SOME CONSTRUCTION EXPERIENCES ON SOFT SOIL USING LIGHT WEIGHT MATERIALS

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ABSTRACT

Time dependent settlement of soft soil poses serious maintenance problem to the developments along the coastal area encountering thick marine deposits. Rehabilitation works for properties suffering settlement problem in soft soil deposits generally face with time and facility services constraints. These constraints hampered the selection of remedial methods which require longer construction duration and ample land spaces. Remedy using lightweight materials made of expanded polystyrene (EPS) blocks is a feasible alternative to overcome the above constraints. As the density of lightweight material is about 1.0 to 1.5% of fill material, post construction settlement can be minimised. Successful application of lightweight material to mitigate differential settlements of the approaches of two piled culverts of an expressway is presented.

1 INTRODUCTION

Quaternary deposit covers the majority of west coast of Peninsular Malaysia. This deposit generally consists of thick layer of unconsolidated soil strata predominantly soft marine clays and silts. As major economic activities and social developments are concentrating along the coastal area, the construction industry is constantly facing with challenges dealing with soft soil construction.

The characteristics of soft soil are high compressibility, low shear strength and low permeability. Compare to other type of soils, the strength development of soft soil is time dependent. General construction problems in this deposit are insufficient bearing capacity, excessive post construction settlement and instability on excavation and embankment forming. The engineering characteristics on soft soil are well documented through researches and field trials. Experiences gained from full scale trial embankments in this region on soft Bangkok Clay and Muar Clay are generally referred when dealing with construction in soft soil.

Common construction methods in soft soil are soft soil replacement; Expedite porewater dissipation and platform settlements through the insertions of prefabricated vertical drains (PVD) and surcharge fills; Modify subsoil bearing capacity through the installation of stone column or sand compaction piles; Embankment basal strengthening with geosynthetics; Use of light weight material made of Expanded Polystyrene blocks to replace conventional fills, etc. The applications of these methods are constrained by technical feasibility, construction cost, space and time constraints and sometimes client's preferences.

Application of lightweight materials dates back to 1972 at Oslo, Norway for the roadwork construction projects. However the first application of this technology in Malaysia is in 1992 for the remedy of settlements of a bridge abutment. Some applications of light weight materials, namely expanded polystyrene (EPS) blocks locally are summarised as follows:

1. Remedial of bridge abutment settlements at Kota Bridge II, Klang, Selangor, 1992.

2. Construction of lightweight road embankment at Teluk Kalung Bypass, Kemaman, Terengganu, 1994.
3. Construction of approach embankment to overpass bridge at Sungai Tengi, Kuala Selangor, Selangor, 1995.
4. Strengthening of a retaining wall behind a rock crusherun quarry, 1996.
5. Remedial of differential settlement problem for a bus terminal platform, 1996.
6. Transition treatment between the approach embankment and a major bridge at the main entrance of Tanjung Pelepas Port, Johor, 1997.
7. Remedial of platform settlement at Sg. Dua Toll Canopy, Penang, 1997
8. Strengthening of bridge abutments on both sides of a bridge, 1999.
9. Transition treatment of a railway bridge abutment founded on the reclamation fills at Tanjung Pelepas Port, Johor, 2001.
10. Mitigate platform settlement at Sg. Dua Toll Canopy Extension Works, Penang, 2002

This paper presents a case history of using EPS for transition treatment at the approaches of two piled culverts at an expressway.

2 ENGINEERING CHARACTERISTICS OF THE LIGHTWEIGHT MATERIAL

Polystyrene foam is manufactured by expanding small semi solid beads (raw material) under controlled pressure and steamed in a chamber. The finished product is very light structure of interlocking cells. With the selection of designated grades of raw materials and manufacturing process control, the desired grade of polystyrene foam can be produced. In civil engineering applications, four common grades are available. These are denoted as Standard Duty (SD), High Duty (HD), Extra High Duty (EHD) and Ultra High Duty (UHD) according to BS 3837 Part 1 (1986).

According to Malaysian Plastics Manufacturers Association, the recommended EPS block size should be 1.244mm*2.464mm*0.533mm (MPSI, 1995). The recommended block dimension however is not widely adopted. Block dimension is pending on the application request and the availability of chamber size.

2.1 Mechanical Properties

Although polystyrene foams are graded according to the maximum compressive strength (Table 1), the stresses which yield occurs are more significant. Considering of repeated loading imposed on the expanded polystyrene fills, which might induced non-recoverable plastic strains, the design yield stress shall be limited to compressive strength at 1% strain ($f_{c'\ 1\%\ strain}$). According to Sanders & Seedhouse (1994), long term creep deformation under cyclic deformation is less significant when the initial compressive strength is limit to 1% strain.

