# TRANSFERRING COEFFICIENT OF SOIL LAYER STRAIN TO SUBWAY STRUCTURE DURING EARTHQUAKES

**Jianyi Zhang[1], Xiaoming Yuan[2], Jin Xu[3] And Rui Sun[4]**

[1] *Assistant, Dept. of Geotechnical Engineering, Institute of Disaster Prevention Science and Technology, Sanhe. China*
[2] *Postgraduate, Dept. of Geotechnical Engineering, Institute of Engineering Mechanics, Harbin. China*
[3] *Professor, Dept. of Geotechnical Engineering, Institute of Engineering Mechanics, Harbin. China*
[4] *Professor, Dept. of Geotechnical Engineering, Institute of Engineering Mechanics, Harbin. China*
*Email: b532@163.com, yxmiem@163.com, jxu0086@gmail.com, iemsr@163.com*

**ABSTRACT :**

The response and damage of the underground structure under the seismic action are usually controlled by the deformation of soils and the seismic design of the underground structure should be based on the displacement principal. The transformation of the free-field displacements to the underground structure is analyzed in the paper. On the basic of soil strain transfer to structure, defined as STC, and taking subway structure as object, By using the two-dimensional nonlinear dynamic FEM suitable for the larger deformation and seismic time history, the effects of variation of the parameters including the input earthquake motion, the soil property and soil layer as well as the feature of the underground structure on the STC are investigated. The calculated results indicate: (1) The STC decreases with the increasing of input acceleration amplitudes approximately and the relation between can be described as parabola; (2) Generally, The STC in the soft clay is linearly proportional to the modulus of the soil and the STC in the harder clay with the equivalent shear wave velocity larger than 220m/s is the hyperbolic relation with the modulus of the soil; (3) The influence of the soil layer thickness for soil layer with the depth less than 40 meters can be neglected basically; (4) For the structure with the width-to-depth section ratio from 1 to 2, the STC keeps a constant basically; (5) If the buried depth of structure is less than 10 meters, the buried depth of the structure can be ignored basically.

**KEYWORDS:** Underground structure, Strain transferring coefficient, Soil, Deformation

## 1. INTRODUCTION

Recently, on the one hand, underground structure is becoming more and more important with the development of industrial and agricultural production and the improvement of urban culture. Most parts of China are earthquake zone, the seismic design and safety assessment of underground structure will become the important problem concerned by the engineer staff. On the other hand, the multiplied quantity of underground structure and frequent appearance of underground structure damage, the seismic issues of underground structure are got more attention by the earthquake workers of the world. Particularly, the Kobe earthquake in 1995, the subway of Kobe were seriously destroyed, that the seismic research of underground structure became unprecedented popular.

To the underground structure, the important thing of design is focused on the longitudinal and surrounding soil, it usually think that, the view of this design is applied to small and medium-size outside diameter underground structure. Now, structures such as shield tunnel and underground squares with complicated and large-scale cross-sections increase so fast that the seismic design for the cross-sections becomes more and more significant. However, proper methodologies of lateral seismic design for underground structures are not well-fledged due to the complexity of interactions between underground structure and surrounding soil (SSI). Many engineers and researchers are always working for the design of horizontal underground structure. Although the 2-D or 3-D dynamic computer program for the interaction of soil and underground structure are well used in researching the lateral dynamic property of underground structure, the engineers usually get confused or indigestible when input and output data are various and the results are difficult to analyze.

## 2. LATERAL-STRAIN-TRANSFORM NUMERICAL MODEL

### *2.1 Question*

Now, we draw the conclusion that: The different seismic properties between the ground structure and underground structure are when the main factor to the ground structure is the change of structure natural frequency characteristics, but the primary effect to the underground structure is foundation movable characteristics.

From the research actuality at home or abroad, the lateral seismic calculation method of underground structure is not perfect. The ground motion of the underground structure has been often researched, but study of the interactions and common deformation between the soil layer and structure has small proportion, and it has considered less on the change of the material of the soil layer, the shape of structure, the change of stiffness. In most cases, the same method doesn't content with the both aspects hereinbefore. Moreover, plane dynamic FEM method solves the above problems, but as a result of the high cost and complexity, it has greatly limit on the usage.

Base on these, this article researches the lateral seismic design method of subway station that can be described as rectangular or equivalent rectangular and proposes STC model.

### *2.2 STC model*

*2.2.1 Definition*

The soil being selected is light big than structure in the free site. The dimensions of the four sides are extended 0.5m in horizontal direction. This is because the effect of surrounding soil's disturbance in the construction, shown in figure 1.

