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Ground Improvement for Redevelopment of Former Landfill

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GROUND IMPROVEMENT FOR REDEVELOPMENT OF FORMER LANDFILL

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ABSTRACT

A former industrial landfill site was selected for the design and construction of a large industrial building. Due to the soil and groundwater conditions along with potential environmental impacts discussed in this paper, support of the building using shallow spread foundations or conventional deep foundations, such as driven or cast-in-place piles or drilled piers were not considered to be reasonable foundation support alternatives. Therefore, ground improvement was deemed the best alternative to support the building, floor slabs and machine foundations for the project, although timber piles with a structural slab were also considered. Controlled modulus columns and rammed aggregate piers were the two options considered feasible for the project since these two methods would generate little to no soil cuttings or groundwater at the ground surface requiring special handling and disposal to a regulated landfill. Controlled modulus columns were ultimately selected by the Owner and designed for vertical compression and uplift loading conditions for the building and for support of machine foundations and floor slabs.

INTRODUCTION

A 115,000 square-foot facility at the Port of Monroe, Michigan was constructed to manufacture steel towers for wind-powered electrical generators (wind turbines). The site of the facility is a Brownfield redevelopment project and is part of a 38-acre industrial waste landfill created between the 1940s and 1970s to reclaim coastal marshes adjoining Lake Erie. The environmental site assessment identified human direct contact and vapor intrusion risks on the property associated with the former landfill. The geotechnical evaluation indicated there were significant settlement issues associated with the heavy floor loading required for the construction of the larger tower structures on top of the variable and unconsolidated landfill materials encountered at the site.

The building consists of a single-story, slab-on-grade, high-bay prefabricated, steel-framed structure. Column loads range from about 22 to 328 kips and wall loads are assumed to be in the 2 to 4 kips per lineal foot range. In addition, the building houses equipment to process flat steel stock, assumed to weigh as much as about 70 kips. The proposed slab loads for the structure varied from 200 to 1200 psf.

Special heavy-duty pavement systems were also required due to the large traffic loads from heavy-duty transport vehicles used to move and load the large towers from the plant to storage areas, railhead and the port facility.

The former industrial landfill site is adjacent to a creek and in close proximity to Lake Erie. Based on previous geotechnical and environmental field explorations performed on and near the site, the industrial fill extends as deep as about 14 feet below the ground surface and is underlain by localized organic soil or sand deposits; or sand or clay fill. These deposits are underlain by lean clays and clay hardpan and finally limestone rock. The lean clays and clay hardpan act as an aquiclude separating the leachate from industrial waste of the former landfill from the underlying groundwater aquifer in the underlying rock formation. The rock deposit typically is encountered about 27 to 33 feet below the ground surface. The industrial soils and groundwater in contact with them are environmentally impacted.

Due to these soil and groundwater conditions, the state environmental regulatory agency expressed concern about compromising the quality of the groundwater in the underlying rock formation and thus required that the borings for the geotechnical evaluation not extend into underlying rock formation for this project. Therefore, the borings performed for this project extended a maximum of 22.5 feet below the ground surface. Likewise, the state environmental regulatory agency restricted any foundation system for the structure from extending to the underlying rock formation and potentially compromising the groundwater quality.

This paper presents generalized information about the soil and groundwater conditions and various options considered for support of the building, floor slabs and machine foundations and a detailed discussion on the option ultimately selected by the Owner.

SUBSURFACE CONDITIONS

Soil Conditions

A series of 48 borings were performed at the site for the project. The soil conditions encountered at the boring locations generally consisted of surficial topsoil underlain by industrial fill overlying one or a combination of buried organic soil deposits, sand or clay fill or natural sand; underlain by lean clays to the explored depths of the borings. A generalized summary of the soils encountered in the borings is given below, beginning below the Stratum 1 materials consisting of surficial topsoil and proceeding downward:

Stratum 2: Industrial Fill. Industrial fill consisting of mixtures of foundry sand and other soil constituents along with significant amounts of miscellaneous debris was encountered below the surficial topsoil or at the existing ground surface extending about 6 to 13.5 feet below the existing ground surface. Standard Penetration Test resistances (N-values) ranging from 3 blows per foot (bpf) to 30 blows for 0 inches (i.e., sample refusal) of penetration were obtained in the fill, indicating a very loose to extremely dense condition. The higher N-values are most likely due to encountering debris or obstructions within the fill which would not allow penetration of the sampler.

Stratum 3: Organic Soil (Organic Silt/Clay or Peat), Sand, Sand or Clay Fill. A layer of organic silt or clay ranging from about 1.5 to 7 feet thick and extending to about 10 to 13.5 feet below the ground surface was encountered underlying the existing fill at 18 borings. Moisture contents varied from about 26 to 186 percent.

A layer of peat ranging from about 1 to 4 feet thick and extending about 7.5 to 15 feet below the ground surface was encountered underlying the existing fill at six borings. Moisture contents of representative samples of peat ranged from about 142 to 245 percent.

