HYDRODYNAMIC LOADS ON GEOMEMBRANES IN OPEN WATER CANALS

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ABSTRACT: In Germany numerous concrete-faced open water canals are being used for hydropower production, of which some are as old as 80 years. The inevitable ageing of the concrete results in the loss of water and in problems affecting the slope stability. A modern approach for the rehabilitation of such canals is the installation of a geomembrane-based facing onto the existing concrete. In case of a damage of such a membrane during operation, water can flow in between the concrete and the membrane and a dynamic water pressure will develop. This results in a load onto the fixation of the membrane, which must prevent it from tearing out. The loads occurring onto the membrane due to damages have not yet been thoroughly investigated. For the purpose of studying loads onto geomembranes a canal in the Laboratory of Hydraulic and Water Resources Engineering of the Technische Universität München has been lined with different types of geomembranes and miscellaneous tests have been carried out. In this paper results of the tests in the canal in the Laboratory will be presented together with suggestions for the design of geomembrane-based sealing systems. Furthermore a unit for testing the fixation of geomembranes has been designed to enhance presently common systems.

1 INTRODUCTION

Worldwide many kilometres of concrete-faced diversion channels are in service. As a result of ageing of the concrete, the facing can be expected to gradually lose its water-tightness after 50 years. This can result in the loss of water, and more serious, in a reduction of slope stability as a result of the permanent moisture in the subgrade.

Up to now in most cases the concrete lining is replaced by a new one, which is rather cost-consuming, or a new layer of concrete or asphaltic concrete is simply placed on top of the existing one. This involves a reduction of the cross-section and thus a decrease of water transport capacity.

An economically and technically highly competitive alternative to concrete or asphaltic concrete systems is the use of geomembranes. These have been used in hydraulic applications for decades, and for the rehabilitation of water conveyance canals since 1978.

Recent projects in Germany include the rehabilitation of the Isarkanal with a PVC-geocomposite (Figure 1) and the Alz Kanal with FPP- and HDPE-geomembranes.

Figure 1: Lining with PVC, Isarkanal, Germany, 2000

Research works are being carried out at the Technische Universität München to define possible loading cases and to optimize the means of fixation in terms of safety and economy.

2 DESIGN OF REHABILITATION MEASURES

2.1 *Technology*

When rehabilitating the concrete face of an open water canal, the separate liners are placed loosely into the canal and welded one to another. Anchors are then fixed into the concrete and steel profiles are used to clamp the membranes in place (Figure 2).

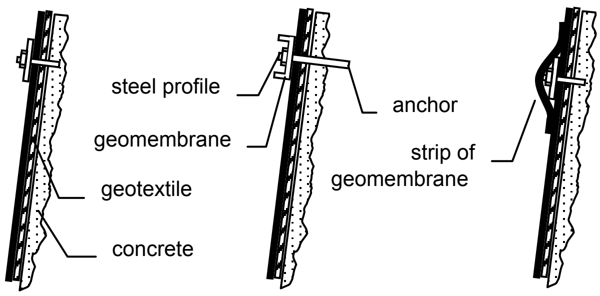

Figure 2: Examples for fixation of membranes on concrete

As there is a draining geotextile placed underneath, during regular operation no pressure can develop below the membranes and theoretically no fixation is need. If however heavy or sharp-edged objects fall into the canal (Figure 3), the membranes can be damaged. In this case water can flow beneath the membrane and due to the velocity of the water, a hydrodynamic water pressure will develop. This water pressure inflates the membrane and requires sufficient fixation in order to prevent the membrane from being torn out and e.g. clogging intake structures.

Figure 3: Two of 18 cars found during the draw-down of 8.6 km section of the Innkanal after 19 years, Germany, 2003

The tearing out of the geomembrane must be prevented for any loading case through appropriate design of the fixation.

2.2 *Design*

2.2.1 *Load*

For a conservative design of the fixation of geomembranes the loading case 'damage of a membrane perpendicular to the direction of flow, from one fixation profile to the next' (Figure 4) must be taken into account.

