

INTERNATIONAL SOCIETY FOR SOIL MECHANICS AND GEOTECHNICAL ENGINEERING



This paper was downloaded from the Online Library of the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE). The library is available here:

<https://www.issmge.org/publications/online-library>

This is an open-access database that archives thousands of papers published under the Auspices of the ISSMGE and maintained by the Innovation and Development Committee of ISSMGE.

Investigations on the safety against hydraulic failure of excavation pits with consideration of adhesion

Enquête sur la prévention des défaillances hydrauliques des tranchées en considération de l'adhésion

Dipl.-Ing. Nicholas Andermahr

Chair of Geotechnical Engineering, RWTH Aachen University, Germany, andermahr@geotechnik.rwth-aachen.de

ABSTRACT: The adhesion of cohesive soil (Emscher marl) to a diaphragm wall along the embedment length is a resistance factor against hydraulic failure, which is investigated by the chair of Geotechnical Engineering at RWTH Aachen University. Failure modes of uplift and hydraulic heave are discussed and analyzed. Two types of laboratory tests are developed to consider the different modes of failure. Direct shear tests are carried out to determine effective adhesion that can be considered in the verifications against hydraulic heave. Depending on how the test is conducted the adhesion reaches values of 8 % to 35 % of effective cohesion. Uplift failure can be described as simple shear failure under undrained conditions. Therefore an uplift test with water pressure as acting force is developed.

1 INTRODUCTION

In Europe verifications against hydraulic failure in terms of uplift and hydraulic heave are regulated in European standard EC-7. In addition, the national rules of DIN 1054 have to be considered in Germany. The applied standards do not provide reliable instructions how to take cohesion/adhesion into account. However, high cohesion combined with adhesion of soil has a significant influence on the values of soil resistance against hydraulic failure. The neglect of secured cohesion/adhesion of soil leads to an uneconomic dimension of the embedment depth, if safety against hydraulic failure is decisive. Therefore, the aim of the research project "Safety against hydraulic failure with consideration of adhesion" is the determination of a realistic value of adhesion between the pit wall and the soil as well as its inclusion in the verification of resistance against hydraulic failure. Collected data and soil samples of the infrastructure project "Sewer Emscher" will be used to carry out numerical simulations and laboratory tests. Compared to this construction project, the current research focuses on the adhesion of the Emscher marl at diaphragm walls.

In this paper bonding mechanisms of adhesion are discussed followed by an analysis of hydraulic failure of excavation pits in cohesive soil. Subsequently, conclusions to determine the value of adhesion in laboratory tests are given and first test results are presented.

2 BONDING MECHANISMS

To develop appropriate laboratory tests the bonding mechanisms in general need to be considered and discussed. There are many theories to describe adhesion. They vary depending on the science sector regarded. The bonding mechanisms are divided into mechanisms with and without bridging material between the adhesive materials. Adhesion without bridging material is distinguished between specific (intermolecular) adhesion and mechanical adhesion (Juhart 2011). The specific adhesion can be traced to valence bond, van der Waals forces and electrostatic attraction (Rumpf 1958). Mechanical adhesion describes a compound due to the geometric structure, interlocking and friction as well as the cohesion of the materials. The surface roughness influences mainly the value of mechanical adhesion. Great surface roughness leads to high values of adhesion especially when two phases are separated by shearing forces. It is hardly possible to determine specific and mechanical adhesion separately because of overlapping effects (Juhart 2011).

Bonding mechanisms with bridging material are distinguished into mechanisms with liquid and solid bridges. Liquid bridges are further divided either into liquid bridges that are moving freely or non moving freely.

A discussion of the bonding mechanisms regarding the adhesion of Emscher Marl in conjunction with diaphragm walls leads to the mechanical adhesion as the major and realistic bonding mechanism. This mechanism occurs when fresh concrete is poured in the diaphragm wall lamellas and is allowed to harden.

