# Study on Seepage Characteristics of Soil-rock Mixture Considering the Influence of Gap Grading Conditions

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**Abstract.** The seepage action leads to a significant loss of fine particles in soil-rock mixtures, which is the primary reason for the seepage failure of hydraulic structures. Existing research mainly focuses on the comprehensive effects of varying fine particle content and confining pressure on the seepage characteristics of soil-rock mixtures, with little attention given to the evolutionary characteristics of seepage under different gap intervals and particle size continuity conditions. Based on this, this paper conducts indoor GDS triaxial permeability tests and coupled numerical simulations to study the effects of gap intervals and particle size continuity on the seepage characteristics of soil-rock mixtures. The results indicate that when the gap interval remains the same, an increase in particle size continuity inhibits the development of internal pores within the soil-rock mixture, leading to a decreasing trend in the permeability coefficient of the samples. Meanwhile, expanding the gap interval reduces the occurrence of local blockage and particle accumulation within the skeletal pores, resulting in an increase in the permeability coefficient of the samples.

**Keywords:** Soil-rock Mixture; Gap interval; Gap-graded; Seepage characteristics; Permeability coefficient

## 1 Introduction

Soil-rock mixtures, due to their heterogeneity and permeability, represent a unique yet extremely important component in hydraulic engineering. The foundation cover layer of hydraulic structures exhibits a wide particle size gradation and uneven particle distribution, and this kind of material is highly permeable, and under the action of seepage, the fine particles are taken away by the water flow and transported along the direction of seepage in the pore space of the skeleton, which leads to changes in the internal structure of the cover layer, and is prone to cause seepage damages. making it susceptible to seepage failure. Therefore, studying the seepage characteristics and influencing factors of gap-graded soil-rock mixtures is of significant scientific and engineering importance.


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Currently, numerous scholars both domestically and internationally have studied the mechanisms influencing the seepage characteristics of gap-graded soil-rock mixtures through experimental methods or numerical simulations. Zhang and Zhao et al. [1] investigated the evolutionary characteristics of internal seepage in soil-rock mixtures with different rock contents. Shafiee [2] explored the evolution patterns and physical mechanisms of seepage characteristics in soil-rock mixtures with varying stone content through triaxial permeability tests and compaction experiments. Shire and O'Sullivan et al. [3] utilized numerical simulation methods to study the performance of mixtures under different fine particle contents and varying particle size ratios between coarse and fine aggregates. Su and Dai et al. [4] investigated the characteristics and mechanisms of seepage erosion in cohesionless soils based on a coupled model. CFD-DEM is widely used as a method to simulate the microscopic seepage characteristics of fluid-solid coupling, which can be used to see the process of seepage damage development from different time scales, and reflect the microscopic characteristics through the parameters of contact force chain and coordination number, and provide a deeper understanding of the basic mechanism of seepage within the soil.

Previous studies mainly focused on univariate factors such as particle content and stress changes. In contrast, this research considers the interactions among multiple factors. By combining experiments and simulations, this study comprehensively analyzes the impact of gradation and particle size continuity on the seepage characteristics of soil-rock mixtures. This approach aims to understand the changing mechanisms during the seepage process of soil-rock mixtures, preventing severe consequences such as dam leakage and uneven settlement, which is crucial for ensuring the safe operation of engineering projects.

## 2 GDS Triaxial Test

### 2.1 Sample Material

In this experiment, remolded samples of a clay and gravel mixture were used, with the basic physical parameters shown in Table 1. The clay mineral composition was analyzed using X-ray diffraction testing techniques, which revealed that the primary components are cronstedtite, kaolinite, and a small amount of quartz. Notably, the content of cronstedtite reached as high as 57.8%, while the proportion of quartz was only 4.1%.

**Table 1.** Basic physical parameters of soil foundation

| Liquid Limit/% | Plastic Limit/% | Maximum Dry Density/$g \cdot cm^3$ | Optimum Moisture Content/% |
|---|---|---|---|
| 35.0 | 17.2 | 2.02 | 11.3 |

Before sample preparation, refer to similar studies [5]to determine the gravel threshold value as 2 mm, the maximum rock particle size in the soil-gravel mixture sample is determined to be 8 mm. Particles are sorted into five particle size groups ranging from 0.5 to 8 mm through sieving, and by adjusting combinations of the missing particle size ranges, seven groups of gap gradation are obtained. The gradation curve is shown in Figure 1. The sample has a diameter of 50 mm, a height of 100 mm, Rock content of 40%.

