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Experimental and numerical investigation of soil liquefaction

(Experimentelle und numerische Untersuchung der Bodenverflüssigung)

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Introduction

Soil liquefaction is a soil phenomenon that can occur in loose, saturated, coarse-grained soils. The highest tendency to soil liquefaction have sandy soils. Investigations of soil liquefaction are usually carried out using cyclic tests in a triaxial apparatus. However, testing in cyclic triaxial device is complicated and time-consuming. A new testing procedure, in form of an identification test, has been developed at the Institute of Geotechnical Engineering at the TU Dresden.

The aim of this work is:

- First, to investigate the liquefaction potential of a Silica sand using the identification test.
- second, to study the main impact factors on liquefaction using numerical simulations.

The numerical simulations are perfromed using FEM-software Tochnog. The hypoplastic constitutive model with intergranular strain is used to describe the soil behaviour in the numerical simulations.

Silica sand

Silica sand is coarse-grained, uniformly graded sand. Figure 1 shows the grain size distribution of the Silica sand. The hypoplastic parameters of the Silica sand are summarized in Table 1 and Table 2.

φ_c' [°]	e_{d0} [-]	e_{c0} [-]	e_{i0} [-]	h_s [MPa]	n [-]	ß [-]	α [-]
30	0.573	0.847	0.974	3600	0.26	1.7	0.2

Table 1: Hypoplastic parameters for model by von Wolffersdorff

R[-]	m_R[-]	m_T [-]	$ß_r$ [-]	X [-]	θ [-]
0.00005	8	4	0.7	0.5	10

Table 2: Hypoplastic parameters for model with intergranular strain by Niemunis and Herle

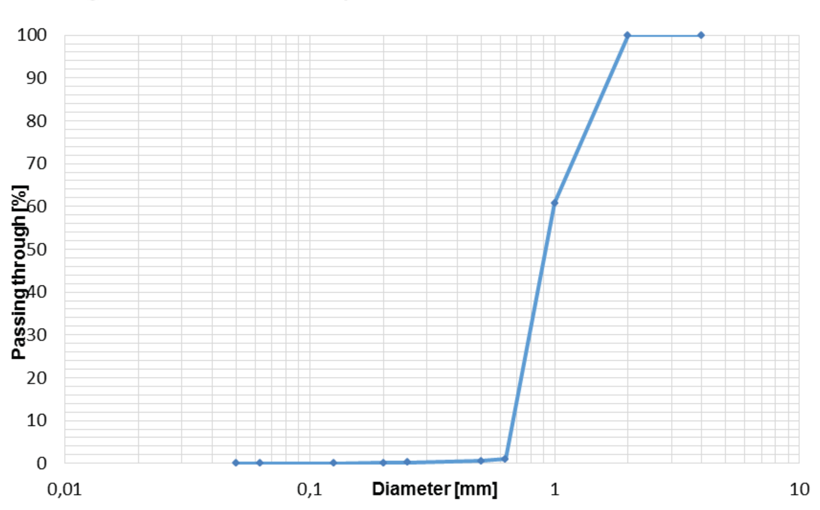

Fig. 1: Grain size distribution curve

Identification test

A sketch of the set-up of the test is shown in Figure 2. At the beginning of the test, a loose deaerated sand specimen (1) is installed into a rubber membrane (2). The total stress (relative air pressure) (3) during the test remains constant and equal to zero. By applying suction (negative PWP) to the bottom of the specimen (4), usually -30 kPa, the specimen develops positive effective stresses (p = p' + u = 0 → p' = - u > 0 kPa). After applying the suction, a cyclic horizontal loading (displacement controlled) is applied to the specimen under undrained conditions (5). The loading is performed by horizontally translating the top plate (6) of the specimen. During the test, the pore water pressure is measured and evaluated at the bottom of the specimen (7). During the shearing (cyclic loading), the stresses are transferred from the sand to the water.