Table 1 Engineering properties of lightweight expanded polystyrene foam

Grade	Density Kg/m^3	$f_{c'\ 1\%\ strain}$ KN/m^2	$f_{c'\ 10\%\ strain}$ KN/m^2	$f_{v'}$ KN/m^2	Water Absorption, % volume after 1 year
SD	15	21	70	90-120	5.0
HD	20	45	110	120-150	4.0
EHD	25	70	150	150-190	3.8
UHD	30	100	190	190-220	3.5

(Source: Sanders & Seedhouse, 1994)

Poissons Ratio of polystyrene is in the range of 0.00 to 0.02, indicating that the lateral deflection is insignificant under vertical load.

The shear strength ($f_{v'}$) of polystyrene foams is as high as the compressive strength at 10% strain, $f_{c' \ 10\% \ strain}$ (Table 1). In engineering applications, the design shear strength is governed by the frictional resistance between the rigid blocks instead of shear strength of polystyrene material. From published information, the frictional resistance coefficient is taken as 0.50 or equivalent to an angle of 27^0.

2.2 Water Absorption

The water absorption of polystyrene materials for short-term exposure is less than 5% by volume (Table 1). As the polystyrene foam consists of closed cellular structure, the water uptake is limited to the interconnected voids between the beads. Based on the test results of retrieved samples installed below the ground for 24 years, NRPA (2000) reported that the water absorption of the polystyrene foams are below 1% by volume where blocks are placed above highest groundwater or flood level; Where the foams are periodically submerged, the water absorption can be up to 4% in volume. In permanently submerged case, the water absorption can reach as high as 10% by volume.

In consideration to the water absorption property, NRRL (1992) recommends that the minimum unit weight of $1.0KN/m^2$ should be adopted for stability and settlement analysis.

2.3 Temperature, Combustibility and Ultra Violet Light Effects

Polystyrene foams are dimensional stable when subjected to a temperature of 75^0C to 85^0C. Beyond which some instability may form. This property is crucial when layers of HDPE protective sheets are field seamed on top of the polystyrene blocks using hot wedge fusion or extrusion welding methods. The preheating mechanisms may transfer heats as high as the melting points of HDPE and cause dimensional instability should proper protection is not introduced.

Polystyrene foams are combustible when ignited in the presence of large volume of oxygen. The rate of heat released by combustion is rapid and fire will propagate rapidly once started. Self-extinguishing type (SE quality) EPS may be specified where the risk of ignition is a concerned.

When exposed to ultra violet lights, the surface layer of polystyrene foams will progressively discolour and became brittle. Protection against sun light during handling and storage is required.

2.4 Chemical Resistance

Polystyrene is resistant to most substances naturally occurring in the ground, natural earth fills and ground water. It can resist chemical attack of some substances like dilute inorganic acids, alkalis, salts, humid acids, most alcohols, solvent free bitumens, gypsum and Portland cements, water based paints and adhesives. However, there are a range of substances which may attack the surface of polystyrene such as some vegetable oils, animal fats, paraffin oils, diesel fuels, hydrocarbons like methane, petrol and tar oils, organic solvents such as ketones, ethers and esters. Protection layer such as HDPE sheets or protective slab should be provided against the risk of chemical attacks.

2.5 Biological Resistance

Polystyrene is resistant to bacterial and fungal attack. There is no nutritional value and should not attract animals (Sanders & Seedhouse, 1994). Sealing of polystyrene blocks with HDPE sheets or concrete surround should be considered where burrowing of some animals are likely.

3 LIGHTWEIGHT POLYSTYRENE DESIGNS

There are two design functions in lightweight polystyrenes, namely (1) Load Reduction or Settlement Reduction Function and (2) Earth Pressure Reduction Function. In local construction industry, the first function is commonly applied.

To arrive at a satisfactory design, the followings should be considered:-

I. Ground at the particular project site should be investigated. Subsoil information such as soil profile, strength parameters etc should be established to permit embankment stability and settlement analyses.
II. Maximum flood level or groundwater table fluctuation for the design life of structure or embankment should be established.
III. Sufficient overburden should be provided on top of polystyrene blocks against potential uplifting and floatation. The factor of safety against floatation or uplift should be 1.20.
IV. Imposed loads such as overburden dead load, vertical vehicle loads, braking and impact loads and construction loads should be considered in the selection of polystyrene grades.
V. Overall stability analysis of polystyrene fill embankment or platform should be carried out.
VI. To ensure internal stability of polystyrene blocks, sufficient resistance against horizontal loads or lateral acting pressures from the abutting earth should be assessed.
VII. Bearing capacity and magnitude of settlement of polystyrene fill should be analysed.
VIII. Proper end treatment should be allowed to achieve good riding quality.

