Column-Supported Embankment Solves Time Constraint For New Road Construction

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ABSTRACT: Geosynthetic-reinforced column-supported embankments (GRCSE) have emerged as an effective alternative to conventional geotechnical solutions when constructing on soft soils. This paper will present a case history of a recently completed project that used GRCSE to solve the problem of rapidly constructing an embankment over soft compressible soil. The paper will focus on the design methodology used to design the column-supported embankment, the construction quality control measures used during construction (i.e., automated monitoring system for installation of piles, etc.) and the overall performance of the system. The project was completed on time and settlements of the finished embankment were within project requirements (i.e., less than 1 inch).

1.0 INTRODUCTION

The problems associated with constructing highway embankments over soft compressible soil (i.e., large settlements, embankment instability and the long period of time required for consolidation of the foundation soil) has lead to the development and/or extensive use of many of the ground improvement techniques used today. Wick drains, surcharge loading, geosynthetic reinforcement, stone columns, and vibro-concrete columns have all been used to solve the settlement and embankment stability issues associated with construction on marginal soils. However, when time constraints are critical to the success of the project, owners have resorted to another innovative approach: geosynthetic reinforcement column supported embankments (GRCSE). In the last 15 years, this technology has been used successfully on several projects both in the US and abroad.

Column supported embankments consist of vertical columns that are designed to transfer the load of the embankment through the soft compressible soil layer to a firm foundation. The selection of the type of column used for the CSE will depend on the design loads, constructability of the column, cost, etc. The load from the embankment must be effectively transferred to the columns to prevent punching of the columns through the embankment fill creating differential settlement at the surface of the embankment. If the columns are placed close enough together, soil arching will occur and the load will be transferred to the columns. In order to minimize the number of columns required to support the embankment and increase the efficiency of the design, a load transfer platform (LTP) reinforced with geosynthetic reinforcement is being used on a regular basis. The load transfer platform consists of one or more layers of geosynthetic reinforcement placed between the top of the columns and the bottom of the embankment (Figure 1).

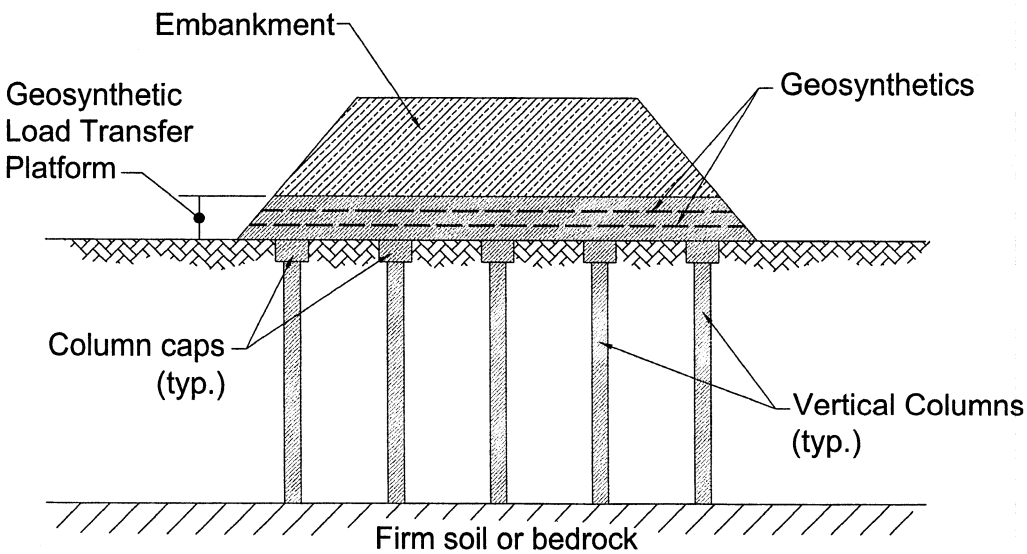

Figure 1. Geosynthetic Reinforced Column Supported Embankment.

2.0 DESIGN METHODOLOGY

2.1 Column Design

The load that a column is required to carry is typically based in the tributary area for each column. The embankment and any surcharge load is assumed to be carried in its entirety by the columns.

