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Investigations of Soft Soil Stabilization by Mass Stabilization Methods for Construction of Dike and Rural Roads

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ABSTRACT: Nowadays, costs for soft soil improvement account for a large proportion of the total construction expenses. According to statistics of construction cost in Viet Nam, these costs were about 20% - 35% of the total expenses. As a result, advanced technologies have been applied to reduce the costs; one of them was mass stabilization technology. This paper introduces a study on soft soil stabilization using mass stabilization method experimented via a full-scale physical model, and comparison between settlement results computed by analytical formulas and the physical model.

Keywords: Mass stabilization, Deep mixing, Soft soil improvement, Binder, Dike

1. INTRODUCTION

There are several popular methods to create reinforcing mass in soft soil treatment, three of them are (Phung et al., 2015): (1) the deep mixing method creating continuous mass; (2) digging the soil to mix with binder, then spray down and compact; (3) Mass stabilization using Allu's equipment. In these methods, the third method has many advantages in accordance with conditions of Vietnam, especially in Cuu Long area. An Allu's equipment system consists of three parts (Phung et al., 2015): power mixer (PM) – connected to the excavator; pressure feeder (PF) to push the binder through the tube into the ground; and the control system (DAC) - measurement, control, data supply during construction.

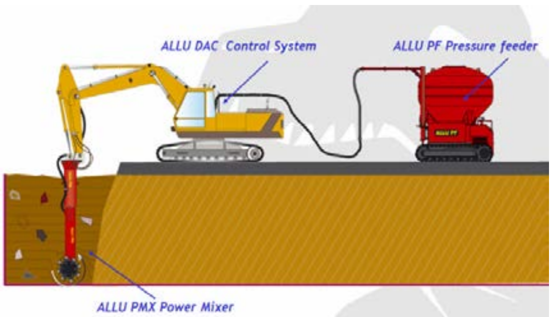

Figure 1 Allu's equipment system

ALLU Systems uses compressed air to transfer dry binder from the container into the soil throughout a tube that connected to power mixer. Through the DAC device, it can control both the PF function and adjust the volume of the binder pump to the ground. This helps the soft soil improvement processing obtain the good quality and economical. To create the reinforcing mass, the blades cut soil slowly from the top and mix with the binder. The Allu's technology is especially effective in muddy areas because it does not need any additional solutions. Thus, this technology has the advantage of fast construction, economic efficiency, material, and energy savings. In addition, this method is easy to compatible with surrounding structures and environment (with no settlement differences). Besides, because of using soil in place, it makes transportation costs reduced as well as no vibration, no noisy and non-polluted environment during construction. The disadvantage is that the initial investment cost of equipment is quite high.

2. CACULATION METHODS FOR EMBANKMENT AND MASS STABILIZATION

For creating a legal basis to apply mass stabilization technology in Vietnam, The Ministry of Agriculture and Rural Development (MARD) has developed the based standard TCVN 04: 2014/VTC based on the experience of applying deep-mixing technology in Vietnam (Phung et al., 2016) combined with several research results in recent years (Vietnam standard TCVN, 2012). In this standard, the calculation method for embankment on soft soil used mass stabilization technology is described as follows (Nguyen et al., 2014):

2.1 Selection of strength and thickness of reinforced mass

2.1.1 Preliminary selection of strength of reinforced mass is not less than q_u according to the following formula:

$$q_u = F_s \gamma_w H \qquad (1.1)$$

in which:

- q_u = strength of reinforced mass (kN/m^2);
- γ_w = wet weight of embankment (kN/m^3);
- H = height of embankment (m);
- F_s = factor of safety, F_s=1,1

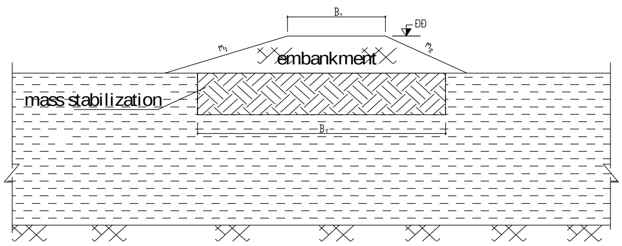

Figure 2 Diagram for settlement

2.1.2 Selection the appropriate thickness of reinforced mass (H_T) in order to make the ground behaviour to be in the linear phase and weak soil under the reinforced mass ensured load bearing capacity. Then the following conditions are described:

$$P = R_{tc} \qquad (1.2)$$

in which:

- P = load acting on the ground under reinforced mass (kN);
- R_{tc} = standard strength of soil below reinforced mass (kN),

was determined by the following formula:

$$R_{tc} = m(A\gamma b + B\gamma H + Dc) \qquad (1.3)$$

in which:

- m = coefficient of working condition, m=1;
- B_T = width of reinforced mass (m);
- H_T = depth of reinforced mass (m);
- c = cohesion of soft soil (kN/m^2);
- γ = the unit weight of the ground ($\gamma=\gamma_{wd}$ if above groundwater level, and $\gamma=\gamma_{dnd}$ if below groundwater level);
- A, B, D = coefficients depend on the friction angle of the soil, selected in the table 1.1.

