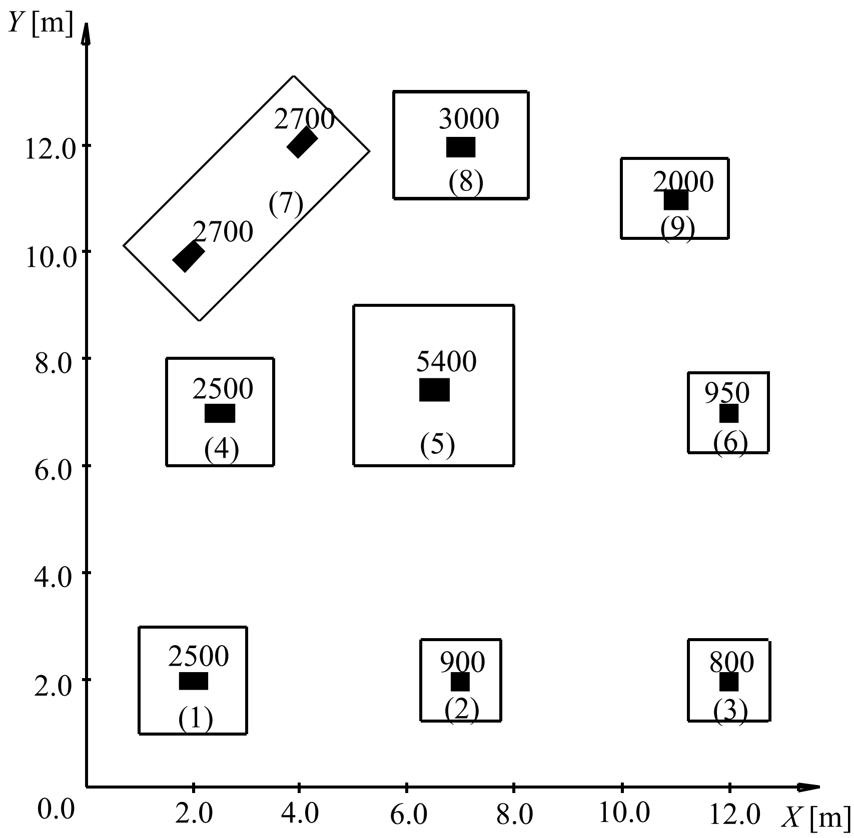
9-Settlements of Footing Groups by the Program *GEO Tools*



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Preface

In 1961, *Kany* proposed for the first time at the *LGA* Soil Mechanics Institute the use of electronic computing systems for settlement calculations. For this purpose, a computer program was developed for the ZUSE Z 23 electronic computer, and it was presented at the German Soil Mechanics Conference in Berlin in 1964. The first detailed program documentation was published by *LGA* Nuremberg in 1966 (2nd edition 1972) [9].

After the development of computer technology, this program was rewritten in FORTRAN IV (1976, 1973) considering additional effects on the analysis such as reloading of the soil behavior, the limit depth of the soil, temperature change, and soil lowering.

After retirement, *Kany* established a private firm, *GEOTEC* and developed a series of *GEOTEC* programs. The main programs of *GEOTEC* were *SETZ* (Settlement of Footing Groups), *ELBAL* (Elastic Beam Foundation), *STPLA* (Analysis of Rigid Slab) and *ELPLA* (Analysis of Elastic Slab).

In 1996, the program *SETZ* was started by Prof. *Kany* was redeveloped with the help of Prof. *El Gendy* as version 5.0 of the *SETZ* [26]. At that time, *SETZ* was executable on the IBM compatibles with the MS-DOS operating system. The graphics programs were designed for the HP7475A plotter from Hewlett-Packard with the widely used HPGL graphics language.

After the death of Prof. *Kany*, Prof. *M. El Gendy* and Dr. *A. El Gendy* further developed the program to meet the needs of practice. They inserted the present settlement calculation of footing groups in the option "9- Settlements of footing groups" in program *GEO Tools*. In addition to the settlement calculation of footing groups in *GEO Tools*, various Geotechnical problems are also presented.

Calculation of the settlements of footings by the program *GEO Tools*

Preliminary remarks

The calculation option "9- Settlements of footing groups" in *GEO Tools* program is used to calculate the settlements and tilting of groups of rigid centrally loaded rectangular footings on stratified subsoil. The settlements are calculated for bilinear deformation behavior of the soil according to the theory of elasticity. The settlements at 4 corner points and at the middle of the footing are calculated. For each layer, Modulus of Compressibility for loading and reloading can be defined. The self-weight of the footings and the foundation depth of the footings are considered. Height differences in the footing bases are also considered. If desired, the subsoil stresses and the limit depths of the settlements can be determined. The calculations are based on DIN 4019.

Calculation of foundation settlements using the *GEO Tools* described in this book can also be calculated using the *ELPLA* program and the same results can be obtained. *GEO Tools* is a simple user interface program and requires little information to define a problem. It is preferable to use it for a simple footing geometry. In addition, *ELPLA* can read data files of a settlement problem that are defined by *GEO Tools*. With some modifications to this data, the user can recalculate the problem by *ELPLA*.

9 Settlements of Footing Groups

9.1 Introduction

The calculation of the settlements for practical construction tasks requires a considerable amount of time and money in the case of extensive structures. On the other hand, for the processing of foundation engineering tasks, results are often required quickly for which the person responsible does not have the time required for manual calculations, or at least not for extensive comparison calculations with different soil pressures and foundation depths.

The settlement calculations included in the *GEO Tools* program system under the designation "Settlement of footing groups" are explained and presented below with different practical examples. *GEO Tools* was developed for the electronic calculation of the settlements of a group of rectangular and centrally loaded isolated footings on any stratified subsoil.

Based on DIN 4019, Part 1 and Part 2 [8] and the EVB [24], the settlements are determined considering the pressure overlap of neighboring footings according to the theory of the elastically isotropic half-space and Hooke's law of deformation. It is also possible to examine the dependencies of the settlements of the footing dimensions and foundation depths for each footing. The self-weight of the footing, which depends on the footing thickness and dimensions, is also considered.

Due to the mutual influence, tilting and torsion of the footings occur despite the central load. These can be examined as the settlements are calculated at the 4 corners and at the middle of each footing.

9.2 Preliminary Calculations

9.2.1 Determining the overburden pressure q_v and the average unit weight of the soil γ_F

For the calculation of the settlements some intermediate values are needed, which must be determined first. The overburden pressure q_v [kN/m^2] by the earth load removed during the excavation pit results from the unit weights γ_i [kN/m^3] of $n_{z.F}$ layers lying above the foundation depth and the layer thicknesses h_i [m] according to the formula

$$q_v = \sum_{i=1}^{i=n_{z.F}} (\gamma_i \ h_i) \tag{1}$$

The average unit weight γ_F [kN/m^3] of the soil above the foundation depth as a weighted average in the area from the original ground surface level to the depth t_F [m] below the ground surface is obtained by

$$\gamma_F = \frac{q_v}{t_F} = \frac{\sum_{i=1}^{i=n_{z.F}} (\gamma_i \ h_i)}{t_F} \tag{2}$$

Figure 9.1 shows the chosen designations of the calculation

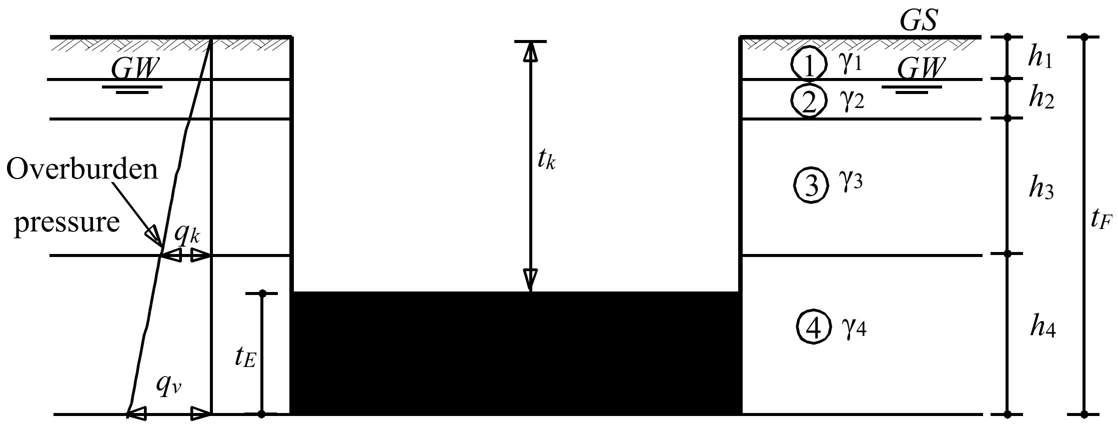


Figure 9.1 Determining overburden pressure q_v

Foundation depth t_F is given by

$$t_F = t_k + t_E \tag{3}$$

With the footing thickness t_E and the depth of the top edge of the footing t_k, and by comparing the bottom edges of the layers with the foundation depth t_F, it is determined in which layer i, possibly divided by the foundation depth, the foundation depth lies.

In addition, the average unit weight γ_E of the soil along the footing thickness t_E is used for the bearing capacity calculations. For this purpose, the overburden pressure q_k at the footing surface (depth t_k below ground level) is first determined using the formula

$$q_k = \sum_{i=1}^{i=n_{z.k}} (\gamma_i \, h_i) \tag{4}$$

where $n_{z.k}$ means the number of the possibly divided layer in or under which the footing surface (depth t_k) lies. Then the unit weight of the soil along the footing thickness is given by

$$\gamma_E = \frac{q_v - q_k}{t_E} \tag{5}$$

9.2.2 Determining the mean soil pressure q_o

A distinction is made as to whether the base of the footing is above or below the groundwater level.

9.2.2.1 The base of the footing is above the groundwater level

For footings without groundwater pressure, the mean soil pressure q_o [kN/m^2] is determined from the total load P [kN] = applied load P_A + footing weight P_E:

$$q_o = \frac{P_A + P_E}{A \times B} = \frac{P}{A \times B} \tag{6}$$

Overburden pressure, which is reloading pressure

$$q_v = \gamma_F \, t_F \tag{7}$$

The reduced soil pressure is then the loading pressure

$$q_E = q_o - q_v \tag{8}$$

Equation 8 also considers the influence of the reloading $q_v = \gamma_F \times t_F$ of the subsoil. This reloading of the subsoil is almost always present when the base of the footing at depth t_F is below the original ground level, i.e. the existing ground level before excavation.

If the reloading part (overburden pressure) is not available, the following applies

$$q_E = q_o \tag{9}$$

where:

q_o	Soil pressure on the footing base	[kN/m^2]
q_v	Overburden pressure on the footing base	[kN/m^2]
q_E	Loading part on the footing base	[kN/m^2]
q_w	Groundwater pressure on the footing base	[kN/m^2]

P	Total load on the footing base	[kN]
	(Including the footing weight)	
P_A	Applied load on the footing	[kN]
P_E	Self-weight of the footing	[kN]
A	Footing dimension in X direction	[m]
B	Footing dimension in Y direction	[m]
$A \times B$	Ap Area of the footing	[m^2]
t_F	Foundation depth	[m]
	(Depth of the foundation level below the original ground surface level)	
γ_i	Unit weight of the soil above the foundation level	[kN/m^3]
γ_F	Average unit weight of the soil	[kN/m^3]
	above the foundation level (Eq. 2).	

9.2.2.2 The base of the footing is below the groundwater level

In the case of footings whose base (depth t_F [m] below the ground level) lies below the groundwater level (depth t_W [m] below ground level), the footings will be exposed to an additional negative pressure q_w on the footing base (area $A \times B$) due to the buoyancy P_W [kN]

$$q_W = \frac{P_W}{A_P} = (t_F - t_W)\,\gamma_w \tag{10}$$

where γ_w is the unit weight of the water = 9.81 [kN/m^3].

Equation 11 is then used instead of Eq. 8

$$q_E = q_o - q_W - q_v \tag{11}$$

9.2.3 Determining the self-weight of the footing P_E

Because the foundation dimensions A, B and footing thickness d change the self-weight P_E of the footing, P_E can be calculated automatically. To consider the self-weight of the footing, approximately block-shaped footings with the base area $A \times B$, the thickness $d = t_E$ and the unit weight of the footing concrete γ_b [kN/m^3] are used.

Then the footing weight P_E is

$$P_E = A\,B\,t_E\,\gamma_b \tag{12}$$

where:

γ_b	Unit weight of the footing concrete (by default 25 [kN/m^3])	[kN/m^3]
t_F	Foundation depth under the ground surface $t_F = t_E + t_K$	[m]
t_E	Embedment thickness of the footing (= Footing thickness) [m]	
t_K	Basement depth (= Depth of the footing surface under the ground surface) [m]	

If $\gamma_b = 0$ is defined in the data, the footing weight is zero $P_E = 0$ (Self-weight of the footing is neglected).

9.2.4 Bilinear deformation behavior of the subsoil

A simplified way was supposed to improve the deformation behavior of the soil by dividing the stress settlement curve into two regions, Figure 9.2. In the first region the ground will settle until reaching an overburden load q_v according to the Modulus of Compressibility W_s. In the second region after reaching the load q_v the ground will settle more under load q according to the Modulus of Compressibility E_s until reaching the total load q_o.

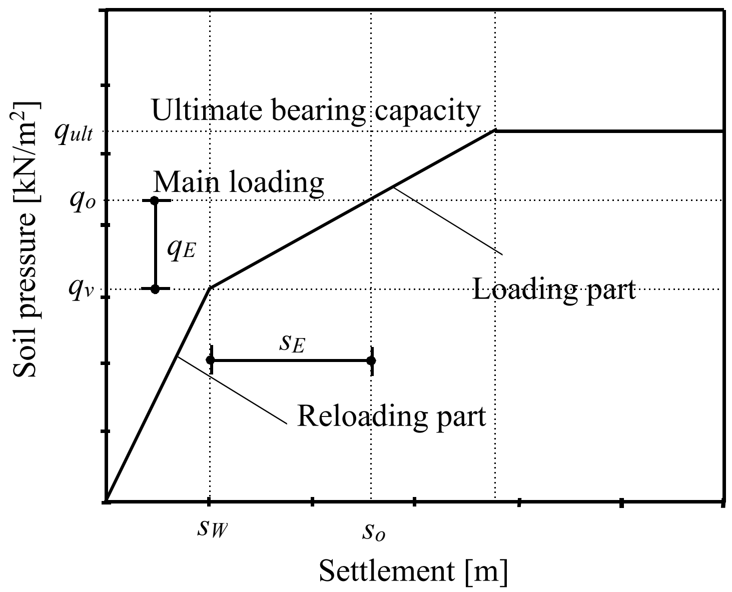


Figure 9.2 Load settlement diagram (bilinear relation)

The bilinear relation of the soil deformation may be taken into consideration as follows.

The settlement s_o of the footing can be derived from two variations such that (Figure 9.2)

$$s_o = s_W + s_E \tag{13}$$

This settlement s_o is due to the total contact pressure q_o on the footing, which is given by

$$q_o = q_v + q_E \tag{14}$$

The flexibility coefficients of the soil are determined from these settlements with the mean contact pressure q_o on the footing.

where:

s_E	Settlement due to loading (Modulus of Compressibility E_s)	[m]
s_W	Settlement due to reloading (Modulus of Compressibility E_W)	[m]
s_o	Total settlement of the footing	[m]

9.2.5 Determining the limit depth z_g of the settlement influence

9.2.5.1 General

Settlement observations at ground levels and at the footing base of buildings have shown that, from a certain depth z_g below the building, there are no more deformations despite the presence of additional stresses in the subsoil (DIN standards). To obtain this depth, there are two different criteria:

a- The limit depth z_g of the settlement influence depends on the width *B* of the building.

$$z_g = c_s\ B \tag{15}$$

Previously the value $c_s = 2$ was assumed. However, this criterion does not cover the building load and is only rarely used today.

-b The limiting depth z_g of the settlement influence depends on the ratio

$$c_s = \frac{\sigma_z}{\sigma_{z\gamma}} \tag{16}$$

where:

c_s	Limit depth ratio	[-]
σ_z	Stress in soil from footing load (loading part)	[kN/m^2]
$\sigma_{z.\gamma}$	Stress from soil weight at depth *z*	[kN/m^2]

This criterion was introduced for the first time in the regulations of the Soviet standard, but later also in the DIN standards and recommendations EVB (1993), whereby the limit depth z_g is assumed to be the depth at which the value $c_s = 0.2$ is reached. Investigations by *Amman/ Breth* (1972) show, however, that the value can increase to $c_s = 0.8$. This applies to heavily loaded and coarse-grained soils. In DIN 4019 Part 1 $c_s = 0.2$ is recommended.

9.2.5.2 Calculation method

The user can already take method a) into account when defining data. Of the specified criteria a) and b), the second method is used in the program at the user's request. For this purpose, the limit depth ratio $0 < c_s < 1$ is defined with the data.

9.2.5.3 Iterative calculation method

First, the soil weight $\sigma_{z.\gamma}$ at different depths and then the stresses σ_z from the footing load under the footing are determined. If the limit depth is reached, the iteration is aborted.

The stress σ_z from footing load in the depth *z* of layer *i* is obtained as shown in Figure 9.3 as follows

$$\sigma_z = \sigma_{zE} + \sum \sigma_{zkE} \tag{17}$$

The stress from the soil weight $\sigma_{z.\gamma}$ at depth *z* is obtained as a sum

$$\sigma_{z\gamma} = \sum_{i=i_z}^{n_z} \gamma_i \, h_i \tag{18}$$

with these values, according to Eq. 16, the stress ratio is

$$c_s \ \text{vorh} = \frac{\sigma_z}{\sigma_{z\gamma}} \tag{19}$$

The calculation is carried out in steps downwards, whereby the increment d_z must be specified. $d_z = B/10$ is recommended. The final limit depth value z_g is calculated from the two lowest calculated values by linear interpolation.

$$z_g = z_o + (c_s - c_o)\frac{z_u - z_o}{c_u - c_o} \tag{20}$$

where:

c_s	Limit depth ratio = input value	
c_o	Stress ratio at the top edge of the layer z_o (strip of thickness d_z)	[-]
	$c_o = \sigma_{z.\gamma.o} / \sigma_{z.o}$	
c_u	Stress ratio c_u at the bottom edge of the layer z_u (strip of thickness d_z)	[-]
	$c_u = \sigma_{z.\gamma.u} / \sigma_{z.u}$	

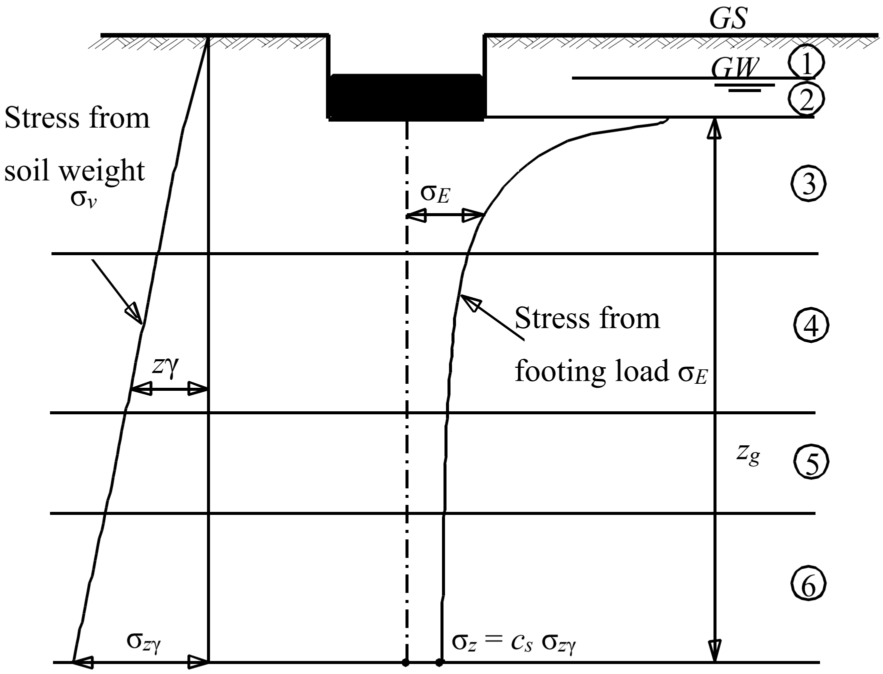


Figure 9.3 Example for determining the limit depth z_g under a footing (No stress overlap from neighboring footings)

9.2.6 Variable foundation levels by neighboring footings

Sometimes, by determining the influence of the neighboring footings or the interaction among system of footings, the foundation levels of the footings are variable as shown in Figure 9.4. In this case, the foundation levels of the footings must be related to a specified datum H_m.

The z-value of flexibility coefficient for any soil layer under the footing can be expressed by

$$z_{ikl} = (z_{il} - t_{fi}) - H_{mi} + H_{mk} \tag{21}$$

It should be noticed that the foundation level H_m under the specified datum is negative.

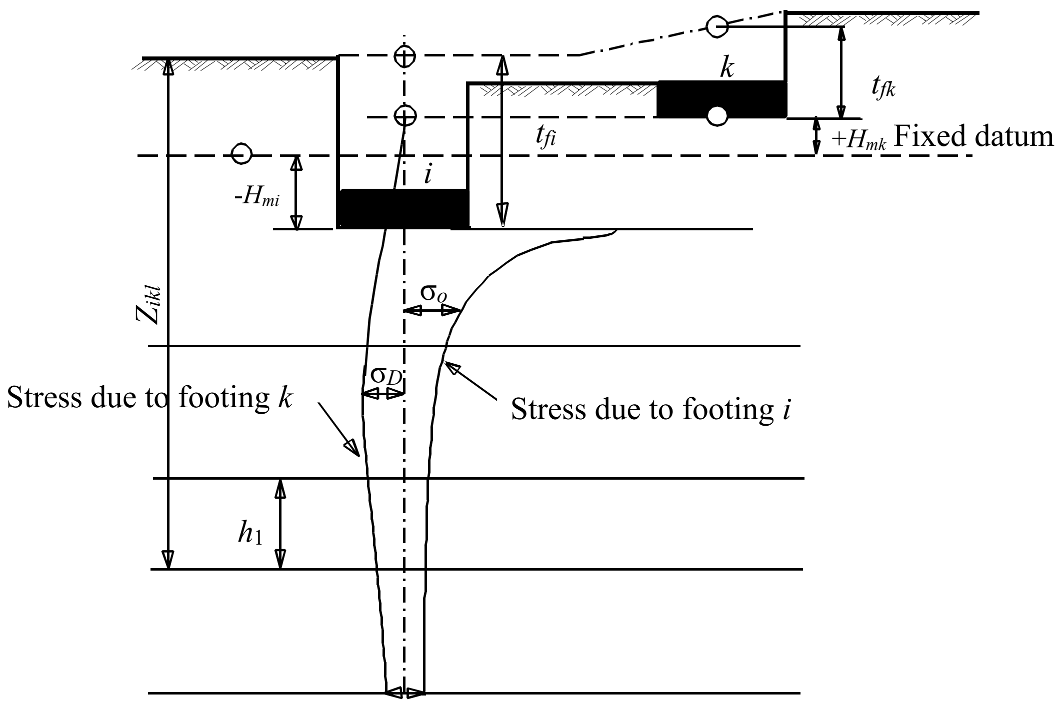


Figure 9.4 Different foundation depths for neighboring footings

9.3 Settlements of loaded areas

9.3.1 Settlement at a depth *z* due to a loaded area

According to *Steinbrenner* (1934), the settlement s_h at a depth z under the corner of the loaded area on the surface of the elastic layer of thickness h (Figure 9.5) is given by

$$s_h = \frac{q\,(1-\nu_s{}^2)}{2\,\pi\,E}\left(b\ln\frac{(c-a)\,(m+a)}{(c+a)\,(m-a)} + a\ln\frac{(c-b)\,(m+b)}{(c+b)\,(m-b)}\right) - \frac{q\,(1-\nu_s-2\,\nu_s{}^2)}{2\,\pi\,E}\left(z\tan^{-1}\frac{a\,b}{z\,c}\right) \qquad (22)$$

where c and m in the Eq. 22 are defined by the following expressions:

$$c = \sqrt{a^2+b^2+z^2} \quad \text{und} \quad m = \sqrt{a^2+b^2}$$

where in Eq. 22:

s_h	Settlement of the corner of a loaded area	[m]
a,b	Dimensions of the loaded area	[m]
z	Depth of the layer under the ground surface	[m]
q	Intensity of the loaded area at the surface of the elastic layer	[kN/m^2]
E	Modulus of Elasticity of the soil (unrestrained lateral)	[kN/m^2]
ν_s	*Poisson's* ratio of the soil	[-].

Poisson's ratio ν_s is considered constant for all soil layers as its value is between 0.3 and 0.5 for most soil types. Then, Eq. 22 is in a simple form for a constant *Poisson's* ratio of the soil

$$s_h = \frac{q}{E}\,f \qquad (23)$$

The settlement factor f, can also be obtained from tables and curve according to *Kany* (1974) as a function of a, b and z.

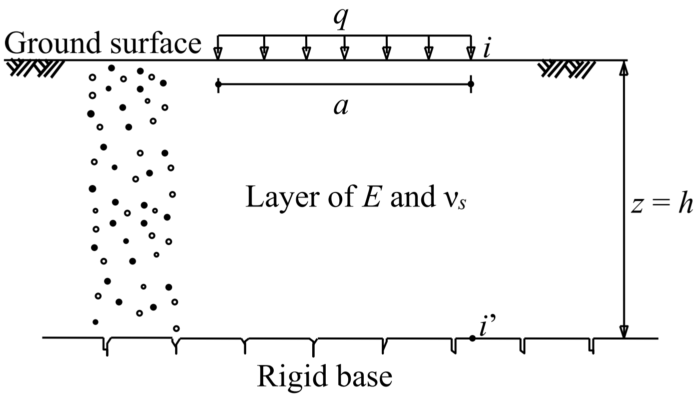


Figure 9.5 Elastic layer on a rigid base

9.3.2 Settlement of multi-layers due to a loaded area

Obviously, it can generalize this approach to consider multi-layers of soil. Each has different elastic material and thickness as shown in Figure 9.6. The vertical settlement of a layer l in an n layered system is given by

$$s_l = q\left(\frac{f^{(l)} - f^{(l-1)}}{E^{(l)}}\right) = q\left(\frac{\Delta f^{(l)}}{E^{(l)}}\right) \tag{24}$$

where in general:

E_l Modulus of Elasticity of the lth layer (unrestrained lateral) [kN/m^2]

q Loaded area at the surface of the elastic layer [kN/m^2]

$\Delta f^{(l)}$ $f^{(l)}$ - $f^{(l-1)}$ Difference in the settlement coefficients f between the lower edge z_l and upper edge $z_{(l-1)}$ of the l-th layer (with a total of n layers)

The total settlement for n layered system is

$$s = q\left(\frac{f^{(1)}}{E^{(1)}} + \sum_{l=2}^{n}\frac{\Delta f^{(l)}}{E^{(l)}}\right) \tag{25}$$

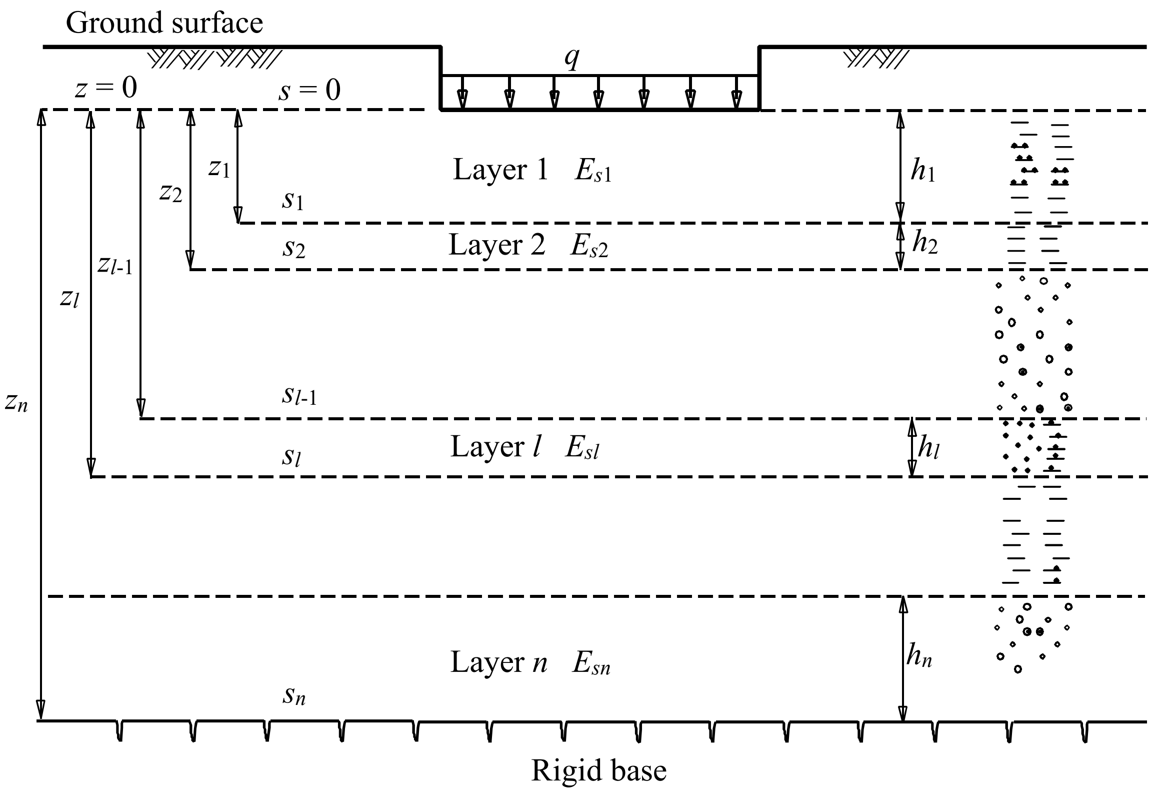


Figure 9.6 Layered system

9.3.3 Settlement at an interior point of loaded area

So far it has been considered the settlement beneath a corner of a loaded area. To find the settlement at any other point, the principle of superposition can be used. The settlement at an interior point of the rectangular loaded area is given by the sum of the settlements at the corners of four sub-loaded areas.

To determine the settlement coefficient $f^{(l)}$ for a layer l at an interior point i of the rectangular loaded area shown in Figure 9.7, the Formula of *Kany* (1974) can be applied as

\

$$f^{(l)} = f^{(l)}{}_1 + f^{(l)}{}_2 + f^{(l)}{}_3 + f^{(l)}{}_4$$

$$= \frac{1}{2\pi} \sum_{n=1}^{4} \left[(1-\nu_s^2) \left\{ b_n \ln \frac{(c_n - a_n)(M + a_n)}{(c_n + a_n)(M - a_n)} + a_n \ln \frac{(c_n - b_n)(M + b_n)}{(c_n + b_n)(M - b_n)} \right\} + (1 - \nu_s - 2\nu_s^2)\, z_l \tan^{-1} \frac{a_n\, b_n}{z_l\, c_n} \right] \quad (26)$$

It applies to the settlement of a loaded load area with dimensions a and b

$$c_n = \sqrt{a_n^{\,2} + b_n^{\,2} + z_l^{\,2}} \quad \text{und} \quad M = \sqrt{a_n^{\,2} + b_n^{\,2}}$$

The value z_l means the level of the lower side of the layer l from the foundation level.

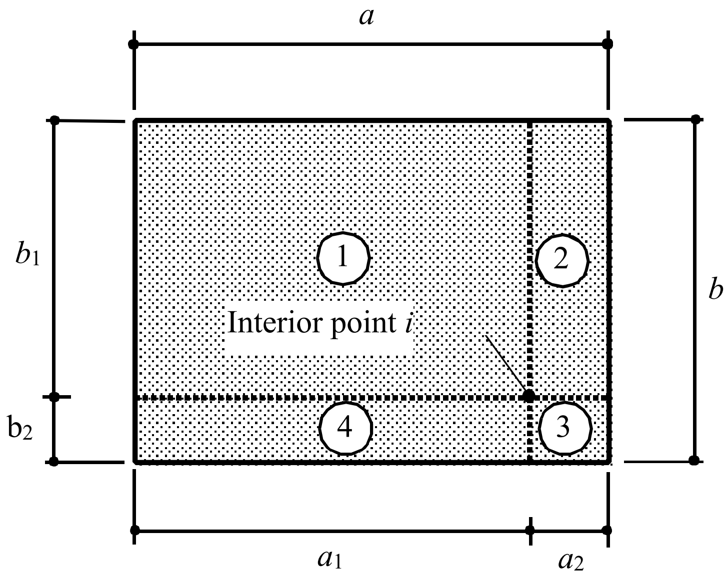


Figure 9.7 Superposition of four loaded areas to find the settlement at an interior point i

9.3.4 Settlement at a point outside the loaded area

Adding and subtracting corner settlements for four loaded areas can obtain the settlement of any point outside the loaded area as shown in Figure 9.8. First, the settlement s_1 is determined as if the whole area is defined with load q. Then, the settlements due to the two corners of the loaded areas s_2 and s_3 are subtracted. Finally, the settlement s_4 is added since it has been subtracted twice in s_2 and s_3. Using the same process, the settlement coefficient $f^{(l)}$ for a layer l at an exterior point i of the rectangular loaded area shown Figure 9.8 is given by

$$f^{(l)} = f^{(l)}{}_1 - f^{(l)}{}_2 - f^{(l)}{}_3 + f^{(l)}{}_4 \qquad (27)$$

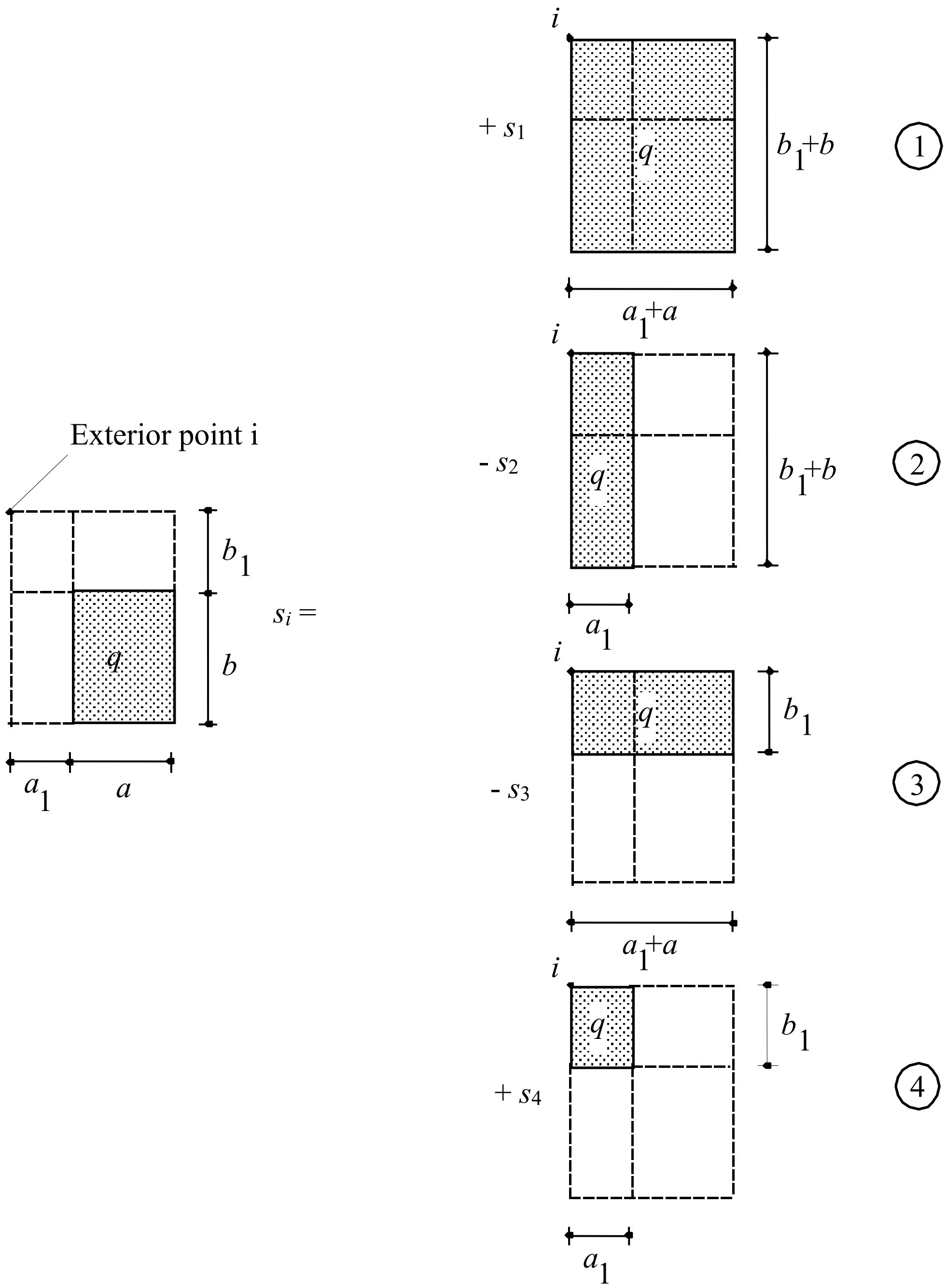
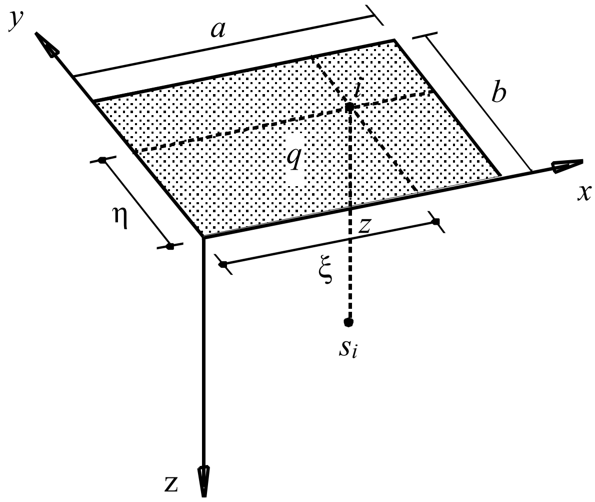


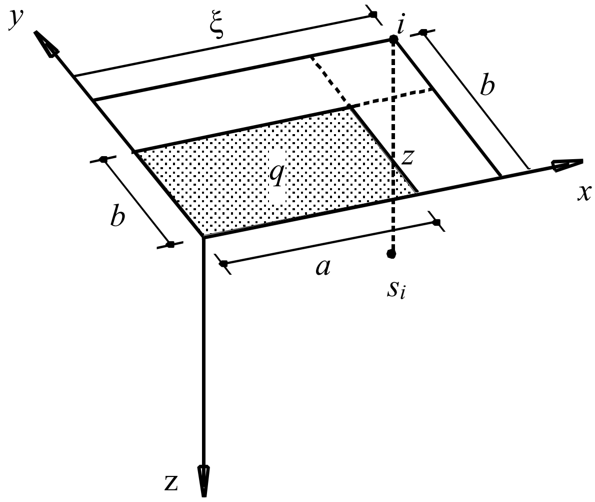
Figure 9.8 Superposition of four loaded areas to find the settlement at an exterior point *i*

For any point *i* of coordinates (ζ, η) inside or outside the loaded area $a \times b$ (Figure 9.9), the settlement coefficient $f^{(I)}$ can be obtained according to *Poulos/ Davis* (1974) using the principle of superposition by the following general Equation:

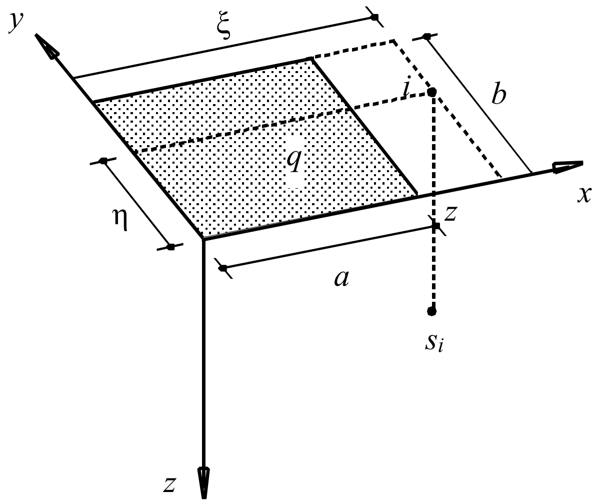
$$f^{(I)} = f(\zeta,\eta) - f(\zeta-a,\eta) - f(\zeta,\eta-b) + f(\zeta-a,\eta-b) \tag{28}$$



a) Point i lies inside the loaded area



b) Point i lies outside the loaded area



c) Point i lies outside the loaded area

Figure 9.9 Superposition of four loaded areas to find the settlement at any point *i*

9.4 Settlement of footings

9.4.1 Introduction

GEO Tools program can be used to calculate the influence of neighboring footings on rectangular footings on any layered subsoil. When calculating the settlement, a distinction must be made between the settlements from the loading s_E and those from reloading s_W of the subsoil. These arise from the stresses σ_z in the subsoil due to the load P of the footing to be examined i (applied load on the footing P_A and the self-weight of the footing P_E) and from the stress due to neighboring footings k.

9.4.2 Determining settlements due to the footing load

When determining the settlements s_o due to the footing load P

$$P = P_A + P_E \tag{29}$$

of the footing i (dimensions A and B), three cases must be distinguished:

Fall 1: Overburden pressure q_v = 0 und soil pressure $q_E = q_o\text{-}q_w$
(no overburden)

This case occurs when the depth of footing surface is $t_K = 0$ and the foundation depth is $t_E = 0$. Here the settlements alone s_o is obtained from the deformations s_E due to loading modulus E_s

$$s_o = s_E \tag{30}$$

Fall 2: Overburden pressure $q_v \neq 0$, soil pressure $q_E \leq 0$
(no loading, because of overburden pressure ≥ Total loading)

Here the settlements alone s_W is obtained from the deformations s_W due to reloading modulus W_s.

$$s_o = s_W \tag{31}$$

Fall 3: Overburden pressure $q_v \neq 0$ and soil pressure $q_E > 0$
(General case: Loading- and reloading)

Here, the stress q_v is decisive for the calculation of the settlement s_W due to reloading and the stress q_E for the calculation of the settlement s_E due to loading.

Then the total settlement s_o is

$$s_o = s_W + s_E \tag{32}$$

9.4.3 Settlement at the characteristic point of the footing

The formula of *Steinbrenner* (1934), which is used for the settlement calculation, is valid for surface loadings, in which the surface loading is assumed to be flexible, while the isolated footing can be treated as rigid footing. Therefore, the settlement of the footing is calculated at the characteristic point. *Graßhoff* (1955) defined the characteristic point to be that point of a surface area loaded by a uniformly distributed pressure, where the settlement due to that pressure is identical with the displacement of a rigid footing of similar dimensions and loading. The self-settlement of a footing is determined at the characteristic point (a_c = 0.87a and b_c = 0.87b) as shown in Figure 9.10.

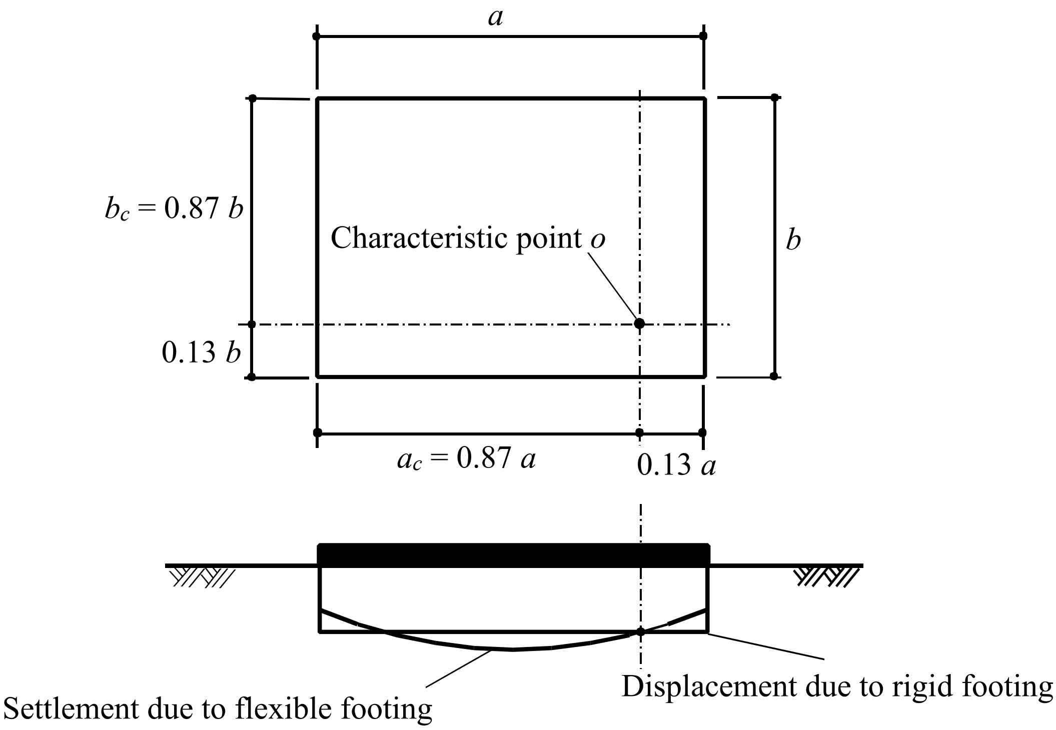


Figure 9.10 Characteristic point of the settlement

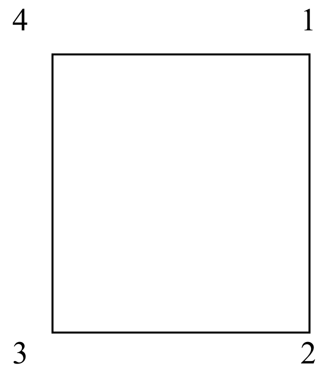
9.4.4 Settlements due to pressure overlapping of neighboring footings

9.4.4.1 Introduction

Because of the three-dimensional pressure propagation in the subsoil, in addition to the settlements explained in the last section due to load P_i [kN] of the examined footing *i*, in footing groups ($N_P > 1$) there are often significant settlement components from influences of neighboring footings *k*.

9.4.4.2 Settlement from overlapping pressures at the corners of the footing

The neighboring footings *k* cause additional settlements in the footing *i* to be calculated due to overlapping pressures. The program can be used to calculate the settlements at the 4 corners of the assumed rigid footing (see sketch for the order of the corners to be calculated).



Top right corner 1, bottom right corner 2, bottom left corner 3 and top left corner 4

The procedure for determining the influence of the load P_k on the calculation point *i* is as follows:

At point *k* with the coordinates x_k, y_k (Figure 9.11) and the applied height H_m under a common fixed datum is a footing with a total load P_k [kN] and an earth load P_{KV} (Overburden pressure) that relieves the subsoil before the start of construction by removing it:

$$P_k = P_{Ak} + P_{Ek} \tag{33}$$

To explain the method for calculating the settlements s_{ik} from pressure overlaps of neighboring footings *k*, the settlement influence originating from footing *k* is to be examined for footing *i*. This is done by the superposition using Eq. (28) according to Figure 9.9.

Experience shows that when calculating the influence of neighboring footings, there are only significant settlement influences if the footing *k* is not very far away from studied point *i*.

A neighboring footing *k* is shown in Figure 9.11. This footing causes an additional settlement component on the examined footing *i*. The influence on the settlement is to be examined below.

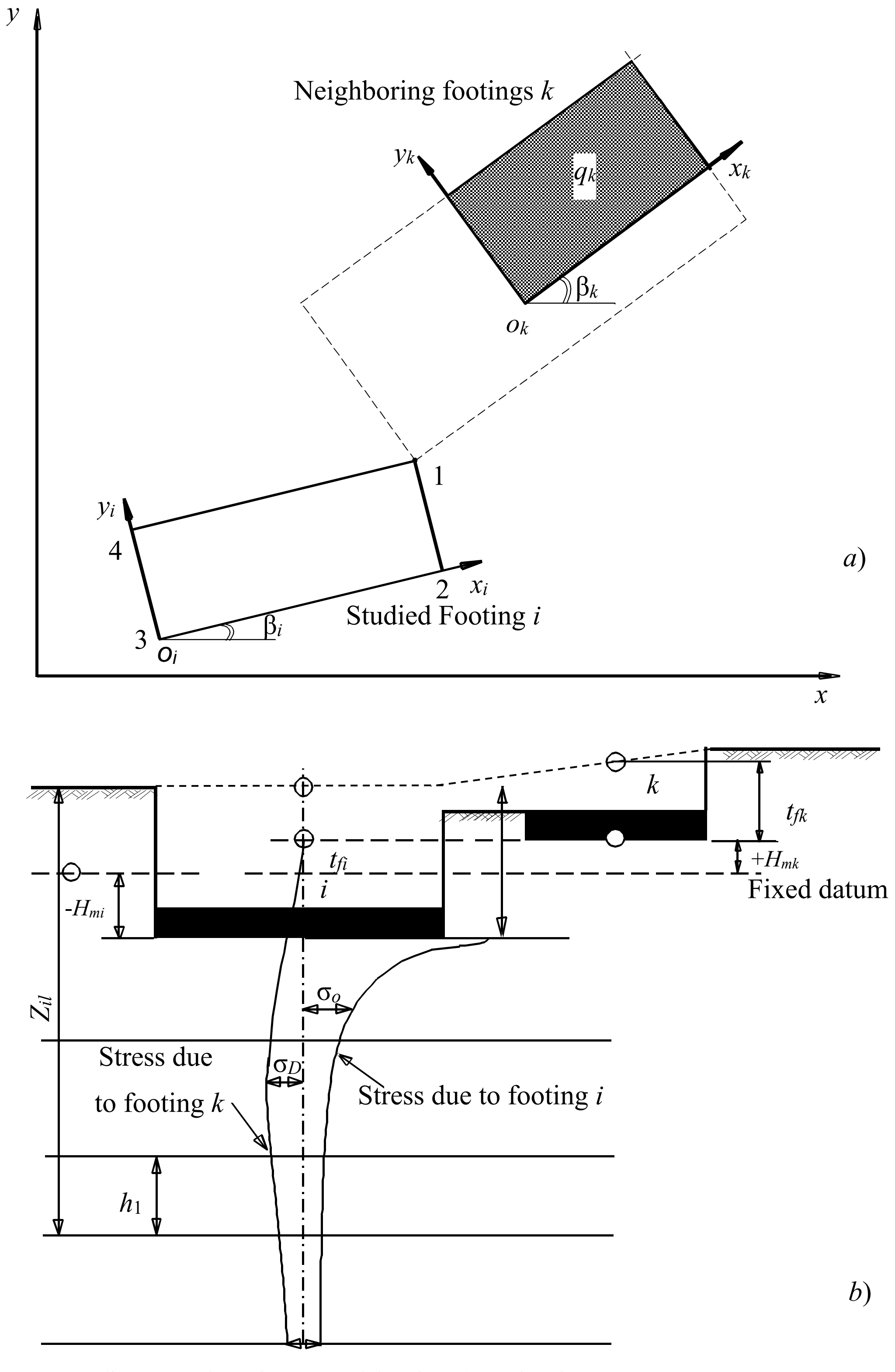


Figure 9.11 Influence of settlement of footing k on footing i

a) Plan of the footing to be examined with neighboring footing

b) Cross-section of the footing to be examined with the neighboring footing

First of all, for the 4 corner points of the footing to be examined, the settlement component $s_{il.D}$ is calculated from the pressure overlap of the neighboring footing. With the dimensions A_k, B_k of the neighboring footing k, the settlement of the l-th layer of the footing i due to the influence of neighboring footing k is determined based on Eq. (28) using the principal of superposition:

The total settlement s_{il} of the footing i at the corner point l is

$$s_{il} = sl' = s_{i.o} + s_{il.D} \tag{34}$$

where:

$s_{i.o}$ Settlement at the characteristic point of footing i due to stress from examined footing i

$s_{il.D}$ Part of settlement at the corner l of the examined footing i from the pressure overlap of the neighboring footing k

9.4.5 Correction of the corner settlements (due to rigidity of the footings)

To obtain rigid settlement at corners 1 ... 4 from the influence of the neighboring footings considering the rigidity of the footings, the settlements are compensated. For this purpose, the following arithmetic operations are carried out:

The average settlement s_m is calculated with the basic settlements $s1'$ ... $s4'$:

$$s_m = (s1' + s2' + s3' + s4') / 4$$

This allows the following intermediate results to be calculated:

$$D1 = s_m - s1'$$
$$D2 = s_m - s2'$$
$$D3 = s_m - s3'$$
$$D4 = s_m - s4'$$

and

$$D1.3 = (| D1 | + | D3 |) / 2$$
$$D2.4 = (| D2 | + | D4 |) / 2$$

With these intermediate results, the correction settlements $s1.D$, $s2.D$, $s3.D$, $s4.D$ at the corners 1 ... 4 of the calculated footing can be determined. There are four different cases:

a) If $s1 > s3$, then becomes $s1.D = s_m + D1.3$

$s3.D = s_m - D1.3$

b)	If $s1 \leq s3$, then becomes	$s1$.D	$= s_m$ - D1.3
		$s3$.D	$= s_m$ + D1.3
c)	If $s2 > s4$, then becomes	$s2$.D	$= s_m$ + D2.4
		s4.D	$= s_m$ - D2.4
d)	If $s2 \leq s4$, then becomes	s2.D	$= s_m$ - D2.4
		$s4$.D	$= s_m$ + D2.4

9.5 Modulus of subgrade reaction k_s

Modulus of subgrade reaction k_s [kN/m^3] for footing i is determined from

$$k_s = \frac{q_o - q_w}{s_m} \tag{35}$$

where:

q_o = Contact pressure [kN/m^2] under the footing i

q_w = Ground water pressure [kN/m^2] under the footing i

s_m = Average settlement [m] of the footing i from the load of the footing i and from the influence of the loads of (N_{FD}-1) neighboring footings.

N_{FD}= The number of footings in the system of footing group.

