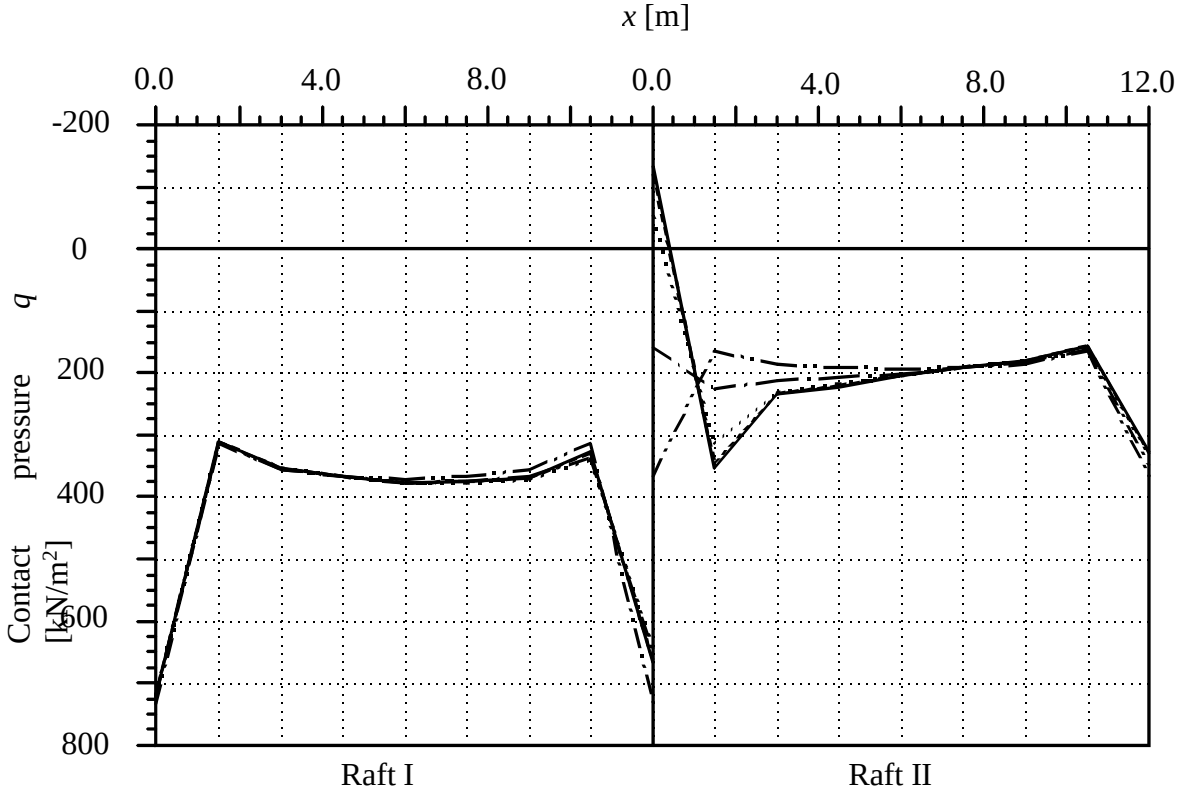

Figure 4.20 Contact pressures *q* at the middle section of rafts I and II (constructed at the same time)

