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INFLUENCE OF GRADING ON SEISMIC SETTLEMENT OF LOESS

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ABSTRACT

Seismic settlement is often observed on loess ground during strong earthquake. The amount of settlement can be up to meters. To prevent it through ground treatment, it is necessary to have understanding of the factors that influencing development of seismic settlement. In this paper, based on laboratory study, the effect of sand, clay and silt particles on seismic settlement of loess is studied. The change of grading is achieved through adding clay particles (Kaolin) and sand particles. The study shows that within the range of test, add of either sand or clay particles can reduce development of settlement. But in terms of their role with regard to development of seismic settlement, they are different. Sand particles can strengthen soil skeleton of loess and reduce the number of larger sized pores. The clay particles, on the other hand, strengthen cementation of loess so as to reduce development of residual strain. This study also reveals the mechanism of seismic settlement of loess. The result presented in this paper can be used to evaluate seismic settlement of loess. It also provide some useful clue to design ground treatment based on soil grading, especially through adding sand, which can be economic and effective to treat seismic settlement of loess ground under certain circumstance.

Keywords: loess, grading, seismic settlement, earthquake, influence

INTRODUCTION

Loess is a kind of loose Quaternary silt deposit contains more than 50% of the particles with size from 5 to 75μm. It is common in most part of Northwest China. Since it is first recognized in the Rhine Valley in Germany in 1830's and in the lower Mississippi River in 1846, loess provides a daunting task for Civil Engineers (Foumer, 1996). In China, loess study is also important starting from 1950's. But the emphasis is mainly on collapsibility of loess for a long time. During strong earthquakes, loess ground can develop large amount of settlement, which is called "dynamic collapsibility". It is identified that loess ground can develop seismic settlement up to one meter (Mustafaev, 1984). Several Chinese literature also reported or study on seismic settlement of loess (Zhang, 1987; He,1990; Wang,2003). It is believed that the weak cementation of its structure and under-consolidation make loess very vulnerable under dynamic load. After a moderate earthquake, the 1995 Yongdeng 5.8 Earthquake in Gansu province of China, large amount of seismic settlement is observed in the meizoseismal zone (Figure 1). Seismic settlement can cause substantial damage by triggering landslides, damaging buildings etc. Based on previous study, the purpose of this paper is to study the effect of grading on seismic settlement of loess and this can also provide better understanding of the mechanism of seismic settlement of loess.

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Figure 1. The step-like fissure caused by seismic settlement (by J.S. Liu, 1995)

METHODS AND SAMPLES OF THE STUDY

Dynamic triaxial test is a standard test to study the dynamic characteristics of soil. In this study, dynamic load in sinusoid form is applied on sample to induce residual deformation, which can be used to evaluate seismic settlement of loess ground under strong earthquake.

Seismic settlement of loess has much to do with microstructure of loess. But microstructure of loess has several facets, such as grading, pore composition, cementation and particle packing. But the current study method is unable to investigate all aspects of the microstructure. It is more realistic to study one aspects of microstructure of loess at a time. In this study, grading is the factor to be considered.

Under certain condition, grading actually determines the pore composition and cementation. Therefore, grading can reveal some important aspects of microstructure of loess, if it cannot show all the aspects of it. After all grading is the most convenient parameter for study.

In this study, remolded samples are used to have samples with different grading. The approach is two-fold: for three groups of samples, sand particle is added to increase the content of coarse particles, for other four groups of samples, Kaolin is added to increase the fine content. Thus a wide range of grading can be obtained for the purpose of study.

The basic parameters of the seven groups of samples are listed in Table 1 &2.

