USE OF THE OBSERVATIONAL APPROACH FOR EMBANKMENT CONSTRUCTION ON ORGANIC SOIL DEPOSITS IN SRI LANKA

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Abstract

Road embankments on organic soil deposits cause stability issues during the construction stage and consolidation settlement problems during the post construction stage. As the conservative approach, which designs road embankments using unfavourable or prismatic ground conditions, becomes uneconomical or not feasible for construction of road embankments on organic soil deposits observational approach is very often used for such design and construction. In the observational approach, the most probable or more optimistic ground conditions are considered in the initial design. The risks associated with using most probable soil properties are managed by reviewing the initial design through the analysis of the observational data obtained during the construction stage. In this regards, analysis tools to assess the stability of the embankment during construction stage and the estimation of the degree of consolidation during ground improvement phase are extremely important. Even though there is large number of analytical methods available to use for the data analysis, not much research is done to identify the tools relevant to the organic soft soils found in Sri Lanka. This research is aimed at investigation of the analytical tools that can be used to analysis of settlement monitoring data obtained during the implementation of the observational approach for construction of the road embankments over the soft soil deposits in Sri Lanka.

Keywords: Observational Approach, organic soil, Matsuo chart, Asaoka method, hyperbolic method

1. Introduction

Road traces are very often run through low-lying grounds with soft soil deposits at shallow depths to minimize issues related to compensation and resettlement. This has often been the case with new road embankments constructed in the highly populated western coastal belt of Sri Lanka. Even though running new road traces through such grounds minimizes certain social issues, construction of high road embankment on such weak compressible grounds to avoid flooding is a major challenge faced by geotechnical engineers. The stability of the road embankment on very weak ground is a very serious concern during the construction stage of the embankment and the post construction secondary consolidation settlements pose serious questions regarding the long term serviceability and maintenance of the road embankment constructed over such soft soil deposits.

Due to the high variability of the soft ground conditions generally encountered in soft compressible soil deposits, an initial design using unfavourable or prismatic ground conditions becomes uneconomical or sometimes not feasible. Therefore, very often most probable or more optimistic ground conditions are considered in the initial design and the risks associated with such assumptions are managed by reviewing the initial design through observational data obtained during the construction stage. However, no well defined methodology is available for the implementation of this observational approach in embankment construction over soft soil deposits. The objective of this research is to investigate the effectiveness of commonly used analytical tools in implementation of the observational approach for the design and construction of embankments over soft soil deposits in Sri Lanka. In this regard, emphasis is made in this research to investigate the analytical tools used to assess the stability of the embankment slopes and estimation of the degree of consolidation using observed settlement.

2. Background and Approach

In the observational approach, the most probable material parameters, in place of the worst material properties generally used in traditional design approach, are used for the design. Therefore, there is a higher possibility of failure as the probability of having soil with lower strength than the designed strength is high. The risk of embankment failure associated with such an approach is minimized by assessing the stability of the embankment slopes during construction.

Matsuo and Kawamura (1977) developed charts for monitoring the stability of the embankment slopes on soft grounds based on the lateral displacement of the toe of the embankment (δ) and the vertical settlement (ρ_t) at the centre of the embankment. Other criteria such as settlement rate and displacement rate are also considered in assessing the stability of embankments on soft grounds. If the observed factor of safety falls below the expected level, the construction plan should be changed to maintain the required level of safety.

The construction sequence like time for removal of surcharge or putting an additional surcharge are carried out based on the estimated degree of consolidation of the soft soil deposit under the embankment using pore pressure measurements and/or settlement monitoring data. However, in most cases pore pressure measurements are not available and the assessment of the degree of consolidation depends mainly on the settlement monitoring data.

A method of predicting the primary consolidation settlement from the observed data has been proposed by Asaoka (1978). It is a graphical approach to estimate final total primary consolidation settlement and settlement rates from settlement data obtained during a certain time period. Ariyaratna and Thilakasiri (2011) based on the data from the vacuum consolidated sections of the soft soil deposits from Southern Expressway Project, showed that the Asaoka method can be used to accurately estimate the total primary consolidation settlement of Sri Lankan peaty soil.