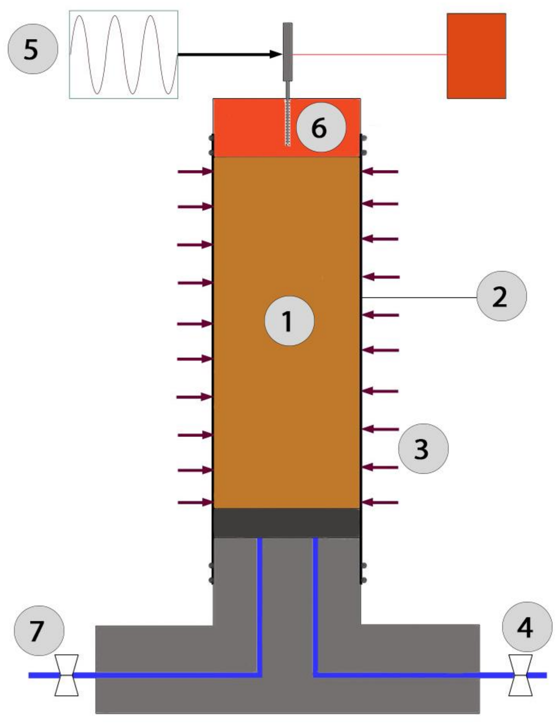
Fig. 2: The set-up of an identification test

This leads to a decrease in the effective stresses. The test is manually terminated when the effective stresses reached a defined value, usually 10 kPa. For the evaluation of the test, the number of loading cycles necessary for a defined decrease of effective stresses is of interest.

- The specimen dimensions in all tests were approximately D/H = 50/100 mm.
- The saturation degree in the tests was S_r = 97 (± 2%).
- The initial reffective stress is p'_0 = 30 kPa and the termination criteria is when the effective stress reaches p' = 10 kPa.

Test results

Figure 3 shows that the identification test is reproducible (using frequency = 1 Hz and double amplitude = 2.43 (± 4%) mm).

