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WHITE PAPER

CMC RIGID INCLUSIONS (CMC)® RIGID INCLUSIONS VS. STONE COLUMNS/ AGGREGATE PIERS

CONTROLLED MODULUS COLUMNS (CMC)® RIGID INCLUSIONS VS. STONE COLUMNS/ AGGREGATE PIERS

INTRODUCTION Engineers that are unfamiliar with the numerous types of ground improvement techniques often fail to make the appropriate distinctions between Controlled Modulus Column (CMC)® rigid inclusions and Stone Columns (SCs)/Aggregate Piers (APs), particularly at the design stage. It is necessary to be aware of the various design parameters and site-specific construction considerations when recommending the appropriate technique for a given project site.

BACKGROUND SCs and APs are inclusions of stone, often installed using a predetermined area replacement ratio that is based on an empirically determined soil improvement factor. SCs were initially developed to expand the potential uses of the vibroflotation equipment beyond the limits of pure Vibro Compaction (VC). VC is a common means of ground improvement to treat clean, granular soils but is generally ineffective in silty or clayey sands with higher fines content. With the introduction of a granular media, such as sand or stone, the engineering properties of the in situ soil could be enhanced. The added granular material reinforces in situ soils and allows the soil mass to be analyzed as an improved soil with enhanced equivalent stiffness, yielding increased bearing capacity and reduced settlement properties. As the SC technique developed, design models (Elastic, Priebe, Balaam & Boker) using concepts such as area replacement ratios, stiffness ratios and sand/aggregate friction angles allowed engineers to calculate predicted settlements for specific loads.

SCs and APs are ideal solutions for soils that can be categorized as being too compressible for economical shallow foundations but not weak enough to warrant a deep pile foundation. In practice, a stiffness ratio typically between 5 to 10 (ratio of the modulus of the column over the modulus of the surrounding soils [Mc/Ms]) is used in design to determine an equivalent composite modulus for the improved layer. A settlement improvement factor (i.e., the ratio between the settlement of the improved and unimproved soil) of 3 is typically the highest value that can be achieved. This limits the effectiveness of SCs for highly compressible soils. Therefore, in very soft soils the expected stiffness of the SC/AP-reinforced soils may be less than what is needed to meet the project settlement requirements.

Furthermore, where there are very soft soil conditions, SCs and APs themselves may not be internally stable, leading to bulging or shearing failures under vertical loading due to a lack of horizontal confinement. Historically, despite the limitations of SCs and APs in very soft soils, the use of SCs and APs has grown tremendously across the United States in areas and for structures where intermediate foundation solutions can be used to the benefit of a project.

Development of CMC Rigid Inclusions

The initial development of CMC rigid inclusions has been directly related to the limitations of SCs and APs in very soft or organic soils. CMC rigid inclusions are installed using a displacement tool and are made of concrete or mortar that sets up to form an internally stable element to reinforce poor soils, without a risk of bulging in layers with low lateral confinement. The concrete or mortar has a modulus of deformation several orders of magnitude higher than the surrounding soils. As a result, CMC rigid inclusions remain highly effective in very soft soils and in certain situations can reduce settlement 10 to 20 times more effectively than SCs and APs. CMCs are typically designed using finite element models and are predicated on the ability of the load from the structure to arch through a Load Transfer Platform (LTP) into the CMC rigid inclusion, effectively bypassing the soft soils and carrying the load to a more competent layer at depth.

Differences in Design Approach between SCs/APs and CMC Rigid Inclusions

Most design methods for SCs and APs assume the following hypotheses based on the fact that the stiffness of the soil and the columns are in the same relative range:

1. Equal settlement planes/strain compatibility between columns and soil
2. Lateral expansion of the columns
3. Load transfer is a function of the area replacement ratio

