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EMBANKMENT CONSTRUCTION USING COLUMN SUPPORTED EMBANKMENT

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ABSTRACT

The construction of roadway embankments over soft, compressible soils challenges designers with managing large and differential settlements, maintaining embankment stability, and minimizing construction costs associated with long consolidation periods. These challenges can be successfully tackled with the use of an in-situ soil improvement technique such as the Column Supported Embankment (CSE). The Column Supported Embankment involves constructing a pattern of cement-grouted columns in-situ, using the vibro-displacement or displacement-auger technique. The columns are constructed to bear on dense sand strata underlying cohesive strata that would otherwise consolidate under the embankment loading. A load transfer platform (LTP) is used to effectively distribute the embankment loads onto the series of cement-grouted columns. This paper presents a project case history involving the planning and construction of Column Supported Embankments for the proposed widening of New Jersey's Garden State Parkway over Bass River.

The soil improvement solution called Column Supported Embankment (CSE) is presented. In addition, a comparison of different Column installation techniques such as Controlled Modulus Columns (CMC) and Vibro Concrete Shaft (VCS)/Vibro Concrete column (VCC) is presented. The results of static load tests performed on sacrificial columns and data obtained from instrumentation installed during construction to assess performance of CSE are also presented. The performance of the Column Supported Embankment system is assessed for each system with different installation techniques for the columns and Load Transfer Platforms with either geogrid or geotextile from similar installations in different projects. Finally, conclusions are presented regarding the design and construction aspects of the Column Supported Embankment.

INTRODUCTION

The New Jersey Turnpike Authority's (Authority) Garden State Parkway Interchange 30 to Interchange 80 Widening Program will provide three travel lanes with standard shoulders, northbound and southbound. At the heart of this 50 mile widening program is the Bass River crossing at milepost 51.9. To accommodate the proposed highway widening a new structure will be constructed offline, twelve feet to the east of the existing 1954 Bass River Bridge. The new structure will temporarily carry four lanes of traffic, two lanes in each direction, during the rehabilitation of the 1954 Bass River Bridge. Upon completion, each structure will accommodate three traffic lanes with standard shoulders. Construction of the new bridge requires the construction of roadway embankments on either side of the proposed structure. Refer to Figure 1 for the project location.

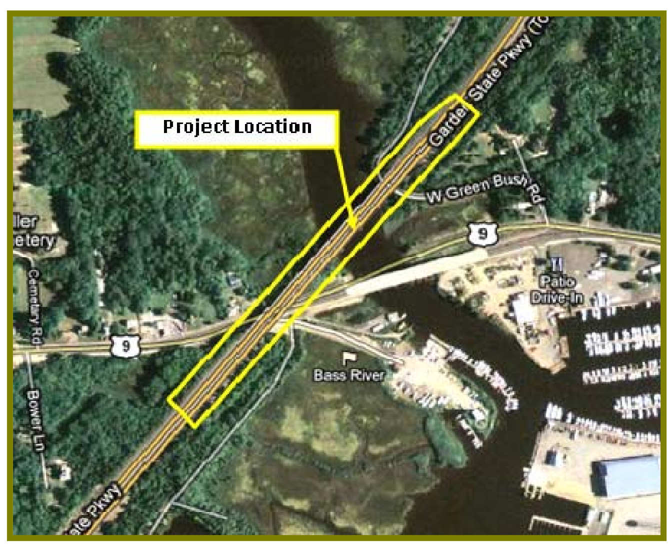

Fig 1. Project Location Map

The proposed road profile results in raising the grade behind the bridge's abutments. The fill will result in elevating the existing grade to +43 feet at the proposed south abutment and +34 feet at the proposed north abutment. The embankment fill also necessitates the construction of retaining walls for grade separation and to minimize disturbance to wetlands.

This paper presents the design considerations and construction methods adopted to construct the mainline roadway embankments that required subgrade improvement. Also presented are recommended construction procedures to ensure that the subgrade improvement provides adequate bearing capacity, stability and/or mitigates the effects of settlement.

