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Investigation of the influence of water to soil

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ABSTRACT: The recent past has witnessed repeated incidences of damage by mass flow of soil-water mixtures. The occurrence of these incidences is the motivation to analyse the influence of water to the stability of the soil more closely in order to assess the onset and mechanics of such destructive incidences and to estimate the corresponding risk. Currently at the Institute and the Laboratory of Geotechnics at the Technische Universität Darmstadt experiments to analyse the phenomenon of water in soil stability are in progress. Large scale experiments are performed to investigate the characteristics of saturated granulate mass flow.

1 INTRODUCTION

The investigation of the flow behaviour of saturated soil is analysed at the Institute and Laboratory of Geotechnics at the Technische Universität Darmstadt together with the Institute of Continuum Mechanics at the Ruhr-Universität Bochum in a project supported by the DFG (Deutsche Forschungsgemeinschaft, German Research Foundation). The goal of this investigation is to gain by experimental investigation a detailed understanding of the flow behaviour of granulate-fluid mixtures. The grain size, grain shape and its distribution, the water content and conditions of pressures, etc., are the influencing factors. The study is performed by using coarse grained water-saturated soils, which excludes complexities of cohesive internal forces. The experimental set-up is a rectangular experimental rig, which allows the formulation of well defined boundary conditions so that the flow conditions are controllable and reproducible. To initiate the flow of the composed material, a rectangular flap, built-in within the lowest side element of the experimental rig, is rapidly opened. The plane flow which ensues through this discharge unit is observed through a glass front wall of the experimental rig.

2 THEORETICAL ASPECTS OF THE ANALYSES OF THE FLOW BEHAVIOUR OF FLUID-GRANULATE MIXTURES

The velocity of water is a multiple faster than the velocity of the saturated soil because of the viscosity caused by the grains. The viscosity of Newtonian liquids is defined as follows:

Viscosity is a property of a flowable set of compounds, under the influence of pressure to flow and gets irreversible deformable. The adjusted pressure at the deformation depends only on the deformation velocity: The pressure can also be seen as the cause of the deformation velocity.

The viscosity is also called dynamic viscosity (η) with the unit of Ns/m². The kinematic viscosity (ν) is the dynamic viscosity related to the density with the unit of m²/s (Gross et al. 2009).

The flow of an incompressible fluid out of an opening is a elemental flow mechanic problem. The stationary velocity v of a fluid is described by Toricelli at a small outflow section with the gravitation constant g and the height of the fluid above the outflow section as follows (see Figure 1):

$$\mathrm{v} = \sqrt{2gh} \tag{1}$$

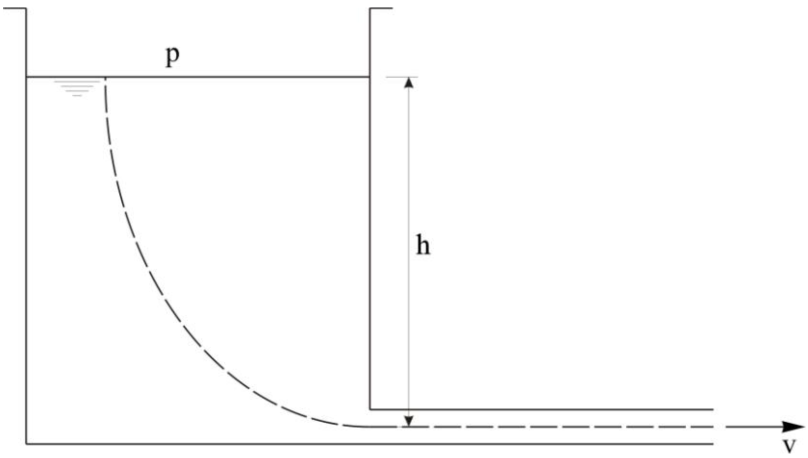

Figure 1. Qutflow of a incompressible fluid out of a container

The equation basis of the assumption, that in the observed fluid a hydrostatic pressure p exists and that shear stress is not going to assign to the wall. That means that the equation (1) assumes the following:

$$p = \rho g h \tag{2}$$

An essential part of the analyses of the flow behaviour of fluid-granulate mixtures is the Theory of Mixtures (Schneider & Hutter 2009, Bowen 1976, Drew & Passman 1999, Truesdell 1966) respectively the amelioration in the Theory of Porous Media (TPM) (Ehlers 1996, Ehlers & Bluhm 2002). The TPM is a general continuum mechanics and thermodynamic concept to describe macroscopically the multiphase material. Generally there are two different possibilities to describe the different components. On the one hand the single constituents can be described by itself with the classical continuum mechanics on the other hand a conceptual average of the whole region of the solid and fluid components can be build. In case of the unknown geometry of the inner pore structure the transfer and contact condition cannot be described accurately with the consideration of the single components. That is why the Theory of Porous Media uses the second alternative with the “smeared” multi-component continuum. A detailed report of the TPM can be found in Ehlers 1996 and Ehlers & Bluhm 2002.

