OLYMPUS PROJECT

SILVERTOWN, LONDON

Ground improvement by Bi-Modulus Column (BMC®)

DESIGN REPORT

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Client MCLAREN

Revision	Date	Prepared by	Checked by	Detail of modifications
A	13/08/2024	JJ	BT	First issue (preliminary and confidential)
P01	16/12/2024	JJ	FB	Revision including ancillary buildings and retaining walls design
C01	01/04/2025	JJ	CS	Revision following comments from Cundall
C02	02/05/2025	JJ	CS	Revised Canopy and Retaining walls designs
C03	02/06/2025	JJ	CS	Updated Testing Regime + obstruction methodology + Guardhouse SSL and thickness corrected + comments from Cundall

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1. INTRODUCTION

It is proposed to construct a giant data centre in Silvertown, London. The proposed construction footprint runs over Made Ground, Superficial Alluvium above River Terrace deposits.

Due to the presence of compressible soil layers, a direct construction of any type of structure without soil improvement or replacement will lead to unacceptable post construction settlements and deformations.

The concerned structures are the **external areas (service yard, hardstands, and paths) of the new development (excluding the central substation area) treated with BMC and some ancillary buildings (dust canopy, guardhouse, waste and water tanks) treated with CMC, and with an additional route north side for an additional fibre route treated also with BMC, covering a total area of around 35,600 m**^{2}. These external areas are highlighted in purple and orange, in figure 1 below.

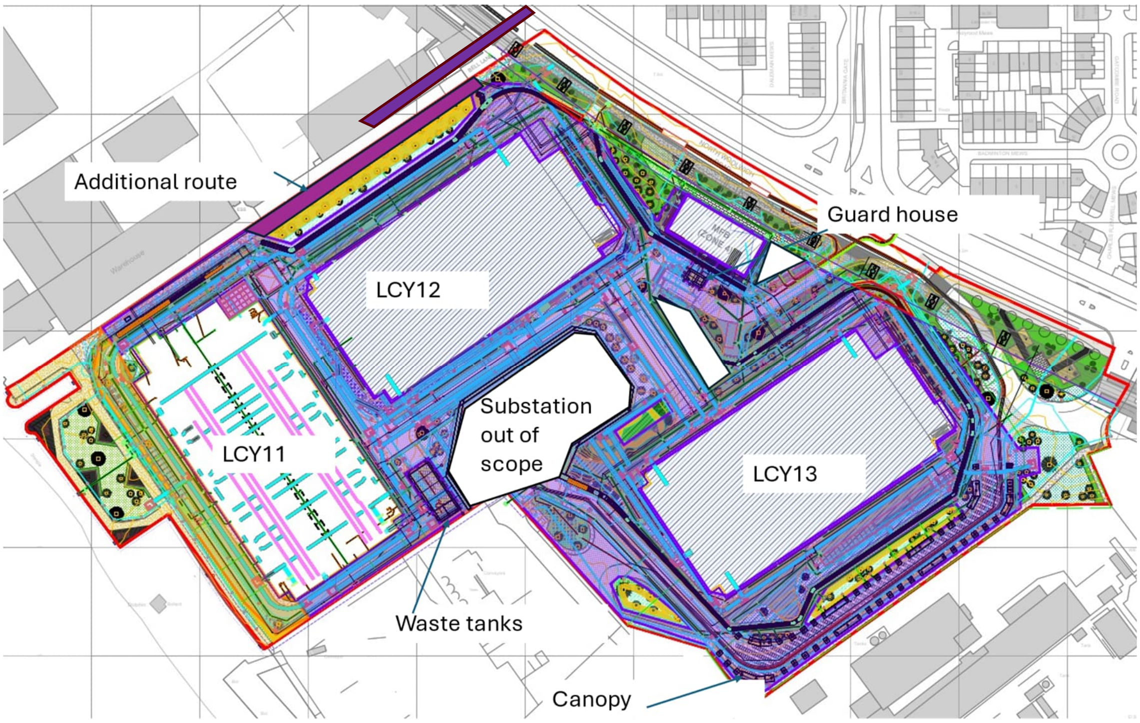


Figure 1 - Site layout with CMC treatment area in orange and purple

The present document consists in a **preliminary design repor**t for ground improvement with **the Bi-Modulus Column (BMC) and the Controlled Modulus Columns (CMC)** techniques. The aim of the BMC solution is to control the settlements and provide a higher bearing capacity by creating a composite material [BMC+soil] and [CMC+soil].

2. REFERENCES DOCUMENTS

This report has been established from the following documents:

[1] Menard DESIGN Proposal referenced BT/V29949/DESIGN, dated 07/06/2024
[2] Ground Investigation Report, DUNELM, report reference: H30219 revision: 02, issued on: 05/04/2024
[3] Phase 2 – Geotechnical and Geoenvironmental Assessment, Cundall, report reference LCY01-CDL-XX-XX-RP-GE-20004, revision: P01, issued on: 24/05/2024
[4] CPT report by Lankelma, report no 01 P-108474_02, rev 01_02, dated 31/01/2024
[5] Cundall Specification for Ground treatment, report no LCY10-CDL-XX-XX-SP-GE-50002, revision: P01 , issued on: 07/08/2024
[6] Bi-Modulus column treatment area overview by Burrows Graham, drawing number: LCY10-BGL-XX-XX-DR-C-20120, rev C07 received 23/04/2025, inclusive of Drainage services and strip footing dust canopy foundation
[7] Earthworks platform Cut/Fill sheets 1-4, by Burrows Graham, drawing number: LCY10-BGL-XX-XX-DR-C-20101 to 20104, rev C01 dated 18/10/24
[8] Earthworks platform levels sheets 1-4, by Burrows Graham, drawing number: LCY10-BGL-XX-XX-DR-C-20105 to 20108, rev C01 dated 18/10/24
[9] External levels sheets 1 to 4,by Burrows Graham, drawing number: LCY10-BGL-XX-XX-DR-C-20201, rev C01 dated 25/10/24
[10] External services Below Ground services sheets 1-4, drawing number: LCY10-PPA-XX-XX-DR-N-99000 to 99003, rev C01 dated 01/11/24
[11] Civil services external works kerbs & surfacing layout, drawing number: LCY10-CDL-XX-XX-DR-C-40101, rev P02 dated 06/09/24
[12] Pile Mat design by Structemp, drawing number OLP-STT-ZZ-ZZ-DR-MCL15-15001, rev P05, dated 08/11/2024
[13] Dust canopy foundation plan, by Burrows Graham, drawing number LCY10-BGL-DC-BF-DR-S-30201, rev C02, dated 30/04/2025
[14] Dust canopy foundations – Bearing Pressure Contours, by Burrows Graham, drawing number 40117-BGL-SK-S-00035, rev -
[15] Retaining Wall sheets 1-10, by Burrows Graham, drawing number LCY10-BGL-XX-XX-DR-C-40921, rev C01, dated 05/11/2024
[16] Confirmation acceptance of 50 mm residual settlements criteria from McLaren, received by email on 19/11/2024
[17] Guardhouse general arrangement, Burrows Graham, drawing number: LCY10-BGL-GH-ZZ-DR-S-30201, rev C01, dated 30/04/2025
[18] Waste and Water tank building sheet 1, by Burrows Graham, drawings number: LCY10-BGL-WS-00-DR-S-30201, rev C01, dated 21/11/2024
[19] Waste and Water tank building sections, by Burrows Graham, drawing number LCY10-BGL-WS-ZZ-DR-S-30401, rev C01, dated 21/11/2024
[20] Civils services proposed improvements river wall plan & sections sheets 1-4, CUNDALL, drawings number: LCY10-CDL-XX-XX-DR-C-50504 to 50507, revision P01, dated: 07/08/2024

[21] Commented preliminary design report, CUNDALL, issue: LCY10-VBM-XX-XX-DR-X- LCY10-VBM-XX-XX-RP-X-00001_1_DOC-COM001_AT01_LCy10-VBM-XX-XX-RP-X-00001_Ver1_CDL_Status C, dated 02/09/2024
[22] Obstruction recorded LCY11, Gallagher, drawing LCY10-GLG-XX-XX-DR-X-00007, revision P05, dated 25/10/2024
[23] Email from McLaren load bearing pressure complementary information dated 9/12/2024
[24] Comments on design report rev C01 by Burrows Graham, COM002, confirmation on bearing pressure to provide under the retaining walls and the dust canopy strip foundation, dated 04/04/2025

3. TECHNICAL

3.1. Bi-Modulus Column

3.1.1. Description of the ground improvement technique

The Bi-Modulus Column (BMC) process is a ground improvement technique associating on its lower part a rigid inclusion element in the form of Controlled Modulus Column (CMC), topped up on its upper part with a granular flexible inclusion in the form of Vibro Stone Column (VSC).

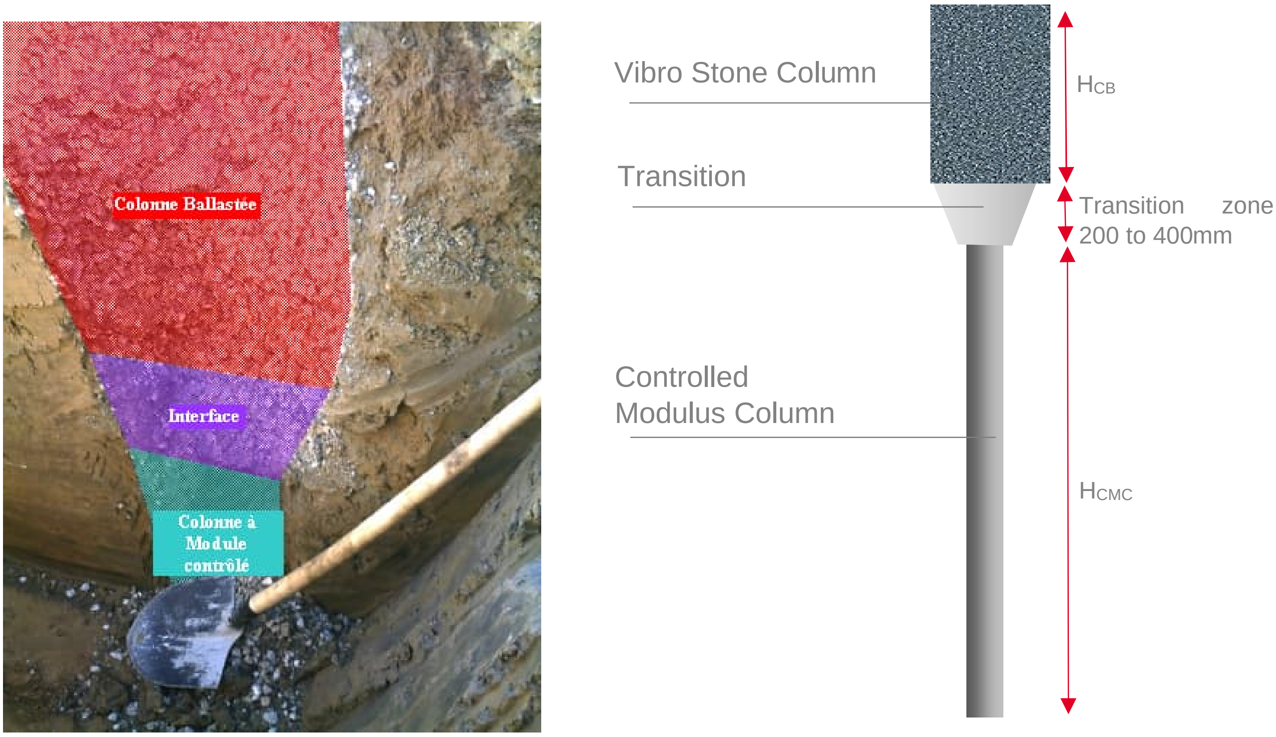


Figure 2 – Description of the Bi-Modulus Column (BMC) system

The Bi-Modulus Columns (BMC) ground improvement technique is intended to improve the soil globally and to reduce its deformability by the use of mixed inclusions (rigid and flexible). It does not aim to bypass the compressive ground or to build piles that will directly support the entire load from the structure. The objective is to reduce global and differential settlement by relieving the soil from a part of the loads imposed by the structure.

These columns distribute the loads uniformly throughout the soil mass that thus behaves as a composite [concrete column + surrounding soil material]. The entire process is vibration free and operates in-the-dry without spoils, which allows for cleaner project sites.

Bi-Modulus Columns can be considered as a particular type of Semi Rigid Inclusions that can be carried out with a various number of execution method (rotation, vibration, percussion…).

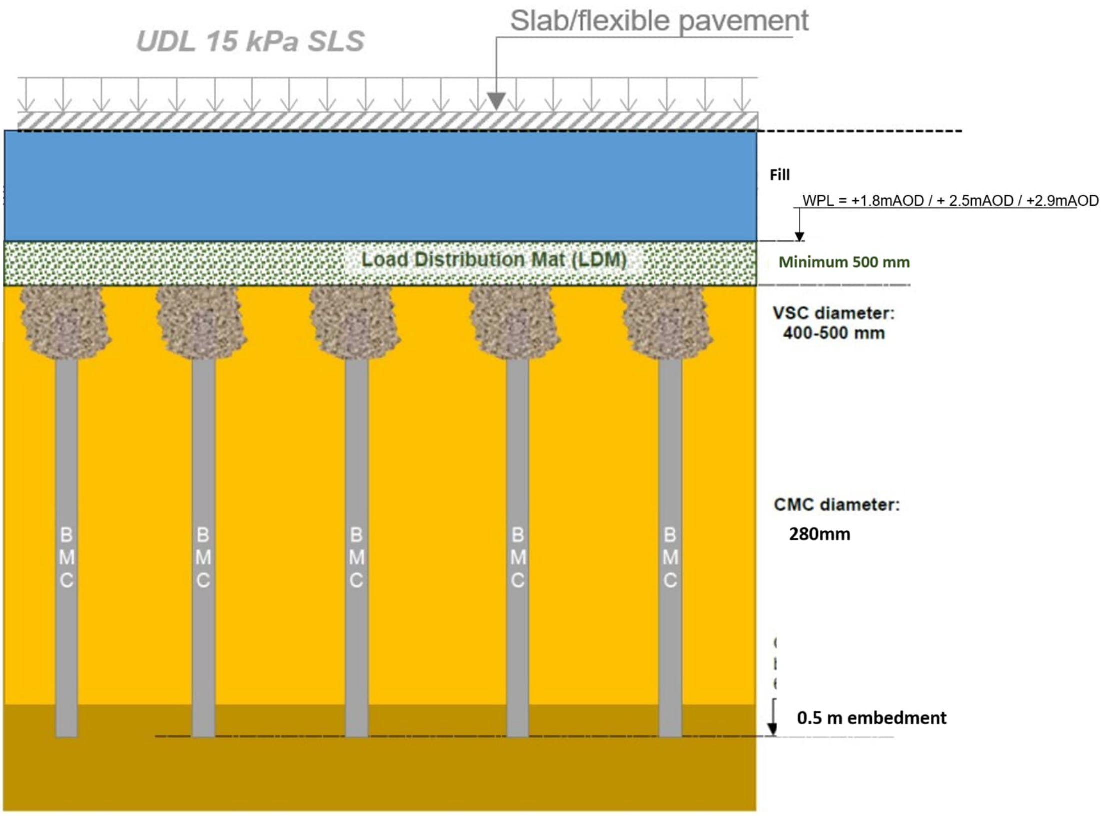


Figure 3 - typical cross section with BMC

3.1.2. Method of execution

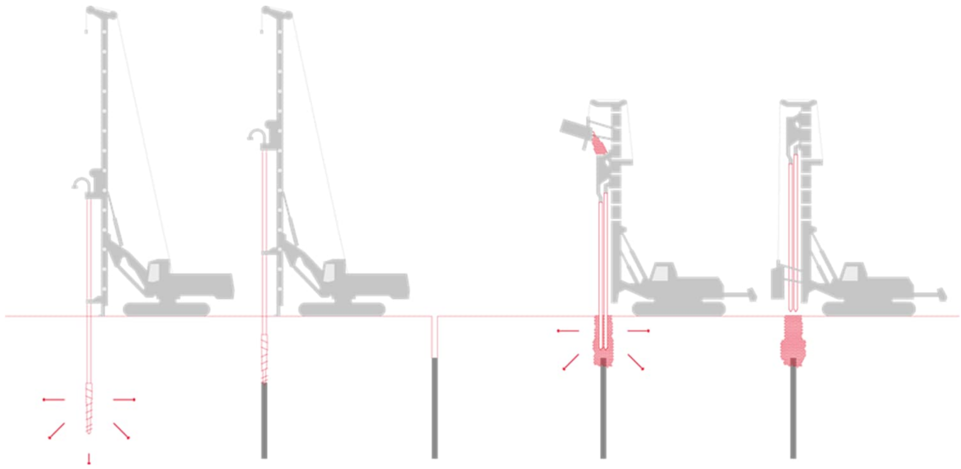


Figure 4 - BMC installation process

The lower part of the BMCs is installed using the CMC process. A specially designed auger, powered by equipment with large torque capacity and high static down thrust, displaces the soil laterally, with virtually no spoil or vibration. The displacement auger is pushed into the ground to the required depth resulting in an increment of the skin friction between the column and the surrounding soil.

During the auger extraction process, a column is developed by grouting under controlled limited pressure (less than 5 bars) through the stem of the displacement auger to achieve a predetermined stiffness ratio with the surrounding soil. The result is a composite soil/concrete ground reinforcement system. Current practice is to install columns with diameter varying between 280 and 450 mm.

The upper part of the BMCs is installed using the bottom feed VSC system. Within a few hours after the installation of the CMC element, when the concrete is still fresh, the Vibro Stone Column (VSC) head is built using a special rig fitted with a Vibroflot system.

Under combined effect of sustained vibrations, its own weight and the pull-down force, the 'Vibroflot' bottom feed penetrates the soil down to the prescribed depth. During penetration, the soil is displaced laterally without any spoil extraction.

As the 'Vibroflot' bottom feed is lifted, the ballast material falls down by gravity in the void that is created. The aggregates are inserted and compacted by extraction and re-penetration of the vibrating probe through repeated incremental lifts of 30 to 50 cm, each cycle being repeated till the probe reaches the surface.

Figure 5 - BMC Setup on site

3.2. Controlled Modulus Column

3.2.1. Description of the ground improvement technique

The Controlled Modulus Columns ground improvement technique is intended to improve the soil globally and to reduce its deformability by the use of rigid concrete inclusions. It does not aim to bypass the compressive ground or to build piles that will directly support the entire load from the structure. The objective is to reduce global and differential settlement by relieving the soil from a part of the loads imposed by the structure.

These columns distribute the loads uniformly throughout the soil mass that thus behaves as a composite [concrete column + surrounding soil material]. The entire process is vibration free and operates in-the-dry without spoils, which allows for cleaner project sites.

Controlled Modulus Columns can be considered as a particular type of Rigid Inclusions that can be carried out with a various number of execution method (rotation, vibration, percussion…).

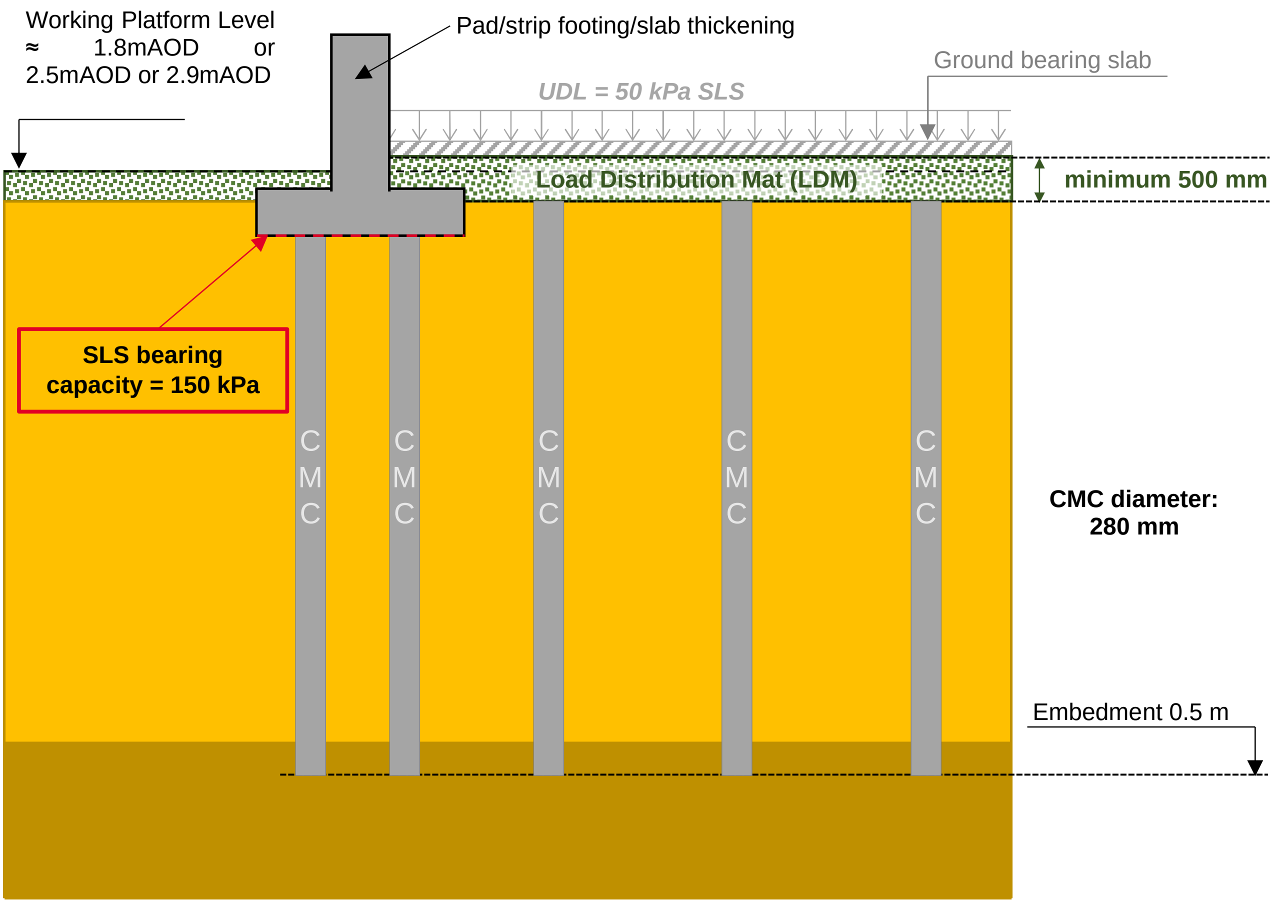


Figure 6 - Typical cross section of footing and ground bearing slab on CMC

3.2.2. Method of execution

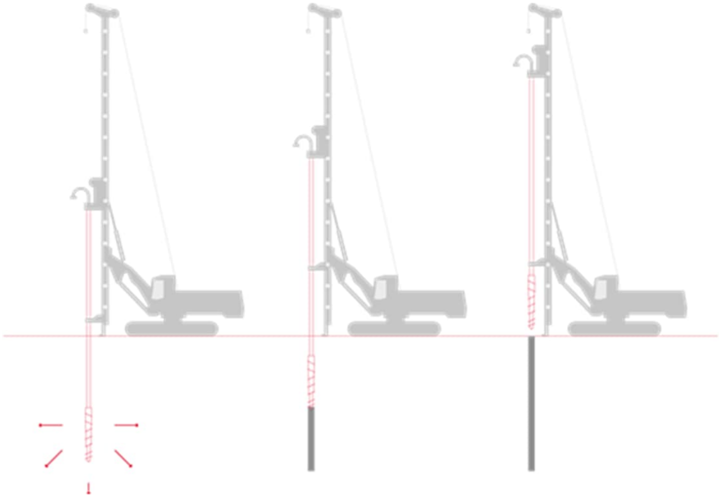


Figure 7 - CMC installation process

A specially designed auger, powered by equipment with large torque capacity and high static down thrust, displaces the soil laterally, with virtually no spoil or vibration. The displacement auger is pushed into the ground to the required depth resulting in a local increment of the density of the surrounding soils around the auger. In the case that one or several layers to drill are too compact, a regular CFA auger can be used.

During the auger extraction process, a column is developed by concreting under controlled limited pressure (less than 5 bars) through the stem of the displacement auger to achieve a predetermined stiffness ratio with the surrounding soil. The result is a composite soil/concrete ground improvement system. Current practice is to install columns with diameter varying between 280 and 450 mm.

Figure 8 - CMC setup on site

3.3. Adaptation to the project

3.3.1. Ground improvement principle

The foreseen ground reinforcement system consists in installing vertical mixed inclusions (BMC) in order to create a composite [soil + BMC] material. Beneath the slab/pavement, it is required to place a compacted Load Distribution Mattress between the underside of the slab/pavement and the head of the BMC in order to homogenize the behaviour of the reinforced soil.

3.3.2. Characteristics of the CMC portion of the BMC

The characteristics of the CMC part of the BMC for this project will be:

CMC diameter [m]	Concrete			
	Young's Modulus E_Y [MPa]	Characteristic compressive strength f_{ck28} [MPa]	Chemical Class	Slump
0.28	8,500	12	DC-4	S4

Table 1 - CMC characteristics

The design compressive strength of the concrete is given by:

$$f_{cd} = \min\left(\alpha_{cc} k_3 \frac{f^*_{ck}}{\gamma_C}; \alpha_{cc} \frac{f_{ck}}{\gamma_C}; \alpha_{cc} \frac{C_{max}}{\gamma_C}\right)$$

Where:

- α_{cc} = 0.8 for unreinforced concrete
- γ_C = 1.5 (partial factor for the concrete)
- k_3 = 1.2 in Domain 1 (CMC required for bearing capacity) and 1.5 in Domain 2 (CMC for settlement control only)
- f^*_{ck}: characteristic compressive strength of the CMC concrete determined from the following formula:

$$f^*_{ck} = inf\{C_{max}; f_{ck}\} \frac{1}{k_1 k_2}$$

- f_{ck}: characteristic compressive strength of the concrete at 28 days (measured on cylinders)
- C_{max} = 35 for CMC with soil displacement

We have:

$$k_1 = 1.3 \text{ and } k_2 = 1.3 - d/2 = 1.16$$

Hence:

$$f^*_{ck} = \inf(f_{ck}; C_{max}) \frac{1}{k_1 k_2} = 8.0\ MPa$$

In SLS conditions, the average stress in the CMC is limited to:

$$f_{cd,av,SLS} = 0.3 k_3 f^*_{ck} = \begin{cases} 2.9\ MPa \text{ in Domain 1} \\ 3.6\ MPa \text{ in Domain 2} \end{cases}$$

In ULS conditions, the average stress in the CMC is limited to:

$$f_{cd,av,ULS} = \min(f_{cd}, 7\ MPa) = \begin{cases} 5.1\ MPa \text{ in Domain 1} \\ 6.4\ MPa \text{ in Domain 2} \end{cases}$$

3.3.3. Characteristics of the VSC portion of the BMC

The characteristics of the VSC part of the BMC for this project will be:

Anticipated VSC diameter* [m]	Young's Modulus E_Y [MPa]	Unit Weight γ [kN/m^3]	Friction Angle φ [°]
0.40	50	20	38

Table 2 - VSC characteristics

*The diameter of the VSC depends on the properties of the surrounding soil and as such, over the length of the entire VSC, variable diameters could be created due to variable layers with different soil conditions

Allowable stress in the VSC q_a is calculated according to the formula as follow:

$$q_{a,SLS} = q_{re}/2$$

$$q_{a,ULS} = q_{re}/1.5$$

Factors or safety of 2 at SLS and 1.5 at USL are considered. With q_{re} ultimate lateral stress:

$$q_{re} = tan^2\left[\pi/4 + \varphi_c^{'}/2\right] \times \sigma_r$$

With $\varphi_c^{'} = 38°$, $tan^2\left[\pi/4 + \varphi_c^{'}/2\right] = 4$.

Therefore, allowable stress q_a is :

$$q_{a,SLS} = 2 \times \sigma_r$$

$$q_{a,ULS} = 2.66 \times \sigma_r$$

with σ_r : lateral stress taken equal to the limit pressure pl*.

Note : this is equivalent of applying a coefficient of 1.33 to the allowable SLS stress to get the allowable ULS stress:

$$q_{a,ELU} = 1.33\, q_{a,ELS}$$

In the layer receiving the VSC heads, the allowable stress in the VSC is therefore:

Soil layer	pl* [kPa]	$q_{a,SLS}$ [kPa]	$q_{a,ULS}$ [kPa]
Engineered fill	**1,250**	**2,500**	**3,325**
Layer 1 – Made ground	**800**	**1,600**	**2,128**
Layer 2 - Alluvium	**200**	**400**	**532**

Table 3 - Maximum allowable stress in the VSC head

4. GROUND CONDITIONS

Our design is based on the ground conditions described in the above site investigation reports [2],[3] and [4]. The ground conditions are homogeneous over the site.

The typical soil profile is the following:

- Made Ground (sandy mixture)
- Soft Clay (Alluvium) with pockets of peat
- Medium dense to dense gravels (River Deposits)

The calculations were carried out for the conservative soil profile detailed in the table below. All the values of the design parameters have been derived from correlations based on CPT.

		Top	Bottom	γ	q_c	E_m	α	p_l	E_Y	ν
		(mAOD)	(mAOD)	(kN/m^3)	(MPa)	(MPa)	(-)	(MPa)	(MPa)	(-)
1	Made Ground (sandy mixture)	2	0.5	18	5	8.75	1/3	0.8	26.3	0.3
2	Soft Clay (Alluvium)	0.5	-2.9	18	0.4	2	1	0.2	2	0.3
3	Medium dense gravels (River Deposits)	-2.9	-4	20	6	10.5	1/3	1.0	31.5	0.3
4	Dense gravels (River Deposits)	-4	-6.2	20	12	21	1/3	2.1	63	0.3
	CMC part	-2.5	-4.5	22	-	-	-	-	8,500	0.2
	VSC part	Var	-2.5	18	-	-	-	-	50	0.3
	WP	2.9/2.5/1.8	2.4/2.0/1.3	20	-	12.5	1/4	1.7	50	0.3
	Fill	Var	2.9/2.5/1.8	20	-	-	-	-	40	0.3

Table 4 - Soil profile and geotechnical parameters

Notes:

- Fill material added on top of the working platform can enact as the Load Distribution Mattress as long as it is a well graded compacted granular material meeting our minimum compaction specifications.
- CMC will be embedded 0.5 m into dense gravels layer
- The symbols used in the table above are: γ = bulk unit weight, q_c = CPT cone resistance, E_m = Pressuremeter Modulus, α = rheological coefficient, E_Y = Young's modulus, p_l = pressure limit, ν = Poisson's ratio.
- Ground water level was considered at -0.725mAOD, as an in between value from the groundwater monitoring records (between -3.3 and +1.85 mAOD) . Groundwater level fluctuations have negligible influence on the final design.
- Pockets of peats have been accounted in the design by degrading the modulus of the Alluvium layer

5. CALCULATIONS METHODOLOGY FOR BMC

5.1. Principle of the finite element model

The finite element calculation presented in this document is an axial-symmetrical calculation carried out thanks to Plaxis v24.2. The radius R of the model is defined to represent a grid mesh L x L:

$$\pi \times R^2 = L \times L$$

The hereafter picture illustrates the principle of an axial-symmetrical calculation:

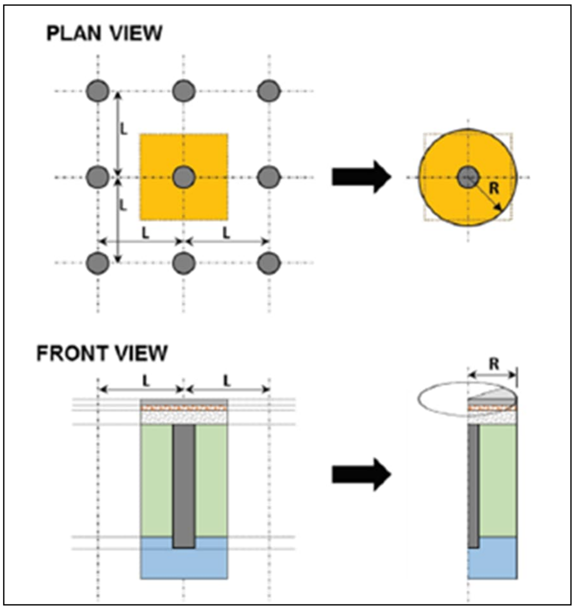


Figure 9 – Principle of axial-symmetrical calculation

5.2. Initial Earthwork platform Cut/Fill

Initial Cut/Fill earthwork are undertaken to reach "proposed formation level" (FRM) at either +2mAOD or +1.3mAOD, see [7].

As fill reaches up to 0.7m on certain area, it was conservatively assumed that 0.7m fill was added on, for all our Plaxis modelling with a fill scenario.

Similarly, for every cut scenario, it was conservatively assumed that no material was cut and therefore EGL=FRM. (case for the proposed formation level at 1.3mAOD)

5.3. Calculations parameters and assumptions

The Plaxis axial-symmetrical model is the following:

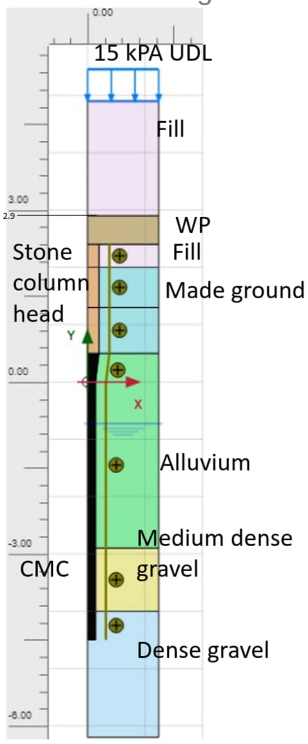


Figure 10 – Finite element model

A total of 2 grid spacings have been considered, with the radius of each model summarized in the table below.

	Grid spacing (m x m)	R_{eq} (m)
Model 1.	2.8 m x 2.8m	1.579
Model 2.	2.2 m x 2.2m	1.241

Table 5. Equivalent radius per model

A Uniformly Distributed Load of 15 kPa is applied above the top of the pavement structure or slab, . as agreed with McLaren and confirmed by email [23].

The calculation stages for the modelling are shown hereafter:

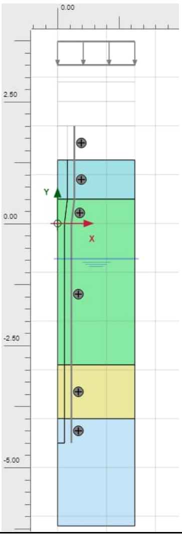
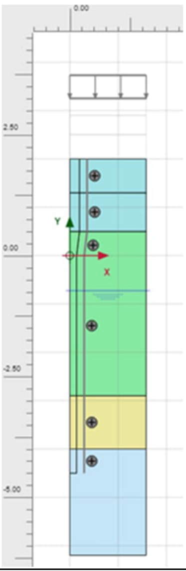
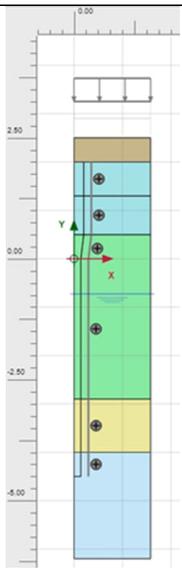
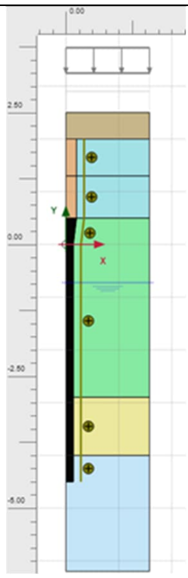
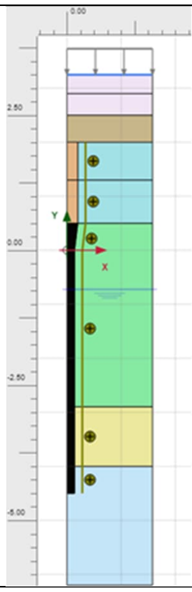
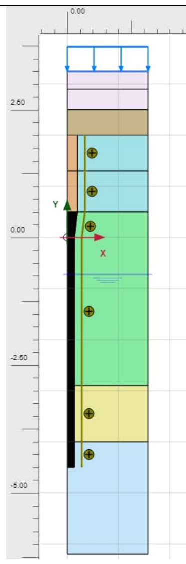
					
Step 0: Initial conditions at EGL	Step 1: Earthwork Cut/Fill to reach FRM	Step 2: Working platform installation	Step 3: BMC installation	Step 4: fill installation to reach finished level	Step 5: UDL activation

Table 6 – Calculation stages for the modelling

With calculation stages going as the following:

1) From initial conditions Existing Ground Level, there are some earthworks (either cut or fill) to reach the "proposed formation level" FRM, as per Burrows Graham Earthworks platform C-F drawings [7], to reach FRM of either +1.3 or +2.0 mAOD.
2) Then working platform is installed as per StrucTemp's design [12] for the elevation of the top of the working platform to reach either +1.8, +2.5 or +2.9mAOD.
3) From these working platforms, our BMC are installed.
4) Further engineered fill is installed after the installation of our BMC to reach the desired external levels, as designed by Burrows Graham [8].
5) Final stage is activation of the 15 kPa UDL.

