A Study of Single Stone Column Bearing Capacity from a Full-Scale Plate Load Test in Long Son Project

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ABSTRACT

The ultimate bearing capacity of stone columns is very important in the design of soil improvement. The bulging failure mechanism is the most common failure mechanism reported. However, it depends on the surrounding soil at the site, necessitating a site-specific study of single-stone column bearing capacity. The current paper presents the full-scale plate load test of the single stone column in the Long Son Petrochemical Project, Vietnam in order to verify the bearing capacity of single stone column. A single stone column of 800 mm diameter was installed at the site by vibroflot. An 800 m circle full-scale plate test was carried out on site. The stone properties followed the Vietnamese standard TCVN 7572. The settlement result of the plate load test verifies the single stone column bearing capacity of 882.5 kPa.

Keywords-full-scale test; stone column; bearing capacity

I. INTRODUCTION

The bearing capacity of single stone columns has been extensively studied [1-5]. In general, the ultimate bearing capacity of columns depends on the geometry of the column, its material properties, and the properties of the soft soil. The effect of the length of the stone column is almost negligible on the bearing capacity because most of the load is transferred from the column to the surrounding soil through sides and very little load is transferred to the bottom which is similar to the effects of piles in the granular soil [4]. A non-linear analysis of an isolated stone column embedded in a semi-infinite medium of sandy soil using 2D numerical modeling with the PLAXIS software is presented in [4]. Bulging failure is the most common in long columns, where the length to diameter (L/D) ratio is more ranges between 4 and 6 [5]. The numerical modeling of a single and a group of stone columns has been analyzed using finite element software in [5] and several analytical solutions were presented. However, the bearing capacity as well as the material properties of stone columns are not always the same. For example, design loads on stone-columns ordinarily vary between 200 to 500 kN [6]. A method for the evaluation of the stone column bearing capacity by using the limit analysis method was presented in [7, 8]. A simple analytical method was developed for the estimation of the bearing capacity of an isolated stone column failed by bulging failure mechanism [9]. Most of existing approaches for bulging mechanism need several mechanical parameters for prediction of ultimate bearing capacity. It means that the case study of stone column in Vietnam is necessary in order to verify the analytical solution from full-scale load test.

The study location and the borehole layout are shown in Figure 1 and the typical soil profile, indicated in Figure 2, consists of three layers: (1) Filling soil (SM, SC-SM, SC): clayed sand, silty sand, silty clayed sand, medium dense with an average Standard Penetration Value (SPT) N equal to 10 blows, (2) silty sand, silty clayed sand, clayed sand with $N = 11$ blows, and (3) Granite rock, moderately to slightly weathered, hard and assumed as un-compressible. The PBH indicates the borehole logs and PERT is soil resistivity test.

The undrained shear strength of layer No. 1 and No. 2 taken from the unconfined compress test are averaged to 70 kPa and 30 kPa, respectively.

II. SITE WORKS AND PLATE LOAD TEST

Depending on the soil conditions, a range of techniques is available for forming stone columns. One of the most commonly used techniques is the vibroflotation technique. This technique utilizes a vibrator poker known as the vibroflot as shown by Figure 3.

Vibro-displacement stone columns involve the use of a vibroflot which comprises of a hydraulic or electric powered eccentric weight assembly enclosed in a heavy tubular steel casing. The vibroflot is suspended from the crawler crane or excavator, whichever is suitable for this project. The nose of the vibroflot is tapered to aid the penetration of the ground whilst the vertical fins prevent the vibroflot from rotating during penetration. Compressed air is used to assist the penetration of the vibroflot to reach the desired depth. Water jet would be used if the vibroflot with only compressed air can not reach the desired depth.