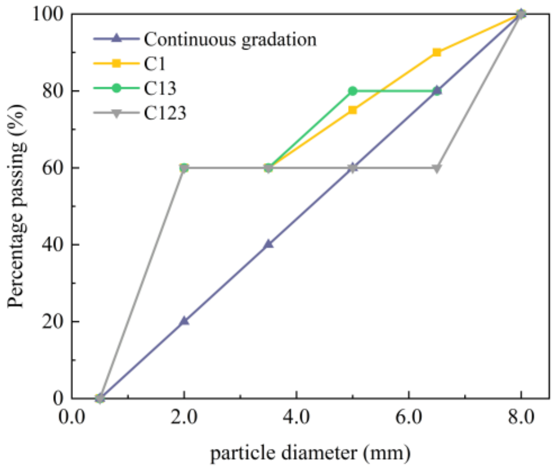


**Fig. 1.** Particle size distribution (PSD) of test samples

### 2.2 Test Equipment and Methods

The permeability test is conducted using the GDS triaxial permeability testing system. The three controllers are connected to the computer and the permeability chamber, transmitting pressure through water in the controllers.

To simplify the experiment, it is assumed that the soil-gravel mixture sample is only subjected to confining pressure and seepage pressure. The seepage pressure is set at a constant value of 0.08MPa, a confining pressure of 0.2MPa was selected. Using the GDS triaxial permeameter allows for a direct observation of the permeability coefficients of different samples, thereby enabling the analysis of the seepage characteristics of soil-rock mixtures under various gradation conditions.

### 2.3 Analysis of Test Results

Figure 2 shows the results of the permeability coefficients for seven groups of gap-graded soil-rock mixtures. From the figure, it can be observed that as the gap interval increases, the permeability coefficient of the samples also increases. This indicates that a larger gap interval results in larger internal pores and an increased occurrence of downward displacement of particles. When the gap intervals are the same, a comparison of the data in the figure reveals that with the enhancement of particle size continuity, the permeability coefficient shows a decreasing trend. This is because in a closely packed state, the porosity of the samples decreases, leading to denser pores between the soil and rock particles, thereby reducing the permeability coefficient of the samples.

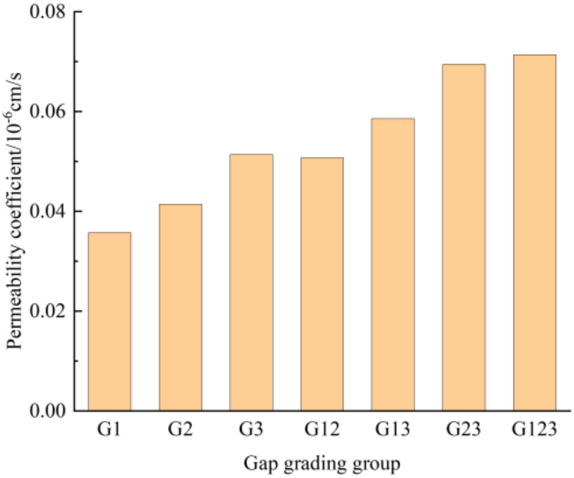


**Fig. 2.** Permeability coefficients of seven groups of samples under 0.2MPa confining pressure conditions

# 3 Numerical Modelling

CFD-DEM coupling consists of three modules: the DEM module, the CFD module, and the CFD-DEM coupling module. The DEM module generates particle models, the CFD module is responsible for generating fluid grids, and the CFD-DEM coupling module primarily facilitates the coupling of the two types of data [6]. During the coupling process, the motion of the soil particles follows Newton's second law, which is calculated to provide the force and displacement of the particles. The motion process of the infiltrating water flow in the soil provides the average velocity and pressure of the flow field by solving the momentum and continuity equations. The computed data are then sent to the coupling module to solve for the interaction forces between the soil particles and the fluid.

