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Utilization of EPS Geofoam for Bridge Approach Structure on Soft Bangkok Clay

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Abstract. Differential settlement along bridge approach structure is one of the continuing problems for highway construction in Bangkok and its vicinities due to soft ground foundation. To minimize the differential settlement and serviceability failure, an approach slap on piles with varies pile length is a current geotechnical engineering practice for the bridge approach structure construction. Instead of ground reinforcement by piles as a bearing unit, EPS Geofoam could be utilized as a lightweight embankment along the bridge approach, and could be an alternative solution to reduce differential settlement problem and repair works in the city area in which fast construction time is the main requirement. Two case studies of bridge approach structure were investigated, and different types of bridge approach structure, including approach slap on pile with different pile length distributions, and application of EPS, were evaluated in terms of engineering performance and construction and maintenance cost, and time. The results show that utilizing domestic EPS Geofoam for bridge approach structure could increase the construction cost by 20 to 30%, however, it could save construction period and could reduce the long-term maintenance cost.

Keywords. Bridge approach structure, EPS Geofoam, differential settlement, relief pile

1. Introduction

Differential settlement along bridge approach structure has been one of geotechnical challenging problems found in Bangkok and its vicinities because the subsoil consists of soft delta deposits. The highway embankment, which is construction on 8 to 15 m thick soft Bangkok Clay, could have a large settlement due to primary consolidation. In contrast, the bridge foundation, consisting of long piles, transfers the load to a firm layer and, as a result, a minimal settlement occurs. After construction and usage, high differential settlement could reduce road safety and cause driver discomfort, and require regular maintenance works.

To reduce the differential settlement along bridge approach structure in Bangkok and suburb areas, an approach slab on relief piles has been utilized and become a common practice for a highway construction. For a local road and street with light traffic on firm ground, an approach slab on embankment has been constructed. Instead of the relief pile solution on Soft Bangkok Clay, a light weight material could replace the compacted embankment material and the settlement is reduced due to low overburden pressure. For example, Expanded Polystyrene (EPS) which is a light weight material, has been utilized for highway construction and civil works more than 40 years. In Europe and US continent, approximately 70% of EPS market is currently used for construction industry (Yamanaka, et al., 1996; Horvath, 1999;http://www.geofoam.com, www.EPSFoamPro.com).

Figure 1. An example of EPS Geofoam construction for bridge approach structure at Wat-Nakorn-In Bridge, Bangkok, 2002

In Thailand, more than 85 percent of EPS is mainly used for packaging industries and EPS Geofoam had been introduced for lightweight embankment construction more than 20 years and some individuals start to utilize it for building construction due to its light weight and good insulation properties (Hiranpradit, 2013). Available records show that 4 trial embankment sections using EPS Geofoam had been constructed, illustrated in Figure 2, and only one section (Point 1, in Figure 2) was failed by uplifting problem. This study reviews utilization of domestic EPS for bridge approach structure on Soft Bangkok Clay. Series of laboratory testing program were conducted on domestic EPS Geofoam products and compared with the ASTM standards for highway construction, including density (ASTM C303-10,D1622-08), compressive resistance (ASTM C165, D1621-10), flexural strength (ASTM C203-05a, reapproved 2012), and oxygen index (ASTM D2863-12) (Vardhanabhuti et al., 2014). The long-term engineering performance, and construction cost and maintenance were evaluated through 2 case studies located in the north and south of Bangkok.