The hyperbolic method (Tan 1971; Chin 1975 & Tan 1995) has also been recognized as an important tool in analyzing settlement monitoring data. Usually this is used to evaluate future settlement, based on measured settlement data. In this method, it is assumed that settlement time curve follows a hyperbolic variation.

3. Analysis of the Settlement Monitoring Data

3.1 Investigation of the stability of the embankment slopes

3.1.1 Ensuring stability during design stage

The embankment height, soft layer thickness and properties of soil are considered in selecting critical sections of the embankment during the design stage. The soil strength parameters of the ground, improved using crushed stone piles (CSP) and sand compaction piles (SCP), are analysed with the use of the area replacement ratio. Equivalent unit weight, angle of friction and cohesion are calculated for the improved soil layer neglecting stress concentration effect of CSP/SCP. Strength gain effect is also accounted in the design stage. Generally it is assumed that at full lift height of the embankment, 50% degree of consolidation is achieved during the construction time for a constant strength gain factor of 0.3 as shown in Eq. [1],

$$\frac{\Delta C_u}{\Delta \sigma_v'} = 0.3 \qquad \text{..... (1)}$$

A model of the embankment and the underlying soil is prepared and analysed. A critical failure surface obtained using Geoslope software is shown in Figure 1. In most cases, a short term FOS of more than 1.3 is required.

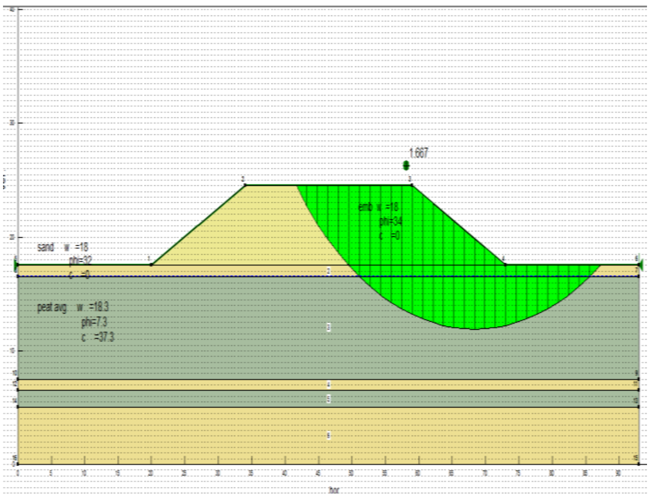

Figure 1: Critical failure surface of a typical section of the embankment

3.2 Ensuring short term stability during construction stage

The embankment stability will be more decisive during stage by stage filling because strength gain is occurring gradually with time. Therefore, it is on the safer side to analyse short term stability through settlement data. Using Matsuo chart with vertical settlement vs. displacement/settlement plot provide information on a trend of failure. If the factor of safety falls below as shown in figure 6 the construction plan can be changed. Generally the loading rate is reduced taking account of the visible reduction in factor of safety. Sometimes other criteria are also used. For example in the Colombo Katunayake Expressway (CKE) project the settlement per day should be less than 9mm and the lateral displacement should be less than 4mm per day.

3.3 Prediction of the Degree of Consolidation from Settlement Monitoring Data

There are large number of methods to estimate the degree of consolidation from settlement monitoring data. However, Asaoka method (1978) and Hyperbolic method (Tan 1971; Chin 1975 & Tan 1995) are very commonly used in the field.

3.3.1 Asaoka Method (1978)

In this method the measured time-settlement curve is plotted to an arithmetic scale. The total primary consolidation settlement, ρ_c is given where the straight line (*I*) fitted through the points plotted as (ρ_{i-1},ρ_i) intersects the 45° line (ρ_{i-1}= ρ_{i}), as shown in Figure 2. From the slope of the graph β_1 the coefficient of consolidation, C_V, can also be estimated.

