Geosynthetic-Reinforced Column-Support Embankment Design Guidelines

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Abstract

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) have lead to the development and/or extensive use of many of the ground improvement techniques today. Wick drains, surcharge loading, and geosynthetic reinforcement, 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.

Column supported embankments (CSE) 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 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.

This paper will present the guidelines for the design of column supported embankments developed by the authors under contract with the Federal Highway Administration. These guidelines were developed based on a review of current design methodologies and a parametric study of design variables using numerical software (FLAC).

1.0 DESCRIPTION

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., and is not the focus of this paper (see Collin, 2004). The load from the embankment must be effectively transferred to the columns to prevent punching of the columns through the embankment fill causing 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. Figure 1 shows a conventional CSE. The columns are spaced relatively close together, and some battered columns are required at the sides of the embankment to prevent lateral spreading. In order to minimize the number of columns required to support the embankment and increase the efficiency of the design, a geosynthetically reinforced load transfer platform (LTP) may be used. 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 2 shows schematically a CSE with geosynthetic reinforcement.

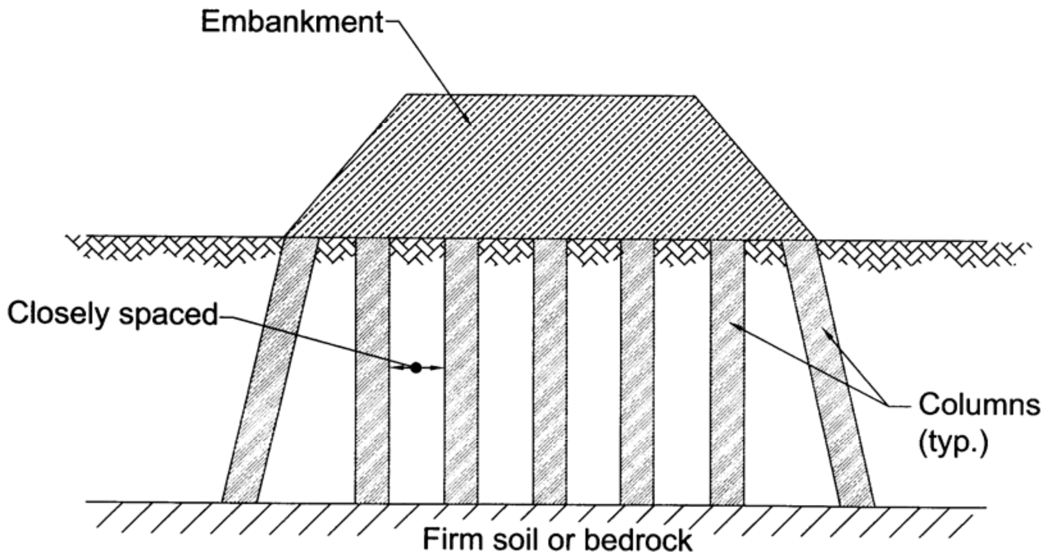

Figure 1. Conventional Column Supported Embankment

2.0 DESIGN CONCEPTS

The design of column supported embankments must consider both limit state, and serviceability state failure criteria. The limit state failure modes are shown in Figure 3. The columns must be designed to carry the vertical load from the embankment without failing (Figure 3a). The columns are typically assumed to carry the full load from the embankment. The lateral extent of the columns under the embankment must be determined (Figure 3b). The load transfer platform must be designed to transfer the vertical load from the embankment to the columns (Figure 3c). The potential for lateral sliding of the embankment on top of the columns must be addressed (Figure 3d). Finally, global stability of the system must be evaluated (Figure 3e).