For purposes of determining the design vertical load in the column, it is convenient to associate the tributary area of soil surrounding each column, as illustrated in figure 2. For a triangular column spacing, the tributary area forms a regular hexagon about the column, and may be closely approximated as an equivalent circle having the same total area. For triangular column spacing, the effective diameter is equal to 1.05 times the center to center column spacing (typical center to center column spacing ranges from 1.5 to 3.0 m). For square column spacing, the tributary area forms a square and the effective diameter (diameter D_e) is equal to 1.13 times the center to center column spacing.

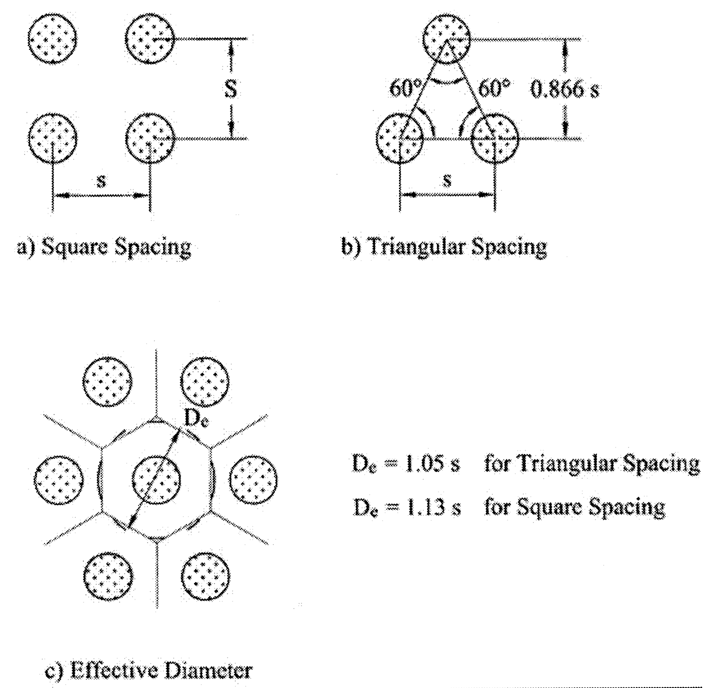

Figure 2. Column Layout

The required design vertical load (Q_r) in the column is determined according the following equation:

$$Q_r = \pi(D_e/2)^2\ (\gamma H + q)$$

where: D_e = effective tributary area of column
H = height of embankment
q = live and dead load surcharge (typically 12 kPa)
γ = unit weight of the embankment soil

2.2 Load Transfer Platform (LTP) Design

There are two fundamentally different approaches for the design of the load transfer platform. The first approach, which is used by the British Standard, the Swedish (Rogbeck et al., 2002, Rogbeck et al., 1998), and the German methods (Alexiew and Gartung, 1999, and Alexiew, 2003), is for the reinforcement to act as a catenary. The reinforcement transfers the load from the embankment fill to the columns through catenary tension in the reinforcement as shown in Figure 3. In essence, the reinforcement behaves as a structural element and any benefits achieved by the creation of a composite reinforced soil mass are ignored. The primary assumptions in the catenary theory are:

- Soil arch forms in the embankment
- Reinforcement is deformed during loading
- The reinforcement is modeled as if only one layer of reinforcement is used; if more than one layer of reinforcement is used, only the tensile strength of the multiple layers is considered.

The second approach for the design of the load transfer platform (Collin Method) is to use multiple layers of reinforcement to create a stiff reinforced soil mass (Collin, 2004). The Collin Method is a refinement of a method sometimes referred to as the Guido Method (Bell et al., 1994, and Hewlett and Randolph, 1988). The reinforced soil mass acts as a beam to transfer the load from the embankment above the platform to the columns below. The beam theory is based on the following requirements and assumptions:

- The thickness (h) of the load transfer platform is equal to or greater than one half the clear span between columns (s-d).
- A minimum of three layers of extensible (geosynthetic) reinforcement is used to create the load transfer platform.
- Minimum distance between layers of reinforcement is 20 cm.
- Select fill is used is used in the load transfer platform.
- The primary function of the reinforcement is to provide lateral confinement of the select fill to facilitate soil arching within the height (thickness) of the load transfer platform.
- The secondary function of the reinforcement is to support the wedge of soil below the arch.
- All of the vertical load from the embankment above the load transfer platform is transferred to the columns below the platform.
- The initial strain in the reinforcement is limited to 5%.