The load acting on the reinforcing mass was defined as follows:

$$P = \gamma_w H + q_{xe} B \tag{1.4}$$

in which:

- γ_w = the weight of the embankment (kN/m^3);
- H_T = depth of reinforced mass (m);
- q_{xe} = live-load distribution of the vehicle on the embankment (kN/m^2);
- B = width at top of embankment (m).

Table 1.1 Value of A, B, D coefficients

Friction angle φ (°)	Coefficients		
	A	B	D
0	0	1,00	3,14
2	0,03	1,12	3,32
4	0,06	1,25	3,51
6	0,10	1,39	3,71
8	0,14	1,55	3,93
10	0,18	1,73	4,17
12	0,23	1,94	4,42
14	0,29	2,17	4,69
16	0,36	2,43	5,00
18	0,43	2,72	5,31

2.2 Calculation by the first limiting state

2.2.1 Stability examination of circular sliding surface

2.2.1.1 Embankment material: There are 3 cases for the embankment, including: (1) Embankment was bulk material with a friction angle > 30°. For this case, according to British Standard BS 8003, it was not essential to examine the overall stability of the slide; (2) Embankment was cohesive soil, weak in-place that embank in multiplied stages or one stage using geotextile. In this case, as embankment met the stability requirement or geotextile met the loading capacity, no overall stability is required. However, it is difficult to determine when it was enough and when it is not enough. Therefore, it was necessary to monitor the overall stability of the slope in this case.

2.2.1.2 Reinforced mass: This mass was considered as a homogeneous, isotropic material. This mass directly transfers the load from the embankment to the ground and played the most important role in stabilizing of the embankment.

2.2.1.3 Depending on the case, the circular sliding can be cut only on the embankment or cut through the reinforced mass. Stable condition k ≥ [k].

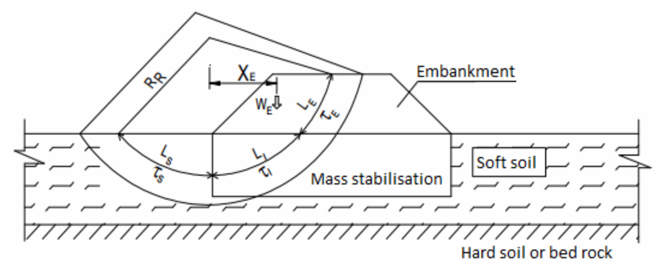

Figure 3 Calculation schema of overall stability

2.2.1.4 The overall sliding stability coefficient FS was defined by:

$$F_s = \frac{R_R(1_E\tau_E + 1_I\tau_I + 1_S\tau_S)}{X_E W_E} \tag{1.5}$$

in which :

- l_E = the length of circle sliding in embankment (m);
- l_I = the length of circle sliding in reinforced mass (m);
- l_S = the length of circle sliding in soft soil (m);
- R_R = radius of circle sliding (m);
- W_E = the weight of the embankment (kN);
- X_E = the horizontal arm of the embankment;
- τ_E = shear strength of the embankment (kN);
- τ_I = shear strength of weak ground (kN);
- τ_S = shear strength of soft soil (kN).

At present, the facto of safety can be quickly estimated by using numerical simulations in Geotech such as Geo-slope, Plaxis, etc.

2.3 Calculation by the second limiting state

Total of settlement S were determined by settlement of reinforced mass and the settlement of soft ground below the reinforced mass:

$$S = \Delta h_1 + \Delta h_2 \tag{1.6}$$

in which:

- S = total settlement of reinforced mass (m);
- Δh_1 = settlement of reinforcement mass (m);
- Δh_2 = settlement of soft ground under stabilization mass (m).

