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CONSTRUCTION OF A NEW HIGHWAY EMBANKMENT ON THE SOFT CLAY SOIL TREATMENT BY STONE COLUMNS IN MALAYSIA

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Abstract

To continue of the second phase of the East Coast Expressway between Kuantan and Kula Terengganu in Malaysia system innovative solution are required. In this new phase there are embankment region has been subjected to extensive soft clay soil. These comprise typically of clayey silts of very high water content and undrained shear strengths in the range of 8 to 11 kPa to depths of up to 8 m. To support an embankment, heights of up to 12 m were filled and thereafter Vibro Replacement treatment was carried out to treat the very soft soil. Extensive instrumentation using rod settlement gauges, inclinometers and piezometers were installed to monitor the performance of the Vibro Replacement treatment. This paper reports on aspects of design, installation and the measured results from the instrumentation scheme.

Keywords: Ground improvement, Stone column, Highway embankment.

1. Introduction

The project Lebuhraya Pantai Timur 2 (LPT2) is a continuation of the first phase of the East Coast Expressway (LPT1) between Karak to Jabor (in Kuantan state). The second phase calls for new highway which was constructed between Kuantan and Kula Terengganu in the state of Terengganu in Malaysia over a total length of 173 km (see Fig. 1). This figure indicates to the location of the project site in Malaysia. The geotechnical design of the project includes ground improvement of the existing foundation to sustain the imposed dead and traffic loads for highway.

The highway embankments in the project have heights ranging from 10 to 12.5 m. The top of the embankment has a minimum width of 32 m. The side slopes

Nomenclatures

C_h	Coefficient of consolidation for horizontal flow
C_{ref}	Coefficient of consolidation
d_e	Diameter of the equivalent soil cylinder
E_{ref}	Elasticity modulus
k_x	Vertical permeability
k_y	Horizontal permeability
q_{all}	Allowable load
$R_{inter.}$	Strength reduction factor in the interface
T_h	Time factor for consolidation

Greek Symbols

γ_{sat}	Saturated soil unit weight
γ_{unsat}	Unsaturated soil unit weight
φ	Internal friction angle
ν	Poisson ratio
ψ	Dilatancy angle

of the embankments have gradients of 1V:2H. Berms of 2 m width are provided on either side of embankments which were greater than 5 m in height as shown in cross section of the geometry of embankment in Fig. 4. The presence of clayey silts to depths of 8 m with shear strength values ranging between 8 and 11 kPa posed serious problems of stability and long term settlements. The soil was unable to support required high earth embankment. After considering various options using earth fill and treatment by using the Vibro Replacement for the underlying soft soil was adopted.

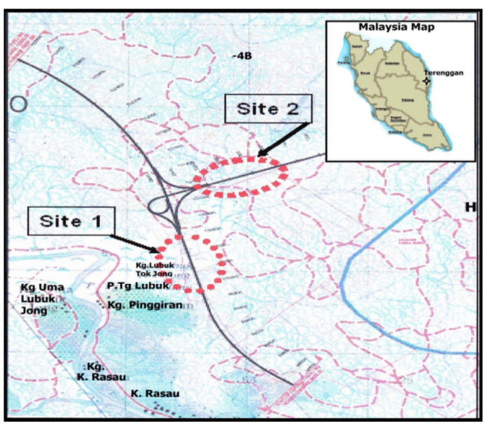

Fig. 1. Location Plan of the LPT2 Expressway in Malaysia.

This paper describes the design and execution of the treatment works and assesses the performance based on monitoring results. Stone columns were adopted as ground treatment due to its economic reason and lead to again a time of consolidation [1]. Vibro Replacement with stone columns is a subsoil improvement method in which large-sized columns of coarse backfill material are installed in the soil by means of special depth vibrators.