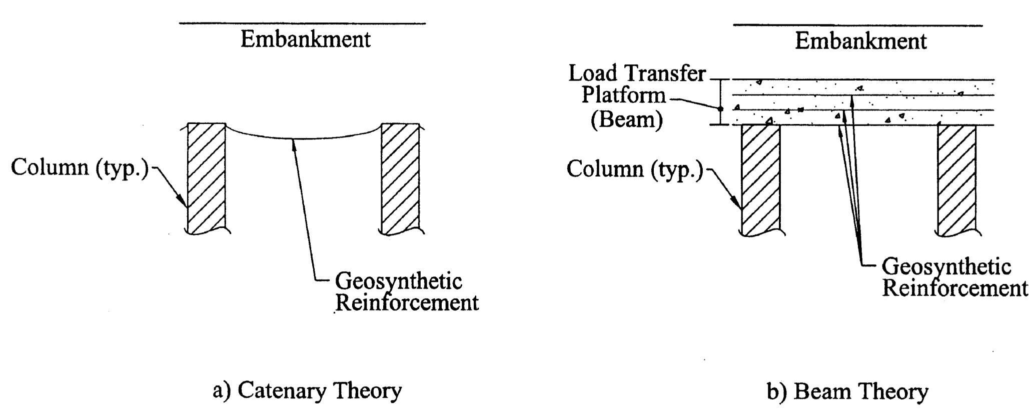

Figure 3. Load Transfer Mechanisms (Collin, 2004)

The vertical load carried by each layer of reinforcement is a function of the column spacing pattern (i.e., square or triangular) and the vertical spacing of the reinforcement. If the subgrade soil is strong enough to support the first lift of fill, the first layer of reinforcement is located 0.15 to 0.25 m above subgrade. Each layer of reinforcement is designed to carry the load from the platform fill that is within the soil wedge below the arch. The fill load attributed to each layer of reinforcement is the material located between that layer of reinforcement and the next layer above (Figure 4).

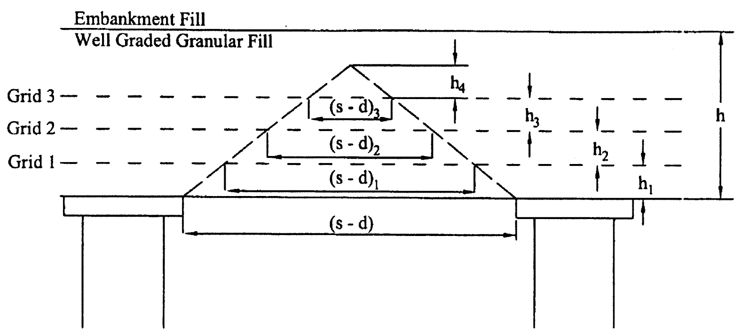

Figure 4. Load Transfer Platform Design Collin Method

The uniform vertical pressure on any layer (n) of reinforcement (W_{Tn}) may be determined from the equation below:

W_{Tn} = ((area at reinforcement layer n + area at reinforcement layer (n+1))/2)(layer thickness) (load transfer platform fill density))/(area at reinforcement layer n)

$$W_{Tn} = [(s\text{-}d)_n^{\,2} + (s\text{-}d)_{n+1}^{\,2}]\, h_n\, \gamma / (s\text{-}d)_n^{\,2}$$ for square or triangular pattern

The tensile load in the reinforcement is determined based on tension membrane theory (Giroud et al., 1990) and is a function of the amount of strain in the reinforcement. The tension in the reinforcement is determined from the following equation:

$$T_{rpn} = W_{Tn}\, \Omega\, D/2$$

where: D = design span for tension membrane
= $(s\text{-}d)_n$ for square pattern
= $(s\text{-}d)_n \tan 30°$ for triangular pattern