Strata of sand about 1.5 to 3.5 feet thick and extending about 11 to 13 feet below the ground surface were encountered underlying the Stratum 2 soils at 13 borings. N-values varied from 1 to 10 bpf indicating a very loose to medium dense condition.

Sand fill about 1.5 to 4.5 feet thick and extending about 10 to 14 feet below the ground surface was encountered at nine borings. N-values of 2 to 17 bpf indicate a very loose to medium dense condition. However, most of the samples indicated the sand fill was in a very loose to loose condition.

A layer of wood fragments about 1 to 1.5 feet thick and extending about 13 feet below the ground surface was encountered at two borings.

A layer of clay fill, about 2.5 feet thick and extending to about 10 feet below the ground surface was encountered at one boring. An undrained shear strength of about 0.6 ksf indicates a medium condition. The corresponding moisture content was about 23 percent.

Stratum 4: Lean Clays. Lean clays were generally encountered underlying the fill, sands or organic soil deposits extending the explored depths of the borings. These clays can sub-divided into two distinct layers, as follows:

Stratum 4a: In general, the lower undrained shear strengths in the clay layer were observed at the top of the layer and varied from 0.2 to greater than 4.5 ksf with N-values less than about 40 bpf. Moisture contents varied from about 11 to 33 percent.

Stratum 4b: The higher undrained shear strengths and N-values and lower moisture content in the clay layer were observed in the lower portion of the layer. The undrained shear strengths were typically greater than 4.5 ksf and the N-values were typically greater than 50 bpf. Moisture contents typically ranged from about 9 to 14 percent.

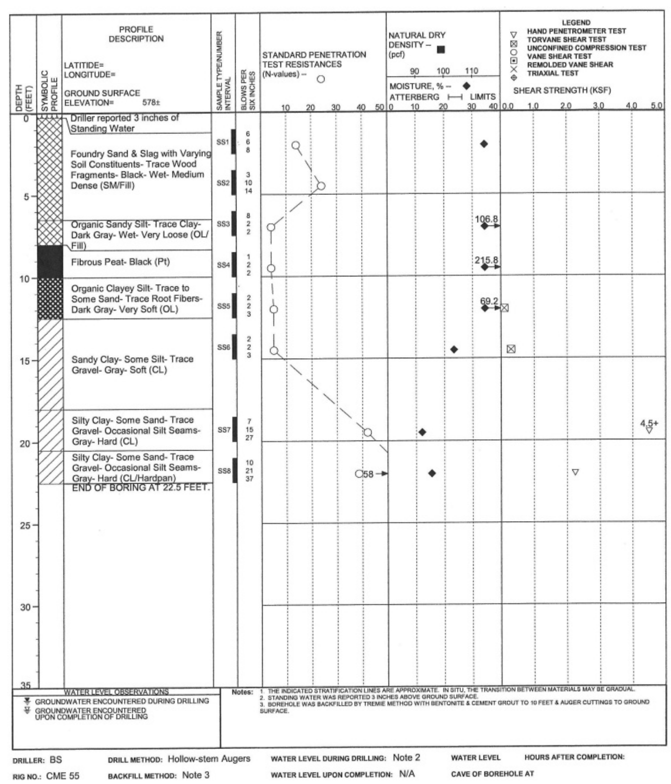

Figure 1: Typical Boring Log

Groundwater Conditions

During drilling operations, groundwater was encountered at the existing ground surface to about 12 feet below the existing ground surface. At several borings, about 3 to 6 inches of standing water was reported at the surface. The observed groundwater levels were typically in the fill above relatively impervious clay deposits and likely represent a perched water condition.

INTERPRETATION AND RECOMMENDATIONS

Existing Fill Considerations

The project site is a former industrial landfill and the fill is underlain by compressible peat and/or organic silts/clays in many areas. Therefore, there is a significant risk of poor foundation and grade-slab performance (due to excessive total and/or differential settlements) if conventional structural elements (i.e., shallow spread foundations and slabs-on-grade) are constructed on these soils. Therefore, these conditions should be addressed by either improving the ground beneath the structure or by using timber piles with a structural slab, as described later in this paper.

With respect to pavements and the rail line, placement of pavements and the rail line over uncontrolled fill and/or organic soils underlying the fill is not recommended since there is an increased risk of settlement, deflection related cracking and failure of the road/pavement surface and differential settlement of the rail lines. Typically, complete removal of the unsuitable fill, organic soil, and other deleterious materials and replacing them with engineered fill or crushed aggregate is recommended. However, since the existing fill and organic soil deposits are fairly extensive, the removal of these deep deposits is not economically feasible and in the case of this site, prohibitive, since the soil and groundwater are environmentally impacted.

