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VERIFICATION OF GEOTECHNICAL NUMERICAL SIMULATIONS BY MODEL TESTS USING PIV TECHNIQUE

PART II. NUMERICAL SIMULATIONS

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Abstract

Numerical simulations regarding the stability of shallow foundations located near cantilever retaining walls have been carried out using Plaxis ver. 8.4 commercial code, based on three shear strength criteria for soils i.e. Coulomb-Mohr, Matsuoka-Nakai and Lade-Duncan. The results have been compared with the model test results described in Part I of the paper. According to the Experimental Soil Engineering concept (ESE), the comparison served for a selection of the shear strength criterion reflecting the best quantitative and qualitative results of model tests.

Streszczenie

Symulacje numeryczne stateczności fundamentów bezpośrednich posadowionych w sąsiedztwie kątowych ścian oporowych wykonano w programie Plaxis w wersji 8.4. W obliczeniach numerycznych wykorzystano trzy kryteria wytrzymałości gruntu na ścinanie: Coulomba-Mohra (CM), Matsuoki-Nakaiego (MN) i Ladego-Duncana (LD). Wyniki symulacji numerycznych porównano z wynikami własnych badań modelowych opisanych w części I. Na podstawie analizy wymienionych porównań zgodnie z koncepcją Experimental Soil Engineering (ESE) wskazano kryteria wytrzymałości gruntów na ścinanie najlepiej odwzorowujące ilościowe i jakościowe wyniki badań modelowych.

Keywords: **Stability of shallow foundations; Numerical simulations; Verification of various shear strength criteria of soils.**

1. INTRODUCTION

Numerical simulations, particularly regarding complex foundation-loads-subsoil (FLS) systems require reliable verification based on modern model tests. Typical example of such a system may be the problem of stability of shallow foundations located near cantilever retaining walls.

In the part II of the paper the methodology and the results of numerical simulations for complex FSL system versus model test results have been described.

2. NUMERICAL SIMULATIONS

2.1. General remarks

Selection of commercial geotechnical software for the analysis of stability of complex FLS system was based on the following conditions:

- a code should include various shear strength criteria for soils,
- there should be a possibility for proper discretisation of individual FLS system elements both in a stage of initial stress generation as well as during introducing displacements of the foundation analysed,
- full visualization of the results,
- reliability of the code and results produced.

The above conditions are fulfilled by Plaxis commercial code ver. 8.4. with three shear strength criteria for soils i.e. Coulomb-Mohr, Matsuoka-Nakai and Lade-Duncan. The first one is already built in the code, whereas two others have been implemented by Cudny [1] using User-Defined Soil Models tool. The details regarding mentioned criteria and its practical application have been described in the papers [1] and [2].

For verification of numerical simulations the Authors have used the results of own model test results described in [3] and [4].

2.2. Boundary conditions

In order to carry out the numerical simulations the boundary conditions have been assumed for shallow foundations and cantilever retaining wall as well as uniform subsoil. The conditions which correspond to the conditions of model tests are the following:

A. Shallow foundation and cantilever retaining wall were made of steel plates:
  - elastic material with $E = 3 \cdot 10^8$ kPa and $\nu = 0.0$,

B. Natural subsoil made of dry medium sand called Rybaki 3, with the following parameters:
  - effective angle of internal friction $\phi = 35.2°$,
  - effective cohesion $c = 2.5$ kPa (assumed for calculations according to Plaxis manual recommendations),
  - oedometric compressibility modulus $M_0 = 200037$ kPa,
  - Young's modulus $E = 17000$ kPa,
  - Poisson's ratio $\nu = 0.24$,
  - unit weight $\gamma = 16.22$ kN/m^3.

The model has been discretised using 6-node triangular elements (Fig. 1). During the course of simulations the subsequent phases of constructing the models in model tests have been implemented i.e.: generation of initial stress (Fig. 1a), foundation of cantilever retaining wall (Fig. 1b), placement of backfill and generation of the displacements of shallow foundations (Fig. 1c).

Contact zone between shallow foundation, cantilever retaining wall and subsoil was covered by very dense mesh without introducing contact elements. The detailed description of the applied procedure has been included in [3].

2.3. Results of numerical simulations

The results of numerical simulations for three different shear strength criteria have been presented for 7 representative FLS systems among the total number of 16 model tests carried out.