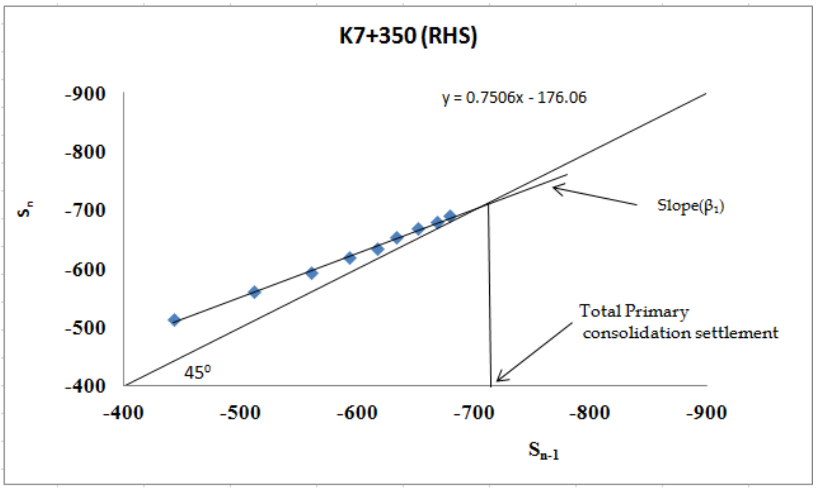

Figure 2: Typical use of the Asaoka method to estimate the total primary consolidation settlement

Determination of the degree of consolidation of the soft soil layer and prediction of the time required to achieve 95% degree of consolidation is done using the estimated total primary consolidation settlement, ρ_c and the settlement observed at present.

3.3.2 Hyperbolic Method

The relationship between settlement (δ) and time (t) assumed to follow a hyperbolic curve by a linear equation given in Eq[2].

$$\frac{t}{\delta} = \mathrm{B} + \mathrm{At} \quad ..... (2)$$

Therefore, gradient of this plot can be identified as constant A, as shown in Figure 3. When time tends to infinity inverse of the slope of the graph at linear segment will give the ultimate settlement.

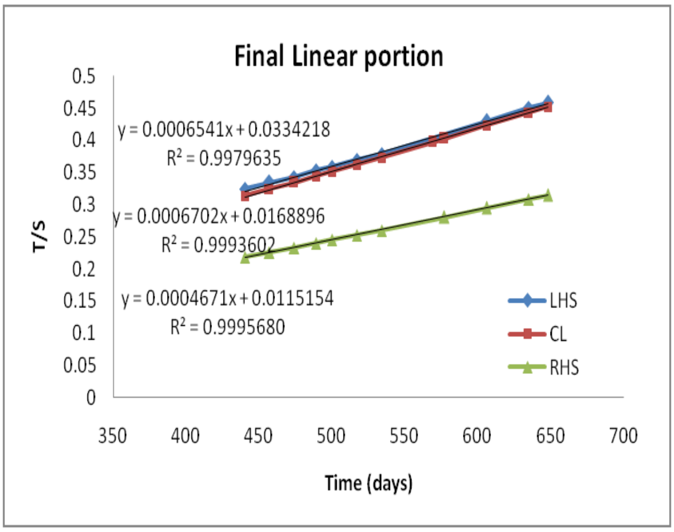

Figure 3: Transformed hyperbolic plot (final segment)

$$\text{Ultimate settlement} = \frac{1}{gradient} \quad ..... (3)$$

For the sample data set shown in Figure 3, the slope is 0.000467 and hence, the estimated final consolidation settlement is 2141 mm from Eq[3].

It is generally observed that different primary consolidation settlements are obtained when settlement monitoring data segments at different times are considered in the hyperbolic method. For example, as shown in figure 4 the initial segment is used for the calculation of ultimate settlement and the estimated primary consolidation settlement is greater than the value previously found for final linear segment as shown in Figure 3. Tan (1994) proposed reasonable prediction can be made through a correction factor of 0.824 for inverse initial gradient.