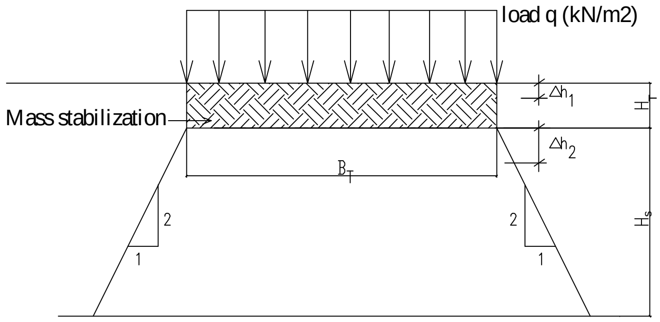

Figure 4 Calculation diagram for reinforcement mass

Δh_1 was determined as as follows:

$$\Delta h_1 = \frac{qH_T}{E_T} \tag{1.7}$$

$$q = \frac{\gamma_w H + Q}{B_T} \tag{1.8}$$

in which:

- q = distributed load on the reinforced mass (kN/m^2);
- Q = concentrated load on the reinforced mass (kN);
- H_T = depth of reinforced mass (m);
- E_T = elastic modulus of reinforced mass (kN/m2).

Δh_2 was determined as follows:

$$\Delta h_2 = \frac{C_C}{1+e_0} H_S 1g \frac{\sigma'_0 + q'}{\sigma'_0} \tag{1.9}$$

$$q' = \frac{qB_T}{B_T + \frac{H_S}{2}} \tag{1.10}$$

in which:

- Δh_2 = calculated settlement of ground (m);
- q' = loading on soft soil below reinforced mass (kN/m^2);
- H_s = the thickness of soft soil below reinforced mass (m);
- C_c = compression index of soft soil under pile tip;
- e_0 = porosity ratio of soft soil under pile tip;
- σ_0' = effective stress (kN/m^2).

3. EXPERIMENT TO DETERMINE SETTLEMENT BY PHYSICAL MODEL

3.1 Experimental purposes

The experiment purposes: (1) evaluate effectiveness of mass stabilization method; (2) verify the results calculated by analytical resolution.

3.2 Site of Tests

The experiments were built at Thanh Oai industry zone, near the Ba La street, Ha Dong town, 10km from Ha Noi capital. This location was selected because of its wide layout for carrying out the tests.

3.3 Test design

Digging soil to the depth of 40cm to build test models. The test models were constructed by brick and cement M100. The thickness of model wall was 35 cm and the height was 2.0 m. The container dimensions were 1.0 x 8.0 x 2.0 m. Front of container was made by glass thickness 15 mm and laid on steel frame system I20 by 5 mm rubber bearings in thickness and 12 mm in width. Loading system was placed inside the container. There were two I10 shaped steel bars connected two sides of steel frame.

3.4 Treating soil in model

The model soil was the same as the soil in reinforced mass. Before treatment, taking 12 samples for tests in the laboratory. The test results were shown in Table 1.2. After treatment, the soil was placed in 10cm thick into the model. At the same time, a layer of sawdust used for marking was also placed on the glass. Sawdust layers were taken photos to mark the displacement of the soil during loading (PIV technique).

Table 1.2 Physical criteria of the experimental soil

TT	Parameters	Unit	Value
1	Natural Moisture (W)	%	54,9
2	Natural density (γ_ω)	g/cm^3	1,6
3	Dry density (γ_c)	g/cm^3	1,04
4	Density (Δ)	g/cm^3	2,62
5	Degree of saturation (G)	(%)	94,20
5	Porosity (n)	e_o	60,37
6	Porosity ratio		1,52
7	Soil viscosity (Is)		0,82
8	Angle of interior friction (φ)	Độ	$5^0 0'$
9	Cohesion (c)	(kG/cm^2)	0,09
10	Compressibility coefficient (a)	(cm^2/kG)	
	$a_{0\div0,25}$		0,23
	$a_{0,25\div0,5}$		0,19
	$a_{0,5\div1,0}$		0,15
	$a_{1,0\div2,0}$		0,10

After each test, the model soil was re-processed as shown in Figure 6. The soil was then consolidated for a period of 3 months before carrying the tests.

