Deltares

MPM validation with centrifuge tests: pilot case pile installation

Part 2: Hypoplasticity

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1206750-005

Deltares

Title
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Project	Reference	Pages
1206750-005	1206750-005-HYE-0002	32

Keywords
Material Point Method (MPM), pile installation, Hypoplasticity

Summary
Numerical calculations using the dynamic MPM-code of Deltares are performed to simulate the installation of jacked piles. Aim of the project is the validation of the numerical calculations using results of centrifuge tests, which were carried out at Deltares. The centrifuge tests were performed to analyse the installation effects of jacked piles and for the simulation of static and rapid load tests, see Huy (2008). This is follow-up of the work "On the validation of the Material Point Method (MPM)", Rohe et al. (2013) and "MPM validation with centrifuge tests: pilot case pile installation, Part 1: Mohr-Coulomb", Elkadi et al. (2013).

Aim of the numerical simulations is to model the pile installation effects to create the load-displacement behaviour resulting from the installation. After the simulation of the installation phase, the loading scheme has to be applied which corresponds to the static load test as used in the centrifuge experiment.

The work is divided into two phases; first phase, which is reported earlier in part 1, is the analysis using the elastic-plastic model commonly used in practice, the Mohr-Coulomb model. Validation using this model is followed in phase two, which is reported here, with the hypoplastic model. The validation and material calibration is done on dry medium-dense Baskarp sand (R_D=54%) and afterwards analysis is performed for loose sand.

The results showed that the model properties needs to be calibrated based on the expected stress range either using lab experiments, element tests, or both. With a calibrated material set, the model as implemented in MPM is able to simulate the pile installation and STL as in the centrifuge experiments with good agreement.

Version	Date	Author	Initials	Review	Initials	Approval	Initials
	Dec. 2013	dr. A.S. Elkadi		dr.ir. P. Holscher		dr.ir. P.R. Wellens	
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final

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1 Introduction

1.1 Goal of this work

Goal of the project is to validate calculations using the Material Point Method (MPM code of Deltares) with results of centrifuge experiments on pile installation and static load testing in Baskarp sand.

1.2 Overview of the performed work

Numerical calculations using MPM are performed for the jacked installation of an initially partly embedded pile in dry sand. In the centrifuge tests, three different initial densities of the sand have been investigated (loose, medium-dense, and dense sand). In this work, calculations are performed for two different material parameter sets corresponding to two different densities, namely medium dense and loose sand. The mesh used in this analysis was readily available within the PhD work of Phuong Nugyen. The hypoplastic material model is used to model the sand. The parameters needed for the model are first calibrated using experimental and analytical results from literature and numerical element tests. The calculation phases of the numerical simulations follow closely the procedure as applied in the centrifuge tests carried out at Deltares under supervision of Paul Hölscher, see Huy (2008) and Hölscher et al. (2012).

2 Parameters for the Hypoplasticity material model

In this chapter, model simulations of pile installation applying the hypoplasticity model, which is a material model suited to describe hypoplastic behaviour of granular material such as sand. The hypoplastic model implemented in the Deltares MPM code is based on the formulation of Von Wolffersdorff, 1996 and further extended with the intergranular strain concept to describe small changes of stress and strain.

2.1 Hypoplastic model parameters

The hypoplastic material, model as implemented in the Deltares MPM code, is described in detail in Rohe et al. (2013). The model captures the influence of mean pressure and density along various deformation paths and the soil behaviour is bounded by asymptotic states including the critical state. As stated by von Wolffersdorff, the hypoplastic constitutive relation requires eight parameters (see Table 2.2), the granular stiffness h_s, the critical friction angle φ_c, the critical void ratio e_{c0} at zero pressure, the minimum and maximum void ratios e_{d0} and e_{i0} at zero pressure, and the constants n, α and β. Anaraki (2008), performed experiments on Baskarp sand to determine their hypoplastic material properties, which are summarised in Table 2.1.

Table 2.1 Hypoplastic parameters for Baskarp sand (Anaraki, 2008)

Parameter	φ_c [°]	h_s [MPa]	n	e_{d0}	e_{c0}	e_{i0}	α	β
Baskarp sand	31	4000	0.42	0.548	0.929	1.08	0.12	0.96

These parameters are described in Table 2.2.

Table 2.2 Parameters of the basic hypoplastic material model according to von Wolffersdorff (1996)

Parameter		*Description*
φ_c	[°]	critical friction angle (critical state friction angle)
h_s	[MPa]	granular hardness, determines the inclination of the void ratio limits
n	[-]	determines the curvature of the void ratio limits
e_{d0}	[-]	minimum reference void ratio (initial value at zero stress)
e_{c0}	[-]	reference void ratio for critical state (initial value at zero stress)
e_{i0}	[-]	maximum reference void ratio (initial value at zero stress)
α	[-]	determines the dependency of peak friction angle w.r.t. relative density
β	[-]	determines the dependency of soil stiffness w.r.t. relative density

The parameters listed above are considered as basis parameter set for simulating the pile installation as described further in this report. However, in order to check the suitability of these parameters in simulating the pile installation in the centrifuge experiments, element tests using Plaxis (with same hypoplastic model implementation as in MPM) are performed to simulate the laboratory experiments by Anaraki (2008) and Deltares on Baskarp sand. These element tests are described in the following sections.

2.2 Simulation of Oedometer tests

Figure 2.1 shows the oedometric response with void ratio (e) as function of the effective stress (σ_v) for different specimens with an initial void ratio varying between 0.657 (dense) and 0.823 (loose). In addition, simulated response from the element test is presented as well. At low axial pressures (<200 kPa) the numerical results match well the experimental results for both specimens. However, under high axial pressure (>200 kPa), the matching between experimental and numerical result is obtained only in dense and medium dense specimens. For loose specimens, numerical results give significantly stiffer response as compared to the experimental result.

In the hypoplastic model, the parameter h_s denotes the granulate hardness and is used as a reference pressure. This parameter is determined and valid for a limited pressure range. Occurrence of e.g. grain crushing at higher pressures changes the granular properties, thus the value of h_s. An attempt to get a better fit for the loose sand, h_s value of 2GPa is used instead of 4GPa.

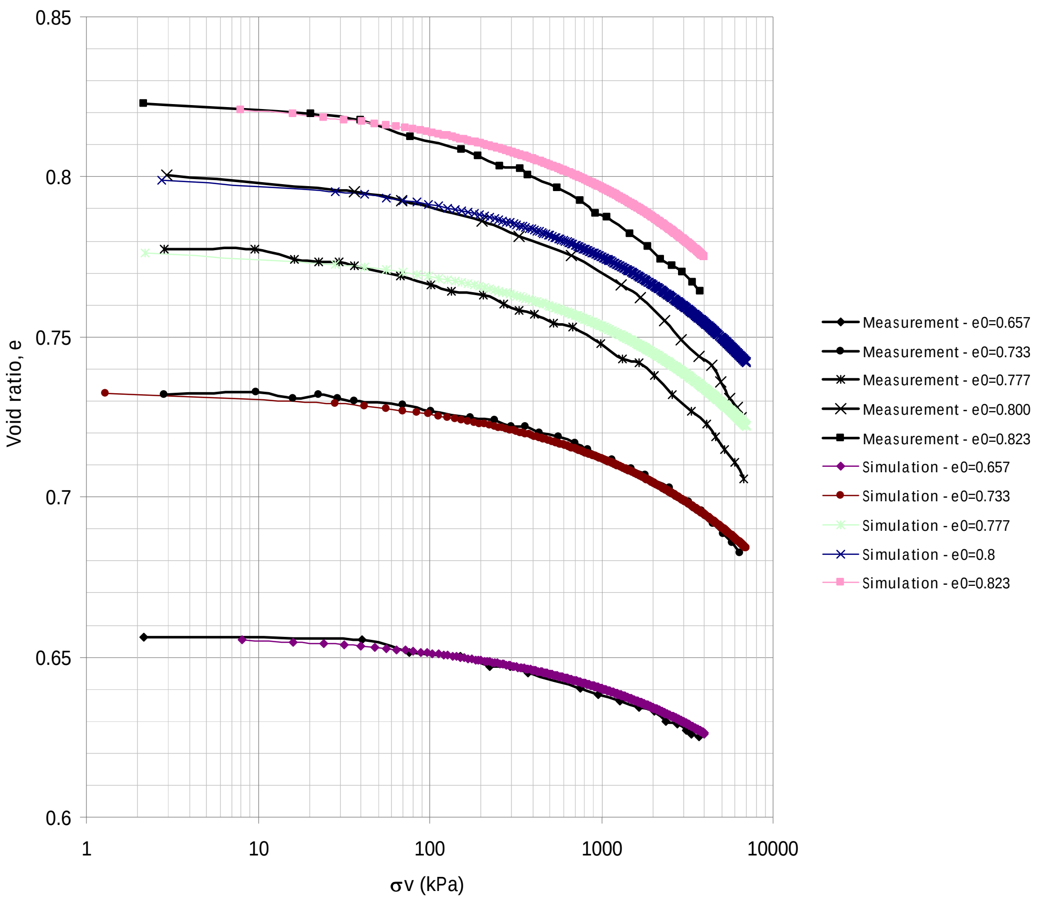


Figure 2.1 Oedometric test, comparison between measurement and element test (h_s = 4GPa)

Figure 2.2 shows the oedometric response with the updated h_s value of 2GPa instead of 4GPa. The result shows the good agreement between the element tests and the experiments for the loose sand (e_0 > 0.75).

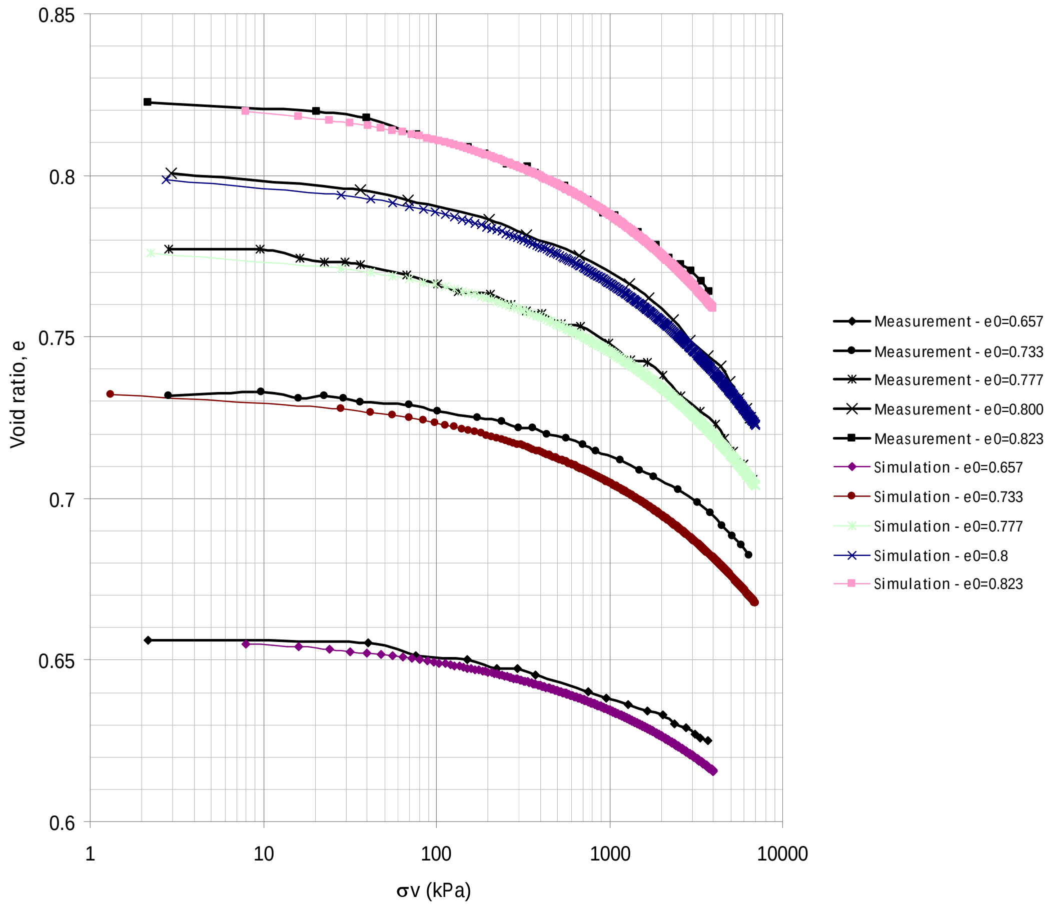


Figure 2.2 Oedometric test, comparison between measurement and element test (h_s = 2GPa)