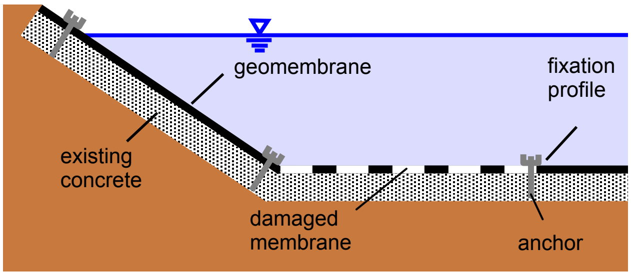

Figure 4: Example of Damage of geomembrane in bottom area between two fixation frofiles

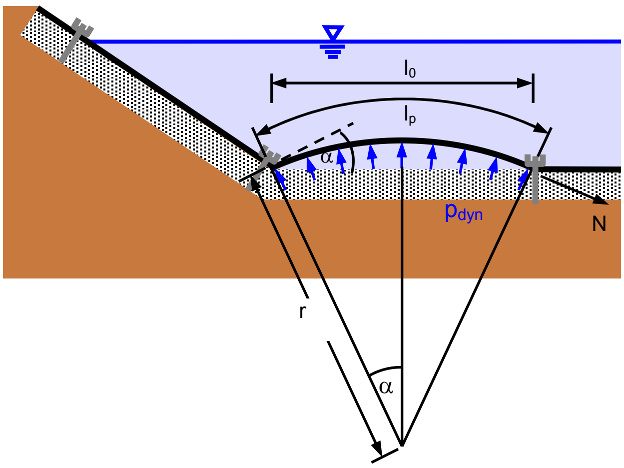

Figure 5: Deformation of membrane due to hydrodynamic pressure

In this case the hydrodynamic water pressure, which develops under the membrane, can be calculated as follows

$$p_{dyn} = \rho \cdot g \cdot \frac{v^2}{2g} = \frac{1}{2} \rho \cdot v^2 \quad (1)$$

where ρ = density of water and v = mean velocity of the water. According to the geometry the normal force N is:

$$N = p_{dyn} \cdot r \quad (2)$$

with r = radius of the deformed memnrane.

Under the use of the material's law the following equation can be applied

$$N = \sigma \cdot A = \varepsilon \cdot EA = \frac{l_p - l_0}{l_0} \cdot EA \quad (3)$$

with σ = stress, ε = elongation, E = modulus of elasticity, A = cross-sectional area and l_p, l_0 = length of the membrane (Figure 5). With the simplification of assuming a constant modulus of elasticity, the load onto the fixation is calculated by iteration.

2.2.2 *Fixation*

To carry the now known loads, the fixation must be designed. For the materials which are in use here, like PVC, HDPE and FPP however, there presently are no guidelines available for anchor-steel-profile fixation systems.

3 INVESTIGATIONS

The investigations at the Institute of Hydraulic and Water Resources Engineering of the Technische Universität München are being carried out in two separate parts. On one hand the possibly occurring loads should be defined and on the other hand the efficiency of the fixation systems is being studied.

3.1 *Tests in the Canal: Loads*

A 75 long and 4 m wide canal in the laboratory has been well instrumented and lined with geomembranes. During the tests a discharge of up to 4 m³/s can produce flow rates of about 1 m/s. A prepared cut in the bottom of the membrane can be opened and the actual forces occurring at the fixations can be measured in kN/m. Water pressure cells record the hydrodynamic pressure below the membrane. Water level gauges and a propeller observe the stream flow and a supersonic bottom profiler measures the deformation of the membrane (Figure 6).

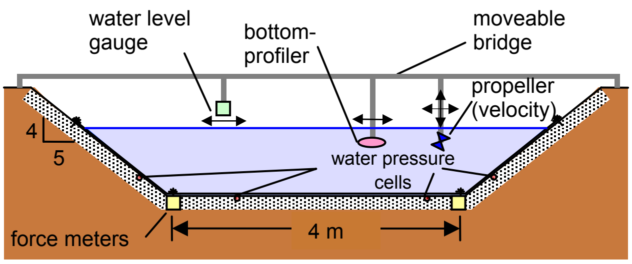

Figure 6: Instrumentation of canal in laboratory, cross-section

The first general question was whether the membrane behaves in the predicted way and develops a barrel shaped deformation. Figure 7 shows the canal lined with a PVC-geocomposite and a discharge of about 1 m/s. A cut had been prepared and was opened during the test (Figure 7, bottom). As presumed the water flew underneath the membrane, filling it from the end of the lined section up till the area of the cut. Slight dynamical processes have been observed, but in general static conditions established.