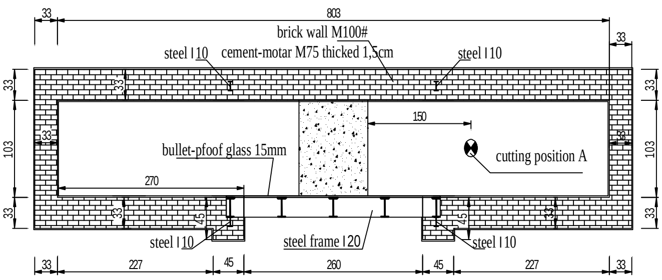

Figure 5 Shear test location

Table 1.3 Shear resistance of the soil model

TT	Depth (m)	Shear resistance S_u (kg/cm^2)	Remark
1	0,2	0,11	The results are comparable to soil tests at the sampling site and in the laboratory
2	0,4	0,09	
3	0,6	0,10	

Before carrying out the compression tests, the shear test was carried out for monitoring and evaluation the shear resistance S_u to compare between two experiments. If the S_u was not suitable, the moisture of soil could be adjusted. The location of shear test as shown in figure 5 and the test results were shown in the Table 1.3.

Figure 6 Soil in the model after processing

3.5 Fabrication of reinforcing mass

The soil for making reinforcement mass and using in the laboratory were taken in the ground, then transported to laboratory of Hydraulic construction Institute (HyCI). Here, the soil was dried and pounded before return to the test model. Before processing on the model to simulate the reinforcement mass, dried soil + cement + roadcerm mixture were created based on experience [6]. Then water was added to create a mass that water content was the same as natural soil. The whole mixture was poured into a 0.5 m^3 mixer box. This mixture was put into the model to make the reinforcement mass.

- Cement: Cement used in the test was PCB 40 with the content of 200 kg/m^3.
- Additive roadcerm: 1% of cement volume.

3.6 The experiment equipment

Figure 7.1 Hydraulic jack

Figure 7.2 Pressure sensor

Laboratory equipment includes:

- Loading jack: To increase the loading load on the reinforced mass at different levels based on the experimental design. The jack could be loaded 20 tons. A gauge with the accuracy of 0.2 ton was attached on the jack to read data that produced by China as shown in Figure 7.1.
- Stress sensor (sensor): To measure the stress at the bottom of reinforced mass in each load level. The sensor has a diameter of 28 mm, a thickness of 6.5 mm, could be measured stress in range

of 0 ÷ 0.2 MPa, made by China, as shown in Figure 7.2. The layout of sensors S1, S2, S3, S4 and S5 were shown in Figure 8.

- The Data sensor (Data Taker DT80) was used to record the data from a pressure transmitter then transfer to the computer, made in Australia, which can be connected and recorded simultaneously with five sensors, as shown in Figure 7.3.
- Specific Gravity Test: To measure the vertical displacement of the compression table and the ground surface at different load levels. The range of specific gravity test was up to 50 mm and have a precision of 0.01 mm, was made in China and was arranged in both symmetric sides through the centre, far 10 cm from the edge of the table.
- Steel compression table was used to transfer the concentrated load from the hydraulic jack to the foundation. This compression table was made of steel, 1cm in thickness, 1m x 1m in dimension, was reinforced at both side by I10 shaped I10 steel bars to increase the hardness, as shown in Figure 7.4.
- Laptop: storing and analysing data from the reader.
- Digital Cameras: A digital camera with a projection light and a cover to capture the displacement of points in the background.

Figure 7.3 Data reader

Fig 7.4 Compressed steel

3.7 Standards used for experiments

Vietnamese standard TCVN 9354-2012. Soils - In situ test methods for determination of deformation module by plate loading.
Japanese standard JSF: T25-80T. Experimental method for field bench press for ground.

3.8 Experimental diagram

Layout of experimental equipment was arranged as below:

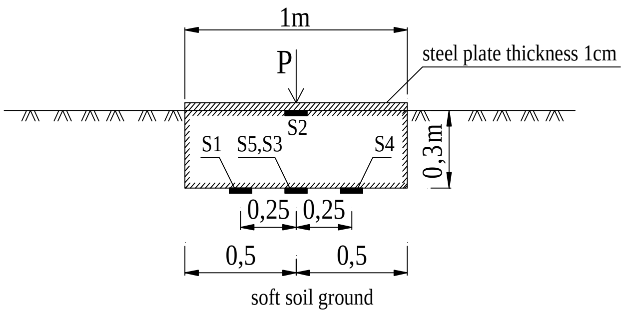

Figure 8 Layout of stress measuring device

Figure 9 Devices measuring of installation settlement

3.8 Experiment design

After installing experiment model as shown in Figure 10, carrying out the experiment with load level in the Table 3 for two cases:

- case 1: compression soil without mass stabilization;
- case 2: compression soil with mass stabilization.

