Redevelopment of Brownfield sites using Controlled Modulus Columns as an alternate to Deep Foundations

Frederic Masse, Chris Parinella & Robert Wyman
Menard, Pittsburgh, PA

ABSTRACT
Controlled Modulus Columns (CMC) is a ground improvement technology that allows shallow foundations on sites that traditionally require deep foundations. The CMC installation is attractive from an environmental perspective because it utilizes displacement augers, thereby avoiding the spoil and disposal required with traditional augers. The reverse flight auger displaces the soil laterally densifying the soil around it. In addition the hole is backfilled with cement grout under moderate pressure that also densifies the surrounding soils. The system is capped by a granular well-compacted platform which serves as a load transfer layer to transmit the load from the structure to the semi-rigid CMCs. The load is then transmitted to a stronger bearing stratum below, or shed into surrounding soils at greater depth.
Our paper will focus on the use of CMC to mitigate long term settlements and improve bearing capacity at two brownfield sites, one in Pennsylvania for the construction of a large produce warehouse and one in New Jersey for the construction of a Retail development. We will develop the sustainability / green construction aspects of CMC design and installation, using these particular cases.

RÉSUMÉ
Les Colonnes a Module Contrôle (CMC) sont une technique d'amelioration des sols qui permet d'utiliser des fondations superficielles sur des projets qui necessitent generalement des fondations profondes. L'installation des CMCs est interessant d'un point de vue environemental car cette technique utilise des tarrieres refoulantes, permettant ainsi d'eviter la generation et la necessite d'avoir a evacuer des deblais contamines. La tarriere refoulante deplace le sol lateralement creant ainsi un effort de densification du sol environnant. Le système est recouvert d'un matelas granulaire compacte qui sert de couche de repartition transmettant les efforts et charges de la superstructure aux CMCs semi-rigides. La charge est ensuite transmise en pointe de CMCs aux couches profondes plus denses ou distribuee par frottement aux couches sous-jacentes.
Cet article portera l'attention sur l'utilisation des CMCs pour réduire les tassements a long terme et améliorer la capacité portante de sols sur deux sites contamines, un en Pennsylvanie pour la construction d'une plateforme logistique et l'autre dans le New Jersey pour la construction d'un nouveau centre commercial. Nous développerons l'aspect développement durable / environnement du design des CMCs ainsi que de leur installation en utilisant ces projets comme exemples.

1 INTRODUCTION

Foundation subgrade is typically evaluated for both strength (bearing capacity) and service (settlement). The traditional approach was to use piles to control settlement at sites with poor quality soils. The piles became the supporting elements for the foundation and were designed to resist lateral and vertical loads applied to the foundation. However, the pile capacity required to control settlement may be significantly lower than that required to support the foundations. Therefore, the service goal may require an inefficient system because the pile system generally ignores the strength of the soil surrounding the piles (at the exception of pile-raft systems). Ground improvement is typically more efficient because its design utilizes the strength of the soil while providing additional strength, if required, and meeting service requirements. (Plomteux & al, 2003)

With widespread acceptance in the market place, many engineers are choosing ground improvement techniques to provide suitable foundation subgrade at sites that would have traditionally required deep foundations. This article discusses the Controlled Modulus Columns (CMC) ground improvement technique and two case histories highlighting the use of this technique.

2 OVERVIEW OF THE TECHNOLOGY

CMC are a sustainable and cost-effective ground improvement technology that transmit load from the foundation to a lower bearing stratum through a composite CMC/soil matrix. CMCs have been installed in a variety of soils including, uncontrolled fill, organics, peat, soft to stiff clay, silt, municipal solid waste, and loose sands. Typically, the CMC is installed through the soft or compressible soils and into dense sand, stiff clay, glacial till, or other competent material that serves as the bearing stratum.

2.1 Installation Methodology (see figure 1 and figure 2)

CMCs 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 unconfined compressive strength of the grout is adapted to the requirements of the design and varies between 1,000 and 3,000 psi for typical applications.
CMCs are installed without generating spoils or creating vibrations. The grout for the CMC element is placed with enough back pressure to avoid collapse of the displaced soils during auger withdrawal. The installation process allows for the creation of a column with the diameter that is at least as large as that of the auger. CMCs are installed with drilling equipment that has large torque capacity and high static down thrust to efficiently displace and compress the surrounding soil laterally.
The auger is advanced while turning and displaces the soil. Upon reaching the desired depth, grout is pumped through the end of the auger and into the soil cavity as the auger is withdrawn. Column diameters typically range from 11 to 18 inches and are selected based on the loading conditions, and the site geotechnical conditions.