Additionally the performance of several Column Supported Embankment (CSE) systems including Controlled Modulus Columns (CMC) and Vibro Concrete Shaft (VCS)/Vibro Concrete column (VCC) are discussed. Finally, recommendations regarding design and construction issues related to CSE are presented.

DESIGN CONSIDERATIONS

The proposed Parkway widening is approximately 60-feet laterally from the existing roadway embankment. Part of the road extension is located on the existing slopes of the existing roadway and the rest of the extension is located beyond the existing roadway slopes. This relationship creates a slope failure risk and an additional lateral force on the retained fill/MSE wall as shown below Fig 2.

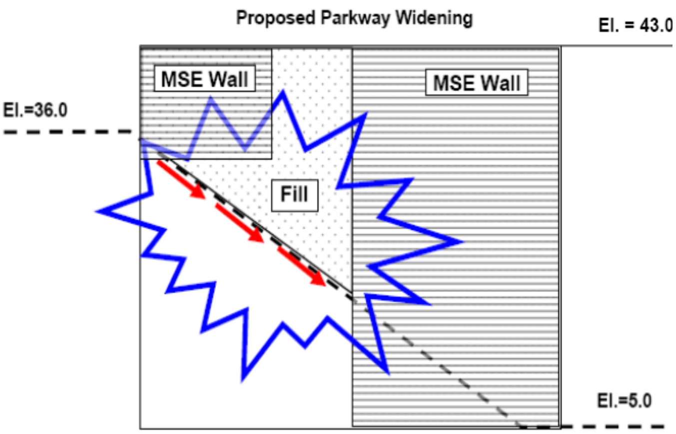

Fig 2. Project Location Map

Figure 3 depicts the typical subsurface soil stratification encountered within the proposed fill area. The upper soil layer underneath the proposed fill consists of sand with interbedded compressible organic cohesive stratum overlaying dense sand. In addition, the in-situ and laboratory-testing programs indicate that the organic cohesive stratum is non-homogenous; therefore, the settlement process is likely to occur in a non-linear pattern and is expected to exhibit excessive differential settlement.

The thickness of the upper interbedded cohesive deposit layer is approximately 10-feet and the consistency ranges from very soft to stiff based on field SPT data. Based on field observation and laboratory test results, it was concluded that the cohesive soil underneath the existing parkway embankment is over-consolidated with an over-consolidation ratio (OCR) of around 2.0 and the cohesive soil beyond the slopes of the existing roadway is slightly over-consolidated with an OCR of around 1.5. Also, field and laboratory-testing programs indicated that the shear strength of the soil beneath existing parkway embankment was around 800 psf and around 300 psf outside the slopes. The observed characteristics of cohesive soil is attributed to past construction activity and geometry of the existing Parkway.

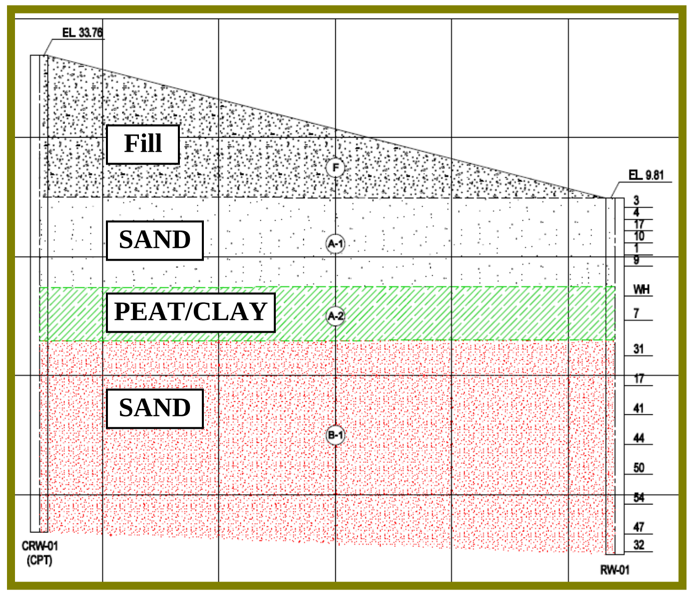

Fig 3. Surface Profile

The stability analyses indicated that the organic cohesive stratum, underlying the alignment at a depth around 8-feet from the existing grade, has insufficient shear strength to support the load of the embankment fill. In addition, the maximum height of fill behind the MSE wall will result in additional lateral forces due to lateral thrust or squeezing of the compressible soil. Accordingly, ground improvement and treatment was determined to be required.

