Example 5.3 Effect of girders on the raft rigidity

1 Description of the problem

Ribbed raft may be used for many structures with heavy loads or large spans, if a flat level for the first floor is not required. Consequently, concrete is reduced. Such structures are silos and elevated tanks. In spite of this type of foundation has many disadvantages if used in normally buildings, it still is used by many designers. Such disadvantages are the raft needs deep foundation level under the ground surface, fill material on the foundation to make a flat level and an additional slab on the fill material to construct the first floor. The use of the ribbed raft relates to the simplicity of analysis by hand calculations.

First, both of the two rafts with and without ribs are clearly save and correct, but there is still a question, whose one of the two types is more rigid? To answer this question the following example is presented.

Consider the foundation of an elevated tank may be designed for both types of foundations. The foundation has the dimensions of 20 [m] × 20 [m] and transmits equal loads for all 25 columns, each of 1000 [kN]. The loads give average contact pressure on soil q_{av} = 62.5 [kN/m^2]. Columns are equally spaced, 4 [m] apart, in each direction as shown in Figure 5.14.

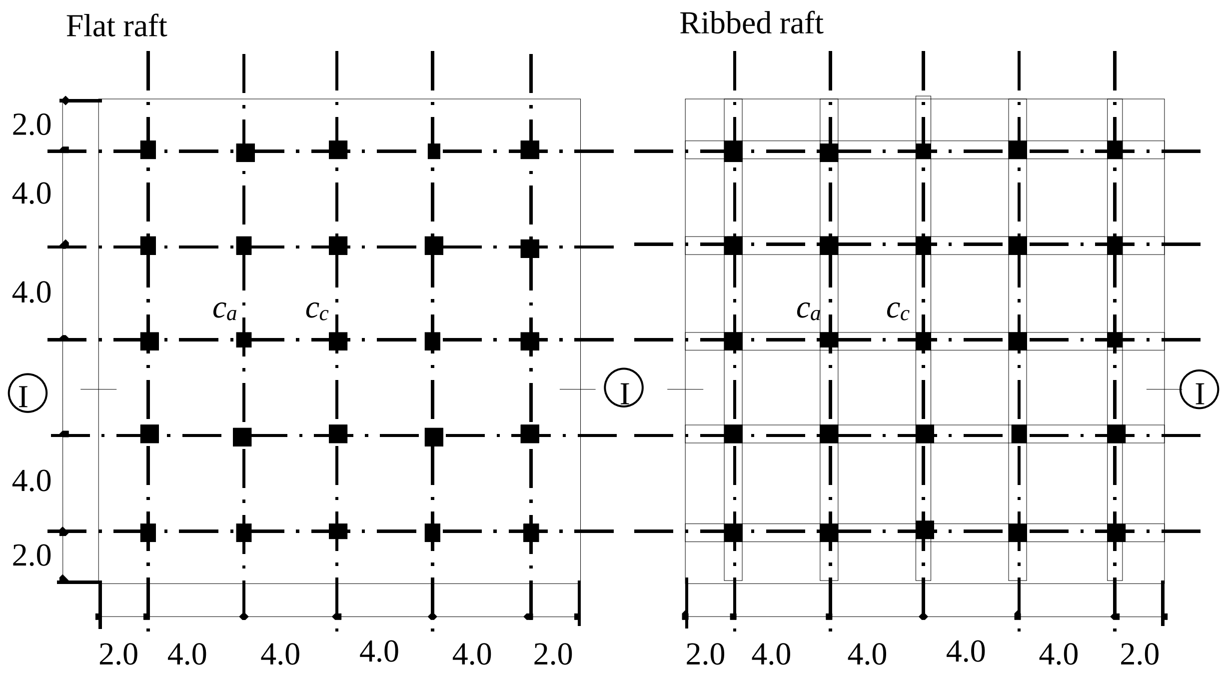

Figure 5.14 General plan of rafts

The analysis of the foundation is carried out to study the effects of soil types, rigidity of girders and slabs. A detail description of each parameter is presented as follows.

