Acta Technica 62 (2017), No. 5A, 115–122

Filtration and hydraulic permeability of soilbag structures: experimental and calculation results

ZHOU Bo[2,3], WANG Hong-yu[2], WANG Xiao-dong[2], JI Jing-hui[2]

Abstract. Farmland drainage ditch slumps restrict recirculation of water resources in the irrigation area of Ningxia in China. To address this problem, soilbags are applied for farmland drainage ditch slope protection, because of their double efficacy in solid slope collapse prevention and water purification. Filtration and permeability performance of soilbag technology was studied using a clogging and permeability test, which was performed with gradient ratio and penetration test instruments. Different hydraulic gradients and building structures were tested. The clogging test shows that a rapid increase in the hydraulic gradient can decrease the permeability coefficient of the soil-geotextiles system by 77.99%, lower filtration, reduce soil content per unit area, and increase leakage. The influence of the size of the soilbag (two different sizes were tested) and their arrangement was investigated. Penetration tests demonstrated that an overlapped structure with staggered joints significantly reduced the overall permeability coefficient. With a smaller bag size, the permeability coefficient of structure was larger. The permeability coefficient ratio with different bag arrangements was as high as 90.75%. The results indicate that flow through a soilbag structure is governed solely by the gaps between neighboring containers and that flow through the soil in the containers can be neglected. The arrangement of soilbags thus strongly affects the permeability of the structure. Combining these results with a masonry plan for slope protection in engineering applications with soilbags, the equivalent permeability coefficient of the soilbag slope protection increased 100% and seepage pressure decreased 50%, which effectively improved the stability of the slope protection.

Key words. Soilbag, filtration characteristic, permeability coefficient, gradient ratio, seepage pressure.

[1]Acknowledgement - This work was supported by the national natural science fund project (41462010); Ningxia college scientific research project (NGY2016244); Ningxia university graduate student innovation project funding (GIP201635).

[2]Workshop 1 - College of Civil and Hydraulic Engineering ,Ningxia University, Yinchuan 750021, China

[3]Workshop 2 - Yinchuan Energy Institute, Ningxia, Yinchuan 750105, China

1. Introduction

Recently, soilbag techniques have been rapidly developing in the field of geosynthetic materials research and application. Soilbags are made of soil, sand, gravel, construction waste, or other materials filled into geotextile bags. At present,soilbag technology has been widely applied in civil engineering, water conservancy, port maintenance, road traffic, and other large projects(Koerner, 2000). Guanglu Li's research group applied polypropylene geotextile bags in terraced field ridges and walls and studied the economic benefit, failure mode and stability of this method(Bai et al., 2014; Li et al., 2015). However, the application of soilbags in agricultural drainage channel regulation and in farmland drainage ditch slope reinforcement has not been well studied(Korkut et al., 2007; Aysha et al., 2013a; Aysha et al., 2013b). In northwest China, where drainage of excess water in farmland irrigation areas is a common issue, the largest problem comes from seepage deformation caused by the collapse of slope and channel flow resulting from scour and alternating wet-dry and freezing-thawing cycles. Soilbags have the dual functions of filtration for drainage and protection through reinforcement. Other research shows that soilbags can alleviate frost heave deformation (Li et al., 2013). At the same time, the biggest problems are seepage deformation caused by slope collapse and channel flow that cause slope scouring, alternating wet-dry and freezing-thawing cycles, and the influence of natural environment factors. In soilbag use, clogging is the most important criteria for ensuring that the geotextiles can be used long-term. To determine whether geotextiles meet the desired clogging criteria, a gradient ratio test is needed. Tang et al. (2013) used gradient ratio tests for filtration parameters along with the change in tensile strain of the geotextiles. Chen et al. (2006) simulated fine-grained soil particles in an arch structure for a stability filtration test, demonstrating that the use of large-aperture geotextile filters reduced siltation. Hu et al. (2002) studied the operating period of geotextiles in an integrated filtration test as part of research for the Shenzhen River regulation project, which provided strength loss data during long-term intensity attenuation. Hsin-Yu et al. (2001)obtained geotextile gradient ratios and permeability coefficients using a gradient ratio test. Therefore, siltation research on the filtration ability of a soil-fabric system is particularly important.The permeability coefficient is an important parameter in the calculation and analysis of fixed slope stability and seepage. For bank revetment structures, permeability is proportional to stability (Recio, 2008). Very high permeability and friction coefficients were found between layers(Recio, 2008) when studying the permeability coefficient of soilbags in different arrangements.

