SOFT GROUND IMPROVEMENT TECHNIQUES USED IN PORT ACCESS ROAD PROJECT

by

Mr. U.G. Mallawa Arachchi

Abstract

Port Access road is being constructed as part of the Japanese funded Port of Colombo Expansion Project. The main objective of this roadway is to provide better facilities for the Port traffic, specially for container carrying vehicles those expected to increase in number within the next three years.

A special feature of this project is that almost 90% of the total length of 1.8 km has to be built on extensively swampy area. Hence soft ground improvement constitutes a major part of the Construction Process.

The method of surcharging with fill material (preloading) has been adopted together with several other methods for improvement of soft ground. This paper briefly describes the methods adopted with particular reference to the materials and equipment used. Field investigation and monitoring system and some basic aspects of analysis are also dealt with briefly.

Due to limitations in land availability, development of areas with soft soil would play a vital role in Construction in this country. Knowledge on the methods adopted in Port Access Road would be useful in making decisions on suitable method of soft ground improvement.

1.0 Introduction

The Port Access Road (which is now under construction) connects Colombo Port to Prince of Wales Avenue at Ingurukade Junction. It crosses Aluthmawatha road through a box culvert and crosses K. Cyril C. Perera Mawatha (Bloemendhal Road) with a Flyover Bridge. The road has been designed to have a 4- lane dual carriageway with average total width of 17.5 m. Nearly 1.5 km out of the total length of 1.8 km is to be constructed over a marshy area.

Road structure consists of an asphalt pavement on embankment fill. Maximum height of the embankment (7.0 m) occurs at the flyover bridge location.

Preliminary site investigations revealed that the project area is covered with soft soil which consists of organic clay. Thickness of the soft soil layer varies from 4.0 m to 10.0 m. Stability during construction and consolidation settlement of soft soil layer are two main factors considered in the design stage. Since the total construction period is limited to 30 months, it is essential to complete the embankment filling within about 20 months. However, the specified allowable continued settlement of the road pavement is 300 mm in 3 years in view of serviceability requirements. After a thorough investigation and analysis it has been decided to adopt the method of surcharge filling to achieve the necessary improvement of soft ground.

Surcharging means the application of an extra load during construction period in order to obtain required consolidation of soft soil prior to commissioning the structure. From the economical and other considerations, placing the earth fill material has been decided as the most suitable method of surcharging. The method of surcharging is discussed in detail later in this paper.

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He also serves as a Visiting Lecturer in the Centre for Housing Planning and Buildings.
In order to ensure stability and rapid consolidation, it is necessary to adopt several other methods in association with surcharging. Such methods used in the Project are:

a. Surface Treatment Method  
b. Vertical Drain Method  
c. Counterweight Fill Method  
d. Gradual Loading Method

Fig (1) of Appendix (1) shows a summarised form of different methods adopted.

Each of these methods is described in the forthcoming sections.

2.0 Surface Treatment Method

This method involves the preparation of soft soil surface for safe construction. Main purposes of this process are:

a. Providing trafficability required for construction operations.

b. Distribution of loads thus preventing local base failure and sinking or stretching of filled soil.

c. Increased safety factor against sliding.

Commonly adopted methods for surface treatment consists of either covering of soft ground surface with a net and/or sheet or treatment with a stabilizing agent and then placing a layer of fill material.

Originally intended method of surface treatment was to provide coconut fronds tied to a bamboo frame laid on the ground and to provide a sand blanket of 1.0 m thickness. In view of the difficulties in procurement and laying of coconut fronds, a synthetic sheet (FAGOT sheet) was proposed by the Contractor as an alternative material.

2.1 Materials and Method

2.1.1 Bamboo frame

Locally available bamboo with sufficient strength are used. The minimum sizes specified are 50 mm diameter and 5.0 m length. After clearing of vegetation, bamboo poles are placed on soft ground manually and tightened securely with coir strings to form a 1.0 m square grid.

2.1.2 Synthetic sheet (FAGOT sheet)

This is a permeable sheet which has a sufficient tensile strength to withstand the loads during construction. 12 m x 40 m sheets are laid manually over the bamboo frame and joined with binding wire.