Because of these concerns, several ground-improvement alternatives were investigated, with consideration given to the construction schedule and cost. The following alternatives were investigated:

- Replacement of soft soil strata with suitable soils
- Support the approach fills and MSE walls with non-reinforced concrete-columns such as Vibro Concrete Columns (VCC) or Vibro Concrete Shafts (VCS), or

- Controlled Modulus Columns (CMC) with reinforced geosynthetic load transfer platform (LTP), generically referred to as Column Supported Embankment (CSE)
- Stage the construction of the embankment fill and utilize traditional surcharge and wick drains to force primary consolidation

A soil replacement technique was not recommended due to the concern of massive over-excavation and the potential impact on the existing parkway. A staged construction embankment fill with surcharge and wick drains was the preferred engineering solution, since the soils were not significantly weak and the presence of weak organic soil was not extensive. However, Column Supported Embankment (CSE) was selected as the alternatives analysis results indicated the total direct costs involved with ground-improvement techniques were less than the indirect costs associated with impacts to bridge construction, construction duration and post-construction maintenance needs resulting from residual settlement. Ground improvement with CSE was recommended from station 1235+00 thru 1243+00 here and after referred to as the South approach and from station 1253+00 through 1257+00 here and after referred as the North approach. No ground improvement measures were recommended between station 1228+00 and 1235+00 (south approach) and 1257+00 through 1262+00 (North approach) due to favorable subsurface conditions.

COLUMN SUPPORTED EMBANKMENT (CSE)

The Column-Supported Embankment (CSE) soil improvement solution involves constructing a pattern of in-situ columns made of concrete. The selection of the column type used for CSE depends on design loads, cost and constructability. The columns are constructed to bear on the dense sand strata underlying the cohesive strata that would otherwise consolidate under embankment loading. A load transfer platform (LTP) is used to efficiently distribute the embankment load onto the series of cement-grouted columns. The LTP consist of a soil mass reinforced with one or more layers of geosynthetic reinforcement. The standard configuration for design and construction of CSE with LTP for transportation projects across the United States follows the configuration depicted in Figure 4 below.

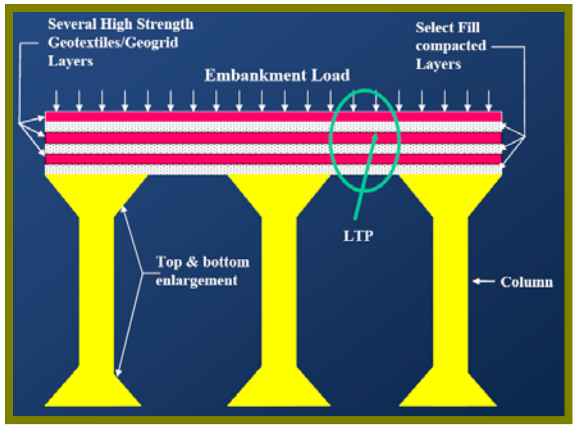

Fig 4. CSE Design Concept

Non-reinforced concrete columns are commonly used in CSE construction throughout the United States. The column is designed to carry the load based on the tributary area for each column. The embankment and any surcharge load are typically assumed to be carried in their entirety by the column. Since the method of installation for the concrete column involves the densification of sandy soil, the nominal bearing resistance can be closer to that of a driven pile than that of a drilled shaft (Mankbadi et al 2004). The design of the load transfer platform (LTP) is based on the use of multiple layers of geosynthetic reinforcement to create a stiff reinforced soil mass which achieves load transfer to the columns through soil arching (Collin Et al, 2005). According to the FHWA, who performed parametric studies using calibrated finite element analyses (FLAC model) to understand the behaviors of geosynthetic-reinforced column-supported embankments, it was determined that geosynthetic reinforcement layers in LTP reduces maximum settlement (Collin, et al, 2006).