3 HYDRAULIC FAILURE OF EXCAVATION PITS IN COHESIVE SOIL AND DETERMINATION OF ADHESION

A literature review to analyse the hydraulic failure mechanisms of uplift and hydraulic heave in cohesive soil has been conducted. Failure due to uplift in clayey soil was recently investigated by Hong and Wang (2016). Depending on the ratio of the excavation width B and the thickness of the excavation bottom D the resistance against uplift exceeds the overburden pressure up to 35 percent ($B/D = 1,0$). For shallow excavation pits up to a ratio of $B/D \leq 3$ a simple shear failure along the wall surface was observed. A rigid-body movement with constant volume, respectively constant water content w , within the failing soil layer is identified. The capability to resist uplift forces (water pressure) exceeding the overburden pressure results from the undrained shear strength c_u of clay. Thus the value of adhesion has to be determined in laboratory tests with undrained conditions and constant water content.

The failure mechanism of hydraulic heave in cohesive soil was observed to start at the bottom of the wall as a crack, followed by crack opening and closing processes leading to an increase of water content and a final sole heave (Wudtke 2014). A fluid flow as driving influence on hydraulic heave supposes drained conditions. Consequently, effective shear parameters (φ' ; c' or δ' , a') have to be considered. The shear strength of the contact zone shall be determined in laboratory tests with drained conditions.

The two different modes of failure lead to two types of laboratory test to determine the value of adhesion. For determining the value of adhesion considering uplift failure a new laboratory test is developed at the Chair of Geotechnical Engineering at RWTH Aachen University, which is described in section 3.3. To determine the value of adhesion under drained conditions regarding hydraulic heave direct shear tests with marl-concrete contact are carried out.

3.2 Integration of adhesion in the verification of the safety

Regarding uplift failure as rigid-body movement under undrained conditions, the adhesion can be considered and taken into account as a constant value along the embedment depth.

The integration of adhesion resulting from cohesion in the verification of the safety against hydraulic heave is more difficult. Cohesion, as part of shear strength of cohesive soil that is independent of normal stress, leads to a higher resistance against hydraulic heave than a granular soil can apply. In granular soil a flow force $f_s = \Delta h / \Delta l \cdot \gamma_w$ canceling the vertical effective density $\gamma^* = \gamma - f_s \leq 0$ along the embedment depth leads to a failure. Hence, the magnitude of flow force a granular soil can resist is defined as the critical hydraulic gradient $i_{crit} = \gamma / \gamma_w$.

A cohesive soil can resist higher hydraulic gradients $i_{crit} \gg \gamma / \gamma_w$ before failure occurs. However, when the hydraulic gradient in cohesive soil reaches $i = \gamma / \gamma_w$ a damage of the soil structure arises. This damage can be explained by an expansion of pore space and an increase of water content, which leads to the reduction of cohesion. The resistance due to cohesion therefore has to be reduced in the damaged areas of the soil ($i > \gamma / \gamma_w$) (Wudtke 2014). The magnitude of the reduction depends on the critical hydraulic gradient i_{crit} of the cohesive soil and the present hydraulic gradient i . Wudtke (2014) presents a laboratory test to determine i_{crit} of cohesive soil and proposes a linear relation between i_{crit} and the reduction of the cohesion for $\gamma / \gamma_w < i < i_{crit}$.

3.3 Determination of adhesion

To determine the possible value of adhesion in the verification of the safety against uplift a new laboratory test is developed at the Chair of Geotechnical Engineering at RWTH Aachen University. The uplift-test is a waterproof steel box in which a piece of marl is placed on a thin layer of sand. To simulate the major bonding mechanism (see chapter 2) concrete is poured into the box and is allowed to harden. After the marl is saturated in closed mode the box is opened and a vertical hydraulic pressure is applied. The pressure is raised until failure occurs. To observe the displacement of the marl one side of the box is made of perspex to enable PIV measurement (see figure 1). When the water pressure exceeds the overburden pressure, the adhesion is calculated by the vertical balance of forces.

