Dynamic properties of loose sand using numerical analysis-A case at Hong Thai Tay coal transportation road project (Vietnam)

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Abstract. In this paper, a study was conducted to investigate the dynamic behaviors of loose sand collected from Hong Thai Tay coal transportation road project (Vietnam). Cyclic direct simple shear tests (CDSS) were performed on the soil using a finite element method program. The CDSS test was controlled under drained strain condition with the vertical effective consolidation stress of 100 kPa. In addition, the other dynamic control parameter, cyclic stress ratio, was subjected to vary in the range of 0.04-0.1. A total of 30 cyclic direct simple shear tests were performed with respect to the number of uniform cyclic cycle and cyclic stress ratio to determine the dynamic parameters of the sand plasticity model. Eventually, the dynamic properties of the investigated sand were observed through various dynamic aspects. As a result, the strain amplitude of the loose sand in this study slightly increased within the first fifteen-loading cycles. From the sixteenth cycle, huge increments were observed during the cyclic test. This result agreed well with that of excess pore water pressure ratio, that is, the development of excess pore water pressure reached about 1.0 after fifteen cycles of loading. Moreover, the obtained results of the shear modulus reduction ratio from this study were compared to those of sand from the literature reviews.

Keywords: Dynamic properties, Loose sand, Numerical analysis, Hong Thai Tay Project.

1 Introduction

Hong Thai Tay coal transportation road is one of the very important projects in the development strategy of Dong Bac corp-port company. It is used as the main coal transport route from mining areas to Hong Thai Port (e.g., Trang Bach coal mine, Coal mine numbers 91, 618, and 397). From the site investigation, a thick loose sand layer (i.e., up to 3 meters) was observed near the underpass through highway 18A of Hong Thai Tay coal transportation road. As well-known, loose sand is susceptible to liquefaction during the dynamic (e.g., earthquake) and cyclic (e.g., truck movement) excitations. The liquefaction phenomenon is most often observed in saturated, loose

C. Ha-Minh et al. (eds.), *CIGOS 2019, Innovation for Sustainable Infrastructure*,
Lecture Notes in Civil Engineering 54,
https://doi.org/10.1007/978-981-15-0802-8_110

(low density or uncompacted), sandy soils because loose sand has a tendency to compress when a load is applied.

Many researchers have addressed the dynamic properties of sand using mathematical solutions [1, 2] and numerical analysis [3-5]. In this study, the Soil-Test option in a Finite Element Method program, Plaxis 2D, was adopted to simulate the cyclic direct shear test (CDSS). The CDSS test was controlled under drained strain condition with the vertical effective consolidation stress of 100 kPa. In addition, the other dynamic control parameter, cyclic stress ratio, was subjected to vary in the range of 0.04-0.1. A total of 30 cyclic direct simple shear tests were performed with respect to the number of uniform cyclic cycle and cyclic stress ratio to determine the dynamic parameters of the sand plasticity model.

2 Methodology

2.1 Selection of material

The soil used for the simulation in this study was the loose sand from Hong Thai Tay coal transportation road (Quangninh, Vietnam). The sand is classified as silty sand (SM). Soil classification parameters based on the Unified Soil Classification System (USCS). All physical properties of the sand, such as its unit weight, natural water content, fine particle, and specific gravity, are tabulated in Table 1.

Table 1. Physical properties of the loose sand

Properties	Loose sand
Unit weight (tons/m^3)	1.90
Natural water content (%)	26.77
Specific gravity	2.69
D10 (μm)	5
Particles < 75 μm (%)	13.98
Color	Yellow

2.2 Constitutive model used in the numerical analysis

PM4Sand model is the elasto-plastic, critical state compatible, bounding surface plasticity model. It is a very attractive model for the industry due to a small number of parameters to be calibrated. They are mostly related to the commonly available data in the design practice [6]. It originally developed from the Dafalias-Manzari model [7, 8] with substantial improvements made by Boulanger and Ziotopoulou [9]. There are various inherent advantages of using PM4Sand model for the evaluation of dynamic properties of sand (e.g., good approximation of empirical correlations used in practice including the post-liquefaction settlements, accurate stress-strain and pore pressure build-up simulations, accurate simulation of the accumulation of shear strain and strength degradation, easy prediction of number of loading cycles to liquefaction)

[10]. The input parameters used in the numerical analyses are detailed in Table 2. The procedure for input parameters calibration is presented clearly in Plaxis Manual [6].