The geosynthetic reinforcement is included as an integral part of the LTP. There are two fundamentally different approaches widely used to the design of the LTP, the British Standard BS8006 and the Collin method. According to the British Standard, the approach fill load is transferred to the column through catenary tension in the reinforcement. Essentially, the reinforcement behaves as a structural element and any benefit achieved by the creation of a composite soil mass is ignored. According to the Collin method, the reinforced soil mass acts as a beam to transfer the load from the fill to the column below. The Collin method generally results in larger column-to-column spacing and thicker LTP than the British Standard approach.

CONCRETE COLUMN INSTALLATION TECHNOLOGY

Column installation technology is still evolving. Depending on the ground improvement constructor’s patented technology, in-situ concrete columns are installed using the vibro-displacement known as Vibro-Concrete Column (VCC)/Vibro Concrete Shaft (VCS) or displacement-auger technique known as Controlled Modulus Column (CMC). In some circumstances, ground improvement contractors have asserted that the characteristics of soft soil around the column are significantly improved through densification resulting from their unique patented technology. The theory being that the improved soil, rather than negligible, interacts with the columns to transfer loads as a system. They often submit a request to eliminate geosynthetic reinforcement from LTP; however the cost savings from eliminating geosynthetic reinforcement runs between 2% to 4% of the total CSE cost.

CSE RECOMMENDATIONS

At the Bass River Bridge site, CSE was recommended at two separate levels to facilitate embankment fill construction over the existing slope (see Figure 5). The lower level CSE alleviates concerns for settlement and the upper level CSE alleviates the risk of slope failure created by additional lateral forces on the east face MSE wall.

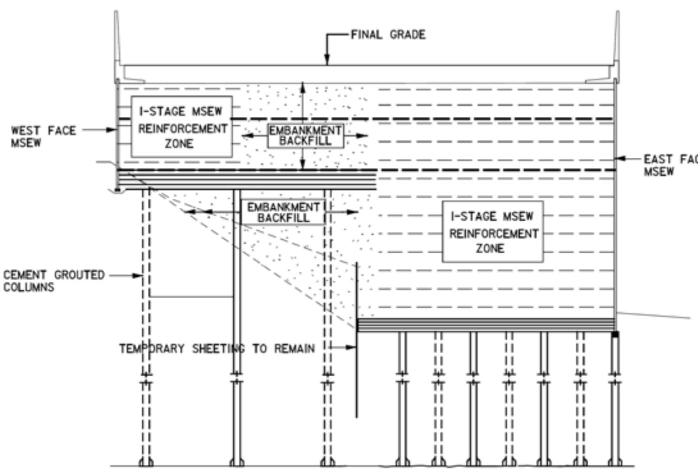

Fig 5. CSE Recommendation

The type of columns used in CSE are often dictated by the ability of the General Contractor to procure the service of a ground improvement specialty sub-contractor at competitive cost, since the columns account for around 90% of total CSE cost. In most circumstances, the design engineer's CSE recommendations are Value Engineered (VE) for the same reason. To avoid the VE process while allowing flexibility and encouraging project cost savings, the Bass River project contract documents required a performance/design specification to allow the prospective contractors to choose the CSE system that best suits their construction capabilities. The performance/design requirements of the project specifications were as follows:

1) The settlement between columns at the top of the LTP, after construction of the LTP, shall be less than 2-inches.
2) The maximum post-construction differential settlement across the width of the platform shall be less than 1-inch.
3) The maximum allowable differential settlement along the proposed MSE walls shall not exceed 1- inch per 100-feet.
4) The design of the LTP is based on an allowable long-term strain of 5%.
5) The system shall not cause any additional loading on the adjacent abutment piles and retaining walls.
6) The system shall not cause any settlement of the adjacent roadway.
7) Verify the load carrying capacity on sacrificial demonstration columns prior to construction of production columns.