## 3.1 Simulation Process

The simulation process is as follows, in the initial stage, generation of the discrete element model. Preloading is then applied using FISH language to release internal stress. In the seepage simulation phase, gravity is not considered. The seepage direction is vertical downward, with the top serving as the water inlet and the bottom as the water outlet. Constant water pressures are maintained at both the top and bottom, while the confining pressure remains unchanged.

### 3.2 Results and Discussion

From Figure 3, it can be observed that after the seepage process stabilizes, the sample G123, which has the largest gap interval, exhibits the highest permeability coefficient. In contrast, the sample G1, with the smallest missing particle size range, shows the lowest permeability coefficient. The simulation results are consistent with the aforementioned experimental results. This is attributed to the increase in gap interval, which amplifies the distance between particle sizes, leading to an increased number of seepage pathways that allow particles to pass through quickly and reducing the occurrence of particle buildup.

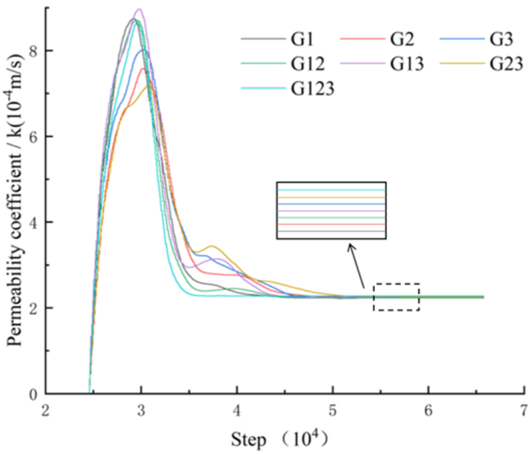


**Fig. 3.** Simulation results of the permeability coefficients for seven sets of samples

## 4 Conclusion

This study combined indoor experiments with numerical simulations to conduct infiltration tests on seven groups of samples with different gap widths, and analyzed the gap distance and gap continuity soil-rock mixtures. The main research results are as follows:

(1) The larger the gap interval of the sample, the greater the permeability coefficient. When the gap interval is smaller, the connections between particles become tighter, resulting in far fewer pore. Under seepage action, the downward displacement of particles is reduced, and the seepage pathways gradually get filled, which in turn affects and decreases the permeability coefficient.

(2) When the gap intervals are the same, an increase in continuity between particle sizes results in a decrease in the permeability coefficient. This is due to the reduction of pores within the soil-rock mixture, which leads to particle blockage and accumulation. As a result, the number of seepage channels within the samples decreases, inhibiting the development of seepage.

However, in this study, to improve computational efficiency in the simulations, angular stones were represented as spherical particles, which does not accurately reflect the impact of factors such as the angularity of stones in actual engineering. Future simulation studies could use non-spherical particles to simulate angular stones based on gradation conditions, thereby better replicating the actual shape of the stones.

## References

1. Zhang, X., M. Zhao, and K. Wang, (2022) Understanding the Influence of Rock Content on Streaming Potential Phenomenon of Soil–Rock Mixture: An Experimental Study.Sensors,22(2): p.585.
2. Shafiee, A., (2008) Permeability of compacted granule–clay mixtures. Engineering Geology, 97(3): p.199-208. https://doi.org/10.1016/j.enggeo.2008.01.002
3. Shire, T., C. O'Sullivan, and K.J. Hanley, (2016) The influence of fines content and size-ratio on the micro-scale properties of dense bimodal materials. Granular Matter,18(3): p.52. 10.1007/s10035-016-0654-9
4. Su, H., Dai, D., et al., (2023) Experimental and DEM-CFD Coupling Investigations on the Characteristics and Mechanism of Seepage Erosion for Cohesionless Soil. Water, 15(17): p. 3085.
5. Yang, X., et al., (2023) Numerical investigation of the seepage mechanism and characteristics of soil-structure interface by CFD-DEM coupling method. Computers and Geotechnics, 159: p. 105430. https://doi.org/10.1016/j.compgeo.2023.105430
6. Di Felice, R., (1994) The voidage function for fluid-particle interaction systems. International Journal of Multiphase Flow, **20**(1): p. 153-159. https://doi.org/10.1016/0301-9322(94)90011-6