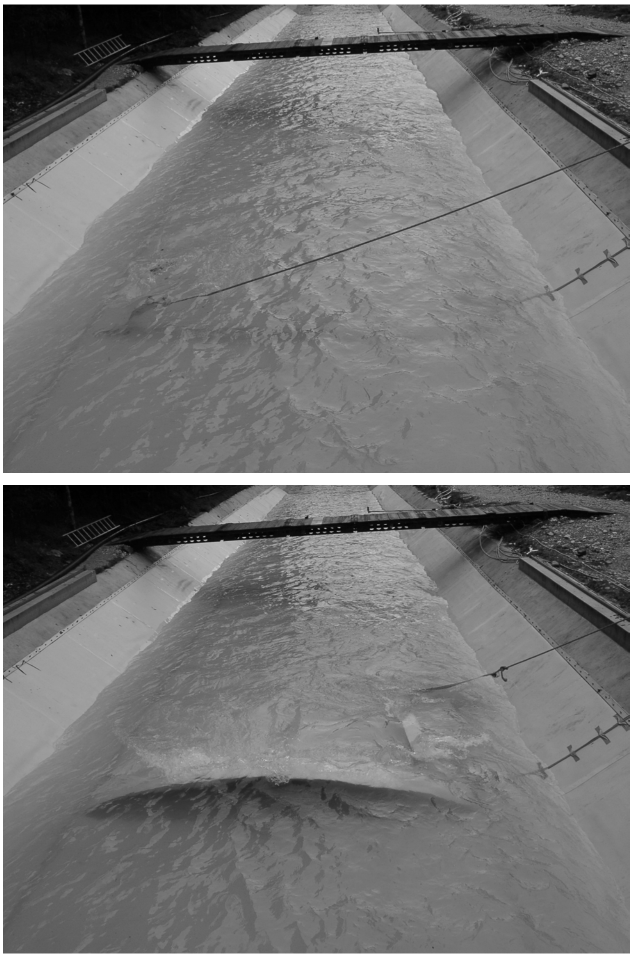

Figure 7: Geomembrane before and after opening of cut

The recorded data allows a comparison of the calculated loads onto the fixations with the actual ones.

3.1.1 *HDPE geomembrane*

For the first test series a 2.5 mm HDPE geomembrane was installed. During the maximum discharge of 2 m³/s during that test a mean water velocity of 1 m/s was measured. After the opening of the 4 m-cut the membrane inflated and the force meter in the vicinity displayed about 11 kN/m (Figure 8).

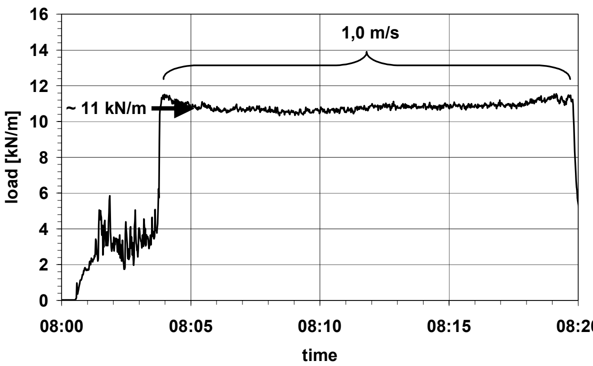

Figure 8: Reading of anchor-load (HDPE membrane)

The calculation according to chapter 2.2.1 and presuming a modulus of elasticity of 670 MN/m² and taking into account the difference of water level in front and behind the cut of 8 cm results into a load of 10.6 kN/m, which matches the measured value of 11 kN/m very well.

