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DESIGN OF DEEP FOUNDATIONS USING SOIL STRUCTURE INTERACTION

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Abstract: The paperwork presents a comparison between the classic of calculating deep foundations and a modeling method that uses soil structure interaction. A method used for solving a raft foundation is used on piled raft. A numerical sample shows the differences between the classical approach and the approach that uses soil structure interaction.

Key words: deep foundation design, piled raft.

1. INTRODUCTION

Piled foundations are used in cases where good foundation soil is at great depths or in case of large loads given by the structure. Piles can also be used to reduce settlements on a raft foundation.

2. GENERALITIES

In a classic approach on piled foundations all the actions given by the structure are transferred to the piles, and the raft is used only as a transfer element. A realistic approach for piled foundations is to transfer loads to the soil under the raft and to the piles. This can be done by modelling the soil-structure interaction. By taking into account the pressure between the raft and the soil technical and economical advantages may be obtained by reducing the length of the piles or the number of piles. The stresses in the raft can also be reduced.

Modeling the soil-structure interaction is a complex problem and involves a lot of parameters.

3. MODELLING SOIL STRUCTURE INTERACTION USING JEMOCIKLIN METHOD

This is an approximative method and the contact condition between the raft and the support is written in a finite number of points. This method is using the Winkler soil model. The raft is resting on points that represent soil and piles. In the support points of raft, resorts with different rigidity k for soil and for pile, are used.

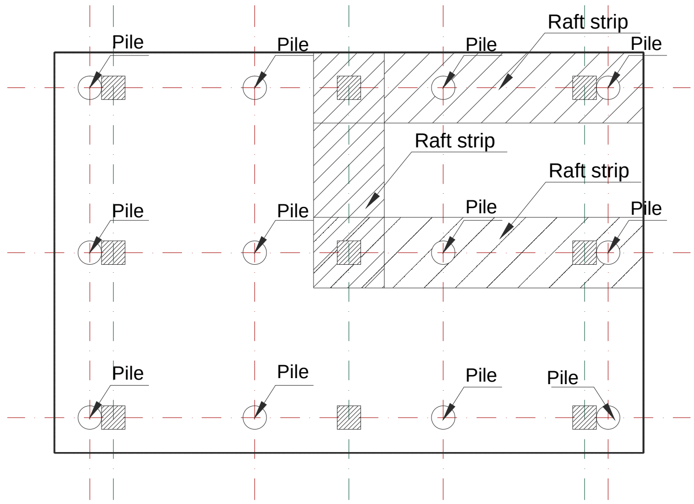

Fig. 1 Main strips of the raft.

This problem can be simplified and reduced to a plane problem of soil structure interaction and can be headed in the next steps:

- The base system is a beam fixed at one end where initial parameters must be known, the rotation of beam φ_0, and the settlement z_0.
- Beam is divided into n segments.
- The k resorts are replaced with reactive forces in soil and piles.
- Deformation of beam given by reactive forces of soil and piles must be equal to deformation of beam given by structural forces.

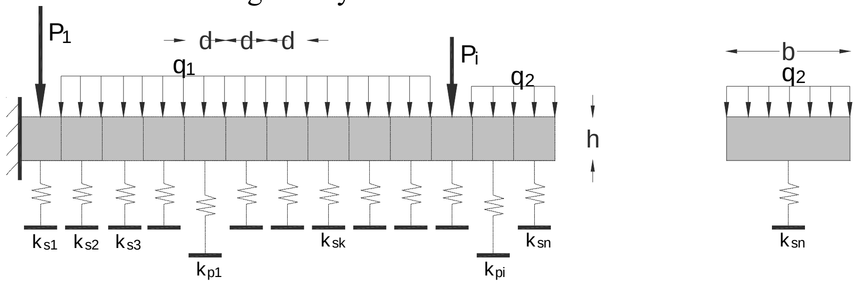

Fig. 2 Raft strip resting on k resorts

The equilibrium equations for the base system are:

