

Experimental and Numerical Study of the Effect of PET Recycling Admixtures on Pore Water Pressure and Output Discharge in Homogeneous Earth Dams

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ABSTRACT: This study analytically and experimentally investigates the leakage in homogenous earth dam (clay) reinforced by recycled PET. First, the effect of PET addition on permeability of clay in geotechnical laboratory is evaluated, according to the results of first step, a physical model of homogenous earth dam is prepared in laboratory flume, both in PETs or without PETs and measured the water height in dam body using piezometers installed on flume body and also leakage discharge was calculated. Third, phreatic line formed in the body of dam and the pore pressure of it was analyzed regarding the first and second phases. The impact of output discharge reduction on dam stability was also studied in software; PET addition impact on output discharge reduction was 23.14%. Discharge reduction lead to increase of dam stability.

Keywords: Homogenous Earth Dam, Permeability Test, Physical Model, PLAXIS, PET

ORIGINAL ARTICLE
 PII: S225204301500007-5
 Received 18 Mar. 2014
 Accepted 25 Aug. 2014
 Published 25 Jan. 2015

INTRODUCTION

Water passing through the dam body is one of the major problems of geotechnical engineers. In general, in leakage related issues, soil is considered as an integrated environment with numerous integrated pores. Therefore, leakage is inevitable; for optimization of passing discharge, leakage should be calculated accurately to totally recognize passing leakage. Calculation have significant role on stability of dam and accurate estimation of it reduces implementation costs.

An appropriate method for reducing leakage in earth dam, passing discharge and a new method for reducing it using PET recycling material are the main objectives of this study.

REVIEW OF LITERATURE

Water movement law in saturated porous environment is described by Darcy as:

$$Q=k.i.A$$

where, Q is passing water discharge, K hydraulic conductivity of soil, A, flow cross section, and I hydraulic slope, calculated as:

$$i = \frac{\partial h}{\partial s}$$

where, S is the water movement length through a porous environment. In this base, water movement in soil equation was presented by Laplace formula as follow:

$$k_x \frac{\delta^2 h}{\delta x^2} + k_y \frac{\delta^2 h}{\delta y^2} + k_z \frac{\delta^2 h}{\delta z^2} = 0$$

where, h is total hydraulic load in specified point. This equation is presented for heterogeneous soil

condition; in homogenous soil condition, $K_x=K_y=K_z$ and Laplace formula is as:

$$\frac{\delta^2 h}{\delta x^2} + \frac{\delta^2 h}{\delta y^2} + \frac{\delta^2 h}{\delta z^2} = 0$$

Graphic solving of this equation in two-dimension leads to two series of perpendicular lines called flow line and equipotential line. These lines form flow network. Another way of solving Laplace formula is numerical solving. Currently, a robust software pack has been offered to analyze porous medium, with basis of various numerical methods such as finite difference and finite element. In this study finite element method has been used by PLAXIS software.

Sing (2008) studied leakage process of a homogenous earth dam with heel filter using finite element method. For simplicity, he assumed an isotropic dam located on an impermeable foundation with stable leakage condition. For numerical solving of problem, SEEP-W, PLAXIS and ANSYS programs were used. Numerical analysis of piezometric pressure within a filter indicated reduction, while analytical model indicate zero equipotential line within filter; however, the result was not accurate, zero equipotential line means lack of flow within the filter while, as it's clear, water leakage from earth dam body flows from filter to outside and leakage flow is because of a gradient hydraulic and inequality of piezometric head in filter. Hence, result of finite element analysis lead to more accurate answer.

Ataei et al (2004) presented a numerical model based on boundary alkane method to analyze leakage of earth dam along with layer and shield foundation. To determine accuracy of results of model, two examples were solved for layer foundation (including two layers with different permeability) and homogenous foundation

along with shield concrete foundation, and the results were compared using MSEP software that uses finite element method to draw flow network; results of the study approved accuracy of presented model.

Nourani and Babakhani (2009) investigated leakage of Sattarkhan earth dam using meshless RBF method and leakage was estimated by calculating hydraulic potential of various points. Results of RBF modelling indicates that compared to finite difference method, this method has appropriate accuracy and calculations are less.

Orumiei and Barzegar (2007) predicted leakage for pre-construction Chirabad earth dam and offered the best way to control leakage. In this plan, foundation and body were modelled using PLAXIS software and finally according to the results, injection method was suggested for sealing alluvial foundation.