2.3 Simulation of triaxial tests

2.3.1 Triaxial test results carried out by Anaraki (2008) on dense sample

Tests on dense Baskarp samples were performed with three confining pressures:

- σ = 50 kPa, e = 0.59
- σ = 100 kPa, e = 0.6
- σ = 200 kPa, e = 0.6

The obtained experimental results and the numerical simulation of the drained triaxial compression tests performed on dense samples of Baskarp sand are shown in Figure 2.3. The simulated peak shear strength and the residual shear strength are in accordance with laboratory experiments. The volumetric behaviour as simulated is qualitatively (shape) in accordance with the experimentally obtained results. However, simulated dilatancy angle is smaller as compared with the experimental results. According to Anaraki, in the test with the initial effective confining pressure of 50 kPa, the initial stiffness behaviour as observed in the measurements is not representative and is merely due to logging error by the program. This logging error has also its effect on the simulated volumetric response.
According to Anaraki (2008), the lower dilatancy angle in the element tests are probably linked to effects of lubricated ends and slenderness ratio. Conventional test conditions, i.e. slenderness ratio of 2 and no application of lubricated ends, lead to a pronounced stress peak. Shear banding occurs and simultaneously, the increase of the volumetric strain is abruptly stopped.

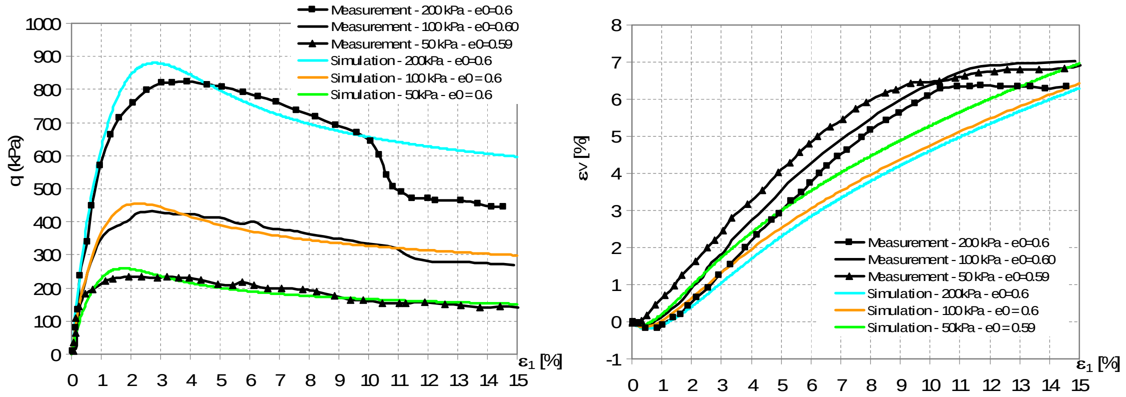


Figure 2.3 Numerical simulation of triaxial compression test (Anaraki, 2008) on dense sand specimens. Left: Deviatoric stress vs. axial strain and right: Volumetric strain vs. axial strain.

Lubricated platens in combination with a slenderness ratio of 1, i.e. conditions comparable with the simulation of the element test, result in a much smoother curves for both stress-strain and volumetric behaviour.

2.3.2 Triaxial test results carried out by Anaraki (2008) on loose sample

Tests on loose Baskarp samples were performed with three confining pressures:

- σ = 50 kPa, e = 0.70
- σ = 100 kPa, e = 0.84
- σ = 200 kPa, e = 0.81

The results of the triaxial tests on loose sand are plotted in Figure 2.4. For loose sand, the initial stiffness response, peak shear strength and the residual shear strength of numerical simulations are quantitatively in accordance with the experimental data. However, in the experimental data, mobilisation of the peak shear strength, especially for high confining pressure, is more gradual compared to the numerical simulation. The volumetric behaviour as simulated is qualitatively (shape) in accordance with the experimentally obtained results. There is agreement in dilatancy angle between the simulation and the experiments, which is different from the case of the dense sand (Figure 2.4 right). This could be linked to the less pronounced peak in loose samples with a more ductile behaviour.

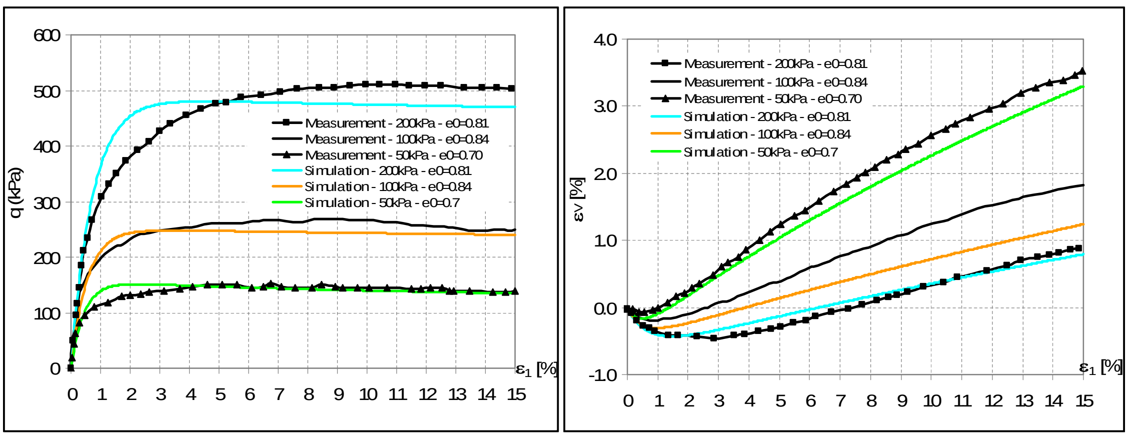


Figure 2.4 Numerical simulation of triaxial compression test (Anaraki, 2008) on loose sand specimens. Left: Deviatoric stress vs. axial strain and right: Volumetric strain vs. axial strain.

2.3.3 Triaxial test result carried out at Deltares (2006)

Triaxial tests in Deltares on Baskarp sand were done with a confining pressure of 200 kPa and with two different densities:

- σ = 200 kPa, e = 0.67
- σ = 200 kPa, e = 0.75

Figure 2.5 and Figure 2.6 give the simulation versus the experimental results for the dense and loose sand, respectively.

The results show a higher measured stiffness response and higher measured peak shear strength compared to the simulations. The residual shear strength agrees however. The volumetric behaviour as simulated is qualitatively (shape) in accordance with the experimentally obtained results. The simulated dilatancy angle is smaller compared with the experimental results for both dense and loose samples. The reason for the difference in response between the triaxial tests of Anaraki and the Deltares tests is not clear. It is noteworthy that the initial stiffness from Deltares tests was reported rather high for the medium-dense sand (~ 85 MPa). The reason could be attributed for example to difference in test conditions and/or difference in Baskarp sand type used. This is since it is observed that in the literature reference is made to a number as well (e.g. Baskarp sand No. 15) suggesting possible different types of this sand. The description in Anaraki and Deltares tests refers only to Baskarp sand.

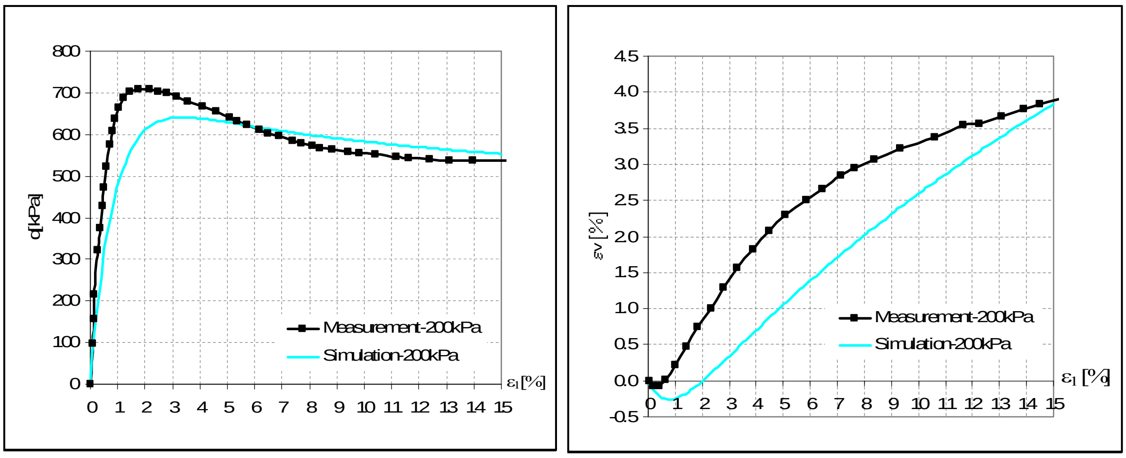


Figure 2.5 Numerical simulation of triaxial compression test (Deltares, 2006) on medium dense specimen e=0.67. Left: Deviatoric stress vs. axial strain and right: Volumetric strain vs. axial strain

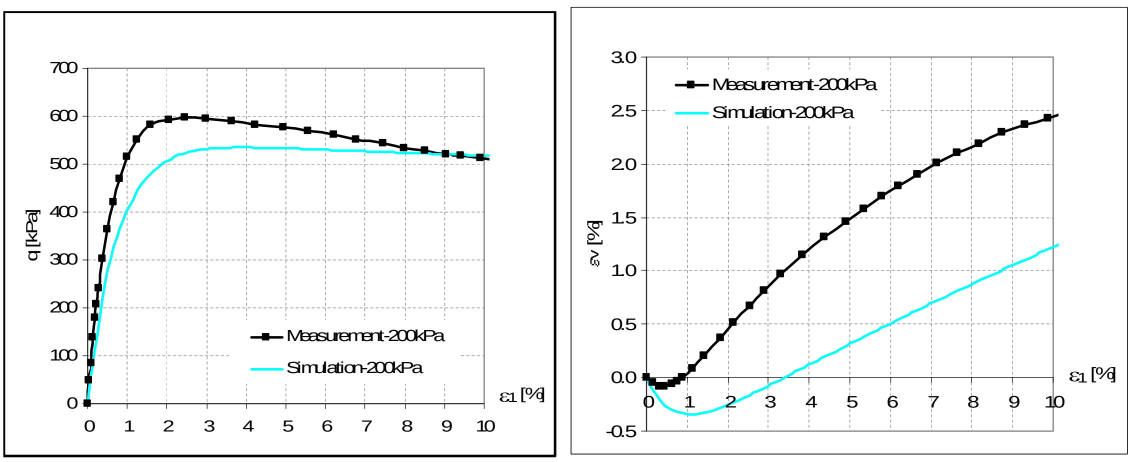


Figure 2.6 Numerical simulation of triaxial compression test (Deltares, 2006) on loose specimen e = 0.75. Left: Deviatoric stress vs. axial strain and right: Volumetric strain vs. axial strain

2.4 Intergranular strain (IGS) parameter set

The intergranular strain concept is essential for the modelling of small loading cycle in which elastic deformations occur. It especially occurs in dynamic numerical models, as the wave propagation through the soil will be reflected at each material point. It means that the process of loading and unloading cycles always happens during simulation. Therefore, the use of hypoplastic model with IGS will help to reduce the effect of ratcheting.