4 CASE HISTORY

4.1 Site Condition

Based on borehole exploration results (Fig.1), the subsoil at the site can be divided into three layers, namely medium stiff granular layer, soft to medium CLAY layer and medium dense SAND layer

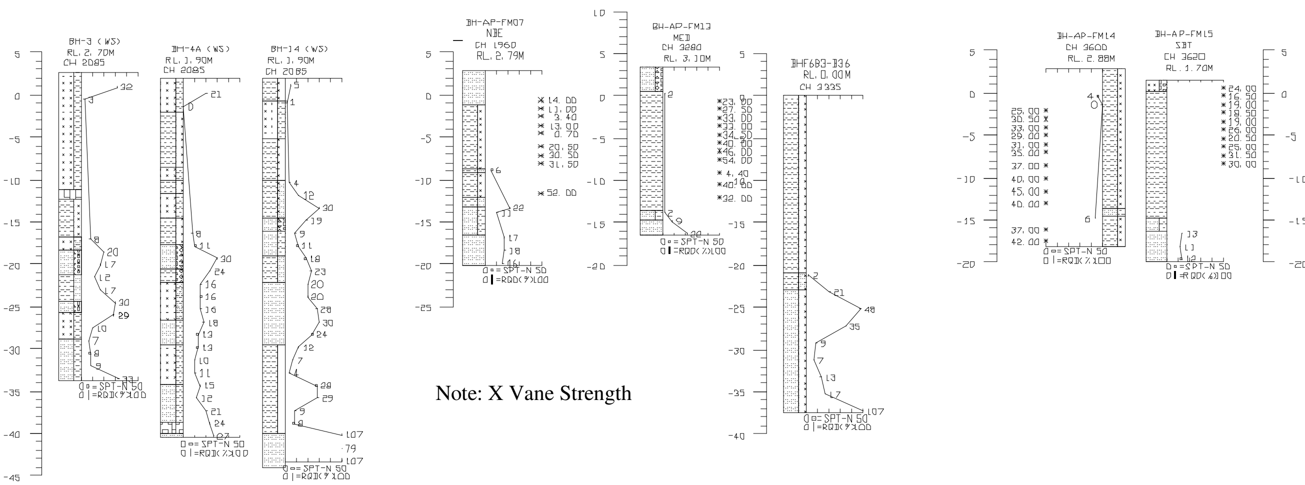

Fig. 1 Subsoil profiles at piled culvert approaches

The granular layer is either reddish to yellowish brown medium stiff sandy clayey SILT or light grey silty to gravelly SAND with thickness varied from 2.5m to 3.0m.

The soft to medium clay layer is occurred beneath the sandy subsoil layer. The thickness of clay layer varied from 15.0m to 20.0m. Occasional sand lenses could be found within this thick deposit. The undrained shear strength at the upper clay varied from 10kPa to 40kPa while at lower clay layer, undrained vane shear strength was about 30kPa to 60kPa.

Liquid limit and plastic limit of clayey soil varied from 85% to 125% and 35% to 45% respectively. The plasticity index (PI) was about 25% to 75% with an average of 50%. Compression Ratio of clayey soil was in the range of 0.25 to 0.40. The upper 4.0m to 7.0m were generally lightly overconsolidated.

4.2 Project Brief

The project consists of topping up the road embankment on the existing expressway. The embankment of the expressway, which was constructed about 10 years ago and was designed by other consultant, has experienced settlement of about 800mm from its as built level of RL 3.87m. Over the service periods, pavement regulating and overlay works were carried out along the settling carriageway and the transition humps at the RC box culverts crossing.

Owing to a few flood events in the end of 1998 and 1999, which recorded the peak flood levels of about RL 3.50m to RL 3.70m, the embankment of the expressway was proposed to be raised up to arrive at a flood free scenario. The redesigned finish road level is RL 4.60m. Additional embankment fill mainly consists of crusherun of about 1.60m would be placed on top of the embankment.