Ω = dimensionless factor

Table 1. Values of Ω

Ω	Reinforcement Strain (ε)%
2.07	1
1.47	2
1.23	3
1.08	4
0.97	5

3.0 CASE HISTORY PROJECT REQUIREMENTS

The construction of a road for a new residential section of the Kingsmill development in Williamsburg, Virginia faced several challenges. The new road crosses an existing golf course. The LPGA has one of their annual tournaments at this course every spring. The new road had to be constructed in a three month time period in order not to affect the golf tournament. The road crosses the golf course in an area that has been identified as a wetland. The original geotechnical report recommended that the section of roadway that crosses the wetland be a bridge structure. The solution that the project owner selected was to use a GRCSE to support back to back segmental retaining walls (utilized to minimize the width of the GRCSE) with an asphalt pavement above the retaining walls (Figure 4).

Soil borings revealed that the presence of up to 4 m of organic clay (OH) and peat (PT), beginning at a depth of 3 to 7 meters below the ground surface. Above the organic clay layer was a layer of loose to medium dense sand. The organic peat was tested to be very soft/loose, and very compressible. Underlying the organic soils, and extending to the boring termination depth of 12 to18 meters, the soils generally consisted of Silty Sand (SM) with some marine shell fragments (Yorktown Formation). The standard penetration test (SPT) results, N-values, recorded within these soils ranged from 4 to 24 blows per 0.3 m, indicating that the granular soils were of very loose to medium dense relative density, with the penetration resistances increasing with depth. The groundwater table was within 1 m of existing grade.

The proposed road is approximately 3.5 meters above existing grade. Over 25cm of settlement would occur from the weight of the new fill. Surcharge loading and prefabricated vertical drains were considered. However, the time required for the settlement to occur was not acceptable.

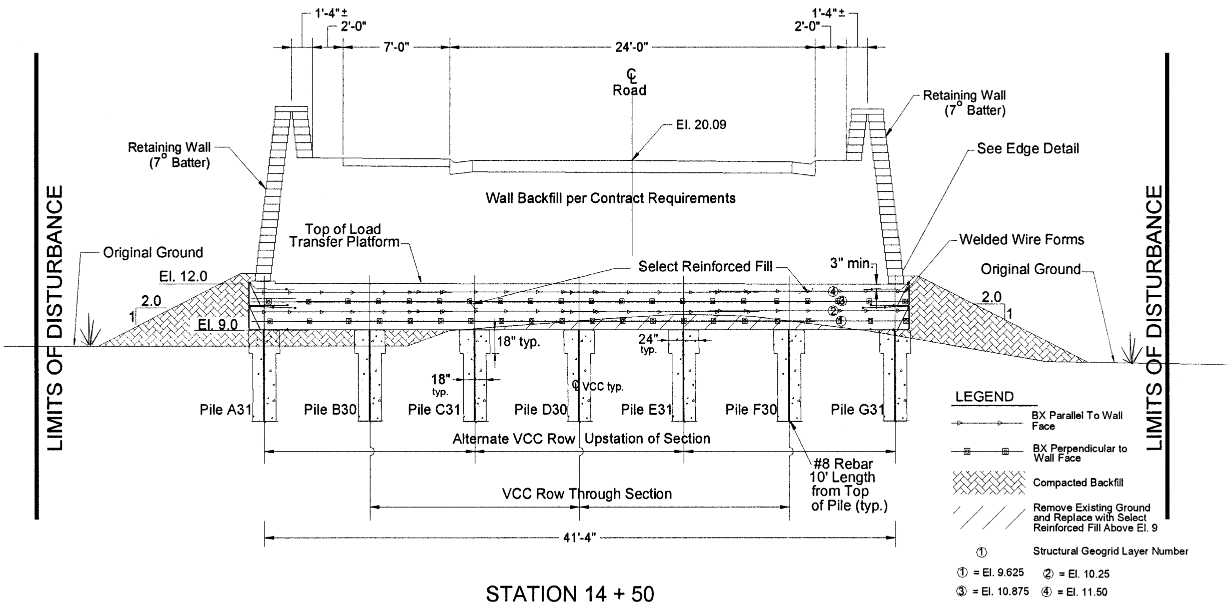

Figure 4. Kingmills Cross-Section

3.1 Auger Cast in Place Pile (ACIP)

Auger cast in place piles were selected as the columns for this project. ACIP consist of drilling to a desired depth with a continuous flight auger, and then as the auger is slowly withdrawn, concrete grout is injected through the auger's stem. One reason that this pile column system was selected for the project is that the installation method minimizes the noise and vibrations typically associated with driven piles. In the residential community where the project was located, this was of utmost importance.