$$\begin{cases} \delta_{11} \cdot x_1 + \delta_{12} \cdot x_2 + \ldots + \delta_{1k} \cdot x_k + \ldots + \delta_{1n} \cdot x_n - z_0 - \varphi_0 \cdot a_1 - \Delta_{1P} = 0 \\ \delta_{21} \cdot x_1 + \delta_{22} \cdot x_2 + \ldots + \delta_{2k} \cdot x_k + \ldots + \delta_{2n} \cdot x_n - z_0 - \varphi_0 \cdot a_2 - \Delta_{2P} = 0 \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ \delta_{k1} \cdot x_1 + \delta_{k2} \cdot x_2 + \ldots + \delta_{kk} \cdot x_k + \ldots + \delta_{kn} \cdot x_n - z_0 - \varphi_0 \cdot a_k - \Delta_{kP} = 0 \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ \delta_{n1} \cdot x_1 + \delta_{n2} \cdot x_2 + \ldots + \delta_{nk} \cdot x_k + \ldots + \delta_{nn} \cdot x_n - z_0 - \varphi_0 \cdot a_n - \Delta_{nP} = 0 \end{cases} \tag{1}$$

Static equilibrium must be also verified using next relations:

$$\sum_{i=1}^{n} P_i - \sum_{i=1}^{n} x_i = 0 \tag{2}$$

$$\sum_{i=1}^{n} P_i \cdot a_{Pi} - \sum_{i=1}^{n} x_i \cdot a_i = 0 \tag{3}$$

The terms in equation (1),(2) and (3) represent:

δ_{ik} deformation of beam in section i given by soil/pile reaction in section k.

P_i structural forces acting on element i.

x_i soil/pile reaction as a concentrated load acting in center of element i.

a_{Pi} P_i force lever related to fixity point of base system.

a_i lever of x_i soil/ pile reaction related to fixity point of base system.

z_0 system settlement in fixity point.

φ_0 system rotation in fixity point

Δ_{iP} beam deformation due to structural forces acting on beam

δ coefficients have two components :

$$\delta_{ik} = v_{ik} + f_{ik} \tag{4}$$

where:

v_{ik} soil settlement in section i due to x_k force acting in section k

f_{ik} beam deformation (for chosen base system) in section i under x_k force acting in section k.

The terms v_{ik} are equal to zero and terms v_{ii} are given by relation:

$$v_{ii} = \frac{1}{C_i} \tag{5}$$

Where: $C_i = k_i \cdot d$ - settlement coefficient on element i.

terms :

$$f_{ik} = \frac{d^2}{D} w_{ik} \tag{6}$$

where:

D cylindrical rigidity of plate/raft and is given by relation:

$$D = \frac{h^3 E_r}{12 \cdot \left(1 - \upsilon_c^{\,2}\right)} \tag{7}$$

Where:

E_r Young modulus for the material used in raft (concrete).

υ_c Poisson ratio for concrete.

h height of raft.

w_{ik} is given by relation:

$$w_{ik} = \frac{a_i^{\,2}}{2} \cdot \left(a_k - \frac{a_i}{3}\right) \tag{8}$$

Note:

If $\frac{a_i}{3} > a_k$ then $w_{ik} = 0$

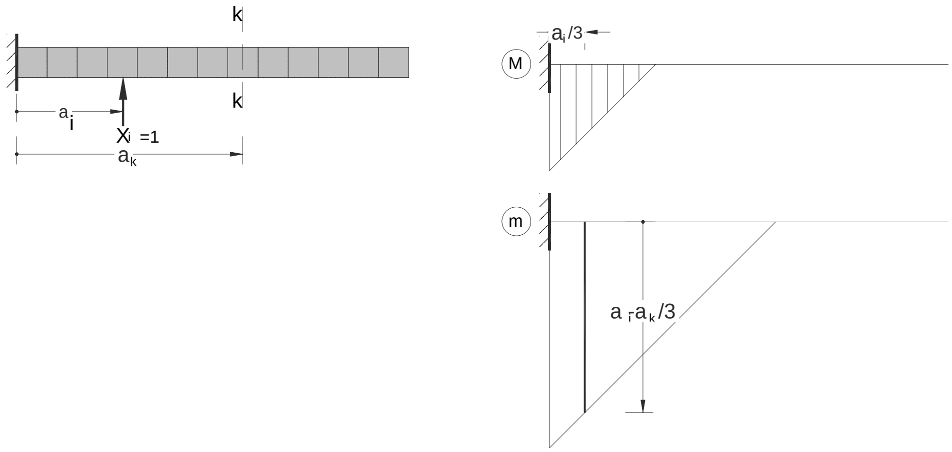

Fig. 3 Calculating w_{ik} coefficients.

3.1 Settlement coefficient evaluation

Settlement coefficient *k* represents the ratio between load and settlement of a surface and can be expressed with relation:

$$k = \frac{P}{s} \tag{9}$$

Where:

P concentrated load on a surface

s medium settlement of surface when P is acting.

Evaluation of settlement coefficient k_p for piles can be made by using the results of static load on a pile or by using bearing capacity of the pile and evaluate a probable settlement.

When evaluating the settlement coefficient for soil under the raft k_s the settlement of the pile group or pile must be taken into account. In a raft section in vicinity of the pile, the soil settlement is equal to the pile settlement.

3.2 Results

Starting with initial parameters (rotation φ_0 and settlement z_0) in the fixity point of beam the equilibrium system (1) can be solved. Equation system (1) can be written using the matrix:

$$[\delta] \cdot [x] = [\Delta_p] \tag{10}$$

Or:

$$[x] = [\delta^{-1}] \cdot [\Delta_p] \tag{11}$$

By reducing the spatial problem to a plane problem the raft is converted to a beam chosen depending on the points (surfaces) where loads are acting. Settlements must be equal in common points of raft strips. The static equilibrium equations must be checked using relations (2) and (3). The reactive forces x_i can be compared with bearing capacity of soil and piles.

Based on pressures obtained on i elements the beam internal stresses can be obtained for chosen raft strip.

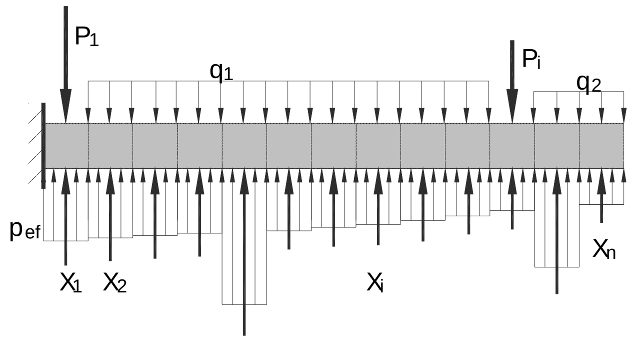

Fig. 4 Distribution of reacting pressure.

4. NUMERICAL SAMPLE

A raft for a frame structure with vertical loads:

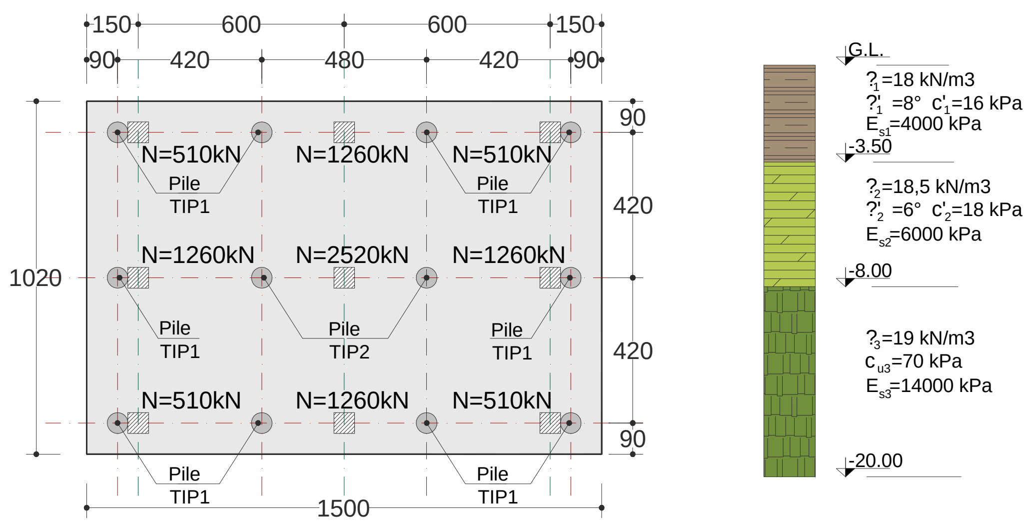

Fig. 5 Raft geometry.

The raft is resting on piles with characteristics presented in table 1.

Table 1. Pile characteristics.

Type of pile	Diameter [mm]	Length [m]	Bearing capacity [kN]
TIP 1	600	10	685
TIP 2	600	13.5	1100

Medium settlement of pile group is estimated according to STAS 2561 at a value of 2,9 cm. The settlement coefficient for piles k_p evaluated by theoretical aspects has a value of 30000-55000kN/m^3. For the raft the settlement coefficient is evaluated at 3000-5000 kN/m^3.

The raft was divided into 2 main strips where loads are acting. For every strip an evaluation with Jemociklin method was made.

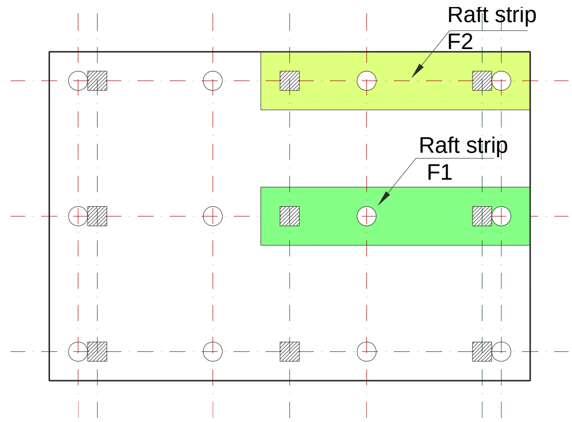

Fig. 6 .Raft strips.

The raft stripes are presented in figure 6. Every strip is divided in elements with 60 cm length. The strips are 180 cm wide.
Reactive pressure on every strip is presented in figure 6 and in the tables below.

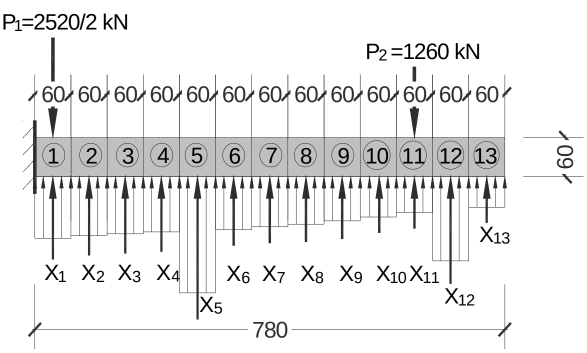

Fig. 6 .Raft strip F1

Table 2. Reactions for raft strip 1.