The settlement s_m is determined by the sum of the settlement portions of N_{FD} footings. This simplification is the basis of the modulus of subgrade reaction method, in which the settlement of field i depends only on the loading of the same field i.

In the program, the moduli of subgrade reactions for all N_{FD} footings of a system of footings can be determined.

9.6 Soil properties and parameters

9.6.1 Introduction

The elastic properties of the soil are defined in *GEO Tools* by the following two different parameters:

1. Modulus of Compressibility E_s ($1/m_v$)
2. Modulus of Elasticity E

E_s [kN/m^2] is the reciprocal value of the coefficient of volume change m_v [m^2/kN]

For each soil layer, the input data maybe are

Depth of the layer from the ground surface	z	[m]
Modulus of Compressibility for loading (constant in a layer t)	E_s	[kN/m^2]
Modulus of Compressibility for reloading (constant in a layer)	W_s	[kN/m^2]
Modulus of Elasticity for loading (constant in a layer)	E	[kN/m^2]
Modulus of Elasticity for reloading (constant in a layer)	W	[kN/m^2]
Unit weight of the soil	γ_s	[kN/m^3]
Poisson's ratio of the soil	ν_s	[-].

The following sections describe these properties of the soil. Furthermore, the soil characteristics for different soil types are listed in tables, which may be used in the primary analysis.

If the Moduli of Compressibility E_s and W_s are determined from a confined compression test, *Poisson*'s ratio will be taken $\nu_s = 0.0$. If the other Moduli of Elasticity E and W are used in the equations derived in the previous section, *Poisson*'s ratio will be taken to be $\nu_s \neq 0$. In general, *Poisson*'s ratio ranges in the limits $0 < \nu_s < 0.5$.

9.6.2 *Poisson*'s ratio ν_s

Poisson's ratio ν_s for a soil is defined as the ratio of lateral strain to longitudinal strain. It can be evaluated from the Triaxial test. *Poisson*'s ratio ν_s can be determined from at-rest earth pressure coefficient K_o as follows

$$\nu_s = \frac{K_o}{1+K_o} \tag{36}$$

Some typical values for *Poisson*'s ratio are shown in Table 9.1 according to *Bowles* (1977). *Poisson*'s ratio in general ranges between 0 and 0.5.

Table 9.1 Typical range of values for *Poisson*'s ratio ν_s according to *Bowles* (1977)

Type of soil	*Poisson*'s ratio ν_s [-]
Clay, saturated	0.4 - 0.5
Clay, unsaturated	0.1 - 0.3
Sandy clay	0.2 - 0.3
Silt	0.3 - 0.35
Sand, dense	0.2 - 0.4
Sand, coarse (void ratio = 0.4 - 0.7)	0.15
Sand, fine grained (void ratio = 0.4 - 0.7)	0.25
Rock	0.1 - 0.4

9.6.3 Moduli of compressibility E_s and W_s

The equations derived in the previous section for calculation of flexibility coefficients require either the moduli of compressibility for loading E_s and reloading W_s or moduli of elasticity for loading E and reloading W for the soil. The yielding of the soil is described by these elastic moduli. The moduli of compressibility E_s and W_s can be determined from the stress-strain curve through a confined compression test (for example Odometer test) as shown in Figure 9.12. In this case, the deformation will occur in the vertical direction only. Therefore, if the moduli of compressibility E_s and W_s are determined from a confined compression test, *Poisson*'s ratio will be taken $\nu_s = 0.0$. If the other moduli of elasticity E and W are used in the equations derived in the previous section, *Poisson*'s ratio will be taken to be $\nu_s \neq 0$. In general, *Poisson*'s ratio ranges in the limits $0 < \nu_s < 0.5$.

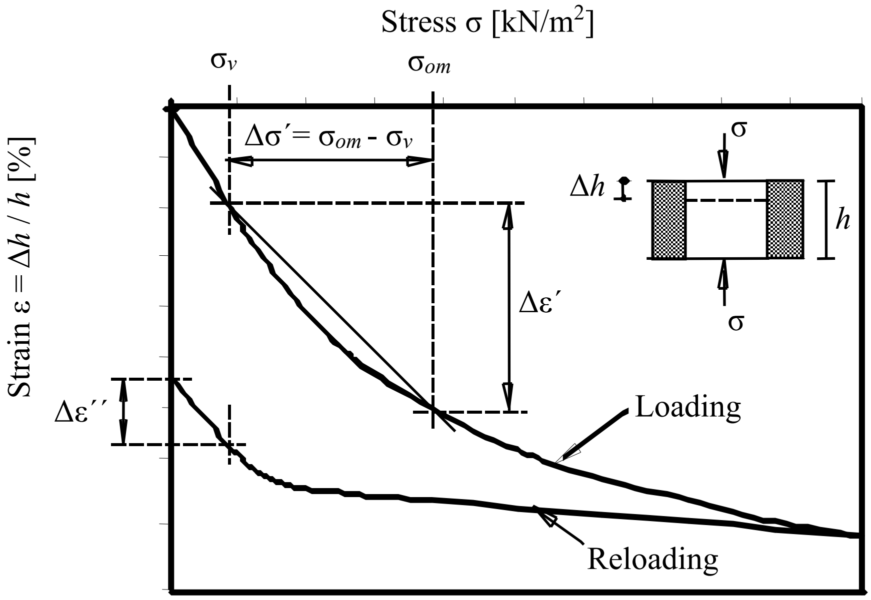


Figure 9.12 Stress-strain diagram from confined compression test (Oedometer test)

The modulus of compressibility E_s [kN/m^2] (or W_s [kN/m^2]) is defined as the ratio of the increase in stress $\Delta\sigma$ to decrease in strain $\Delta\varepsilon$ as (Figure 9.12)

$$\left.\begin{aligned} E_s &= \frac{\Delta\sigma'}{\Delta\varepsilon'} = \frac{\sigma_{om}-\sigma_v}{\Delta\varepsilon'} \\ W_s &= \frac{\Delta\sigma''}{\Delta\varepsilon''} = \frac{\sigma_v}{\Delta\varepsilon''} \end{aligned}\right\} \tag{37}$$

where

$\Delta\sigma'$	Increase in stress from σ_v to σ_{om}	[kN/m^2]
σ_v	Stress equal to overburden pressure	[kN/m^2]
σ_{om}	Stress equal to expected average stress on the soil	[kN/m^2]
$\Delta\varepsilon'$	Decrease in strain due to stress from σ_v to σ_{om}	[-]
$\Delta\sigma''$	Increase in stress due to reloading	[kN/m^2]
$\Delta\varepsilon''$	Decrease in strain due to reloading	[-].

The moduli of compressibility may be expressed in terms of either void ratio or specimen thickness. For an increase in effective stress Δσ to decrease in void ratio Δ*e*, the moduli of compressibility E_s [kN/m^2] and W_s [kN/m^2] are then expressed as

$$\left.\begin{aligned} E_s &= \frac{1}{m'_v} = \frac{\Delta\sigma'\,(1+e'_o)}{\Delta e'} \\ W_s &= \frac{1}{m''_v} = \frac{\Delta\sigma''\,(1+e''_o)}{\Delta e''} \end{aligned}\right\} \qquad (38)$$

where

m'_v	Coefficient of volume change for loading	[m^2/kN]
m''_v	Coefficient of volume change for reloading	[m^2/kN]
e'_o	Initial void ratio for loading	[-]
e''_o	Initial void ratio for reloading	[-]
$\Delta e'$	Decrease in void ratio due to loading	[-]
$\Delta e''$	Decrease in void ratio due to reloading	[-].

The values of E_s and W_s for a particular soil are not constant but depend on the stress range over which they are calculated. Therefore, for linear analysis it is recommended to determine the modulus of compressibility for loading E_s at the stress range from σ_v to σ_{om}, while that for reloading W_s for a stress increment equal to the overburden pressure σ_v. On the other hand, since the modulus of compressibility increases with the depth of the soil, for more accurate analysis the modulus of compressibility may be taken increasing linearly with depth. Also, according to *Kany* (1976) the moduli of compressibility E_s and W_s may be taken depending on the stress on soil. In these two cases, the moduli of compressibility E_s and W_s can be defined in the analysis for several sub-layers instead of one layer of constants E_s and W_s.

As a rule, before the analysis the soil properties are defined through the tests of soil mechanics, particularly the moduli of compressibility E_s and W_s. For precalculations Table 9.2 for specification of the modulus of compressibility E_s can also be used.

According to *Kany* (1974), the values of W_s range between 3 to 10 times of E_s. From experience, the modulus of compressibility W_s for reloading can be taken 1.5 to 5 times as the modulus of compressibility E_s for loading.

For geologically strongly preloaded soil, the calculation is often carried out only with the modulus of compressibility for reloading W_s. In this case, the same values are defined for E_s and W_s.

Matching with the reality, satisfactory calculations of the settlements are to be expected only if the soil properties are determined exactly from the soil mechanical laboratory, field tests or back calculation of settlement measurements.

Table 9.2 shows mean moduli of compressibility E_s for various types of soil according to EAU (1990).

Table 9.2 Mean moduli of compressibility E_s for various types of soil

Type of soil	Modulus of compressibility E_s [kN/m^2]
Non-cohesive soil	
Sand, loose, round	20000 - 50000
Sand, loose, angular	40000 - 80000
Sand, medium dense, round	50000 - 100000
Sand, medium dense, angular	80000 - 150000
Gravel without sand	100000 - 200000
Coarse gravel, sharp edge	150000 - 300000
Cohesive soil	
Clay, semi-firm	5000 - 10000
Clay, stiff	2500 - 5000
Clay, soft	1000 - 2500
Boulder clay, solid	30000 - 100000
Loam, semi-firm	5000 - 20000
Loam, soft	4000 - 8000
Silt	3000 - 10000

9.6.4 Moduli of elasticity *E* and *W*

The equations derived in the previous section to determine the flexibility coefficients are used with moduli of elasticity *E* and *W* for unconfined lateral strain with *Poisson*'s ratio $\nu_s \neq 0$. It must be pointed out that, when defining *Poisson*'s ratio by $\nu_s = 0$ (limit case), the moduli of compressibility E_s and W_s for confined lateral strain (for example from Odometer test) also can be used.

The modulus of elasticity is often determined from an unconfined Triaxial compression test, Figure 9.13. Plate loading tests may also be used to determine the in-situ modulus of elasticity of the soil as elastic and isotropic.

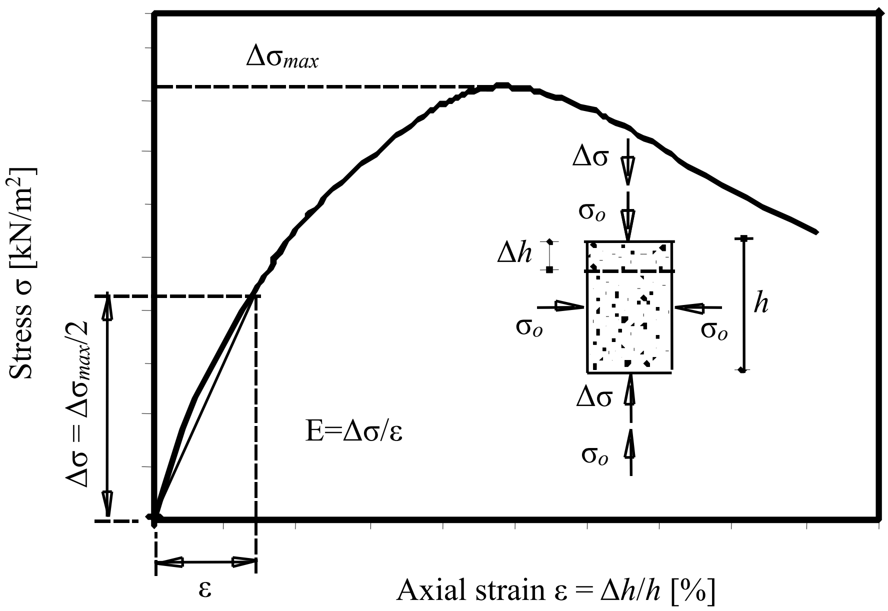


Figure 9.13 Modulus of elasticity *E* from Triaxial test

It is possible to obtain an expression for the moduli of elasticity *E* and *W* in terms of moduli of compressibility E_s, W_s and *Poisson*'s ratio ν_s for the soil as

$$\left.\begin{aligned} E &= E_s \frac{1-\nu_s-2\nu_s^2}{1-\nu_s} \\ W &= W_s \frac{1-\nu_s-2\nu_s^2}{1-\nu_s} \end{aligned}\right\} \qquad (39)$$

The above equation shows that:

- In the limit case $\nu_s = 0$ (deformation without lateral strain), the values of *E* and E_s (also *W* and W_s) are equal

- In the other limit case ν_s = 0.5 (deformation with constant volume), the moduli of elasticity will be $E = 0 \times E_s$ and $W = 0 \times W_s$. In this case, only the immediate settlement (lateral deformation with constant volume) can be determined.

Table 9.3 shows some typical values of modulus of elasticity according to *Bowles* (1977).

Table 9.3 Typical range of moduli of elasticity E for selected soils

Type of soil	Modulus of elasticity E [kN/m^2]
Very soft clay	3000 - 3000
Soft clay	2000 - 4000
Medium clay	4500 - 9000
Hard clay	7000 - 20000
Sandy clay	30000 - 42500
Silt	2000 - 20000
Silty sand	5000 - 20000
Loose sand	10000 - 25000
Dense sand	50000 - 100000
Dense sand and gravel	80000 - 200000
Loose sand and gravel	50000 - 140000
Shale	140000 - 1400000

9.6.5 Settlement reduction factor α

From experience the real consolidation settlements are different from those calculated. Settlements *s* are multiplied by a factor α according to German standard DIN 4019, page No. 1. According to this standard, the following reduction factors in Table 9.4 can be applied:

Table 9.4 Reduction factors α according to DIN 4019, page No. 1

Soil type	α
Sand and silt	0.66
Normally and slightly over consolidated clay	1.0
Heavily over consolidated clay	0.5 - 1

In *GEO Tools*, the moduli of compressibility E_s and W_s are divided by α as follows

$$\left.\begin{aligned} \overline{E}_s &= \frac{E_s}{\alpha} \\ \overline{W}_s &= \frac{W_s}{\alpha} \end{aligned}\right\} \qquad (40)$$

In the final result, this process is equivalent to the following equation

$$\overline{S} = \alpha\, s \qquad (41)$$

9.7 Defining the project data

9.7.1 Firm Header

When printing the results, the main data (firm name) are displayed on each page at the top in two lines or in graphic presentation at the identification box. Firm name can be defined, modified, and saved using the "Firm Header" Option from the setting Tab (see Figure 9.14).

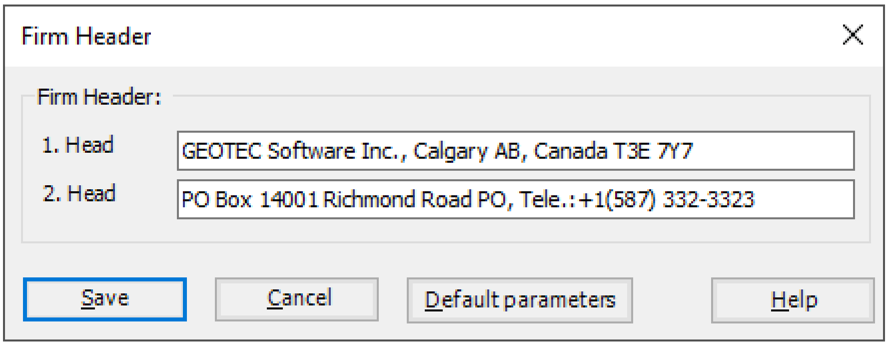


Figure 9.14 Firm Header

9.7.2 Task of the program *GEO Tools* (Analysis Type)

The program *GEO Tools* can be used to analyze various problems in Geotechnical Engineering for shallow and deep foundations, Figure 9.15.

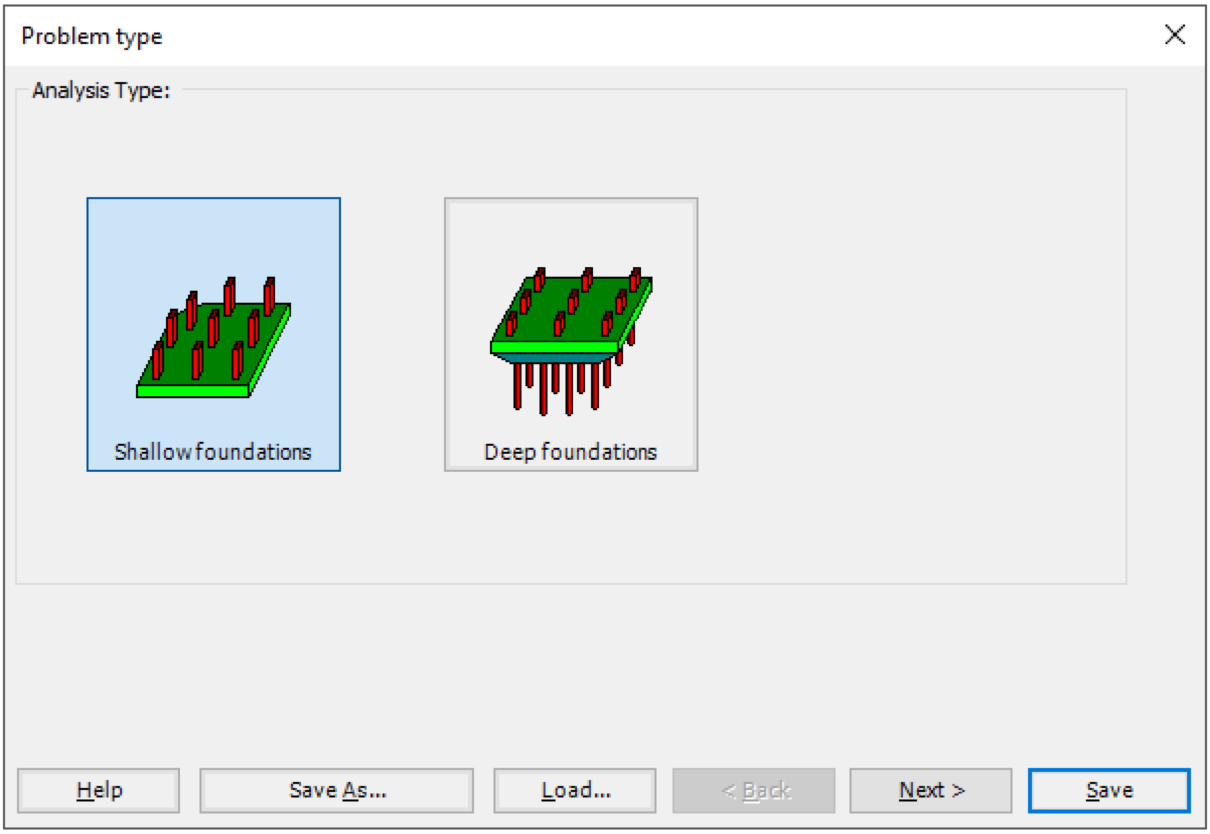


Figure 9.15 Problem type

According to the main menu in Figure 9.16 the following geotechnical problems can be calculated for shallow foundations:

1. Stresses in soil
2. Strains in soil
3. Displacements in soil
4. Consolidation settlement
5. Degree of consolidation
6. Time-settlement curve
7. Displacements of rigid raft
8. Consolidation of rigid raft
9. Settlements of footing groups
10. Analysis of a beam foundation
11. Modified Cam-Clay Model

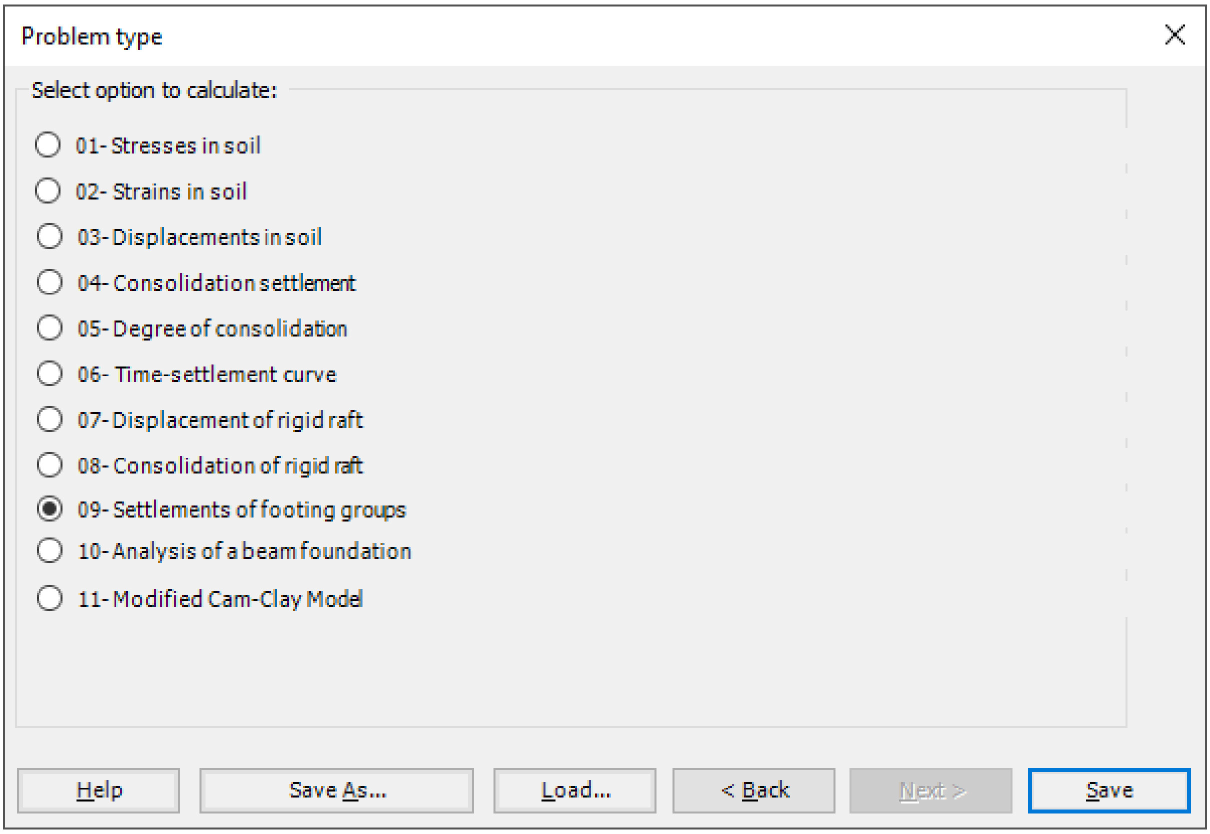


Figure 9.16 Problem type for shallow foundation

In menu of Figure 9.16, select the option:

09- Settlement of footing groups

The following paragraph describes how to determine the settlement of footing groups by the program *GEO Tools* with an example.

9.7.3 Description of the example

The settlements for two footings, including the influence of the overlapped stress of footings, are determined. In addition, the limit depth of the soil under the footings is determined. Data to be defined are dimensions of footings and subsoil.

9.7.4 Project Identification

Example 0: Test example for two footings (2 isolated footings)

File name: SZ5

In the program, it must be distinguished between the following two data groups:

1 System data (For identification of the project that is created and information to the output for the printer).

2 Soil data (Soil properties and so on).

The defining input data for these data groups is carried out as follows:

After clicking on the "Project Identification" Option, the following general project data are defined (Figure 9.17):

Title: Title label

Date: Date

Project: Project label

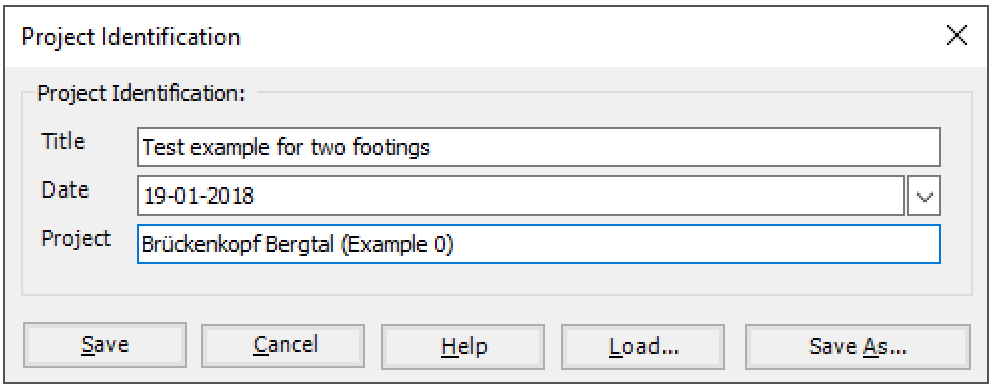


Figure 9.17 Project Identification

9.7.5 Main Soil Data

After clicking the "Settlements of footing groups" option, the following basic subsoil data is defined (Figure 9.18):

Limit depth:

D_z	Strip thickness for depth by iteration	[m]
C_s	Standard ratio of limit depth ($0 \le C_s \le 1$)	[-]

Main Soil Data:

α	Settlement reduction factor ($\alpha \le 1$)	[-]
Tw	Groundwater depth under the ground surface	[m]
γ_b	Unit weight of footing concrete	[kN/m^3]
	(by default $\gamma_b = 25$)	

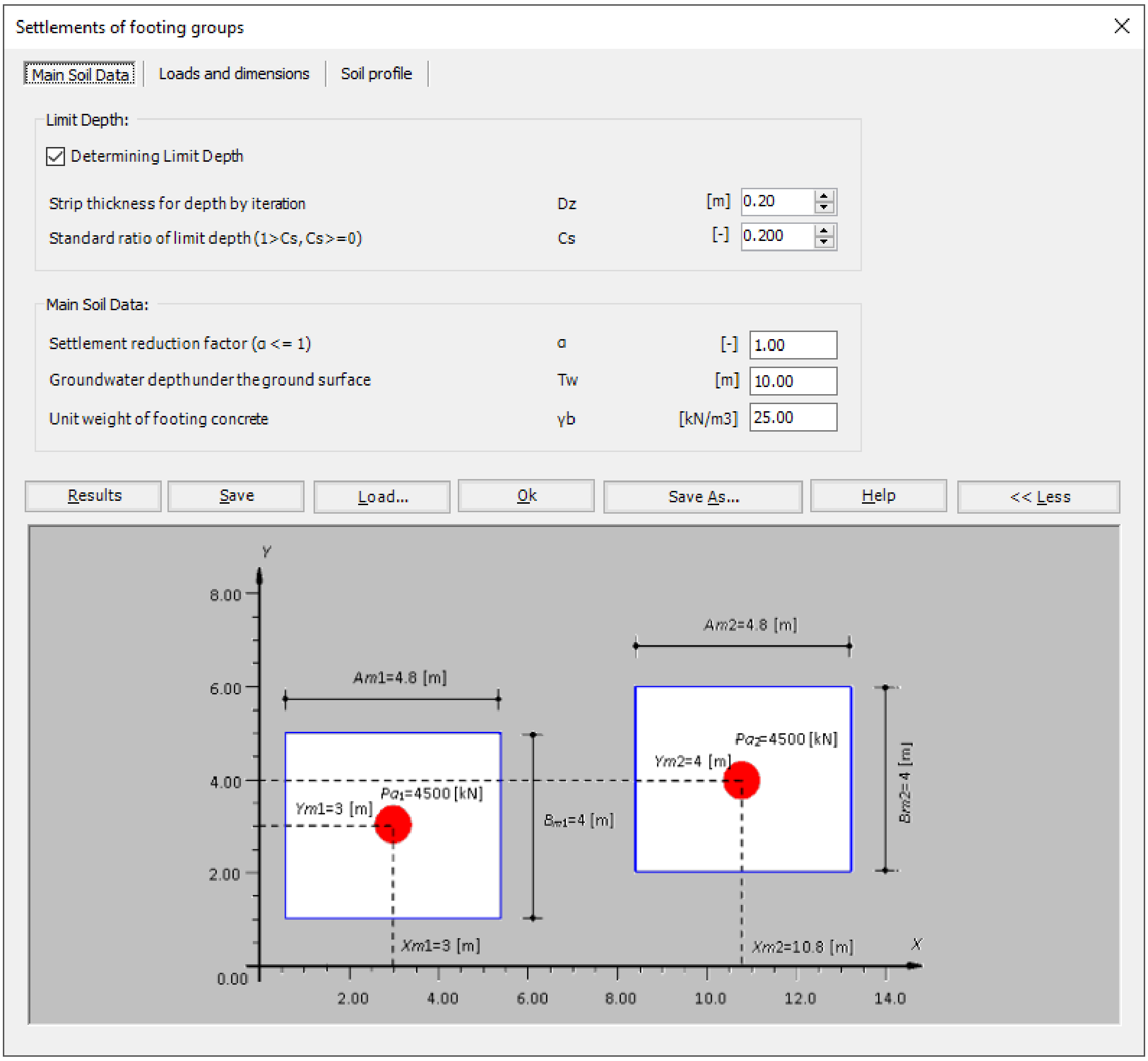


Figure 9.18 Main Soil Data

9.7.6 Loads and dimensions

The settlements at the corners of the isolated footings depend on the dimensions and the length of the isolated footings in the coordinate system, on the loads and the soil layers. After clicking on the "Loads and dimensions" tab in Figure 9.18, the following table of data in the form of Figure 9.19 is defined. The following data are required for each isolated footing:

Pa	Load on footing	[kN]
Am	Footing length	[m]
Bm	Footing breadth	[m]
Dm	Thickness of the footing	[m]
Tf	Foundation depth	[m]

ß	Rotating angle	[°]
Xm,*Ym*	Location of the footing center in the coordinate system	[m]
Hm	Height of the base of the footing above the fixed point	[m]

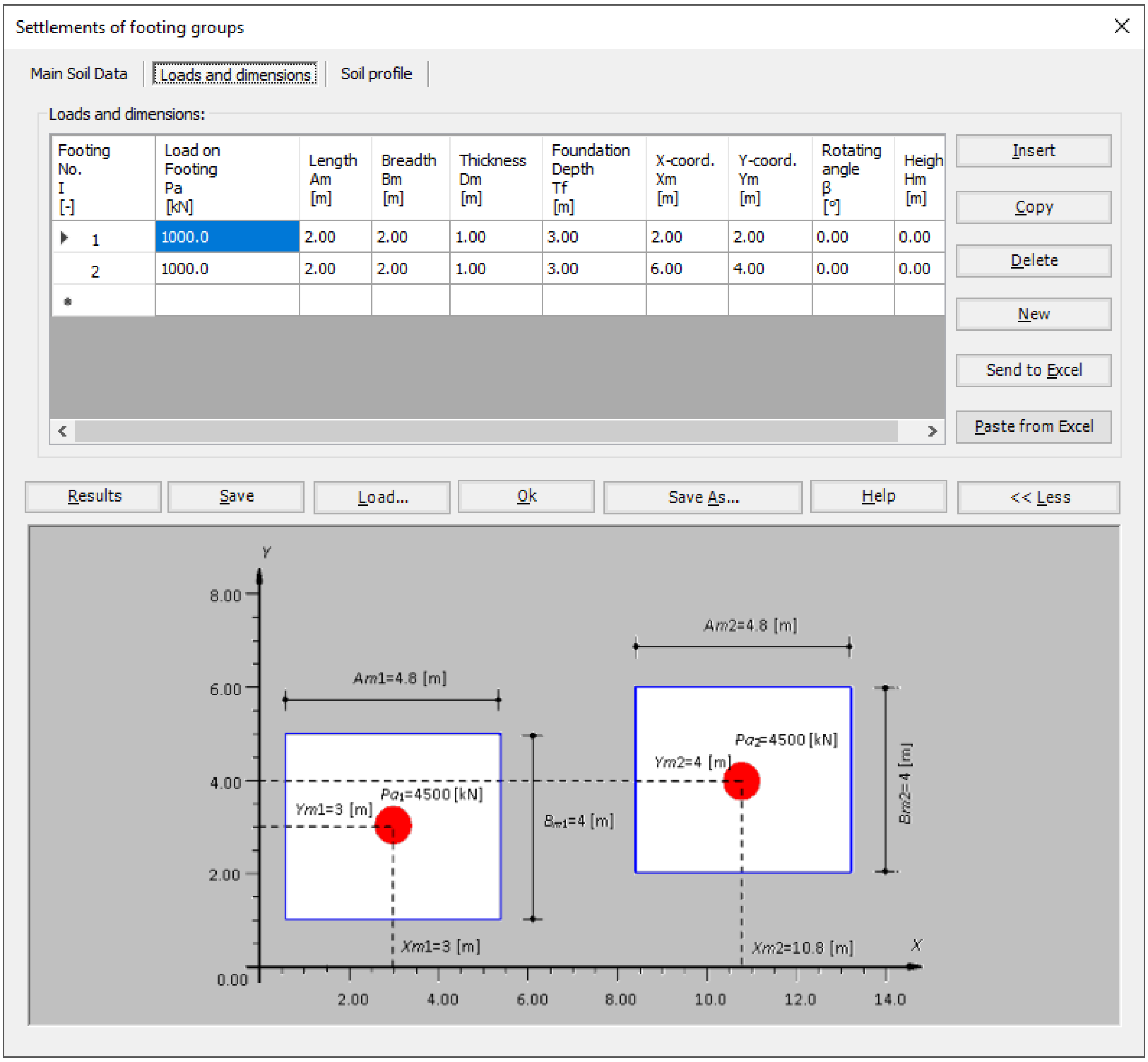


Figure 9.19 Loads and dimensions

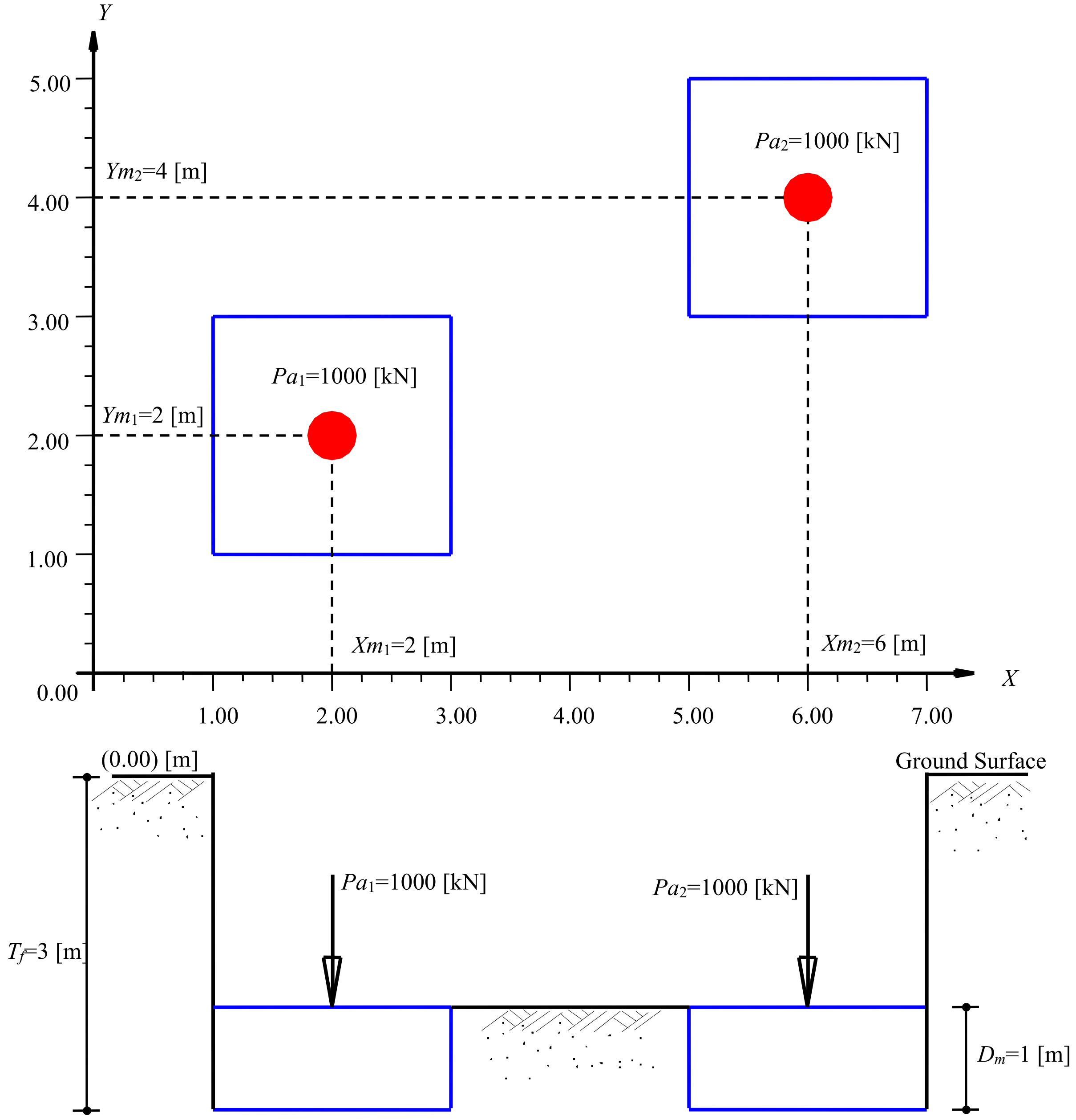


Figure 9.20 Plan and section through footings 1 and 2
(Arrangement of the footings in the coordinate system)

9.7.7 Soil profile

After clicking the "Soil profile" tab in Figure 9.19, the subsoil data are defined in (Figure 9.21). Several layers of the soil are defined, data of each layer are:

Z	Level of layer under ground (Measured from ground level)	[m]
E_S	Modulus of compressibility for loading (Constant in layers)	[kN/m^2]
W_S	Modulus of compressibility for reloading (Constant in layers)	[kN/m^2]
ν_s	*Poisson's* ratio	[-]
γ_s	Unit weight of the soil	[kN/m^3]
BOD	Soil name.	

Constraint moduli with constrained side strain (Moduli of compressibility) *Es* and *Ws* from tests with constrained side strain (e.g. from compression tests) are defined. This means that $\nu_s = 0$ must be entered as the *Poisson's* ratio.

If other moduli for unconfined lateral strain (moduli of elasticity) *E* and *W* are used, the *Poisson's* ratio $\nu_s \neq 0$ must be set. In any case, the *Poisson's* ratio of the soil ν_s lies within the limits $0 < \nu_s < 0.5$.

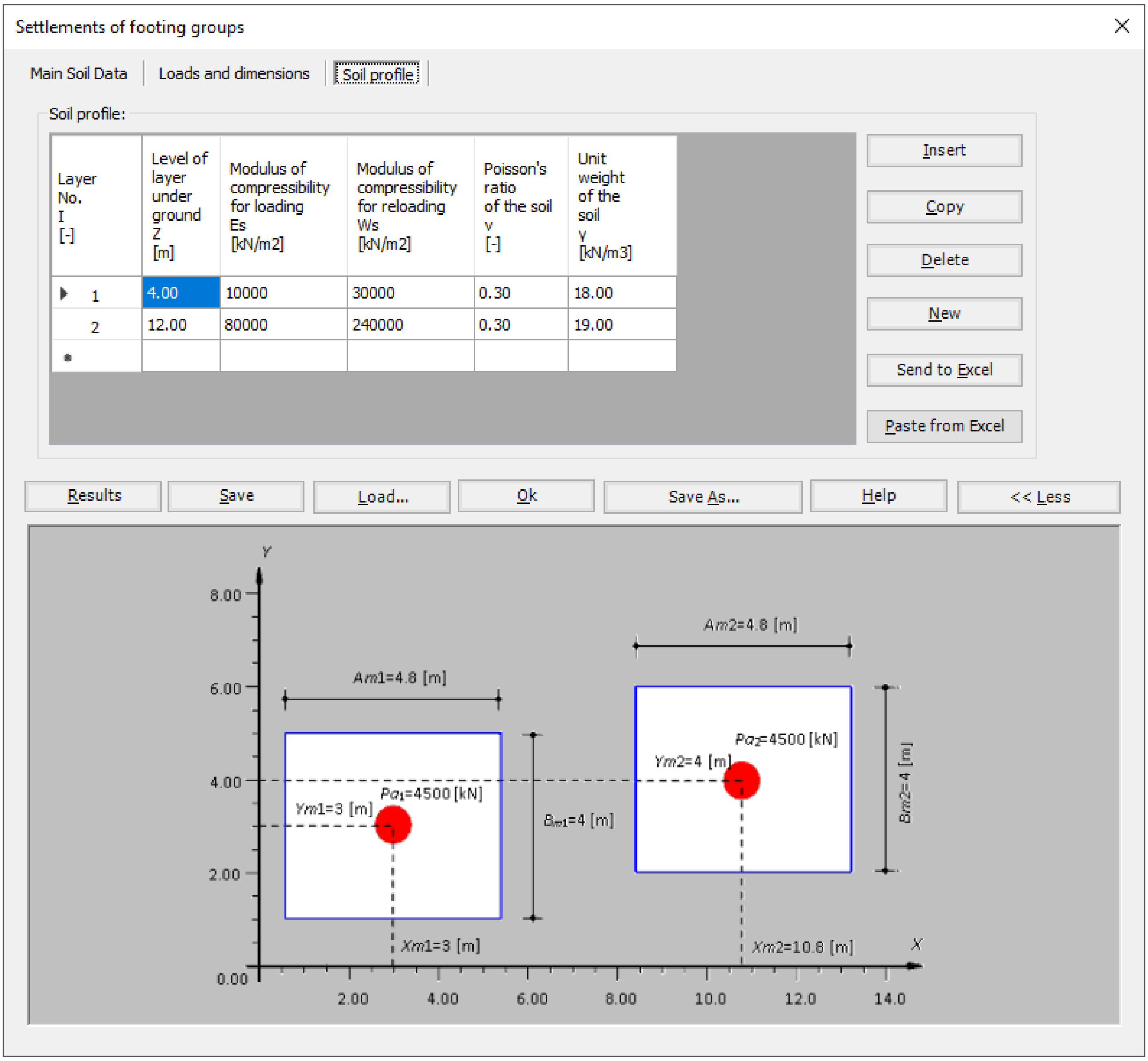


Figure 9.21 Soil profile

9.8 Numerical Examples

9.8.1 Introduction

The application possibilities of the program *GEO Tools* for the settlement calculation of footing groups are presented below in some numerical examples. The examples were carried out to verify and test the application of the proposed procedures outlined in this book.

9.8.2 Example 1: Double footings (2 isolated footings)

File name SZ1

9.8.2.1 Description of the problem

A simple example is presented to demonstrate the use of *GEO Tools*. The footing group shown in Figure 9.22 consists of two footings standing on a subsoil with two layers. The following soil properties in Table 9.5 are defined.

Table 9.5 Soil properties

Layer No. I	Soil name	Depth of the soil layer under the ground surface Z [m]	Modulus of compressibility for loading Es [kN/m^2]	reloading Ws [kN/m^2]	Unit weight of the soil γ_s [kN/m^3]
1	Sand	6.0	35000	96000	20
2	Silt	7.5	6100	16300	19

For centric loads of Pa = 4500 [kN] on each footing, the settlements at corners 1 ... 4 of the two footings No. 1 and No. 2 are to be calculated using the *GEO Tools* program.

α = 1 is defined as the reduction factor and νs = 0 as the *Poisson's* ratio. The Standard ratio of limit depth is Cs = 0.2 and the groundwater depth is Tw = 7.5 [m]. Unit weight of the footing concrete γ_b = 25 [kN/m³].

The dimensions of the two footings and their foundation depths Tf and embedment thickness Te (footing thickness) are shown in Figure 9.22.

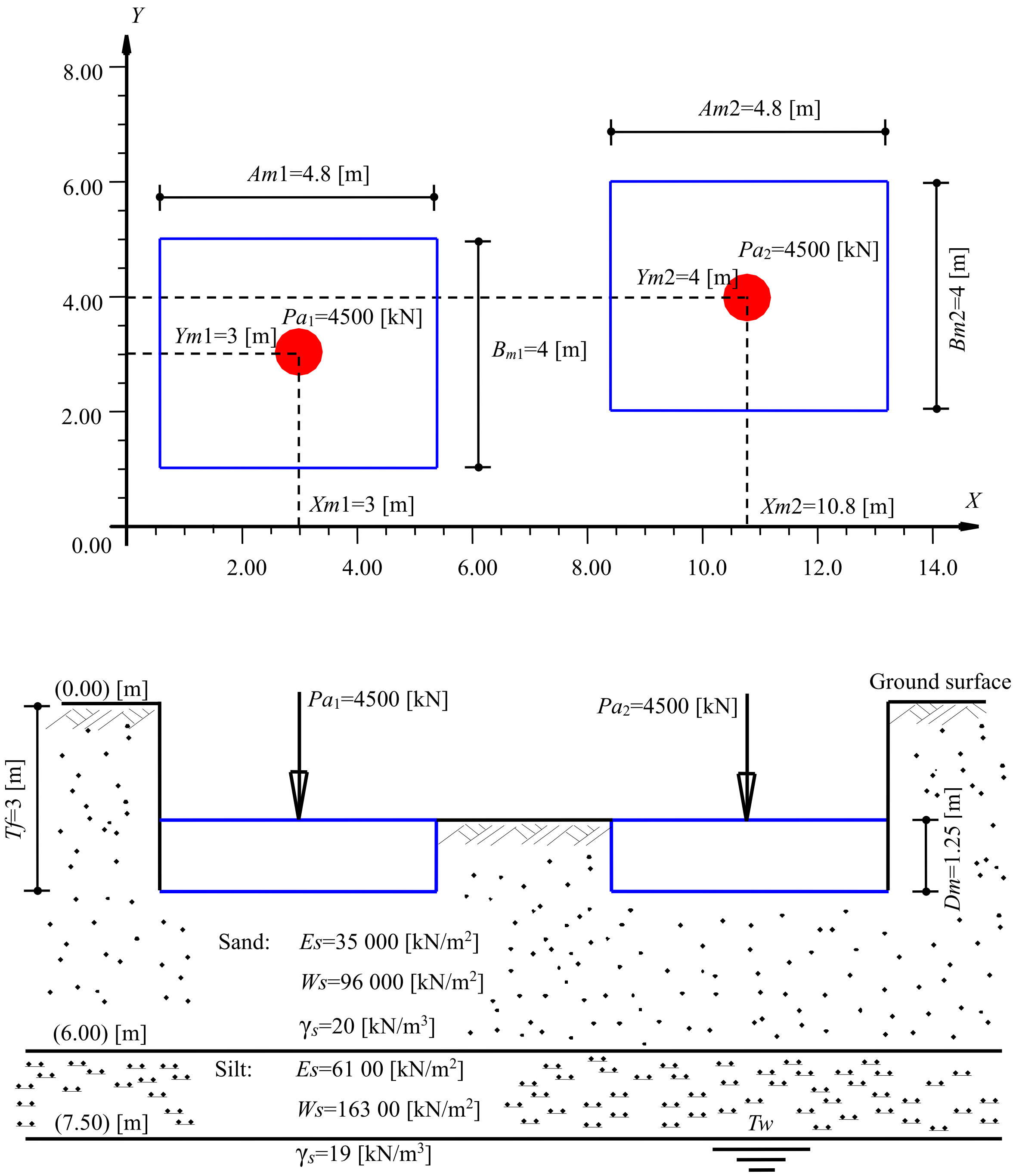


Figure 9.22 Footing group in plan and section

9.8.2.2 Analysis of the project

9.8.2.2.1 Defining the project identification

The project identification data, main soil data, loads and dimensions and soil profile are defined using the *GEO Tools* program in the following steps.

The project identification data are defined with the option "Project Identification". Depending on the purpose of the calculation, the following data are defined (Figure 9.23):

Title:	Two isolated footings
Date:	22-01-2018
Project :	User's Manual

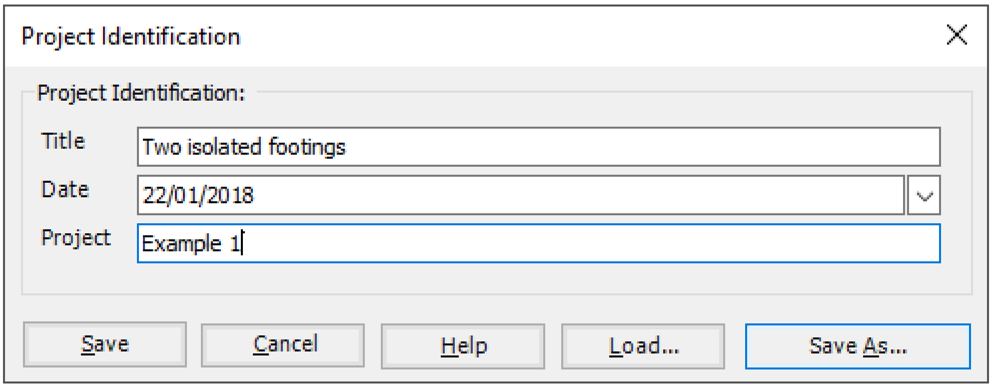


Figure 9.23 Project identification

9.8.2.2.2 Data for the purpose of settlement calculation

After clicking the "Settlements of footing groups" option, the data are defined for the purpose of the settlement calculation (Figure 9.24).

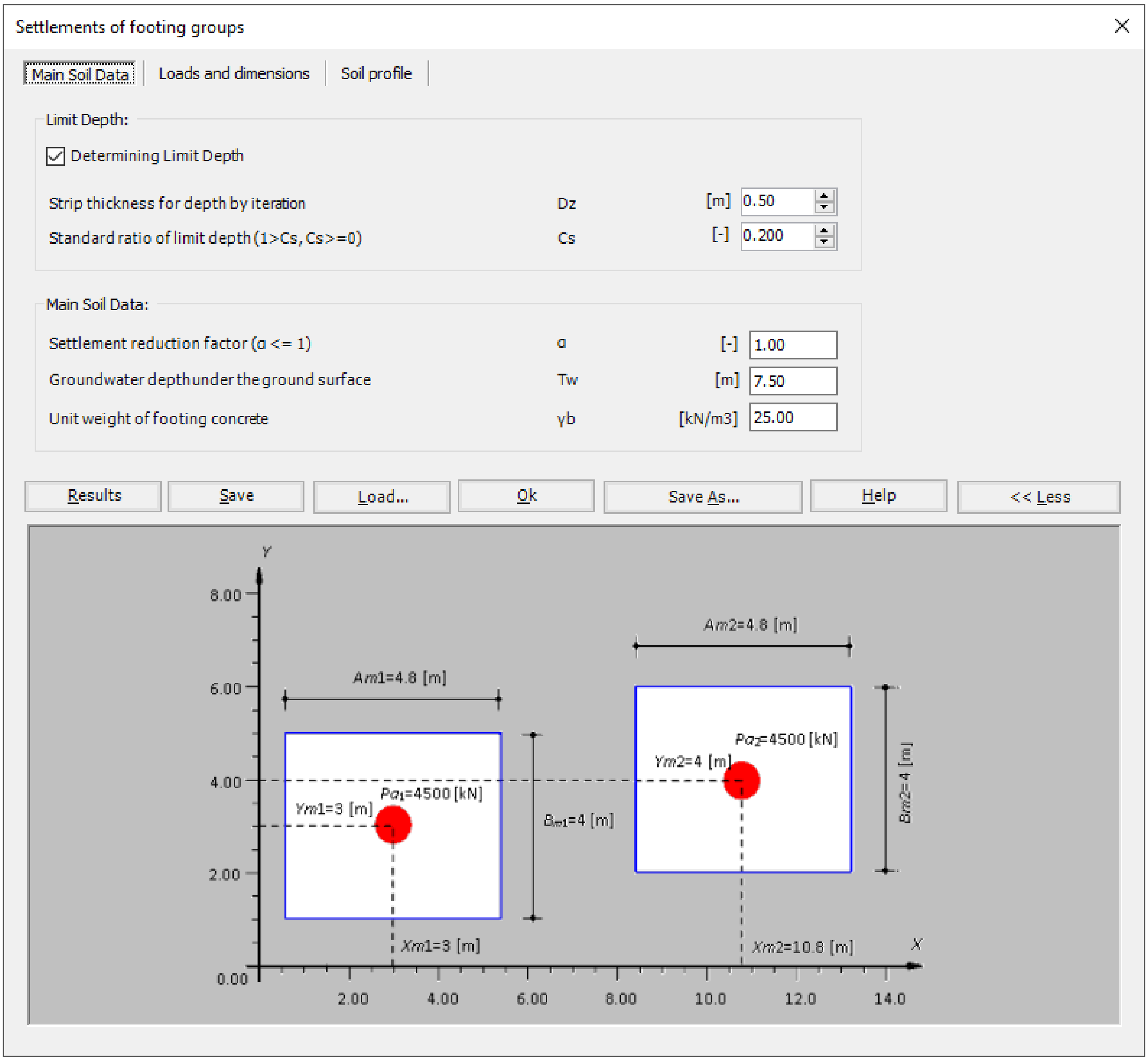


Figure 9.24 Settlements of footing groups

9.8.2.2.3 Calculation of limit depth

After the query as to whether the limit depth should be calculated at all, the following calculation values for the limit depth calculation are defined (Figure 9.24):

Dz	= Strip thickness for depth by iteration	= 0.5	[m]
Cs	= Standard ratio of limit depth (0<= C_s<=1)	= 0.2	[-]

9.8.2.2.4 Defining the main soil data

Then the following values are defined (Figure 9.24):

α	= Settlement reduction factor (α<=1) according to DIN 4019 = 1 [-]		
Tw	= Groundwater depth under the ground surface	= 7.5	[m]
γ_b	= Unit weight of footing concrete	= 25	[kN/m³]

9.8.2.2.5 Geometric data

As system data, the data of the foundation geometry are defined. After clicking on the "Loads and dimensions" tab, the geometric data for each of the two footings are defined in the following order:

Pa	Load on footing	[kN]
Am	Footing length	[m]
Bm	Footing breadth	[m]
Dm	Thickness of the footing	[m]
Tf	Foundation depth	[m]
ß	Rotating angle	[°]
Xm,*Ym*	Location of the footing center in the coordinate system	[m]
Hm	Height of the base of the footing above the fixed point	[m]

The defined data is shown in Figure 9.25.