3 EXPERIMENTAL INVESTIGATION

To analyse the flow behaviour of saturated non-cohesive soil at the Institute and Laboratory of Geotechnics at Technische Universität Darmstadt large scale experiments have been conducted. Therefore an experimental rig has been build with a height of 3 m, a width of 1.0 m and a depth of 0.5 m (see Figure 2). The front is made of 5 cm thick glass to observe the flow behaviour whereas the other sides have been made of steel. At the back side wall at a distance of 15 cm a perforated metal plate has been installed and a filter course filled between it. Thereby it is possible to add additionally water through the filter course in the soil during the test procedure without generating turbulences.

With the investigation we want to analyse in the first step the worst case scenario therefore we use non-cohesive material. That is why we performed the experiments with sandy gravel. The properties of the test material are given in Table 1 and the grain-size distribution curve is shown in Figure 3.

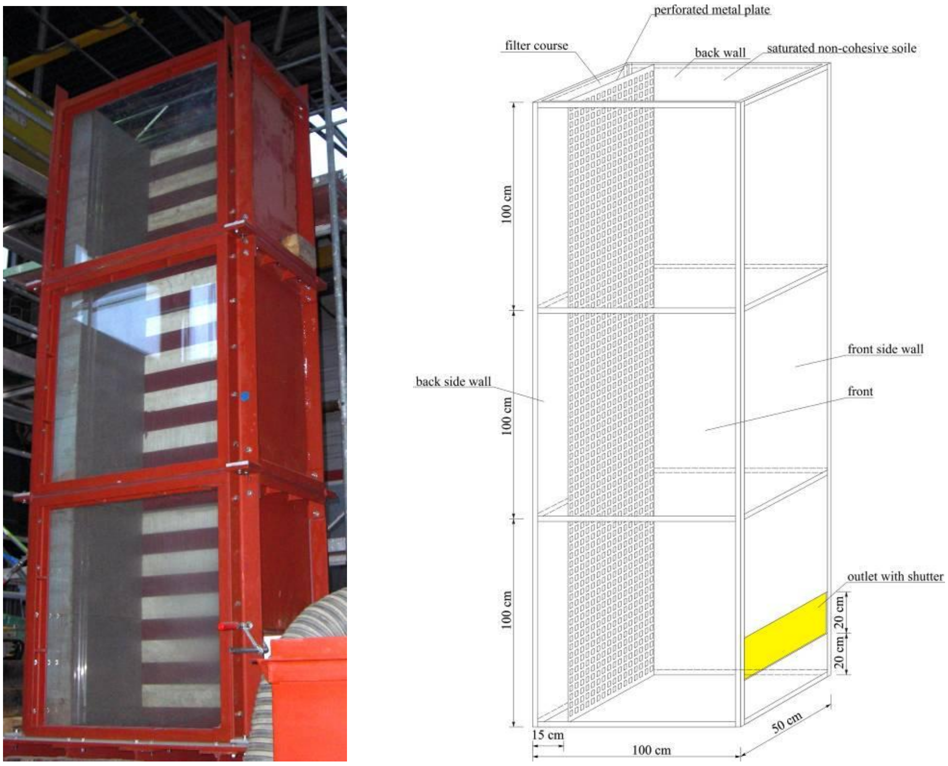

Figure 2. Experimental rig to analyse the flow behaviour of a fluid-granulate mixture

Table 1. Soil properties of the test material

Grain density	ρ_s	2.628 g/cm³
Density of loose bearing	min ρ_d	1.814 g/cm³
Density of dense bearing	max ρ_d	1.989 g/cm³
Hydraulic conductivity	k	$2 \cdot 10^{-3}$ m/s

