Dynamic Characteristics of Gravelly Soil Mixed with Different Fine Contents

Lianjun Yang¹, Enlong Liu¹,²,³ and Xu Peng¹

¹ State Key Laboratory of Hydraulics and Mountain River Engineering, College of Water Resources and Hydropower, Sichuan University, Chengdu 610065, China
² State Key Laboratory of Frozen Soil Engineering, Northwest Institute of Eco-Environment and Resources, Chinese Academy of Sciences, Lanzhou 730000, China
³ Corresponding author
E-mail: yanglj9733@stu.scu.edu.cn, liuenlong@scu.edu.cn

Abstract. For the purpose of investigating the influence of fine contents on the dynamic properties of mixed soil, a series of triaxial tests were conducted on the gravelly soil mixed with fine contents. The confining pressures of 100, 150, and 200 kPa were selected. The dynamic triaxial tests were carried out on the samples with 0%, 20%, and 40% fine contents respectively. The axial dynamic strain and pore water pressure curves of the specimens were obtained when different excitation forces were applied. The experimental results indicated that the strength of mixed soils presented an increasing tendency with the increase of confining pressures. Under low confining pressure, the strength increased at first then decreased with the increase of fine contents, while appearing to downtrend under high confining pressure. When the excitation force was large, the axial dynamic strain and pore water pressure increased rapidly.

1. Introduction
The "5.12" Wenchuan earthquake caused large-scale geological disasters, especially sudden large-scale landslides. Many landslides caused by earthquakes were also recorded in the history of disasters abroad [1, 2]. There are many reasons for landslides. According to the situation of earthquake-initiated landslides in southwestern China, many landslides slide along the slip band composed of gravel and clay particle [3]. The initiation and movement of the landslides were closely related to the dynamic properties of the mixed soil of fine-coarse particles when seismically loaded. Therefore, studying the dynamic properties of this coarse-grained and fine-grained mixed soil is of great significance in terms of studying the mechanism of earthquake-initiated landslides.
Many studies on the dynamic characteristics of pure sand and pure clay samples have been done [4-6]. During the past decades, many researchers have carried out some experiments to study the mechanical properties of fine-coarse mixtures. Abedi and Yasrobi [7] carried out triaxial static tests on the fine particles with different specific gravity gravels under different confining pressures and dry densities, and considered that the content of fine particles had an effect on the mechanical properties of the mixed soil. Skemptom [8] proposed that the characteristics of clay-sand mixed soil were closer to that of sand when the content of fine particles was less than 25%, and the residual strength of that was almost completely determined by sliding friction between fine particles when more than 50%. Prakasha and Chandrasekaran [9] found that the pore pressure and strain development of the Indian Marine sand-clay mixture under cyclic loading were determined by the combination of effective void
ratio and cyclic stress ratio of the sand-clay mixture. Liu et al. [10] studied the soil dynamic characteristics of the mixed soil with coarse-grained sand (particle size of 1 mm-2 mm) mixed with different mass fractions of clay particles (less than 0.075 mm). The different proportion of coarse and fine particles in the soil has a great influence on the dynamic characteristics of the soil, while the study on the dynamic characteristics of the mixed soil mixed with silty in gravel is very few. In this paper, the dynamic triaxial tests were used to analyze the effect of fine particle content and confining pressure on the dynamic characteristics of saturated coarse (6-20 mm) and fine (less than 0.50 mm)-grained mixed soil, the development models of the dynamic pore pressure and axial strain of mixed soil were analyzed, and the dynamic characteristics of gravel mixed soil with fines were preliminarily discussed.

2. Specimen preparation methods
The materials used are coarse particles with a particle size of 6-20 mm (specific gravity of 2.752) and fine particles with a particle size of less than 0.50 mm (specific gravity of 2.345). The samples are prepared according to the mass ratio of fine particles to coarse particles, and the mass ratios in percentage of the components are 0:100, 20:80, and 40:60, that is, the content of fine particles is 0%, 20%, and 40%, respectively. The three groups have the corresponding dry densities of 1.605 g/cm³, 1.741 g/cm³, and 1.570 g/cm³.

The specimen is cylindrical with dimension D × H = 100 mm × 200 mm. In order to ensure the comparability of samples with different fine-grained content, all soils are divided into five layers of beating, each layer is beaten 15 times. After compaction, the layer is just 4 cm high, scraping between the layers. After the fifteenth impact of the last layer, it just fills the entire container. The specimens are then saturated by vacuum saturation, after consolidation, three groups of specimens are subjected to dynamic triaxial tests at confining pressures of 100, 150, and 200 kPa.

The testing instrument used is a GCTS system. In the dynamic triaxial cyclic test, the apparatus can automatically measure and record the axial displacement (axial strain), pore pressure, cyclic numbers of loading and specimen volume change. A sinusoidal waveform with a frequency f = 1.0 Hz to apply dynamic stress is selected, and three different excitation forces (F_e) are applied under each confining pressure, and the tests stop when the axial strain of the samples reaches 7%.

