RESEARCH ON CHARACTERISTICS OF CYCLIC DEFORMATION PHASES OF SOILS DISTIBUTED IN URBAN AREA HANOI FOR SEISMIC DESIGN

Nguyen Van Phong
Hanoi University of Mining and Geology, Hanoi, Vietnam
Corresponding author' Email: nvphongdcct@gmail.com

Abstract. The article introduces the characteristics of cyclic deformation stages and divides the cyclic strain into four phases: elastic, assuming elastic (linear), elastic - plastic (non-linear) and slide. From which, the paper presents results of defining cyclic deformation characteristics of seven soil types within the study area for the first three phases for seismic design. In which, the characteristics of elastic phase (G_{max}) are determined by the experimental formula, while the characteristics of the next two phases (G_{tl}, D_{tl} and G_{tv}, D_{tv}) are determined directly by cyclic triaxial apparatus. The cyclical deformation characteristics of each soil type in each phase were analyzed in stress – strain loops to illustrate and clarify the phasic characteristics of the soil.

Keywords: cyclic triaxial test; earthquakes in Hanoi; cyclic characteristics; cyclic deformation stages.

1.Introduction

Now days, construction activities in Hanoi are in the process of rapid development, more and more great structures such as high buildings, overhead and underground traffic systems are being built and planned. In addition, Hanoi is located in the strong earthquake zone. As a greater structure, the impact of earthquakes and other seismic are also increasing. Therefore, the design of these structures must be involved earthquake resistance. In handling these, the dynamic properties of the ground are essential for modeling.

Under the effect of dynamic loads, the soil is deformed to varying degrees depending on the magnitude of the dynamic stress, each dynamic deformation phase has specific characteristics needed for the design. The design of seismic resistance only ensures accuracy and reliability if the full soil characteristics of each dynamic deformation phase are defined fully.

In recent years, some researches on the soil dynamic properties in Hanoi have been published. These results, however, are limited to the introduction of deformation characteristics at very small strain level for some soil types. Therefore, the study and identification of specific indicators for different dynamic deformation phases has both scientific and practical significance.

2.Theoretical basis of cyclic deformation phases

Dynamic deformation at a point in the ground depends on the magnitude of the dynamic load, the stress condition, the soil type and the distance from the point to the load. The law of changing dynamic deformation characteristics has been studied by many authors such as Ishihara, Vucetic, ... ([3], [4]). Whereby, soil strain is divided into 3 phase based on the degree of strain: very small strain, the strain (ε) is smaller than the threshold of elastic strain (ε_{tl}); small strain, when ε is larger than ε_{tl} and smaller than the threshold of volumetric strain (ε_{tv}); medium to large strain: the strain ε is larger than 10^{-2}% to a few percent.

Based on the characteristics of each phase and mechanical models can be used, this paper divided the soil strain into four phases: elastic, assuming elastic (linear), elastic - plastic (non-linear) and slide (summarized in table 1).

Table 1. The phrases of soil cyclic deformation

The model of the phases	Deformation phrases	The degree of strain	Volume change	Deformation characteristics Change	Type of loads
Elastic ($\varepsilon \leq \varepsilon_{tl}$)	Elastic	very small	No	No (G_{max}, $D_{min} = 0$)	Seismic waves; Transportation,. . .
Assuming elastic $\varepsilon_{tl} \leq \varepsilon \leq \varepsilon_{tv}$	linear (compaction)	small	Yes	Yes (G_l, D_l)	Transportation, machine foundations, weak earthquakes
Elastic - plastic $\varepsilon_{tv} < \varepsilon < \varepsilon_{sl} = 0,5 \div 2\%$	non-linear	medium	Yes	Yes (G_{nl}, D_{nl})	Strong earthquake
Plastic	slide	large	No	No (G_{min}, D_{max})	Strong earthquake

Thus, the design of the seismic resistance should be based on specific characteristics corresponding to the level of dynamic deformation and chosen the appropriate calculation model. The strain thresholds of each soil are different depending on the composition, properties and stress conditions.

3.Characteristics of stratigraphy and soil properties in Hanoi area

3.1.Characteristics of stratigraphy

Based on the analysis of documents on Quaternary geology and engineering geology [2], sedimentary components of Hanoi and Le Chi formation are mostly gravel and its distribution is in great depth, so studying their dynamic properties is less meaningful. Meanwhile, sediments formations of Vinh Phuc, Hai Hung and Thai Binh distributed at a depth close to the surface and have sensitive component with the effect of dynamic loads. So that, the soil of this sediments is the object of study and divided in detail to 7 types of soil:

1. Alluvial deposits ($aQ_2^3tb_1$): stiff to very stiff clay - sandy clay with greyish brown to yellowish brown in colour (layer 1). The average depth of the top layer is around 3.0 m;

2. Alluvial - lake - bog deposits ($albQ_2^3tb_1$): soft clay - sandy clay with greyish brown, darkish grey in colour, mixed organic matters (layer 2). The depth distribution of the top layer is about 15m, the deepest is 28m.