2 Soil

Three subsoil models are considered:

i) Simple assumption model (conventional method) that assumes linear distribution of contact pressure on the bottom of the slab. The model considers no interaction between the raft and the subsoil

ii) *Winkler*'s model that represents the subsoil by isolated springs

iii) Layered model that considers the subsoil as continuum medium

The raft resting on a soil layer of 20 [m] is equal to the raft side, overlying a rigid base. The soil types are represented by the modulus of elasticity E_s, for layered model, which yields modulus of subgrade reaction k_s for *Winkler*'s model. Table 5.1 shows the different soil types examined in this example according to the soil properties E_s and k_s. *Poisson*'s ratio is taken $\nu_s = 0.3$ for all soil types.

Table 5.1 Soil properties for different soil types

E_s [kN/m^2]	5000	10000	15000	20000	25000	30000	35000	40000	45000	50000
k_s [kN/m^3]	583	1166	1749	2332	2915	3498	4081	4664	5247	5830

3 Concrete material

The parameters of raft material are *Young*'s modulus $E_b = 2 \times 107$ [kN/m^2], *Poisson*'s ratio $\nu_b = 0.25$ and shear modulus $G_b = 1 \times 107$ [kN/m^2].

4 Girders

A rectangular cross section is used for the girders with constant width of 0.40 [m]. The effect of girder rigidity is studied by varying its depth d_g. Influence of the effective flange width of the slab on the moment of inertia of the girder is neglected.

5 Slab

For different chosen values of girder depth d_g, the corresponding values of slab thickness are 0.25, 0.30, 0.35, 0.40, 0.45 and 0.50 [m].

6 Analysis and discussion

The study of the raft is done for both cases, with and without girders. First the foundation is designed using working stress method according to the Egyptian code of practice (ECP), for concrete and steel grades f_c = 60 [kg/cm^2] and f_s = 1400 [kg/cm^2] respectively. The design is carried out using the classical method without interaction between the soil and the foundation. Through this design the dimensions of the raft with girders are slab thickness d_s = 0.25 [m], girder depth d_g = 0.85 [m] and girder width b_g = 0.40 [m], while the thickness for the flat raft is d_r = 0.55 [m]. The analysis is focused on the layered Continuum model, because it is more realistic than *Winkler*'s model for simulation of most soil types.

6.1 System rigidity

A good advantage of the foundation rigidity analysis, proposed by *El Gend*y (1998), is the possibility to find the system rigidity of rafts having any shape, such as ribbed rafts, considered in this example. Therefore, series of computations are carried out for many variables with the parameter k_r obtained at the center of the raft, to compare between the system rigidity of the two types of rafts with and without girders.

Figure 5.15 shows the parameter k_r with the raft thickness d_s in case of the flat raft while Figure 5.16 shows the parameter k_r with girder depth d_g at different slab thickness in case of the ribbed raft. Both of the two figures are considered for soil of Es = 10000 [kN/m^2].