3. Test results and analysis
3.1. Pore water pressure

The specimens are subjected to dynamic cyclic triaxial tests at confining pressure of 100, 150, and 200 kPa. The mass contents of the silty in percentage are 0, 20, and 40 respectively. In order to study the effect of different excitation forces on the dynamic pore pressure of the group of specimens, the peak pore pressure of each cycle in the group is taken for a summary study.

![Figure 1](image.png)

**Figure 1.** Curves of dynamic pore pressure-cyclic numbers of loading under 100 kPa.

3.1.1. Results of consolidated confining pressure of 100 kPa. For the confining pressure of 100 kPa, the peak value of the dynamic pore pressure-cyclic numbers curves of the gravel mixed soil under the
excitation forces of 0.55, 0.60, and 0.65 kN are presented in Figure 1. In this group, with the increase of vibration time, the dynamic pore water pressure gradually increases. All the dynamic pore pressure-cyclic numbers curves show that the dynamic pore pressure increases rapidly at the initial stage, with its value approaching the confining pressure, the rising trend will gradually become slow. According to the cyclic numbers at the end of the test, all the specimens under confining pressure of 100 kPa show that the specimens are the least vulnerable to damage when the fine content is 20%, followed by the fine content group of 0%, and finally the silty content group of 40%. It’s the same as the decreasing order of dry density, which can be considered as the key to affect the dynamic strength of this group.

![Figure 2](image)

**Figure 2.** Curves of dynamic pore pressure-cyclic numbers of loading under 150 kPa.

### 3.1.2. Results of consolidated confining pressure of 150 kPa

For the confining pressure of 150 kPa, three excitation forces of 0.65, 0.75, and 0.85 kN are selected in this group. The peak value of the dynamic pore pressure-cyclic number curves of the gravel mixed soil are presented in Figure 2. It shows the same properties as the specimens under the confining pressure of 100 kPa. For a large excitation force, the dynamic pore pressure rises rapidly at the initial stage, with its value approaching the confining pressure, the rising trend of that will gradually become slow. However, when the excitation force is small (such as 0.65 kN), the curves of dynamic pore pressure-cyclic numbers are in the form of arc sine function curves before the pore pressure reaches the confining pressure value.

All the specimens under confining pressure of 150 kPa show that the number of cycles at failure is less and less as the content of silty increases. Thus it can be concluded that the content of fine-grained soil plays a decisive role in the dynamic strength of this group.

![Figure 3](image)

**Figure 3.** Curves of dynamic pore pressure-cyclic numbers of loading under 200 kPa.

### 3.1.3. Results of consolidated confining pressure of 200 kPa

For the confining pressure of 200 kPa, the excitation forces are 0.8, 0.9, and 1.1 kN respectively. The peak value of the dynamic pore pressure-cyclic number curves of the gravel mixed soil are presented in Figure 3. Similar to the samples under confining pressure of 150 kPa, when the excitation force is small, the number of cycles at failure is larger, and the number of cycles required for failure gradually decreases with the increase of excitation force.
Under the same excitation forces, the number of cycles for failure becomes smaller and smaller as the content of silty increases. Thus the softening effect of silty on the soil skeleton is the decisive factor affecting the dynamic strength of the mixed soil.

3.1.4. Analysis of curves of dynamic pore pressure-cyclic Numbers of Loading. With the increase of the loading time, the dynamic pore water pressure presents an increasing tendency. When the fine particles content is 0%, the dynamic pore pressure increases fast with the number of cycles, and finally can reach close to the consolidated confining pressure. For the fines content of 40%, the dynamic pore water pressure increases slowly with the number of cycles, and the larger the content of fine particles is, the smaller the pore water pressure is when the specimen reaches failure. In addition, though the pore pressure increases slowly under fines content 40%, the earliest the failure occurs.

For the specimens with the same content of fine grains, the greater the excitation force is, the faster the increase rate of dynamic pore water pressure is, the greater the maximum pore water pressure is, and the smaller the number of cycles is when the failure occurs. When the excitation force is large, the dynamic pore pressure can increase to a large value and tends to be stable under a small number of cycles; when the excitation force is small, the rate of pore pressure rise is small, and the dynamic pore pressure will increase to a large value only under a large cyclic number. Even for the fine-grained content of 40% under low confining pressures, the dynamic pore pressure does not reach stability when the test is terminated (the axial strain is 7%), and the dynamic pore pressure at this time is still much less than the consolidated confining pressure.

For the dynamic pore pressure growth curves at the same fine particles content, the larger the confining pressure is, the higher the number of cycles required for failure will be. This is mainly due to the increase of confining pressure, which makes the structure more compactly, and thus it makes the load bearing capacity of the skeleton stronger, and increases the consolidation and drainage at the same time, resulting in slower increase of pore pressure.