In this paper, soilbag technology was used for farmland drainage ditch slope protection in the irrigation area of Ningxia province in China. The permeability coefficient and the filtration ability of the entire structure were assessed.

2. Materials and Methods

2.1. Soil and geotextile

Soil was taken from the ShengLi ditch slope in Qingtongxia Yesheng town of Ningxia. The physical properties for the soil samples are given in Table 1. For the experiments, black polypropylene non-woven fabric geotextiles from the Shandong Yizheng Haicheng Nonwoven Material Corporation were used.

Table 1. Physical properties of test soils

Soil particle composition / %				Density	LI Test / %			Permeability coefficient
Less than 0.075 mm	0.075–0.315 mm	0.315–1 mm	1–2 mm	Natural Density/ g cm^{-3}	W_L /%	W_P /%	I_P /%	I_L /%
44.63	33.95	15.35	6.07	1.717	30.5	16.3	14.2	4.63×10^{-5}

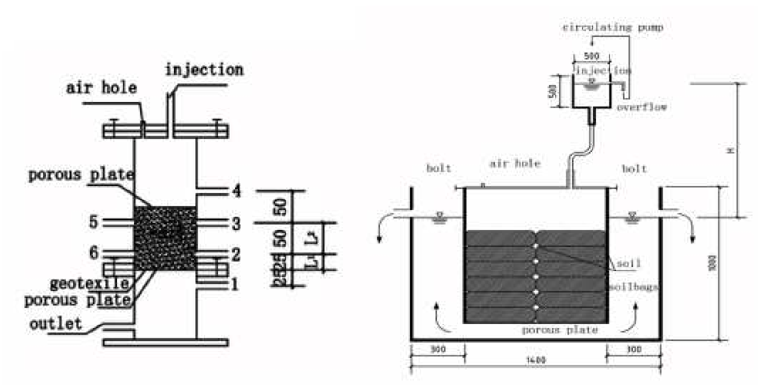
2.2. Test method and instruments

2.2.1. Soil-fabric system for the filtration test Filtration tests were performed according to standard test procedures. The gradient ratio test apparatus was constructed as shown in Figure 1a, with an instrument section of 100 mm by 100 mm. Upper and lower containers were included, with a screw for clamping the geotextile in place. Six piezometric tubes were fixed on the measuring pressure plate, with a measurement scale of 1 mm. The water injection and outlet included an overflow device to ensure constant head. Once the test instrument was ready, the soaked geotextiles were placed in the instrument. The soil was divided evenly into four layers in the instrument, according to the standard dry density of 1.71 g/cm^3. Each layer was tapped with a wooden hammer to 25 mm thickness. Permeable slabs supported the geotextiles and were placed above the filled soil. Before the test, the piezometric tubes were closed at locations 1-6, with the water supply entering slowly from the bottom of the instrument. When the water level reached 5 mm above the soil, the system was soaked at saturation for 5 h. Water was then injected from above the hole, and the water level regulated. Air holes were closed after venting gas, and piezometric tubes 1-6 were opened. After the readings stabilized, measurements were taken every hour for 24 hours. The total head was set to 40 cm, 70 cm, and 110 cm, with corresponding hydraulic gradients of i = 4, 7, and 11. Two hydraulic gradient change methods were investigated. In the first, i was gradually increased to 4, 7, or 11, while in the second, i increased directly to 11. The lower container in the test instrument allowed for collection of the seepage water for soil content analysis after drying and weighing. After each test, the fabric was removed, dried, and weighed to analyze the surface soil content and internal soil mass.

GR refers to the hydraulic gradient ratio of geotextile specimens to above 25 mm and of soil sample fabric from 25 to 75 mm in the experiment, as calculated by Formula (1). A larger GR indicates a worse fabric filter, as it would experience easy clogging.

$$\tau = \tau_0 \left(1/2 - \xi\right) , \quad (1)$$

where $H_{1-2}$is the water head in the piezometric tube between 1 and 2 (mm); H_{2-3} is the water head between 2 and 3 (mm); L_1 and L_2 are the seepage path lengths (mm); and δ is the geotextile thickness (mm).This test determines the soil-geotextile filter properties of permeability coefficient, gradient ratio (GR), soil content per unit area (μ), and soil quantity.



