Acceleration accumulation during cyclic loading of dry sand in small scaled experiments.

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Abstract

Our aim is the prediction of soil densification during different forms of impact compaction. Therefore we investigate the interdependency of soil and compactor in a small scaled experimental setup in the field of gravity (so called 1g-test). The behaviour of the soil specimen is observed with a high speed camera and quantified by the PIV/DIC-Method. The acceleration of the falling weight is measured also. We found that the peak of the acceleration increases related to a simple function.

1 Introduction

The behaviour of soil subjected to impact loads is still a recent topic of research because of its nowadays more and more practical relevance due to the development of new compaction technologies. Soil is heterogeneous and can be described by different amounts of water, air and solid (Figure 1). Within this model the void ratio is $e = V_V / V_S$ and compaction can be understood as reduction of the void ratio. The stiffness and the friction angle of the material increases by the compaction.

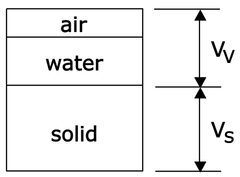

Figure 1 Model of soil consisting of solids, water and air

Generally, on can distinguish *static*, *harmonic dynamic* and *transient dynamic* forms of soil compaction technologies. The distinction between static and dynamic methods is not obvious. As related by Wichtmann[i] the frequency of the soil reaction must hold the condition

$$\hat{u}\,(2\,\pi\,f_s)^2 \ll g$$

for static or quasi-static loading forms. Otherwise inertial forces are relevant regarding the behaviour of the system. Because the Parameter $\hat{u}$ and f_s depend on the compaction technology and the soil no strict loading frequency can be defined to separate static and dynamic loading. Irrespective of this fact a common frequency threshold is 5 Hz.

The harmonic dynamic and transient dynamic types of soil compactors are of interest for this work and will be briefly described. Harmonic dynamic working technologies are e.g. dynamic drum rollers. The drum is usually excited by an adjustable directed vibrator. The quality of the compaction is measured online with systems depending on the manufacturer. The transient dynamic systems usually work with impact loads, e.g. the dynamic compaction or the impact compaction.

As already mentioned harmonic dynamic soil compactors can monitor the densification while the compaction is in process. Transient dynamic soil compaction technologies have a lack of such systems especially because there is no satisfying correlation between the degree of compaction measured with filed methods (e.g. CPT) and relevant parameters measured on the compaction machine. Within this Paper we want to show the interaction of dry sandy soil and an impact compactor in a small scaled experimental setup. The understanding of this interaction and its interdependency could be a first step towards a process-accompanying compaction monitoring system for transient dynamic soil compactors.

2 Experiments with transient dynamic soil compactors

2.1 Experimental setup, instrumentation and test design

The experimental setup used in this study is shown in Figure 2 schematically. A regional dry Sand was used for this study. The soil specimen is prepared by air raining with an initial density of $\rho_0 = 1{,}62\ kg/m^3$. The specimen has a dimension of 880 x 620 x 400 mm (L x H x D). The used raining method is presented more into detail in[iii,iv]) A thick sheet of Perspex on one side of the container caring the specimen allows an insight into the soil during impact loading. The loads are applied by a guided and halved weight falling close to the Perspex. Thus we assume axial symmetric loading under gravity in our experiment. Other so called 1g-experiments with impact loads are reported e.g. in[v]. With our setup we can change the initial density of the soil, the weight, the falling height, the diameter and the acceleration of the falling weight.

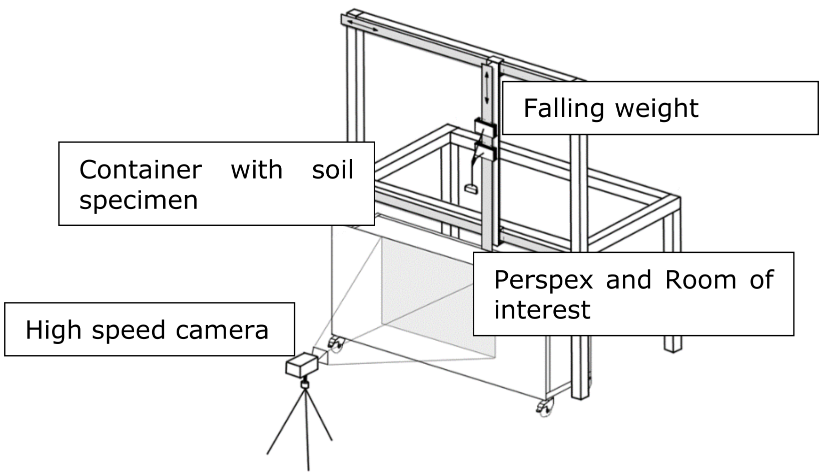

Figure 2 Experimental setup and its components

Table 1 Configurations investigated during the experiments.