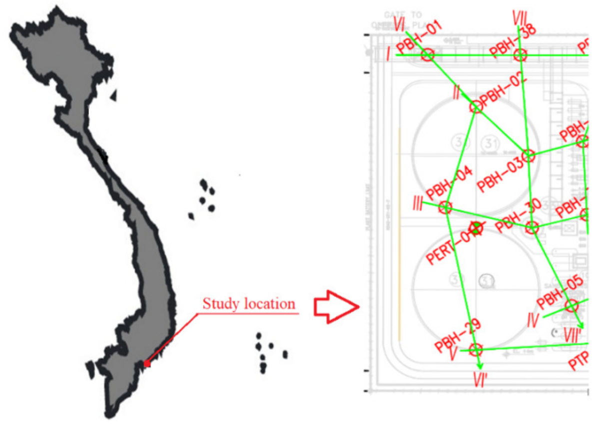
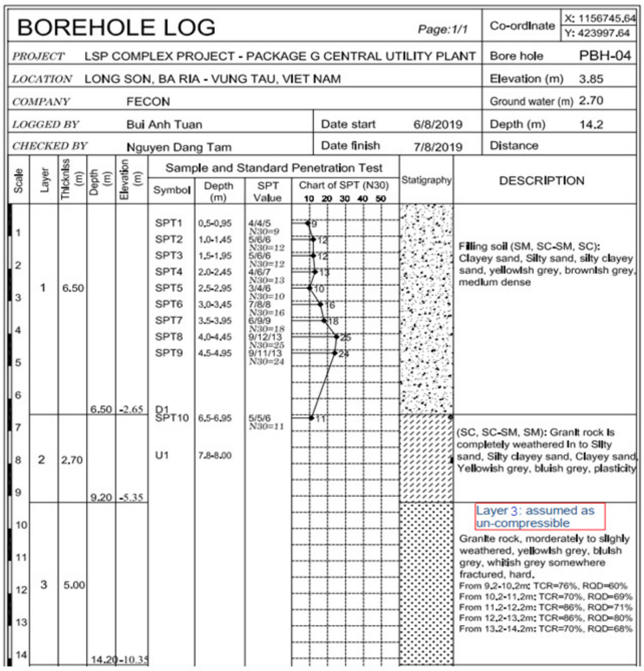


Fig. 1. Location of trial stone column work and borehole layout.



BOREHOLE LOG	Page:1/1	Co-ordinate	X: 1156745.64 Y: 423997.64
PROJECT	LSP COMPLEX PROJECT - PACKAGE G CENTRAL UTILITY PLANT	Bore hole	PBH-04
LOCATION	LONG SON, BA RIA - VUNG TAU, VIET NAM	Elevation (m)	3.85
COMPANY	FECON	Ground water (m)	2.70
LOGGED BY	Bui Anh Tuan — Date start 6/8/2019	Depth (m)	14.2
CHECKED BY	Nguyen Dang Tam — Date finish 7/8/2019	Distance	

Layer	Thickness (m)	Depth (m)	Elevation (m)	Symbol	Depth (m)	SPT Value	DESCRIPTION
1	6.50	6.50	-2.65	SPT1	0.5-0.95	4/4/5 N30=9	Filling soil (SM, SC-SM, SC): Clayey sand, Silty sand, silty clayey sand, yellowish grey, brownish grey, medium dense
				SPT2	1.0-1.45	5/6/6 N30=12	
				SPT3	1.5-1.95	5/6/6 N30=12	
				SPT4	2.0-2.45	4/6/7 N30=13	
				SPT5	2.5-2.95	3/4/6 N30=10	
				SPT6	3.0-3.45	7/8/8 N30=16	
				SPT7	3.5-3.95	6/9/9 N30=18	
				SPT8	4.0-4.45	9/12/13 N30=25	
				SPT9	4.5-4.95	9/11/13 N30=24	
				D1			
2	2.70	9.20	-5.35	SPT10	6.5-6.95	5/5/6 N30=11	(SC, SC-SM, SM): Granit rock is completely weathered in to Silty sand, Silty clayey sand, Clayey sand, Yellowish grey, bluish grey, plasticity
				U1	7.8-8.00		
3	5.00	14.20	-10.35				Layer 3: assumed as un-compressible Granite rock, morderately to slighly weathered, yellowish grey, bluish grey, whitish grey somewhere fractured, hard. From 9.2-10.2m: TCR=76%, RQD=60% From 10.2-11.2m: TCR=70%, RQD=69% From 11.2-12.2m: TCR=86%, RQD=71% From 12.2-13.2m: TCR=86%, RQD=80% From 13.2-14.2m: TCR=70%, RQD=68%