There is a risk of premature pavement and rail line distress if the highly variable fill, buried organic soils and deleterious materials are left in place beneath the railroad structures and pavements. The most feasible approach for paved areas and the rail line is to attempt to mitigate potential differential settlement with some surface improvements and then manage the long-term settlements with a maintenance program. Due to the poor soil conditions, the pavement maintenance program will be more aggressive than typical applications. Surface improvements should include a pre-load surcharge program for the rail line, and the proposed steel storage areas to essentially allow future settlements to occur prior to placing the final pavements and railroad tracks. To reduce the affect of these settlements on pavement sections, paving could be delayed for several years (or as long as possible) and place crushed material at the surface until differential settlements across the pavement areas have stabilized. Likewise, in areas where differential settlement occurs along the rail line alignment, re-leveling of the railroad ties and track will likely need to be periodically performed.

Settlement of the pavements and rail line will likely occur due to elastic compression of the generally granular industrial fill, degradation of organic materials and compression of the buried organic soil deposits. Much of this type of settlement is expected to occur over an extended period of time. The amount of settlement is a function of the weight of new fill placed over the existing subgrade.

Foundations

The environmental and economic constraints on the development required that no soil cuttings be generated by the construction. In addition, the underlying clay aquiclude could not be penetrated, and future workers be adequately protected from the underlying hazards of the landfill materials. Conventional deep foundations generally did not meet these requirements and various recently developed ground improvements techniques were considered.

Two potential foundation systems were considered to support the building and machine foundations and the floor slabs for this project. The first option consists of a ground improvement method, which if implemented, would allow the construction of conventional shallow spread foundations and grade slabs. The other option consists of driven timber piles with a structural floor slab. Both of these options are sensitive to the environmental conditions at the site, in that they generate little to no soil cuttings which would not require special handling and disposal to a regulated landfill. Other ground improvement and foundation methods were considered but not pursued due to viability in terms of economics and/or environmental considerations.

Based on our evaluation, ground improvement techniques using controlled modulus columns (CMC) or rammed aggregate piers (RAP) provide distinct advantages over the timber pile option, as indicated below:

- The depth of the CMC or RAP foundations will be less than that for pile foundations. Since the CMC or RAP option requires extending the CMC or RAP to competent bearing soil in contrast to piles which need to extend into suitable soil and into the underlying hardpan, the tip elevation of the CMC or RAP elements will be at many locations higher than the tip elevation of the timber piles. From an environmental impact perspective, this is advantageous.
- It is anticipated there will be variability in the capacity of the piles due to the amount of fill present and how much pile penetration occurs into suitable subgrade.
- CMC's or RAP's do not require pile caps or grade beams. Rather, conventional shallow spread and machine foundations can be constructed over the

improved subgrade.

- CMC's and RAP's can also be used to support the floor slab. Since CMC's or RAP's are used with an aggregate mat below the floor slab, conventional slab-on-grade construction can be used without a structural slab required in combination with the timber pile option.

Both foundation systems are described herein.

Ground Improvement Systems

Conventional spread foundations can be constructed over the ground improved with the CMC's or RAP's. The design bearing pressure and maximum foundation settlements are based on the size, number and spacing of the CMC's or RAP's. Additional analysis and design was required to achieve the optimum combination of the CMC's or RAP's and design bearing pressure from the contractor selected to construct the foundation system.

Controlled Modulus Columns

Controlled Modulus Columns™ (CMC's) is a patented technology by DGI-Menard, Inc. (www.menardusa.com) of Bridgeville, PA. The CMC's are installed with specially designed augers, powered by equipment with large torque capacity and high static down thrust, which displaces the soil laterally, with virtually no soil cuttings or vibration. The augers are extended through the poor soils and into the underlying stable soil formation creating a cylindrical space in the ground. During the auger extraction process, the column is filled with a cement-based grout under moderate pressure. The diameter, spacing, and grouting procedures for the CMC's are designed to achieve a predetermined stiffness ratio with the surrounding soil. The result is a composite soil/grout ground improvement system.

Rammed Aggregate Piers

In general, rammed aggregate piers consist of a cylindrical excavation filled with compacted crushed aggregate. Due to the variable nature and depth of the existing fill, variable depths of perched groundwater conditions, and environmentally impacted soil and groundwater present at this site, impact RAP® installed using the dry, bottom-feed method was recommended. The major benefits of these systems are that the aggregate piers can be installed without generating soil cuttings along with their ability to be installed below groundwater and these systems can be installed without water. Augering can be performed as needed to loosen soils without generating soil cuttings provided the augers are rotated in an opposite direction during withdrawal. Pre-auguring at each pier location could be used to shallower depths to identify existing below-grade obstructions that require removal by excavation with a back-hoe or excavator.

The impact RAP® method involves penetrating the existing soil to a predetermined depth with a large steel hollow mandrel equipped with a plate at the bottom of the mandrel. Crushed aggregate is fed into a hopper located near the top of the mandrel, which directs the aggregate through the hollow mandrel to bottom of the mandrel and plate. The aggregate exits from the bottom of the mandrel and is compacted by incremental and successive penetrations from the mandrel as the aggregate level becomes higher in the cylindrical excavation.

