RIGID INCLUSION SUPPORT OF ROADWAYS

By Sonia Sorabella Swift, P.E. and Martin G. Taube, P.E., P.G.

AS OUR CITIES GROW and the needs of our societies change, we often look toward optimizing our infrastructure. Reducing daily traffic on heavily-travelled roadways is a common focus for many state Departments of Transportation. Very often, that involves reconstructing roadways wider than the original footprint, widening the roadway into adjacent areas, and building walls to divert or improve traffic flow. However, those areas may not always provide a suitable foundation, especially when tall walls are planned. Some form of a column supported embankment system is commonly used to support such construction. The type of columns and their design can vary widely – from traditional pile foundations with pile caps at the individual column locations to rigid inclusions (RIs) with a load transfer platform over the entire supported area to stone columns. Menard's patented variation of a rigid inclusion is the Controlled Modulus Column (CMC)™. In this article, we will focus on CMCs and their support of roadway projects. We will describe CMCs, explain how they are used, and review two recent projects where CMCs were used to support transportation projects.

Description of Controlled Modulus Columns (CMCs)™

CMCs are small-diameter grouted columns that are installed through soft or variable soils to reduce settlement and increase bearing capacity. CMCs are 12.5-, 15.6-, or 17.75-inch-diameter columns installed with a displacement auger. CMCs are typically unreinforced, though structural steel can be added, as necessary to resist high compressive, tensile, or flexural forces. When supporting embankments, wall fills, or other mass structures, CMCs are not generally connected to the structure nor do they require a pile cap. CMCs are generally separated by the superstructure by a load transfer platform (LTP), which can range from 6 inches to 3 or more feet thick. The load transfer platform is generally a dense-graded aggregate that is placed and compacted in an engineered manner. The purpose of the LTP is to distribute the loads from the point of application to the CMCs while reducing stress concentrations and eliminating the need for pile caps.

CMCs, as do piles, support the applied loads thereby reducing the load on soft compressible soils that would require large movements to mobilize their resistance – doing so reduces settlement. However, unlike piles, CMCs share the load with the surrounding soils. The load from the structure is shared between the CMC and the surrounding soil. See Fig. 1 for a schematic of how the CMC ground improvement system supports the applied loads.

In the remainder of this article, we will focus on two roadway projects where CMC ground improvement was used to reduce settlement and improve bearing capacity. In both cases, the ground improvement was supporting mechanically stabilized earth (MSE) walls designed by The Reinforced Earth Company (RECo) and any retained or associated backfill.

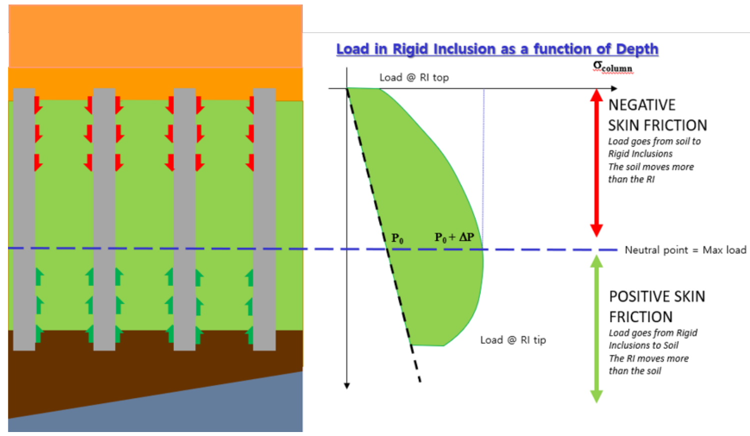

Fig 1. Interaction of the soil and CMC – depiction of load transfer

Case Study 1: South Capitol Street Corridor Project

CMCs were used to support roadway fills and mechanically stabilized earth (MSE) walls for the South Capitol Street Corridor project in Washington, D.C. This nearly $1 billion project will include the replacement of the Frederick Douglass Memorial Bridge, including two approach ovals east and west of the Anacostia River, the replacement of an interchange, and the construction of several traffic ramps.

