

# Design of Controlled Modulus Columns without Load Transfer Platform

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## ABSTRACT

Ground improvement by means of Controlled Modulus Columns (CMCs) usually involves the construction of a Load Transfer Platform (LTP) over the CMCs, especially for construction of low embankments over soft soil, to carry the overburden load and transfer to the CMCs, thereby not loading the surrounding soft soils, and avoiding excessive total and differential settlement. This paper provides a case study of a design undertaken for CMCs without an LTP, taking advantage of a relatively high embankment (4.5 m). Compacted fill and gravel working platform layers have been considered to be sufficient to dissipate any differential settlement at the surface of the embankment, without a need for an LTP. Available settlement monitoring data has confirmed the settlement to be within tolerable limits. Advantages of this method include time and cost savings, as well as environmental benefits.

*Keywords:* ground improvement, controlled modulus columns, finite element analysis

## 1 INTRODUCTION

With the increase in population especially in large cities, there is a corresponding increase in the need for additional buildings and infrastructure. Existing structures are likely to have been developed where the ground conditions are readily suitable, i.e. exhibiting high bearing capacity and low compressibility. Such areas are near depletion especially in large cities, and new structures are required to be constructed in remaining unsuitable ground conditions where typically additional construction measures are required to meet the functionality requirements of the structures. Some of these measures include ground improvement and piling, and a range of these construction measures are available, determined by considering several factors such as the cost, available time for construction, functionality requirements, availability of materials, and the applicability in the ground condition.

Controlled Modulus Columns (CMCs) are a ground improvement method that involves installation of rigid concrete columns in a grid pattern using a rotary displacement auger. They are typically used in areas where large embankments, such as bridge abutments, are constructed over soft soils that are too deep for some other ground improvement methods, and when some degree of settlement can be tolerated.

The intent of the CMCs is to transfer the majority of the vertical load of the embankment to the stiffer ground on which the CMCs are embedded in and minimise the vertical load on the overlying soft soil, thereby reducing settlement. They are different to piled embankments, where the piles are expected to support all of the vertical load. (Larisch et al, 2014)

To facilitate the load transfer to the CMCs, a load-transfer platform (LTP), generally comprised of a granular mattress and geogrids, is usually constructed over the CMCs. However, LTPs may be omitted where it is considered that the majority of the embankment load could be transferred to the CMCs via soil arching, which effectively serves the purpose of an LTP. A relatively thick embankment would be required for this to occur. The removal of the LTP reduces costs, construction time and environmental impact. (Wong and Muttuvel, 2012). It should be noted that this may be possible in certain situations and the discussions in this paper should not be interpreted as removal of LTP in *all* design cases.

The theory of soil arching is discussed in BS 8006:2010, based on Marston's formula and the Hewlett and Randolph method (1988). Partial arching and full arching are achieved when the height of the embankment is greater than  $0.7 \times$  clear spacing and  $1.4 \times$  clear spacing, respectively.

The spacing of the CMCs require careful consideration. Closer spacings would reduce settlement while increasing cost, and therefore the selection of the most effective spacing is an important part of CMC design. Wong and Muttuvel (2012) have shown in their numerical parametric analyses that the predicted embankment settlement increases rapidly beyond a spacing to column diameter ratio of about 4.

Due to the soils being laterally displaced during the installation, close spacings can affect the adjacent CMCs by either, depending on their condition, inducing cracking if the concrete has been set (Larisch et al, 2014), or induce heaving or necking if the concrete is still wet. The latter is referred to as wet-construction in this paper.

This paper discusses a design that was undertaken for CMCs without an LTP, using the wet-construction method, and some observations during construction and settlement monitoring.

## 2 GEOTECHNICAL GROUND MODEL

The design was undertaken for an area underlain by a 6.5 m thick soft estuarine layer, overlying residual soils and weathered material comprising stiff to hard clayey material. The proposed final embankment height was 4.5 m, comprising 1.5 m granular working platform to facilitate construction activities on the soft soil and 3.0 m engineered fill. The developed ground model is summarised in Table 1 and shown in Figure 2a. The adopted settlement parameters are summarised in Table 2. The groundwater level was adopted as 0.3 m below top of soft clay layer.