PET materials were also used in studies of Ajdarpor et al., Tarbiat Modarres University, to stabilize sandy soil and clay.

Washi (2013) analysed the use of PET in construction of earth dam with different angles to enhance stability of reinforce soft soil, and the results were influential and appropriate.

Despite these studies, there are little research to examine the effect of PET recycled material on different soils or their impact in using these material on earth dams. This study investigates the effect of PET recycling material on clay (the impact of reduction or increase of permeability on clay), as well as using clay and PET on earth dam. After studying geotechnical, experimental model and software, it was indicated that reinforcement of clay by PET has significant effect; pore pressure and phreatic line were also studied.

MATERIAL AND METHODS

Experimental equipment

Geotechnical study: first, clay and PET were studied geotechnical. In this step, clay with low adhesion is used. This soil include pasty limit of 38.16, liquid limit of 65.28, plasticity cue of 12.26 and grain density of 7.2, and placed in cl soil class. Fine grain soil gradation curve used in dam model is indicated in Figure 1.

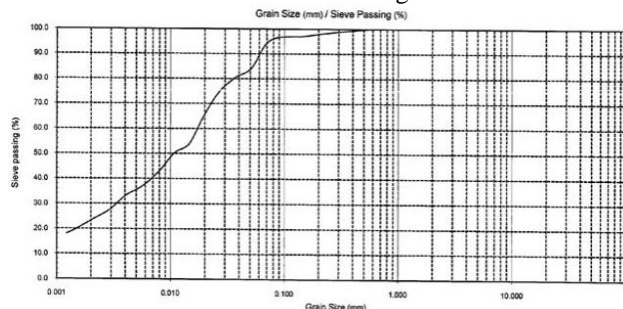


Figure 1. Dam body soil gradation curve

In this step, soil reinforcement by PET was random and PET was added to soil for about 0-1% of soil weight. According to random admixture of PET and clay (RDFR), position and angle of PET location in sample is not clear and micro math model can't be used. Therefore, macro and homogenous model was used to test density and permeability of all three samples and the results were averaged. To prepare dam body materials, first the solid was dried in oven in 115°C; after preparation the particles

were separated from each other by slamming. To prepare PET, first it was washed in sieve no. 200 to separate the particles adhesive to PET. Then, the PET is thrown in the water. Since the special weight of PET is more than special weight of water, particles mixed with PET are suspended in the water and the PET deposit at the bottom of container. After preparation of PET and clay, they are mixed with specified percentage. In first test (pure clay), after standard proctor compaction test, calculating special dry weight and optimal moist, and Reymold sample (the method of preparing suitable sample) using acquired information, the coefficient of permeability test was implemented. This information is considered as the results of control sample and other results are evaluated based on these tests. In next steps, PET was added to clay for about 0.1% of clay weight.

Permeability (test method with descending load potential) and compaction (standard proctor method) are calculated and their results are shown in Table 1.

Table 1. Results of compaction test

Pet to soil ratio	Densitometry	
	γ_{max}	ω_{opt}
0	1.684	18.71
0.1	1.689	17.51
0.2	1.685	18.31
0.3	1.682	18.67
0.4	1.687	18.36
0.5	1.687	18.87
0.6	1.666	19.71
0.7	1.676	17.58
0.8	1.669	19.32
0.9	1.688	16.56
1	1.655	21.78

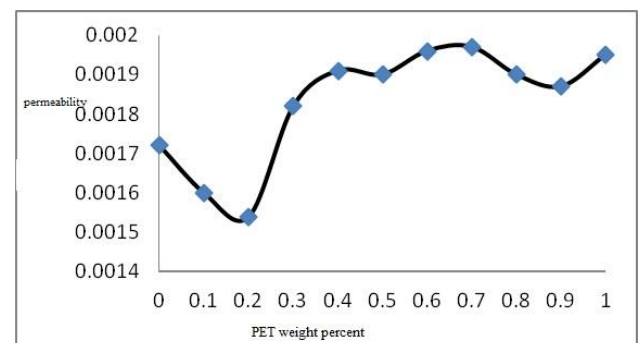


Figure 2. Permeability changes of soil consolidation

Permeability coefficient changes in different weight percentage of PET in clay are indicated in Figure 2. Review of this diagram indicates that using PET, permeability coefficient from 0.0018 cm/s for non-reinforced sample reached to 0.00157 in its normal mode. This reduction indicates that low potential influence reinforcement of soil in improvement of soil strength against permeability.

