Controlled Modulus Columns (CMC) : Application to the support of Mechanically Stabilized Earth Walls (MSE Walls)

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2011 Pan-Am CGS Geotechnical Conference

ABSTRACT
The patented CMC system fits in the generic category of inclusions. The design technology behind the development and experience with CMC makes them uniquely efficient for the immediate support of MSE walls and embankments for public transportation, other infrastructure facilities, large storage tanks, and building facilities.
Traditional embankment and fill wall construction for road and rail corridors had placed little value on time in developing the engineering schemes for settlement control prior to placing pavement. As an improvement to the least first cost alternative – waiting for primary consolidation to occur - when working above fine-grained soils prone to long term consolidation, wick drains with surcharge have been commonly applied to speed up the settlement process. This approach can still take up to 1 year depending on site conditions, wick drain spacing, thickness of the slow-draining layer, and the degree of consolidation desired prior to paving. Accelerated construction of embankments, with immediate placement of roadway pavements over compacted embankment fills offers a very desirable solution.
CMCs, as well as other types of rigid and semi-rigid inclusions systems, are an ideal solution for the immediate support of embankments. CMCs are designed using special proprietary finite element techniques that include the effects of load sharing between the distribution platform, the columns, and the surrounding improved ground. The paper summarizes the design approach, and presents case histories of completed public facilities supported on CMC foundations. The case of an MSE bridge approach in Southern New Jersey will be discussed in details and the support of another MSE Wall in Northern New Jersey will be briefly presented.

RÉSUMÉ
Les Colonnes a Module Contrôle (CMC) sont une technique d'amelioration des sols qui rentrent directement dans la categorie des inclusions. Les techniques de dimensionnement derrière le développement de la technique des CMCs les rendent particulièrement attractives pour le support de murs en Terre Armée et de remblais pour les projets lies au transports et autres infrastructures publiques, larges réservoirs pétroliers et bâtiments résidentiels ou industriels.
Les projets de remblais traditionnels et murs de soutènements pour routes et voies ferroviaires placent généralement peu d'importance sur le temps nécessaire pour développer une approche satisfaisante pour le contrôle des tassements avant le placement du goudron. Une amélioration évidente de cette technique (attendre que la consolidation primaire soit terminée) pour des sols fins avec risque de tassements long terme importants est l'utilisation de drains verticaux en combinaison avec une surcharge. Cette technique a été utilisée pour accélérer la consolidation. Néanmoins, cette approche peut prendre plusieurs mois voire années suivant les conditions du site, la maille des drains verticaux, l'épaisseur de la couche compressible imperméable et le degré de consolidation nécessaire sous la charge du remblai. Ainsi, la possibilité de construire un remblai sur sols compressible avec possibilité de bituminer la voie immédiatement après offrent des avantages certains et présente une alternative intéressante. La technique des CMCs est une solution idéale pour la construction rapide de remblais. Les CMCs sont dimensionnées grâce a des techniques brevetées qui incluent les effets de répartition de contraintes a l'intérieur du matelas de répartition, les CMCs et le sol environnant. Cet article donne un résume l'approche au niveau du dimensionnement et présente deux projets qui ont été réalises pour des infrastructures publiques aux Etats Unis : le remblai d'approche utilisant un mur en terre armée dans le sud du New Jersey sera discute en détail et le support d'un autre mur en terre armée dans le Nord du New Jersey sera brièvement revu.

1 INTRODUCTION

Traditional embankment and fill wall construction for road and rail corridors had placed little value on time in developing the engineering schemes for settlement control prior to placing pavement. As an improvement to the least first cost alternative – waiting for primary consolidation to occur - when working above fine-grained soils prone to long term consolidation, wick drains with surcharge have been commonly applied to speed up the settlement process. This approach can still take up to 1 year depending on site conditions, wick drain spacing, thickness of the slow-draining layer, and the degree of consolidation desired prior to paving. Accelerated construction of embankments, with immediate placement of roadway pavements over compacted embankment fills offers a very desirable solution. The combination of Mechanically Stabilized Earth Walls (MSE Walls) with Rigid and semi-rigid inclusions such as CMCs represents a very attractive technological leap in the design of embankment on soft grounds.(Dumas et al – 2003) This paper after discussing the design aspect of the CMC technology and its advantages when combined with an MSE Wall system will present two case histories where this approach was successfully applied.