Timber Piles

Driven timber piles with a working load capacity of 15 to 20 tons (ultimate capacity 38 to 50 tons) could be used in combination with a structural floor slab at this site. The capacity of the piles will primarily be a function of the depth of embedment of the pile into the clay below the unsuitable fill and organic/compressible soil deposits. For a working load of 15 to 20 tons, the pile tip would need to extend to the hardpan which was encountered between about 16.5 to 22 feet below the ground surface across the footprint of the building.

Downdrag loads on the pile can occur due to settlement of the soils surrounding the piles. If the finish floor elevation of the building is constructed more than 2 feet above the existing ground surface, the net capacity of the piles will need to be reduced to account for possible downdrag. The downdrag load could be as high as about 10 tons per pile. Thus, the net working load of piles driven to an allowable capacity of 20 tons with downdrag loads is reduced about 10 tons per pile. For this case, in effect, this at least doubles the number of piles required for the project. The estimated pile capacities are based on a minimum pile tip diameter of 8 inches.

There are methods to reduce the settlement of the soils after the piles are driven while still raising site grades, such as surcharging the soils, or using an ultra-lightweight fill (e.g., geofoam). However, these methods may take time to implement and/or add significant costs to the development of the site.

Due to the information developed from the geotechnical evaluation, the pile tips should extend no deeper than 22.5 feet below the existing ground surface level. In some areas, it is possible the full pile capacity may not be reached without driving the piles deeper than this level.

Obstructions within the existing fill may be encountered during driving of the piles. A heavy removable steel spud could be used to create a pilot hole through the fill to reduce potential damage to the pile due to obstructions and hard driving. Depending on the offsets required due to obstructions, the pile cap may need to be enlarged. Obstructions may also knock the pile out of vertical or horizontal alignment during driving.

Estimated settlement of the piles under the anticipated maximum working loads are expected to be about 1/2-inch or less, including the elastic compression of the pile. Differential settlement is estimated to be about one half the total settlement.

OVERVIEW OF CONTROLLED MODULUS COLUMNS

The best overall ground improvement solution consisted of Controlled Modulus Columns ™ (CMCs). The CMCs provided the required support for the proposed structure while protecting the underlying bedrock aquifer from contamination by landfill leachate while generating no construction wastes or excess fill. Once the CMCs were constructed, vapor intrusion mitigation systems were installed under the conventional shallow foundations and grade slabs for the manufacturing and office building.

The Controlled Modulus Column (CMC) technology was ultimately chosen for the support of the industrial building and designed to reduce the global deformability of the soil mass through the installation of semi-rigid soil reinforcement columns. 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 industrial building within allowable ranges. CMC's are not intended to directly support the loads imposed by the structure, but to improve the soil globally in order to control settlement. The dimensions, spacing, and material of the CMC's 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 desired value for the equivalent composite deformation modulus of the improved soil.

Contrary to the timber piling option evaluated for the support of the industrial building, the CMC technique did not require the use of structural slabs. Instead, the CMC's were installed 2 to 3 feet below the bottom of a slab-on-grade (See Figure 2). A layer of compacted granular material called the Load Transfer Platform (LTP) was then installed above the top of the CMC's and below the slab-on-grade after installation of the CMC elements. The main purpose of this LTP was to transfer the load from the structure to the CMC's without the requirement of the heavily reinforced structural slabs needed with the timber pile option. The load is transferred to the CMC through arching within the high angle of internal friction compacted granular LTP and through side friction below the top of the CMC's. The system was designed to transfer a majority (greater than 80%) of the load to the CMC's while the remainder of the load is transmitted into the soils between the CMC's.

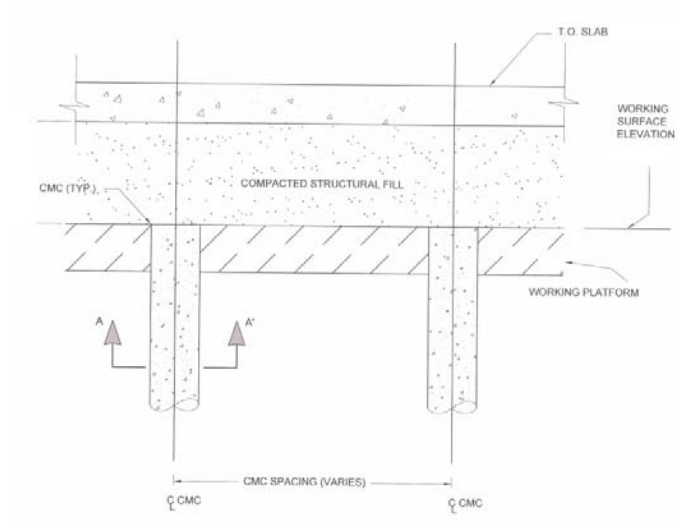

Figure 2: Typical Section of LTP at Slab

Under the individual spread foundations, CMC's were installed in groups of elements terminating 6 inches below the bottom of the foundations. The number of elements installed below each foundation was governed by the ability of the surrounding soils to share the load with the CMC elements while maintaining deformations within acceptable tolerances. Similar to the slab support, compacted Load Transfer Platform material is placed between the top of the CMC and the bottom of the foundations and no pile cap or structural connection to the foundation is required. However, since several of the foundations for the industrial building required uplift resistance, centralized bars with plate connections were placed in several of the elements to resist uplift forces.