Ground improvement was required over a portion of the project footprint, as shown in the hatched areas of Fig. 2. Within the ground improvement area, the construction includes MSE walls up to 35 feet high and embankment fills up to 28 feet for which CMCs were used to mitigate settlement and enhance stability. The soil profile consisted of general fill, soft alluvial clay, dense sand and gravel, and stiff clay (Potomac Formation). The estimated settlement in the soft alluvial clay was larger than the project requirements due to the presence of the soft alluvial clay. Both 12.5-inch-diameter and 17.75-inch diameter CMCs were used at spacings ranging from 5 feet to 10 feet. More than 3,600 CMCs were installed from 7 different benches across the site to accommodate existing grades and follow-on work. CMCs were installed approximately 30 to 40 feet deep into the dense sand and gravel layer for support of the embankments and MSE walls. For the more heavily loaded CMCs that supported the structural elements that will be described in the following section, the CMCs were terminated in the Potomac Formation.

The proposed construction runs over multiple old, in-service utilities that could not tolerate any stress or settlement due to the construction (according to the project specifications). As such, solutions that spanned the utilities were required. A concrete slab of varying thickness was used to span a fragile 108-inch-diameter sewer pipeline and 48-inch-square-precast-concrete box beams were used to span twin utilities that were buried just a few feet below working grades on site. CMCs with a single steel reinforcing center bar (requested by the utility owner) were used to support these structures. The center to center spacing of the CMCs perpendicular to the pipe run was 26.5 ft for the concrete slab and 62 feet for the precast--concrete box beams. The axial forces on the CMCs supporting these structures were over 250 kips. The CMCs were not structurally connected to the slab or box beams. Multiple single-element load tests were successfully performed to confirm the load-carrying capacity of the CMCs. The load test supporting the concrete box beams held 580 kips at a deflection less than 0.4 inch.

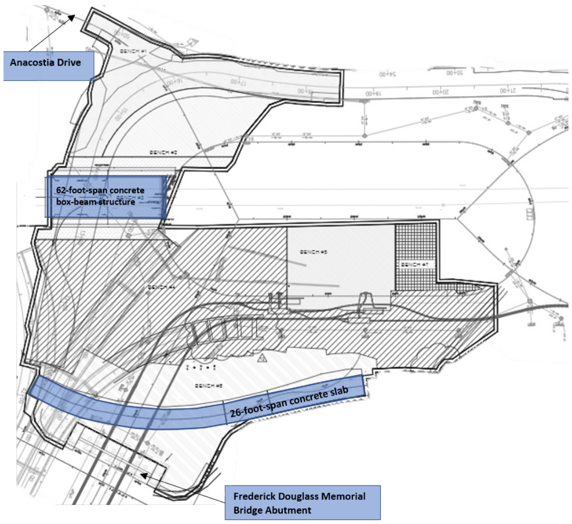

Fig. 2 – Overview of CMC-supported area at S. Capitol Bridge project including the structural components

We used finite element PLAXIS models, both axisymmetric and plane strain to design the CMCs throughout the project. Because of the varying conditions, we ran many different analyses at different locations to evaluate settlement of the system, load in the CMCs, and interaction between adjacent areas. Special attention was focused on the transitions from the structural elements to the surrounding embankments to avoid hard points or abrupt changes in settlement.

Case Study 2: I-35 at Deep Fork Creek

CMCs were used to support new MSE walls and embankment fills constructed as part of the widening of the existing Interstate 35 as it crosses over Deep Fork Creek in Oklahoma City, Oklahoma. The support was a combination of embankment support and the support of an MSE wall with a backslope. A total of just over 1,000 CMCs were installed for the two phases of this project, supporting separate walls on the northbound and southbound sides of I-35. The fill heights range from 10 to 23 feet and the soil conditions consisted of sandy lean clay, over 40 feet of soft clay, silty sand, and sandstone. Given the height of the proposed construction and the thickness of the clay, estimated settlement was larger than the acceptable 1 inch post-construction settlement. In addition to settlement concerns, the proposed fill presented a concern for overall global stability of the widened embankment.