The different scenarios considered are summarised in the table hereafter:

Model	Earthwork	Proposed formation level FRM	WP	Coverage height from FRM	Finished level	Coverage height from CMC head*	Grid spacing	External surface
	(-)	(mAOD)	(mAOD)	(m)	(mAOD)	(m)	(m x m)	
1	Fill +0.7m	2.0	2.5	1.25	3.25	3.25	2.8 m x 2.8m	Flexible pavement
2				0.25	2.25	2.9	2.2 m x 2.2m	
3			2.9	1.25	3.65	3.15	2.8 m x 2.8m	
4				2.5	4.9	4.4	2.2 m x 2.2m	
5	Cut 0 m	1.3	1.8	2.5	3.8	3.8	2.2 m x 2.2m	
6				0.7	2.0	2.9	2.2 m x 2.2m	
7	Fill +0.7m	2.0	2.5	1.25	3.25	3.25	2.8 m x 2.8m	Concrete slab

Table 7 -Summary Plaxis models scenarios.

*for low height of fill placed on top of working platform to reach the desired finished levels, depth of the VSC part have been increased to ensure sufficient coverage height above the CMC in order to prevent any dimpling “egg-box” effect.

Notes:

- For the cases of post BMC installation excavation required for the installation of any services routes or manholes, no formal verification has been carried out as the exact loading case for each service has not been given. However, one can safely assume that load case for any manholes or services is a net unloading and is not the worst case compared to supporting the full fill scenarios.

6. CALCULATIONS RESULTS FOR BMC

6.1. Model 1. Earthwork fill +0.7m - WP 2.5mAOD – 1.25m of coverage height form FRM

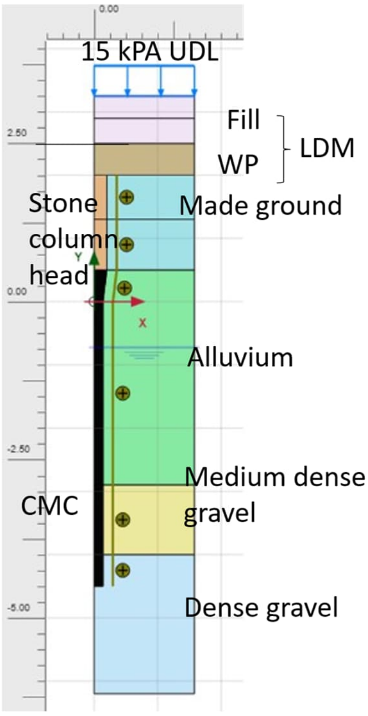


Figure 11 - Plaxis model 1 – Earthwork fill +0.7m WP 2.5mAOD - 1.25m of coverage height from FRM

6.1.1. Settlements results

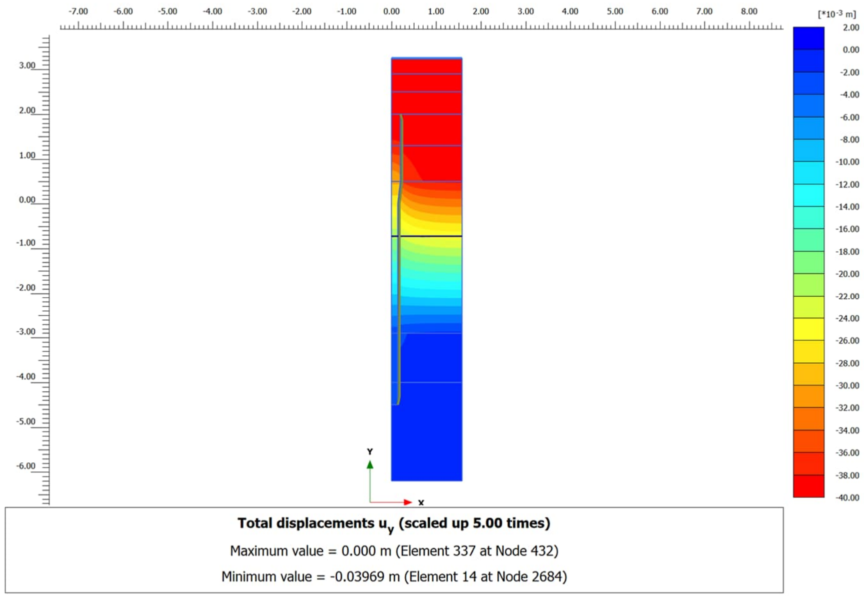


Figure 12 - total settlements after fill installation - model 1

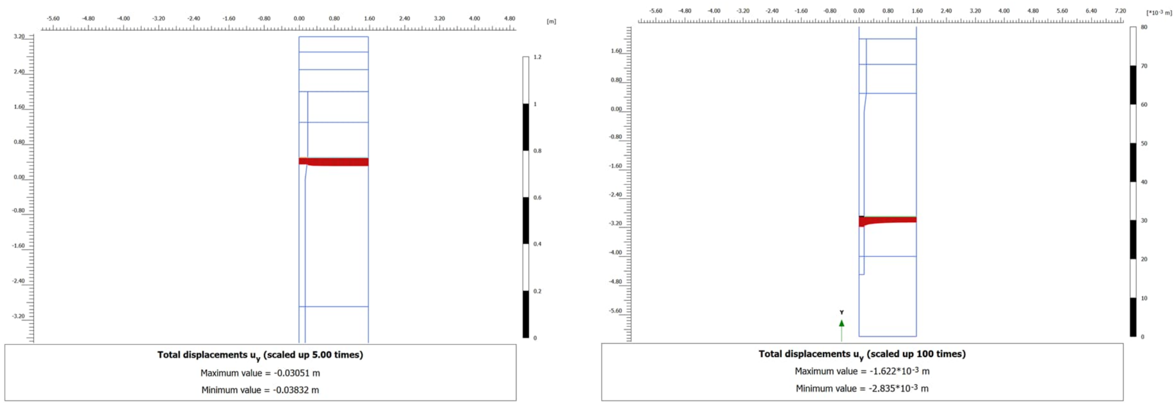


Figure 13 - Total settlements in the alluvium layer after fill installation – model 1

Assuming a 10-weeks consolidation period, a consolidation degree of 80% can be considered in the alluvium layer without PVD. Assuming consolidation takes place in the granular layers as the fill is being installed, the remaining residual settlements to consider are summarised in the table below:

Layer	Settlements after embankment installation (mm)	Residual settlements after embankment settlements (mm)
Alluvium	=38-1=37	8

Table 8 – Total and Residual Settlements in the cohesive layers after installation of the fill – model 1

These residuals settlements due to the installation of the fill in the cohesive layers, need to be considered with the residual settlements occurring after the activation of the UDL.

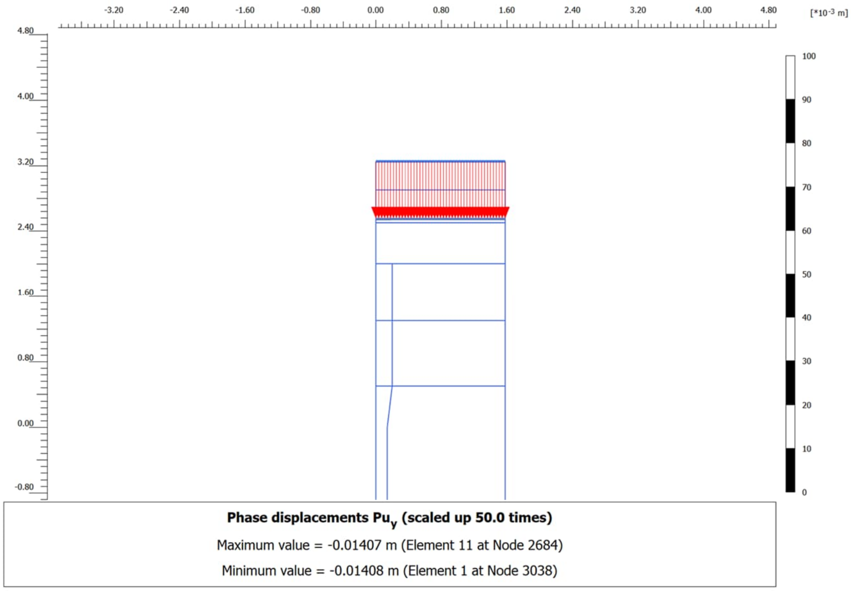


Figure 14 - Residual settlements after UDL activation - model 1

Therefore, the total residual settlements expectable after a 10-weeks consolidation period are about 22mm.

Inversely, maximal residual settlements acceptable from fill installation are of 36 mm before reaching the design specification of 50mm. U_{min}= 1-36/37=3% with 3% degree of consolidation achieved in 1 week without PVD. See detailed consolidation calculation in Appendix 1.

6.1.2. Load in the column

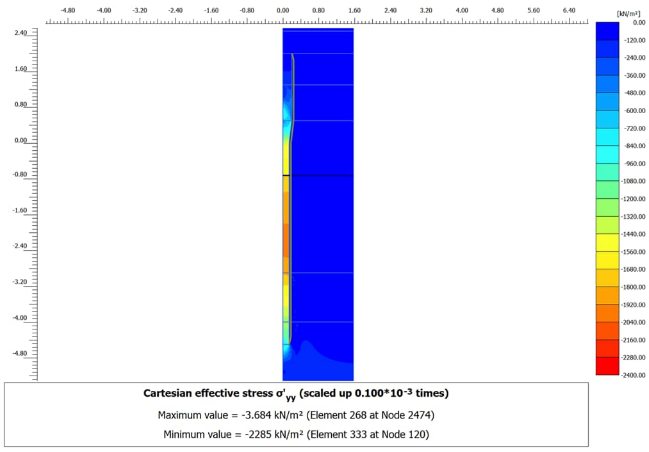


Figure 15 - effective stress distribution after UDL activation - model 1

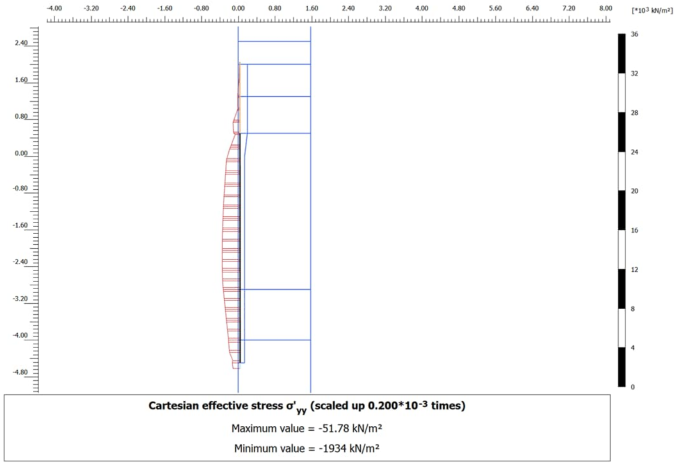


Figure 16 - effective stress in the CMC – model 1

Maximum effective stress in the VSC is about 730 kPa, which is inferior to the allowable vertical stress in the made ground layer, see Table 3.

Maximum effective stress in the CMC is about 2285 kPa, corresponding to a maximum load of 141kN in the CMC.

Conclusion: **The settlements remain lower than 50 mm and the stresses in the BMC are acceptable.**

6.2. Model 2. Earthwork fill +0.7m - WP 2.5mAOD –0.25m of coverage height from FRM

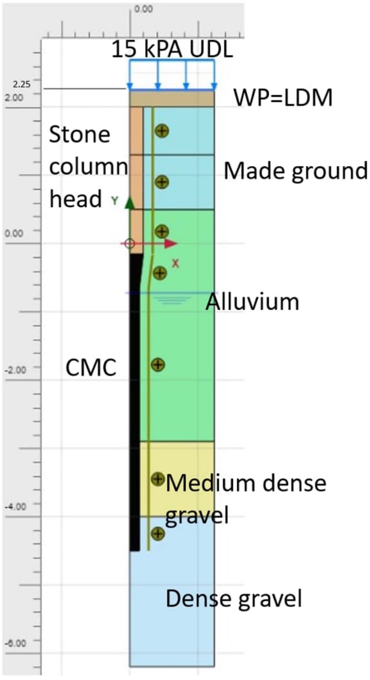


Figure 17 - Plaxis model 2 – Earthwork fill +0.7m - WP 2.5mAOD – 0.25m of coverage height from FRM

6.2.1. Settlements results

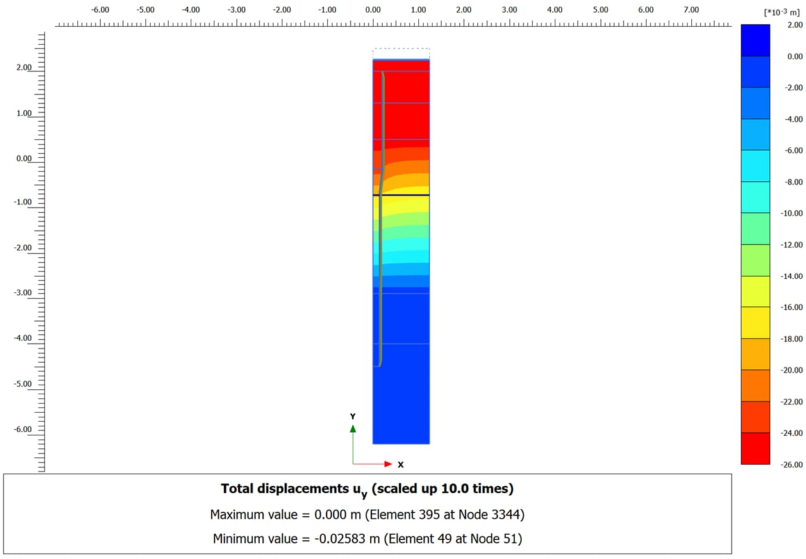


Figure 18 - total settlements after reaching finished level - model 2

Assuming a 10-weeks consolidation period, a consolidation degree of 80% can be considered in the alluvium layer without PVD. But here, assuming conservatively that although consolidation takes place in the granular layers as the fill is being installed, the settlements to consider in the alluvium layer correspond to the total displacement in Figure 18

The remaining residual settlements to consider are summarised in the table below:

Layer	Settlements after embankment installation (mm)	Residual settlements after embankment settlements (mm)
Alluvium	=26	6

Table 9 – Total and Residual Settlements in the cohesive layers after installation of the fill – model 2

These residuals settlements due to the installation of the fill in the cohesive layers, need to be considered with the residual settlements occurring after the activation of the UDL.

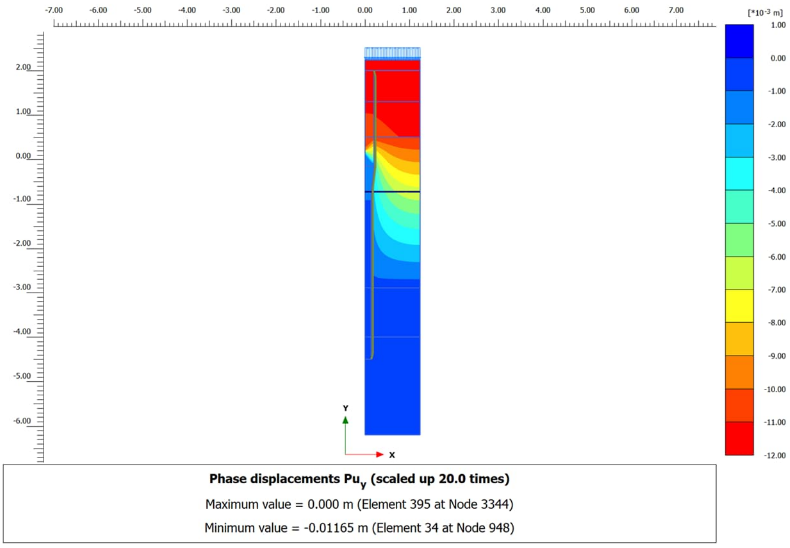


Figure 19 - Residual settlements after UDL activation - model 2

Therefore, the total residual settlements expectable after a 10-weeks consolidation period are about 18mm.

Inversely, maximal residual settlements acceptable from fill installation are of 38 mm before reaching the design specification of 50mm. Therefore, there is no need for a consolidation period in this scenario.

6.2.2. Load in the column

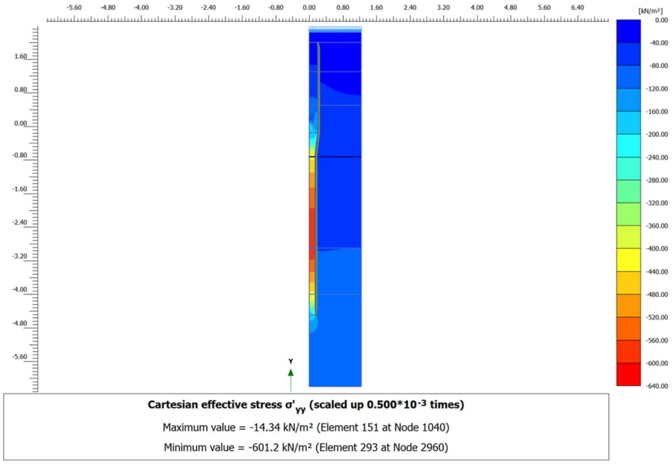


Figure 20 - effective stress distribution after UDL activation - model 2

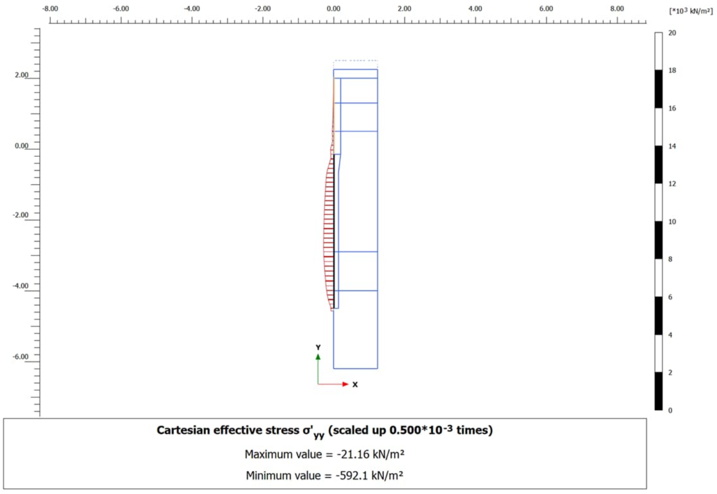


Figure 21 - effective stress in the CMC – model 2

Maximum effective stress in the VSC is about 100 kPa in the made ground (210 kPa in the alluvium), which is inferior to the allowable vertical stress in their respective layer, see Table 3.

Maximum effective stress in the CMC is about 601 kPa, corresponding to a maximum load of 37 kN in the CMC.

<u>*Conclusion:*</u> **The settlements remain lower than 50 mm and the stresses in the BMC are acceptable.**

6.3. Model 3: Earthwork fill +0.7m - WP 2.9mAOD – 1.25m of coverage height from FRM

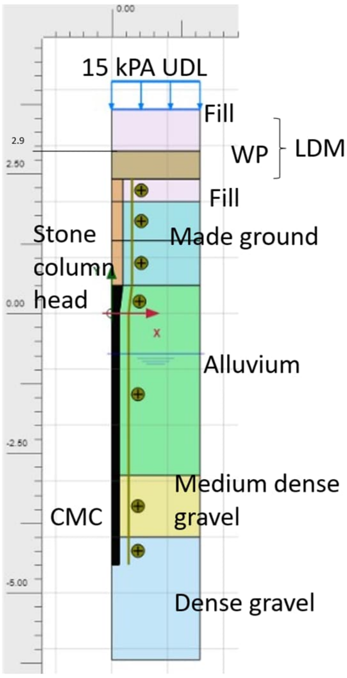


Figure 22 - Plaxis model 3 – Earthwork fill +0.7m - WP 2.9mAOD – 1.25m of coverage height from FRM

6.3.1. Settlements results

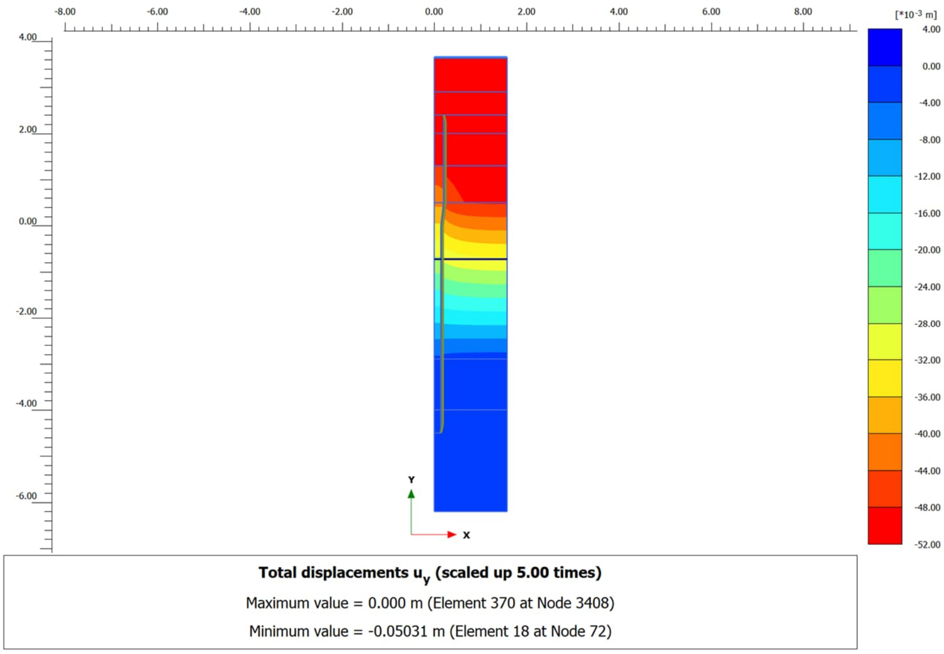


Figure 23 - total settlements after fill installation - model 3

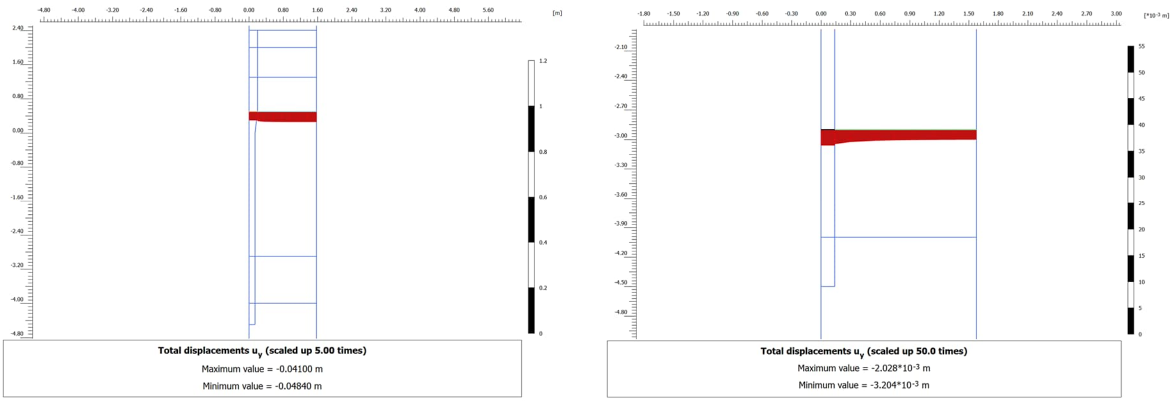


Figure 24 - total settlements in the alluvium layer after fill installation – model 3

Assuming a 10-weeks consolidation period, a consolidation degree of 80% can be considered in the alluvium layer without PVD. Assuming consolidation takes place in the granular layers as the fill is being installed, the remaining residual settlements to consider are summarised in the table below:

Layer	Settlements after embankment installation (mm)	Residual settlements after embankment settlements (mm)
Alluvium	=48.4-2≈47 mm	10

Table 10 – Total and Residual Settlements in the cohesive layers after installation of the fill – model 3

These residuals settlements due to the installation of the fill in the cohesive layers, need to be considered with the residual settlements occurring after the activation of the UDL.

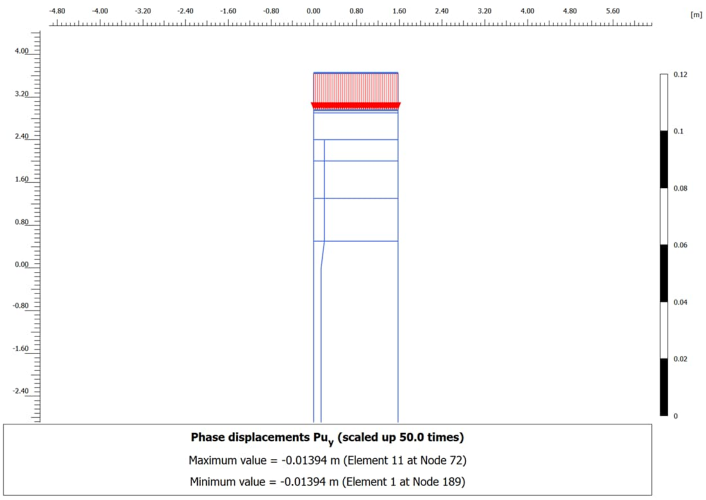


Figure 25 -Residual settlements after UDL activation – model 3

Therefore, the total residual settlements expectable after a 10-weeks consolidation period are about 24 mm.

Inversely, maximal residual settlements acceptable from fill installation are of 36 mm before reaching the design specification of 50mm. U_{min}= 1-36/47=23.4% with 24% degree of consolidation achieved in 1 week without PVD. See detailed consolidation calculation in Appendix 1.

6.3.2. Load in the column

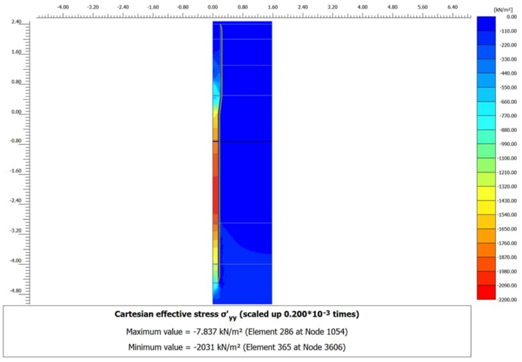


Figure 26 - effective stress distribution after UDL activation - model 3

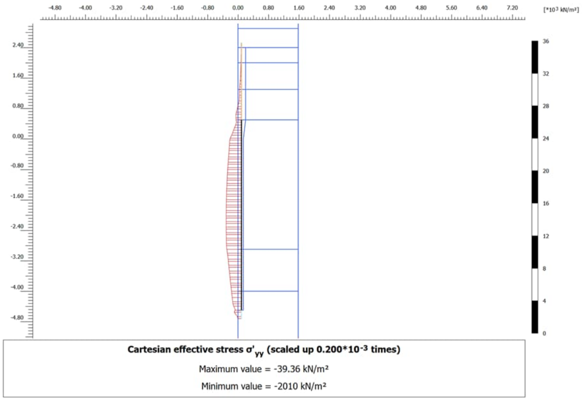


Figure 27 - effective stress in the CMC – model 3

Maximum effective stress in the VSC is about 730 kPa in the made ground (60 kPa in the fill) which is inferior to the allowable vertical stress in their respective layer, see Table 3.

Maximum effective stress in the CMC is about 2031 kPa, corresponding to a maximum load of 125 kN in the CMC.

Conclusion: **The settlements remain lower than 50 mm and the stresses in the BMC are acceptable.**

6.4. Model 4: Earthwork fill +0.7m - WP 2.9mAOD – 2.5m of coverage height from FRM

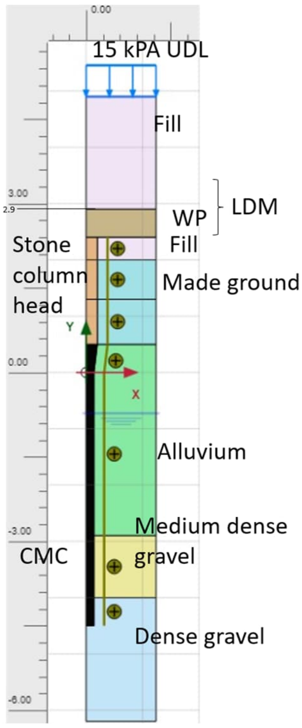


Figure 28 - Plaxis model 4 – Earthwork fill +0.7m - WP 2.9mAOD – 2.50m of coverage height from FRM

6.4.1. Settlements results

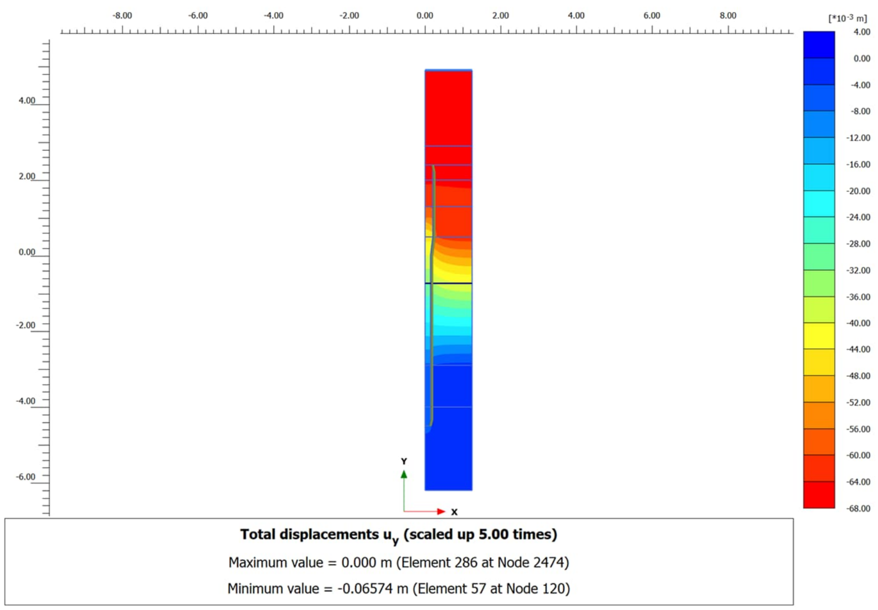


Figure 29 - total settlements after fill installation - model 4

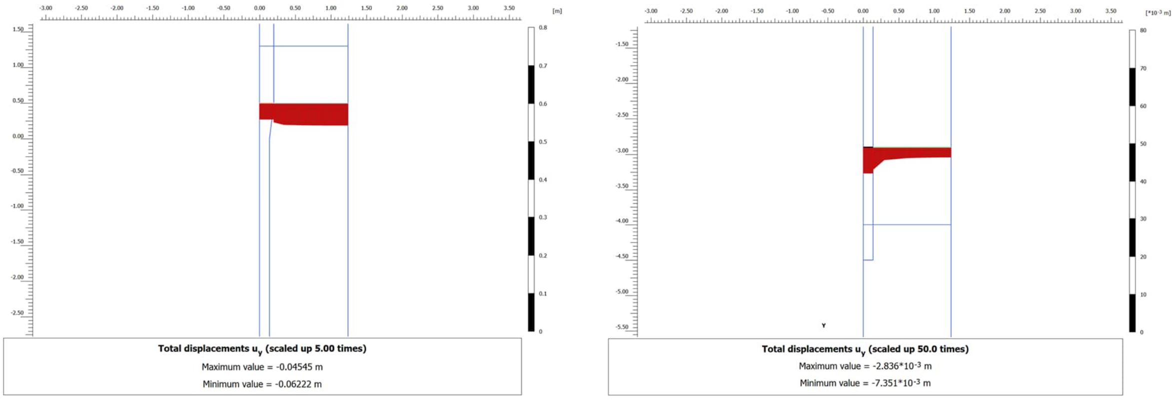


Figure 30 - total settlements in the clay layer after fill installation – model 4

Assuming a 10-weeks consolidation period, a consolidation degree of 80% can be considered in the alluvium layer without PVD. Assuming consolidation takes place in the granular layers as the fill is being installed, the remaining residual settlements to consider are summarised in the table below:

Layer	Settlements after embankment installation (mm)	Residual settlements after embankment settlements (mm)
Alluvium	=62.2.8-2.8≈60	12

Table 11 – Total and Residual Settlements in the cohesive layers after installation of the fill

These residuals settlements due to the installation of the fill in the cohesive layers, need to be considered with the residual settlements occurring after the activation of the UDL.

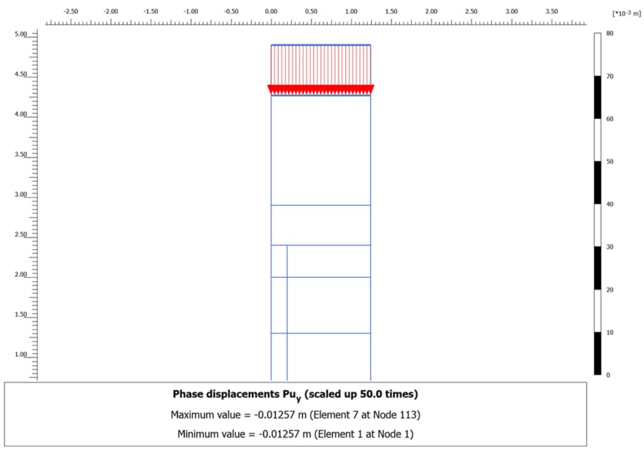


Figure 31 Residual settlements after UDL activation – model 4

Therefore, the total residual settlements expectable after a 10-weeks consolidation period are about 25 mm.

Inversely, maximal residual settlements acceptable from fill installation are of 37 mm before reaching the design specification of 50mm. U_{min}= 1-37/30=38.3% with 39% degree of consolidation achieved in 3 weeks without PVD. See detailed consolidation calculation in Appendix 1.

6.4.2. Load in the column

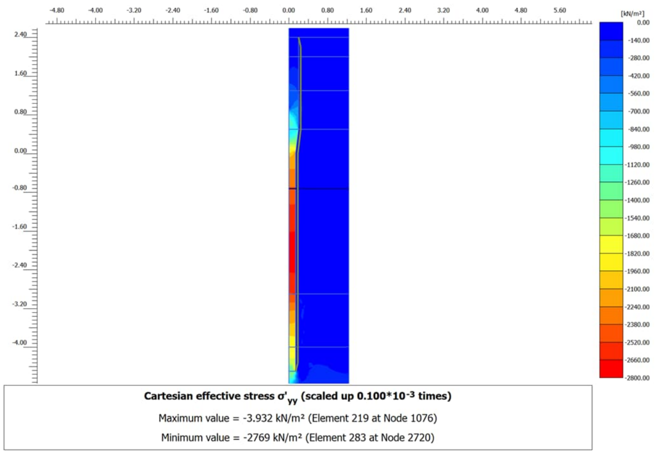


Figure 32 - effective stress distribution after UDL activation – model 4

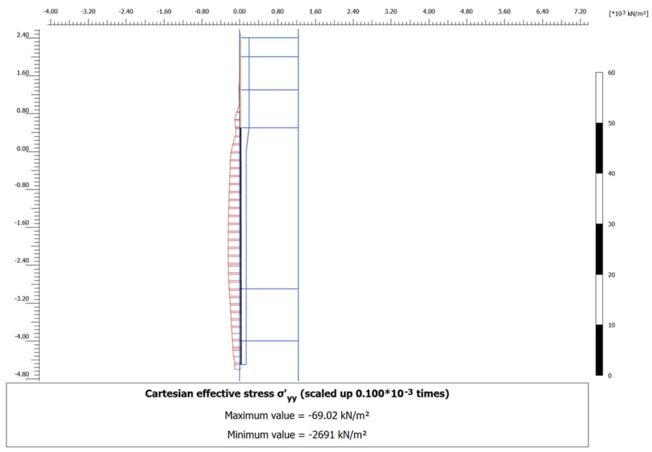


Figure 33 - effective stress in the CMC – model 4

Maximum effective stress in the VSC is about 1300 kPa in the made ground (90 kPa in the fill) which is inferior to the allowable vertical stress in their respective layer, see Table 3.

Maximum effective stress in the CMC is about 2769 kPa, corresponding to a maximum load of 170 kN in the CMC.

