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INFLUENCE OF DISTANCE BETWEEN CEMENT-FLY ASH-GRAVEL PILES ON THE FOUNDATION TREATMENT IN VIETNAM

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ABSTRACT: According to the Vietnam government's statistics, there are currently about 19 thermal power plants in operation, annually emitting about 20 million tons of fly ash which is classified as hazardous waste. This causes an urgent environmental problem. In the context of lack of construction materials, the research aiming at promoting consumption of the fly ash through the application of CFG (cement - fly ash - gravel) pile - a type of pile using a mixture of cement, fly ash, aggregate handles the foundation for construction, that may help to consume a part of the fly ash. Experimental research in the laboratory and field has been conducted. In the laboratory, the authors produced 126 samples of CFG pile mixtures and selected the optimal mixture which ensures the pile strength greater than 10MPa while still using fly ash to replace the maximum adhesive. In the field experiment, the authors performed to construct an experimental model with CFG piles under an embankment. Soil Pressure Cells and Settlement Plate was set up to monitor the development and load transfer. This paper assessed the influence of the distance between CFG piles on soft soil treatment. The optimal ratio of fly ash to cement in the mixture is from 20% to 35%, and the appropriate distance between the piles is from 4d to 6d (d- diameter of the pile). This can be an effective solution for soft soil treatment because it is feasible in terms of price and construction time. Moreover, this solution is also easy for quality control in Vietnam.

Keywords: CFG (cement-fly ash-gravel); Composite foundation, Experimental research, Distance effect, Arching effect

1. INTRODUCTION

As a developing country, Vietnam has been facing short of electricity, resulting in more and more new thermal power plants constructed in order to meet the increasing demands. These thermal power plants have been emitting a large amount of hazardous waste such as ash (consist of 75% of fly ash), which causes environmental pollution. This is considered as a consequence of the development, causing a problem for Vietnamese authorities [1]. In this circumstance, the researches on applying fly ash as a construction material have been conducted since the 80s of this century. However, the objective of those studies mainly focused on creating high-quality fly ash mixture as an adhesive for concrete. Recently, studies in Vietnam have focused on the consumption of fly ash, such as fill material in roadbed [2,3], roller-compacted concrete [4], pervious concrete [5-6], geopolymer concrete [6,7], and ultra-high-performance concrete (UHPC) [8-9] for infrastructure works. In this trend, the application of a large amount of fly ash to produce low-cost, low-strength concrete mixture for foundation treatment is very necessary.

The CFG (Cement Flying-ash Gravel) pile is a type of pile using a mixture of cement, fly ash, the aggregate of stone (gravel) to form a low-strength concrete pile for foundation treatment in basic construction works. Depending on pile length, the distance between piles, pile cap cushion layer, and the mixture ratio of pile materials, the pile can meet the required bearing capacity of the foundation treated, getting high bearing capability, small variation and simple for construction. The low-cost CFG piles have been applying in many constructions in several countries over the world. However, there is no theoretical study and experiment in Vietnam on the application of CFG pile on foundation treatment in constructions. Therefore, with advantages in foundation treatment in construction and solving a great deal of fly ash for thermal power plants, the application of CFG piles is efficient and appropriate for purposes consist of saving cost, simple to implement, quality assurance and straightforward to control quality. In addition, other advantages of this solution are decreasing the pollution caused by fly ash and solving the soil waste of thermal power plants.

Consequently, the research on the application of CFG piles in foundation treatment in construction which has practical significance and feasible plays an important role in improving quality and reducing the cost of constructions in Vietnam.

2. CFG PILES IN SOFT SOIL FOUNDATION TREATMENT

2.1 CFG Development

Application of CFG pile is classified as an embankment measure on piles system according to the list of embankment treatment methods on soft soil.

CFG piles together with soil between piles and pile cap cushion layer form a composite foundation to ensure stability for the embankment on soft soil.