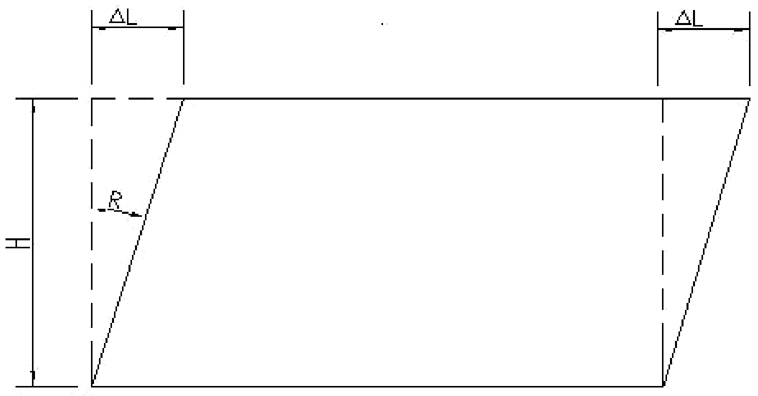


Figure 1 Soil shear strain

In figure 1, the definition of shear strain of the soil is:

$$R_{tu} = \frac{\Delta L}{H} \tag{2.1}$$

$\Delta L$ ——lateral displacement strain of top point of structure in uniform shear strain (m);

$H$ ——Height of soil (m).

The structures occurring lateral displacement accompanied with the shear deformation in earthquake are mainly influenced by bending and shearing. The structure has integrity and its stiffness is large than the soil's, the interaction between structure and soil will lead to the whole rigid body rotation of the structure. It demands to remove the rigid body rotation when calculating the shear strain of the structure, shown in figure 2.

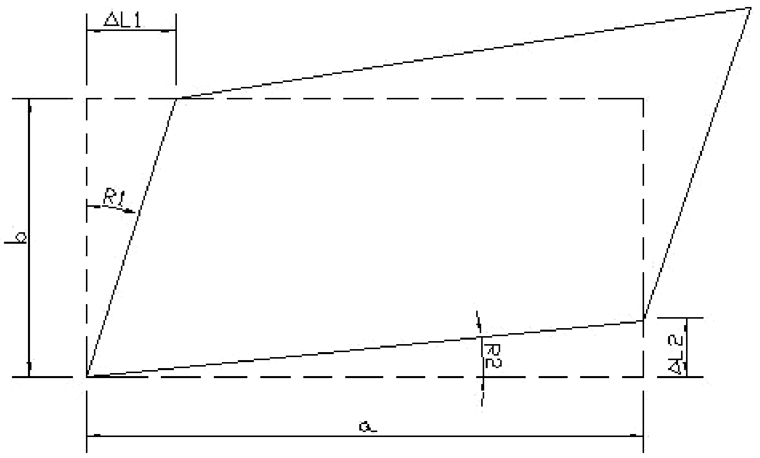


Figure 2 Shear strain of the structure

The definition of shear strain of the structure is:

$$R_{jie} = R_1 - R_2 \tag{2.2}$$

$$R_1 = \frac{\Delta L_1}{b}, \quad R_2 = \frac{\Delta L_2}{a}$$

$a$ ——structure's width (m);

$b$ ——structure's height (m);

$\Delta L_1$ ——the difference value of displacement between left top point and down point of the structure (m);

$\Delta L_2$ ——the difference value of displacement between right top point and down point of the structure (m);

$R_1$ ——whole lateral displacement strain of structure;

$R_2$ ——whole rigid body rotation strain of structure.

The quotient between soil shear strain and structure shear strain is defined as Strain Transform Coefficient (STC):

$$STC = R_{jie} / R_{tu} \tag{2.3}$$

*2.2.2 Calculation Steps of Model*

From the LSSRLI-1 or SHAKE91 one dimensional linearization method for computing earthquake response of ground layered soil, according the soil shear strain formula (2-1), the $R_{.tu}$ can be calculated and then be input in (2-3) to get $R_{.jie}$ Finally, the maximum displacement ΔL could be got.

According figure 3, the dynamic additional moment and shear force of the underground structure can be calculated by putting the maximum displacement to top of the structure and setting the bilateral of the end lap as fixed supports.