2. Subsoil Conditions

The general subsoil stratification can be classified to three zones depend on the site investigation gathered and from soil profile shown in Fig. 2. First zone covers the upper soil stratum comprising of brownish grey sandy silt or dark clay of law plasticity and brownish yellow grey peat with organic material up to 20% found between changes CH98500-CH1000575 for the main alignment and between CH1850-CH2235 for the spur road. The thickness of this layer ranges about 1-10m with SPT (N) values of 5-50 blows per 300mm penetration for the sandy silt/clay and an average of 8 m for the peat soil with SPT (N) values of 0-5 blows per 300mm penetration. The second zone comprises stiff-very stiff clay with sand and confined between upper layer and third layer below. The thickness of this various between 2-10 m with SPT (N) value of 20-50/blows per 300mm penetration. The third layer found in site is sandstone and siltstone. Table 1 shows the properties of soil layers as well as stone columns material.

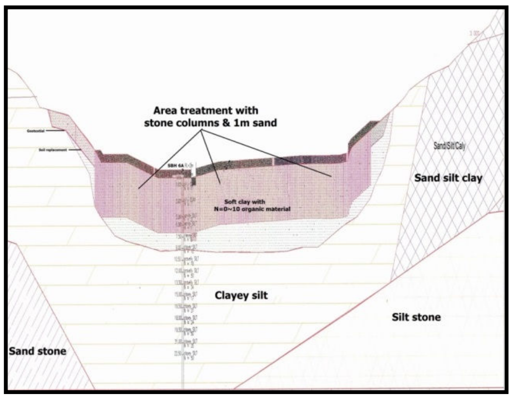

Fig. 2. Cross Section of Boreholes (CH100450).

Table 1. Parameters Design of Materials.

Mohr-Coulomb		Embankment Fill	Firm Clay	Sand Layer	Firm Clay	Soft Clay
Type		Drained	Drained	Drained	Undrained	Undrained
γ_{unsat}	[kN/m³]	20.00	12.00	20.00	16.00	15.00
γ_{sat}	[kN/m³]	20.00	22.00	20.00	17.00	15.00
k_x	[m/day]	1.000	1.00	1.000	0.000	0.000
k_y	[m/day]	1.000	1.00	1.000	0.000	0.000
E_{ref}	[kN/m²]	20,000	120,000	20,000	15,000	1,200
ν	[-]	0.300	0.300	0.300	0.400	0.400
c_{ref}	[kN/m²]	5.00	0.00	0.00	23.0	10.0
φ	[°]	30.00	42.00	35.00	28.00	23.00
ψ	[°]	0.00	0.00	0.00	0.00	0.00
$R_{inter.}$	[-]	1.00	1.00	1.00	1.00	1.00
Interface	[-]	Neutral	Neutral	Neutral	Neutral	Neutral

3. Technical Solutions

3.1. Vibro-replacement method

Vibro replacement with stone columns is a subsoil improvement method in which large-sized columns of coarse backfill material are installed in the soil by means of special depth vibrators. The stone columns and the intervening soils form an integrated foundation support system having low compressibility and improved load-bearing capacity. Vibro-replacement with stone columns allows for the treatment of a wide range of soils, from soft clays to loose sands, by forming reinforcing elements of low compressibility and high shear strength. In addition to improving strength and deformation properties, stone column density in situ soil, rapidly drain the generated excess pore water pressures, accelerate consolidation and minimize postconstruction settlement [2]. Normally the columns fully penetrate the weak layer with the result that the stone column and natural soil combination develop greatly enhanced bearing capacity and reduced compressibility characteristics. The method is an ideal solution for use on embankments as it negates the effect of a 'hard point'. The dry or wet method of installation can be used depending on the proximity to the existing railway track and water sources [3, 4]. The size of the vibrator is around 40 cm and penetration of the vibrator into the ground with water jetting will result in a hole of diameter 50-60 cm being created. An annular space is created between the vibrator and the hole through which the stone is fed to the compaction point. The up and down motion of the vibrator is used to laterally displace the stone into the ground and at the same time compact the stone column. This will resulted in the creation of the required diameter of the column. Figure 3 illustrates the process of installation of the Vibro-stone column.