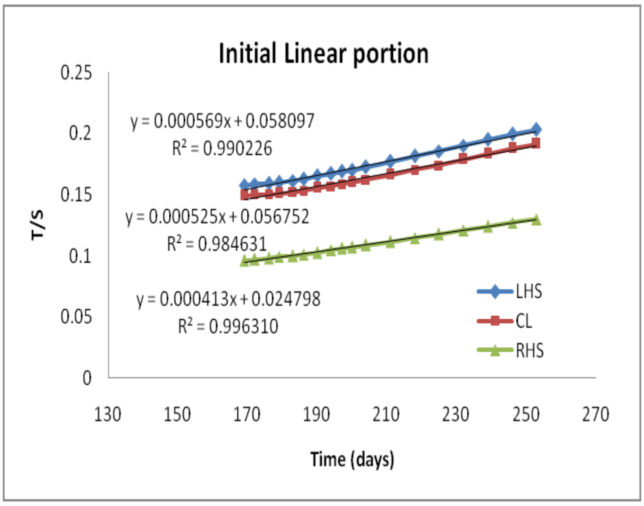

Figure 4: Transformed hyperbolic plot at chainage K1+750 (initial segment)

4. Results

4.1 Matsuo chart for failed sections

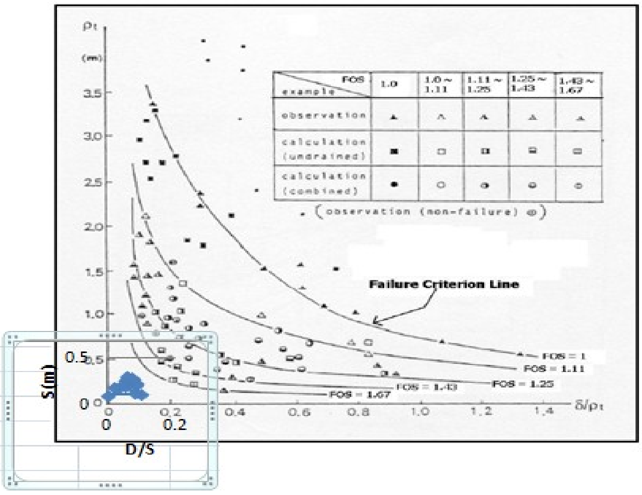

Figure 5: Matsuo Chart for failed section 1 of an embankment

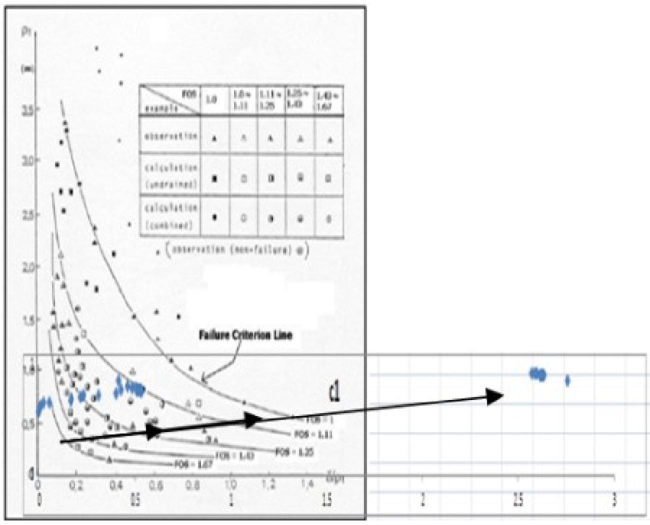

Figure 6: Matsuo Chart for failed section 2 of an embankment

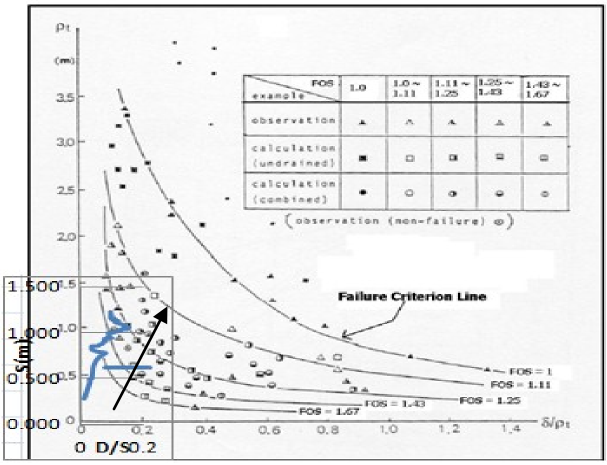

Figure 7: Matsuo Chart for failed section 3 of an embankment

4.2 Predicted Primary Consolidation Settlements and the Degree of Consolidation

Some sections of the Colombo – Katunayake Expressway (CKE) project were analysed using the Asaoka method and the Hyperbolic method. In this analysis, Hyperbolic method was used in two ways; initial settlement data after reaching the maximum surcharge level with the factor

0.824 as suggested by Tan (1994) and the final segment of the settlement monitoring data. The results are given in Table 1.

Table 1: Comparison of predicted settlements of Asaoka method vs Hyperbolic method

Chainage		Predicted consolidation settlement			D.O.C.(%)		
		Asaoka method	Hyperbolic method		Asaoka method	Hyperbolic method	
			Final portion	Initial portion with modifying factor		Final portion	Initial portion with modifying factor
K1+600	**L**	748	925	973	100	94	90
	C	1279	1428	1564	100	97	89
	R	920	1028	1033	100	99	99
K1+625	**L**	1133	1330	1433	100	96	89
	R	1234	1363	1346	100	98	100
K1+700	**L**	1339	1570	1665	100	94	89
	C	2039	2217	2146	100	98	100
	R	1730	1839	1995	100	99	91
K1+725	**L**	1486	1662	1655	100	98	98
	R	2045	2193	2168	100	98	99
K1+750	**L**	1247	1529	1448	100	92	98
	C	1324	1492	1570	100	96	91
	R	1950	2141	1995	100	96	100
K1+775	**L**	1076	1570	1665	100	94	89
	R	1973	1839	1995	100	99	91
K5+600	**L**	1414	1880	2197	100	77	66
	C	1422	2217	2264	99	63	62
	R	1009	1839	1803	100	56	57
K5+675	**L**	769	935	1199	100	84	66
	C	1138	1209	1306	91	86	79
	R	803	1052	1105	100	79	76