(a) Apparatus for gradient ratio tests (b) Apparatus for permeability tests

Fig. 1. Apparatus for gradient ratio tests(units:mm)

2.2.2. Determination of permeability coefficients for soilbag structures Two soilbag sizes were made using the black polypropylene: 30 × 40 × 10 cm and 20 × 30 × 8 cm. In order to fully utilize the bag body tension, each bag was filled 80% at a filling density of 1.71 g/cm^3.

The penetration test instrument was constructed of a large test box with constant head permeability. The box body size was 140 × 60 × 140 cm (Figure 1b). To decrease the side wall effect, the soilbag contact surface was treated with a petroleum oil filling and compacting process. The soilbag wall structure consisted of a homogeneous porous medium. The seepage coefficient of permeability from Darcy's law was used to solve for k, as shown in Formula (2).

$$\mathrm{k} = \frac{QL}{HA} \quad (2)$$

where Q is the seepage discharge (cm^{3}s^{-1}); A is the soilbag wall cross sectional area (cm^2); H is the head (cm); and L is the soilbag wall height (cm);

To study the influence of different bags sizes and arrangements on the permeability coefficient, tests were performed at different hydraulic gradients. Permeability coefficients were measured for eight soilbag configurations, with two different soilbag sizes, staggered or aligned arrangements, and varying seepage path lengths (soilbag wall heights).

3. Results and Discussion

3.1. Permeability coefficients and gradient ratios for soil-fabric systems

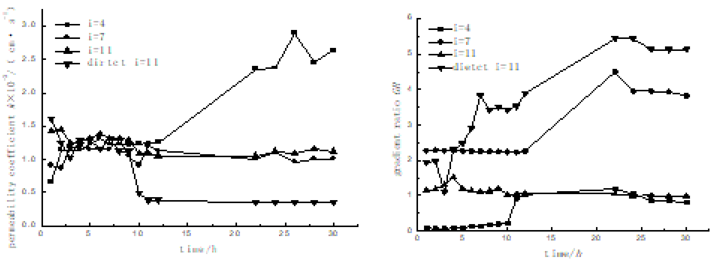
As shown in Figure 2a, the permeability coefficients of the soil-fabric systems with different hydraulic gradients changed with time. At the hydraulic gradient of $i = 4$, the permeability coefficient increased slowly, and as i increased from 7 to 11, the permeability coefficient gradually stabilized, indicating that the fabric and soil particles gradually developed a filter structure. When i increased directly to 11, the permeability coefficient of the system decreased by 77.99%. This decrease was caused by the sudden increase in seepage flow, which caused the soil pressure to increase and led to gradual movement and rearrangement of adjacent soil. Local soil particles then formed through compaction, which caused the permeability coefficient for the entire system to decrease with time. At the same time, fine particles at the bottom entered the fabric with a certain seepage force. Fine particles trapped within the fabric pore structure then caused the fabric permeability coefficient to decrease.

As shown in Figure 2b, the GR of the soil-fabric systems with different hydraulic gradients changed with time. At the hydraulic gradient of $i = 4$, the GR increased from 0.055 to 1.19, stabilizing at 0.8 after 24 h. At the beginning of the test, there was more erosion of fine particle soil, causing the filtration performance to reduce. After 20 h of filtration performance enhancement, the fabric filter layer and soil particles formed an arch structure, leading to a stable filter system that ensured smooth seepage. After this stabilization, large losses of soil particles did not happen again. At $i = 7$, during the early stage of the experiment, the GR was < 3, but after 16 h, GR increased to 4.5 and filtration performance worsened. This was mainly because soil particles entered the fabric pore structure. Reduction of the effective aperture and disorder of the non-woven fiber arrangement caused the fabric to be more likely to intercept soil particles. When i increased gradually to 11, the GR tended to be stable. When i increased directly to 11, the GR filtration performance was reduced after 6 h, indicating that the hydraulic gradient increased directly in a short period of time and thus reduced the fabric siltation performance.