3.1.2 *PVC geocomposite*

For the second testing series the HDPE membrane was exchanged by a 2.5 mm PVC geocomposite. During the maximum discharge of 4 m³/s the mean velocity of the water was 0.7 m/s. The velocity is lower than during the HDPE-test, because the softer PVC membrane inflates more and the reduction of the area of flow results in a higher water level at the same discharge. The load reached about 8 kN/m (Figure 9).

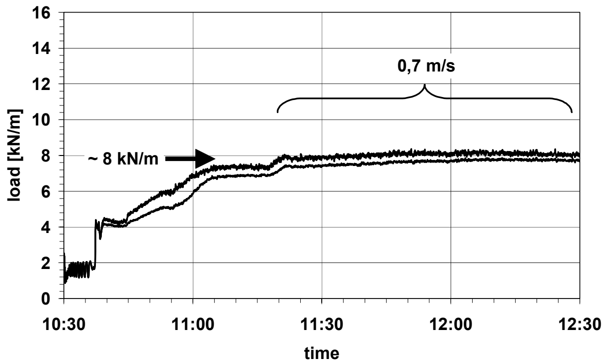

Figure 9: Two readings of anchor-load (PVC-geocomposite)

The calculation for the PVC test, taking into account a modulus of elasticity of 50 MN/m² and a drop in water level of 17.5 cm, results in a load of 7.0 kN/m, which is in an the equal order as the measured value of 8 kN/m during the tests.

3.1.3 *FPP geomembrane*

A third test was carried out with a 2.5 mm FPP geomembrane. The maximum discharge of 4 m³/s resulted in an average velocity of 1 m/s and a load of about 8 kN/m (Figure 10).
The calculation with a modulus of elasticity of 130 MN/m² and a drop in water level of 7.0 cm predicts a load of 6.5 kN/m, a little less than the measured value of 8 kN/m.

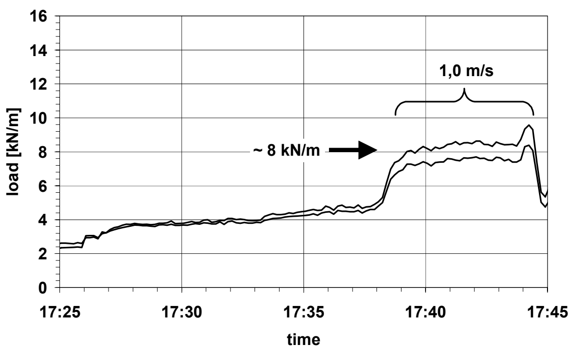

Figure 10: Two readings of anchor-load (FPP-geomembrane)

3.1.4 *Conclusion of the Canal Tests*

The proposed calculation in chapter 2.2.1 meets reality well. The measurement for HDPE complies exactly with the calculation, in the case of PVC 14 % less have been calculated, for FPP 20 % less.

3.2 *Test on Stand: Fixation*

Only when the design loads are known the fixation can be designed. As there are no design criteria defined for the fastening of geomembranes with an anchor-steel bar system, a testing unit has been designed and built in the laboratory in Obernach (Figure 11 and Figure 12).

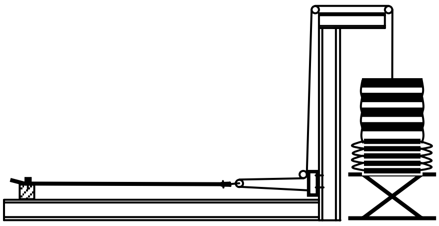

Figure 11: Drawing of testing unit

The stand is designed, so that geomembrane-probes of 1 or 2 meters in width can be loaded with up to 31 kN. The concrete probe can be replaced, so that different subgrades with a variable roughness and diverse anchor diameters and spacings can be used. The load is applied via a steel cable and deflection roller system by weights. The weights are placed on a lifting table which is lowered in order to hang up each weight separately – attaining a force controlled loading close to reality.