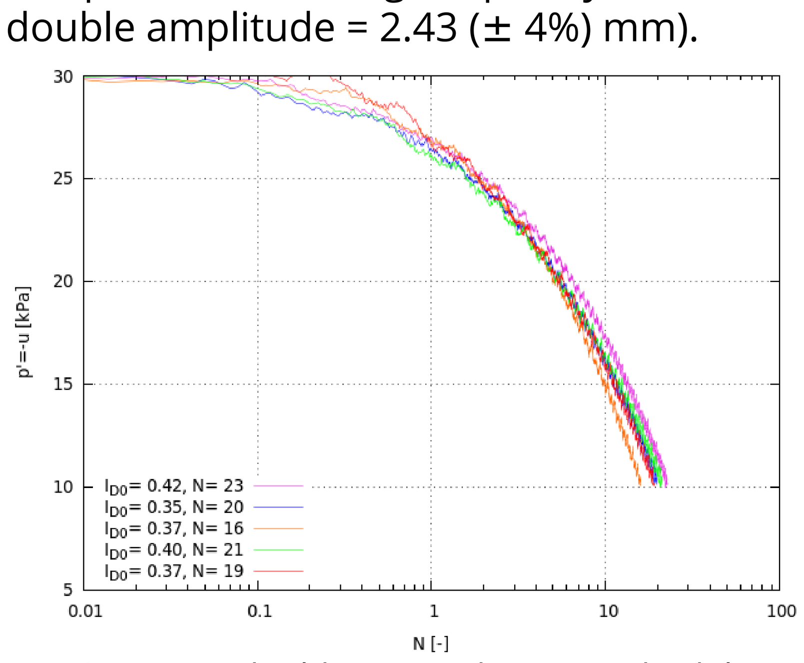

Fig. 3: PWP build-up in the reproducibility

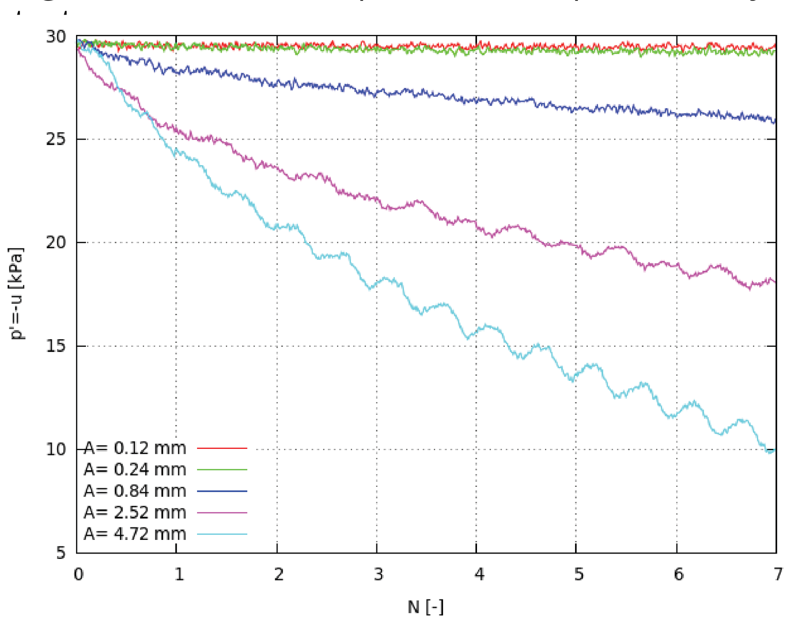

Fig. 4: PWP build-up in identification tests using different amplitudes for N = 7 cycles (Frequency = 1 Hz)

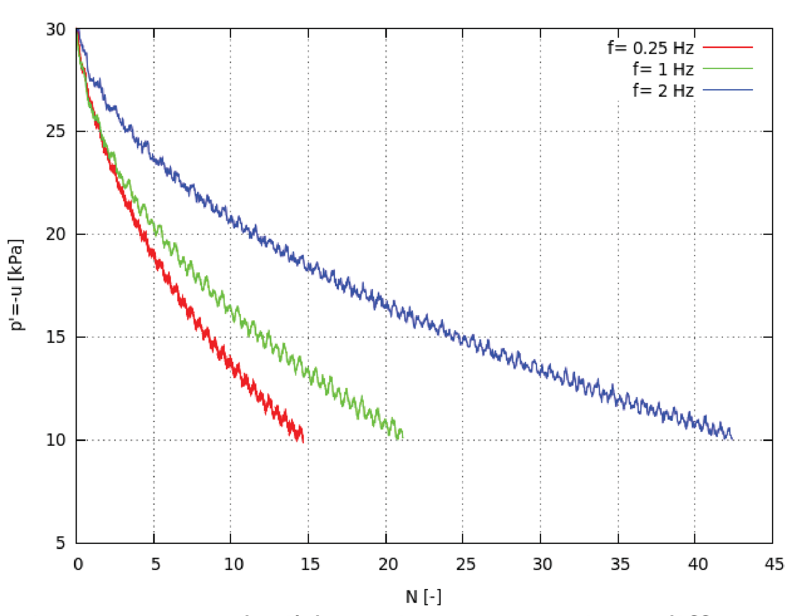

Fig. 5: PWP build-up in tests using different frequencies (double-amplitude = 2.52 ± 4% mm)

Figure 4 shows that the higher the amplitude is, the lower number of cycles is needed to achieve the wanted decrease of effective stresses. While Figure 5 shows that the higher the frequency is, the larger the number of cycles is needed to achieve the liquefaction criterion in the identification test.

Numerical simulations

Figure 6 shows a sketch of the 2D numerical model. The model has the dimensions of 0.05 m x 0.1 m. The model is fixed at the bottom. The sand specimen is surrounded from the sides by a membrane (right and left edges). The membrane has a thickness of 0.5 mm and a stiffness of 1.2 MPa. An interface exists between the membrane and the specimen.

The model is subjected to a distributed loading σ = 100 kPa (relative air pressure) from three sides (top, right and left). The gravity force g = 10 m/s² is also applied. The top edge of the model is loaded horizontally with a displacement-sine wave with a frequency f = 1 Hz and a displacement-amplitude (peak amplitude) A = 0.8×10^{-4} m. The initial stresses, void ratio and pore water pressure are summarized in Table 3. Using the initial void ratio of e_0 = 0.738 gives an initial relative density of approximately I_{D0} = 0.4. The saturation degree in all simulations is set to 99%, unless it was mentioned otherwise.

