Example 2.2 Analysis of an irregular raft on irregular subsoil

1 Description of the problem

A general example is carried out to show the applicability of the different mathematical models for analysis of irregular rafts on irregular subsoil.

In one case the raft carries many types of external loads: concentrated loads [kN], uniform load [kN/m^2], line load [kN/m] and moments [kN.m] in both *x*- and *y*-directions as shown in Figure 2.18.

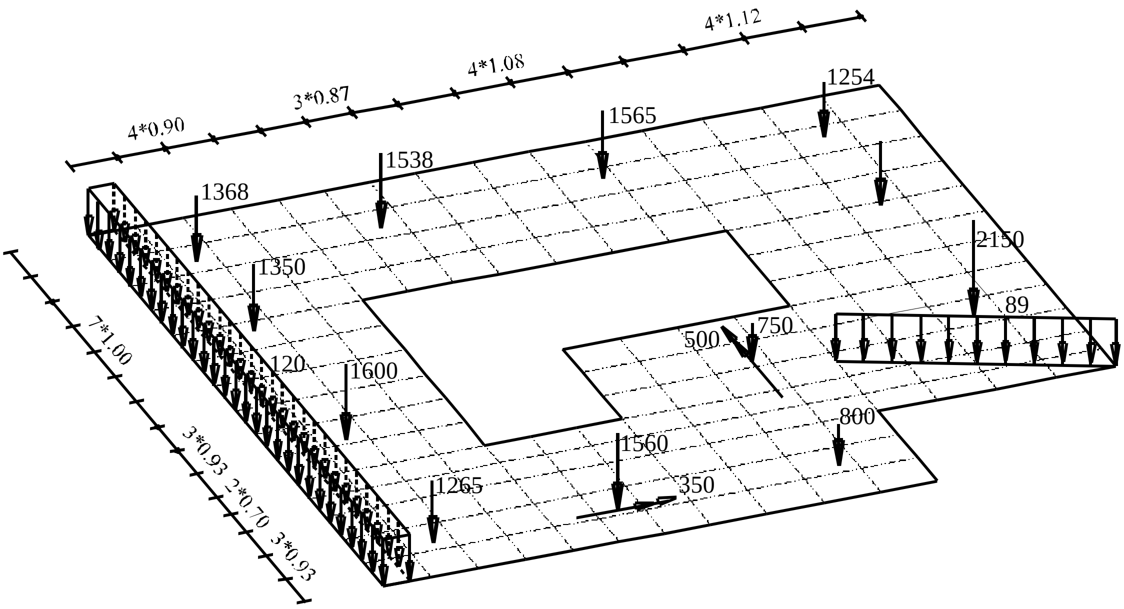
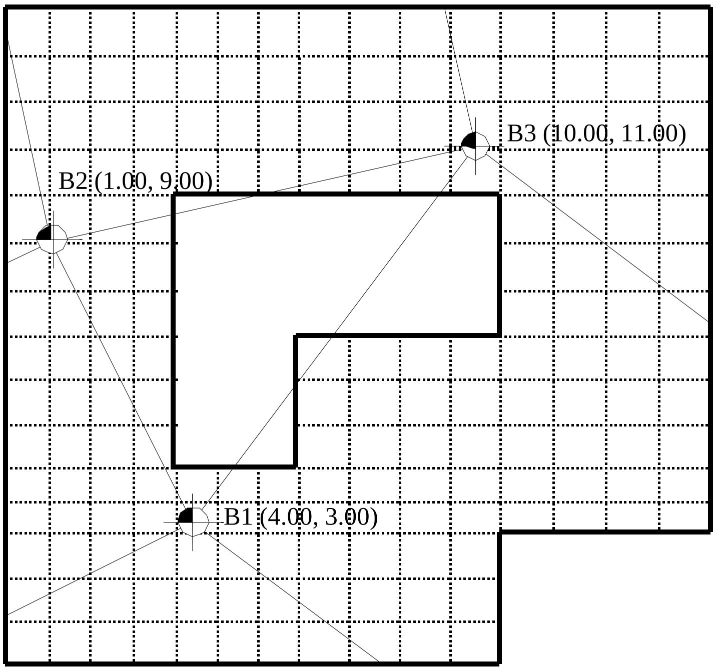