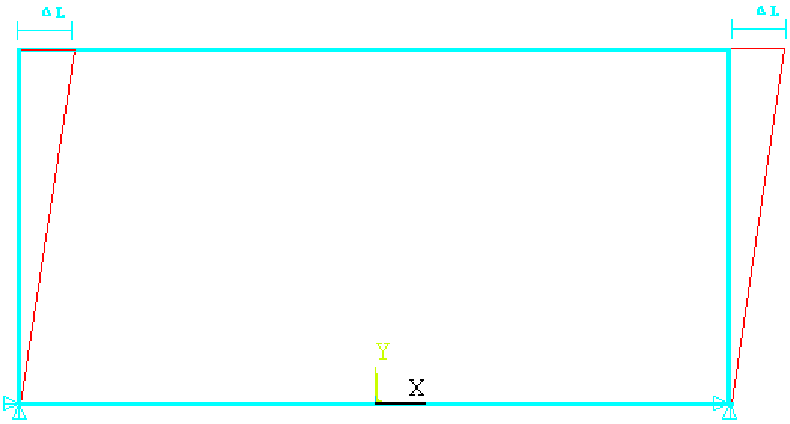


Figure 3 Schematic Diagram of Structure Static Calculation

## 3. CALCULATING CONDITION AND SELECTING PARAMETERS

To the STC model, the object is to investigate the law of strain transform of underground structure by using IEM SD4 plan dynamic finite program. Selecting typical conditions, making large calculation and analyzing the parameters are the important things. The selecting of basic parameters should be researched specially.

The dimension of the underground structure is 8m×4m×0.5m. The program uses five sets parameters to analyze, shown in table 1. When analyzing one parameter, the other parameter keeps invariant.

Table 1 Variable and constant

| Question NO. | different shear modular ratio | different depth of soil layer (m) | different structure width-to-depth ratio | different structure buried depth (m) | different bedrock acceleration (g) |
|---|---|---|---|---|---|
| 1 | X | 20 | 2 | 5 | 0.2 |
| 2 | 1 | X | 2 | 5 | 0.2 |
| 3 | 1 | 20 | X | 5 | 0.2 |
| 4 | 1 | 20 | 2 | X | 0.2 |
| 5 | 1 | 20 | 2 | 5 | X |

To every set of parameter, variable X's values are:

(1)Question 1---the change of shear modular ratio's influence on underground structure: 0.4,0.5,0.6,0.7,0.8,0.9, 1.0,1.1,1.2,1.3,1.4,1.5,2.0,2.5,3.0,3.5,4.0,4.5,5.0,5.5,6.0,7.0,8.0,9.0,10.0. The shear modular ratio JQB is that: first, the equivalent shear modular $G_{se}$ equals the square equivalent shear wave velocity $V_{se}$ multiplies with equivalent soil layer density $\rho_{se}$. Then the ratio is the equivalent shear modular $G_{tu0}$ of one depth and different equivalent shear modular $G_{tu1}$ of the other same depth.

$$JQB = \frac{G_{tu1}}{G_{tu0}} \tag{3.1}$$

$G_{tu0}$: shear modular of reference point;

$G_{tu1}$: the other equivalent shear modular.

(2)Question 2--- the change of different soil layer depth's influence on the underground structure: 20, 25, 30, 35, 40;

(3)Question 3--- the change of different structure width-to-depth ratio's influence on the underground structure: 1, 1.25, 1.5, 1.75, 2.0;

(4)Question 4--- the change of different structure buried depth's influence on the underground structure: 2m,

5m, 8m;
(5)Question 5--- the change of different bedrock acceleration's influence on the underground structure: 0.1, 0.15, 0.2, 0.25, 0.3, 0.4.
To every set of calculating program, the factors in program SD4 have influence on the selection of quantification. For example, the maximum shear modular, shear modular ratio and damping ratio, the shape of inputting bedrock wave (Kobe, El-Centro, Loma- Prieta, Northbridge, Taft, TangShan et.), the peak value of the earthquake wave are the contents of the research.
Five sets parameters and six earthquake waves are considered in the calculation. Then the results of calculation are averaged. That because the problem is complex. The parameters can be concluded in 3 conditions: earthquake motion, soil property, structure feature.

### *3.1 Analysis of inputting earthquake motion*

To simulate different earthquake motion' influences on the underground structure STC, six different earthquake waves' peak accelerate values are normalized as: 0.1g, 0.15g, 0.2g, 0.25g, 0.3g, 0.4g. The 36 different conditions that soil with and without underground structures are in numerical calculations. The relation between average value and the STC are shown in figure 4.