The CMC technology was also well suited to handle the very soft organic soil deposits at the project site. Contrary to a stone column solution or RAP's which require a minimum lateral confinement to avoid bulging when loaded, the CMC's do not require confinement due to the use of a sanded grout composition and can effectively be installed in these very soft soils.

DESIGN OF CONTROLLED MODULUS COLUMNS

Summary of CMC Design

The CMC design evaluated the use of 12.5-inch-diameter CMC's installed through the fill, organics, and soft clay and terminating in the stiff clays at depth. As previously mentioned, the proposed slab load varied from 200 to 1200 pounds per square foot while the proposed foundation loads ranged from 22 kips to 328 kips.

To analyze the expected behavior of the system, the boring logs were reviewed and the soil profile with the worst conditions within the footprint of the proposed building was selected for modeling. Although compressible soils (organics and soft clay) were not encountered in all of the borings, they were encountered sporadically beneath the entire building footprint. However, the use of CMC's helped to stiffen the entire soil mass so that the behavior of the entire system behaves relatively uniform.

In order to estimate the behavior of the CMC elements subjected to the various slab loads, several finite element 2D axisymmetrical models were completed analyzing a unit cell surrounding a CMC. Because of the symmetry of the loading conditions, using an axisymmetrical approach to model a grid of discrete cylindrical elements such as the Controlled Modulus Columns, the design can be simplified from a complex 3D geometry to a more manageable 2D unit cell centered on a CMC with an area equivalent to the CMC pattern.

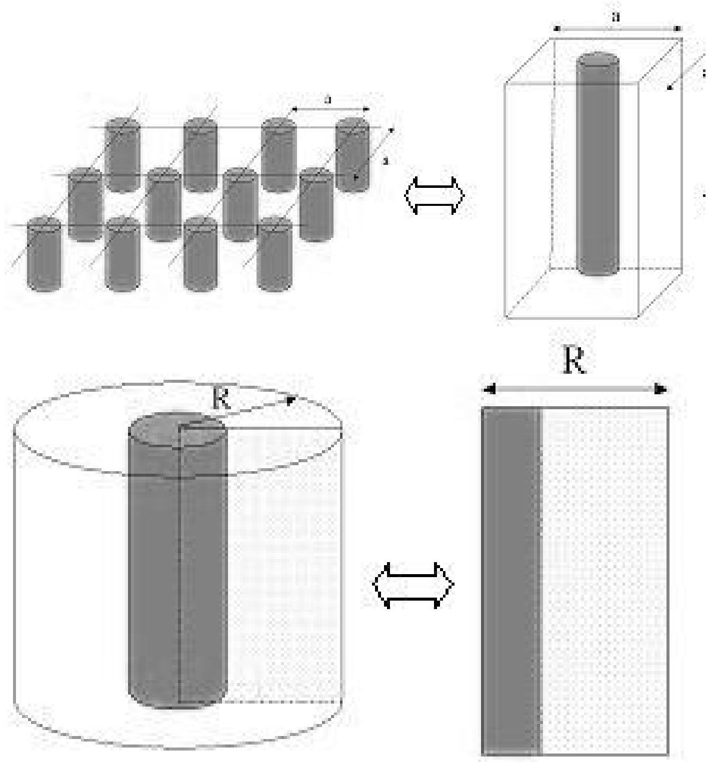

Figure 3: Simple Geometry Transformation

Results of each of the axisymmetrical models were evaluated to verify that adequate load transfer occurred between the soils and the CMC, proper long-term settlement control was achieved, CMC stresses were acceptable, and that CMC tip settlements were within typical values of 0.2 to 0.5 inches. Figure 4 provides one example of the deformed mesh produced by the finite element models.

For each axisymmetrical model, the CMC spacing was verified for the given load conditions on the slab. Not only was the total settlement of the system checked, but careful evaluation of the settlement output for each model was necessary to cross-check that the surface of the slab experienced relatively uniform settlement. Results of the models determined that CMC spacings of 6 to 10 feet were sufficient to support the proposed slab loads while maintaining project settlement requirements.