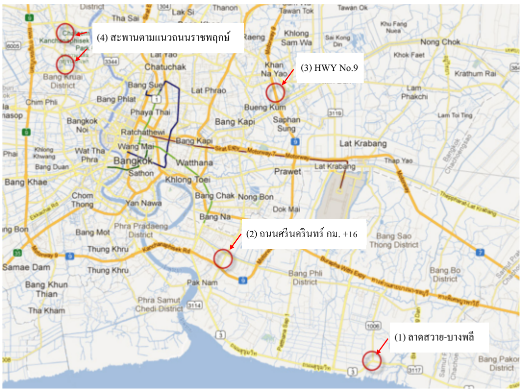

Figure 2. EPS Geofoam construction for road embankment in Thailand

2. Engineering Properties of domestic EPS

EPS Geofoam is a thermal plastic polystyrene which is very light weight, durable, and has a decent compressive resistance comparing to typical construction materials, as shown in Tables 1 and 2 (adapted from Miki; 1996). In Thailand, EPS Geofoam is produced from resin or bead supplied by Thai petroleum industry and imported resin from neighbor countries such as China, Indonesia, and Vietnam. The domestic EPS Geofoam (including flammable and inflammable classification) has 5 grades and the density ranges from 12.8 kg/m^3 to 32.2 kg/m^3, as shown in Table 3. The commercial size of domestic EPS Geofoam block is 0.6m x 1.2m x 6m. Engineering properties of domestic EPS Geofoam specimens were determined in a laboratory and compare with the ASTM standard requirement (ASTM D6817), summarized in Table 4. Long term deformation, settlement induced by cyclic loading, and interface shearing resistance had been studied (Vardhanabhuti et al, 2014). Significant EPS behaviors include the non-failure stress-strain behavior, and noticeable time dependent deformation when the strained increase higher than 1%, and cyclic loading dependent deformation (see Figures 3 and 4). The critical criteria of EPS for construction industry is the strain control (ε = 1%) within elastic limit stress and Oxygen Index. Based on extensive laboratory testing of EPS samples for construction, the domestic EPS has a good quality assurance and standard deviation (STD) of the test results is relatively low. However, the STD value tends to increase as the EPS Grade (or density) increases. (Vardhanabhuti et al., 2014)

Table 1. Comparisons of unit weight of EPS Geofoam and different light weight embankment and construction materials

No.	Material	Unit Weight (kg/m^3)
1	EPS	16 - 32
2	Air foamed mortar and air foamed light weight soil	> 500
3	Coal ash and granular slag	1,000 – 1,500
4	Hollow structures	1,000
5	Wood chips	700 – 1,000
6	Tie chip	700 - 900
7	Concrete	2,300
8	Asphalt	2,300
9	Soils	1,600 – 2,500

Table 2. Comparisons of compressive strength (q_u) of EPS Geofoam and construction materials

No.	Material	q_u (kg/cm^2)
1	EPS (ε = 1%)	0.3 – 0.8
	(ε = 5%)	0.7 – 1.9
	(ε = 10%)	0.8 – 2.3
2	Concrete (28 days)	300
3	Brick	35
4	Soft clay	0.25 – 0.5
5	Stiff clay	1 – 2

Table 3. Available domestic EPS Geofoam grades and ASTM requirement (ASTM D6817)

Standard	Density, kg/m^3 (lb/ft^3)				
ASTM	EPS 12	EPS 15	EPS 19	EPS 22	EPS 29
	11.2 (0.70)	14.4 (0.90)	18.4 (1.15)	21.6 (1.35)	28.8 (1.80)
Thai	II	III	IV	V	VI
	12.8 (0.8)	16.0 (1)	20.0 (1.25)	24.0 (1.5)	32.0 (2)

Table 4. Average engineering properties of EPS Geofoam in Thailand (Vardhanabhuti et al, 2014)

Properties	EPS III	EPS IV	EPS V	EPS VI
Density (kg/m^3)	15.4	19.2	23.0	30.7
q_u (kPa) $\varepsilon = 1\%$	34	48	62	91
$\varepsilon = 5\%$	81	110	139	198
$\varepsilon = 10\%$	92	123	153	215
Flexural Strength(kPa)	144	205	265	387
Elastic Modulus (kPa)	2,365	3,950	6,765	8,340
Coef. of Interface Friction	0.64	0.65	0.60	0.60

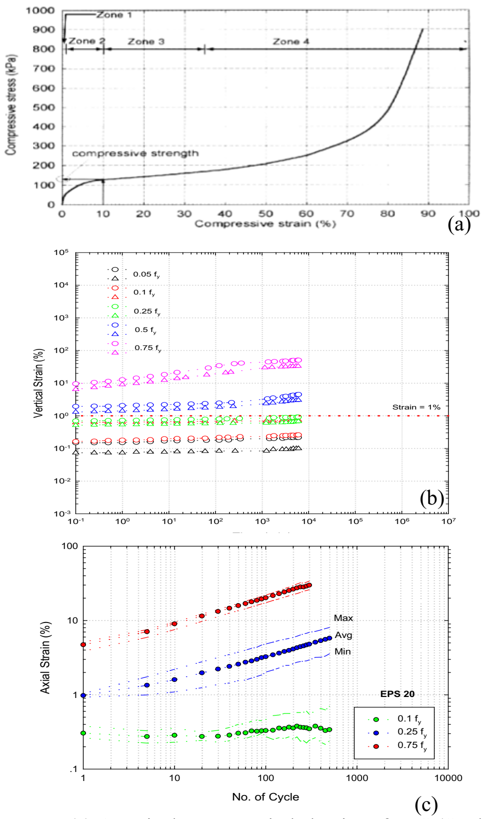

Figure 3. (a) A typical stress-strain behavior of EPS (Stark et al., 2004), (b) An example of Long-term Deformation behavior and (c) Influence of cyclic loading of domestic EPS Geofoam specimen Grade IV (5x5x5cm)

3. Case Studies of Bridge Approach Structure on Soft Bangkok Clay

Two bridge approach structures were studied, including (1) Bang Ta Nai Bridge (on HWY.345, finish construction in 2007) located in North of Bangkok and (2) Klong Kut-Baan Boh Bridge (on HWY. No.35, finish construction in 2008) located in the South of Bangkok. The soil profiles are shown in Figure 4. The lengths of bridge approach structure are 49.5 m and 75 m, for Bang Ta Nai Bridge and Klong Kut-Baan Boh Bridge, respectively.