Figure 2.18 Raft dimensions [m] and loads

2 Soil properties

Three boring logs characterize the subsoil under the raft. Each boring has three layers with different soil materials. The moduli of compressibility of the three layers for loading are E_{s1} = 9500 [kN/m^2], E_{s2} = 22000 [kN/m^2] and E_{s3} = 120000 [kN/m^2] while for reloading are W_{s1} = 26000 [kN/m^2], W_{s2} = 52000 [kN/m^2] and W_{s3} = 220000 [kN/m^2]. *Poisson*'s ratio is 0.0 [-] for all soil layers. The level of foundation is d_f = 2.7 [m] while the level of ground water is *GW* = 1.5 [m]. Unit weight of the soil above the ground water is γ_s = 19 [kN/m^3] while under the ground water is γ'_s = 9 [kN/m^3]. The effect of reloading and water pressure is taken into account. Figure 2.19 shows boring logs and locations.

a)



b)

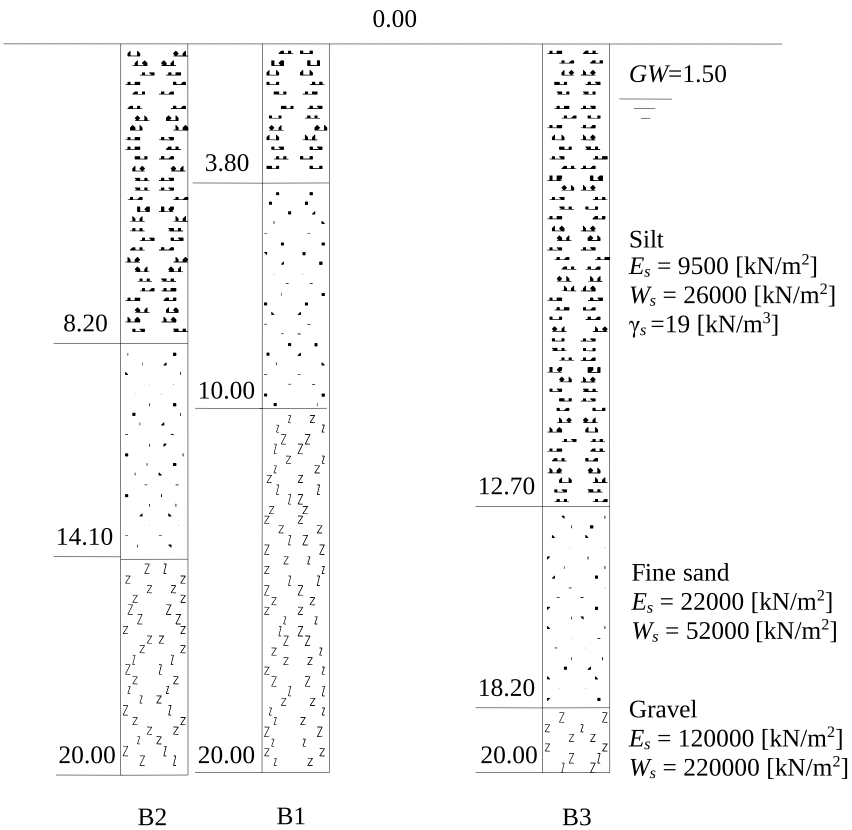


Figure 2.19 a) Boring locations and interpolation regions
b) Boring logs B1 to B3

3 Raft material and thickness

The raft material is supposed to have the following parameters:

Young's modulus	E_b	= 2 × 107	[kN/m^2]
Poisson's ratio	ν_b	= 0.25	[-]
Unit weight of raft material	γ_b	= 0.0	[kN/m^3]
Raft thickness	d	= 0.5	[m]

Unit weight of raft material is chosen to be γ_b = 0.0 to neglect the own weight of the raft in the analysis.

4 Analysis of the raft

The analysis of the raft is carried out by the eight mathematical calculation methods in Table 2.1. The methods are represented by the three subsoil models: Simple assumption, *Winkler*'s and Continuum models.

Table 2.1 Calculation methods

Method No.	Method
1	Linear contact pressure
2	Constant modulus of subgrade reaction
3	Variable modulus of subgrade reaction
4	Modification of modulus of subgrade reaction by iteration
5	Modulus of compressibility method for elastic raft on half-space soil medium
6	Modulus of compressibility method for elastic raft on layered soil medium (iter.)
7	Modulus of compressibility method for elastic raft on layered soil medium (eli.)
8	Modulus of compressibility method for rigid raft on layered soil medium

To carry out a comparison for the different calculation methods and mathematical models, the example is analyzed first by the modulus of compressibility method 7 for layered soil medium. Then, the same example with the same loads is analyzed again by the other seven different numerical calculation methods. The elastic parameters are assumed to represent the same type of soil, which is considered in the first analysis. By weighing the elastic parameters of each layer in a multilayered system according to its influence on settlement an "equivalent" modulus of compressibility for the entire subsoil mass for isotropic elastic half-space model 5 and an "equivalent" constant modulus of subgrade reaction for *Winkler*'s model 2 are determined. Main moduli of subgrade reactions for the three boring logs can be also determined for *Winkler*'s model 3. The equivalent elastic parameters can then be used to obtain the settlements, contact pressures, moments and shear forces in the raft by the different calculation methods.