3.2. Permeability coefficient of the soilbag wall

3.2.1. Permeability coefficients of soilbag walls with different layering The soilbag wall configurations used for the permeability tests are shown in Figure 3.

Note:(a)M1 Large bags lined up (b)M2 Large bags with staggered joints on top and lined up on the bottom(c)M3 Large bags with staggered joints(d)M4 Small bags on top and large bags on the bottom, both lined up (e)M5 Small bags with staggered joints on top and large bags lined up on the bottom (f)M6 Small bags on top and large bags on the bottom, all with staggered joints (g)M7 Small bags lined up(h)M8



(a) Permeability coefficient (b) *GR*

Fig. 2. Permeability coefficients and gr vs time for soil-textile systems

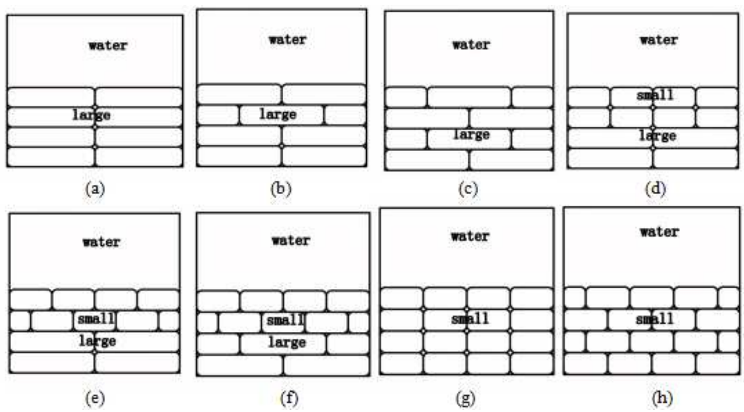


Fig. 3

Small bags with staggered joints.

The measured permeability coefficients are given in Table 2. The smallest permeability coefficient of 1.34×10^{-3} cm.s^{-1} was found for M6, which had small bags on top and large bags on the bottom with staggered joints. The largest permeability coefficient of 1.45×10^{-2} cm.s^{-1} was found for M7, which had all small bags lined up. The value for M7 was nearly 10 times larger than that for M6, and 10^3times larger than that for undisturbed soil of 4.63×10^{-5} cm s^{-1}. The permeability coefficients values followed the order M6 $<$ M3 $<$ M8$<$ M1 $<$ M7.Experimental results indicate that wall seepage through the soilbags depends on the gaps between the bags, with more gaps causing larger permeability coefficients. The smaller bags had a larger permeability coefficient because even though the gap sizes were smaller, there were a larger number of gaps. Additionally, staggered joints with their overlapping structure reduced the permeability coefficient, since the seepage path variable length is longer and energy loss is increased. The permeability coefficients of the soilbags ranged from 1.34×10^{-3} to 1.45×10^{-2} m?s^{-1} for the different configurations, indicating that arrangement affects the permeability coefficient ratio as much as 90.75%.

Table 2. Permeability test results

Model	Head, H /cm	Hydraulic gradient, i	Flow, Q /mL?s^{-1}	Permeability Coefficient, k /cm s^{-1}	Average value of k /cm s^{-1}
M1	55 80 105	1.3 1.9 2.5	68.83 102.86 110.30	1.23×10^{-2} 1.26×10^{-2} 1.03×10^{-2}	1.17×10^{-2}
M2	55 80 105	1.6 2.4 3.1	25 35.48 41.07	3.52×10^{-3} 3.44×10^{-3} 3.03×10^{-3}	3.33×10^{-3}
M3	55 80 105	1.7 2.5 3.3	16.67 23.59 27.49	2.21×10^{-3} 2.15×10^{-3} 1.91×10^{-3}	2.09×10^{-3}
M4	55 80 105	1.3 1.9 2.4	36.66 50.29 64.36	6.53×10^{-3} 6.16×10^{-3} 6.01×10^{-3}	6.23×10^{-3}
M5	55 80 105	1.4 2 2.6	10.17 14.22 11.87	1.69×10^{-3} 1.62×10^{-3} 1.03×10^{-3}	1.45×10^{-3}
M6	55 80 105	1.3 2 2.5	8.33 9.07 17.19	1.42×10^{-3} 1.06×10^{-3} 1.53×10^{-3}	1.34×10^{-3}
M7	55 80 105	1.7 2.4 3.2	120 130.64 206.56	1.64×10^{-2} 1.23×10^{-2} 1.48×10^{-2}	1.45×10^{-2}
M8	55 80 105	1.3 1.9 2.4	30.17 42.94 52.8	5.37×10^{-3} 5.26×10^{-3} 4.93×10^{-3}	5.19×10^{-3}