2 CONTROLLED MODULUS COLUMNS OVER MSE WALLS

2.1 Behavior of MSE Walls on soft grounds

It has long been established that Mechanically Stabilized Earth (MSE) Structures (see figure 1) tolerate a certain amount of total and differential settlements. The excellent performance of the early Reinforced Earth ® walls and abutments constructed in the 1970’s and 1980s’s that underwent settlements instilled confidence in engineers and owners, and led to widespread use of MSE walls as the retaining wall type of choice when building on soft soils. (Anderson & al – 1991) When expected differential settlements become excessive for the walls, several solutions can be developed :

- Single stage construction
- Phased construction
- Two-stage construction

In addition to primary settlements which occur during the construction of an MSE wall, the tolerance to post construction foundation settlements of the pavement, utilities and other structures built atop MSE walls need to be considered in determining the need for foundation improvements. (Abraham et al – 1999)

Figure 1 – view of an MSE Wall structure

Depending on the site conditions, schedule and other constraints, these construction methods can be combined with ground improvement techniques. Because they do not require lateral confinement when receiving compressive loads and therefore allow a tighter control of settlement as compared to aggregate based systems such as rammed aggregate piers or stone columns, rigid inclusions solutions such as Controlled Modulus Columns (CMC) are often preferred in very soft soil conditions and have been widely used in recent years. In addition to that, the authors have experience with value engineering projects that were initially designed for 2-stage construction, and were subsequently redesigned into single stage walls on CMC ground improvement. Significant economies are possible with expanded application of this approach.

2.2 The CMC Technology : concepts

Deep foundations have typically been placed into two reasonably distinct categories: rigid and deformable. Rigid Deep Foundations (RDF) include steel, concrete, timber, and auger-cast piles. Stone columns are an example of Deformable Deep Foundations (DDF).
RDF function by having direct contact with the surface loads and transmitting these loads either through end-bearing, skin-friction, or a combination of the two. The settlement of these systems is dependent on the deflection of the RDF element.

Predicted settlements for DDF are typically greater than that of rigid deep foundations. The distribution of stresses between the soil and the deep foundations determines the magnitude of settlement resulting from loading of soil reinforced by DDF. This stress redistribution is a function of the ratio between the respective stiffness of the DDF and the soil. Allowable settlements in a deformable system are dependent on acceptable tolerances specific to local utilities, drainage, and surrounding features.
Controlled Modulus Column (CMC) technology requires the addition of a third category of deep foundations – composite soil-inclusion system. CMC technology performs somewhere between rigid and deformable deep foundations, because the long-term deformation modulus of the CMC is between that of RDF and DDF.

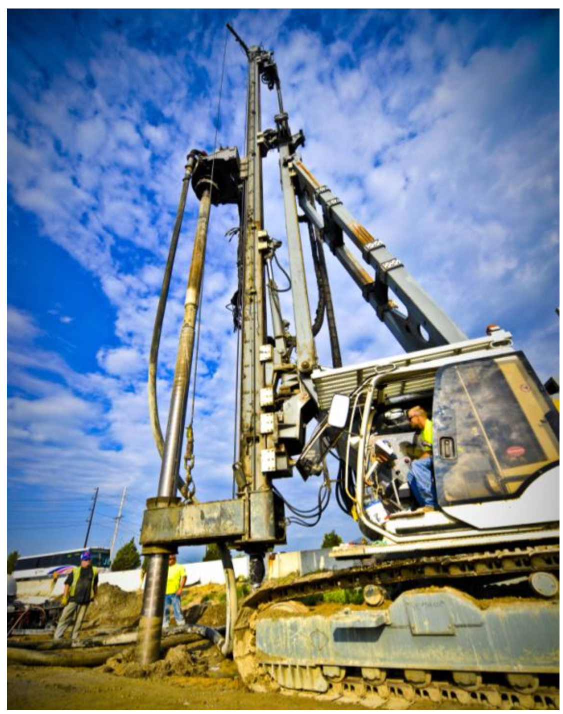

Figure 2 – view of a CMC Rig and setup

Depending on the material used for the CMC, this modulus can vary between 500 MPa (72.5 ksi) and 12,000 MPa (1,740 ksi).

The CMC system reduces the global deformability of the soil mass by the use of semi-rigid soil reinforcement columns. These columns distribute the loads throughout the soil mass in a composite material behaviour. The dimensions, spacing, and material of the CMCs are based upon the development of an optimal combination of support from the columns and the soil mass to limit settlements for the project within the allowable range, and to obtain the requested value for the equivalent deformation modulus of the improved soil.

The CMC technology is adaptable to most compressible soils and permits construction without removing and replacing soft soils or installing rigid deep foundations.

The main advantages of the CMC system include:.

- Applicable for a wide variety of soils including organic soils, peat, mixed fills, and soft and variable alluvial soils. Material is grouted in place with the use of a displacement auger in order to reinforce the ground
- Deformation modulus of the CMC elements is 50 – 3,000 times that of the soil (weakest stratum)
- A load transfer platform of generally granular fill (LTP) is placed over the CMC reinforced ground that has a modulus less than that of the CMC elements which can be partially penetrated by the inclusions to promote strain compatibility/ load sharing between all the components
- In granular soils, densification due to the lateral displacement may occur between the columns by virtue of the displacement drilling process
- Virtually no spoils are generated by the drilling process which eliminates the need to manage spoils and the potential unearthing of contaminated soils

Additionally, CMC's do not generate vibrations during installation, which allows for construction in sensitive areas. The use of CMC)is an ideal solution for the support of MSE Walls, steepened slopes and conventional embankments.