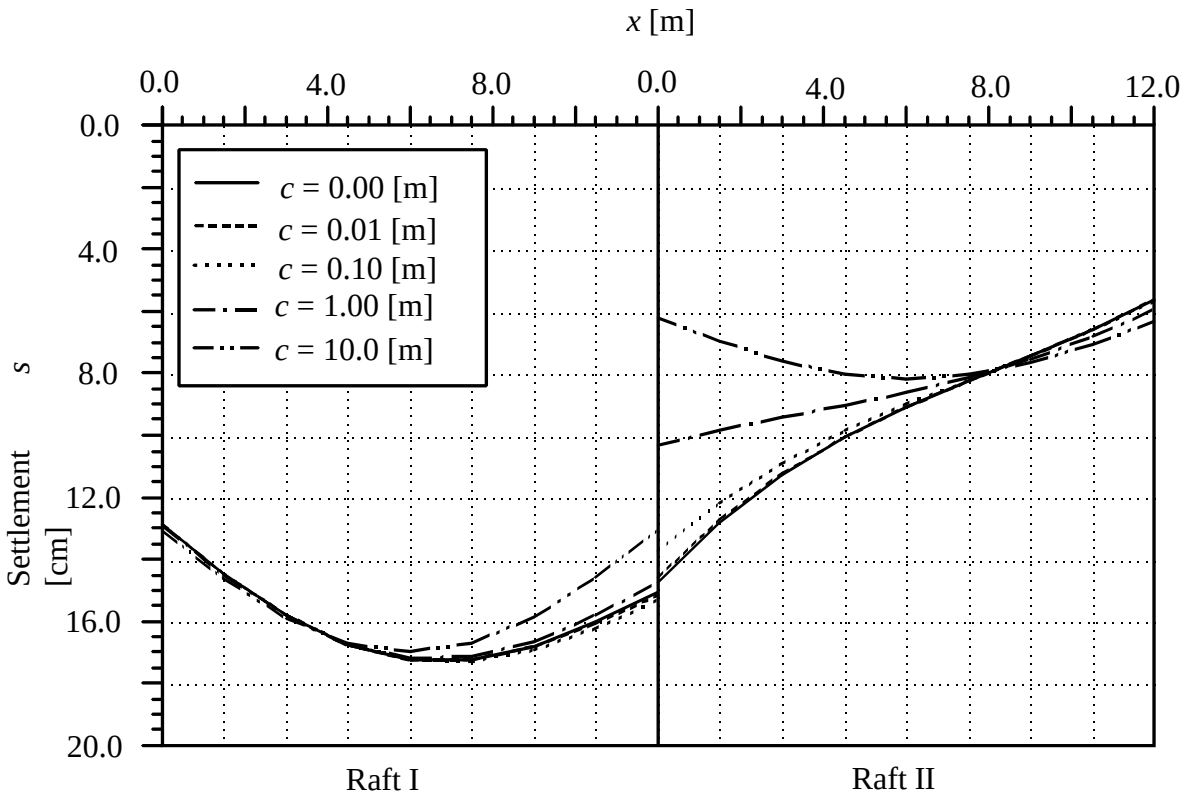

Figure 4.21 Settlements *s* at the middle section of rafts I and II (constructed at the same time)

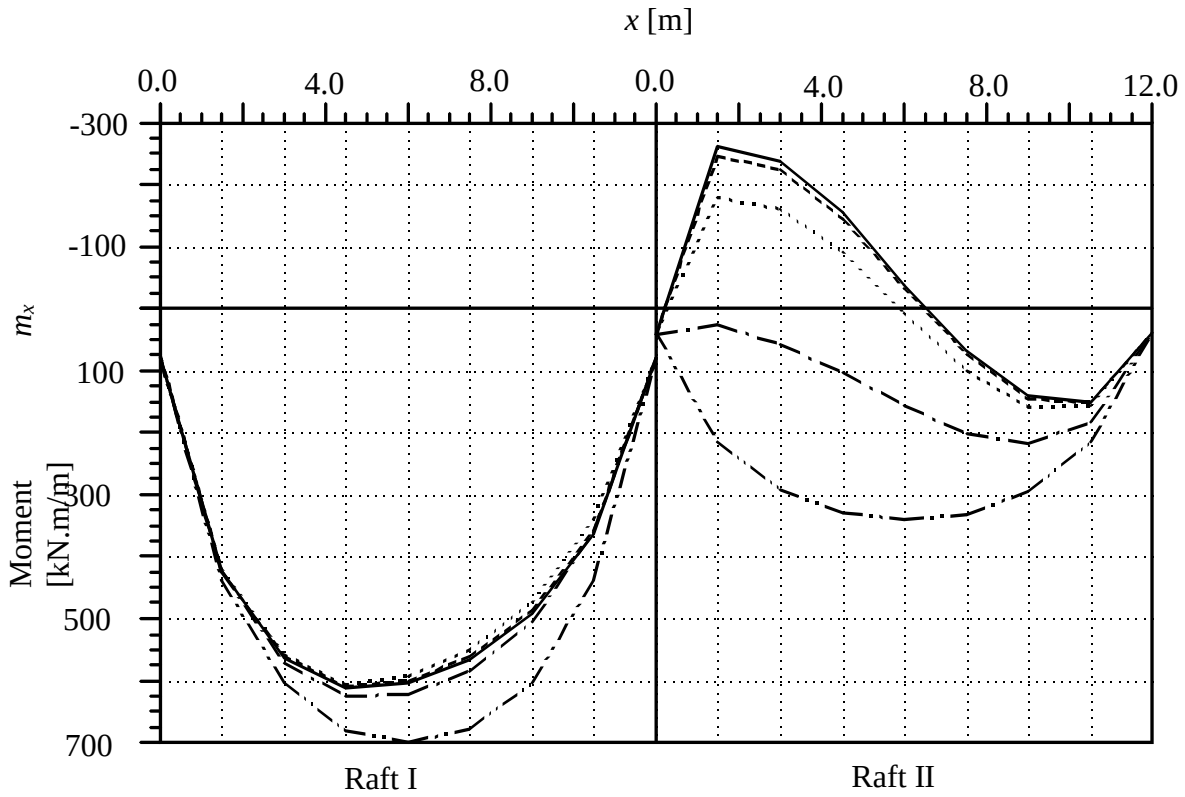

Figure 4.22 Moment m_x at the middle section of rafts I and II (constructed at the same time)