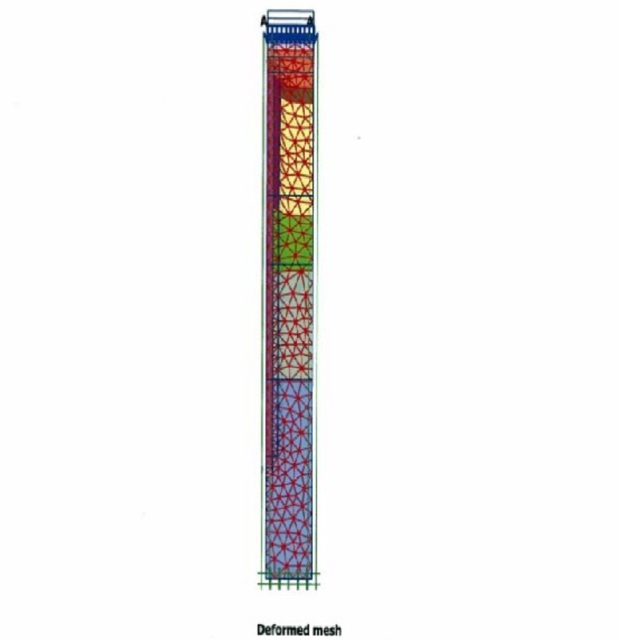

Figure 4: Deformed Mesh for Axisymmetrical Model

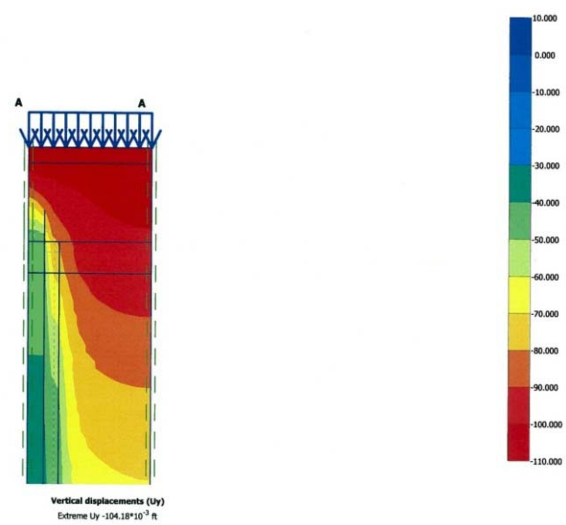

Figure 5: Displacement Shadings for Axisymmetrical Model

Within the finite element model outputs, it is also possible to analyze the 'arching' mechanism that takes place in the Load Transfer Platform that is critical to the design of the system. Figure 6 displays a zoomed- in view of the LTP for one of the axisymmetrical models. If the LTP were designed to be too thin, proper arching of the stresses would not occur within the LTP, and stress points associated with high bending moments would be introduced into the slab along with increased loads into the less resistant upper soils. Conversely, if the LTP is designed too thick, additional, unwarranted load would be added to the ground improvement system resulting in excessive settlements.

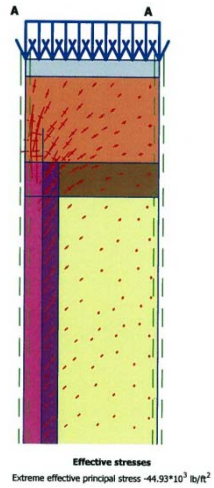

Figure 6: Effective Stresses in Load Transfer Platform

Following the completion of several axisymmetrical models, a three-dimensional finite element model was analyzed to evaluate the performance of one of the higher loaded foundations for the industrial building. The three-dimensional foundation model allowed careful evaluation of a smaller, more manageable 3D geometry to better assess the differential long-term settlement of the column bays. Although the modeling is more complex, time-consuming, and tedious than the conventional 2D analysis, it provides better representation of the actual performance of the inclusion-soil interaction that occurs over a smaller, non-symmetrical region of the industrial building.

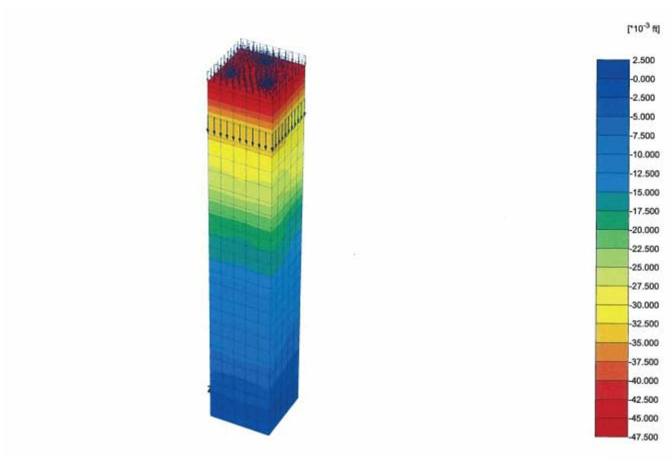

Figure 7: Settlement Profile for 3D Foundation Model

For modeling purposes, it was assumed that the embedment of the CMC's in the stiff clay was several feet (above the groundwater in the rock formation); however, the termination depth and criteria for the CMC's were ultimately based on the results of a single element load test as discussed below.

Each of the models predicted approximately 1 inch of long-term settlement. The project criteria limits the maximum long-term differential settlement, which is typically measured over a column bay or equivalent distance (30 feet), to 0.5 inch. The selection of the CMC spacing was directly based on the design analyses and the corresponding slab loads, such that the settlement resulting from the proposed CMC layout meets the project criteria of 1 inch long-term settlement and 0.5 inch long-term differential settlement.