In 1985, the Institute of Foundation Engineering of China Academy of Building Research studied the application of CFG pile in foundation with ballast pile added to cement and fly ash to create high-strength piles. CFG piles are made by specialized machine, and the mixture of CFG pile materials is poured into the pre-drilled borehole and then the piles are formed in the ground. With advantages of high load capability, small variation, simple for construction and low cost, this method is widely applied for construction include buildings, roads, railways and depots in China and some countries in the world. Researches in China on theoretical models, calculation theory, technical requirements on materials and construction techniques have been conducted. D.Xiao et al. (2018) conducted a series of 3D centrifuge model tests on an approach embankment over a silty clay deposit reinforced by CFG piles combined with geogrid. Through a numerical study, the research shown that the performance of abutment piles is significantly improved when reinforcing the ground with CFG piles beneath the approach embankment. In addition, if the ground replacement ratio of the pile-reinforced grounds above 4.9%, the effect of CFG pile foundations is limited [10].

2.2 Structure, Specifications and Working Principle of the CFG piles

The CFG piles have a diameter from 350mm to 600mm. By changing cement content and proportion in the CFG pile mixture, the strength grade of CFG piles varies from C10 to C25, and it also is between the rigid pile and flexible pile [11, 12]. The CFG piles work with soil between piles through its cap cushion arrangement, which forms the composite foundation. As a result, the foundation can utilize bearing capability of soil between piles and also transfer the embankment load to hard soil layer in order to increase stability, reduce settlement risk for the embankment and bring high technical and economic efficiency. Furthermore, the CFG pile effectively make use of fly ash released from the thermal power plants. , the CFG pile does not need reinforcement steel, which helps to save materials cost, so this enhances economic efficiency.

The CFG pile method is calculated and designed based on working principle of the composite foundation. The main factors including composition and proportion of pile materials, pile length, the distance between piles, size of pile cap, structure and thickness of cushion and construction technique need carefully calculating, designing, experimenting, analyzing to meet requirements on bearing capacity of foundation treated.

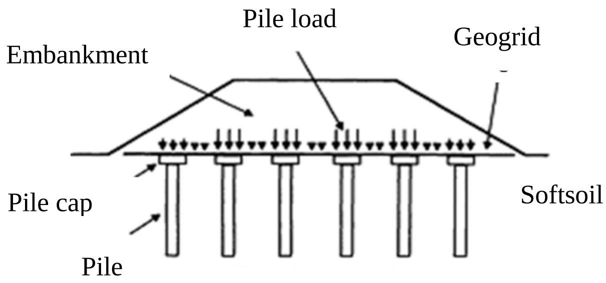

Fig. 1 Stress of embankment on the composite foundation.

The distance between relies on bearing capability of the composite foundation, properties of geological layers and construction techniques. The experimental studying on centrifugal model shows that the distance between piles should be from 3 to 6 times as large as pile diameter [13]. In order to reduce cost, the distance between piles should be set as large as possible; however, there is no experimental study on the distance between piles which is 6 times as large as pile diameter.

The length of the pile is designed to end at the geological layer which has sufficient bearing capability to transfer the load from the embankment. In other cases, pile length can be calculated based on the frictional forces. Because the pile strength is larger than the embankment strength so the stress on piles are also higher than that on the soil between piles (Figure 1).

The pile cap is commonly made of concrete in order to distribute the load from the embankment on the pile, decrease the pile diameter, increase the distance between piles, and save materials. The dimension of pile cap affecting the load distribution ability of the cushion is designed as 10% to 30% as large as of working area of pile cross-section [13].

The cushion on pile cap is designed to adjust the stress of piles and soil between piles, reduce stress at pile cap, reinforce bearing capability of the foundation. Design of cushion is an important step in the composite foundation, which is an essential task to ensure the bearing capability of piles and foundation. Composition of the cushion should be medium grain size sandstone, coarse-grained sand, selected sand, ballast aggregate or pebble gravel with the size of sandstone no larger than 30mm. A geotextile layer can be spread on the pile cap to form a cushion distributing the load on piles. The cushion should be 150÷500mm thick, and compression strength is not greater than 0.9. The thickness of the cushion increases accordingly the rise of pile diameter and distance between piles [14].

Based on theoretical study and experimental design the CFG pile for foundation treatment with the distance between piles which is 6 times as large as of pile diameter. The authors have conducted the field experiments to evaluate the working ability of composite foundation and piles in which distance between piles ranges from 4d to 6d of piles (d is pile diameter) corresponding to embankment model with a height of 4m.