Quantitative results in the form of load-settlement relation as well as qualitative results represented by displacement fields have been compared with the results of model tests, Figs. 2-9.

The analysis of the quantitative results presented (Figs. 2, 4, 6 and 8) shows that bearing capacities of shallow foundations located near cantilever retaining wall are the best approximated by MN criterion. For majority of cases analysed, the calculated values are higher then those obtained from model tests (7÷31%). When the CM criterion is concern the calculated results underestimate the model test results (24÷47%), whereas for LD criterion – overestimate these results (42÷69%). It should be also noted that for all shear strength criteria, the calculated values are obtained at significantly higher settlements than that measured during model tests.

In turn, the analysis of qualitative results presented in the form of displacement fields, Figs 3, 5, 7, 9 shows that:

- the shape and range of simulated displacement fields for each of the criteria applied is very similar to each other for every of the FLS systems assumed,
- for each of the FLS systems analysed, calculated shape and range of displacement fields is in good agreement with that observed in model tests,
- the shape and range of displacement fields for FLS system analysed (shallow foundations near cantilever retaining wall) for both numerical simulations and model tests are completely different than

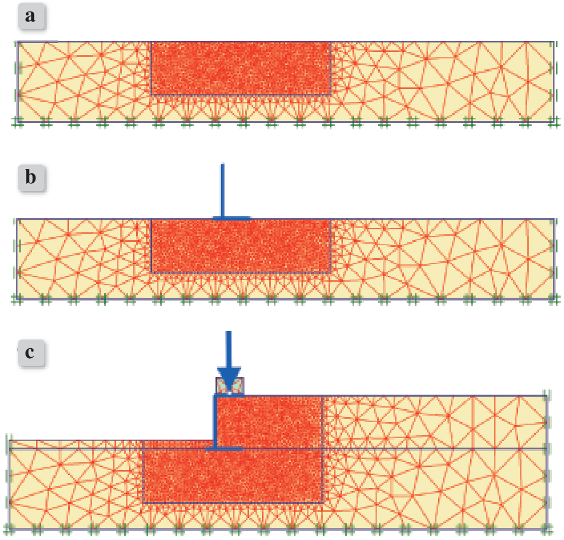

Figure 1.
Discretisation phases for foundation-load-subsoil (FLS) system

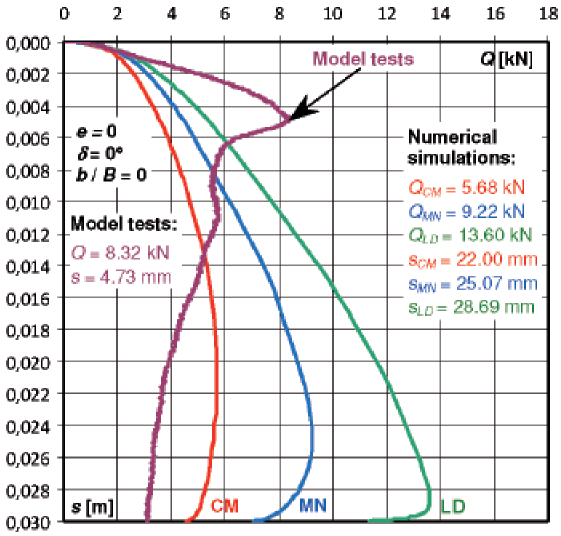

Figure 2.
Comparison of the quantitative results for vertical, axial load and b / B = 0

that obtained for shallow foundation, only. In the first case it covers the subsoil area under the foundations as well as behind, in front of and partly under the cantilever retaining wall.

2.4. Verification of numerical simulations

Numerical simulations of bearing capacity of shallow foundations located in various distances *b* / *B* from the edge of cantilever retaining wall and for various systems of external loads (vertical – axial, eccentrical, axial – inclined ones), aimed at possibly the best reproduction of the conditions applied in model tests