IMPLEMENTED CSE SYSTEM

The construction contract of GSP widening program at Bass River was traditional design-bid-build. Bass River Bridge's general contractor; Northeast Remsco Construction, Inc., selected the ground improvement specialty subcontractor DGI Menard, Inc/GEI as their consultant to design and implement the chosen CSE system. The Design-Build team (Northeast Remsco–DGI Menard, Inc/GEI) designed their CSE system using a 3D finite element analyses program called "PLAXIS". The recommendation consisted of a Cemented Grouted Column installed using the displacement Auger Technique i.e., controlled Modulus Column (CMC) with a 1-foot thick working platform, or LTP, with no geosynthetic reinforcement to create stiff reinforced soil mass. The contractor's justification for eliminating the LTP's geosynthetic reinforcement was based on an anticipated soil improvement gained in the vicinity of each column, which is expected to result from their particular method of column installation.

PLAXIS is a very powerful finite element analyses tool available to foundation engineers used to analyze the deformation and stability of soil structures in geo-engineering applications. The program uses "advanced soil model parameters" such as dilatancy angle, unload-reload modulus, Oedometer Modulus, Bulk Modulus, vertical permeability, horizontal permeability, change of permeability, tensile strength and interface behavior, increase of stiffness and increase of cohesion. A majority of the "advanced soil model parameters" are derived using limited research literature and often the derived parameters are not fully representative of site conditions.

While gathering "advanced soil model parameters" for the "site-specific" finite element analyses, PLAXIS program users must understand the program's inherent limitations and limited basis for its derived internal modeling parameters. In our opinion, due to lack of available research literature, the selection process of "advanced soil model parameters" is very subjective and causes the PLAXIS model to develop with significant uncertainty or risk. Therefore, the Design-Build team's proposal for a LTP with no geosynthetic reinforcement was rejected.

The final approved LTP was a modification of the original system, in which one layer of biaxial geogrid was used. The approval was granted, taking several factors into consideration: 1) the close spacing of the CMC's proposed for the lower level CSE 2) relatively supportive subsurface soil condition, and 3) project history of completed projects in the vicinity of the site with similar site conditions.

CMC LOAD TEST PROGRAM

An ultimate load capacity and load deformation prediction method for concrete columns is limited. The primary uncertainties are related to the installation procedures and the characteristics of the subsurface condition when the columns are installed. Therefore, a load-testing program is often required by project specification, with the goals of the program being:

1. Establish an installation procedure based on the performance of the column
2. Verify that the CMC is capable of sustaining the applied axial load

The project specified that two CMC's are to be static load tested: TP1 is the test column at the South approach and TP2 is the test column at North approach. The physical characteristics and termination criteria of both tests CMC's were nearly identical to each other as detailed in Table 1. The test columns were to be loaded to a maximum capacity of 309 kips, or 150% of the design load, as specified in the project documents. The load test was performed in general conformance with ASTM D-1143/D1143M-07 using the Quick Load Test procedure.

Table 1. CMC Installation Data

I.D	CMC Length (ft)	CMC Diameter (inch)	Termination Torque (kip-ft)	Concrete Volume (ft^3)
TP-1	21.03	18.0	150	42.0
TP-1A	20.58	18.0	150	44.2
TP-2	19.13	18.0	150	40.5

During the load test, the TP-1 deflected 1.87 inches at 309 kips and at 165 percent of design load (339 kips) TP-1 deflected 2.74 inches and resulted in a plunging failure. Therefore, an additional test column (TP-1A) within proximity of TP-1 was installed and a static load test was conducted to verify the load carrying capacity. The results of TP-1A was similar to that of TP-1 indicating that the ultimate load carrying capacity and allowable load carrying capacity of the CMC's are less than originally anticipated. Therefore, remedial action was taken. The Design-Build team installed additional CMC's to reduce the required column design load at the South approach. Refer to Figure 5 for load deformation curve of TP-1 and 1A.