The intergranular strain concept as implemented in the Deltares MPM code includes 5 parameters (Niemunis and Herle, 1997), namely, m_R, m_T, R, ,β_r, *and* χ. These parameters are defined in Table 2.3.

Table 2.3 Parameters of the intergranular strain model as extension of the basic hypoplastic material model.

Parameter		*Description*
m_R	[-]	defines the initial shear modulus for very small strains for a 180° reversal of stress path
m_T	[-]	defines the initial shear modulus for very small strains for a 90° reversal of stress path
R	[-]	size of the elastic space (in strain space)
β_r	[-]	defines the degradation of the stiffness for changing strain
χ	[-]	defines the degradation of the stiffness for changing strain

Proposed small strain stiffness parameters (IGS 1-2) are given in Table 2.4, which are based on literature. Since there is no experimental data available on cyclic oedometer test, it is suggested for choosing suitable IGS parameters that the initial stiffness of the oedometer response with IGS parameters should be nearly similar as the one without IGS. Figure 2.7 gives results of cyclic oedometer element tests with and without IGS. The results indicate that ICS parameters sets' 1 and 2 deviate from the simulation without IGS in terms of initial stiffness. Two new parameter sets were suggested and tested, namely IGS 3 and 4. The results are also given in Figure 2.7. Sets 3&4 describe the initial stiffness better when compared with the set without IGS, sets 1&2.

Table 2.4 Proposed parameter sets for small strain stiffness

Parameters	m_R	m_T	R_{max}	β_R	χ
IGS 1(1)	5	2	1e-4	0.5	6
IGS 2(2)	5	2	1e-4	1	2
IGS 3	5	2	1e-4	1	1
IGS 4	5	2	5e-5	1	1
No IGS	0	0	0	0	0

(1) Niemunis and Herle (1997), Henke (2010), Issam (2013)

(2) Pham et al. (2010)

In order to determine which parameter set to use during pile installation analysis, small-scale simulations (smaller mesh boundary at R=6D instead of 26D) were performed with pile installation until 4.7D. The results are shown in Figure 2.8. The results with the parameters sets' IGS 1-2 show dilation near the pile tip, which is not realistic (close to one void ratio). It is expected to that this zone is a compaction zone. The set IGS4 shows dilation in the top soil layers, which is not realistic as well. The parameter set IGS 3 shows most realistic behaviour and therefore this set is chosen for the pile installation analysis.

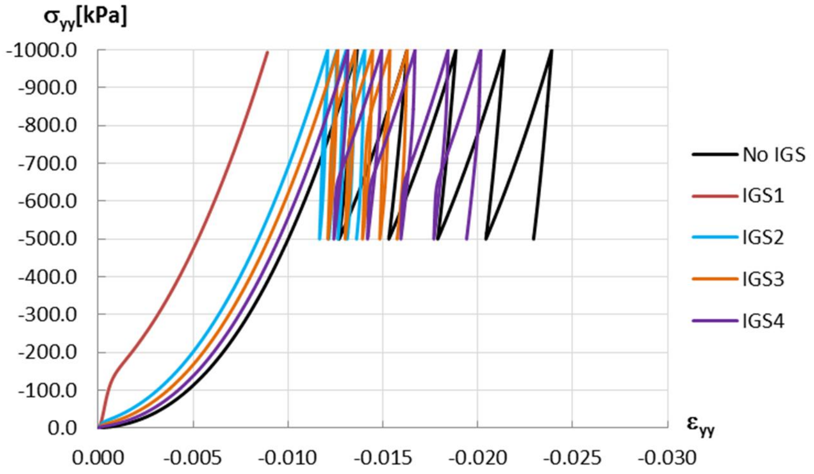
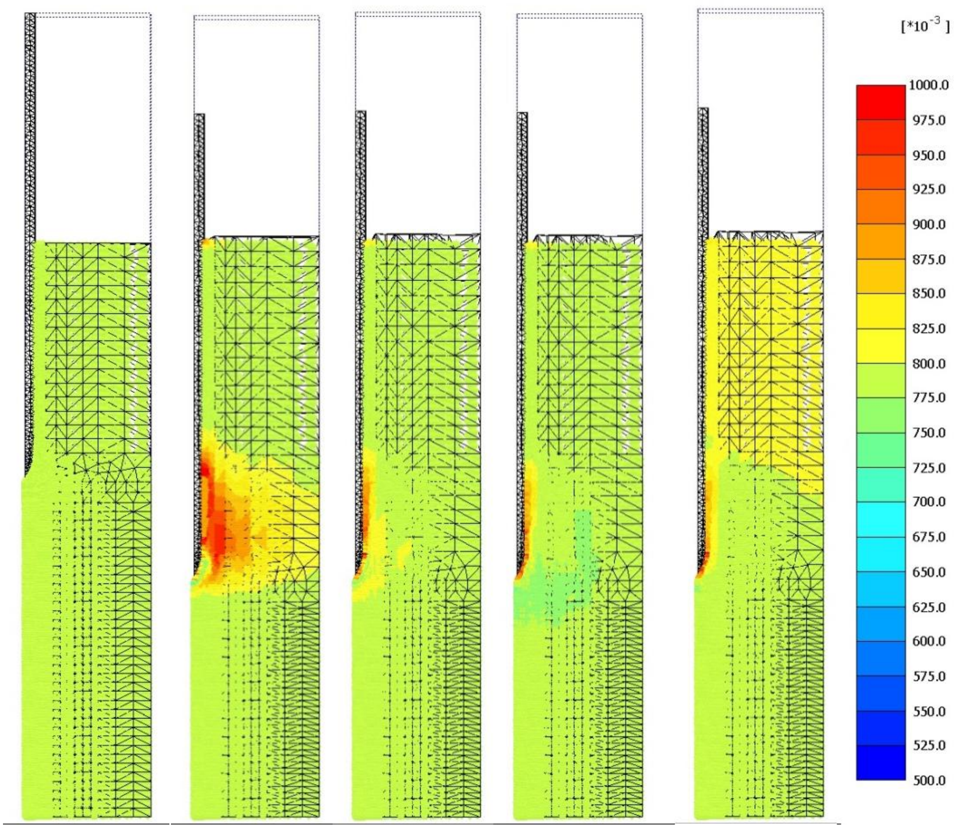


Figure 2.7 Cyclic Odometric simulation on Baskarp sand with difference sets of small strain stiffness



a) Initial e b) IGS1 c) IGS 2 d) IGS 3 e) IGS 4

Figure 2.8 Influence of small strain stiffness parameters on the result of void ratio after 4.7D penetration

3 Modelling jacked pile installation in MPM using Hypo-plasticity material model

In this chapter, model simulations of pile installation applying the hypoplasticity are presented to simulate the centrifuge tests (Huy, 2010). The numerical model used hereafter is identical to the model used in part 1 of this report (Elkadi et.al. 2013) in terms of geometry, mesh, boundary conditions, and pile installation procedure.

3.1 Simulation of centrifuge test using basis parameter set

The parameter set described as given in Table 2.1 together with IGS parameter set 3 (Table 2.4) is used to simulate the pile installation performed in the centrifuge experiments. As discussed in part 1 (Elkadi et al. 2013) of the report, the comparison with the experiments is done for the head force result. Figure 3.1 shows the results of this simulation for both the medium dense and loose Baskarp sand.

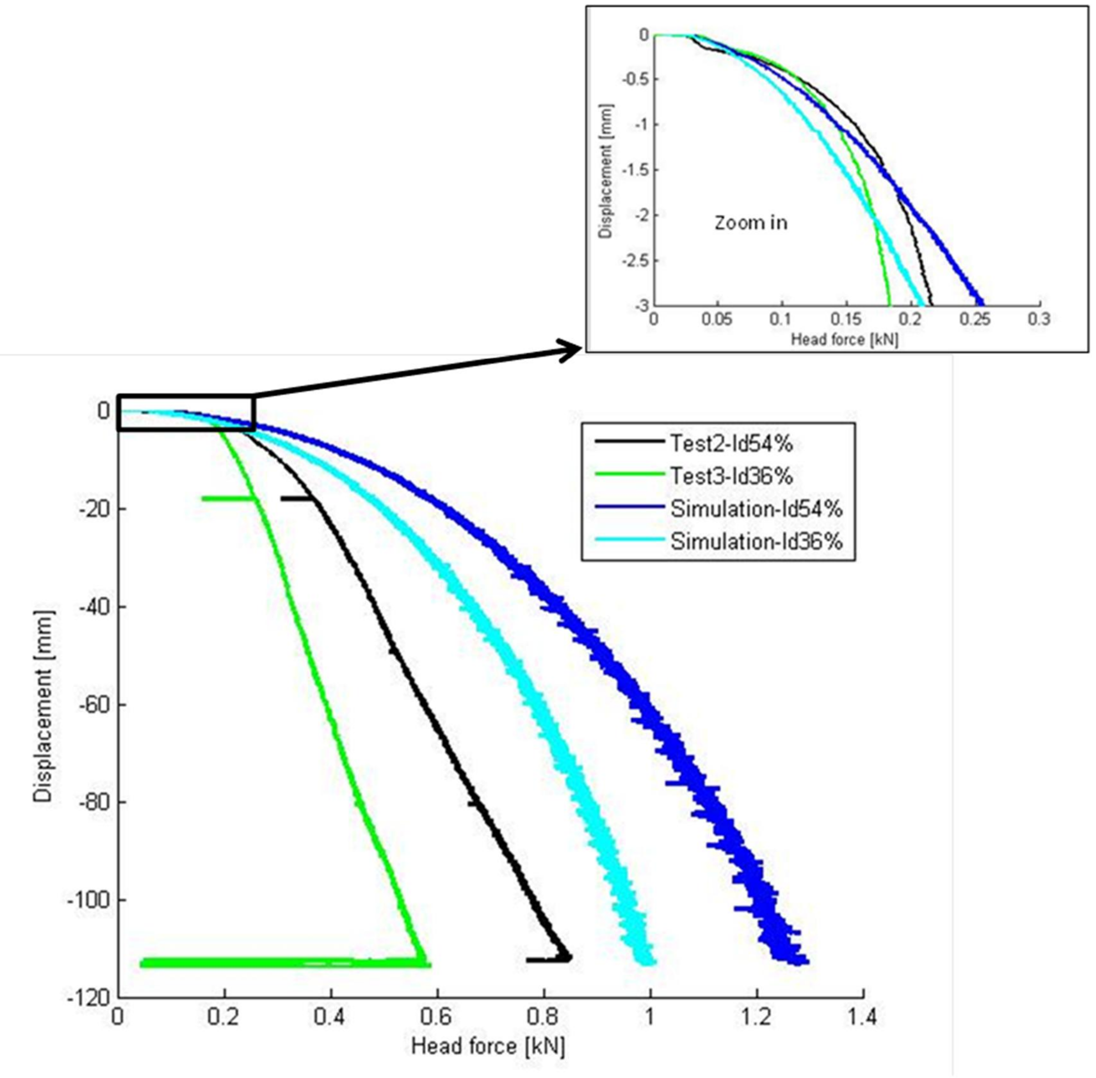


Figure 3.1 Simulation of centrifuge test with hypoplastic model, using basis parameter set