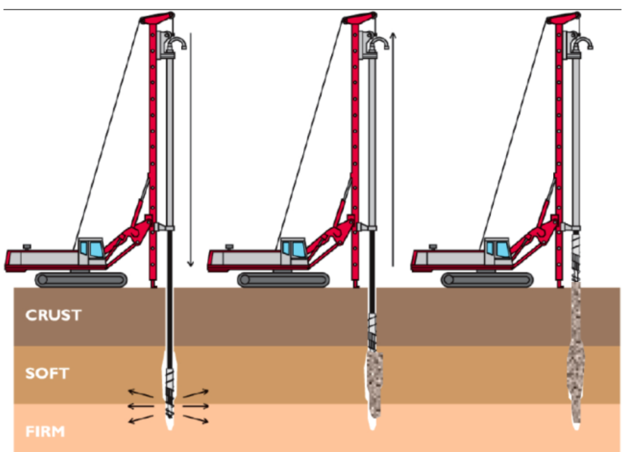


FIGURE 1 Typical CMC installation procedure.

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. 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:

- 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 from which a profile can be generated.

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 overbreak 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.

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 QC include monitoring fluid 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.

2.2 Advantages of CMCs over traditional technologies

When selecting the appropriate ground improvement technology, knowledge of the benefits of each system is key. Because CMCs are a relatively new technology many potential users are not aware of its benefits. From a financial perspective, CMCs reduce cost when compared to more traditional pile foundations or excavation and replacement of unsuitable soils because less construction materials are required, the installation of CMCs is faster than the installation of piles, and spoil disposal is eliminated. In addition, the use of CMCs has the following benefits, which relate to the overall sustainability of the project:

- Promotes development of brownfield sites underlain by poor quality soils;
- Avoids excavation and replacement of poor quality soils and limits spoil, reducing waste generation;
- Avoids driving long steel piles to bedrock;
- Provides a cost-effective solution compared to conventional foundation systems;

- Allows for the lengths of CMCs to be adjusted in the field without splicing or cutting;
- Reduces schedule for installation;
- Reduces design costs associated with the design of pile caps, grade beams, and structural slabs, which are required when using a deep foundation system;
- Reduces the cost of the structure by substituting pile caps, grade beams and structural slabs with spread footings and slabs-on-grade
- Improves the performance of the methane barrier system when required by eliminating complex detailing around pile caps
- Eliminates the need to hand utilities under structural slab as utilities are installed directly within the Load Transfer Platform.
- Improves the overall quality of the slab by allowing construction of the slab under roof
- Reduces the carbon footprint associated with foundations by significantly reducing concrete and steel quantities.

FIGURE 2 Installation of CMCs.

While CMCs are an attractive financial and sustainable option, they have also demonstrated that the performance of the system is comparable to that of deep pile foundations. Typical CMC designs limit total settlement of a structure to 1 inch and differential settlement to 0.5 inch.

2.3 CMC Design Methodology

The behavior of an individual inclusion is predicated on reaching equilibrium under loads (Combarieu & al, 1988) as shown on Figure 3. While the inclusion is being compressed by the load, negative skin friction is acting in its upper part and positive skin friction in its lower part. When the equilibrium is reached, the stresses acting on the inclusion can be divided into four components:

- The vertical load, Q at the top of the inclusion
- The negative skin friction acting on the upper portion of the inclusion
- The positive skin friction acting at the lower portion
- The vertical reaction at the tip

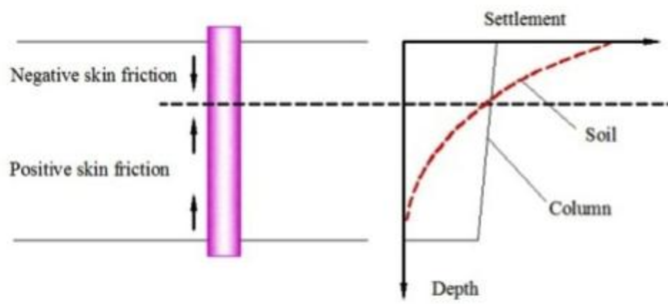


FIGURE 3. Settlement distribution between soil and an isolated inclusion.

The load of the structure is usually distributed to a network of inclusions by the Load Transfer Platform (LTP). The LTP is usually made of well-graded granular backfill and is designed to allow arching of the load of the slab / footings onto the CMCs. The thickness, quality and adequacy of the LTP is one of the key factor in the design of CMCs. While high-tensile strength high-modulus geotextile can be used in some cases, the deformations calculated within the LTP are usually too small to allow for the full development of the geotextile tensile strength which renders in many cases the geotextile reinforcement under utilized. A typical bi-axial high strength geotextile develops its full tensile strength at around 5% elongation. For the typical application under buildings where settlement in the order of ½ to 1 inch are predicted, it is not possible to reach the level of deformation required to fully develop the tensile strength of the geotextile. High strength geotextiles are therefore rarely used and designed within the LTP for CMCs applications under buildings (Masse & al, 2008).