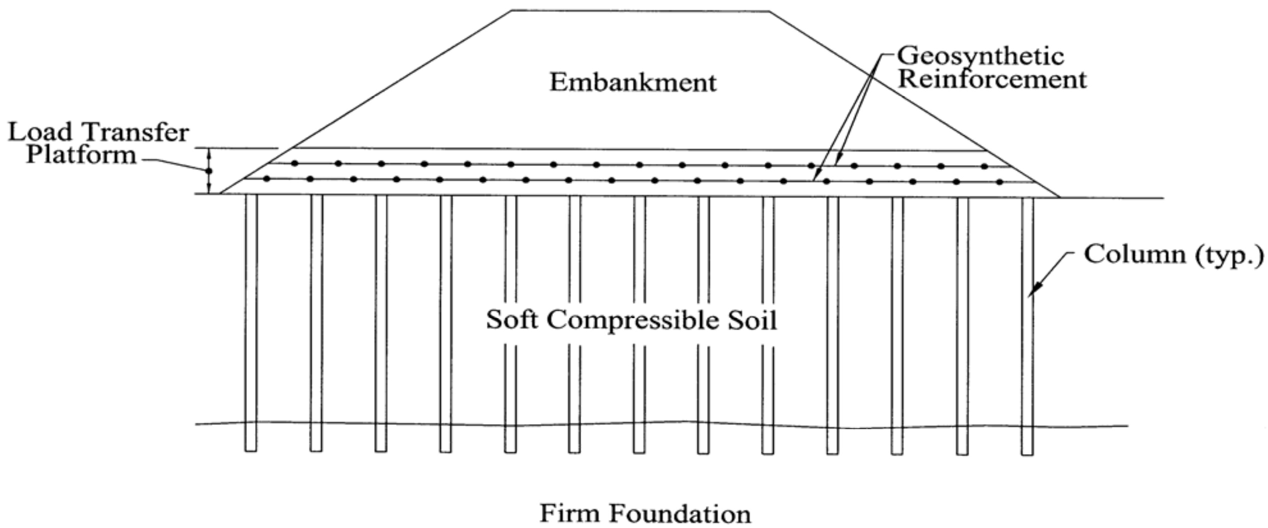

Figure 2. Column supported embankment with a geosynthetic reinforced load transfer platform

In addition to limit state analysis, serviceability state design must be considered. The strain in the geosynthetic reinforcement used to create the load transfer platform should be kept below some maximum threshold to preclude unacceptable deformation reflection (*i.e.,* differential settlement) at the top of the embankment. Settlement of the columns must also be analyzed to assure that unacceptable settlement of the overall system does not occur, as shown in Figure 4.

The general design steps for a CSE are provided below:

1. Estimate preliminary column spacing (use feasibility assessment guidelines).
2. Determine required column load.
3. Select preliminary column type based on required column load and site geotechnical requirements.
4. Determine capacity of column to satisfy limit and serviceability state design requirements.
5. Determine extent of columns required across the embankment width.
6. Select LTP design approach (*i.e.,* catenary or beam).
7. Determine reinforcement requirements based on estimated column spacing (step 1). Revise column spacing as required.
8. Determine reinforcement requirements for lateral spreading.
9. Determine overall reinforcement requirements based on LTP and lateral spreading.
10. Check global stability.
11. Prepare construction drawings and specifications.