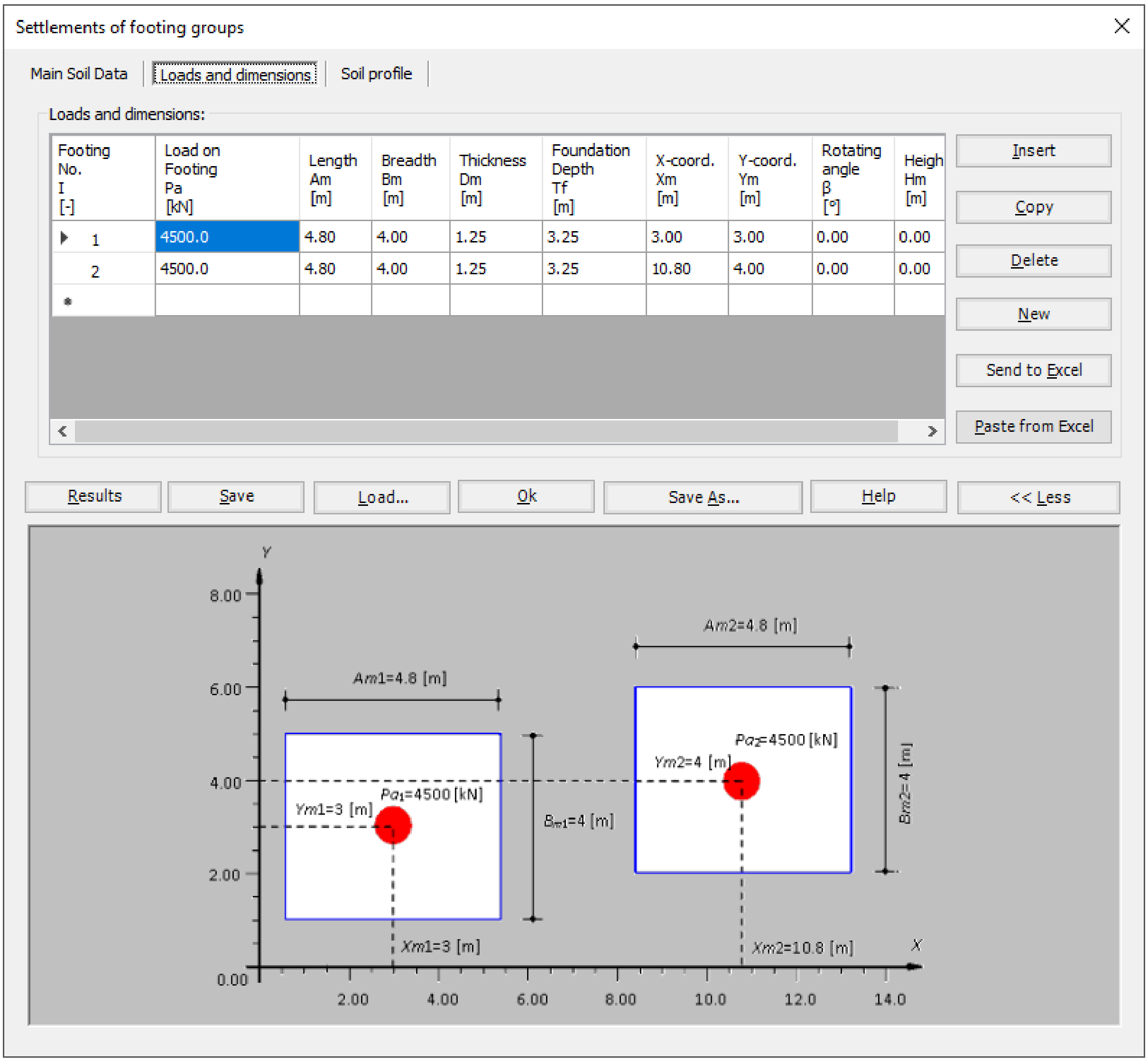


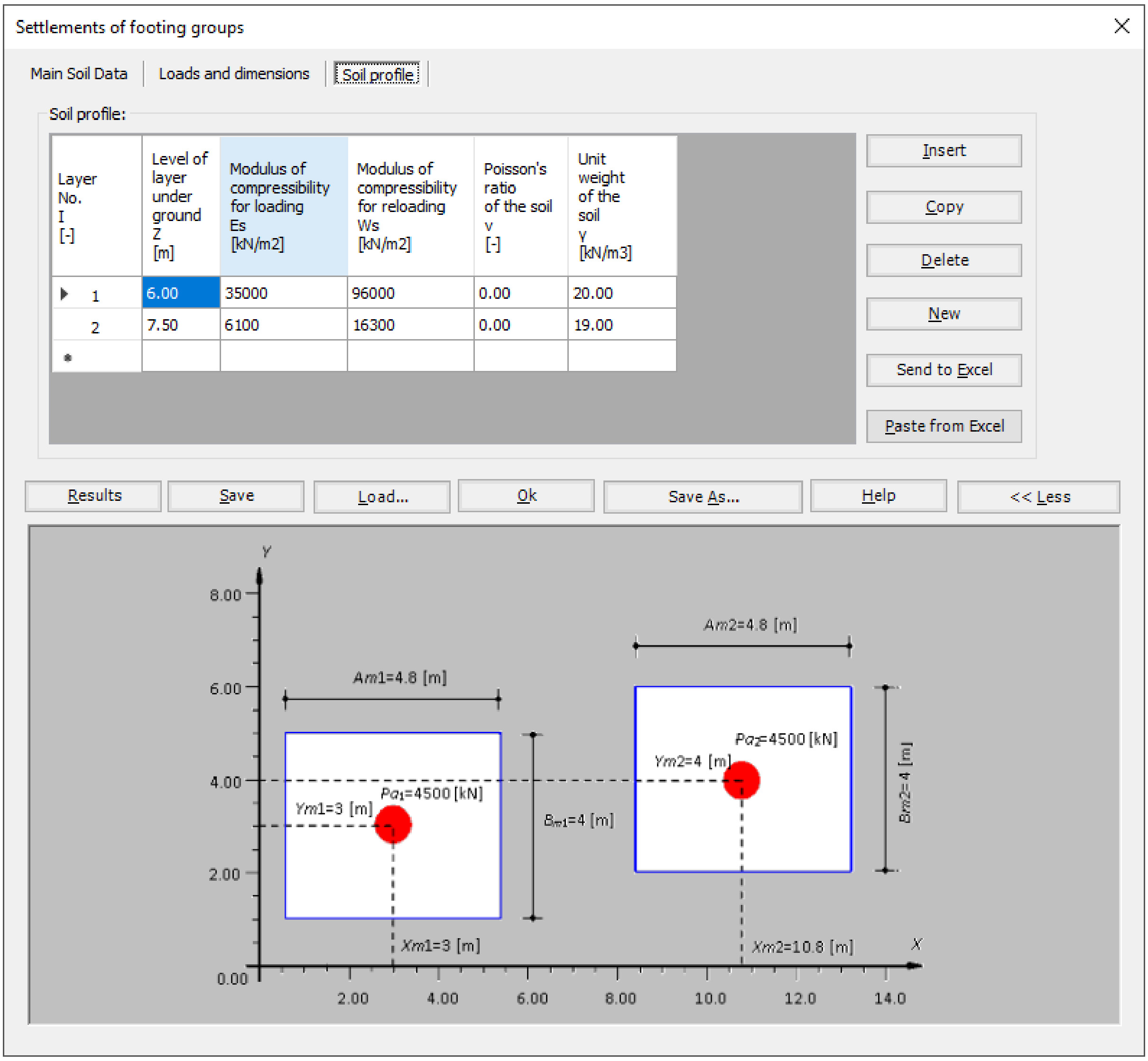
Figure 9.25 Loads and dimensions

9.8.2.2.6 Defining soil data

As soil data, the following data are defined for the two layers after clicking on the "Soil profile" tab (Figure 9.26):

Z	Level of layer under ground (Measured from ground level)	[m]
E_S	Modulus of compressibility for loading (Constant in layers)	[kN/m^2]
W_S	Modulus of compressibility for reloading (Constant in layers)	[kN/m^2]
ν_s	*Poisson's* ratio	[-]
γ_s	Unit weight of the soil	[kN/m^3]

BOD Soil name.



Layer No. I [-]	Level of layer under ground Z [m]	Modulus of compressibility for loading Es [kN/m2]	Modulus of compressibility for reloading Ws [kN/m2]	Poisson's ratio of the soil ν [-]	Unit weight of the soil γ [kN/m3]
1	6.00	35000	96000	0.00	20.00
2	7.50	6100	16300	0.00	19.00
*					

Figure 9.26 Soil profile

9.8.2.2.7 Settlement calculation

After saving the data and clicking the "Results" button, the computer starts calculating the limit depth. The strip thickness *Dz* = 0.5 [m] is used for calculation. The limit depth is *Zg* = 10.37 [m]. This depth is below the lower edge of the second layer, so it has no influence on the result of the settlement calculation, because the depth of the second layer is defined as 7.5 [m].

9.8.2.2.8 Presentation of data and results

In the *GEO Tools* there are numerous options for the printout of the data and results that can be carried out by the user.

The data and results for example 1 are listed in tabular form on the first next two pages. Then, the next 6 pages contain graphical representations of the data and results. There are numerous other display options.

```
**********************************************************
                         GEO Tools
                        Version 13
          Program authors M. El Gendy/ A. El Gendy
**********************************************************
Title: Two isolated footings
Date: 22/01/2018
Project: Example 1
File: SZ1

----------------------------------------------------------
Settlements of footing groups
----------------------------------------------------------

Data of limit depth:

Strip thickness for depth by iteration        Dz [m]     = 0.5
Standard ratio of limit depth (1>Cs, Cs>=0)   Cs [-]     = 0.2

Main Soil Data:

Groundwater depth under the ground surface    Tw [m]     = 7.50
Settlement reduction factor                   α  [-]     = 1.00
Unit weight of footing concrete               γb [kN/m3] = 25.00

Overburden pressure                           Qv [kN/m2] = 65.0
Loading                                       Qe [kN/m2] = 200.6
Contact pressure                              Qo [kN/m2] = 265.6
Limit depth under ground surface              ZG [m]     = 10.37
Limit depth lies under last layer

Loads and dimensions:
```

Footing No. I	Load on Footing Pa [kN]	Length Am [m]	Breadth Bm [m]	Thickness Dm [m]	Foundation Depth Tf [m]	X-coord. Xm [m]	Y-coord. Ym [m]	Rotating angle β [°]	Height Hm [m]
1	4500.0	4.80	4.00	1.25	3.25	3.00	3.00	0.00	0.00
2	4500.0	4.80	4.00	1.25	3.25	10.80	4.00	0.00	0.00

Boring:

Layer No. I [-]	Level of layer under ground z [m]	Modulus of compressibility for loading Es [kN/m2]	Modulus of compressibility for reloading Ws [kN/m2]	Poisson's ratio of the soil νs [-]	Unit weight of the soil γs [kN/m3]
1	6.00	35000	96000	0.00	20.00
2	7.50	6100	16300	0.00	19.00

Stress on soil against depth (Footing No. 1/ Max. Load):

Iteration No.	Depth under foundation	Stress due to foundation	Stress from neighboring foundations	Sum of stresses	Stress from soil weight	ratio
I	z	SE	SD	SU=SE+SD	SV	SU/SV
	[m]	[kN/m2]	[kN/m2]	[kN/m2]	[kN/m2]	[-]
0	0.00	265.6	0.0	265.6	65.0	4.09
1	0.50	230.2	0.0	230.2	75.0	3.07
2	1.00	172.0	0.1	172.1	85.0	2.02
3	1.50	136.9	0.2	137.1	95.0	1.44
4	2.00	115.0	0.6	115.5	105.0	1.10
5	2.50	99.3	1.0	100.3	115.0	0.87
6	3.00	86.9	1.6	88.5	124.8	0.71
7	3.50	76.6	2.2	78.9	134.3	0.59
8	4.00	67.9	2.9	70.8	143.8	0.49
9	4.50	60.3	3.6	63.9	153.3	0.42
10	5.00	53.7	4.3	58.0	162.8	0.36
11	5.50	48.0	5.0	52.9	172.3	0.31
12	6.00	43.0	5.6	48.5	181.8	0.27
13	6.50	38.6	6.0	44.7	191.3	0.23
14	7.00	34.9	6.5	41.3	200.8	0.21
15	7.50	31.6	6.8	38.3	210.3	0.18

Settlement calculation for rigid centric loaded footings

```
Footing No.: 1
Overburden pressure                       Qv  [kN/m2] = 65.0
Loading                                   Qe  [kN/m2] = 200.6
Contact pressure                          Qo  [kN/m2] = 265.6
Modulus of subgrade reaction              ks  [kN/m3] = 9910.9

Final settlements of rigid footing:
Settlement of the corner: right up         S1  [cm]    = 2.85
Settlement of the corner: right down       S2  [cm]    = 2.82
Settlement of the corner: left down        S3  [cm]    = 2.68
Settlement of the corner: left up          S4  [cm]    = 2.71
Average settlement                         Sm  [cm]    = 2.76

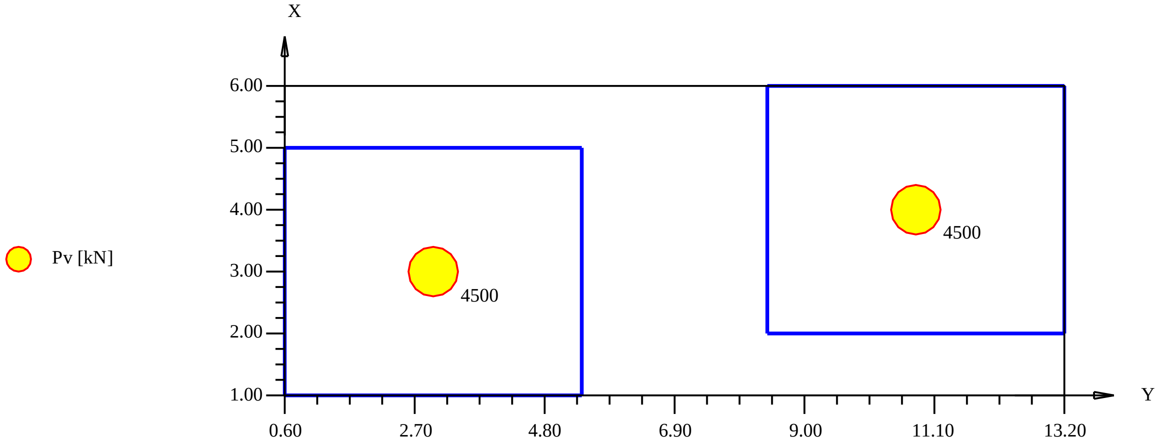
Immediate settlement parts:
Settlement of the corner: right up         Sf1 [cm]    = 1.81
Settlement of the corner: right down       Sf2 [cm]    = 1.79
Settlement of the corner: left down        Sf3 [cm]    = 1.81
Settlement of the corner: left up          Sf4 [cm]    = 1.81
Average settlement                         Smf [cm]    = 1.81

Footing No.: 2
Overburden pressure                       Qv  [kN/m2] = 65.0
Loading                                   Qe  [kN/m2] = 200.6
Contact pressure                          Qo  [kN/m2] = 265.6
Modulus of subgrade reaction              ks  [kN/m3] = 9432.7

Final settlements of rigid footing:
Settlement of the corner: right up         S1  [cm]    = 2.68
Settlement of the corner: right down       S2  [cm]    = 2.71
Settlement of the corner: left down        S3  [cm]    = 2.85
Settlement of the corner: left up          S4  [cm]    = 2.82
Average settlement                         Sm  [cm]    = 2.76

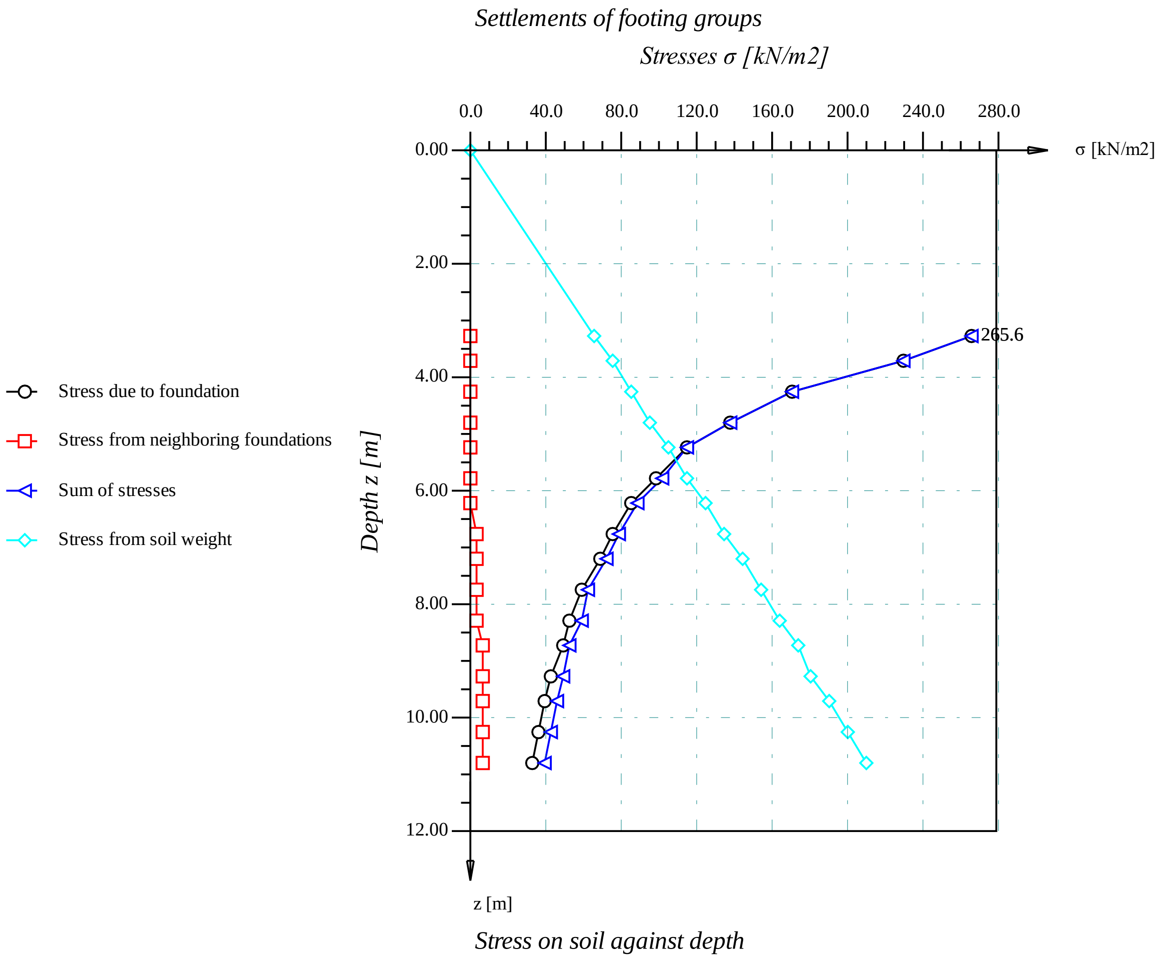
Immediate settlement parts:
Settlement of the corner: right up         Sf1 [cm]    = 1.81
Settlement of the corner: right down       Sf2 [cm]    = 1.81
Settlement of the corner: left down        Sf3 [cm]    = 1.81
Settlement of the corner: left up          Sf4 [cm]    = 1.79
Average settlement                         Smf [cm]    = 1.81
```

Method (8) (Layered soil model)
Modulus of Compressibility for Rigid Raft



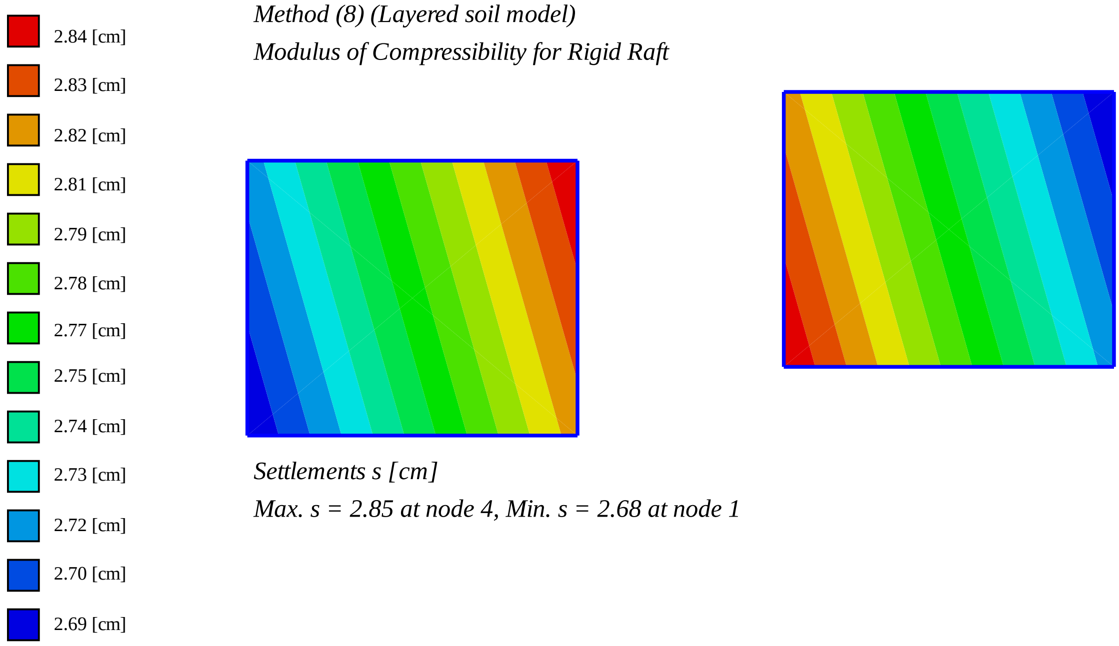
System of loading Pv [kN]

GEOTEC Software Inc., Calgary AB, Canada T3E 7Y7 PO Box 14001 Richmond Road PO, Tele.:+1(587) 332-3323	
Scale: 100	**Title: Two isolated footings**
File: SZ1	**Date: 22/01/2018**
Page No.:	**Project: Example 1**



GEOTEC Software Inc., Calgary AB, Canada T3E 7Y7 PO Box 14001 Richmond Road PO, Tele.:+1(587) 332-3323	
Scale: 3281	**Title: Two isolated footings**
File: SZ1	**Date: 22/01/2018**
Page No.:	**Project: Example 1**

Method (8) (Layered soil model)
Modulus of Compressibility for Rigid Raft

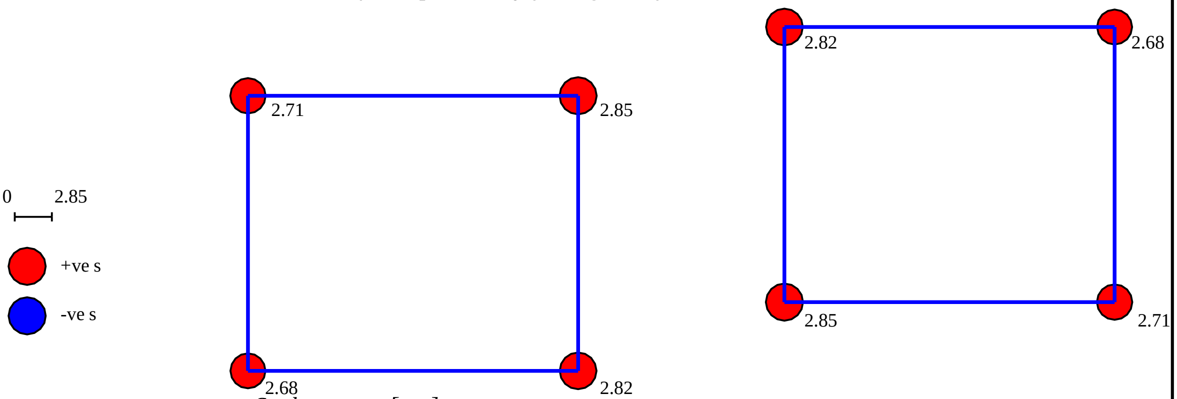


Settlements s [cm]
Max. s = 2.85 at node 4, Min. s = 2.68 at node 1

GEOTEC Software Inc., Calgary AB, Canada T3E 7Y7 PO Box 14001 Richmond Road PO, Tele.:+1(587) 332-3323	
Scale: 90	**Title: Two isolated footings**
File: SZ1	**Date: 22/01/2018**
Page No.:	**Project: Example 1**

Method (8) (Layered soil model)

Modulus of Compressibility for Rigid Raft



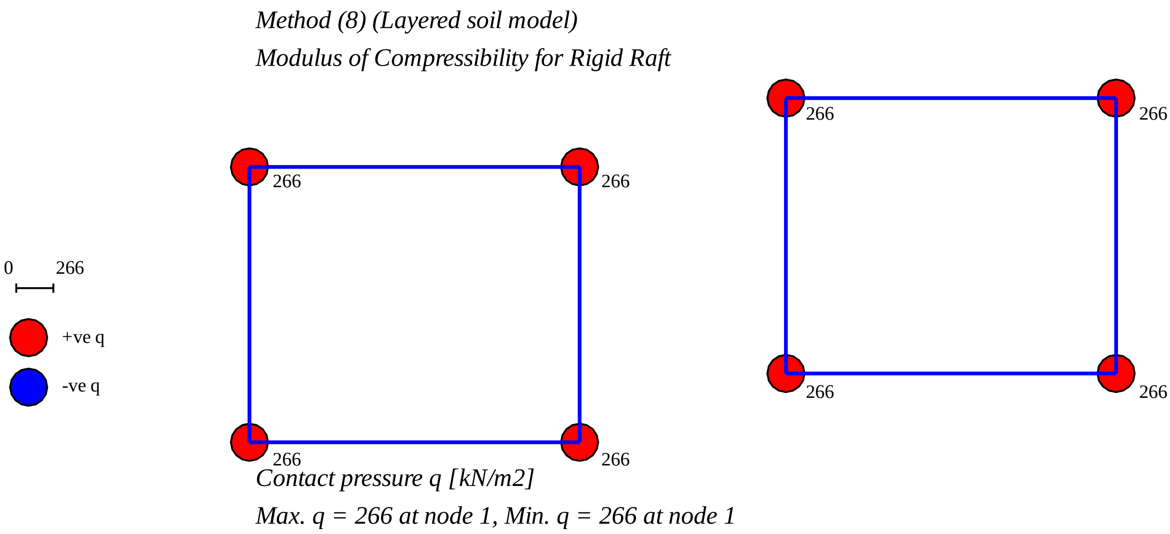
Settlements s [cm]

Max. s = 2.85 at node 4, Min. s = 2.68 at node 1

GEOTEC Software Inc., Calgary AB, Canada T3E 7Y7

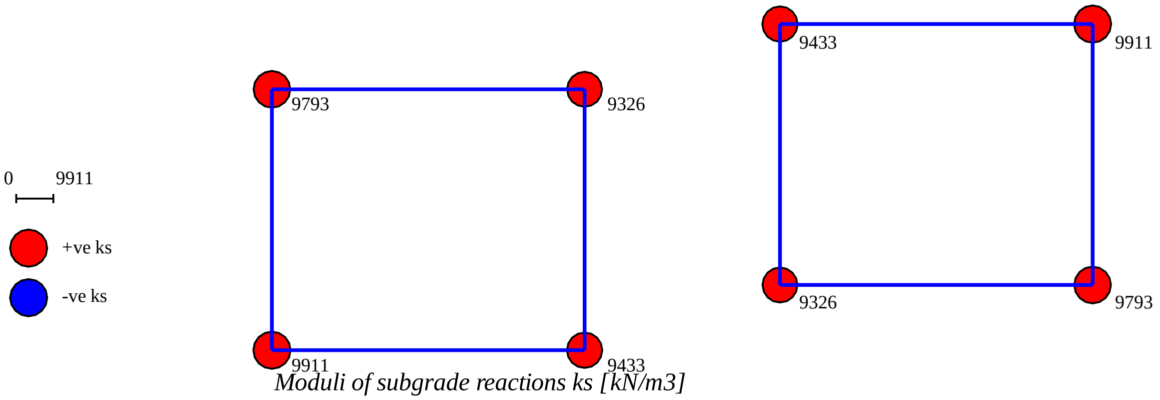
PO Box 14001 Richmond Road PO, Tele.:+1(587) 332-3323

Scale: 90	**Title: Two isolated footings**
File: SZ1	**Date: 22/01/2018**
Page No.:	**Project: Example 1**



GEOTEC Software Inc., Calgary AB, Canada T3E 7Y7 PO Box 14001 Richmond Road PO, Tele.:+1(587) 332-3323	
Scale: 90	**Title: Two isolated footings**
File: SZ1	**Date: 22/01/2018**
Page No.:	**Project: Example 1**

Method (8) (Layered soil model)
Modulus of Compressibility for Rigid Raft



Moduli of subgrade reactions ks [kN/m3]
Max. ks = 9911 at node 1, Min. ks = 9326 at node 4

GEOTEC Software Inc., Calgary AB, Canada T3E 7Y7 PO Box 14001 Richmond Road PO, Tele.:+1(587) 332-3323	
Scale: 95	**Title: Two isolated footings**
File: SZ1	**Date: 22/01/2018**
Page No.:	**Project: Example 1**

9.8.3 Example 2: Two adjacent rectangular footings
File names DI1, DI2

9.8.3.1 Description of the problem

GEO Tools is to be used to calculate the self-settlements and the settlements and tilting from overlapping stress for the footing group shown in Figure 9.27. The group consists of two rectangular footings close to each other. Both footings are loaded symmetrically to each other in the X direction.

According to Figure 9.27b, the subsoil consists of silt layer to a depth of 5.00 [m] below the ground surface. Under the silt layer there is practically incompressible rock (sandstone).

The following soil properties are considered for the silt layer (layer no. 1):

Modulus of compressibility for loading	Es	= 5000	[kN/m^2]
Modulus of compressibility for reloading	Ws	= 15000	[kN/m^2]
Unit weight of the soil	γ_s	= 18.5	[kN/m^3]

No groundwater has been observed.

The load acts on each of the two footings is:

$Pa1 = Pa2 = 1800$ [kN].

From the unit weight of the footing concrete γ_b = 25 [kN/m^3] and the dimensions, *GEO Tools* calculates the self-weight of the footing and takes it into account in the settlement calculation.

For a good assessment of the proposed calculation, the settlement of the footing is calculated twice as follows:

i) Without stress overlap (only self-settlement)
ii) With stress overlap

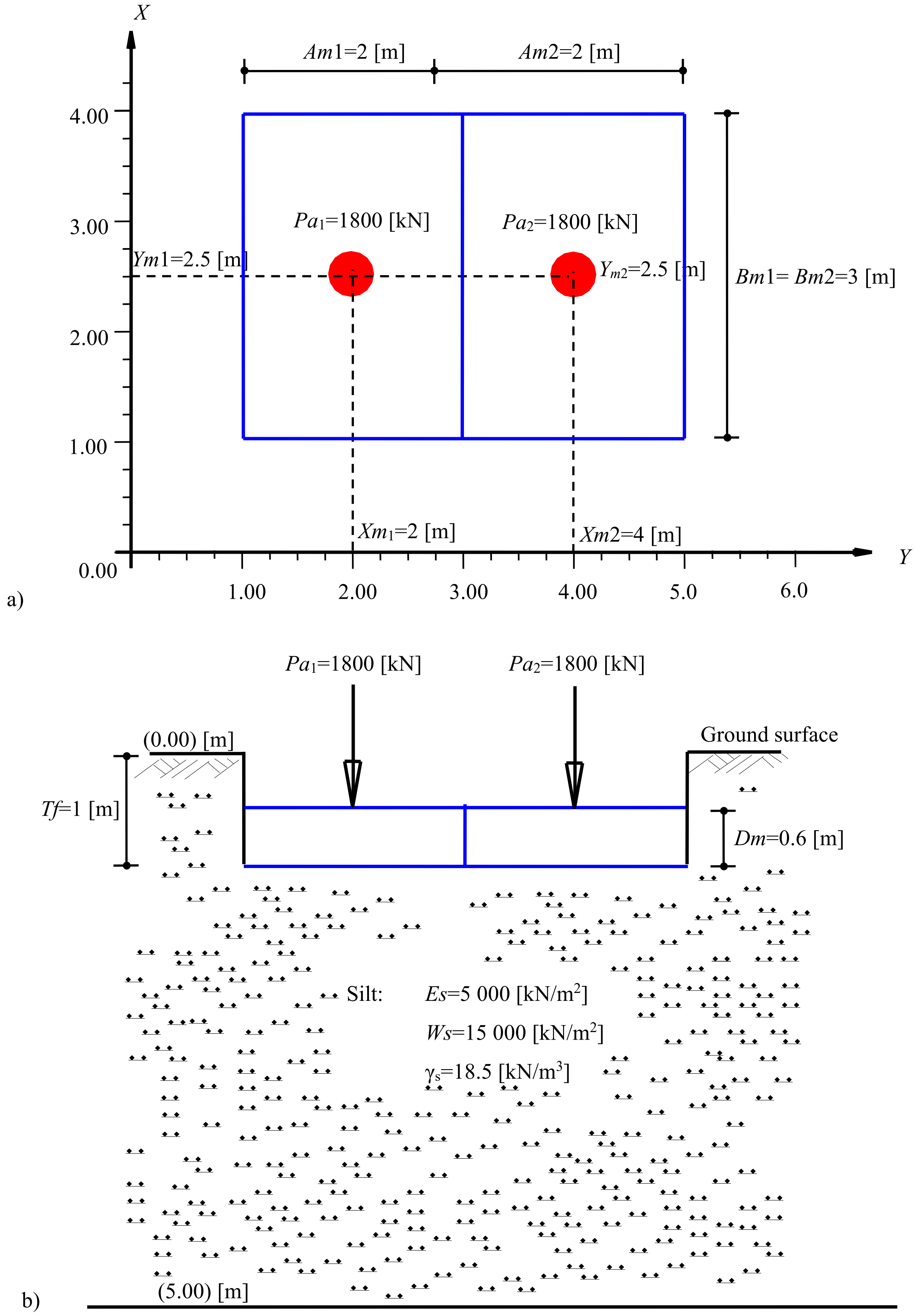


Figure 9.27 Representation of the footings
a) Plan
b) Section through the footings and the subsoil

9.8.3.2 Analysis of the project

The limit depth is *Zg* = 6.52 [m] for the single footing only, while for two adjacent rectangular footings *Zg* = 8.16 [m]. The limit depth is below the lower edge of layer 1, so it has no influence on the result of the settlement calculation, because the depth of the layer is defined as 5 [m].

Figure 9.28 shows settlements obtained by *GEO Tools*. The total settlements and tilting with the influence of the neighboring footing are shown in dashed lines. Self-settlement due to only the centrically loaded footing without interaction is presented in dot-dash lines.

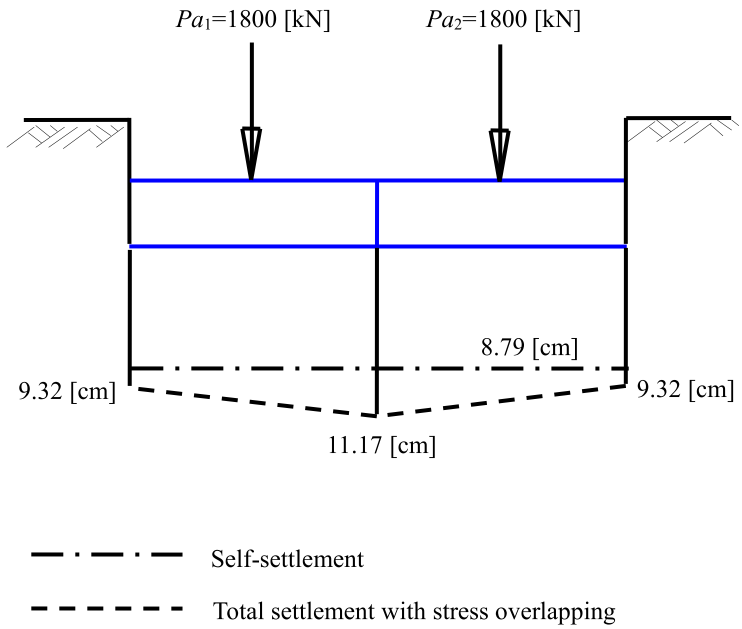


Figure 9.28 Settlements and tilting of footings 1 and 2

9.8.3.3 Presentation of data and results

The input data and results of the settlement calculations for footings 1 and 2 are shown on the next pages.

```
**********************************************************
                         GEO Tools
                        Version 13
          Program authors M. El Gendy/ A. El Gendy
**********************************************************
Title: Two adjacent rectangular footings
Date: 7.10.89
Project: Without interaction--Example 2
File: DI1

----------------------------------------------------------
Settlements of footing groups
----------------------------------------------------------

Data of limit depth:

Strip thickness for depth by iteration        Dz [m]     = 0.5
Standard ratio of limit depth (1>Cs, Cs>=0)   Cs [-]     = 0.2

Main Soil Data:

Groundwater depth under the ground surface    Tw [m]     = 10.00
Settlement reduction factor                   α  [-]     = 1.00
Unit weight of footing concrete               γb [kN/m3] = 25.00

Overburden pressure                           Qv [kN/m2] = 19
Loading                                       Qe [kN/m2] = 297
Contact pressure                              Qo [kN/m2] = 315
Limit depth under ground surface              ZG [m]     = 6.52
Limit depth lies under last layer

Loads and dimensions:
---------------------------------------------------------------------------------------------
Footing  Load on  Length  Breadth  Thickness  Foundation  X-coord.  Y-coord.  Rotating  Height
    No.  Footing                                   Depth                         angle
      I       Pa      Am       Bm         Dm          Tf        Xm        Ym         β      Hm
            [kN]     [m]      [m]        [m]         [m]       [m]       [m]       [°]     [m]
---------------------------------------------------------------------------------------------
      1     1800    2.00     3.00       0.60        1.00      1.50      2.00      0.00    0.00
---------------------------------------------------------------------------------------------

Boring:
---------------------------------------------------------------------------
Layer  Level of       Modulus of       Modulus of    Poisson's  Unit weight
  No.     layer  compressibility  compressibility        ratio  of the soil
          under      for loading    for reloading  of the soil
         ground
    I         z               Es               Ws           νs           γs
  [-]       [m]          [kN/m2]          [kN/m2]          [-]      [kN/m3]
---------------------------------------------------------------------------
    1      5.00             5000            15000         0.00        18.50
---------------------------------------------------------------------------
```

```
Stress on soil against depth (Footing No. 1/ Max. Load):
-----------------------------------------------------------
```

Iteration No. I	Depth under foundation z [m]	Stress due to foundation SE [kN/m2]	Stress from soil weight SV [kN/m2]	ratio SE/SV [-]
0	0.00	315	19	17.03
1	0.50	215	28	7.75
2	1.00	146	37	3.94
3	1.50	111	46	2.40
4	2.00	88	56	1.59
5	2.50	71	65	1.09
6	3.00	58	74	0.78
7	3.50	47	83	0.57
8	4.00	40	93	0.43
9	4.50	33	102	0.33
10	5.00	28	111	0.25
11	5.50	24	120	0.20
12	6.00	21	130	0.16

```
Settlement calculation for rigid centric loaded footings

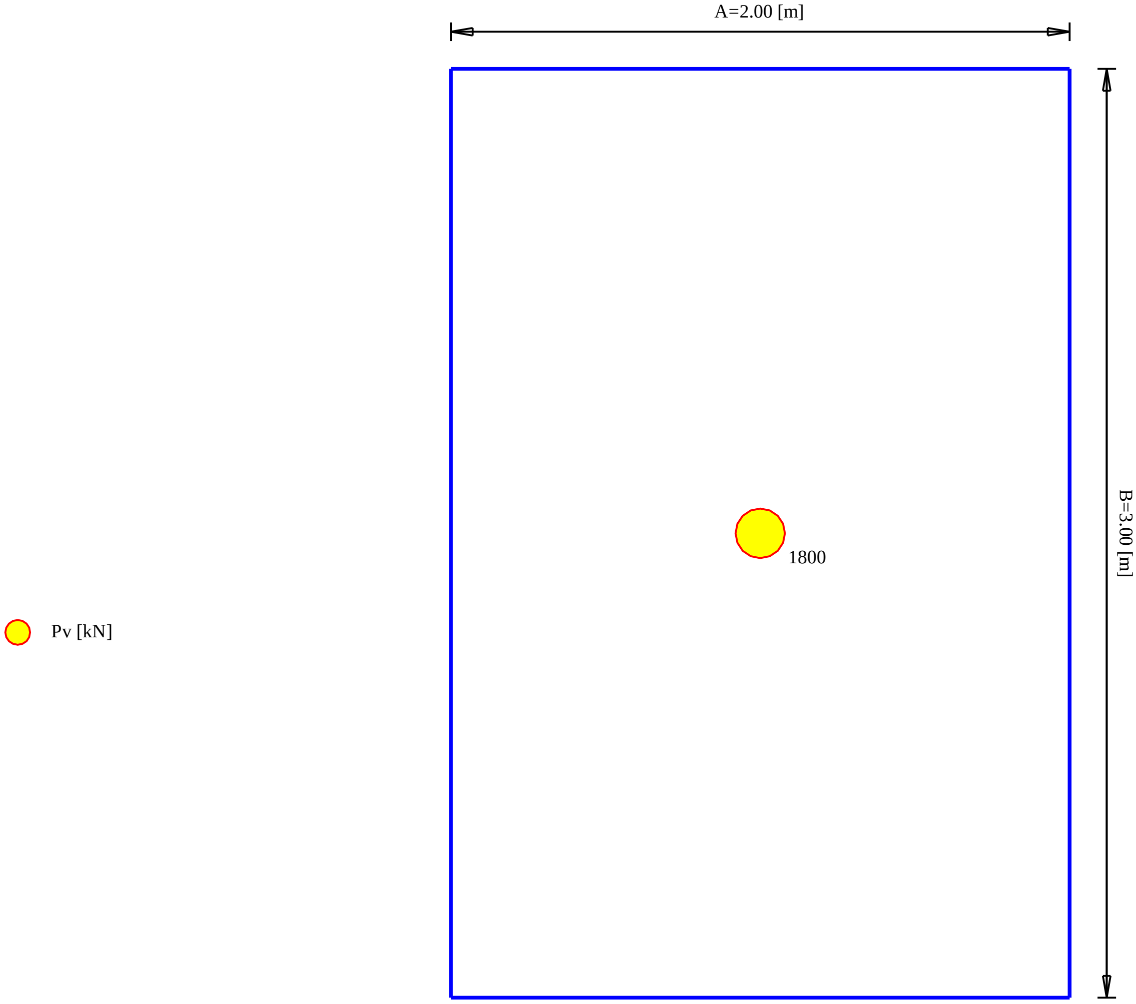
Footing No.: 1
Overburden pressure                          Qv  [kN/m2] = 19
Loading                                      Qe  [kN/m2] = 297
Contact pressure                             Qo  [kN/m2] = 315
Modulus of subgrade reaction                 ks  [kN/m3] = 3584

Final settlements of rigid footing:
Settlement of the corner: right up           S1  [cm]    = 8.79
Settlement of the corner: right down         S2  [cm]    = 8.79
Settlement of the corner: left down          S3  [cm]    = 8.79
Settlement of the corner: left up            S4  [cm]    = 8.79
Average settlement                           Sm  [cm]    = 8.79

Immediate settlement parts:
Settlement of the corner: right up           Sf1 [cm]    = 5.72
Settlement of the corner: right down         Sf2 [cm]    = 5.72
Settlement of the corner: left down          Sf3 [cm]    = 5.72
Settlement of the corner: left up            Sf4 [cm]    = 5.72
Average settlement                           Smf [cm]    = 5.72
```

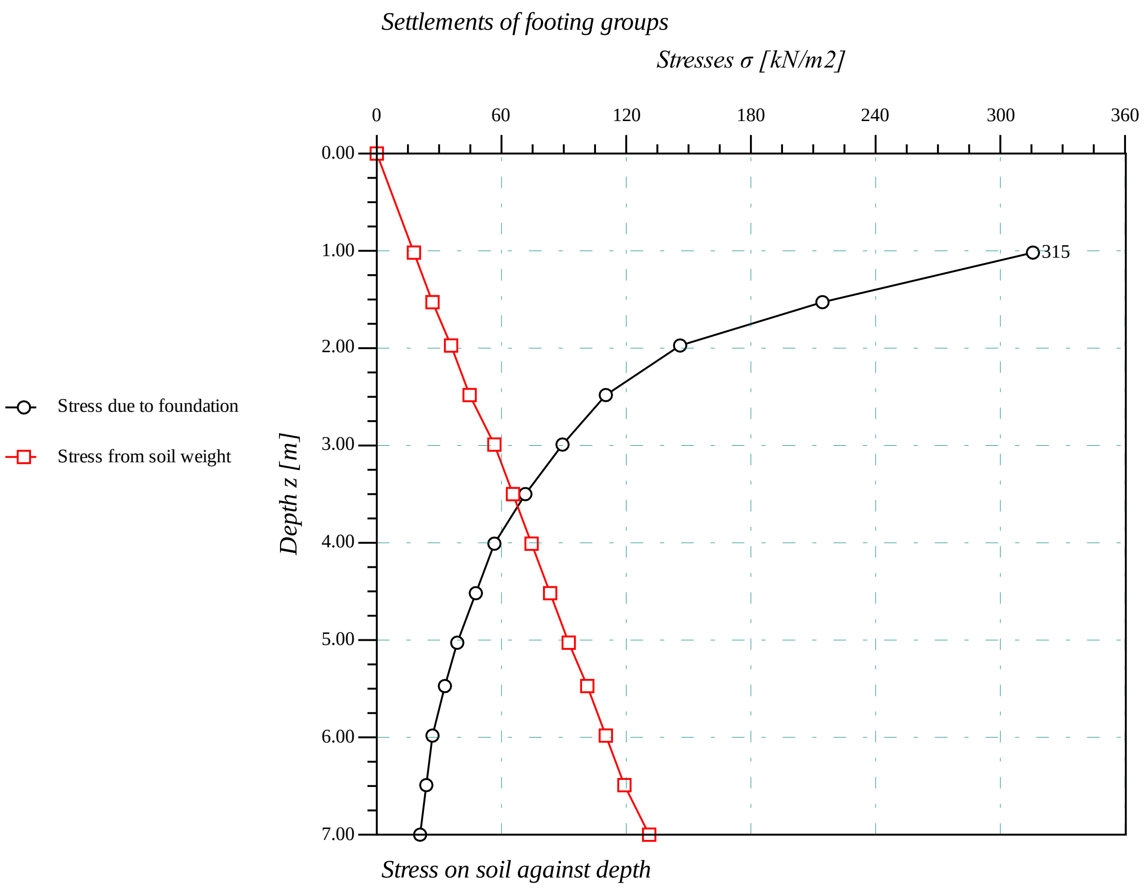
Method (8) (Layered soil model)

Modulus of Compressibility for Rigid Raft



System of loading Pv [kN]

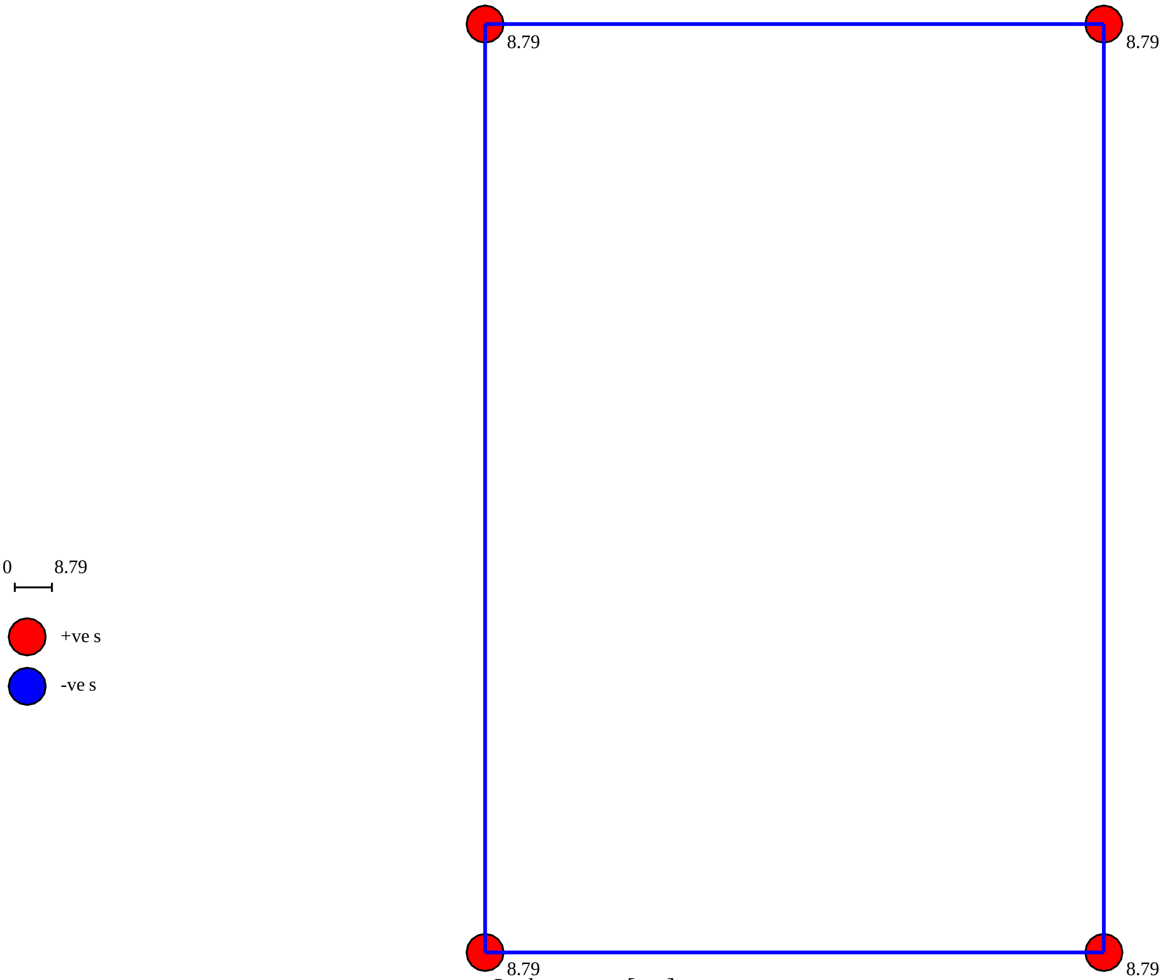
GEOTEC Software Inc., Calgary AB, Canada T3E 7Y7 PO Box 14001 Richmond Road PO, Tele.:+1(587) 332-3323	
Scale: 20	**Title: Two adjacent rectangular footings**
File: DI1	**Date: 7.10.89**
Page No.:	**Project: Without interaction--Example 2**



GEOTEC Software Inc., Calgary AB, Canada T3E 7Y7 PO Box 14001 Richmond Road PO, Tele.:+1(587) 332-3323	
Scale: 2978	**Title: Two adjacent rectangular footings**
File: DI1	**Date: 7.10.89**
Page No.:	**Project: Without interaction--Example 2**

Method (8) (Layered soil model)

Modulus of Compressibility for Rigid Raft



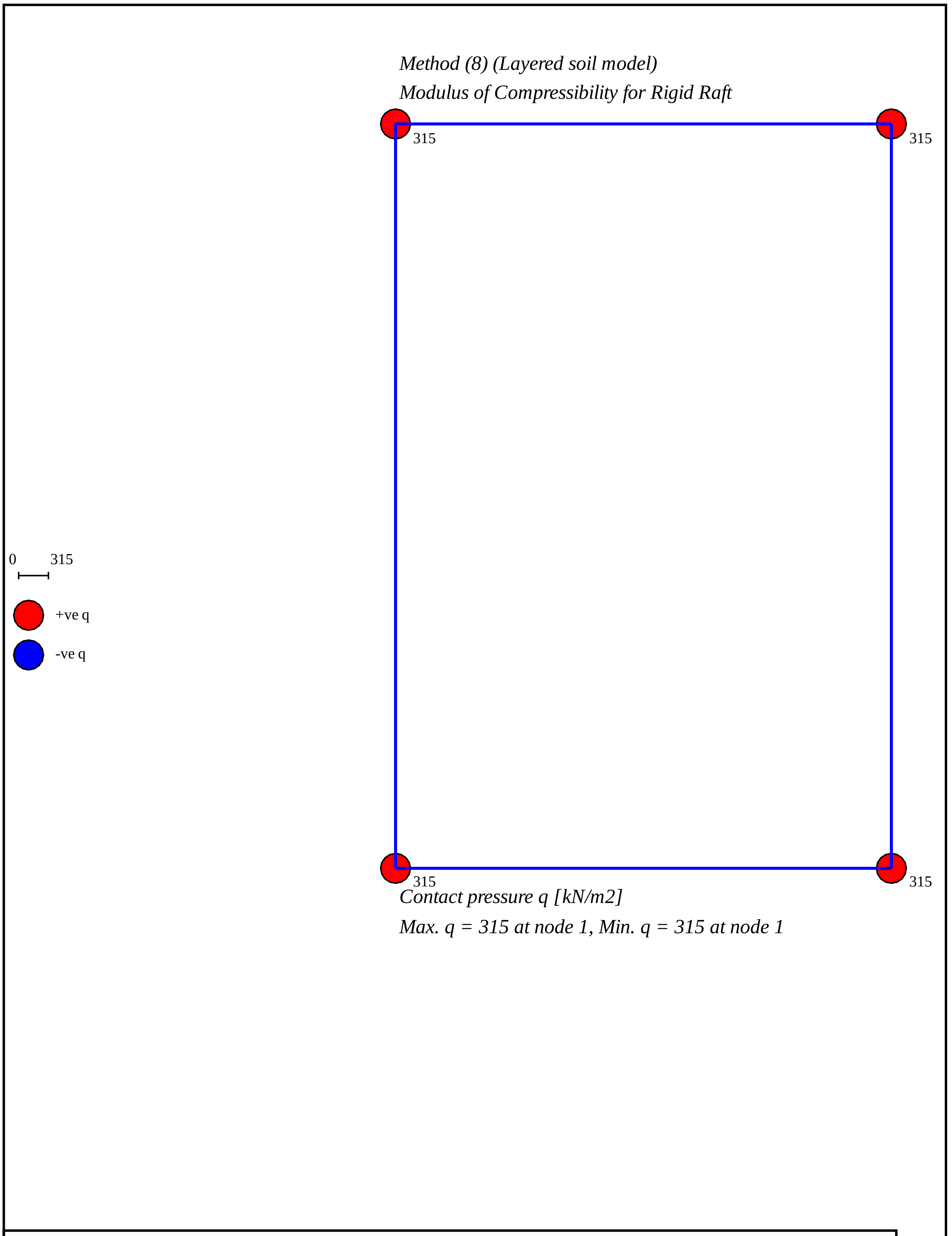
Settlements s [cm]