Conclusion: **The settlements remain lower than 50 mm and the stresses in the BMC are acceptable.**

6.5. Model 5: Earthwork cut -0.0m - WP 1.8 mAOD – 2.5m of coverage height from FRM

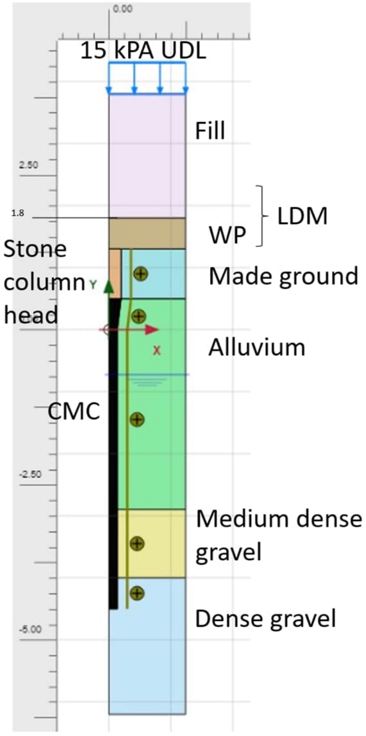


Figure 34 - Plaxis model 5 – Earthwork fill +0.0m - WP 1.8mAOD – 2.5m of coverage height from FRM

6.5.1. Settlements results

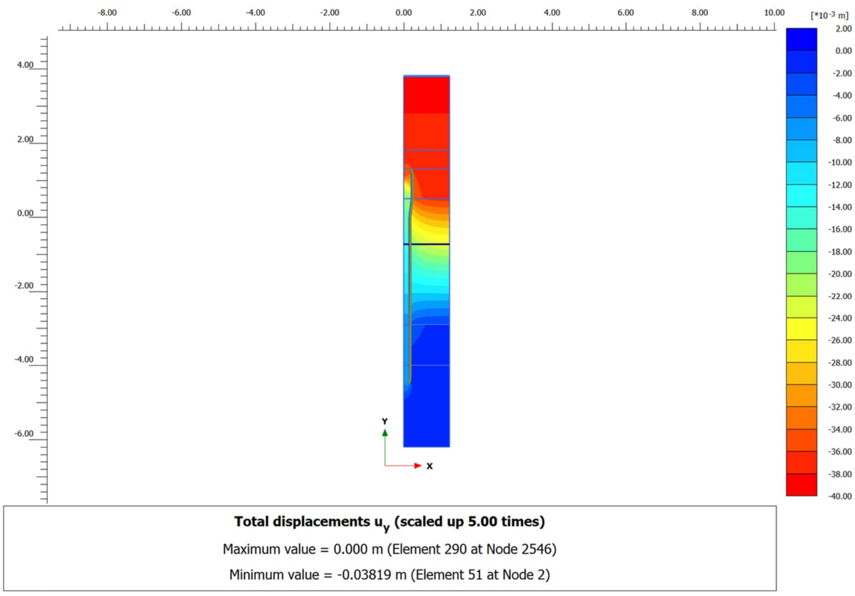


Figure 35 - total settlements after fill installation - model 5

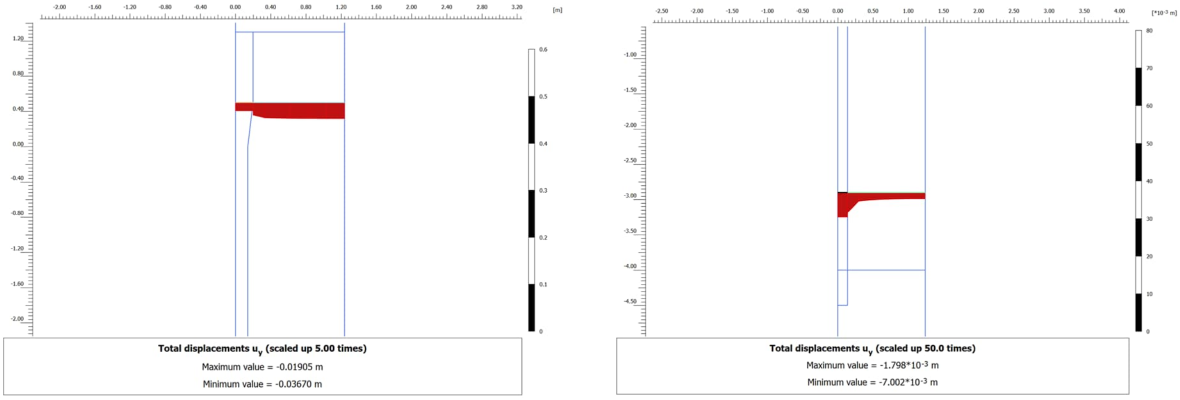


Figure 36 - total settlements in the clay layer after fill installation – model 5

Assuming a 10-weeks consolidation period, a consolidation degree of 80% can be considered in the alluvium layer without PVD. Assuming consolidation takes place in the granular layers as the fill is being installed, the remaining residual settlements to consider are summarised in the table below:

Layer	Settlements after embankment installation (mm)	Residual settlements after embankment settlements (mm)
Alluvium	=36.7-1.7≈35	7

Table 12 – Total and Residual Settlements in the cohesive layers after installation of the fill

These residuals settlements due to the installation of the fill in the cohesive layers, need to be considered with the residual settlements occurring after the activation of the UDL.

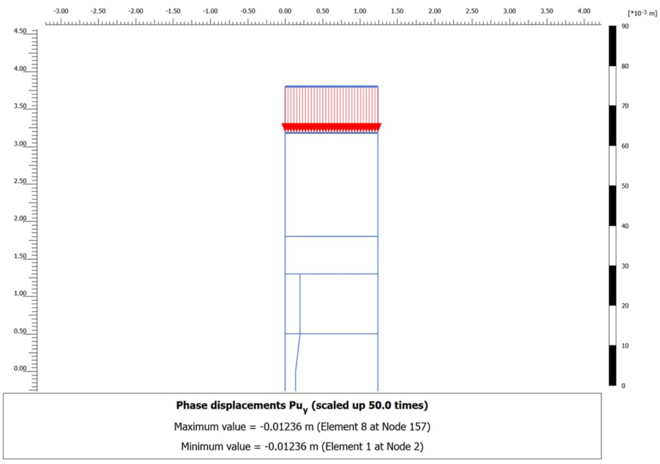


Figure 37 -Residual settlements after UDL activation – model 5

Therefore, the total residual settlements expectable after a 10-weeks consolidation period are about 20mm.

Inversely, maximal residual settlements acceptable from fill installation are of 37 mm before reaching the design specification of 50mm. U_{min}= 1-35/37=5.4% with 6% degree of consolidation achieved in 1week without PVD. See detailed consolidation calculation in Appendix 1.

6.5.2. Load in the column

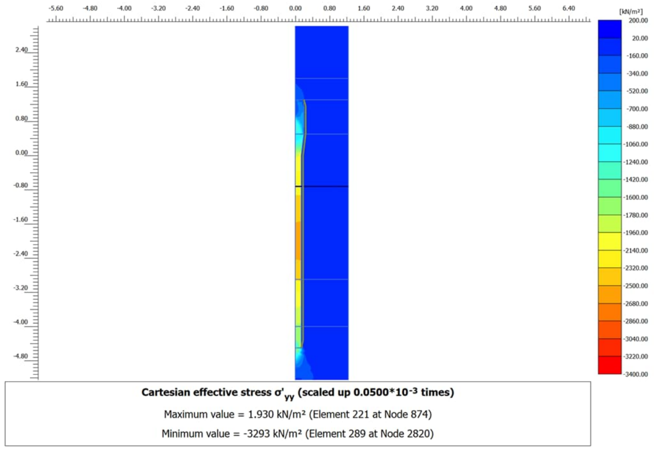


Figure 38 - effective stress distribution after UDL activation – model 5

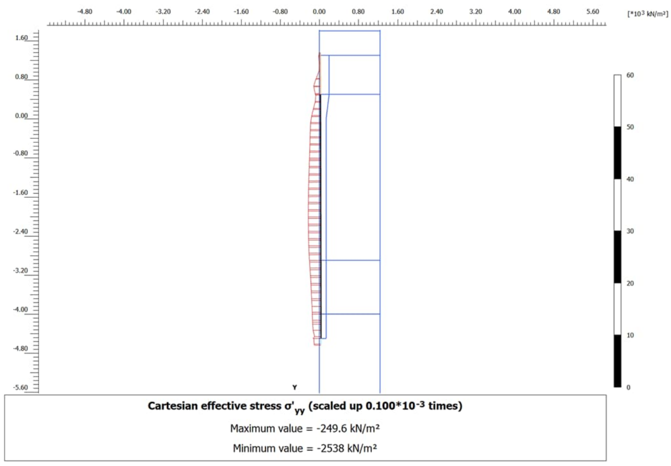


Figure 39 - effective stress in the CMC – model 5

Maximum effective stress in the VSC is about 1340 kPa is inferior to the allowable vertical stress in the made ground layer, see Table 3.

Maximum effective stress in the CMC is about 3293 kPa, corresponding to a maximum load of 203 kN in the CMC.

Conclusion: **The settlements remain lower than 50 mm and the stresses in the BMC are acceptable.**

6.6. Model 6: Earthwork cut -0.0m - WP 1.8 mAOD – 0.7m of coverage height from FRM

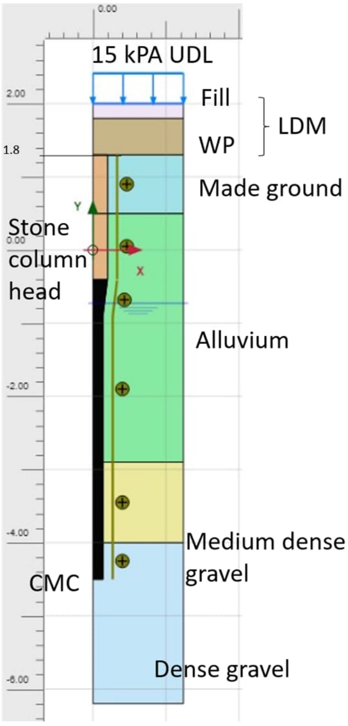


Figure 40 - Plaxis model 6 – Earthwork fill +0.0m - WP 1.8mAOD – 2.50m of coverage height from FRM

6.6.1. Settlements results

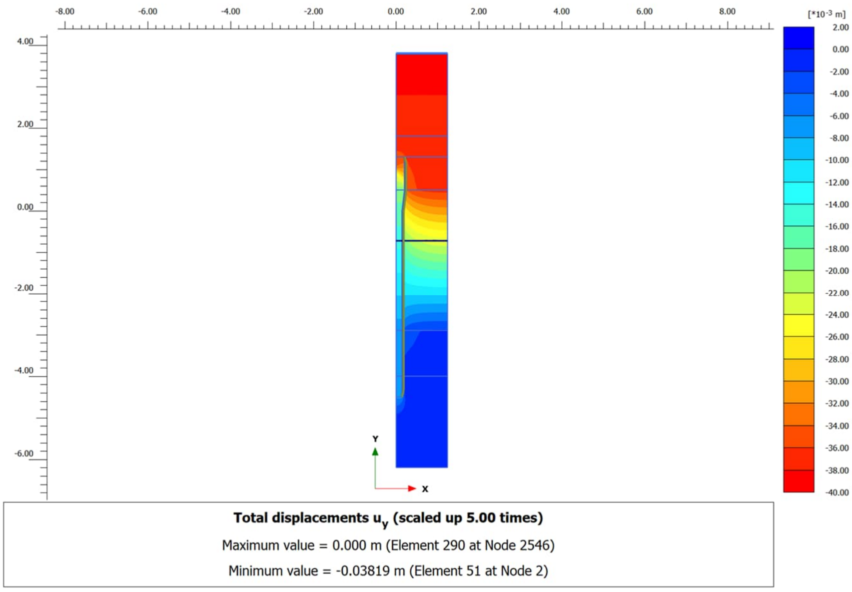


Figure 41 - total settlements after fill installation - model 6

Assuming a 10-weeks consolidation period, a consolidation degree of 80% can be considered in the alluvium layer without PVD. But here, assuming conservatively that although consolidation takes place in the granular layers as the fill is being installed, the settlements to consider in the alluvium layer correspond to the total displacement in Figure 18

The remaining residual settlements to consider are summarised in the table below:

Layer	Settlements after embankment installation (mm)	Residual settlements after embankment settlements (mm)
Alluvium	≈15mm	3

Table 13 – Total and Residual Settlements in the cohesive layers after installation of the fill – model 6

These residuals settlements due to the installation of the fill in the cohesive layers, need to be considered with the residual settlements occurring after the activation of the UDL.

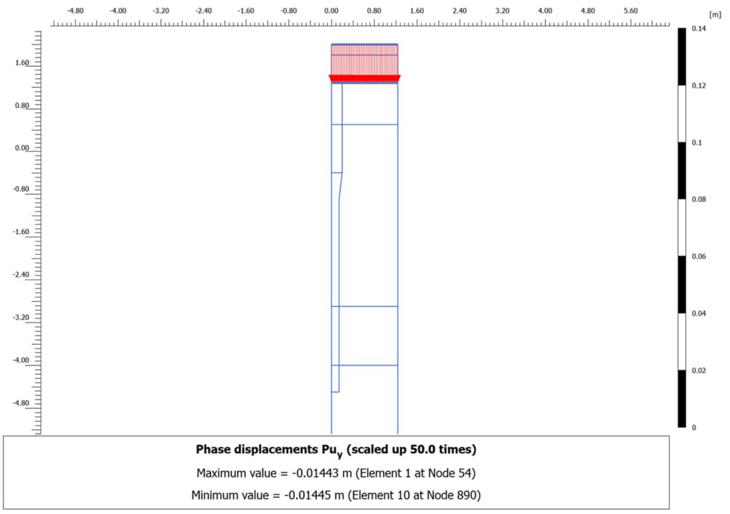


Figure 42 -Residual settlements after UDL activation – model 6

Therefore, the total residual settlements expectable after a 10-weeks consolidation period are about 18 mm.

Inversely, maximal residual settlements acceptable from fill installation are of 35 mm before reaching the design specification of 50mm. Therefore, there is no need for a consolidation period in this scenario.

6.6.2. Load in the column

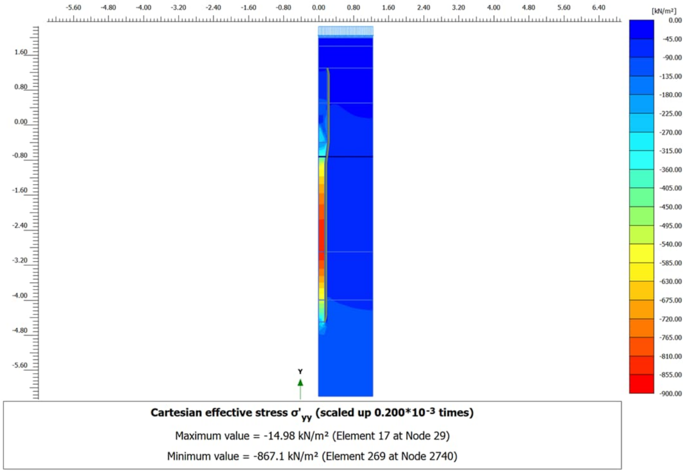


Figure 43 - effective stress distribution after UDL activation – model 6

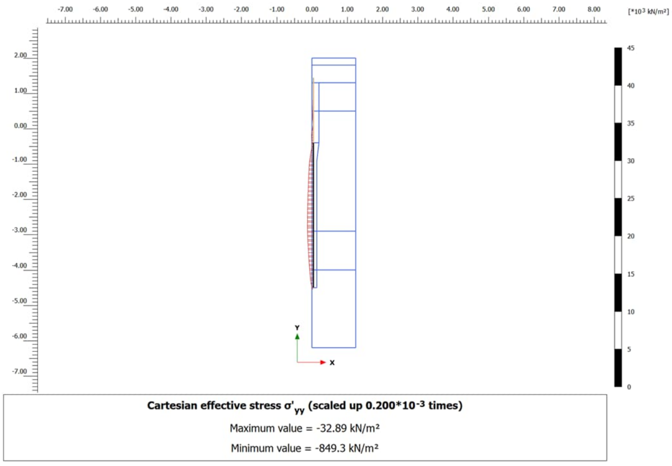


Figure 44 - effective stress in the CMC – model 6

Maximum effective stress in the VSC is about 103 kPa in the made ground (301 kPa in the alluvium), which is inferior to the allowable vertical stress in their respective layer, see Table 3.

Maximum effective stress in the CMC is about 867 kPa, corresponding to a maximum load of 54 kN in the CMC.

Conclusion: **The settlements remain lower than 50 mm and the stresses in the BMC are acceptable.**

6.7. Model 7: Earthwork fill +0.7m - WP 2.5 mAOD – 1.25m of coverage height from FRM (concrete slab)

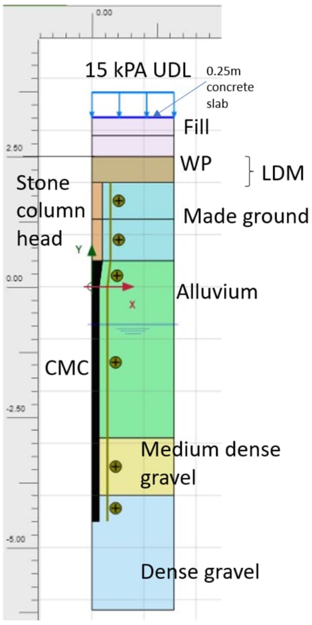


Figure 45 - Plaxis model 6 – Earthwork fill +1.4m - WP 2.5mAOD – 1.25m of coverage height from FRM (concrete slab)

6.7.1. Settlements results

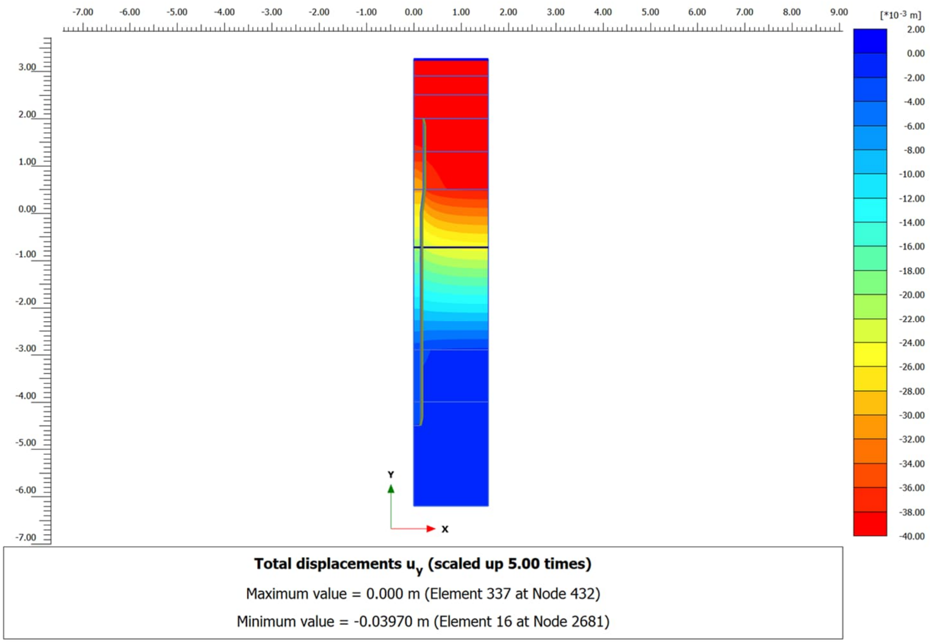


Figure 46 - total settlements after fill installation - model 7

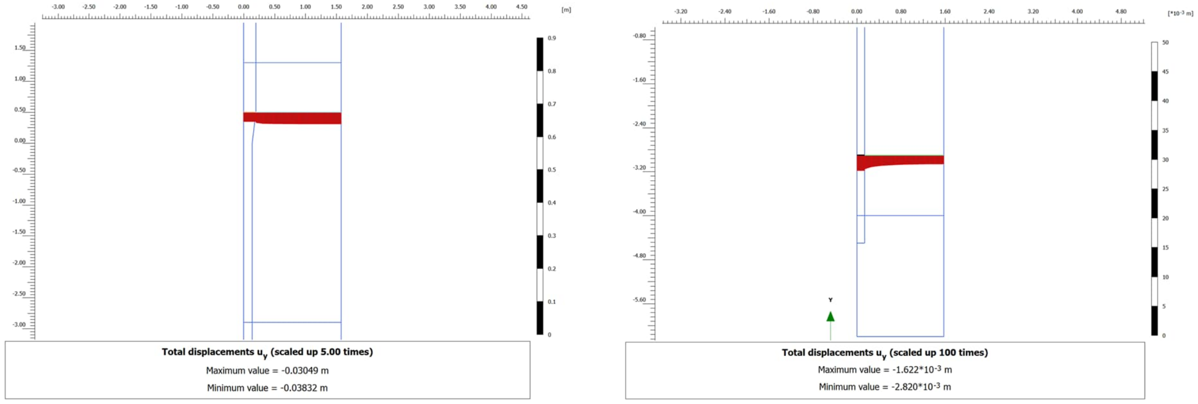


Figure 47 - total settlements in the clay layer after fill installation – model 7

Assuming a 10-weeks consolidation period, a consolidation degree of 80% can be considered in the alluvium layer without PVD. Assuming consolidation takes place in the granular layers as the fill is being installed, the remaining residual settlements to consider are summarised in the table below:

Layer	Settlements after embankment installation (mm)	Residual settlements after embankment settlements (mm)
Alluvium	=38.3-1.6≈37mm	8

Table 14 – Total and Residual Settlements in the cohesive layers after installation of the fill – model 7

These residuals settlements due to the installation of the fill in the cohesive layers, need to be considered with the residual settlements occurring after the activation of the UDL.

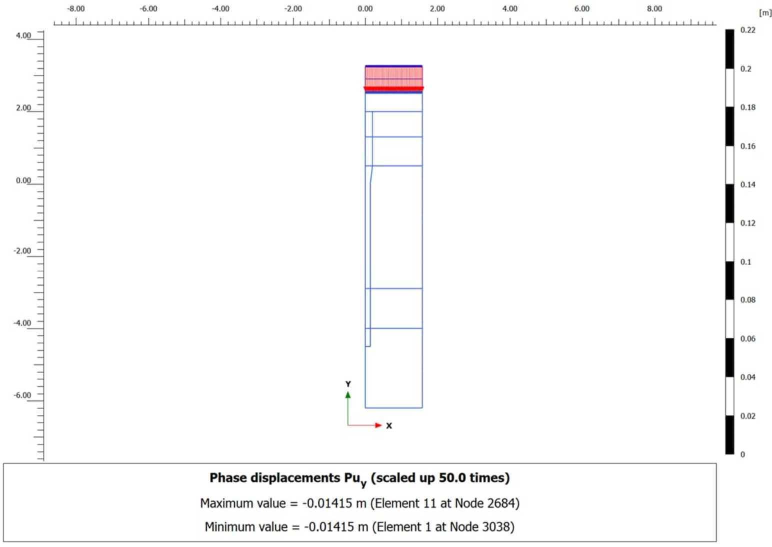


Figure 48 -Residual settlements after UDL activation – model 7

Therefore, the total residual settlements expectable after a 10-weeks consolidation period are about 22 mm.

Inversely, maximal residual settlements acceptable from fill installation are of 35 mm before reaching the design specification of 50mm. U_{min}= 1-35/37=5.4% with 6% degree of consolidation achieved in 1 week without PVD. See detailed consolidation calculation in Appendix 1.

6.7.2. Load in the column

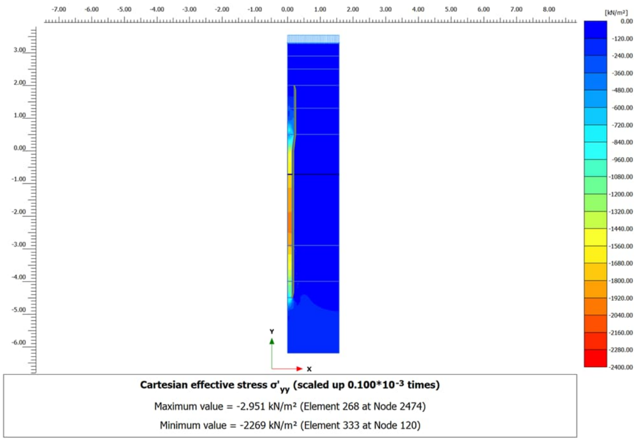


Figure 49 - effective stress distribution after UDL activation – model 7

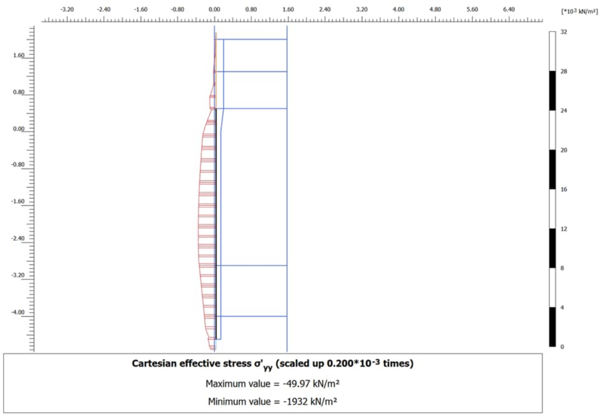


Figure 50 - effective stress in the CMC – model 7

Maximum effective stress in the VSC is about 740 kPa, which is inferior to the allowable vertical stress in the made ground layer, see Table 3.

Maximum effective stress in the CMC is about 2269 kPa, corresponding to a maximum load of 140kN in the CMC.

Conclusion: **The settlements remain lower than 50 mm and the stresses in the BMC are acceptable.**

7. CALCULATIONS RESULTS FOR CMC

7.1. Footings

The calculations of the CMC beneath the footings of the ancillary buildings are carried out using the CMCLTP software, in which the deformations and the stresses are calculated by iterations according to the O. Combarieu method (“Fondations mixtes” [Mixed foundations], LCPC, 1988), taking into account the Frank and Zhao behaviour laws for the CMC-soil interactions.

The calculations are carried out for each footing type, considering the SLS bearing pressures of 150 kPa for the foundations of the dust canopy, the waste and water tank building, and the foundations of the guardhouse, as indicated on the Burrows Graham foundation drawings ([13][14] and [18][19] and[17].) and reconfirmed by email [23]. The main results of the calculations are shown in the table below, and the details of the calculations are presented in Appendix 2 for some selected cases.

Building	Pad Type	Length	Width	SLS bearing pressure	SLS vertical load	No of CMC	Settlement	SLS Stress in the CMC
(-)	(-)	(m)	(m)	(kPa)	(kN)	(-)	(mm)	(MPa)
Guardhouse	pad	0.65	0.65	150	63	1	<5	0.86

Table 15 - Design results for pad footings

Building	Strip Type	Width	SLS bearing pressure	SLS vertical load	No of CMC	Settlement	SLS Stress in the CMC
	(-)	(m)	(kPa)	(kN/lm)	(-)	(mm)	(MPa)
Waste and Water tank	GB01	1	150	150	1 every 2 m	< 5	2.95
Guardhouse	Strip	0.9	150	135	1 every 2.2 m	< 5	2.94
Dust Canopy	Strip	1.5	150	225	2 every 1.8 m	5	2.80

Table 16 - Design results for strip footings

Conclusion: **The settlements under the working loads remain acceptable (<50 mm) and the stresses in the CMC are lower than the allowable value.**

7.2. Ground bearing slab

Calculations of the ground improvement under the ground bearing slab are carried out using an axisymmetric model with the CMCAXI software.

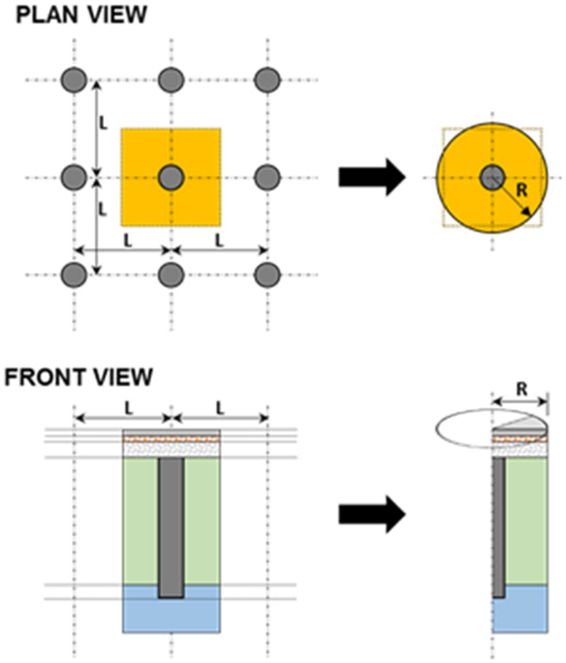


Figure 51 - Principle of axisymmetric modelling

The main results are presented below, the detailed calculations are presented in Appendix 3.

Zones	SLS UDL	CMC Grid	Settlements	SLS Stress in the CMC	Tensile stress in slab induced by consolidation settlements
(-)	(kPa)	(m x m)	(mm)	(MPa)	(MPa)
Waste and Water tank	50	2.3 x 2.3	24	3.1	0.5
Guardhouse	50	2.5 x 2.5	33	3.0	0.8

Table 17 - Calculation results for ground bearing slab

Conclusion: **The long-term settlements considering quasi-permanent service loads remain lower than 50 mm and the stresses in the CMC are acceptable.**

Note: Maximum envelope moments induced in the slab by the long-term consolidation settlements of the reinforced soil reach up to 5.2kN.m/lm (5.0 kN.m/lm for guardhouse), which is equivalent to a maximum tensile stress of 0.5 MPa for a 250 mm thick slab (0.8 MPa for a 250 mm thick slab), which is much lower than the tensile resistance of the plain concrete (2.5MPa for a C28/35 250mm thick). These moments are to be considered by the slab designer for additional load cases not covered in this design report if any.

7.3. Retaining walls

The calculations of the ground improvement beneath the retaining wall footings are carried out using the BMCLTP software, in which the deformations and the stresses are calculated by iterations according to the O. Combarieu method ("Fondations mixtes" [Mixed foundations], LCPC, 1988), taking into account the Frank and Zhao behaviour laws for the CMC-soil interactions. The stone columns part of the BMC design is following the Goughnour and Bayuk method (1979).

The calculations are carried out for each footing type, considering the SLS bearing pressures of 100 kPa as indicated in the comment [24].Due to variability of the retaining wall dimension and elevation, only representative cases have been displayed : narrowest, widest, shallowest and deepest strip portion scenarios. The main results of the calculations are shown in the table below, and the details of the calculations are presented in Appendix 4.

Case	Top of foundation	Width	SLS bearing pressure	SLS vertical load	No of CMC	Settlement	SLS Stress in the VSC	SLS Stress in the CMC
(-)	(mAOD)	(m)	(kPa)	(kN/lm)	(-)	(mm)	(MPa)	(MPa)
1	3.2	1.0	100	100	1 every 2.5 m	5	0.12	0.5
2	1.55	2.5	100	250	1 every 2.5 m	15	0.57	1.6
3	3.2	2.2	100	150	1 every 2.5 m	9	0.19	0.9
4	0.7	2.2	100	220	1 every 2.5 m	35	0.27	1.10

Table 18 - Design results for retaining wall strip footings

Conclusion: **The settlements under the working loads remain acceptable (< 50 mm) and the stresses in the BMC are lower than the allowable value.**

8. OBSTRUCTION METHODOLOGY

Probing and ground analysis tend to demonstrate the presence of significant number of obstructions in the ground: existing piles, existing concrete foundations and concrete slab. [22]

Menard is proposing a methodology on site to deal with the obstructions. Details of the obstruction methodology is provided in Appendix 5. In essence, depending on the depth of the obstructions from the WPL, we would suggest to either to:

- Dig out the obstruction when located a depth from 0 to 3 m under the WPL
- Readapt locally the BMC grid when encountering an obstruction between 3 to 6.5 m below WPL
- Stopped the VSC on the obstruction when beyond 6.5m below the WPL.

Menard would also suggest additional probing to fine tune the positions of the obstructions and additional CPT campaign to ensure compliance of stopping the VSC on the deepest obstructions.

9. QUALITY CONTROL

9.1. Monitoring and recording

- Layout drawing showing the location of each CMC will be produced by Menard.
- Calibration drilling(s) close to existing soil investigation borehole(s) to calibrate drilling parameters to each layer of the geotechnical profile and to define an “embedment” criteria will be done.
- The execution of each CMC is controlled by the operator and recorded by an on-board computer. The parameters controlled are: verticality of the mast, depth of treatment, concrete volume, continuity and integrity of each column. A special software enables the site technician to plot the profile of each CMC together with the data recorded during the drilling process.
- 1 of every 10 data recording is handed to the Engineer after the execution of the works.
- The work done is also recorded by a log of each CMC showing the CMC reference number, penetration length, concrete volume and a note of any unusual circumstances encountered during the installation (depth of predrilling, refusals, etc.). This log will be recorded on our standard Daily Record Sheet.
- 'As built' record drawings showing the execution numbers of each CMC will be provided.

9.2. Testing

- Concrete sampling for measurement of the compressive strength: 5 samples per day per rig, 2 of them are tested at 7 days, 2 of them at 28 days and 1 spare,
- Vertical load tests up to 1.5 times the nominal load of the CMC or to a maximum load of 40t whichever is the least. We have allowed for **1 plate load test per week (based on continuous work) per rig per technique (1 test for CMC/week and 1 test for VSC /week), accounting for a total of maximum 24 tests**. The load test comprises a 600 mm circular plate which is positioned centrally over a CMC/VSC on a layer of sand. The load is applied centrally to the plate by a hydraulic jack using the CMC rig as a “reaction block”. The procedure for those tests is as follows:

Load Stage	Load applied	Comparator reading times
1	20% Q_{max}	1 and 5 min
2	0% Q_{max}	1 and 5 min
3	20% Q_{max}	1, 2, 3, 4, 5, 10 and 15 min
4	40% Q_{max}	1, 2, 3, 4, 5, 10 and 15 min
5	60% Q_{max}	1, 2, 3, 4, 5, 10 and 15 min
6	80% Q_{max}	1, 2, 3, 4, 5, 10, 15, and 30 min
7	100% Q_{max}	1, 2, 3, 4, 5, 10, 15, 30 and 60 min
8	50% Q_{max}	1 and 5 min
9	0% Q_{max}	1 and 5 min

Table 19 - Loading procedure for plate load test of CMCs and VSCs

Notes:

- The load stages are to be carried out for not less than the times specified above or until the settlement is equal or less than 0.02 mm per minute.

- The maximum stress in a CMC is 3.3 MPa corresponding to a maximum nominal load of 203 kN. As such, the maximum load applied during the load test will be Q_{max} =305 kN.
- Similar maximum load Q_{max} =305 kN will be applied for VSC test.

- **Dummy footing test**: 5 no. dummy foundation tests has been allowed for using a 0.6m x 1.5m steel plate covering 2no. CMCs. The steel plate is place directly on the head of the CMCs. This will be taken to a maximum load of 1.5 x 203 = 305 kN (338 kPa). The load will be held for a period of 12 hours.

The increments for this will be as below:

W.L.	Applied Load	Minimum Hold
10%	34 kPa	10 min
0%	0 kPa	10 min
25%	84.5 kPa	30 min
50%	169 kPa	30 min
75%	253.5 kPa	30 min
100%	338 kPa	12 hours
75%	253.5 kPa	30 min
50%	169 kPa	30 min
25%	84.5 kPa	30 min
0%	0 kN	10 min

Table 20 - loading procedure for dummy footing test

10. CONCLUSION

The design for BMC ground improvement below the concerned structures has been carried out using the FEM models. The calculation results show the good behaviour of the footings and ground bearing slabs in terms of settlements under working loads. They show also that the BMC structural integrity is ensured.

The CMC part of diameter **280 mm** will be installed using a concrete with a minimum compressive strength of **12 MPa** and will be keyed **0.5 m into the dense gravel layer**. As such, their depth is expected to be around **6 m to 8 m from the working platform level.** Depending on the local characteristics of the soils, BMC could be shorter or longer.

The VSC part of diameter **400mm** will be installed to a depth allowing a **minimum of 0.5m of stone column head underneath the services invert levels.**

The BMC will be arranged in a square grid ranging from **2.2 m x 2.2 m to 2.8 m x 2.8 m**. A Load Distribution Mattress (LDM) of minimum thickness **500 mm/1000 mm** is required between the head of the BMC and the underside of the slab/flexible pavement. Working platform material and any class 6F engineered fill can enact as the LDM. The compaction requirements are **CBR > 10% or subgrade reaction coefficient Kw > 50 MPa/m.**

The BMC configuration is summarized in the table below:

Bi-Modulus Columns (BMC)		
CMC part	***Diameter***	280 mm
	Embedment	Min 0.5 into Dense Gravels (river deposits)
	Concrete compressive strength	Min. $f_{ck} = 12\ MPa$
	Design chemical class	DC-4
VSC Part	***diameter***	400 mm
Beneath slab/flexible pavement	***Grid***	2.2 m x 2.2 m to 3 m x 3 m
	Load Distribution Mat	Minimum 500 mm thick under slab Minimum 1000 mm thick (WP + class 6F engineer fill) under flexible pavements , CBR > 10%
Beneath retaining walls	***Spacing***	1 BMC every 2.5 m
	Load Distribution Mat	none

Table 21 - Summary of BMC arrangement

The design for CMC ground improvement below the concerned structures has been carried out using the O. Combarieu iterative method, taking into account the behaviour laws of Frank & Zhao. The calculation results show the good behaviour of the footings in terms of settlements under working loads. They show also that the CMC structural integrity is ensured.

The CMC part of diameter **280 mm** will be installed using a concrete with a minimum compressive strength of **12 MPa** and will be keyed **0.5 m into the dense gravel layer**. As such, their depth is expected to be around **6 m to 8 m from the working platform level.** Depending on the local characteristics of the soils, CMC could be shorter or longer.

The number of CMC beneath the strip footings will vary **between 1 every 0.9m to 1 every 2.2m** depending on the strip size. No LDM is required below the footings.