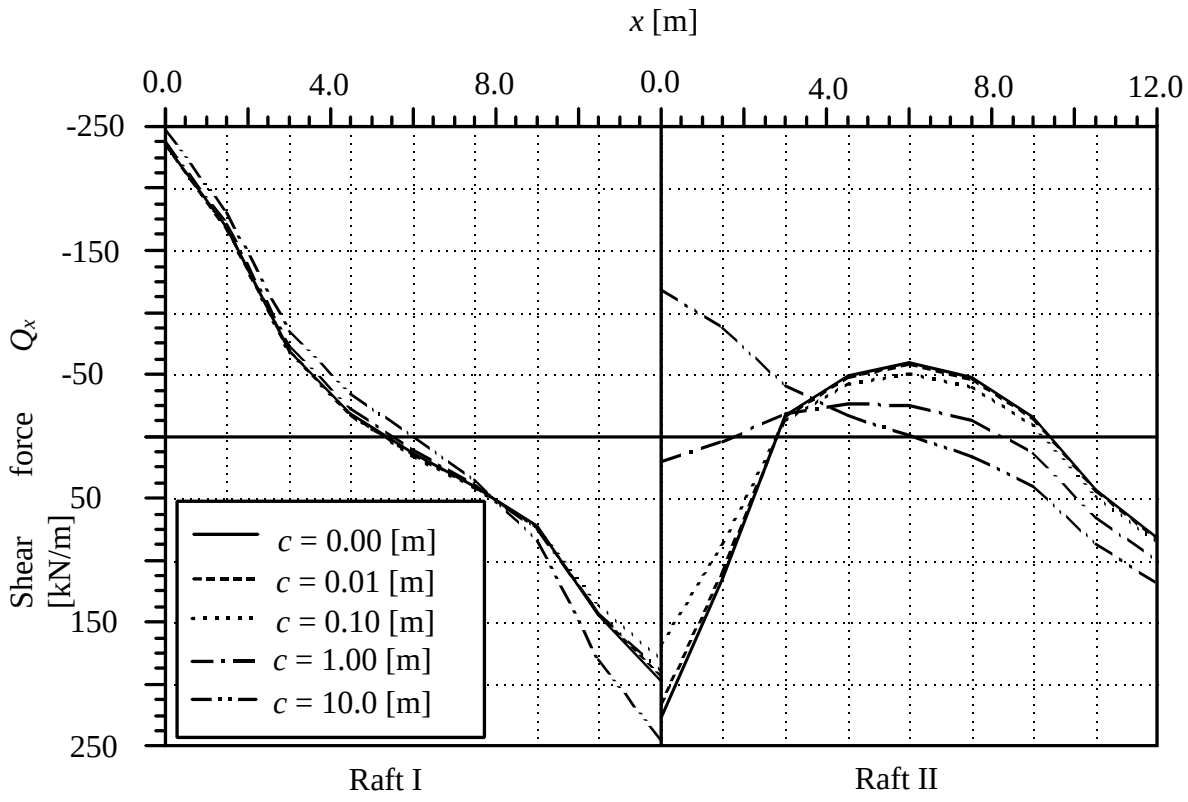

Figure 4.23 Shear forces Q_x at the middle section of rafts I and II (constructed at the same time)