Figure 4 shows how the load is distributed from the structure to the bearing layer. The load distribution between CMCs and surrounding soil is based on reaching an equilibrium between deformations of the CMCs and the surrounding soils. The design of a network of inclusions is thus based on a good knowledge of the distribution of stresses and deformations in the soil and the inclusions.

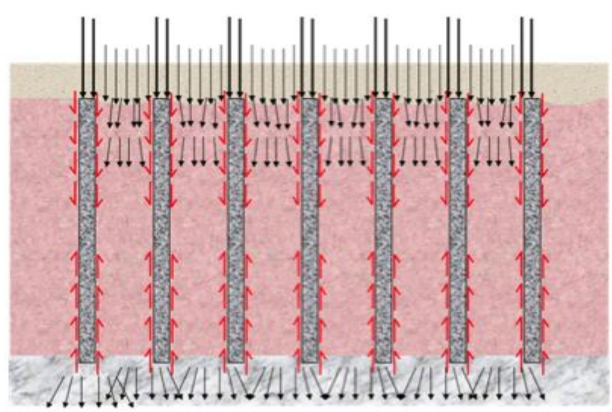


FIGURE 4 Load distribution between soil and an inclusion network.

While calculation methods have been proposed by various authors (see Combarieu & al, 1988), with the development of more powerful computers, finite element method (FEM) analysis has quickly become the method of choice when designing a network of CMCs (see figure 5).

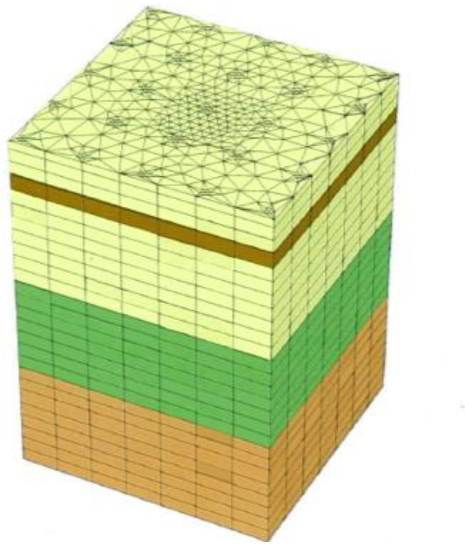


FIGURE 5 Example of 3D FEM model for support of slab and footings on CMCs

While we discuss the use of CMCs to support buildings in this paper, CMCs also have been used for a variety of other applications including foundations for tanks, mechanically stabilized earth (MSE) walls, and embankments. We present several case histories to discuss the sustainable, green construction aspects of CMC design and installation.

3 CASE HISTORY : PRODUCE WAREHOUSE IN PHILADELPHIA

3.1 Overview of the Project

The project is a produce market located near the Philadelphia International Airport. Built on a former Municipal landfill, this brownfield redevelopment project includes the construction of a single story produce distribution center approximately 550,000 square foot. The building is approximately 34 feet in height with a foot print of 425 feet by 1,295 feet and a continuous full perimeter loading apron for loading/unloading of delivery trucks. To support the high surface loads, Menard implemented a alternate design-build ground improvement solution using Controlled Modulus Columns (CMCs).

FIGURE 6 Architectural rendering of the project

3.2 Ground Conditions

Because the site was a former landfill (now closed), the conditions throughout the site were very heterogeneous which created a challenge in the design of the ground improvement system. Overall the area was underlain by a thick heterogeneous layer of existing municipal solid waste (MSW) fill. The consistency of the MSW as well as its thickness varied widely across the building footprint. The MSW ranges in thickness from 14 feet to 33 feet and at times was overlain by a layer of variable fill that did not contain waste. The MSW encountered in the borings was loose and was easily penetrated in general. However, obstructions such as wood, metal, concrete debris and bricks were encountered (see figure 7).

FIGURE 7 Test Pit showing MSW layer

Under this layer of municipal waste, a thick layer of organic silt with some clay and sand was generally present. The thickness of this layer was highly variable from 2 feet to up to 18 feet. Based on SPT performed at the site, the organic layer can be described as soft. Beneath the organic soils, dense sand was found in the borings with N-Values averaging around 50 blows, providing a competent bearing layer for the CMC design. Bedrock composed of decomposed schist was found at least 45 feet below grade.

The presence of the MSW and the underlying organic silts were unsuitable to support up to 10 feet of new fill under the finished floor of the building with heavy floor loads. Without implementation of a support system, both long-term consolidation settlement and degradation of the MSW over time were calculated to be unacceptable for this type of structure.