The CMC configuration is summarized in the table below:

Controlled Modulus Columns (CMC)		
CMC	***Diameter***	280 mm
	Embedment	Min 0.5 into Dense Gravels (river deposits)
	Concrete compressive strength	Min. f_{ck} = 12 MPa
	Design chemical class	DC-4
Beneath footings	***Allowable bearing pressure***	150 kPa SLS
	Spacing	1 CMC below pads footings 1 CMC every 0.9 / 2.2 m below strip footings
	Load Distribution Mat	None
Beneath slab	***Load case***	50 kPa
	Grid	2.3 x 2.3 to 2.5 x 2.5
	Slab geometry	250 mm thick (C28/35)
	Load distribution Mat	Minimum 500 mm thick CBR>10%

Table 22 - Summary of CMC arrangement

APPENDIX 1: DETAILED CALCULATIONS FOR CONSOLIDATION DEGREE

Vertical Drains consolidation

Project name : ***V29949 - Project Olympus - Silvertown, London***
Layer 2 - Alluvium clay with peat - 2.8x2.8 spacing

DATA Input

Soil parameters		*Value*	*Unit*
Vertical consolidation coefficient	Cv	***2.7E-07***	m²/s
Radial consolidation coefficient	Cr	***8.1E-07***	m²/s
Drained sides (1 ou 2)		***2***	
Drained thickness	h	***3.4***	m

Vertical drains parameters		*Value*	*Unit*
Mesh	L	***2.8***	m
Triangular (1.05); Squared (1.13)		***1.13***	
PVD diameter	d	***0.05***	m

Definitions

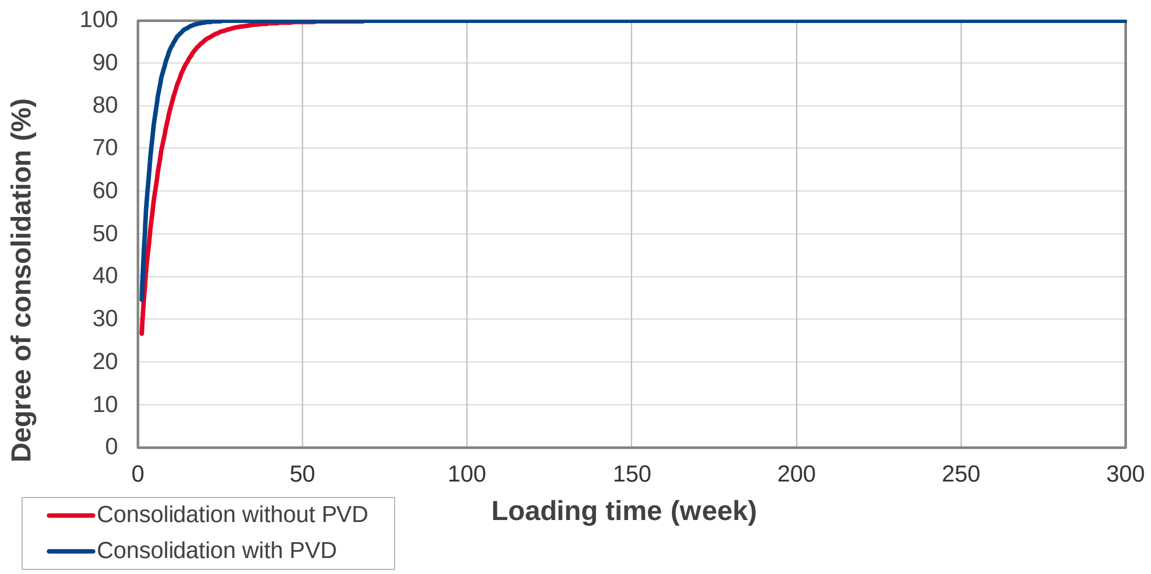
$$F(n) = \frac{n^2}{n^2-1}\ln(n) - \frac{3n^2-1}{4n^2}, \text{ et } n = \frac{D}{d}$$

$$T_v = \frac{C_v \times t}{H_{dr}^2}$$

$$U_v = \left(1 + \frac{1}{2T_v^3}\right)^{\frac{-1}{6}}$$

$$U_r = 1 - e^{\left(\frac{-8C_r \times t}{D^2 F(n)}\right)}$$

Graphical results



Results and verifications

Degree of consolidation		*Value*	*Unit*
Loading time	**t**	***4***	***weeks***
Consolidation without PVD (vertical)	Uv	53.16	%
Consolidation with PVD (global)	U	70.45	%

$$(1 - U) = (1 - U_v)(1 - U_r)$$

Consolidation target		*Value*	*Unit*
Degree of consolidation	U	***80***	%
Loading time			
Loading without PVD	t	10	weeks
Loading with PVD	t	6	weeks

Vertical Drains consolidation

Project name :	*V29949 - Project Olympus - Silvertown, London*
	Layer 2 - Alluvium - model 1 - consolidation target 3%

DATA Input

Soil parameters		*Value*	*Unit*
Vertical consolidation coefficient	Cv	*2.7E-07*	m²/s
Radial consolidation coefficient	Cr	*8.1E-07*	m²/s
Drained sides (1 ou 2)		*2*	
Drained thickness	h	*3.4*	m

Vertical drains parameters		*Value*	*Unit*
Mesh	L	*2.8*	m
Triangular (1.05); Squared (1.13)		*1.13*	
PVD diameter	d	*0.05*	m

Definitions

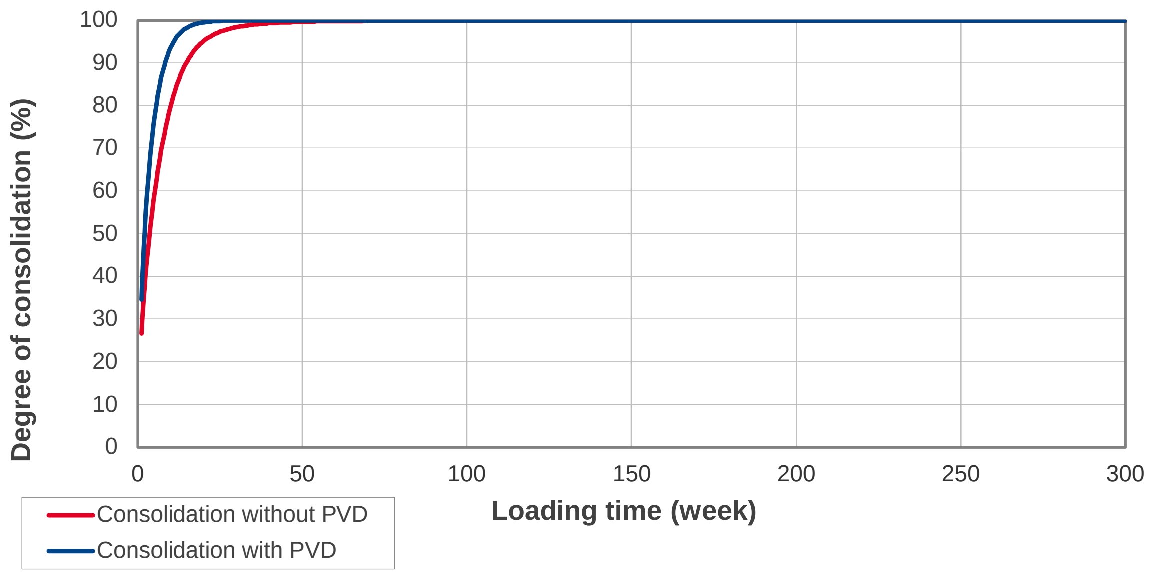
$$F(n) = \frac{n^2}{n^2-1}\ln(n) - \frac{3n^2-1}{4n^2}, \text{ et } n = \frac{D}{d}$$

$$T_v = \frac{C_v \times t}{H_{dr}^2}$$

$$U_v = \left(1 + \frac{1}{2T_v^3}\right)^{\frac{-1}{6}}$$

$$U_r = 1 - e^{\left(\frac{-8C_r \times t}{D^2 F(n)}\right)}$$

Graphical results



Results and verifications

Degree of consolidation		*Value*	*Unit*
Loading time	**t**	*4*	*weeks*
Consolidation without PVD (vertical)	Uv	53.16	%
Consolidation with PVD (global)	U	70.45	%

$$(1 - U) = (1 - U_v)(1 - U_r)$$

Consolidation target		*Value*	*Unit*
Degree of consolidation	U	*3*	%
Loading time			
Loading without PVD	t	1	weeks
Loading with PVD	t	1	weeks

Vertical Drains consolidation

Project name : *V29949 - Project Olympus - Silvertown, London*
Layer 2 - Alluvium - model 3 - consolidation target 24%

DATA Input

Soil parameters		Value	Unit
Vertical consolidation coefficient	Cv	*2.7E-07*	m²/s
Radial consolidation coefficient	Cr	*8.1E-07*	m²/s
Drained sides (1 ou 2)		*2*	
Drained thickness	h	*3.4*	m

Vertical drains parameters		Value	Unit
Mesh	L	*2.8*	m
Triangular (1.05); Squared (1.13)		*1.13*	
PVD diameter	d	*0.05*	m

Definitions

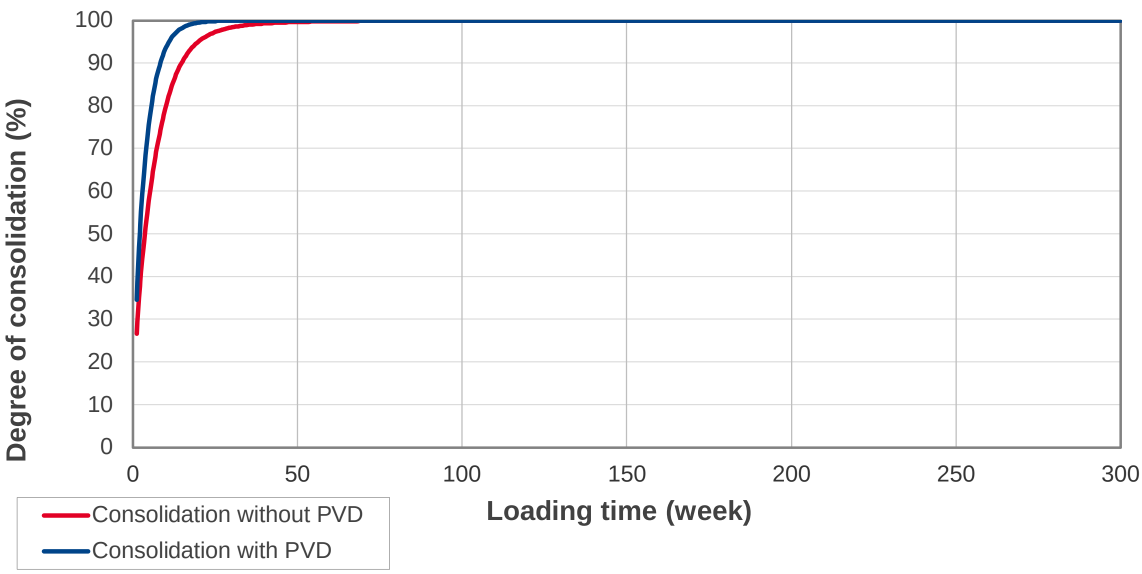
$$F(n) = \frac{n^2}{n^2-1}\ln(n) - \frac{3n^2-1}{4n^2}, \text{ et } n = \frac{D}{d}$$

$$T_v = \frac{C_v \times t}{H_{dr}^2}$$

$$U_v = \left(1 + \frac{1}{2T_v^3}\right)^{\frac{-1}{6}}$$

$$U_r = 1 - e^{\left(\frac{-8C_r \times t}{D^2 F(n)}\right)}$$

Graphical results



Results and verifications

Degree of consolidation		Value	Unit
Loading time	**t**	*4*	*weeks*
Consolidation without PVD (vertical)	Uv	53.16	%
Consolidation with PVD (global)	U	70.45	%

$$(1 - U) = (1 - U_v)(1 - U_r)$$

Consolidation target		Value	Unit
Degree of consolidation	U	*24*	%
Loading time			
Loading without PVD	t	1	weeks
Loading with PVD	t	1	weeks

Vertical Drains consolidation

Project name : ***V29949 - Project Olympus - Silvertown, London***
Layer 2 - Alluvium - model 4 - consolidation target 39%

DATA Input

Soil parameters		Value	Unit
Vertical consolidation coefficient	Cv	*2.7E-07*	m²/s
Radial consolidation coefficient	Cr	*8.1E-07*	m²/s
Drained sides (1 ou 2)		*2*	
Drained thickness	h	*3.4*	m

Vertical drains parameters		Value	Unit
Mesh	L	*2.8*	m
Triangular (1.05); Squared (1.13)		*1.13*	
PVD diameter	d	*0.05*	m

Definitions

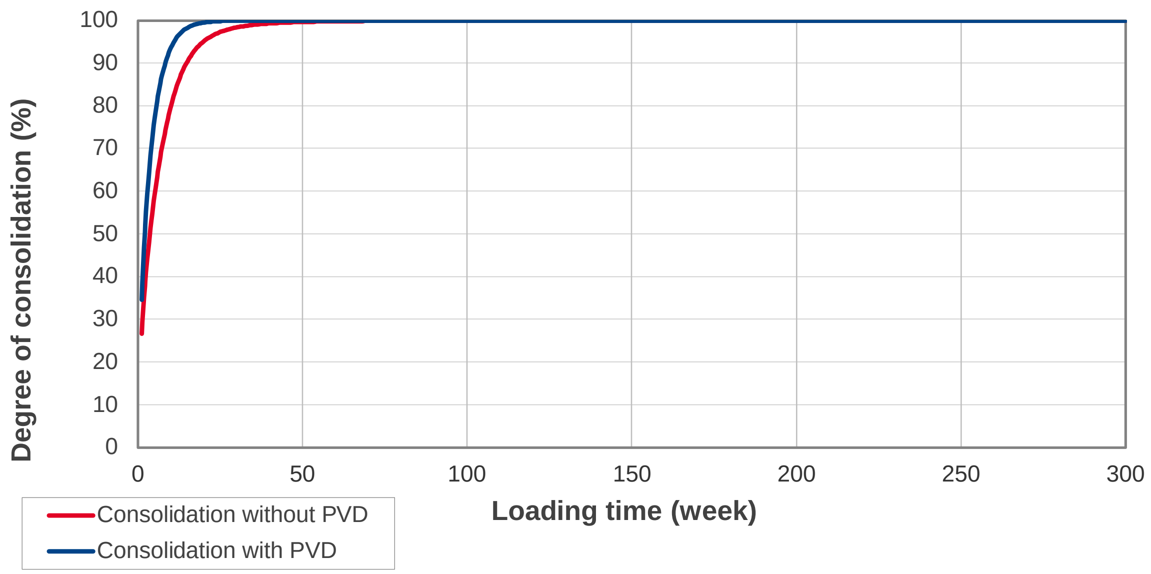
$$F(n) = \frac{n^2}{n^2-1}\ln(n) - \frac{3n^2-1}{4n^2}, \text{ et } n = \frac{D}{d}$$

$$T_v = \frac{C_v \times t}{H_{dr}^2}$$

$$U_v = \left(1 + \frac{1}{2T_v^3}\right)^{\frac{-1}{6}}$$

$$U_r = 1 - e^{\left(\frac{-8C_r \times t}{D^2 F(n)}\right)}$$

Graphical results



Results and verifications

Degree of consolidation		Value	Unit
Loading time	**t**	*4*	*weeks*
Consolidation without PVD (vertical)	Uv	53.16	%
Consolidation with PVD (global)	U	70.45	%

$$(1-U) = (1-U_v)(1-U_r)$$

Consolidation target		Value	Unit
Degree of consolidation	U	*39*	%
Loading time			
Loading without PVD	t	3	weeks
Loading with PVD	t	2	weeks

APPENDIX 2: DETAILED CALCULATIONS FOR THE CMC BENEATH THE FOOTINGS

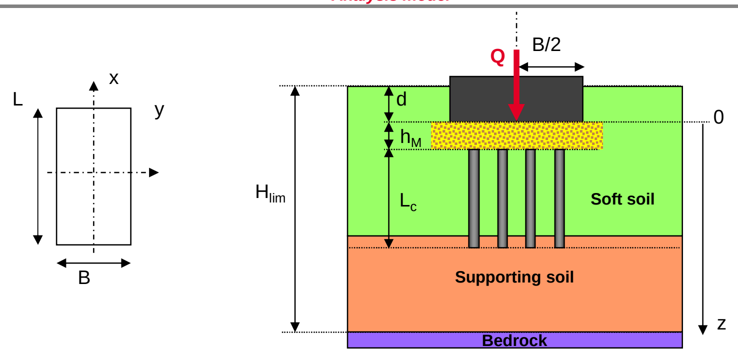
CALCULATION OF FOOTING ON CONTROLLED MODULUS COLUMNS

Project name : **V29949 - Project Olympus - Silvertown**
Guardhouse - Pad

Rectangular footing : 0.65 m x 0.65 m embedded of 0.44 m loaded at 63.375 kN

Calculation according to O.Combarieu method (Fondations mixtes. LCPC 1988)
Taking into account the Frank & Zhao method for the settlement calculation of CMC

Analysis model



Soil improvement definition

Dimensions

L_c	6.3 m	*Columns length*	H	6.3 m	*Anchoring depth of CMC from the the footing base*
D_c	0.28 m	*Columns diameter*	R_c	0.14 m	*Columns radius*

Description of the columns material

E_c	8,500,000 kPa	*Young modulus*
f_{ck}	12.0 MPa	*28-day unconfined compressive strength*

Soil displ. : With — Type of control : Load-bearing capacity
ULS : Fundamental — Presence of reinf. : No

$f_{cd;avg;SLS}$	3.4 MPa	*SLS average compressive stress allowable by the material*
$f_{cd;avg;ULS}$	6.1 MPa	*ULS average compressive stress allowable by the material*

Description of bearing soil layer

q_b	4,800 kPa	*Limit soil resistance at the column bottom*
k_q	4.8	*Frank & Zhao factor for the toe (extracted from the table below)*
E_m	63,000 kPa	*Pressuremeter modulus*

k_q values (according to Frank & Zhao)	
Fine-grained soils	11
Coarse-grained soils	4.8

Description of the footing

Type of footing : Rectangular

Dimensions of the rectangular footing :

L	0.65 m	*Length of the footing*
B	0.65 m	*Width of the footing*

Number of CMC under the footing :

n	1	*Number of CMC under the footing*

Description of natural soil surrounding the columns

q_{net}	500 kPa	*Net soil resistance under the footing without reinforcement*

Spheric component :
λ_c 1.10
α_c 0.25

Deviatoric component :
λ_d 1.12
α_d 0.35

*Terms λ are **automatically** extracted from the table below (as a function of L/B)*
(Note : for a strip footing we consider L/B=∞)

L/B : 1.00

L/B	cercle	carré	2	3	5	20
λ_c	1,00	1,10	1,20	1,30	1,40	1,50
λ_d	1,00	1,12	1,53	1,78	2,14	2,65

Description of the Load Transfer Platform

h_M	0.00 m	*LTP thickness*

Description of natural soil

H_w 2.53 m *Depth of the groundwater table in relation to the footing underside*

Layer n°	H (m)	E_m (kPa)	α (-)	q_s (kPa)	k_T (-)	γ (kN/m^3)	Ktanδ (-)	z (m)
1	0.50	12,500	0.25	105	0.8	20	1.00	0.50
2	0.80	8,750	0.33	80	0.8	18	1.00	1.30
3	3.40	2,000	1.00	14	2.0	18	0.20	4.70
4	1.10	10,500	0.33	90	0.8	20	1.00	5.80
5	0.50	21,000	0.33	135	0.8	20	1.00	6.30
6	1.70	21,000	0.33	135	0.8	20	1.00	8.00

Notations

- *H* — *Thickness of the layer*
- *E_m* — *Pressuremeter modulus of the layer*
- α — *Structural coefficient*
- *q_s* — *Ultimate skin friction in the layer (NF P 94-262)*
- *K'* — *Frank & Zhao factor for the friction (according to the table below)*
- *z* — *Depth of the layer base*
- γ — *Unit weight of the layer*
- *Ktanδ* — *Empirical factor related to the type of inclusion and to soil nature*

Note : By convention, the bottom of CMC is at layer n° 5.

k_T values (according to Frank & Zhao)	
Fine-grained soils	2
Coarse-grained soils	0.8

Results

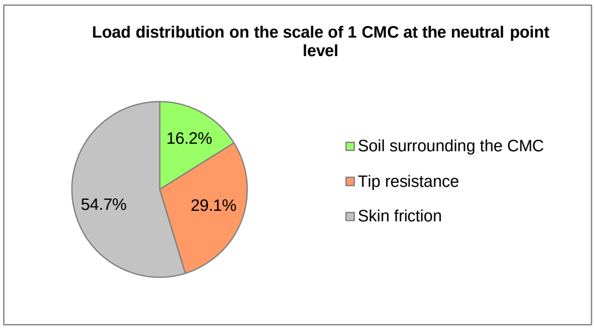
SLS load applied on the footing :
$Q(-h_M)$ **63** kN

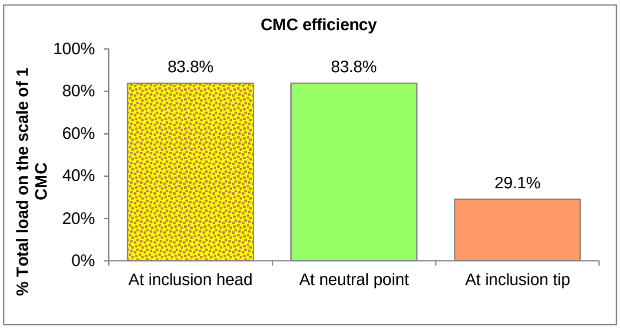
Reinforced soil settlement :
W **1** mm

Settlement distribution

Settlement of deep layers (below CMC)	0 mm
Punching at the inclusion tip	0 mm
Punching at the inclusion head	0 mm
Elastic shortening of the inclusion	0 mm

SLS load distribution	*per inclusion*	*% total load*	*on all*	*% total load*
Load applied on the inclusion head	53.1 kN	83.8%	53.1 kN	83.8%
Negative skin friction along the inclusion	0.0 kN	0.0%	0.0 kN	0.0%
Max. load in inclusion	53.1 kN	83.8%	53.1 kN	83.8%
Positive skin friction	34.7 kN	54.7%	34.7 kN	54.7%
Load applied on the inclusion tip	18.4 kN	29.1%	18.4 kN	29.1%
Neutral point depth	0.00 m			
Stress in the soil at the LTP base	28.4 kPa			
Load transferred to the soil at the LTP base	10.2 kN	16.2%	10.2 kN	16.2%

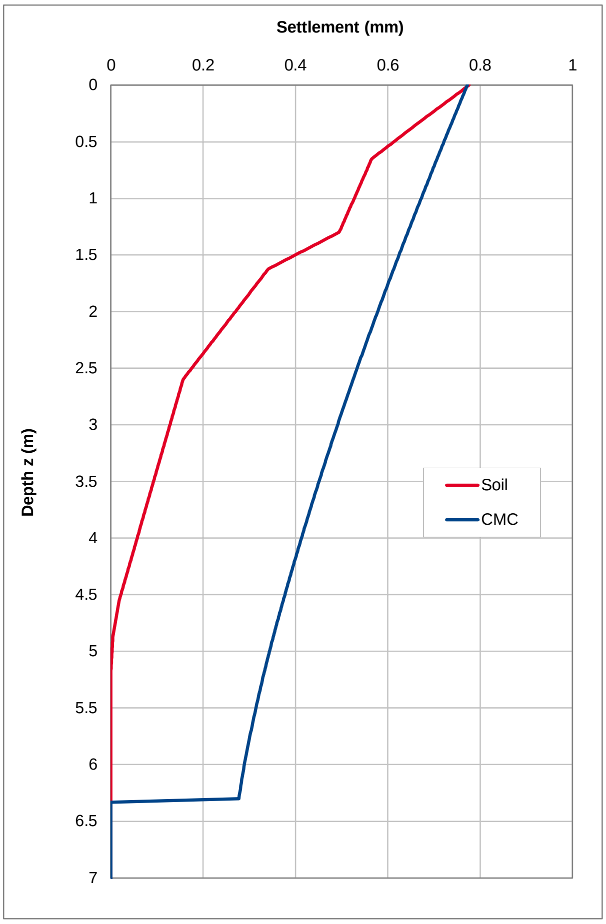


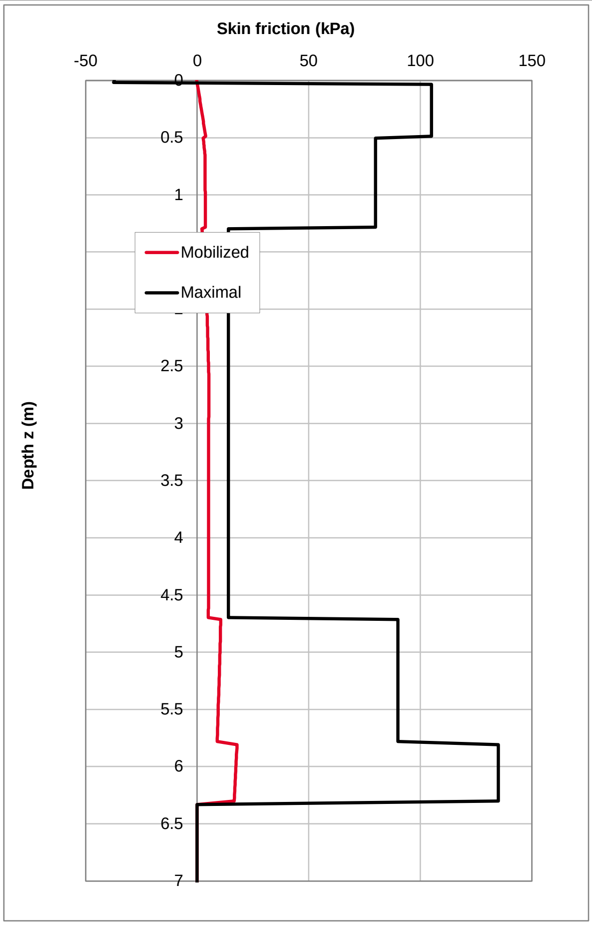


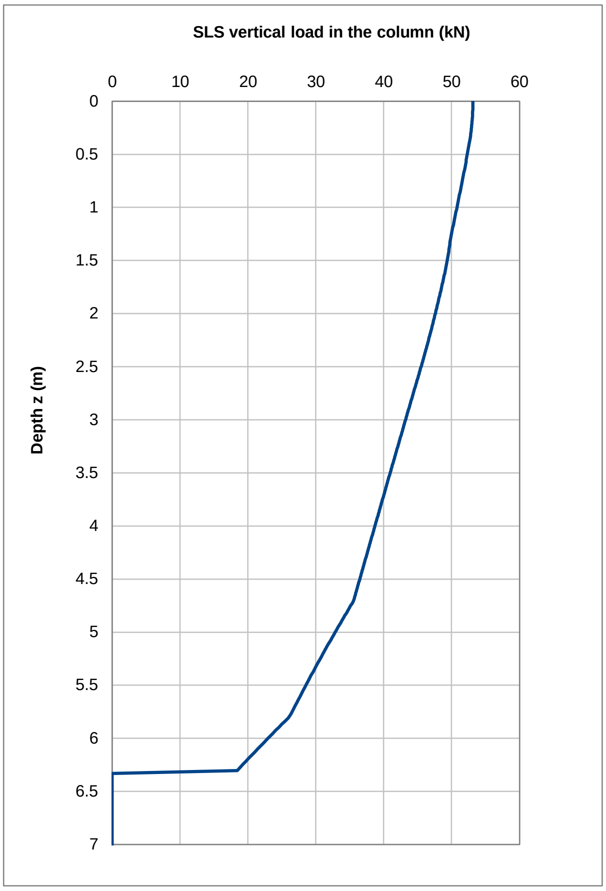
$$N_{ED} \leq R_{v;d} = \frac{q_{net} \times S}{\gamma_{R;d;v} \times \gamma_{R;v}}$$ → **Domain :** **2**

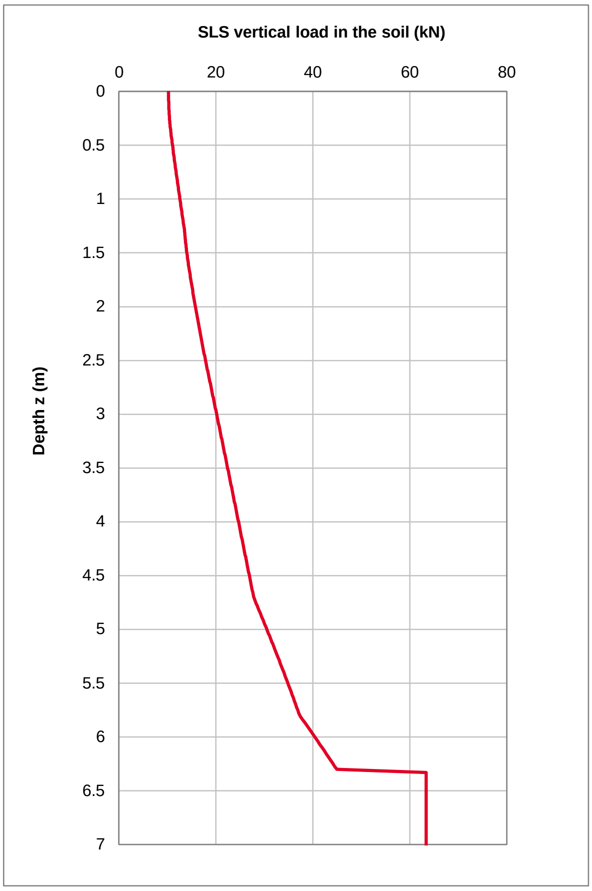
STR verifications: compressive stresses in CMC	*SLS*		*ULS*	
The material used allows an average compressive stress of	3.43 MPa	OK	6.10 MPa	OK
The average compressive stress in the columns is	**0.86 MPa**		**1.29 MPa**	

Graphic results







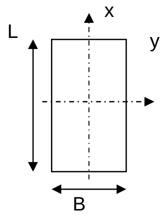


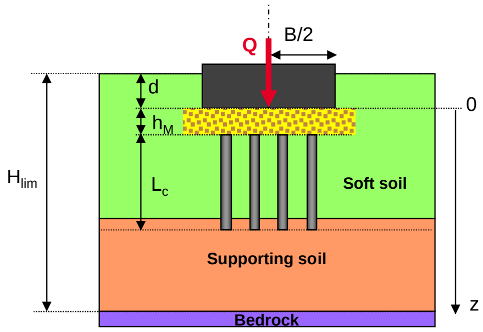
Project name : V29949 - Project Olympus - Silvertown
Waste Tank - Strip

Strip	footing :	2.00 m x 1.00 m	embedded of	0.80 m	loaded at	150 kN/ml

Calculation according to O.Combarieu method (Fondations mixtes. LCPC 1988)
Taking into account the Frank & Zhao method for the settlement calculation of CMC

Analysis model





Soil improvement definition

Dimensions

L_c	6.85 m	*Columns length*	H	6.85 m	*Anchoring depth of CMC from the the footing base*
D_c	0.28 m	*Columns diameter*	R_c	0.14 m	*Columns radius*

Description of the columns material

E_c	8,500,000 kPa	*Young modulus*
f_{ck}	12.0 MPa	*28-day unconfined compressive strength*

Soil displ. : With — Type of control : Load-bearing capacity
ULS : Fundamental — Presence of reinf. : No

$f_{cd;avg;SLS}$	3.4 MPa	*SLS average compressive stress allowable by the material*
$f_{cd;avg;ULS}$	6.1 MPa	*ULS average compressive stress allowable by the material*

Description of bearing soil layer

q_b	4,800 kPa	*Limit soil resistance at the column bottom*
k_q	4.8	*Frank & Zhao factor for the toe (extracted from the table below)*
E_m	63,000 kPa	*Pressuremeter modulus*

k_q values (according to Frank & Zhao)

Fine-grained soils	11
Coarse-grained soils	4.8

Description of the footing

Type of footing : Strip

Dimensions of the strip footing :

L	2 m	*Length of the typical area*
B	1 m	*Width of the footing*

Number of CMC under the footing :

n	1	*Number of CMC under typical area*

Description of natural soil surrounding the columns

q_{net}	500 kPa	*Net soil resistance under the footing without reinforcement*

Spheric component :
λ_c 1.50
α_c 0.27

Deviatoric component :
λ_d 2.65
α_d 0.37

Terms λ are ***automatically*** *extracted from the table below (as a function of L/B)*
(Note : for a strip footing we consider L/B= ∞)

L/B : 20.00

L/B	cercle	carré	2	3	5	20
λ_c	1,00	1,10	1,20	1,30	1,40	1,50
λ_d	1,00	1,12	1,53	1,78	2,14	2,65

Description of the Load Transfer Platform

h_M	0.00 m	*LTP thickness*

Description of natural soil

H_w 3.08 m *Depth of the groundwater table in relation to the footing underside*

Layer n°	H (m)	E_m (kPa)	α (-)	q_s (kPa)	k_τ (-)	γ (kN/m³)	Ktanδ (-)	z (m)
1	0.35	12,500	0.25	105	0.8	20	1.00	0.35
2	1.50	8,750	0.33	80	0.8	18	1.00	1.85
3	3.40	2,000	1.00	14	2.0	18	0.20	5.25
4	1.10	10,500	0.33	90	0.8	20	1.00	6.35
5	0.50	21,000	0.33	135	0.8	20	1.00	6.85
6	1.70	21,000	0.33	135	0.8	20	1.00	8.55

Notations

H	*Thickness of the layer*	γ	*Unit weight of the layer*
E_m	*Pressuremeter modulus of the layer*	Ktanδ	*Empirical factor related to the type of inclusion and to soil nature*
α	*Structural coefficient*		
q_s	*Ultimate skin friction in the layer (NF P 94-262)*		
K'	*Frank & Zhao factor for the friction (according to the table below)*		
z	*Depth of the layer base*		

Note : By convention, the bottom of CMC is at layer n° 5.

k_τ values (according to Frank & Zhao)	
Fine-grained soils	2
Coarse-grained soils	0.8

Results

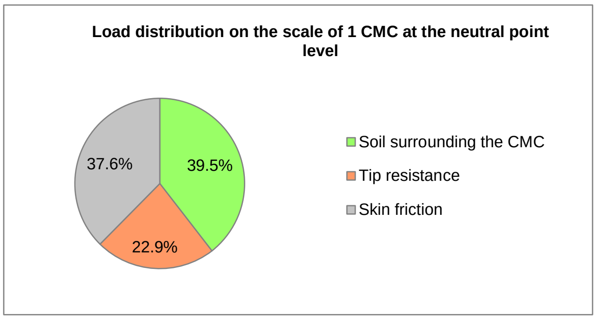
SLS load applied on the footing :
$Q(-h_M)$ **150** kN/ml

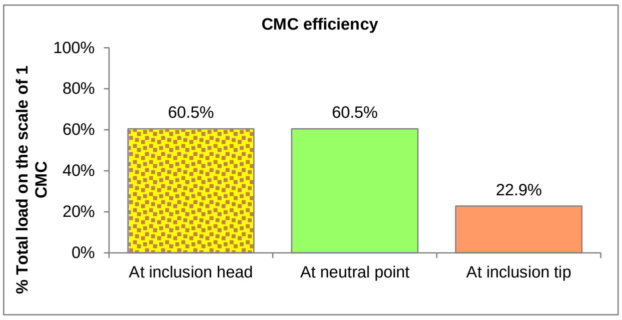
Reinforced soil settlement :
W **3** mm

Settlement distribution

Settlement of deep layers (below CMC)	0 mm
Punching at the inclusion tip	1 mm
Punching at the inclusion head	0 mm
Elastic shortening of the inclusion	2 mm

SLS load distribution	per inclusion	% total load	on all	% total load
Load applied on the inclusion head	181.5 kN	60.5%	181.5 kN	60.5%
Negative skin friction along the inclusion	0.0 kN	0.0%	0.0 kN	0.0%
Max. load in inclusion	181.5 kN	60.5%	181.5 kN	60.5%
Positive skin friction	112.8 kN	37.6%	112.8 kN	37.6%
Load applied on the inclusion tip	68.7 kN	22.9%	68.7 kN	22.9%
Neutral point depth	0.00 m			
Stress in the soil at the LTP base	61.1 kPa			
Load transferred to the soil at the LTP base	118.5 kN	39.5%	118.5 kN	39.5%