3.2. Axial strain

For the purpose of investigating the relationship between the axial strain and cyclic numbers of loading, the saturated specimens with three consolidation stressess of 100, 150, and 200 kPa are selected, and three different excitation forces are applied under each confining pressure with a frequency of 1.0 Hz. The results are shown in Figure 4-6, in which the axial strain is the value according to the maximum, that is, the peak value.

![Figure 4](image_url). Curves of axial strain-cyclic numbers of loading under 100 kPa.
Based on analysis from Figure 4-6, the following results were obtained:

(1) At low fine particles content, the axial strain shows a tendency to increase in the reverse direction in the early or middle period of the vibration. In particular, if the excitation force is very small, the axial strain will first experience a long waiting period, there is no obvious change in the axial strain at this stage, and the reverse trend will appear later. With the increase of the cyclic numbers, the negative strain begins to decrease after reaching the extreme value, and the positive strain then appears until it fails. The smaller the excitation force is, the greater the reverse extreme value of the axial strain is, and the longer the negative strain lasts.

The reasons for this are as follows. Because the sine wave type excitation force is used in this experiment, that is, they are repeatedly applied alternately in tension and in compression. The sample has a small initial pore pressure and large effective stress during the half period of the applied compressive stress, the soil skeleton is difficult to compress, thus the positive axial strain is less than the negative one. However, with the increase of the cycling times, the pore pressure gradually increases, and the effective stress decreases, resulting in a sharp increase in the positive axial strain, causing the axial strain to become larger and larger under the same dynamic stress.

(2) All the samples at high fine particle content only show positive strain, and the growth rates are slow in the early stage while fast in the later stage.

(3) The stage after the strain reaches the reverse extreme value or increases at a faster rate is called the stable failure stage. In the stage of stability failure, the growth rate of axial strain is almost the same under the same confining pressure. Therefore, it can be considered that the magnitude of the excitation force only changes the time for the specimens to reach the stable failure period. What’s more, the higher the content of silty is, the higher the reverse extreme value of the axial strain is, the smaller the number of cycles corresponding to the occurrence of positive axial strain is, and the faster the growth rate of the axial strain is in the stage of stability failure.

4. Conclusions
The key findings are as follows:
(1) At the beginning of dynamic triaxial test, the dynamic pore water pressure rises rapidly, and the rising trend becomes gentle with the value approaching to the confining pressure. In the samples with lower content of fine particles, the negative strain appears for a period of time. However, the samples with higher content of fine particles only show positive strain, which is almost unchanged in the early stage and increases rapidly in the stable failure stage.

(2) With the same percentage of fine, the larger the excitation force is, the less cyclic number needed to destroy.

(3) The greater the confining pressure is, the higher the dynamic strength of the sample is.

(4) The effect of fine content on the dynamic strength of the sample is different. At a low confining pressure of 100 kPa, the greater the dry density is, the higher the dynamic strength is. For the samples with confining pressure of 150 kPa and 200 kPa, the higher the fine content is, the lower the dynamic strength is.

(5) The increase in pore pressure plays a crucial role in the destruction of the sample. In the tests, most samples start to fail rapidly when the pore pressure rises to a certain value.

5. References
[1] Keefer D K 2000 Statistical analysis of an earthquake-induced landslide distribution - the 1989 Loma Prieta, California event Eng. Geol. 58(3-4) 231-49.
[2] Collins B D, Kayen R and Tanaka Y 2012 Spatial distribution of landslides triggered from the 2007 Niigata Chuetsu-Oki Japan Earthquake Eng. Geol. 127 14-26.
[3] Yuan X M, Cao Z Z, Sun Y and Chen L W 2009 Preliminary research on liquefaction characteristics of wenchuan 8.0 earthquake Chin J Rock Mech Eng 28(6) 1288-96.
[4] Thevanayagam S 1998 Effect of fines and confining stress on undrained shear strength of silty sands J. Geotech. Geoenviron. Eng. 124(6) 479-91.
[5] Cao C L, Sun Y F and Dong B 2009 Study on dynamical intensity features of silt with different clay-particle contents Coast. Eng. 28 27-32.
[6] Zhou J, Yang Y X and Jia M C 2009 Effect of fines content on Liquefacton properties of saturated silty sands J. Hydraul. Eng. 40 1184-88.
[7] Abedi M, Yasrobi S S 2010 Effects of plastic fines on the instability of sand Soil Dyn. Earthq. Eng. 30(3) 61-7.
[8] Skempton A W 1985 Residual strength of clays in landslides, folded strata and the laboratory Geotechnique 35(1) 3-18.
[9] Prakash K S and Chandrasekaran V S 2005 Behavior of marine sand-clay mixtures under static and cyclic triaxial shear J. Geotech. Geoenviron. Eng. 131(2) 213-22.
[10] Liu E L, Song C H, Luo K T and Wan L 2010 Investigation on dynamic mechanical properties of mixed soils composed of fine-coarse particles World Earthquake Engineering 26(Supp)(S1) 28-31.

Acknowledgements
This research was supported by National Key Research and Development of China (Project No.2017YFC1501003).