17th International Conference
ENGINEERING MECHANICS 2011
Svratka, Czech Republic, 9 – 12 May 2011

THE IMPACT OF GROUNDWATER ON ARTIFICIALLY COMPACTED SOILS

M. Brouček[*], **P. Kuklík**[**]

Abstract: *The paper presents analysis of laboratory experiments on soils that are usually classified as coarse grained soils and are often used as backfill for trenches from pipes and conduits. The reason for selecting coarse grained soil is a generally accepted fact that fine soils suffer with soil structure collapse when the matric suction is cancelled while for coarser soils such as sands or gravel this problem is frequently neglected. The main aim is to show the effect of rising and varying groundwater to the settlement of the foundation structure. Experiments are carried out on large soil specimens created in the laboratory using compactors. The effect of compaction and moisture inside the specimen to the settlement is taken into account.*

Keywords: ***Settlement, groundwater table variation, structure collapse, particles redistribution, matric suction.***

1. Introduction

Recently reported increasing number of damaged structures built on artificially compacted soils such as pavements, roads, etc. caused raised interest in evaluation of effect the groundwater has on the compacted soils. Similar problems have been reported in structures built on soils that have not experienced significant contact with groundwater.

The idea of the influence of groundwater on the mechanical behaviour of soils, in natural or changed state, is not innovative when considering the idea itself. However the research effort was in the past mainly focused on avoiding difficulties in the area of hydraulic structures and deep excavations. The aim was to formulate empirical recommendations which would ensure certain conditions inside the soil or dam body. For civil engineering structure purposes the whole area is being neglected apart from foundations on clays. Current standards do not take the influence of the groundwater table variations into the account neither for the design purposes of newly built structures nor for back analysis of the damage of the already built.

2. Experiments and tested soils

The governing idea of the implemented experiments is to provide set of laboratory results for different artificially compacted soil that are often used as backfill for trenches. Additionally the results obtained should allow for comparison with the in-situ results. The aim is to describe the soil behaviour under the semi-constant load, which could represent an upper structure, while vary the groundwater table position. For similar load and settlement values measured in situ on the appropriate type of the soil we can evaluate the influence of the probable groundwater change to the upper structure in advance without complicated and expensive large scale in-situ experiments. This will allow us to improve the standards for newly constructed soil structures in areas where groundwater table variation potentially occurs. Another use of the results presented is improvement of the loss functions used for evaluation of flood damage (Kang, Su and Chang, 2005).

---

[*] Ing. Miroslav Brouček: Department of Hydraulic Structures, Faculty of Civil Engineering, Czech Technical University in Prague; Thákurova 7; 166 29, Prague; CZ, e-mail: miroslav.broucek@fsv.cvut.cz

[**] doc. Pavel Kuklík, CSc.: Department of Mechanics, Faculty of Civil Engineering, Czech Technical University in Prague; Thákurova 7; 166 29, Prague; CZ, e-mail: kuklikpa@fsv.cvut.cz

With a general classification of the structures based on the changes in subsoil it is easy to present an improved risk analysis of the flood areas which is an impartial, not place dependent and useful tool for any cost-effective analysis of suggested protective measures.

The experiments have been prepared with use of experience gathered from small scale inundation experiments recently carried out.

2.1. Description of the experiments

The soil sample's stand is a reinforced concrete box without the top covering part. The bottom part contains a system of pipes 12.5 mm in diameter that is connected to the large water storage tank. The box is horizontally constricted by steel beams in two levels. Steel frame is attached to the box to take the reaction force and additional small frame presents an inertial body to which the deformations are measured. The inside size of the box are 1 x 1 x 1 m.

The test itself is similar to static plate load test which is described in standards and is often used in practice so no special arrangements are needed for comparison with in-situ tests. Load is applied through a hydraulic jack to the steel plate 2 cm thick and 30 cm in diameter. The load is measured in the hydraulic system and once more in the pressure cell between the reaction frame and the hydraulic jack. Two settlement sensors which are used for measuring the settlement are installed on the plate and have guaranteed accuracy 0.01 mm. An a) part of Fig. 1 shows a scheme of the experiment while b) part shows the experiment in reality ready for testing.