Max. s = 8.79 at node 1, Min. s = 8.79 at node 1

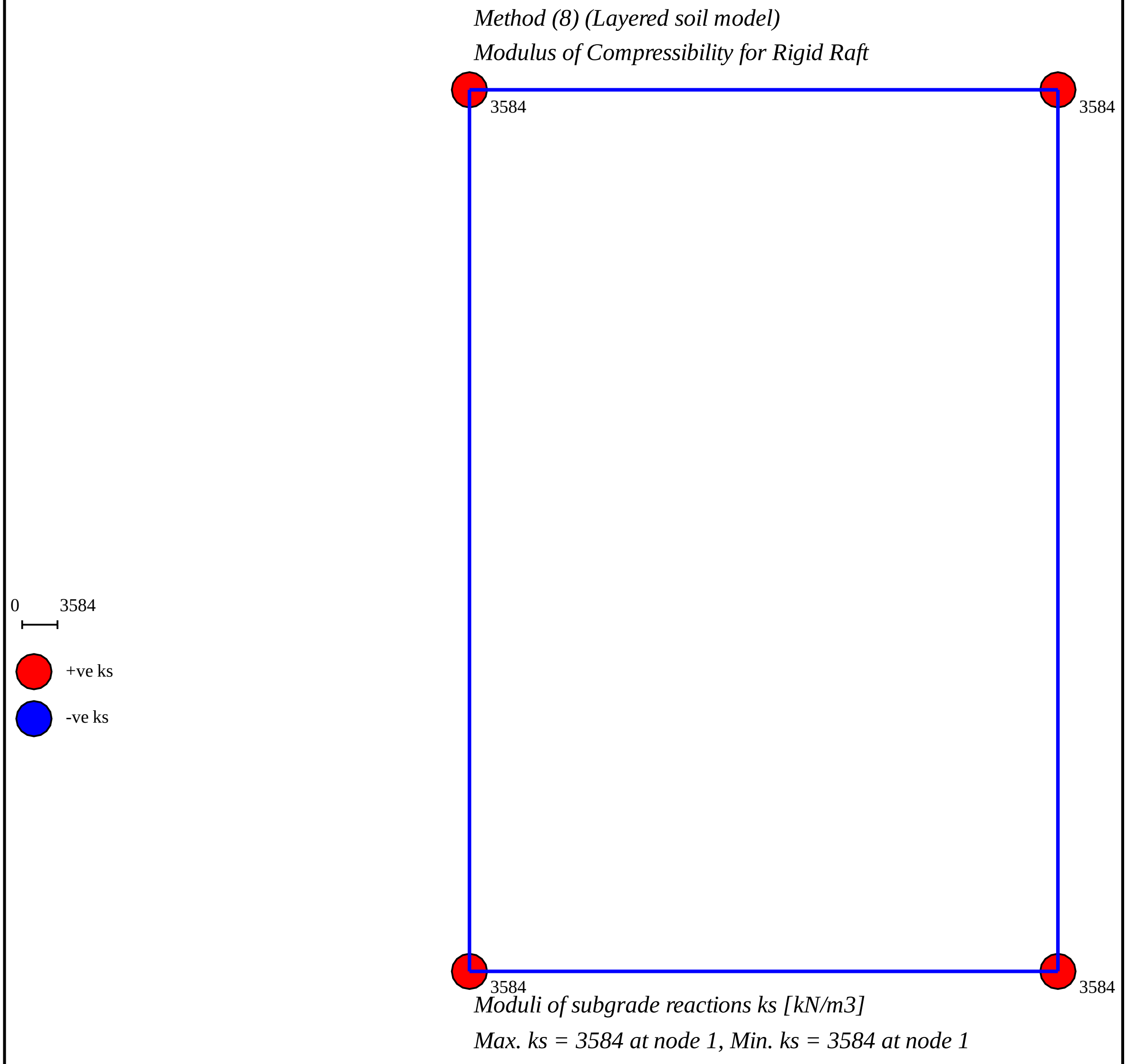
GEOTEC Software Inc., Calgary AB, Canada T3E 7Y7

PO Box 14001 Richmond Road PO, Tele.:+1(587) 332-3323

Scale: 20	**Title: Two adjacent rectangular footings**
File: DI1	**Date: 7.10.89**
Page No.:	**Project: Without interaction--Example 2**



GEOTEC Software Inc., Calgary AB, Canada T3E 7Y7 PO Box 14001 Richmond Road PO, Tele.:+1(587) 332-3323	
Scale: 20	**Title: Two adjacent rectangular footings**
File: DI1	**Date: 7.10.89**
Page No.:	**Project: Without interaction--Example 2**



GEOTEC Software Inc., Calgary AB, Canada T3E 7Y7
PO Box 14001 Richmond Road PO, Tele.:+1(587) 332-3323

Scale: 20	**Title: Two adjacent rectangular footings**
File: DI1	**Date: 7.10.89**
Page No.:	**Project: Without interaction--Example 2**

```
**********************************************************
                         GEO Tools
                        Version 13
          Program authors M. El Gendy/ A. El Gendy
**********************************************************
Title: Two adjacent rectangular footings
Date: 7.10.89
Project: With interaction-Example 2
File: DI2

----------------------------------------------------------
Settlements of footing groups
----------------------------------------------------------

Data of limit depth:

Strip thickness for depth by iteration        Dz [m]     = 0.5
Standard ratio of limit depth (1>Cs, Cs>=0)   Cs [-]     = 0.2

Main Soil Data:

Groundwater depth under the ground surface    Tw [m]     = 10.00
Settlement reduction factor                   α  [-]     = 1.00
Unit weight of footing concrete               γb [kN/m3] = 25.00

Overburden pressure                           Qv [kN/m2] = 19
Loading                                       Qe [kN/m2] = 297
Contact pressure                              Qo [kN/m2] = 315
Limit depth under ground surface              ZG [m]     = 8.16
Limit depth lies under last layer

Loads and dimensions:
```

Footing No. I	Load on Footing Pa [kN]	Length Am [m]	Breadth Bm [m]	Thickness Dm [m]	Foundation Depth Tf [m]	X-coord. Xm [m]	Y-coord. Ym [m]	Rotating angle β [°]	Height Hm [m]
1	1800	2.00	3.00	0.60	1.00	1.50	2.00	0.00	0.00
2	1800	2.00	3.00	0.60	1.00	3.50	2.00	0.00	0.00

Boring:

Layer No. I [-]	Level of layer under ground z [m]	Modulus of compressibility for loading Es [kN/m2]	Modulus of compressibility for reloading Ws [kN/m2]	Poisson's ratio of the soil νs [-]	Unit weight of the soil γs [kN/m3]
1	5.00	5000	15000	0.00	18.50

Stress on soil against depth (Footing No. 1/ Max. Load):

Iteration No.	Depth under foundation	Stress due to foundation	Stress from neighboring foundations	Sum of stresses	Stress from soil weight	ratio
I	z	SE	SD	SU=SE+SD	SV	SU/SV
	[m]	[kN/m2]	[kN/m2]	[kN/m2]	[kN/m2]	[-]
0	0.00	315	0	315	19	17.03
1	0.50	215	3	218	28	7.86
2	1.00	146	16	162	37	4.37
3	1.50	111	31	142	46	3.08
4	2.00	88	40	128	56	2.30
5	2.50	71	42	113	65	1.74
6	3.00	58	40	98	74	1.32
7	3.50	47	36	84	83	1.01
8	4.00	40	32	72	93	0.78
9	4.50	33	28	62	102	0.61
10	5.00	28	25	53	111	0.48
11	5.50	24	22	46	120	0.38
12	6.00	21	19	40	130	0.31
13	6.50	18	17	35	139	0.25
14	7.00	16	15	31	148	0.21
15	7.50	14	14	28	157	0.18

```
Settlement calculation for rigid centric loaded footings

Footing No.: 1
Overburden pressure                          Qv  [kN/m2] = 19
Loading                                      Qe  [kN/m2] = 297
Contact pressure                             Qo  [kN/m2] = 315
Modulus of subgrade reaction                 ks  [kN/m3] = 3381

Final settlements of rigid footing:
Settlement of the corner: right up           S1  [cm]    = 11.17
Settlement of the corner: right down         S2  [cm]    = 11.17
Settlement of the corner: left down          S3  [cm]    = 9.32
Settlement of the corner: left up            S4  [cm]    = 9.32
Average settlement                           Sm  [cm]    = 10.25

Immediate settlement parts:
Settlement of the corner: right up           Sf1 [cm]    = 6.81
Settlement of the corner: right down         Sf2 [cm]    = 6.81
Settlement of the corner: left down          Sf3 [cm]    = 5.68
Settlement of the corner: left up            Sf4 [cm]    = 5.68
Average settlement                           Smf [cm]    = 6.24

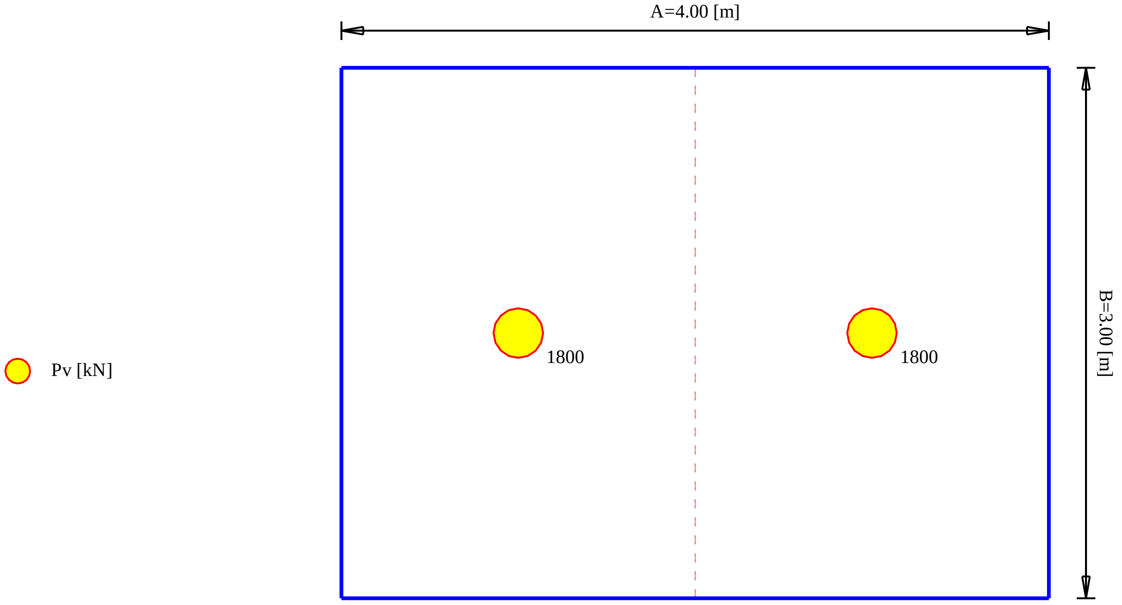
Footing No.: 2
Overburden pressure                          Qv  [kN/m2] = 19
Loading                                      Qe  [kN/m2] = 297
Contact pressure                             Qo  [kN/m2] = 315
Modulus of subgrade reaction                 ks  [kN/m3] = 2819

Final settlements of rigid footing:
Settlement of the corner: right up           S1  [cm]    = 9.32
Settlement of the corner: right down         S2  [cm]    = 9.32
Settlement of the corner: left down          S3  [cm]    = 11.17
Settlement of the corner: left up            S4  [cm]    = 11.17
Average settlement                           Sm  [cm]    = 10.25

Immediate settlement parts:
Settlement of the corner: right up           Sf1 [cm]    = 5.68
Settlement of the corner: right down         Sf2 [cm]    = 5.68
Settlement of the corner: left down          Sf3 [cm]    = 6.81
Settlement of the corner: left up            Sf4 [cm]    = 6.81
Average settlement                           Smf [cm]    = 6.24
```

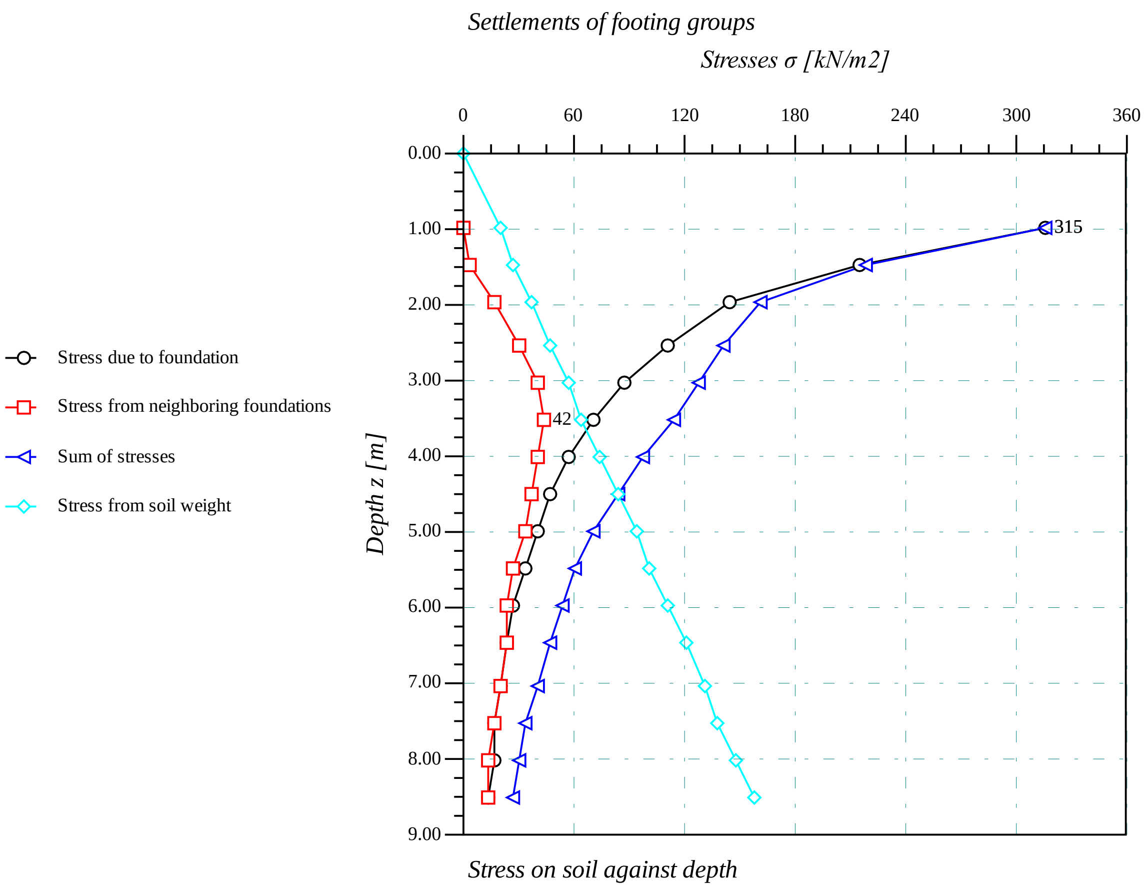
Method (8) (Layered soil model)

Modulus of Compressibility for Rigid Raft



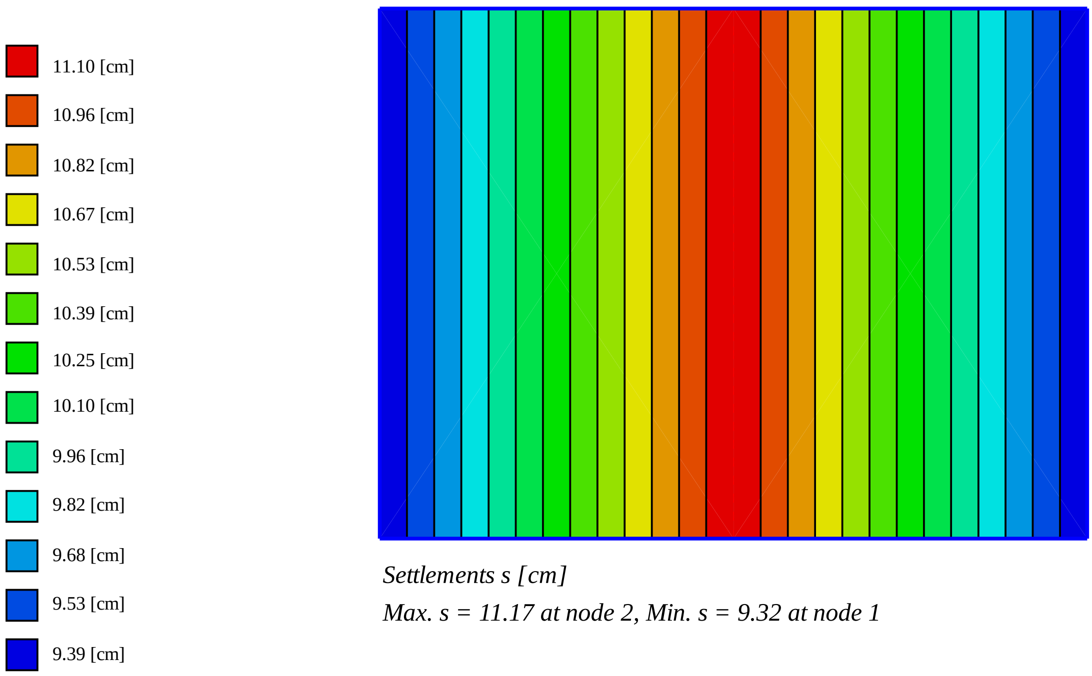
System of loading Pv [kN]

GEOTEC Software Inc., Calgary AB, Canada T3E 7Y7 PO Box 14001 Richmond Road PO, Tele.:+1(587) 332-3323	
Scale: 35	**Title: Two adjacent rectangular footings**
File: DI2	**Date: 7.10.89**
Page No.:	**Project: With interaction-Example 2**



GEOTEC Software Inc., Calgary AB, Canada T3E 7Y7 **PO Box 14001 Richmond Road PO, Tele.:+1(587) 332-3323**	
Scale: 3359	**Title: Two adjacent rectangular footings**
File: DI2	**Date: 7.10.89**
Page No.:	**Project: With interaction-Example 2**

Method (8) (Layered soil model)
Modulus of Compressibility for Rigid Raft



Settlements s [cm]
Max. s = 11.17 at node 2, Min. s = 9.32 at node 1

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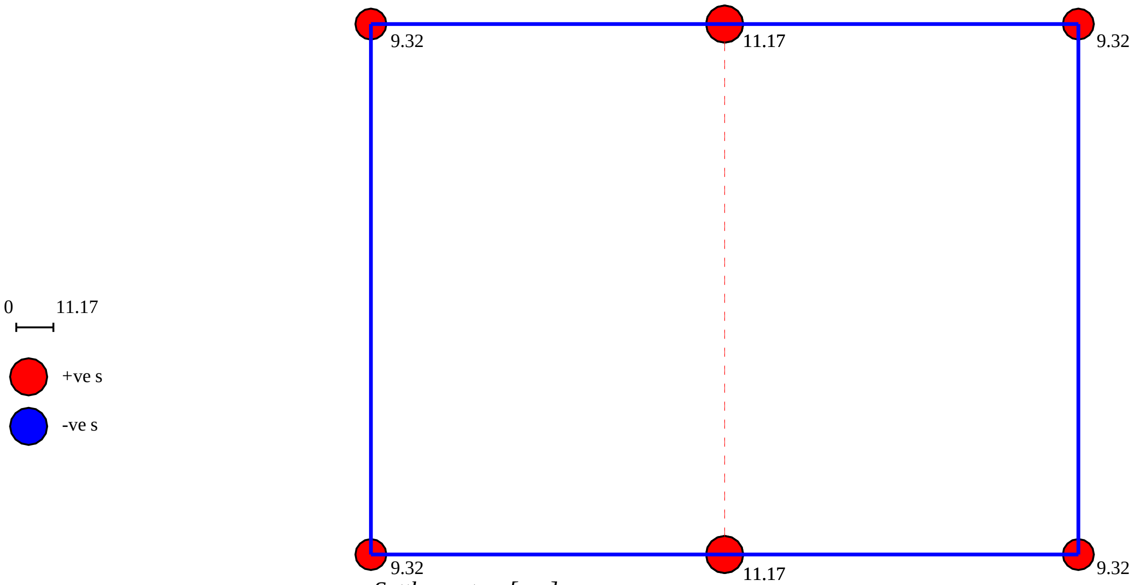
Scale: 35	**Title: Two adjacent rectangular footings**
File: DI2	**Date: 7.10.89**
Page No.:	**Project: With interaction-Example 2**

Method (8) (Layered soil model)

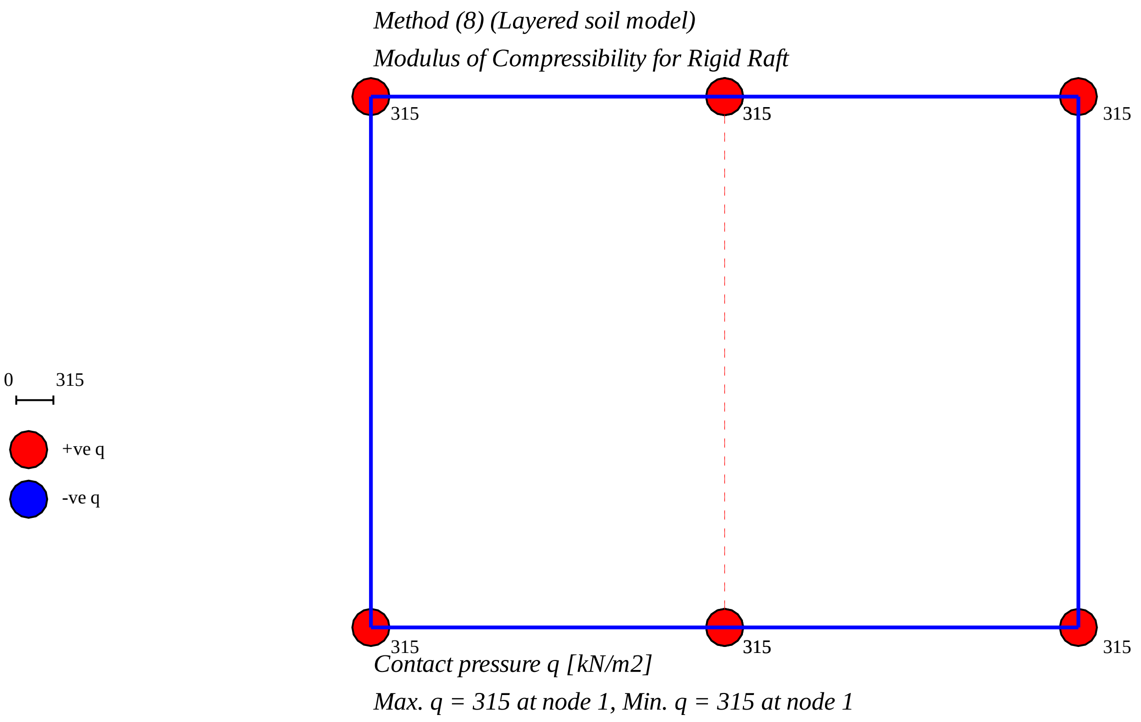
Modulus of Compressibility for Rigid Raft



Settlements s [cm]

Max. s = 11.17 at node 2, Min. s = 9.32 at node 1

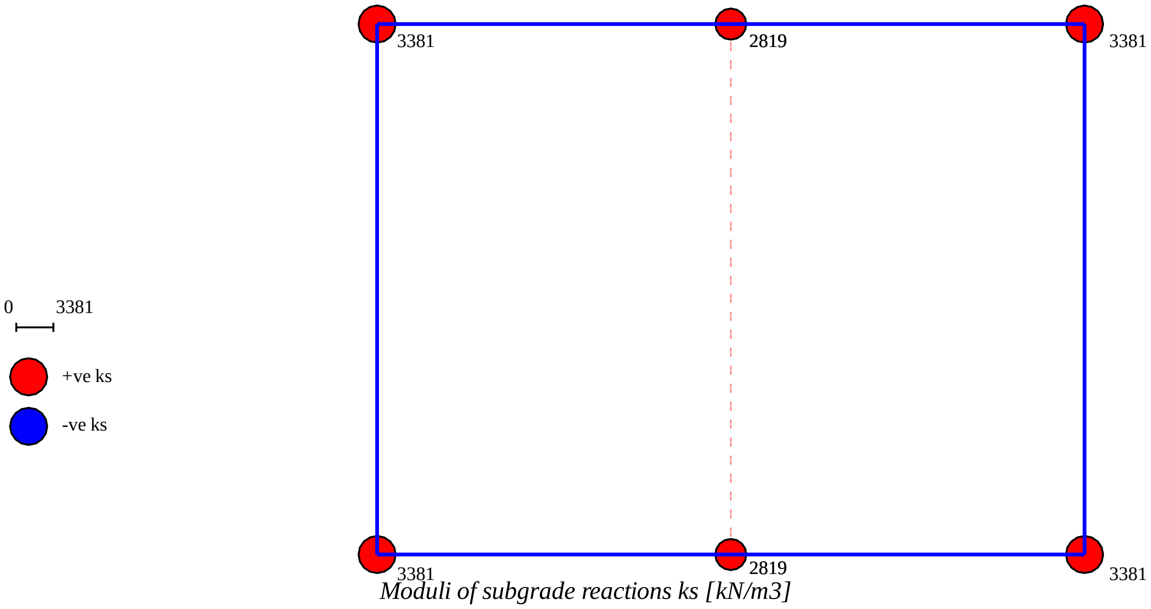
GEOTEC Software Inc., Calgary AB, Canada T3E 7Y7 PO Box 14001 Richmond Road PO, Tele.:+1(587) 332-3323	
Scale: 35	**Title: Two adjacent rectangular footings**
File: DI2	**Date: 7.10.89**
Page No.:	**Project: With interaction-Example 2**



GEOTEC Software Inc., Calgary AB, Canada T3E 7Y7 PO Box 14001 Richmond Road PO, Tele.:+1(587) 332-3323	
Scale: 35	**Title: Two adjacent rectangular footings**
File: DI2	**Date: 7.10.89**
Page No.:	**Project: With interaction-Example 2**

Method (8) (Layered soil model)

Modulus of Compressibility for Rigid Raft



Moduli of subgrade reactions ks [kN/m3]

Max. ks = 3381 at node 1, Min. ks = 2819 at node 2

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PO Box 14001 Richmond Road PO, Tele.:+1(587) 332-3323	
Scale: 35	**Title: Two adjacent rectangular footings**
File: DI2	**Date: 7.10.89**
Page No.:	**Project: With interaction-Example 2**

9.8.4 Example 3: Footing group of six isolated footings
File names GR1, GR2

9.8.4.1 Description of the problem

It is required to calculate the settlements of the footing group of six isolated footings shown in Figure 9.29. The footings are centrally loaded with (including footing weight):

$$Pa1 = Pa3 = Pa4 = Pa6 = 1650 \ \text{[kN]}$$

and

$$Pa2 = Pa5 = 2250 \ \text{[kN]}.$$

The following subsoil parameters are considered:

Table 9.6 Soil properties

Layer No. I	Soil name	Depth of the soil layer under the ground surface Z [m]	Modulus of compressibility for Loading Es [kN/m²]	Modulus of compressibility for Reloading Ws [kN/m²]	Unit weight of the soil γ_s [kN/m³]
1	Sand, silty	1.3	32000	89000	19.0
2	Sand, silty	4.3	32000	89000	11.2
3	Sand, gravely	7.7	98000	135000	11.0

Poisson's ratio is taken to be $\nu_s = 0$, while the reduction factor is $\alpha = 1$. No limit depth calculation is required. The groundwater is at a depth of $Tw = 1.3$ [m] under the ground surface.

Dimensions of the footings 1 to 6 are presented in Figure 9.29a. The foundation depths (uniform $Tf = 2.1$ [m]) and the footing thicknesses (constant thickness $Dm = 1.1$ [m]) are presented in Figure 9.29b.

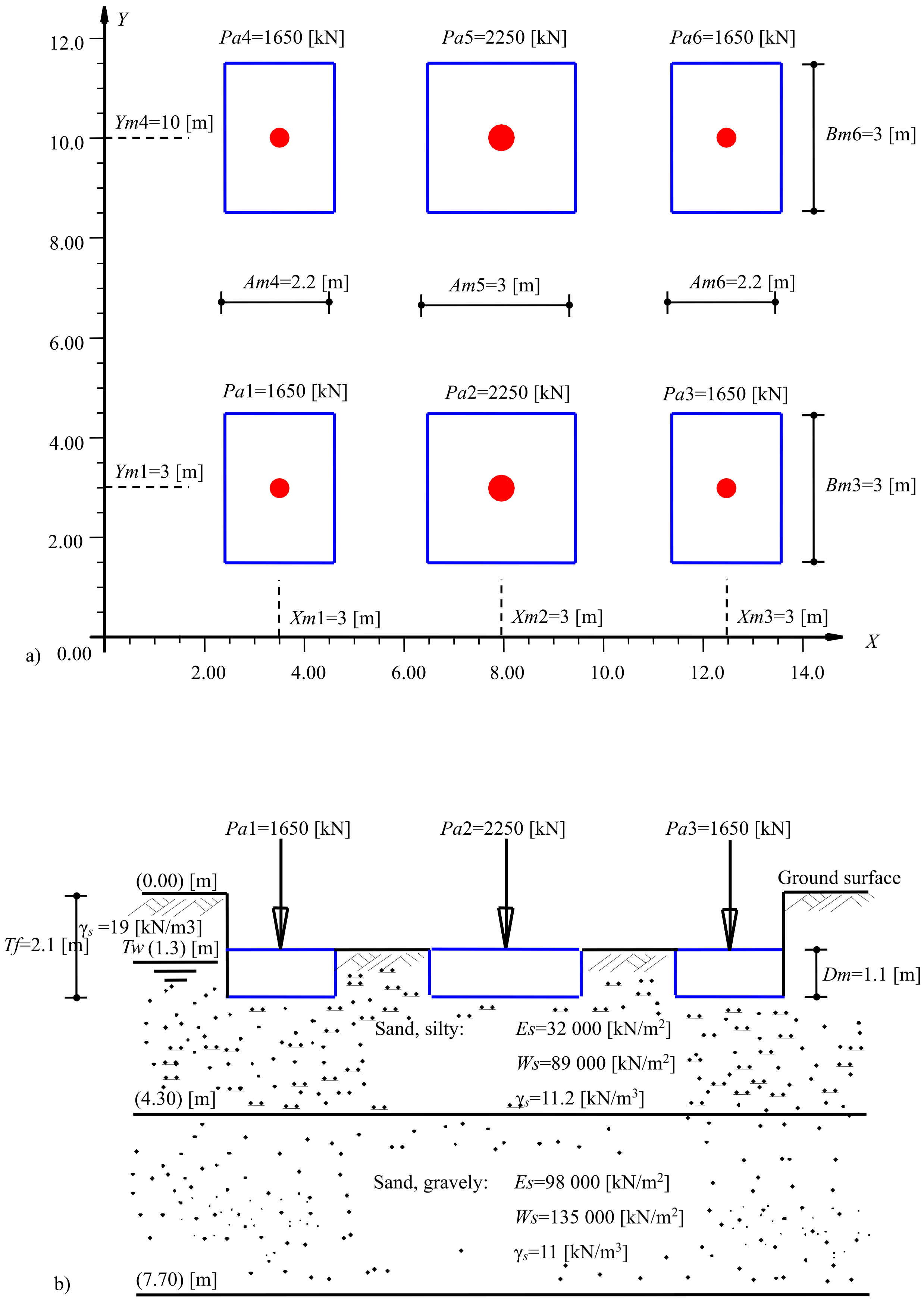


Figure 9.29 Representation of the footing group a) Plan, b) Section

9.8.4.2 Results by GEO Tools

From the analysis, the settlements reach the following values:

Footing 1 and 4	S = 0.93 to 0.99 [cm]
Footing 2 and 5	S = 1.13 to 1.17 [cm]
Footing 3 and 6	S = 0.93 to 0.99 [cm].

9.8.4.3 Presentation of data and results

The input data and results of the settlement calculations for the footing group obtained by *GEO Tools* are shown on the next pages.

```
**********************************************************
                         GEO Tools
                        Version 13
          Program authors M. El Gendy/ A. El Gendy
**********************************************************
Title: Test example for 6 footings
Date: 23-01-2018
Project: Without limit depth-Example 3
File: GR1

----------------------------------------------------------
Settlements of footing groups
----------------------------------------------------------

Main Soil Data:

Groundwater depth under the ground surface     Tw [m]     = 1.30
Settlement reduction factor                    α  [-]     = 1.00
Unit weight of footing concrete                γb [kN/m3] = 0.00
```

Loads and dimensions:

Footing No. I	Load on Footing Pa [kN]	Length Am [m]	Breadth Bm [m]	Thickness Dm [m]	Foundation Depth Tf [m]	X-coord. Xm [m]	Y-coord. Ym [m]	Rotating angle β [°]	Height Hm [m]
1	1650	2.20	3.00	1.10	2.10	3.50	3.00	0.00	0.00
2	2250	3.00	3.00	1.10	2.10	8.00	3.00	0.00	0.00
3	1650	2.20	3.00	1.10	2.10	12.50	3.00	0.00	0.00
4	1650	2.20	3.00	1.10	2.10	3.50	10.00	0.00	0.00
5	2250	3.00	3.00	1.10	2.10	8.00	10.00	0.00	0.00
6	1650	2.20	3.00	1.10	2.10	12.50	10.00	0.00	0.00

Boring:

Layer No. I [-]	Level of layer under ground z [m]	Modulus of compressibility for loading Es [kN/m2]	Modulus of compressibility for reloading Ws [kN/m2]	Poisson's ratio of the soil νs [-]	Unit weight of the soil γs [kN/m3]
1	1.30	32000	89000	0.00	19.00
2	4.30	32000	89000	0.00	11.20
3	7.70	98000	135000	0.00	11.00

```
Settlement calculation for rigid centric loaded footings

Footing No.: 1
Groundwater pressure                       Qw  [kN/m2] = 8
Overburden pressure                        Qv  [kN/m2] = 34
Loading                                    Qe  [kN/m2] = 208
Contact pressure                           Qo  [kN/m2] = 242
Modulus of subgrade reaction               ks  [kN/m3] = 25914

Final settlements of rigid footing:
Settlement of the corner: right up         S1  [cm]    = 0.99
Settlement of the corner: right down       S2  [cm]    = 0.97
Settlement of the corner: left down        S3  [cm]    = 0.93
Settlement of the corner: left up          S4  [cm]    = 0.96
Average settlement                         Sm  [cm]    = 0.96

Immediate settlement parts:
Settlement of the corner: right up         Sf1 [cm]    = 0.52
Settlement of the corner: right down       Sf2 [cm]    = 0.53
Settlement of the corner: left down        Sf3 [cm]    = 0.54
Settlement of the corner: left up          Sf4 [cm]    = 0.53
Average settlement                         Smf [cm]    = 0.53
```

```
Footing No.: 2
Groundwater pressure                      Qw  [kN/m2] = 8
Overburden pressure                       Qv  [kN/m2] = 34
Loading                                   Qe  [kN/m2] = 208
Contact pressure                          Qo  [kN/m2] = 242
Modulus of subgrade reaction              ks  [kN/m3] = 25046

Final settlements of rigid footing:
Settlement of the corner: right up        S1  [cm]    = 1.17
Settlement of the corner: right down      S2  [cm]    = 1.13
Settlement of the corner: left down       S3  [cm]    = 1.13
Settlement of the corner: left up         S4  [cm]    = 1.17
Average settlement                        Sm  [cm]    = 1.15

Immediate settlement parts:
Settlement of the corner: right up        Sf1 [cm]    = 0.58
Settlement of the corner: right down      Sf2 [cm]    = 0.60
Settlement of the corner: left down       Sf3 [cm]    = 0.60
Settlement of the corner: left up         Sf4 [cm]    = 0.58
Average settlement                        Smf [cm]    = 0.59

Footing No.: 3
Groundwater pressure                      Qw  [kN/m2] = 8
Overburden pressure                       Qv  [kN/m2] = 34
Loading                                   Qe  [kN/m2] = 208
Contact pressure                          Qo  [kN/m2] = 242
Modulus of subgrade reaction              ks  [kN/m3] = 25279

Final settlements of rigid footing:
Settlement of the corner: right up        S1  [cm]    = 0.96
Settlement of the corner: right down      S2  [cm]    = 0.93
Settlement of the corner: left down       S3  [cm]    = 0.97
Settlement of the corner: left up         S4  [cm]    = 0.99
Average settlement                        Sm  [cm]    = 0.96

Immediate settlement parts:
Settlement of the corner: right up        Sf1 [cm]    = 0.53
Settlement of the corner: right down      Sf2 [cm]    = 0.54
Settlement of the corner: left down       Sf3 [cm]    = 0.53
Settlement of the corner: left up         Sf4 [cm]    = 0.52
Average settlement                        Smf [cm]    = 0.53

Footing No.: 4
Groundwater pressure                      Qw  [kN/m2] = 8
Overburden pressure                       Qv  [kN/m2] = 34
Loading                                   Qe  [kN/m2] = 208
Contact pressure                          Qo  [kN/m2] = 242
Modulus of subgrade reaction              ks  [kN/m3] = 24452

Final settlements of rigid footing:
Settlement of the corner: right up        S1  [cm]    = 0.97
Settlement of the corner: right down      S2  [cm]    = 0.99
Settlement of the corner: left down       S3  [cm]    = 0.96
Settlement of the corner: left up         S4  [cm]    = 0.93
Average settlement                        Sm  [cm]    = 0.96

Immediate settlement parts:
Settlement of the corner: right up        Sf1 [cm]    = 0.53
Settlement of the corner: right down      Sf2 [cm]    = 0.52
Settlement of the corner: left down       Sf3 [cm]    = 0.53
Settlement of the corner: left up         Sf4 [cm]    = 0.54
Average settlement                        Smf [cm]    = 0.53
```

```
Footing No.: 5
Groundwater pressure                        Qw  [kN/m2] = 8
Overburden pressure                         Qv  [kN/m2] = 34
Loading                                     Qe  [kN/m2] = 208
Contact pressure                            Qo  [kN/m2] = 242
Modulus of subgrade reaction                ks  [kN/m3] = 21393

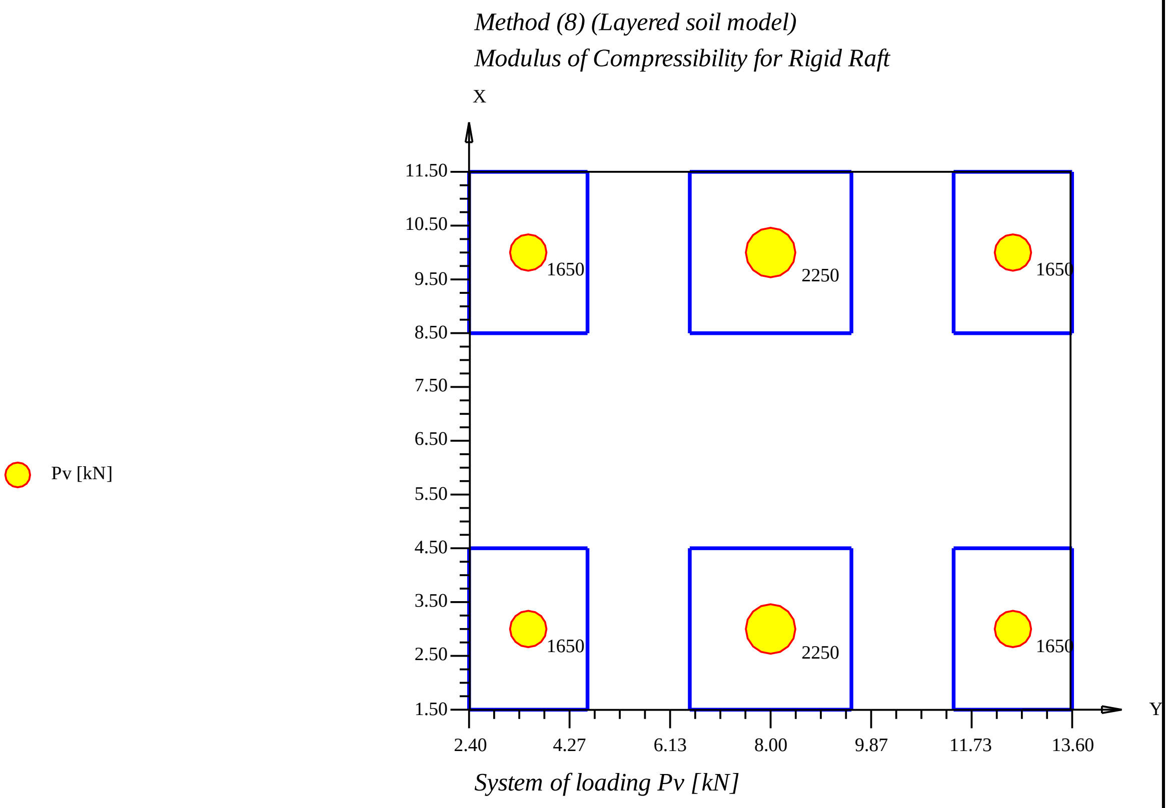
Final settlements of rigid footing:
Settlement of the corner: right up          S1  [cm]    = 1.13
Settlement of the corner: right down        S2  [cm]    = 1.17
Settlement of the corner: left down         S3  [cm]    = 1.17
Settlement of the corner: left up           S4  [cm]    = 1.13
Average settlement                          Sm  [cm]    = 1.15

Immediate settlement parts:
Settlement of the corner: right up          Sf1 [cm]    = 0.60
Settlement of the corner: right down        Sf2 [cm]    = 0.58
Settlement of the corner: left down         Sf3 [cm]    = 0.58
Settlement of the corner: left up           Sf4 [cm]    = 0.60
Average settlement                          Smf [cm]    = 0.59

Footing No.: 6
Groundwater pressure                        Qw  [kN/m2] = 8
Overburden pressure                         Qv  [kN/m2] = 34
Loading                                     Qe  [kN/m2] = 208
Contact pressure                            Qo  [kN/m2] = 242
Modulus of subgrade reaction                ks  [kN/m3] = 21393

Final settlements of rigid footing:
Settlement of the corner: right up          S1  [cm]    = 0.93
Settlement of the corner: right down        S2  [cm]    = 0.96
Settlement of the corner: left down         S3  [cm]    = 0.99
Settlement of the corner: left up           S4  [cm]    = 0.97
Average settlement                          Sm  [cm]    = 0.96

Immediate settlement parts:
Settlement of the corner: right up          Sf1 [cm]    = 0.54
Settlement of the corner: right down        Sf2 [cm]    = 0.53
Settlement of the corner: left down         Sf3 [cm]    = 0.52
Settlement of the corner: left up           Sf4 [cm]    = 0.53
Average settlement                          Smf [cm]    = 0.53
```



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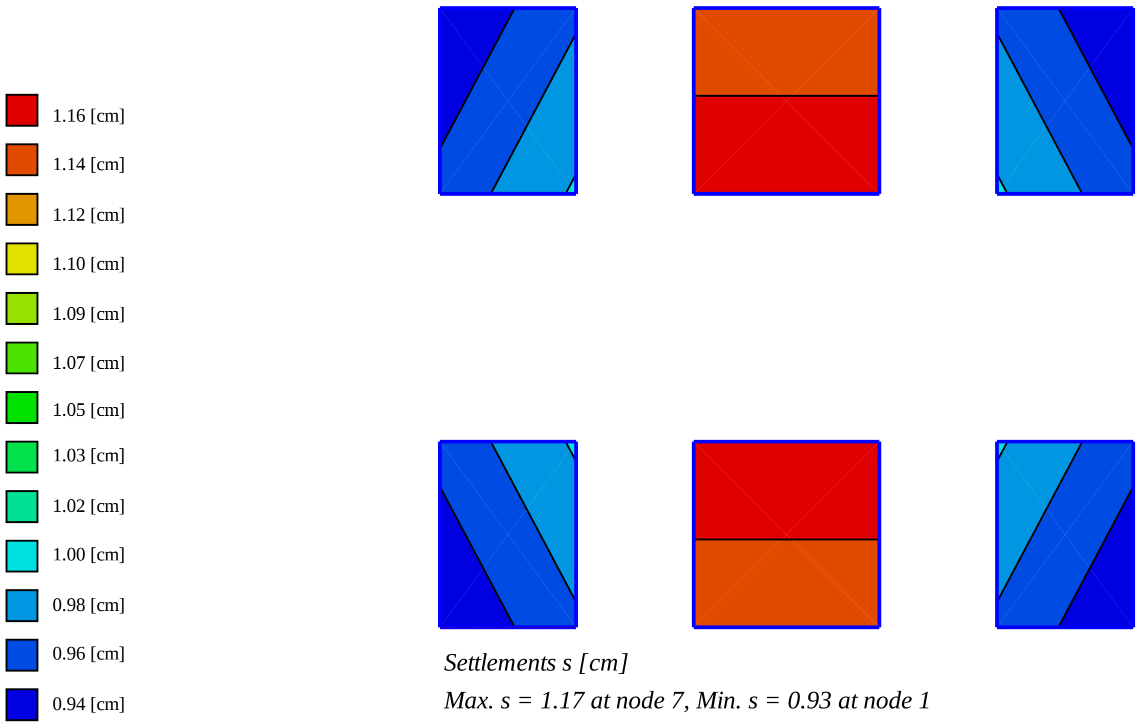
Scale: 115	**Title: Test example for 6 footings**
File: GR1	**Date: 23-01-2018**
Page No.:	**Project: Without limit depth-Example 3**

Method (8) (Layered soil model)

Modulus of Compressibility for Rigid Raft



Settlements s [cm]

Max. s = 1.17 at node 7, Min. s = 0.93 at node 1

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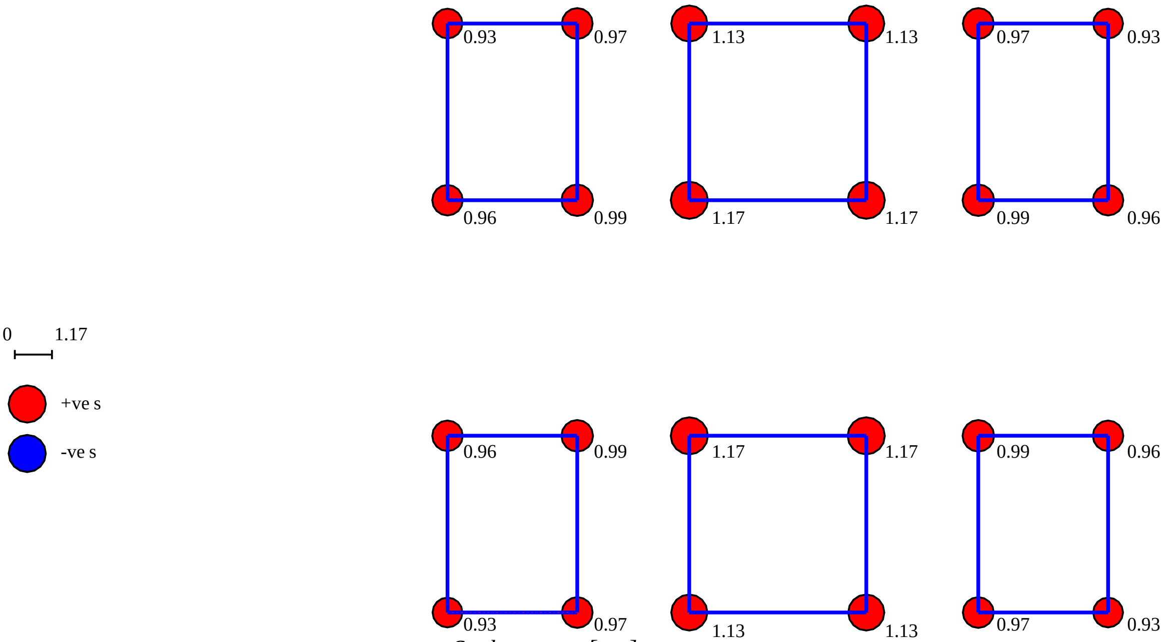
Scale: 100	**Title: Test example for 6 footings**
File: GR1	**Date: 23-01-2018**
Page No.:	**Project: Without limit depth-Example 3**

Method (8) (Layered soil model)

Modulus of Compressibility for Rigid Raft



Settlements s [cm]

Max. s = 1.17 at node 7, Min. s = 0.93 at node 1

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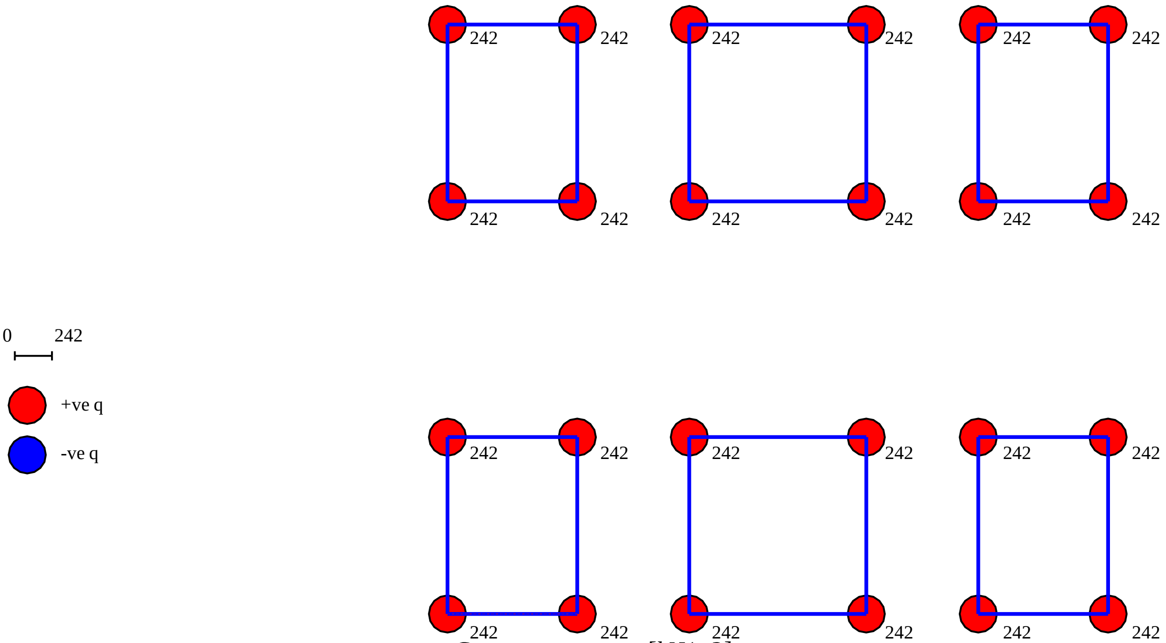
Scale: 105	**Title: Test example for 6 footings**
File: GR1	**Date: 23-01-2018**
Page No.:	**Project: Without limit depth-Example 3**

Method (8) (Layered soil model)

Modulus of Compressibility for Rigid Raft



Contact pressure q [kN/m2]

Max. q = 242 at node 1, Min. q = 242 at node 1

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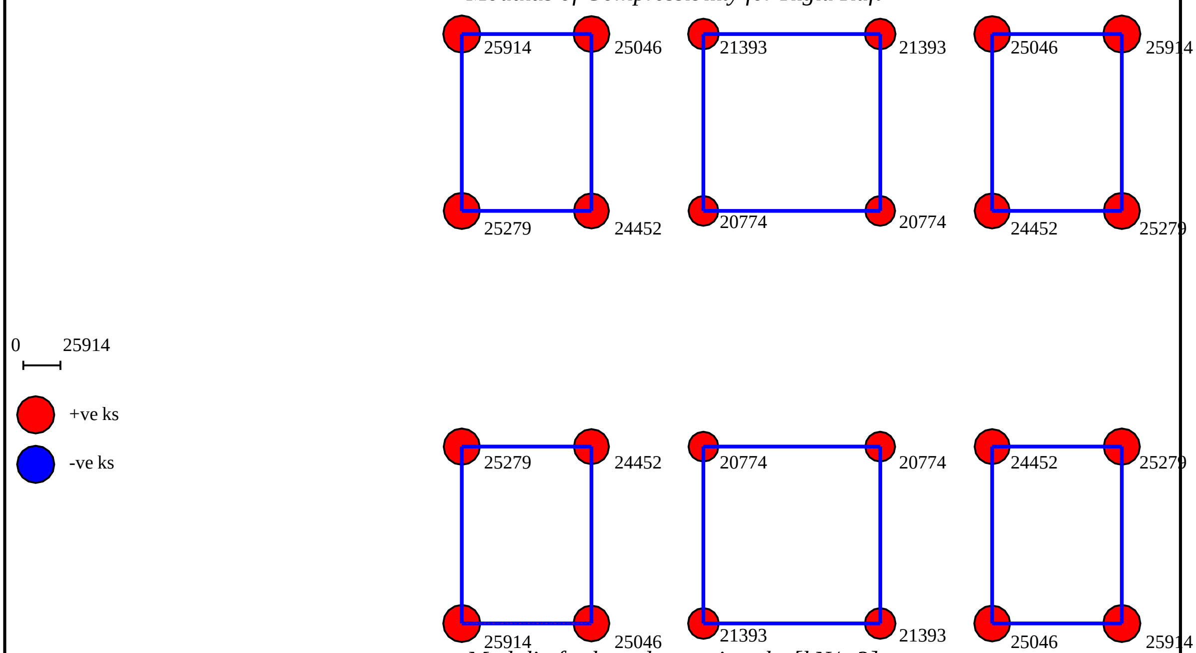
Scale: 105	**Title: Test example for 6 footings**
File: GR1	**Date: 23-01-2018**
Page No.:	**Project: Without limit depth-Example 3**

Method (8) (Layered soil model)

Modulus of Compressibility for Rigid Raft



Moduli of subgrade reactions ks [kN/m3]

Max. ks = 25914 at node 1, Min. ks = 20774 at node 7

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Scale: 105	**Title: Test example for 6 footings**
File: GR1	**Date: 23-01-2018**
Page No.:	**Project: Without limit depth-Example 3**

9.8.5 Example 4: Footing group of nine isolated footings

File name SZ4

9.8.5.1 Description of the problem

The influence of limit depth on the behavior of footings is explained by investigating the differential settlements for a system of nine isolated footings. The settlements are to be calculated from the footing group shown in Figure 9.30 und Table 9.7. The footings are centrally loaded. The footing thickness is Dm = 0.5 [m]. The unit weight of the footing concrete is γ_b =25 [kN/m^3].