Table 1: Ground model

Thickness (m)	Material	Unit Weight (kN/m <sup>3</sup> )	Young's Modulus (MPa)	Undrained Shear Strength (kPa)	Drained Cohesion (kPa)	Drained Friction Angle (°)
3.0	Engineered fill	20	40	-	5	30
1.5	Working platform	20	60	-	1	45
6.5	Soft Clay	16	Refer Table 2	15	1	23
1.0	Stiff Clay	18	20	50	3	27
4.0	Very Stiff Clay	19	30	100	4	28
> 5.0	Hard Clay	20	40	200	5	30

Table 2: Summary of settlement parameters

Compression Ratio CR = $C_c/(1+e)$	Compression / Recompression Ratio $C_c/C_r$	Secondary Compression Index $C_\alpha/C_c$	Coefficient of Consolidation $C_v$ (m <sup>2</sup> /year)	Over-Consolidation Ratio
0.375	7.5	2.5%	10.0	Varies

## 3 ANALYSIS

The design was undertaken for a range of CMC centre to centre spacings between 4.0 × diameters and 5.5 × diameters in a square pattern, for an embedment depth into the Very Stiff Clay layer ranging between 0.5 m and 2.0 m.

The analysis was undertaken by a finite element software package, PLAXIS 2D (Version 22), using the axisymmetry model. Finite element modelling was adopted over conventional approaches, as some conventional approaches may underpredict the efficacy of columns and foundation soil (Yapage, et al. 2013).

The width of the axisymmetry model was determined based on the equivalent tributary area of a single CMC based on the spacing and square grid layout pattern. The CMC was modelled with the Linear Elastic model, with a diameter of 0.36 m and Young's Modulus of 12 GPa. The Soft Soil Creep model has been used to model the soft clay layer, and Mohr-Coulomb model was used for remaining materials.

The following analysis staging was adopted in PLAXIS, based on the proposed construction sequence:

- Initial Phase (K0 Procedure) Not applicable
- Construct Working Platform 14 days
- Hold Construction 14 days
- Install CMC 14 days
- Hold Construction 14 days
- Construct Fill Embankment 14 days
- Finalise Construction 30 days
- Design Life (Post-construction) 50 years

The assessed post-construction settlement results are summarised in Table 3 and Figure 1.

Table 3: Summary of assessed post-construction settlement results

Spacing		Embedment (m)			
Diameter	m	0.5	1.0	1.5	2.0
4.0 D	1.44	39	40	25	22
4.5 D	1.62	145	140	70	64
5.0 D	1.80	179	177	75	75
5.5 D	1.98	237	230	218	214

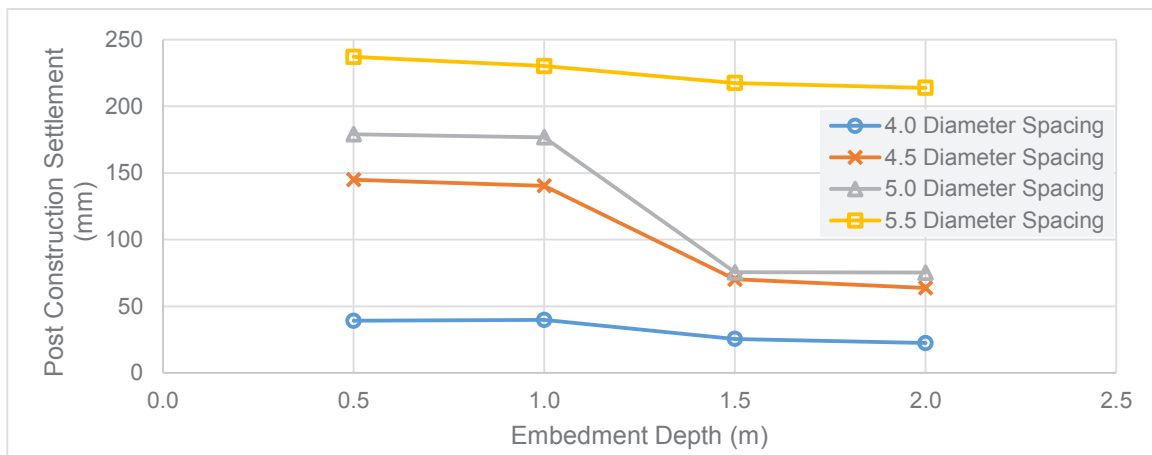


Figure 1: Assessed post-construction settlement results

Figure 1 shows that the settlement is significantly lower for the spacing of 4.0 diameter, which is comparable to analyses by Wong and Muttuvel (2012). Based on BS 8006, only the spacing of 4.0 diameter achieves full soil arching, whereas other spacings only achieve partial soil arching, which agrees with the assessed values.