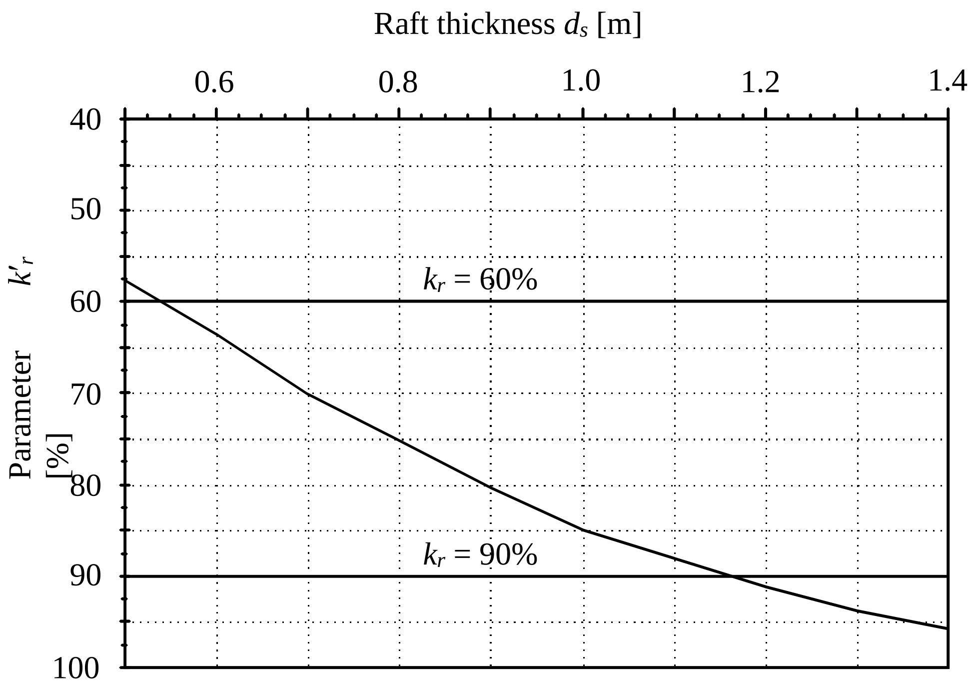

Figure 5.15 Parameter k_r with raft thickness at the center of the raft (E_s =10000 [kN/m^2])

From these figures, it can be found that the flat raft of thickness d_r = 0.55 [m] gives parameter k_r = 60 [%] while the raft of slab thickness d_s = 0.25 [m] and girder depth d_g = 0.85 [m] gives parameter k_r = 52 [%]. This means the ribbed raft designed by the classical method has rigidity less than that of the flat raft designed also by the same method. The ribbed raft, which gives parameter k_r = 60 [%] equals to that of the flat raft, can be easily obtained from Figure 5.16. In which may be had one of the following dimensions in Table 5.2.

Table 5.2 Dimensions of ribbed rafts, which give parameter k_r = 60 [%]

Slab thickness d_s [m]	0.25	0.30	0.35	0.40	0.45	0.50
Girder depth d_g [m]	1.25	1.20	1.15	1.10	0.90	0.75

From Figure 5.16, it can be concluded that the slab thickness d_s for rafts with a small girder d_g has great influence on the system rigidity. This influence decreases by increase the girder depth d_g until d_g = 2.0 [m], then becomes constant. This means that the girders of depth d_g > 2.0 give most the system rigidity.