K5+800	**L**	1269	1369	1376	100	92	92
	R	1156	1174	1383	99	98	83
K7+350	**L**	1075	1668	1485	100	73	82
	C	1342	1850	1746	100	82	87
	R	706	877	792	100	89	98

5. Conclusion

Matsuo chart provides signs of safety factor reduction in only two of the three failed embankment sections considered. The other failed section has not shown it clearly. It may be a sudden failure due to stockpiling of the fill material on the embankment or any other reason. If the failure is due to gradual loading and the resulting gradual yielding of the underline soft soil, Matsuo chart may indicate gradual reduction of the factor of safety. However, whether the failure is denoted by the FoS 1 in the Matsuo chart should be further investigated.

Except for very few sections, the degree of consolidation (DoC) estimated considering the settlement data immediately after reaching the full surcharge load and the same estimated considering the latter settlement data agrees reasonably well. This finding will enhance the effective of the Hyperbolic method, as the DoC can be estimated using the initial settlement data.

According to Table 1, it is seen that the degree of consolidation predicted from the Asaoka method is generally more than the same estimated using the hyperbolic method. When one considers the sections with lower degree of consolidation (DoC) estimated from the Hyperbolic method, Asaoka method predicts 100% degree of consolidation. However, when one considers the rates of settlement of those sections after reaching 100% DoC from the Asaoka method, the estimated coefficient of secondary consolidation seems to be high. This indicates that the settlement may include some primary consolidation settlement as well. Therefore, one could argue whether Asaoka method over predicts the primary consolidation settlement. However, further research may be required to draw firm conclusions on this.

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