2.3 The CMC Technology : Construction

Controlled Modulus Columns are constructed by use of a displacement auger which laterally compresses the soil mass while generating virtually no spoils. The CMC displacement auger is hollow, which allows placement of the specially-designed grout column, as the auger is withdrawn. The grout is injected under moderate pressure, typically less than 10 bars (150 psi).
The equipment used to advance the displacement auger is specially designed to transmit high torque loads and strong down-thrust to efficiently displace and compress the soil laterally. The auger is advanced while turning and displaces the soil.

Upon reaching the desired depth, grout is pumped through the hollow stem of the auger and into the soil bore as the auger is withdrawn at a pre-defined rate that is calibrated to avoid necking. With a conventional continuous flight auger, "negative displacement", stress relief, or even lateral mining around the auger is inevitable. This creates a movement of the surrounding soils which are loosened by the augering process toward an active (Ka) condition. This condition creates a risk of necking. On the contrary, with the CMC displacement auger, the effect is opposite: the soil adjacent to the auger is displaced laterally by the displacement stem portion of the auger and brought to a denser passive (Kp) state of stresses. Since no spoil is generated, a full displacement of the soils equivalent to the size of the tool occurs, creating enough displacement to insure that this Kp state is reached. Stress relief does not occur and the risks of necking the CMC are nonexistent, except in a case of operator error.
Quality control of the CMC and monitoring to catch any operator error is done with real time monitoring of the following installation parameters (see figure 3):

- Speed of rotation -
- Rate of advancement and withdrawal of the auger -
- Torque, down-thrust (crowd) during the drilling phase -
- Depth of element
- Time of installation
- Grout pressure in the line at the top of the drill string
- Volume of grout as a function of depth

The grout pressure is monitored by a sensor located at the top of the concrete line above the swivel attached to the mast drilling head. The CMCs are usually installed using a target over- break of 5 to 10% of the volume of grout. During the grout phase, pressure readings are kept to a moderate positive pressure. Any loss in pressure can reveal a soft or loose soil zone that may not have been detected during the geotechnical investigation.

Figure 3 – view of on-board QC monitoring system

A significant benefit of the recordation of installation parameters is that changes in subsurface conditions can be detected in the field, and more importantly, column depths can be adjusted based on the encountered conditions as detected by the response of the drilling equipment. The recorded drilling parameters of down

pressure, speed and torque are readily interpreted in the field during drilling and changes in stratigraphy can be sensed based on ease or difficulty of drilling. This ability to adjust column lengths in the field offers a significant advantage over most other forms of column installation.
Other forms of Quality control include grout properties for consistency with the expectations of the design mix, and sampling, curing and testing of samples for grout strength. Load testing (ASTM D1143) is routinely done when there is no previous experience with elements capacities in the subject strata. Other in-situ testing such as PIT (Pile Integrity Tests) and dynamic loads tests (e.g. Statnamic) have also been used.

2.4 The CMC Technology : Design Principles

Conceptually, the soil–CMC mass behaves as a composite mass of greater stiffness than the initial untreated ground, reducing settlements induced by the weight of the structure to within allowable ranges. CMCs are not intended to directly support the loads imposed by the structure or MSE wall, but to improve the global response of the soil in order to control settlement. The dimensions, spacing, and composition of the CMCs are based upon the development of an optimal combination of support from the columns and the surrounding soil to limit settlements for the project within the allowable range, and to obtain the required value for the equivalent composite deformation modulus of the improved soil.
The tops of CMCs are typically installed 1 to 3 ft below the bottoms of the MSE structure or embankment. A layer of compacted granular material referred to as the load transfer platform (LTP) is installed above the top of the CMCs and below the structure following installation of the CMCs. The main purpose of the LTP is to transfer the load from the embankment / MSE Wall to the CMCs without using pile caps between the structure bottom and the CMCs. The load is transferred to the CMCs through arching within the high phi-angle LTP and through side friction below the top of the CMCs. The system is generally designed to transfer 50 to 95% of the load to the CMCs while the remainder of the load is transmitted to the soils between the CMCs. (see figure 4) The ratio of load sharing is dependent upon the type and stiffness of the soils between the CMCs as well as the allowable settlement for the structure. It is sometimes believed or recommended that a heavy reinforcement of the Load Transfer Platform using several layers of high tensile geogrids is required for the design of the LTP, However, it is the opinion and practical experience of the authors that such a design is not necessary in the case of support of MSE structure. If the requirements for several layers of geogrid is dictated to increase the rigidity of the LTP, the authors believe that the deformations calculated and observed for MSE structures on CMC are too small to allow the full development of the tension in the geogrid layers. The maximum tensile strength developed by a geogrid is commonly obtained at 5% deformation. (Collin et al – 2004) This strength at 5% deformation is commonly used in the different design method as a justification for the use of geogrid layers with an LTP. It is easy to verify using for example a catenary model that for typical allowable and observed settlements under MSE walls, the deformations in the geogrid are usually under 1 to 2% at most. The tensile strength developed in the geogrid layer is therefore much smaller than assumed by design. Large deformation are required for the geogrid layers to be effective. Beyond that, the reinforcement provided by the MSE wall strips is usually located within 2 to 3 ft of the top of the CMC and act as an horizontal reinforcement improvement the load transfer to the CMCs. Of course, these stresses due to the arching above the top of the CMCs need to be taken into account into the design of the wall system and it is not uncommon that additional steel reinforcement are placed at the bottom of the wall to limit this overstress.