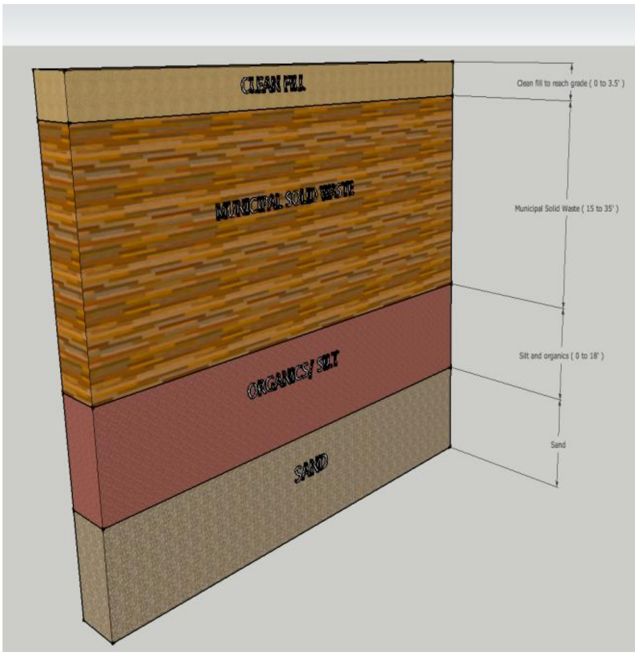
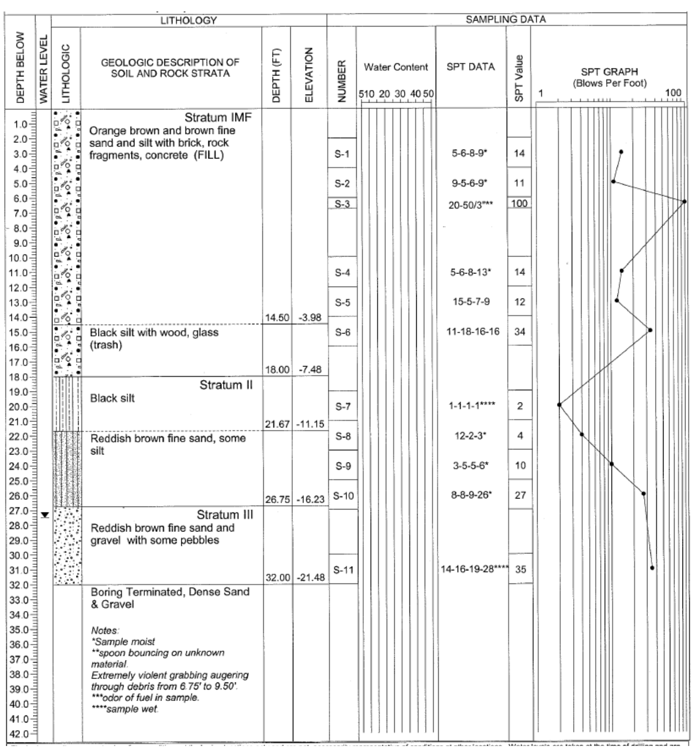


FIGURE 8 Typical Geotechnical Section



Geologic Description of Soil and Rock Strata	Depth (FT)	Elevation	Number	SPT Data	SPT Value
Stratum IMF Orange brown and brown fine sand and silt with brick, rock fragments, concrete (FILL)			S-1	5-6-8-9*	14
			S-2	9-5-6-9*	11
			S-3	20-50/3"**	100
			S-4	5-6-8-13*	14
			S-5	15-5-7-9	12
	14.50	-3.98			
Black silt with wood, glass (trash)			S-6	11-18-16-16	34
	18.00	-7.48			
Stratum II Black silt			S-7	1-1-1-1****	2
	21.67	-11.15			
Reddish brown fine sand, some silt			S-8	12-2-3*	4
			S-9	3-5-5-6*	10
	26.75	-16.23	S-10	8-8-9-26*	27
Stratum III Reddish brown fine sand and gravel with some pebbles			S-11	14-16-19-28****	35
	32.00	-21.48			
Boring Terminated, Dense Sand & Gravel					

Notes:
**Sample moist*
***spoon bouncing on unknown material.*
Extremely violent grabbing augering through debris from 6.75' to 9.50'.
****odor of fuel in sample.*
*****sample wet.*

FIGURE 9 Typical SPT Boring

3.3 CMC Alternate Design Build Solution

The original foundation design proposed the use of either 8-inch-diameter timber piles or 12-inch-diameter grouted steel pipe piles, both driven to a depth of approximately 50 feet. In addition, thickened reinforced pile caps, internal grade beams, and a 12-inch-thick reinforced, 2-way structural slab would be required to connect the piles to the superstructure. Figure 10 shows a typical detail of the connection at pile cap.