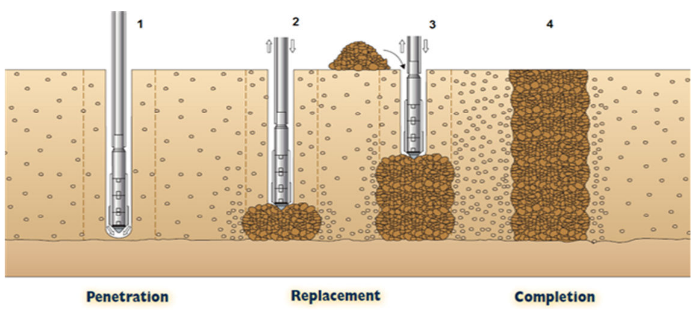

Fig. 3. Vibro-Replacement Method Process.

3.2. Ground improvement design

The design of the ground improvement works has to satisfy the following criteria under the application of dead load from the embankment and traffic live load of 15 kPa.

i. Overall embankment stability with a minimum factor of safety of 1.4 (long-term).
ii. Maximum post-construction settlement of 250 mm in five years.
iii. Differential settlement in transition area between treated and untreated embankment not exceeding 50 mm over 100 mm length.
iv. Bearing capacity safety factor 1.4 (short- term).

The design of stone columns was carried out in accordance with Priebe's method using computer software in order to meet the performance criteria [5].

The treated area is between CH 1875 to CH 2280. Out of this whole area, the area between CH 2120 to CH 2225 is more critical since the embankment height reaches up to 12 m and lies directly on thick deposits of very soft. The stone column with a 1 m diameter has used for treatment depending variation of road geometry and soil condition, where it's disturbed by squared grid pattern 2 m c/c with length ranging from 7-8 m.

3.3. Stone column design methodology

The following idealized conditions are assumed in the design: the column is based on a rigid layer; the column material is incompressible, the design considers the group effect of the columns and the contribution of the attribute soil surrounding the columns, column material shears from the beginning whereas the surrounding soil reacts elastically.

3.3.1. Embankment stability

The construction of a 12 m high embankment needs accuracy in the design to ensure safety. Slope stability analyses were carried out using the Bishop's slip circular method with the aid of various computer software including PLAXIS 2D and GEO-SLOPE. The soft soil is treated with stone columns and modelled as composite soil mass. This mass having improved parameter to be used it in the slope stability calculations of the embankment. The improved composite soil parameters were assessed in accordance with Priebe's method. The typical composite effective shear strength parameters of the improved soft soil are in the range of 2 to 4 kPa and friction angle are in the range of 20 to 25°. For the critical zone, the treatment was extended to a width beyond the toe of the embankment on both sides and also required the construction of a 5.5 m high stabilizing berm of width 2 m measured embankment. The typical cross-section showing the geometry of embankment along with extended width of treatment and stabilizing berm is shown in Fig. 4.

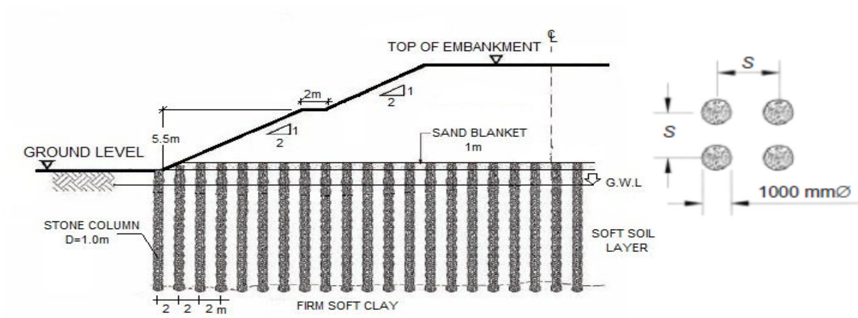

Fig. 4. Cross Section Showing the Geometry of Embankment.