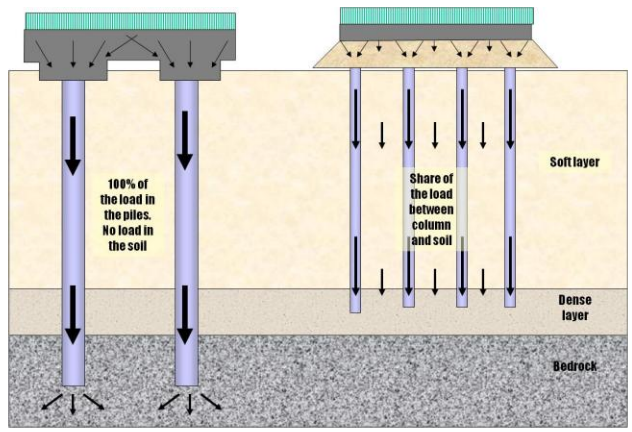

Figure 4 – Load distribution- pile solution vs CMC solution

CMCs are designed using numerical modeling techniques that include the effects of load sharing from the wall or the slope to the distribution layer, the columns and the surrounding improved soils. In particular, it is critical to understand the behavior at the interface MSE Wall / Load Transfer Platform (LTP) / CMC in order to accurately model the load transfer mechanism and to avoid large differential settlement of the CMC into this layer.
Design calculations are usually performed using PLAXIS or an equivalent software package and leads to the selection of the spacing of the CMCs. The evaluation also gives the stresses in the ground and in the column resulting from the stress distribution model. It is thus possible to refine the design parameters (diameter of the columns, grid of installation, thickness of the transfer layer and compression strength of the grout) to optimize the total cost of the solution. Once the design parameters have been chosen at the discrete level of a single column, a global 3D calculation can be performed using the same numerical modeling program to take into account specific boundary conditions such as:

- variable height of fill along the same section or non-symmetric loading conditions
- horizontal loads due to train braking friction on tracks for a railway embankment
- rapidly varying thickness of compressible ground along a given section
- variable CMC grid of installation

Consideration should also be made to verify that the MSE Wall strips are adequately designed for an overstress due to the additional load induced by the arching effect towards the CMC elements within the LTP and within the MSE Wall mass itself. Good open dialogue and communication between the CMC designer and the MSE Wall designer is therefore required at all stages of the process.

3 CASE STUDY : BRIDGE APPROACH AND ROAD WIDENING IN NEW JERSEY

3.1 Description of the Project

As part of the work of the widening of the Garden State Parkway in South New Jersey, the New Jersey Turnpike authorities needed to build a new bridge parallel to the East to the existing one over the Mullica River Bridge for a future lane configuration of three 12-foot lane (from two lanes initially) with 5 foot inside shoulder and 12 foot outside shoulders in both directions.. The widening of the existing road leading to the new bridge will be performed by building an MSE Wall abutment which offers the advantage of involving less encroachment and impact on the wetlands area compared to a classical slope solution

3.2 Soil conditions

This area is located within the Atlantic Coastal Plain Geologic Province. The soils can be generally categorized as Pleistocene lowland alluvial deposits overlaying Tertiary marine sediments. These deposits form the Cape May formation. In portion of the site, the alluvial deposits can be covered by more recent tidal marsh soils deposited in the tidal estuaries along the coastal areas and inland streams during the post-Pleistocene era as a result of drowning of stream valleys along coastal lines due to a raise in the sea levels.