2.1.3 Sand Blanket

A sand layer is laid on the sheet to a thickness of 1.0 m. The sand blanket serves two major purposes. i.e. It provides trafficability during construction and it acts as a drainage medium for the water expelled to due consolidation of soft soil layer. Material for sand blanket can be either river sand, sea sand or quarry dust which has good drainage characteristics. Specified grading for the material is as follows:

<table>
<thead>
<tr>
<th>B.S. sieve size</th>
<th>Percentage by weight passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 mm</td>
<td>Up to 100</td>
</tr>
<tr>
<td>5 mm</td>
<td>not more than 85</td>
</tr>
<tr>
<td>No. 25</td>
<td>not more than 45</td>
</tr>
<tr>
<td>No. 200</td>
<td>not more than 5</td>
</tr>
</tbody>
</table>

A perforated pipe network is provided within the sand blanket to drain the water collected, to peripheral drains.

3.0 Vertical Drain Method

In order to achieve the required degree of consolidation under surcharge load within the limited construction period, it is necessary to accelerate expulsion of water entrapped in soft soil. This is done by reducing the length of drainage path. Vertical Drain Method is one of the commonly adopted methods for this purpose.

Vertical drains means continuous vertical columns of pervious material installed in compressible clayey soil for the purpose of collecting and discharging water expelled during consolidation. There are two main types of vertical drains;

a. Sand drains  
b. Prefabricated drains

Method of computation of consolidation settlement under the influence of vertical drains is given in Eqn (1) in Appendix (2).

In sand drain method, vertical columns of sand are installed in soft soil at a predetermined interval. This is a traditional type of vertical drain which had been used as far back as in 1934. The contract for Fort Access Road
specified sand drains of 400 mm diameter to be provided on a 2.0 m square grid.

Contractor's proposal to use 100 mm wide prefabricated drains in lieu of sand drains was accepted. The drain pitch was reduced to 1.2 m in order to obtain same consolidation characteristics as in the original method. An approximate cost saving of about 10% over initial cost of sand drains was offered to the client by this proposal.

3.1 Prefabricated Drains

Prefabricated drain means a plastic pipe wrapped inside a filter. Drainage occurs through the continuous vertical passage between core and exterior filter. The material is available in the form of long bands. This type has several advantages over sand drains. Low cost, fast installation and ensured drain continuity are the most important features. Clean site of installation, lightweight installation equipment and negligible subsoil disturbance are several other advantages.

Table 2 provides some of the important properties of the drain material.

### Table 2

**Properties of the Prefabricated Drain Material**

<table>
<thead>
<tr>
<th>Property</th>
<th>Units</th>
<th>Specified Requirements</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>Core</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Film</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dimension of drain</td>
<td>Width</td>
<td>100 - 2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Depth</td>
<td>1 to 4</td>
<td></td>
</tr>
<tr>
<td>Coefficient of permeability of drain filter</td>
<td>m/ft</td>
<td>$9.5 	imes 10^{-4}$</td>
<td></td>
</tr>
<tr>
<td>Discharge capacity of drain</td>
<td>m³/s/m</td>
<td>$1.5 	imes 10^{-5}$</td>
<td></td>
</tr>
<tr>
<td>Soil retention capacity</td>
<td>m³/ft³</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td>Tensile Strength of entire drain</td>
<td>kN/m</td>
<td>$&gt;100$</td>
<td>min 7% max 10%</td>
</tr>
<tr>
<td></td>
<td>kN/m²</td>
<td>$&gt;100$</td>
<td>min 7% max 10%</td>
</tr>
<tr>
<td>Tensile Strength of filter</td>
<td>kN/m²</td>
<td>$&gt;3$</td>
<td>min 7% max 10%</td>
</tr>
<tr>
<td></td>
<td>kN/m²</td>
<td>$&gt;3$</td>
<td>min 7% max 10%</td>
</tr>
<tr>
<td>Elevation of entire drain</td>
<td>m</td>
<td>$&lt;10$</td>
<td></td>
</tr>
<tr>
<td>Elevation of filter</td>
<td>m</td>
<td>$&lt;10$</td>
<td></td>
</tr>
</tbody>
</table>

Installation of prefabricated drains is carried out by using a mandrel attached to a rig. Rig can be fitted to either a bulldozer or a crane. Drain material is wound around a reel and attached to the mandrel. A light steel plate (shoe) is fixed to the end of the drain and then mandrel is lowered into the ground and taken back leaving the drain. (See Fig (2) of Appendix (1) for Installation Equipment).

The crawler crane with mandrel attachment has an output of 40 - 50 drains (approx. 400 m) per hour for continuous working.

4.0 Gradual Loading Method

The strength of soft ground is gained gradually with expulsion of water in consolidation process. Therefore the rate of loading should be controlled to avoid instability problems.

