ROCZNIKI INŻYNIERII BUDOWLANEJ – ZESZYT 11/2011
Komisja Inżynierii Budowlanej Oddział Polskiej Akademii Nauk w Katowicach

NUMERICAL ANALYSIS OF THE INTERACTION OF THE SHALLOW (CIRCULAR, SQUARE, STRIP) FOUNDATIONS WITH SUBSOIL

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1. Introduction

At the foundations, there is a direct contact between the foundations and subsoil. The contact surface (at the level of the foundation joint) between shallow foundation and subsoil causes a change of the stress states. From point of view of the structure, it is the main factor of the "above ground structure and foundation" stiffness, stiffness of the foundation and loading intensity. This paper analysed the effect of the stiffness and bond at the level of the foundation joint of the circular, square and strip foundations on the intensity and distribution of contact stresses.

2. Boundary conditions of the problem

The problem of the interaction between shallow foundations and subsoil is solved by mathematical modelling using Finite Element Method (FEM). Computer program ANSYS® [3] was used to solve the problem. The contact task is solved as a 3-D problem according to assumptions of the linear elastic half-space theory.

a) Geometrical shape and stiffness of foundation structure

Geometrical shape is one of the most general factors which affect the relative stiffness of the system. This factor can be relatively exactly determinate for all shallow foundations. Geometrical parameters and stiffness of solved circular, square and strip foundation models are given in Tab. 1.

Table 1. Geometrical characteristics and stiffness of the shallow foundations

Geometrical shapes of foundations	Ratio L/B (-)	Foundation dimensions			Foundation relative stiffness STN 73 1001 [2] k (-)
		Width B (mm)	Length L (mm)	Thickness t (mm)	
SQUARE	1	200	200	2.5 to 100	0.0159 - 1009.62
CIRCULAR	-	240	-	5 to 100	0.073 - 584.2
STRIP	≅ 10	65	630	5 to 100	0.004 - 32.3 *

* stiffness in length direction “L“ of strip foundations

The foundation relative stiffness ”k” is defined according to the formula [2]:

$$k = \frac{E_f}{E_{def}} \left(\frac{t}{L} \right)^3 \qquad (1)$$

where “E_f“ is the modulus of elasticity of a foundation and “E_{def}“ is the modulus of elasticity of subsoil. For assessments of stiffness in width direction then L=B. For relative stiffness k<1 the foundation is a flexible and for k>1 the foundation is a rigid.

b) Physical properties of the foundation and subsoil models

From the physical point of view, the model with steel foundation is considered. This model is put on the dense sand subsoil (Fig. 1). The volume of subsoil under foundation is modelled as the cylinder with diameter and height 0.8m. The physical properties of foundations and subsoil are listed in Tab. 2. Model of foundation was loaded by axial forces of various values “F_i“, which generate the average contact stress of value from σ_{m1}=3.2kPa to σ_{m7}=76.5kPa, i.e. in the elastic zone of dense sand subsoil.

Table 2. Physical properties of foundations and subsoil

Model	Material	Physical properties		
		Modulus of elasticity E (MPa)	Poisson’s ratio ν (-)	Relative density I_D (-)
Foundation	Steel	210 000	0.20	-
Subsoil	Sand	26	0.28	0.7

c) Bond and friction at the contact surface

From point of view of the effects of bond and friction, two following cases were modeled:

- bi-directional bond (transmission of pressure and tensile forces, and shear forces at the solid contact between foundation and subsoil),
- one-directional bond with friction (transmission only due to pressure forces, and shear forces depended on the value of the angle of internal friction ϕ=35°),

The disadvantage of the bi-directional bond model is the transmission of the tension forces between foundation and subsoil. Model with one-directional bond describes more precisely the behavior of real foundation.

d) Mathematical methods and calculation models

Soil-structure interaction is solved using the deformation variant of FEM. Three-dimensional finite element “SOLID45” is used. One-directional bond are modeled using “CONTA174” and “TARGE170” contact elements. The Coulomb theory [3] for friction modeling between foundation and subsoil is used. Schematic representation of the computing models of rigid shallow foundation (t=100 mm) with a bi-directional bond with resulting meshing of finite elements and the static boundary conditions is showed in Fig. 1.