Table 1. Basic parameters of samples with sand addition

Group No.	Dry density (g/cm^3)	Weight percentage of sand addition (%)	W (%)	Number of samples
S5	1.5	5%	12	6
S10	1.5	10%	12	6
S18	1.5	18%	12	6

Table 2. Basic parameters of samples with calyy addition

Group No.	Dry density (g/cm^3)	Weight percentage of clay addition (%)	W (%)	Number of samples
C5	1.5	5%	12	6
C10	1.5	10%	12	6
C15	1.5	15%	12	6
C18	1.5	18%	12	6

EFFECTS OF SAND PARTICLES ON RESIDUAL STRAIN OF LOESS

Figure 2 and 3 are respectively residual strain of the group of samples with different sand addition under cyclic times of 10 and 30. All the curves obey the relationship as given by formula (1) with fitting coefficient ≥0.99.

$$\varepsilon_r = a \cdot \sigma_d + b \cdot \sigma_d^2 \quad (1)$$

In Formula (1), ε_r is residual strain in %, σ_d is amplitude of dynamic load in kPa.

It can be found that under any cyclic times, the group with larger sand addition develops less residual strain. That is, sand addition improves the performance of loess.

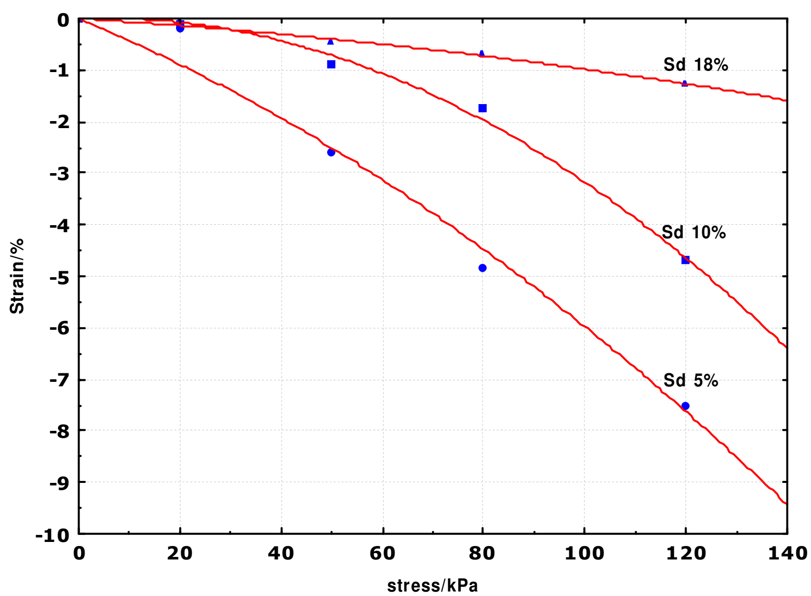

Figure 2. Residual strain of loess sample with different sand addition (Cyclic time=10)

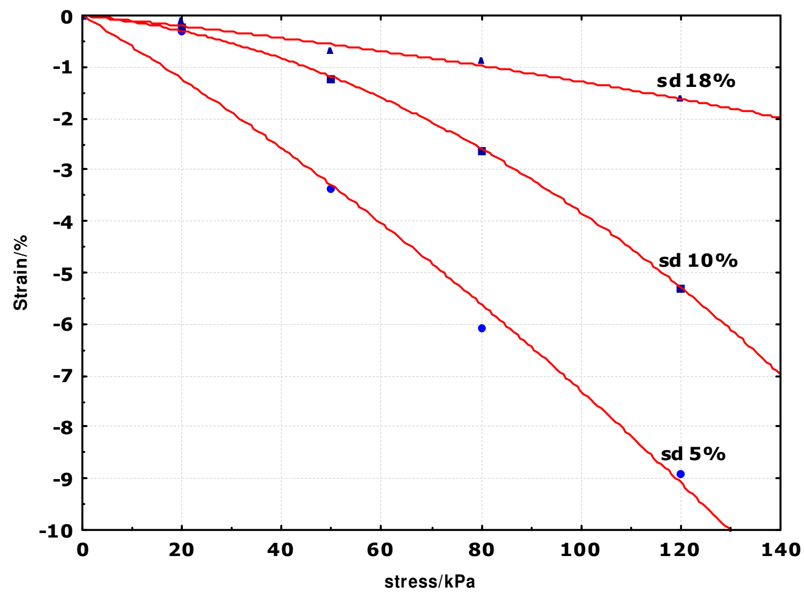

Figure 3. Residual strain of loess sample with different sand addition (Cyclic time=30)