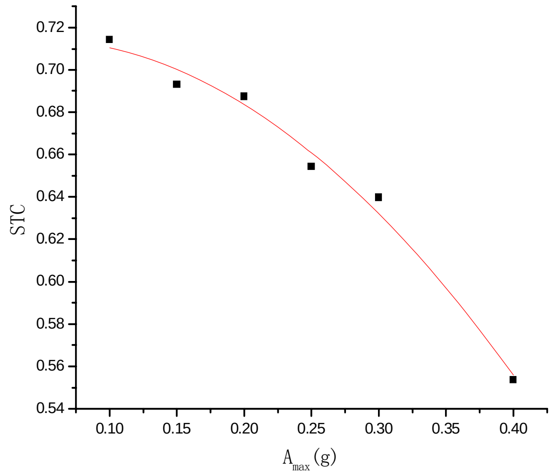


Figure 4 Relation curve between STC and $A_{max}$

Then

$$STC = 0.713 + 0.102 \times A_{max} - 1.237 \times A_{max}^2, \quad 0.1 \le A_{max} \le 0.4 \tag{3.2}$$

The inputting earthquake waves' peak values $A_{max}$ fit well with the STC. When the inputting earthquake waves' peak values increase, the STC values decrease. When the peak value changes from 0.1g to 0.4g, that the STC value changes from 0.7 to 0.55. The relation between can be described as parabola $y = ax^2$ ($a$<0, $x$>0).

### *3.2 Analysis of soil property*

The relationships between STC and soil layer's soft-hard (different shear modular ratio JQB) and different soil layer depth are researched when inputting six typical earthquake waves.
*3.2.1Different shear modular ratio*
First, different shear modular ratio JQB can be divided into two groups (Ⅰ)0.4～1.5 and (Ⅱ)1.5～10, according to the shear velocity and soil property.
To the group (Ⅰ)0.4～1.5, the relation curve between STC and JQB is shown in figure 5.

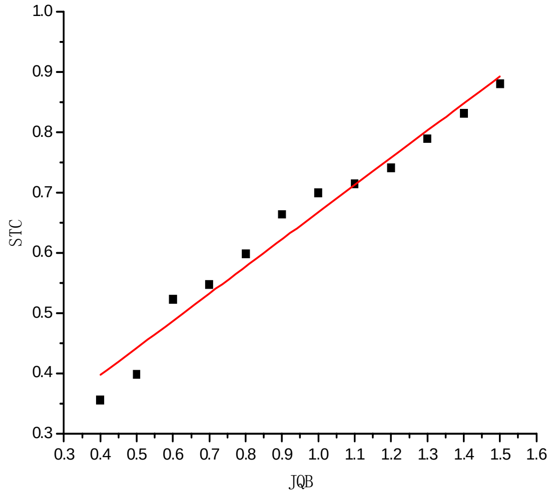


Figure 5 Relation curve between STC and JQB (0.4~1.5)

From figure 5, to soft clay or muddy clay, the curve of JQB and STC exhibits linear relation.
To the group (Ⅱ) 1.5～10, the relation curve between STC and JQB is shown in figure 6.

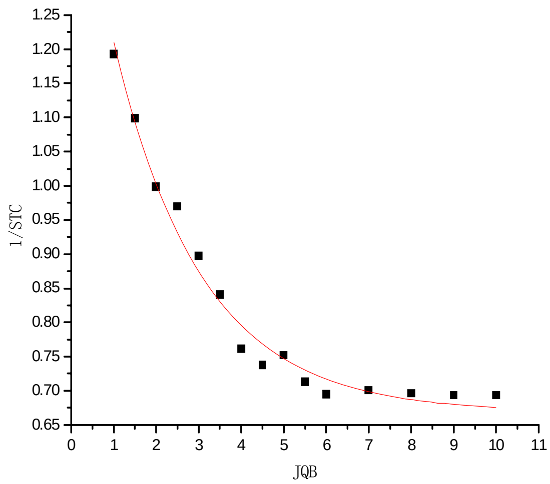


Figure 6 Relation curve between 1/STC and JQB (1.5~10)

From figure 6, to clay (shear velocity > 220m/s), the curve of JQB and STC exhibits hyperbola relation.
Combining the results of figure 5 and figure 6:

$$STC = \begin{cases} 0.217 + 0.451 \times JQB, & 0.4 \le JQB \le 1.5 \\ 1 \big/ \left(0.669 + 0.876 \times 0.612^{JQB}\right), & 1.5 \le JQB \le 10 \end{cases} \quad (3.3)$$

The degree of soft-hard of soil has significantly influence on the STC, when the soil becomes harder, the STC increases. But after the soil gets hard at a certain degree, the STC increases slowly and changes to be steady.