The results show nearly 50% overestimation in the pile bearing capacity for both sands. The initial stiffness seem to be in reasonable agreement with the experiment, however, in the simulation mobilisation of shaft strength seem to be at much slower rate when compared with the experiment resulting in overestimation of the bearing capacity. As discussed in part 1 of this report (Elkadi et al. 2013), the pile tip is always under high stress level. The maximum stress at the pile tip in the end of installation is about 8 MPa and 5 MPa for medium dense and loose sand, respectively. Since these stresses exceed largely the stresses used in determining the hypoplastic model parameters, it is necessary verify the applicability of the parameters in this case and adapt as necessary.

3.2 Behaviour of sand under high stress level

3.2.1 Background information

Luong et al (1983) performed triaxial tests on dense Fontainebleau sand specimens with cell pressure range from 0.5 MPa to 30 MPa. The results of their tests are shown in Figure 3.2. When increasing cell pressure, the stiffness, peak shear strength, as well as the residual shear strength gradually decreases. The volumetric behaviour is shown to be influenced by stress level. The dilation angle calculated from the test is smaller at higher stress level. From 16 MPa cell pressure and higher, there is only compaction behaviour observed.

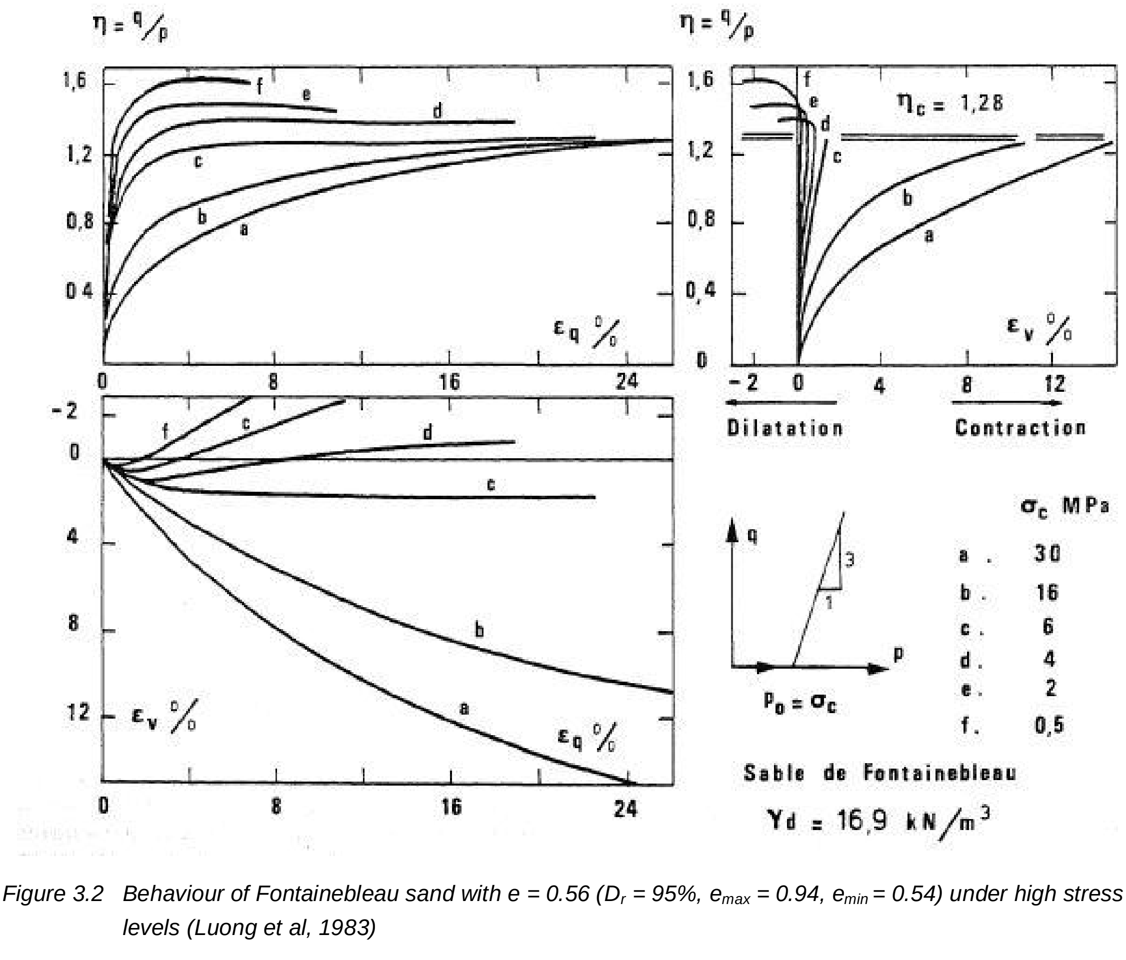


Figure 3.2 Behaviour of Fontainebleau sand with e = 0.56 (D_r = 95%, e_{max} = 0.94, e_{min} = 0.54) under high stress levels (Luong et al, 1983)

3.2.2 Analytical calculation of friction and dilation angles as function of stress level and relative density.

Bolton, M., 1986 discussed the stress dependency of the angle of friction for sands and presented the following theory to calculate it.

For triaxial compression

$$\varphi'_{\max} - \varphi'_{crit} = 3I_R \tag{2.1}$$

The relative dilatancy index I_R is calculated as:

$$I_R = I_D(Q - \ln p') - R$$

In which I_D is the relative density of sand and p' is the applied stress level

For quartz sand (Bolton 1986), Q=10, R=1, ϕ'_{crit}=31 deg., then

$$I_R = I_D(10 - \ln p') - 1 \tag{2.2}$$

Bolton also gave the formula to calculate the maximum dilation rate in failure state as

$$\left(-\frac{d\varepsilon_V}{d\varepsilon_1}\right)_{\max} = 0.3I_R \tag{2.3}$$

Schanz and Vermeer (1996) show that the dilatancy angle could be defined as:

$$\sin\psi = -\frac{\dfrac{d\varepsilon_V}{d\varepsilon_1}}{2 - \dfrac{d\varepsilon_V}{d\varepsilon_1}} \tag{2.4}$$

Resulting in the form:

$$\sin\psi = \frac{0.3I_R}{2 + 0.3I_R} \tag{2.5}$$

Table 3.1 gives the calculated results of friction angle and dilation angle when increasing stress level using the equations (2.1) and (2.5) above. At stress levels of 16 MPa and 30 MPa, there is contractive behaviour taking place with negative dilation, which is in good agreement with the triaxial test results of Luong et al (1983).

Table 3.1 Calculated friction and dilation angles for dense sand based on Bolton formula

p [kPa]	ID	IR	φ_c	φ_{max}	$(-d\varepsilon_V/d\varepsilon_1)_{max}$	$\sin\psi_{max}$	ψ_{max}
500	0.95	2.596	31	38.788	0.779	0.280	16.277
2000	0.95	1.279	31	34.837	0.384	0.161	9.264
4000	0.95	0.621	31	32.862	0.186	0.085	4.886
6000	0.95	0.235	31	31.706	0.071	0.034	1.955
16000	0.95	-0.696	31	28.911	-0.209	-0.117	-6.698
30000	0.95	-1.294	31	27.119	-0.388	-0.241	-13.930

3.3 Modelling of triaxial test under high cell pressure using hypoplastic model

Several triaxial tests are simulated by element test in Plaxis using the hypoplastic model with the same conditions of cell pressure and relative density of 95% as in the experiments of Luong. The simulation uses the original hypoplastic parameter set in Table 2.1. The results of element test are shown in Figure 3.3 and given in Table 3.2.

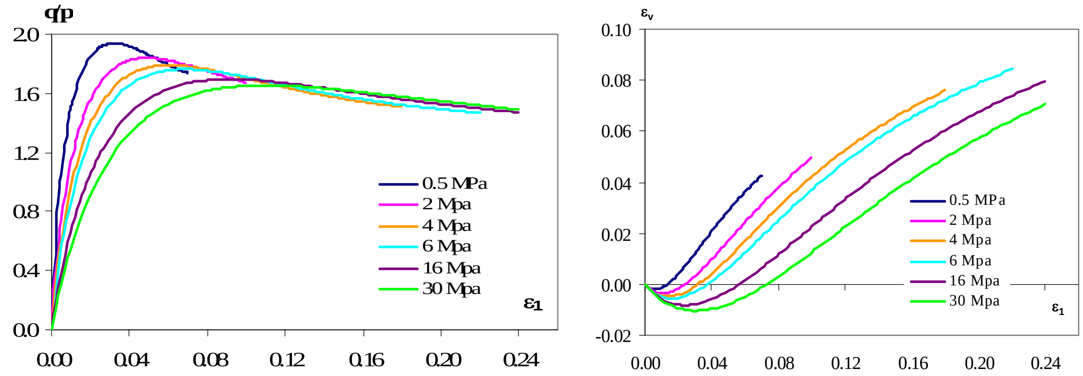


Figure 3.3 Modelling of Baskarp sand e = 0.567 (D_r = 95%, e_{max} = 0.929, e_{min} = 0.548) under high stress level using hypoplastic model in element test in Plaxis.