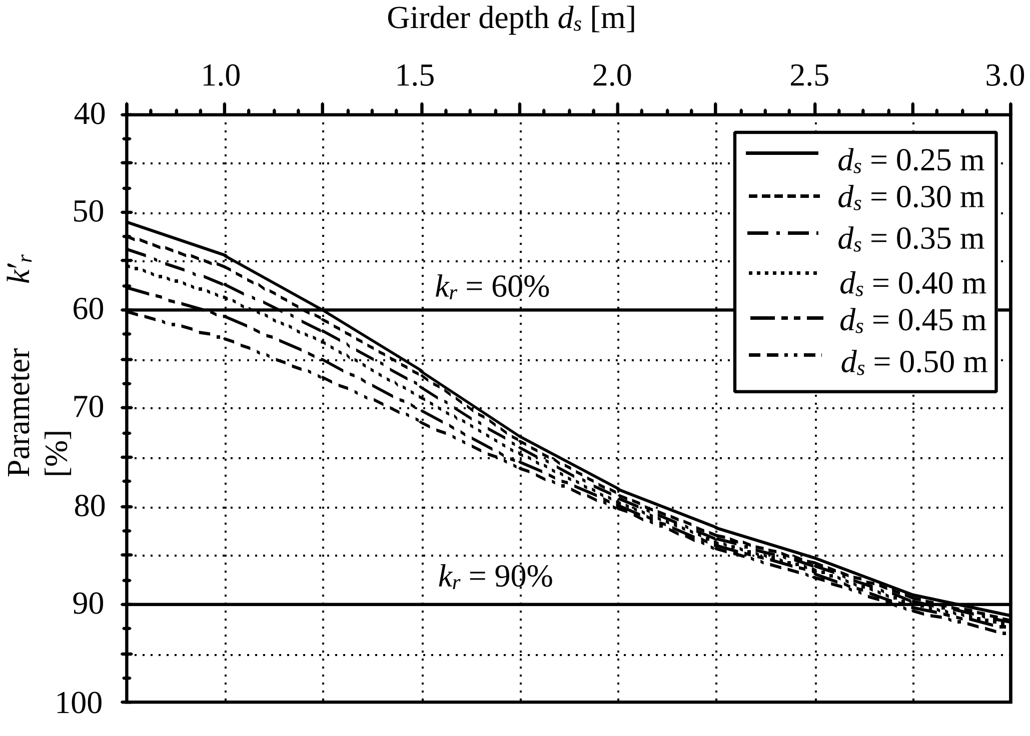

Figure 5.16 Parameter k_r with girder depth at the center of the raft (E_s = 10000 [kN/m^2])

To check the system rigidity of the rafts with and without girders at different soil types, the parameter k_r for three selected rafts is plotted with the soil modulus E_s as shown in Figure 5.17.

The three rafts are:

Raft 1 flat raft of thickness d_r = 0.55 [m]
Raft 2 ribbed raft with slab thickness d_s = 0.25 [m] and girder depth d_g =0.85 [m]
Raft 3 ribbed raft with slab thickness d_s = 0.25 [m] and girder depth d_g =1.25 [m]

Figure 5.17 shows that the rafts 1 and 3 that have the same system rigidity at soil type E_s = 10000 [kN/m^2] have also the same system rigidities for all soil types. The range of the difference in k_r of raft 2 and raft 1 (or raft 3) is 20 [%] to 5 [%] for weak soil of E_s = 5000 [kN/m^2] to medium soil of E_s = 20000 [kN/m^2]. This difference decreases slowly for E_s > 20000 [kN/m^2] with increase of E_s until stiff soil of E_s = 45000 [kN/m^2], then k_r of raft 2 becomes identical with that of raft 3.

To show the influence of the soil types on the system rigidity of ribbed rafts, the parameter k_r is plotted with the girder depth at different soil types as shown in Figure 5.18. The raft has 0.25 m slab thickness. From Figure 5.18, it can be noted that, the system rigidity of raft on weak soil increases quickly rather than that of raft on stiff soil with increase of girder depth. At a small depth d_g, the difference in k_r of raft on weak soil and that of raft on stiff soil is small. This difference increases slowly until depth d_g = 1.75, then becomes nearly constant for the other depths more than 1.75 [m].