Fig. 2. Typical borehole log (PBH 04).

Fig. 3. Dry bottom feed stone column operation at LSP.

The typical set up to carry out the installation of stone column using vibro-displacement method is as shown by following Figure 2. Basically, a base-machine (a crawler crane or an excavator) will be used to lift the vibroflot together with the stone hopper and follow-tube. In addition, the power-pack will be mounted in the base-machine to power the vibroflot.

The formed stone column diameter will naturally vary with the technique and the soil condition. Generally, the weaker the soils, the larger the diameter of the stone column. (Figure 4). The stone column installation work can be stopped and considered finished if one criterion is satisfied:

1. Stone column length reached the specified length in the drawings.
2. Hard soil is reached:
   - For vibro-displacment by bottom feed method: resistance reached 200 A for electric moto or 400 bar for hydraulic moto.
   - For vibration hammer with steel pipe: the penetration length is less than 30 cm in 1 min. This value will be verified during triaxial test and be advised by supervisors.
3. Rock is reached and cannot penetrate any more: The installation of the stone column stops.

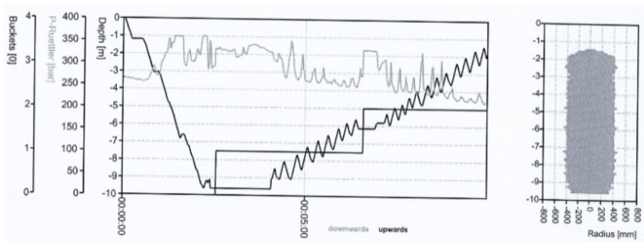


Fig. 4. Sample of recorded data for one stone column point using vibro-displacement by bottom feed method.

Fig. 5. Single plate load test of the trial stone column.

Trial work is conducted to a stone column carried out on site. The 800 mm diameter plate load test of single stone column also was setup as shown in Figure 5 in order to check whether the improved ground met the design criteria or not.

The stone material should be supplied from local quarries with sufficient quantity for this project. The material must meet the requirements shown in Table I.

TABLE I. STONE MATERIAL REQUIREMENTS

Property	Standard	Requirement		Site value
Aggregate (soaked) crushing value	[10]	< 30%		11.6%
Resistance to degradation by abration and impact in a Los Angeles machine	[10]	≤ 40% at 500 rounds		25%
Elongation and flakiness index	[10]	< 30%		17.43%
Grain size	[10]	Passing percentage		Site value
	Sieve size	Max	Min	
	50mm	100	100	100
	37.5mm	100	85	91
	25mm	55	25	27.47
	20mm	20	0	3.10
	14mm	0	0	0

The group load test was carried out in accordance with the settlement measurement process. Testing load step and load retention time can be seen in Table II. The settlement of the concrete plate was measured right after 0, 5, 10, 15, 30, 60, 90, 120, and 180 min the start of the test.

III. PLATE LOAD TEST OF SINGLE STONE COLUMN

The testing pressure is decided by the actual load on the single stone column in the operation work. Hence, the working pressure on the single stone column needs to be determined by 2D asymmetrical model in Plaxis [11] (Figure 6) with the uniform loading pressure of 239 kPa at the depth of 1000 mm on a circle with a diameter of 54800 mm. The thickness of the stone layer is 2000 mm on a circle diameter of 63800 mm, the 800 mm diameter stone column has a length of 8750mm, and the stone column spacing is 1800 mm. The material properties are taken as in Table II for the Mohr-Column model in Plaxis software.