Table 3.2 Calculated friction and dilation angle based on simulated triaxial results

σ_3[kPa]	σ_1-σ_3	σ_1+σ_3	sinφ	φ[°]	dε_v/dε_1	ψ[°]
-500	-2740	-3740	0.733	47.107	-0.844	17.260
-2000	-9510	-13510	0.704	44.743	-0.736	15.611
-4000	-17800	-25800	0.690	43.624	-0.662	14.406
-6000	-25600	-37600	0.681	42.910	-0.636	13.968
-16000	-62400	-94400	0.661	41.377	-0.526	12.018
-30000	-111000	-171000	0.649	40.475	-0.456	10.690

In the simulation results, the friction and dilation angles are observed to reduce when increasing the cell pressure. However, this reduction is not significant as in the experimental (Luong) and analytical (Bolton) results. At stress level of 6 MPa, the element test simulations give 43° for friction angle and 14° for dilation angle, whereas both analytical and experimental results give much lower friction angle (31°) and no dilation. There is no contracting behaviour observed in the simulations at 30 MPa. Therefore, it is concluded that the hypoplastic model with the basis parameter set (from experiments by Anaraki 2008) is not sufficiently able to model the dependency of friction angle and dilation angle on high stress levels. This could be due to the stress range used in the experiments to determine the parameters, which is different (much lower) than the stresses encountered around the pile tip during pile installation. Due to the difficulty in performing lab experiments at such high pressures to determine a more suitable parameter set, it is proposed to examine the model parameters and propose a new parameter set, which could better represent soil behaviour under high stresses. The following discussed this based on suggestions from literature and the second author's (Phoung Nguyen) ongoing PhD research work.

3.4 Modified parameters for Hypoplastic model under high stress level

3.4.1 Reduction of maximum and minimum void ratio

Rohe (2010) studied the dependency of void ratio on the stress level and suggested the following expressions for the parameters e_{d0}, e_{c0}, and e_{i0}:

$$e_{c0}^{*} = 0.9501 - 0.0702\ln\left(0.0003\,\sigma_v'^2 + 0.0256\,\sigma_v' + 2.1669\right).$$

$$e_{d0}^{*} = 0.6768 - 0.1698\ln\left(0.0003\,\sigma_v'^2 + 0.0256\,\sigma_v' + 2.1669\right).$$

$$e_{i0}^{*} = 1.0926 - 0.0807\ln\left(0.0003\,\sigma_v'^2 + 0.0256\,\sigma_v' + 2.1669\right).$$

Based on these expressions, the void ratio parameters at a vertical stress level ($\sigma_{v'}$) of 10MPa are e_{d0}=0.51; e_{c0}=0.88; and e_{i0}=1.01.

3.4.2 Reducing peak shear strength and dilation behaviour by changing parameter α

Herle and Gudehus (1999) indicated that the exponent α could be obtained by considering a peak state in a triaxial compression test from the equation below:

$$\alpha = \frac{\ln\left[6\dfrac{(2+K_p)^2 + a^2K_p(K_p - 1 - \tan\nu_p)}{a(2+K_p)(5K_p-2)\sqrt{4+2(1+\tan\nu_p)^2}}\right]}{\ln((e-e_d)/(e_c-e_d))} \qquad (2.6)$$

With the peak ratios

$$K_p = \frac{1+\sin\varphi_p}{1-\sin\varphi_p} \qquad (2.7)$$

$$\tan\nu_p = 2\frac{K_p - 4 + 5AK_p^2 - 2AK_p}{(5K_p-2)(1+2A)} - 1 \qquad (2.8)$$

in which, $A = \dfrac{a^2}{(2+K_p)^2}\left[1 - \dfrac{K_p(4-K_p)}{5K_p-2}\right]$ (2.9)

and, $a = \dfrac{\sqrt{3}(3-\sin\varphi_c)}{2\sqrt{2}\sin\varphi_c}$ *(2.10)*

The void ratio (e) can be calculated as follows:

$$e_p = e_{p0}\exp\left[-\left(\frac{3p_s}{h_s}\right)^n\right] \qquad (2.11)$$

For isotropic compression e=e_p, e_{p0}=e_{o0}, h_s (granulate hardness) and exponent n can be determined from compression test in the specific pressure range, and p_s is defined as the skeletal pressure.

Based on (2.6), the relation between parameter α and the pressure can be plotted as in Figure 3.4.

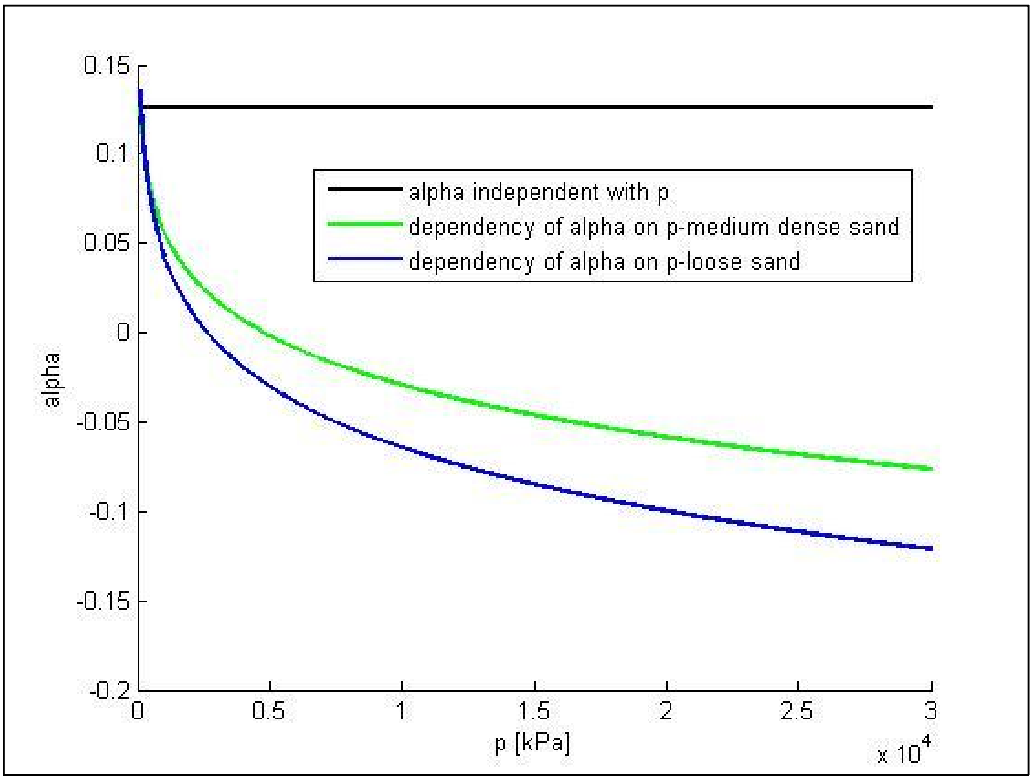


Figure 3.4 Exponent α versus pressure p in case of isotropic compression (using hypoplastic parameter set of Anaraki, medium dense sand e_0 = 0.68, and loose sand e_0 = 0.75)

The influence of the exponent α is further examined using element test simulations for Baskarp sand (relative density R_D = 95%) at cell pressure of 6 MPa. The results of the element tests with variation of α are plotted in Figure 3.5. They suggest that choosing a more suitable value for α could improve the analysis capability of predicting installation effects and behaviour of sand under high stress levels.

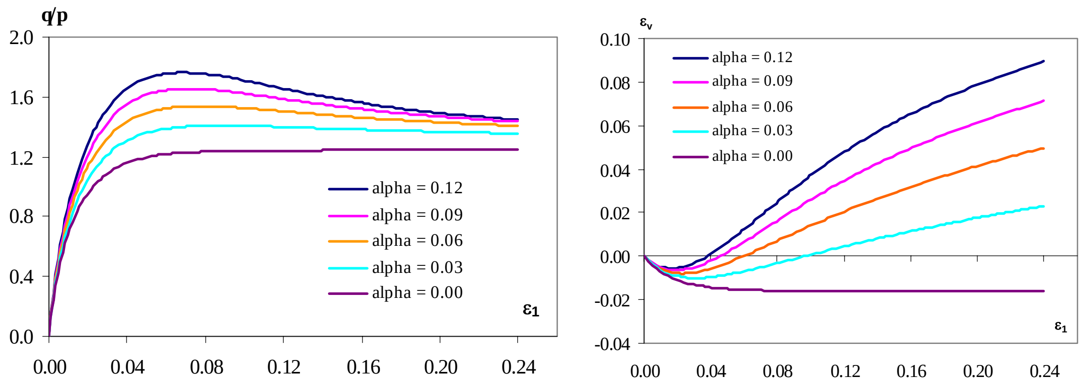


Figure 3.5 Influence of the variation of α on simulated triaxial response (Baskarp sand – R_D = 95% - σ =6MPa)

3.4.3 Proposed modified parameter sets for hypoplastic model under high stress level

Based on the above, Phuong (2013) suggested modifying the hypoplastic model parameter set in order to get a good response under high stress level in the pile installation simulations. The modified parameter set is given in Table 3.3.

Table 3.3 Suggested modified parameters for the Hypoplastic model under high stress level

	φ_c [°]	h_s [Mpa]	e_{d0} [-]	e_{c0} [-]	e_{i0} [-]	α [–]	β [–]	e_0 [-]
Original parameter*	31	4000	0.548	0.929	1.08	0.12	0.96	
Modified parameter (R_D = 54%)	30	4000	0.51	0.88	1.01	0.03	0.96	0.68
Modified parameter (R_D = 36%)	30	2000	0.51	0.88	1.01	0.03	0.96	0.75

* Original parameter set according to Table 2.1 .

The modified parameter sets is then first used to simulate the triaxial compression test of medium dense sand and loose sand under a cell pressure of 10 MPa, which is nearly similar to the stress under the pile tip. The result of element test triaxial response is shown in Figure 3.6. The figure shows results for triaxial test with the original parameter set and modified parameter set for medium dense sand. Also results for triaxial compression at low cell pressure (0.1 MPa) is given for comparison. It is clear that the modified parameter set helps to reduce peak shear strength as well as dilation behaviour at high cell pressure, which agrees well with experimental and analytical findings as discussed earlier.

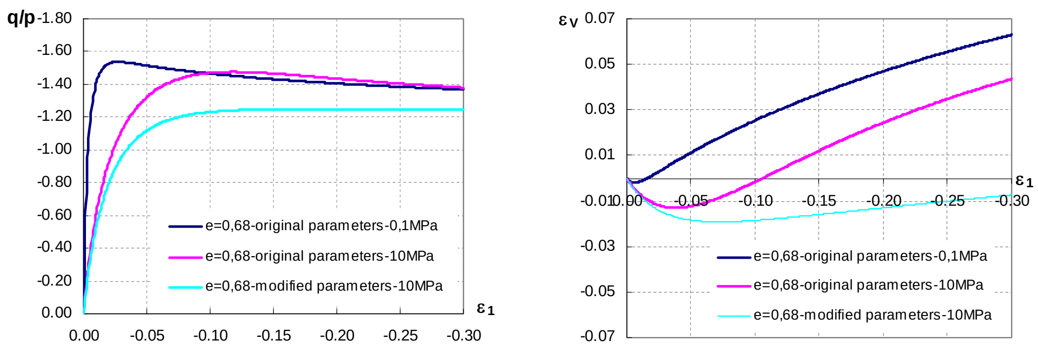


Figure 3.6 Triaxial simulation of Baskarp sand e =0.68 using hypoplastic model and modified parameter

4 Simulation of centrifuge test by modified parameter set

The set of modified parameters in Table 3.3 is used to simulate the centrifuge test in MPM. The results are shown in Figure 4.1 and Figure 4.2 for medium dense sand and loose sand, respectively. Analysis with two different values of α, namely 0.03 and 0.06, are shown. The modified parameters show a better fit with the experiments in terms of pile head force. In the medium dense sand (Figure 4.1), for α=0.06, the head force is captured quite well but the gradient of the force mobilisation is over-estimated. On the other hand, for α=0.03, the gradient is better captured until a displacement of about 70 mm where after faster mobilisation takes place in the simulation leading to a lower estimation of the head force. In both cases α remains constant during the whole simulation. It is suggested that reducing α gradually during the analysis in correspondence to the increasing stress level. This needs improvement in the hypoplastic model and is beyond the focus of this report. For the loose sand (Figure 4.2) similar observation as with the medium dense sand applies. However, there is more deviation in the initial elastic response and both simulations result in underestimation of the pile head force.