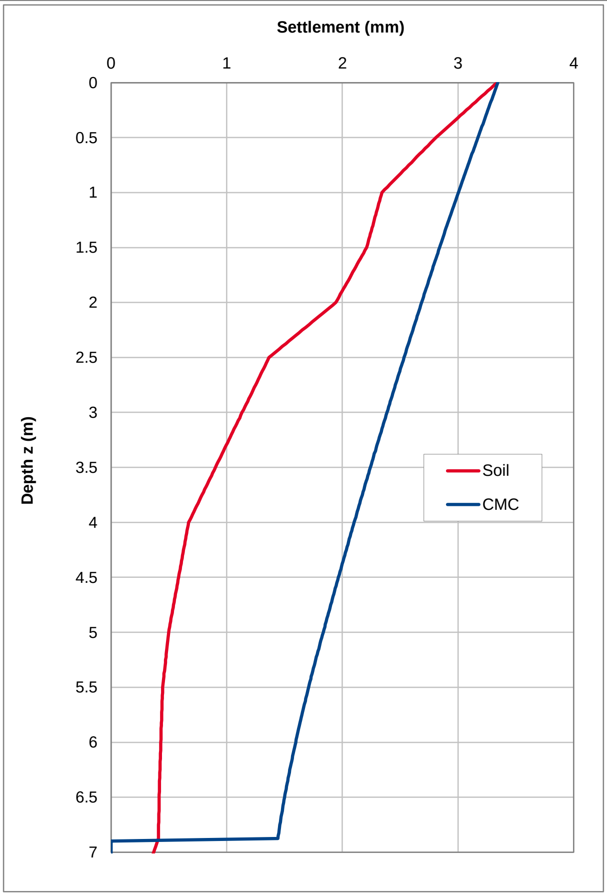


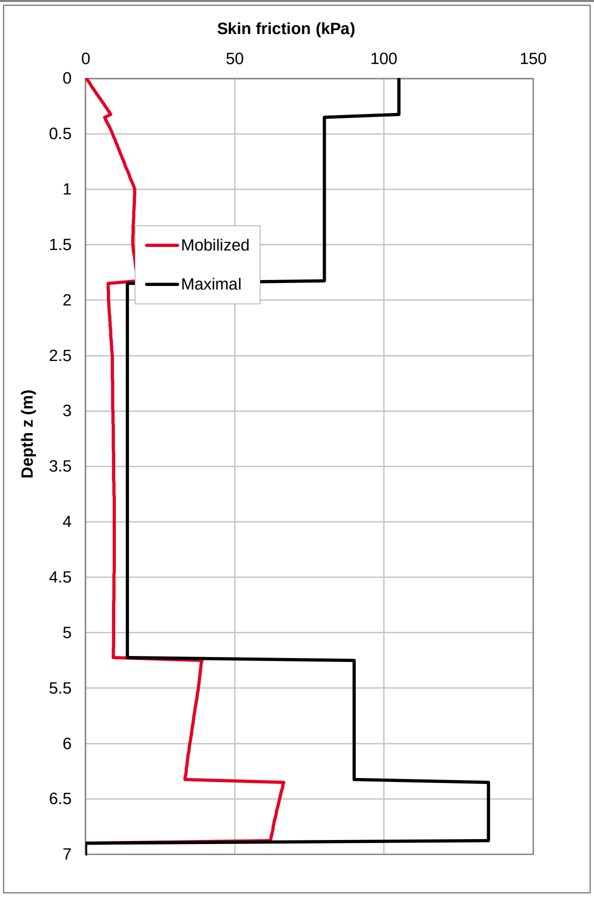


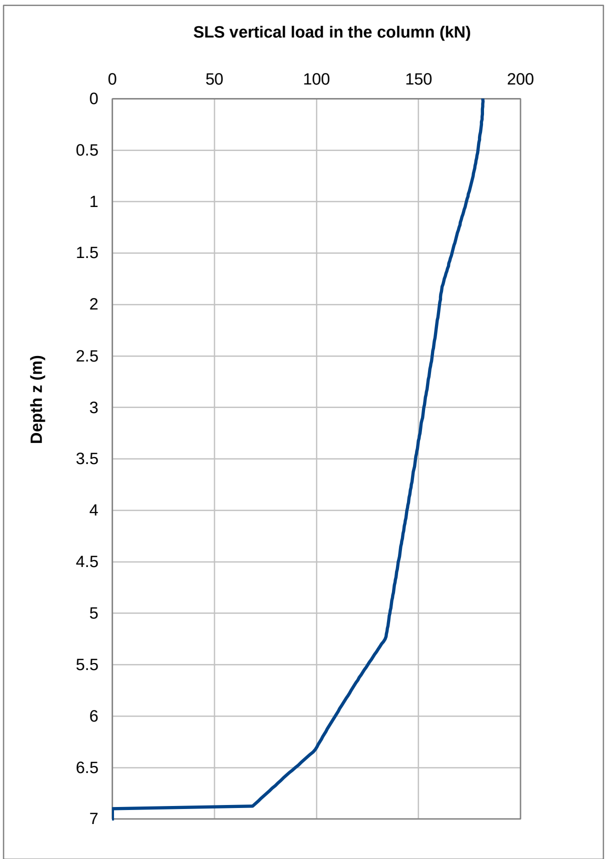
$$N_{ED} \leq R_{v;d} = \frac{q_{net} \times S}{\gamma_{R;d;v} \times \gamma_{R;v}}$$ → **Domain : 2**

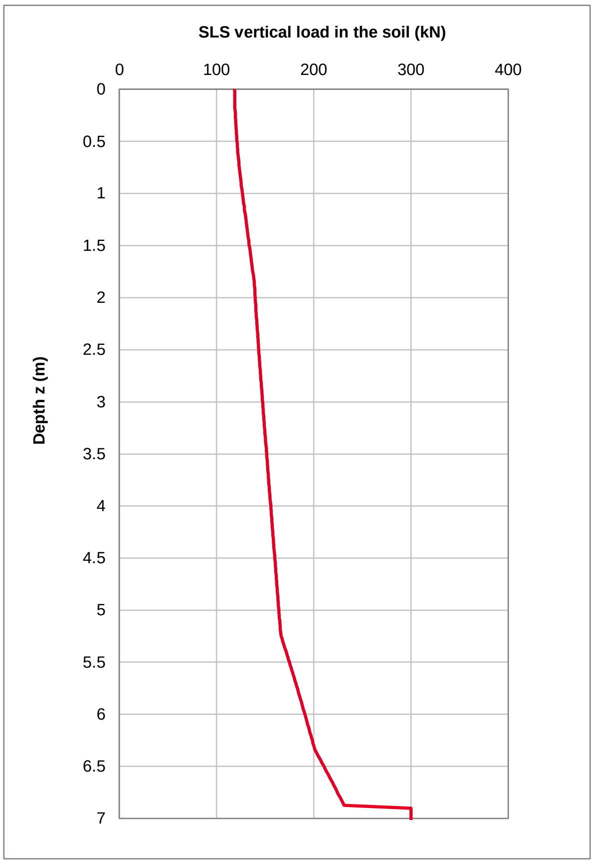
STR verifications: compressive stresses in CMC	SLS		ULS	
The material used allows an average compressive stress of	3.43 MPa	OK	6.10 MPa	OK
The average compressive stress in the columns is	**2.95 MPa**		**4.42 MPa**	

Graphic results







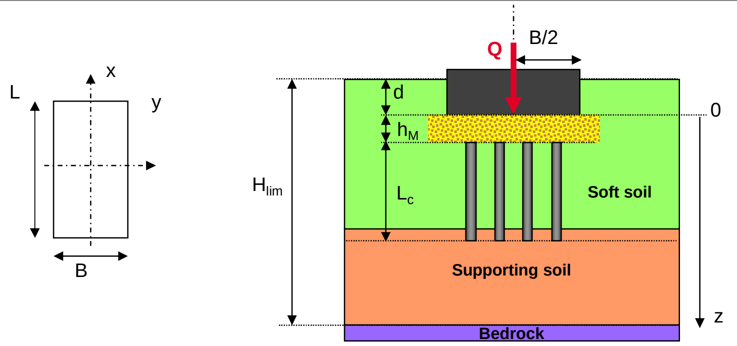


Project name : V29949 - Project Olympus - Silvertown
Guardhouse- Strip

Strip footing : 2.20 m x 0.90 m embedded of 0.44 m loaded at 135 kN/ml

Calculation according to O.Combarieu method (Fondations mixtes. LCPC 1988)
Taking into account the Frank & Zhao method for the settlement calculation of CMC

Analysis model



Soil improvement definition

Dimensions

L_c	6.3 m	*Columns length*	H	6.3 m	*Anchoring depth of CMC from the the footing base*
D_c	0.28 m	*Columns diameter*	R_c	0.14 m	*Columns radius*

Description of the columns material

E_c	8,500,000 kPa	*Young modulus*
f_{ck}	12.0 MPa	*28-day unconfined compressive strength*

Soil displ. : With — Type of control : Load-bearing capacity
ULS : Fundamental — Presence of reinf. : No

$f_{cd;avg;SLS}$	3.4 MPa	*SLS average compressive stress allowable by the material*
$f_{cd;avg;ULS}$	6.1 MPa	*ULS average compressive stress allowable by the material*

Description of bearing soil layer

q_b	4,800 kPa	*Limit soil resistance at the column bottom*
k_q	4.8	*Frank & Zhao factor for the toe (extracted from the table below)*
E_m	63,000 kPa	*Pressuremeter modulus*

k_q values (according to Frank & Zhao)	
Fine-grained soils	11
Coarse-grained soils	4.8

Description of the footing

Type of footing : Strip

Dimensions of the strip footing :

L	2.2 m	*Length of the typical area*
B	0.9 m	*Width of the footing*

Number of CMC under the footing :

n	1	*Number of CMC under typical area*

Description of natural soil surrounding the columns

q_{net}	500 kPa	*Net soil resistance under the footing without reinforcement*

Spheric component :
λ_c 1.50
α_c 0.25

Deviatoric component :
λ_d 2.65
α_d 0.37

Terms λ are ***automatically*** *extracted from the table below (as a function of L/B)*
(Note : for a strip footing we consider L/B= ∞)

L/B : 20.00

L/B	cercle	carré	2	3	5	20
λ_c	1,00	1,10	1,20	1,30	1,40	1,50
λ_d	1,00	1,12	1,53	1,78	2,14	2,65

Description of the Load Transfer Platform

h_M	0.00 m	*LTP thickness*

Description of natural soil

H_w 2.53 m *Depth of the groundwater table in relation to the footing underside*

Layer n°	H (m)	E_m (kPa)	α (-)	q_s (kPa)	k_τ (-)	γ (kN/m³)	Ktanδ (-)	z (m)
1	0.50	12,500	0.25	105	0.8	20	1.00	0.50
2	0.80	8,750	0.33	80	0.8	18	1.00	1.30
3	3.40	2,000	1.00	14	2.0	18	0.20	4.70
4	1.10	10,500	0.33	90	0.8	20	1.00	5.80
5	0.50	21,000	0.33	135	0.8	20	1.00	6.30
6	1.70	21,000	0.33	135	0.8	20	1.00	8.00

Notations

H	*Thickness of the layer*	*γ*	*Unit weight of the layer*
E_m	*Pressuremeter modulus of the layer*	*Ktanδ*	*Empirical factor related to the type of inclusion and to soil nature*
α	*Structural coefficient*		
q_s	*Ultimate skin friction in the layer (NF P 94-262)*		
K'	*Frank & Zhao factor for the friction (according to the table below)*		
z	*Depth of the layer base*		

Note : By convention, the bottom of CMC is at layer n° 5.

k_τ values (according to Frank & Zhao)	
Fine-grained soils	2
Coarse-grained soils	0.8

Results

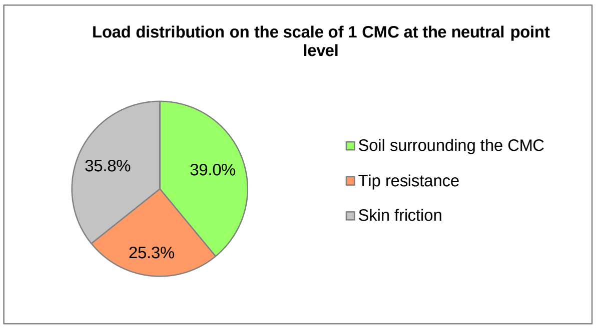
SLS load applied on the footing :
Q($-h_M$) **135** kN/ml

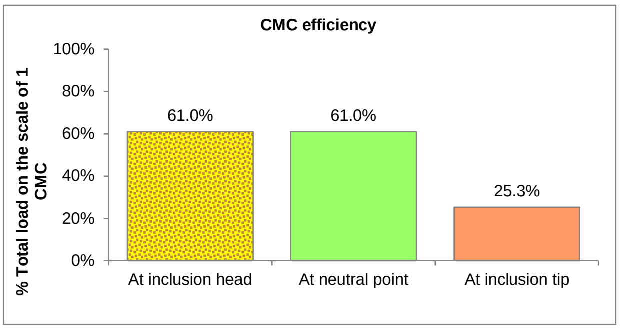
Reinforced soil settlement :
W **3** mm

Settlement distribution

Settlement of deep layers (below CMC)	0 mm
Punching at the inclusion tip	1 mm
Punching at the inclusion head	0 mm
Elastic shortening of the inclusion	2 mm

SLS load distribution	*per inclusion*	*% total load*	*on all*	*% total load*
Load applied on the inclusion head	181.2 kN	61.0%	181.2 kN	61.0%
Negative skin friction along the inclusion	0.0 kN	0.0%	0.0 kN	0.0%
Max. load in inclusion	181.2 kN	61.0%	181.2 kN	61.0%
Positive skin friction	106.2 kN	35.8%	106.2 kN	35.8%
Load applied on the inclusion tip	75.0 kN	25.3%	75.0 kN	25.3%
Neutral point depth	0.00 m			
Stress in the soil at the LTP base	60.4 kPa			
Load transferred to the soil at the LTP base	115.8 kN	39.0%	115.8 kN	39.0%

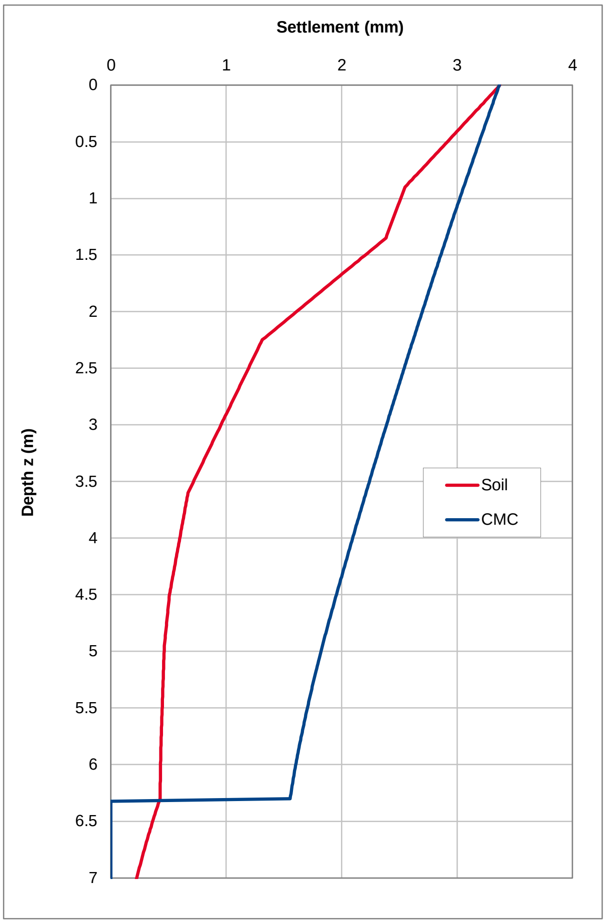


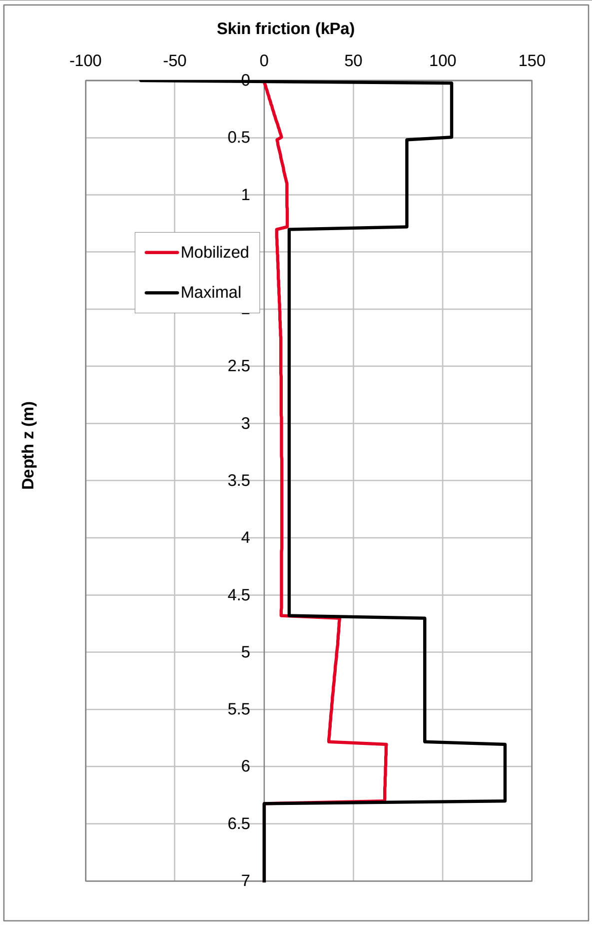


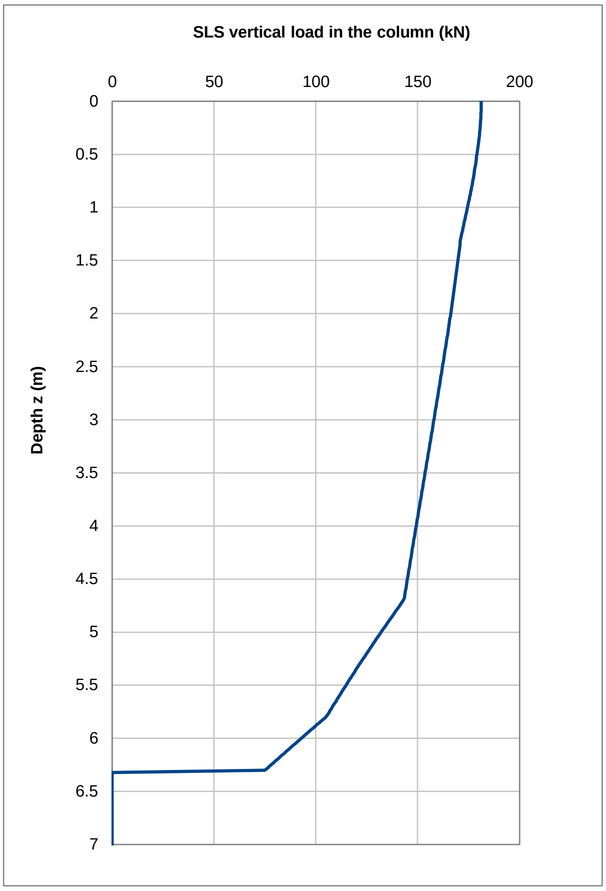
$$N_{ED} \leq R_{v;d} = \frac{q_{net} \times S}{\gamma_{R;d;v} \times \gamma_{R;v}}$$ → **Domain : 2**

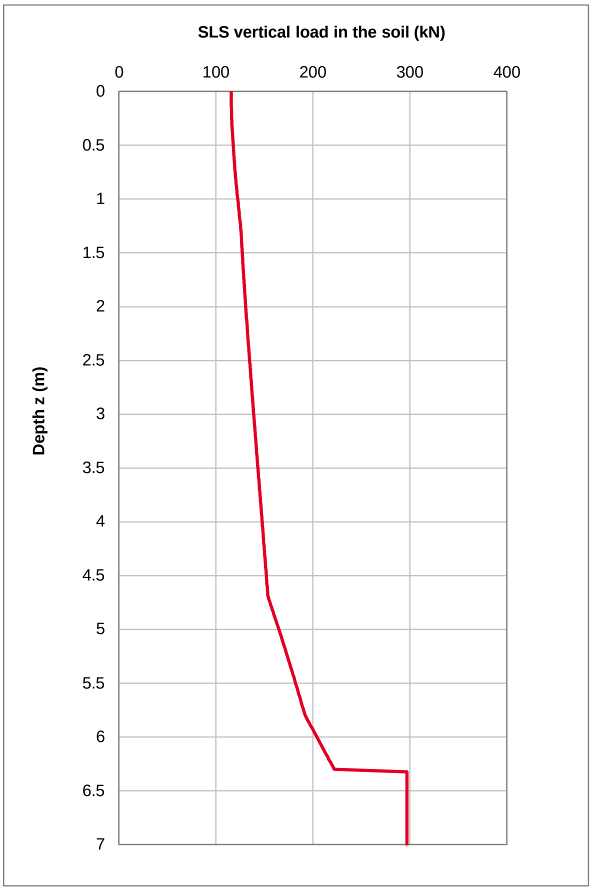
STR verifications: compressive stresses in CMC	*SLS*		*ULS*	
The material used allows an average compressive stress of	3.43 MPa	OK	6.10 MPa	OK
The average compressive stress in the columns is	**2.94 MPa**		**4.41 MPa**	

Graphic results









CALCULATION OF FOOTING ON CONTROLLED MODULUS COLUMNS

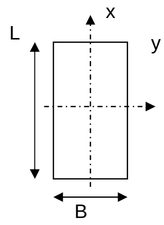
MENARD

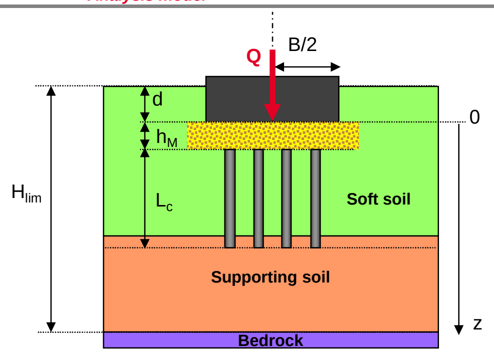
Project name : **V29949 - Project Olympus - Silvertown**
Dust Canopy Strip foundation

Strip footing : 1.80 m x 1.50 m embedded of 0.90 m loaded at 225 kN/ml

Calculation according to O.Combarieu method (Fondations mixtes. LCPC 1988)
Taking into account the Frank & Zhao method for the settlement calculation of CMC

Analysis model





Soil improvement definition

Dimensions

L_c	5.4 m	*Columns length*	H	5.4 m	*Anchoring depth of CMC from the the footing base*
D_c	0.28 m	*Columns diameter*	R_c	0.14 m	*Columns radius*

Description of the columns material

E_c	8,500,000 kPa	*Young modulus*
f_{ck}	12.0 MPa	*28-day unconfined compressive strength*

Soil displ. : With — Type of control : Load-bearing capacity
ULS : Fundamental — Presence of reinf. : No

$f_{cd;avg;SLS}$	2.9 MPa	*SLS average compressive stress allowable by the material*
$f_{cd;avg;ULS}$	5.1 MPa	*ULS average compressive stress allowable by the material*

Description of bearing soil layer

q_b	4,800 kPa	*Limit soil resistance at the column bottom*
k_q	4.8	*Frank & Zhao factor for the toe (extracted from the table below)*
E_m	21,000 kPa	*Pressuremeter modulus*

k_q values (according to Frank & Zhao)	
Fine-grained soils	11
Coarse-grained soils	4.8

Description of the footing

Type of footing : Strip

Dimensions of the strip footing :

L	1.8 m	*Length of the typical area*
B	1.5 m	*Width of the footing*

Number of CMC under the footing :

n	2	*Number of CMC under typical area*

Description of natural soil surrounding the columns

q_{net}	230 kPa	*Net soil resistance under the footing without reinforcement*

Spheric component :

λ_c 1.50
α_c 0.48

Deviatoric component :

λ_d 2.65
α_d 0.60

*Terms λ are **automatically** extracted from the table below (as a function of L/B)*
(Note : for a strip footing we consider L/B= ∞)

L/B : 20.00

L/B	cercle	carré	2	3	5	20
λ_c	1,00	1,10	1,20	1,30	1,40	1,50
λ_d	1,00	1,12	1,53	1,78	2,14	2,65

Description of the Load Transfer Platform

h_M	0.00 m	*LTP thickness*

Description of natural soil

H_w 1.625 m — *Depth of the groundwater table in relation to the footing underside*

Layer n°	H (m)	E_m (kPa)	α (-)	q_s (kPa)	k_T (-)	γ (kN/m^3)	Ktanδ (-)	z (m)
1	0.40	8,750	0.33	80	0.8	18	1.00	0.40
2	3.40	2,000	1.00	14	2.0	18	0.20	3.80
3	1.10	10,500	0.33	90	0.8	20	1.00	4.90
4	0.50	21,000	0.33	135	0.8	20	1.00	5.40
5	1.70	21,000	0.33	135	0.8	20	1.00	7.10

Notations

H	*Thickness of the layer*	*γ*	*Unit weight of the layer*
E_m	*Pressuremeter modulus of the layer*	*Ktanδ*	*Empirical factor related to the type of inclusion and to soil nature*
α	*Structural coefficient*		
q_s	*Ultimate skin friction in the layer (NF P 94-262)*		
K'	*Frank & Zhao factor for the friction (according to the table below)*		
z	*Depth of the layer base*		

Note : By convention, the bottom of CMC is at layer n° 4.

k_T values (according to Frank & Zhao)	
Fine-grained soils	2
Coarse-grained soils	0.8

Results

SLS load applied on the footing :
Q($-h_M$) **225** kN/ml

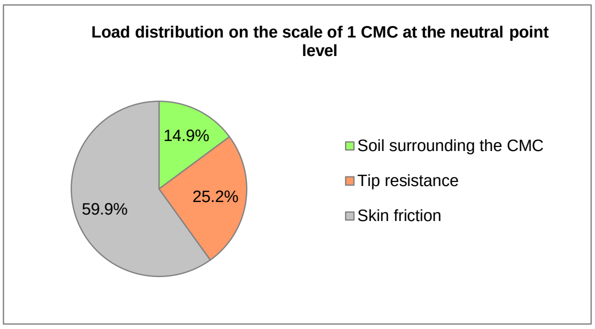
Reinforced soil settlement :
W **5** mm

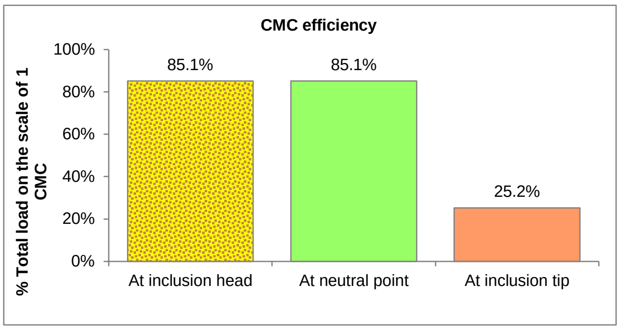
Settlement distribution

Settlement of deep layers (below CMC)	1 mm
Punching at the inclusion tip	2 mm
Punching at the inclusion head	0 mm
Elastic shortening of the inclusion	1 mm

SLS load distribution

	per inclusion	% total load	on all	% total load
Load applied on the inclusion head	172.4 kN	42.6%	344.8 kN	85.1%
Negative skin friction along the inclusion	0.0 kN	0.0%	0.0 kN	0.0%
Max. load in inclusion	172.4 kN	42.6%	344.8 kN	85.1%
Positive skin friction	121.3 kN	30.0%	242.7 kN	59.9%
Load applied on the inclusion tip	51.0 kN	12.6%	102.1 kN	25.2%
Neutral point depth	0.00 m			
Stress in the soil at the LTP base	23.4 kPa			
Load transferred to the soil at the LTP base	30.1 kN	7.4%	60.2 kN	14.9%





$$N_{ED} > R_{v;d} = \frac{q_{net} \times S}{\gamma_{R;d;v} \times \gamma_{R;v}} \rightarrow$$ **Domain : 1**

STR verifications: compressive stresses in CMC

	SLS		ULS	
The material used allows an average compressive stress of	2.86 MPa	OK	5.09 MPa	OK
The average compressive stress in the columns is	**2.80 MPa**		**4.20 MPa**	

GEO verifications : creep resistance and bearing capacity of the ground — SLS

Footing (as defined in french National Application Standards Shallow foundations NF P 94 261)

The soil resistance below the footing is	256 kN	OK
The load applied on the soil at the footing base is	**60 kN**	

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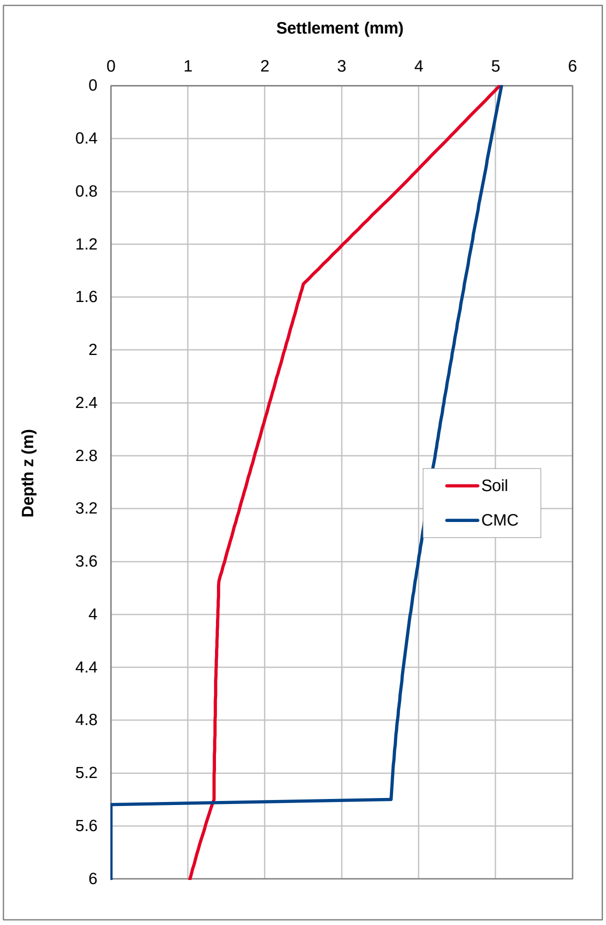
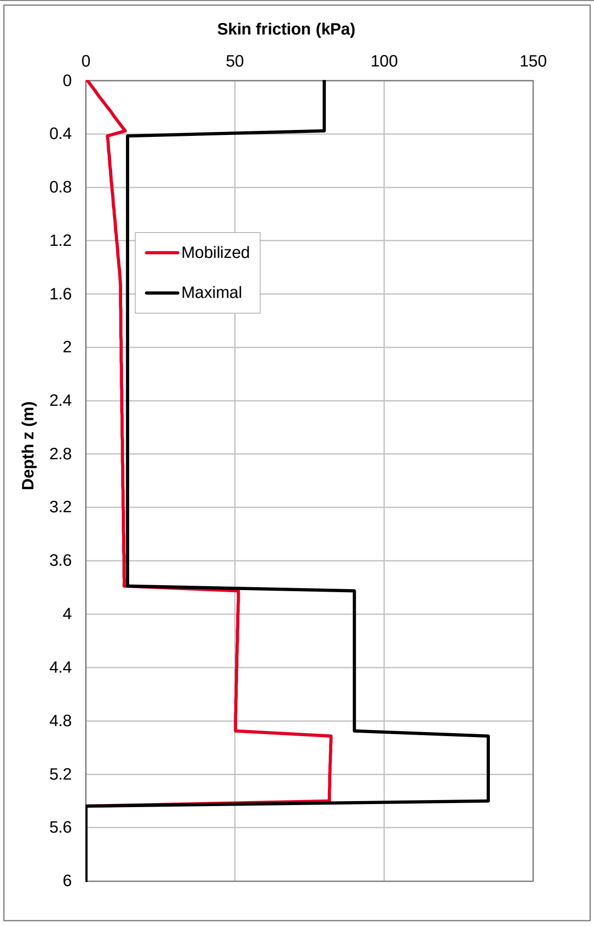
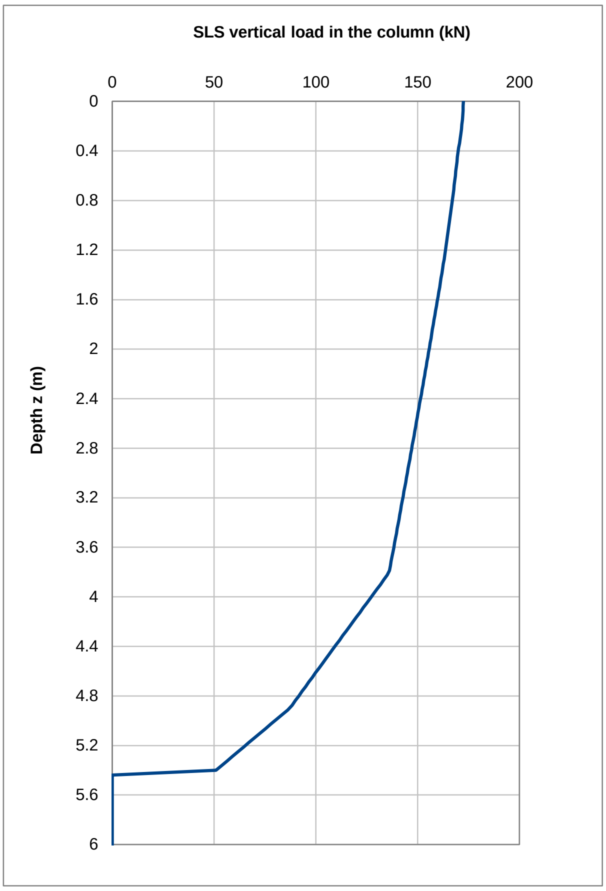
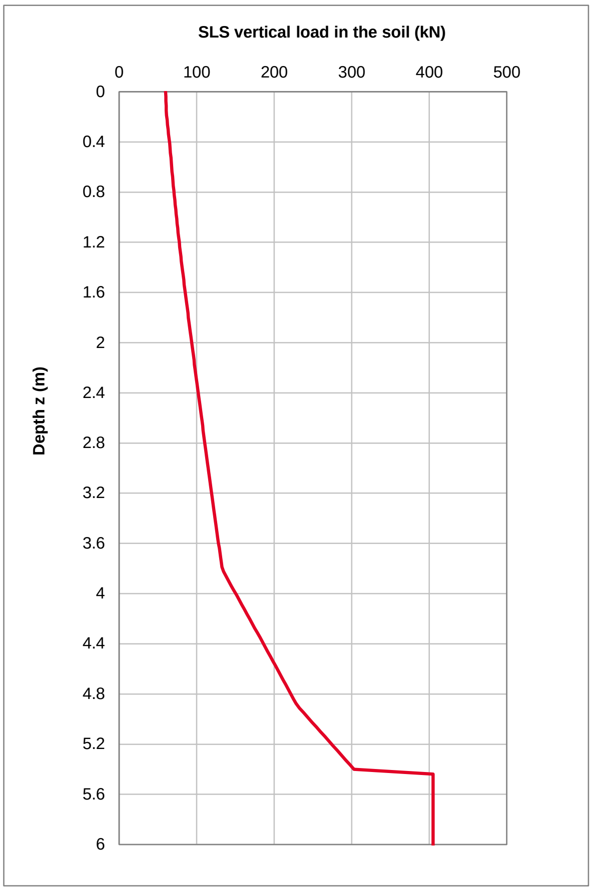
GEO verifications : global bearing capacity of the ground	*SLS*		*ULS*	
The global soil resistance taking into account the CMC is	886 kN	OK	1,130 kN	OK
The load applied on the soil at the footing base is	405 **kN**		**608 kN**	

Graphic results





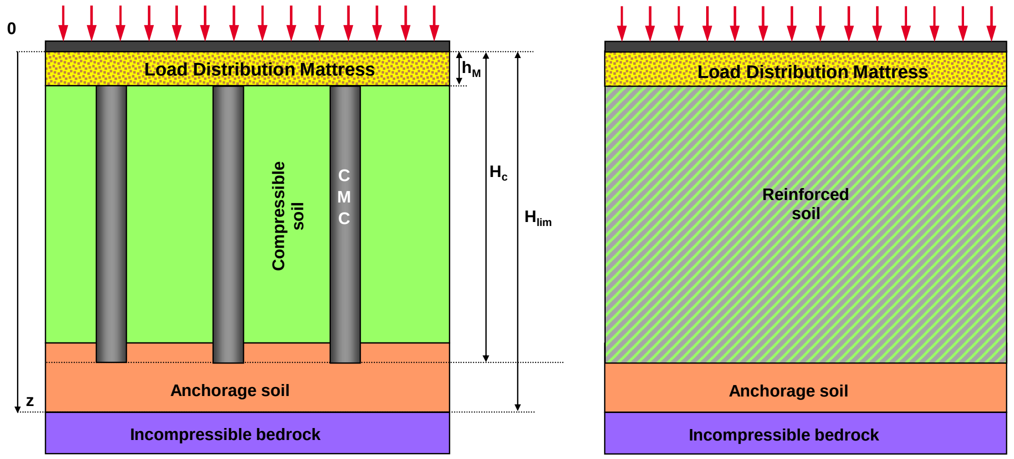




APPENDIX 3: DETAILED CALCULATIONS FOR THE CMC BENEATH GROUND BEARING SLAB

Project name: *V29949 - Project Olympus - Silvertown*
Waste Tank - Slab

Analysis model



Description of reinforced soil

Dimensions

H_c	**6.30**	m	*CMC anchoring depth from LDM top*
D_c	**0.28**	m	*Columns diameter*

Description of the the column material

Verifications STR based on: ASIRI

f_{ck}	**12**	MPa	*28-day unconfined compressive strength*

Soil displ.: With | Type of test: **Load-bearing capacity** | Presence of steel: **No** | ULS: Fundamental