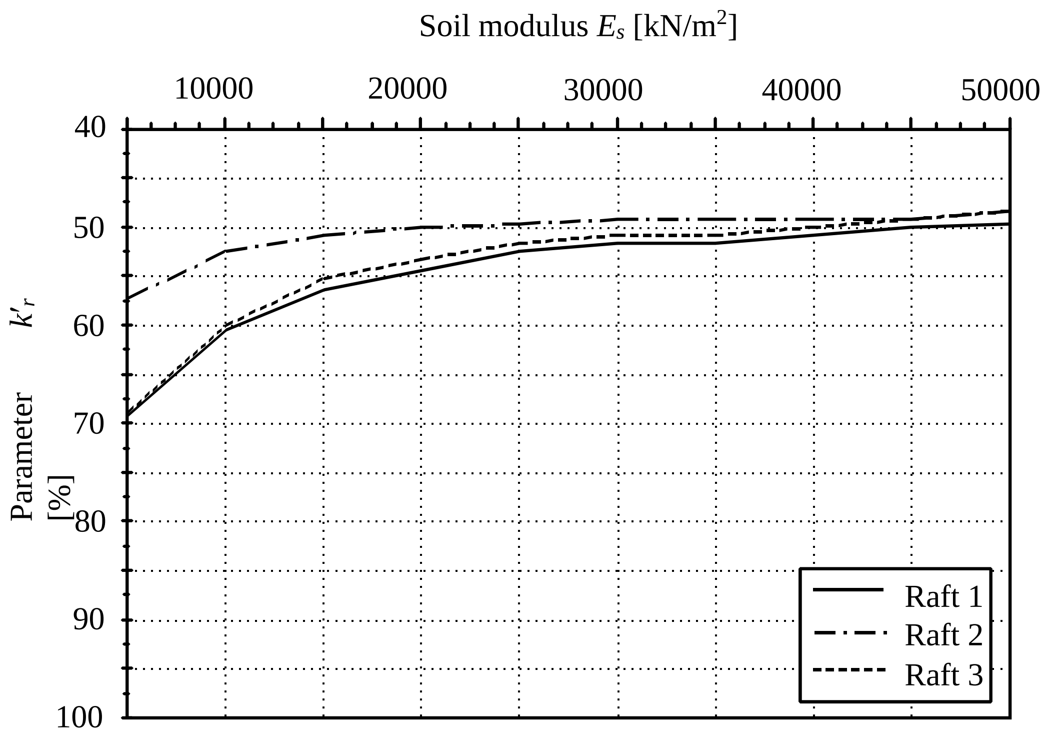

Figure 5.17 Parameter k_r with soil modulus E_s at the center of the raft

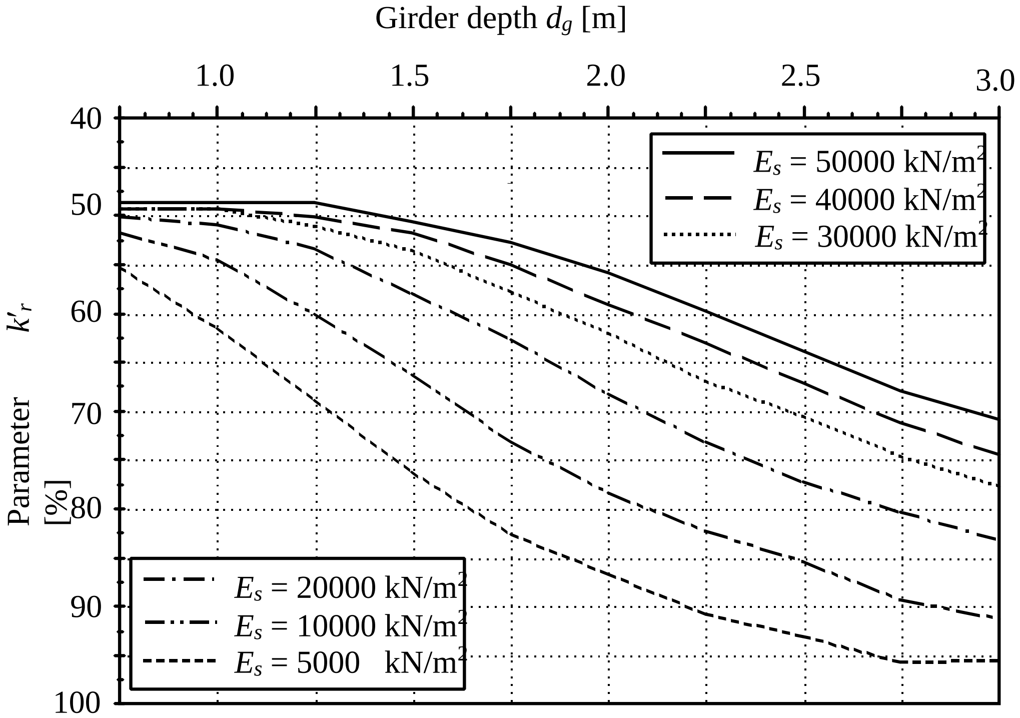

Figure 5.18 Parameter k_r with girder depth at different soil types at the center of the raft