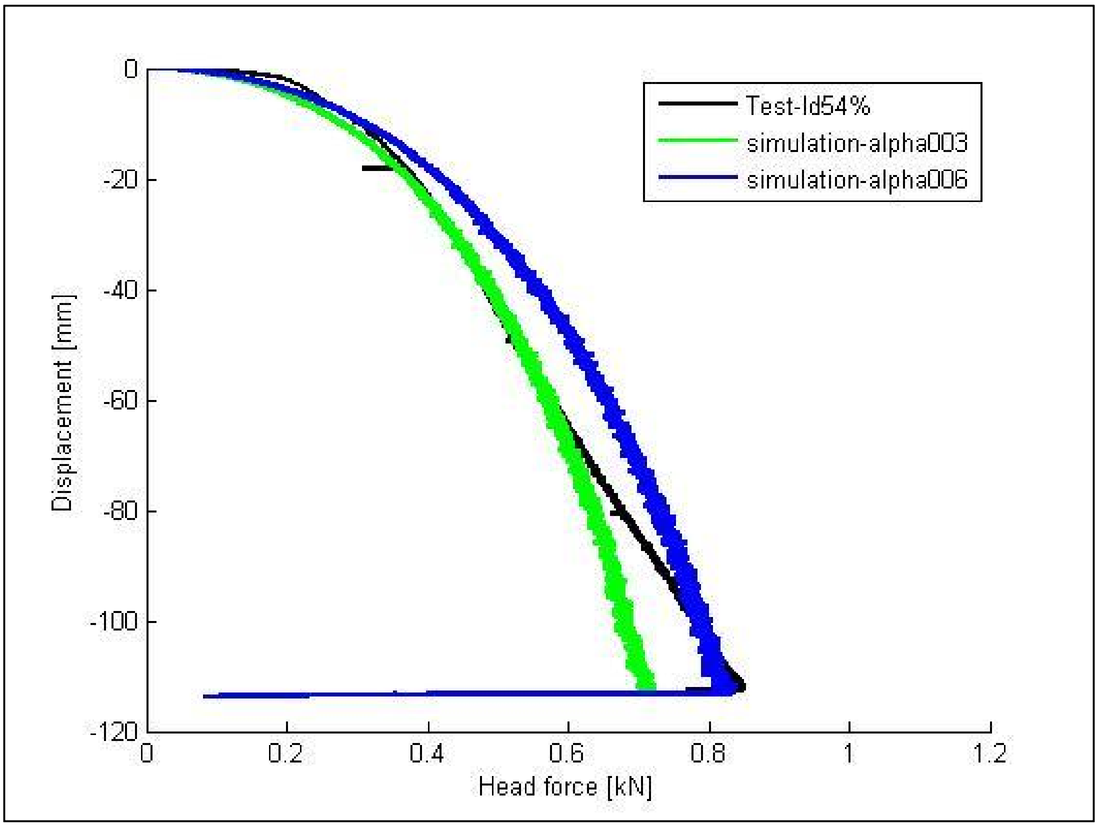


Figure 4.1 Load displacement curve for medium dense sand, comparison between simulation and centrifuge test result for α=0.03 and α=0.06.

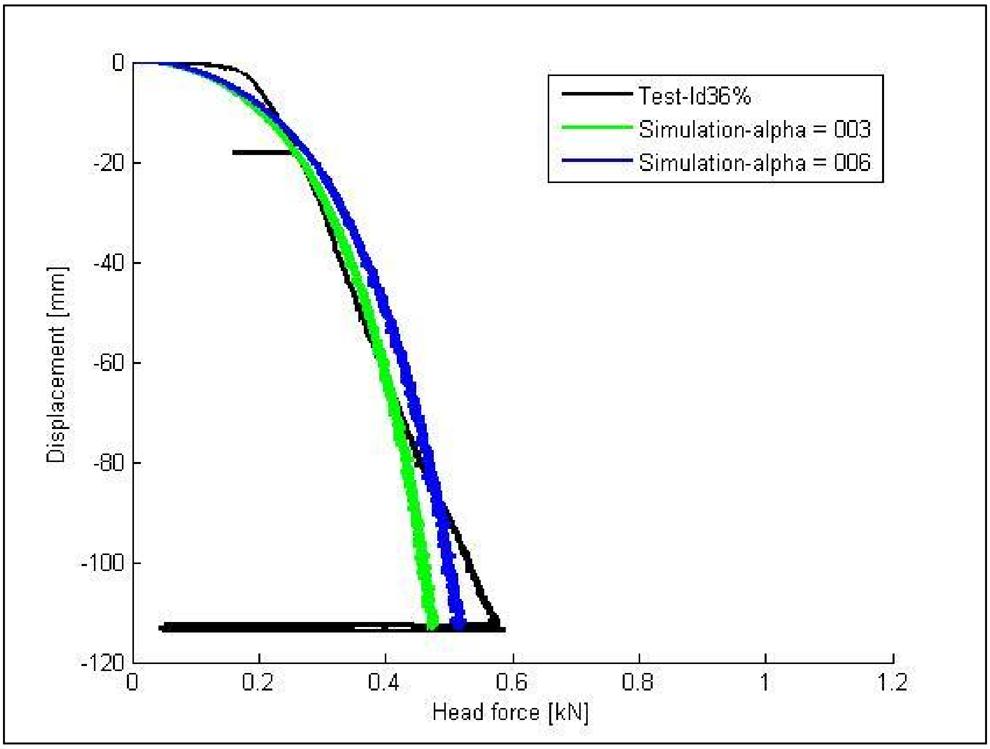


Figure 4.2 Load displacement curve for loose sand, comparison between simulation and centrifuge test result for α=0.03 and α=0.06.

5 Simulation of static load test (SLT)

After the simulation of the pile installation, it was continued with the relaxation phase and then the SLT with 0.1D penetration. In the relaxation phase of the centrifuge test, the pile was unloaded to approximately 0 kN. In MPM, the relaxation phase was modelled by applying a prescribed velocity in the pile head in order to pull the pile upwards to unload it.

Four different cases are modelled for the medium dense sand as given in Table 5.1. In the 1st case, MPM-1, the pile is embedded fully at 20D, then the SLT is carried out directly to illustrate the influence of including installation effects. In MPM-2, the pile embedded 10D and installation took place for the remaining 10D. For both the installation and SLT, the basis parameter set is used. MPM-3 is similar to MPM-2 but in this case, the modified parameter set as suggested in Table 3.3 for medium dense sand is used. In MPM-4, the difference with last two is that the modified parameter set is used during pile installation and then the basis set is used for the SLT.

As shown in Figure 5.1, MPM-4 gives the best fit with the centrifuge test in terms of pile bearing capacity after 0.1D penetration. It is clear that without installation effect, the bearing capacity of the pile is significantly underestimated. On the other hand, the three cases with installation effect, MPM-2, MPM-3, and MPM-4, give much better result in terms of pile bearing capacity. Therefore, it is necessary to include the installation effect when simulating the SLT and for realistic prediction of pile bearing capacity. The reason why the case MPM-4 shows better fit despite the fact that the hypoplastic parameter set used during the SLT test is the original set and different than the one used for the installation phase is attributed, in our view, to the difference in stress levels near pile tip between SLT and installation phase.

Table 5.1 List of different simulation case in SLT phase

Case	*Embedded depth*	*Installation depth*	*Hypoplastic parameter set used during installation phase*	*SLT*	*Hypoplastic parameter set used during SLT phase*
MPM-1	20D	-	-	0.1D	Original
MPM-2	10D	10D	Original	0.1D	Original
MPM-3	10D	10D	Modified	0.1D	Modified
MPM-4	10D	10D	Modified	0.1D	Original

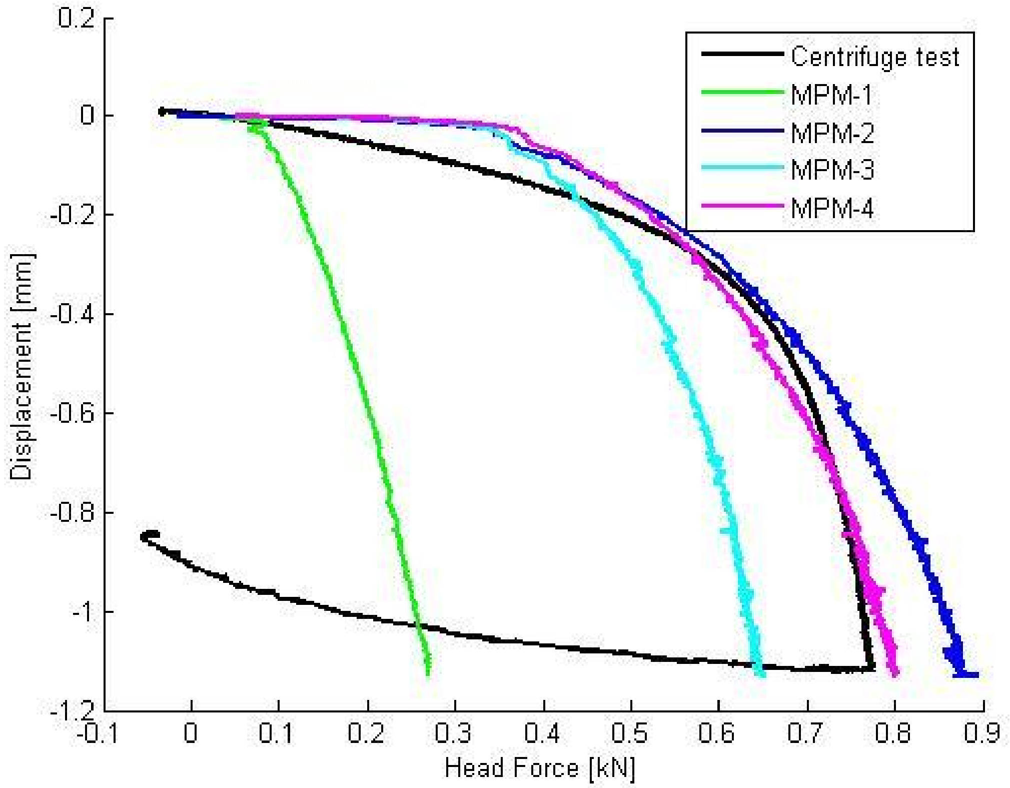


Figure 5.1 Load – displacement curve during SLT by MPM for medium dense sand

6 Conclusions and recommendations

In this report, the progress of part 2 the project 1206750-005 is described, during which the jacked installation of displacement pile in the centrifuge experiment is modelled using the MPM code with hypoplasticity material model. First parameter calibration took place for medium-dense Baskarp sand with relative density of 54% to arrive at a parameter set that best matches the experimental results. Afterwards, prediction for the loose sand material was done. Finally, simulation of the Static Load test (SLT) is performed. The centrifuge experiments used for validation are from Huy, 2008.