3. Alluvial deposits ($aQ_2^3tb_1$): medium dense, fine sand with blackish grey – brownish grey in colour (layer 3). The depth distribution of the top layer is about 10-20m, the deepest is 34m.

4. Marine deposits ($mQ_2^{1-2}hh_2$): firm to stiff, bluish grey clay (layer 4). The thickness of the layer is small and scattered.

5. Lake - swampy deposits ($lbQ_2^{1-2}hh_1$): very soft to soft clay – sandy clay with blackish grey in colour, mixed organic matter (layer 5). Depth distribution is from a few meters to over 20m.

6. Alluvial deposits ($aQ_1^3vp_2$): stiff to very stiff clay - sandy clay with spotted yellowish brown – redish brown in colour (layer 6). The depth and thickness of the layer varies sharply from a few meters to tens of meters.

7. Alluvial deposits ($aQ_1^3vp_1$): medium dense to dense, fine - medium sand with yellowish grey (layer 7).

The distribution characteristics of these layers are shown on table 1. It can be seen that the depth and the thickness of each soil layer in the research area vary significantly. Soils with swampy origins (layer 2, 5) are the most variable; followed by soils with fluvial origins (layer 1, 3, 6, 7); the distribution depth and the thickness of soils with marine origins (layer 4) are relatively stable.

Table 2. The distribution characteristics of different soil layers in the Hanoi area

No	Soil types	Main distribution areas	Distribution depth/average (m)	Thickness/ average (m)
1	Layer1	Center, the west and the south of Hanoi	(1÷10)/5	(2÷16)/8
2	Layer 2	The south of Hanoi (Hoang Mai, Thanh Tri district) and center (Hoan Kiem, Hai Ba Trung district)	(3 ÷ 20)/10	(1,2÷20)/12
3	Layer 3	The south of Hanoi (Hoang Mai, Thanh Tri district)	(3÷30)/12	(4÷30)/14
4	Layer 4	Scattered distribution in the center and the west of Hanoi (Nam Tu Liem district) and the east (Gia Lam district)	(3÷6)/4	(1÷3)/2
5	Layer 5	Distributes widely from the west to the east, and extends to the south.	(2÷30)/16	(2÷20)/12
6	Layer 6	The north and the east of Hanoi	(1÷17)/10	(5÷10)/7
7	Layer 7	Distributes popularly in almost areas, except for the south of Hanoi.	(10÷35)/18	(6÷16)/10

3.2.Characteristics of stratigraphy and soil properties

The results of some main physical –mechanical properties of different soil types are shown on table 3 and 4. Accordingly, the layer 2 and 3 have the low strength with the small friction angle which will cause the high lateral earth pressure; layer 1 and 6 have the small internal friction angle varying from 13^0 to 14^0 but high cohesion force (28 to 29 kPa), so it is a favorable condition for stability of underground work; sand layers (3, 7).

Table 3. Synthesis of some main properties of cohesive soils

Soil layers	Water content	Wet density	Specific density	Settlement parameters	Cohesion force	Internal friction angle
	W (%)	γ (g/cm^3)	γ_s (g/cm^3)	a_{1-2} (cm^2/kG)	C (kPa)	φ (degree)
Layer 1	32,3	1,90	2,70	0,042	28	13°15’
Layer 2*	52,7	1,67	2,61	0,088	19	2°20’
Layer 4	32,8	1,89	2,69	0,076	22	8°38’
Layer 5*	49,3	1,69	2,65	0,085	17	1°10’
Layer 6	29,3	1,91	2,70	0,036	29	14°23’

* *Strength properties of soft soils (layer 2 and 5) were derived from UU triaxial test.*

Table 4. Grain composition characteristics and mechanical properties of cohesiveless soils

Sand layers	Number of samples	Grain composition (%)				SPT (blow)	Internal friction angle ** (degree)
		Pebble	Gravel	Sand	Silt		
Layer 3	685	0	0,3	89,7	10	12	27
Layer 7	476	0	3,7	92,0	4,3	29	32,3