Table 9.7 Load, dimensions and origin coordinates of the footings

Footing No.	Load *Pa* [kN]	Dimensions: Length *Am* [m]	Dimensions: Bridth *Bm* [m]	Origin coordinates: *Xm* [m]	Origin coordinates: *Ym* [m]	Origin coordinates: β [°]
1	2500	2.0	2.0	1.00	1.00	0
2	900	1.5	1.5	6.25	1.25	0
3	800	1.5	1.5	11.25	1.25	0
4	2500	2.0	2.0	1.50	6.00	0
5	5400	3.0	3.0	5.00	6.00	0
6	950	1.5	1.5	11.25	6.25	0
7	5400	4.5	2.0	2.12	8.7	45
8	3000	2.5	2.0	5.75	11.00	0
9	2000	2.0	1.5	10.00	10.25	0

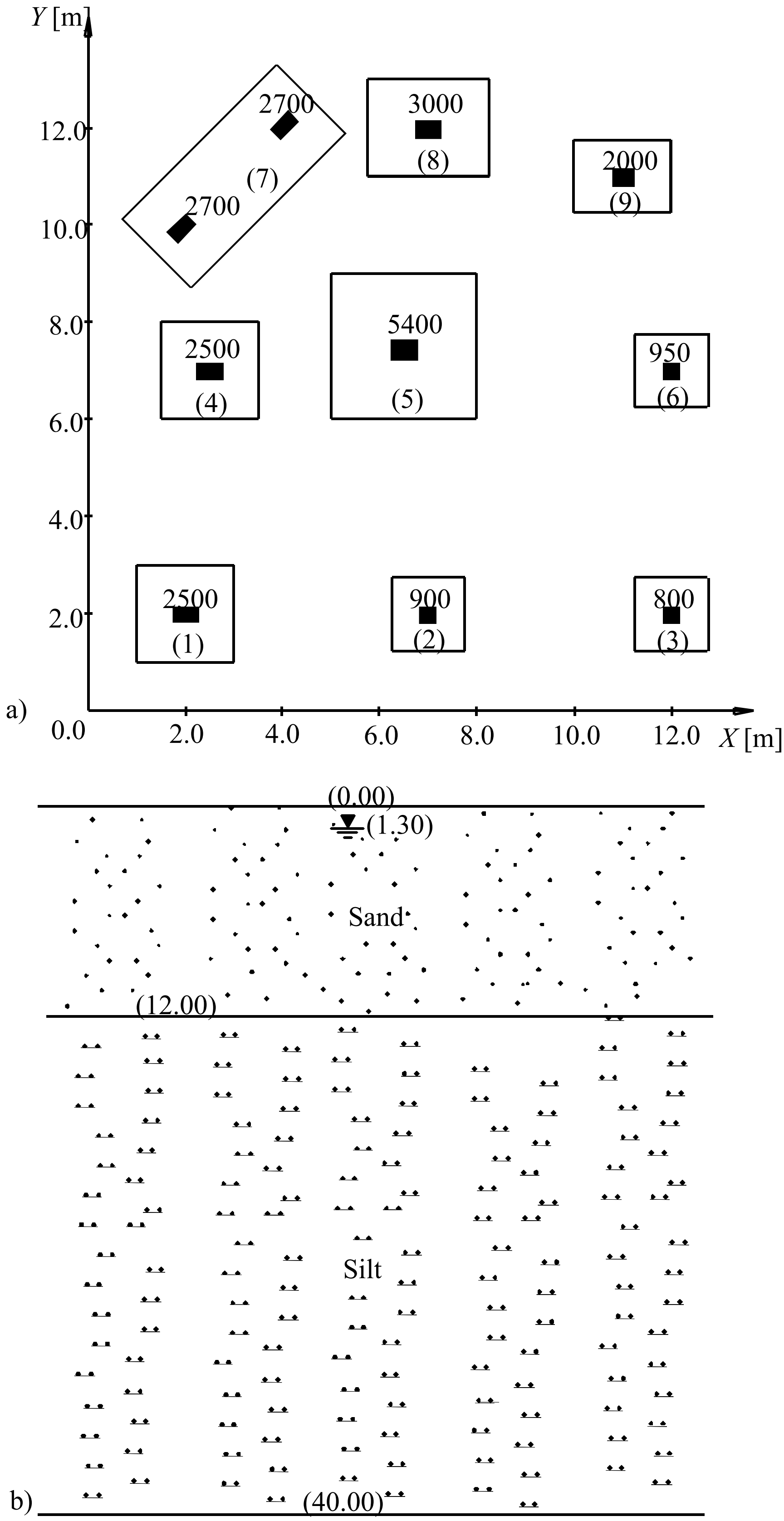


Figure 9.30 a) plan of the footing group with loads [kN], b) Section through the subsoil

9.8.5.2 Soil properties

The subsoil under the foundations are three layers with different soil materials as shown in Table 9.8 and Figure 9.30b.

Poisson's ratio is taken to be $\nu_s = 0.3$ [-] and is constant for all soil layers. The influence of loading and reloading of the soil and the uplift pressure are considered. The groundwater is at a depth of $Tw = 1.3$ [m] under the ground, while the foundation depth for all footings is $Tf = 2.2$ [m].

Table 9.8 Soil properties and depth of layers under the ground surface

Layer No.	Soil name	Depth of the soil layer under the ground surface Z [m]	Undrained modulus for		Unit weight of the soil γ_s [kN/m^3]
			Loading E [kN/m^2]	Reloading W [kN/m^2]	
1	Sand	1.3	98 000	135 000	19
2	Sand	12	98 000	135 000	11.2
3	Silt	40	9 500	12 000	12

9.8.5.3 Analysis and Results

Because the footing dimensions are relatively small, the footings can be treated as rigid footings resting on compressible soil. In this case, it is sufficient to determine the soil settlement at the center of the footing and footing corners. For a good assessment of the proposed calculation, the footing group is calculated twice as follows:

i) Without limit depths, where the last layer for the subsoil is extended to a depth of up to 40 [m] below the ground surface.

ii) The limit depths of the soil for all foundations are obtained from the maximum footing load (footing 5)

The limit depth calculation is carried out, assuming the limit depth at which the value $Cs = 0.2$ is reached.

The limit depth due to the loading of footing 5 is shown in Figure 9.31. The limit depth due to the maximum footing load (footing 5) is 14.06 [m].

Table 9.9 shows the central settlements of the footings for the two cases. As expected, the numerical results show that the limit depth has a significant influence on the settlement of the footings. It can be seen from Table 9.9 that there is a large difference between the settlement values using the two cases. Case i) gives high values of settlement, while in case ii) these are small.

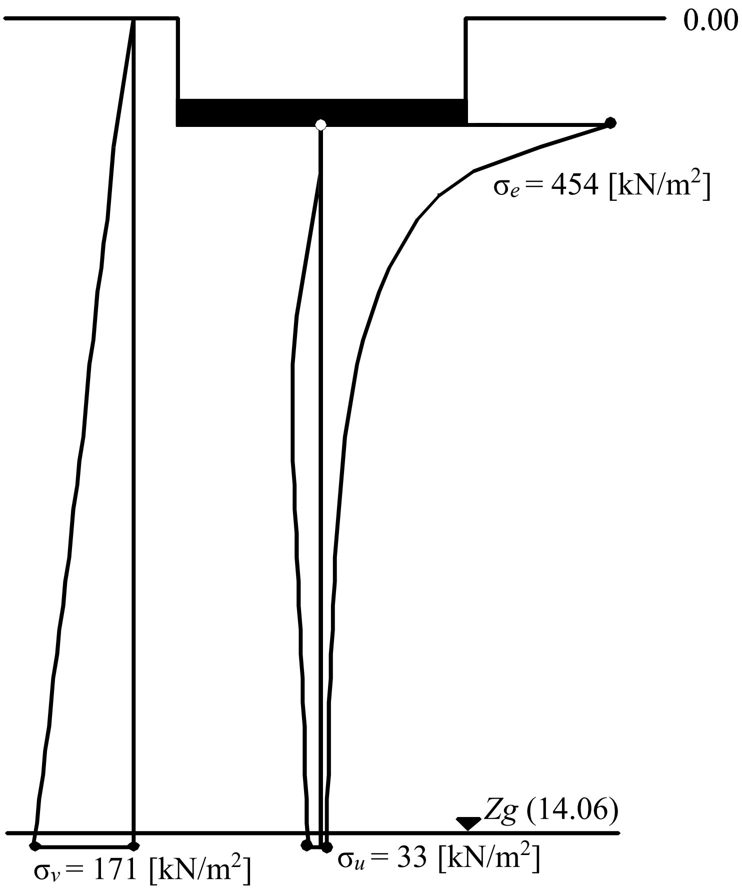


Figure 9.31 Limit depth due to loading of the footing 5

Table 9.9 Central settlement of the footings

Footing No.	Calculation of the central settlement [cm] based on	
	limit depth based on footing 5	without limit depth $Z = 40$ [m]
1	0.95	3.63
2	1.14	4.12
3	0.93	3.52
4	1.34	4.46
5	1.67	5.11
6	1.20	4.17
7	1.30	4.30
8	1.22	4.30
9	0.94	3.58

9.8.5.4 Presentation of data and results

The input data and results of the settlement calculations for footing group of nine isolated footings are shown on the next pages.

```
**********************************************************
                         GEO Tools
                        Version 13
          Program authors M. El Gendy/ A. El Gendy
**********************************************************
Title: Test example for 9 footings
Date: 24-01-2018
Project: Example4
File: SZ4

----------------------------------------------------------
Settlements of footing groups (without limit depth)
----------------------------------------------------------

Main Soil Data:

Groundwater depth under the ground surface    Tw [m]     = 1.30
Settlement reduction factor                   α  [-]     = 1.00
Unit weight of footing concrete               γb [kN/m3] = 25.00

Loads and dimensions:
```

Footing No. I	Load on Footing Pa [kN]	Length Am [m]	Breadth Bm [m]	Thickness Dm [m]	Foundation Depth Tf [m]	X-coord. Xm [m]	Y-coord. Ym [m]	Rotating angle β [°]	Height Hm [m]
1	1200	2.00	2.00	0.50	2.20	2.00	2.00	0.00	0.00
2	1500	2.50	2.00	0.50	2.20	7.00	2.00	0.00	0.00
3	1200	2.00	2.00	0.50	2.20	12.00	2.00	0.00	0.00
4	1500	2.00	2.00	0.50	2.20	2.00	7.00	0.00	0.00
5	2700	3.00	2.00	0.50	2.20	7.00	7.00	0.00	0.00
6	1500	2.00	2.00	0.50	2.20	12.00	7.00	0.00	0.00
7	2700	4.50	2.00	0.50	2.20	3.00	11.00	45.00	0.00
8	1200	2.00	2.00	0.50	2.20	7.00	12.00	0.00	0.00
9	1200	2.00	2.00	0.50	2.20	12.00	12.00	0.00	0.00

Boring:

Layer No. I [-]	Level of layer under ground z [m]	Modulus of compressibility for loading Es [kN/m2]	Modulus of compressibility for reloading Ws [kN/m2]	Poisson's ratio of the soil νs [-]	Unit weight of the soil γs [kN/m3]
1	1.30	98000	135000	0.30	19.00
2	12.00	98000	135000	0.30	11.20
3	40.00	9500	12000	0.30	12.00

```
Settlement calculation for rigid centric loaded footings

Footing No.: 1
Groundwater pressure                       Qw  [kN/m2] = 9
Overburden pressure                        Qv  [kN/m2] = 35
Loading                                    Qe  [kN/m2] = 269
Contact pressure                           Qo  [kN/m2] = 304
Modulus of subgrade reaction               ks  [kN/m3] = 9440

Final settlements of rigid footing:
Settlement of the corner: right up         S1  [cm]    = 4.05
Settlement of the corner: right down       S2  [cm]    = 3.60
Settlement of the corner: left down        S3  [cm]    = 3.22
Settlement of the corner: left up          S4  [cm]    = 3.66
Average settlement                         Sm  [cm]    = 3.63

Immediate settlement parts:
Settlement of the corner: right up         Sf1 [cm]    = 3.63
Settlement of the corner: right down       Sf2 [cm]    = 3.16
Settlement of the corner: left down        Sf3 [cm]    = 2.82
Settlement of the corner: left up          Sf4 [cm]    = 3.22
Average settlement                         Smf [cm]    = 3.21
```

```
Footing No.: 2
Groundwater pressure                       Qw  [kN/m2] = 9
Overburden pressure                        Qv  [kN/m2] = 35

Loading                                    Qe  [kN/m2] = 269
Contact pressure                           Qo  [kN/m2] = 304
Modulus of subgrade reaction               ks  [kN/m3] = 8433

Final settlements of rigid footing:
Settlement of the corner: right up         S1  [cm]    = 4.37
Settlement of the corner: right down       S2  [cm]    = 3.84
Settlement of the corner: left down        S3  [cm]    = 3.87
Settlement of the corner: left up          S4  [cm]    = 4.40
Average settlement                         Sm  [cm]    = 4.12

Immediate settlement parts:
Settlement of the corner: right up         Sf1 [cm]    = 3.92
Settlement of the corner: right down       Sf2 [cm]    = 3.41
Settlement of the corner: left down        Sf3 [cm]    = 3.44
Settlement of the corner: left up          Sf4 [cm]    = 3.95
Average settlement                         Smf [cm]    = 3.68

Footing No.: 3
Groundwater pressure                       Qw  [kN/m2] = 9
Overburden pressure                        Qv  [kN/m2] = 35
Loading                                    Qe  [kN/m2] = 269
Contact pressure                           Qo  [kN/m2] = 304
Modulus of subgrade reaction               ks  [kN/m3] = 8290

Final settlements of rigid footing:
Settlement of the corner: right up         S1  [cm]    = 3.50
Settlement of the corner: right down       S2  [cm]    = 3.11
Settlement of the corner: left down        S3  [cm]    = 3.54
Settlement of the corner: left up          S4  [cm]    = 3.93
Average settlement                         Sm  [cm]    = 3.52

Immediate settlement parts:
Settlement of the corner: right up         Sf1 [cm]    = 3.08
Settlement of the corner: right down       Sf2 [cm]    = 2.73
Settlement of the corner: left down        Sf3 [cm]    = 3.08
Settlement of the corner: left up          Sf4 [cm]    = 3.51
Average settlement                         Smf [cm]    = 3.10

Footing No.: 4
Groundwater pressure                       Qw  [kN/m2] = 9
Overburden pressure                        Qv  [kN/m2] = 35
Loading                                    Qe  [kN/m2] = 344
Contact pressure                           Qo  [kN/m2] = 379
Modulus of subgrade reaction               ks  [kN/m3] = 7504

Final settlements of rigid footing:
Settlement of the corner: right up         S1  [cm]    = 4.78
Settlement of the corner: right down       S2  [cm]    = 4.65
Settlement of the corner: left down        S3  [cm]    = 4.14
Settlement of the corner: left up          S4  [cm]    = 4.27
Average settlement                         Sm  [cm]    = 4.46

Immediate settlement parts:
Settlement of the corner: right up         Sf1 [cm]    = 4.30
Settlement of the corner: right down       Sf2 [cm]    = 4.18
Settlement of the corner: left down        Sf3 [cm]    = 3.70
Settlement of the corner: left up          Sf4 [cm]    = 3.80
Average settlement                         Smf [cm]    = 3.99
```

```
Footing No.: 5
Groundwater pressure                        Qw  [kN/m2] = 9
Overburden pressure                         Qv  [kN/m2] = 35
Loading                                     Qe  [kN/m2] = 419
Contact pressure                            Qo  [kN/m2] = 454
Modulus of subgrade reaction                ks  [kN/m3] = 7841

Final settlements of rigid footing:
Settlement of the corner: right up          S1  [cm]    = 5.06
Settlement of the corner: right down        S2  [cm]    = 5.00
Settlement of the corner: left down         S3  [cm]    = 5.16
Settlement of the corner: left up           S4  [cm]    = 5.22
Average settlement                          Sm  [cm]    = 5.11

Immediate settlement parts:
Settlement of the corner: right up          Sf1 [cm]    = 4.55
Settlement of the corner: right down        Sf2 [cm]    = 4.51
Settlement of the corner: left down         Sf3 [cm]    = 4.64
Settlement of the corner: left up           Sf4 [cm]    = 4.72
Average settlement                          Smf [cm]    = 4.60

Footing No.: 6
Groundwater pressure                        Qw  [kN/m2] = 9
Overburden pressure                         Qv  [kN/m2] = 35
Loading                                     Qe  [kN/m2] = 344
Contact pressure                            Qo  [kN/m2] = 379
Modulus of subgrade reaction                ks  [kN/m3] = 7901

Final settlements of rigid footing:
Settlement of the corner: right up          S1  [cm]    = 3.92
Settlement of the corner: right down        S2  [cm]    = 3.90
Settlement of the corner: left down         S3  [cm]    = 4.43
Settlement of the corner: left up           S4  [cm]    = 4.45
Average settlement                          Sm  [cm]    = 4.17

Immediate settlement parts:
Settlement of the corner: right up          Sf1 [cm]    = 3.47
Settlement of the corner: right down        Sf2 [cm]    = 3.46
Settlement of the corner: left down         Sf3 [cm]    = 3.97
Settlement of the corner: left up           Sf4 [cm]    = 3.99
Average settlement                          Smf [cm]    = 3.72

Footing No.: 7
Groundwater pressure                        Qw  [kN/m2] = 9
Overburden pressure                         Qv  [kN/m2] = 35
Loading                                     Qe  [kN/m2] = 269
Contact pressure                            Qo  [kN/m2] = 304
Modulus of subgrade reaction                ks  [kN/m3] = 6900

Final settlements of rigid footing:
Settlement of the corner: right up          S1  [cm]    = 4.07
Settlement of the corner: right down        S2  [cm]    = 4.48
Settlement of the corner: left down         S3  [cm]    = 4.54
Settlement of the corner: left up           S4  [cm]    = 4.12
Average settlement                          Sm  [cm]    = 4.30

Immediate settlement parts:
Settlement of the corner: right up          Sf1 [cm]    = 3.62
Settlement of the corner: right down        Sf2 [cm]    = 4.01
Settlement of the corner: left down         Sf3 [cm]    = 4.07
Settlement of the corner: left up           Sf4 [cm]    = 3.66
Average settlement                          Smf [cm]    = 3.84
```

```
Footing No.: 8
Groundwater pressure                         Qw  [kN/m2] = 9
Overburden pressure                          Qv  [kN/m2] = 35
Loading                                      Qe  [kN/m2] = 269
Contact pressure                             Qo  [kN/m2] = 304
Modulus of subgrade reaction                 ks  [kN/m3] = 6946

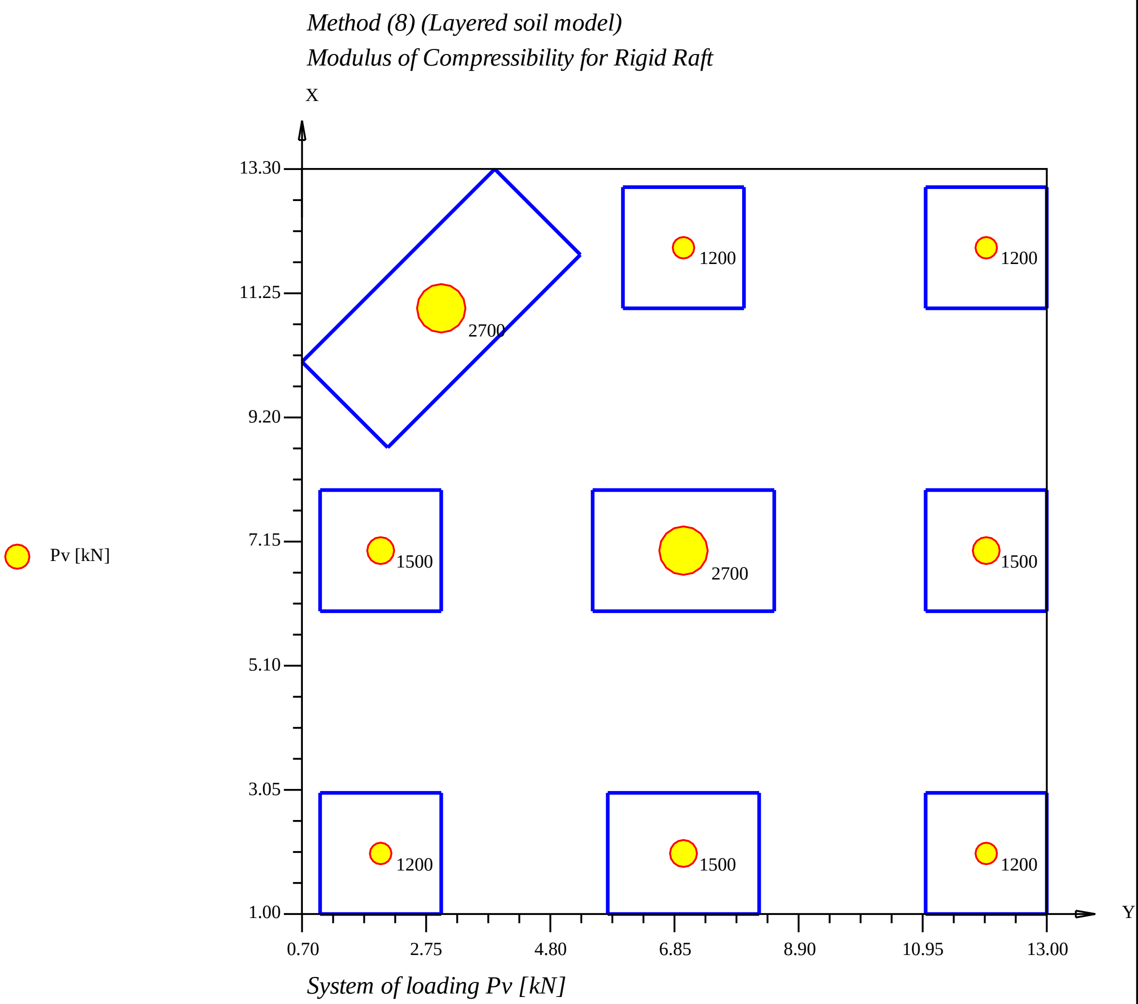
Final settlements of rigid footing:
Settlement of the corner: right up           S1  [cm]    = 3.97
Settlement of the corner: right down         S2  [cm]    = 4.50
Settlement of the corner: left down          S3  [cm]    = 4.63
Settlement of the corner: left up            S4  [cm]    = 4.11
Average settlement                           Sm  [cm]    = 4.30

Immediate settlement parts:
Settlement of the corner: right up           Sf1 [cm]    = 3.55
Settlement of the corner: right down         Sf2 [cm]    = 4.04
Settlement of the corner: left down          Sf3 [cm]    = 4.18
Settlement of the corner: left up            Sf4 [cm]    = 3.66
Average settlement                           Smf [cm]    = 3.86

Footing No.: 9
Groundwater pressure                         Qw  [kN/m2] = 9
Overburden pressure                          Qv  [kN/m2] = 35
Loading                                      Qe  [kN/m2] = 269
Contact pressure                             Qo  [kN/m2] = 304
Modulus of subgrade reaction                 ks  [kN/m3] = 8583

Final settlements of rigid footing:
Settlement of the corner: right up           S1  [cm]    = 3.17
Settlement of the corner: right down         S2  [cm]    = 3.56
Settlement of the corner: left down          S3  [cm]    = 3.99
Settlement of the corner: left up            S4  [cm]    = 3.60
Average settlement                           Sm  [cm]    = 3.58

Immediate settlement parts:
Settlement of the corner: right up           Sf1 [cm]    = 2.78
Settlement of the corner: right down         Sf2 [cm]    = 3.12
Settlement of the corner: left down          Sf3 [cm]    = 3.57
Settlement of the corner: left up            Sf4 [cm]    = 3.16
Average settlement                           Smf [cm]    = 3.16
```



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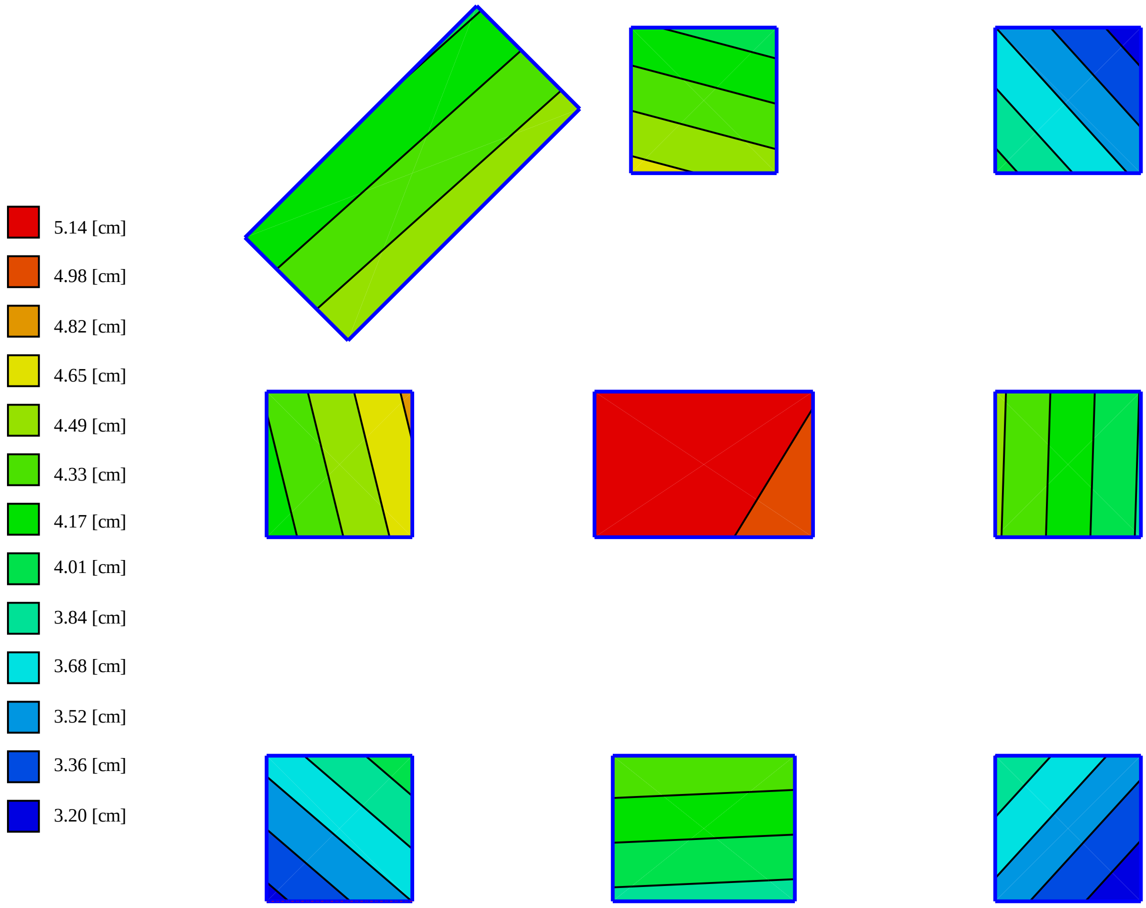
Scale: 100	**Title: Test example for 9 footings**
File: SZ4	**Date: 24-01-2018**
Page No.:	**Project: Example4**

Method (8) (Layered soil model)
Modulus of Compressibility for Rigid Raft



Settlements s [cm]
Max. s = 5.22 at node 19, Min. s = 3.11 at node 10

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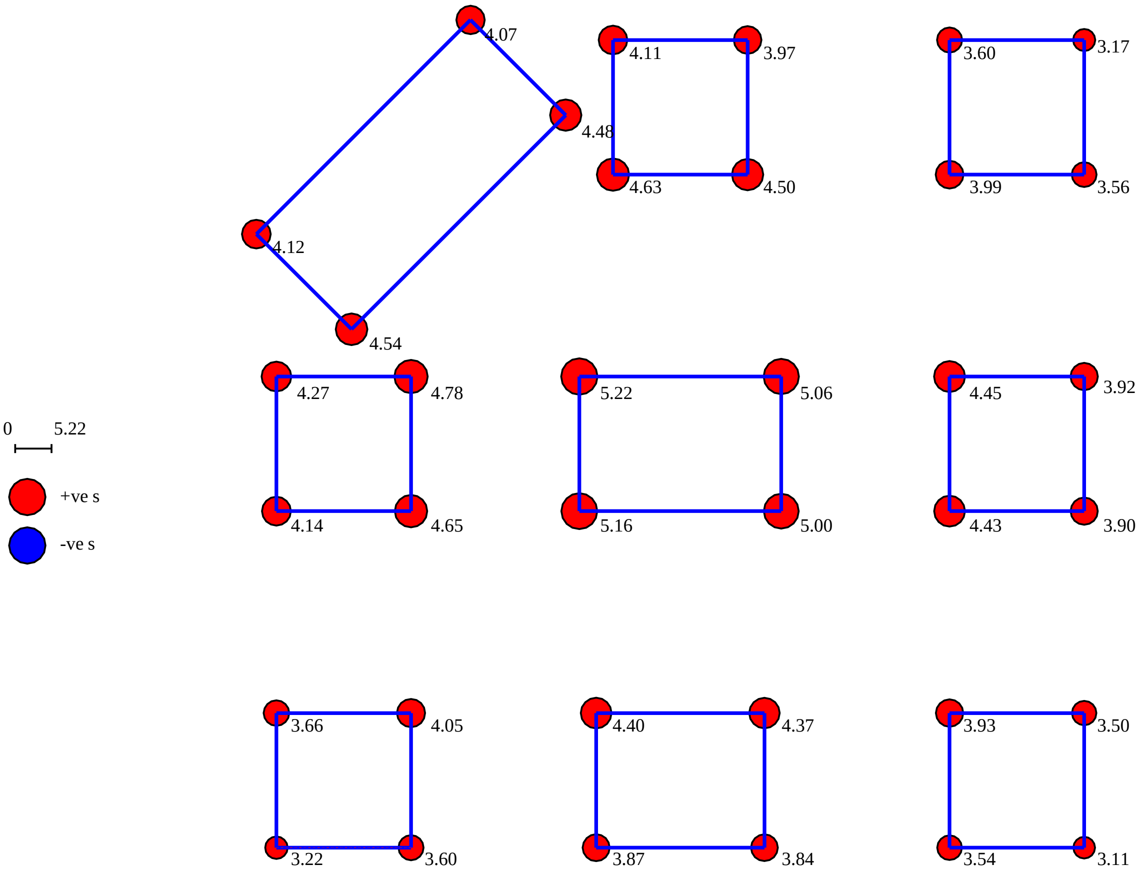
PO Box 14001 Richmond Road PO, Tele.:+1(587) 332-3323	
Scale: 85	**Title: Test example for 9 footings**
File: SZ4	**Date: 24-01-2018**
Page No.:	**Project: Example4**

Method (8) (Layered soil model)

Modulus of Compressibility for Rigid Raft



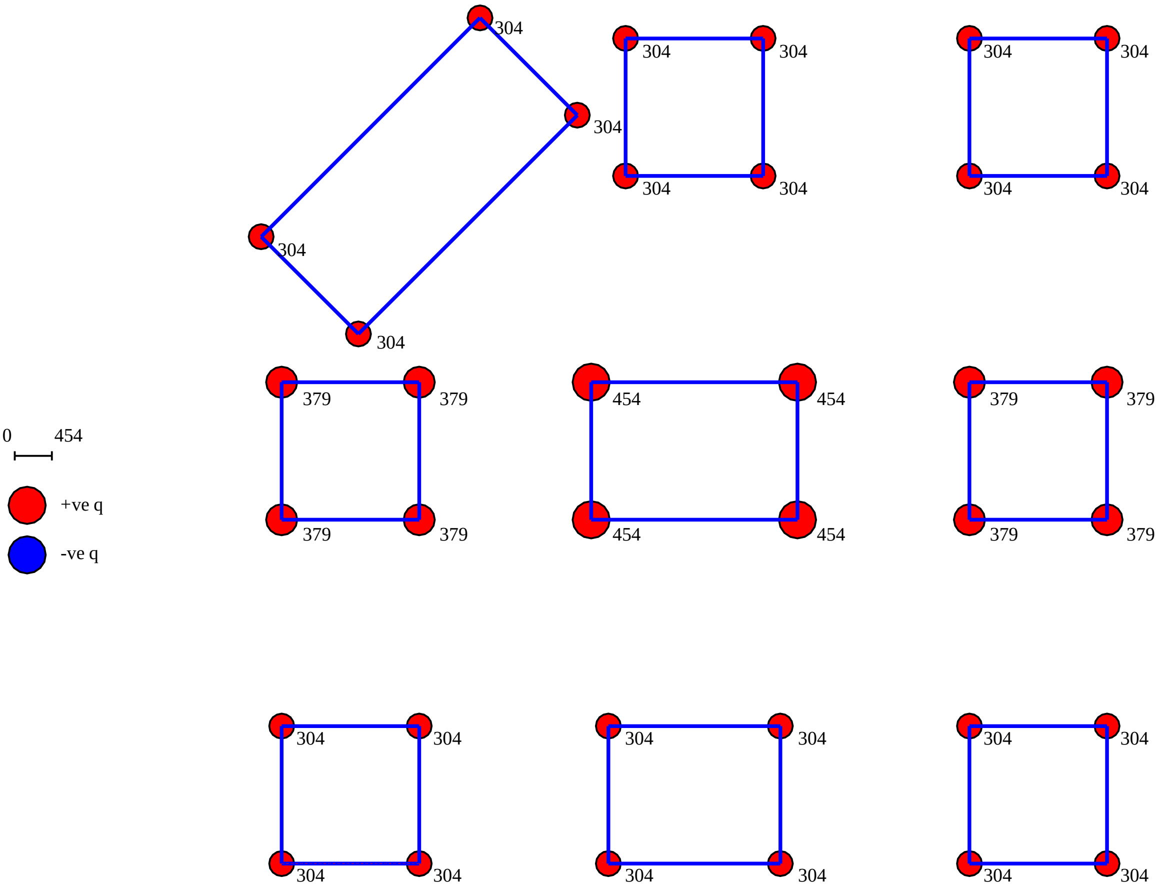
Settlements s [cm]

Max. s = 5.22 at node 19, Min. s = 3.11 at node 10

GEOTEC Software Inc., Calgary AB, Canada T3E 7Y7 PO Box 14001 Richmond Road PO, Tele.:+1(587) 332-3323	
Scale: 90	**Title: Test example for 9 footings**
File: SZ4	**Date: 24-01-2018**
Page No.:	**Project: Example4**

Method (8) (Layered soil model)

Modulus of Compressibility for Rigid Raft



Contact pressure q [kN/m2]

Max. q = 454 at node 17, Min. q = 304 at node 1

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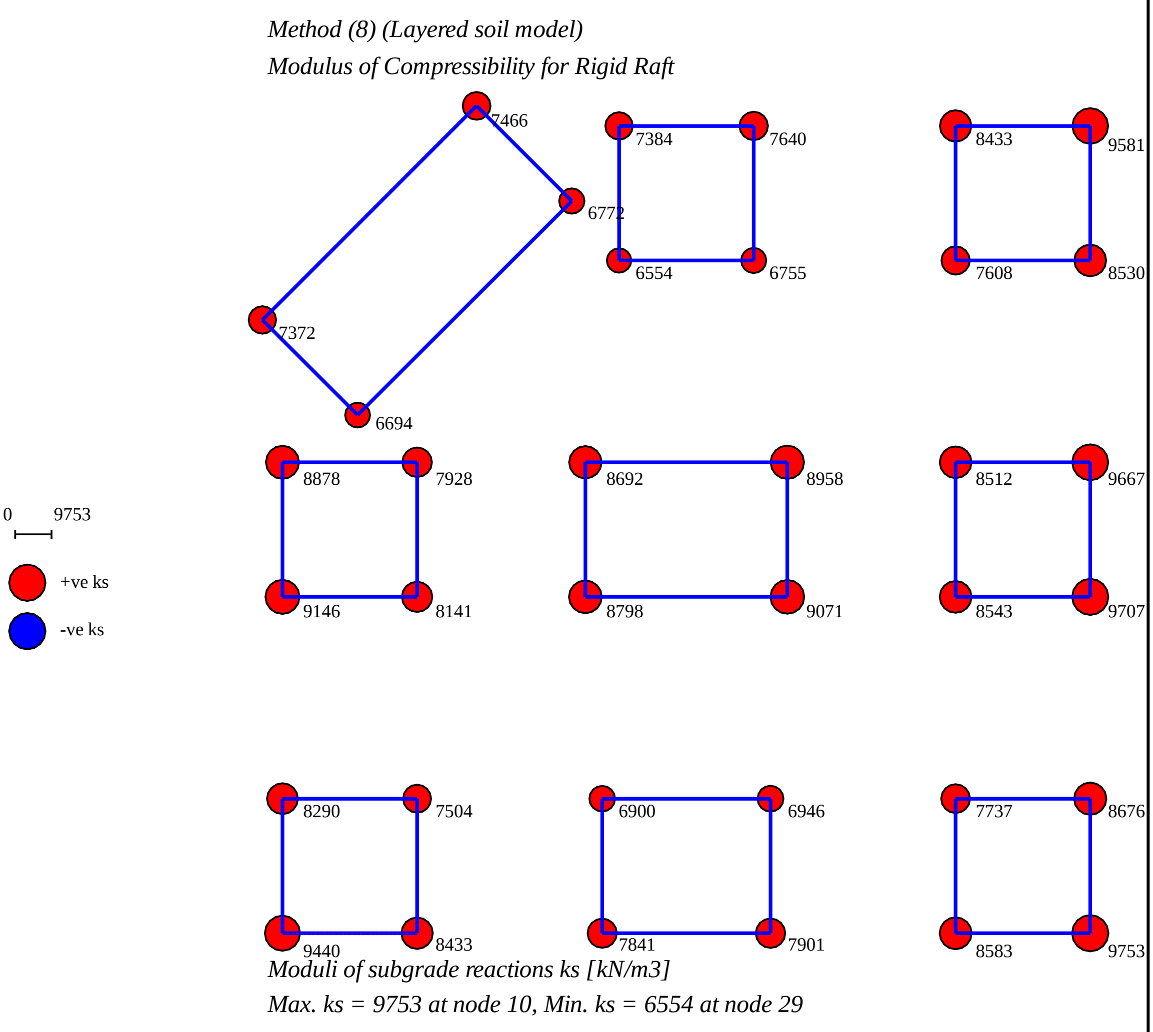
Scale: 90	**Title: Test example for 9 footings**
File: SZ4	**Date: 24-01-2018**
Page No.:	**Project: Example4**



GEOTEC Software Inc., Calgary AB, Canada T3E 7Y7 PO Box 14001 Richmond Road PO, Tele.:+1(587) 332-3323	
Scale: 90	**Title: Test example for 9 footings**
File: SZ4	**Date: 24-01-2018**
Page No.:	**Project: Example4**

```
*************************************************************
                          GEO Tools
                         Version 13
          Program authors M. El Gendy/ A. El Gendy
*************************************************************
Title: Test example for 9 footings
Date: 24-01-2018
Project: Example4
File: SZ4
```

Settlements of footing groups (with limit depth)

Data of limit depth:

Strip thickness for depth by iteration	Dz [m]	= 0.5
Standard ratio of limit depth (1>Cs, Cs>=0)	Cs [-]	= 0.2

Main Soil Data:

Groundwater depth under the ground surface	Tw [m]	= 1.30
Settlement reduction factor	α [-]	= 1.00
Unit weight of footing concrete	γb [kN/m3]	= 25.00
Groundwater pressure	Qw [kN/m2]	= 9
Overburden pressure	Qv [kN/m2]	= 35
Loading	Qe [kN/m2]	= 419
Contact pressure	Qo [kN/m2]	= 454
Limit depth under ground surface (Footing No. 5/ Max. Load)	ZG [m]	= 14.06
Lies at layer	U [-]	= 3

Loads and dimensions:

Footing No. I	Load on Footing Pa [kN]	Length Am [m]	Breadth Bm [m]	Thickness Dm [m]	Foundation Depth Tf [m]	X-coord. Xm [m]	Y-coord. Ym [m]	Rotating angle β [°]	Height Hm [m]
1	1200	2.00	2.00	0.50	2.20	2.00	2.00	0.00	0.00
2	1500	2.50	2.00	0.50	2.20	7.00	2.00	0.00	0.00
3	1200	2.00	2.00	0.50	2.20	12.00	2.00	0.00	0.00
4	1500	2.00	2.00	0.50	2.20	2.00	7.00	0.00	0.00
5	2700	3.00	2.00	0.50	2.20	7.00	7.00	0.00	0.00
6	1500	2.00	2.00	0.50	2.20	12.00	7.00	0.00	0.00
7	2700	4.50	2.00	0.50	2.20	3.00	11.00	45.00	0.00
8	1200	2.00	2.00	0.50	2.20	7.00	12.00	0.00	0.00
9	1200	2.00	2.00	0.50	2.20	12.00	12.00	0.00	0.00

Boring:

Layer No. I [-]	Level of layer under ground z [m]	Modulus of compressibility for loading Es [kN/m2]	Modulus of compressibility for reloading Ws [kN/m2]	Poisson's ratio of the soil νs [-]	Unit weight of the soil γs [kN/m3]
1	1.30	98000	135000	0.30	19.00
2	12.00	98000	135000	0.30	11.20
3	40.00	9500	12000	0.30	12.00

Stress on soil against depth (Footing No. 5/ Max. Load):

Iteration No. I	Depth under foundation z [m]	Stress due to foundation SE [kN/m2]	Stress from neighboring foundations SD [kN/m2]	Sum of stresses SU=SE+SD [kN/m2]	Stress from soil weight SV [kN/m2]	ratio SU/SV [-]
0	0.00	454	0	454	35	13.04
1	0.50	310	0	310	40	7.68
2	1.00	210	1	211	46	4.59
3	1.50	160	3	163	52	3.17
4	2.00	127	7	134	57	2.34
5	2.50	102	12	114	63	1.81
6	3.00	83	16	100	68	1.46
7	3.50	68	21	90	74	1.21
8	4.00	57	25	82	80	1.03
9	4.50	48	29	77	85	0.90
10	5.00	41	31	72	91	0.79
11	5.50	35	33	68	96	0.71
12	6.00	30	34	64	102	0.63
13	6.50	26	35	61	108	0.57
14	7.00	23	35	58	113	0.51
15	7.50	21	34	55	119	0.46
16	8.00	18	34	52	124	0.42
17	8.50	16	33	49	130	0.38
18	9.00	15	32	46	136	0.34
19	9.50	13	31	44	141	0.31
20	10.00	12	29	42	147	0.28
21	10.50	11	28	39	153	0.26
22	11.00	10	27	37	159	0.23
23	11.50	9	26	35	165	0.21
24	12.00	9	25	33	171	0.19

Settlement calculation for rigid centric loaded footings

Footing No.: 1

Groundwater pressure	Qw [kN/m2]	= 9
Overburden pressure	Qv [kN/m2]	= 35
Loading	Qe [kN/m2]	= 269
Contact pressure	Qo [kN/m2]	= 304
Modulus of subgrade reaction	ks [kN/m3]	= 37396

Final settlements of rigid footing:

Settlement of the corner: right up	S1 [cm]	= 1.10
Settlement of the corner: right down	S2 [cm]	= 0.94
Settlement of the corner: left down	S3 [cm]	= 0.81
Settlement of the corner: left up	S4 [cm]	= 0.96
Average settlement	Sm [cm]	= 0.95

Immediate settlement parts:

Settlement of the corner: right up	Sf1 [cm]	= 0.88
Settlement of the corner: right down	Sf2 [cm]	= 0.73
Settlement of the corner: left down	Sf3 [cm]	= 0.63
Settlement of the corner: left up	Sf4 [cm]	= 0.75
Average settlement	Smf [cm]	= 0.75

```
Footing No.: 2
Groundwater pressure                        Qw  [kN/m2] = 9
Overburden pressure                         Qv  [kN/m2] = 35
Loading                                     Qe  [kN/m2] = 269
Contact pressure                            Qo  [kN/m2] = 304
Modulus of subgrade reaction                ks  [kN/m3] = 32164

Final settlements of rigid footing:
Settlement of the corner: right up          S1  [cm]    = 1.23
Settlement of the corner: right down        S2  [cm]    = 1.04
Settlement of the corner: left down         S3  [cm]    = 1.05
Settlement of the corner: left up           S4  [cm]    = 1.24
Average settlement                          Sm  [cm]    = 1.14

Immediate settlement parts:
Settlement of the corner: right up          Sf1 [cm]    = 0.99
Settlement of the corner: right down        Sf2 [cm]    = 0.82
Settlement of the corner: left down         Sf3 [cm]    = 0.83
Settlement of the corner: left up           Sf4 [cm]    = 1.00
Average settlement                          Smf [cm]    = 0.91

Footing No.: 3
Groundwater pressure                        Qw  [kN/m2] = 9
Overburden pressure                         Qv  [kN/m2] = 35
Loading                                     Qe  [kN/m2] = 269
Contact pressure                            Qo  [kN/m2] = 304
Modulus of subgrade reaction                ks  [kN/m3] = 31495

Final settlements of rigid footing:
Settlement of the corner: right up          S1  [cm]    = 0.92
Settlement of the corner: right down        S2  [cm]    = 0.79
Settlement of the corner: left down         S3  [cm]    = 0.93
Settlement of the corner: left up           S4  [cm]    = 1.06
Average settlement                          Sm  [cm]    = 0.93

Immediate settlement parts:
Settlement of the corner: right up          Sf1 [cm]    = 0.72
Settlement of the corner: right down        Sf2 [cm]    = 0.62
Settlement of the corner: left down         Sf3 [cm]    = 0.72
Settlement of the corner: left up           Sf4 [cm]    = 0.85
Average settlement                          Smf [cm]    = 0.73

Footing No.: 4
Groundwater pressure                        Qw  [kN/m2] = 9
Overburden pressure                         Qv  [kN/m2] = 35
Loading                                     Qe  [kN/m2] = 344
Contact pressure                            Qo  [kN/m2] = 379
Modulus of subgrade reaction                ks  [kN/m3] = 27700

Final settlements of rigid footing:
Settlement of the corner: right up          S1  [cm]    = 1.49
Settlement of the corner: right down        S2  [cm]    = 1.40
Settlement of the corner: left down         S3  [cm]    = 1.19
Settlement of the corner: left up           S4  [cm]    = 1.28
Average settlement                          Sm  [cm]    = 1.34

Immediate settlement parts:
Settlement of the corner: right up          Sf1 [cm]    = 1.22
Settlement of the corner: right down        Sf2 [cm]    = 1.13
Settlement of the corner: left down         Sf3 [cm]    = 0.96
Settlement of the corner: left up           Sf4 [cm]    = 1.03
Average settlement                          Smf [cm]    = 1.09
```

```
Footing No.: 5
Groundwater pressure                        Qw  [kN/m2] = 9
Overburden pressure                         Qv  [kN/m2] = 35
Loading                                     Qe  [kN/m2] = 419
Contact pressure                            Qo  [kN/m2] = 454
Modulus of subgrade reaction                ks  [kN/m3] = 29057

Final settlements of rigid footing:
Settlement of the corner: right up          S1  [cm]    = 1.65
Settlement of the corner: right down        S2  [cm]    = 1.62
Settlement of the corner: left down         S3  [cm]    = 1.70
Settlement of the corner: left up           S4  [cm]    = 1.73
Average settlement                          Sm  [cm]    = 1.67

Immediate settlement parts:
Settlement of the corner: right up          Sf1 [cm]    = 1.34
Settlement of the corner: right down        Sf2 [cm]    = 1.33
Settlement of the corner: left down         Sf3 [cm]    = 1.38
Settlement of the corner: left up           Sf4 [cm]    = 1.44
Average settlement                          Smf [cm]    = 1.37

Footing No.: 6
Groundwater pressure                        Qw  [kN/m2] = 9
Overburden pressure                         Qv  [kN/m2] = 35
Loading                                     Qe  [kN/m2] = 344
Contact pressure                            Qo  [kN/m2] = 379
Modulus of subgrade reaction                ks  [kN/m3] = 29290

Final settlements of rigid footing:
Settlement of the corner: right up          S1  [cm]    = 1.11
Settlement of the corner: right down        S2  [cm]    = 1.10
Settlement of the corner: left down         S3  [cm]    = 1.30
Settlement of the corner: left up           S4  [cm]    = 1.30
Average settlement                          Sm  [cm]    = 1.20

Immediate settlement parts:
Settlement of the corner: right up          Sf1 [cm]    = 0.88
Settlement of the corner: right down        Sf2 [cm]    = 0.88
Settlement of the corner: left down         Sf3 [cm]    = 1.05
Settlement of the corner: left up           Sf4 [cm]    = 1.05
Average settlement                          Smf [cm]    = 0.97

Footing No.: 7
Groundwater pressure                        Qw  [kN/m2] = 9
Overburden pressure                         Qv  [kN/m2] = 35
Loading                                     Qe  [kN/m2] = 269
Contact pressure                            Qo  [kN/m2] = 304
Modulus of subgrade reaction                ks  [kN/m3] = 24501

Final settlements of rigid footing:
Settlement of the corner: right up          S1  [cm]    = 1.19
Settlement of the corner: right down        S2  [cm]    = 1.38
Settlement of the corner: left down         S3  [cm]    = 1.41
Settlement of the corner: left up           S4  [cm]    = 1.22
Average settlement                          Sm  [cm]    = 1.30

Immediate settlement parts:
Settlement of the corner: right up          Sf1 [cm]    = 0.96
Settlement of the corner: right down        Sf2 [cm]    = 1.12
Settlement of the corner: left down         Sf3 [cm]    = 1.16
Settlement of the corner: left up           Sf4 [cm]    = 0.98
Average settlement                          Smf [cm]    = 1.05
```

```
Footing No.: 8
Groundwater pressure                        Qw  [kN/m2] = 9
Overburden pressure                         Qv  [kN/m2] = 35
Loading                                     Qe  [kN/m2] = 269
Contact pressure                            Qo  [kN/m2] = 304
Modulus of subgrade reaction                ks  [kN/m3] = 24667

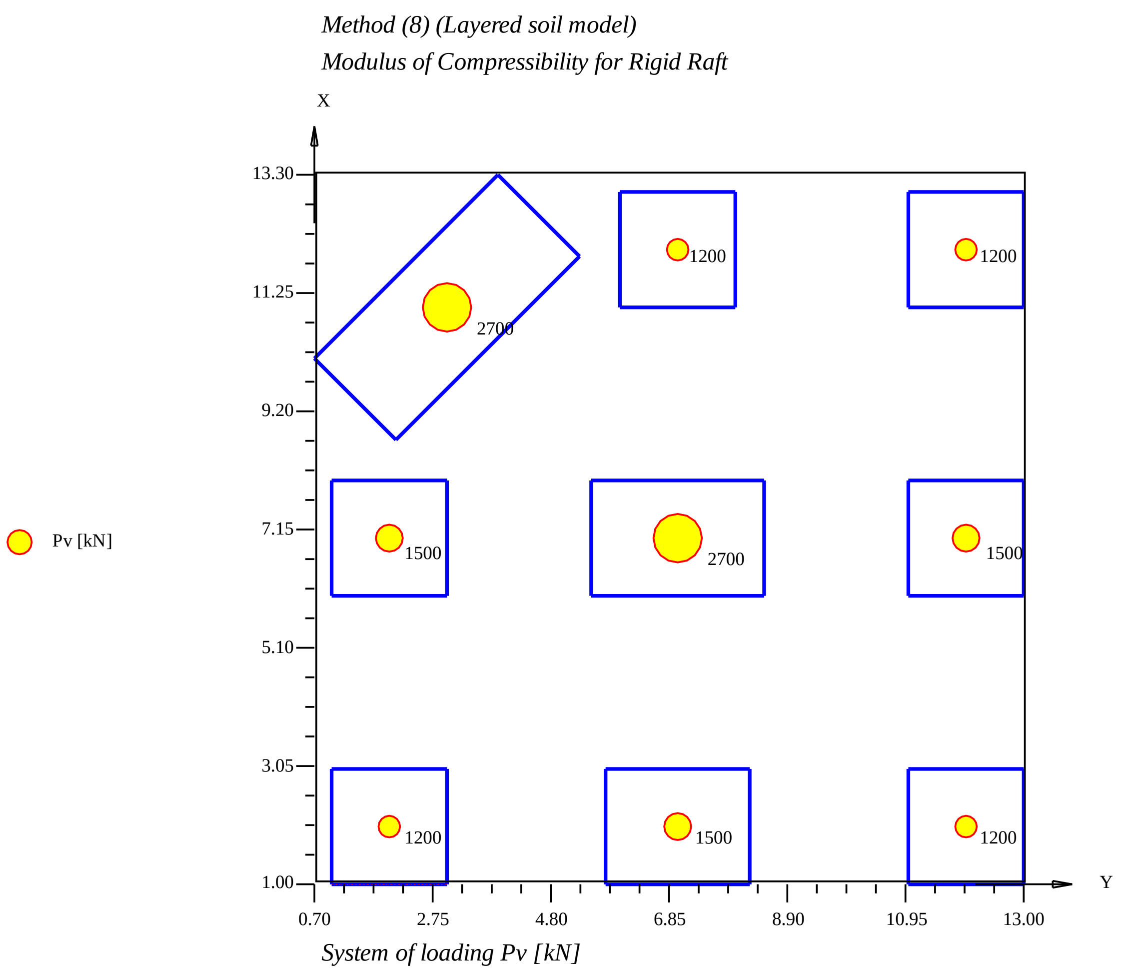
Final settlements of rigid footing:
Settlement of the corner: right up          S1  [cm]    = 1.06
Settlement of the corner: right down        S2  [cm]    = 1.27
Settlement of the corner: left down         S3  [cm]    = 1.37
Settlement of the corner: left up           S4  [cm]    = 1.16
Average settlement                          Sm  [cm]    = 1.22

Immediate settlement parts:
Settlement of the corner: right up          Sf1 [cm]    = 0.85
Settlement of the corner: right down        Sf2 [cm]    = 1.03
Settlement of the corner: left down         Sf3 [cm]    = 1.12
Settlement of the corner: left up           Sf4 [cm]    = 0.93
Average settlement                          Smf [cm]    = 0.98

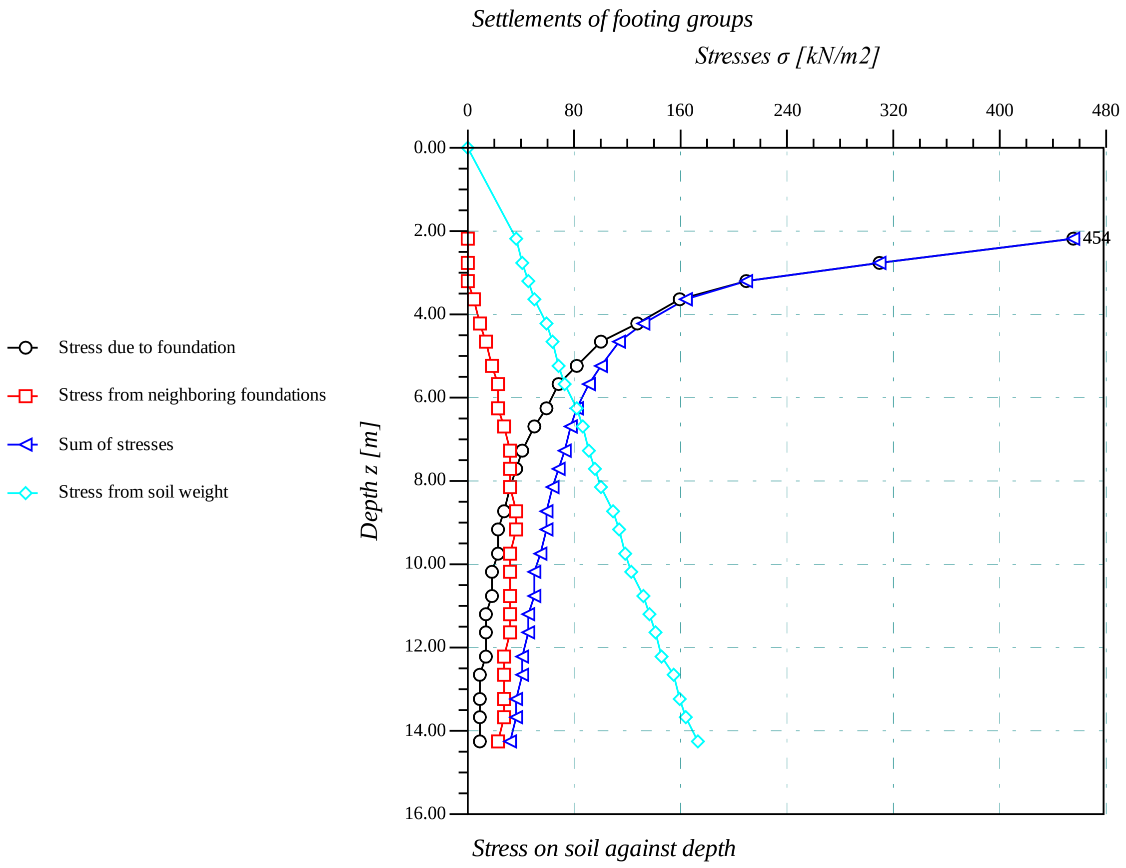
Footing No.: 9
Groundwater pressure                        Qw  [kN/m2] = 9
Overburden pressure                         Qv  [kN/m2] = 35
Loading                                     Qe  [kN/m2] = 269
Contact pressure                            Qo  [kN/m2] = 304
Modulus of subgrade reaction                ks  [kN/m3] = 32490

Final settlements of rigid footing:
Settlement of the corner: right up          S1  [cm]    = 0.80
Settlement of the corner: right down        S2  [cm]    = 0.93
Settlement of the corner: left down         S3  [cm]    = 1.07
Settlement of the corner: left up           S4  [cm]    = 0.94
Average settlement                          Sm  [cm]    = 0.94

Immediate settlement parts:
Settlement of the corner: right up          Sf1 [cm]    = 0.62
Settlement of the corner: right down        Sf2 [cm]    = 0.72
Settlement of the corner: left down         Sf3 [cm]    = 0.86
Settlement of the corner: left up           Sf4 [cm]    = 0.73
Average settlement                          Smf [cm]    = 0.73
```