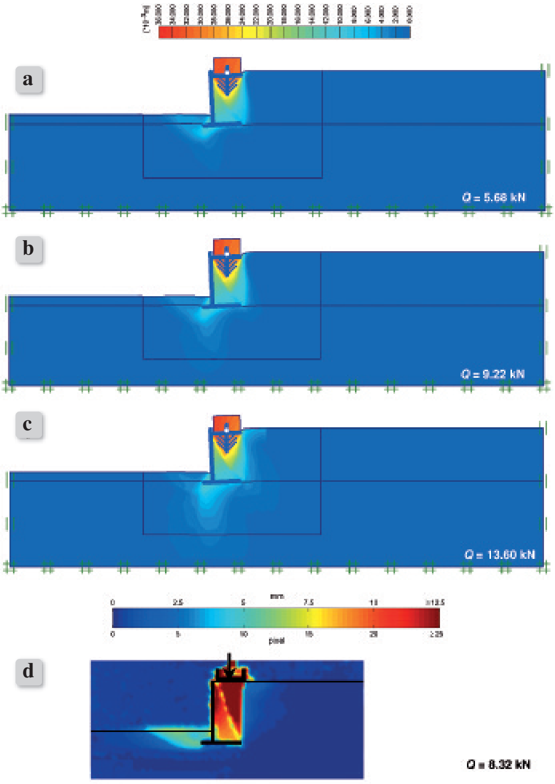

Figure 3.
Displacement fields obtained from numerical simulations (a÷c) versus model test results (d) for vertical, axial load and b / B = 0

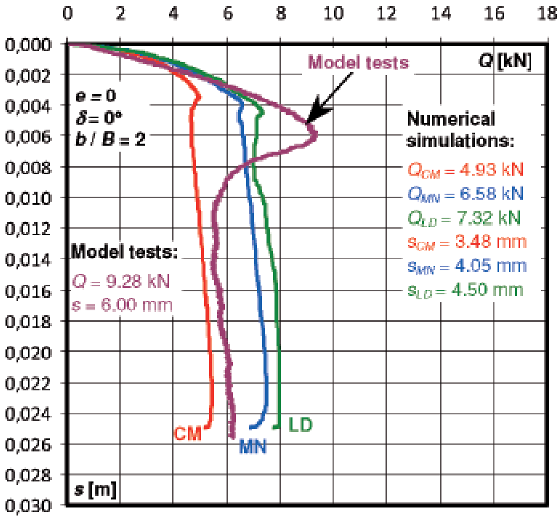

Figure 4.
Comparison of the quantitative results for vertical, axial load and b / B = 2

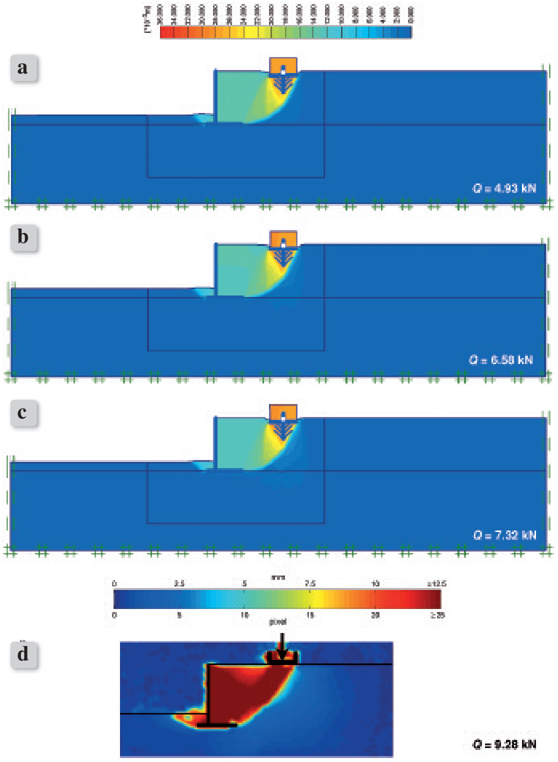

Figure 5.
Displacement fields obtained from numerical simulations (a÷c) versus model test results (d) for vertical, axial load and b / B = 2