To maintain the serviceability of the existing expressway, the construction works at the existing expressway should cause minimum disturbance to the traffic flow and inconvenient to the expressway user. Considering of serviceability requirements, limited land space and minimum construction duration granted, extensive treatment methods on soft soil to mitigate extra settlement caused by the 1.60m fill were ruled out. With the mutual understanding of both the client and the consultant, it was agreeable that the embankment be topped up directly to the redesigned level while the transitions at the approaches of two piled culverts be treated with lightweight expanded polystyrene fill to ensure the ride quality and comfort.

The size of box culverts are 3.0m(W) x 2.3m (H) and made of cast-insitu reinforced concrete. Both culverts were supported by RC square piles, which were installed to 40.5m and 35.1m respectively below the founding level. Upon embankment topping up, the anticipated settlement is about 700mm within the 30 years concession period of the expressway. The settlements of the piled culverts will be negligible thus will form undesirable high humps on the expressway if not treated.

Transition treatment at the box culvert approaches consists of grade HD EPS blocks. The dimension of EPS blocks is 2475mm*1260mm*648mm. To accommodate the settlement profile, varying block thickness was designed along the 50.0m length transition profiles (Fig. 2). Section detail is illustrated in Fig. 3. With this arrangement, the differential settlements between the piled culverts and road embankment will be mitigated.

The design overburden fills above the EPS approaches is adequate against potential uplifting due to the probable maximum flood level of RL 3.70m.