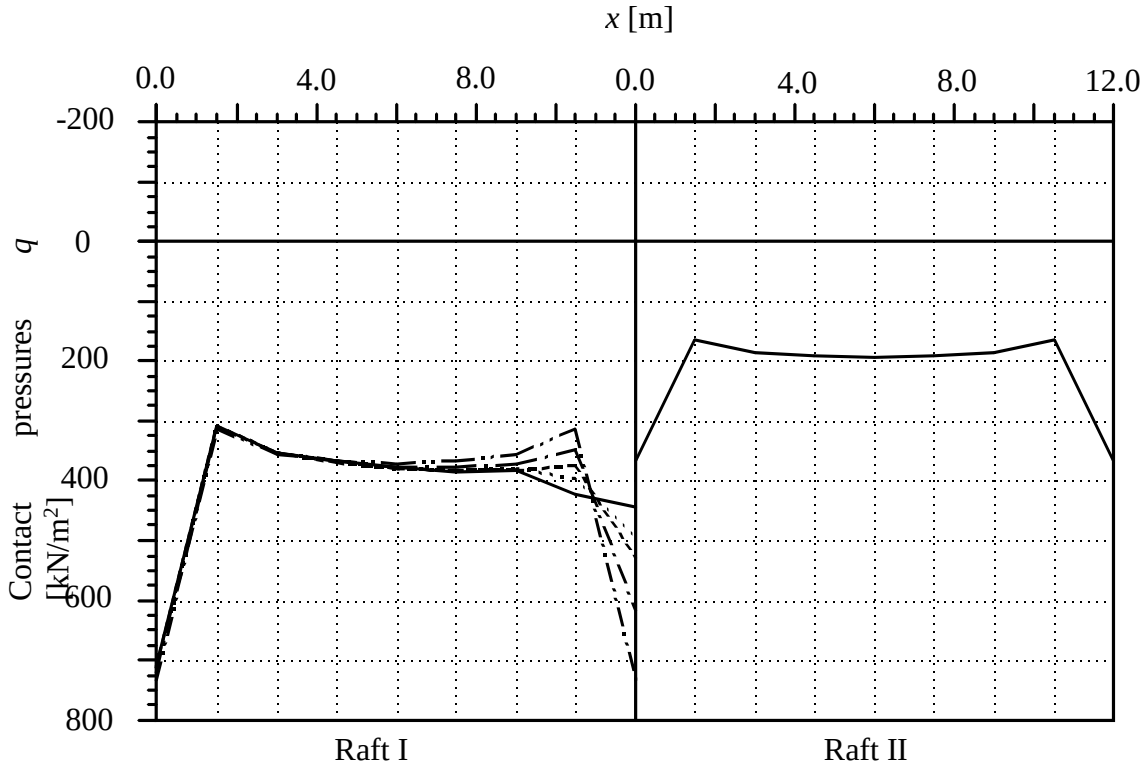

Figure 4.24 Contact pressures q at the middle section of rafts I and II (raft I is constructed first, then later raft II)

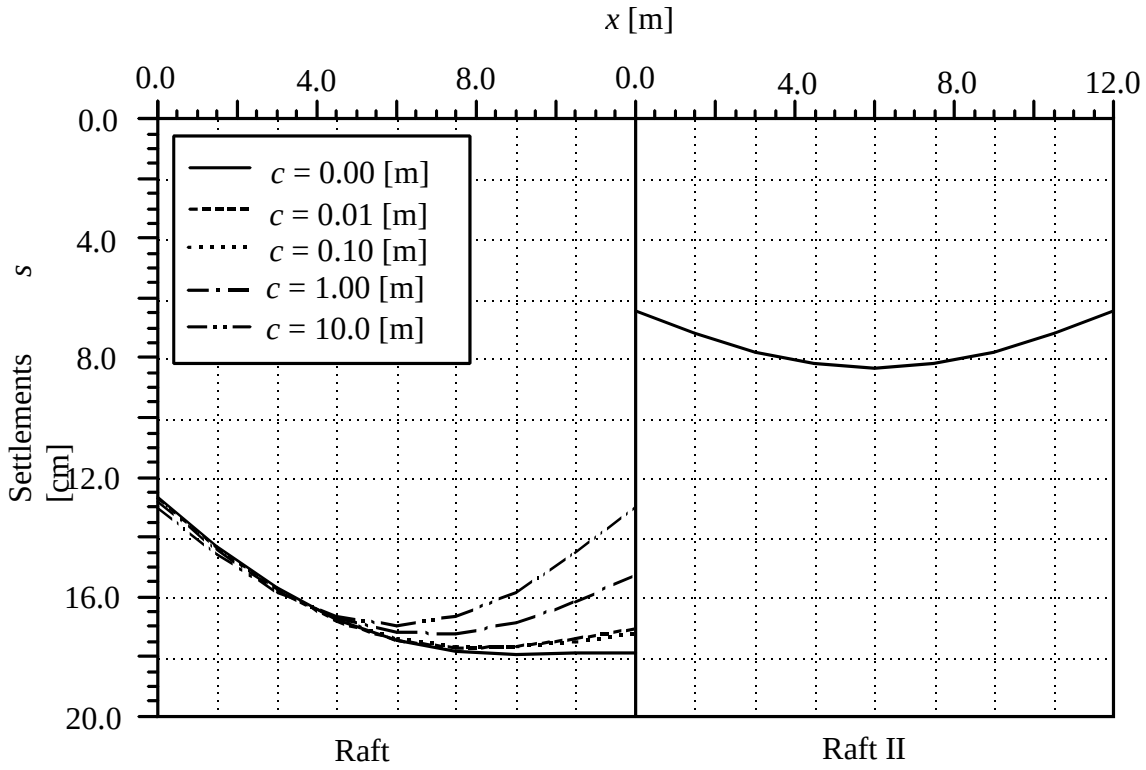

Figure 4.25 Settlements *s* at the middle section of rafts I and II (raft I is constructed first, then later raft II)