3.3.2. Ground settlement and time rate of consolidation

Settlement analyses were carried out using conventional Boussinesq's theory and finite element analysis with aid of computer software VIBRO and PLAXIS, respectively. For the embankment heights of 10 to 12 m with a live load of 15 kPa on stone column treated soft clay soil extending to 8 m depth, the results of analyses predicted a maximum total settlement ranging between 0.45 m and 0.69 m. The result of time rate of consolidation calculations using Balaam [6] and Han [7, 8] methods indicated post construction duration of less than 1 month to achieve an overall degree of consolidation of 90%. The settlement carried out from filed shows that the stone column treated soil drained relatively quickly after constructed an embankment layer [9].

Time rate of settlement can be calculated by using the Terzaghi equation. The time factor for a degree of consolidation of 90% can be obtained from the Balaam and Booker chart and the equations relevant to this calculation are as follows.

$$t = T_h d_e^2 / C_h \qquad (1)$$

$$d_e = 1.128\, s \qquad \text{(For square grid)} \qquad (2)$$

$$T_h = 0.044 \qquad (3)$$

(Balaam and Booker chart for U = 90%, d_e/d = 3), where t is time; T_h is the time factor for consolidation by horizontal drainage; d_e is the diameter of the equivalent soil cylinder; and C_h is the coefficient of consolidation for horizontal flow.

3.3.3. Ground treatment works

The project site was initially preparations and after a series of field tests obtained values of CPTs. The stone columns had to be installed by utilised 'dry' methods using the depth vibrators as developed by Moseley and Priebe [10] as well as Raju et al. [11]. A total sum of over 1000 m of stone columns were installed to dense layers in about 4 months period using 2 wet rigs and 3 dry rigs working on 24 hours basis. A detailed plan showing the treatment boundaries and predominant soil types is shown in Fig. 4. At the approach embankment to bridge over railway line, the stone columns were designed at a closer spacing to allow a smooth transition (differential settlement control) between the piles supported structure and the embankment.

4. Quality Control During Installation

Foundation engineering is the civil engineering discipline with the highest potential for variance between assumed behaviour and actual as-built behaviour. This stems from the large uncertainties in the characteristics of the building material, the in-situ soil. No matter how much field and laboratory exploration data is available, the unknowns and uncertainties will always be greater than for steel, concrete and other construction materials.

- Installation: The site installation history of vibro-stone column monitoring by using the microprocessor controlled system. Outputs obtainable from the system as well as depths, electric currents during the process of penetration and expansion of the hole in the soil and compacted of around it, total time spend on the stone column point and the total compaction time.
- Load Tests of stone columns: In order to assess the immediate settlement characteristics of stone column upon load, plate load tests can be carried out

on selected single and group of four-columns. The size of the plate used for load test is 1500 mm bye 1500 mm for single column and 3000 mm by 3000 mm for group of four columns. The allowable load (q_{all}) for the column can be worked out as follows:-

$$q_{all} = \text{Area of plate in squire meter} \times (\gamma_f \times H + \text{traffic load}) \quad (4)$$

Tests are done by applied load on the stone and soil surrounding for two cycles. The first cycle, the allowable design load is applied and remained for 24 hours. In the second cycle a maximum load of 1.5 times the allowable load. The requirement of the load test is that the settlement should not exceed 50 mm under allowable load and not exceed 80 mm under 1.5 of the allowable load. The results of a typical single column plate load test carried out in the project are presented in Fig. 5.

