ONE-DIMENSIONAL UPWARD SEEPAGE TESTS ON GAP-GRADED COHESIONLESS SOIL

東京工業大学　学生会員　○柯琳
東京工業大学　正会員　　高橋章浩
東京工業大学　正会員　　関栄

1. INTRODUCTION

Seepage-induced erosion resulting from soil particle migration is observed widely. It is the phenomenon, namely “suffusion”, that the fine particles eroded through the voids between the larger particles by seepage flow leaving an intact coarse skeleton. The gap-graded cohesionless soil is vulnerable to suffusion due to its deficiency in certain particle size.

The primary purpose of this paper is to evaluate the hydrological behavior of gap-graded cohensionless soil suffered from one-dimensional seepage flow. The hydraulic conditions which trigger suffusion with specific reference to the influence of fine particle content, relative density and hydraulic gradient were researched. A multi-stage test procedure was developed to assess the condition necessary to trigger the suffusion.

2. TEST SPECIMENS

Those soils with namely “finer fraction” and “coarse fraction”, is vulnerable to erosion. The mixtures of two different types of Silica sand, No.3 and No.8 were used. With larger particle size, the No.3 sand works as the coarse skeleton while the fine No.8 sand is the erodible fine particles. Four soil mixtures are taken as test sands, which are 25%, 20%, 16.7% and 14.3% (Samples A to D) of the fine content, respectively. The grain size distributions of the sands used are shown in **Fig.1**. Two different relative densities are selected for each sample, shown in **Table 1**.

3. TEST APPARATUS

Constant head seepage tests with upward water flow are performed. The main apparatus of the seepage test comprises a cylindrical seepage cell of 100mm internal diameter containing the soil sample. The upper end of the seepage cell is left open to allow for the observation of the erosion process. An overflow pipe fitted at the top part of the seepage cell allows for measurement of the rate of flow through the system. Two 10mm thick plastic rings with waterproof tape were set separately on the top and at the bottom of the soil sample to prevent the formation of large seepage channels between the soil and side wall. The 2mm single-sized glass marbles at the bottom of 170mm thick soil samples serve to break up the incoming flow to ensure uniform water flow on the soil sample. Nonwoven textile is put at the bottom of soil specimen to avoid downward fine particle loss. Water pressures within the soil sample are measured by four stand pipes at four different depths of the soil sample: 120mm, 175mm, 205mm and 265mm from the bottom of the test sample. The constant water head tank supplying water to the system can control the hydraulic gradient across the soil specimen. A schematic diagram of the seepage test apparatus are shown in the **Fig.2**.

4. SPECIMEN PREPARATION

To prevent the segregation of the two different sized particles, moist tamping method is employed (Ladd, 1978).

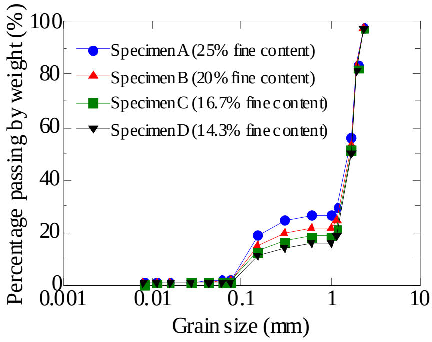

Fig. 1 Grain size distributions of four sands

Table 1 Seepage test specimens

Sample No.	Fine content	Relative density	Void ratio
A-30	25%	30%	0.63
A-60	25%	60%	0.51
B-20	20%	20%	0.69
B-60	20%	60%	0.53
C-20	16.7%	20%	0.70
C-60	16.7%	60%	0.54
D-30	14.3%	30%	0.69
D-60	14.3%	60%	0.58

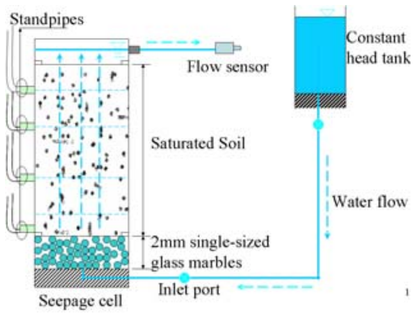

Fig.2 Test schematic diagram

Keywords: suffusion, seepage test, gap-graded soil
Contact address: 2-12-1-M1-3 Ookayama, Meguro-ku, Tokyo 152-8552. Tel: 03-5734-2593, Fax: 03-3-5734-3577

This procedure was also proved effective in obtaining a homogeneous soil condition. The specimen is prepared Layer by layer. A tamping rod is used to compact the soil to the prescribed thickness. Saturation is performed by pumping air from the specimen that is put inside of the vacuum tank. De-air water is purged into the specimen from the bottom at slow rate.