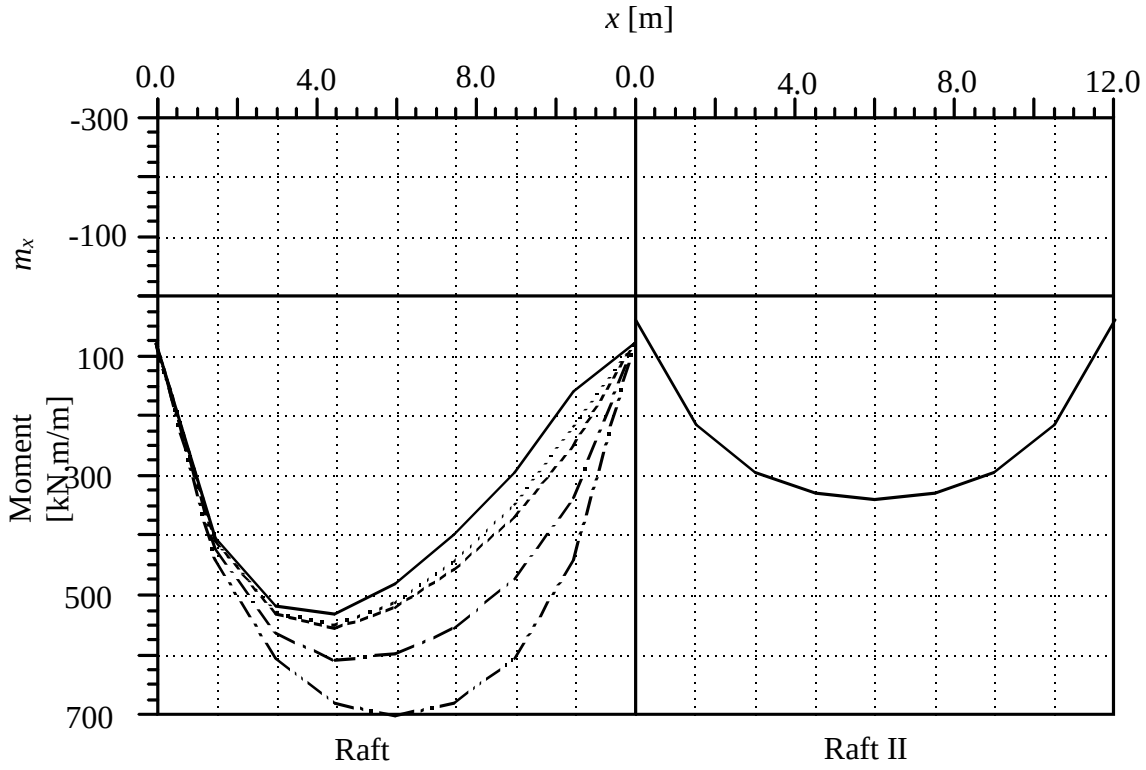

Figure 4.26 Moment m_x at the middle section of rafts I and II (raft I is constructed first, then later raft II)