The design of the ACIP considered both end bearing and frictional resistance along the shaft of the columns in the medium dense sand layer (Yorktown formation). 0.45 meter (18 inch) diameter ACIP pile were utilized for the foundation. The design pile capacity was 445 kN (100 kips) at a length of 17 meters (50 feet). A total of 175 ACIP piles were installed for the project. The pile design was based on a 2.4 meter (8 feet) triangular pile spacing. Pile caps were also included in the design. The caps were required to reduce the clear span between the piles so that a 0.9 meter thick LTP would work. The caps also decreased the potential for punching shear of the column through the LTP.

3.2 Load Transfer Platform

The design of the columns and the load transfer platform is an iterative process. For this project the LTP controlled the design. Using the design method presented in section 2.2, the thickness of the platform was 0.9 meters. The platform was reinforced with three layers of biaxial geogrid, with an ultimate strength of 29 kN/m (2000 plf). The first layer of geogrid was placed 20 cm above subgrade. The second and third layer were spaced 20 cm vertically apart.

4.0 QUALITY CONTROL/QUALTIY ASSURANCE

The contract documents required that automatic monitoring equipment (AME) be used to install the ACIPs. A depth sensor to monitor auger tip depth at all times during installation was required with a real time clock so that the installation drilling rate was recorded during drilling. A magnetic flow meter was used to measure the volume of grout pumped per lineal meter of pile. A grout pressure sensor monitored grout pressure continuously during grouting. All the data was displayed on a screen in the cab of the crane used to install the ACIPs and recorded and saved to an on board computer. The AME was an essential tool that allowed the design engineer to evaluate the acceptability of all ACIPs.

The contract documents also required that one pile load test be performed in accordance with ASTM D1143 for quick load tests. The test pile was loaded to twice the design load with less than1.25 cm of deflection. This was deemed acceptable for the segmental retaining walls and pavement that would be constructed above the columns.

The tolerance on the location of the columns was also specified in the contract documents. The requirement stated: "Pile center shall be located to an accuracy of ± 7.5 cm. Piles shall be plumb within 2%. The top elevation of the piles shall be within ±7.5 cm of the plan elevation." A survey of the completed piles prior to construction of the LTP revealed that many piles were outside the allowed tolerance for location. The spacing between columns, at some locations, was now 2.7 meters (original design spacing 2.4 meters). The load transfer platform was therefore redesigned to accommodate the large columns spacing. The redesigned LTP remained 0.9 meters thick, however, four layers of geogrid reinforcement were required (original design utilized 3 layers of geogrid). The spacing between layers of reinforcement was 19 cm. The LTP and the SRW were complete in the late spring of 2004. Maximum settlement of less than 2.5 cm was recorded along the length of the walls.

5.0 CONCLUSIONS

GRCSE is an emerging technology that has potential advantages over more conventional construction methods when building over soft compressible soil. One major advantage is that the time to construct the embankment is substantially reduced. The time from installation of the indicator piles to completion of the SRW for this project was less than 3 ½ months.

The design of GRCSE is an iterative process between the design of the columns and the design of the LTP. Neither can be designed without consideration of the other.

The design of the LTP for this project was based on the beam method which produces a stiff reinforced prism of soil that effectively distributes the load from the embankment above to the columns below with little anticipated settlement of the final structure.

Quality control/quality assurance programs are a critical component of any construction project. The design of the LTP was adjusted based on the as-built location of the columns to accommodate a larger column spacing than what the original design was based on. This design adjustment to accommodate the field conditions is critical for the successful completion of a project of this nature.

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