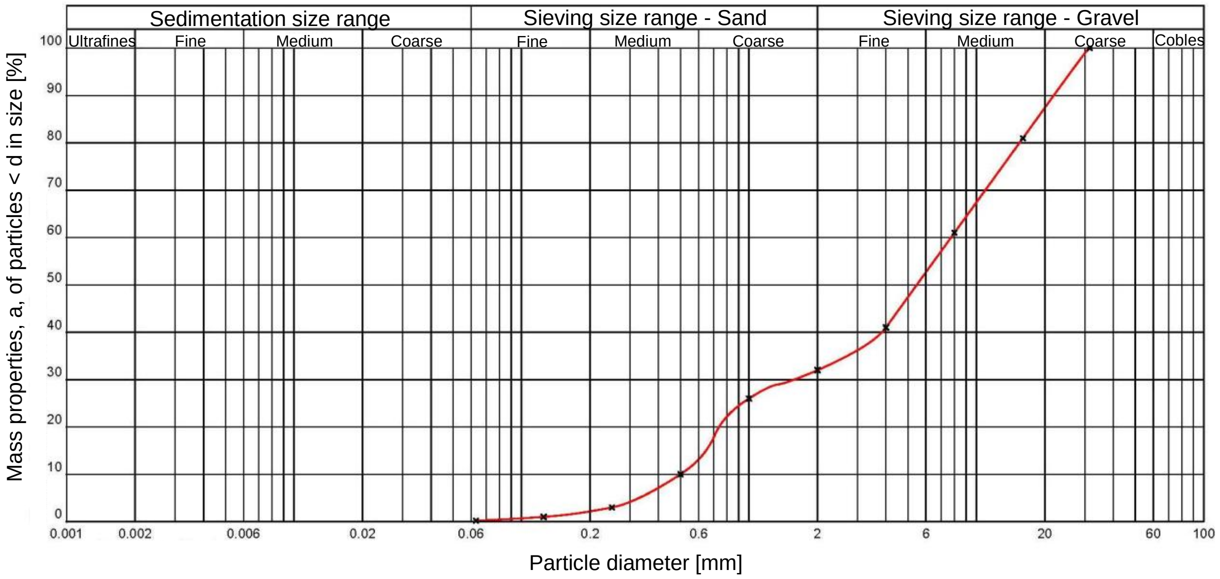

Figure 3. Grain-size distribution curve of the test material

The homogeneous placing of the material is a special challenge. Furthermore there is the request to have a loose packing. After testing different placing techniques we decided to use a new developed special placing apparatus (Figure 4). This apparatus has been constructed with a bit smaller dimensions than the experimental rig (47 cm x 80 cm), so it is possible to crane it into the experimental rig. The volume of the placing apparatus is dimensioned to a 10 cm layer in the experimental rig. With the help of the placing apparatus it is possible to place the test material with a water content of 6% in loose packing in the apparatus as it is defined before. After the filling the placing apparatus is craning into the experimental rig and slowly opened with cables at the top of the experimental rig. This has to be repeated until the height of 2.70 m was reached.

Figure 4. Placing apparatus

At the top of the saturated sandy gravel a 30 cm water layer to the top of the experimental rig was filled. This has the aim to guarantee a saturation of the test material during the test procedure.

To start the experiment the shutter was opened quickly and the saturated soil flows out of the experimental rig in a collecting tray (Figure 5).

During the test procedure the time depending of the outflow is measured, so the flow velocity of the saturated sandy gravel can be detected.

The time of the test procedure is about 12 seconds. The saturated test material flows homogeneously out of the experimental rig until it reaches a height of 1.50 m from the bottom of the experimental rig. At that time the surface of the fluid-granulate mixture gets an inclination to the outlet. At the end the water flows out so the sandy gravel gets drained and the water content gets reduced about 2.2 % point from w = 14.5 % to w = 12.3 %. The inclination of the soil that remains in the experimental rig is about 17°.

The first results of the experimental investigation have shown that the velocity depends on different influencing parameters. In Figure 6 the result of a selected experiment and the velocity of pure water are shown. As it can be detected the flow reaches a very high velocity at the beginning of the test procedure caused by the high pressure and the abruptly discharge. After that the decrease of the overpressure the velocity slows down and increases again. At a height of 1.0 m under the reference level the velocity decreases with decreasing pressure.

The measured velocity of the saturated soil can be compared with the velocity of water. The velocity of water can be determined by the Toricelli equation (1), at a height of 1.90 m the velocity of the water is

$$v = \sqrt{2 \cdot g \cdot h} = \sqrt{2 \cdot 9.81 m/s^2 \cdot 1.90 m} = 6.1 \, m/s \, .$$

Figure 5. Filled test stand (left) and outflow during the test procedure (right)

This correlates to the velocity of the fluid-granulate mixture at a height of 0.5 m below the reference level which is about v = 0.6 m/s. So the velocity of the fluid-granulate mixture is about 10 % of the velocity of pure water.