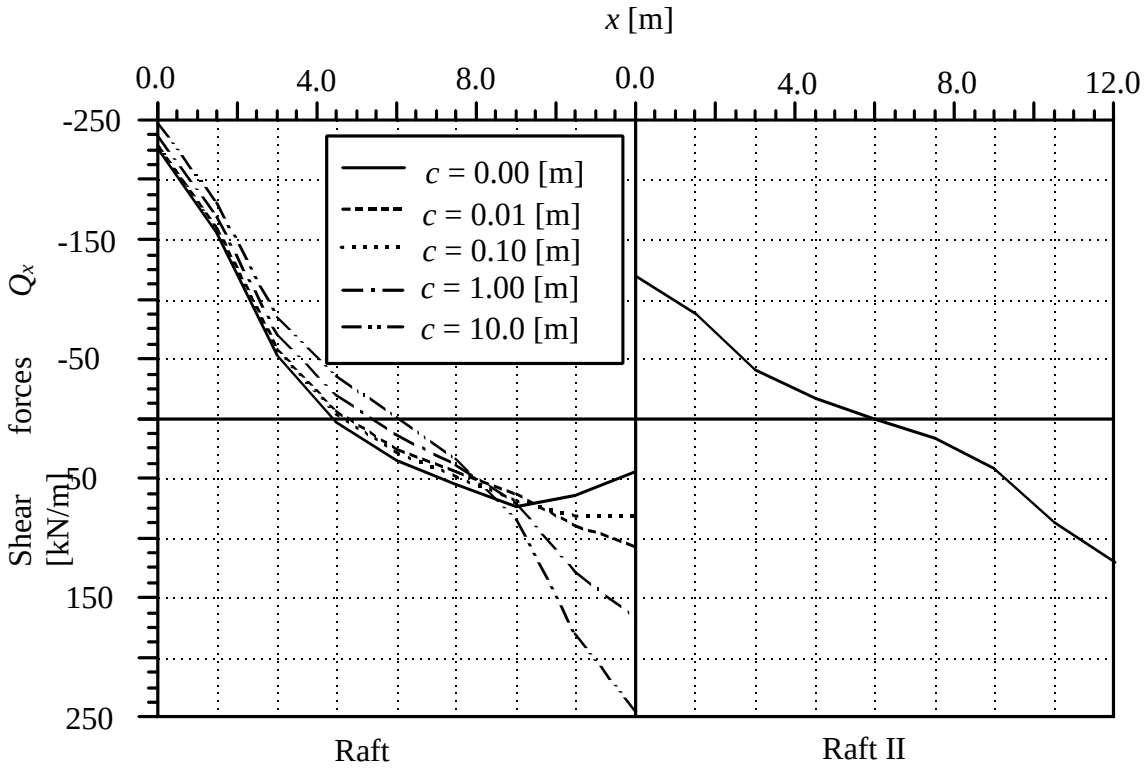

Figure 4.27 Shear forces Q_x at the middle section of rafts I and II (raft I is constructed at first, then later raft II)

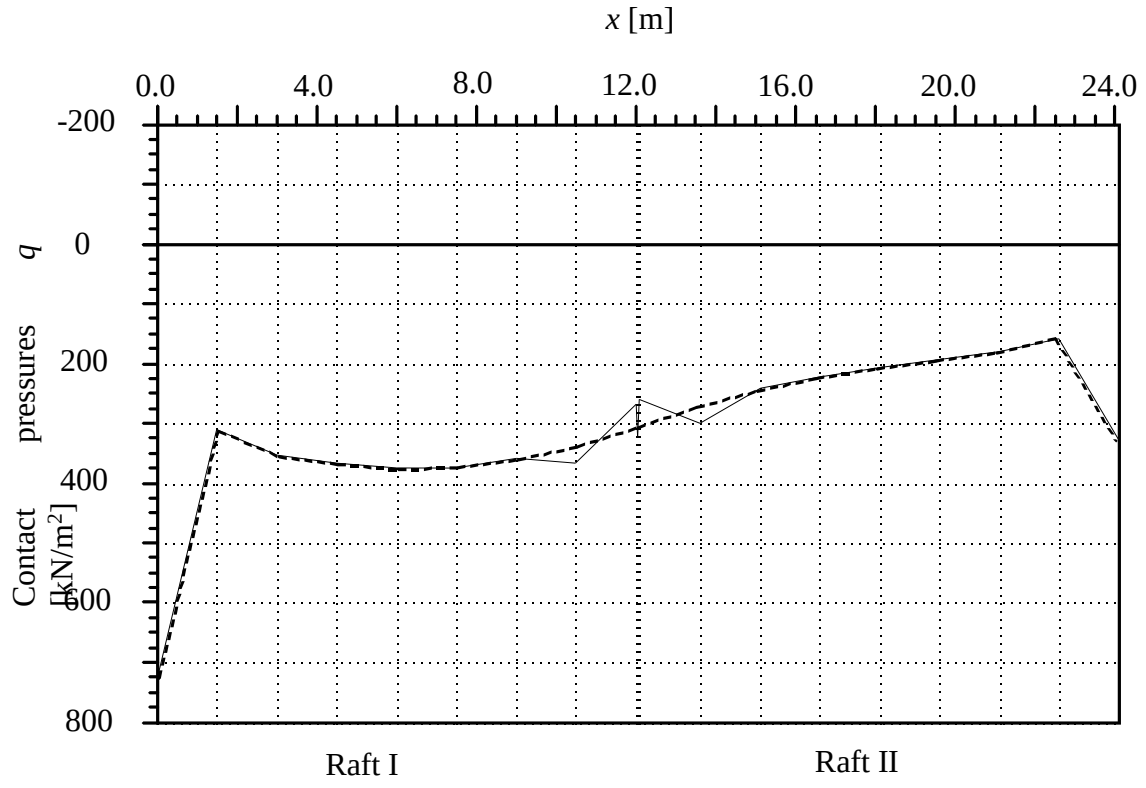

Figure 4.28 Contact pressures q at the middle section of the rafts I and II (case 3 and 4)