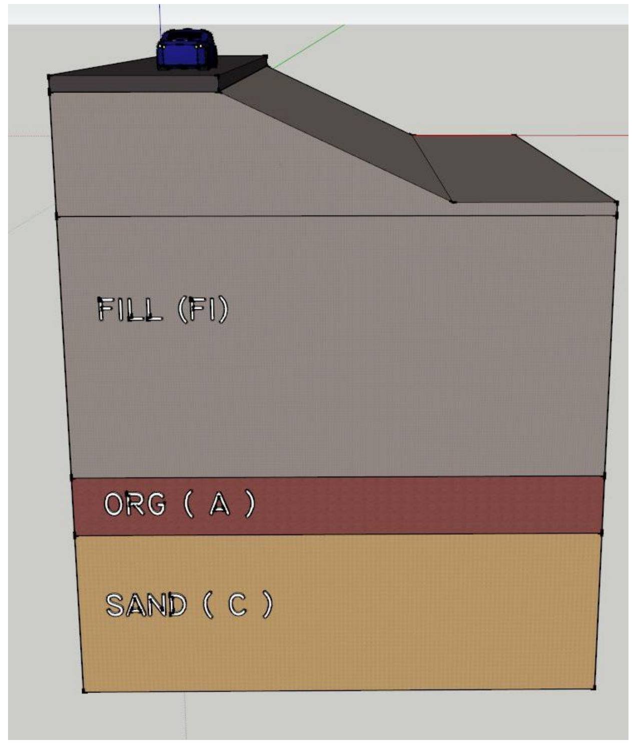

Figure 5 – Typical simplified geotechnical section

Four main stratums were identified in the Geotechnical investigation (Cone Penetration Tests and Standard Penetration Tests) in the area of the MSE wall (see figure 5):

- Existing Embankment fill made of granular material placed during the construction of the existing road. This fill is dense and sandy in nature.
- Upper existing fill layer (sand) due to the mass-excavation and replacement of the marsh deposits with sand during the initial construction of the Garden State Parkway. This layer is loose to dense and extends to about 40 to 50 feet deep at some locations
- The organic layer (tidal marsh deposits) overlaying the existing fill material consists of peat and organic clays and silts and can be up to 25 feet thick on the North Shore of the river.
- A competent sand layer (Tertiary marine deposit of Cohansey Sands) can be found below the organics between 40 and 50 feet below the original ground level.

The site is under tidal influence and the water level at high tide is very close to the existing ground elevation.

3.3 Original Base Design concept

Originally, the designers had anticipated that the following construction sequence would be followed :

- Installation of Stone Columns on close center under the MSE Wall volume to the sand layer

- Construction of the MSE wall with a temporary facing (wire mesh)
- Surcharge of the widened area for up to 6 months
- Final facing is attached using customized connections (2-stage wall)

Wall Heights along this section of the project vary from 12 ft to a maximum of 32 ft.
Because the settlement reduction factor of any stone column design rarely exceeds 3, the original designers were not able to maintain the calculated long term settlements within allowable levels without the use of a surcharge program with a consolidation period of several months. In addition to that, the surcharge program was also dictated by the presence of the organic layer under the existing slopes of the existing road. These slopes are to be backfilled to the top of the new road inducing additional stresses under the existing embankment and therefore creating additional long term settlements. Since no stone columns were going to be installed within the footprint of the existing embankment and were only foreseen under the new MSE wall, the surcharge program was necessary at these locations.

At bid time, several general contractors voiced their interest in offering an alternate solution that would allow the reduction or the elimination of the surcharge program and of the two-stage MSE Wall while providing the same level of performance. Elimination of the surcharge program would offer immediate scheduling benefits to the overall project as the surcharge was on the critical path of the project and there was the risk that the consolidation speed could be slower than expected. Elimination of the two-stage MSE Wall would greatly simplify the job as each connection from the strip located in the temporary wall needs to be manually customized and connected to the permanent facing panels once the consolidation settlement has occurred.

In order to be able to meet these objectives, a paradigm shift was necessary in the design of the MSE Wall + Ground Improvement system.

3.4 Alternate design concept using CMC

While it was possible to support the MSE Wall mass with a more rigid system without the use of a surcharge scheme, there remained the problem of the wedge of new embankment fill located in the back of the MSE wall. This additional unsupported load would create settlements in excess of the allowable limit and would also create an overstress in the support system in the rear of the MSE wall as the load of the unsupported wedge would tend to arch toward the more rigid supported MSE Mass.
It was therefore decided that the whole width of the new embankment and MSE Wall would need to be supported if the surcharge program was to be eliminated.