In a first step the fixation systems, which had been used in the canal tests in the laboratory, have been tested. The systems consisted of an anchor-steel profile system, partly with anchors Ø = 8 mm and a spacing of 20 cm and partly with anchors Ø = 12 mm and a spacing of 25 cm, both with 6/60 mm steel profiles. The tests were carried out up to a point beyond serviceability (Figure 12, right). The aim was to determine the portion of the load being carried by friction between the membrane and the concrete and the steel profile, and the part carried by the contact between the membrane and the anchor directly. For this reason each test was carried out with a membrane with slits in it (friction only, Figure 13 left), with untightened screws (anchors only, Figure 13 middle) and with regular fixation (Figure 13 right).

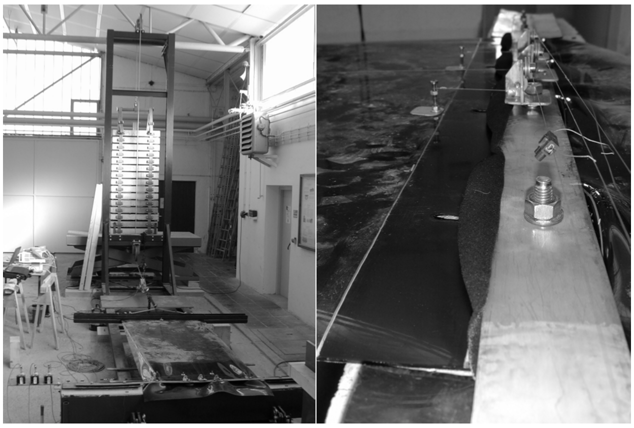

Figure 12: Picture of testing stand; probe

Figure 14 and Figure 15 show the diagrams with two fixation types. The results are very similar, except that a closer spacing of the anchors (Figure 14) improves the part of the load carried by the "anchor only". Obviously the load carried by a proper fixation cannot be defined as the superposition of "anchors only" and "friction only".

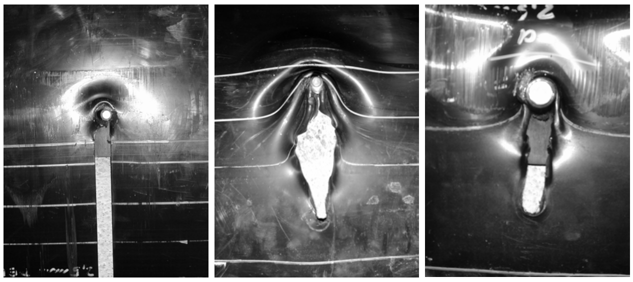

Figure 13: Membrane after test: friction only, anchor only, anchor + friction

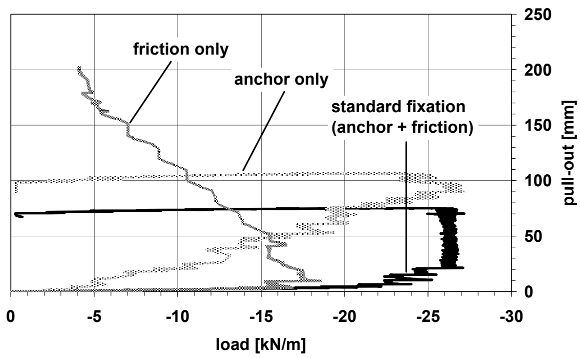

Figure 14: Pull-out test with HDPE, anchor Ø = 8 mm, d = 20 mm

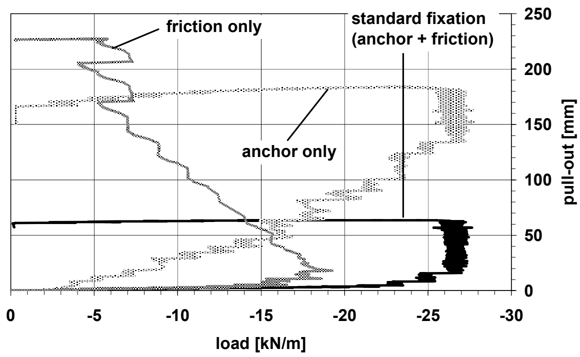

Figure 15: Pull-out test with HDPE, anchor Ø = 12 mm, d = 25 mm

4 PROSPECTS

The loads correlate with the size of the cut, thus could be reduced, if the damage of the membrane is smaller than the ones tested.

The testing stand can be used to check or improve any desired fixation

5 REFERENCE

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