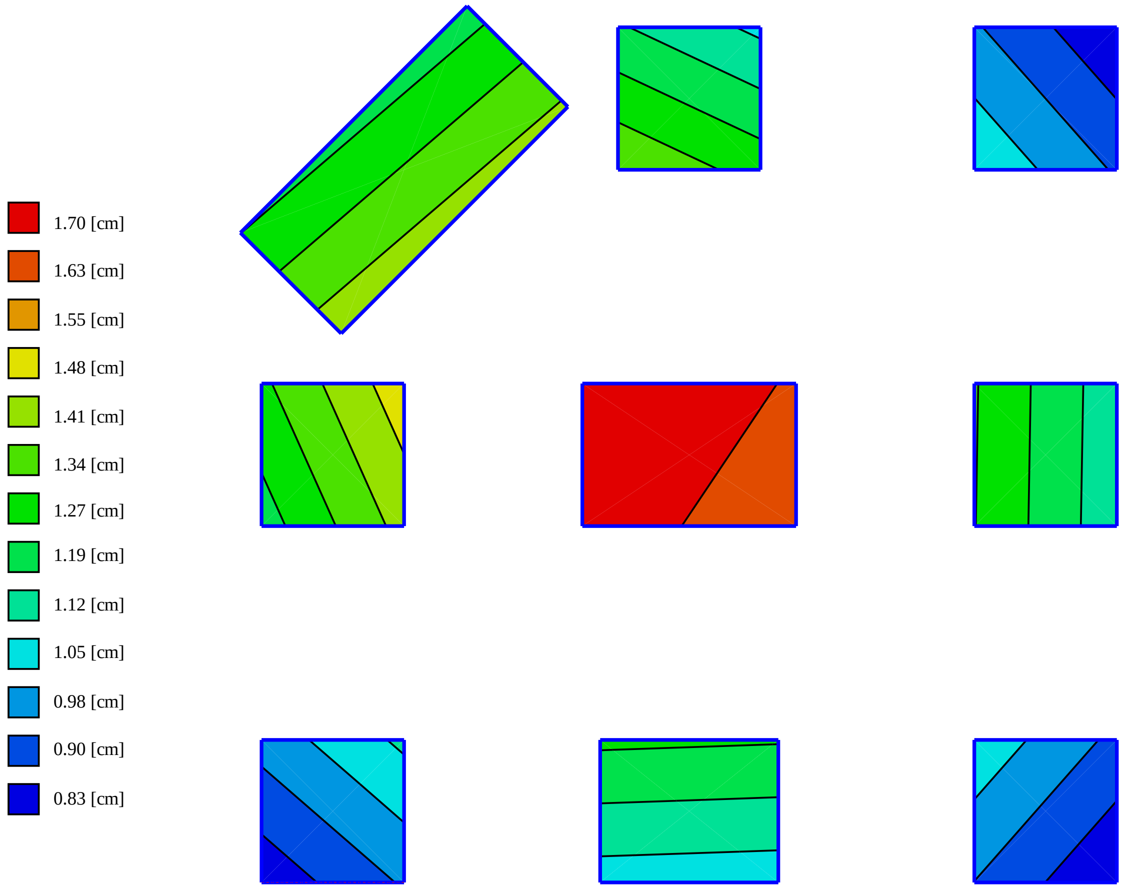


GEOTEC Software Inc., Calgary AB, Canada T3E 7Y7 PO Box 14001 Richmond Road PO, Tele.:+1(587) 332-3323	
Scale: 105	**Title: Test example for 9 footings**
File: SZ4	**Date: 24-01-2018**
Page No.:	**Project: Example4**



GEOTEC Software Inc., Calgary AB, Canada T3E 7Y7 PO Box 14001 Richmond Road PO, Tele.:+1(587) 332-3323	
Scale: 4553	**Title: Test example for 9 footings**
File: SZ4	**Date: 24-01-2018**
Page No.:	**Project: Example4**

Method (8) (Layered soil model)
Modulus of Compressibility for Rigid Raft



Settlements s [cm]
Max. s = 1.73 at node 19, Min. s = 0.79 at node 10

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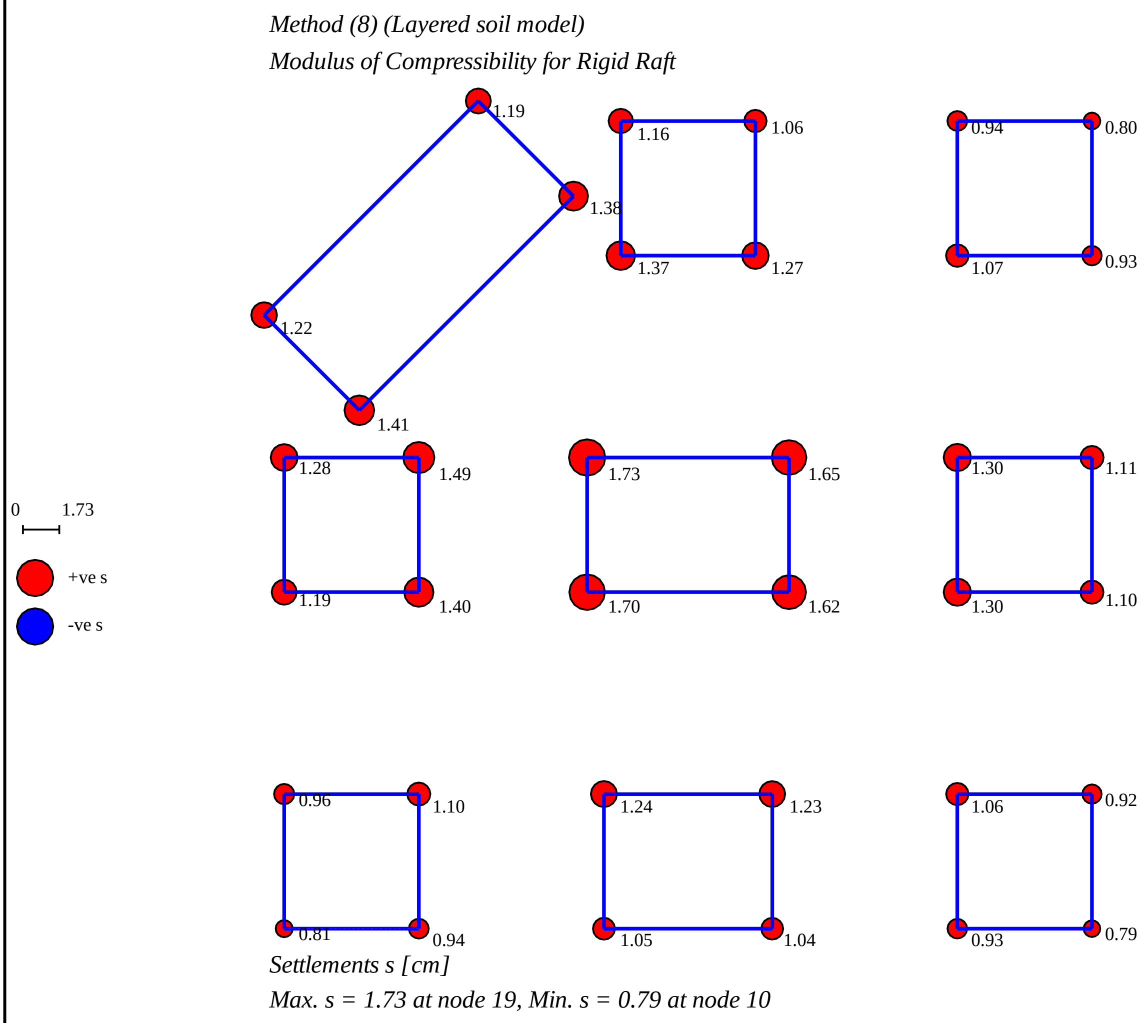
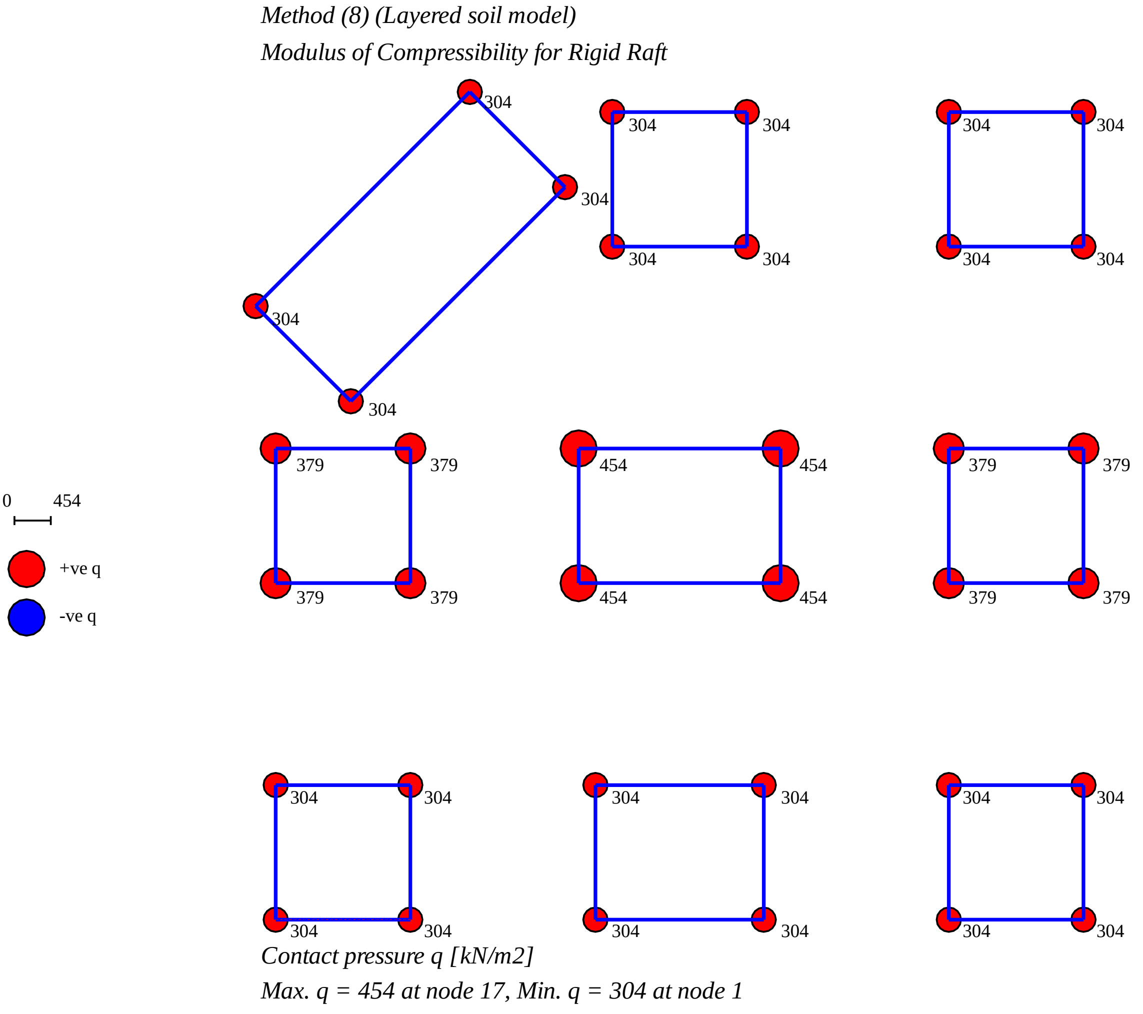
PO Box 14001 Richmond Road PO, Tele.:+1(587) 332-3323	
Scale: 85	**Title: Test example for 9 footings**
File: SZ4	**Date: 24-01-2018**
Page No.:	**Project: Example4**



GEOTEC Software Inc., Calgary AB, Canada T3E 7Y7
PO Box 14001 Richmond Road PO, Tele.:+1(587) 332-3323

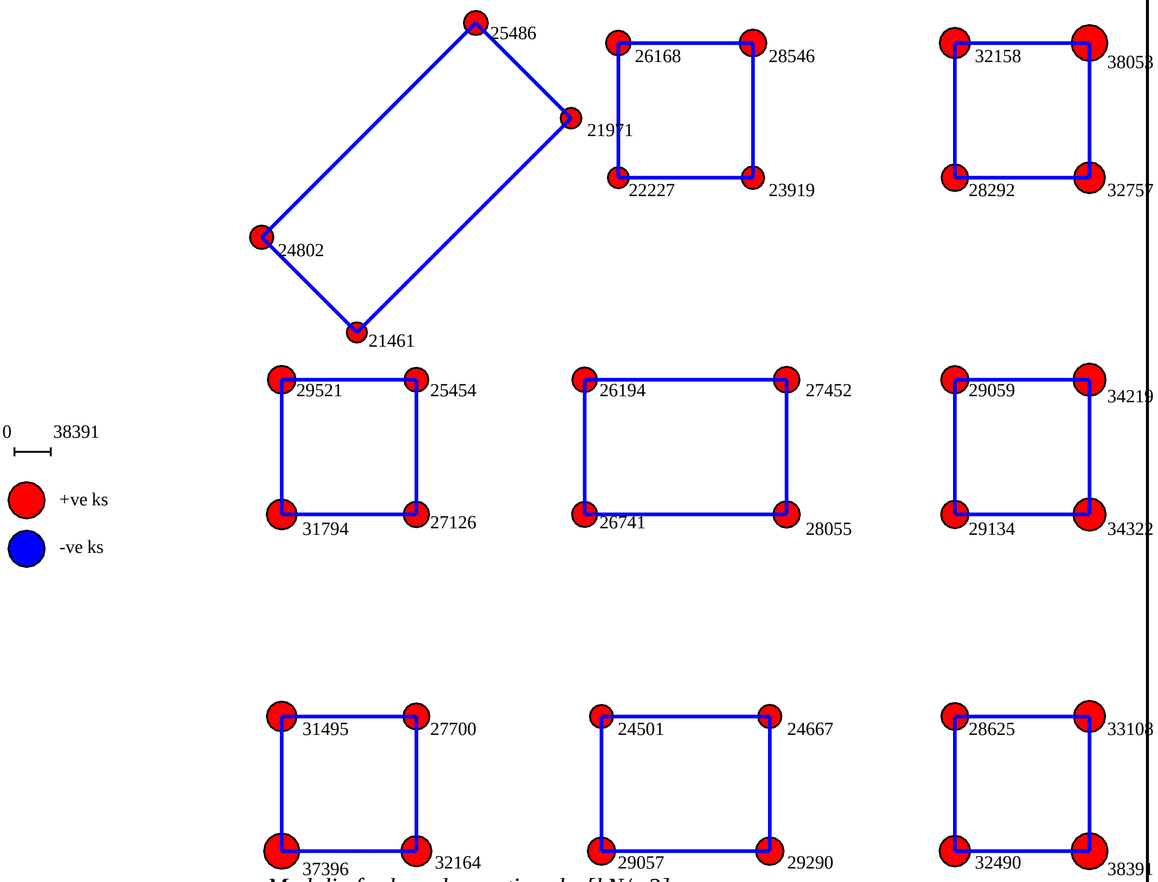
Scale: 90	**Title: Test example for 9 footings**
File: SZ4	**Date: 24-01-2018**
Page No.:	**Project: Example4**



GEOTEC Software Inc., Calgary AB, Canada T3E 7Y7 PO Box 14001 Richmond Road PO, Tele.:+1(587) 332-3323	
Scale: 90	**Title: Test example for 9 footings**
File: SZ4	**Date: 24-01-2018**
Page No.:	**Project: Example4**

Method (8) (Layered soil model)

Modulus of Compressibility for Rigid Raft



Moduli of subgrade reactions ks [kN/m3]

Max. ks = 38391 at node 10, Min. ks = 21461 at node 25

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Scale: 90	**Title: Test example for 9 footings**
File: SZ4	**Date: 24-01-2018**
Page No.:	**Project: Example4**

9.8.6 Example 5: Verifying the main modulus of subgrade reaction k_{sm}

File name BET

9.8.6.1 Description of the problem

It is known that the modulus of subgrade reaction k_s is not a soil constant but is a function of the contact pressure and settlement. It depends on foundation loads, foundation size and stratification of the subsoil. The main modulus of subgrade reaction k_{sm} for a rectangular foundation on layered subsoil can be obtained from dividing the average contact pressure q_o over the settlement s_o under the characteristic point on the foundation, which has been defined by *Graßhoff* (1955). Clearly, this procedure is valid only for rectangular foundations on a layered subsoil model. Determining the main modulus of subgrade reaction k_{sm} for irregular foundation on an irregular subsoil model using another analysis is also possible by *ELPLA*.

In this example, settlement calculations at the characteristic point on the raft, using *Steinbrener's* formula (1934) for determining the settlement under the corner of a rectangular loaded area with the principle of superposition, are used to verify *GEO Tools* analysis for determining the main modulus of subgrade reaction k_{sm}.

Consider the square raft in Figure 9.32, with area of $A_f = 8 \times 12$ [m²] and thickness of $d = 0.6$ [m].

9.8.6.2 Soil properties

The soil under the raft consists of three layers as shown in Figure 9.32 and Table 9.10. *Poisson's* ratio is $\nu_s = 0.0$ [-] for the three layers. The foundation level of the raft is $d_f = 2.0$ [m].

Table 9.10 Soil properties

Layer No.	Type of soil	Depth of layer z [m]	Modulus of compressibility E_s [kN/m²]	Unit weight of the soil γ_s [kN/m³]
1	Clay	9.0	8 000	18
2	Medium sand	14.0	100 000	-
3	Silt	20.0	12 000	-

9.8.6.3 Loads

The raft carries 12 column loads, each is $P = 1040$ [kN].

9.8.6.4 Raft material

The raft material (concrete) has the following properties:

Young's modulus	E_b	$= 2.0 \times 10^7$	[kN/m²]
Poisson's ratio	ν_b	= 0.25	[-]
Unit weight	γ_b	= 0.0	[kN/m³]

Unit weight of the raft material is chosen $\gamma_b = 0.0$ [kN/m³] to neglect the self-weight of the raft.

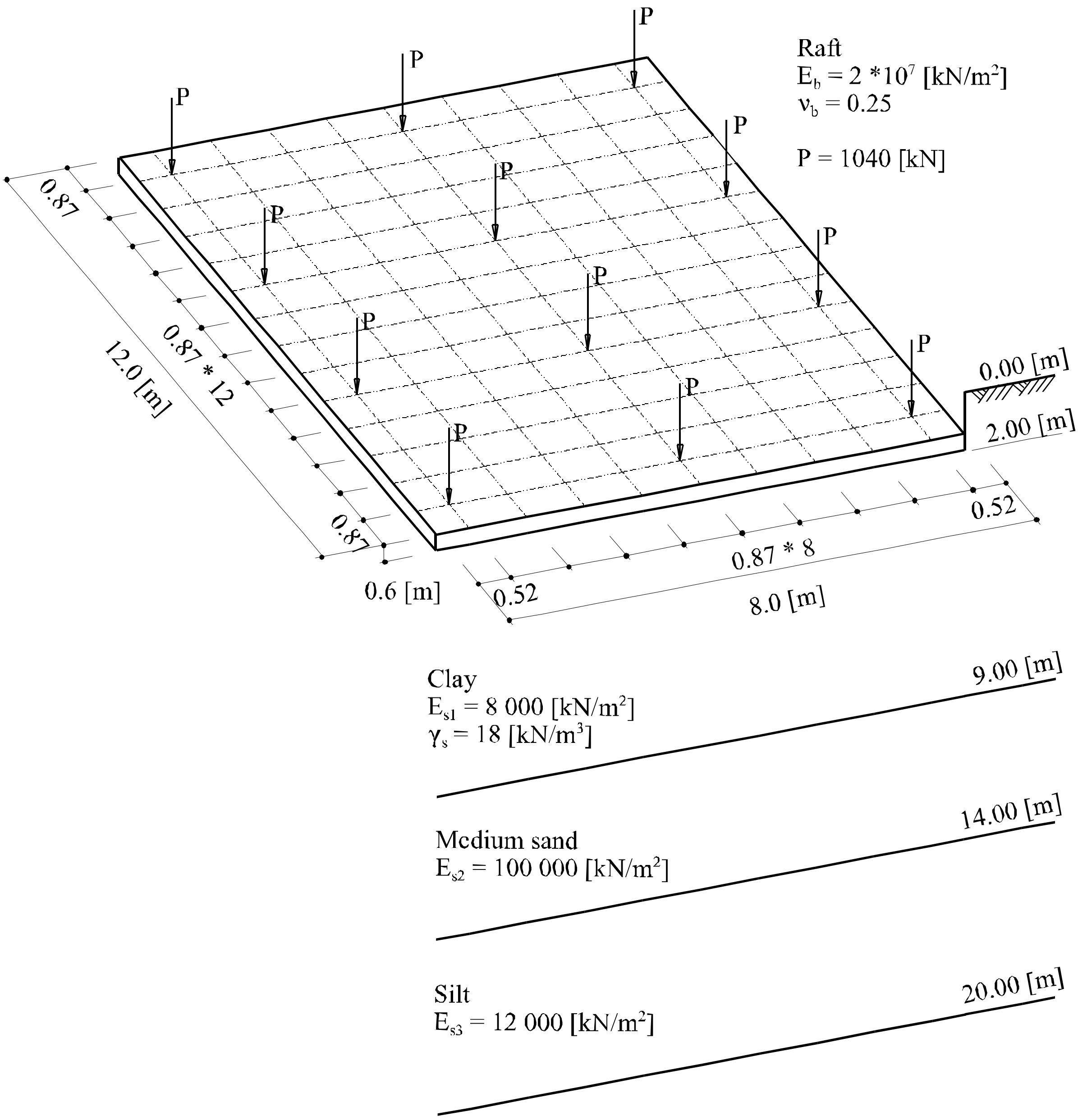


Figure 9.32 Raft dimensions, loads, FE-Net and subsoil

9.8.6.5 Settlement calculations by hand

The average contact pressure q_o is given by

$$q_o = \Sigma P/A_f = 12 \times 1040 \,/\, (8 \times 12) = 130 \text{ [kN/ m}^2\text{]}.$$

The raft settlement is obtained at the characteristic point *o* by hand calculation. This point *o* takes the coordinates a_c = 0.87 *A* and b_c = 0.87 *B* as shown in Figure 9.33. The raft is divided into four rectangular areas I, II, III and IV as shown in Figure 9.33. The settlement of point *o* is then the sum of settlements of areas I, II, III and IV.

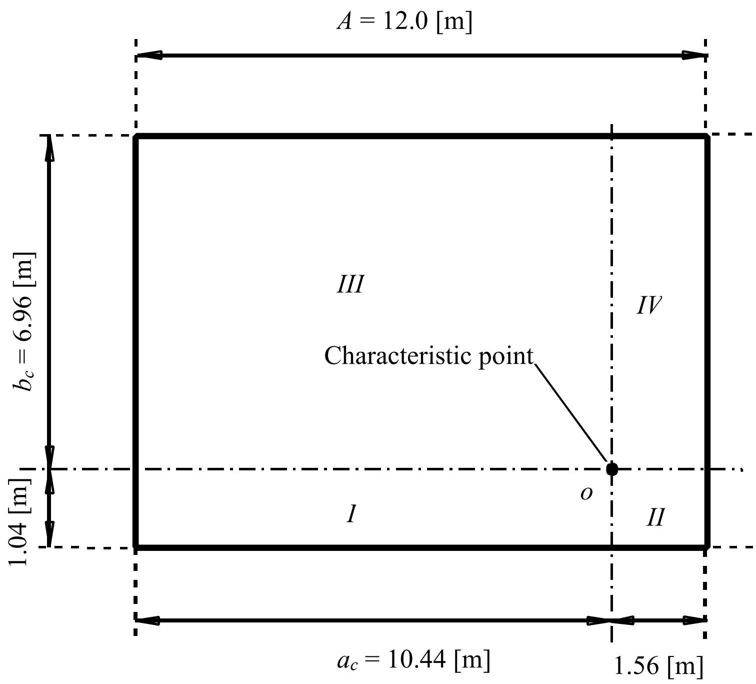


Figure 9.33 Characteristic point o of the settlement on the raft

According to *Steinbrenner* (1934) the settlement *s* of a point lying at a depth *z* under the corner of a rectangular loaded area *a* × *b* and intensity *q* is given by

$$s = \frac{q(1-\nu_s^{\,2})}{2\,\pi\,E_s}\left(b \times \ln\frac{(c-a)(m+a)}{(c+a)(m-a)} + a \times \ln\frac{(c-b)(m+b)}{(c+b)(m-b)}\right) + \frac{q(1-\nu_s-2\nu_s^{\,2})}{2\,\pi\,E_s}\left(z\,\tan^{-1}\frac{a\,b}{z\,c}\right) \qquad (42)$$

The above equation can be rewritten as:

$$s = \frac{q}{2\,\pi\,E_s}\left(B_n + A_n + D_n\right) = \frac{q}{2\,\pi\,E_s}c_n = \frac{q}{E_s}f \qquad (43)$$

Where $m = \sqrt{(a^2+b^2)}$ and $c = \sqrt{(a^2+b^2+z^2)}$

The settlement calculations of the 1st soil layer are carried out in Table 9.11.

Table 9.11 Settlement calculations of the 1st soil layer (z_1 = 7 [m])

Area	a [m]	b [m]	m [m]	c [m]	B_n	A_n	D_n	C_n
I	6.96	1.56	7.133	9.994	4.183	0.904	1.078	6.165
II	1.04	1.56	1.875	7.247	1.500	2.030	0.224	3.754
III	6.96	10.44	12.547	14.368	2.013	3.803	4.380	10.196
IV	1.04	10.44	10.492	12.613	0.351	3.788	0.857	4.996
ΣC_n								25.111

The settlement coefficient f_1 for the 1st layer is given by:

$$f_1 = \Sigma C_n / 2\pi = 25.111/ (2\pi) = 3.997$$

The settlement s_1 for the 1st soil layer is given by:

$$s_1 = q_o f_1 / E_{s1} = 130 \times 3.997/ 8000 = 0.06494 \text{ [m]}$$

In similar manner, the settlement coefficient f_2 for a soil layer until depth z =12 [m] is

$$f_2 = 5.2$$

The settlement s_2 for the 2nd soil layer is given by:

$$s_2 = q_o (f_2 - f_1)/ E_{s2} = 130 (5.2 -3.997)/ 100000 = 0.00156 \text{ [m]}$$

The settlement coefficient f_3 for a soil layer until depth z = 18 [m] is

$$f_3 = 6.038$$

The settlement s_3 for the 3rd soil layer is given by:

$$s_3 = q_o (f_2 - f_3)/ E_{s3} = 130 (6.038 - 5.2)/ 12000 = 0.00908 \text{ [m]}$$

The total settlement s_o for all layers is given by:

$$s_o = s_1 + s_2 + s_3 = 0.06494 + 0.00156 + 0.00908 = 0.07558 \text{ [m]}$$

The main modulus of subgrade reaction k_{sm} is given by:

$$k_{sm} = q_o / s_o = 130/ 0.07558 = 1720 \text{ [kN/m}^3\text{]}$$

9.8.6.6 Comparison of results

Table 9.12 compares the values of modulus of subgrade reaction obtained by using *Steinbrenner's* formula (1934) through hand calculation with that of *GEO Tools*. It shows that the main modulus k_{sm} computed by using *Steinbrenner's* formula and that by *GEO Tools* are nearly the same.

Table 9.12 Main modulus of subgrade reaction k_{sm} computed by using *Steinbrenner's* formula and *GEO Tools*

Item	Hand calculation	*GEO Tools*	Difference [%]
Main modulus k_{sm} [kN/m^3]	1720	1720	0.0

9.8.6.7 Presentation of data and results

The input data and results of the settlement calculations of the raft are shown on the next pages.

```
*********************************************************
                         GEO Tools
                        Version 13
          Program authors M. El Gendy/ A. El Gendy
*********************************************************
Title: Main modulus of subgrade reaction ksm
Date: 04-01-2018
Project: Example 5
File: BET

------------------------------------------------------------
Settlements of footing groups
------------------------------------------------------------

Main Soil Data:

Groundwater depth under the ground surface    Tw [m]     = 20.00
Settlement reduction factor                   α  [-]     = 1.00
Unit weight of footing concrete               γb [kN/m3] = 0.00

Loads and dimensions:
```

Footing No. I	Load on Footing Pa [kN]	Length Am [m]	Breadth Bm [m]	Thickness Dm [m]	Foundation Depth Tf [m]	X-coord. Xm [m]	Y-coord. Ym [m]	Rotating angle β [°]	Height Hm [m]
1	12480	12.00	8.00	0.60	2.00	6.00	4.00	0.00	0.00

Boring:

Layer No. I [-]	Level of layer under ground z [m]	Modulus of compressibility for loading Es [kN/m2]	Modulus of compressibility for reloading Ws [kN/m2]	Poisson's ratio of the soil νs [-]	Unit weight of the soil γs [kN/m3]
1	9.00	8000	8000	0.00	18.00
2	14.00	100000	100000	0.00	18.00
3	20.00	12000	12000	0.00	18.00

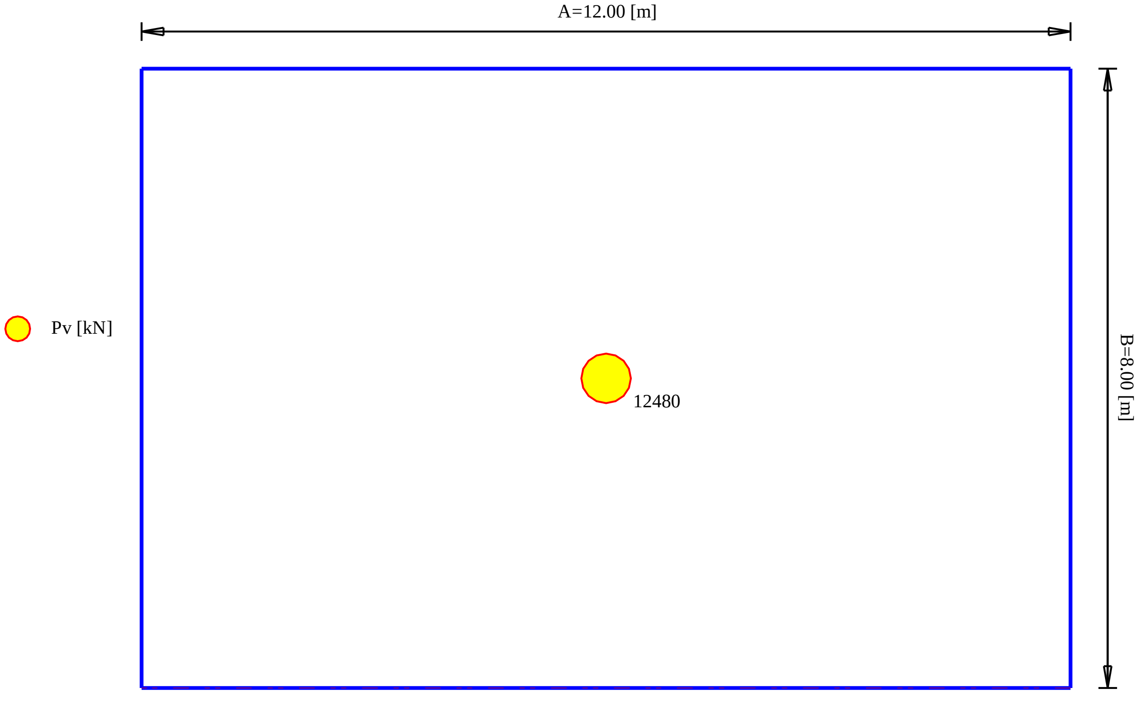
```
Settlement calculation for rigid centric loaded footings

Footing No.: 1
Overburden pressure                         Qv  [kN/m2] = 36
Loading                                     Qe  [kN/m2] = 94
Contact pressure                            Qo  [kN/m2] = 130
Modulus of subgrade reaction                ks  [kN/m3] = 1720

Final settlements of rigid footing:
Settlement of the corner: right up          S1  [cm]    = 7.56
Settlement of the corner: right down        S2  [cm]    = 7.56
Settlement of the corner: left down         S3  [cm]    = 7.56
Settlement of the corner: left up           S4  [cm]    = 7.56
Average settlement                          Sm  [cm]    = 7.56

Immediate settlement parts:
Settlement of the corner: right up          Sf1 [cm]    = 4.57
Settlement of the corner: right down        Sf2 [cm]    = 4.57
Settlement of the corner: left down         Sf3 [cm]    = 4.57
Settlement of the corner: left up           Sf4 [cm]    = 4.57
Average settlement                          Smf [cm]    = 4.57
```

Method (8) (Layered soil model)
Modulus of Compressibility for Rigid Raft



System of loading Pv [kN]

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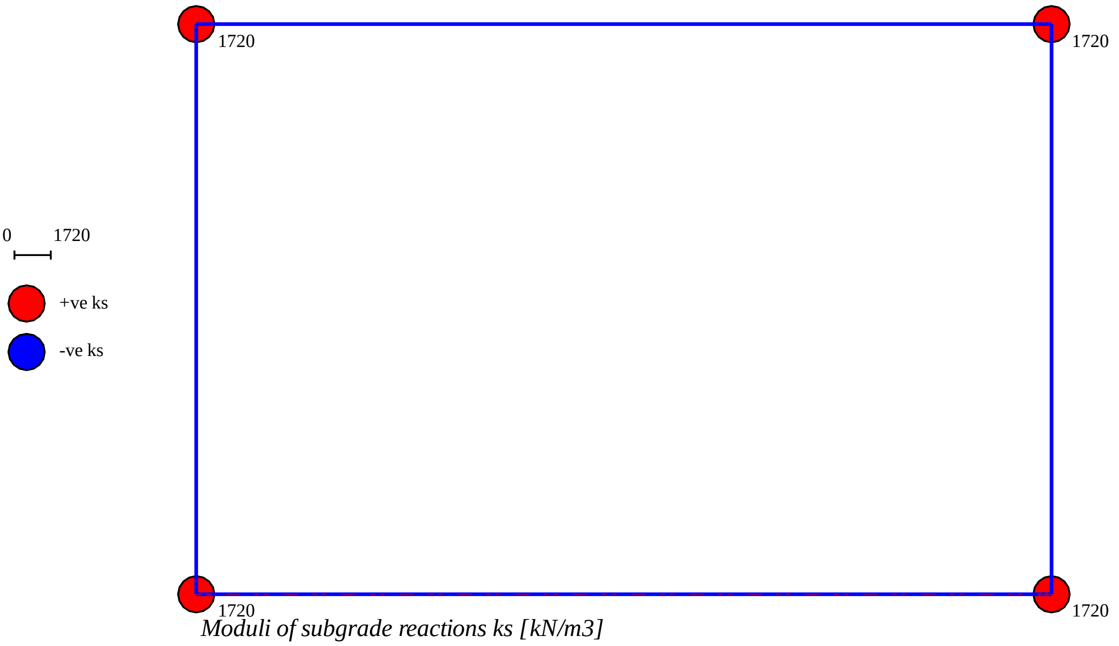
Scale: 80	**Title: Main modulus of subgrade reaction ksm**
File: BET	**Date: 04-01-2018**
Page No.:	**Project: Example 5**

Method (8) (Layered soil model)

Modulus of Compressibility for Rigid Raft



Moduli of subgrade reactions ks [kN/m3]

Max. ks = 1720 at node 1, Min. ks = 1720 at node 1

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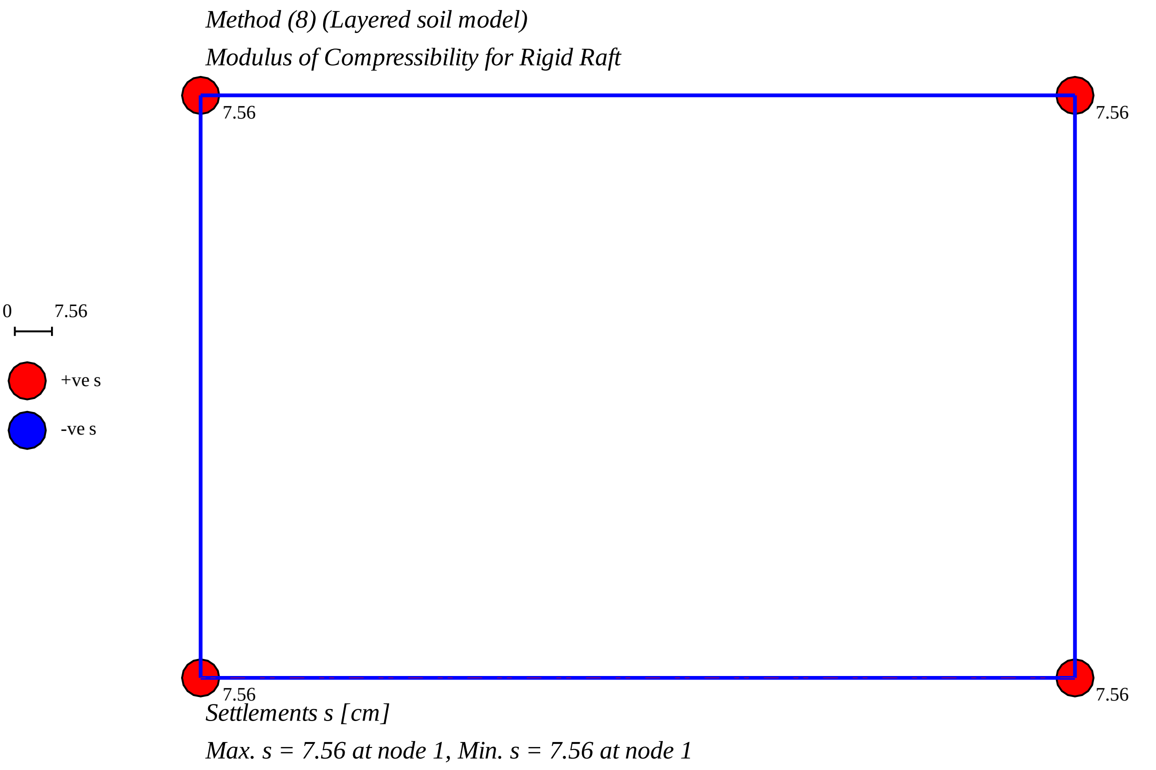
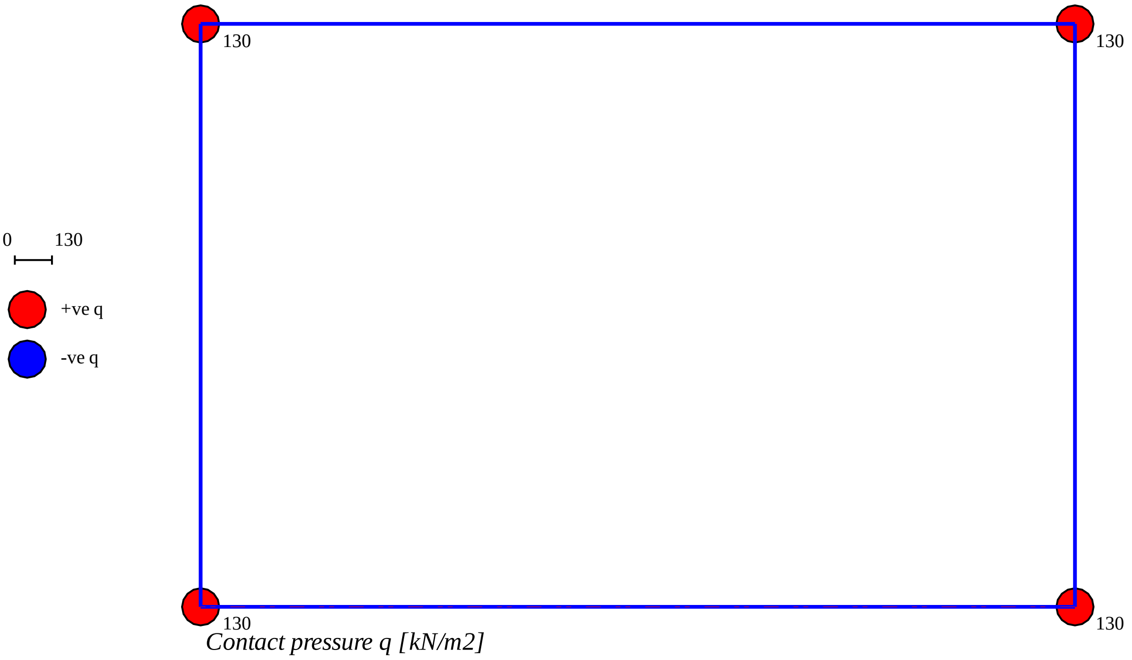
Scale: 85	**Title: Main modulus of subgrade reaction ksm**
File: BET	**Date: 04-01-2018**
Page No.:	**Project: Example 5**



GEOTEC Software Inc., Calgary AB, Canada T3E 7Y7 PO Box 14001 Richmond Road PO, Tele.:+1(587) 332-3323	
Scale: 85	**Title: Main modulus of subgrade reaction ksm**
File: BET	**Date: 04-01-2018**
Page No.:	**Project: Example 5**

Method (8) (Layered soil model)

Modulus of Compressibility for Rigid Raft



Contact pressure q [kN/m2]

Max. q = 130 at node 1, Min. q = 130 at node 1

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PO Box 14001 Richmond Road PO, Tele.:+1(587) 332-3323	
Scale: 85	**Title: Main modulus of subgrade reaction ksm**
File: BET	**Date: 04-01-2018**
Page No.:	**Project: Example 5**

9.8.7 Example 6: Rigid square raft on Isotropic elastic half-space medium

File name QUA

9.8.7.1 Description of the problem

To verify the mathematical model of *GEO Tools* for rigid square raft, the results of a rigid square raft obtained by other analytical solutions from *Kany* (1974), *Fraser/ Wardle* (1976), *Chow* (1987), *Li/ Dempsey* (1988) and *Stark* (1990), Section 5.4, page 114, are compared with those obtained by *GEO Tools*.

The vertical displacement *w* [m] of a rigid square raft on Isotropic elastic half-space medium may be evaluated by

$$w = \frac{P\,B\,(1-\nu_s{}^2)}{E_s}\,I \qquad (44)$$

where:

ν_s *Poisson's* ratio of the soil [-]

E_s *Young's* modulus of the soil [kN/m^2]

B Raft side [m]

I Displacement influence factor [-]

p Load intensity on the raft [kN/m^2]

A square raft on Isotropic elastic half-space soil medium is chosen. In the literatures of *Fraser/ Wardle* (1976), *Chow* (1987), *Li/ Dempsey* (1988) and *Stark* (1990) the raft is divided into nets with different dimensions. The nets range from 2 × 2 to 48 × 48 elements. The net of 16 × 16 elements is used to comparison here. Load on the raft, raft side and the elastic properties of the soil are chosen to make the first term from Eq. 44 equal to unit, hence:

Raft side	B	= 10	[m]
Uniform load on the raft	p	= 500	[kN/m^2]
Modulus of compressibility	E_s	= 5000	[kN/m^2]
Poisson's ratio of the soil	ν_s	= 0.0	[-]

9.8.7.2 Analysis of the raft

The assumption of the isotropic elastic half-space model requires an infinite compressible soil layer under the foundation. To simulate the elastic-isotropic half-space, the subsoil is defined by a layer of 1000 [m].

The available method "9- Settlements of footing groups" in the GEO Tools program can be used here to determine the vertical displacement of the rigid plate on the elastic-isotropic half-space medium. Figure 9.34 shows the quarter of the raft with a net of total 16 × 16 elements.

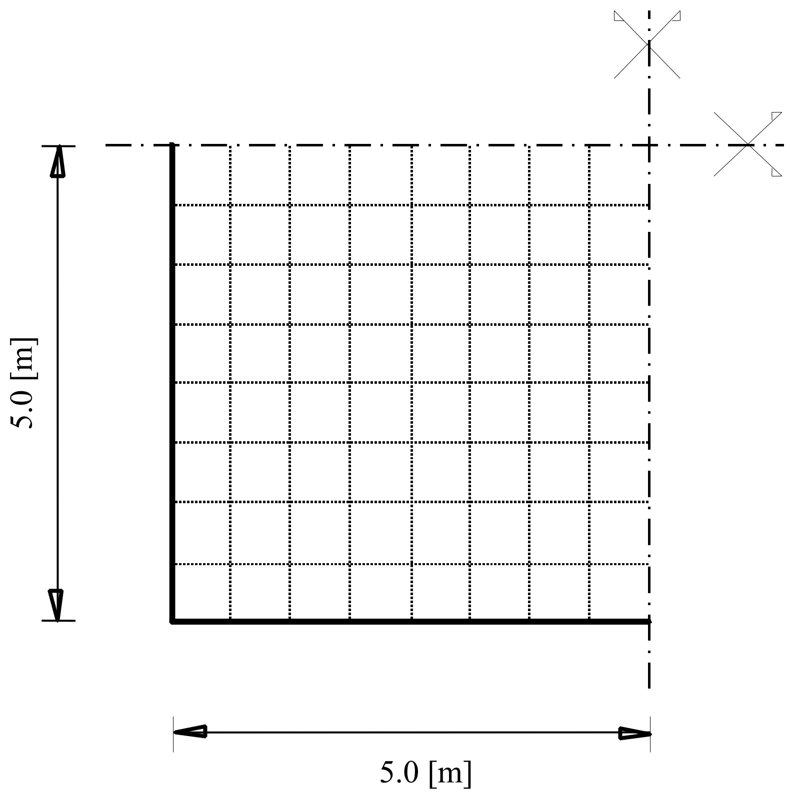


Figure 9.34 Quarter of rigid square raft with dimensions and FE-Net

9.8.7.3 Results

Table 9.13 shows the comparison of the displacement influence factor *I* obtained by *GEO Tools* with those obtained by other published solutions from *Fraser/ Wardle* (1976), *Chow* (1987), *Li/ Dempsey* (1988) and *Stark* (1990) for a net of 16 × 16 elements. In addition, the displacement influence factor *I* is obtained by using *Kany's* charts (1974) through the conventional solution of a rigid raft.