*3.2.2 Different soil depth*

According the engineering practice, the soil depth can be selected from 20m to 40m. The STC doesn't vary with the change of the soil depth Htu. By averaging the five data of STC in table 2, 0.69 can be selected as constant.

***3.3 Analysis of structure feature***

The change law of STC of different buried depth (Ⅰ) and width-to-depth ratio (Ⅱ)of structure are researched by inputting the six different earthquake waves in this section.

Different buried depth (Ⅰ): The buried depth of structure varies from 2m to 8m. The relation between buried depth and STC is shown in table 3. The value of STC could be a constant as 0.673 in 10m buried depth.

Table 2 the relation between soil depth and STC

| Soil depth (m) | 20 | 25 | 30 | 35 | 40 |
|---|---|---|---|---|---|
| *STC* | 0.68755 | 0.67879 | 0.68341 | 0.70683 | 0.71365 |

Table 3 the relation between buried depth and STC

| buried depth (m) | 2 | 5 | 8 |
|---|---|---|---|
| *STC* | 0.67802 | 0.68755 | 0.65224 |

Different width-to-depth ratio (Ⅱ):Keeping the depth of underground structure as 4m, the width of the structure could be changed to 4m, 5m, 6m, 7m and 8m. Those 5 different width-to-depth ratios of structure KBG can be got: 1, 1.25, 1.5, 1.75, 2.0. From table 4, the value of STC could be a constant as 0.66 in 1 ~ 2 width-to-depth ratio.

Table 4 the relation between width-to-depth ratio and STC

| width-to-depth ratio | 1 | 1.25 | 1.5 | 1.75 | 2 |
|---|---|---|---|---|---|
| *STC* | 0.64562 | 0.63629 | 0.65127 | 0.66326 | 0.68755 |

## 4. CONCLUSION

In this article, the dynamic response of rectangular underground structure in whole clay soil is calculated in horizontal earthquake by using numerical method with SD4 program. Next, we will do research on underground structure’s STC from 3 parts:

(1). Research more conditions.

(2). Research underground structure’s STC under vertical earthquake motion or combination of horizontal and vertical earthquake motion

(3). To improve the STC model requests doing the shaking test of soil structure interaction.

## REFERENCES

[1] I.M.Idriss. Finite Element Analysis For the Seismic Response of Earth Banks(1968), Jour. Of Soil Mech. And Found. Div.ASCE,VOL94,No.SM 3.
[2] Lysmer J, Udaka T, Tsai C F, Seed H B.FLUSH – A Computer for Approximate 3-d Analysis of Soil-Structure Interaction Problems. Earthquke Engineering Reseach Center, University of California (1975), Berkeley, Report No. EERC75-30.
[3] Schnabel, Lysmer J, Seed H B.SHAKE91 – A Computer for Conducting Equivalent linear Seismic Response Analysis of Horizontally Layered soil Deposits(1992). Center for Geotechnical Modeling Department of Civil & Environmental Engineering University of California, Davis, California.
[4] Lysmer J, Waas G. Finite dynamic model for infinite media(1972).Journal of the Engineering Mechanics, ASCE,98(1):85~105.
[5] Ying Liu, Junfei XIE. The sandy soil liquefaction (1984)].The earthquake publisher, Peking.
[6] YUAN Xiao-ming, SUN Rui. Laboratory experimental study on dynamic shear modulus ratio and damping ratio of soils (2000). Earthquake Engineering and Engineering Vibration, 20(4):133-139.
[7] Lin Gao, Liang Qinghuai. A seismic design of underground structures(1996).China Civil Engineering

Journal, 29(1):15-24.
[8] FU Peng-cheng, WANG Gang, ZHANG Jian-min. A simplified analysis method for dynamic response of subway tunnel subjected to longitudinally propagating shear waves(2004), Earthquake Engineering and Engineering Vibration,24(3):44-50.
[9] Xu Zhi-yin, Shi Shan-yun, Large-Sized Shaking Table Test and Calculation for Soil-Substructure Dynamic Interaction. YANTU GONGCHENG XUEBAO (1993),Vol15(4):1-7.

**ACKNOWLEDGEMENTS**
This research was supported by Special item for Fundamental scientific research outlay of National Commonweal Institute, Grant No. 2006B03. This support is gratefully acknowledged.