Gradual loading not exceeding 50 mm/day has been specified in the Contract Specifications, taking this fact into consideration. Surcharge filling is required to be done in stages, where filling of a new layer must be started only after attainment of 30% consolidation of the previous layer. Final adjustment can be done upon 90% consolidation under full surcharge load.

Fill layer thickness in each stage has been determined at the design phase using the soil parameters obtained from site investigations.

The following assumptions have been made in the determination of fill layer thickness:

a. Embankment height at any stage is such that a Factor of Safety of 1.1 is maintained in respect of cohesion.

b. Rate of increase of cohesion due to surcharge load is 0.40.

c. Filling load is applied instantaneously after attainment of 80% consolidation under previous load.

d. Effect of Sand Blanket has been ignored.

e. A consolidation factor in horizontal direction ($C_r$) of 100 cm²/day has been used in settlement calculations. [Ref. Eqn (2) of Appendix (2)]

Stability calculations are carried out in order to investigate the possibility of base failure and (circular) slip failure prior to commencement of filling at each stage. Soil parameters necessary for stability calculations are obtained from field measurements. Such methods of analysis and
field measurements will be discussed in the latter part of the paper.

5.0 Counterweight Fill Method

An additional filling is made on the sides of embankment so that additional resisting moment is created against a possible slip failure. Since there is sufficient space available on the sides, this method could be adopted effectively.

6.0 Field Measurements and Investigation

Main purpose of the Field Measurement is to ascertain various parameters required for analysis at each stage of surcharge filling. Such measurements of special importance are;

a. Measurement of settlement and lateral movement
b. Pore water pressure measurement
c. Determination of undrained cohesion of soft soil.

Instrumentation and method of measurement are described in detail in the following sections. A schematic diagram for instrumentation is given in Fig (3) of Appendix (1).

6.1 Measurement of Settlement and Lateral Movement

Settlement Gauge (Settlement Plate) is used for this measurement. This instrument consists of a steel rod welded to a base plate. The plate is placed on the original soft ground surface at the beginning of filling. The rod is surrounded by a tube so that effect of soil friction on the rod is eliminated. More rods and tubes are added as the filling height increases. Level readings on the rod are taken daily so that the settlement on each day can be ascertained. Such settlement gauges have been installed along the centreline of the road and at several other critical points, for this purpose. The piezometer consists of a filter tip which is installed inside a bore-hole and surrounded by sand. This is connected to a digital indicator for taking pressure readings. Daily measurements are taken and plotted to identify any unusual developments.

6.3 Dutch Cone Penetration Test

Dutch (Static) Cone Penetration Test is a useful in-situ test for quick determination of strength of the ground. In this test, a cone with surface area of 10 cm and apex angle of 60° is driven into the ground at a constant speed and resisting force is measured at regular intervals. The cone resistance (q) has shown a direct relationship with undrained cohesion (c_u) of clayey soils. (c_u = q/15)

Values of cohesion in different layers are obtained by this test for using in stability calculations. A typical plot of Dutch Cone Test results is given in Figure (6) of the Appendix (1).

7.0 Method of Analysis

Theoretical analysis is done mainly for the following purposes.

a. Investigation of stability
b. Prediction of final settlement

Such analysis has to be carried out prior to commencement of filling of each layer.

7.1 Stability Calculations

7.1.1 Static Bearing Capacity Analysis

The Factor of Safety against base failure is computed using the measured undrained shear strength of clayey soil. The following equation is applied:

\[ F_s = \frac{N_c \cdot C_u}{\gamma \cdot H} \]  \hspace{1cm} (1)

where,

\[ F_s = \text{Factor of Safety} \]
\[ N_c = \text{Bearing Capacity Factor depending on the nature of soft soil} \]
\[ C_u = \text{Undrained Cohesion (Undrained Shear Strength) of soft soil} \]
\[ \gamma = \text{Bulk Density of soil} \]
\[ H = \text{Height of Embankment} \]

The value of \( N_c \) for the soft soil found in the project area is assumed as 3.6 for this computation. \( C_u \) is obtained from Dutch Cone test results. Density of soil is obtained from laboratory tests.
Maximum safe height of filling is determined using this calculation before commencing of filling of the layer. Allowable safety factor assumed in this analysis is 1.5.