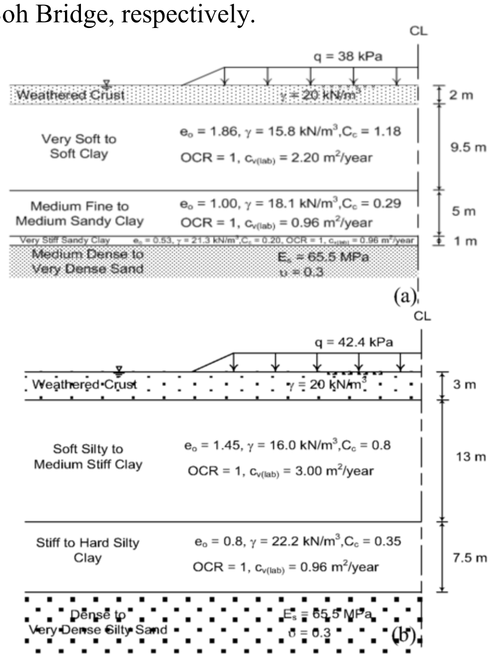

Figure 4. Soil profile (a) Bang Ta Nai Bridge (on HWY.345) and (b) Klong Kut-Baan Boh Bridge (on HWY. No.35)

For each site, three cases of bridge approach structures were analyzed, including Case (I) the typical approach slab on relief piles according to the typical DOH standard drawing which has a constant slope of pile tip and used for construction, Case (II) an approach slab on relief piles with long-term settlement consideration for pile tip variation, and Case (III) EPS Geofoam utilization. For II and III, the primary settlement analysis was considered using Terzaghi' theory of consolidation (Terzaghi, 1943). The results are shown in Figures 5 and 6.

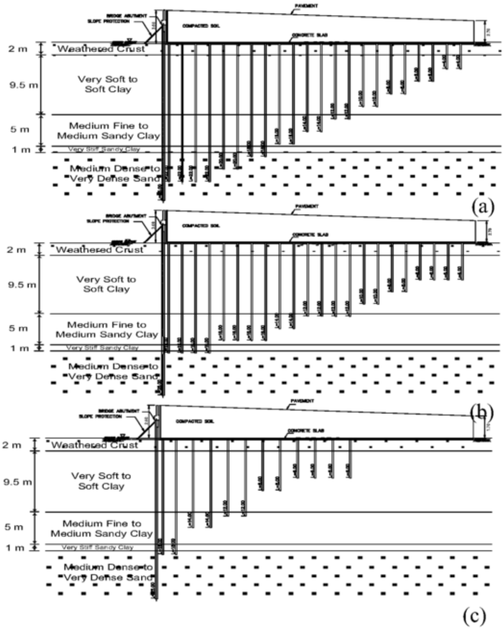

Figure 5. Analysis results of Bang Ta Nai Bridge (a) Case I, (b) Case II and (c) Case III

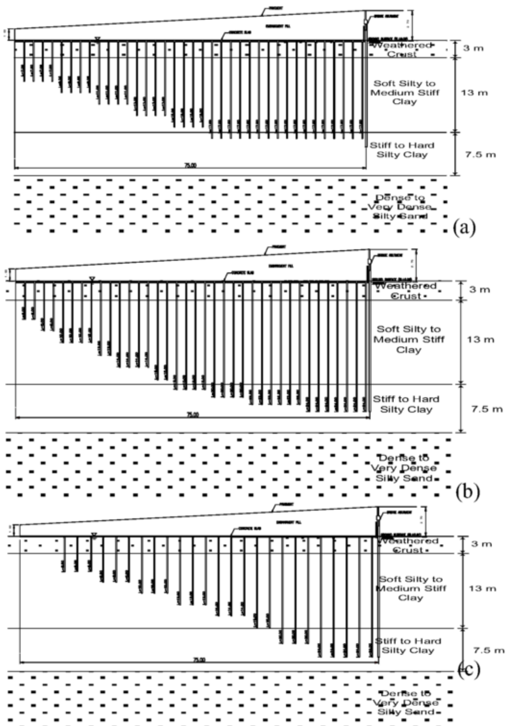

Figure 6. Analysis results of Klong Kut-Baan Boh Bridge (a) Case I, (b) Case II and (c) Case III