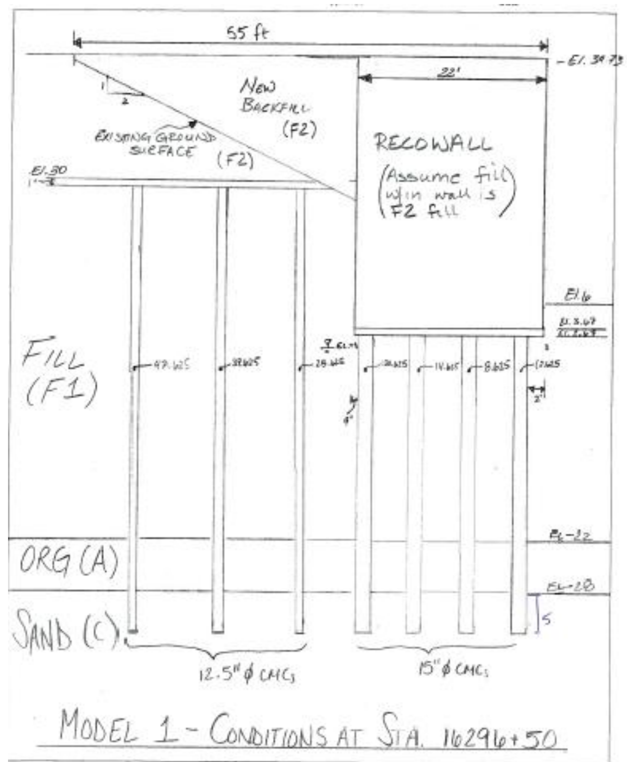

Figure 6 – Typical CMC alternate design section

This created a constructability challenge as part of the new road is located directly under the current existing slopes of the embankment and a benching scheme would be necessary to provide a stable flat safe working platform for the rigs to install the ground improvement system. One solution would have been to create a working platform at the bottom of the MSE Wall, spanning the width of the new roadway using temporary shoring. This solution was quickly ruled out due to the cost of the shoring. The final solution that was implemented on the site was a two-elevation benching scheme as follows (see figure 6):

- preparation of a working platform roughly at the elevation of the bottom of the MSE Wall
- Installation of the CMCs from this lower elevation
- Partial construction of the MSE Wall up to approximately half its full height and backfilling to that elevation in the back of the wall.
- Installation of the CMCs from this mid-tier elevation
- Construction of the MSE Wall to its full height and backfiling to the top of roadway.

This solution presented many advantages over the original scheme and was approved by the Turnpike Authority after an extensive review by their geotechnical consultant.
The design was performed using a 3D analysis of a slice of the profile. A 3D approach was selected because of the highly non-symetrical nature of the problem.(see figure 7). Each stage of construction was modeled in order to model as close as possible the actual stress path within the soft layers. After several iterations of the calculations, it was decided to use two different sizes of CMCs, one for

the lower tier with the highest loads and one for the second tier within the slopes of the existing embankment. The spacing of the CMCs varied along the profile both longitudinally and perpendicularly to the new road in order to take into account the loading conditions and to optimize the design and minimize the risk of differential settlements at different interfaces of each section.
The Soil-Hardening type behaviour in the Plaxis Sofware package was selected for all the soils within the model. (see Plaxis user manual – 2007). The design parameters were derived from the soil investigation using published correlations and accepted methods of interpretation.
A stability analysis was also performed at several sections to verify that a satisfactory factor of safety against failure was maintained at all times during the different stages of construction.

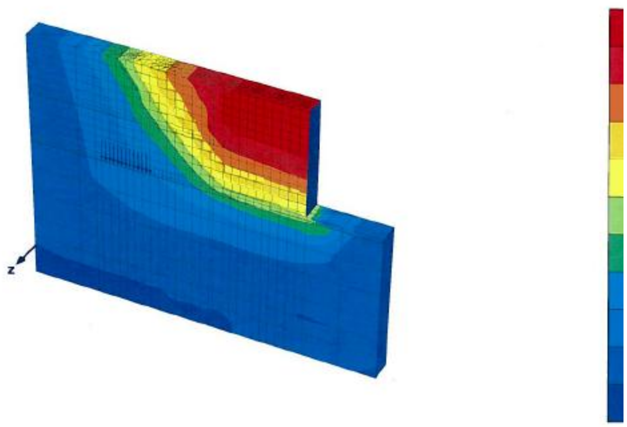

Figure 7 – Typical results of 3D slice Model of Wall + CMC system

3.5 Installation of the CMC - Lessons Learned

The CMCs were installed on each side of the bridge to support the two main MSE Walls. The sequencing of the installation between the lower level platform and the upper level platform presented a few schedule challenges and it is imperative that a good communication between the specialist contractor and the general contractor be maintained at all times. (see figure 8).
While the existing embankment was at times denser then initially anticipated, the rig mobilized on site was powerful enough to quickly overcome this problem.
A total of more than 2,200 CMCs were installed.
Monitoring of the MSE wall was performed by the consultant and the results showed a movement of less than ½ inch during the monitoring period after construction (Wilson-Famhy et al – 2011). No long term settlment value is yet available for this project and it will be interesting to evaluate the performance after several years of traffic.
The success of this project lead the consultant to redesign the next bridge approach crossing the Bass River this time on this stretch of the Garden State Parkway using the same concept for the support of the MSE Walls.