7.1.2 Slip Circle Analysis

Slope stability of the embankment is checked using the slip circle analysis method before commencement of each layer. Specialised computer software is used for the analysis. This software has the facility to analyse a series of possible slip circles and determine the circle with minimum safety factor. Bishop's slice method has been used in the computer programme. Soil parameters in undrained condition are used in the analysis. Dutch Cone test results are used for identification of soil layers with different cohesion values. For simplification, the angle of internal friction is taken as zero for soft soil and 30° for the sand blanket. Bulk density is measured in the laboratory. A safety factor of 1.5 is taken as satisfactory against slip failure.

A typical computer printout on slip circle analysis is shown in Fig. 7 of Appendix 1.

7.2 Prediction of Final Settlement

As discussed under gradual loading method, it is essential to attain 80% of consolidation under any soil layer prior to commencing filling of next layer. Therefore, prediction of final settlement under each layer is necessary. A method based on actual settlement values has been accepted as most appropriate method of analysis. In this method settlement values are assumed to be in the following relationship with time.

\[ S = S_0 + (t-t_0) [\alpha + \beta (t-t_0)] \]  

(2)

Where,

- \( S \) = Settlement at time \( t \)
- \( S_0 \) = Settlement at time \( t_0 \)
- \( t_0 = Time \) at which filling of layer has been completed
- \( \alpha, \beta = Constants \)

This equation can be rearranged to show a straight line relationship as follows:

\[ (t-t_0) / (S-S_0) = \alpha + (t-t_0) \]  

(3)

Daily measured values of settlement are entered into a computer programme which plots the best fit straight line for the relationship given in Equation (3). Gradient of the line is then obtained.

From the equation, as \( t \) tends to infinity, \( S \to S_f \)

where,

\[ S_f = S_0 + 1/\beta \]  

(4)

[See Fig. (8) of Appendix (1) for a typical computer plot of prediction of final settlement].

The value of final settlement thus predicted is used when making the decision to commence filling of next layer.

8.0 Special Consideration in Ground Improvement

8.1 Drainage

Best results of the improvement methods cannot be obtained unless effective drainage is provided on site. Open ditches along two sides of the road were provided at the beginning of construction and drainage from swampy area to outside is ensured throughout the construction period.

8.2 Effect on Adjoining Structures

Soft soil displacement during construction may cause movements in the surrounding area. Claims from owners of adjoining property is unavoidable in this type of construction. Periodic photographs and measurements of the structures close to the site has been specified in the Contract, for proper assessment of damage or movement. Special emphasis has been given on the Oil pipe lines and railway line situated in the close proximity.

9.0 Conclusion

Building structures on soft ground would be unavoidable in near future due to the reduced availability of land. Knowledge on Soft Ground Improvement Techniques would be of immense use for the Civil Engineers. The Port Access Road Project provides a good example for construction involving extensive ground improvement.

Selection of appropriate methods of ground improvement for any particular situation is one of the most important decisions taken in the design stage. Thorough understanding on the theoretical aspects as well as construction techniques is essential for such a decision. Construction methods, field measurements and theoretical background discussed in this paper would provide some useful information for those interested in the field of soft ground improvement.
10.0 Acknowledgement

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11.0 Reference


APPENDIX 1

![Diagram](image)

Fig. (1) - Methods Adopted for Soft Ground Improvement
Illustrative Diagram of settlement Gauge

Fig. (3) - Instrumentation
Fig. (4) - Typical Settlement Curve

Fig. (5) - Typical Pore Water Pressure Curve
**Fig. (6) - Results of Dutch Cone Penetration Test**

<table>
<thead>
<tr>
<th>Center Point</th>
<th>Radius</th>
<th>Safety Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>(4,000, 12,000)</td>
<td>12,000 m</td>
<td>2.480</td>
</tr>
</tbody>
</table>

**Fig. (7) - Slip Circle Analysis**
APPENDIX 2

Equation for radial consolidation (Under influence of vertical drains):

\[ U = 1 - e^{-2TR / F(n)} \]  \hspace{1cm} (1)

where,

- \( U \) = Degree of Consolidation
- \( T_R \) = Time factor as described by Eqn (2)
- \( n \) = Ratio of radius of influence \( r_e \) to actual radius of drain \( r_w \)

\[ T_R = \left( \frac{C_r r_e}{r_w} \right) t \]  \hspace{1cm} (2)

- \( C_r \) = Consolidation Factor in horizontal direction

(This has been taken as 100 cm²/day in the calculations).

\[ F(n) = \frac{n^2 \ln(n) - 3n^2 - 1}{n^2 - 1} \]  \hspace{1cm} (3)