** *The internal friction angle of cohesiveless soils was calculated from SPT values*

4. Characteristics of cyclic deformation in different phases

4.1.The basis of the research methodology selection

It is necessary to use a variety of methods (Table 5) to determine the adequate dynamical characteristics at different phases of soil deformation. However, the method is selected based on the objective research and available equipment is as follows:

At elastic phase, elastic modulus G_{max} was determined based on the SPT results by using fomular:

$G_{max} = \rho V_s^2$ (1)

Where, ρ - soil density, $\rho = \gamma/g$; V_s - shear wave velocity, was determined by these fomulars:

$V_s = 132\ N^{0,271}$ (for clayey soils – Pitilakis, 1999) and

$V_s = 157{,}13 + 4{,}74\ N^{0,5}$ (for sandy soils – Lee, 1992)

The typical parameters for phases of assuming elastic and elastic - plastic were determined by cyclic triaxial test (type Tritech 100 – Controls) in accordance with ASTM - D3999;

Table 5. The dynamic deformation phases, computational models and appropriate methods

Phases	**Typical parameters**	**Assumptions and computational models**	**Appropriate methods**
Elastic	G_{max} (D =0)	Elastic deformation ground	The methods of wave propagation test in the field, cyclic torsional shear tests
Assuming elastic (linear)	G_l, D_l	Linear deformation ground	Cyclic simple shear tests, cyclic triaxial tests; cyclic torsional shear tests, resonant column tests
Elastic - plastic (non-linear)	G_{nl}, D_{nl}	Non -linear deformation ground	
Plastics (sliding)	CRS	Sliding***	Cyclic simple shear tests, cyclic triaxial tests

**** Sliding phase is characterized by parameters of cyclic strength.*

4.2.The quantity and method

To ensure objective research, sampling locations were determined in accordance with common distribution area of study subjects [2]. The quantity of specific research was selected sufficiently for the identification of the full phases and was summarized in Table 5.

Table 5. Quantity of cyclic triaxial test for each soil

Layer	Soil type	Quantity of cyclic triaxial test
Layer 1	Stiff, yellowish grey sandy Clay (S_{tb2})	7
Layer 2	Soft, blackish grey sandy Clay (Y_{tb})	5
Layer 3	Bluish grey fine Sand (C_{tb})	9
Layer 4	Firm, bluish grey Clay (S_{hh})	7
Layer 5	Soft, blackish grey sandy Clay (Y_{hh3})	7
Layer 6	Very stiff, reddish brown sandy Clay (S_{vp})	7
Layer 7	Yellowish grey fine Sand (C_{vp1})	5

Each soil was tested in the same frequency (2Hz) and pressure chamber under the different amplitude of cyclic stress. The maximum of cyclic stress was determined based on earthquake level for each soil. The cyclic deformation phases were devided base on the graphs of stress, strain and pore pressure. Finally, the characteristics of cyclic deformation ware determined for each phase.

4.3.Research results

The soil deformation characteristic is reflected by strain graphs, stress - strain loops, correlated curves of stress – strain and the increase of pore pressure. Therefore, it is necessary to analyze these graphs to study dynamic deformation at different phases.

In the first phase (elastic), stress – strain loops are a straight line, the damping ratio D is zero; elastic strain threshold (ε_{tl}) is approximately 10^{-6} or 10^{-4}%. Thus, the characteristic parameter for this phase is only G_{max} and was determined by (1). The results are summarized in the table 6.

In the second phase (Assuming linear), the loops are stable and the deviation between the loops is very small (fig.1). The characteristics of this phase (G_l, D_l) do not change over time loading and the strain threshold (ε_{tv}) of the soils is about 0,010% to 0,036% (Table 7).

In the non-linear phase: When strain is over the threshold of small strain, pore water pressure started to increase and reached its highest value in sliding phase, strain graph and loops are unstable and disproportionate, so that G_{nl} and D_{nl} change simultaneously by experimental cycle that expressed in separation of the stress – strain curves. The values of G_{nl} and D_{nl} in table 7 were average values.

Summary of the research results is represented in Table 7.