The equivalent elastic parameters are:

For isotropic elastic half space model 5
E_{sm} = 9500 [kN/m^2]

For constant modulus of subgrade reaction model 2
k_{sm} = 3517 [kN/m^3]

For variable modulus of subgrade reaction model 3
k_{sm1} = 5254 [kN/m^3] for Boring B1
k_{sm2} = 2982 [kN/m^3] for Boring B2
k_{sm3} = 2315 [kN/m^3] for Boring B3

5 Results and discussion

The extreme values of the results are given in Table 2.2. Figures 2.20 to 2.28 show the settlements and contact pressures on the raft for the eight calculation methods.

Table 2.2 Maximum and Minimum values of settlements *s* and contact pressures *q* for the different calculation methods

Method	No.	$s_{max.}$ [cm]	$s_{min.}$ [cm]	$q_{max.}$ [kN/m^2]	$q_{min.}$ [kN/m^2]
Linear contact pressure	1	-	-	127	65
Constant modulus of subgrade reactions	2	5.38	0.46	189	16
Variable modulus of subgrade reactions	3	6.52	0.47	194	18
Modification of modulus of subgrade	4	4.42	1.15	586	19
Isotropic elastic half space	5	11.28	8.51	572	16
Modulus of compressibility - elastic raft	6 and 7	4.42	1.15	586	19
Modulus of compressibility - rigid raft	8	4.24	1.51	560	48

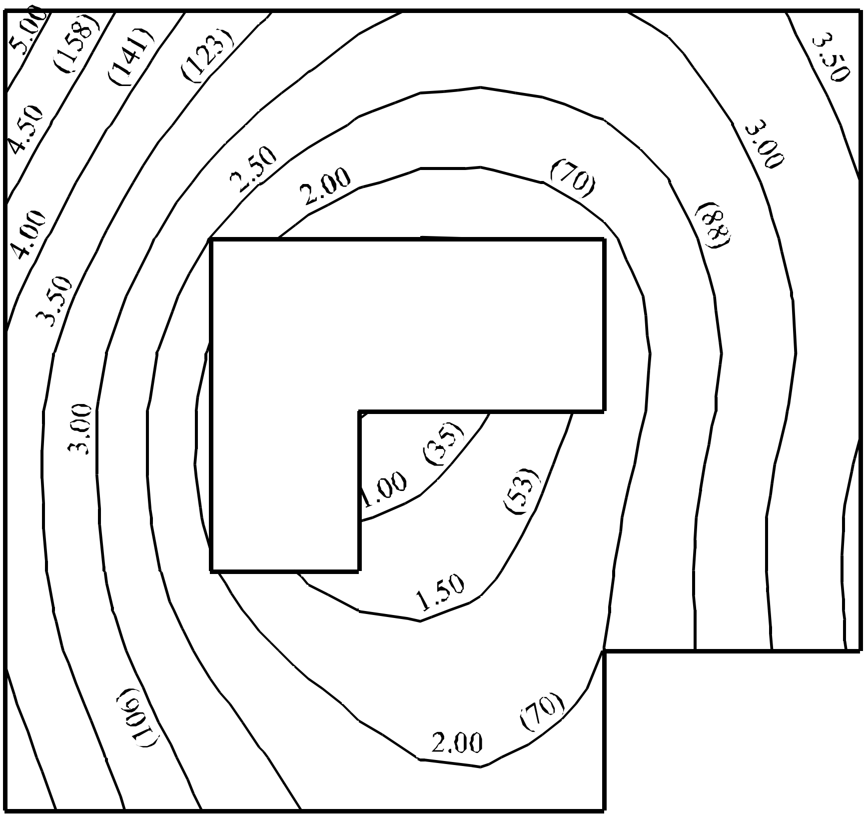


Figure 2.20 Contour lines of settlements [cm] and contact pressures [kN/m^2]
(in brackets for constant modulus of subgrade reaction method 2)