The adopted CMC spacing and embedment depth were determined based on the post-construction settlement criteria. For areas with 200 mm allowable settlement, CMC spacing of 5.0 × diameter and 1.0 m embedment depth were selected. For areas with 100 mm allowable settlement, the same spacing with 1.5 m embedment depth was selected. For areas with 50 mm allowable settlement, CMC spacing of 4.0 × diameter was selected. CMC spacing of 4.0 × diameter was also selected for areas where differential settlement criteria of 50 mm governed, for example, along pipe alignment or areas adjacent to piled structures.

Figure 2 shows a) the ground model, showing the CMC has been constructed from the top of the working platform and embedded into Very Stiff Clay; b) the principal stress directions showing soil arching within the embankment fill and working platform layers; and c) displacement contours, from the case analysed for 5 × diameter spacing and 1.5 m embedment (with selected values labelled on the contours for clarity). The displacement contours show the relative movement of the CMC to the soil. In the upper portion of the soft soil, or above the ‘neutral plane’, the soil moves more than the CMC, applying negative skin friction to the CMC. In the lower portion of the soft soil, or below the ‘neutral plane’, the soil moves less than the CMC. (Muttuvel and Wong, 2012)

The principal stress plots showing soil arching and sensitivity assessments with and without LTP were used to justify an LTP was not required. The latter are not part of the scope of this paper.