Calculation of deformation modulus: **Concrete**

E_c	8,500,000	kPa	*Young's modulus*
$f_{cd;avg;SLS}$	3.4	MPa	*SLS average compressive stress allowable by the material*
$f_{cd;avg;ULS}$	6.1	MPa	*ULS average compressive stress allowable by the material*

Description of column-soil interaction laws

Concerning the columns base and shaft, the load transfer curves are based on: **Frank & Zhao (1982) / NF P 94-262 (2012)**

Description of bearing soil layer:

q_b	**4,800**	kPa	*Limit soil resistance at the column bottom*	E_M	10.5	MPa	*Pressuremeter modulus at column bottom*

Soil type: coarse

Description of natural soil surrounding the columns

q_{net}	**500**	kPa	*Ultimate resistance of the soil surrounding the columns*

Grid dimensions according to: **Column spacing (equivalent square mesh)**

A	5.29	m²	*Grid section area*
S	**2.30**	m	*Column spacing (equivalent square mesh)*

Description of the load transfer platform

h_M	**0.5**	m	*Thickness of LDM*
φ	**38**	°	*Internal friction angle*
c'	**0**	kPa	*Cohesion*

State: **Added**

Soil profile

H_{lim}	**9.10**	m	*Limit depth of model (geotechnical bedrock or seismic bedrock) from LDM top*
H_w	**3.675**	m	*Depth of the groundwater table from LDM top*

N° Soil	Nature	z_{sup} (m)	z_{inf} (m)	Soil type	E_M (kPa)	α (-)	E_Y (kPa)	ν (-)	γ (kN/m³)	q_s (kPa)	Ktanδ -
1	Load Distribution Mattress	0.00	0.50	coarse	12,500	0.25	50,000	0.30	20		1.00
2	remaining WP	0.50	0.90	coarse	12,500	0.25	50,000	0.30	20	105	1.00
3	made ground sandy	0.90	2.40	coarse	8,750	0.33	26,250	0.30	18	80	1.00
4	soft clays	2.40	5.80	fine	2,000	1.00	2,000	0.30	18	14	0.20
5	Medium dense gravel	5.80	6.90	coarse	10,500	0.33	31,500	0.30	18	90	1.00
6	Dense gravels	6.90	9.10	coarse	21,000	0.33	63,636	0.30	18	135	1.00

Notations

z_{sup}	*Depth of layer top*	γ	*Unit weight of the layer*
z_{inf}	*Depth of layer base*	q_s	*Limit skin friction for the layer*
E_Y	*Young's modulus in the layer*	E_M	*Pressuremeter modulus in the layer*
ν	*Poisson's coefficient*	α	*Structural coefficient*

Remark

According to Frank and Zhao, the following parameters are used with either as fine-grained or as coarse-grained soil:

End-bearing: k_q values	
Fine-grained soils	11 E_M / D_c
Coarse-grained soils	4.8 E_M / D_c

Skin friction: k_τ values	
Fine-grained soils	2 E_M / D_c
Coarse-grained soils	0.8 E_M / D_c

Overview of the stresses applied in the axisymmetrical calculation

		Permanent (kPa)	Variable (kPa)	TOTAL (kPa)
Uniform stress	q_0		50	50

Uniform factored surcharge applied at the LTP base	q_0	**50**	kPa
Factored surcharge applied on the grid at the LTP base	Q	**265**	kN

Results

Settlement W **25** mm

Settlement distribution

Settlement of deep layers (below CMC)	2	mm
Punching at the inclusion bottom	11	mm
Punching at the inclusion head	10	mm
Elastic shortening of the inclusion	2	mm
Settlement of LTP	0	mm

SLS load distribution	per inclusion	% total load
Negative skin friction in LDM	12.5 kN	4.7%
Load applied on inclusion head	93.0 kN	35.2%
Negative skin friction along the inclusion	90.4 kN	34.2%
Max. load in inclusion	183.3 kN	69.3%
Positive skin friction	60.8 kN	23.0%
Load applied on inclusion bottom	122.5 kN	46.3%
Depth of neutral point	4.00 m	
Stress in soil at CMC top level	32.8 kPa	
Load transferred to the soil at CMC top level	171.5 kN	64.8%

Equivalent homogenized soil profile

- load distribution mat

Thickness = 0.5 m

E_{oed} = 67.3 MPa

- reinforced soil

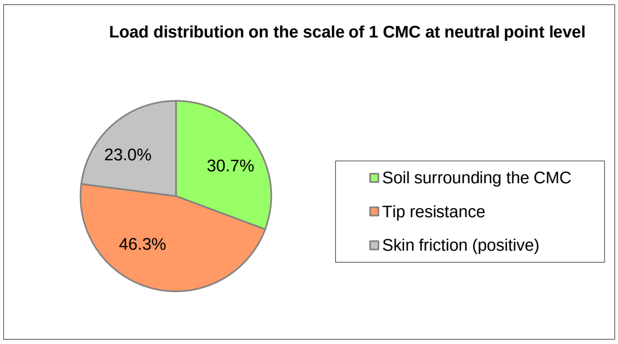
Thickness = 5.8 m

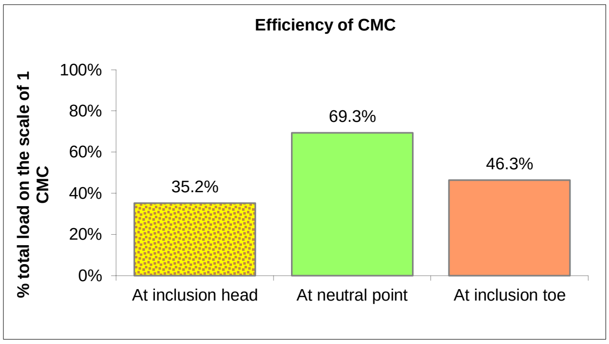
E_{oed} = 12.7 MPa

- soil underlying the reinforced soil

Thickness = 2.8 m

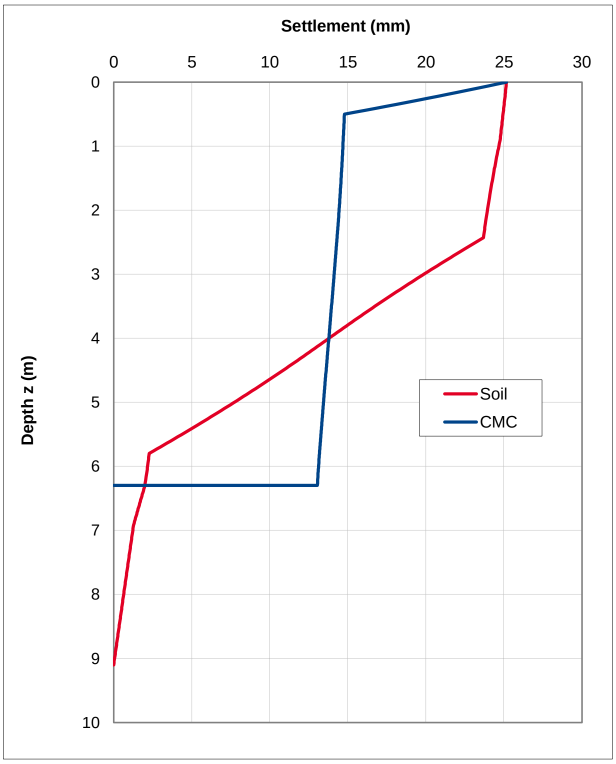
E_{oed} = 70.0 MPa

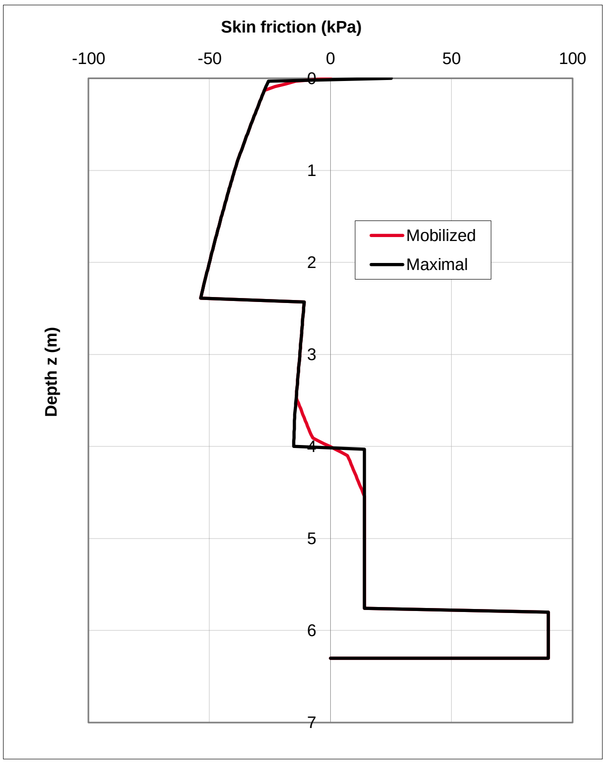


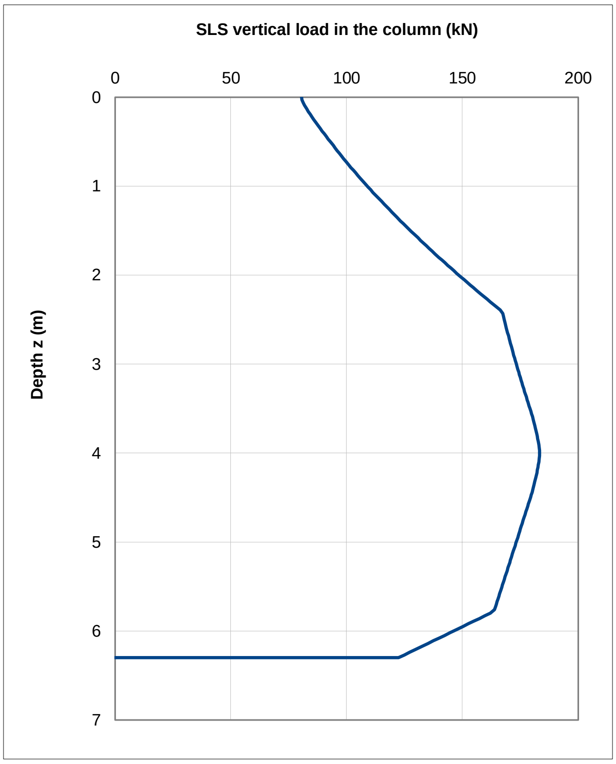


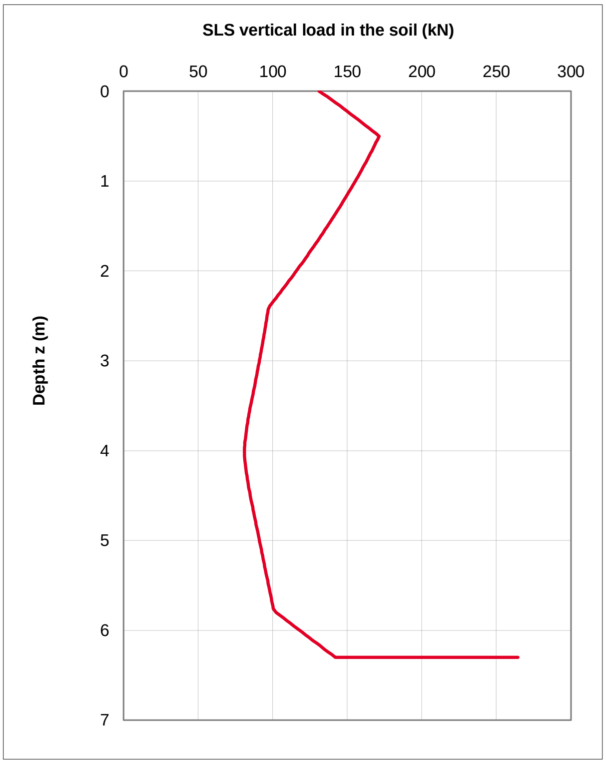
STR verifications: compressive stresses in CMC	*SLS*		*ULS*	
The material used allows an average compressive stress of	3.4 MPa	OK	6.1 MPa	OK
The average compressive stress in the columns is	**3.0 MPa**		**5.3 MPa**	

Graphic results







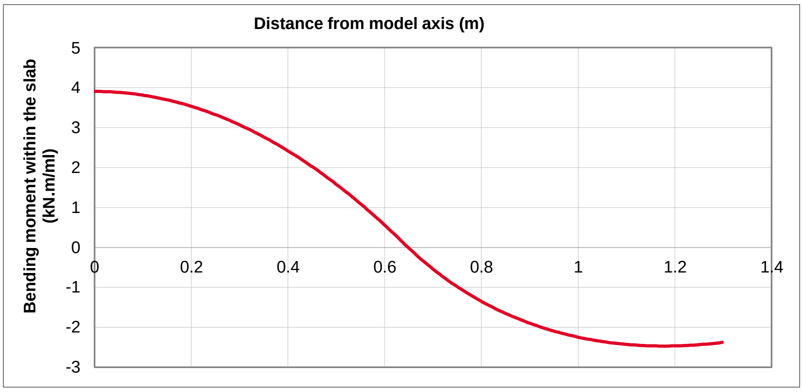


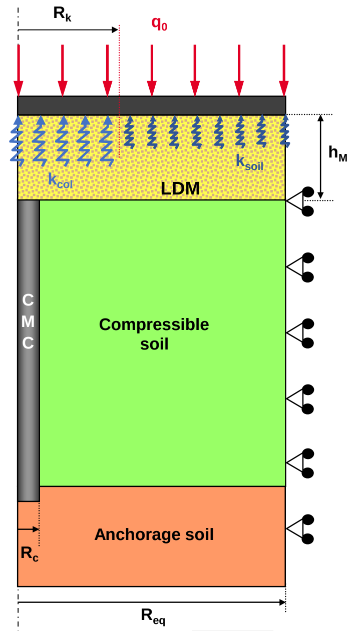
Determination of bending moments M_{sup} and M_{inf} within the slab

The moment in the slab can be determined by a model of a circular plate with a radius R_{eq} on elastic supports. The interaction of the slab and the foundation is modeled by springs with properties estimated for a given loading level. This approach is not applicable for a TR34 ground bearing slab design under a UDL.

The opposite simplified distribution of subgrade reaction coefficients is used for the calculation of the bending moment. This is characterized by:

R_k	0.64 m	*Diffusion radius underneath the ground slab*
σ_{soil}	25.1 kPa	*Average stress applied to the soil (directly below the slab)*
σ_{col}	86.5 kPa	*Average stress applied to the CMC along the diffusion radius R_k (directly below the slab)*
k_{soil}	1.00 MPa/m	*Subgrade reaction coefficient on the underside of a slab removed from the CMC ($R > R_k$)*
k_{col}	3.4 MPa/m	*Subgrade reaction coefficient on the underside of a ground slab adjacent to the axis of the CMC ($R < R_k$)*





Slab thickness	250	mm
Slab Concrete fck	28	MPa

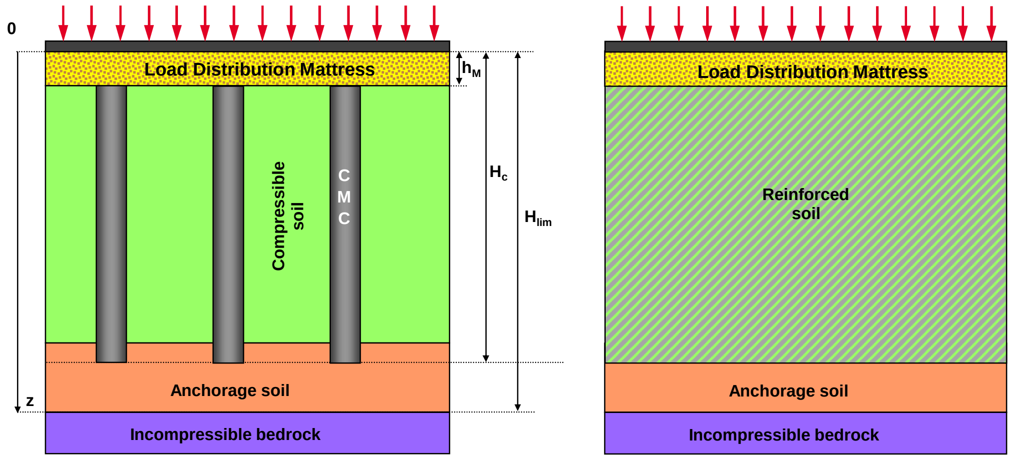
M_{sup}	3.9 kN.m/ml	*Bending moment that loads the upper fiber of the slab in tension*
M_{inf}	-2.5 kN.m/ml	*Bending moment that loads the lower fiber of the slab in tension*

Slab verification: induced tensile stress in the slab from long term consolidation settlements under specified UDL

The slab plain concrete can receive an allowable tensile stress of (TR34 approach)	2.5 MPa	OK
The maximum tensile stress in the slab (envelop moments) is	**0.6 MPa**	

Project name: *V29949 - Project Olympus - Silvertown Guardhouse - Slab*

Analysis model



Description of reinforced soil

Dimensions

H_c	***7.24***	m	*CMC anchoring depth from LDM top*
D_c	***0.28***	m	*Columns diameter*

Description of the the column material

Verifications STR based on: ASIRI

f_{ck}	***12***	MPa	*28-day unconfined compressive strength*

Soil displ.: With — Type of test: ***Load-bearing capacity*** — Presence of steel: ***No*** — ULS: Fundamental

Calculation of deformation modulus: ***Concrete***

E_c	8,500,000	kPa	*Young's modulus*
$f_{cd;avg;SLS}$	3.4	MPa	*SLS average compressive stress allowable by the material*
$f_{cd;avg;ULS}$	6.1	MPa	*ULS average compressive stress allowable by the material*

Description of column-soil interaction laws

Concerning the columns base and shaft, the load transfer curves are based on: ***Frank & Zhao (1982) / NF P 94-262 (2012)***

Description of bearing soil layer:

q_b	***4,800***	kPa	*Limit soil resistance at the column bottom*	E_M	21.0	MPa	*Pressuremeter modulus at column bottom*

Soil type: coarse

Description of natural soil surrounding the columns

q_{net}	***500***	kPa	*Ultimate resistance of the soil surrounding the columns*

Grid dimensions according to: ***Column spacing (equivalent square mesh)***

A	3.42	m²	*Grid section area*
S	***1.85***	m	*Column spacing (equivalent square mesh)*

Description of the load transfer platform

h_M	***0.94***	m	*Thickness of LDM*
φ	***38***	°	*Internal friction angle*
c'	***0***	kPa	*Cohesion*

State: ***Added***

Soil profile

H_{lim}	**8.94**	m	*Limit depth of model (geotechnical bedrock or seismic bedrock) from LDM top*
H_w	**3.465**	m	*Depth of the groundwater table from LDM top*

N° Soil	Nature	z_{sup} (m)	z_{inf} (m)	Soil type	E_M (kPa)	α (-)	E_Y (kPa)	ν (-)	γ (kN/m³)	q_s (kPa)	Ktanδ -
1	Load Distribution Mattress	0.00	0.94	coarse	12,500	0.25	50,000	0.30	20		1.00
2	Remaining WP	0.94	1.44	coarse	12,500	0.25	50,000	0.30	20	105	1.00
3	Made ground	1.44	2.24	coarse	8,750	0.33	26,250	0.30	18	80	1.00
4	Alluvium	2.24	5.64	coarse	2,000	1.00	2,000	0.30	18	14	0.20
5	Medium dense gravel	5.64	6.74	fine	10,500	0.33	31,500	0.30	18	90	1.00
6	Dense gravels	6.74	8.94	coarse	21,000	0.33	63,636	0.30	18	135	1.00

Notations

z_{sup}	*Depth of layer top*	γ	*Unit weight of the layer*
z_{inf}	*Depth of layer base*	q_s	*Limit skin friction for the layer*
E_Y	*Young's modulus in the layer*	E_M	*Pressuremeter modulus in the layer*
ν	*Poisson's coefficient*	α	*Structural coefficient*

Remark

According to Frank and Zhao, the following parameters are used with either as fine-grained or as coarse-grained soil:

End-bearing: k_q values	
Fine-grained soils	11 E_M / D_c
Coarse-grained soils	4.8 E_M / D_c

Skin friction: k_τ values	
Fine-grained soils	2 E_M / D_c
Coarse-grained soils	0.8 E_M / D_c

Overview of the stresses applied in the axisymmetrical calculation

		Permanent (kPa)	Variable (kPa)	TOTAL (kPa)
Uniform stress	q_0		50	50

Uniform factored surcharge applied at the LTP base	q_0	**59**	kPa
Factored surcharge applied on the grid at the LTP base	Q	**201**	kN

Results

Settlement W **25** mm

Settlement distribution

Settlement of deep layers (below CMC)	1	mm
Punching at the inclusion bottom	2	mm
Punching at the inclusion head	19	mm
Elastic shortening of the inclusion	2	mm
Settlement of LTP	0	mm

SLS load distribution	per inclusion		% total load
Negative skin friction in LDM	25.3	kN	12.6%
Load applied on inclusion head	80.7	kN	40.1%
Negative skin friction along the inclusion	74.8	kN	37.2%
Max. load in inclusion	155.5	kN	77.3%
Positive skin friction	102.0	kN	50.7%
Load applied on inclusion bottom	53.4	kN	26.6%
Depth of neutral point	5.25	m	
Stress in soil at CMC top level	35.9	kPa	
Load transferred to the soil at CMC top level	120.4	kN	59.9%

Equivalent homogenized soil profile

- load distribution mat

Thickness = 0.94 m

E_{oed} = 67.3 MPa

- reinforced soil

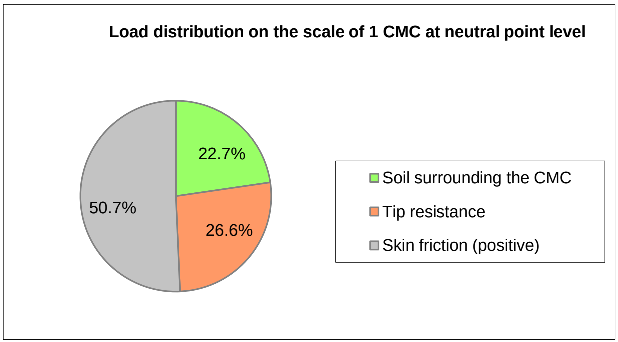
Thickness = 6.3 m

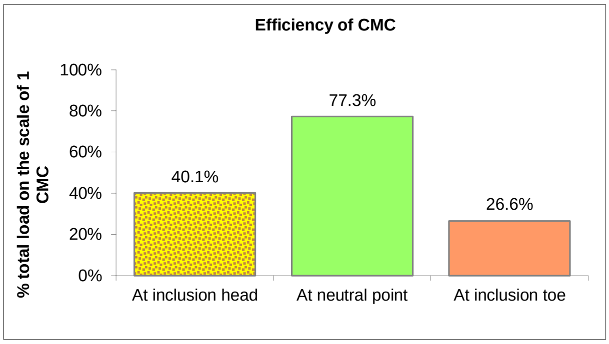
E_{oed} = 16.2 MPa

- soil underlying the reinforced soil

Thickness = 1.7 m

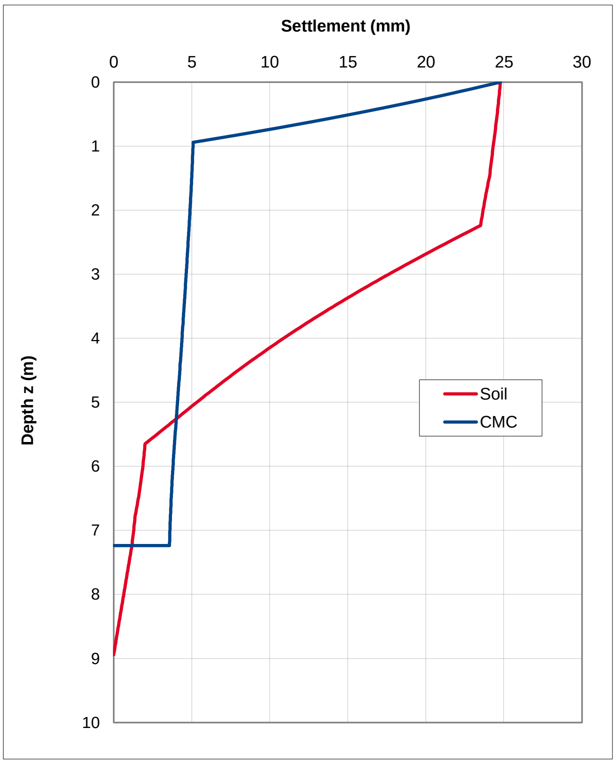
E_{oed} = 85.7 MPa

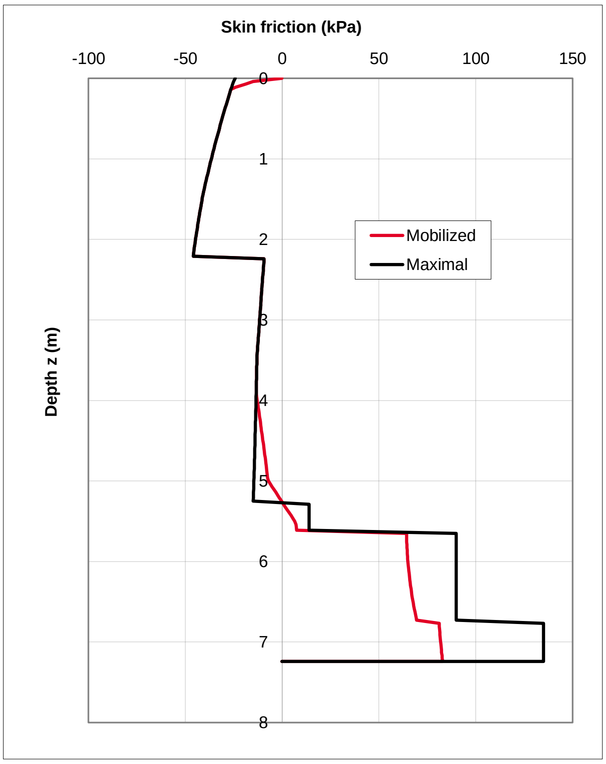


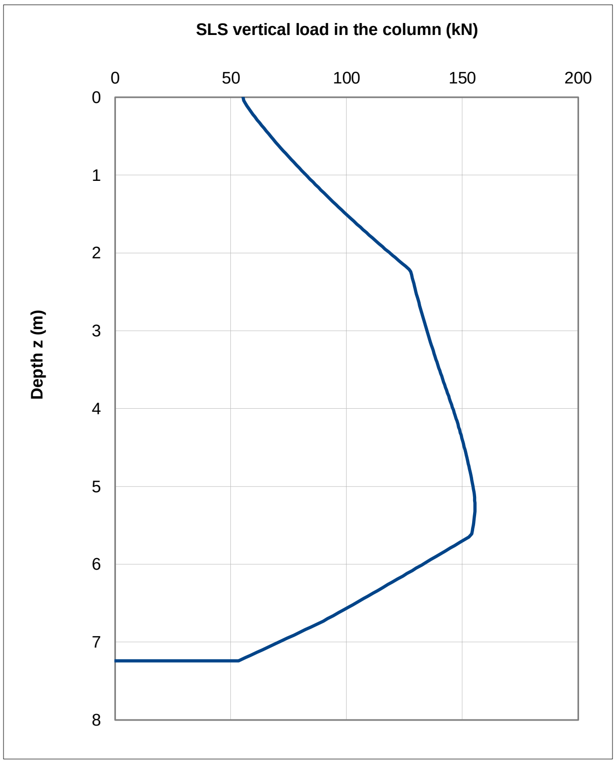


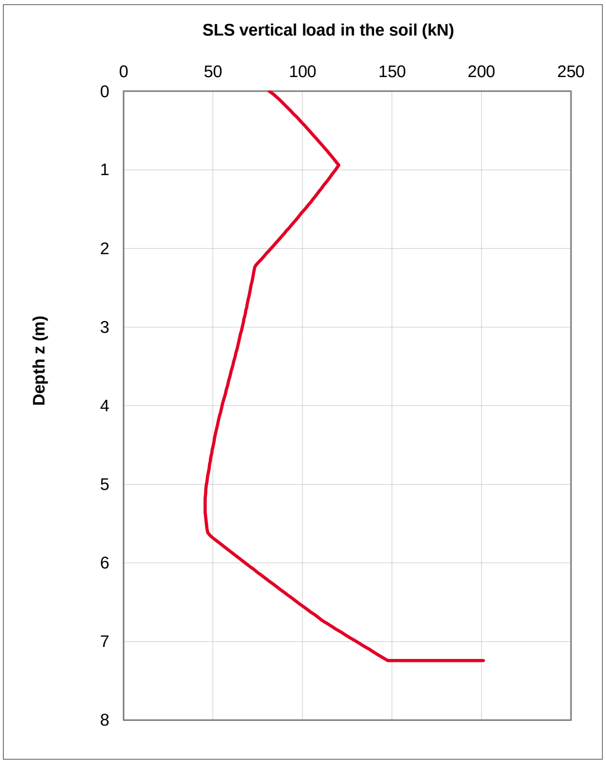
STR verifications: compressive stresses in CMC	*SLS*		*ULS*	
The material used allows an average compressive stress of	3.4 MPa	OK	6.1 MPa	OK
The average compressive stress in the columns is	**2.5 MPa**		**4.3 MPa**	

Graphic results







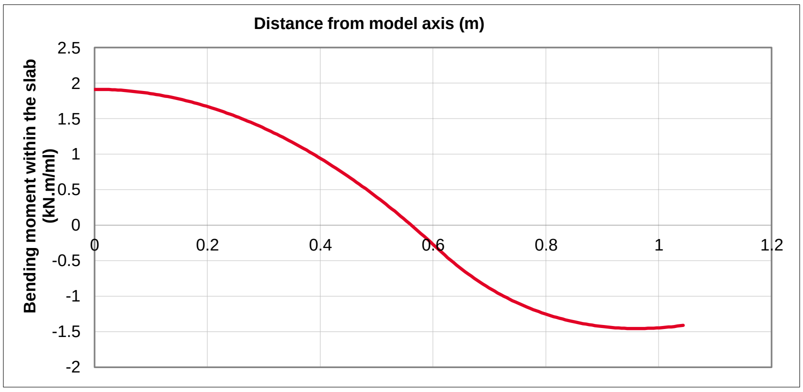


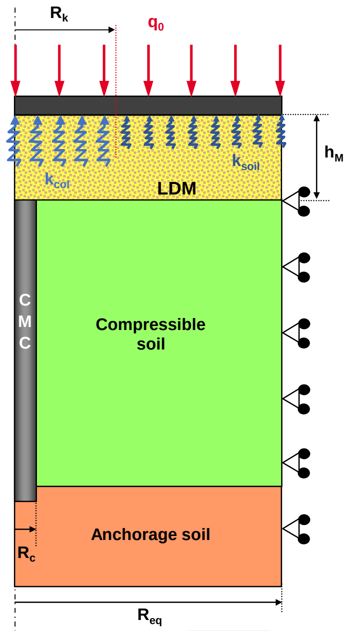
Determination of bending moments M_{sup} and M_{inf} within the slab

The moment in the slab can be determined by a model of a circular plate with a radius R_{eq} on elastic supports. The interaction of the slab and the foundation is modeled by springs with properties estimated for a given loading level. This approach is not applicable for a TR34 ground bearing slab design under a UDL.

The opposite simplified distribution of subgrade reaction coefficients is used for the calculation of the bending moment. This is characterized by:

R_k	0.61	m	*Diffusion radius underneath the ground slab*
σ_{soil}	24.3	kPa	*Average stress applied to the soil (directly below the slab)*
σ_{col}	70.3	kPa	*Average stress applied to the CMC along the diffusion radius R_k (directly below the slab)*
k_{soil}	0.98	MPa/m	*Subgrade reaction coefficient on the underside of a slab removed from the CMC ($R > R_k$)*
k_{col}	2.8	MPa/m	*Subgrade reaction coefficient on the underside of a ground slab adjacent to the axis of the CMC ($R < R_k$)*





Slab thickness	150	mm
Slab Concrete fck	28	MPa

M_{sup}	1.9	kN.m/ml	*Bending moment that loads the upper fiber of the slab in tension*
M_{inf}	-1.5	kN.m/ml	*Bending moment that loads the lower fiber of the slab in tension*

Slab verification: induced tensile stress in the slab from long term consolidation settlements under specified UDL

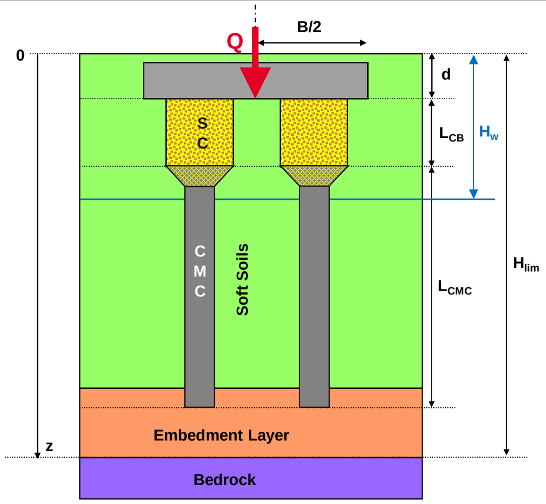
The slab plain concrete can receive an allowable tensile stress of (TR34 approach)	2.7	MPa	
The maximum tensile stress in the slab (envelop moments) is	**0.9**	**MPa**	OK

APPENDIX 4: DETAILED CALCULATIONS FOR THE BMC BENEATH THE RETAINING WALLS FOOTINGS

Project :

V29949 - Project Olympus - Silvertown
Retaining Wall as strip footing - 1m width - WP 2.9mAOD - ToF 3.2mAOD - 100 kPa

Analysis Model

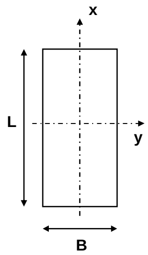


This is a calculation sheet for a ground of Bi-Modulus Columns under a footing.

Stone column part of the calculation is done by the Goughnour & Bayuk method (1979).

The stone columns part is assimilated to an equivalent distribution mattress.

Calculation of the CMC part according to O.Combarieu method (Fondations mixtes - LCPC 1988) Taking into account the Frank & Zhao method for the settlement calculation of CMC.