While technically sound, This solution presented several disadvantages :

- High Cost of the Superstructure : Because of the need to span the load between piles, the slab and pile caps were to be heavily reinforced in both directions and the thickness needs to be increased compared to a slab-on-grade solution.
- Because the site is located over a landfill, a methane-collection system was designed using an impervious membrane under a layer of clean granular backfill. The Presence of piles creating penetrations into the membrane rendered the installation and sealing of the membrane very costly and time consuming.
- Because of the risk of long term settlement of the MSW and organics, all the piping located under the slab needed to be attached to the slab with hangers.
- The structural slab has to be built before the structure can be erected creating a lower quality of finish compared to a slab poured under roof.
- Environmental risk of cross-contamination of the layers located below the MSW during the pile driving operations by creating preferred paths along the shaft of the pile for leachate downward flow.
- Depth of the piles : The piles were designed to be bearing on the bedrock (schist) and would have averaged a depth of roughly 50 ft.

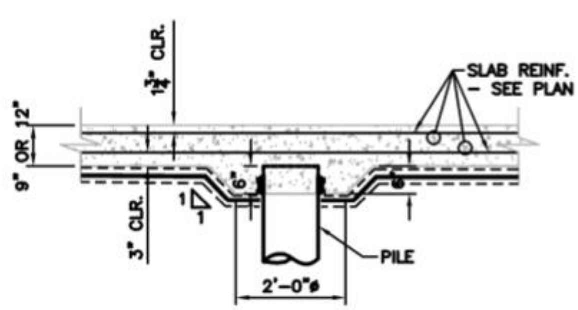


FIGURE 10 Typical structural detail of connection between pile and structural slab

Menard's alternative design proposed CMCs to support the entire facility including the loading dock apron around the building perimeter.

The warehouse was supported using 12.5-inch-diameter CMCs drilled to a depth of approximately 35 feet into the dense sand layer. The CMCs were placed under individual footings and beneath the slab. The CMC support allowed for the use of spread footings and a 6-inch-thick slab-on-grade and eliminated the need for internal grade beams. Figure 11 shows a section of the Load Transfer Platform below the slab and below the footings with relation with the elevation of the CMCs and the Methane barrier.

The main purpose of the CMCs was to minimize the settlement of the warehouse, which could have been significant if some type of support was not provided.

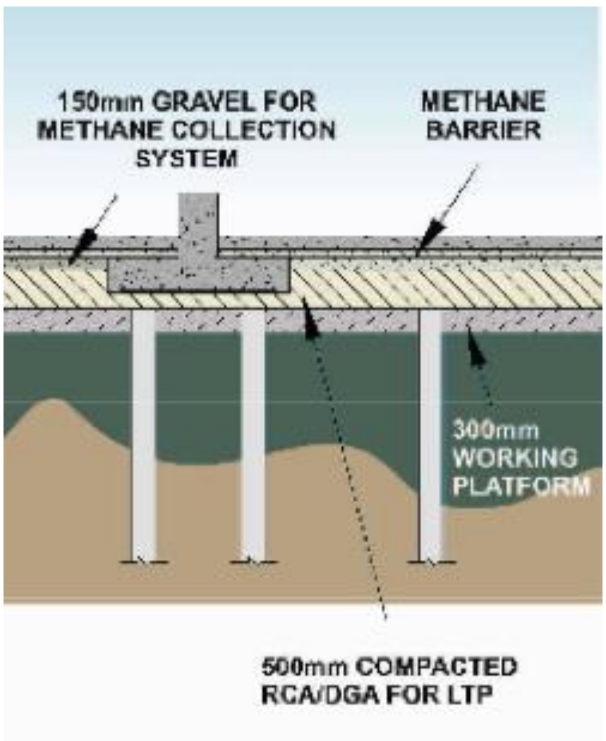


FIGURE 11 Typical section of the CMC design

As far as the constructability of the system is concerned, the most significant advantages of the alternate design were :

1) the change from a structural floor and pile caps system to a thinner slab-on-grade, with conventional spread footings, creating significant savings in the cost of the structure itself

2) a simpler and more continuous vapour membrane system with minimal sealed penetrations to enhance quality, reliability and cost of the vapour barrier over the MSW.

3) The slab-on-grade was constructed after the building was under roof allowing for a better floor finish and quality

4) all utilities were installed within the Load Transfer Platform eliminating the need to hand the piping to the slab

The design of the CMC system was performed using Finite Element Analysis. Based on the loads and grades, a CMC diameter of 12.5 inch was selected for all the elements. The spacing of the CMCs varied depending on the initial grade of the site, different loads within the building, thickness of the MSW and Organics and final elevation of the slab. The spacing of the CMCs varied from 6 feet on center to 10 feet on center across the building.