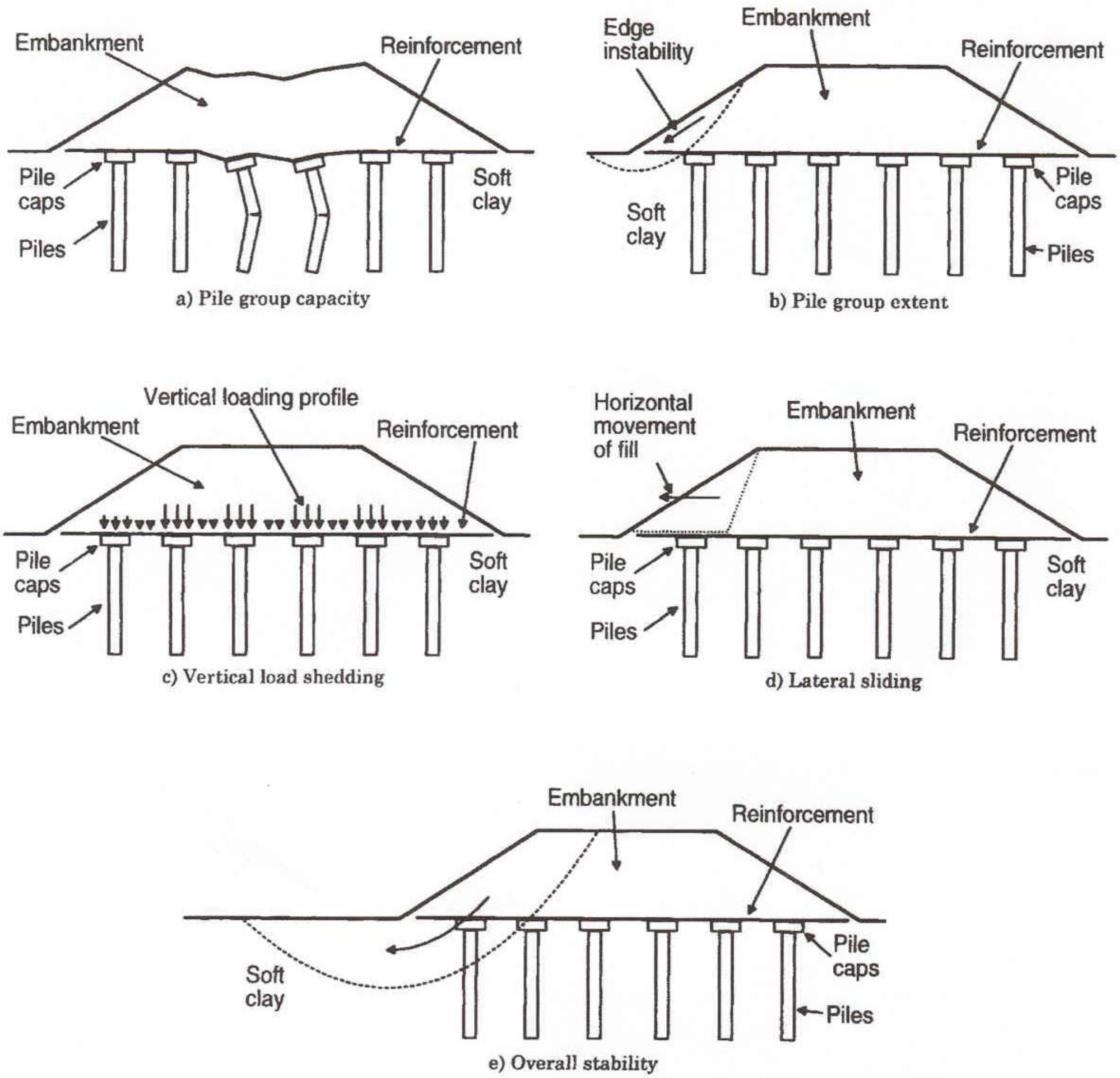

Figure 3. Limit State Failure Modes (BS8006)

The majority of the design steps follow conventional geotechnical engineering practice and is covered extensively in British Standard BS 8006 and the paper "*Column Supported Embankment Design Considerations*" (Collin, 2004) and will only be briefly covered within this paper. The much more controversial aspect of the design, the design of the load transfer platform (LTP) will be the focus of this paper.

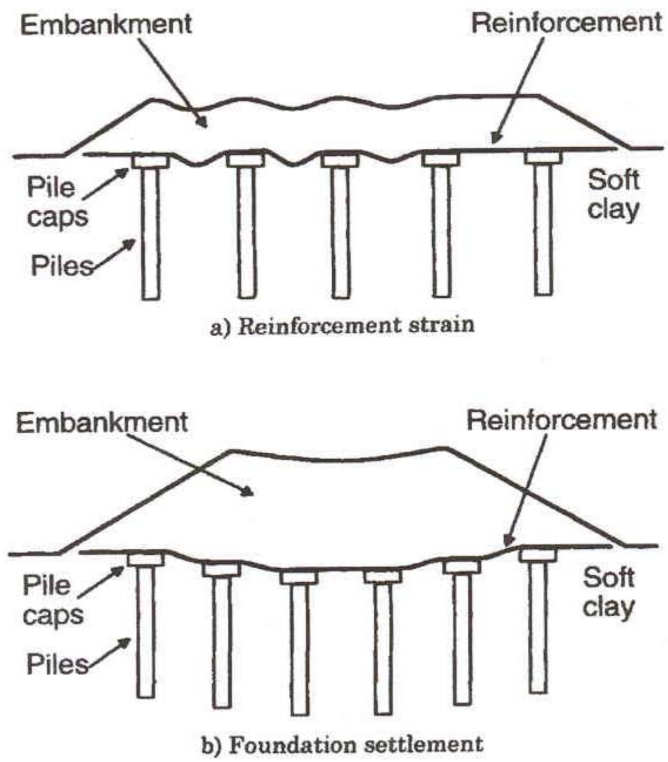

Figure 4. Serviceability State (BS8006)

3.0 COLUMN DESIGN

The selection of column type is most often based on constructability, load capacity, and cost. The load that a column is required to carry is typically based on the tributary area for each column. The embankment and any surcharge load is typically assumed to be carried in their 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 5. Although the tributary area forms a regular hexagon about the column, it can be closely approximated as an equivalent circle having the same total area. For square column pattern, the effective diameter (diameter D_e) is equal to 1.13 times the center-to-center column spacing. For triangular column pattern, 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- 3.0 m (5-10 ft.)).

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

$$Q_r = \pi(D_e/2)^2 (\gamma H + q) \quad (1)$$

where: D_e = effective tributary area of column
H = height of embankment
q = live and dead load surcharge (typically 12 kN/m^2 (250 psf))
γ = unit weight of the embankment soil