Using data of the three groups of samples under cyclic time of 20, the relationship of sand content and residual strain is study. It is found that there is a linear relationship between sand content and residual strain of loess samples, which can expressed as formula (2).

$$\varepsilon_r = a + b \cdot S \qquad (r>0.99) \qquad (2)$$

In formula (2), S is sand content in percentage, a and b are both fitting constants. Figure 4 shows this relationship between sand content and residual strain under different stress level after cyclic time of 20.

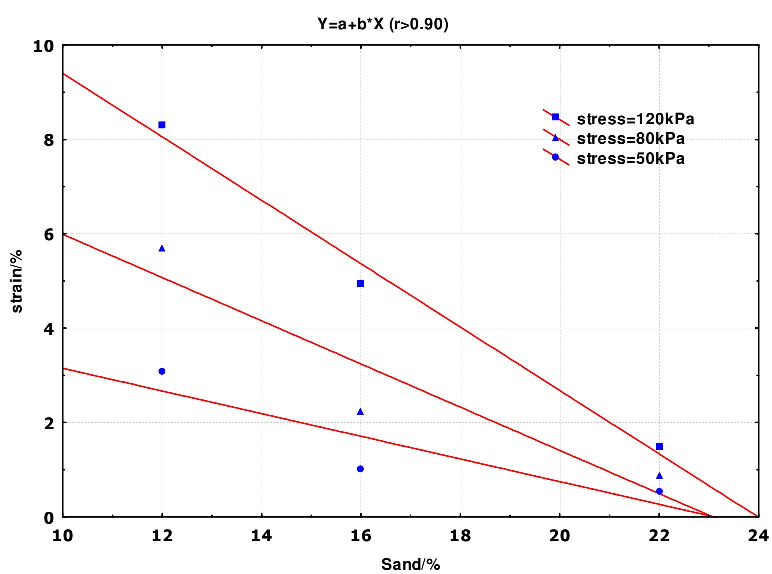

Figure 4. The effect of sand content on residual strain of loess under different stress level

(cyclic time=20)

EFFECT OF CLAY PARTICLES ON RESIDUAL STRAIN OF LOESS

Figure 5 and 6 are respectively residual strain of the four groups of loess samples under cyclic times of 10 and 30.

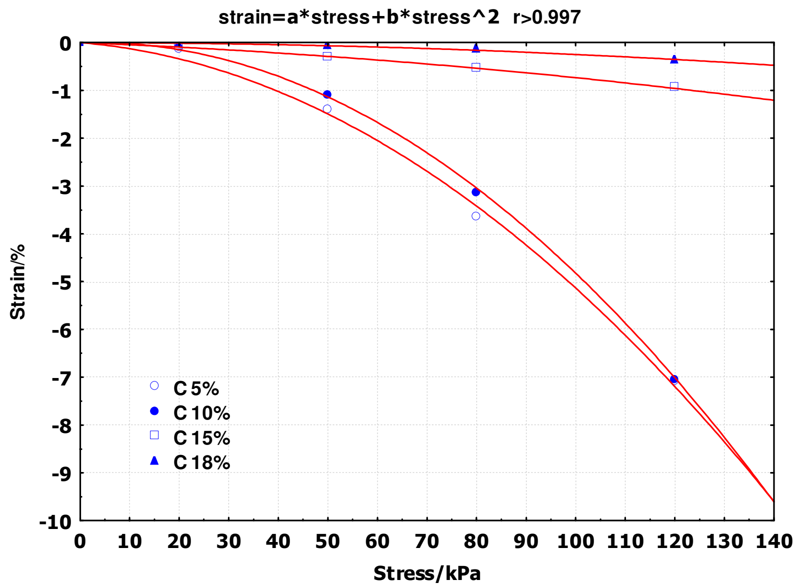

Figure 5. Residual strain of loess sample with different clay addition (Cyclic time=10)