Dam construction in the flume: second step uses the results of the first phase to construct dam in two states: with and without PET in the flume. The tests have been conducted in a flume with 5 meters length, 1.5 meters height, and 1 meter width. To construct dam in both states, clay with horizontal slope of 2 and vertical slope of 1 in downstream and upstream crust critically with 60cm height, 1 m width, 30 cm crest width and 2.70 m of below base length were used. To measure pore pressure of earth

dam body, piezometers were installed to flume body, as indicated in Figure 3.



Figure 3. in vitro model of earth dam in full (left) and empty (right) reservoir. The soil used in construction of this dam is C1 type, used in total dam body

To study critical state (increase of pore pressure of dam), drainage has not been used to study the whole body in terms of flow line and pore pressure. Using PET, it achieved more than 95 compaction in soil layers with 7 cm height, 30 back and forth rounds and 30 kg roll. To measure output discharge, the control valve installed under the flume was used. To saturate pore environment of soil, the water was placed in 55 cm height for 5 days and then pore pressure and output discharge were measured in two states.

Modeling: in third step, modeling of finite element of dam in PLAXIS software, the earth dam was totally homogenous and analyzed with explored results of soil mechanic laboratory in both with and without PET condition to compare the achieved result and review the effect of PET on dam body and results of analysis. Characteristics of earth dam body before and after adding PET, and also characteristics of substrate soil are presented in Tables 3, 4, and 5.

Table 3. characteristics of dam body soil before using PET in PLAXIS software

Application	Sign	Value	Unit
Material type	-	MC	-
Material behavior	-	Drained	-
Special weight of soil	γ_{unsat}	20	KN/m ³
Special weight of saturation	γ_{sat}	20.62	KN/m ³
Permeability coefficient in direction X	K_x	0.027	m/day
Permeability coefficient in direction Y	K_y	0.027	m/day
Young model	E_{ref}	35000	KN/m ³
Poisson ratio	ν	0.3	-

Table 4. characteristics of dam body soil after using PET in PLAXIS software

Application	Sign	Value	Unit
Material type	-	MC	-
Material behavior	-	Drained	-
Special weight of soil	γ_{unsat}	20	KN/m ³
Special weight of saturation	γ_{sat}	20.62	KN/m ³
Permeability coefficient in direction X	K_x	0.020	m/day
Permeability coefficient in direction Y	K_y	0.020	m/day
Young model	E_{ref}	35000	KN/m ³
Poisson ratio	ν	0.3	-

Table 5. characteristics of substrate soil of dam in PLAXIS software

Application	Sign	Value	Unit
Material type	-	MC	-
Material behavior	-	Drained	-
Special weight of soil	γ_{unsat}	18	KN/m ³
Special weight of saturation	γ_{sat}	20	KN/m ³
Permeability coefficient in direction X	K_x	0.080	m/day
Permeability coefficient in direction Y	K_y	0.080	m/day
Young model	E_{ref}	35000	KN/m ³

RESULTS AND DISCUSSION

Discretization of dam model: this section considers modeling and numerical analysis of model in previous section using finite element numerical model and PLAXIS 2D software. Discretization criteria of this software are Moreclomb criteria. Dimensions of model are in accordance with dimensions prepared in soil mechanic laboratory. For soil mass modeling, the dimension of work surface is 5.3 m of X positive, and 1 m in Y positive. Position and dimensions of the model are indicated in Figure 4.

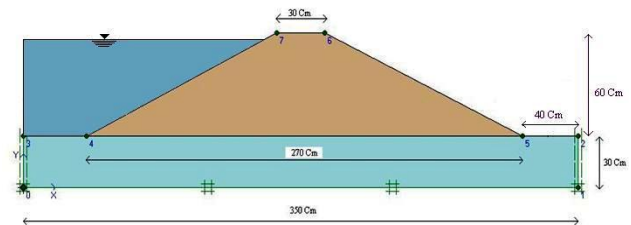


Figure 4. Under study dam

After allocation of mechanical and geometrical parameters and behavior models of substrate and dam mass, meshed was used for numerical analysis of finite element, as shown in Figure 5.