no.	m [kg]	h [m]	d [m]	N	R	identifier
01	4,500	0,80	0,100	12	4	m4_5-h0_8-D100_N101 … *_N412
02	4,500	1,00	0,100	12	4	m4_5-h1_0-D100_N101 … *_N412
03	4,500	1,20	0,100	12	4	m4_5-h1_2-D100_N101 … *_N412
04	5,625	0,64	0,100	12	4	m5_625-h0_64-D100_N101 … *_N412
05	6,750	0,53	0,100	12	4	m6_75-h0_53-D100_N101 … *_N412
06	4,800	1,20	0,150	24	1	m4_8-h1_2-D150_N101 … *_N124
07	7,090	1,01	0,125	24	1	m7_09-h1_01-D125_N101 … *_N124
08	47,38	0,34	0,300	12	2	m47_38-h0_34-D300_N101 … *_N212
09	47,38	0,34	0,435	12	2	m47_38-h0_34-D435_N101 … *_N212
10	47,38	0,46	0,300	12	2	m47_38-h0_46-D300_N101…*_N212
11	47,38	0,91	0,300	12	2	m47_38-h0_91-D300_N101 … *_N212

m … mass of the falling weight

h … falling height

d … diameter of the falling weight

N … impacts bevor sample reconstitution

R … reruns

The reaction of the soil specimen during the applied loading condition is captured by a high speed camera recording at 1600 fps. The images are then processed with the PIV/DIC-Method (Particle Image Velocimetry / Digital Image Correlation). This method calculates the field of displacement by a cross-correlation algorithm which compares discrete regions of the picture pair-by-pair. An acceleration transducer measuring in three axis gather the behaviour of the falling weight during and post impact. Because we capture both the soil and the compactor behaviour we are able to investigate its interdependency.

As already mentioned several parameters of the setup can be modified. Varying these parameters in 11 different configurations we observed over 384 impacts. As shown in Table 1 we rerun various configurations to show the variance of the results.

2.2 experimental data

The contour line plots shown in section 3 represents the depth of improvement 0,125 s after the impact occurred. This depth of improvement (DOI) is the lower boundary which holds the condition:

$$u_y > -4{,}5mm$$

The x- and y-coordinate of the diagrams are related to the diameter of the falling weight to minimize the so called 'scaling effect' of 1g-model tests[vi]. To assess the acceleration data the signal was low-pass filtered with a cut off frequency of 100 Hz.

3 Results

Figure 3 shows the depth of improvement of series no. 01 (see Table 1) in the above mentioned manner. The maximum depth of improvement for the rerun series N301-N312 is shown in Figure 3 alongside. The biggest deviation along these maximum values is 7,7 % related to series N101-N112.

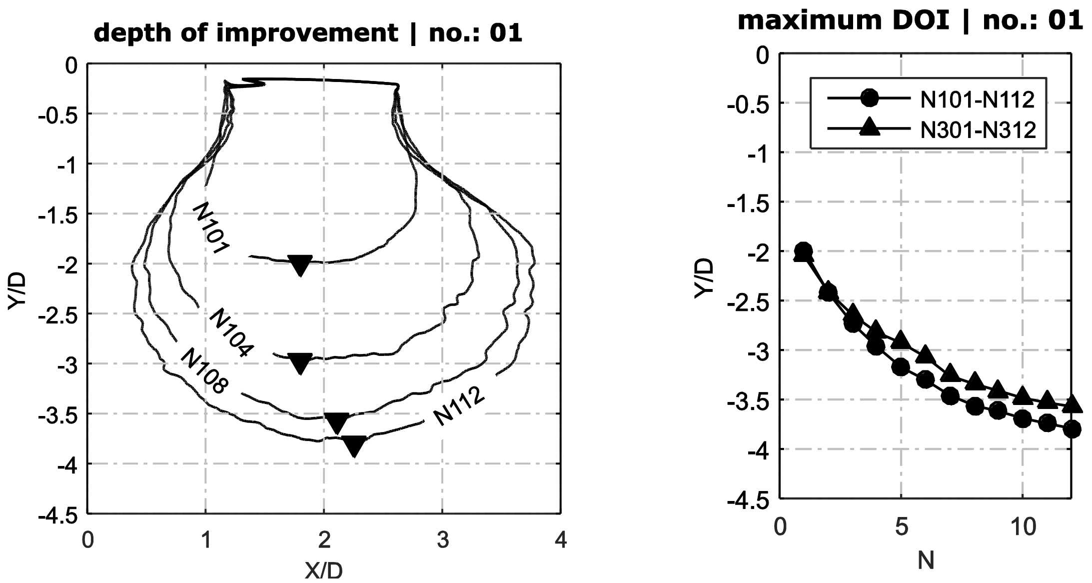

Figure 3 Depth of improvement and maximum depth of improvement of configuration no.: 01

The acceleration in multiples of the gravity ($g = 9{,}81\,m/s^2$) is shown in Figure 4. The mean deviation of the maximum acceleration is 2,7% compared to the rerun series N301-N312 (without concerning the first impact) as shown in Figure 4 alongside.