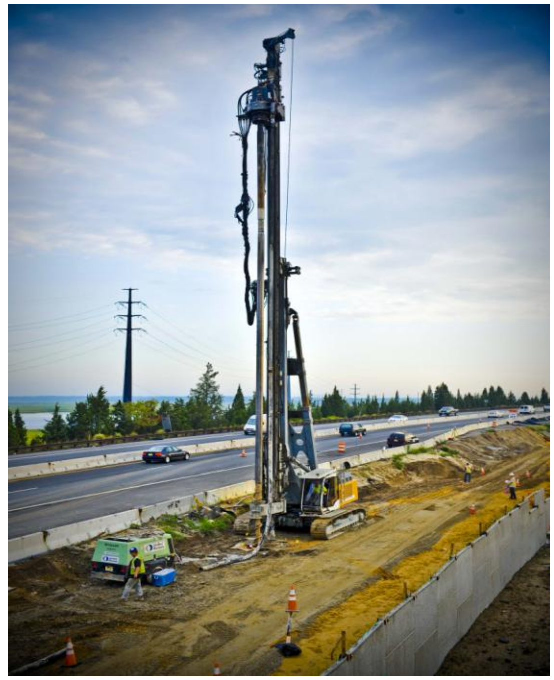

Figure 8 – View of CMC installation during construction of the MSE Wall

4 CASE STUDY : SINGLE STAGE MSE WALL WITH CMC SUPPORT IN NORTHERN NEW JERSEY

4.1 Description of the Project – Soil Profile

This Interchange between two major highways in Northern New Jersey is a $149 million rehabilitation and reconstruction project undertaken to complete the links between the road systems, and improve traffic flow and safety for local communities by allowing a more rapid access to the highways.
This project involved the construction of two new ramps, a bridge approach and a new underpass to allow access to the highways from local communities. The project specified several sections of Mechanically Stabilized Earth (MSE) retaining walls, and embankments supported by ground improvement.
For this project owned and operated by the New Jersey Department of Transportation - NJDOT, ground improvement using CMCs was proposed to help support the bridge approach embankments.
The site is underlain with silt to clay and silt to fine sand with gravel – highly variable fill over bedrock. The fill thickness ranged from five to twenty feet in depth. The average depth to bedrock ranged from 15-35 feet. The fine to coarse sand fill layer included debris consisting of brick, concrete fragments, cinders, wood, metal, and glass.

4.2 CMC Design Alternate

CMCs were proposed as a value-engineering alternate to Vibro concrete columns. To support the embankmets and

MSE wall sections, over 400 CMCs were installed for a total of 8,460 linear feet of grouted column. The maximum depth required for the CMCs was 35 feet.
Although several ground improvement options were considered for the project, CMCs were selected as the most appropriate solution for the job based on the construction schedule, total settlement and overall cost.

Settlement and Stresses were computed using the FEM Software package Plaxis and a combination of 2D-Plain strain as well as axisymetrical modeling techniques in order to represent different proposed loading conditions. See figure 10 & 11) Overall, it was found that there was a good agreement between the two types of model regarding the predicted settlements and the expected load sharing ratios between CMCs and the surrounding soils.

Figure 9 – CMC installation under the MSE Wall

The axisymetrical model was performed using an 18 inch CMC and represented a typical unit cell located beneath the proposed embankment toward the center of the MSE Wall.
The wall height used for this model was 21 ft above the top of the CMCs. The CMCs were extended 1ft into the lower shale with a modeled length of around 25 ft. A plane strain model was also performed for the same profile and section of roadway representing 4 CMCs installed beneath the proposed embankment, MSE wall and roadway.
The results of the plain strain model predict the settlement that will occur during construction of the embankment and MSE Wall and the distribution of load between soil and CMC. This type of modeling also allows to evaluate the global stability of the embankment and MSE wall supported by CMCs and to provide a global factor of safety against failure through a C-phi reduction analysis. Because a 3D configuration is modeled using a 2D plane strain simplification, the CMCs are modeled as infinite walls that extend infinitely perpendicular to the model plane.
Because of this limitation, the stiffness and surface area of the modeled elements need to be adjusted to represent an actual stiffness and surface area of the discrete CMC elements. The results of the 2D plain strain models are shown in the following figures

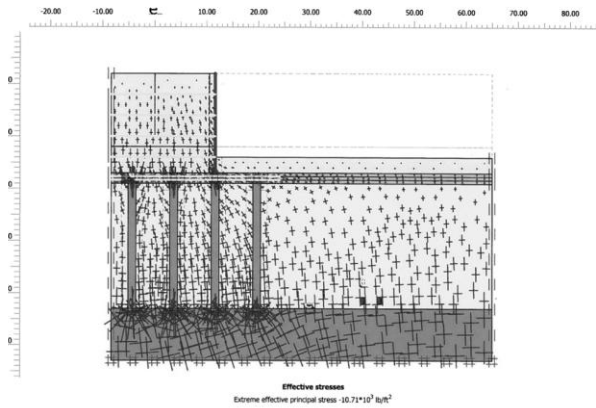

FIGURE 10 stress distribution under the MSE Wall in 2D plane strain model.