3. EXPERIMENT ON LABORATORY TO DEFINE PROPORTION OF FLY ASH IN CFG MIXTURE

3.1 Design of Aggregate for CFG Mixtures

The authors have performed experiments with three different types of fly ash including Pha Lai thermal power plant, Nghi Son thermal power plant, and Ninh Binh nitrogenous fertilizer plant. Then aggregate is mixed to find the appropriate ratio of fly ash/adhesives in CFG mixtures.

In experiment scope, the authors selected the ratio of water to cement is 0.65. The designed sample is 7, and the content of fly ash replacing adhesive varies from 0% to 35%. Through the absolute volume calculation method, the calculation for 1m3 of CFG mixtures is shown in Table 1.

Table 1. Calculation results of concrete mixtures using fly-ash as additives for $1m^3$

F/C (%)	Cement (Kg)	Fly Ash (Kg)	Sand (Kg)	Stone (Kg)	Water (Liter)
0	280	0	802.67	989.33	194.67
10	252	28	799	982.67	194.67
15	238	42	796	980	194.67
20	224	56	793.33	977.33	194.67
25	210	70	790.67	974.33	194.67
30	196	84	788.67	972.67	194.67
35	182	98	786	970.67	194.67

3.2 Experiment Result

The number of experimental samples is prepared according to the standard "TCVN 3118:1993 Concrete – Compression strength" [15].

The number of samples: 6 cube samples: 10 x 10 x 10 (cm) to define compression strength R_n; The total number of samples is 7x6x3=126.

3.3 Aggregate Design Results

The compression strength value selected is the average value of 6 samples. R_n values at 3rd day; 7th day, 14th day and 28th day is recorded. Experimental results show that the CFG mixtures using fly ash from Nghi Son power plant and other places with a proportion of 35% to replace the adhesive still get compression strength value R_n >10MPa, which are suitable to be used in CFG pile construction.

Table 2. Compression Strength R_n values at 28th day of samples adding fly ash from Nghi Son power plant.

F/C	R_i at 28^{th} days (MPa)						R_{ntb6}
	R_{n1}	R_{n2}	R_{n3}	R_{n4}	R_{n5}	R_{n6}	
0%	15.5	15.7	15.8	15.6	15.9	15.7	15.7
10%	14.6	14.8	14.7	14.8	14.9	14.7	14.7
15%	13.2	13	13.1	13.2	13	13.2	13.1
20%	11.7	11.6	11.5	11.6	12	12	11.7
25%	10.9	10.8	10.6	10.7	10.8	10.9	10.8
30%	10.6	10.7	10.8	10.6	10.7	10.5	10.7
35%	10.6	10.7	10.5	10.8	10.5	10.6	10.6

As a result, from selection materials (PC40 but Son cement, Red River river sand, fly ash from Pha Lai, Nghi Son thermal power plants, and Ninh Binh nitrogenous fertilizer plant; gravel and water), the authors have found out optimal aggregate ensuring cost-effectiveness in manufacturing CFG pile for foundation treatment in construction.

4. FIELD EXPERIMENTS ON SITE CFG PILE CONSTRUCTION

4.1 Field Experiments and Geological conditions

Field Experiments is at the experiment site of the National University of Civil Engineering at Ha Nam province, Vietnam.

Using approved geological parameters [16], according to the geological survey report LKBS02, surveyed depth at 15m with geological layers: Covered soil layer: Pond and field mud, brown grey and dark grey colours (1). 0.5m thickness; Clay layer mixed with organic soil, grey-brown colour and soft clay (2) 3.9m thickness; Clay layer mixed with fine sand, brown-grey, dark grey colours, soft clay (3) 7,3m thickness; Mixed sand layer, brown-grey, dark grey colours and soft clay (3) thickness is the rest of surveyed depth. Properties of the soil layers are presented in the appendix. Depth of underground water: 0.00m.

The unit weight of embankment material is 1.8 T/m3 (river sand embankment is compacted at compactness 85%).

4.2 Technical Scale of Experiment

Section 1: Design with different load capacity, and each 20m section arrange piles which are described in Figure 2. Pile is 0.5m diameter, 12m length, and the pile cap is 1.1m diameter with the distance between piles is 3m, the average height of the embankment is 4m.

Section 2: Design with a larger bearing capability than section 1 with a length of 15m for warehouse, the foundation of low-rise buildings (5 stories and lower). Pile is 0.5m diameter and 12.0m length, and the pile cap is 1.1m diameter with the distance between piles is 2m and the average height of the embankment is 4m.