For Bang Ta Nai Bridge, in Case (I), the pile length ranges from 4 m to 22 m, square pattern @ 2 m. The total number of pile is 267. For Case (II), the pile length ranges from 6 to 18 m, square pattern @ 2m. The total number of pile is 267. In Case (III), the pile length ranges from 6 to 18 m, square pattern @ 2.5 m. The total number of pile is 128. For Klong Kut-Baan Boh Bridge, in Case (I) the pile length ranges from 7 m to 17 m, square pattern @ 2 m. The total number of pile is 161. For Case (II), the pile length ranges from 6 to 24 m, square pattern @ 2m. The total number of pile is 121. For Case (III), the pile length ranges from 6 to 24 m, square pattern @ 2.7 m. The total number of pile is 91.

The settlement analysis revealed that the settlement magnitude is mainly contributed from the primary consolidation of the soft Bangkok Clay layer. In Case (I), although the approach slab on pile is utilized, differential settlement problem still occurs, especially at the connection between bridge and highway embankment and the transition zone where the pile tip is in soft soil layer (friction pile behavior) and stiff soil layer (end bearing pile behavior).

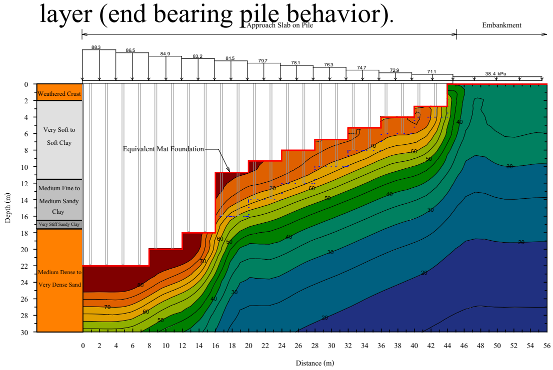

Figure 7. An example of noticeable change in vertical stress distribution underneath approach slab on pile (from friction pile to end bearing pile), Klong Bang Ta Nai Bridge (Vardhanabhuti et. al., 2012)

The construction and long-term maintenance costs were estimated for 25 year life-time structure. Note that, in Thailand, the domestic EPS Geofoam cost is approximately equal to the concrete cost per volume unit. The results show that the approach slab on relief piles (Case I and II) has the lowest construction cost. The construction cost of domestic EPS Geofoam with pile relief is approximately 1.3 to 1.7 times higher than the approach slab on relief piles. However, the construction period of EPS

Geofoam is about 1.3 times faster than the approach slab on relief piles. The typical standard of approach slab on relief piles has the highest maintenance cost because the length of relief pile is not proper designed for subsoil condition which could vary in Bangkok and its vicinity. Therefore, long-term differential settlement occurs and overlaid pavement along the bridge approach has to be done regularly every 2 – 3 years. For 25 years life-time, the maintenance cost could become higher than the construction cost as summarized in Tables 5 and 6 (assuming an interest rate of 3%/year, and 1 Euro = 37 Bahts).

Table 5. A cost estimate analysis for Bang Ta Nai Bridge

Case	Construction (Bahts)	Accumulated maintenance (Bahts/25 years)	Total (Bahts)
I	4,888,735	11,562,262	16,450,997
II	4,759,105	6,037,288	10,796,393
III	8,240,000	6,037,288	14,277,923

Table 6. A cost estimate analysis for Klong Kut-Baan Boh Bridge

Case	Construction (Bahts)	Accumulated maintenance (Bahts/25 years)	Total (Bahts)
I	2,068,245	5,257,787	7,326,031
II	2,294,725	2,745,377	5,040,102
III	2,976,170	2,745,377	5,721,547

4. Conclusions

The long-term performance analysis and cost estimation showed that, for the present construction cost, an approach slab on relief piles is 1.3 to 1.7 times cheaper than the EPS Geofoam on relief piles. However, using the typical DOH standard of approach slab on relief piles (with a constant slope of pile tip), differential settlement problem still occurs. The maintenance cost would be very high, and could be equal to 1.9 to 2.5 times the construction cost. With appropriate settlement analysis and design length of relief pile, the long-term differential settlement could be reduced, minimize the maintenance cost. An advantage of the EPS Geofoam is the short construction period which is about 1.3 times faster than that of approach slab on relief pile. Furthermore, the construction sequence of EPS Geofoam is simple, and noise, vibration and dust pollution are greatly reduced which are currently main problems for construction in Bangkok and urban area. Utilization of EPS Geofoam for a bridge approach structure should not be ignored during the feasibility study for embankment construction on very soft Bangkok Clay for the replacement of existing bridge approach structure in high populated area which environmental aspects and construction period are major concerns.

5. Acknowledgement

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