Table 9.13 Comparison of displacement influence factor *I* obtained by *GEO Tools* with those obtained by other authors for a net of 16 × 16 elements

Displacement influence factor *I* [-]					
Kany (1974)	*Fraser/ Wardle* (1976)	*Chow* (1987)	*Li/ Dempsey* (1988)	*Stark* (1990)	*GEO Tools*
0.85	0.835	0.8675	0.8678	0.8581	0.8539

9.8.7.4 Presentation of data and results

The input data and results of the settlement calculations of the raft are shown on the next pages.

```
**************************************************************
                          GEO Tools
                         Version 13
          Program authors M. El Gendy/ A. El Gendy
**************************************************************
Title: Rigid square raft
Date: 25-01-2018
Project: Example 6
File: QUA

--------------------------------------------------------------
Settlements of footing groups
--------------------------------------------------------------

Main Soil Data:

Groundwater depth under the ground surface     Tw [m]     = 0.00
Settlement reduction factor                    α  [-]     = 1.00
Unit weight of footing concrete                γb [kN/m3] = 0.00

Loads and dimensions:
-----------------------------------------------------------------------------------------------
Footing  Load on  Length  Breadth  Thickness  Foundation  X-coord.  Y-coord.  Rotating  Height
    No.  Footing                                   Depth                         angle
      I       Pa      Am       Bm         Dm          Tf        Xm        Ym         β      Hm
            [kN]     [m]      [m]        [m]         [m]       [m]       [m]       [°]     [m]
-----------------------------------------------------------------------------------------------
      1    50000   10.00    10.00       1.00        0.00      5.00      5.00      0.00    0.00
-----------------------------------------------------------------------------------------------

Boring:
----------------------------------------------------------------------------
Layer  Level of        Modulus of        Modulus of    Poisson's  Unit weight
  No.     layer  compressibility  compressibility        ratio  of the soil
          under      for loading    for reloading  of the soil
         ground
    I         z               Es               Ws           νs           γs
  [-]       [m]          [kN/m2]          [kN/m2]          [-]      [kN/m3]
----------------------------------------------------------------------------
    1   1000.00             5000             5000         0.00        18.00
----------------------------------------------------------------------------

Settlement calculation for rigid centric loaded footings

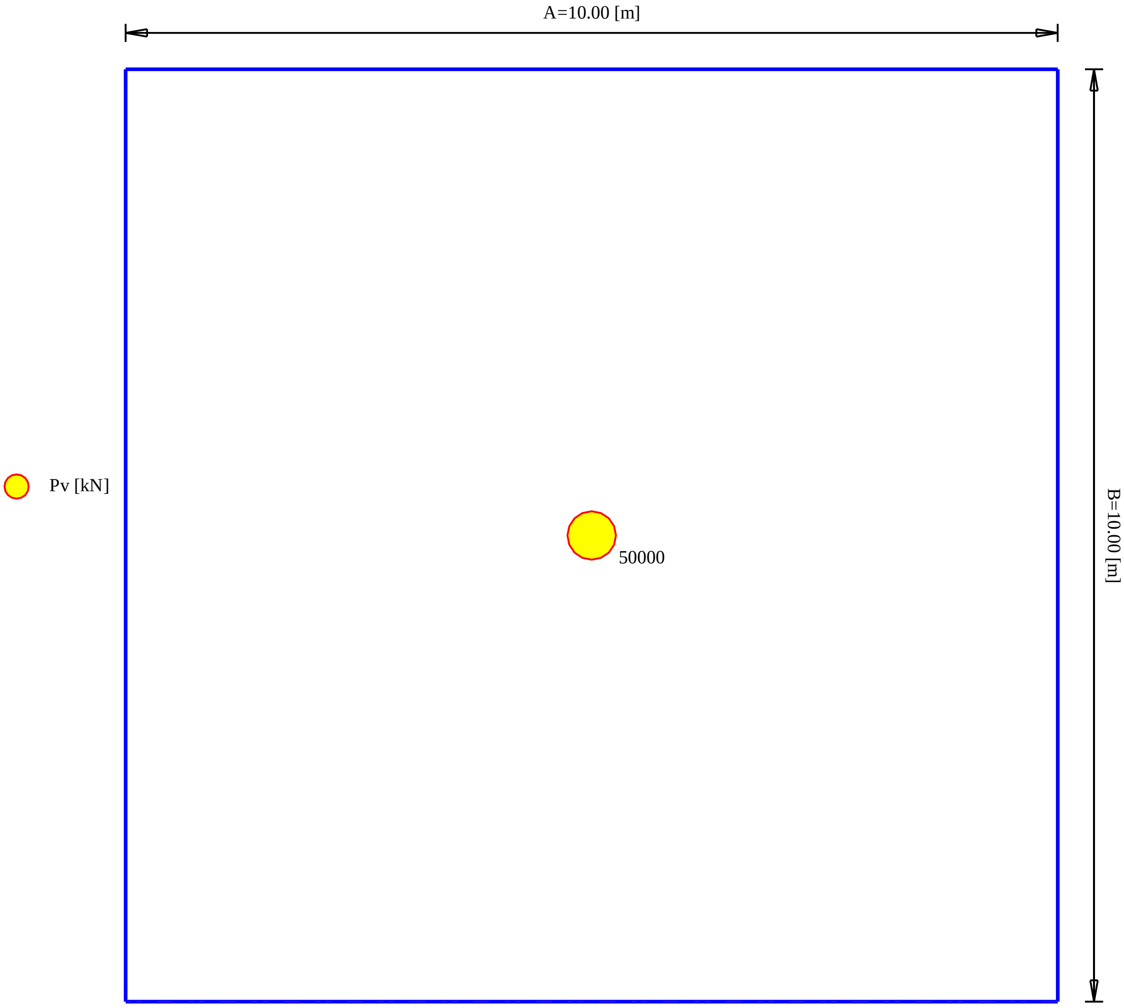
Footing No.: 1
Overburden pressure                         Qv  [kN/m2] = 0
Loading                                     Qe  [kN/m2] = 500
Contact pressure                            Qo  [kN/m2] = 500
Modulus of subgrade reaction                ks  [kN/m3] = 586

Final settlements of rigid footing:
Settlement of the corner: right up          S1  [cm]    = 85.39
Settlement of the corner: right down        S2  [cm]    = 85.39
Settlement of the corner: left down         S3  [cm]    = 85.39
Settlement of the corner: left up           S4  [cm]    = 85.39
Average settlement                          Sm  [cm]    = 85.39

Immediate settlement parts:
Settlement of the corner: right up          Sf1 [cm]    = 63.93
Settlement of the corner: right down        Sf2 [cm]    = 63.93
Settlement of the corner: left down         Sf3 [cm]    = 63.93
Settlement of the corner: left up           Sf4 [cm]    = 63.93
Average settlement                          Smf [cm]    = 63.93
```

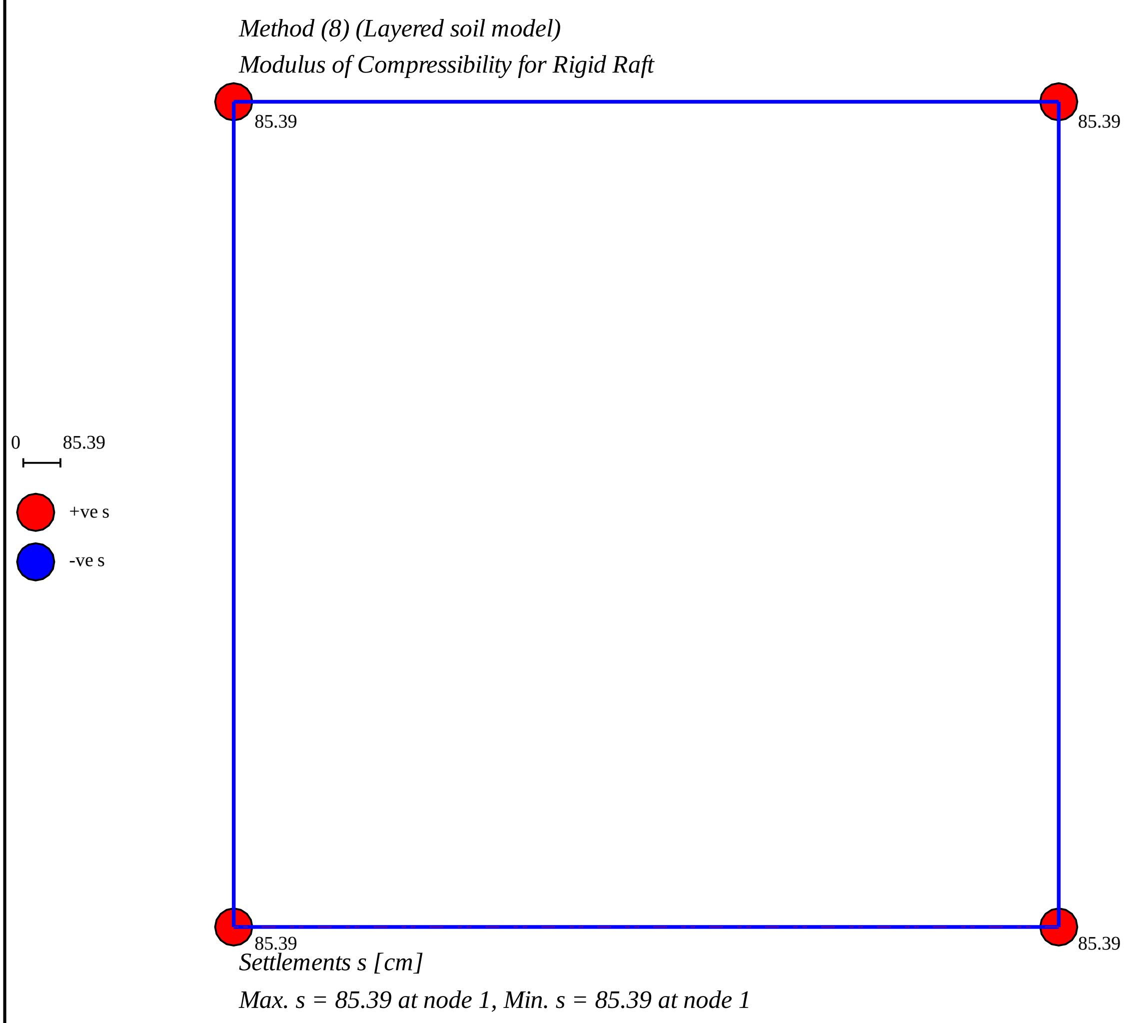
Method (8) (Layered soil model)

Modulus of Compressibility for Rigid Raft



System of loading Pv [kN]

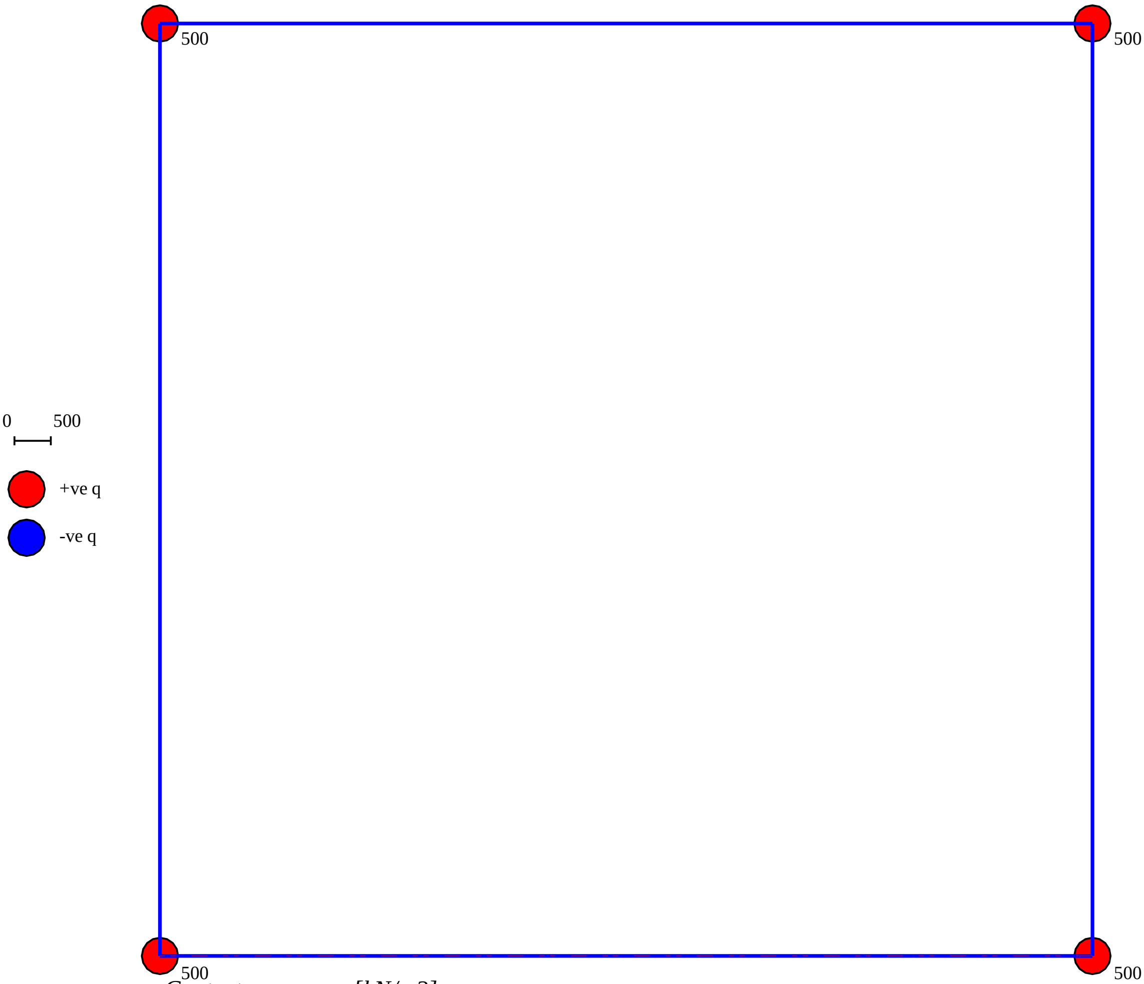
GEOTEC Software Inc., Calgary AB, Canada T3E 7Y7 PO Box 14001 Richmond Road PO, Tele.:+1(587) 332-3323	
Scale: 65	**Title: Rigid square raft**
File: QUA	**Date: 25-01-2018**
Page No.:	**Project: Example 6**



GEOTEC Software Inc., Calgary AB, Canada T3E 7Y7 PO Box 14001 Richmond Road PO, Tele.:+1(587) 332-3323	
Scale: 75	**Title: Rigid square raft**
File: QUA	**Date: 25-01-2018**
Page No.:	**Project: Example 6**

Method (8) (Layered soil model)

Modulus of Compressibility for Rigid Raft



Contact pressure q [kN/m2]

Max. q = 500 at node 1, Min. q = 500 at node 1

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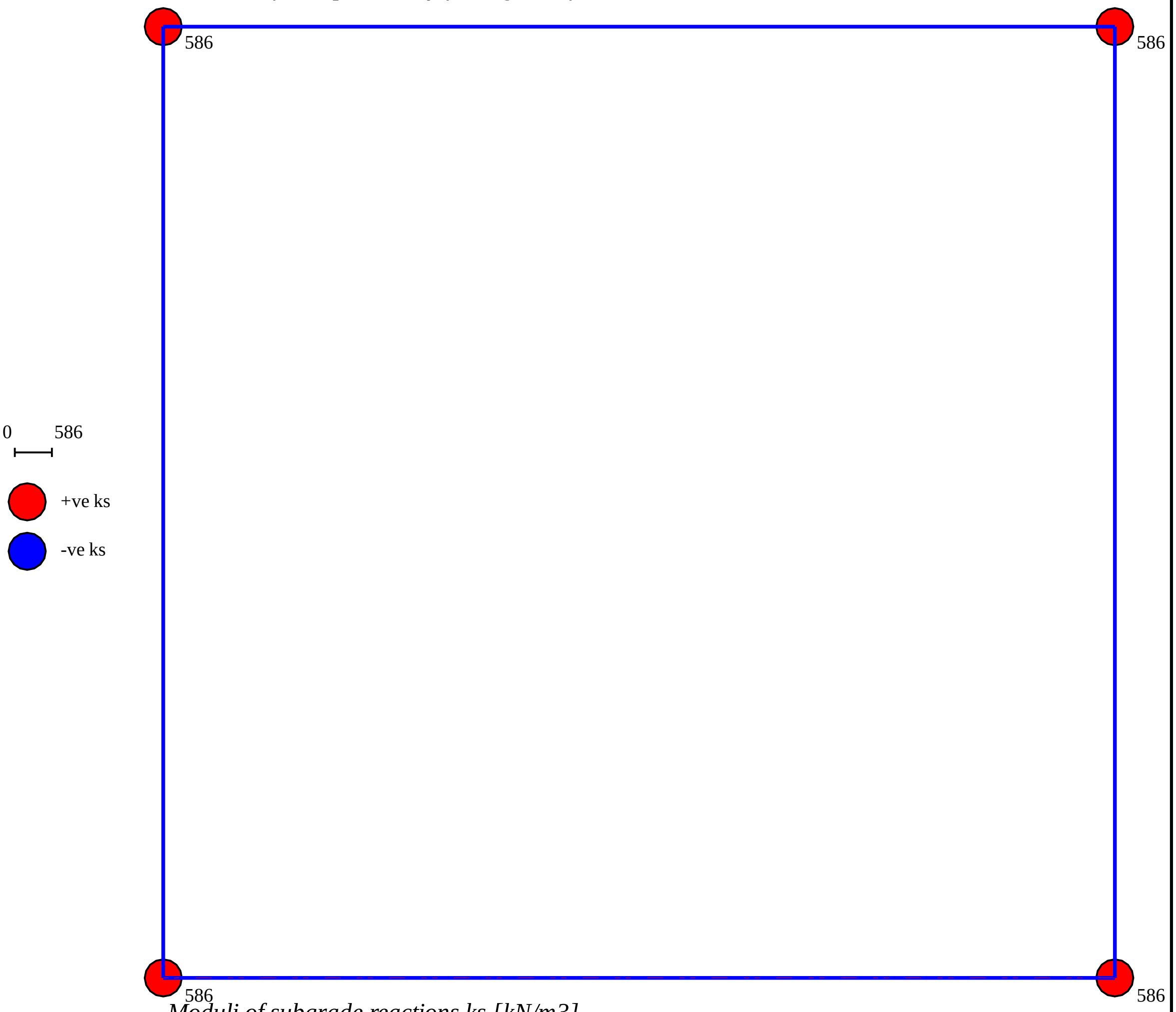
Scale: 65	**Title: Rigid square raft**
File: QUA	**Date: 25-01-2018**
Page No.:	**Project: Example 6**

Method (8) (Layered soil model)

Modulus of Compressibility for Rigid Raft



Moduli of subgrade reactions ks [kN/m3]

Max. ks = 586 at node 1, Min. ks = 586 at node 1

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Scale: 65	**Title: Rigid square raft**
File: QUA	**Date: 25-01-2018**
Page No.:	**Project: Example 6**

9.8.8 Example 7: Immediate settlement under an isolated footing

File name SZ2

9.8.8.1 Description of the problem

GEO Tools can be used to calculate the immediate (elastic) settlement of an isolated footing on a horizontally layered subsoil. undrained moduli *E* and *W* for bilinear deformation behavior are defined. The unit weight of the footing γ_b, the footing thickness and the foundation depth are defined and considered. The modulus of sub grade reaction is also calculated.

An isolated footing *Am*=4 [m] × *Bm*=2 [m], with a uniform load of q = 150 [kN/m^2], is located at a depth *Tf* = 1.0 [m] in a clay layer of 5.0 [m] thick for which the undrained modulus of the layer for loading is E = 40 000 [kN/m^2] and for reloading W = 120 000 [kN/m^2]. The layer is underlain by a second clay layer 8.0 [m] thick for which the undrained modulus of the layer for loading E = 75 000 [kN/m^2] and for reloading W = 225 000 [kN/m^2]. A hard stratum lies below the second layer. A plan of the footing with dimensions and a section through the ground under the footing are shown in Figure 9.35. The unit weight of the footing concrete is γ_b =25 [kN/m^3], while foundation depth under the ground surface is *Dm* = 0.5 [m].

The average immediate (elastic) settlement under the isolated footing with uniform pressure q [kN/m^2] on the surface of saturated clay soil layers, in which the *Poisson's* ratio ν_s = 0.5 [-], should be calculated using the *GEO Tools* program. Such settlement occurs under undrained conditions.

9.8.8.2 Soil properties

Figure 9.35 shows a plan of the isolated footing with dimensions and loading, and also a section in the subsoil of the two layers. The following soil properties for the two layers are defined in Table 9.14:

Table 9.14 Soil properties

Layer No. I	Type of soil	Depth of the soil layer under the ground surface Z [m]	Undrained modulus for loading E [kN/m^2]	reloading W [kN/m^2]	Unit weight of the soil γ_s [kN/m^3]
1	Clay	5	40 000	120 000	18
2	Clay	13	75 000	225 000	18

Poisson's ratio is ν_s = 0.5 [-] for the two layers. The foundation dept of the footing is *Tf* = 1.0 [m].

The redaction factor is α = 1. The limit depth ratio is *Cs* = 0.2 and the groundwater depth is *Tw* = 13 [m] under the ground surface.

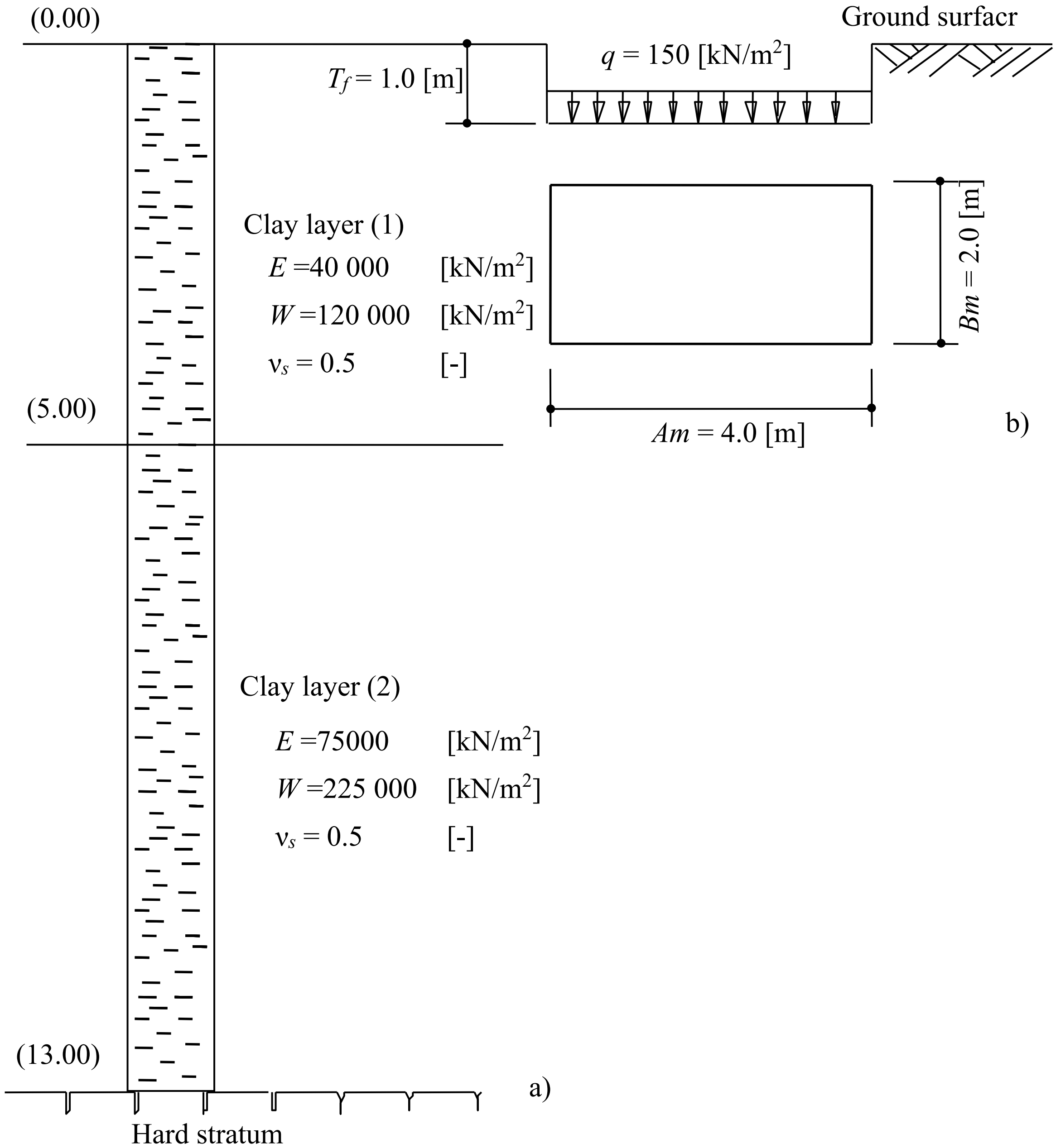


Figure 9.35 a) Section through the soil and the footing
b) Plan of the footing with dimensions and loading

9.8.8.3 Analysis and results

Because the dimensions of the footing are relatively small, the footing can be treated as a rigid footing resting on compressible subsoil. In this case it suffices to determine the immediate settlement at the characteristic point, Figure 9.36.

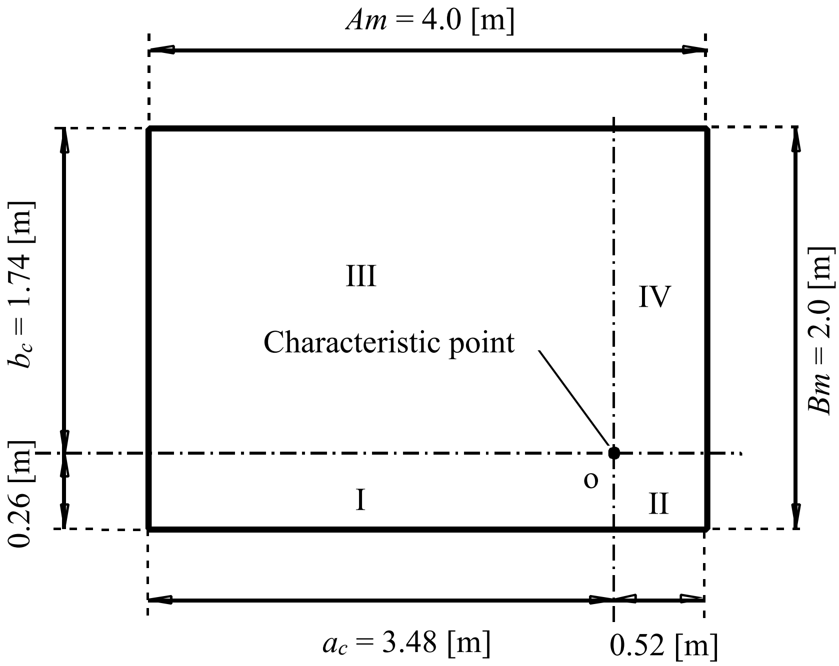


Figure 9.36 Characteristic point *o* of the settlement at the footing

9.8.8.4 Immediate settlement by GEO Tools

After defining and saving the project identification, system data, footing dimension, loading and soil properties by the *GEO Tools* program. The limit depth for the foundation can then be calculated. Then, the immediate settlement is calculated at the characteristic point of the footing.

9.8.8.5 Presentation of data and results

The input data and results of the settlement calculations of the raft are shown on the next pages.

```
**********************************************************
                         GEO Tools
                        Version 13
          Program authors M. El Gendy/ A. El Gendy
**********************************************************
Title: Settlement calculation for an isolated footing
Date: 25-01-2018
Project: Example 7
File: SZ2

----------------------------------------------------------
Settlements of footing groups
----------------------------------------------------------
Data of limit depth:

Strip thickness for depth by iteration                    Dz [m]     = 0.5
Standard ratio of limit depth (1>Cs, Cs>=0)               Cs [-]     = 0.2

Main Soil Data:

Groundwater depth under the ground surface                Tw [m]     = 13.00
Settlement reduction factor                               α  [-]     = 1.00
Unit weight of footing concrete                           γb [kN/m3] = 25.00

Overburden pressure                                       Qv [kN/m2] = 18
Loading                                                   Qe [kN/m2] = 145
Contact pressure                                          Qo [kN/m2] = 163
Limit depth under ground surface (Footing No. 1/ Max. Load) ZG [m]     = 5.58
Lies at layer                                             U  [-]     = 2
```

Loads and dimensions:

Footing No.	Load on Footing	Length	Breadth	Thickness	Foundation Depth	X-coord.	Y-coord.	Rotating angle	Height
I	Pa	Am	Bm	Dm	Tf	Xm	Ym	β	Hm
	[kN]	[m]	[m]	[m]	[m]	[m]	[m]	[°]	[m]
1	1200	4.00	2.00	0.50	1.00	2.00	1.00	0.00	0.00

Boring:

Layer No.	Level of layer under ground	Modulus of compressibility for loading	Modulus of compressibility for reloading	Poisson's ratio of the soil	Unit weight of the soil
I	z	Es	Ws	νs	γs
[-]	[m]	[kN/m2]	[kN/m2]	[-]	[kN/m3]
1	5.00	40000	120000	0.50	18.00
2	13.00	75000	225000	0.50	18.00

Stress on soil against depth (Footing No. 1/ Max. Load):

Iteration No.	Depth under foundation	Stress due to foundation	Stress from soil weight	ratio
I	z	SE	SV	SE/SV
	[m]	[kN/m2]	[kN/m2]	[-]
0	0.00	163	18	9.03
1	0.50	117	27	4.34
2	1.00	82	36	2.26
3	1.50	63	45	1.39
4	2.00	50	54	0.93
5	2.50	41	63	0.65
6	3.00	34	72	0.47
7	3.50	28	81	0.35
8	4.00	24	90	0.27
9	4.50	20	99	0.21
10	5.00	18	108	0.16

```
Settlement calculation for rigid centric loaded footings

Footing No.: 1
Overburden pressure                          Qv  [kN/m2] = 18

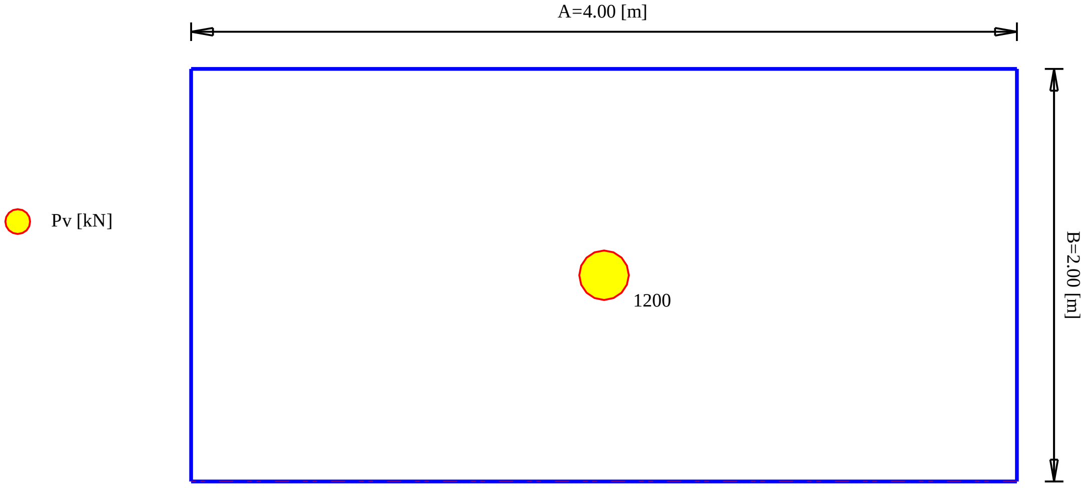
Loading                                      Qe  [kN/m2] = 145
Contact pressure                             Qo  [kN/m2] = 163
Modulus of subgrade reaction                 ks  [kN/m3] = 41711

Final settlements of rigid footing:
Settlement of the corner: right up           S1  [cm]    = 0.39
Settlement of the corner: right down         S2  [cm]    = 0.39
Settlement of the corner: left down          S3  [cm]    = 0.39
Settlement of the corner: left up            S4  [cm]    = 0.39
Average settlement                           Sm  [cm]    = 0.39

Immediate settlement parts:
Settlement of the corner: right up           Sf1 [cm]    = 0.39
Settlement of the corner: right down         Sf2 [cm]    = 0.39
Settlement of the corner: left down          Sf3 [cm]    = 0.39
Settlement of the corner: left up            Sf4 [cm]    = 0.39
Average settlement                           Smf [cm]    = 0.39
```

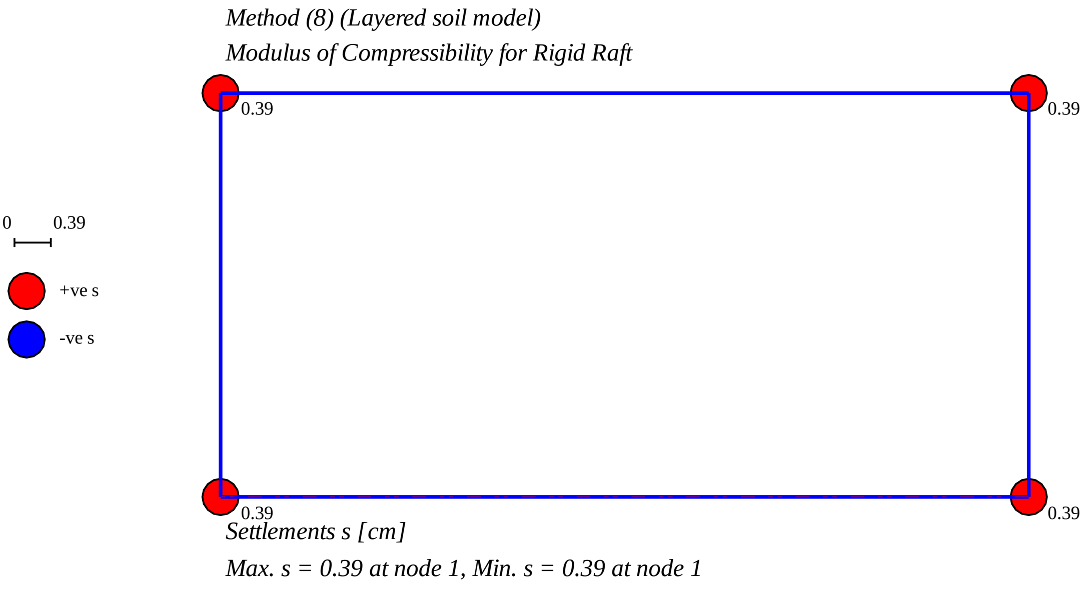
Method (8) (Layered soil model)

Modulus of Compressibility for Rigid Raft

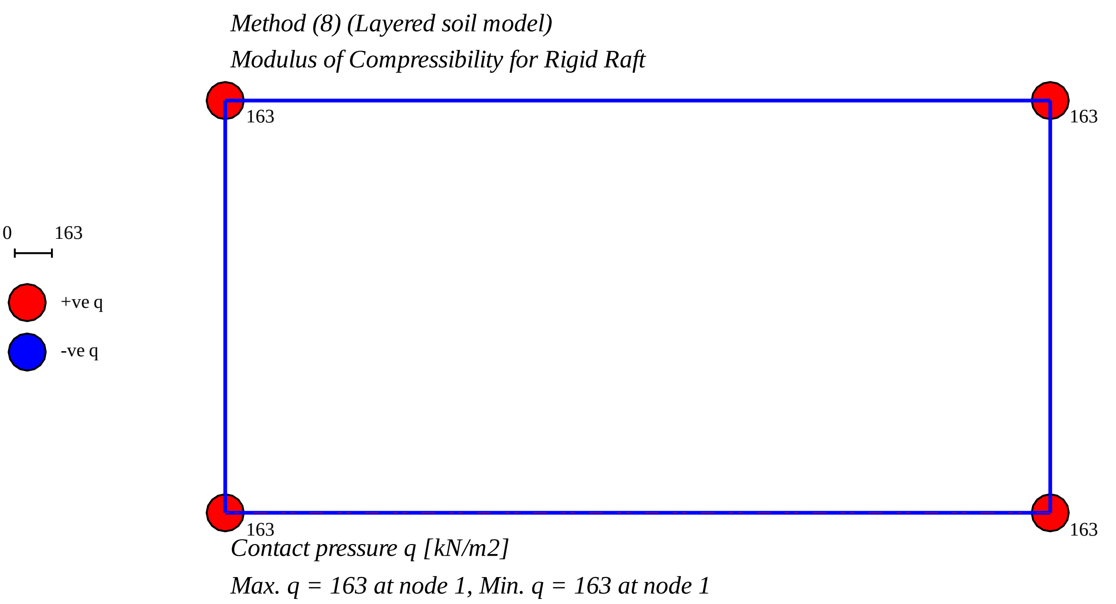


System of loading Pv [kN]

GEOTEC Software Inc., Calgary AB, Canada T3E 7Y7 **PO Box 14001 Richmond Road PO, Tele.:+1(587) 332-3323**	
Scale: 30	**Title: Settlement calculation for an isolated footing**
File: SZ2	**Date: 25-01-2018**
Page No.:	**Project: Example 7**

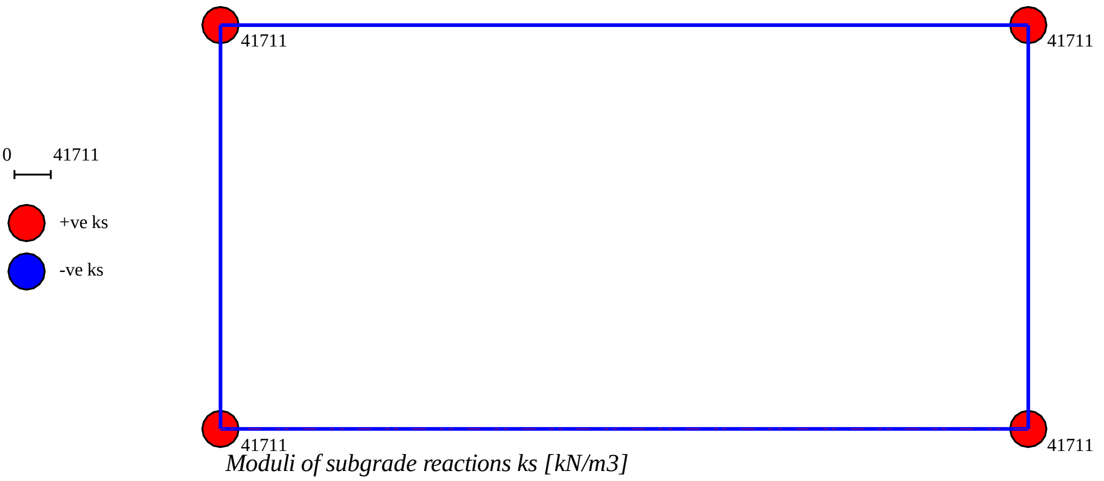


GEOTEC Software Inc., Calgary AB, Canada T3E 7Y7 PO Box 14001 Richmond Road PO, Tele.:+1(587) 332-3323	
Scale: 30	**Title: Settlement calculation for an isolated footing**
File: SZ2	**Date: 25-01-2018**
Page No.:	**Project: Example 7**



GEOTEC Software Inc., Calgary AB, Canada T3E 7Y7 PO Box 14001 Richmond Road PO, Tele.:+1(587) 332-3323	
Scale: 30	**Title: Settlement calculation for an isolated footing**
File: SZ2	**Date: 25-01-2018**
Page No.:	**Project: Example 7**

Method (8) (Layered soil model)
Modulus of Compressibility for Rigid Raft



Moduli of subgrade reactions ks [kN/m3]
Max. ks = 41711 at node 1, Min. ks = 41711 at node 1

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Scale: 30	**Title: Settlement calculation for an isolated footing**
File: SZ2	**Date: 25-01-2018**
Page No.:	**Project: Example 7**

9.8.9 Example 8: System of rigid centrally loaded square plates
File name SZ3

9.8.9.1 Description of the problem

The settlements from stress overlaps for the plate group shown in Figure 9.37, consisting of 36 small square plates lying close together, are to be calculated using the *GEO Tools* program. All plates are loaded in the middle. A concentrated load from a uniform surcharge acts on each of the plates is:

$Pa1 = ... = Pa36 = 135$ [kN].

The plat thickness is $Dm = 0.2$ [m], while the dimensions of a plate are $Am=1.5$ [m] length × $Bm=1.5$ [m] breadth. The unit weight of the plate concrete is $\gamma_b = 25$ [kN/m^3].

9.8.9.2 Soil properties

The group of plates rests on a subsoil with three layers of different soil materials. The following soil properties in Table 9.15 and Figure 9.38 are defined.

Table 9.15 Soil properties and depth of layers for the subsoil

Layer No.	Type of the soil	Depth of the soil layer under the ground surface Z [m]	Modulus of compressibility for loading E_s [kN/m^2]	Modulus of compressibility for reloading W_s [kN/m^2]	Unit weight of the soil γ_s [kN/m^3]
1	Sand	1.65	200 000	200 000	18
2	Sand	3	200 000	200 000	9
3	Silt	12	14 000	14 000	10

The groundwater depth is $Tw = 1.65$ [m] under the ground surface. *Poisson's* ratio is $\nu_s = 0.3$ [-] and constant for all three layers. The foundation depth for all plates is $Tf = 0.2$ [m]. The redaction factor is $\alpha = 1$. The limit depth ratio is $Cs = 0.2$.

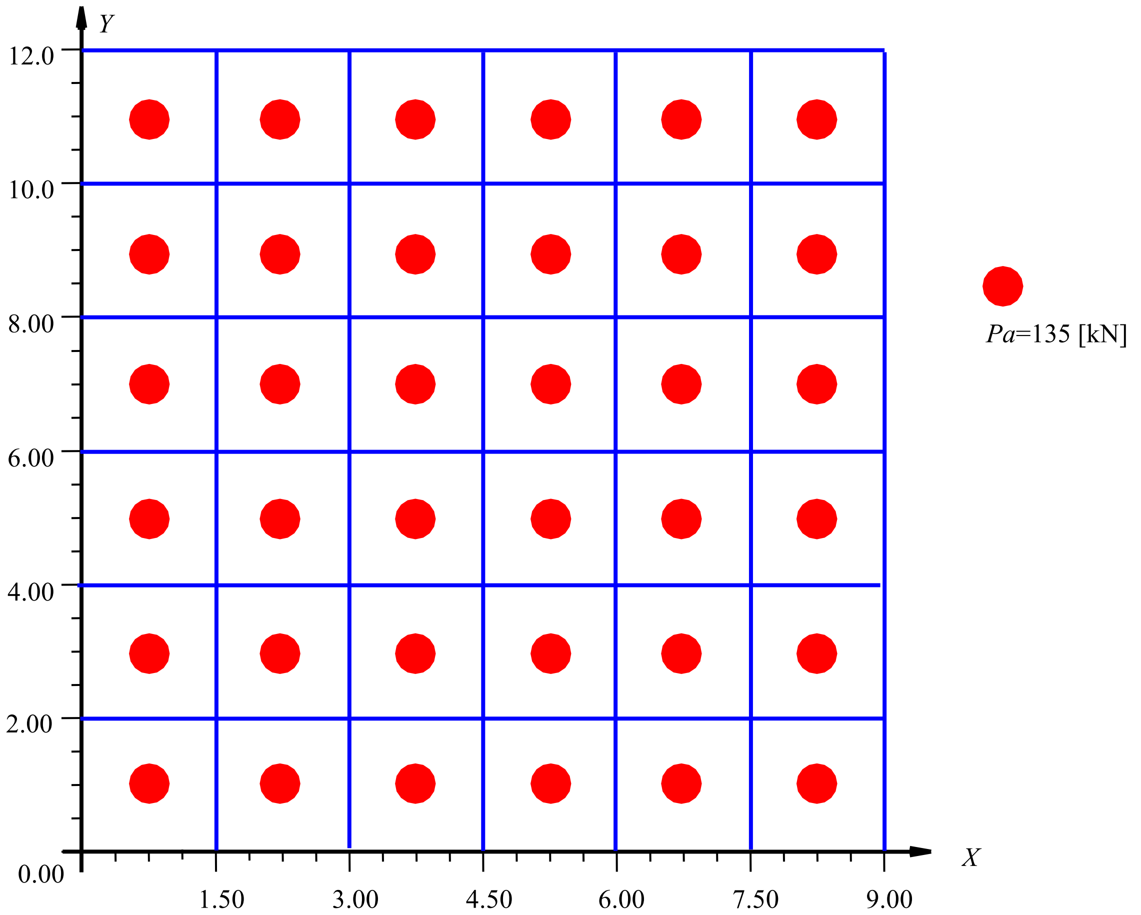

Figure 9.37 Plate group in plan with loads [kN]

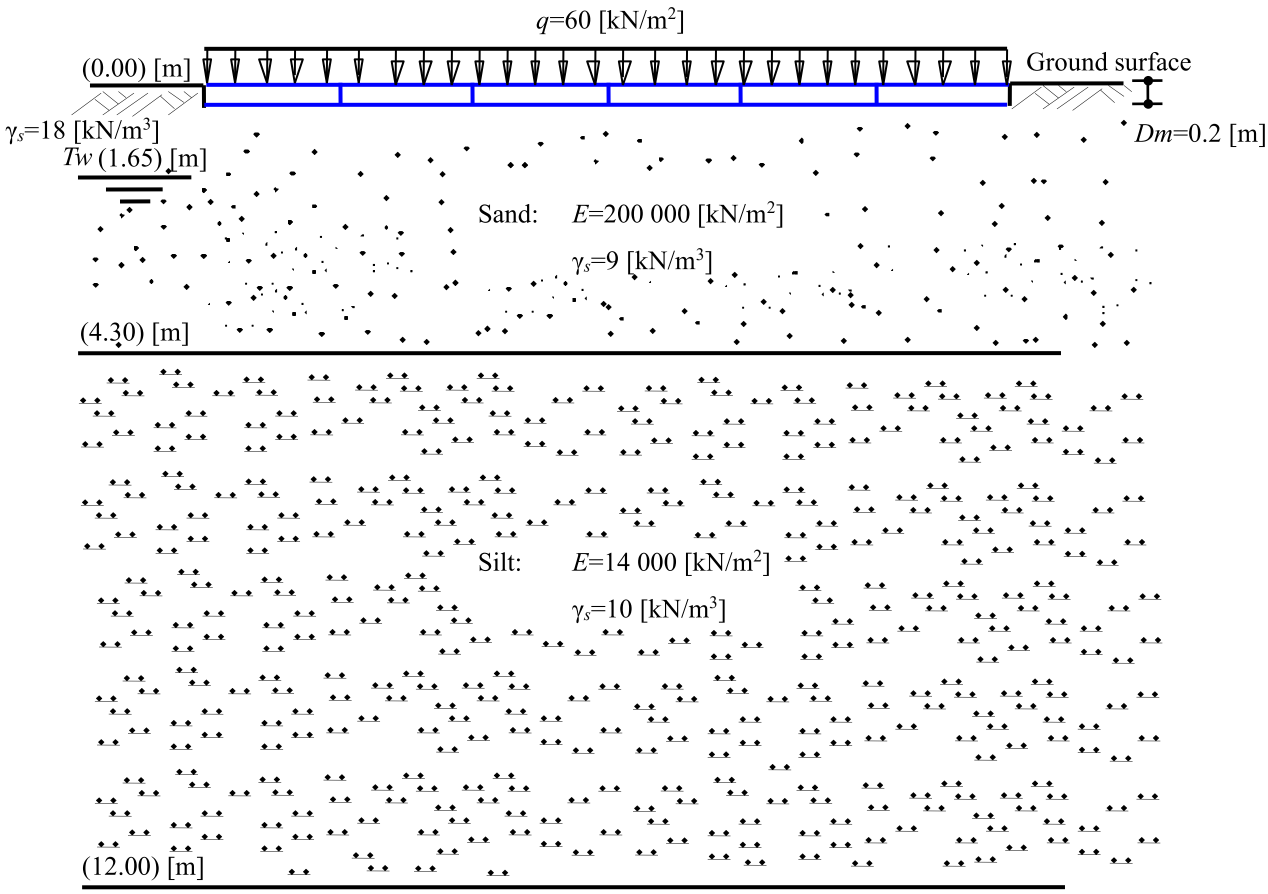

Figure 9.38 Section in the subsoil with loads [kN/m^2]

9.8.9.3 Analysis and results

Because the plate dimensions are relatively small, the plate group can be treated as a system of rigid centrally loaded square plates on a layered subsoil. In this case, it is sufficient to determine the settlements at 4 corner points of each plate including the influence of the stress overlap.

After defining and saving the project identification, system data, footing dimension, loading and soil properties by the *GEO Tools* program. The limit depth for the foundation can then be calculated. Then, the settlements with the influence of the stress overlap are calculated for each of the corners 1 ... 4, namely for all plates No. 1 to No. 36.

9.8.9.4 Presentation of data and results

The input data and results of the settlement calculations for plate group of 36 plates are shown on the next pages.

```
*************************************************************
                         GEO Tools
                        Version 13
          Program authors M. El Gendy/ A. El Gendy
*************************************************************
Title: 36 Pavement plates
Date: 25-01-2018
Project: Example 8
File: SZ3

-------------------------------------------------------------
Settlements of footing groups
-------------------------------------------------------------
Data of limit depth:

Strip thickness for depth by iteration                      Dz [m]     = 0.5
Standard ratio of limit depth (1>Cs, Cs>=0)                 Cs [-]     = 0.2

Main Soil Data:
Groundwater depth under the ground surface                  Tw [m]     = 1.65
Settlement reduction factor                                 α  [-]     = 1.00
Unit weight of footing concrete                             γb [kN/m3] = 20.00

Overburden pressure                                         Qv [kN/m2] = 4
Loading                                                     Qe [kN/m2] = 60
Contact pressure                                            Qo [kN/m2] = 64
Limit depth under ground surface (Footing No. 1/ Max. Load) ZG [m]     = 7.19
Lies at layer                                               U  [-]     = 3

Loads and dimensions:
```

Footing No. I	Load on Footing Pa [kN]	Length Am [m]	Breadth Bm [m]	Thickness Dm [m]	Foundation Depth Tf [m]	X-coord. Xm [m]	Y-coord. Ym [m]	Rotating angle β [°]	Height Hm [m]
1	135	1.50	1.50	0.20	0.20	0.75	0.75	0.00	0.00
2	135	1.50	1.50	0.20	0.20	2.25	0.75	0.00	0.00
3	135	1.50	1.50	0.20	0.20	3.75	0.75	0.00	0.00
4	135	1.50	1.50	0.20	0.20	5.25	0.75	0.00	0.00
5	135	1.50	1.50	0.20	0.20	6.75	0.75	0.00	0.00
6	135	1.50	1.50	0.20	0.20	8.25	0.75	0.00	0.00
7	135	1.50	1.50	0.20	0.20	0.75	2.25	0.00	0.00
8	135	1.50	1.50	0.20	0.20	2.25	2.25	0.00	0.00
9	135	1.50	1.50	0.20	0.20	3.75	2.25	0.00	0.00
10	135	1.50	1.50	0.20	0.20	5.25	2.25	0.00	0.00
11	135	1.50	1.50	0.20	0.20	6.75	2.25	0.00	0.00
12	135	1.50	1.50	0.20	0.20	8.25	2.25	0.00	0.00
13	135	1.50	1.50	0.20	0.20	0.75	3.75	0.00	0.00
14	135	1.50	1.50	0.20	0.20	2.25	3.75	0.00	0.00
15	135	1.50	1.50	0.20	0.20	3.75	3.75	0.00	0.00
16	135	1.50	1.50	0.20	0.20	5.25	3.75	0.00	0.00
17	135	1.50	1.50	0.20	0.20	6.75	3.75	0.00	0.00
18	135	1.50	1.50	0.20	0.20	8.25	3.75	0.00	0.00
19	135	1.50	1.50	0.20	0.20	0.75	5.25	0.00	0.00
20	135	1.50	1.50	0.20	0.20	2.25	5.25	0.00	0.00
21	135	1.50	1.50	0.20	0.20	3.75	5.25	0.00	0.00
22	135	1.50	1.50	0.20	0.20	5.25	5.25	0.00	0.00
23	135	1.50	1.50	0.20	0.20	6.75	5.25	0.00	0.00
24	135	1.50	1.50	0.20	0.20	8.25	5.25	0.00	0.00
25	135	1.50	1.50	0.20	0.20	0.75	6.75	0.00	0.00
26	135	1.50	1.50	0.20	0.20	2.25	6.75	0.00	0.00
27	135	1.50	1.50	0.20	0.20	3.75	6.75	0.00	0.00
28	135	1.50	1.50	0.20	0.20	5.25	6.75	0.00	0.00
29	135	1.50	1.50	0.20	0.20	6.75	6.75	0.00	0.00
30	135	1.50	1.50	0.20	0.20	8.25	6.75	0.00	0.00
31	135	1.50	1.50	0.20	0.20	0.75	8.25	0.00	0.00
32	135	1.50	1.50	0.20	0.20	2.25	8.25	0.00	0.00
33	135	1.50	1.50	0.20	0.20	3.75	8.25	0.00	0.00
34	135	1.50	1.50	0.20	0.20	5.25	8.25	0.00	0.00
35	135	1.50	1.50	0.20	0.20	6.75	8.25	0.00	0.00
36	135	1.50	1.50	0.20	0.20	8.25	8.25	0.00	0.00

Boring:

Layer No.	Level of layer under ground	Modulus of compressibility for loading	Modulus of compressibility for reloading	Poisson's ratio of the soil	Unit weight of the soil
I	z	Es	Ws	νs	γs
[-]	[m]	[kN/m2]	[kN/m2]	[-]	[kN/m3]
1	1.65	200000	200000	0.30	18.00
2	3.00	200000	200000	0.30	9.00
3	12.00	14000	14000	0.30	10.00

Stress on soil against depth (Footing No. 1/ Max. Load):