As was discussed for the previous case study, we used PLAXIS models to estimate the settlement of the ground improvement system. We performed separate models at the locations of the highest general embankment fill and at the location of the highest fill within the MSE area. Based on our modelling, the CMCs were 15.6 inches in diameter and were spaced between 6 and 7 feet on center. The unreinforced CMCs were installed through the existing soils and were terminated on the sandstone at depths between 60 and 75 feet. The CMCs effectively spanned the soft soils and transferred the applied load to the sandstone. The maximum load in the CMCs from our models was 125 kips, which results in a fairly low stress in the CMC element. Because of the soft soils present, the design was primarily controlled by the settlement criteria, not the load in the CMCs. The key to the design was modifying the spacing and diameter of the elements to minimize the amount of load entering the soft soil and causing settlement.

Common Threads in CMC Designs

For typical roadway projects, the CMC design checks the interaction between the wall, the CMC elements, and the surrounding soil or structures. CMC design assumes the MSE wall, typically designed by a specialty MSE wall designer or geotechnical consultant, is stable against internal modes of failure. However, we still check global stability of the embankments using SLIDE, which performs a limit equilibrium analysis, and performed hand calculations to check both sliding and bearing capacity.

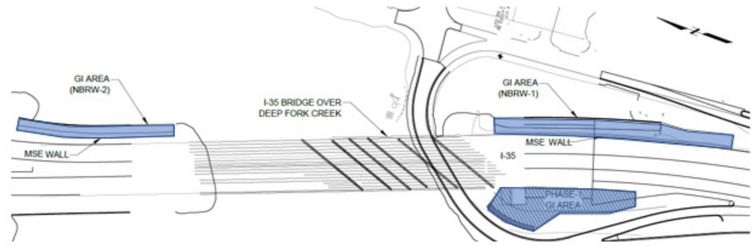

Fig. 3 –CMC-supported areas – Northbound and Southbound

During CMC installation, static load tests were performed at both projects described above, as they are for most CMC projects. The load tests are performed in general accordance with the Quick Test procedure in ASTM D-1143. The CMCs are loaded to a minimum of 150 percent of the design load or more if required for the project. The CMCs are often instrumented with strain gauges to observe the load at various depths within the element. Depending on the size of the project, the number of different sizes of CMCs used, and the variation in the bearing layer, more than one static load test may be performed.

Conclusion

As ground improvement becomes more widely accepted within the industry, it is being used by more and more of the state Departments of Transportation for projects that need settlement control. CMCs, specifically, can be installed for large depths and can be installed in a variety of sizes and spacings to optimize the design to the soil conditions and site geometry. CMCs can often replace deep foundations, especially on projects where settlement is the main concern. CMCs can be reinforced to resist flexural forces due to lateral movements, which are often present at the edges of roadway embankments and MSE walls. Because of the general lack of steel reinforcement within the elements and the elimination of pile caps on top of the CMCs, construction tends to be quicker and less expensive than traditional deep foundations. Although there are times when deep foundations are the most appropriate solution, RIs should be taken into consideration for support of transportation projects over soft soils.

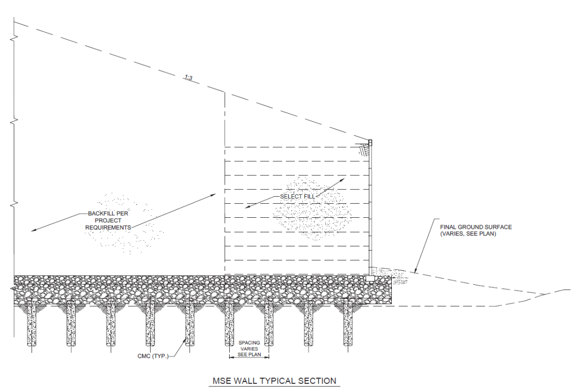

Fig. 4 – Typical Supported Cross section at I-35 at Deep Fork Creek