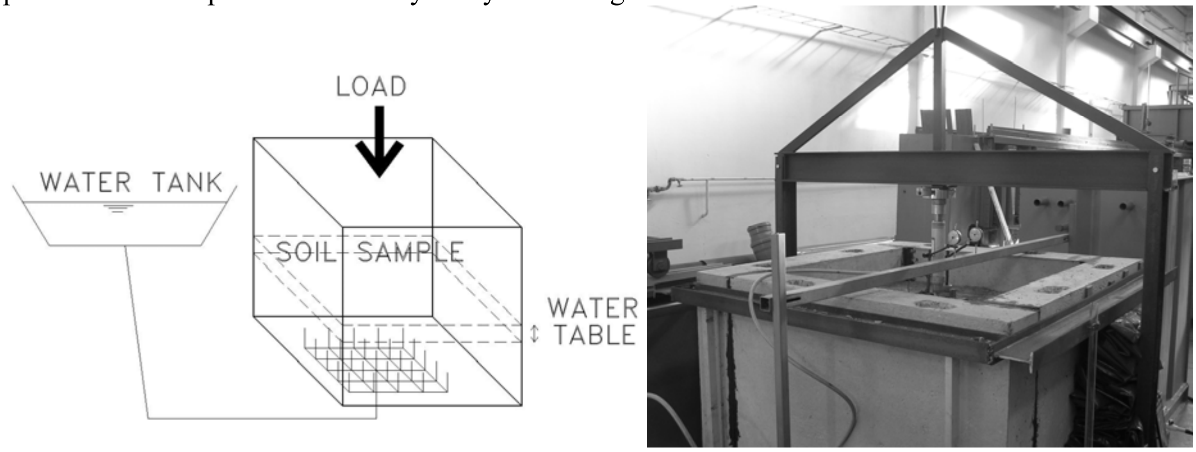

Fig. 1: Experiment - a) scheme; b) photo.

The soil is inserted into the concrete box by layers 15 – 20 cm thick. Each layer is compacted by vibrating plate. Compacting experiment is carried in advance so that the time of vibration is known. The soil contains natural amount of moisture as it is kept in plastic covers after being removed from the site. The time of storage is as short as possible. The moisture content is also tested on small samples.

2.1. Selected results

Results from the experiments are sets of load-displacement curves or time-displacement curves. For the purpose of this paper we selected results from one series of experiments on one soil.

2.2.1. Tested soil characteristics

The presented results were obtained on soil specimen classified as poorly grained gravel, i.e. G2 – GP. The portion of particles larger than 60 mm was 17.3% of the weight. The optimal moisture content and maximal dry soil density was evaluated using standard Proctor test and the compacting experiment prescribed 25 minutes duration of compaction with vibrating plate for each 20 cm thick layer.

This particular soil was obtained from excavation in the central area of the Prague city. In this part of the city the soil is experiencing large groundwater movement especially due to engineering activity linked with lowering water table for foundation work.

This soil has also proved its predisposition for internal erosion and collapse when exposed to high hydraulic gradient or flow pressure. Several road and building accidents were reported regarding this matter.

2.2.2 Results from dry load tests

Following figures show first and third loading tests on dry sample – natural water content. The SM1 and SM2 abbreviations in the charts stand for settlement measurement point 1 and 2. As the plate is instrumented with the joint that allows differential settlement of the plate at least 2 measuring points are necessary.

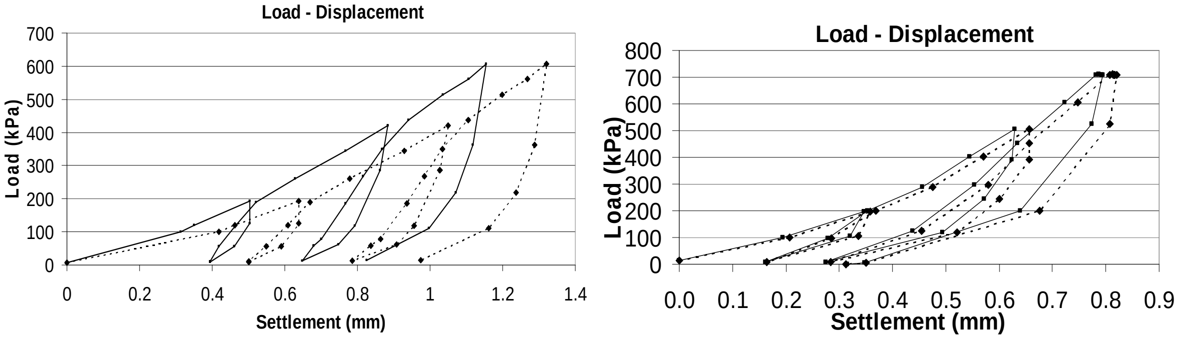

Fig. 2: Loading test nr. 1 and nr. 3 – dry.

Three facts can be nicely observed on the left part of Fig. 3 (Experiment nr. 1). First is the characteristic loop in the unloading/reloading path. As the elastic hysteresis is generally load rate dependant it is quite interesting observation when the load steps were no shorter than 5 minutes each.

Second it is the unloading/reloading path that has different slope than primary loading path. This phenomenon of structural strength vs. void ratio was described in the past (Terzaghi, 1996).

Third important fact observed is small hardening of the material.

The third test proved small creep behaviour of the soil even without the presence of water. Creep was observed in sandy soils in the past (Hsiung, 2008). The important aspects are the magnitude of the creep and the duration. The whole creep behaviour last approximately 1 hour but more than 80% of the creep deformation was reached after first 15 minutes. Following figure shows the results from first loading experiment with water entering the specimen.

