GEOGRID BASAL REINFORCEMENT FOR CONSTRUCTION OF EMBANKMENT ON SOFT SOIL

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ABSTRACT

Fine soil having very low undrained shear strength is often referred as “soft soil”. Construction of embankments on soft soil can be critical because they have a very low strength and high compressibility. Since such soils have a very low permeability \(10^{-5}\) mm/sec - \(10^{-8}\) mm/sec), the failure happens at an undrained condition within a short period after the embankment construction. Pre-consolidation of ground using vertical drains is the classical method generally used to build the embankments on soft soil deposits. This calls for staged construction, with a lean period to allow consolidation of soil to occur. Last two decades have seen a development of technique known piled embankments with basal reinforcement. This technique not only allows for time bound construction but also meet the stringent requirement of allowable settlements for high speed railways and motorways. A brief overview has been given on design of basal reinforced embankment with and without pile foundation and case studies has been presented for both the situations.

1.0 INTRODUCTION

To support the booming economy of our nation there is urgent need to develop infrastructure on fast track basis. This has led to a spurt in construction of various infrastructure projects such as high speed motorways, railways, ports etc. The construction process at such a fast pace poses a challenge to both the designers and executioners. The challenge gets compounded when the structures need to be constructed on treacherous soil deposits – which at times owing to the constriction and want of space can not be avoided. More often than not, it so happens that the soil deposit on which the structure is to be founded is clayey soft soil with relatively very low shear strength and high compressibility. The clayey nature prevents easier pore water dissipation, while the soft nature of the soil makes it more susceptible to large settlements and shear failures. Under such situations the mitigating/remedial measures are generally sought for.

Pre-consolidation of soft clayey deposit aided by use of vertical drains is the classical method that is generally adopted to build embankments on soft clayey deposits. But this method calls for staged construction, with a lean period to allow for consolidation of soil to occur. To reduce the stages of construction basal reinforcement is generally introduced. Last two decades has seen a development of technique known piled embankments with basal reinforcement. This technique not only allows for time bound construction but also meet the stringent requirement of allowable settlements for high speed railways and motorways. Through this paper an attempt has been made to present detailed description about basal reinforced embankment with and without pile foundation with a overview on design, their feasibility under different sub-surface conditions and a case study has been presented wherein piled embankment with basal reinforcement was constructed to support the embankment on deep seated soft clay deposit for high speed railway line in Italy. Conclusions made from the study and recommendations which can be made for the designers have also been presented.
2.0 BASAL REINFORCEMENT

Under normal conditions, in which there is a need to construct an embankment over a typical soft clayey soil stratum, the embankment would tend to fail due to the lateral spreading of the soil present beneath it; i.e., instead of providing stability to the constructed embankment by transferring load to the wider area, it tends to fail the embankment by getting spread laterally itself. A key feature for the remedial measures to be adopted in order to prevent the embankment to collapse due to the lateral spread of the soil beneath should be the one in which this lateral spreading is either stopped (in ideal conditions) or is significantly reduced (in real conditions). As per BS 8006 (1995), the basal reinforcement is defined as a horizontal reinforcing layer, or a mattress placed at the base of the embankment, which has been founded on a weak stratum of the soil. Basal reinforcement stabilizes an embankment over soft ground by preventing lateral spreading of the fill, extrusion of the foundation and overall rotational failure. Figure 1, shows a typical sketch of the basal reinforced embankment.

There have been different methods adopted for design for basal reinforced embankment. A detailed description about the different design approaches is presented in Rowe and Li (2005). However, the basic mechanism of the basal reinforcement with which it gives strength to the embankment and consequently prevents the failure of the embankment which has been founded on the weaker soil stratum is through friction developed at soil-reinforcement-soil interface and its membrane effect (Ghosh and Madhav 1994a; Ghosh and Madhav 1994b). Generally the load in the reinforcement increases to a maximum during construction, and as the foundation consolidates, the reinforcement tension decreases. When the foundation soil has consolidated, it carries the entire embankment load and thereafter theoretically reinforcement is no longer required. BS 8006:1995 (Code of practise for strengthened/reinforced soils and other fills) gives guidelines for design of embankments with reinforced soil foundation based on limit state method and considers the ultimate limit states like local stability, rotational stability, lateral sliding stability, foundation extrusion stability and overall stability and serviceability limit states for strain in the reinforcement and settlement of foundation.

![Figure 1, Typical Details of Basal reinforced embankment](image)

The presence of basal reinforcement alone does not influence the settlement characteristics of the embankment. Thus settlement analysis is required to be performed using conventional procedures to predict the settlement of the embankment. If the settlement analysis predicts that the settlements are within tolerable limits then merely basal reinforcement can be provided to enhance the stability of the embankment. If the settlements are beyond tolerable limits one has to go for pre-consolidation of clayey stratum to reduce the post construction settlement or provide vertical reinforcement such as piles below the embankment.