3. Evaluation of numerical results

From the numerical results, a lot of qualitative and quantitative knowledge’s of the solved problems are obtained. Quantitative comparison results of contact stresses for different values of k is given in Tab. 3. Qualitative interpretation of stiffness affecting on the intensity relative vertical normal (σ_z/σ_m) and shear (τ_{yz}/σ_m) contact stresses for centre and corner of the shallow foundations are shown in Figs. 2, 3, 4.

Table 3. Quantitative comparison of relative vertical normal and shear contact stresses in representative point of rigid and flexible foundations on the contact surface

Geometrical shape of foundations	Point location on contact surface	Contact stresses calculated under average loading intensity σ_m = 50,0 [kPa]							
		Bi-directional bond (with solid contact)				One-directional bond (with friction if f=35°)			
		Relative normal stress		Relative shear stress		Relative normal stress		Relative shear stress	
		σ_z / σ_m [-]		τ_{yz} / σ_m [-]		σ_z / σ_m [-]		τ_{yz} / σ_m [-]	
		R (k>>1)	F (k=0.1)	R (k>>1)	F (k=0.1)	R (k>>1)	F (k=0.1)	R (k>>1)	F (k=0.1)
Square	centre	-0.489	-3.788	0	0	-0.502	-3.785	0	0
	boundary	-1.480	-0.553	0.338	0.390	-1.399	-0.630	0.283	0.250
	corner	-3.095	-0.515	0.569	0.103	-2.500	-0.022	0.437	0.032
Circular	centre	-0.507	-2.815	0	0	-0.518	-2.778	0	0
	boundary	-1.876	-0.372	0.404	0.342	-1.801	-0.413	0.332	0.229
Strip	centre	-0.507	-1.244	0	0	-0.550	-1.361	0	0
	corner	-1.438	0.538	0.267	0.030	-1.048	-0.003	0.172	0.007
	boundary (L)	-1.035	0.449	0.226	0.016	-0.989	-0.003	0.225	0.007

Remark: R – rigid foundation (k>>1, respectively k=30); F – flexible foundation (k=0.1).

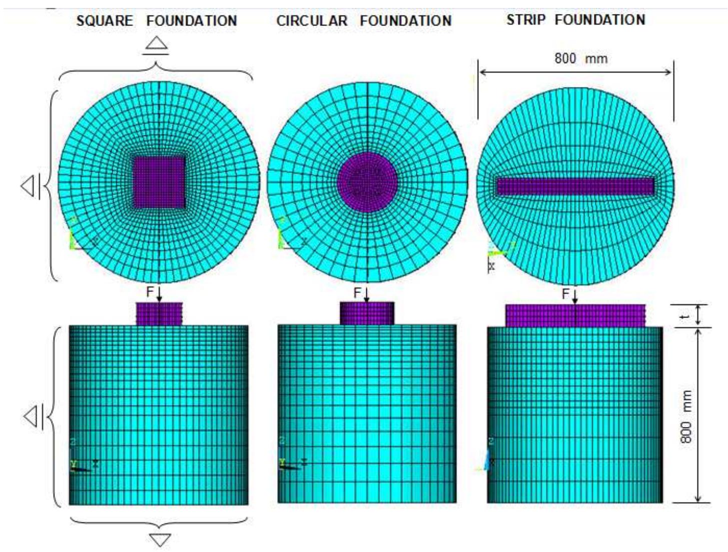

Fig. 1 Numerical models of rigid foundations (t=100 mm) with static boundary conditions