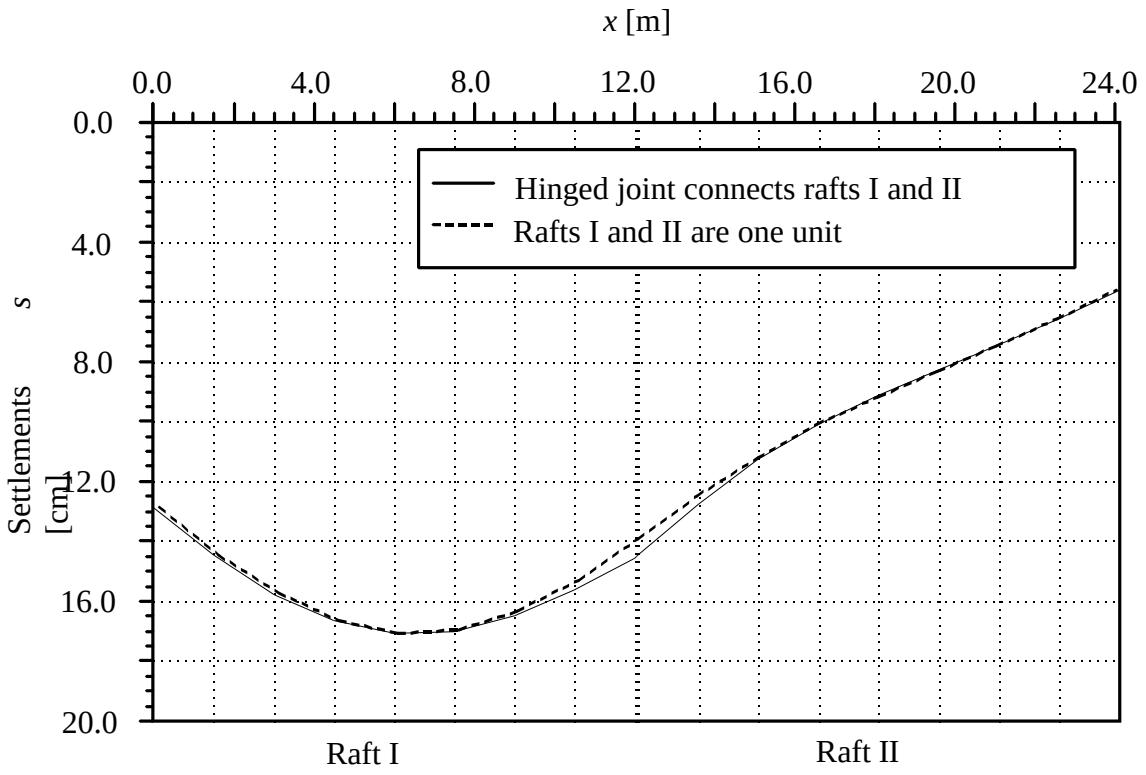

Figure 4.29 Settlements *s* at the middle section of the rafts I and II (case 3 and 4)