In general, the Young modulus depends on the stone properties, the compaction energy, and the properties of surrounding area [1, 2]. The Young's modulus of the columns is usually between 25 and 100 MPa, varying with the confining pressure [3]. In this study, the Young modulus of the stone column is taken as 30000 kPa [12]. For the Young modulus of surrounding soil (E_s), among the formulas in the literature [13-15], a very simple and practical relationship is proposed in [14] for sandy soil with N being the standard penetration value:

$$E_s = N \quad (1)$$

For clay soil, Young modulus of surrounding soil (Es) could be taken from (2) [13] where q_c is the cone penetration pressure:

$$E_s = 3q_c \quad (2)$$

Note that the chosen value of N was the minimum recorded value at each borehole for a conservative estimation. For more clarification, if the N value in a borehole varies between 12 and 16, then N=12 would be used in the calculations. The above middle-low correlation of E_s value was applied for a conservative estimation.

TABLE II. SOIL PARAMETER FOR THE PLAXIS MODEL

Material	Unit weight (kN/m^3)	Friction angle (degree)	Cohesion (kPa)	Poisson ratio	Young modulus (MPa)
Graded aggregate base [16]	22	33	5	0.3	70
Lateral soil (layer 1 and 2)	20	30	24.4	0.3	10
Stone column	20	40	0	0.27	30
Bedrock	27	30	10000 (infinitive value)	0.2	1000 (infinitive value)

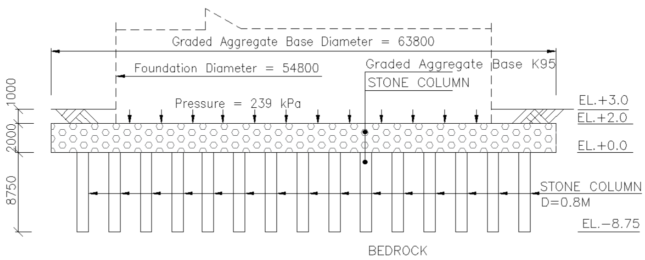


Fig. 6. Loading and structure models.

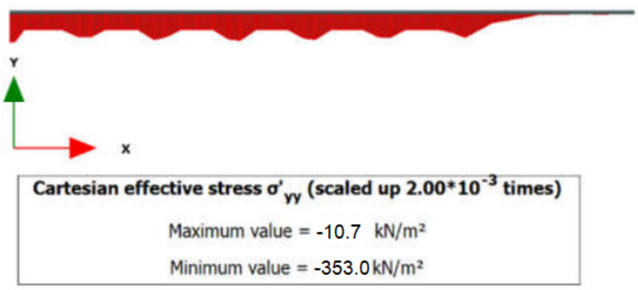


Fig. 7. Pressure distribution on the top of the stone column.

The pressure distribution on the top of the stone column is 353.4 kPa as indicated in Figure 7 for consequence activities. In this study, the testing load on a single stone column is approximated two times the operating load that is 706 kPa. The maximum testing pressure is taken as 125% of the testing pressure as indicated in Table III. The test will be finished if: (1) the total settlement is over 100 mm or (2) the testing load reaches the maximum load. The settlement result versus pressure is shown in Figure 6.

The result of single stone column load test is can be seen in Figure 8. The stone column is working normally in the maximum pressure (882.5 kPa) with a maximum settlement of 20.25 mm.