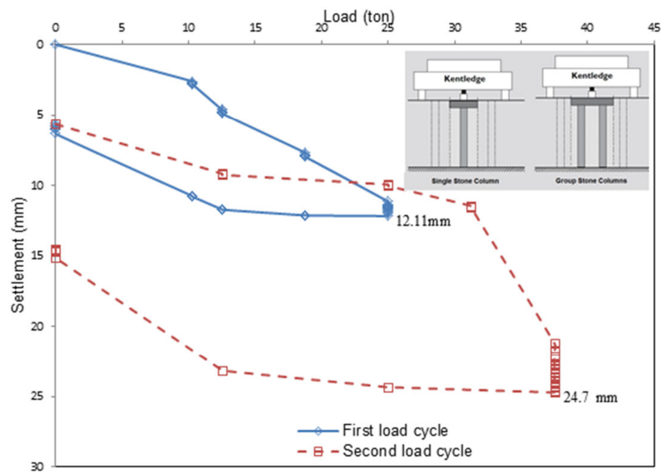

Fig. 5. Load–Settlement Curves for A Single Column Plate Load Test.

5. Settlement Monitoring

The settlement carried out from filed test shows that the stone column treated soil drained relatively quickly after constructed an embankment layer. After one week of applied a fresh embankment layer (5.4 m high), soft soil consolidation will be effective (see Fig. 6). The value of settlement was lower than originally predicted in the design calculations. The highest settlement was recorded at CH 100 450, where the 11.71 m high embankment only subsided about 0.127 m during the construction phase. Post construction settlements were negligible. The difference in the predicted and measured settlements can probably be attributed to the fact that during the installation of the columns, rapid consolidation of the soft soil was already taking place (even before embankment construction has started). This effect is not considered in the design calculations. It should also be noted that embankments of comparable height, constructed over similar untreated soft soils have been known to settle more than 1.0 m [9].

The quick consolidation time is also remarkable, considering that such soils have been known to require more than 6 months achieving 90% consolidation even with the aid of closely spaced prefabricated vertical drains [9]. The stone columns probably acted like huge vertical drains and allowed a six-fold acceleration in the rate of consolidation.

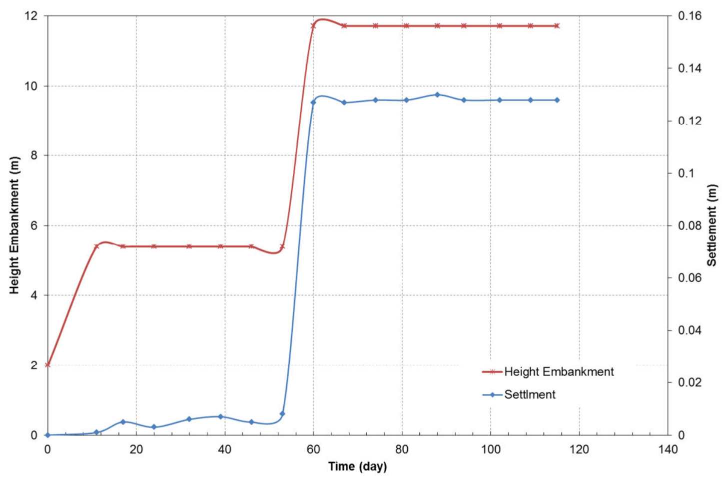

Fig. 6. Typical Settlement Data at 11.71 m High Embankment.

6. Settlement Monitoring

The Vibro-Replacement technique is considered an effective ground improvement solution in dramatically varying soil conditions ranging from ultra-soft mining slimes to loose sandy deposits. In this paper, the design methodology, installation methodology, load testing and field instrumentation for stone column for highway embankments have been discussed. The most important findings from this research are summarized in the following three significant features.

- Firstly, Vibro-stone Columns made it possible to support embankments up to 15 m high in ultra-soft slimes with undrained shear strengths between 5 to 15 kPa which were unable to support even 1 m high embankment in their in situ conditions.
- Secondly, Vibro-stone column embedded in ultra-soft soils improved shear strength and compressibility parameters of ground soils.
- And finally, stone columns provided effective drainage paths to ensure rapid consolidation leading to quick gains in shear strength of in-situ soils. As a result, the treatment offered the acceleration in the overall construction schedule and enabled the project to be completed well within the stipulated duration.

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