Soil Improvement Definition

Footing dimensions

Footing Type	**Filante**		d	**0.3** m	*Footing embedment*
L	**2.5** m	*Longueur de la zone type*	B	**1** m	*Footing width*

Number of BMC under the footing **1**

Description of the stone column part

L_{CB}	**2.40** m	*Stone column length*	γ_{CB}	**20** kN/m^3	*Stone column unit weight*
D_{CB}	**0.4** m	*Stone column diameter*	φ_{CB}	**38** °	*Stone column friction angle*
E_{CB}	**50,000** kPa	*Young Modulus*	$K_{a;CB}$	0.24	*Earth pressure coefficient*
ν_{CB}	**0.33**	*Poisson coefficient*			

Description of the CMC part

L_{CMC}	**5.00** m	*CMC length*	D_{CMC}	**0.28** m	*CMC diameter*
Displacement :	**Avec**		ULS :	**Fondamental**	
Test type :	**Essai de portance**		Reinforcement :	**NON**	
f_{ck}	**12** MPa	*28-day unconfined compressive strength*			
Calcul du module de déformation :	**Béton**				
E_{CMC}	8,500,000 kPa	*Young modulus*			
$f_{cd;moy;ELS}$	3.6 MPa	*CMC material SLS acceptable mean compressive stress*			
$f_{cd;moy;ELU}$	6.4 MPa	*CMC material ULS acceptable mean compressive stress*			

Description of bearing soil layer

q_b	**4,800** kPa	*Limit soil resistance at the column bottom*
k_q	**4.8**	*Frank & Zhao factor for the toe (extracted from the table below)*
E_m	**2,000** kPa	*Pressuremeter modulus*

Values of k_q (from Frank and Zhao)

Fine-grained soils	11
Coarse-grained soils	4.8

Description of natural soil surrounding the columns

q_{net}	**500** kPa	*Ultimate resistance of the soil surrounding the columns*

Description of natural soil

H_{lim}	9.4	m	Limit depth of model (geotechnical bedrock or seismic bedrock)
H_w	3.625	m	Depth of the groundwater table

Layer n°	Nature	z_{sup} (m)	z_{inf} (m)	p_l* (kPa)	E_M (kPa)	α (-)	ν (-)	E_Y (kPa)	q_s (kPa)	$k_τ$ (-)	γ (kN/m^3)	Ktanδ -
1	Fill	0.00	0.30	1,250	10,000	0.33	0.33	30,303	90	0.8	20	1.00
2	WP	0.30	0.80	1,250	12,500	0.33	0.33	37,879	105	0.8	20	1.00
3	Fill	0.80	1.20	1,000	10,000	1.00	0.33	10,000	90	0.8	20	1.00
4	Made ground	1.20	2.70	875	8,750	0.33	0.33	26,515	80	0.8	18	0.45
5	alluvium	2.70	6.10	200	2,000	1.00	0.33	2,000	15	2	18	0.20
6	medium dense gravels	6.10	7.20	1,050	10,500	0.33	0.33	31,818	90	0.8	18	0.45
7	dense gravels	7.20	9.40	2,100	21,000	0.33	0.33	63,636	140	0.8	19	1.00

Notations

z_{sup}	Depth of layer top	ν	Poisson coefficient
z_{inf}	Depth of layer base	E_Y	Young modulus
p_l*	Limit pressure	q_s	Ultimate skin friction
E_M	Pressuremeter modulus	$k_τ$	Frank & Zhao factor for the friction
α	Structural coefficient	γ	Unit weight

Values of $k_τ$ (from Frank and Zhao)	
Sols fins	2
Sols granulaires	0.8

Loading description (SLS)

		Permanente (kN/ml)	Variable (kN/ml)	TOTAL (kN/ml)	$γ_{G,ELU}$	$γ_{Q,ELU}$	$γ_{eq,ELU}$
Vertical load	q_0		100	100	1.35	1.5	1.50

Load applied below footing	Q	100	kN/ml
Stress applied on soil	q_0	100	kPa

→ Domain : 2

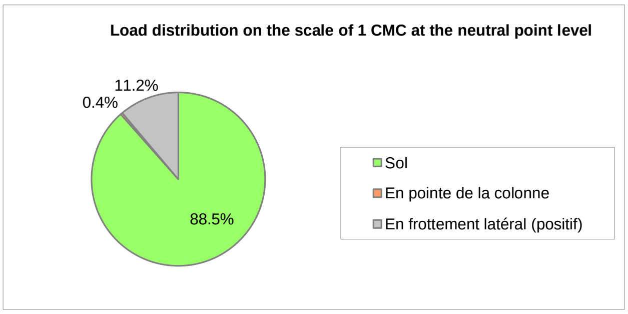
Results

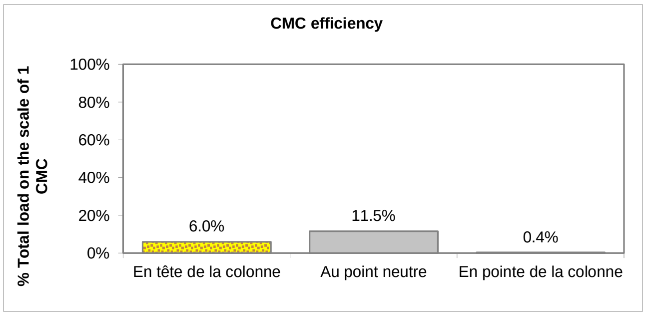
Footing settlement	W	**5**	mm

Settlement distribution

Settlement of deep layers (below CMC)	0 mm
Punching at the inclusion tip	0 mm
Punching at the inclusion head	1 mm
Elastic shortening of the inclusion	0 mm
Settlement of the soil reinforced by VSC	3 mm

SLS load distribution	per inclusion	% total load	on all	% total load
Load applied on SC head	7.2 kN	2.9%	7.2 kN	2.9%
Load applied on SC toe / CMC head	15.0 kN	6.0%	15.0 kN	6.0%
Negative skin friction along the inclusion	13.8 kN	5.5%	13.8 kN	5.5%
Max. load in inclusion	28.8 kN	11.5%	28.8 kN	11.5%
Positive skin friction	27.9 kN	11.2%	27.9 kN	11.2%
Load applied on the inclusion tip	0.9 kN	0.4%	0.9 kN	0.4%
Neutral point depth	4.58 m			
Stress in the soil at BMC head	102.3 kPa			
Load transferred to the soil at BMC head	242.8 kN	97.1%	242.8 kN	97.1%

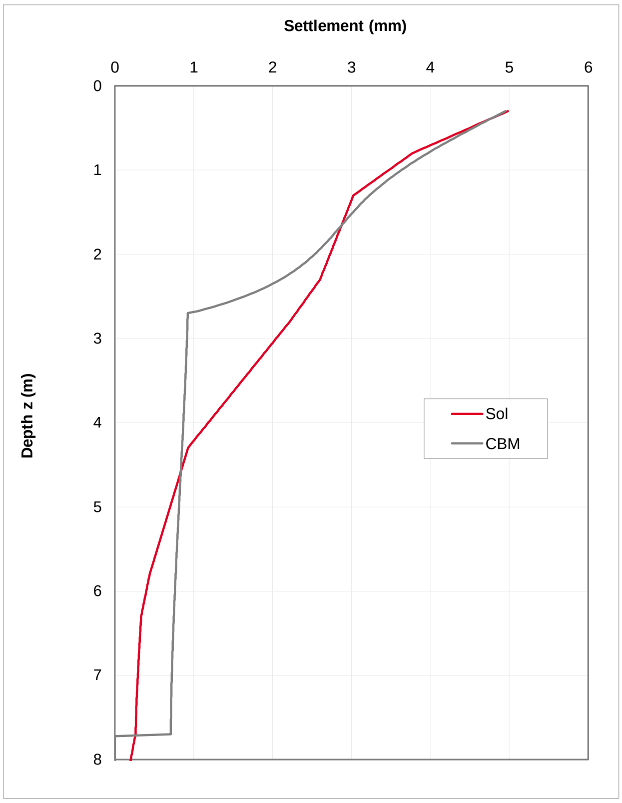


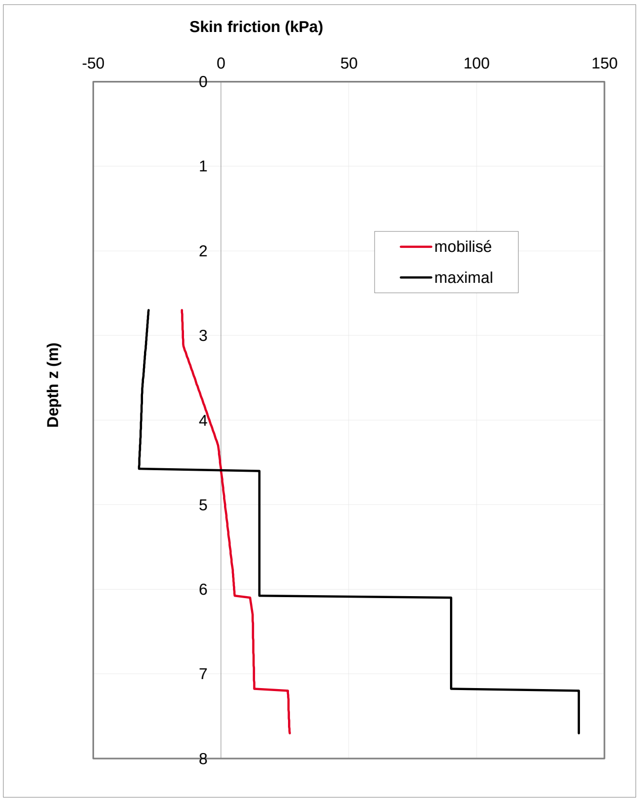


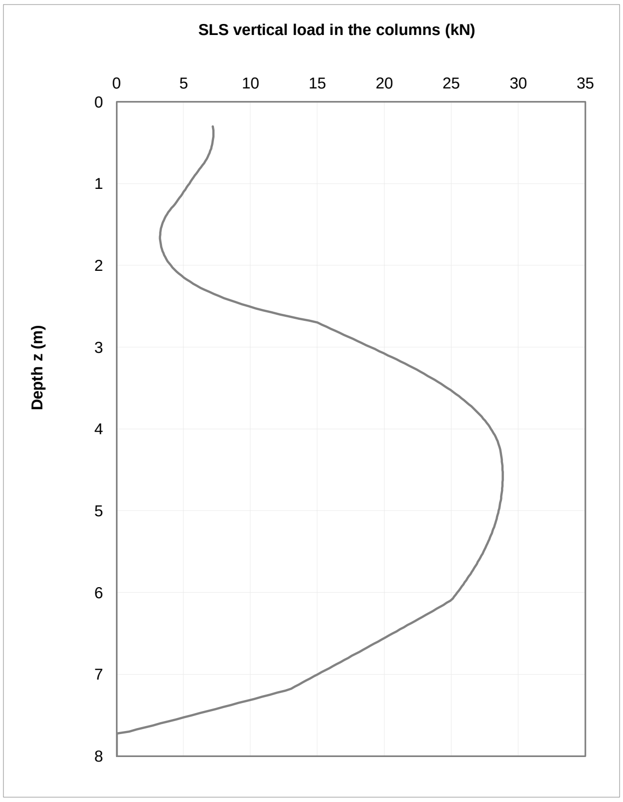
STR verifications: compressive stresses in the CMC part	*SLS*		*ULS*	
The material used allows an average compressive stress of	3.6 MPa	OK	6.4 MPa	OK
The average compressive stress in the columns is	**0.5 MPa**		**0.7 MPa**	

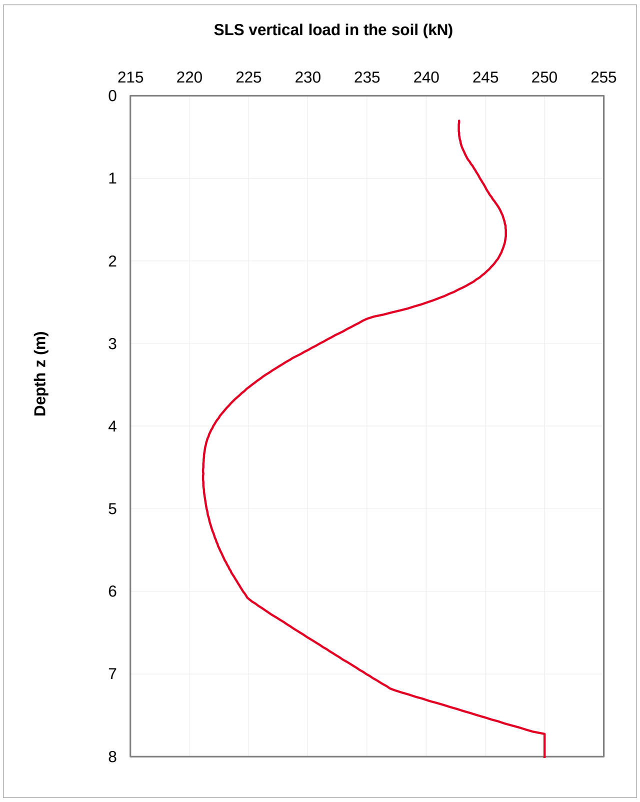
Verification of the compressive stress in the SC part	*SLS*		*ULS*	
The allowable average compressive stress is	2.10 MPa	OK	2.80 MPa	OK
The average compressive stress in the SC part is	**0.12 MPa**		**0.18 MPa**	

Graphis results







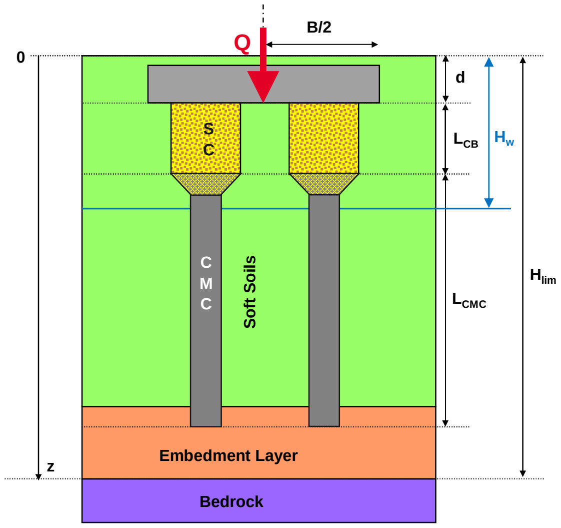


CALCULATION OF FOOTING ON BI-MODULUS COLUMNS

Project :

V29949 - Project Olympus - Silvertown
Retaining Wall as strip footing -2.5m width - WP 1.8mAOD - ToF 1.55mAOD - 100 kPa

Analysis Model

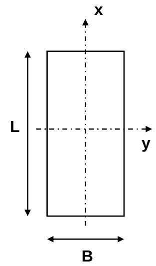


This is a calculation sheet for a ground of Bi-Modulus Columns under a footing.

Stone column part of the calculation is done by the Goughnour & Bayuk method (1979).

The stone columns part is assimilated to an equivalent distribution mattress.

Calculation of the CMC part according to O.Combarieu method (Fondations mixtes - LCPC 1988) Taking into account the Frank & Zhao method for the settlement calculation of CMC.



Soil Improvement Definition

Footing dimensions

Footing Type	Filante					
L	2.5 m	Longueur de la zone type	d	0.55 m	Footing embedment
			B	2.5 m	Footing width

Number of BMC under the footing 1

Description of the stone column part

L_{CB}	0.75 m	Stone column length	γ_{CB}	20 kN/m³	Stone column unit weight
D_{CB}	0.4 m	Stone column diameter	φ_{CB}	38 °	Stone column friction angle
E_{CB}	50,000 kPa	Young Modulus	$K_{a;CB}$	0.24	Earth pressure coefficient
ν_{CB}	0.33	Poisson coefficient			

Description of the CMC part

L_{CMC}	5.00 m	CMC length	D_{CMC}	0.28 m	CMC diameter
Displacement :	Avec		ULS :	Fondamental	
Test type :	Essai de portance		Reinforcement :	NON	
f_{ck}	12 MPa	28-day unconfined compressive strength			
Calcul du module de déformation :	Béton				
E_{CMC}	8,500,000 kPa	Young modulus			
$f_{cd;moy;ELS}$	2.9 MPa	CMC material SLS acceptable mean compressive stress			
$f_{cd;moy;ELU}$	5.1 MPa	CMC material ULS acceptable mean compressive stress			

Description of bearing soil layer

q_b	4,800 kPa	Limit soil resistance at the column bottom
k_q	4.8	Frank & Zhao factor for the toe (extracted from the table below)
E_m	21,000 kPa	Pressuremeter modulus

Values of k_q (from Frank and Zhao)

Fine-grained soils	11
Coarse-grained soils	4.8

Description of natural soil surrounding the columns

q_{net}	230 kPa	Ultimate resistance of the soil surrounding the columns

Description of natural soil

H_{lim}	8	m	*Limit depth of model (geotechnical bedrock or seismic bedrock)*
H_w	2.525	m	*Depth of the groundwater table*

Layer n°	Nature	z_{sup} (m)	z_{inf} (m)	p_l* (kPa)	E_M (kPa)	α (-)	ν (-)	E_Y (kPa)	q_s (kPa)	$k_τ$ (-)	γ (kN/m^3)	Ktanδ -
1	**WP**	0.00	0.50	1,250	12,500	0.33	0.33	37,879	105	2	20	1.00
2	**Made ground**	0.50	1.30	800	8,750	0.33	0.33	26,515	80	0.8	18	0.45
3	**alluvium**	1.30	4.70	200	2,000	1.00	0.33	2,000	15	2	18	0.20
4	**medium dense gravels**	4.70	5.80	1,050	10,500	0.33	0.33	31,818	90	0.8	18	0.45
5	**dense gravels**	5.80	8.00	2,100	21,000	0.33	0.33	63,636	140	0.8	19	1.00

Notations

z_{sup}	*Depth of layer top*	ν	*Poisson coefficient*
z_{inf}	*Depth of layer base*	E_Y	*Young modulus*
p_l*	*Limit pressure*	q_s	*Ultimate skin friction*
E_M	*Pressuremeter modulus*	$k_τ$	*Frank & Zhao factor for the friction*
α	*Structural coefficient*	γ	*Unit weight*

Values of $k_τ$ (from Frank and Zhao)

Sols fins	2
Sols granulaires	0.8

Loading description (SLS)

		Permanente (kN/ml)	Variable (kN/ml)	TOTAL (kN/ml)	$γ_{G,ELU}$	$γ_{Q,ELU}$	$γ_{eq,ELU}$
Vertical load	q_0		250	250	1.35	1.5	1.50

Load applied below footing	Q	250	kN/ml
Stress applied on soil	q_0	100	kPa

→ **Domain :** 1

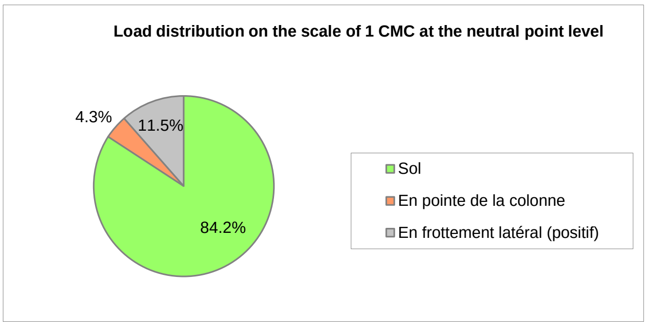
Results

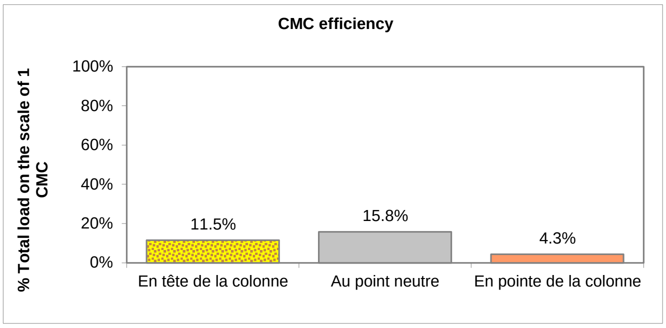
Footing settlement	W	15	mm

Settlement distribution

Settlement of deep layers (below CMC)	3 mm
Punching at the inclusion tip	1 mm
Punching at the inclusion head	7 mm
Elastic shortening of the inclusion	1 mm
Settlement of the soil reinforced by VSC	4 mm

SLS load distribution	per inclusion	% total load	on all	% total load
Load applied on SC head	39.4 kN	6.3%	39.4 kN	6.3%
Load applied on SC toe / CMC head	71.7 kN	11.5%	71.7 kN	11.5%
Negative skin friction along the inclusion	27.0 kN	4.3%	27.0 kN	4.3%
Max. load in inclusion	98.7 kN	15.8%	98.7 kN	15.8%
Positive skin friction	71.9 kN	11.5%	71.9 kN	11.5%
Load applied on the inclusion tip	26.8 kN	4.3%	26.8 kN	4.3%
Neutral point depth	3.18 m			
Stress in the soil at BMC head	95.6 kPa			
Load transferred to the soil at BMC head	585.6 kN	93.7%	585.6 kN	93.7%



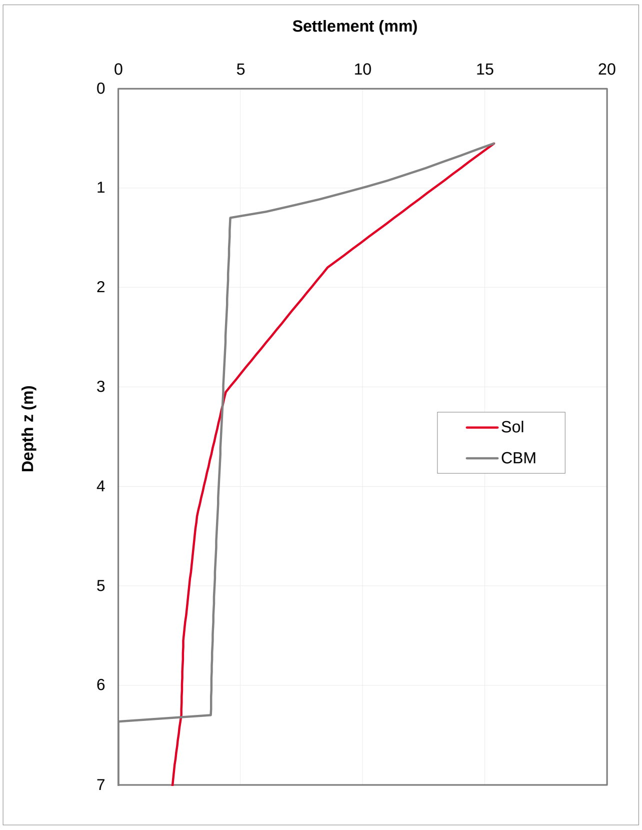


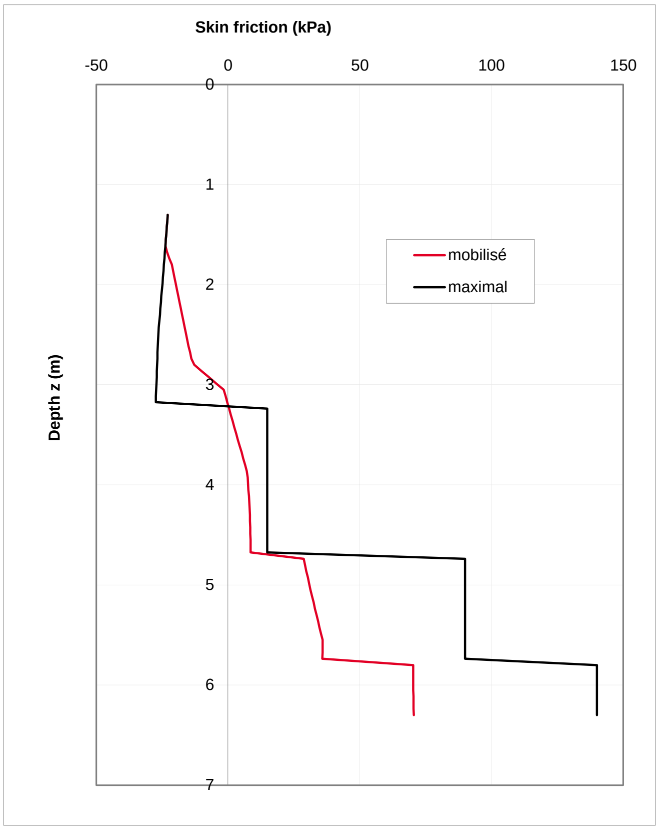
Vérifications GEO : portance globale du terrain	ELS		ELU	
La résistance globale du terrain en prenant en compte les CMC vaut	301 kN/ml	OK	474 kN/ml	OK
La charge appliquée à la base de la semelle est de	**250 kN/ml**		**375 kN/ml**	

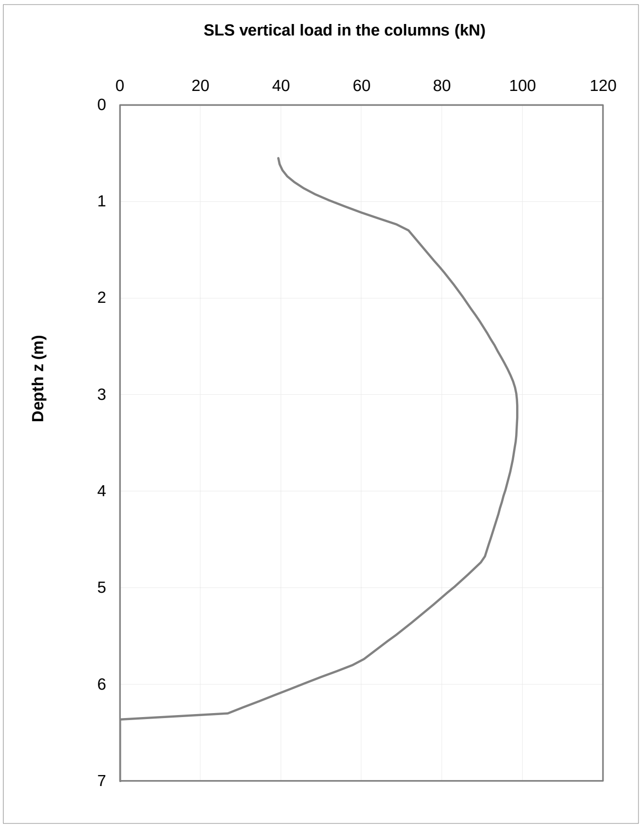
STR verifications: compressive stresses in the CMC part	*SLS*		*ULS*	
The material used allows an average compressive stress of	2.9 MPa	OK	5.1 MPa	OK
The average compressive stress in the columns is	**1.6 MPa**		**2.4 MPa**	

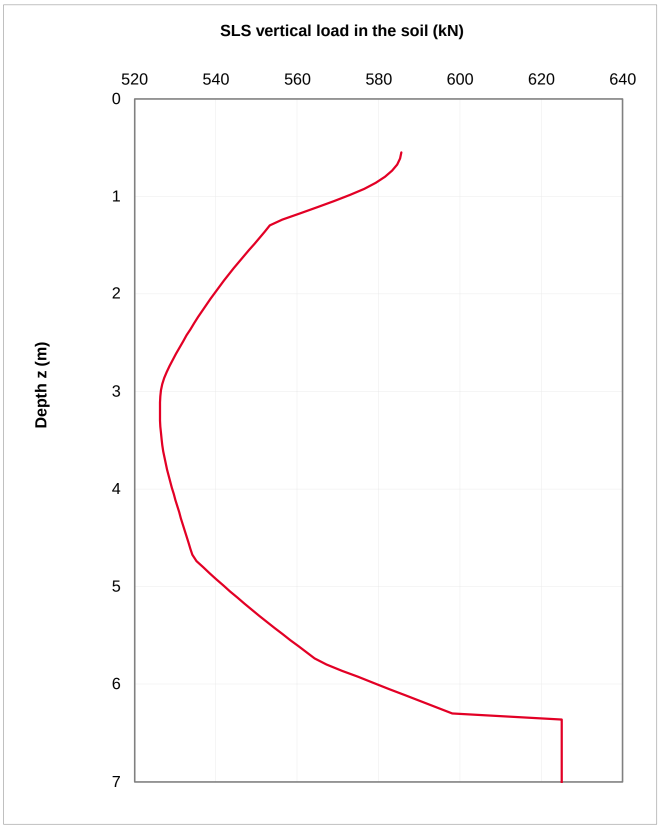
Verification of the compressive stress in the SC part	*SLS*		*ULS*	
The allowable average compressive stress is	1.68 MPa	OK	2.24 MPa	OK
The average compressive stress in the SC part is	**0.57 MPa**		**0.86 MPa**	

Graphis results





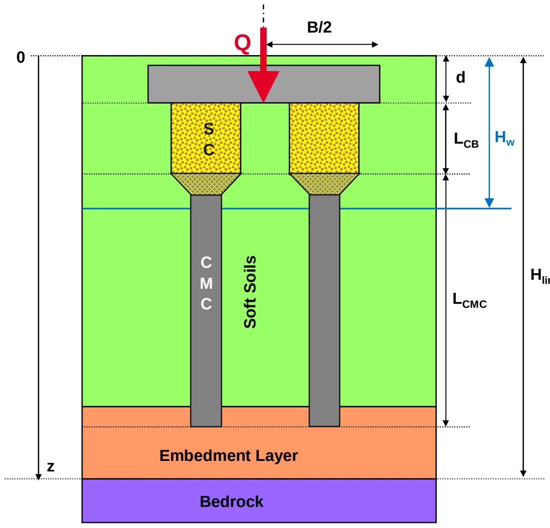




Project :

V29949 - Project Olympus - Silvertown
Retaining Wall as strip footing - 2.2m width - WP 2.9mAOD - ToF 3.2mAOD - 100 kPa

Analysis Model

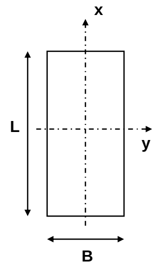


This is a calculation sheet for a ground of Bi-Modulus Columns under a footing.

Stone column part of the calculation is done by the Goughnour & Bayuk method (1979).

The stone columns part is assimilated to an equivalent distribution mattress.

Calculation of the CMC part according to O.Combarieu method (Fondations mixtes - LCPC 1988) Taking into account the Frank & Zhao method for the settlement calculation of CMC.



Soil Improvement Definition

Footing dimensions

Footing Type	*Filante*			d	***0.3***	m	*Footing embedment*
L	***2.5***	m	*Longueur de la zone type*	B	***2.2***	m	*Footing width*

Number of BMC under the footing ***1***

Description of the stone column part

L_{CB}	***2.40***	m	*Stone column length*	γ_{CB}	***20***	kN/m^3	*Stone column unit weight*
D_{CB}	***0.4***	m	*Stone column diameter*	φ_{CB}	***38***	°	*Stone column friction angle*
E_{CB}	***50,000***	kPa	*Young Modulus*	$K_{a;CB}$	0.24		*Earth pressure coefficient*
ν_{CB}	***0.33***		*Poisson coefficient*				

Description of the CMC part

L_{CMC}	***5.00***	m	*CMC length*	D_{CMC}	***0.28***	m	*CMC diameter*
Displacement :	***Avec***			ULS :	***Fondamental***		
Test type :	***Essai de portance***			Reinforcement :	***NON***		
f_{ck}	***12***	MPa	*28-day unconfined compressive strength*				
Calcul du module de déformation :	***Béton***						
E_{CMC}	8,500,000	kPa	*Young modulus*				
$f_{cd;moy;ELS}$	3.6	MPa	*CMC material SLS acceptable mean compressive stress*				
$f_{cd;moy;ELU}$	6.4	MPa	*CMC material ULS acceptable mean compressive stress*				

Description of bearing soil layer

q_b	***4,800***	kPa	*Limit soil resistance at the column bottom*
k_q	***4.8***		*Frank & Zhao factor for the toe (extracted from the table below)*
E_m	***2,000***	kPa	*Pressuremeter modulus*

Values of k_q (from Frank and Zhao)

Fine-grained soils	11
Coarse-grained soils	4.8

Description of natural soil surrounding the columns

q_{net}	***430***	kPa	*Ultimate resistance of the soil surrounding the columns*

Description of natural soil

H_{lim}	9.4	m	*Limit depth of model (geotechnical bedrock or seismic bedrock)*
H_w	3.625	m	*Depth of the groundwater table*

Layer n°	Nature	z_{sup} (m)	z_{inf} (m)	p_l* (kPa)	E_M (kPa)	α (-)	ν (-)	E_Y (kPa)	q_s (kPa)	$k_τ$ (-)	γ (kN/m³)	Ktanδ -
1	Fill	0.00	0.30	1,250	10,000	0.33	0.33	30,303	90	0.8	20	1.00
2	WP	0.30	0.80	1,250	12,500	0.33	0.33	37,879	105	0.8	20	1.00
3	Fill	0.80	1.20	1,000	10,000	1.00	0.33	10,000	90	0.8	20	1.00
4	Made ground	1.20	2.70	875	8,750	0.33	0.33	26,515	80	0.8	18	0.45
5	alluvium	2.70	6.10	200	2,000	1.00	0.33	2,000	15	2	18	0.20
6	medium dense gravels	6.10	7.20	1,050	10,500	0.33	0.33	31,818	90	0.8	18	0.45
7	dense gravels	7.20	9.40	2,100	21,000	0.33	0.33	63,636	140	0.8	19	1.00

Notations

z_{sup}	*Depth of layer top*	ν	*Poisson coefficient*
z_{inf}	*Depth of layer base*	E_Y	*Young modulus*
p_l*	*Limit pressure*	q_s	*Ultimate skin friction*
E_M	*Pressuremeter modulus*	$k_τ$	*Frank & Zhao factor for the friction*
α	*Structural coefficient*	γ	*Unit weight*

Values of $k_τ$ (from Frank and Zhao)

Sols fins	2
Sols granulaires	0.8

Loading description (SLS)

		Permanente (kN/ml)	Variable (kN/ml)	TOTAL (kN/ml)	$γ_{G,ELU}$	$γ_{Q,ELU}$	$γ_{eq,ELU}$
Vertical load	q_0		220	220	1.35	1.5	1.50

Load applied below footing	Q	**220**	kN/ml
Stress applied on soil	q_0	**100**	kPa

→ **Domain :** 2

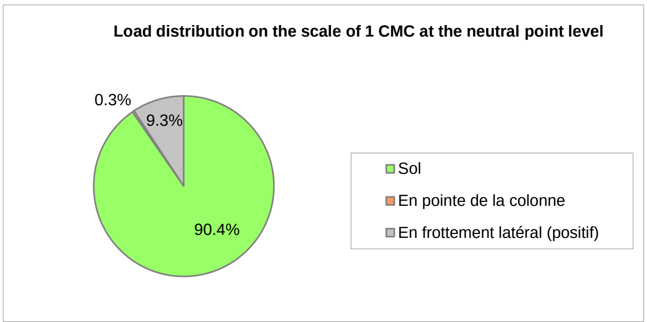
Results

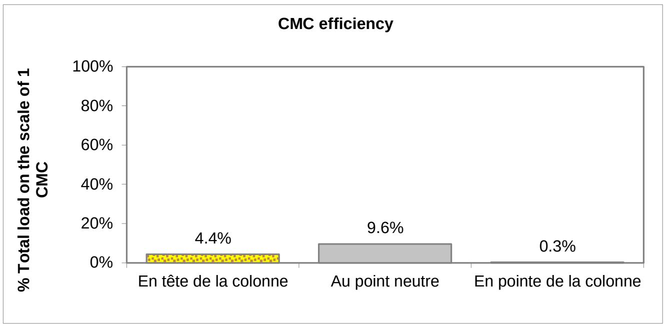
Footing settlement	W	**9**	mm

Settlement distribution

Settlement of deep layers (below CMC)	2 mm
Punching at the inclusion tip	1 mm
Punching at the inclusion head	2 mm
Elastic shortening of the inclusion	0 mm
Settlement of the soil reinforced by VSC	3 mm

SLS load distribution	per inclusion	% total load	on all	% total load
Load applied on SC head	6.1 kN	1.1%	6.1 kN	1.1%
Load applied on SC toe / CMC head	24.4 kN	4.4%	24.4 kN	4.4%
Negative skin friction along the inclusion	28.5 kN	5.2%	28.5 kN	5.2%
Max. load in inclusion	52.9 kN	9.6%	52.9 kN	9.6%
Positive skin friction	51.1 kN	9.3%	51.1 kN	9.3%
Load applied on the inclusion tip	1.8 kN	0.3%	1.8 kN	0.3%
Neutral point depth	5.14 m			
Stress in the soil at BMC head	101.2 kPa			
Load transferred to the soil at BMC head	543.9 kN	98.9%	543.9 kN	98.9%

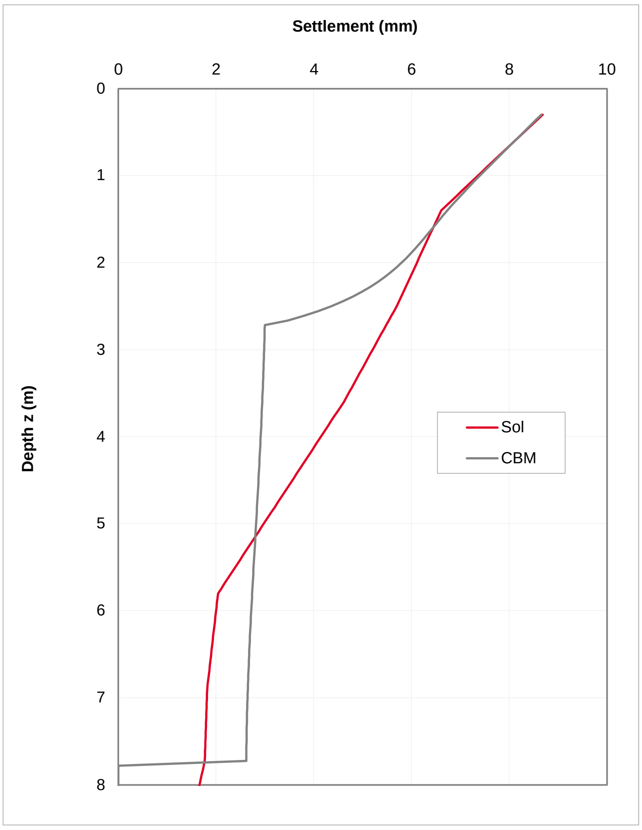


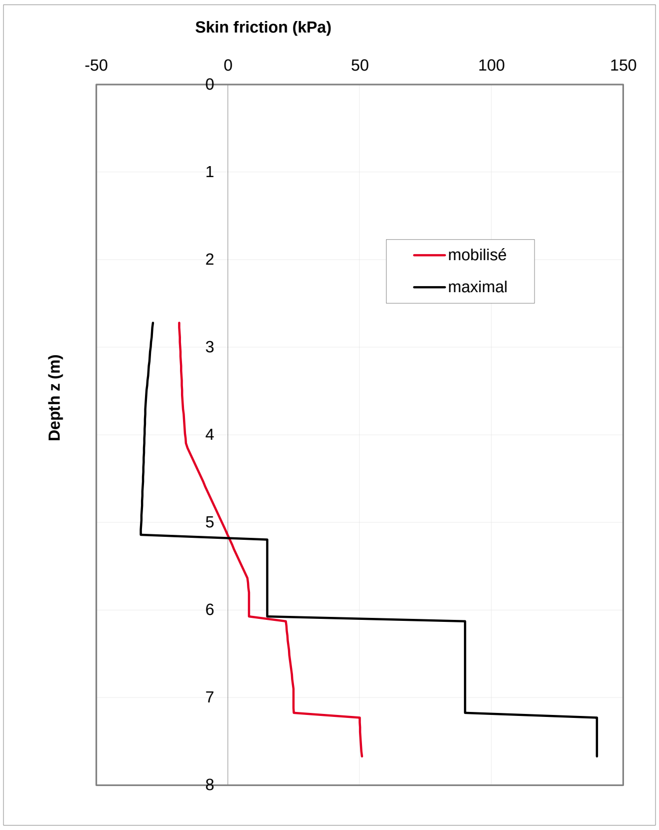


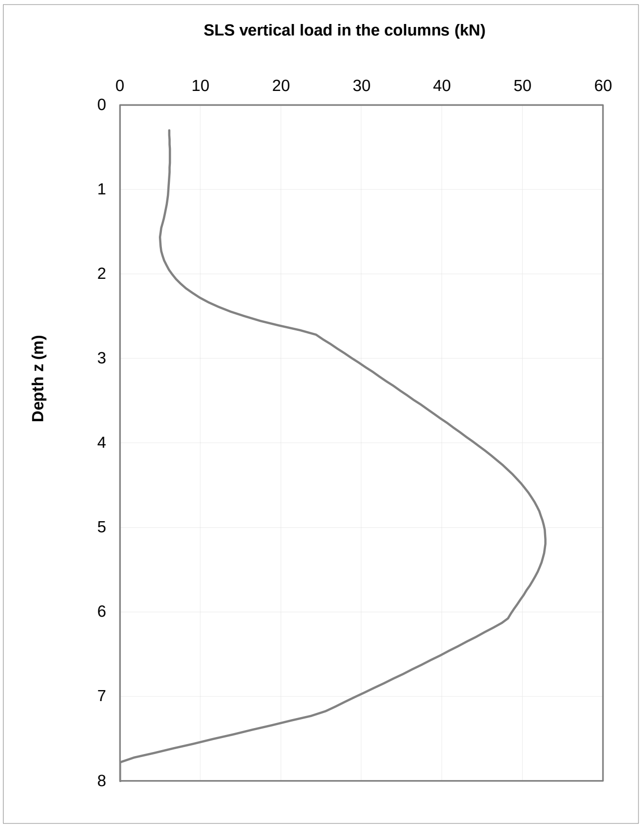
STR verifications: compressive stresses in the CMC part	*SLS*		*ULS*	
The material used allows an average compressive stress of	3.6 MPa	OK	6.4 MPa	OK
The average compressive stress in the columns is	**0.9 MPa**		**1.3 MPa**	

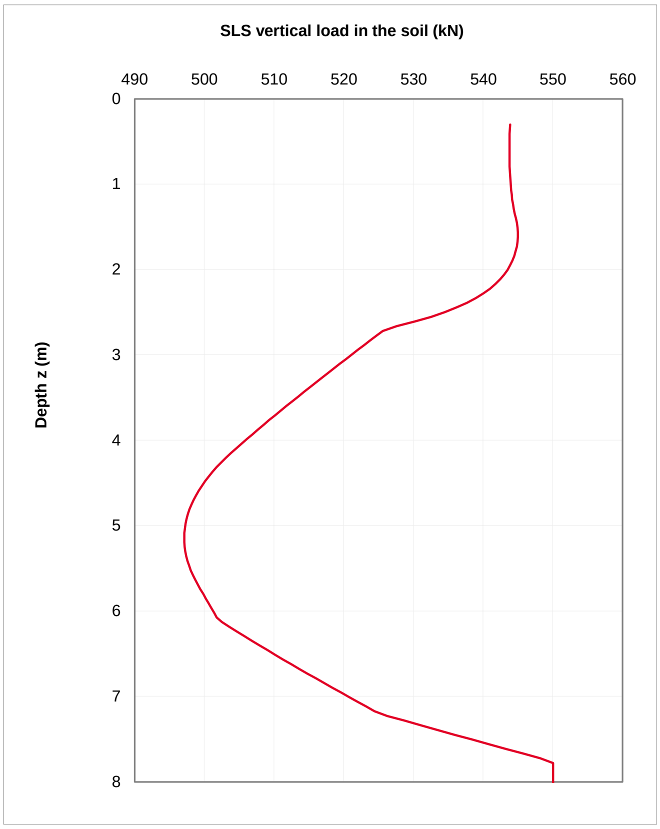
Verification of the compressive stress in the SC part	*SLS*		*ULS*	
The allowable average compressive stress is	2.10 MPa	OK	2.80 MPa	OK
The average compressive stress in the SC part is	**0.19 MPa**		**0.29 MPa**	

Graphis results







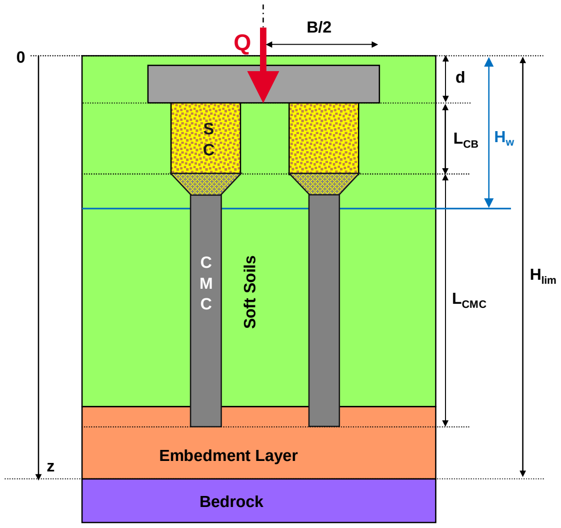


CALCULATION OF FOOTING ON BI-MODULUS COLUMNS

Project :

V29949 - Project Olympus - Silvertown
Retaining Wall as strip footing - 2.2m width - WP 1.8mAOD - ToF 0.7mAOD - 100 kPa

Analysis Model

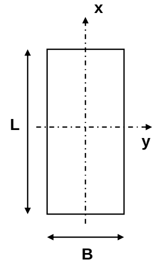


This is a calculation sheet for a ground of Bi-Modulus Columns under a footing.