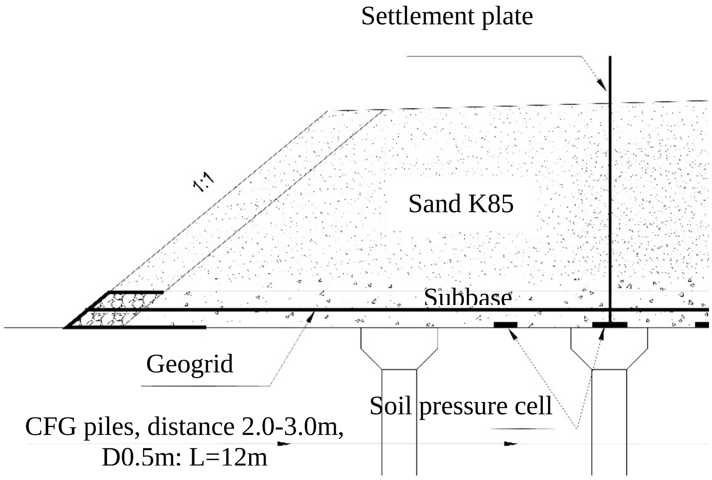

Fig. 2 A haft cross section of experimental embankment in Section 1

4.3 Construction Phase

4.3.1 Materials of CFG pile

CFG pile material: gravel 1x2, from Ha Nam quarry, Red River river sand, Nghi Son thermal power plant fly ash and But Son PC40 cement;

Pile cap cushion materials: crushed rock aggregate type 2 from Ha Nam quarry; Geotextile with tensile strength 50kN/m. Embankment materials: Red River river sand, Unit weight - $\gamma = 1.8$ T/m3. Other materials: bored pipes; Settlement plates.

4.3.2 Construction of CFG Piles

The design parameters of CFG piles are the ratio of fly ash to adhesive (Fly-ash to cement) in which the proportion of fly ash is 25%, and the ratio of water to cement which is 0.65.

Table 3. Selection aggregate for CFG pile construction

F/C (%)	Cement (Kg)	Fly ash (Kg)	Sand (Kg)	Stone (Kg)	Water (Liter)
25	210	70	790.67	974.33	194.67

4.3.3 CFG Pile Construction Technique

Based on the geological survey results, the authors select the mini drilling stuffing technique to conduct construction and form piles according to the design.

Fig. 3 CFG pile construction process

Fig. 4 Pile site after construction

4.3.4 Installation of measuring equipment

The Authors arrange 6 soil pressure cells with 2.0MPa cell at pile cap, 0.2 MPa at soil between pipe cap. Cells position are indicated in Fig.5 and Fig.6.

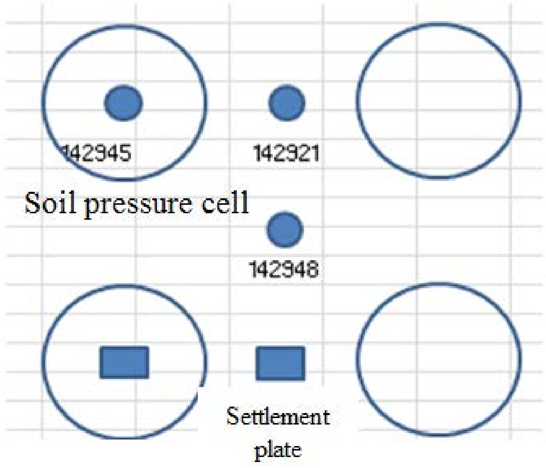

Fig. 5 Soil Pressure Cell diagram at 2m pile distance

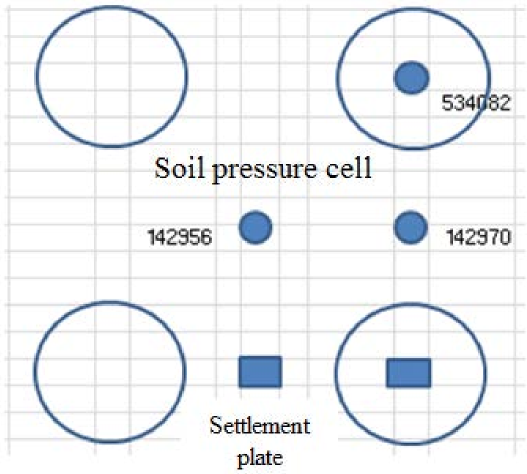

Fig. 6 Soil Pressure Cell diagram at 3m pile distance

5. ANALYSIS OF EXPERIMENT RESULT

5.1 Settlement Monitoring Results by Settlement Plates

Settlement monitoring results is shown in Table 4.