The results as discussed in this report show that the developed MPM-model is capable of predicting load-displacement curves for pile installation in the centrifuge test and SLT with good fit. A calibrated parameter set based on the anticipated stress range near the pile tip for the hypoplasticity model could reasonably well capture the measured pile head force and overall load-displacement behaviour. When looking more closely there are, however, discrepancies between the simulation and the experiments. This is mainly in the gradient of the descending load-displacement curve and initial stiffness. It is suggested based on this work to further improve the exponent alpha in the model parameters to be variable depending on the stress level rather than a constant value. This is expected to improve the model prediction capabilities. However, this is beyond the scope of this report and is to be considered further in the PhD framework of the second author Phuong Nugyen.

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Appendix A

Influence of small strain stiffness parameters β_R, χ and R_{max} in cyclic oedometric simulation

Effect of β_r

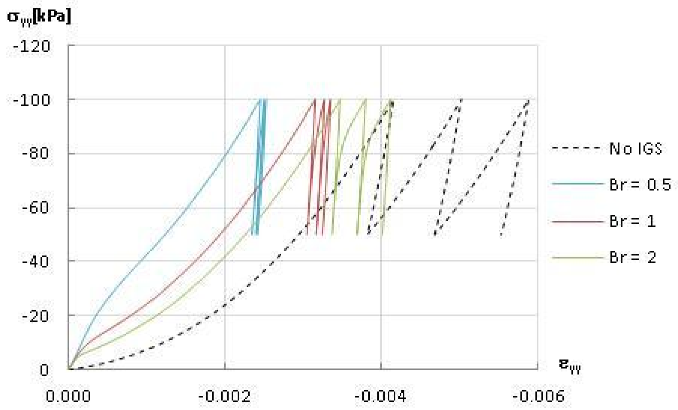

Figure A.1 *Influence of β_R (χ = 1, R_{max} = 1e-4) in odometer test.*

Effect of χ

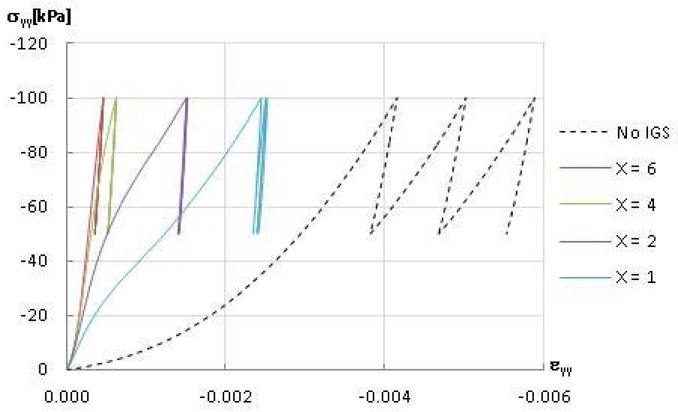

Figure A.2 *Influence of χ (β_R = 0.5, R_{max} = 1e-4) in odometer test.*

Effect of R_{max}

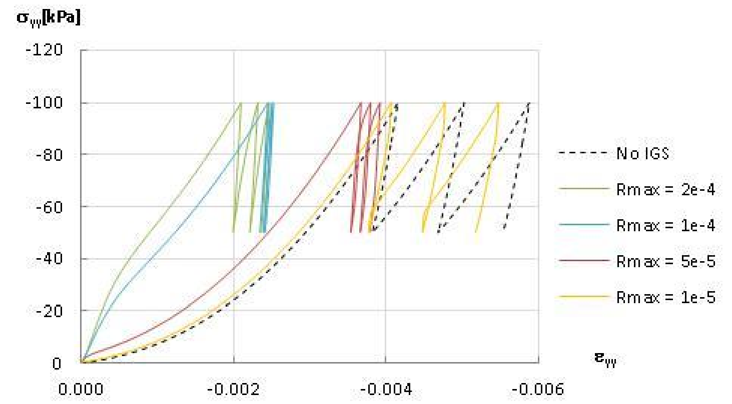

Figure A.3 *Influence of R_{max} (β_R = 1.0, χ = 1.0) in odometer test*

Effect of small strain stiffness to the results of oedometer test

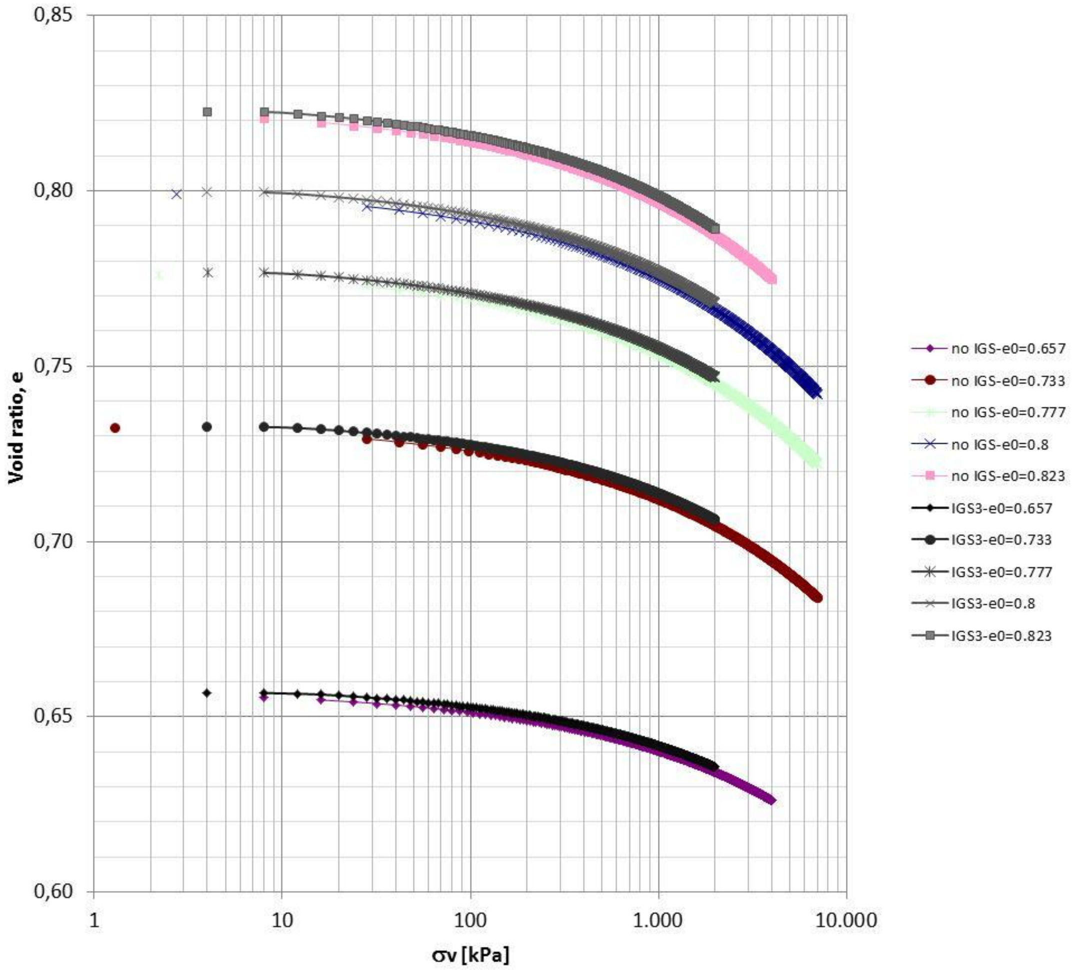

Figure A.4 *Influence of the oedometer test results between simulations using IGS3 and the ones without IGS*

Appendix B

Parametric study – Influence of hypoplastic parameters on the load – displacement curve of the centrifuge test

Influence of h_s(mesh R = 26D, e_0 = 0.75, e_{max} = 0.88, e_{min} = 0.51, α = 0.03, β = 0.96)

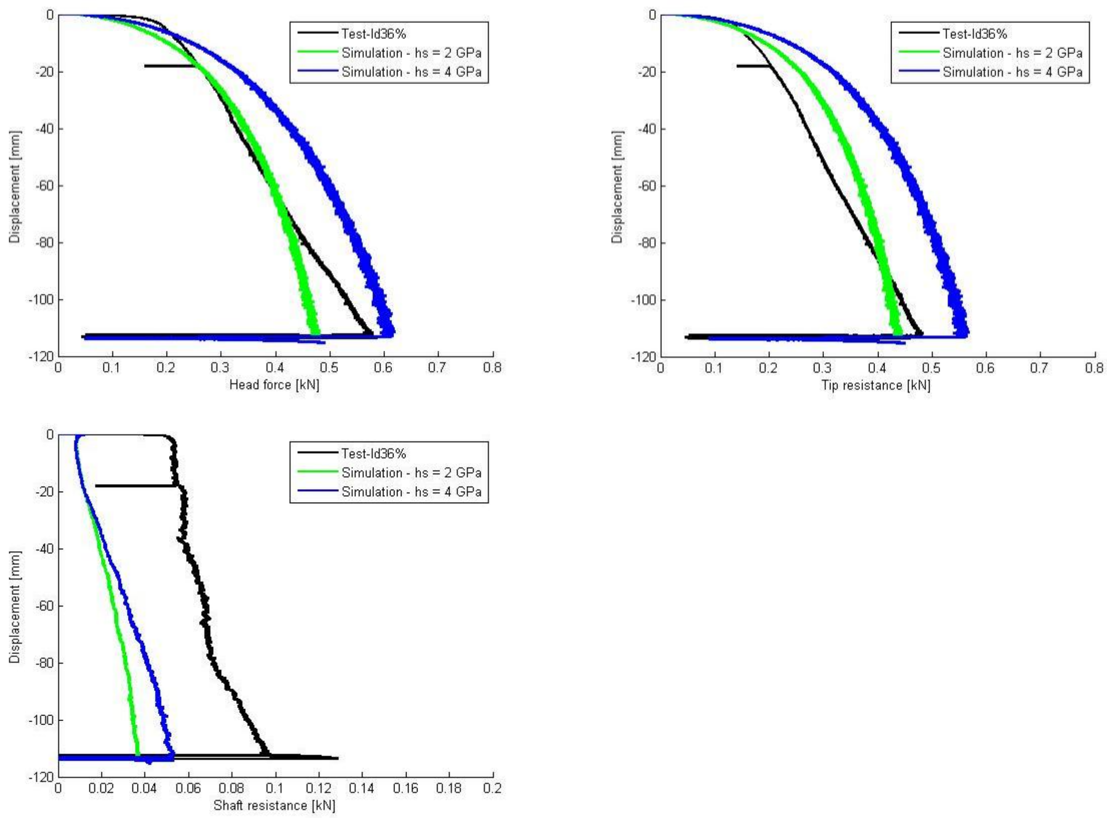

Figure A.5 *Influence of h_s in the calculation as compared to the experimental results*