σ'_{xx} [kPa]	σ'_{yy} [kPa]	e_0 [-]	PWP [kPa]	$\sigma_{xx\text{-membrane}}$ [kPa]	$\sigma_{yy\text{-membrane}}$ [kPa]
30	30	0.738	70	100	100

Table 3: Initial state of the numerical model

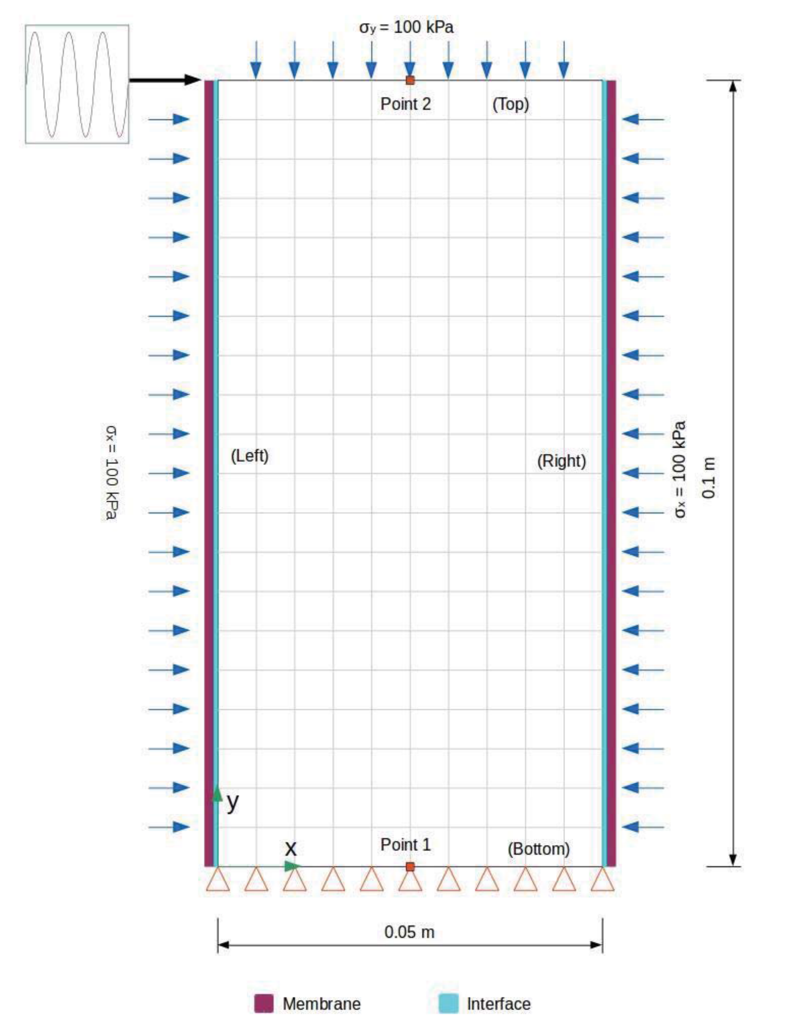

Fig. 6: Geometry and boundary conditions of the 2D numerical model

Simulation results

Using the same time step (0.001 s) and the same mesh size (element length = 0.005 m), different simulations were done to check the influence of amplitude, initial relative density and saturation degree. Figure 7 shows that lower amplitudes require higher number of cycles to achieve liquefaction (the same was shown in Figure 4 from the tests). Figure 8 shows that higher initial relative densities require also higher number of cycles to achieve liquefaction, while lower saturation degrees require higher number of cycles to achieve liquefaction (Figure 9).