Because of the soft nature of the MSW as well as the risk of long term degradation (secondary settlement), it was decided that the upper layer of MSW (about 20 feet) will be dynamically compacted prior to installation of the CMCs. A 15 tons weight dropped from 70 feet was used for the Dynamic Compaction Work as shown in figure 12.

-

FIGURE 12: Dynamic Compaction Operations

A total of more than 11,000 CMCs were installed to support the Warehouse, the Apron areas as well as Utility Corridors around the building area.

3.4 Full Scale Load Test

In order to confirm the results of the design and in addition to other Quality Control procedures (single element load tests, grout testing, On-Board computerized QC print-outs of each CMC..), it was decided to carry out a full scale load test to reproduce the final load conditions of the building and verify the design predictions in terms on total and differential settlement.

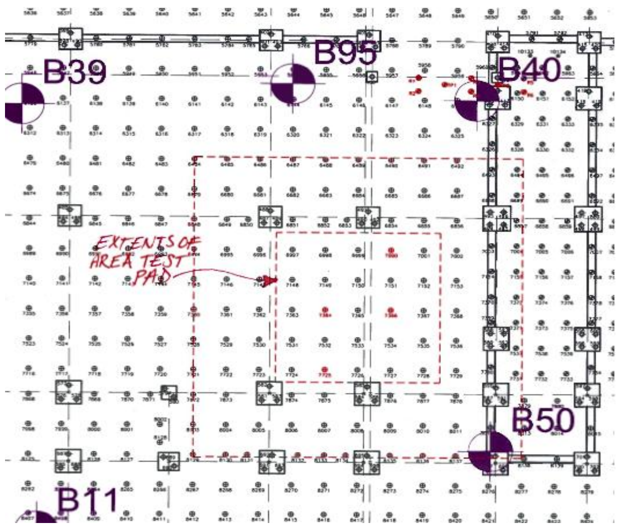


FIGURE 13: Location of Full Scale Test Area

A 50 feet x 50 feet area with the worst geotechnical conditions was selected and CMCs were installed after completion of the Dynamic Compaction works. The grade was raised to the bottom of slab elevation and Settlement plates were installed. The area was then loaded with 6 feet of additional granular soil to represent the warehouse maximum floor load of 600 psf approximately. Figure 13 shows the location of the test area within the building pad with relation with the CMC layout and closest borings.

The settlement of the area was monitored for 3 months twice weekly and a maximum settlement of less than 0.7 inch was recorded as shown on figure 14. This settlement was extrapolated to a long term value be compared with a prediction of the design of about 1.5 inches of total settlement under the slab.

Based on the settlement data, it was estimated that about 60% of the long term settlement had been observed during the 3 months monitoring period. Therefore, the maximum long term settlement was back-calculated to be around 1 inch in this area.

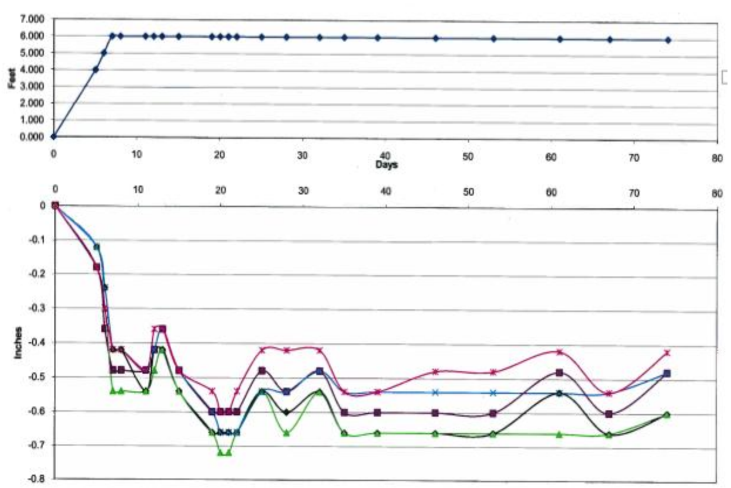


FIGURE 14: Settlement Plate Monitoring Data

FIGURE 15: View of CMC Drill Rigs

3.5 Sustainability Analysis

Because the site was a former landfill, many environmental concerns were emphasized during the initial phase of the development of this site.

For example, any spoils generated by the foundation works would likely require special, costly handling for disposal. An obvious advantage to using CMCs, or any displacement installation method, is that no spoils are generated. In addition, CMCs contain grout only, which is a more sustainable material than reinforced concrete or steel used in piling. Finally, because of the redesign of the structure itself, using slab-on-grade and spread footings in lieu of structural slabs and pile caps, significant savings in material (concrete and steel) are allowed by the CMC technology.