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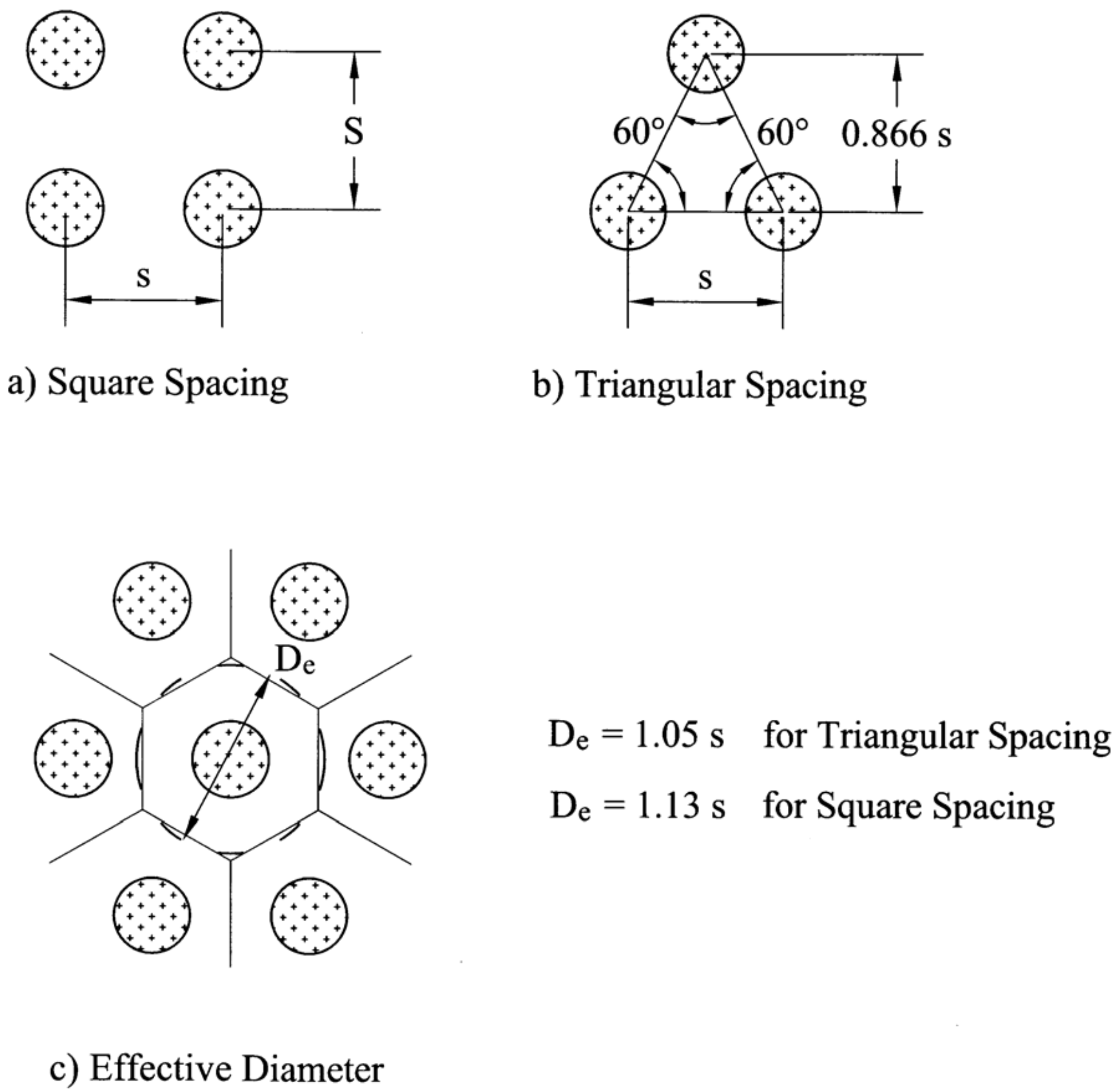

Figure 5. Column Layout

4.0 EDGE STABILITY- LATERAL EXTENT OF COLUMNS

The lateral extent of the column system across the width of the embankment should extend a sufficient distance beyond the edge of the embankment to ensure that any instability or differential settlement that occurs outside the column supported area will not affect the embankment crest (Figure 3b). There are several approaches that may be used to check the edge stability. The computer software developed for FHWA for the design of both reinforced and non-reinforced slopes and embankments, ReSSA, is an excellent tool for checking edge stability.

The British Standard (BS8006) requires that the columns extend to within a minimum distance (L_p) of the toe of the embankment. Figure 6 defines the terms for edge stability. L_p is determined from the following equation:

$$L_p = H(n - \tan\theta_p) \quad (2)$$

where:
- n = side slope of the embankment
- θ_p = is the angle (from vertical) between the outer edge of the outer-most column and the crest of the embankment [$\theta_p = (45 - \varphi_{emb}/2)$].
- φ_{emb} = effective friction angle of embankment fill

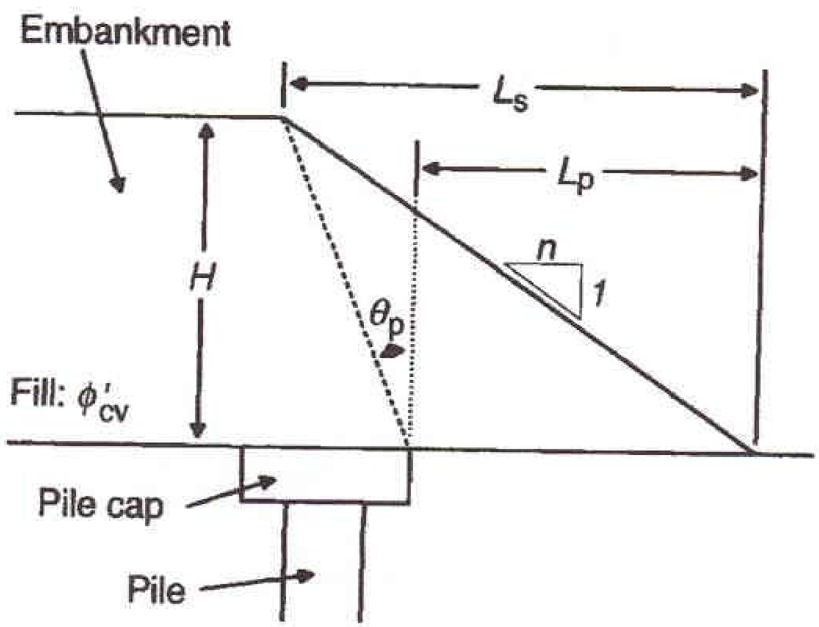

Figure 6. Edge Stability (BS 8006)

The British method is an excellent check of the more rigorous stability analysis using limit equilibrium techniques (*i.e.,* ReSSA). For preliminary designs and/or feasibility analysis, the simplified British approach is sufficient.

