# Study on the Permanent Strain Potential of Silty Soil Liquefaction

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**Abstract.** In order to reasonably carry out dynamic analysis and seismic design of soil and soil-structure interaction system, on the basis of dynamic triaxial tests, a permanent strain potential model for saturated silty soil during seismic liquefaction is established. And it can well fit the development rule of strain during liquefaction of silty soil.

## 1.  Introduction

Under the action of building load or soil self weight, the strength of foundation soil decreases after liquefaction, and the surface appears vertical or lateral deformation, it will cause large area subsidence on the surface of liquefied area, which will cause deformation and destruction of underground structures and lifeline projects. Although in the past few decades，sand liquefaction has been extensively studied, but the study focused primarily on liquefied factors, mechanisms and conditions and terms of the likelihood of the occurrence of liquefaction, liquefied deformation studies are relatively less.

The documnets [1,2] studied the influence of the clay content of the silt liquefaction characteristics, consistent results showed that the dynamic shear stress intensity and clay content is not a linear monotonous increase relationship but a parabolic type. The document [3] studies show that: The stress-strain relationship of the silty soil is similar, and the strain is similar to that of sandy soil, which can be divided into two stages of low strength and strength recovery section. After liquefaction, the deformation of the silt is mainly controlled by the deformation of the low strength stage after liquefaction. The deformation of the low strength stage after the liquefaction of the silty soil with different clay content is linear with the dynamic strain produced by the dynamic load[4]. The vibration frequency, the confining pressure and the maximum axial strain have influence on the stress and strain after the liquefaction. The two stage constitutive model of silty soil liquefaction can better reflect the stress-strain relationship of silty soil after liquefaction. In order to carry out a reasonable soil and soil - dynamic analysis and seismic design structure interaction must be a good understanding of the deformation and strength characteristics of soil under loads through the test, and the need to establish a practical model for the calculation.

## 2. Dynamic triaxial test

The dynamic triaxial test is to consolidate a cylindrical specimen with a certain density and humidity under an axisymmetric three axis stress, after consolidation, a vibration test is performed under undrained conditions. The seismic process is short and the excess pore water pressure is not enough to dissipate. Therefore, the test should be carried out under undrained conditions. Trial consolidation

ratio $K_C$ is 1, isotropic consolidation, confining pressure is 100kPa. Using the initial liquefaction standard, it considers soil liquefaction when $u = \sigma_3$. The test used remodeling samples，multi-storey the wet tamping act molding, and vacuum saturation 24 hours, and saturation rate is greater than 96%. The height of the sample is 80mm, and the diameter is 31.1mm.Experiments are carried out under undrained conditions, and soil samples in each group completed 5 trials. Figure 1 is a typical time history curve of dynamic triaxial test liquefaction test.
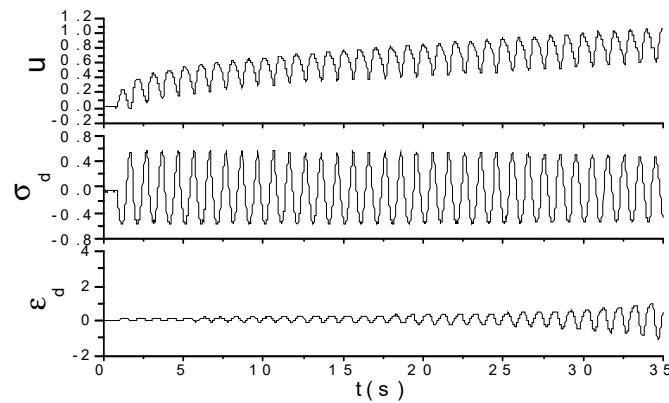


Figure 1. Typical time history curve of dynamic triaxial test liquefaction test.

## 3. Segmented curve model

The deformation of soil under cyclic loading is divided into two parts: round-trip deformation and permanent deformation. Under normal working conditions, the foundation soil is not allowed to produce excessive permanent deformation, because the excessive permanent deformation will cause greater additional stress in the soil and the structure. Therefore, permanent deformation is an important basis for evaluating the performance of soil under cyclic loading. In document [5], introduced a new time parameter $\lambda$, it is considered that in double logarithmic coordinates, the relationship line between $\varepsilon$ and $\lambda$ is a cluster of curves based on the ratio of round-trip shear stress on the maximum round-trip shear surface.