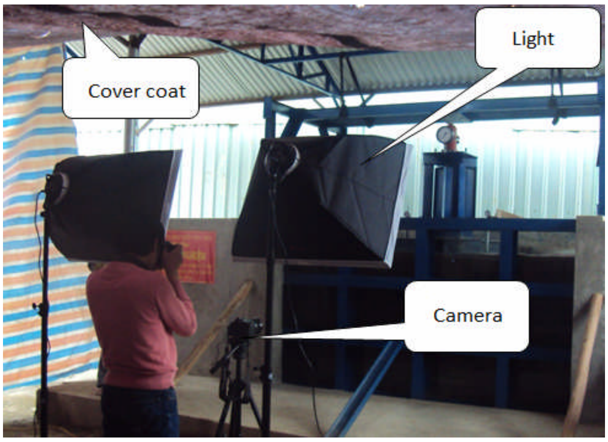

Figure 10 Model installation

Table 3 Loading design

TT	Load level (ton)	Loading (ton/m^2)	Time to maintain the load (minute)
1	0	0	0
2	0,4	0,40	30
3	0,4	0,80	30
4	0,4	1,20	30
5	0,4	1,60	30
6	0,4	2,00	30
7	0,4	2,40	30
8	0,4	2,80	30
9	0,4	3,20	30
10	0,4	3,60	30
11	0,4	4,00	30

3.9 Experimental results and discussion

- **Settlement results:** Measuring the settlement at the end of each loading stage and the final settlement for the case of nature soil and mass stabilization. The results are shown in the table 4:

Table 4 Settlement measurement of two experimental cases

TT	Single-point load (T)	Average settlement of foundation MS (mm)	Average settlement of ground (mm)
1	0	0	0
2	0,40	0,30	1,88
3	0,80	1,3	3,95
4	1,20	3,87	8,93
5	1,60	7,47	20
6	2,00	13,23	38,28
7	2,40	21,75	59,70
8	2,80	40,51	83,71
9	3,20	63,13	120,11
10	3,60	87,71	163,25
11	4,00	120,12	-
12	4,20	133,53	-

The settlement results were graphed as follows:

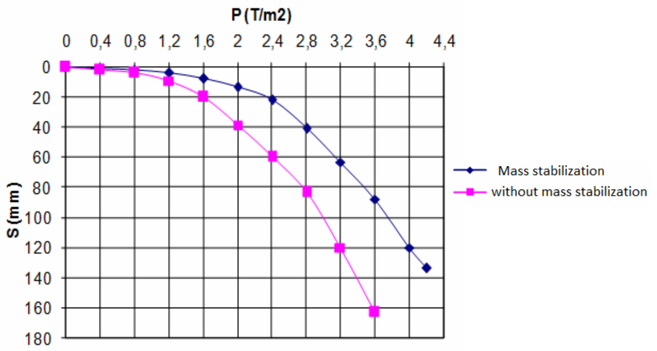

Figure 11 Stress-displacement relations of two experimental cases:

It is can be seen that: for natural ground with the intensity limit of 3,6 (T/m^2), the settlement was 163,25 mm, and for ground with 30 cm thickness of mass stabilization (MS) and intensity limit of 4,2 (T/m^2), the settlement was 133,53 mm. Thus, with the mass stabilization (MS), the bearing capacity of ground was increased by 15% and the settlement was decreased by 46.64% in compared with those of natural ground.

Figure 12 Displacement of ground without reinforcement that marked with sawdust

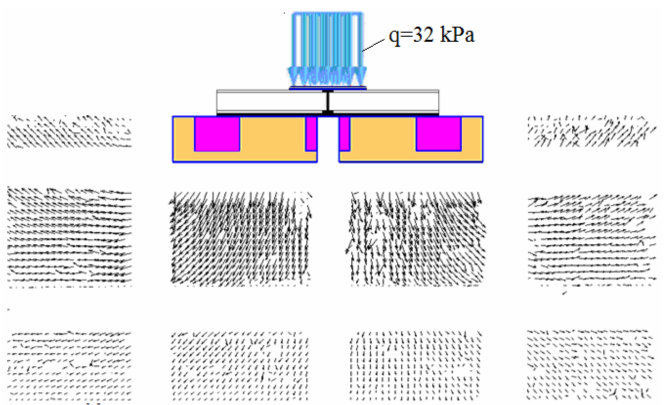

Figure 13 Displacement vector field of the ground at the destructed time was treated with PIV.