Influence of n (mesh R = 6D, e0 = 0.79)

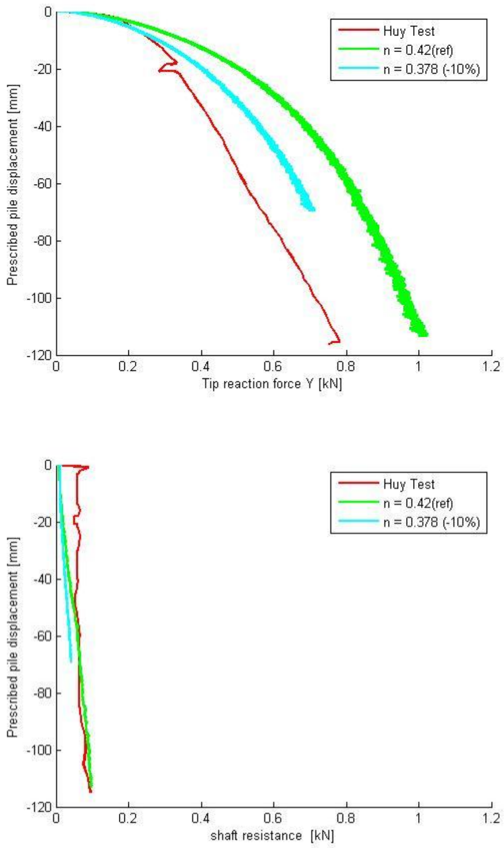

Figure A.6 *Influence of n in the calculation as compared to the experimental results*

Influence of α (R = 6D, e0 = 0.79)

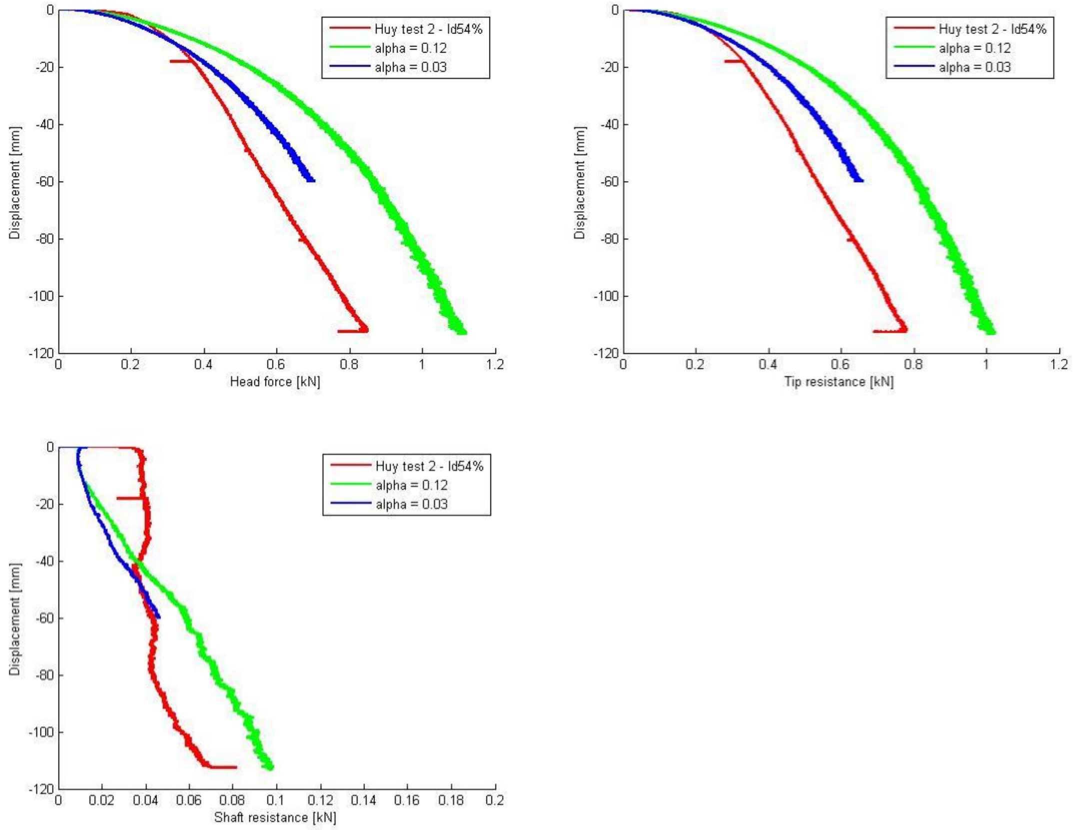

Figure A.7 *Influence of α in the calculation as compared to the experimental results*

Influence of e_{max}, e_{min} (R = 26D, e0 = 0.75, hs = 4GPa, α = 0.03, β = 0.96)

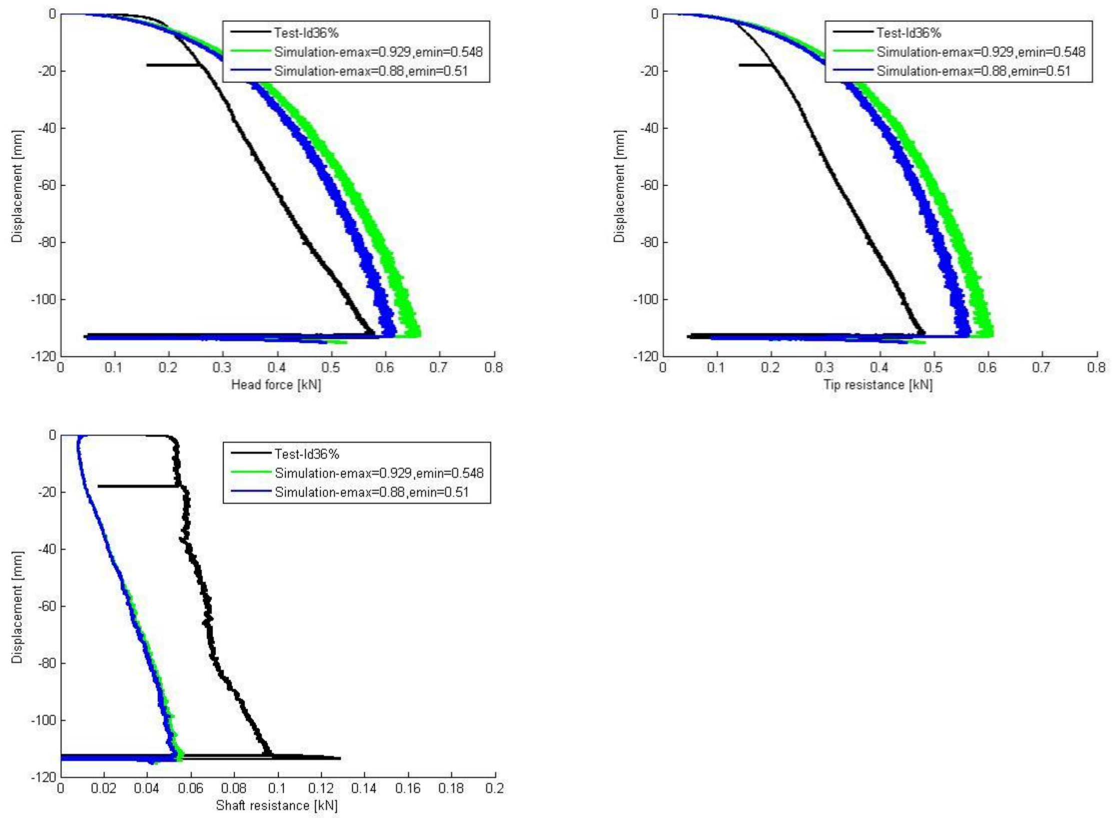

Figure A.8 *Influence of e_{max}, e_{min} in the calculation as compared to the experimental results*

Influence of initial void ratio (mesh R = 26D)

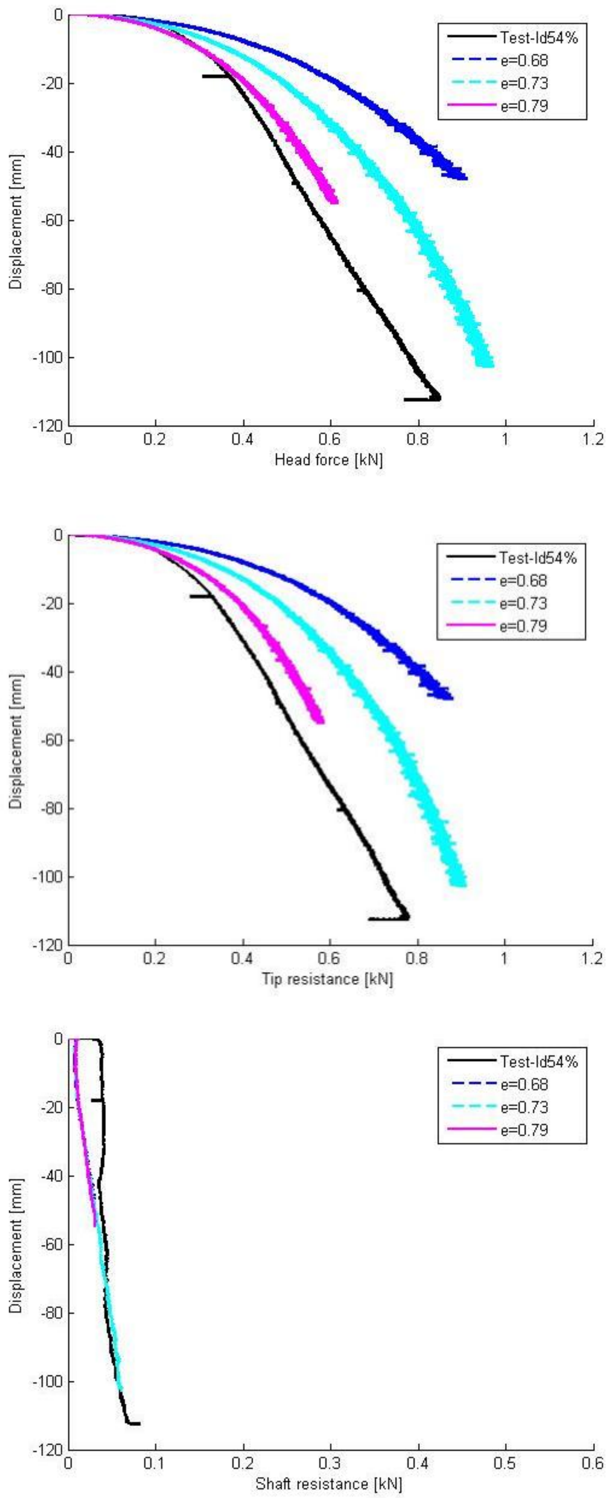

Figure A.9 *Influence of initial void ratio in the calculation as compared to the experimental results*