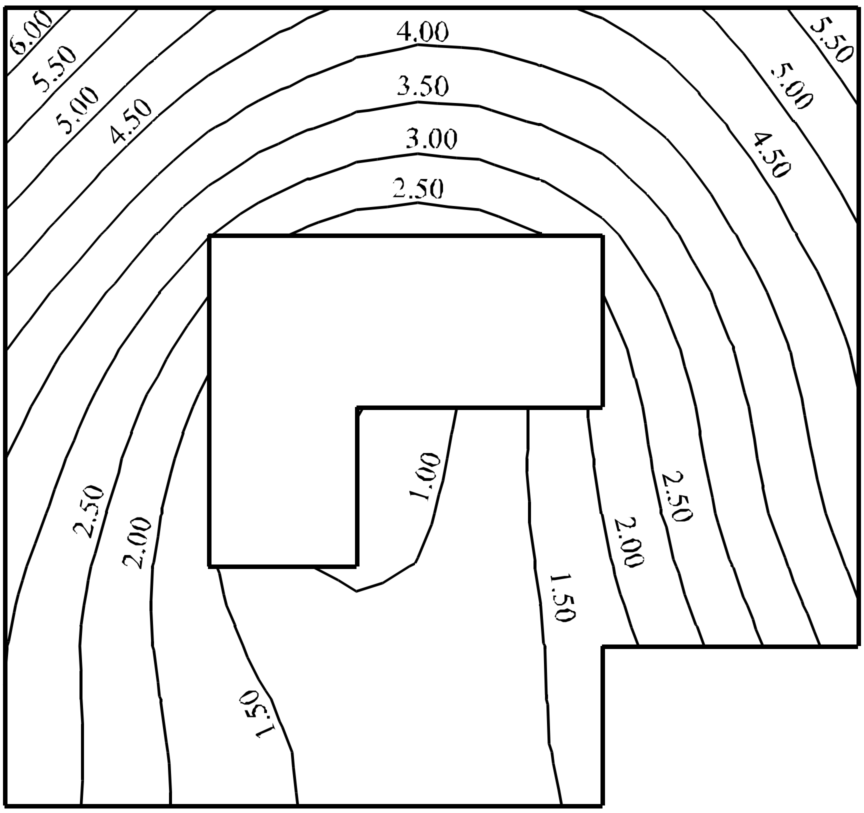


Figure 2.21 Contour lines of settlements [cm] for variable modulus of subgrade reactions 3

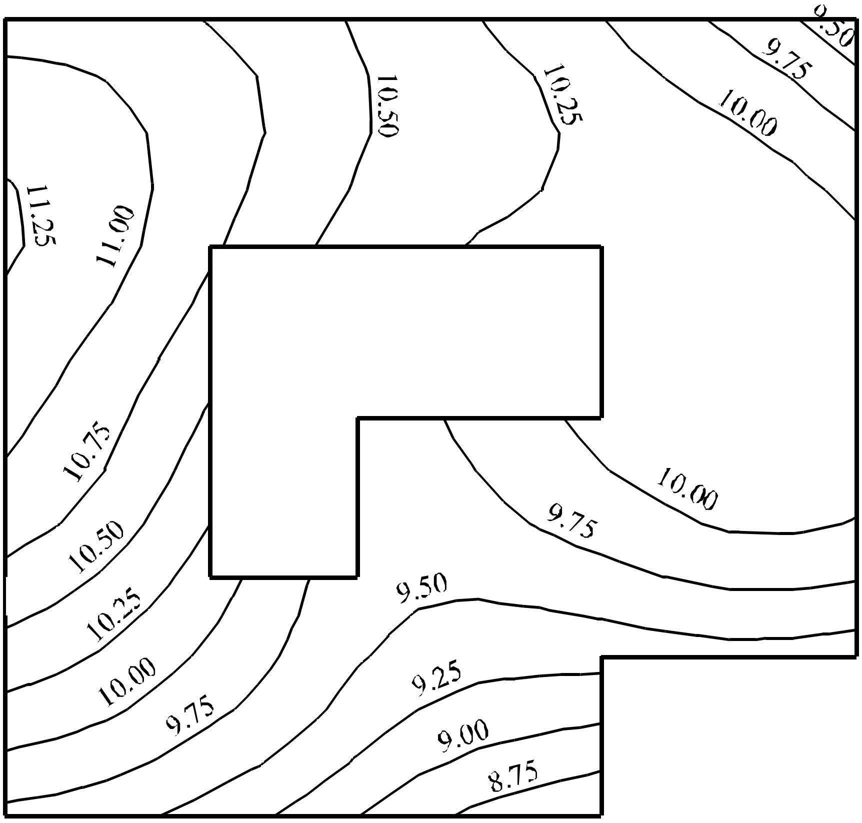


Figure 2.22 Contour lines of settlements [cm] for isotropic elastic half-space model 5