- **Comparison of settlement results for the case of mass stabilization with analytical formula:**

Overall settlement S of mass stabilization was determined by Equation 1.6:

$$S = \Delta h_1 + \Delta h_2 = 114{,}45\ mm$$

Δh_1 was calculated according to Equation 1.7:

$$\Delta h_1 = \frac{qH_T}{E_T} = 0.36\ (mm)$$

in which:

q = distributed load on mass stabilization, q= 4,2 (T/m^2);
H_T = thickness of mass stabilization, H_T=0,3 (m);
E_T = elastic modulus of mass stabilization, was determined by taking samples and conducting tests in the laboratory, E_T= 3500(T/m2).

In case of ground was fully consolidated, Δh_2 was calculated by Equation 1.9 :

$$\Delta h_2 = \frac{C_C}{1+e_0} H_S 1g \frac{\sigma_0' + q'}{\sigma_0'} = 144{,}08\ (mm)$$

in which:

q' = loading on soft soil below mass stabilization, q'=2,27 (T/m^2);
H_s = thickness of soft soil below mass stabilization, H_s =1,7(m);
C_c = compression index of soft soil under pile tip, C_c=0,29;
e_0 = porosity ratio of soft soil under pile tip, e_0= 1,52;
σ_0' = effective stress, σ_0' =0,51(T/m^2).

The results showed that the error between the analytical formula and the experiment was 7.56%. However, analytical formula was applied for the case of full consolidation. In fact, the experiment maintained the compression level at 30 minutes for each load level. Therefore, the soft soil was under full consolidation. Hence, the error between test results and analytical equation could be less than 7.56%.

4. CONCLUSIONS

Mass stabilization technique is an effective method for soft soil improvement. Especially for works such as dikes (embankments), roads in soft soil conditions and difficulties in finding construction materials. Because of several advantages such as construction without additional equipment, using in-place soft soil, and fast construction speed. Mass stabilization technology is a potential method in Vietnam in general and the Mekong Delta in particular.

The calculation method was relatively simple, can use analytical formulas as presented to design. In addition, it is possible to use geotechnical software to calculate.

The results showed that the error between the analytical formula and the experiment was less than 7.56%. This value was acceptable.

5. ACKNOWLEDGEMENT

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1. Research on solutions of soft soil treatment technology by mixing in-place soil with inorganic binder for construction of dikes in the Mekong River Delta.
2. Research on dike crack phenomenon and solutions improvement to protect dike combined rural road.

6. REFERENCES

Phung V. A. et al., (2010) "Research project on deep mixing method and ability applying for Mekong river delta". Report on the studies of the Ministry of Agriculture and Rural Development.

Basic standards TCCS 04:2014/VTC (2014) "Hydraulic construction - Soft soil treatment by mass stabilization technology - Design, construction and acceptance requirements".

Japan standards. Experimental method for field bench press for ground JSF: T25-80T.

Vietnam standard TCVN 9354-2012. Construction soil - Method for determining deformation modulus at field by flat plate.

Phung V. A. et al., (2015) "Research on solutions for soft soil treatment by soil mixing equipment with inorganic binder for hydraulic construction". Report on the studies of the Ministry of Agriculture and Rural Development.

Phung V. A. (2014) “Research on solutions of soft soil treatment technology by mixing in-place soil with inorganic binder for construction of dykes in the Mekong River Delta”. Report on Water Resources Science and Technology for the Mekong Delta and the South East Provinces.

Nguyen Q. D., Phung V. A., Vu N. B. (2014) “Research on Ground Improvement in Ca Mau with cement and cement additives combined”. Journal of Water Resources Science and Technology 2009-2014, ISBN 978-604-67-0392-1.

Allu and Rambol. Mass stabilisation manual. Allu Finland Company. EuroSoilStab. Design Guide Soft Soil Stabilisation. CT97-0351 Project No: BE 96-3177.

Le V. T., Yonglai Z., ShuXin D., Phung V. A., Ha T. L. (2015): “An Numerical Analysis of the Influence of Replacement Area Ratio in Foundation Reinforced with Soil Cement Columns”. The Electronic Journal of Geotechnical Engineering ISSN 1809-3032. Vol.20.8. pp 3821-3828. 5.2015 (EI)

Phung Vinh An, Vu Ba Thao, Nguyen Quoc Dung (2016) “An Analytical Approach for Determining the Bearing Capacity of Soil Cement Column Using Jet Grouting Technology”. 19th Southeast Asian Geotechnical Conference & 2nd AGSSEA Conference (19SEAGC & 2AGSSEA) Kuala Lumpur 31 May – 3 June 2016. pp 937-941.