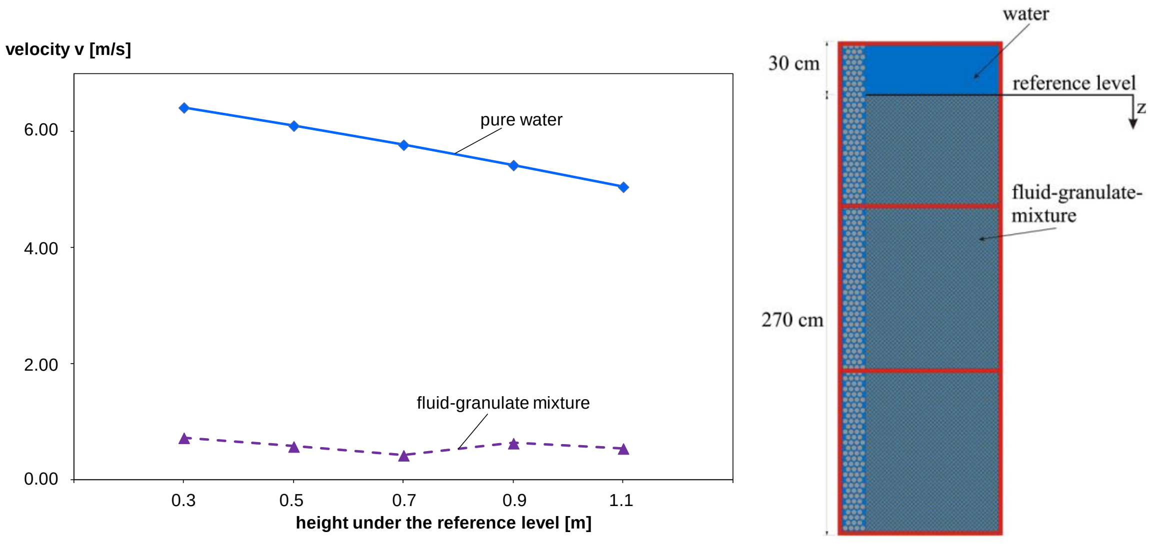

Figure 6. Velocity depending on the height under the reference level

The experiments have shown that the influence of water on the soil stability is immense. The water is carrying the grains along. So the grains have an essential lesser velocity than the water, which transports the grains.

In further investigations the definition of the different velocity of the water and the grains will be a main aspect. Therefore it is planned to observe the flow of the fluid-granulate mixture with the Particle Image Velocimetry (PIV) Method (Katzenbach et al. 2011., Raffel et al. 1998) on the verge of the outflow.

4 CONCLUSION

The incidence damage by mass flow of soil-water mixtures in the recent past has shown that it is very important to analyse the influence of water to the soil stability. The experimental investigation at the Institute and Laboratory of Geotechnics at the Technische Universität Darmstadt together with the numerical analyses of the Institute of Continuum Mechanics at the Ruhr-Universität Bochum is an important step to the understanding of the influence of the stability and the flow behaviour of fluid-granulate mixtures.

REFERENCES

Bowen, R. (1976). Theory of Mixtures. In: A. Eringen (Ed.) Continuum Physics III, pp. 2-127, Academic Press

Drew, D. & Passman, S. (1999). Theory of Multicomponent Fluids, Springer

Ehlers, W. (1996). Grundlegende Konzepte in der Theorie Poröser Medien, Technische Mechanik, 16, 63-76.

Ehlers, W. & Bluhm, J. (Editors) (2002). Porous Media, Springer

Gross, D., Hauger, W., Wriggers, P. (2009). Technische Mechanik, Band 4 Hydromechanik, Elemente der Höheren Mechanik, Numerische Methoden. Springer-Verlag.

Katzenbach, R., Bergmann, C., Ruppert, T., Bachmann, G., Gutberlet, C., Hutter, K. (2011). Particle Image Velocimetry Measuring Methods for Soil Movements in Geotechnics, Darmstadt Geotechnics, 21, 1-94.

Raffel, M., Willert, C., Kompenhans, J. (1998). Particle Image Velocimetry, Springer Verlag, Berlin

Schneider, L. & Hutter, K. (2009). Solid-Fluid Mixtures of Frictional Materials in geophysical and Geotechnical Context, Springer

Truesdell, C. (1966). Sulle basi della termomeccanica I & II. Atti Accad Naz. Lincei. Rend. Cl. Sci. Fis. Mat. Nat. 22 (1957), pp. 33-38 und pp. 158-166. Engl. Translation in: C. Truesdell (Editor), Continuum Mechanics II-IV, Gordon & Breach, New York.