3.0 PILED EMBANKMENT WITH BASAL REINFORCEMENT

For embankments built on deep seated soft clayey deposits it is very difficult to reduce the post construction settlements within allowable limits especially for high speed motorways and railways, and that too within the prescribed time limits for the fast track projects. This calls for use of piled embankment covered with geosynthetic basal reinforcement, provided at the interface of the soft soil’s top and the base of the embankment (BS 8006 1995; Kempton et al. 1998; and Marchi et al. 2006). Figure 2 shows a typical sketch of the piled embankment, covered with raft of the geosynthetic basal reinforcement.

![Figure 2, Typical Sketch of Piled Embankment](image)

Piles are installed through the soft subsoil deposit and generally rest on hard end bearing stratum. The geosynthetic basal reinforcement placed over the pile/ pile caps helps essentially in transferring the load of the embankment to the piles. Pile cap and thrust block are optional and are provided based on the design requirement. Pile caps helps in reducing the tension in the geosynthetic basal reinforcement for a given spacing. Thrust block is provided based on the requirement of end anchorage.
An arching action that develops due to differential movement between the sub-soil and the piled embankment, thus, transmitting bulk of the load from the embankment to the piles. Provision of relatively inexpensive basal reinforcement helps in placing the expensive piles as apart as possible. The geosynthetic basal reinforcement picks up the vertical load not carried directly by the piles and goes into tension. Various design method and numerical techniques such as Finite element method are available for design of this complex problem. BS:8006 gives detailed guidelines for simplified design of basal reinforced piled embankment.

![Diagram of piled embankment with geosynthetic basal reinforcement](image)

Figure 2. Piled embankment with a geosynthetic basal reinforcement (Kempton et al. 1998)

Major consideration in design is to assess the amount of vertical load which is carried by the geosynthetic basal reinforcement and the tension which this load generates in the geosynthetic. Figure 3a gives a design a two-dimensional (2D) model of the problem and figure 3b gives a three dimensional model, which is more close to reality.

![Diagram of two-dimensional and three-dimensional models of piled embankment](image)

Figure 3, (a) Two dimensional representation of piled embankment problem and (b) Three dimensional representation of piled embankment problem (Kempton et. al. 1998)

4.0 CASE STUDY OF BASAL EMBANKMENT - S.MARCO ARGENTANO ROAD PROJECT IN ITALY

During the construction of the 3rd part of the National Highway no. 533 at the location ‘S.Maro Argentano’ in Italy, a marshy land consisting of soft clay was encountered between sections 219 and 225 adjacent to a bridge abutment. This zone had an approximate thickness of 2.50 m which extends for an area of 8,000sqm. Anticipating the instability problems associated with the construction of the 7m (maximum) high embankment, ParalinkTM type M400 was used as a basal reinforcement in between the embankment fill and the soft soil strata as shown in figure 3. ParalinkTM geogrids have a planar structure consisting of a mono-axial array of composite geosynthetic strips, which can effectively absorb the high tensile stresses transferred from the heavy overlying embankment. A non-woven geotextile Terram 1000 was used as a separator between ParalinkTM and the drainage blanket made of sand. Because of the unavailability of relevant Italian National Standard, the authority...
specified that BS8006, 1995 should be used in designing the geogrid foundation layer to minimize the risk in the design of this innovative technique.

Figure 4. Typical cross section of the embankment stabilized with Paralink™ M400

Figure 5, (a) Laying geotextile, (b) Placing of geogrids

Figure 6, Completed structure
5.0 CASE STUDY OF BASAL REINFORCED PILED EMBANKMENT – HIGH SPEED ROAD FROM BOLOGNA TO MILAN, ITALY

The new high speed railway line between Milano to Bologna, Italy, passed through areas of compressible soil in Parma area. This area is also well known for rising spring-water. Basal reinforced piled embankment was used in this area to support railway line in this area (Marchi, et. al., 2006). This construction technique offered superior technical and cost benefits over traditional consolidation based methods. The choice of a non-traditional solution was driven by the need to solve potential localized differential settlements of the railway embankment and the influence of rising spring water, while stratifying the construction time requirements. The traditional construction technique of consolidation could not guarantee that the rate of settlement of the railway embankment would be under the clients specified maximum value of 0.05 m/10 year.

5.1 Geotechnical Information

A detailed site investigation involving both in situ and laboratory testing was performed. Table 1 summarizes the properties of the soils encountered in the area of the piled embankments.

Table 1, Soil characterization

<table>
<thead>
<tr>
<th>Units</th>
<th>Depth From[m] To[m]</th>
<th>( \gamma ) [kN/m³]</th>
<th>E [MPa]</th>
<th>( c_v ) [m²/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMB</td>
<td>–</td>
<td>19.5</td>
<td>&gt; 60</td>
<td>–</td>
</tr>
<tr>
<td>1a</td>
<td>0.0 – 4.0</td>
<td>19.0</td>
<td>7.0</td>
<td>1.5 \times 10^{-7}</td>
</tr>
<tr>
<td>1b</td>
<td>4.0 – 20.0</td>
<td>18.0</td>
<td>5.3 + 0.4z</td>
<td>1.0 \times 10^{-7}</td>
</tr>
<tr>
<td>2a</td>
<td>20.0 – 27.0</td>
<td>18.5</td>
<td>13.0</td>
<td>2.0 \times 10^{-7}</td>
</tr>
<tr>
<td>2b</td>
<td>27.0 – 33.5</td>
<td>19.5</td>
<td>41.0</td>
<td>–</td>
</tr>
<tr>
<td>2c</td>
<td>33.5 – 46.5</td>
<td>19.0</td>
<td>22.5</td>
<td>1.5 \times 10^{-7}</td>
</tr>
<tr>
<td>3a</td>
<td>46.5 – –</td>
<td>19.5</td>
<td>55.0</td>
<td>–</td>
</tr>
</tbody>
</table>