On the other hand, because the stiffness of the CMC rigid inclusions and the

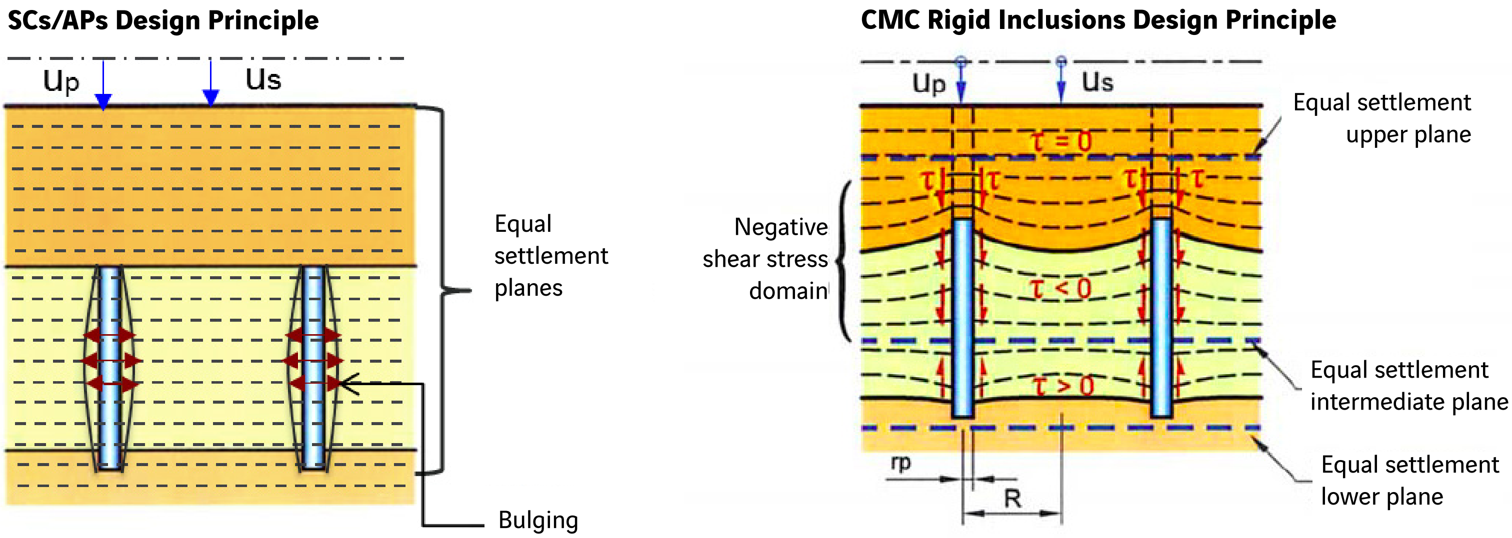

***Fig 1**: Differences in behavior of SCs/APs and CMC rigid inclusions*

surrounding soils is several orders of magnitude different, the strain compatibility hypothesis cannot be used for CMC rigid inclusions. The load transfer between soil and columns is a more complex phenomenon created by differential strain between soil and columns along the side of the columns. There is only one plane of equal settlement between soil and columns (neutral plane) located along the shaft of the columns at depth, but everywhere else the soil and columns do not deform equally and shear stresses are created at the interface. Because of this complicated soil-structure interaction, finite element analysis is often used to accurately model the interactions at play. Applying the methods used for SCs and APs (i.e., strain compatibility hypothesis) to a CMC rigid inclusion solution would lead to erroneous results that may not be conservative.

Another fundamental difference between the behavior of SCs/APs and CMC rigid inclusions is the way the load fom the structure is transmitted to the elements. In the case of SCs/APs, because of the strain compatibility hypothesis, the load is directly transmitted and distributed between the soil and the columns. Therefore, only a very thin LTP (if any) is necessary to equalize the stresses below a slab, for example. For CMC rigid inclusions, the LTP is a key element of the design, as it allows the creation of an arch that will transmit the load from the structure to the CMC rigid inclusions while limiting the load that is directly transmitted to the poor soils.

Ground Improvement Applications and Soil Type

SCs are typically installed in soils that range in classification from loose sands with fines to soft clays and silts. SCs are also the preferred soil improvement technique in soils that have high liquefaction potential, when the fines content is too high for pure VC to be effective. The benefit of using SCs for liquefaction mitigation is threefold: first, the shear strength of the columns helps to reinforce the soil mass. Second, the stone column installation densifies the liquefiable layers between the columns. And third, the void space in the SCs' granular material allows for quick dissipation of excess pore water pressures.