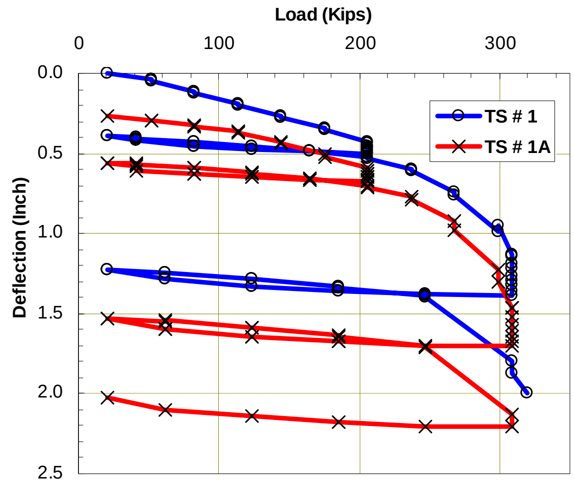

Fig 5. South Approach Test Columns Results

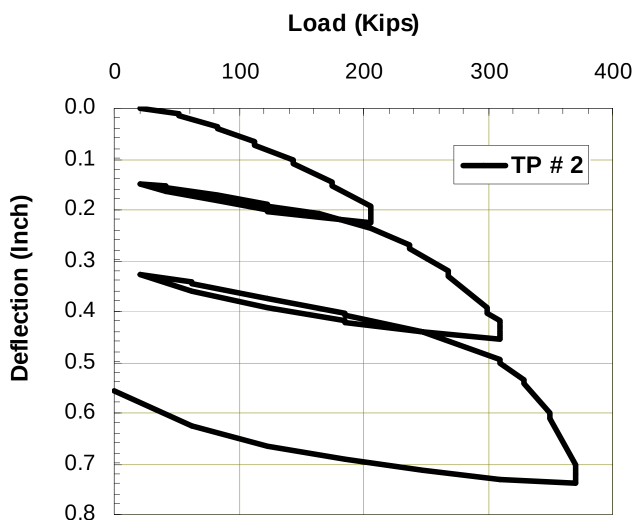

Fig 6. North Approach Test Column Result

During the load test, the TP-2 was loaded to 371 kips, approximately 238% of the design load, and a total deflection of 0.74-inches was observed. Based on the results of TP-2, it was concluded that the performance was acceptable and similar termination criteria was used for production columns at the North approach. Refer Figure 6 for the load deformation curve of TP-2.

Further investigation was conducted to determine the reason that test columns TP-1 and TP-1A performed below the anticipated levels and TP-2 performed above the anticipated levels, since termination depth, installation torque criteria and the characteristics of bearing stratum upon which the columns' tips rest were similar.

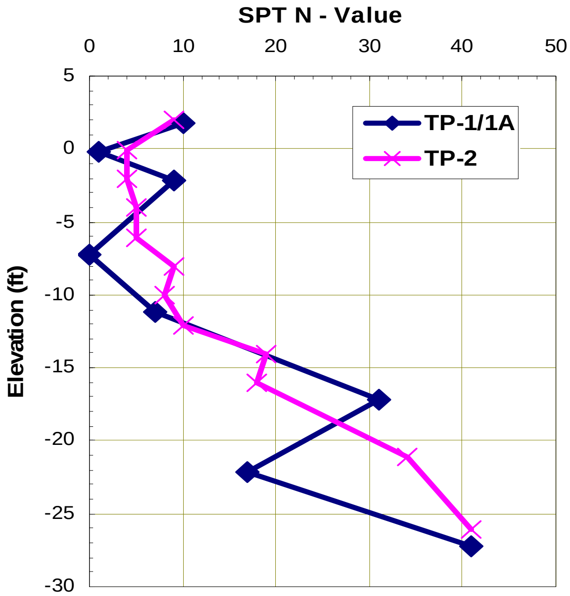

Fig 7. Subsurface Condition at Test Columns

It was determined that the significant difference in performance was a result of the difference in the relative density of overburden soil. Load carrying capacity of the column is a function of overburden pressure and a weaker soil was observed at the South approach compared to the North approach, where denser non-plastic material was observed during subsurface investigation. Additionally, a significant gain in the soil density occurred at TP-2 from construction traffic during bridge foundation work, as the CMC test location was close to the static pile load test. Refer to Fig 7 and 8 for subsurface soil and construction traffic detail.

Fig 8. TP-2 Test Column Location

Additionally, the effects of installation technique on the soil characteristics around each column were investigated. Given the proximity of TP-1 and TP-1A to the production columns, and the contractor's decision to install production columns prior to the test column, presented an ideal investigation opportunity at the South approach. Refer to Figure 9 for details.