6.2 Effect of girders on differential settlement between columns

The effects of the girder rigidity and the soil types on differential settlement are studied by comparing the differential settlement between central column *cc* and its adjacent column ca for the flat raft (raft 1) and ribbed rafts (rafts 2, 3).

Figure 5.19 shows the differential settlement Δf with the soil rigidity represented by its modulus of elasticity E_s. From Figure 5.19, it can be found that the differential settlement Δf decreases quickly with the increase of E_s from E_s = 5000 [kN/m^2] to 10000 [kN/m^2], then decreases slowly with the increase of E_s from 10000 [kN/m^2] to 50000 [kN/m^2] for both raft types. This figure indicates also that the differential settlement Δf for ribbed raft coincides with that of flat raft if the two types have the same rigidity (rafts 1 and 3) for all soil types. It is clear that the ribbed raft designed by classical method (raft 2) has differential settlement higher than that of rafts with and without girders (rafts 1 and 3), which have the same rigidity in case of weak soil. The increasing in differential settlement for raft 2 reaches 33 [%] to 14 [%] compared with those of rafts 1 and 3 in cases of soils have E_s = 5000 [kN/m^2] and E_s = 10000 [kN/m^2] respectively. However, for E_s greater than 25000 [kN/m^2] until for stiff soil the differential settlement for raft 2 becomes less than that of rafts 1 and 3.