5. UPWARD SEEPAGE TESTS RESULTS

All the test specimens except Sample D-30 showed suffusion phenomenon. The typical relationship between hydraulic gradient and flow velocity (SpecimenA-60) is shown in **Fig.3**. At first, the linear relationship between hydraulic gradient and flow velocity indicates no erosion had occurred. After reaching suffusion starting hydraulic gradient, the curve slope began to change, corresponding to the first observation of a small "dancing-like" movement of fine particles. The soil particles were moved by the seepage force along the pore channels. When the critical hydraulic gradient was reached, the "heaving" phenomenon occurs.

The suffusion directly leads to the increasing of porosity, which can be inferred from the post test grading. Thus the hydraulic conductivity will also vary during this process. The discussion is based on the assumption that Darcy's law is applicable in this test. **Fig.4** shows the relationship between average hydraulic gradient and local hydraulic conductivity of Specimen A-60. Before suffusion, the hydraulic conductivity is basically constant irrespective of the hydraulic gradient. When the suffusion starting hydraulic gradient is reached, with a number of fine particles being rushed out due to erosion, the hydraulic conductivity obviously increases.

By comparing the suffusion starting hydraulic gradient among different fine contents, it is found the less the fine content leads to a higher suffusion starting hydraulic gradient. The higher relative density for the same fine content specimen leads to a higher erosion starting hydraulic gradient.

For specimen A-60, B-60 and C-60, two different hydraulic gradients larger than suffusion starting hydraulic gradient are considered to find its influence on fine particle loss. Any fine particles loss could be indicated by a change in the grain size distribution curve, shown in **Fig.5**. A graphical technique proposed by Kenney and Lau (1985) can be used to assess the fraction of eroded fine particles. The results are shown in the **Tables 2~3**. There is a general trend that the higher the average hydraulic gradient is, the higher the fine particle loss is.

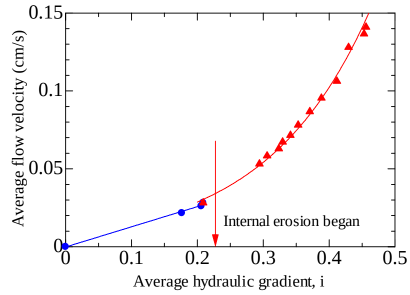

Fig.3 Hydraulic gradient Vs. flow velocity

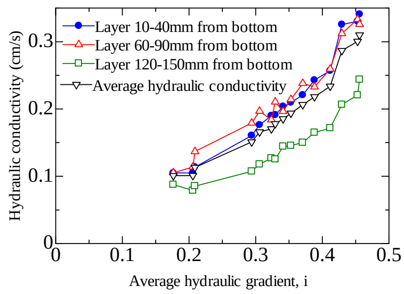

Fig.4 Local hydraulic conductivity variance

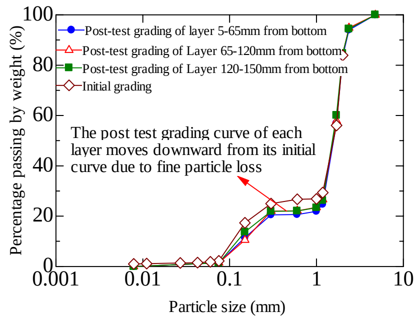

Fig.5 Particle size distribution curve along the depth

Table 2 SpecimenA-60

Hydraulic gradient	0.45	0.51
Average Fine particles loss (%)	3.11	3.38

Table 3 SpecimenB-60

Hydraulic gradient	0.32	0.41
Average Fine particles loss (%)	1.91	2.01

6. CONCLUSIONS

The upward flow seepage tests at constant water head were performed to create suffusion condition, the soils experiencing seepage-induced migration of fine particles. Before suffusion, the relationship between average hydraulic gradient and flow velocity is a linear line through origin. After onset of erosion, due to the effective porosity change, the relationship is no longer linear. The hydraulic conductivity of soils increases with progress of the suffusion. The higher average hydraulic gradient leads to a higher fine particle loss.

REFERENCES

Kenney and Lau (1985): Internal stability of granular filters. Can. Geotech. J., 22, 215~225

Ladd, R.S. (1978): Preparing test specimens using undercompaction. Geotechnical Testing J., 1, No.1, 16~23