Gaps between the soilbags disperse the water pressure. Although the permeability coefficients of soilbags arranged with staggered joints was lower than that for lined up joints, the staggered joints produced better interlocking, which enhanced hydraulic stability in the system. Water flow in gaps between the soilbags determines the permeability coefficient of the entire system. Larger gaps produced larger permeability coefficients, which is consistent with the research conclusions of Recio(2008). Flow is affected by different shapes and sizes in the winding channel. In a hypothetical experiment, instead of actual water flow, the hypothetical flow resistance in an arbitrary volume structure is used. The advantage of this approach is that any non-continuous flow can be analyzed as a continuous flow for theoretical exploration.

4. Conclusion

Through hydraulic gradient ratio tests of soil-soilbag systems using two different soilbag sizes and eight soilbag arrangements, the permeability coefficients were determined and the following can be concluded.

(1) When the hydraulic gradient increased directly, the permeability coefficient of the soil-fabric system decreased, *GR* increased, the filtration performance worsened.

(2) The permeability coefficient of the soil was 4.63×10^{-5}, while that of the soil-fabric was 1.02×10^{-3}, and that of the soilbag structure was 1.45×10^{-2} cm s^{-1}. The permeability mainly depended on the gaps between soilbags.

(3) The soilbag arrangement clearly affected the permeability coefficient of the structure, with values in the order M6 < M3 < M8 < M1 < M7. Smaller bags had larger permeability coefficients. The influence of the soilbag arrangement on the permeability coefficient ratio was as high as 90.75 %.

Due to the limited test conditions, this experiment makes a preliminary determination of the actual permeability coefficients for soilbag structures. This work provides a reference basis for use in the actual construction of soilbag support structures. Future experiments will continue to study the stability of soilbag slope protection during seepage for practical engineering application.

References

[1] R. M. Koerner: *Emerging and future developments of selected geosynthetic applications.* Journal of geotechnical and geoenvironmental engineering *126* (2000), No. 4, 291–306.

[2] Z. F. Bai, G. L. Li, X. Li: *Stability of terraced ridges using polypropylene geotextile bags.* Journal of Northwest A&F Univcrsity(Nat. Sci. Ed) *42* (2014), No. 4, 157–164.

[3] G. L. Li, X. Gao. X. Liu: *The main forms and stability of terraced walls build with polypropylene geotextile bags.* Applied Acoustics *20* (2015), No. 2, 201–206.

[4] R. Korkut, E. J. Martinez: *Geobag performance as scour counter measure for bridge abutments.* Journal of Hydrologic Engineering *13* (2007), No. 1, 431–439.

[5] A. Aysha, P. Gareth: *Performance of a geobag revetment I: quasi-Physical modeling.* Journal of Hydraulic Engineering *139* (2013), No. 8, 865–876.

[6] A. Aysha, P. Gareth: *Performance of a geobag revetment II: numerical modeling.* Journal of Hydraulic Engineering *139* (2013), No. 8, 877–885.

[7] Z. Li, S. H. Wang, L. J. Liu: *Experimental study of frost heave and thawing settlement of soilbags under different freeze-thaw cycles.* Rock and Soil Mechanic *34* (2013), No. 9, 2541–2545.

[8] Y. F. Zhou, Z. M. Wang: *Effect of boundray conditions on the hydraulic behavior of geotextile filtration system.* Geotextiles and Geomembranes *19* (2001), No. 7, 509–527.

[9] R. Lal: *Hydraulic permeability of structures made of geotextile sand containers:Laboratory tests and conceptual model.* Geotextiles and Geomembranes *26* (2008), No. 9, 473–487.

Received November 16, 2017