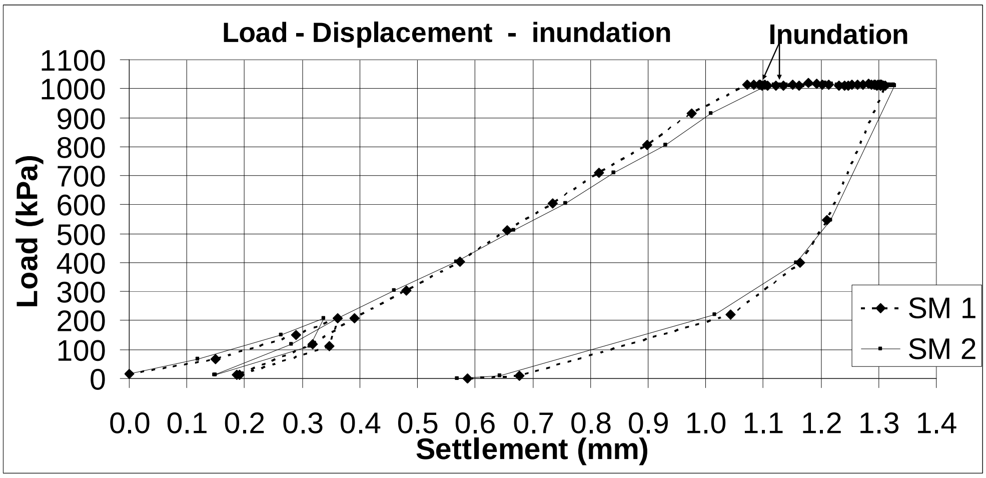

Fig. 3: Loading test nr. 4 – wet.

Before the inundation took place the load was kept constant for a time necessary to eliminate the effect of dry creep. It is important to point out that the highest position of the water table was 40 cm below the surface of the specimen. The inundation caused increase in settlement from 1.1 mm to 1.32 mm in average, i.e. increase by 20%. Although the observed volume change (less than 0.1%) was very low when compared to finer soils, for example 2.5% to 5.8% for sandy silt observed by Jia (Jia et al., 2009), and Fredlund (Fredlund Rahardjo, 1993), (Fredlund and Morgenstern, 1977) or 1.1% for

Mississippi silt observed by Tadepalli (Tadepalli, Rahardjo, Fredlund, 1992) the relative increase in settlement is very high.

When considering the influence zone below the plate we would expect that until the groundwater table reaches the border of the zone no effect on the settlement should be observed. During the first inundation the zone was very close to the bottom and so the change in behaviour took place immediately.

When running dry experiments after the inundation experiments the first response of the sample was very similar to the last loading curve although when doing the same procedure with dry-dry experiment we observe significantly stiffer response. Leaving the specimen to “rest for a long time will cause a small decrease in overconsolidation. Result obtained from the same specimen after 3 months were similar to second loading test on this specimen.

3. Conclusions

The presented experimental results show that coarse soils such as gravel suffers a weak form of particles redistribution due to wetting process and although the volumetric deformation is not as high as in case of finer soils it still presents a great increase in settlement with respect to the applied load and deformation without ground water

The drop in the pore pressure due to drawdown of the water table did not show any significant deformations. This may due to the fact that the increase in an effective pressure due to the drawdown is not high enough when compared with the other involved stresses.

The tested sample also proved creep behaviour in the dry state but the magnitude of the settlement is significantly smaller compared to one caused by the inundation.

The behaviour of the sample also shows better agreement with the critical state constitutive models rather than plasticity models (Sejnoha and Janda, 2006).

Acknowledgement

The authors would like to acknowledge the financial support provided within research projects MSM6840770001, MSM6840770002 and VG20102014056.

References

Fredlund, D.G., Morgenstern, N.R. (1977) Stress state variables for unsaturated soils. J. Geotech. Eng. Div., ASCE 103(GT5), 447-466.

Fredlund, D.G., Rahardjo, H. (1993) Soil mechanics for unsaturated soils, Wiley-IEEE.

Hsiung, B-CH.B. (2008). A case study on the behaviour of a deep excavation in sand. Computers and Geotechnics 36: 665–675.

Jia, G.W., Zhan, L.T., Chen, Y.M. and Fredlund, D.G. (2009). Performance of a large-scale slope model subjected to rising and lowering water levels, Engineering Geology 106: 92-103.

Kang, J-L., Su, M-D., Chang, L-F. (2005) Loss Functions and Framework for Regional Flood Damage Estimation in Residential Area, J. Mar. Sci. Tech., 13(3), 193-199.

Sejnoha, M., and Janda, T. (2006) Formulation of generalized Cam clay model; Engineering Mechanics, vol. 13, no. 5, pp. 367-384.

Tadepalli, R., Rahardjo, H., Fredlund, D.G. (1992) Measurements of matric suction and volume changes during inundation of collapsible soils. Geotechnical Testing Journal, ASTM, 15(2): 115–122.

Terzaghi, K., Peck, R.B., Mesri, G. (1996) Soil Mechanics in Engineering Practice, Wiley-Interscience.