5.0 LATERAL SPREADING

The potential for lateral spreading of the embankment must be analyzed (Figure 7). The geosynthetic reinforcement must be designed to prevent lateral spreading of the embankment. This is a critical aspect of the design, as many of the columns that are appropriate for column supported embankments are not capable of providing adequate lateral resistance to prevent spreading of the embankment without failing.

The geosynthetic reinforcement must be designed to resist the horizontal force due to the lateral spreading of the embankment. The required tensile force to prevent lateral spreading (T_{ls}) is determined from the following equation:

$$T_{ls} = K_a (\gamma H + q)H/2 \qquad (3)$$

where:

K_a = coefficient of active earth pressure ($\tan^2 (45-\varphi_{emb}/2)$)

The minimum length of reinforcement (L_e) necessary to develop the required strength of the reinforcement without the side slope of the embankment sliding across the reinforcement is determined using the equation below:

$$L_e = T_{ls} /[0.5 \gamma H(c_{iemb}\tan \varphi_{emb})] \qquad (4)$$

where:

c_{iemb} = coefficient of interaction for sliding between the geosynthetic reinforcement and embankment fill

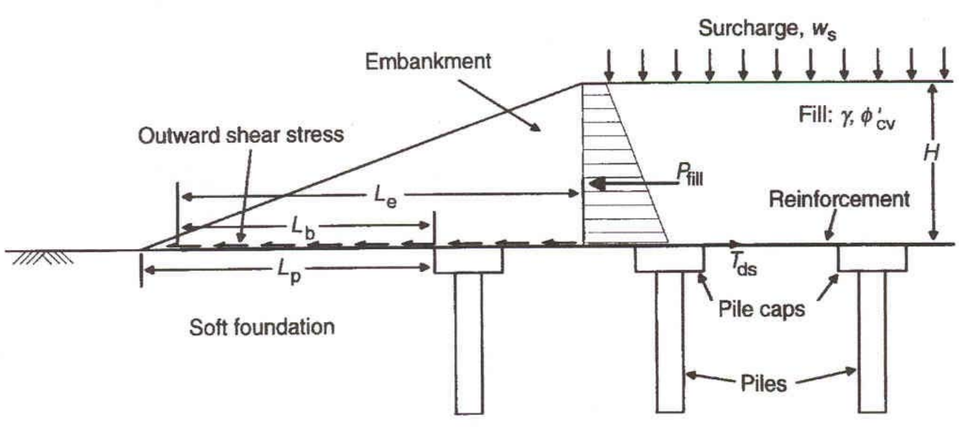

Figure 7. Lateral Spreading (BS 8006)

6.0 LOAD TRANSFER PLATFORM DESIGN

The design of the load transfer platform (Collin Method, Collin, 2004) is based on the use of multiple layers of reinforcement to create a stiff reinforced soil mass (Figure 8). The Collin Method is a refinement of a method sometimes referred to as the Guido Method and assumes that the reinforced soil mass acts as a beam to transfer the load from the embankment above the platform to the columns below. The primary assumptions for the beam theory are:

- A minimum of three layers of reinforcement is used to create the platform.
- Spacing between layers of reinforcement is 200-450 mm (8-18 in.).
- Platform thickness is greater than or equal to one half the clear span between columns.
- Soil arch is fully developed within the depth of the platform.

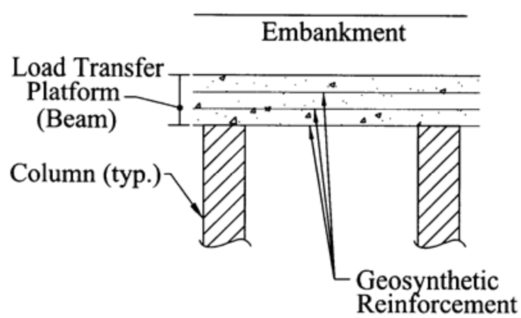

Figure 8. Load transfer mechanism – beam method

6.1 Tension Membrane

In addition to soil arching, the load transfer platform design includes tension membrane theory. The vertical load from the soil within the arch and any surcharge load, if the thickness of the embankment is not great enough to develop the full arch, is carried by the reinforcement. There are several theories available to estimate the tension in the reinforcement (Fluet and Giroud). Figure 9 shows the symbols that will be used in presenting the LTP design. They are defined below:

d	=	diameter of the column
H	=	height of embankment
P_c’	=	vertical stress on the column
q	=	surcharge load
s	=	center-to-center column spacing
T_{RP}	=	tension in the extensible reinforcement
W_T	=	vertical load carried by the reinforcement