Iteration No.	Depth under foundation	Stress due to foundation	Stress from neighboring foundations	Sum of stresses	Stress from soil weight	ratio
I	z	SE	SD	SU=SE+SD	SV	SU/SV
	[m]	[kN/m2]	[kN/m2]	[kN/m2]	[kN/m2]	[-]
0	0.00	64	0	64	4	17.78
1	0.50	34	2	36	13	2.82
2	1.00	21	9	31	22	1.42
3	1.50	15	15	30	30	1.01
4	2.00	11	18	29	35	0.84
5	2.50	8	20	28	39	0.71
6	3.00	6	20	26	44	0.59
7	3.50	5	20	24	49	0.50
8	4.00	4	19	23	54	0.43
9	4.50	3	19	22	59	0.37
10	5.00	3	18	21	64	0.32
11	5.50	2	17	20	69	0.28
12	6.00	2	17	19	74	0.25
13	6.50	2	16	18	79	0.22
14	7.00	1	15	17	84	0.20

```
Settlement calculation for rigid centric loaded footings
Footing No.: 1
Overburden pressure                        Qv  [kN/m2] = 4
Loading                                    Qe  [kN/m2] = 60
Contact pressure                           Qo  [kN/m2] = 64
Modulus of subgrade reaction               ks  [kN/m3] = 19074

Final settlements of rigid footing:
Settlement of the corner: right up         S1  [cm]    = 0.89
Settlement of the corner: right down       S2  [cm]    = 0.65
Settlement of the corner: left down        S3  [cm]    = 0.34
Settlement of the corner: left up          S4  [cm]    = 0.58
Average settlement                         Sm  [cm]    = 0.61

Immediate settlement parts:
Settlement of the corner: right up         Sf1 [cm]    = 0.75
Settlement of the corner: right down       Sf2 [cm]    = 0.44
Settlement of the corner: left down        Sf3 [cm]    = 0.26
Settlement of the corner: left up          Sf4 [cm]    = 0.44
Average settlement                         Smf [cm]    = 0.47

Footing No.: 2
Overburden pressure                        Qv  [kN/m2] = 4
Loading                                    Qe  [kN/m2] = 60
Contact pressure                           Qo  [kN/m2] = 64
Modulus of subgrade reaction               ks  [kN/m3] = 9809

Final settlements of rigid footing:
Settlement of the corner: right up         S1  [cm]    = 1.07
Settlement of the corner: right down       S2  [cm]    = 0.69
Settlement of the corner: left down        S3  [cm]    = 0.54
Settlement of the corner: left up          S4  [cm]    = 0.92
Average settlement                         Sm  [cm]    = 0.81
Immediate settlement parts:
Settlement of the corner: right up         Sf1 [cm]    = 0.90
Settlement of the corner: right down       Sf2 [cm]    = 0.53
```

```
Settlement of the corner: left down          Sf3 [cm]    = 0.42
Settlement of the corner: left up            Sf4 [cm]    = 0.74
Average settlement                           Smf [cm]    = 0.65

Footing No.: 3
Overburden pressure                          Qv  [kN/m2] = 4
Loading                                      Qe  [kN/m2] = 60
Contact pressure                             Qo  [kN/m2] = 64
Modulus of subgrade reaction                 ks  [kN/m3] = 11102

Final settlements of rigid footing:
Settlement of the corner: right up           S1  [cm]    = 1.12
Settlement of the corner: right down         S2  [cm]    = 0.70
Settlement of the corner: left down          S3  [cm]    = 0.66
Settlement of the corner: left up            S4  [cm]    = 1.08
Average settlement                           Sm  [cm]    = 0.89

Immediate settlement parts:
Settlement of the corner: right up           Sf1 [cm]    = 0.92
Settlement of the corner: right down         Sf2 [cm]    = 0.54
Settlement of the corner: left down          Sf3 [cm]    = 0.52
Settlement of the corner: left up            Sf4 [cm]    = 0.89
Average settlement                           Smf [cm]    = 0.72

Footing No.: 4
Overburden pressure                          Qv  [kN/m2] = 4
Loading                                      Qe  [kN/m2] = 60
Contact pressure                             Qo  [kN/m2] = 64
Modulus of subgrade reaction                 ks  [kN/m3] = 7164

Final settlements of rigid footing:
Settlement of the corner: right up           S1  [cm]    = 1.08
Settlement of the corner: right down         S2  [cm]    = 0.66
Settlement of the corner: left down          S3  [cm]    = 0.70
Settlement of the corner: left up            S4  [cm]    = 1.12
Average settlement                           Sm  [cm]    = 0.89

Immediate settlement parts:
Settlement of the corner: right up           Sf1 [cm]    = 0.89
Settlement of the corner: right down         Sf2 [cm]    = 0.52
Settlement of the corner: left down          Sf3 [cm]    = 0.54
Settlement of the corner: left up            Sf4 [cm]    = 0.92
Average settlement                           Smf [cm]    = 0.72

Footing No.: 5
Overburden pressure                          Qv  [kN/m2] = 4
Loading                                      Qe  [kN/m2] = 60
Contact pressure                             Qo  [kN/m2] = 64
Modulus of subgrade reaction                 ks  [kN/m3] = 11804

Final settlements of rigid footing:
Settlement of the corner: right up           S1  [cm]    = 0.92
Settlement of the corner: right down         S2  [cm]    = 0.54
Settlement of the corner: left down          S3  [cm]    = 0.69
Settlement of the corner: left up            S4  [cm]    = 1.07
Average settlement                           Sm  [cm]    = 0.81

Immediate settlement parts:
Settlement of the corner: right up           Sf1 [cm]    = 0.74
Settlement of the corner: right down         Sf2 [cm]    = 0.42
Settlement of the corner: left down          Sf3 [cm]    = 0.53
Settlement of the corner: left up            Sf4 [cm]    = 0.90
Average settlement                           Smf [cm]    = 0.65

Footing No.: 6
Overburden pressure                          Qv  [kN/m2] = 4
Loading                                      Qe  [kN/m2] = 60
Contact pressure                             Qo  [kN/m2] = 64
Modulus of subgrade reaction                 ks  [kN/m3] = 9223

Final settlements of rigid footing:
Settlement of the corner: right up           S1  [cm]    = 0.58
Settlement of the corner: right down         S2  [cm]    = 0.34
Settlement of the corner: left down          S3  [cm]    = 0.65
Settlement of the corner: left up            S4  [cm]    = 0.89
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Average settlement                          Sm  [cm]    = 0.61

Immediate settlement parts:
Settlement of the corner: right up          Sf1 [cm]    = 0.44
Settlement of the corner: right down        Sf2 [cm]    = 0.26
Settlement of the corner: left down         Sf3 [cm]    = 0.44
Settlement of the corner: left up           Sf4 [cm]    = 0.75
Average settlement                          Smf [cm]    = 0.47

Footing No.: 7
Overburden pressure                         Qv  [kN/m2] = 4
Loading                                     Qe  [kN/m2] = 60
Contact pressure                            Qo  [kN/m2] = 64
Modulus of subgrade reaction                ks  [kN/m3] = 6937

Final settlements of rigid footing:
Settlement of the corner: right up          S1  [cm]    = 1.07
Settlement of the corner: right down        S2  [cm]    = 0.92
Settlement of the corner: left down         S3  [cm]    = 0.54
Settlement of the corner: left up           S4  [cm]    = 0.69
Average settlement                          Sm  [cm]    = 0.81

Immediate settlement parts:
Settlement of the corner: right up          Sf1 [cm]    = 0.90
Settlement of the corner: right down        Sf2 [cm]    = 0.74
Settlement of the corner: left down         Sf3 [cm]    = 0.42
Settlement of the corner: left up           Sf4 [cm]    = 0.53
Average settlement                          Smf [cm]    = 0.65

Footing No.: 8
Overburden pressure                         Qv  [kN/m2] = 4
Loading                                     Qe  [kN/m2] = 60
Contact pressure                            Qo  [kN/m2] = 64
Modulus of subgrade reaction                ks  [kN/m3] = 5958

Final settlements of rigid footing:
Settlement of the corner: right up          S1  [cm]    = 1.27
Settlement of the corner: right down        S2  [cm]    = 1.08
Settlement of the corner: left down         S3  [cm]    = 0.87
Settlement of the corner: left up           S4  [cm]    = 1.06
Average settlement                          Sm  [cm]    = 1.07

Immediate settlement parts:
Settlement of the corner: right up          Sf1 [cm]    = 1.07
Settlement of the corner: right down        Sf2 [cm]    = 0.88
Settlement of the corner: left down         Sf3 [cm]    = 0.72
Settlement of the corner: left up           Sf4 [cm]    = 0.88
Average settlement                          Smf [cm]    = 0.89

Footing No.: 9
Overburden pressure                         Qv  [kN/m2] = 4
Loading                                     Qe  [kN/m2] = 60
Contact pressure                            Qo  [kN/m2] = 64
Modulus of subgrade reaction                ks  [kN/m3] = 9663

Final settlements of rigid footing:
Settlement of the corner: right up          S1  [cm]    = 1.31
Settlement of the corner: right down        S2  [cm]    = 1.09
Settlement of the corner: left down         S3  [cm]    = 1.04
Settlement of the corner: left up           S4  [cm]    = 1.26
Average settlement                          Sm  [cm]    = 1.18

Immediate settlement parts:
Settlement of the corner: right up          Sf1 [cm]    = 1.10
Settlement of the corner: right down        Sf2 [cm]    = 0.90
Settlement of the corner: left down         Sf3 [cm]    = 0.86
Settlement of the corner: left up           Sf4 [cm]    = 1.06
Average settlement                          Smf [cm]    = 0.98

Footing No.: 10
Overburden pressure                         Qv  [kN/m2] = 4
Loading                                     Qe  [kN/m2] = 60
Contact pressure                            Qo  [kN/m2] = 64
Modulus of subgrade reaction                ks  [kN/m3] = 9155
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Final settlements of rigid footing:
Settlement of the corner: right up          S1  [cm]    = 1.26
Settlement of the corner: right down        S2  [cm]    = 1.04
Settlement of the corner: left down         S3  [cm]    = 1.09
Settlement of the corner: left up           S4  [cm]    = 1.31
Average settlement                          Sm  [cm]    = 1.18

Immediate settlement parts:
Settlement of the corner: right up          Sf1 [cm]    = 1.06
Settlement of the corner: right down        Sf2 [cm]    = 0.86
Settlement of the corner: left down         Sf3 [cm]    = 0.90
Settlement of the corner: left up           Sf4 [cm]    = 1.10
Average settlement                          Smf [cm]    = 0.98

Footing No.: 11
Overburden pressure                         Qv  [kN/m2] = 4
Loading                                     Qe  [kN/m2] = 60
Contact pressure                            Qo  [kN/m2] = 64
Modulus of subgrade reaction                ks  [kN/m3] = 5934

Final settlements of rigid footing:
Settlement of the corner: right up          S1  [cm]    = 1.06
Settlement of the corner: right down        S2  [cm]    = 0.87
Settlement of the corner: left down         S3  [cm]    = 1.08
Settlement of the corner: left up           S4  [cm]    = 1.27
Average settlement                          Sm  [cm]    = 1.07

Immediate settlement parts:
Settlement of the corner: right up          Sf1 [cm]    = 0.88
Settlement of the corner: right down        Sf2 [cm]    = 0.72
Settlement of the corner: left down         Sf3 [cm]    = 0.88
Settlement of the corner: left up           Sf4 [cm]    = 1.07
Average settlement                          Smf [cm]    = 0.89

Footing No.: 12
Overburden pressure                         Qv  [kN/m2] = 4
Loading                                     Qe  [kN/m2] = 60
Contact pressure                            Qo  [kN/m2] = 64
Modulus of subgrade reaction                ks  [kN/m3] = 5738

Final settlements of rigid footing:
Settlement of the corner: right up          S1  [cm]    = 0.69
Settlement of the corner: right down        S2  [cm]    = 0.54
Settlement of the corner: left down         S3  [cm]    = 0.92
Settlement of the corner: left up           S4  [cm]    = 1.07
Average settlement                          Sm  [cm]    = 0.81

Immediate settlement parts:
Settlement of the corner: right up          Sf1 [cm]    = 0.53
Settlement of the corner: right down        Sf2 [cm]    = 0.42
Settlement of the corner: left down         Sf3 [cm]    = 0.74
Settlement of the corner: left up           Sf4 [cm]    = 0.90
Average settlement                          Smf [cm]    = 0.65

Footing No.: 13
Overburden pressure                         Qv  [kN/m2] = 4
Loading                                     Qe  [kN/m2] = 60
Contact pressure                            Qo  [kN/m2] = 64
Modulus of subgrade reaction                ks  [kN/m3] = 9155

Final settlements of rigid footing:
Settlement of the corner: right up          S1  [cm]    = 1.12
Settlement of the corner: right down        S2  [cm]    = 1.08
Settlement of the corner: left down         S3  [cm]    = 0.66
Settlement of the corner: left up           S4  [cm]    = 0.70
Average settlement                          Sm  [cm]    = 0.89

Immediate settlement parts:
Settlement of the corner: right up          Sf1 [cm]    = 0.92
Settlement of the corner: right down        Sf2 [cm]    = 0.89
Settlement of the corner: left down         Sf3 [cm]    = 0.52
Settlement of the corner: left up           Sf4 [cm]    = 0.54
Average settlement                          Smf [cm]    = 0.72

Footing No.: 14
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Overburden pressure                          Qv  [kN/m2] = 4
Loading                                      Qe  [kN/m2] = 60
Contact pressure                             Qo  [kN/m2] = 64
Modulus of subgrade reaction                 ks  [kN/m3] = 9663

Final settlements of rigid footing:
Settlement of the corner: right up           S1  [cm]    = 1.31
Settlement of the corner: right down         S2  [cm]    = 1.26
Settlement of the corner: left down          S3  [cm]    = 1.04
Settlement of the corner: left up            S4  [cm]    = 1.09
Average settlement                           Sm  [cm]    = 1.18

Immediate settlement parts:
Settlement of the corner: right up           Sf1 [cm]    = 1.10
Settlement of the corner: right down         Sf2 [cm]    = 1.06
Settlement of the corner: left down          Sf3 [cm]    = 0.86
Settlement of the corner: left up            Sf4 [cm]    = 0.90
Average settlement                           Smf [cm]    = 0.98

Footing No.: 15
Overburden pressure                          Qv  [kN/m2] = 4
Loading                                      Qe  [kN/m2] = 60
Contact pressure                             Qo  [kN/m2] = 64
Modulus of subgrade reaction                 ks  [kN/m3] = 5738

Final settlements of rigid footing:
Settlement of the corner: right up           S1  [cm]    = 1.35
Settlement of the corner: right down         S2  [cm]    = 1.30
Settlement of the corner: left down          S3  [cm]    = 1.24
Settlement of the corner: left up            S4  [cm]    = 1.29
Average settlement                           Sm  [cm]    = 1.30

Immediate settlement parts:
Settlement of the corner: right up           Sf1 [cm]    = 1.13
Settlement of the corner: right down         Sf2 [cm]    = 1.08
Settlement of the corner: left down          Sf3 [cm]    = 1.04
Settlement of the corner: left up            Sf4 [cm]    = 1.08
Average settlement                           Smf [cm]    = 1.09

Footing No.: 16
Overburden pressure                          Qv  [kN/m2] = 4
Loading                                      Qe  [kN/m2] = 60
Contact pressure                             Qo  [kN/m2] = 64
Modulus of subgrade reaction                 ks  [kN/m3] = 5934

Final settlements of rigid footing:
Settlement of the corner: right up           S1  [cm]    = 1.29
Settlement of the corner: right down         S2  [cm]    = 1.24
Settlement of the corner: left down          S3  [cm]    = 1.30
Settlement of the corner: left up            S4  [cm]    = 1.35
Average settlement                           Sm  [cm]    = 1.30

Immediate settlement parts:
Settlement of the corner: right up           Sf1 [cm]    = 1.08
Settlement of the corner: right down         Sf2 [cm]    = 1.04
Settlement of the corner: left down          Sf3 [cm]    = 1.08
Settlement of the corner: left up            Sf4 [cm]    = 1.13
Average settlement                           Smf [cm]    = 1.09

Footing No.: 17
Overburden pressure                          Qv  [kN/m2] = 4
Loading                                      Qe  [kN/m2] = 60
Contact pressure                             Qo  [kN/m2] = 64
Modulus of subgrade reaction                 ks  [kN/m3] = 9223

Final settlements of rigid footing:
Settlement of the corner: right up           S1  [cm]    = 1.09
Settlement of the corner: right down         S2  [cm]    = 1.04
Settlement of the corner: left down          S3  [cm]    = 1.26
Settlement of the corner: left up            S4  [cm]    = 1.31
Average settlement                           Sm  [cm]    = 1.18

Immediate settlement parts:
Settlement of the corner: right up           Sf1 [cm]    = 0.90
Settlement of the corner: right down         Sf2 [cm]    = 0.86
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Settlement of the corner: left down          Sf3 [cm]    = 1.06
Settlement of the corner: left up            Sf4 [cm]    = 1.10
Average settlement                           Smf [cm]    = 0.98

Footing No.: 18
Overburden pressure                          Qv  [kN/m2] = 4
Loading                                      Qe  [kN/m2] = 60
Contact pressure                             Qo  [kN/m2] = 64
Modulus of subgrade reaction                 ks  [kN/m3] = 11804

Final settlements of rigid footing:
Settlement of the corner: right up           S1  [cm]    = 0.70
Settlement of the corner: right down         S2  [cm]    = 0.66
Settlement of the corner: left down          S3  [cm]    = 1.08
Settlement of the corner: left up            S4  [cm]    = 1.12
Average settlement                           Sm  [cm]    = 0.89

Immediate settlement parts:
Settlement of the corner: right up           Sf1 [cm]    = 0.54
Settlement of the corner: right down         Sf2 [cm]    = 0.52
Settlement of the corner: left down          Sf3 [cm]    = 0.89
Settlement of the corner: left up            Sf4 [cm]    = 0.92
Average settlement                           Smf [cm]    = 0.72

Footing No.: 19
Overburden pressure                          Qv  [kN/m2] = 4
Loading                                      Qe  [kN/m2] = 60
Contact pressure                             Qo  [kN/m2] = 64
Modulus of subgrade reaction                 ks  [kN/m3] = 5958

Final settlements of rigid footing:
Settlement of the corner: right up           S1  [cm]    = 1.08
Settlement of the corner: right down         S2  [cm]    = 1.12
Settlement of the corner: left down          S3  [cm]    = 0.70
Settlement of the corner: left up            S4  [cm]    = 0.66
Average settlement                           Sm  [cm]    = 0.89

Immediate settlement parts:
Settlement of the corner: right up           Sf1 [cm]    = 0.89
Settlement of the corner: right down         Sf2 [cm]    = 0.92
Settlement of the corner: left down          Sf3 [cm]    = 0.54
Settlement of the corner: left up            Sf4 [cm]    = 0.52
Average settlement                           Smf [cm]    = 0.72

Footing No.: 20
Overburden pressure                          Qv  [kN/m2] = 4
Loading                                      Qe  [kN/m2] = 60
Contact pressure                             Qo  [kN/m2] = 64
Modulus of subgrade reaction                 ks  [kN/m3] = 6937

Final settlements of rigid footing:
Settlement of the corner: right up           S1  [cm]    = 1.26
Settlement of the corner: right down         S2  [cm]    = 1.31
Settlement of the corner: left down          S3  [cm]    = 1.09
Settlement of the corner: left up            S4  [cm]    = 1.04
Average settlement                           Sm  [cm]    = 1.18

Immediate settlement parts:
Settlement of the corner: right up           Sf1 [cm]    = 1.06
Settlement of the corner: right down         Sf2 [cm]    = 1.10
Settlement of the corner: left down          Sf3 [cm]    = 0.90
Settlement of the corner: left up            Sf4 [cm]    = 0.86
Average settlement                           Smf [cm]    = 0.98

Footing No.: 21
Overburden pressure                          Qv  [kN/m2] = 4
Loading                                      Qe  [kN/m2] = 60
Contact pressure                             Qo  [kN/m2] = 64
Modulus of subgrade reaction                 ks  [kN/m3] = 9809

Final settlements of rigid footing:
Settlement of the corner: right up           S1  [cm]    = 1.29
Settlement of the corner: right down         S2  [cm]    = 1.35
Settlement of the corner: left down          S3  [cm]    = 1.30
Settlement of the corner: left up            S4  [cm]    = 1.24
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Average settlement                          Sm  [cm]    = 1.30

Immediate settlement parts:
Settlement of the corner: right up          Sf1 [cm]    = 1.08
Settlement of the corner: right down        Sf2 [cm]    = 1.13
Settlement of the corner: left down         Sf3 [cm]    = 1.08
Settlement of the corner: left up           Sf4 [cm]    = 1.04
Average settlement                          Smf [cm]    = 1.09

Footing No.: 22
Overburden pressure                         Qv  [kN/m2] = 4
Loading                                     Qe  [kN/m2] = 60
Contact pressure                            Qo  [kN/m2] = 64
Modulus of subgrade reaction                ks  [kN/m3] = 19074

Final settlements of rigid footing:
Settlement of the corner: right up          S1  [cm]    = 1.24
Settlement of the corner: right down        S2  [cm]    = 1.30
Settlement of the corner: left down         S3  [cm]    = 1.35
Settlement of the corner: left up           S4  [cm]    = 1.29
Average settlement                          Sm  [cm]    = 1.30

Immediate settlement parts:
Settlement of the corner: right up          Sf1 [cm]    = 1.04
Settlement of the corner: right down        Sf2 [cm]    = 1.08
Settlement of the corner: left down         Sf3 [cm]    = 1.13
Settlement of the corner: left up           Sf4 [cm]    = 1.08
Average settlement                          Smf [cm]    = 1.09

Footing No.: 23
Overburden pressure                         Qv  [kN/m2] = 4
Loading                                     Qe  [kN/m2] = 60
Contact pressure                            Qo  [kN/m2] = 64
Modulus of subgrade reaction                ks  [kN/m3] = 7164

Final settlements of rigid footing:
Settlement of the corner: right up          S1  [cm]    = 1.04
Settlement of the corner: right down        S2  [cm]    = 1.09
Settlement of the corner: left down         S3  [cm]    = 1.31
Settlement of the corner: left up           S4  [cm]    = 1.26
Average settlement                          Sm  [cm]    = 1.18

Immediate settlement parts:
Settlement of the corner: right up          Sf1 [cm]    = 0.86
Settlement of the corner: right down        Sf2 [cm]    = 0.90
Settlement of the corner: left down         Sf3 [cm]    = 1.10
Settlement of the corner: left up           Sf4 [cm]    = 1.06
Average settlement                          Smf [cm]    = 0.98

Footing No.: 24
Overburden pressure                         Qv  [kN/m2] = 4
Loading                                     Qe  [kN/m2] = 60
Contact pressure                            Qo  [kN/m2] = 64
Modulus of subgrade reaction                ks  [kN/m3] = 11102

Final settlements of rigid footing:
Settlement of the corner: right up          S1  [cm]    = 0.66
Settlement of the corner: right down        S2  [cm]    = 0.70
Settlement of the corner: left down         S3  [cm]    = 1.12
Settlement of the corner: left up           S4  [cm]    = 1.08
Average settlement                          Sm  [cm]    = 0.89

Immediate settlement parts:
Settlement of the corner: right up          Sf1 [cm]    = 0.52
Settlement of the corner: right down        Sf2 [cm]    = 0.54
Settlement of the corner: left down         Sf3 [cm]    = 0.92
Settlement of the corner: left up           Sf4 [cm]    = 0.89
Average settlement                          Smf [cm]    = 0.72

Footing No.: 25
Overburden pressure                         Qv  [kN/m2] = 4
Loading                                     Qe  [kN/m2] = 60
Contact pressure                            Qo  [kN/m2] = 64
Modulus of subgrade reaction                ks  [kN/m3] = 11804
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Final settlements of rigid footing:
Settlement of the corner: right up         S1  [cm]    = 0.92
Settlement of the corner: right down       S2  [cm]    = 1.07
Settlement of the corner: left down        S3  [cm]    = 0.69
Settlement of the corner: left up          S4  [cm]    = 0.54
Average settlement                         Sm  [cm]    = 0.81

Immediate settlement parts:
Settlement of the corner: right up         Sf1 [cm]    = 0.74
Settlement of the corner: right down       Sf2 [cm]    = 0.90
Settlement of the corner: left down        Sf3 [cm]    = 0.53
Settlement of the corner: left up          Sf4 [cm]    = 0.42
Average settlement                         Smf [cm]    = 0.65

Footing No.: 26
Overburden pressure                        Qv  [kN/m2] = 4
Loading                                    Qe  [kN/m2] = 60
Contact pressure                           Qo  [kN/m2] = 64
Modulus of subgrade reaction               ks  [kN/m3] = 6937

Final settlements of rigid footing:
Settlement of the corner: right up         S1  [cm]    = 1.06
Settlement of the corner: right down       S2  [cm]    = 1.27
Settlement of the corner: left down        S3  [cm]    = 1.08
Settlement of the corner: left up          S4  [cm]    = 0.87
Average settlement                         Sm  [cm]    = 1.07

Immediate settlement parts:
Settlement of the corner: right up         Sf1 [cm]    = 0.88
Settlement of the corner: right down       Sf2 [cm]    = 1.07
Settlement of the corner: left down        Sf3 [cm]    = 0.88
Settlement of the corner: left up          Sf4 [cm]    = 0.72
Average settlement                         Smf [cm]    = 0.89

Footing No.: 27
Overburden pressure                        Qv  [kN/m2] = 4
Loading                                    Qe  [kN/m2] = 60
Contact pressure                           Qo  [kN/m2] = 64
Modulus of subgrade reaction               ks  [kN/m3] = 9223

Final settlements of rigid footing:
Settlement of the corner: right up         S1  [cm]    = 1.09
Settlement of the corner: right down       S2  [cm]    = 1.31
Settlement of the corner: left down        S3  [cm]    = 1.26
Settlement of the corner: left up          S4  [cm]    = 1.04
Average settlement                         Sm  [cm]    = 1.18

Immediate settlement parts:
Settlement of the corner: right up         Sf1 [cm]    = 0.90
Settlement of the corner: right down       Sf2 [cm]    = 1.10
Settlement of the corner: left down        Sf3 [cm]    = 1.06
Settlement of the corner: left up          Sf4 [cm]    = 0.86
Average settlement                         Smf [cm]    = 0.98

Footing No.: 28
Overburden pressure                        Qv  [kN/m2] = 4
Loading                                    Qe  [kN/m2] = 60
Contact pressure                           Qo  [kN/m2] = 64
Modulus of subgrade reaction               ks  [kN/m3] = 5958

Final settlements of rigid footing:
Settlement of the corner: right up         S1  [cm]    = 1.04
Settlement of the corner: right down       S2  [cm]    = 1.26
Settlement of the corner: left down        S3  [cm]    = 1.31
Settlement of the corner: left up          S4  [cm]    = 1.09
Average settlement                         Sm  [cm]    = 1.18

Immediate settlement parts:
Settlement of the corner: right up         Sf1 [cm]    = 0.86
Settlement of the corner: right down       Sf2 [cm]    = 1.06
Settlement of the corner: left down        Sf3 [cm]    = 1.10
Settlement of the corner: left up          Sf4 [cm]    = 0.90
Average settlement                         Smf [cm]    = 0.98

Footing No.: 29
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Overburden pressure                          Qv  [kN/m2] = 4
Loading                                      Qe  [kN/m2] = 60
Contact pressure                             Qo  [kN/m2] = 64
Modulus of subgrade reaction                 ks  [kN/m3] = 7348

Final settlements of rigid footing:
Settlement of the corner: right up           S1  [cm]    = 0.87
Settlement of the corner: right down         S2  [cm]    = 1.08
Settlement of the corner: left down          S3  [cm]    = 1.27
Settlement of the corner: left up            S4  [cm]    = 1.06
Average settlement                           Sm  [cm]    = 1.07

Immediate settlement parts:
Settlement of the corner: right up           Sf1 [cm]    = 0.72
Settlement of the corner: right down         Sf2 [cm]    = 0.88
Settlement of the corner: left down          Sf3 [cm]    = 1.07
Settlement of the corner: left up            Sf4 [cm]    = 0.88
Average settlement                           Smf [cm]    = 0.89

Footing No.: 30
Overburden pressure                          Qv  [kN/m2] = 4
Loading                                      Qe  [kN/m2] = 60
Contact pressure                             Qo  [kN/m2] = 64
Modulus of subgrade reaction                 ks  [kN/m3] = 5918

Final settlements of rigid footing:
Settlement of the corner: right up           S1  [cm]    = 0.54
Settlement of the corner: right down         S2  [cm]    = 0.69
Settlement of the corner: left down          S3  [cm]    = 1.07
Settlement of the corner: left up            S4  [cm]    = 0.92
Average settlement                           Sm  [cm]    = 0.81

Immediate settlement parts:
Settlement of the corner: right up           Sf1 [cm]    = 0.42
Settlement of the corner: right down         Sf2 [cm]    = 0.53
Settlement of the corner: left down          Sf3 [cm]    = 0.90
Settlement of the corner: left up            Sf4 [cm]    = 0.74
Average settlement                           Smf [cm]    = 0.65

Footing No.: 31
Overburden pressure                          Qv  [kN/m2] = 4
Loading                                      Qe  [kN/m2] = 60
Contact pressure                             Qo  [kN/m2] = 64
Modulus of subgrade reaction                 ks  [kN/m3] = 6033

Final settlements of rigid footing:
Settlement of the corner: right up           S1  [cm]    = 0.58
Settlement of the corner: right down         S2  [cm]    = 0.89
Settlement of the corner: left down          S3  [cm]    = 0.65
Settlement of the corner: left up            S4  [cm]    = 0.34
Average settlement                           Sm  [cm]    = 0.61

Immediate settlement parts:
Settlement of the corner: right up           Sf1 [cm]    = 0.44
Settlement of the corner: right down         Sf2 [cm]    = 0.75
Settlement of the corner: left down          Sf3 [cm]    = 0.44
Settlement of the corner: left up            Sf4 [cm]    = 0.26
Average settlement                           Smf [cm]    = 0.47

Footing No.: 32
Overburden pressure                          Qv  [kN/m2] = 4
Loading                                      Qe  [kN/m2] = 60
Contact pressure                             Qo  [kN/m2] = 64
Modulus of subgrade reaction                 ks  [kN/m3] = 5035

Final settlements of rigid footing:
Settlement of the corner: right up           S1  [cm]    = 0.69
Settlement of the corner: right down         S2  [cm]    = 1.07
Settlement of the corner: left down          S3  [cm]    = 0.92
Settlement of the corner: left up            S4  [cm]    = 0.54
Average settlement                           Sm  [cm]    = 0.81

Immediate settlement parts:
Settlement of the corner: right up           Sf1 [cm]    = 0.53
Settlement of the corner: right down         Sf2 [cm]    = 0.90
```

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Settlement of the corner: left down         Sf3 [cm]    = 0.74
Settlement of the corner: left up           Sf4 [cm]    = 0.42
Average settlement                          Smf [cm]    = 0.65

Footing No.: 33
Overburden pressure                         Qv  [kN/m2] = 4
Loading                                     Qe  [kN/m2] = 60
Contact pressure                            Qo  [kN/m2] = 64
Modulus of subgrade reaction                ks  [kN/m3] = 6138

Final settlements of rigid footing:
Settlement of the corner: right up          S1  [cm]    = 0.70
Settlement of the corner: right down        S2  [cm]    = 1.12
Settlement of the corner: left down         S3  [cm]    = 1.08
Settlement of the corner: left up           S4  [cm]    = 0.66
Average settlement                          Sm  [cm]    = 0.89

Immediate settlement parts:
Settlement of the corner: right up          Sf1 [cm]    = 0.54
Settlement of the corner: right down        Sf2 [cm]    = 0.92
Settlement of the corner: left down         Sf3 [cm]    = 0.89
Settlement of the corner: left up           Sf4 [cm]    = 0.52
Average settlement                          Smf [cm]    = 0.72

Footing No.: 34
Overburden pressure                         Qv  [kN/m2] = 4
Loading                                     Qe  [kN/m2] = 60
Contact pressure                            Qo  [kN/m2] = 64
Modulus of subgrade reaction                ks  [kN/m3] = 5870

Final settlements of rigid footing:
Settlement of the corner: right up          S1  [cm]    = 0.66
Settlement of the corner: right down        S2  [cm]    = 1.08
Settlement of the corner: left down         S3  [cm]    = 1.12
Settlement of the corner: left up           S4  [cm]    = 0.70
Average settlement                          Sm  [cm]    = 0.89

Immediate settlement parts:
Settlement of the corner: right up          Sf1 [cm]    = 0.52
Settlement of the corner: right down        Sf2 [cm]    = 0.89
Settlement of the corner: left down         Sf3 [cm]    = 0.92
Settlement of the corner: left up           Sf4 [cm]    = 0.54
Average settlement                          Smf [cm]    = 0.72

Footing No.: 35
Overburden pressure                         Qv  [kN/m2] = 4
Loading                                     Qe  [kN/m2] = 60
Contact pressure                            Qo  [kN/m2] = 64
Modulus of subgrade reaction                ks  [kN/m3] = 5060

Final settlements of rigid footing:
Settlement of the corner: right up          S1  [cm]    = 0.54
Settlement of the corner: right down        S2  [cm]    = 0.92
Settlement of the corner: left down         S3  [cm]    = 1.07
Settlement of the corner: left up           S4  [cm]    = 0.69
Average settlement                          Sm  [cm]    = 0.81

Immediate settlement parts:
Settlement of the corner: right up          Sf1 [cm]    = 0.42
Settlement of the corner: right down        Sf2 [cm]    = 0.74
Settlement of the corner: left down         Sf3 [cm]    = 0.90
Settlement of the corner: left up           Sf4 [cm]    = 0.53
Average settlement                          Smf [cm]    = 0.65

Footing No.: 36
Overburden pressure                         Qv  [kN/m2] = 4
Loading                                     Qe  [kN/m2] = 60
Contact pressure                            Qo  [kN/m2] = 64
Modulus of subgrade reaction                ks  [kN/m3] = 4877

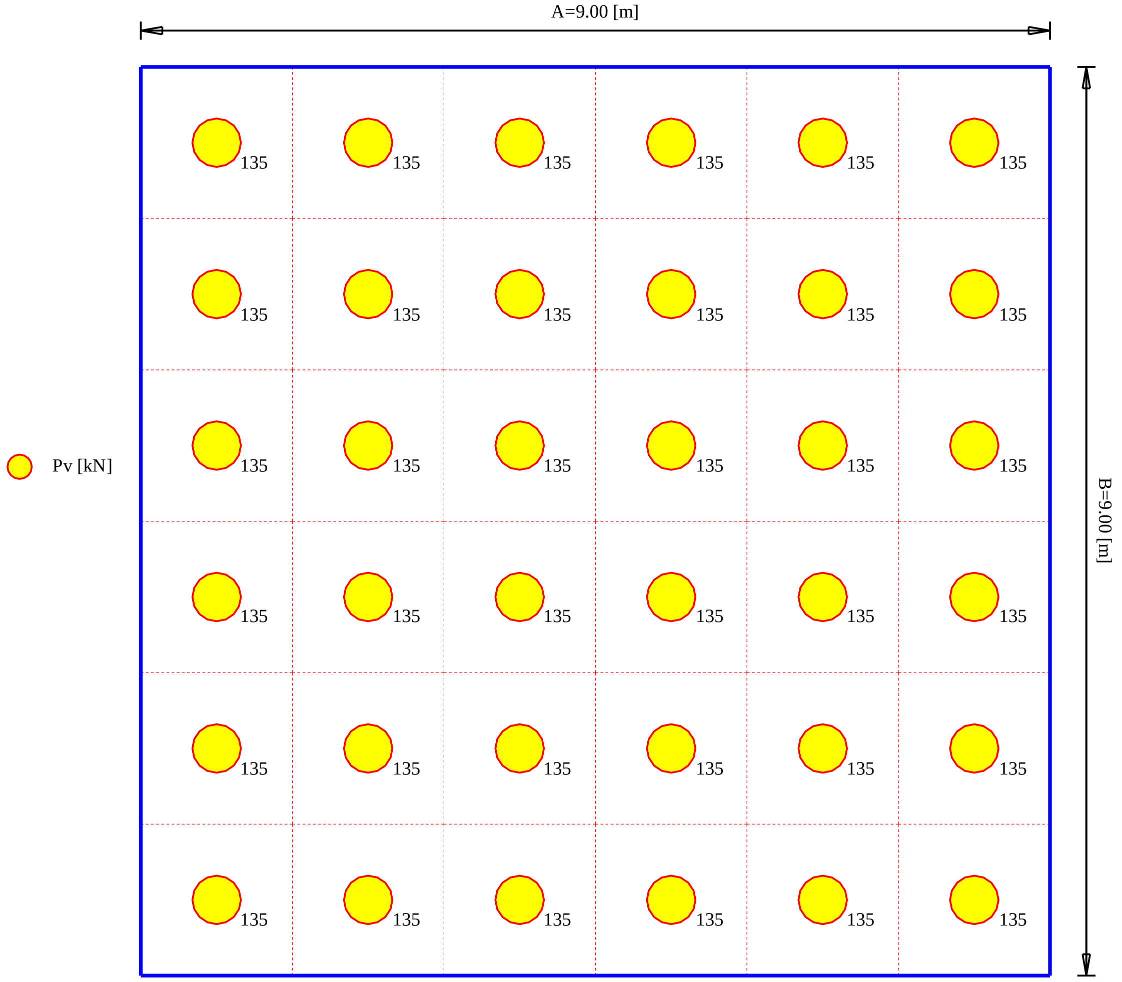
Final settlements of rigid footing:
Settlement of the corner: right up          S1  [cm]    = 0.34
Settlement of the corner: right down        S2  [cm]    = 0.58
Settlement of the corner: left down         S3  [cm]    = 0.89
Settlement of the corner: left up           S4  [cm]    = 0.65
```

```
Average settlement                          Sm  [cm]    = 0.61

Immediate settlement parts:
Settlement of the corner: right up          Sf1 [cm]    = 0.26
Settlement of the corner: right down        Sf2 [cm]    = 0.44
Settlement of the corner: left down         Sf3 [cm]    = 0.75
Settlement of the corner: left up           Sf4 [cm]    = 0.44
Average settlement                          Smf [cm]    = 0.47
```

Method (8) (Layered soil model)

Modulus of Compressibility for Rigid Raft

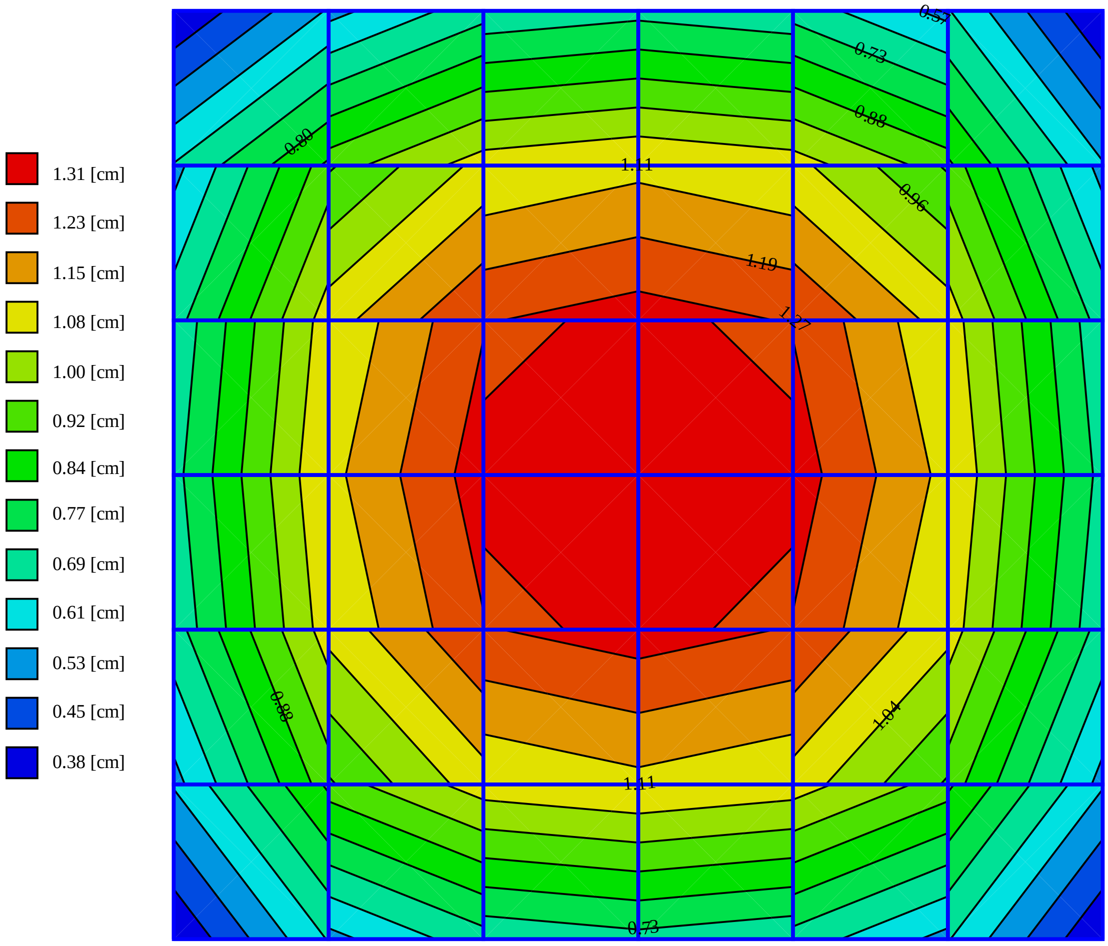


System of loading Pv [kN]

GEOTEC Software Inc., Calgary AB, Canada T3E 7Y7 PO Box 14001 Richmond Road PO, Tele.:+1(587) 332-3323	
Scale: 60	**Title: 36 Pavement plates**
File: SZ3	**Date: 25-01-2018**
Page No.:	**Project: Example 8**

Method (8) (Layered soil model)

Modulus of Compressibility for Rigid Raft



Settlements s [cm]

Max. s = 1.35 at node 60, Min. s = 0.34 at node 144

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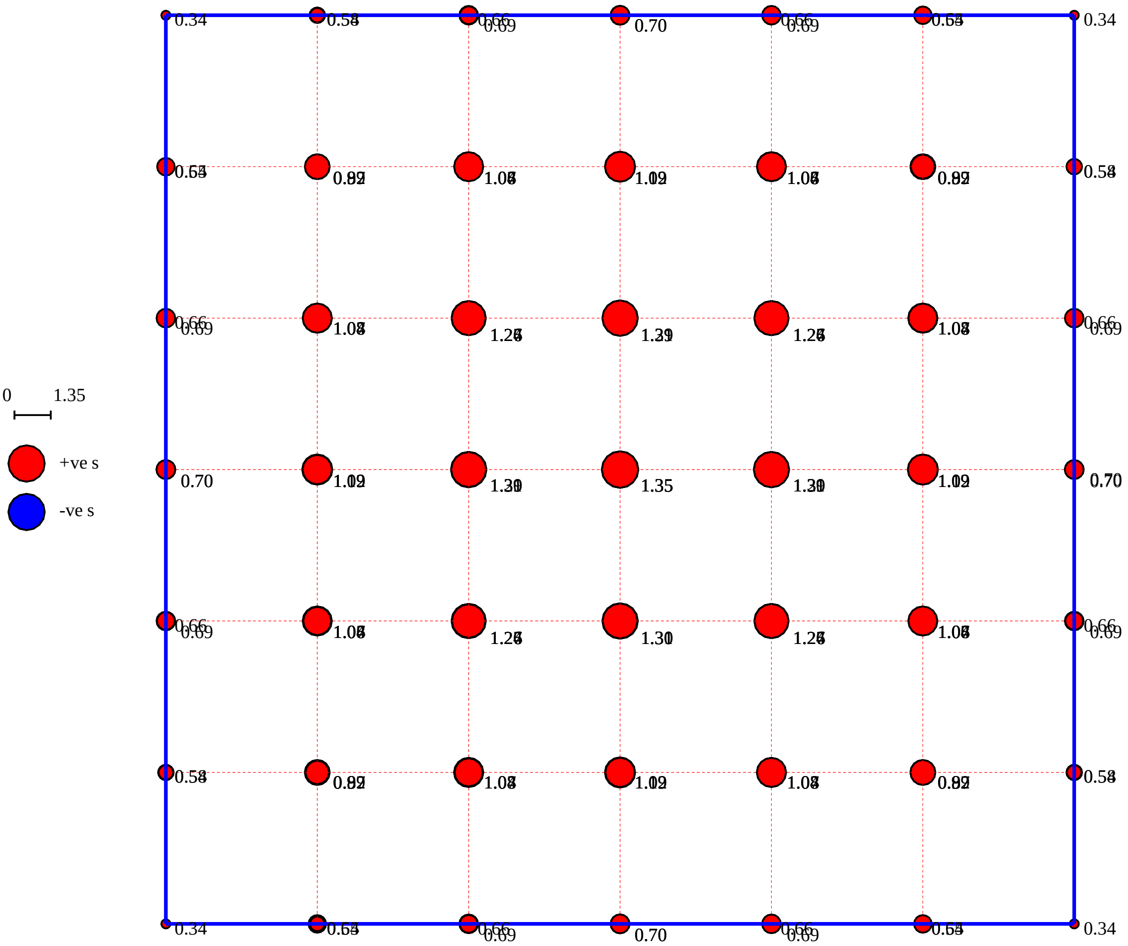
Scale: 60	**Title: 36 Pavement plates**
File: SZ3	**Date: 25-01-2018**
Page No.:	**Project: Example 8**

Method (8) (Layered soil model)

Modulus of Compressibility for Rigid Raft



Settlements s [cm]

Max. s = 1.35 at node 60, Min. s = 0.34 at node 144

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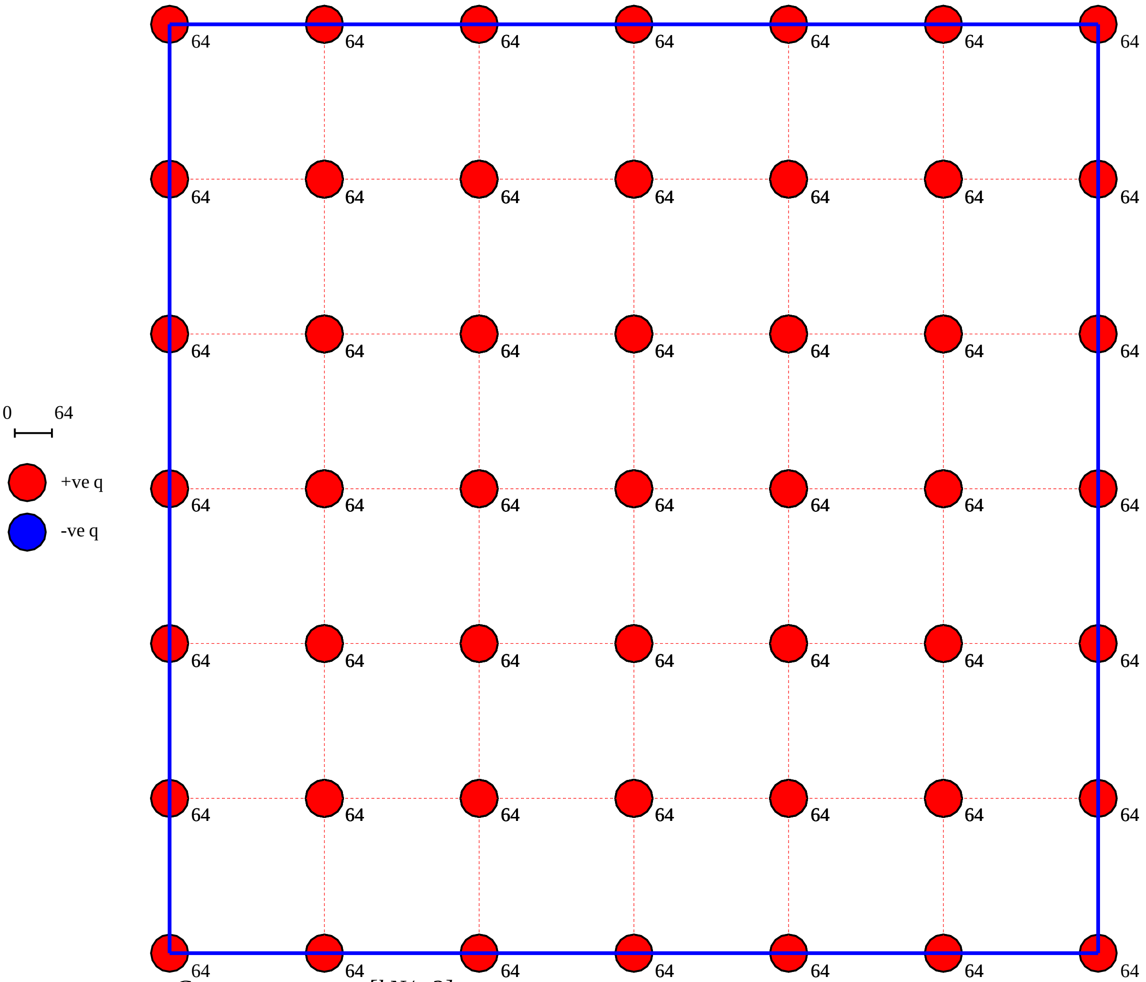
Scale: 60 **File: SZ3** **Page No.:**	**Title: 36 Pavement plates** **Date: 25-01-2018** **Project: Example 8**

Method (8) (Layered soil model)

Modulus of Compressibility for Rigid Raft



Contact pressure q [kN/m2]

Max. q = 64 at node 1, Min. q = 64 at node 1

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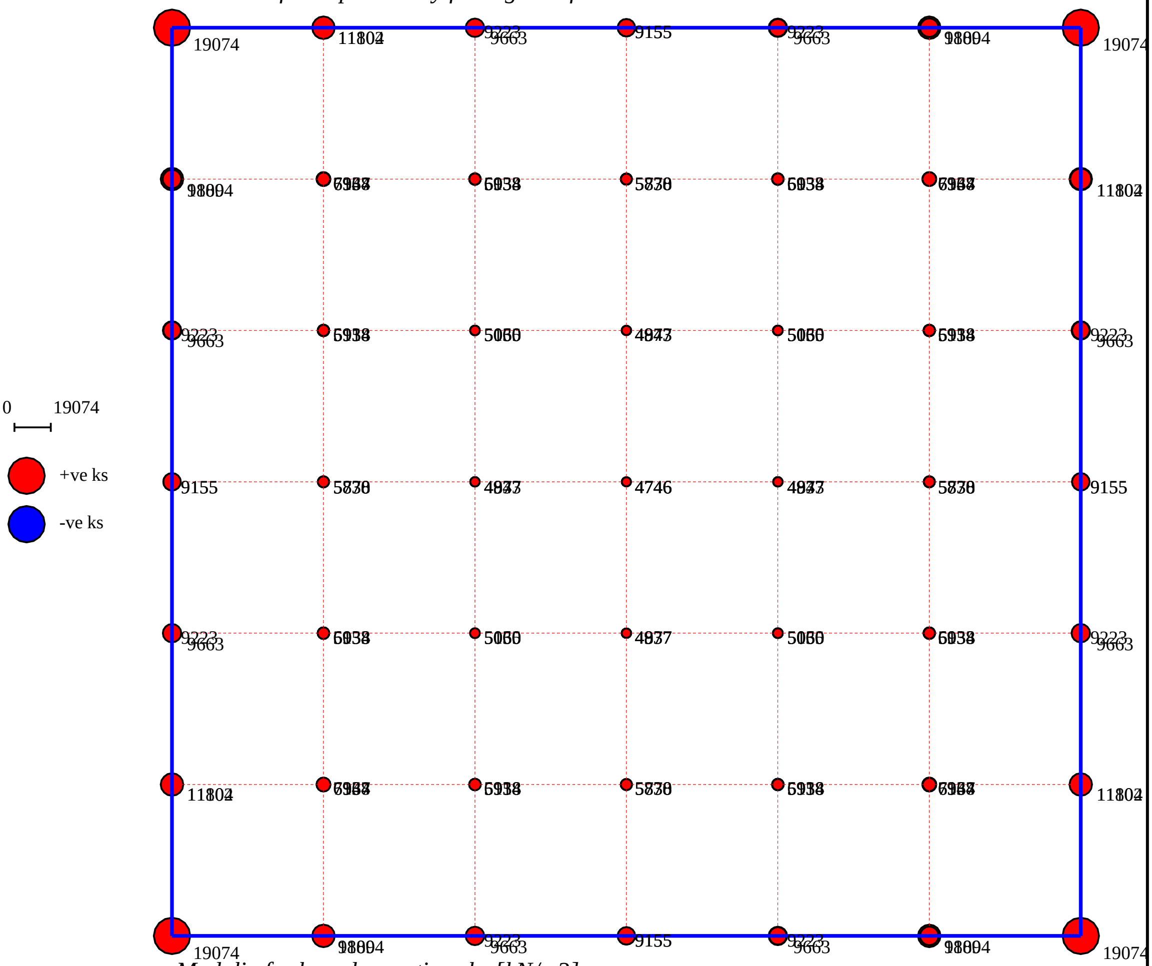
Scale: 60	**Title: 36 Pavement plates**
File: SZ3	**Date: 25-01-2018**
Page No.:	**Project: Example 8**

Method (8) (Layered soil model)

Modulus of Compressibility for Rigid Raft



Moduli of subgrade reactions ks [kN/m3]

Max. ks = 19074 at node 144, Min. ks = 4746 at node 60

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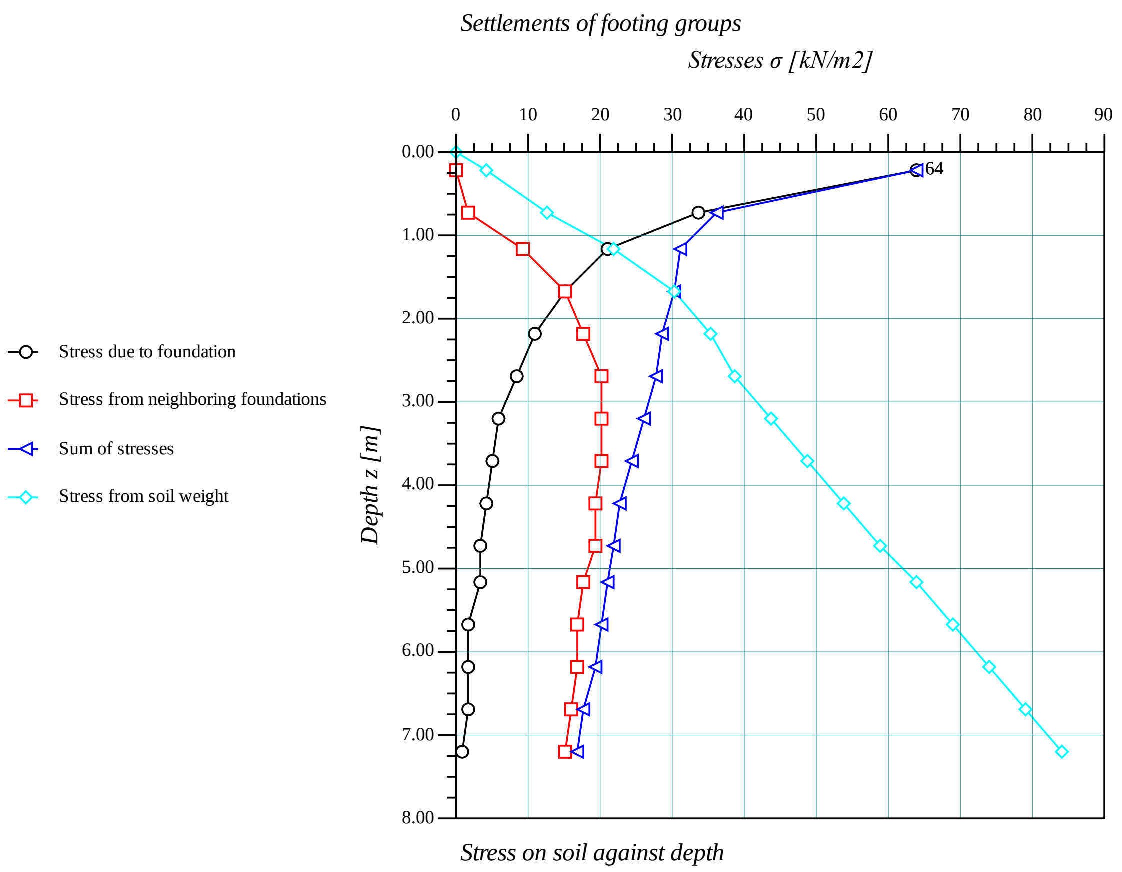
Scale: 60	**Title: 36 Pavement plates**
File: SZ3	**Date: 25-01-2018**
Page No.:	**Project: Example 8**



GEOTEC Software Inc., Calgary AB, Canada T3E 7Y7 PO Box 14001 Richmond Road PO, Tele.:+1(587) 332-3323	
Scale: 841	**Title: 36 Pavement plates**
File: SZ3	**Date: 25-01-2018**
Page No.:	**Project: Example 8**

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