We compared the environmental impacts of a pile foundation and the CMC ground improvement and found a 25% reduction in the carbon footprint of the foundations by selecting CMCs instead of pile foundations.

The carbon footprint offset calculation was based on the difference in quantity and carbon footprint values for the concrete, steel, and grout associated with the piles and the CMCs only. Figure 16 shows that the CMC solution presented a significant reduction in equivalent carbon emission as compared to the original design. This evaluation does not include any benefits of the redesign of the structure, the accelerated schedule associated with the CMC design, nor with the additional carbon footprint required to dispose of extra, potentially contaminated, soils associated with the deep foundation scheme.

It is likely, although we did not carry out the calculations, that a total reduction in carbon footprint ranging from 35% to 50% should be expected with the CMC alternate design.

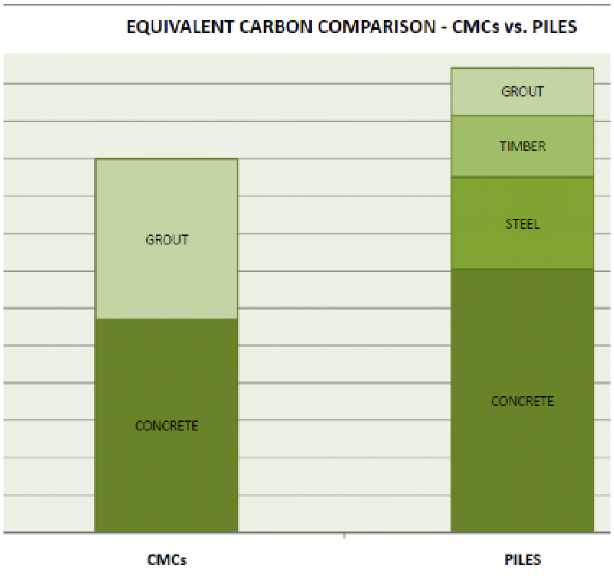


FIGURE 16: Sustainability analysis CMCs vs Piles

4 CASE HISTORY : RETAIL DEVELOPMENT IN BAYONNE, NJ

4.1 Overview of the Project

The project is located on the site of a former industrial complex demolished in 2008, in Bayonne, NJ. Prior to being redeveloped, the site was the location of an oil bulk storage facility including large above-ground petroleum tanks. The redevelopment of this site includes ten retail structures with associated parking lots and roadways forming a new shopping complex on a 30 acres brownfield site The buildings sizes range from 2,000 square feet for a chain restaurant to about 150,000 square feet for a large home improvement store.

4.2 Ground Conditions

A site specific environmental evaluation uncovered the presence of potential chemical hazards and contamination in various concentrations and located several hot spots that needed to be remediated. Volatile organic compounds (VOC), semi-volatile organic compounds (SVOCs), polychlorinated biphenyls (PCBs), and metals including hexavalent chromium were all found during the environment investigation. During construction, because of the presence of these known contaminants, special drilling and handling procedures were required. The geology at the site is typical of the regional geology of the northern part of New Jersey. The extensive soil investigation performed at the site revealed the presence of an upper layer of miscellaneous urban fills which were encountered in all borings to depths of up to 25 to 30 feet. N values were inconsistent because of the heterogeneous nature of the fill materials. Some of the fill materials were saturated with oil. Below this man-made fill layer, organic soils were found in most borings with thickness varying from 0 ft to up to 15 ft in some locations. This organic layer consisted of peats and organic silty clays. Laboratory tests revealed water contents between 65% and 385% with organic contents between 5 and 10%. Consolidation tests performed on the organics showed initial void ratios between 3.5 and 5.4 with compression indices between 2.1 and 3.2. Sandy deposits below were typically classified as fine to medium sands with varying amounts of gravel, silt and clays. The water table was encountered about 5 feet below ground surface.