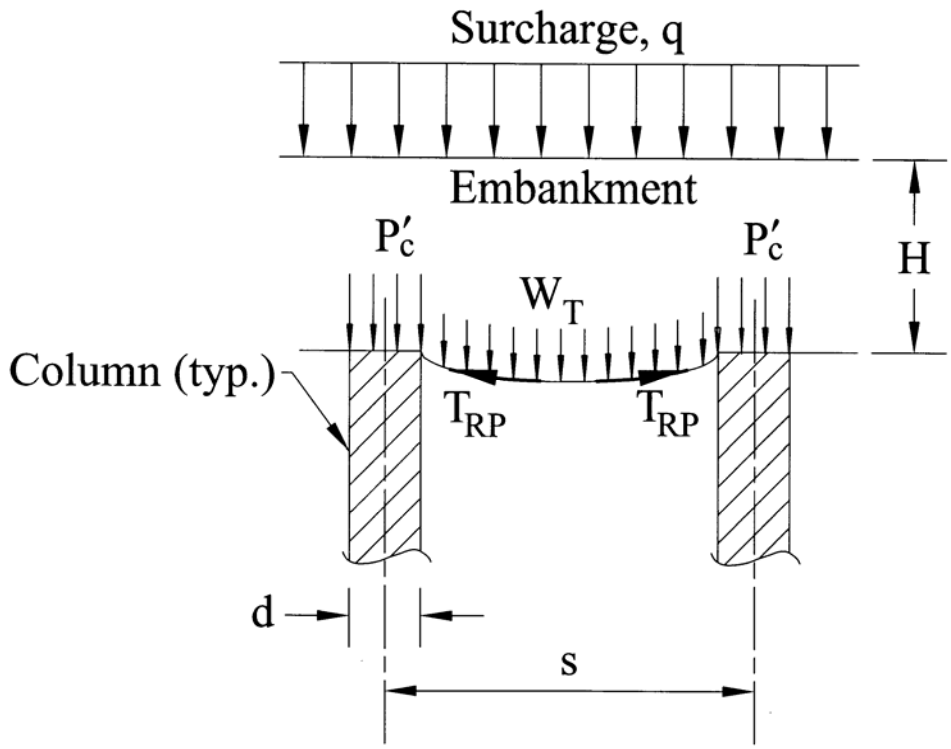

Figure 9. Definition of terms

6.2 Beam Method

The beam (Collin) method is based on the following 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 150 mm (6 in.).
- Select fill 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.
- 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%.

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 0.15-0.25 m (6-10 in.) 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 10).

The uniform vertical load on any layer (n) of reinforcement (W_{Tn}) may be determined from the equation below for an angle of arching of 45 degrees:

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)

$$W_{Tn} = [A_n + A_{n+1}]\, h_n\, \gamma / 2\, A_n \qquad (5)$$

where: A = Area at reinforcement layer n or n+1
= $[(s\text{-}d) - 2(\Sigma \text{ReinforcementVertical Spacing}/\tan 45)]^2$ for square column spacing
= $[(s\text{-}d) - 2(\Sigma \text{ReinforcementVertical Spacing}/\tan 45)]^2 \sin 60/2$ for triangular column spacing

The tensile load in the reinforcement is determined based on tension membrane theory and is a function of the amount of strain in the reinforcement. The tension in the reinforcement is determined from the following equation:

$$T_{rpn} = W_{Tn}\, \Omega\, D/2 \qquad (6)$$

where: D = design span for tensioned membrane
= $1.41*[(s\text{-}d) - 2(\Sigma \text{Vertical Spacing}/\tan 45)]$ for square column spacing
= $0.867*[(s\text{-}d) - 2(\Sigma \text{Vertical Spacing}/\tan 45)]$ for triangular column spacing
Ω = dimensionless factor from tensioned membrane theory

Table 1. Values of Ω. (Giroud et al., 1990)