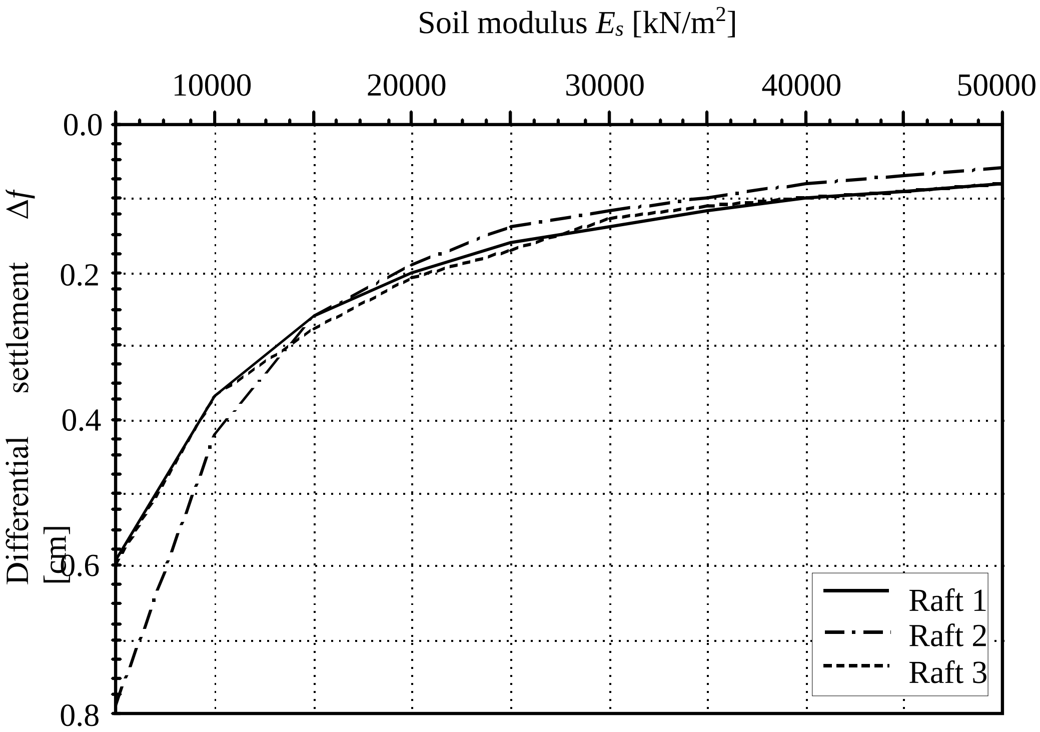

Figure 5.19 Differential settlement Δf between columns with soil modulus E_s

6.3 Effect of girders on contact pressure

The contact pressure under the ribbed rafts (raft 2 and 3) at section I-I for two soil types, weak and stiff, are compared with that of flat raft (raft 1).

The soil modulus for weak soil is E_s = 5000 [kN/m^2] while for stiff soil is E_s = 50000 [kN/m^2] in case of layered model. The corresponding modulus of subgrade reactions for these two soil types are k_s = 583 [kN/m^3] and k_s = 5830 [kN/m^3] for weak and stiff soil respectively in case of *Winkler*'s model.

Figure 5.20 shows the distribution of contact pressure at section I-I for *Winkler*'s model, while Figure 5.21 shows the distribution for layered model. The contact pressure according to the conventional method is plotted at the same figures. As the contact pressure distribution is similar to that of settlement distribution for *Winkler*'s model. Therefore, Figure 5.20 shows also the settlement at section I-I multiplied by the modulus k_s.

The effect of girders on the contact pressure is clear along the rafts for both *Winkler*'s and layered models. Such effect is very remarkable for weak soil, where the presence of girders increases the contact pressure under the girders. On the other hand, the girders decrease this contact pressure in the middle of the panels. Other figures, not included, show that the presence of girders leads to negative pressure at the corner of the raft in case of layered model for raft 2 of the less rigidity. The contact pressure of ribbed raft locates within the average range that of flat raft, if the two types have the same rigidity (rafts 1 and 3). This is obvious for stiff soil where may be coinciding with it. For the conventional method, the effect of girders plays no role on the contact pressure where is constant for all soil types and equal to the average load on the raft.