Table 4. Settlement monitoring results at distance between piles is 2m

Plate	Settlement Value by Day (cm)					
	Day 1	Day 3	Day 5	Day 10	Day 30	Day 60
#1	1.7	2.3	2.3	2.3	2.4	2.4
#2	5.2	6.3	6.4	6.5	6.5	6.5

Findings:

Foundation is completely stable, settlement measurement results show that the settlement value at soil between piles is higher than that on the pipe. Settlement measurement results at 3m pile distance are higher than these at the 2m pile distance.

Settlement values of soil between piles are small at first and gradually increase over time. After the 3rd day, the values become stable, reaching a maximum at 9.2cm.

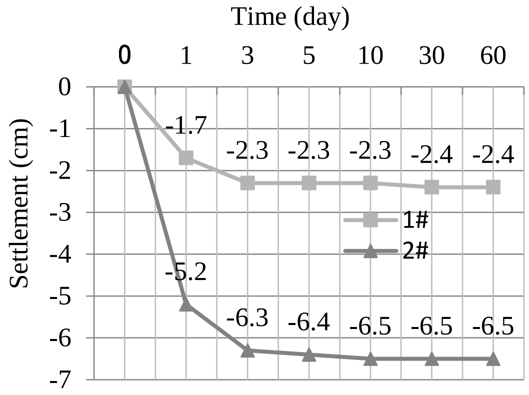

Fig. 7 Settlement measurement results at 2m pile distance

Table 5. Settlement measurement results at 3m pile distance

Plate	Settlement Value by Day (cm)					
	Day 1	Day 3	Day 5	Day 10	Day 30	Day 60
#3	2.2	3.2	3.2	3.3	3.4	3.5
#4	6.2	8.8	8.9	9.0	9.1	9.2

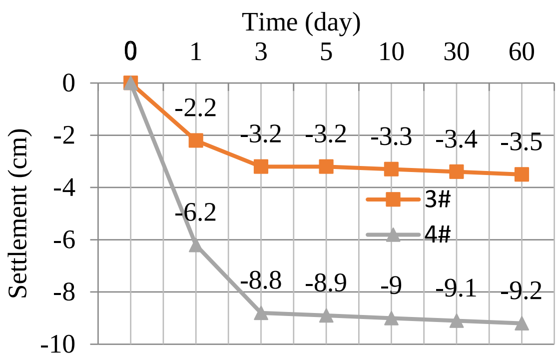

Fig. 8 Settlement measurement results at 3m pile distance

5.2 Pressure Measurement Results at Pile Cap and Soil between Piles

Pressure measurement results at pile cap and soil between piles are shown in table 6.

Table 6. Pressure measurement results at pile cap and soil between piles at 2m pile distance

Cell	Pressure value (MPa)				
	CP	CP	CP	Day 1	Day 3
142945	0.028	0.042	0.077	0.108	0.119
142921	0.022	0.033	0.061	0.054	0.058
142948	0.015	0.019	0.03	0.027	0.029
Cell	Pressure value (MPa)				
	Day 5	Day 10	Day 30	Day 60	/
142945	0.13	0.141	0.143	0.144	/
142921	0.053	0.05	0.048	0.049	/
142948	0.028	0.027	0.026	0.026	/

Construction Process (CP)

Pressure measurement values on soil and soil between piles show that the values do not clearly change at the beginning of construction process until the embankment reach 4m height where the values significantly change and pressure of load gradually transfer to piles through pile cap cushion layer. The maximum value at the pile cap is 0.143MPa, and minimum value at soil between 4 piles is 0.026MPa. Foundation works on the principle of composite and on vertical then pressure values also change and gradually stable.