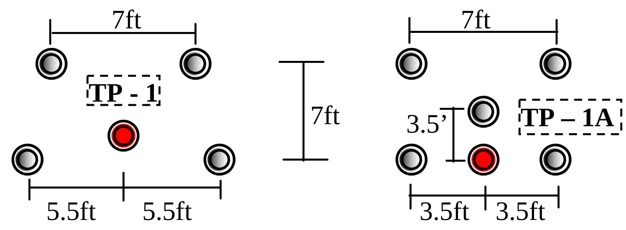

Fig 9. Test/Production Columns Layout

Due to the recorded test columns' TP-1 and 1A deformation behavior, the improvement of soil characteristics in the vicinity of each column is not evident. The claim that the installation technique provides improvement in soil characteristics appears to be premature. TP-2 was not considered for the above investigation, because at the TP2 location, the overburden soil consists primarily of non-plastic material, it has a 3-foot thick layer of peat material, and is anticipated to compress or settle quickly upon loading.

Therefore, it is our opinion that CSE be designed neglecting any expected gains in soil strength from the column installation process.

PERFORMANCE EVALUATION

Settlement platforms and slope inclinometers were utilized to monitor the CSE system performance. The field instrumentation readings indicated that the CSE system had experienced a maximum lateral deflection of 13 mm (0.5 in) and a vertical settlement of 50 mm (1.97 in).

It is noted that the maximum allowable settlement is less than 51 mm (2.0 in). No prediction was made for lateral deformation. However, it is assumed that this value is negligible given the stability of the system. Based on field instrumentation readings, it can be concluded that the CSE with CMC element is adequate for supporting the MSE wall and embankment fill.

The Design-Build team installed a set of strain gauges at North approach to monitor strain in the geosynthetic reinforcement and/or to evaluate the need for reinforcement in LTP. However, data from the strain gauges was not analyzed by the authors, as the area chosen for monitoring was subject to up to 6 months of construction traffic resulting in significant densification prior to CSE installation.

COMPARISON STUDY

The performance of CSE using CMC in this project was compared to the performance of CSE using VCC/VCS at completed projects in region, for better understanding of the significance of Concrete Column type. Table 2 below lists the other projects and the maximum observed movements.

Table 2. South Jersey CSE Data

Project	CSE Elements	LTP Reinforcement	Lateral Deflection Observed	Maximum Settlement Observed
Bass River	CMC/LTP	Geo-grid	0.5 in	1.97 in
Route 52	VCS/LTP	Geo-grid	0.6 in	1.20 in
Rt 9, Nacote Creek	VCC/LTP	Geotextile	0.5 in	1.60 in

It was concluded that the available Concrete Column options i.e., CMC, VCC or VCS, are effective for ground improvement. Also, LTP reinforced with either geotextiles or geogrids are effective and will enhance the ability of the LTP to distribute the embankment load onto the series of underlying columns.

CONCLUSIONS

1. The Column Supported Embankment (CSE) ground improvement solution is an effective and viable solution where approach embankments are to be constructed over soft ground and within limited rights-of-way.
2. The CSE with CMC, VCC or VCS are effective ground improvement measures.
3. Cemented Grouted Columns can be designed in a similar fashion as driven piles with respect to reliance on their end bearing capacity. A load test program is essential since the installation procedure has an impact on the ultimate load carrying capacity.
4. Instrumentation-monitoring data indicates that the Cement Grouted column solution, in conjunction with either geogrid or geotextile reinforced-sand platforms, can successfully support high embankments.
5. Load transfer platforms without geosynethic reinforcement should be investigated further. Until further research is conducted, use of a geosynthetic reinforced LTP is recommended.
6. Load transfer platforms designed by either the British Standard or the Collin approach are effective with respect to the transfer of the fill load to the column below.
7. Finite element analyses using either PLAXIS or FLAC are effective as long as the user of the program understands the limitations and applicability of the unique soil parameters used by the software.
8. Commercial software program such as PLAXIS or FLAC should enhance the user-friendliness of the software by utilizing soil parameters common to the geo-engineering profession.

ACKNOWLEDGEMENT

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