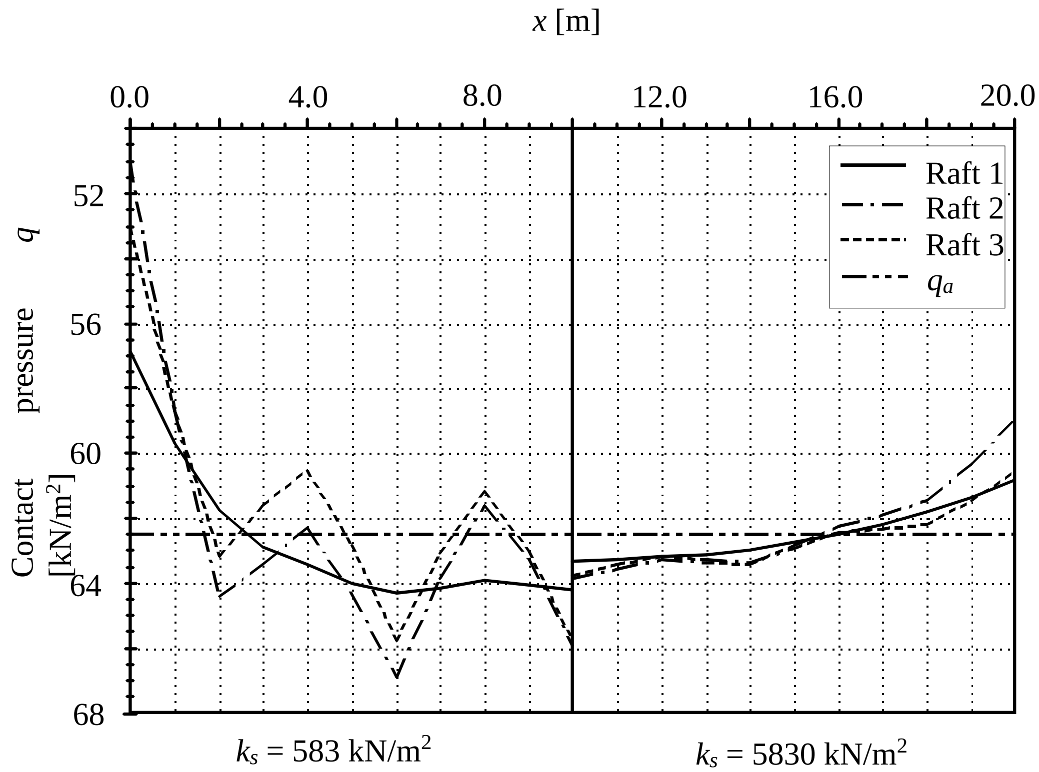

Figure 5.20 Contact pressure at section I-I for *Winkler*'s model

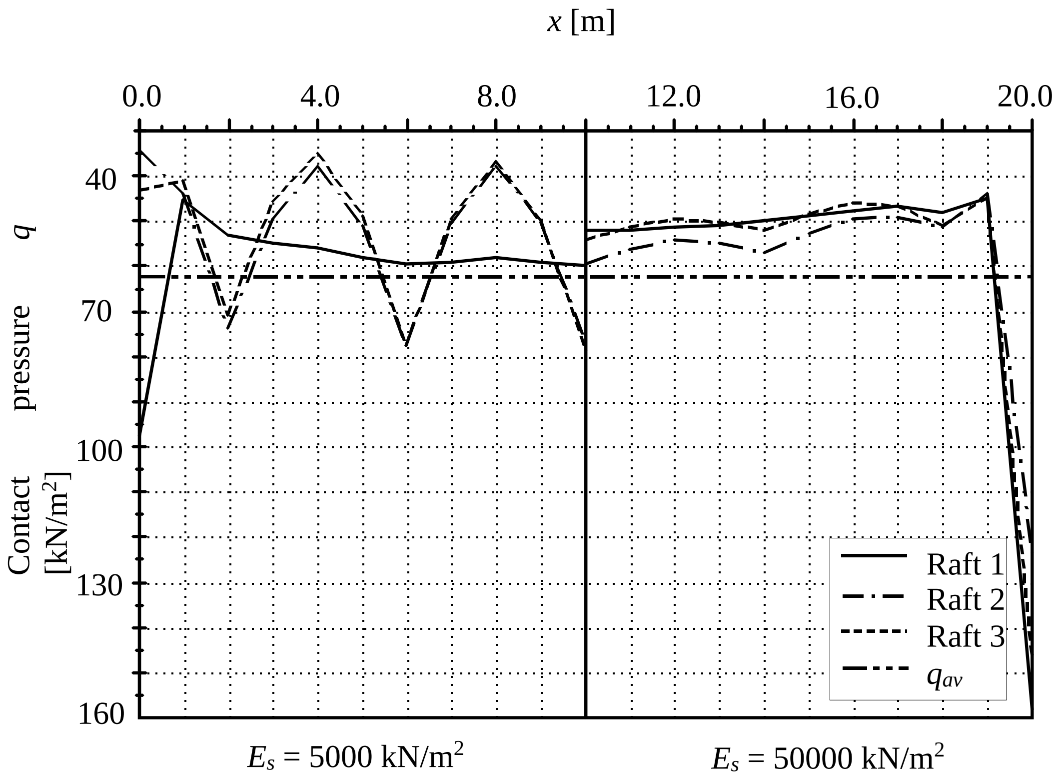

Figure 5.21 Contact pressure at section I-I for layered model