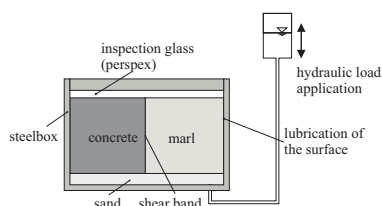


Figure 1. View of test stand to carry out uplift tests.

Since the test stand is currently manufactured unfortunately, no test results can be presented so far.

Direct shear tests with marl-concrete contact are carried out to determine adhesion under drained conditions. Thereby the surface of the marl is left smooth after the sample was cut out from a block of marl to prevent an increasing effect of surface roughness. The marl-concrete contact was produced with two different methods. To determine the minimum value of adhesion the concrete was poured into the lower shear frame and the marl sample was laid on top (see figure 2 left). To create a more realistic bonding mechanism (see chapter 2) the marl sample was fitted in the lower shear frame at first and the fresh concrete was poured on top (see figure 2 right). After consolidation- and saturation-phase, the tests series were conducted at a very slow feed rate to ensure drained conditions.

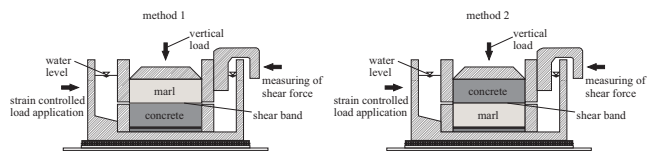


Figure 2. Test apparatus for direct shear tests; left: method 1; right: method 2

3.3.1 Values of adhesion under drained conditions

The relation between peak shear stress and normal stress of a smooth marl surface and the concrete is shown as arithmetic mean with the standard deviation in figure 3 for method 1 and method 2. Method 1 was carried out with three marl samples (T1, T2, T3) while method 2 was only carried out with marl T3.

The evaluation according to the Mohr/Coulomb criterion provides the value of the effective adhesion a' . Referred to the cohesion c' of the marl samples it becomes evident that the minimum value of adhesion determined by method 1 is $a'/c' = 8\%$. Method 2 testing leads to a significant increase of the value of adhesion up to 35% of the cohesion.

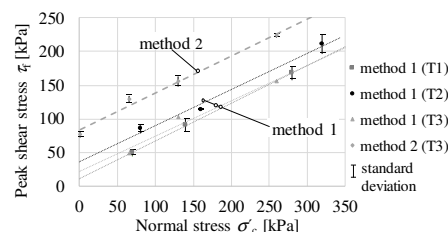


Figure 3. Relation between peak shear stress and normal stress of Emscher marl and concrete

4 CONCLUSION AND OUTLOOK

The determination of the value of adhesion with direct shear tests does not consider the damage of soil structure due to hydraulic induced pore expansion. Therefore, the integration of adhesion in the verification of the safety against hydraulic heave has to be checked in every particular case. The key issue of integrating a cohesive or an adhesive resistance of soil against hydraulic flow is the determination of the reduction of the shear strength due to the hydraulic induced pore space expansion. Since there is no reliable method to determine the shear strength of hydraulically damaged soil, the integration of adhesion or cohesion in the verification of the safety against hydraulic heave has not been fully clarified.

For the uplift failure the value of adhesion shall be determined via the developed uplift-test. The value can probably be considered as a constant value along the embedment length. First test results are pending and expected to be present soon.

5 REFERENCES

- DIN 1054: Subsoil – Verification of the safety of earthworks and foundations – Supplementary rules to DIN EN 1997-1
- DIN EN 1997-1: 2014. Eurocode 7 : Geotechnical design – Part 1: General rules; German version.
- Hong Y. and Wang L. 2016. *Deformation and Failure Mechanism of Excavation in Clay Subjected to Hydraulic Uplift*. Hangzhou, Zhejiang University Press
- Juhart J. 2011. *Adhäsion von UHPC an Stahl und Glas*. Graz University of Technology, Graz.
- Rumpf H. 1958. Grundlagen des Agglomerierens. *Chemie Ingenieur Technik* (3), 144-158.
- Wudtke R.-B. 2014. *Hydraulischer Grundbruch in bindigem Boden*. Bauhaus Universität Weimar, Weimar