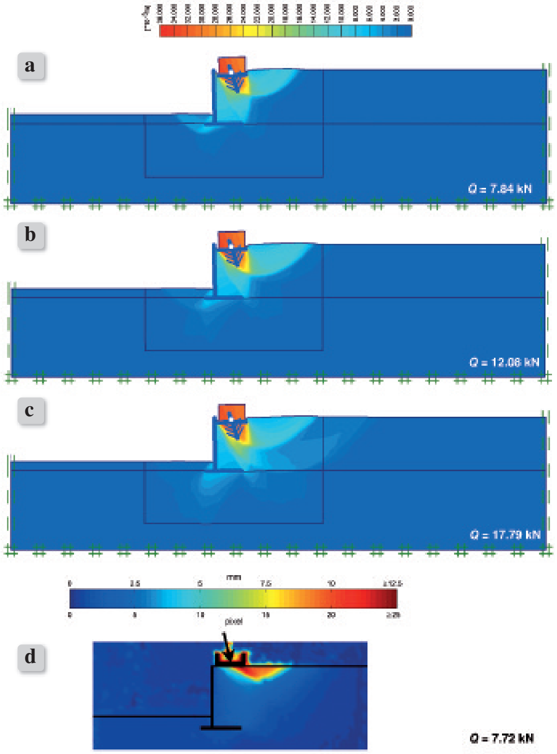

Figure 7.
Displacement fields obtained from numerical simulations (a÷c) versus model test results (d) axially inclined load $\delta = 20°$ and b / B = 0

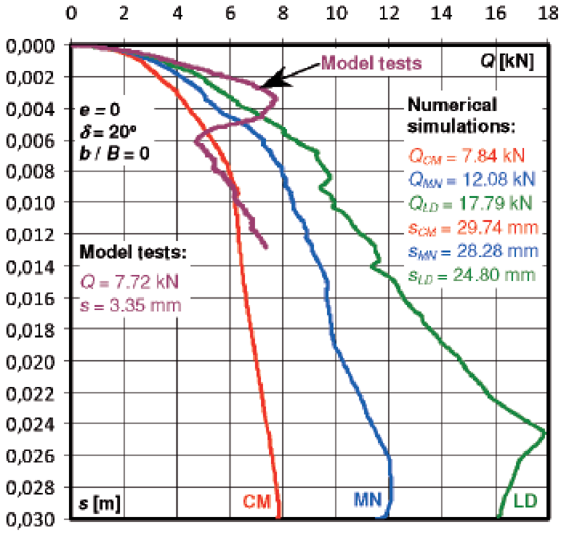

Figure 6.
Comparison of the quantitative results for axially inclined load $\delta = 20°$ and b / B = 0

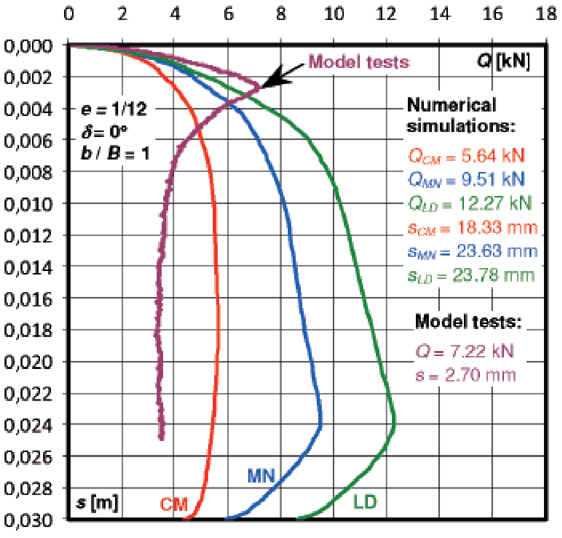

Figure 8.
Comparison of the quantitative results for vertical load acting eccentrically ($e = 1/12$) and b / B = 1

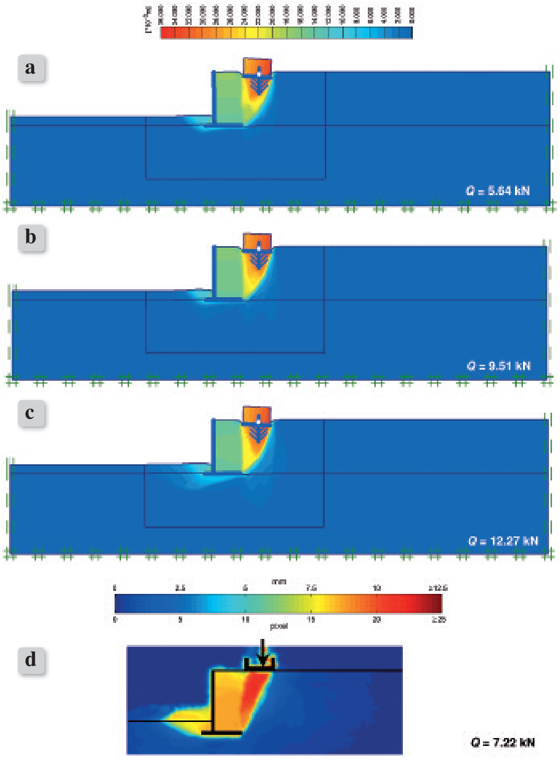

Figure 9.
Displacement fields obtained from numerical simulations (a÷c) versus model test results (d) for vertical load acting eccentrically (*e* = 1/12) and b / B = 1

and described in details in [4]. Thus, comparing the qualitative and quantitative results of these tests with those obtained from numerical simulations one can verify the assumptions implemented for the calculations. The verification relied on the selection of the following:

- appropriate discretisation approach,
- best suited shear strength criterion,

for which the agreement between quantitative and qualitative results was the best.

In order to do that the calculated values of bearing capacity for shallow foundation Q_{num} have been compared with those obtained from model tests Q_{exp} by determining so called conformity factor n':

$$n' = \frac{Q_{num}}{Q_{exp}} \qquad (1)$$

The values of all conformity factors have been shown in Table 1.

Table 1.
Conformity factors of bearing capacity of shallow foundation obtained from numerical simulations and model tests

Loading scheme	Test Q_{exp} [kN]	Shear strength criterion	Calculations Q_{num} [kN]	Conformity factor n'
e = 0 δ = 0° b / B = 0	8.32	CM **MN** LD	5.68 **9.22** 13.60	0.68 **1.11** 1.63
e = 0 δ = 0° b / B = 1	5.86	**CM** **MN** LD	**4.93** **7.26** 8.34	**0.84** **1.23** 1.42
e = 0 δ = 0° b / B = 2	9.28	CM MN **LD**	4.93 6.58 **7.32**	0.53 0.71 **0.79**
e = 0 δ = 0° b / B = ∞	17.71	CM **MN** LD	12.10 **19.94** 26.19	0.68 **1.10** 1.47
e = 0 δ = 20° b / B = 0	7.72	**CM** MN LD	**7.84** 12.08 17.79	**1.01** 1.56 2.30
e = 1/12 δ = 0° b / B = 0	8.98	CM **MN** LD	6.87 **9.60** 14.69	0.76 **1.07** 1.63
e = 1/12 δ = 0° b / B = 1	7.22	**CM** **MN** LD	**5.64** **9.51** 12.27	**0.78** **1.31** 1.69

The analysis of the values of conformity factors shows that:

- the best agreement between numerical simulations and model tests for bearing capacity was obtained for Matsuoka-Nakai (5 cases) and Coulomb-Mohr (2 cases) criteria,
- conformity factors for Matsuoka-Nakai criterion vary from 1.07 to 1.31, which means that calculated values of Q_{num} can be overestimated from 10 to 30%, approximately,
- conformity factors for Coulomb-Mohr criterion vary from 0.53 to 0.84, which means that calculated values of Q_{num} can be underestimated,
- conformity factors for Lade-Duncan criterion vary from 1.42 to 1.69, which means that calculated values of Q_{num} can be overestimated from 40 to 70%, approximately.

It has to be pointed out that the discrepancies of the results presented, are likely resulting from extremely complex FLS system analysed, which can be influenced mainly by the following factors:

- alternate distance between shallow foundation and cantilever retaining wall,

- values of eccentricity and inclination of the load acting on shallow foundations,
- direction of inclination and eccentricity of shallow foundation (towards or apart from the cantilever retaining wall).

For simpler (basic) FLS system ($e = 0$, $\sigma = 0°$, $b/B = \infty$) conformity coefficient for Matsuoka-Nakai criterion was 1.1, thus showing good agreement between calculated and experimental results.

3. SUMMARY

The considerations regarding the verification of numerical simulations by the results obtained from model tests have both cognitive as well as practical aspects for two main reasons, namely:

- they indicate the reliable methodology of numerical simulations regarding discretisation of FLS systems and the selection of appropriate shear strength criterion,
- they make the geotechnical design of shallow foundations located near cantilever retaining walls much easier. Such systems are very complex, not included in current geotechnical codes (e.g. EUROCODE 7 and Polish Geotechnical Code PN-81/B- 03020).

It should be also pointed out that the results and conclusions presented can be applied only for the conditions corresponding to those applied in model tests. For other conditions, the numerical simulations can be treated as some preliminary approximations only, requiring further experimental verification.

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