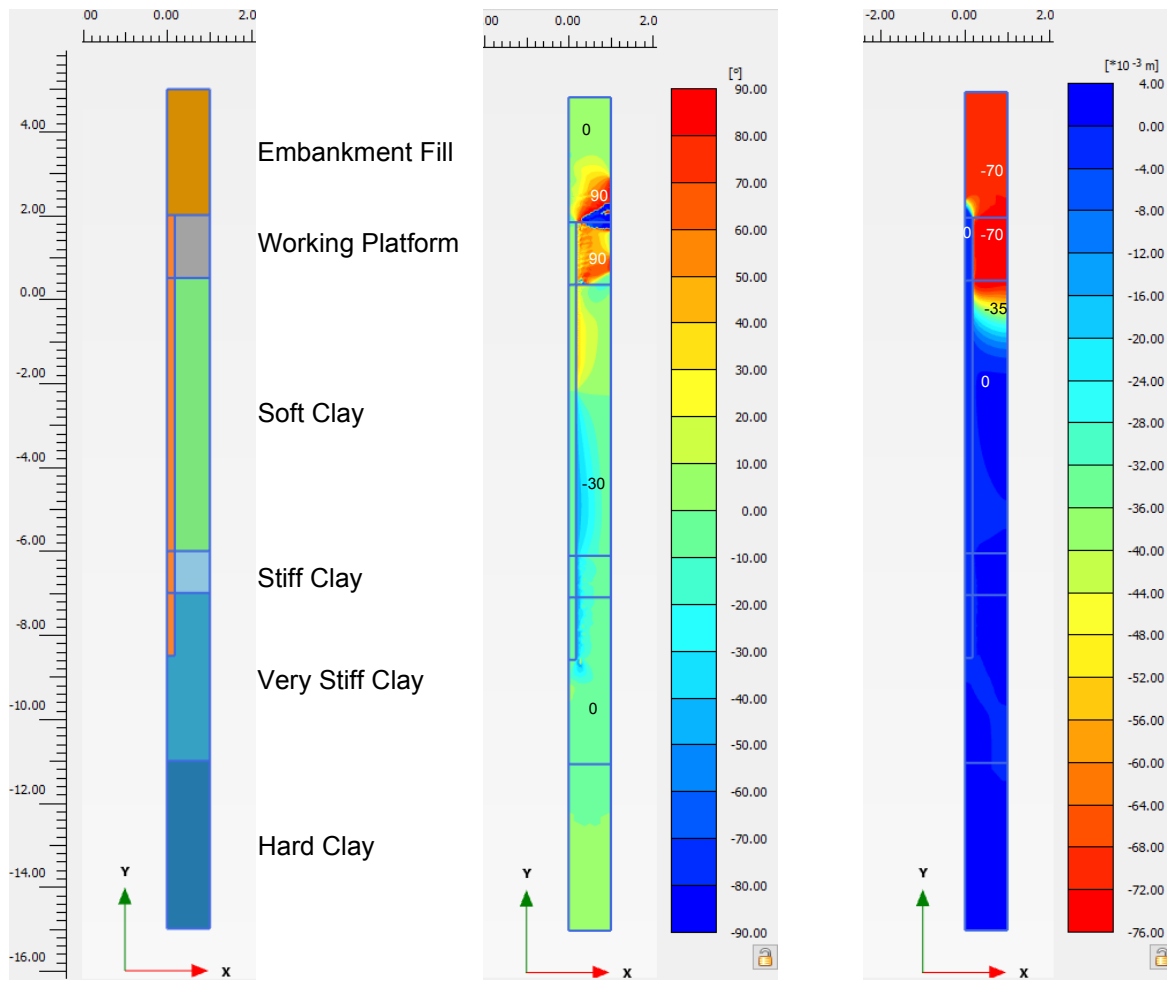


Figure 2: PLAXIS Outputs: a) Model; b) Principal stress directions; c) Displacement Contours

#### 4 CONSTRUCTION

Prior to the installation of CMCs, a trial construction was undertaken to confirm applicability of the wet-construction method, using a group of 5 CMCs in two different areas. As anticipated, when a CMC was being installed adjacent to a freshly installed CMC, heaving was observed in the latter, creating a shallow puddle of wet concrete. However, based on the approximate volume of the displaced concrete, it was assessed that the reduction in diameter was relatively minor when the CMC spacing was no less than  $4 \times$  diameters. Figure 3 shows a CMC being installed on the left, with heaving of wet concrete observed in a previously installed CMC to its right.

When the purpose of the CMCs and surrounding structures were considered, it was decided that the presence of cracks would be more detrimental to the CMCs compared to having a slightly reduced diameter. The wet-construction method also reduced the construction time, as it was not necessary to wait until the concrete had fully set before an adjacent CMC was installed.

In other cases, it might be considered that the risk of having reduced diameter or necking are more critical the risks of having cracked CMCs. Careful consideration should be made before deciding which construction method should be adopted. There are benefits and risks associated with both methods. An increased spacing reduces the likelihood of forming cracks or having reduce diameter.



Figure 3: *Heaving of wet concrete during installation of an adjacent CMC*

## 5 SETTLEMENT MONITORING

Based on the assessment results, the anticipated amount of construction settlement was approximately 230 mm depending on the adopted CMC spacing and embedment, with 150 mm of settlement occurring prior to CMC installation, and 80 mm post CMC installation.

Settlement was monitored via settlement plates that were installed once the CMCs were installed. The settlement during working platform placement and CMC installation could not be monitored. The monitored data from settlement plate installation to two months after embankment construction showed that the actual settlements were less than 50 mm.

There are a few reasons that may have led to this difference between assessed and monitored values:

- Due to difficulties during construction, the settlement plates could not be installed before the working platform was constructed. Depending on the permeability, more settlement may have undergone than assessed. Sensitivity assessment showed that the assessed settlement during and post construction are highly sensitive to the adopted permeability values.
- The assessed construction sequence was longer than the actual construction staging.
- The CMCs were installed to target depths based on either the torque readings or the interpreted base level of the soft soil layer.
  - i. If the torque measurement was not sensitive, the CMC may have been installed deeper than required.
  - ii. This depth was measured from not the tip of the auger, but approximately 0.5 m above the tip, and therefore the actual embedment depth may be deeper than the proposed by 0.5 m.

## 6 CONCLUSION

This paper discussed the design of CMC without the use of an LTP, and observations made during the installation of CMCs while the adjacent CMC was still wet. Relatively thick layers of working platform and embankment, 1.5 m and 3.0 m, respectively, were proposed, and assessments were carried out to confirm soil arching was achieved to transfer the majority of the embankment loads to CMCs without an LTP, for a CMC spacing of up to  $5.0 \times$  diameter. A range of CMC spacings and embedment depths were assessed using PLAXIS 2D axisymmetry model to determine the most cost-effective configuration, based on the imposed settlement criteria.

Trial CMC installation was carried out to ensure the wet-construction method was not detrimental to the performance of the CMCs. Minor heaving was observed, and the assessed remaining diameter was considered to be adequate. The monitored settlement was less than the estimated settlement, which may be attributed a few factors during both design and construction.

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