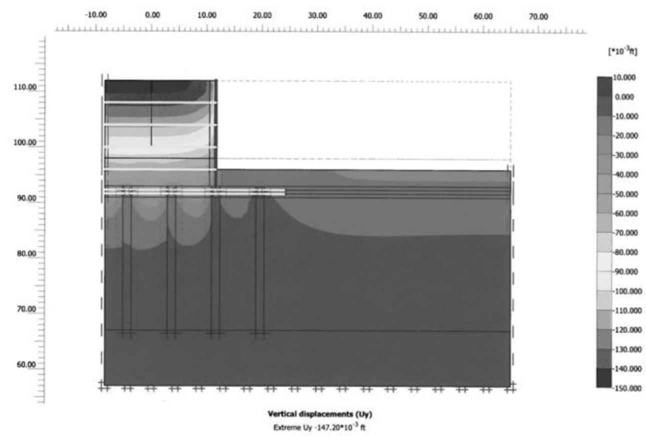

FIGURE 11: Settlement Profile under the MSE Wall in 2D plane strain model.

The results of the axisymetrical model showed a total settlement of 1.6 inches at the top of the MSE Wall with a tip movement of the CMCs limited to 0.1 inch. The plane strain model resulted in a total settlement of 1.8 inches at the top of the MSE wall with a similar CMC tip movement. Both models showed that approximately 60% of the applied load was carried by the CMCs and 40% by the surrounding soils, results in line with other sites with similar conditions.
Two single element modulus tests were performed on two different CMCs to verify the geotechnical capacity of the CMCs. The maximum load applied on the 18 inch elements during the test was 280 Kips. (see figure 12)
The MSE Wall was constructed using the Reinforced Earth Company Wall System.

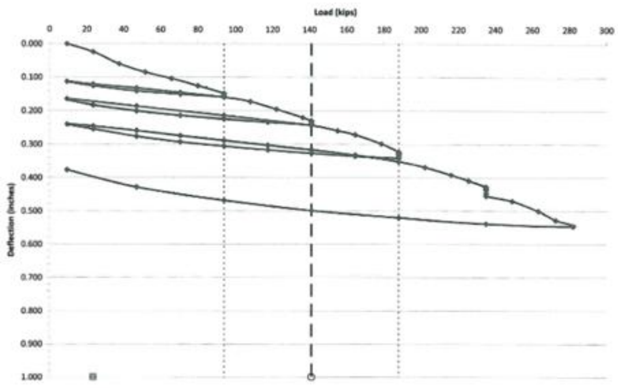

FIGURE 12: Single Element Modulus Test

The MSE Wall was instrumented and movements were recording during several months. The settlement data showed a maximum movement of around 1 inch after the monitoring period as shown below.

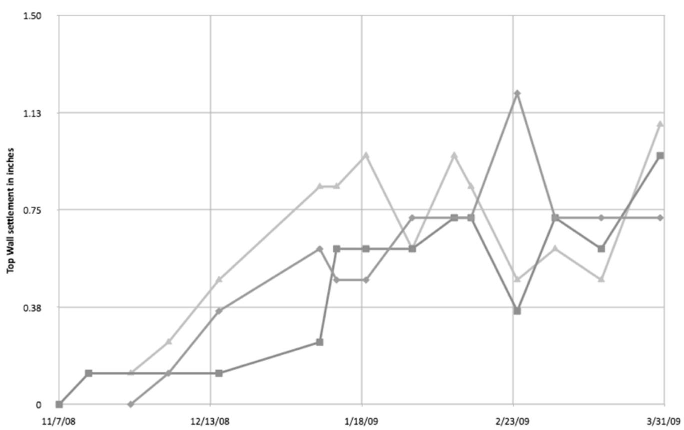

FIGURE 13 CMC-supported MSE Wall monitoring results

5 CONCLUSION

CMC technology spans a wide range of economical alternative solutions for heavily loaded structures, high MSE Walls, embankments, and bridge abutments when two-stage MSE Walls or even piling or other deep foundations are the initially envisioned improvement method. By eliminating heavy structural mats and pile caps, while at the same time allowing the compatible sharing of support with the soil by using a Load Transfer Platform, it results in the optimal use of all materials. Since the elements do not drain, long term consolidation is discouraged, and undesirable vertical transport of groundwater contaminants is not promoted. Spoil generation is virtually nil, eliminating the costly disposal of contaminated ground. Performance is more predictable and subject to less variation, since real time monitoring allows for adjustment of column depth as the site is under progress and the bearing conditions vary. Speed of construction is enhanced for MSE Wall and embankment since traditional steps (Wall surcharging with or without use of wick drains or 2- stage MSE Walls) are eliminated.

Although this paper focusses on two cases in New Jersey, the combination of MSE Walls with CMC has gained acceptance in many DOTs across the country and is being widely used in many parts of the world where soft soils are a concern for the long term performance of the roads. The flexibility of the MSE mass combined with the high performance level of the CMC system in terms of settlement control and bearing capacity improvement makes for a very attractive global system for road widening and bridge approaches.

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