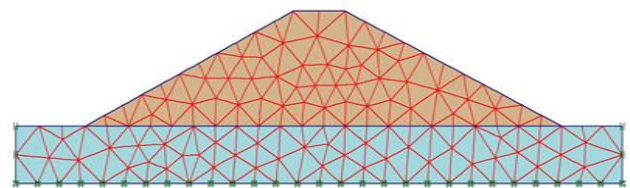


Figure 5. Meshed dam

Applying boundary condition

After meshing, finite element modelling is completed, and the boundary condition should be applied before calculation. This is to solve the model to achieve primary balance and acquiring primary condition before calculations. Pore pressure, water height and output discharge, analyzed in steps 2 and 3, are indicated as follow along with cavity pressure and phreatic line. Pore pressure reduction is between 5% - 10%.

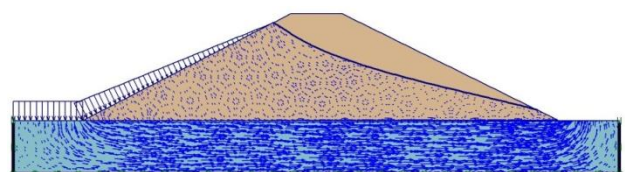


Figure 6. Cavity pressure and phreatic line

Table 6. pore pressure and water height in body of dam

X (m)	Y (m)	Pore pressure before addition of PET [kN/m ²]	Pore pressure after addition of PET [kN/m ²]	Water height in dam body (m)
0.41	0.30	5.44	5.28	0.84
0.45	0.31	5.29	5.23	0.84
0.48	0.32	5.16	4.95	0.84
0.51	0.34	4.97	4.73	0.84
0.53	0.30	5.23	5.02	0.82
0.54	0.32	5.05	5.05	0.83
0.55	0.31	5.13	4.62	0.82
0.58	0.31	5.09	4.68	0.82
0.60	0.30	5.13	4.67	0.81
0.63	0.30	5.09	4.78	0.81
0.66	0.30	5.04	4.84	0.80
0.69	0.30	5.00	4.16	0.80
0.71	0.31	4.90	4.60	0.80
0.74	0.31	4.857	4.43	0.80
0.77	0.35	4.55	4.32	0.80
0.78	0.31	4.77	4.68	0.79
0.81	0.33	4.59	4.26	0.79
0.85	0.46	3.68	3.42	0.83
0.89	0.34	4.40	4.00	0.78
0.82	3.21	3.49	0.47	0.90
0.82	3.36	3.54	0.46	0.92
0.84	2.72	2.90	0.55	0.94
0.80	3.38	3.72	0.43	0.96
0.81	3.10	3.45	0.46	0.98
0.78	3.61	3.84	0.40	1.0
0.74	3.99	4.38	0.30	1.10
0.84	1.54	1.64	0.68	1.17
0.84	1.24	1.30	0.70	1.27
0.83	0.92	0.92	0.74	1.35
0.81	0.54	0.54	0.75	1.48
0.88	0.00	0.00	0.88	1.58
0.60	2.95	2.95	0.30	1.88
0.59	2.65	2.88	0.30	1.91
0.57	2.46	2.67	0.30	2
0.57	1.92	2.04	0.36	2.06
0.54	2.15	2.37	0.30	2.16
0.52	2.05	2.15	0.30	2.26
0.50	1.82	1.98	0.30	2.35
0.47	1.32	1.42	0.33	2.49
0.45	1.26	1.37	0.31	2.58
0.42	0.92	0.98	0.32	2.74
0.38	0.69	0.77	0.30	2.91
0.35	0.49	0.52	0.30	3.01
0.35	0.06	0.06	0.34	3.04
0.34	0.31	0.31	0.31	3.05
0.34	0.17	0.18	0.32	3.06
0.33	0.19	0.21	0.31	3.09
0.32	0.23	0.25	0.30	3.10

The output discharges before and after addition of PET is presented in Table 7.

Table 7. the effect of PET on output discharge

The effect of PET (%)	After addition	Before addition
+23.14	0.000475	0.000618

CONCLUSION

1. Soil reinforcement using PET leads to reduction of output discharge about 23.14%
2. Using PET in earth dam body (clay reinforcement) reduces pore pressure about 5-10%.
3. Appropriate amount of PET in clay according to sustainability condition is 0.3% of clay weight.
4. Application of PET reduces this material in environment and benefits environment.

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