Conversely, the soil conditions where SCs are least suitable are very soft clays and silts with low shear strengths, typically less than 300 to 500 psf. In these conditions, the soil is not stiff enough to provide adequate confinement for the column, and the SC itself is then at risk of bulging when

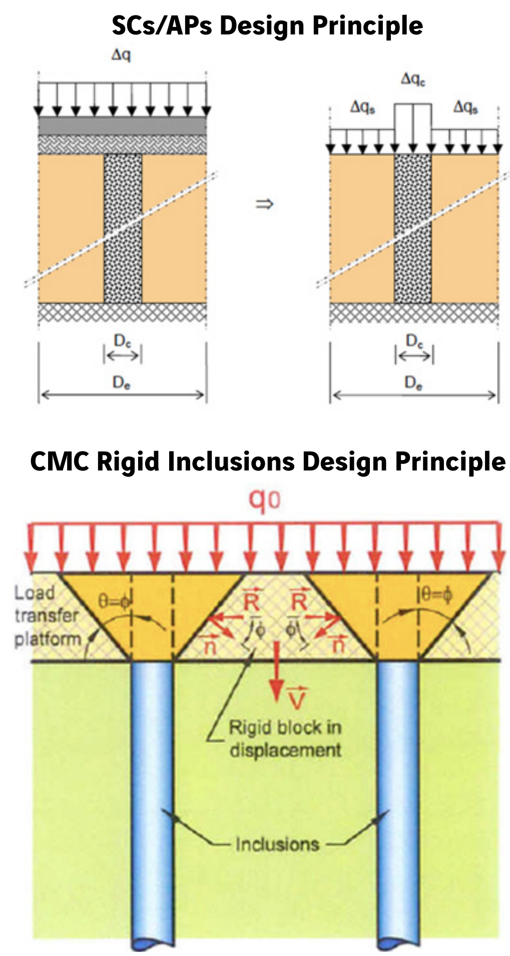

***Fig 2**: Differences in load transfer mechanism in the LTP*

Fig 3 *Installation of SCs (dry bottom feed method) and of CMC rigid Inclusions (displacement auger)*

a vertical load is applied, potentially creating large deformations.
CMC rigid inclusions can be used in virtually all soil types, including gravel, sand, clay, silt, peat, and various fills. CMC rigid inclusions are most commonly used to reinforce very soft cohesive soils, where the use of aggregate-based columns is not appropriate. In granular soils, CMC rigid inclusions are often used as a solution on projects where improvement is needed adjacent to settlement- and vibration-sensitive structures, where non-vibratory techniques are necessary. In highly seismic areas, CMC rigid inclusions may need structural reinforcement and/or a hybrid approach with stone columns/earthquake drains to effectively mitigate seismic risk.

Construction Considerations
For SCs, where stiff or dense soils are encountered or when high area replacement ratios are required, predrilling may be required to achieve the design stone column diameter and depth.

CMC rigid inclusions may also need to be predrilled in very stiff or obstructed layers. However, the drill rigs that install CMC rigid inclusions (high torque and high thrust/pull down force) can penetrate much stiffer/denser ground than can be penetrated with vibratory flots.

CMC rigid inclusions are often installed on grids ranging from 4 to 10 feet on center, but should not be installed on spacings less than 3.5 times the diameter. Similarly, it is extremely rare to see SCs/APs installed with replacement ratios higher than 25 to 30%.

Obstructions such as buried foundations, slabs and naturally occurring cobbles/boulders will not be able to be penetrated with either SCs or CMC rigid inclusions, and predrilling or relocation of either type of ground improvement system may be necessary.

Uplift resistance may be provided with either technique, though it is highly simplified and more economical to use the CMC rigid inclusion, as steel reinforcement can simply be set in the fresh grout upon installation of the column.

Both SCs and CMC rigid inclusions can be installed to depths of over 100 feet, but because of significantly faster installation rates for very deep applications, CMC rigid inclusions are typically more economical. CMC rigid inclusions also allow for greater bearing pressures and a tighter settlement performance in many cases.

CONCLUSION Both SC/APs and CMC rigid inclusions offer economical intermediate foundation solutions. Selection of one technique over the other is often based either on economic considerations or on the presence of very soft or organic layers within the profile requiring improvement. The load applied by the structure to the compressible soils is also a consideration, as the settlement reduction factor with SCs/APs is typically limited to 2 to 3. To achieve higher performance with SCs/APs would require replacement ratios that are typically not constructible.

Other considerations that play a role in the selection of the proper ground improvement technique are depth of the improvement, nature of the improvement required (e.g. settlement reduction, enhanced bearing capacity, slope failure prevention, liquefaction mitigation) and schedule and equipment availability.

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GOING FORWARD: Do you have a project that you think would be a good candidate for a SC/APs or CMC Rigid Inclusions?

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