In this method, a straight line with a slope of 1 is tangent to the curve, and the cut points are divided into two segments, and the relationship is represented by piecewise functions. However, when using this method to analyze the test data of this test soil sample, it is found that the fitting effect in the first quadrant is poor, and the selection of tangent points(segment point) used in this method is difficult, the error of the tangent point will lead to the curve after segmentation which is not consistent with the functional relation proposed in document [5].Therefore, based on this method, we describe the development of strain by improved piecewise function..

According to cyclic load test, the stress and strain time history curves can be measured. When there is no permanent strain in a cycle, the stress-strain hysteretic curve will be closed. When the permanent strain occurs, the increment of the permanent strain is $\Delta\varepsilon_{P,i} = \varepsilon_{i+1} - \varepsilon_i$, and the permanent strain generated by the N round-trip:

$$\Delta\varepsilon_{P,N} = \sum_{i=1}^{N} \Delta\varepsilon_{P,i} \qquad （1）$$

Obviously, the permanent strain is related to the amplitude of the round-trip stress and the number of trips. The number of reciprocating actions is a separate integral quantity, which is inconvenient in mathematical processing. Therefore, the time parameter $\lambda$ is used instead of the number of reciprocating actions. According to the test results, the relationship between $\varepsilon_{P,\lambda}$ and $\lambda$ is obtained when the initial shear stress ration is constant, to make a straight line with slope 1 tangent to the curve, the tangent point divides the curve into two sections, and the tangent point coordinates are $(\lambda_0, \varepsilon_{P,\lambda,0})$,

so a pair of new coordinates can be introduced：

$$\left. \begin{array}{l} \eta = \lg \dfrac{\lambda}{\lambda_0} \\[3mm] \xi = \lg \dfrac{\varepsilon_{P,\lambda}}{\varepsilon_{P,\lambda,0}} \end{array} \right\} \tag{2}$$

The line between $\xi$ and $\eta$ is a curve through the origin, and the curves are distributed in the first and third quadrants. In the document [5], it is suggested that the curve in the third quadrant is expressed as the following equation:

$$\xi = \frac{\eta}{1 + b_1 \eta} \tag{3}$$

Rewrite above equation as:

$$\frac{\eta}{\xi} = 1 + b_1 \eta \tag{4}$$

It considers that the strain points in the third quadrant have passed the above transformation, the relationship between $\eta$ and $\dfrac{\eta}{\xi}$ is a straight line passing through (0, 1) points and the slope of this line is $b_1$.

The curve in the first quadrant is expressed as the following equation::

$$\eta = \frac{\xi}{1 + b_2 \xi} \tag{5}$$

Rewrite above equation as:

$$\frac{\xi}{\eta} = 1 + b_2 \xi \tag{6}$$

It considers that the strain points in the first quadrant have passed the above transformation, the relationship between $\xi$ and $\dfrac{\xi}{\eta}$ is a straight line passing through (0, 1) points and the slope of this line is $b_2$.

When using the above method to analyze the experimental data, it is difficult to select the tangent points of the line with the slope of 1 and the curve of the test point. The transformation of the test data can not be well conformed to (3) and (5), that is, the transformed lines often fail to pass (0, 1) points. Therefore, on the basis of the above methods, the expressions (3) and (5) are rewritten as follows:

The third quadrant:
$$\xi = \frac{\eta}{a_1 + b_1 \eta} \tag{7}$$

The first quadrant:
$$\eta = \frac{\xi}{a_2 + b_2 \xi} \tag{8}$$

The above two equations can better describe the development of strain, and in the analysis of the above two equations, it is not necessary to strictly request the tangent point of the straight line and the curve as the piecewise point of the curve, and take a point as $(\lambda_0, \varepsilon_{P,\lambda,0})$ coordinate point near the curve turning point with experience, and the fitting effect is also good. The fitting results of the test data are shown in figure 2-4.
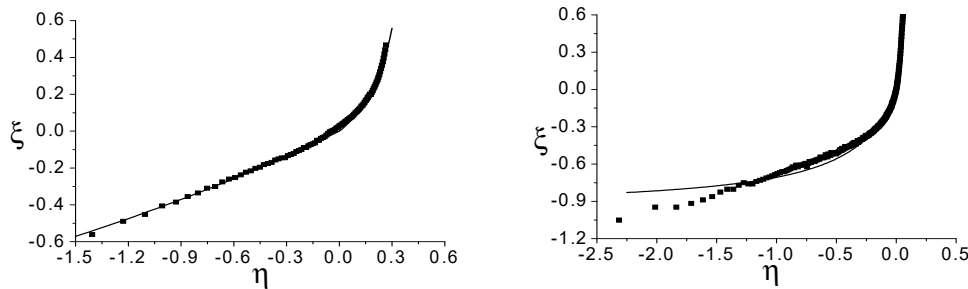
Figure 2. Regression curves of $\xi$ and $\eta$ for soil samples with dry density equal to $1.40\,g/cm^3$ .
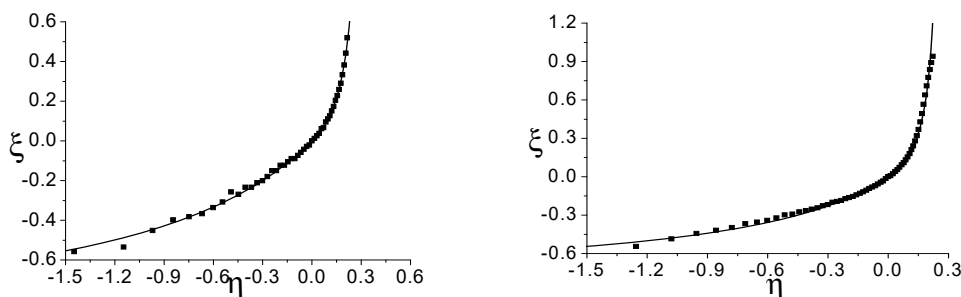


Figure 3.   Regression curves of $\xi$ and $\eta$ for soil samples with dry density equal to $1.50\,g/cm^3$ .
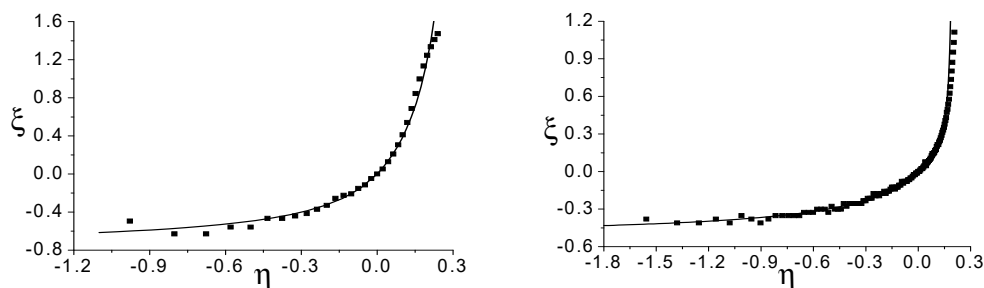


Figure 4.   Regression curves of $\xi$ and $\eta$ for soil samples with dry density equal to $1.60\,g/cm^3$ .

Thus, to represent a curve requires six parameters, $\lambda_0, \varepsilon_{P,\lambda,0}, a_1, b_1, a_2, b_2$ .Obviously, these six parameters depend on the cyclic shear stress ratio of the maximum cyclic shear plane. Where $\lambda_0$ and $\varepsilon_{P,\lambda,0}$ are selected limit is not very strict, $a_1, b_1, a_2, b_2$ are shape parameters of the model, can be determined by the least squares method based on the test data.

## 4. Conclusion
The above analysis shows that the above method can well describe the law of strain development in the process of soil sample liquefaction, but its disadvantage is that the parameters of the reference are too much, the amount of calculation is large, the precision of the parameters will determine the accuracy of the calculation, and the value of the parameters should be determined as much as possible when the model is used. Based on the principle of practicability, a simpler and more intuitive model can be considered to describe the development of strain.

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