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

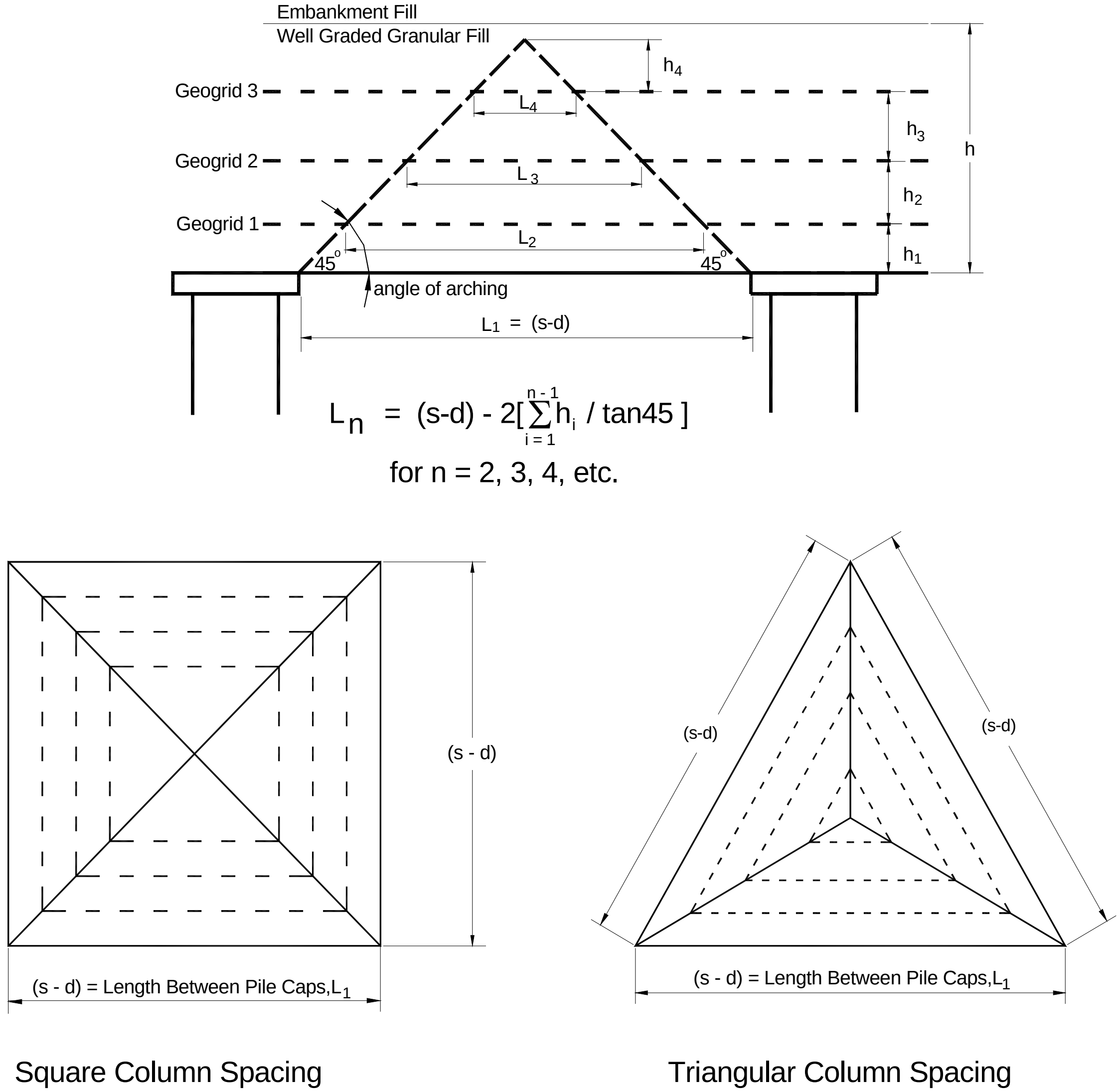

Figure 10. Load transfer platform design Collin method

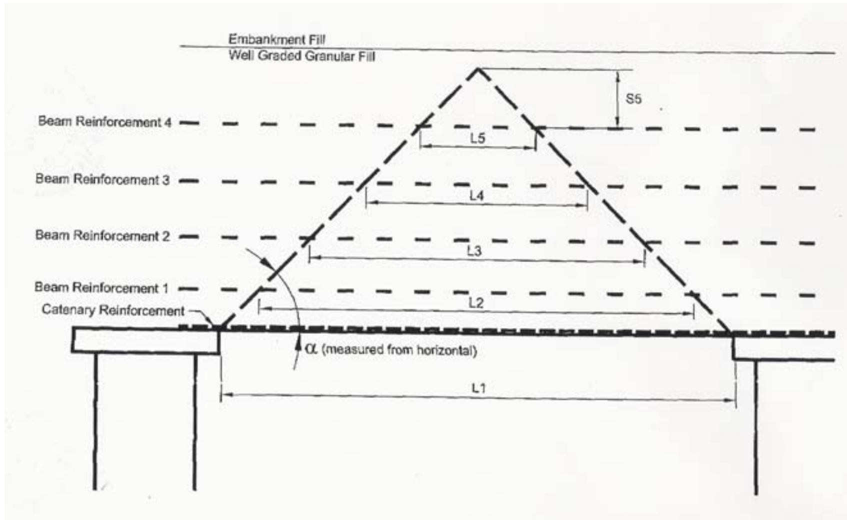

Figure 11. Modified beam method reinforcement

6.3 Modified Beam Method

Based on research recently completed (Collin, et. al., 2005) using numerical modeling the above procedure has been modified. The modification involves the addition of one layer of reinforcement at subgrade. This layer of reinforcement is designed as a catenary to carry the load from the soil below the arch (Figure 11).