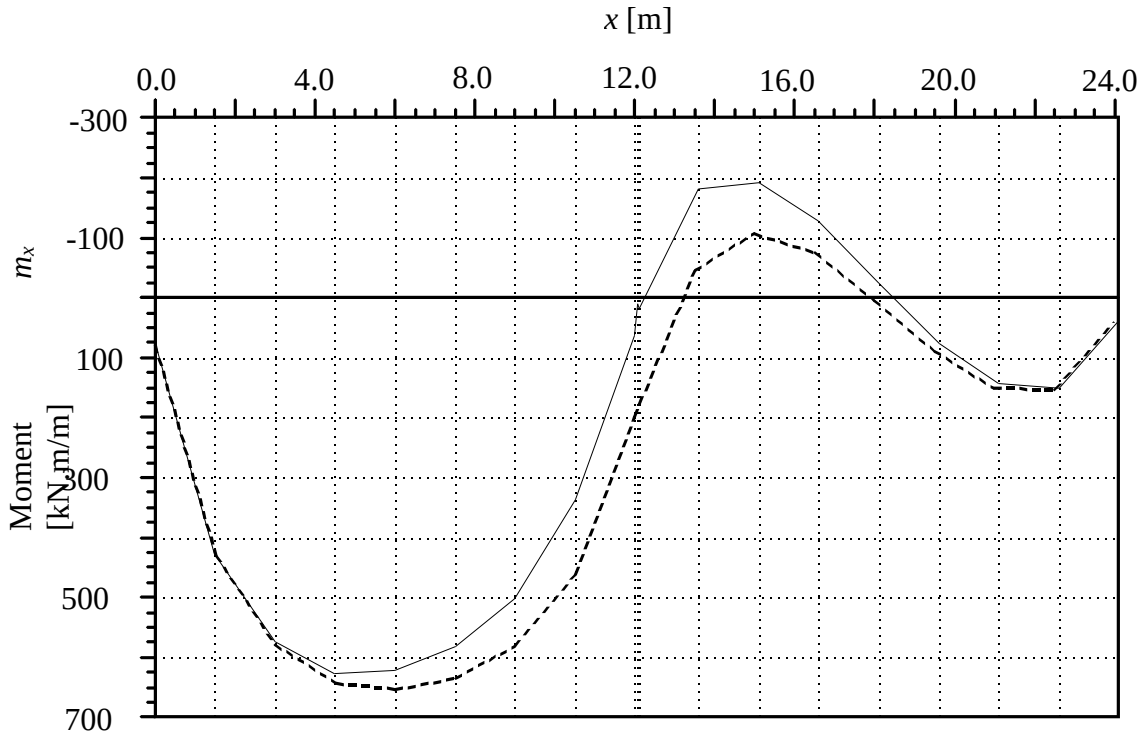

Figure 4.30 Moments m_x at the middle section of the rafts I and II (case 3 and 4)

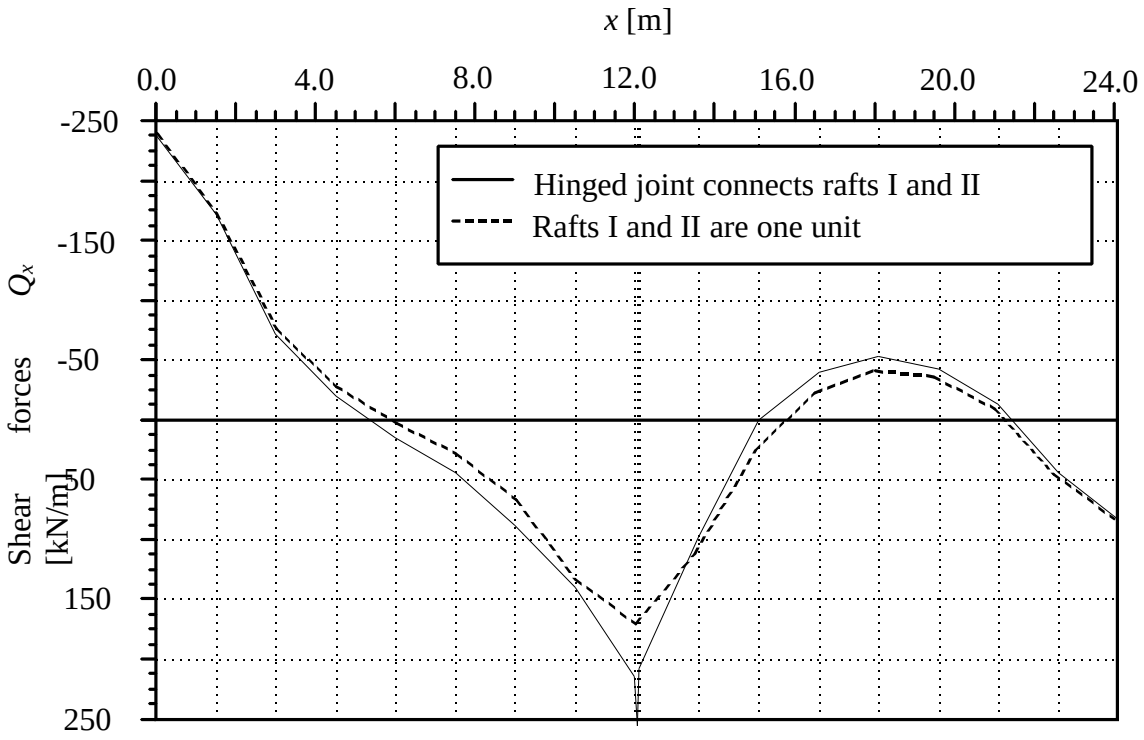

Figure 4.31 Shear forces Q_x at the middle section of the rafts I and II (case 3 and 4)