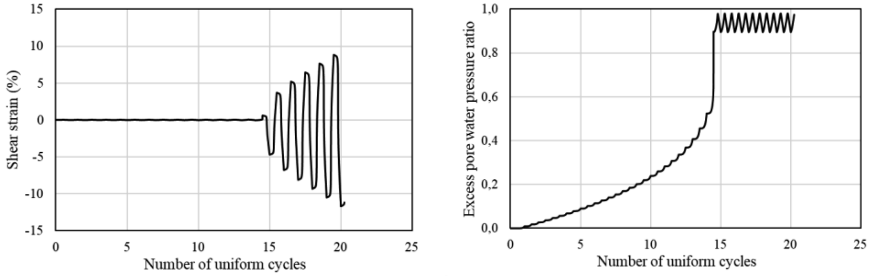
Table 2. Input parameters for numerical analysis

Soil types	Loose sand
Site	Quangninh, Vietnam
Unit weight (kN/m^3)	26.6
Friction angle (degrees)	12
Cohesion (kPa)	13.1
Elastic modulus (Mpa)	6.0
Shear modulus coefficient (Mpa)	425.77
Relative density (%)	29
Contraction rate parameter hp_0	0.05

3 Results and analysis

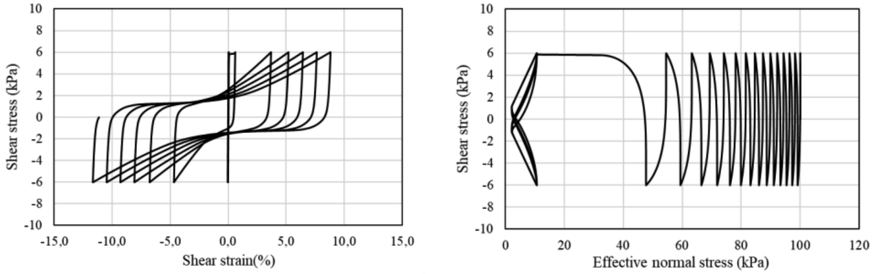
3.1 Dynamic properties from CDSS

The results from CDSS including shear stress-shear strain, effective normal stress-shear stress, number of uniform cycles-shear strain, and the number of uniform cycles-excess pore water pressure ratio are shown in Fig. 1. During cyclic loadings, the shear strain continuously fluctuated with respect to uniform cycles and finally reached the maximum value of 11.68 %. However, the fluctuation increased pronouncedly after the fifteenth cycles (See Fig. 1a). This result agreed well with that of excess pore water pressure ratio, that is, the development of excess pore water pressure reached about 1.0 after fifteen cycles of loading (See Fig. 1b). It should be noted that the liquefaction of sand arises after the pore water pressure ratio reaches 1.0. As well-known, the nature of the soil behavior changes after the initial liquefaction reaches (i.e., pore water pressure ratio reaches 1.0). These changes are exhibited in the shapes of the stress-strain loops (Fig. 1c) the stress path (Fig. 1d). These changes are also observed in Fig. 1c and Fig. 1d after 15 cycles. In particular, after the fifteenth cycle, the stress path approached and then crossed the phase transformation line. This finding can be explained by the concept of CDSS test. When an element of such soil is loaded cyclically, it exhibits a tendency to contract or compress. Under saturated conditions, this tendency for contraction results in an increase in pore water pressure. The effective stress, therefore, decreases and the soil becomes softer. Note that the effective normal stress decreases with each cycle (see Fig. 1d), and the tangent shear modulus (i.e., the slope of the stress-strain curve in Fig. 1c), reduced as the effective normal stress diminished [11]. This is the reason for the dramatic increase in shear strain after the initial liquefaction.