The uniform vertical load on the catenary layer of reinforcement (W_{TC}) may be determined from the equation below:

W_{TCn} = (volume pyramid below the arch) (load transfer platform fill density)/(area at reinforcement catenary layer)

$$W_{Tn} = h_n \gamma / 3 \qquad \text{Square or Triangular column spacing} \qquad (7)$$

The tensile load in the reinforcement is determined based on tension membrane theory and is a function of the amount of strain in the reinforcement. The tension in the reinforcement is determined from the following equation:

$$T_{rpC} = W_{TC} \, \Omega \, D/2 \qquad (8)$$

where: D = design span for tensioned membrane
= 1.41*[(s-d) - 2(ΣVertical Spacing/tan45)] for square column spacing
= 0.867*[(s-d) - 2(ΣVertical Spacing/tan45)] for triangular column spacing
Ω = dimensionless factor from tensioned membrane theory

The reinforcement to create the beam above the catenary layer of reinforcement is designed according to equations 5 and 6.

7.0 CONCLUSIONS

The used of CSE is expanding both in the US and abroad. Numerous design guidelines have been developed for the design. Currently there are at least 5 to 10 methods to design the load transfer platform. The method presented here is one that has been developed by the authors and used with great success. However, the recommendations provided in this paper cover only the basic steps in the design of the LTP. The detailing of the platform (i.e., edge detail), selection of geosynthetic reinforcement, creep characteristics of the geosynthetic, overlaps, etc. are beyond the scope of this paper but must be considered in the design.

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REFERENCES

Bell, A.L., Jenner, C., Maddison, J.D., and Vignoles, J. (1994), "Embankment support using geogrids with Vibro Concrete Columns." *Proceedings, 5th International Conference on Geotextiles, Geomembranes and Related Products*, 1, Singapore.

British Standard BS 8006 (1995), *Code of Practice for Strengthened/Reinforced Soils and Other Fills*. British Standard Institution, London.

Collin, J.G., Han, J., and Huang, J. (2005), "Design Recommendations for Column Supported Embankments," FHWA-HRT-XXX-XX, August.

Collin, J.G. (2004) "Column Supported Embankment Design Considerations", Proceedings 52nd Annual Geotechnical Conference, University of Minnesota, Minneapolis, MN. February 27, 2004.

Collin, J.G., Watson, C.H., and Han, J. (2005), "Column Supported Embankment Solves Time Constraint for New Road Construction", ASCE Geo-Frontiers Conference, Austin TX, January, 2005.

Elias, V., Lukas, R., Bruce, D., Collin, J.G., and Berg, R.R. (2004) *Ground Improvement Methods Reference Manual,* Federal Highway Administration FHWA NHI-04-001, July 2004.

Giroud, J.P., Bonaparte, R., Beech, J.F., and Gross, B.A. (1990), "Design of soil layer-geosynthetic systems overlying voids." *Geotextiles and Geomembrane*, Elsevier, 9(1).

Han, J.

Han, J., and Collin, J.G., (2005), "Geosynthetic Support Systems over Pile Foundations", GRI 18 Conference: Geosynthetics in Transportation and Geotechnical Engineering, Austin, Texas, January, 2005.

Han, J., Collin, J.G., and Huang, J. (2004), "Recent Developments of Geosynthetic Reinforced Column Supported Embankments", 55th Annual Highway Geology Symposium, Kansas City, MO, September, 2004.

Han, J. (2003), "Development of Design Charts for Geotechnically Reinforced Embankments on Deep Mixed Columns." *National Deep Mixing Cooperative Research Program, Project No NDM 202.*

Han, J. (1999), "Design and construction of embankments on geosynthetic reinforced platforms supported by piles." *Proceedings of 1999 ASCE/PaDOT Geotechnical Seminar*, Central Pennsylvania Section, ASCE and Pennsylvania Department of Transportation, Hershey, PA.

Huang, J., Collin, J.G., and Han, J. (2005), "Geogrid-Reinforced Pile-Supported Railway Embankments – Three Dimensional Numerical Analysis", Transportation Research Board – 84th Annual Meeting, January 9-13, 2005, Washington, D.C.

Huang, J., Collin, J.G., and Han, J. (2005), "3D Numerical Modeling of a Geosynthetic-Reinforced Pile-Supported Embankment – Stress and Displacement Analysis", 16thInternational Conferenceon Soil Mechanics and Geotechnical Engineering, September 12-16, 2005, Osaka, Japan (in press).

Jenner, C.G., Austin, R.A., and Buckland, D. (1998), "Embankment support over piles using geogrids." *Proc. of 6th International Conference on Geosynthetics*, Vol. 1.

McNulty, J.W. (1965), "An Experimental study of arching in sand." *Technical Report* No. I-674, U.S. Army Engineer Waterways Experiment Station, Corps of Engineers, Vicksburg, Mississippi.

Reid, W.M. and Buchanan, N.W. (1984), "Bridge approach support piling." *Piling and Ground Treatment*, Thomas Telford Ltd, London.

Young, L.W., Milton, M.N., Collin, J.G., and Drooff, E. (2003), "Vibro-Concrete Columns and Geosynthetic Reinforced Load Transfer Platform Solve Difficult Foundation Problem." *Proceedings for 22nd World Road Congress, South Africa.*