The CMC's beneath the foundations were subjected to both compressive and tensile loads. To resist the tensile loads, a steel reinforcing bar was installed full-length as required in CMC's beneath the foundations subjected to uplift loads.

Results of the models indicated that maximum compressive loads in the CMC's beneath the slabs and foundations ranged from 65 to 80 kips which is typical for this type of application and loading condition. Furthermore, tensile loads were calculated to be on the order of 30 kips per CMC. Four load tests (two compressive and two tensile) were proposed to verify the design and performance of the CMC system.

<u>Summary of Installation Technique</u>

Each of the CMC's was installed for the industrial building using the previously mentioned specially-designed displacement augers. The grouting of the CMC was completed with enough back pressure to avoid collapse of the gap left by the auger during withdrawal (typically less than 100 psi is necessary). The auger was advanced by laterally displacing the surrounding soils, powered by equipment with large torque capacity and high static down thrust.

Figure 8: Installation of CMC's at Project Site

Figure 9: Installation of CMC's with Reinforcing Bar

Upon reaching the desired depth for each CMC, grout or mortar was pumped through the hollow stem of the auger and into the soil cavity as the auger was withdrawn. The rate of withdrawal of the auger during grouting was controlled by the operator by using on-board computers which plot the column's theoretical grout volume versus the actual grout volume placed along the depth of the CMC resulting in a consistent width column without the possibility of "necking" taking place.

The entire process produced minimal soil cuttings, which was ideal for working on this environmentally impacted site by eliminating the risk of handling and disposing of contaminated in-situ material. Combined with the ability to terminate the elements above the rock formation, the CMC installation provided a superior solution to the client.

Figure 10: Minimal Soil Cuttings from Installation Process

Load Testing of Controlled Modulus Columns

Load deflection tests were performed to evaluate the load carrying capacity of the CMC's in compression and tension as predicted in the design. Two load deflection tests were performed on unreinforced 12.5-inch-diameter elements in compression in general accordance with ASTM D-1143/D1143M-07 using the Quick Load Test procedure. For the tensile CMC's, two load deflection tests were performed on 12.5-inch-diameter elements reinforced with a full-length steel reinforcing bar. These tensile tests were performed in general accordance with ASTM D-3689 using the Quick Load Test procedure.

The load deflection tests were performed in two locations on site representing the worst-case boring and the worst-case existing fill locations. Each of the CMC test elements installed were approximately 20 feet long and terminated in the stiff clay bearing stratum.

In order to verify the ground improvement design, the load tests were analyzed to check that the full design load reached the tip as predicted in the finite element modeling. The actual tip deflection of the CMC was then compared with the predicted tip deflection from the finite element modeling as a cross check that proper embedment in the bearing stratum was achieved and CMC performance was optimized. For this particular project, tip deflections during the compressive load tests were well below the design predictions, which were on the order of 0.2 to 0.4 inches (See Figure 11).

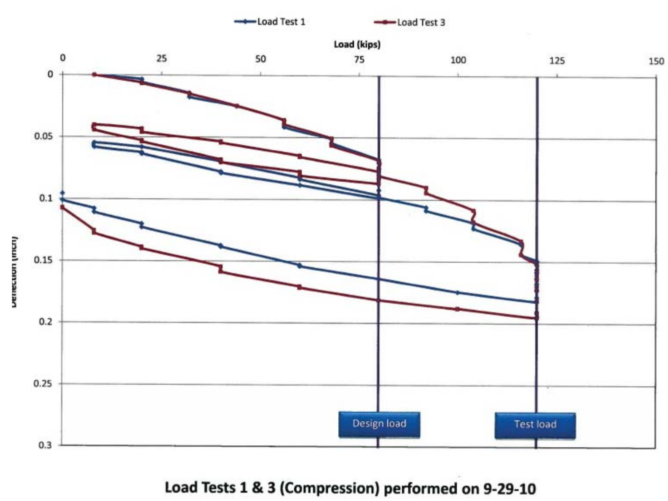

Figure 11: Compressive Load Tests for Industrial Building Settlement vs. Applied Load

Similarly, the tensile tests were evaluated to verify that test load deflections were kept within current codes and standards as given by the project specifications, which allowed for less than 0.5 inches of tensile CMC deflection. Results of both tensile tests (See Figure 12) showed deflections well below the requirements for the project, with less than 0.2 inches of total deflection at the design load.