5.2 Description of Designed Solution

The final solution, designed in accordance with BS 8006 (1995), consisted of 0.5 m diameter continuous flight augured (CFA) piles installed at 2 m centres on a square grid. The length of the piles varied depending on the height of the embankment and the results of the settlement analysis. No pile caps were used and the high tensile polyester geogrid was installed with a thin layer of sand separating the geogrid and the pile top, Figure 7.

Figure 7, Details of Geogrid Reinforced Piled Embankment for High Speed Railway Line Embankment
A maximum short-term design strain of 4%, with a further 1% creep strain over the design life, was used in the calculation of the tension in the reinforcement. The strength of the reinforcement ranged from 900 to 1050 kN/m depending on the height of the embankment. Two layers of geogrid, one in the longitudinal and the second in the transverse direction were installed. (Refer Figure 8 a and b).

In the transverse direction the geogrid was anchored using 0.5 m of gravel, around which the grid was rapped, to achieve the required anchorage length specified by the design method (BS 8006, 1995), Figure 9.

![Figure 8](image1.jpg)

(a) (b)

Figure 8, (a) Installation of transverse geogrids, (b) Installation of longitudinal geogrids

![Figure 9](image2.jpg)

Figure 9, Installation geogrids near to bridge abutment

5.3 Reinforcement Material

Railway embankments are considered a particular severe application due to the very restrictive tolerance on settlement. The selected geogrid had not only to meet the strength requirements and have a maximum elongation over the design life of 5%; it also had to have its long-term properties certified by an independent competent testing and certification authority like the British Board of Agreement.
ParaLink™, (refer Figure 10) manufactured Liner Composites, UK, that was widely used for similar application worldwide and certified by the BBA (BBA Agrément Certificate Nos 3338- 1997 and 4065-2003) as basal reinforcement of embankments since the 1997, was selected for this application. ParaLink™ consisted of high tenacity polyester encased in a polyethylene sheath. Details of the product are given in Naughton et al. (2005).

Figure 10, ParaLink™ used as Basal Reinforcement for Piled Embankment

5.4 Settlement Calculations

Based on the soil parameters obtained from the site investigation the magnitude of settlement was estimated using elastic techniques. The analysis indicated that the use of piles to support the embankment would reduce, by a third, the rate of settlement over a 10 year period (3-13 years), Table 2, resulting in rates of settlements well below the clients maximum rate of 0.05 m/10 year.

<table>
<thead>
<tr>
<th>Height of embankment [m]</th>
<th>Construction method</th>
<th>Magnitude of settlement, η</th>
<th>Rate of settlement Δη/Δt [m/10 years]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>3 years [m]</td>
<td>13 years [m]</td>
</tr>
<tr>
<td>7.0</td>
<td>No Piles</td>
<td>0.18</td>
<td>0.23</td>
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<td></td>
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<td>0.05</td>
<td>0.07</td>
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<tr>
<td>6.0</td>
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<td>0.14</td>
<td>0.19</td>
</tr>
<tr>
<td></td>
<td>Piles</td>
<td>0.04</td>
<td>0.06</td>
</tr>
<tr>
<td>5.0</td>
<td>No Piles</td>
<td>0.14</td>
<td>0.18</td>
</tr>
<tr>
<td></td>
<td>Piles</td>
<td>0.05</td>
<td>0.06</td>
</tr>
<tr>
<td>4.0</td>
<td>No Piles</td>
<td>0.09</td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td>Piles</td>
<td>0.04</td>
<td>0.05</td>
</tr>
</tbody>
</table>

6.0 CONCLUSIONS

Basal reinforcement can be very effectively used for construction of embankments over soft soils, satisfying the stability criteria. However, if the post construction settlements are beyond the acceptable limits, there is a need to go for alternative methods.

Basal reinforced pile embankment pose distinct advantages over conventional consolidation based methods for construction of high embankments over deep seated marine clay deposits. The use of basal reinforced pile embankments enable construction of embankment in one go, without any lean period and post construction settlements can be maintained well within tolerable limits even for structures such as high speed railway line, which have very stringent requirements of post construction settlement. The technique may appear cost prohibitive at first glance, but the benefit that user can draw from the early completion of the project may prove the system to be economically viable as well.

The simplified method of analysis over estimates the strength of basal reinforcement for pile embankments. However, rigorous analysis can be performed using numerical methods such as Finite Element Method to refine the solution.
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