Element	1	2	3	4	5	6	7	8	9	10	11	12	13
Reaction X_i [kN]	82,2	82,1	79,3	74,9	1074,9	77,6	77,1	76,5	76,1	75,5	74,9	595,1	73,9
Pile reaction	=1670 kN (66% from total load)												
Raft reaction	=850 kN (34% from total load)												

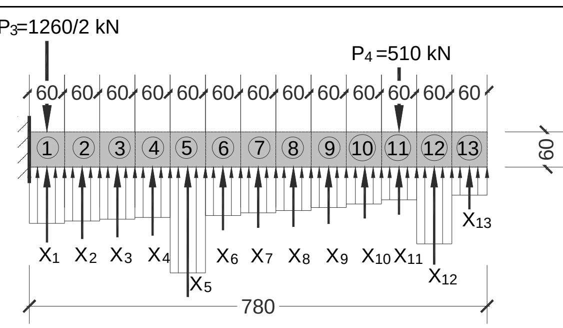

Fig. 7 .Raft strip 2

Table 3. Reactions for raft strip 2

Element	1	2	3	4	5	6	7	8	9	10	11	12	13
Reaction X_i [kN]	37,7	37,7	36,9	35,5	391,4	36,2	35,2	35,3	34,9	34,4	34,0	357,3	33
Pile reaction	=748,7 kN (65% from total load)												
Raft reaction	=356,8 kN (35% from total load)												

To show the advantages of a piled raft using soil structure interaction for the same raft strip an evaluation that is not considering the reactive pressure between the raft and the soil was made. The characteristic of the piles obtained are presented in table 4 and the pile reactions in table 5.

Table 4. Pile characteristic

Pile type	Diameter [mm]	Length [m]	Bearing capacity [kN]
TIP 1	600	12	920
TIP 2	600	19	1740

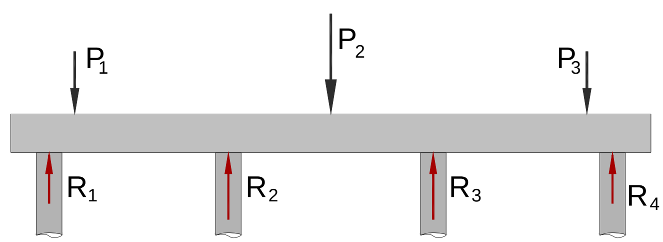

Fig. 8 Pile reactions for a raft strip.

Table 5. Loads transferred in piles.

<table>
<tr><th colspan="13">Raft strip 1</th></tr>
<tr><td rowspan="2">Load [kN]</td><td colspan="4">P_1</td><td colspan="4">P_2</td><td colspan="4">P_3</td></tr>
<tr><td colspan="4">1260</td><td colspan="4">2520</td><td colspan="4">1260</td></tr>
<tr><td rowspan="2">Reaction [kN]</td><td colspan="3">R_1</td><td colspan="3">R_2</td><td colspan="3">R_3</td><td colspan="3">R_4</td></tr>
<tr><td colspan="3">860</td><td colspan="3">1660</td><td colspan="3">1660</td><td colspan="3">860</td></tr>
<tr><th colspan="13">Raft strip 2</th></tr>
<tr><td rowspan="2">Load [kN]</td><td colspan="4">P_1</td><td colspan="4">P_2</td><td colspan="4">P_3</td></tr>
<tr><td colspan="4">510</td><td colspan="4">1260</td><td colspan="4">510</td></tr>
<tr><td rowspan="2">Reaction [kN]</td><td colspan="3">R_1</td><td colspan="3">R_2</td><td colspan="3">R_3</td><td colspan="3">R_4</td></tr>
<tr><td colspan="3">512,5</td><td colspan="3">627,5</td><td colspan="3">627,5</td><td colspan="3">512,5</td></tr>
</table>

5. CONCLUSIONS

Jemociklin method for evaluation of soil structure interaction is an approximative method and is reduced to a plane problem to simplify things.

By taking into account the soil-structure interaction from the 65% from total load was transferred to the piles and 35% to the raft.

Pile reactions are 30-35% lower in case of soil-structure interaction than in the case where loads are transferred only to the piles.

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