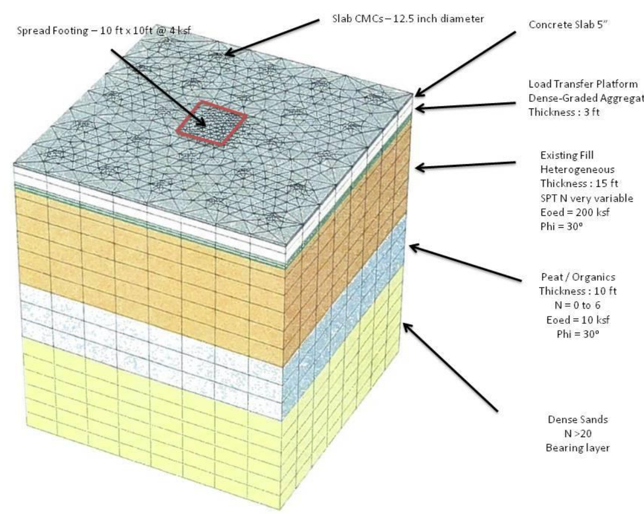


FIGURE 17: FEM Model of slab and footing supported by CMC system

4.3 CMC Alternate Design Build Solution

While initially contemplated that 9 out of 10 buildings be supported by wooden piles and structural slabs, a CMC solution was eventually adopted for the project because of the overall savings in the construction of the structure offered by a slab on grade and spread footings solution. Because of the presence of high concentration of contamination in the ground, the fact that the CMC system does not bring spoil to the surface played a very significant role in the selection of this technique over other ground improvement technologies. In addition to that, the CMC auger can also penetrate obstructions that may damage wooden piles or significantly slow their advancement without costly predrilling.
The CMC system was designed to support the weight of the additional structural fill to reach final grade (up to 7 feet of additional fill required) as well as the live load on the floor slabs (varying from 100 to 700 psf). A Load

Transfer Platform 2 to 4 feet thick depending on the structures was placed above the top of the CMC elements to adequately transfer the load from the floor slabs to the CMCs. No geogrid reinforcement was placed within the LTP. Figure 17 shows the typical section used to model the system in a Finite Element Program. FEM is used in most cases to design CMC systems.

The difference in use, proposed loading, required structural performance, and soil conditions required a re-evaluation of the design of the CMC system for each building. However, the CMC size, spacing and configuration can easily be modified to optimize the system for varying conditions. The CMCs were placed under individual footings and beneath the slabs for each of the structures, as required.

The CMC support allowed for the use of spread footings and 4- to 6-inch-thick slabs-on-grade and eliminated the need for internal grade beams and pile caps.

During production, a full scale load test consisting of two x 50ft x 50 ft area with two different grid of CMCs loaded using an 4 ft high embankment representing the future slab load was monitored using settlement plates., strain gages and piezometers The measured settlement remained within the allowable settlement value of one inch, confirming the adequacy of the design.

A total of more than 4,000 CMC Elements, 12.5 inch in diameter were installed across all structures.

FIGURE 18: Aerial view of the site

4.4 Sustainability Analysis

While no specific Carbon Footprint analysis was performed for this project, one of the main reason that the system was selected over other ground improvement technologies such as Aggregate Piers/ Stone Columns is the absence of spoil generation with the CMC system. The CMC technology has been accepted on several occasions by the NJDEP as an acceptable solution to improve soft grounds without risking cross-contamination of the clean lower aquatar by pollutants located in the upper fill layers.

Based on our past experience, we anticipate a 15 to 25% reduction in the carbon footprint of the foundations by selecting CMCs instead of pile foundations. As discussed previously, this would account for the difference in quantity and carbon footprint values for the concrete, timber, and grout associated with the two different schemes. It does not include any benefits of the accelerated schedule associated with the CMC design, nor with the additional carbon footprint required to dispose of extra, potentially contaminated, soils associated with the deep foundation scheme (predrilling).

5 CONCLUSION

The use of ground improvement and the CMC system provide cost and schedule savings and a more sustainable solution for construction of foundations on sites with poor quality soils as compared to a more traditional solution using piles, piles caps, grade beams and a structural slab. This approach is especially suited to Brownfield developments and has been successfully designed and applied to a number of projects for warehouses, retail developments and condominiums. A carbon footprint calculation can be used to demonstrate the benefits of the system (Masse et al, 2008). A more detailed calculation including soil disposal issues could be developed.

REFERENCES

Masse, F. & al. (2004) CMC: potential application to Canadian soils with a new trend in ground improvement - CGS 2004, Winnipeg, Canada

Plomteux, C. Spaulding, C., Simmons, G. (2003) – "Reinforcement of Soft Soils by Means of Controlled Modulus Columns"– Soil and Rock America 2003, pp 1687-1694

Plomteux, C. & al (2003) – "*Controlled Modulus Columns (CMC): Foundation system for Embankment support: a case history" – Geosupport 2004,* Orlando, USA, pp 980-992

Combarieu, O. (1988) – Amelioration des sols par inclusions rigides verticals – application a l'edification de remblais sur sols mediocres-Revue Francaise de geotechnique n 44, pp. 57-59

Combarieu, O. (1988)-Calcul d'une foundation mixte-Note d'information technique LCPC

Masse F. & al (2008) – Ground Improvement Technologies for a Sustainable World – ASCE Geo-Institute – Geocongress 2008