TABLE III. TESTING LOAD, TIME HOLD FOR LOAD RETENTION

Load step (% of testing load)	Testing pressure, *q* (kPa)	Time hold (minute)
25	176.5	30
50	353	30
75	529.5	30
100	706	30
125	882.5	180
100	706	15
75	529.5	15
50	353	15
25	176.5	15
0	0	15

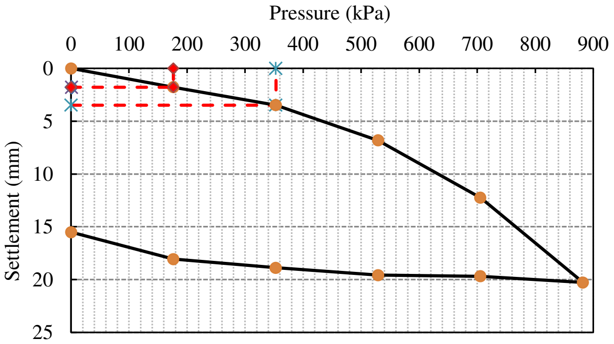


Fig. 8. Pressure versus settlement curve of the testing plate.

On the other hand, the single stone column bearing capacity can be calculated by [17]:

$$q_{ult} = \left\{\sigma_{r0} + c\left[1 + ln\frac{E_c}{2c(1+\nu)}\right]\right\}\frac{1+sin\,\varphi}{1-sin\,\varphi} \quad (3)$$

where: σ_{r0} is the total initial in-situ lateral stress, c is the undrained shear strength, E_c is the Young modulus of the stone column, ν is the Poisson ratio, and φ is the friction angle of the stone column.

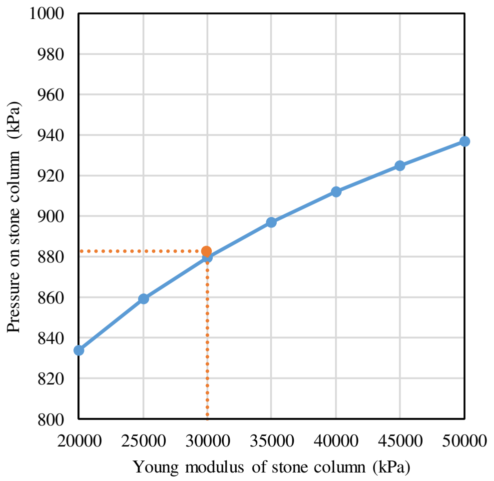


Fig. 9. Pressure versus Young modulus of a stone column.

Applying (3) to the soil parameters in Table II, the single stone column acquired bearing capacity is 882.5 kPa if the total initial in-situ lateral stress is taken at the depth of one stone column diameter (16 kPa). The settlement result in Figure 8 shows that the bearing capacity of the single stone column taken as (3) is reasonable. Furthermore, we can investigate the variety of the single stone column bearing capacity versus the Young modulus of stone column and total initial in-situ lateral stress around stone column in Figures 9 and 10.

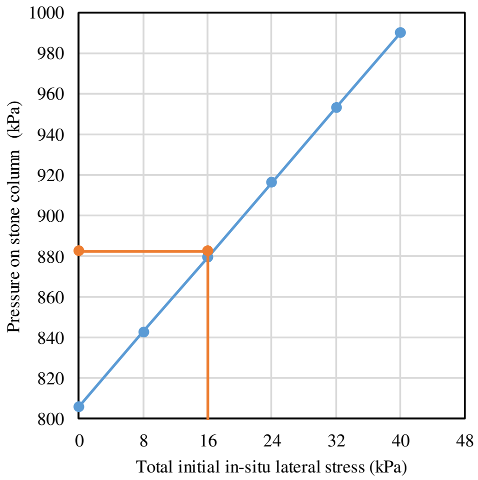


Fig. 10. Pressure versus total initial in-situ lateral stress around the stone column.

IV. CONCLUSION

A trial stone column and plate load test of a single stone column were carried out in the Long Son Petrochemical Project, Vietnam. The construction procedure and the single load test were done carefully to acquire the stone column quality. The settlement result of the plate load test and the analytical solution verify the bearing capacity of a single stone column from a typical analytical formula in the considered Vietnam site.

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