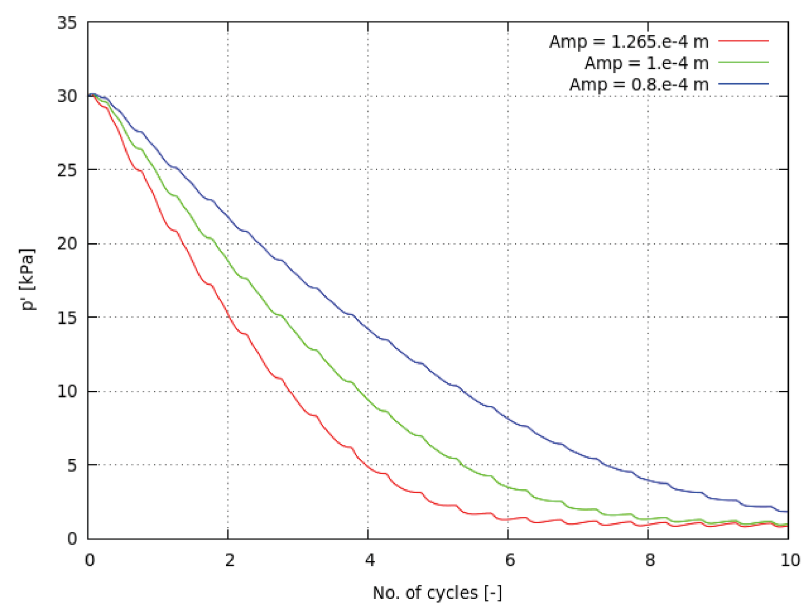

Fig. 7: Influence of using different amplitudes

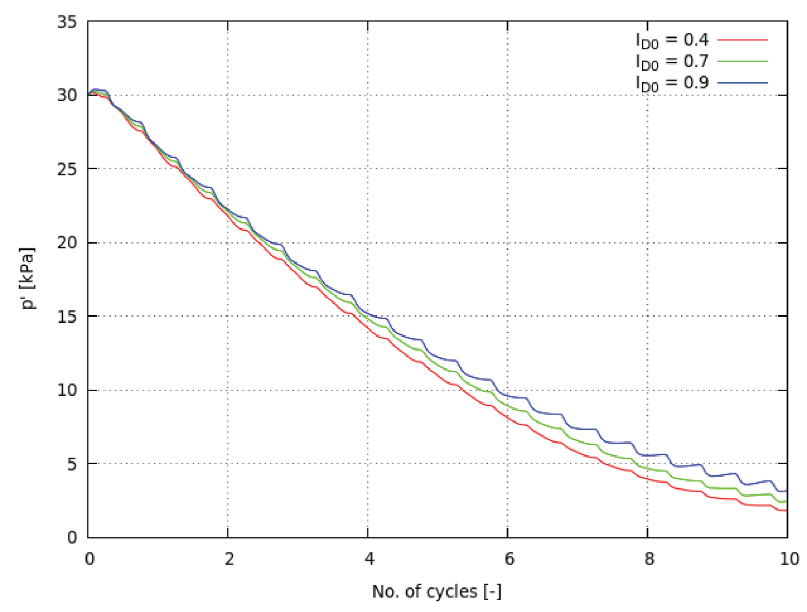

Fig. 8: Influence of using different initial relative densities

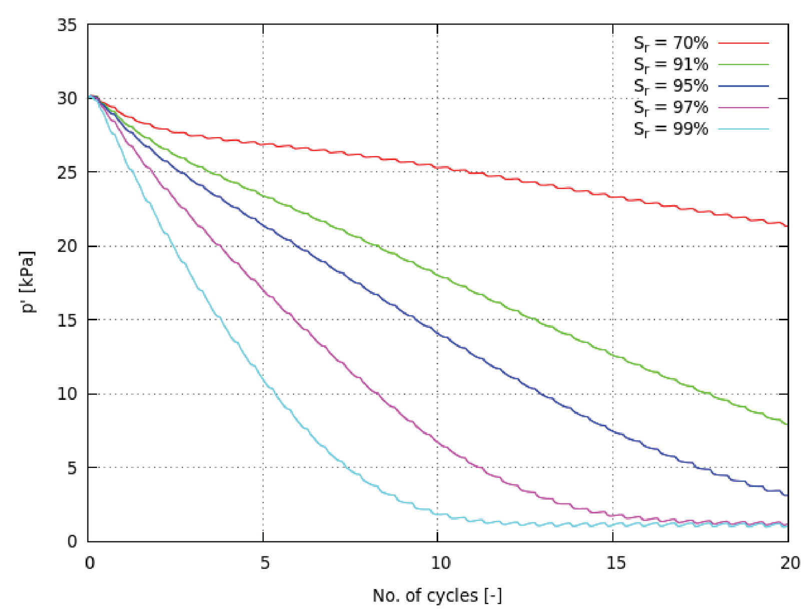

Fig. 9: Influence of different saturation degrees

Summary

In this project, multiple identification tests were performed. The results from the tests showed that the identification test is reproducible. It showed also that with higher amplitudes, a lower number of cycles was needed to achieve the wanted decrease of effective stresses. While with higher loading frequencies, larger number of cycles was needed. The simulations done on the numerical model showed the same influence of the amplitude as in the identification tests. It was also found that lower initial relative density requires a lower number of cycles to achieve liquefaction. While having higher saturation degree requires lower number of cycles.

Further development can be done to the numerical model later by simulating the top plate and applying the load there. This development might be able to make the results from the simulation close to the one from the identification test and perhaps allowing a comparison between them.

Project
Project work

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Abgabe
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