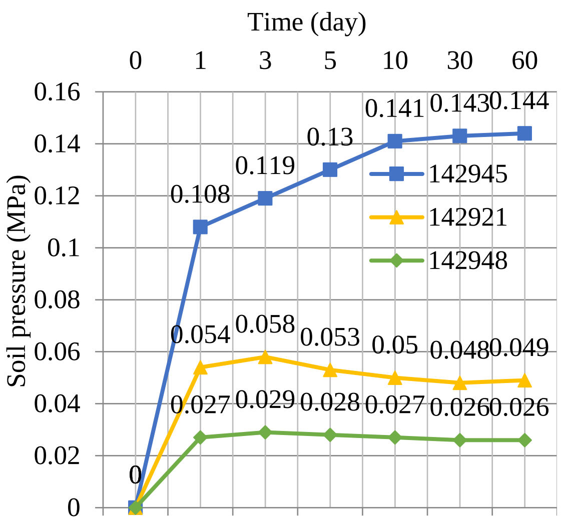

Fig. 9 Soil pressure results at 2m pile distance

The experimental results indicate that soil pressure in pile cap and soil between piles increase over time, which clearly are showed in the construction phase. And then the soil pressure in pile cap continues to rise and become stable after 60 days, and the soil pressure in soil between piles gradually decrease and become stable.

Table 7. Pressure measurement results at pile cap and soil between piles at 3m distance

Cell	Pressure value (MPa)				
	CP	CP	CP	Day 1	Day 3
534082	0.016	0.039	0.069	0.097	0.107
142970	0.024	0.049	0.066	0.067	0.068
142956	0.017	0.036	0.071	0.074	0.077
Cell	Pressure value (MPa)				
	Day 5	Day 10	Day 30	Day 60	/
534082	0.119	0.131	0.136	0.137	/
142970	0.066	0.064	0.062	0.064	/
142956	0.075	0.072	0.07	0.07	/

Construction Process (CP)

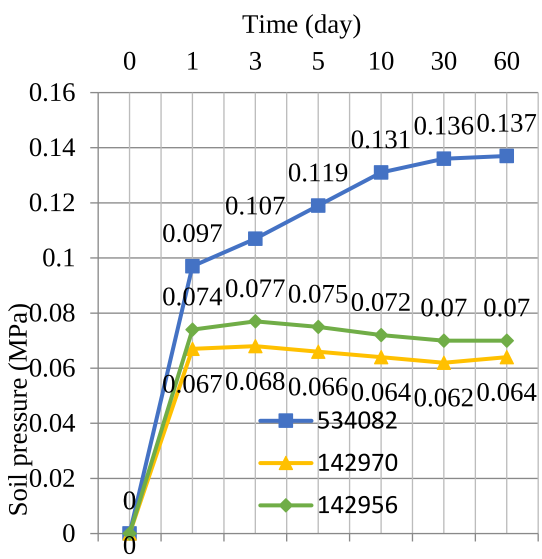

Fig. 10 Soil pressure results at 3m pile distance

This development shows that when the settlement difference between the pile and the soil between piles is 4.1cm and 5.7cm for the cases that distance between the piles is 2.0m and 3.0m, respectively, the embankment load start to distributing, and mainly focusing on the pile caps, which gradually form arching effect on pile caps. When the arching effect forms, the soil pressure between the piles will decline gradually, and depending on the difference between the piles and soil between the piles, this value may change to 0. In addition, the experimental results also show that in the case that the distance between piles is 2.0m has the soil pressure between piles is smaller than that of the case that this distance is 3.0m, 0,026MPa compared to 0.07MPa.

6. CONCLUSION AND SUGGESTIONS

6.1 Conclusion

In conclusion, the study yields several interesting results. Firstly, after conducting the laboratory experiment, the authors detected that the optimal ratio of fly ash to cement in the mixture is from 20% to 35%. This show that using CFG piles in treatment foundation contribute to consuming a significant amount of fly ash emitted annually. Secondly, through field experiment, the study proves that the optimal distance between piles is from 2.0 to 3.0m which equal to 4d to 6d, with d is the diameter of the pile. This distance between piles can treat effectively the foundation with high stability at a small settlement value. In the present context, using CFG piles in treatment foundation help to solve a large amount of fly ash in an efficient, sustainable and friendly way. The research is a useful reference for CFG pile design and construction standard development in Vietnam in the future.

7. ACKNOWLEDGEMENT

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