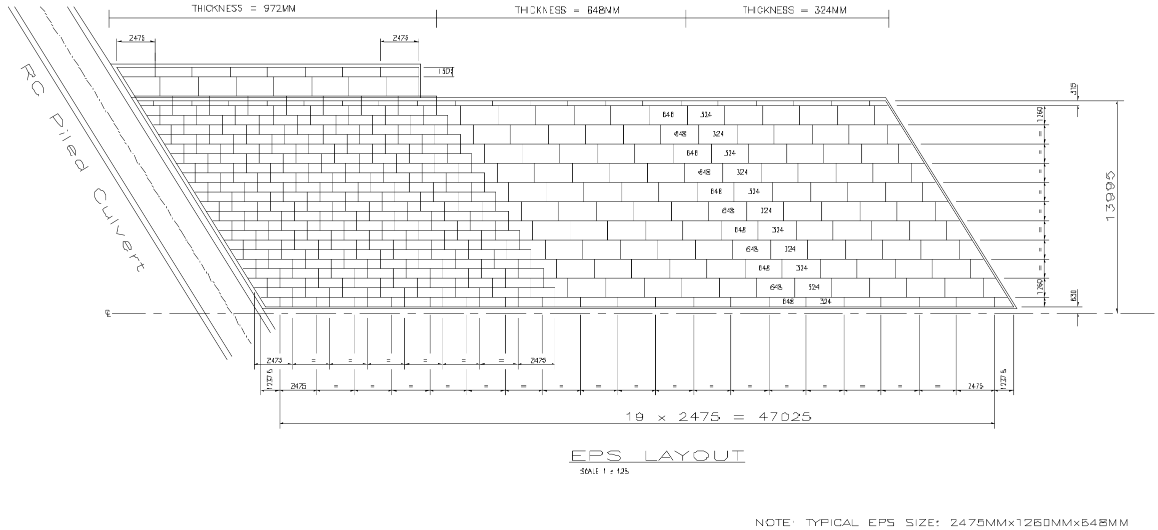

Fig. 2 Arrangement of lightweight polystyrene blocks at culvert transition

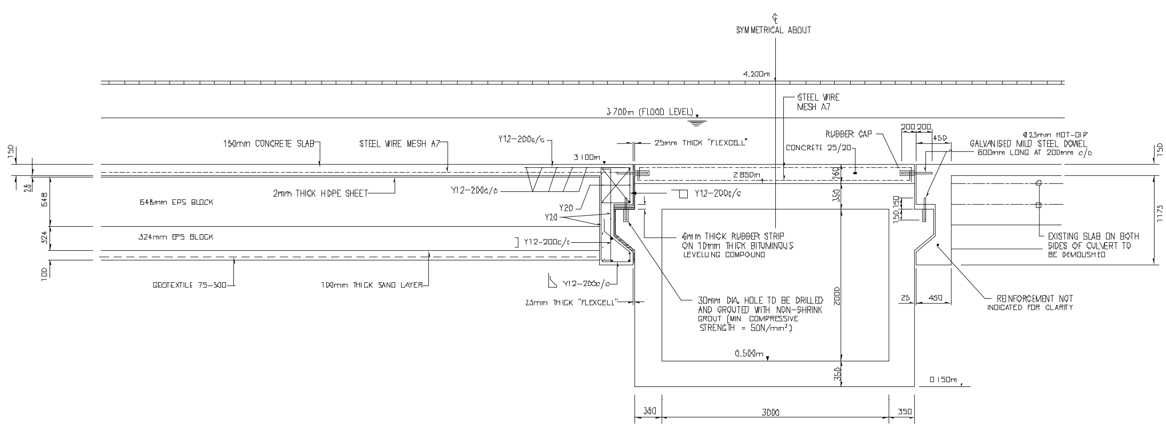

Fig. 3 Section view of culvert transition

5. CONSTRUCTION

Embankment topping up construction was commenced on mid 2002. Due to serviceability constraints, the construction of both the embankment and the EPS transitions at the culvert approaches cannot be carried out in single stage. In fact, the construction planning has to accommodate contra flow traffic management. Typical construction planning and traffic management is shown in Fig. 4.

The construction sequence at the transition approaches of piled culverts was carried out in the following manner:

- Nominal excavation depth of approximately 400mm was carried out and a layer of non-woven geotextile separator was spread on the excavated platform. A hand compacter was used to compact the sand leveling layer.
- EPS blocks were placed on the compacted sand blanket.
- HDPE sheets were laid on the finish polystyrene blocks. Welding of HDPE sheets were carried out immediately. Non-destructive air pressure test was carried out to ensure seal quality.
- BRC reinforced concrete slab was cast above the polystyrene blocks.
- The crushed aggregate layer was spread on the slab and continuing with road base construction.

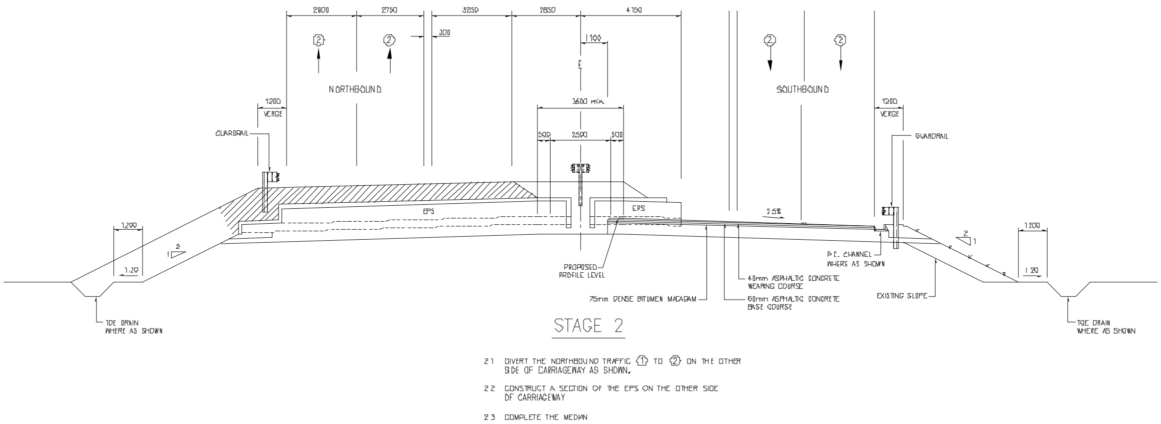

Fig. 4 Typical construction planning and traffic diversion

Based on the site experience, the main problems encountered during the installation of EPS blocks are the follows:-

- Product quality: The standard EPS block used for construction was 2475mm*1260mm*648mm and weighs 40.0Kg. Quality check at site revealed that the supply weigh was highly inconsistent, range from 30.0Kg to 45.0Kg. Subsequent to the rejection of some products, the quality was improved.
- Platform preparation: The construction tolerances on platform preparation for the laying of EPS blocks were difficult to achieve when excavated into soft layer. Some unevenness was occurred where sand leveling thickness was inadequate.
- Water inclusions: Occasionally, the occurrence of surface runoff flowing into the excavation had caused some slight movement of EPS blocks when the interlocking spikes were not at placed and temporary overburden load or pumping means were not provided.
- To maintain traffic flow, the transitions were constructed in three stages. The arrangement of EPS blocks in an interlocking manner to enhance continuity was difficult.

The transition construction is 0.50 years from completion during the writing of this paper. Settlement monitoring along the transition is quite recent. Meaningful settlement profile will be provided at a later stage when more data are available.

6 CONCLUSIONS

As presented in the case history in this paper, due to site and time constraints the use of EPS blocks was an ideal alternative to mitigate differential settlement problems between rigid piled culvert and settling embankment after topping up. Some difficulties such as product quality, platform preparation and inclement weather conditions may jeopardize the progress of works.

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BIOGRAPHY

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