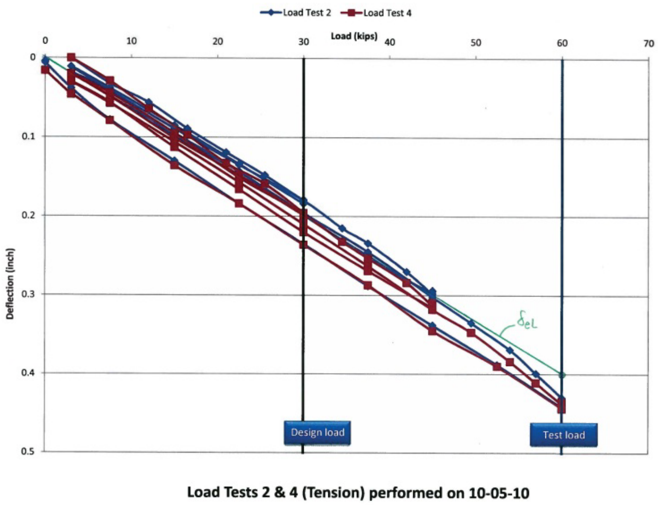

Figure 12: Tensile Load Tests for Industrial Building Settlement vs. Applied Load

Successful completion of all four of the tests confirmed that the CMC's would perform in accordance with the design in both compression and tension. Furthermore, since the same installation techniques used for the test elements were used during the installation of each CMC, the behavior of the resulting production CMC's were consistent with the design.

<u>Quality Control of CMC Installation</u>

Quality control of each of the CMC's was verified using the following methods: laboratory compressive strength tests of grout, vertical load tests on isolated columns, and by monitoring the following installation parameters:

- Speed of rotation and advancement/withdrawal rate of the auger
- Torque, down-thrust (crowd) during the drilling phase
- Depth of element
- Pressure and volume of grout

For each of the installed CMC's, a computer log (See Figure 13) was produced which displayed a print-out of the above parameters in both a time and depth display method. These computer logs were reviewed daily as a cross check that the critical parameters used in the design of the CMC's were met and/or exceeded for the CMC's installed on the project.

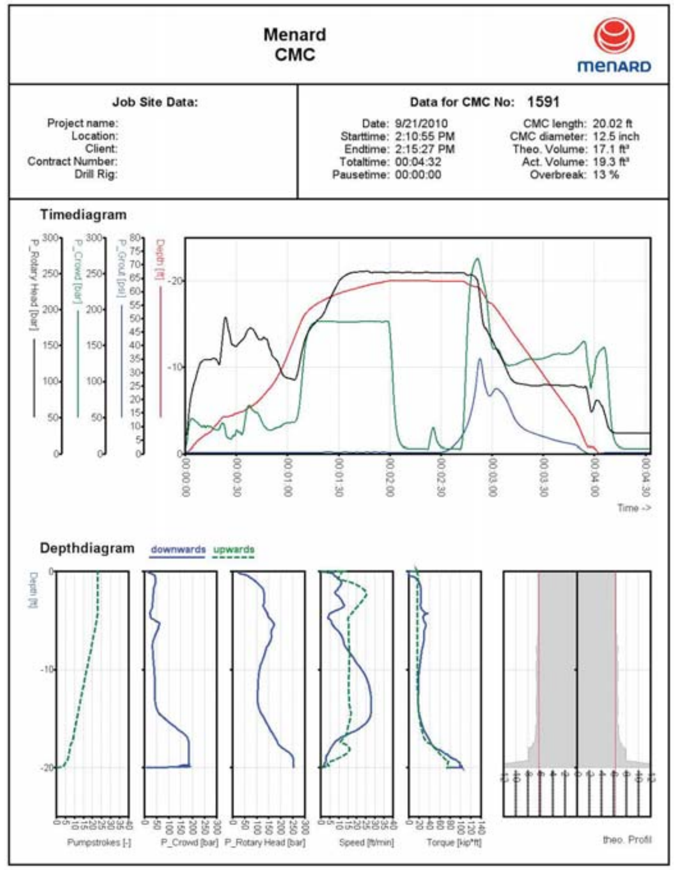

Figure 13: Computer Log from Industrial Building

CONCLUSIONS

This paper presents a practical and sustainable solution to a project with challenging soil and groundwater conditions coupled with environmental impacts at a former industrial landfill site. This Brownfield site was successfully transformed into a useful and productive facility which manufactures tower elements for wind turbine power generation, a green technology. Further, the use of ground improvement with controlled modulus columns (CMC's) provided support to the industrial building and its floor slab, providing two significant sustainable outcomes:

- No soil cuttings were generated from the installation of the CMC's and thus these materials, which would require special handling and disposal at a regulated landfill, was not required. This resulted in significant cost savings to the owner and from an environmental perspective, saved precious landfill space.
- The vertical extent of the tips of the CMC elements was limited to the upper clays and did not penetrate into the underlying water-bearing rock formation. This was a priority of the project to protect the underlying water-bearing rock formation from being compromised environmentally.

In addition to the geotechnical benefits provided to the owner and community for redeveloping a Brownfield site, Soil and Materials Engineers, Inc. developed exposure mitigation strategies that allowed safe use of the contaminated site and assisted the owner to obtain over $5,000,000 in Brownfield financing, which made project economically feasible.

REFERENCES

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