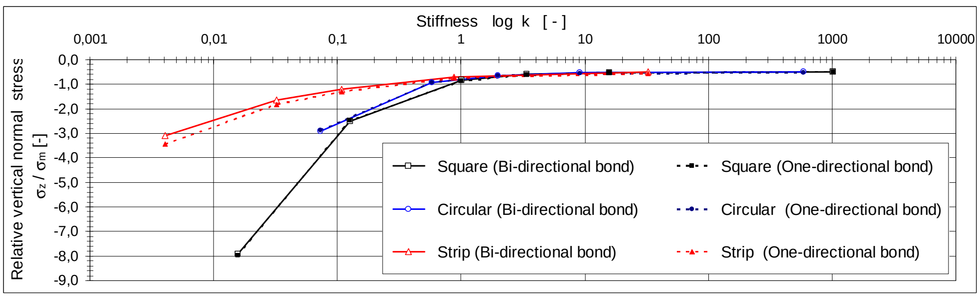

Fig. 2 Influence of rigidity and bonding on the normal stress under centre of foundation

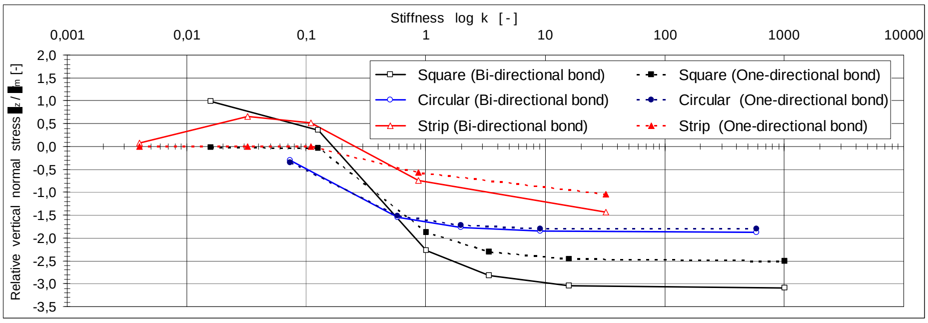

Fig. 3 Influence of rigidity and bonding on the normal stress under corner of foundation

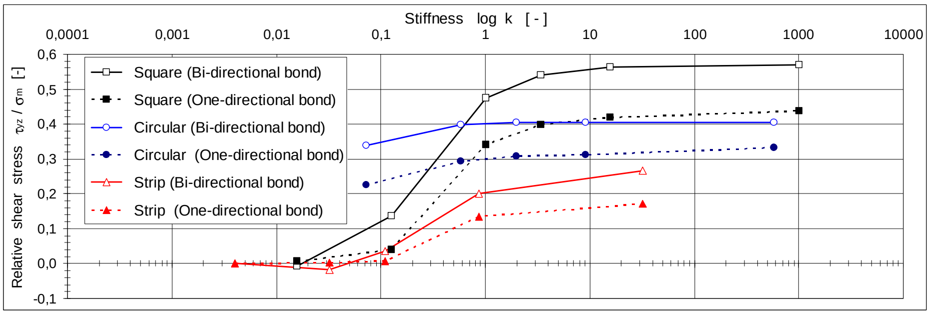

Fig. 4 Influence of rigidity and bonding on the shear stress under corner of foundation

4. Conclusion

Correct assessment of the values of the contact stresses in the foundation bottom affect significantly the reliable design of foundations. Presented calculations show that taking into account the effect of stiffness, bond and friction in the foundation bottom allows in practical solutions the realistic and economical design of shallow foundations with respect of the required reliability.

References

[1] Hruštinec Ľ.: Interaction analysis of the shallow foundations with subsoil. Ph.D. Thesis, Bratislava, 2002, 689 pp. (In Slovak).
[2] STN 73 1001: Subsoil under shallow foundation. Slovak Standard, 1987, (In Slovak).
[3] ANSYS®: User's Manual, Swanson Analysis System, Inc., Volume I. - IV., 1999.

NUMERICKÁ ANALÝZA INTERAKCIE PLOŠNÝCH (KRUHOVÝCH, ŠTVORCOVÝCH , PÁSOVÝCH) ZÁKLADOV S PODLOŽÍM

Zhrnutie

V článku sa zaoberáme numerickou analýzou kontaktných napätí pod tuhými a ohybnými plošnými (kruhovými, štvorcovým a pásovým) základmi. Analýza je zameraná na vplyv tuhosti a väzby na veľkosť zvislých normálových a šmykových napätí.

Dedication:
This article is dedicated to the jubilee of our friend Prof. Dr. Eng. Jan Kubik, University of Opole.