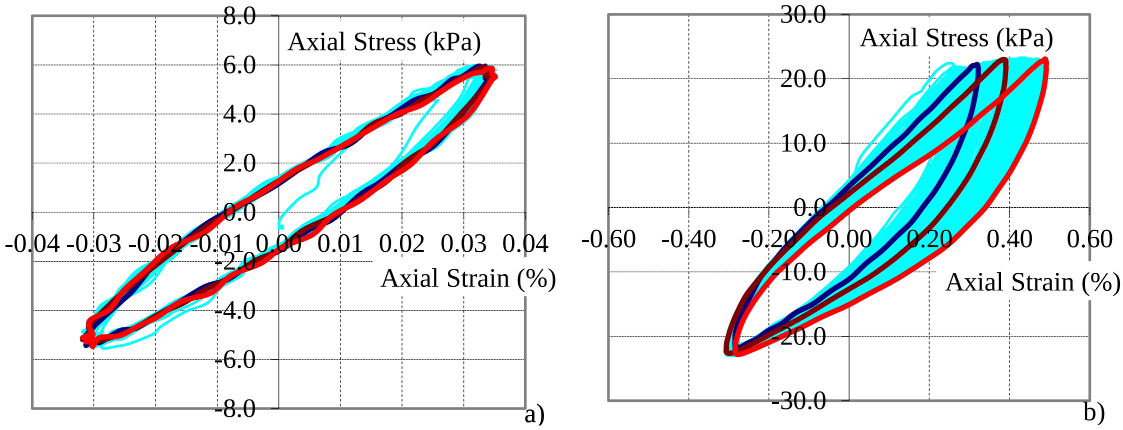

Fig. 1. The typical form of stress-strain loop in Assuming linear phase (a) and Non-linear phase (b)

Table 6. The results determining the elastic modulus G_{max} for each soil

Soil types	Vertical effective stress, (σ'_v)	According to the results of SPT			
		N_{30}	$N_{1(60)}$	(V_s)	(G_{max})
	kPa	Blows		m/s	kPa
Layer 1	70	6	7,02	214,5	87890
Layer 2	94	4	4,04	192,2	62793
Layer 3	110	16	14,94	176,1	55814
Layer 4	94	6	6,06	214,5	85129
Layer 5	126	3	2,62	177,8	52147
Layer 6	150	11	8,79	252,8	127824
Layer 7	230	27	17,43	181,8	61118

Table 7. The characteristic parameters of phases for each soil

Soils	Cyclic Stress Ratio threshold		The Strain threshold		Assuming elastic Phase		Elastic - plastic Phase	
	CSR_l	CSR_{nl}	ε_{tv}	ε_{sl}	G_l (kPa)	D_l	G_{nl} (kPa)	D_{nl}
Layer 1	0.13	0.41	0.018	0.5	15233	0.112	5195	0.194
Layer 2	0.18	0.42	0.025	0.42	6799	0.092	2769	0.182
Layer 3	0.22	-	0.01	-	18325	0.089	12545	0.128

Layer 4	0.14	0.25	0.03	0.62	8816	0.112	2429	0.176
Layer 5	0.13	0.46	0.036	0.055	6943	0.115	1787	0.200
Layer 6*	0.22	-	0.025	-	43736	0.101	13177	0.141
Layer 7*	-	-	-	-	26415	0.114	13701	0.120

** The soils were tested with maximum of cyclic stress but had not reached the sliding phase.*

5.Conclusions and Recommendations

The cyclic deformation of the soils in Hanoi area is divided into four phases based on the cyclic deformation characteristics and usable models: elastic, assuming elastic (linear), elastic - plastic (non-linear) and slide. In which, the first three phases belong to the issue of dynamic deformation and dynamic stress propagation, while the fourth phase belongs to the dynamic strength. The stress and strain threshold of each phase varies by the soil type (summarized in table 7). The specific characteristic of elastic phase is G_{max}. While, G_l, D_l are characteristic parameters of assuming elastic phases and have little change. In non-linear phase, the characteristic parameters G_{nl} and D_{nl} change over time under dynamic load.

The seismic design should be based on the cyclic stress threshold and the soil type to select the calculation model, thence determining the characteristic parameters corresponding to the model (in phase) for calculation.

References

[1] Nguyen Van Phong, Le Trong Thang, 2013. Study of dynamic properties of clayed soil of Thai Binh formations distributed in the Hanoi area by Cyclic triaxial tests, Scientific - Technical Journal of Mining and geology, Hanoi, No. 44/10, pp 5-11.

[2] Nguyen Van Phong, 2016. Research on mechanical properties of Quaternary sediments distributed in Hanoi area under dynamic loads, PhD thesis, Hanoi University of Mining and Geology.

[3] Ishihara K. (2003), Soil Behaviour in Earthquake Geotechnics, Oxford Sience Puplications

[4] Vucetic M. (1994). Cyclic threshold shear strains in soils, Journal of Geotechnical Engineering, ASCE, vol. 120, no. 12.