(a) Shear strain under cyclic loading

(b) Excess pore water pressure under cyclic loading



(c) Shear stress vs shear strain under cyclic loading

(d) Shear stress vs effective normal stress under cyclic loading

Fig. 1. Dynamic properties of the loose sand of CDSS

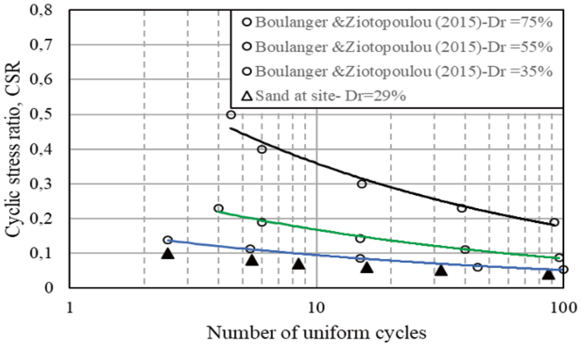


Fig. 2. Cyclic stress ratio vs number of uniform cycles as compared to Boulanger and Ziotopoulou [9]

The relationship between the cyclic stress ratio and the number of uniform cycles is plotted in Fig. 2. As shown, the cyclic stress ratio decreases with an increase in the number of uniform cycles. In this sense, larger loading amplitudes (i.e., involving the cyclic stress ratio) produced the initial liquefaction in smaller numbers of cycles than lower loading amplitudes. This finding agreed well with that reported by Boulanger and Ziotopoulou [9].

3.2 Shear modulus reduction ratio curves

In this study, shear modulus reduction-shear strain curves with respect to the vertical effective stresses (i.e., 100 kPa, 500 kPa, 1000 kPa, 1500 kPa, and 2000 kPa) were built up based on the hysteresis loops obtained by CDSS tests (Fig. 3). As shown, shear modulus almost keeps constant with small shear strain but it starts going down with large strain (i.e., larger than 0.001%), regardless of the vertical effective stress values. In addition, shear modulus reduction ratio was relatively sensitive to the vertical effective stress. Expectedly, the slope of the tangent of shear modulus ratio curves increased as an increase in vertical effective stress. Eventually, it is interesting to note that all results from this study were in between the lower and upper bounds of Seed, Wong Robert [12], regardless of vertical effective stress.

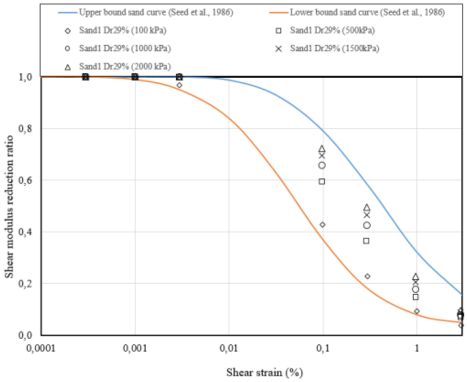


Fig. 3. Shear modulus reduction ratio curves of the studied sand as compared to Seed, Wong Robert [12]

4 Conclusions

The result of the shear strain obtained from CDSS agreed well with that of the pore water pressure ratio. The shear strain started increasing considerably and the development of excess pore water pressure reached about 1.0 after the same uniform cycles (i.e., fifteen cycles of loading). At this point, the shapes of the stress-strain loops also changed, systematically.

The relationship between the cyclic stress ratio and the number of uniform cycles was also clarified in this study. An increase in cyclic stress ratio resulted a decrease in the uniform cycles. In other words, the higher cyclic stress ratios would cause the initial liquefaction in smaller numbers of cycles than lower cyclic stress ratios.

The shear modulus reduction curves were also built up in this study based on the hysteresis loops. As an agreement with previous studies, a strong effect of the effective normal stress on the shear modulus reduction ratio was observed. The shear modulus of the soil reduced in a slower rate with the higher vertical effective stress.

Acknowledgement

This work was supported by Hanoi University of Mining and Geology and Dong Bac corp-port company.

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