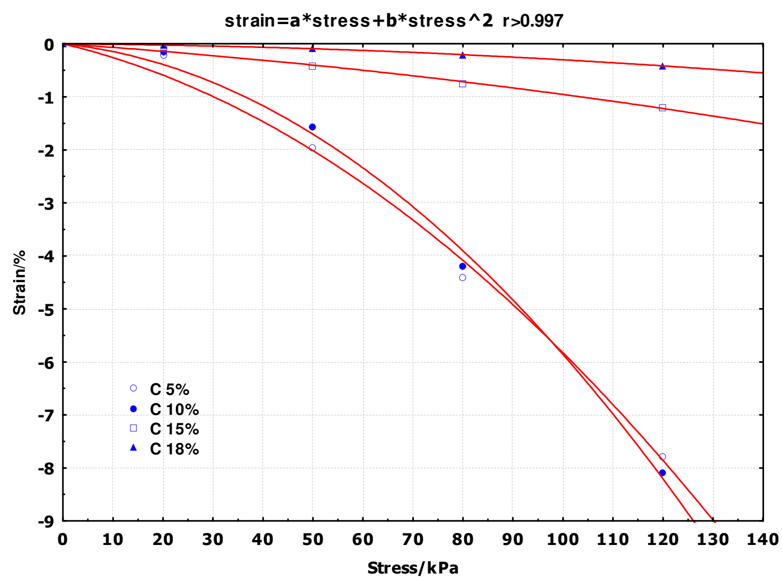

Figure 6. Residual strain of loess sample with different clay addition (Cyclic time=30)

It can be seen from Figure 5 and 6 that, generally speaking, the increase of clay addition also improves the performance of loess sample and reduce development of residual strain under the same stress level. All the curves in Figure 5 & 6 obey the same relationship as formula (1) with fitting coefficient >0.99.

But when the clay addition is in small amount, the effect is not very significant, especially when the clay addition is below 10%.

In the same way, the data of residual strain of loess samples with different clay addition under cyclic times 10 is analyzed to study the effect of clay content on dynamic residual strain of loess. The result is given as Figure 7.

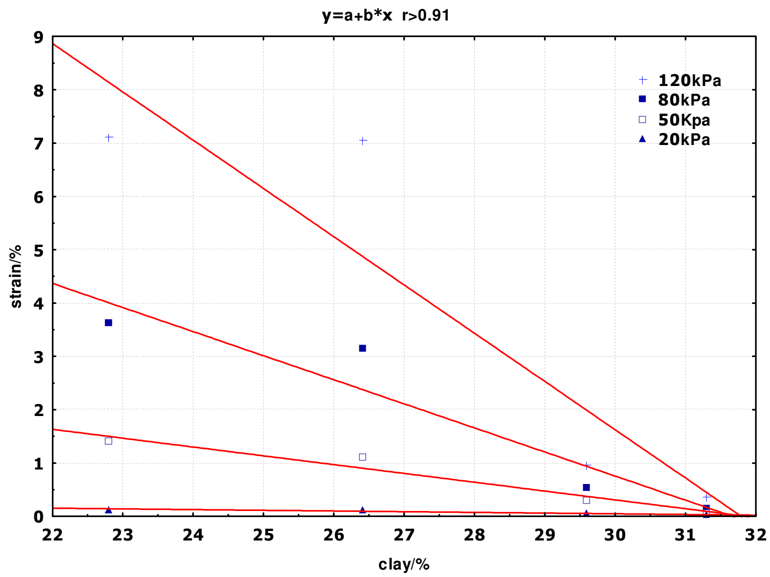

Figure 7. Effect of clay content on dynamic residual strain of loess under different stress level (Cyclic time=10)

In Figure 7, largely the increase of clay content will result less dynamic residual strain of loess. The observed linear relationship between clay content and dynamic residual strain of loess may also affected by the factor that only limited data are available, and the data is more or less scattering. But in any way, it shows that the increase of clay addition also reduces the development of residual strain of loess under the same stress level.