The signal of acceleration investigated shows good compliance with recent field investigations presented by Adam[vii] or Kirstein[viii]. Thus we can investigate the interdependencies between

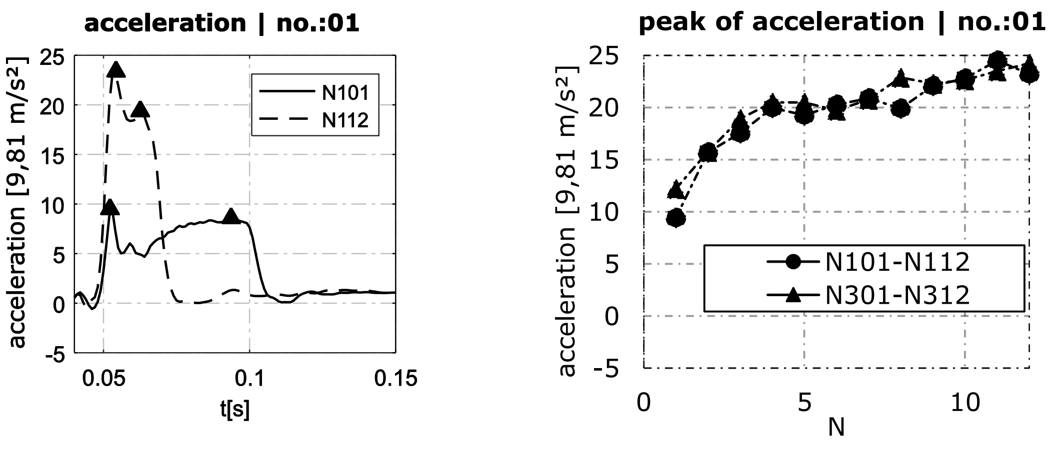

Figure 4 Curve of the acceleration and maximum values of acceleration compared to the rerun

the soil and a compactor applying impact loads in laboratory environment with our setup at least in a qualitative manner.

With increasing densification we recognised an increase in the peak of acceleration, which is in good compliance with the experimental work of Poran[vi]. Other authors[ix,vii] propose the use of a simple viscoelastic material model to assume the soil behaviour. The viscoelastic model predicts a constant damping factor which holds the condition: $\hat{a}_n/\hat{a}_{n+1} = const.$ Actually the behaviour of the system is strongly non-linear. As shown in Figure 4 we can not endorse this condition with our experiments. Obvious there is no clear convergence for this condition.

It is well established that dynamic soil properties (shear module and material damping) strongly depend on the applied shear strain and various soil properties[x]. Furthermore an accumulation of plastic strain[i] can be observed during cyclic loading, which is obvious eminent in our experiment (see Figure 4 right). This effect is known as ratcheting and functionally described in several forms of the type $\dot{\epsilon_p} \propto \ln(N)$[i]. We can show that during a ratcheting failure the peak of the acceleration also shows this behaviour. A good fit of the acceleration peak can be found with the function:

$$\hat{a} = m \ \ln(N) + n$$

As shown in Figure 5 we could fit the acceleration peak of conf. no. 06 with $R^2 = 99{,}2\%$. A more promising approach to describe the soil behaviour under impact loading should be possible with these both theories in mind.

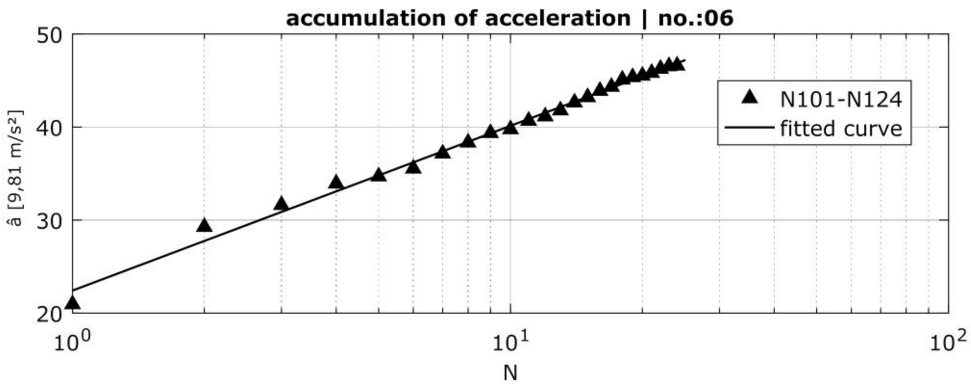

Figure 5 Accumulation of acceleration in dry sandy soil during cyclic impact loading

4 Conclusion

Small scaled experiments can be a good springboard to entrench new technologies or methods for soil compaction. Nevertheless there are boundaries. Especially the small stress level within the 1g environment is a limiting factor. The proposed dependencies must be validated in field tests. But besides that, small scaled experiments are low cost, reproducible and quickly done. That is why they are a major element in the establishment of modern compaction technologies and methods. Regarding our small scaled experiments we can summarize the following:

a) The experimental method is reproducible.
b) The acceleration measured on the falling weight shows good compliance with field tests.
c) The progression of the peak of acceleration proves the experiments made by Poran[vi]
d) We object the simplification of the viscoelastic model
e) The well-known ratcheting behaviour seems to be true for the peak of acceleration too

The improvement of the found dependency shown in section 3, especially regarding the units of the coefficients of fitting (m, n) and its reliance on soil and system parameters is of interest for further research.

5 Acknowledgement

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