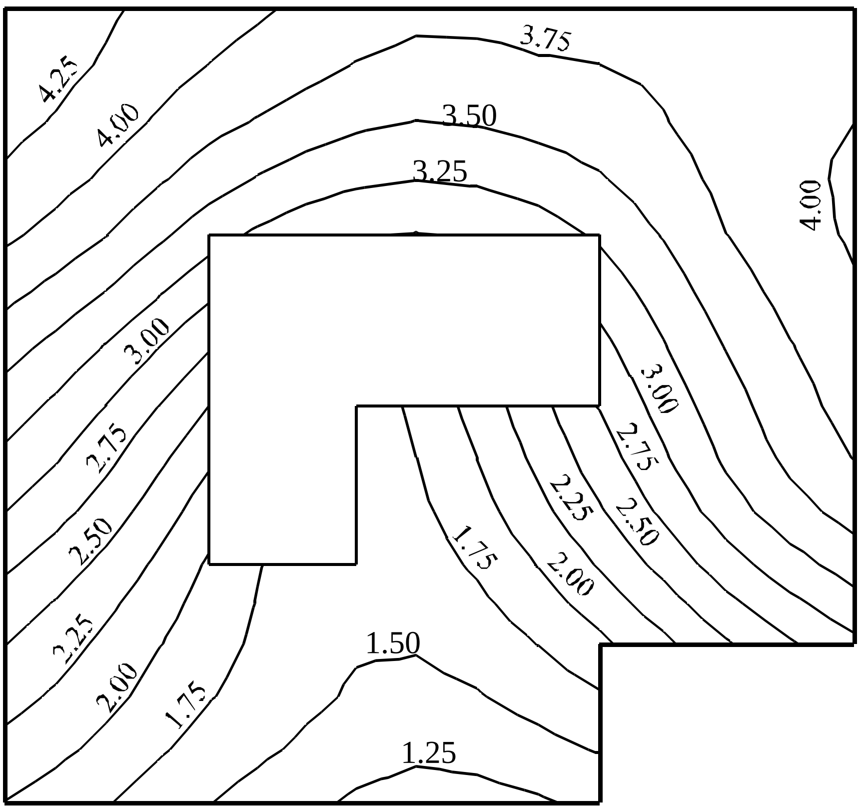


Figure 2.23 Contour lines of settlements [cm] for methods 4, 6 and 7

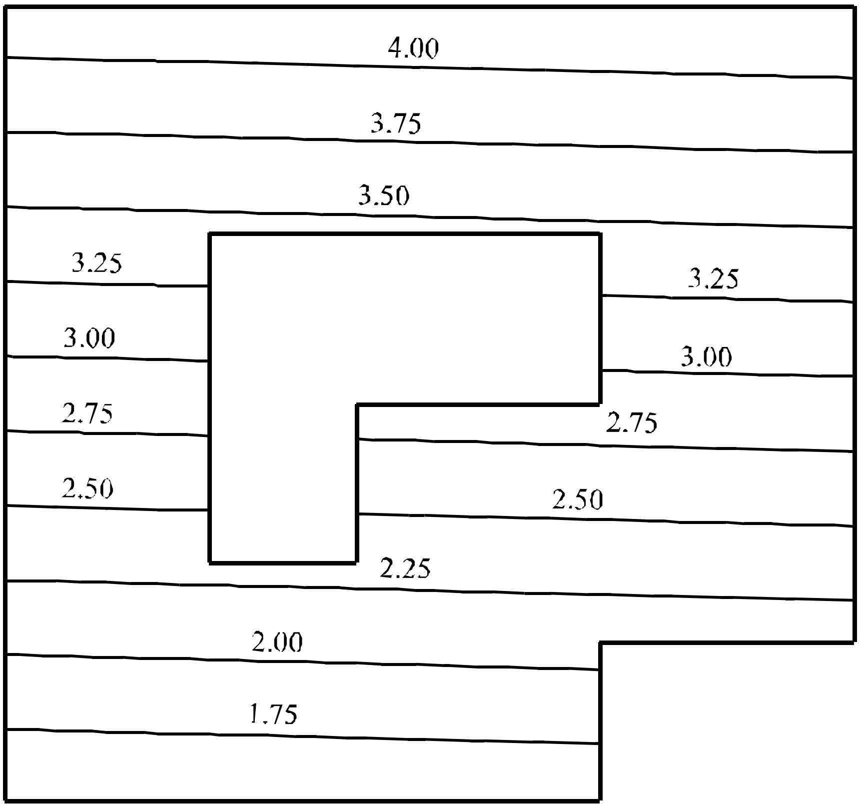


Figure 2.24 Contour lines of settlements [cm] under rigid raft 8

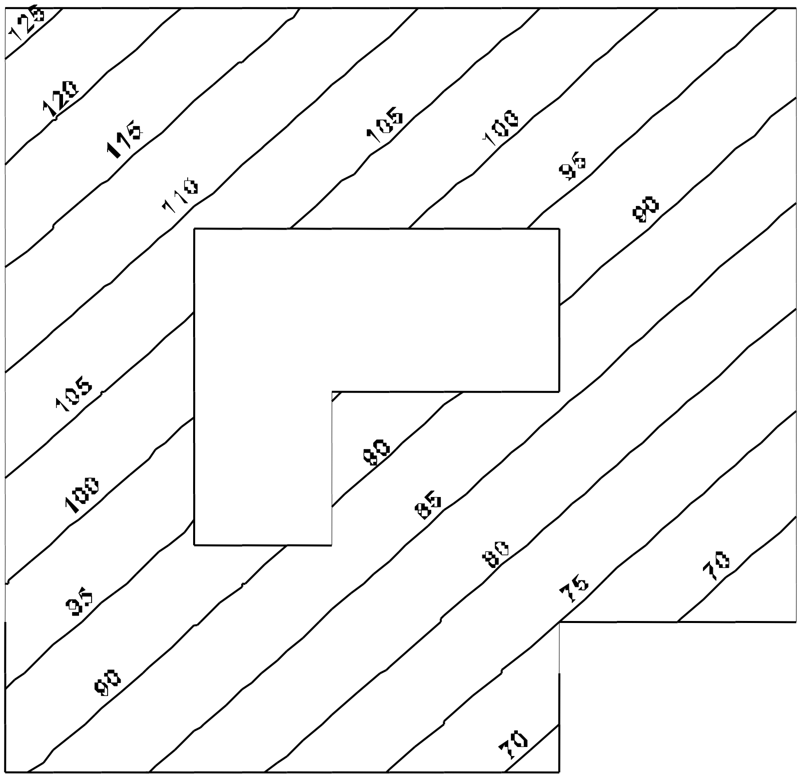


Figure 2.25 Contour lines of contact pressures [kN/m^2] by method 1

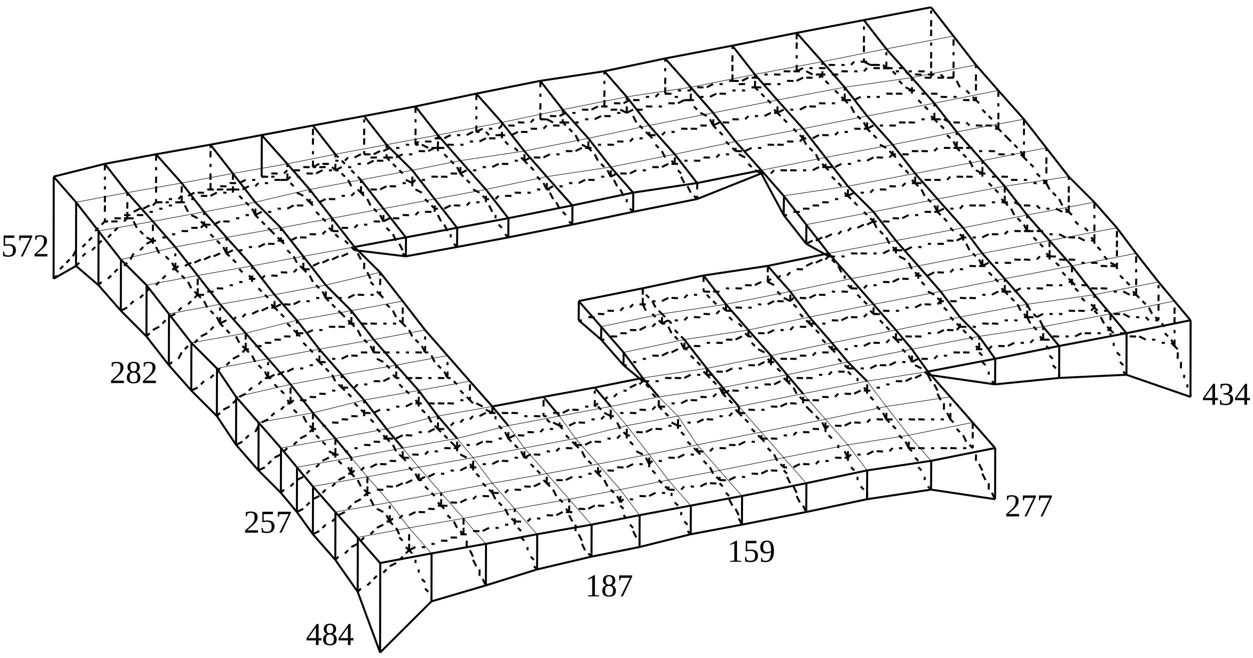


Figure 2.26 Contact pressures [kN/m^2] for isotropic elastic half-space model 5

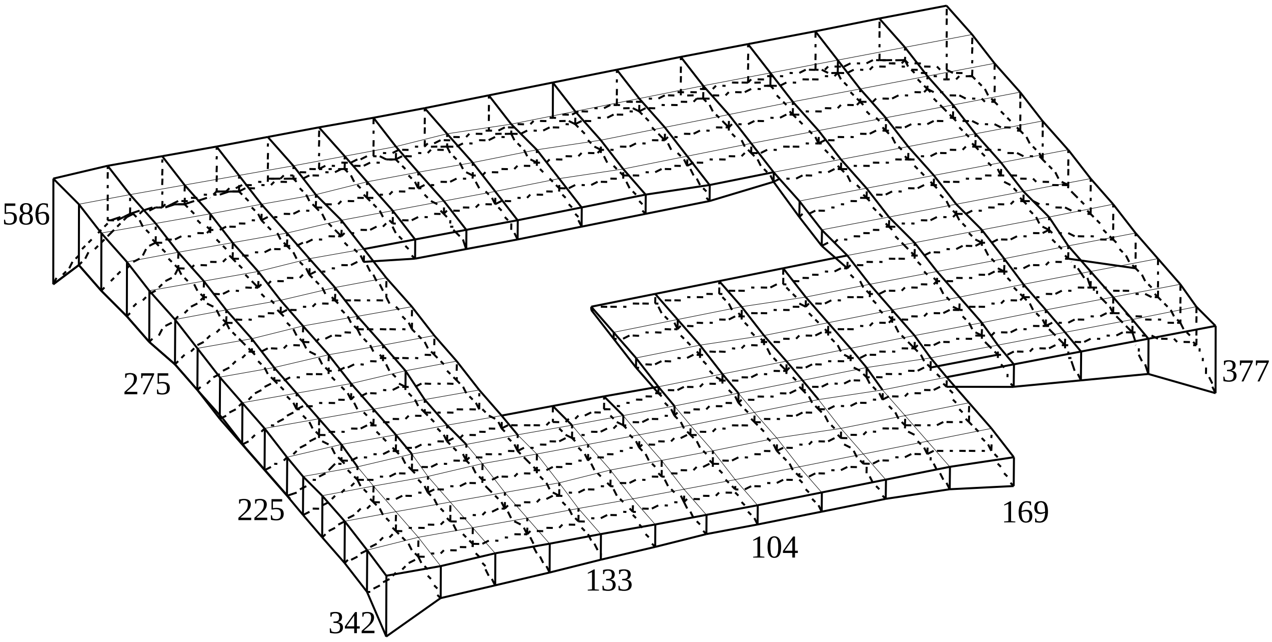


Figure 2.27 Contact pressures [kN/m^2] for methods 4, 6 and 7

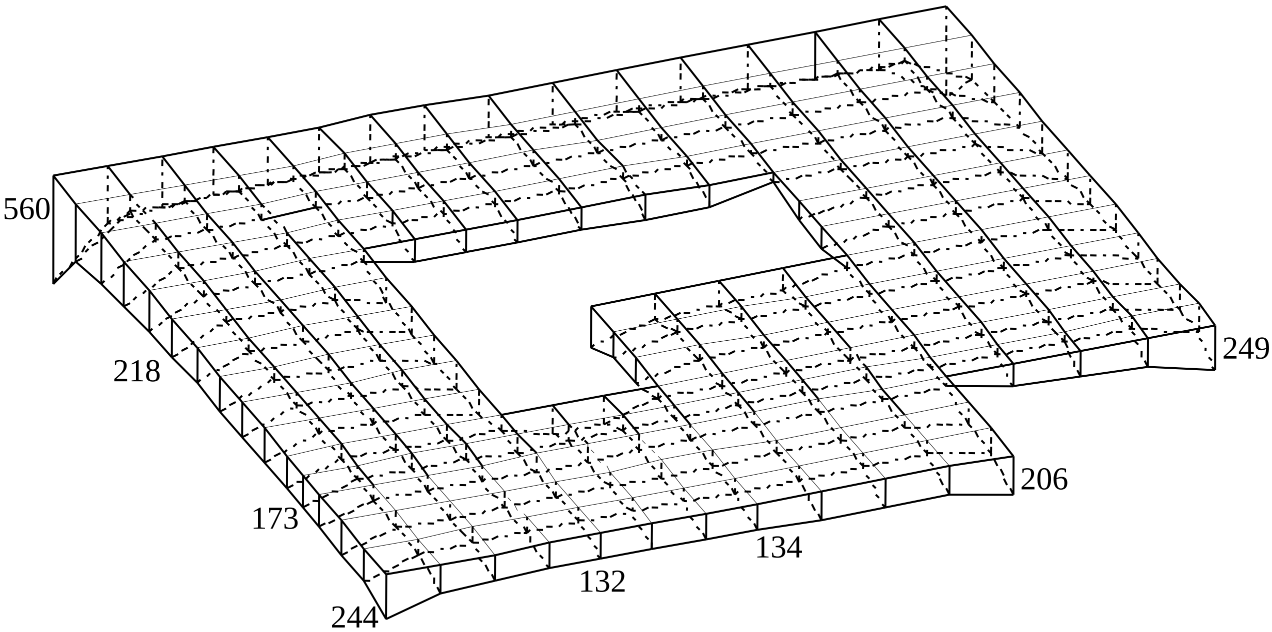


Figure 2.28 Contact pressures [kN/m^2] under the rigid raft 8

Through Table 2.2 and Figures 2.20 to 2.28 the following conclusions can be drawn:

- It is important to say that the linear contact pressure method 1 does not depend on the behavior of the subsoil mass below the foundation and there is no compatibility between raft deformation and soil settlement in this method

- The elastic parameters for isotropic elastic half-space 5 and constant modulus of subgrade reaction 2 are valid for the whole subsoil mass but for the variable modulus of subgrade reaction 3 are variable from a node to another

- For the two iteration methods 4 and 6 and rigid raft 8, the elastic parameters are the same as those of the first analysis method 7 and can be taken without any change

- The influence of surrounding structures and external loads can be taken into consideration only for the Continuum model (methods 4, 5, 6, 7 and 8)

- The influences of temperature change cannot be taken into consideration for the Linear contact pressure (method 1)

- Furthermore, the influence of reloading can be taken into consideration only for the methods 4, 6, 7 and 8

- The results of calculation of the rigid raft (method 8) do not change from the raft thickness $d = d_{\text{rigid}}$ to $d = \infty$

- As from the assumption of the isotropic elastic half-space model 5, the soil under the foundation extends to an infinitely thick layer. The settlement will be similar in shape but greater in value to that of the layered model 7, Figures 2.21 and 2.23

- The Continuum model (methods 4, 5, 6, 7 and 8) shows that the contact pressure is minimum on the middle of the raft and maximum at its edges, Figures 2.26, 2.27 and 2.28

- Figure 2.25 shows that the contact pressure for the Linear contact pressure (method 1) takes linear form under the raft

- As from the assumption of *Winkler*'s model (method 2) the soil pressure q_i at any point i will be equal to the settlement s_i at that point multiplied by the modulus of subgrade reaction k_s. The contour lines of contact pressures will be similar to that of settlements, only the values of s_i should be multiplied by k_s. Therefore, the contour lines of both contact pressures and settlements are plotted in a figure for the *Winkler*'s model 2 as shown in Figure 2.20

- It can be seen from Table 2.2 that the maximum and minimum values of contact pressures for the Linear contact pressure, constant modulus of subgrade reaction and variable modulus of subgrade reaction are nearly the same. In addition, the maximum and minimum values of settlements for constant and variable modulus of subgrade reaction methods (methods 2 and 3) are nearly the same