COMPREHENSIVE DISCUSSION ON THE EFFECT OF GRADING ON DYNAMIC RESIDUAL STRAIN OF LOESS

The above results shows that increase of either sand or clay content can reduce dynamic residual strain. But their mechanisms are different. Sand particles are mainly act as skeleton of loess, when there are more sand particles, the compressibility of the loess skeleton is reduced, and as a result, the residual strain of loess under certain dynamic loads will become less. For clay content, it mainly acts as cementation agent. The more the clay content is, the stronger the cementation of loess would be. Hence, higher clay content leads to smaller residual strain.

Since clay content, sand content and silt content altogether is 100%. And furthermore, the effect of sand content and clay content is actually similar as far as residual strain is concerned; it is logic to use the content of silt as single indicator of the effect of grading on dynamic residual strain of loess.

In fact, this is reasonable not only because of numerical relationship mentioned above. There is material basis. The cause of seismic settlement of loess is the collapse of large pores in loess which is result of both under-consolidation and large and shear-vulnerable pores composed by several silt particles. So, higher silt content means more of large pores, which will lead to more settlement under certain ground motion effect. Data analysis shows that the relationship between silt content and residual strain under certain stress level can be expressed as formula (3):

$$\varepsilon_r = l + k \cdot C_{silt} \quad (3)$$

In formula (3) l and k are fitting constant, C_{silt} is silt content in percentage.

Using formula (1) and (3), the relationship to predict residual strain of loess with stress level and silt content can be expressed as formula (4):

$$\varepsilon_r = k_1 + k_2\sigma_d + k_3\sigma_d^2 + k_4 \cdot C_{silt} \quad (4)$$

The fitting result under cyclic time 10 is shown as figure 8.

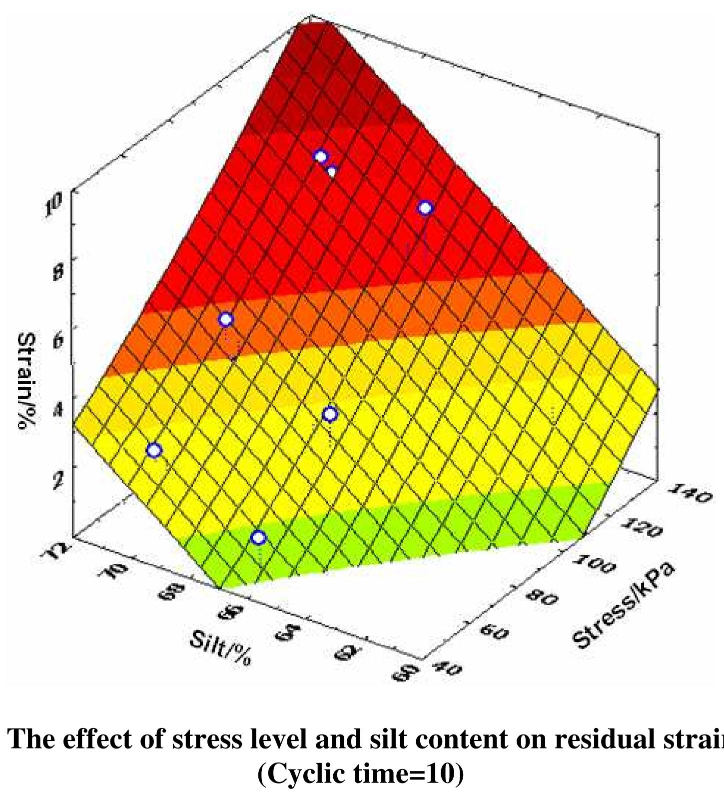

Figure 8. The effect of stress level and silt content on residual strain of loess (Cyclic time=10)

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