Stone column part of the calculation is done by the Goughnour & Bayuk method (1979).

The stone columns part is assimilated to an equivalent distribution mattress.

Calculation of the CMC part according to O.Combarieu method (Fondations mixtes - LCPC 1988) Taking into account the Frank & Zhao method for the settlement calculation of CMC.



Soil Improvement Definition

Footing dimensions

Footing Type	Filante			d	1.4	m	Footing embedment
L	2	m	Longueur de la zone type	B	2.2	m	Footing width

Number of BMC under the footing 1

Description of the stone column part

L_{CB}	0.40	m	Stone column length	γ_{CB}	20	kN/m^3	Stone column unit weight
D_{CB}	0.4	m	Stone column diameter	φ_{CB}	38	°	Stone column friction angle
E_{CB}	50,000	kPa	Young Modulus	$K_{a;CB}$	0.24		Earth pressure coefficient
ν_{CB}	0.33		Poisson coefficient				

Description of the CMC part

L_{CMC}	4.50	m	CMC length	D_{CMC}	0.28	m	CMC diameter
Displacement :	Avec			ULS :	Fondamental		
Test type :	Essai de portance			Reinforcement :	NON		
f_{ck}	12	MPa	28-day unconfined compressive strength				
Calcul du module de déformation :	Béton						
E_{CMC}	8,500,000	kPa	Young modulus				
$f_{cd;moy;ELS}$	2.9	MPa	CMC material SLS acceptable mean compressive stress				
$f_{cd;moy;ELU}$	5.1	MPa	CMC material ULS acceptable mean compressive stress				

Description of bearing soil layer

q_b	4,800	kPa	Limit soil resistance at the column bottom
k_q	4.8		Frank & Zhao factor for the toe (extracted from the table below)
E_m	21,000	kPa	Pressuremeter modulus

Values of k_q (from Frank and Zhao)

Fine-grained soils	11
Coarse-grained soils	4.8

Description of natural soil surrounding the columns

q_{net}	140	kPa	Ultimate resistance of the soil surrounding the columns

Description of natural soil

H_{lim}	8	m	*Limit depth of model (geotechnical bedrock or seismic bedrock)*
H_w	2.525	m	*Depth of the groundwater table*

Layer n°	Nature	z_{sup} (m)	z_{inf} (m)	p_l* (kPa)	E_M (kPa)	α (-)	ν (-)	E_Y (kPa)	q_s (kPa)	k_τ (-)	γ (kN/m^3)	Ktanδ -
1	***WP***	0.00	0.50	***1,250***	***12,500***	***0.33***	***0.33***	***37,879***	***105***	***2***	***20***	***1.00***
2	***Made ground***	***0.50***	1.30	***800***	***8,750***	***0.33***	***0.33***	***26,515***	***80***	***0.8***	***18***	***0.45***
3	***alluvium***	***1.30***	4.70	***200***	***2,000***	***1.00***	***0.33***	***2,000***	***15***	***2***	***18***	***0.20***
4	***medium dense gravels***	***4.70***	5.80	***1,050***	***10,500***	***0.33***	***0.33***	***31,818***	***90***	***0.8***	***18***	***0.45***
5	***dense gravels***	***5.80***	8.00	***2,100***	***21,000***	***0.33***	***0.33***	***63,636***	***140***	***0.8***	***19***	***1.00***

Notations

z_{sup}	*Depth of layer top*	ν	*Poisson coefficient*
z_{inf}	*Depth of layer base*	E_Y	*Young modulus*
p_l*	*Limit pressure*	q_s	*Ultimate skin friction*
E_M	*Pressuremeter modulus*	k_τ	*Frank & Zhao factor for the friction*
α	*Structural coefficient*	γ	*Unit weight*

Values of k_τ (from Frank and Zhao)	
Sols fins	2
Sols granulaires	0.8

Loading description (SLS)

		Permanente (kN/ml)	Variable (kN/ml)	TOTAL (kN/ml)	$\gamma_{G,ELU}$	$\gamma_{Q,ELU}$	$\gamma_{eq,ELU}$
Vertical load	q_0		***220***	220	***1.35***	***1.5***	1.50

Load applied below footing	Q	**220**	kN/ml
Stress applied on soil	q_0	**100**	kPa

→ **Domain :** **1**

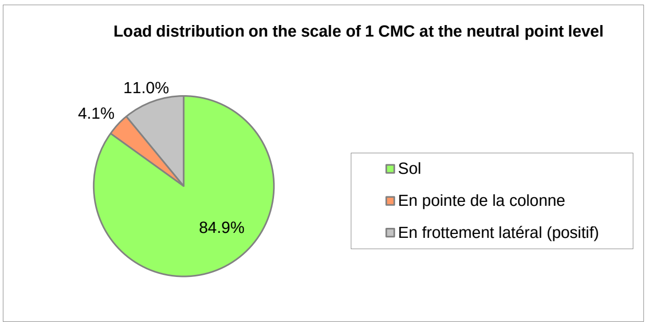
Results

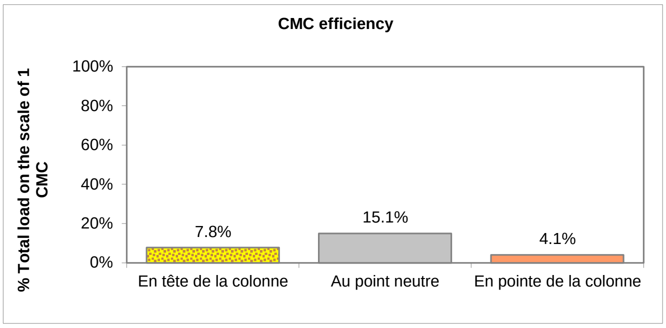
Footing settlement	W	**35**	mm

Settlement distribution

Settlement of deep layers (below CMC)	2	mm
Punching at the inclusion tip	1	mm
Punching at the inclusion head	20	mm
Elastic shortening of the inclusion	0	mm
Settlement of the soil reinforced by VSC	11	mm

SLS load distribution	*per inclusion*	*% total load*	*on all*	*% total load*
Load applied on SC head	12.0 kN	2.7%	12.0 kN	2.7%
Load applied on SC toe / CMC head	34.2 kN	7.8%	34.2 kN	7.8%
Negative skin friction along the inclusion	32.0 kN	7.3%	32.0 kN	7.3%
Max. load in inclusion	66.2 kN	15.1%	66.2 kN	15.1%
Positive skin friction	48.3 kN	11.0%	48.3 kN	11.0%
Load applied on the inclusion tip	17.9 kN	4.1%	17.9 kN	4.1%
Neutral point depth	3.93 m			
Stress in the soil at BMC head	100.1 kPa			
Load transferred to the soil at BMC head	428.0 kN	97.3%	428.0 kN	97.3%



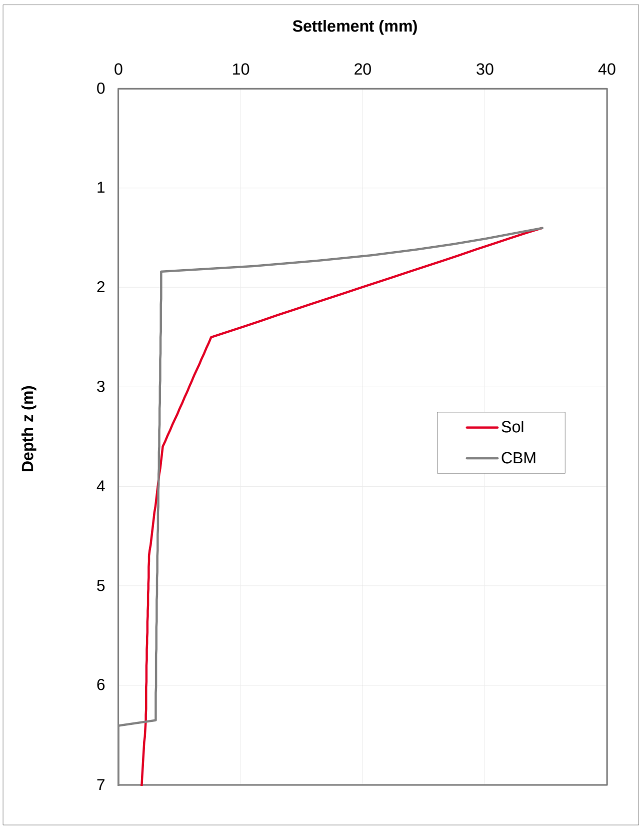


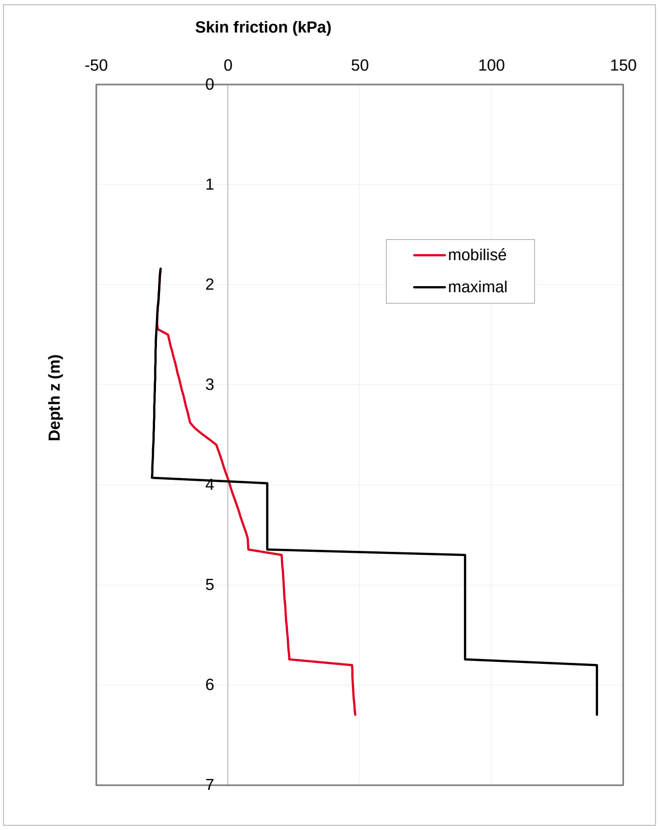
Vérifications GEO : portance globale du terrain	*ELS*		*ELU*	
La résistance globale du terrain en prenant en compte les CMC vaut	226 kN/ml	OK	346 kN/ml	OK
La charge appliquée à la base de la semelle est de	**220 kN/ml**		**330 kN/ml**	

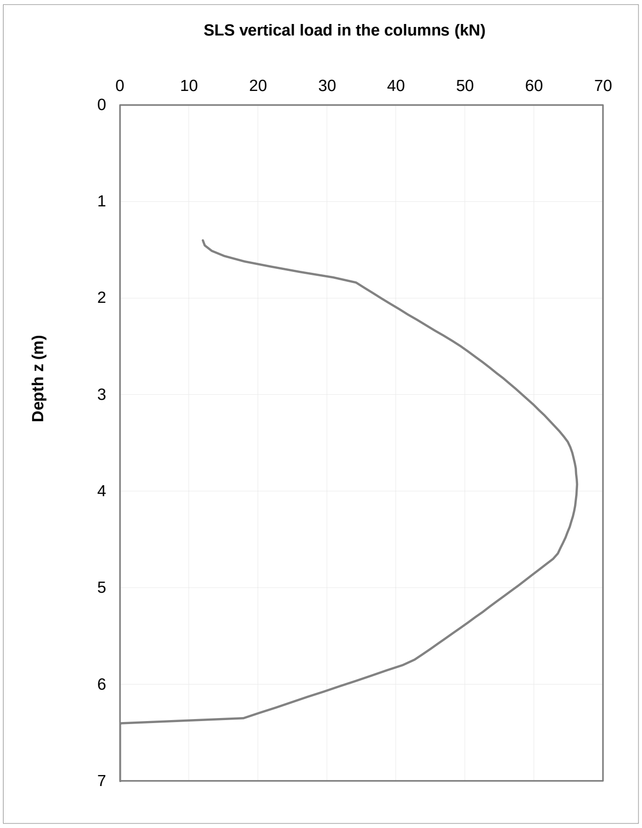
STR verifications: compressive stresses in the CMC part	*SLS*		*ULS*	
The material used allows an average compressive stress of	2.9 MPa	OK	5.1 MPa	OK
The average compressive stress in the columns is	**1.1 MPa**		**1.6 MPa**	

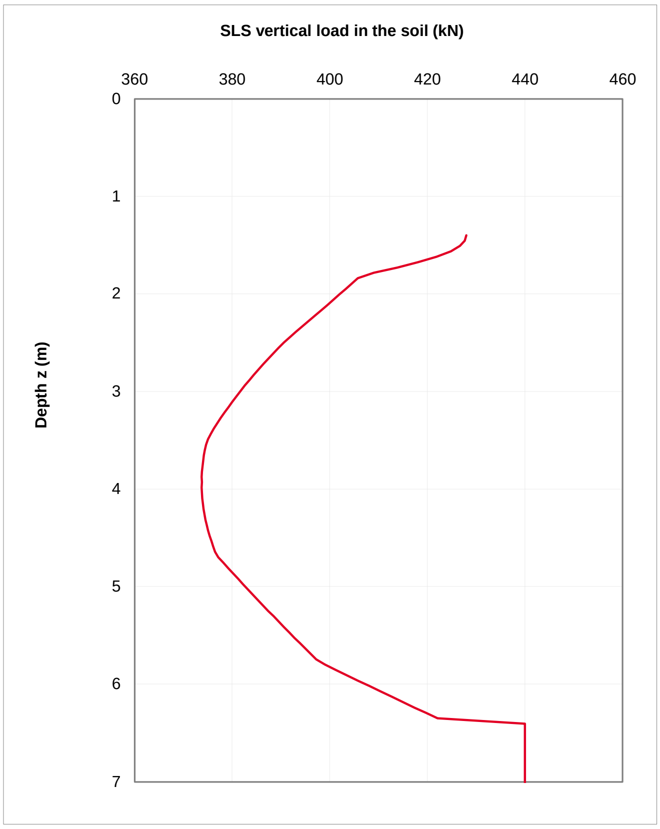
Verification of the compressive stress in the SC part	*SLS*		*ULS*	
The allowable average compressive stress is	0.42 MPa	OK	0.56 MPa	OK
The average compressive stress in the SC part is	**0.27 MPa**		**0.41 MPa**	

Graphis results





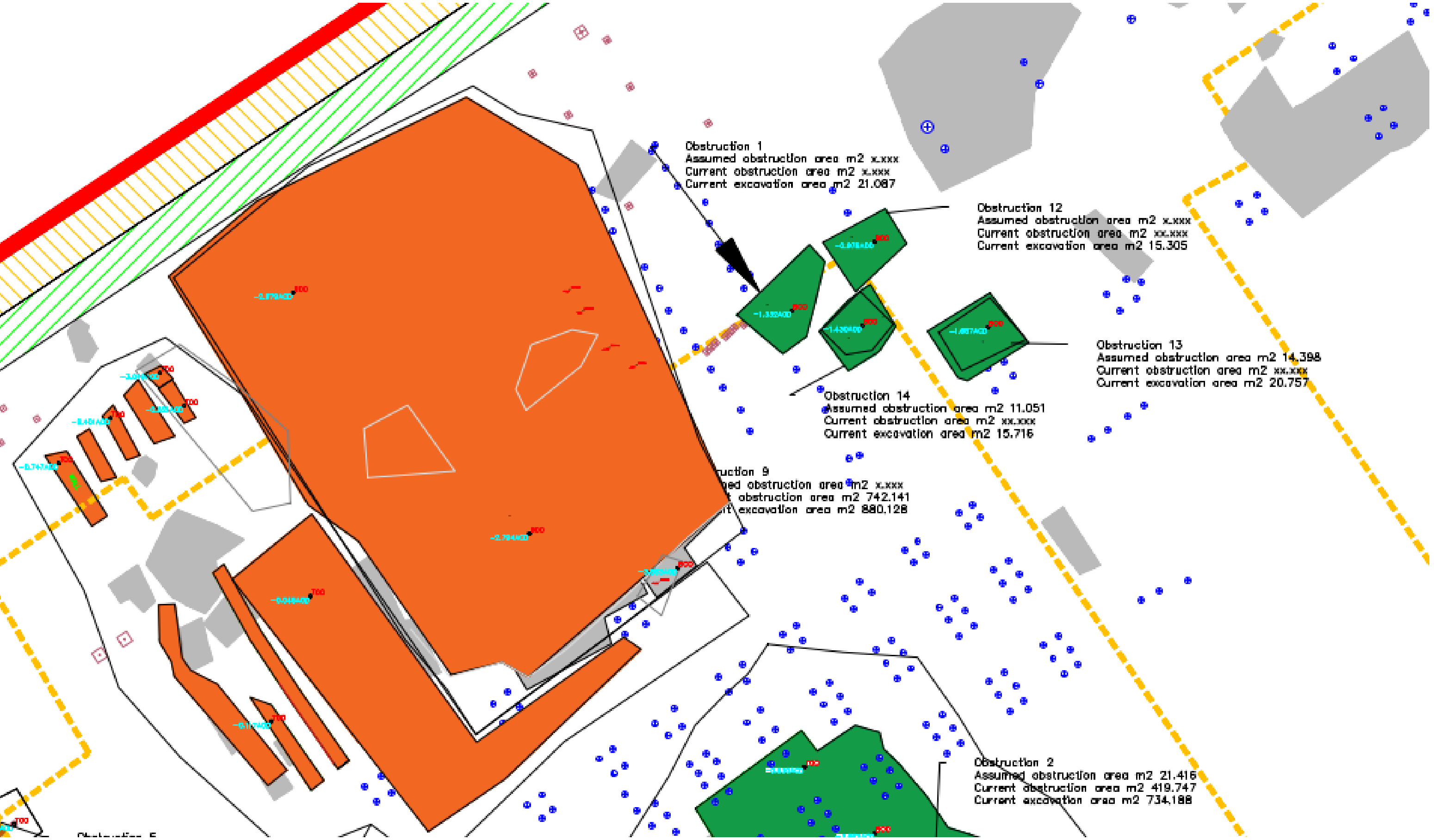




APPENDIX 5: DETAILED OBSTRUCTION METHODOLOGY

V29949 – Silvertown – Olympus Project

Obstruction methodology v.2



Depending on the depth of the obstruction

Obstructions between 0 and 3m below WPL
→ *Removal by Main Contractor*

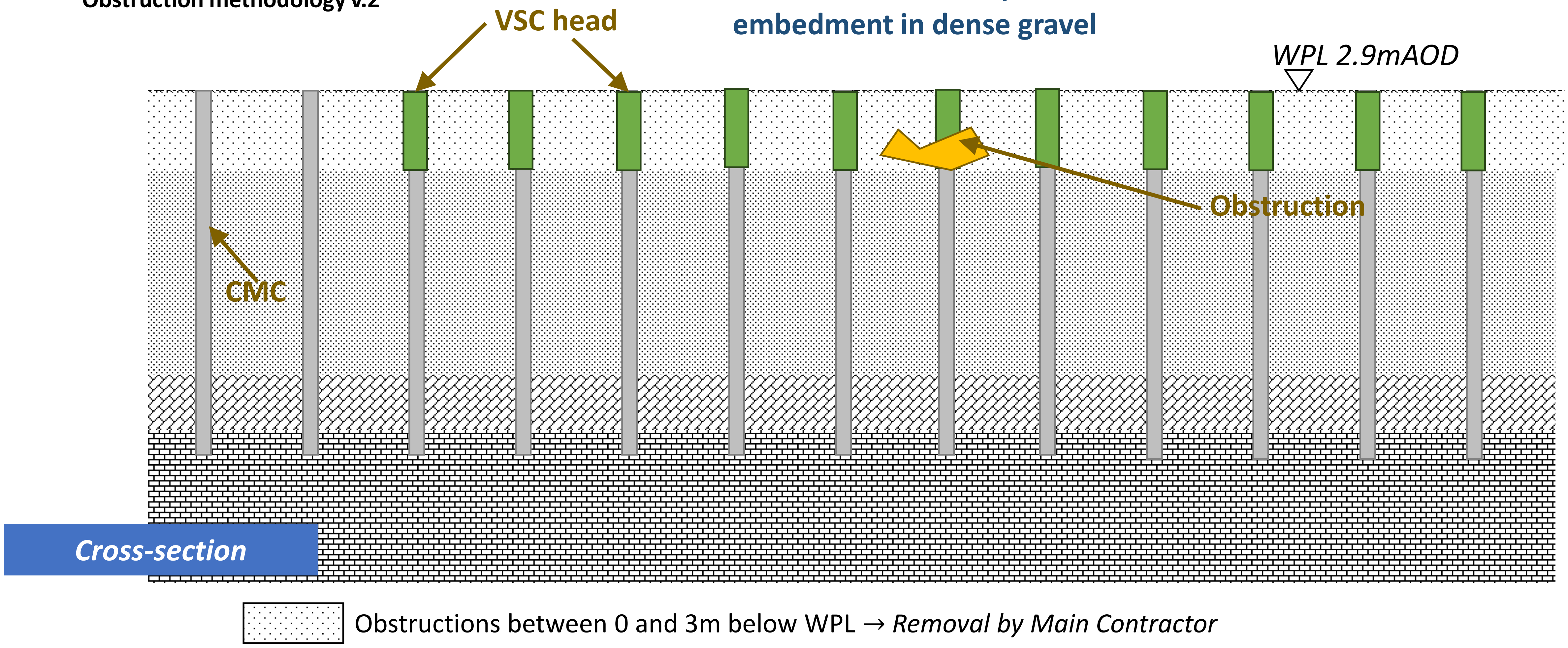
Obstructions between 3 and 6.5m below WPL
→ *Adaptation of the BMC grid (see page 2)*

Obstructions beyond 6.5m below WPL
→ *BMC cast on the obstruction*

V29949 – Silvertown – Olympus Project

Obstruction methodology v.2

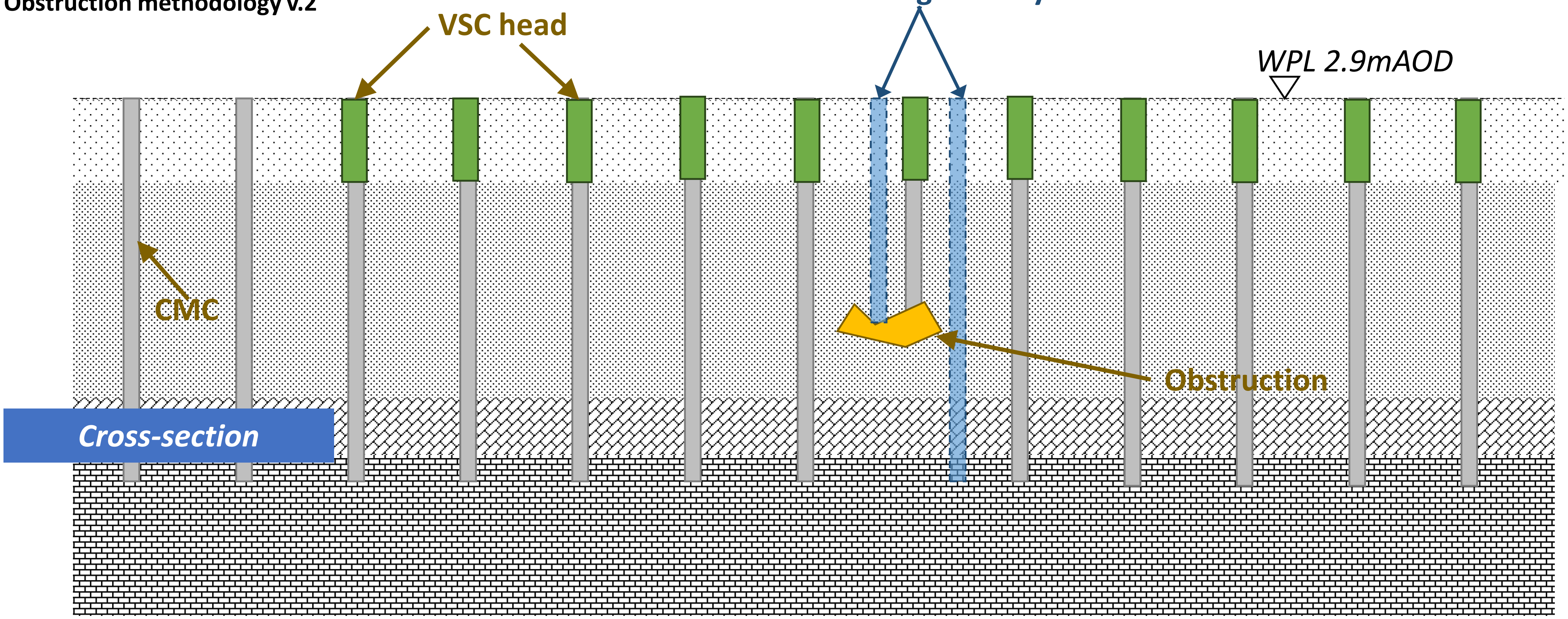
Removal of obstruction between 0-3m, then installation of BMC/CMC with embedment in dense gravel

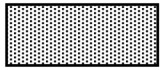


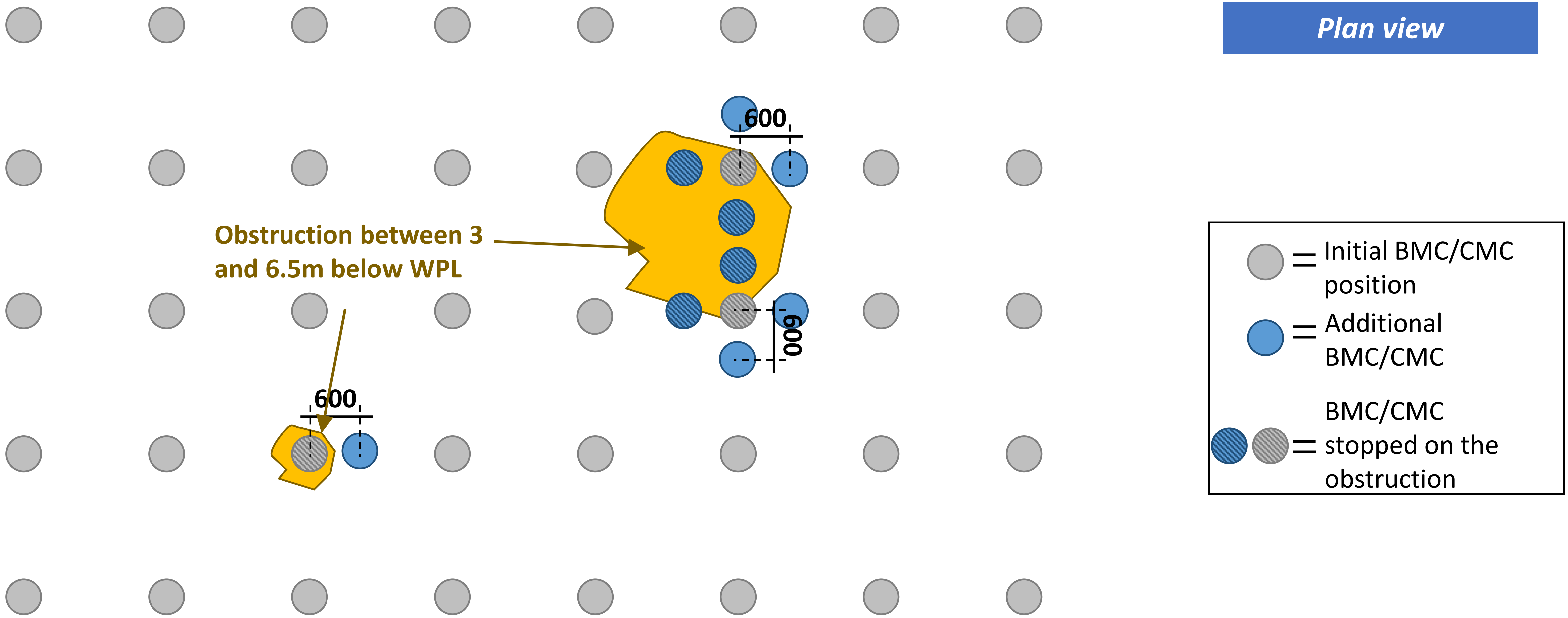
V29949 – Silvertown – Olympus Project

Obstruction methodology v.2

At 3 - 6.5m, additional BMC/CMC's around the obstruction embedded in the dense gravel layer

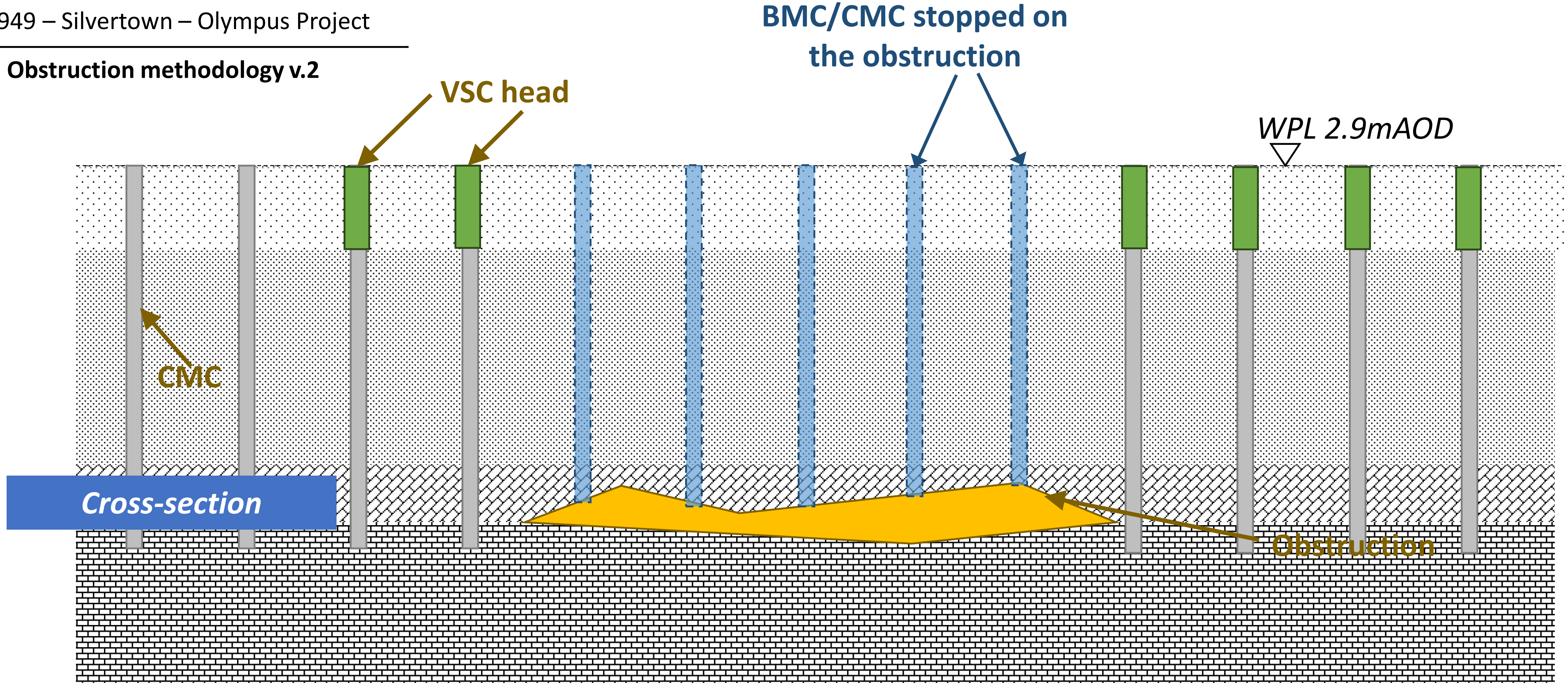


 Obstructions between 3 and 6.5m below WPL → *Adaptation of the BMC grid (see page 4)*

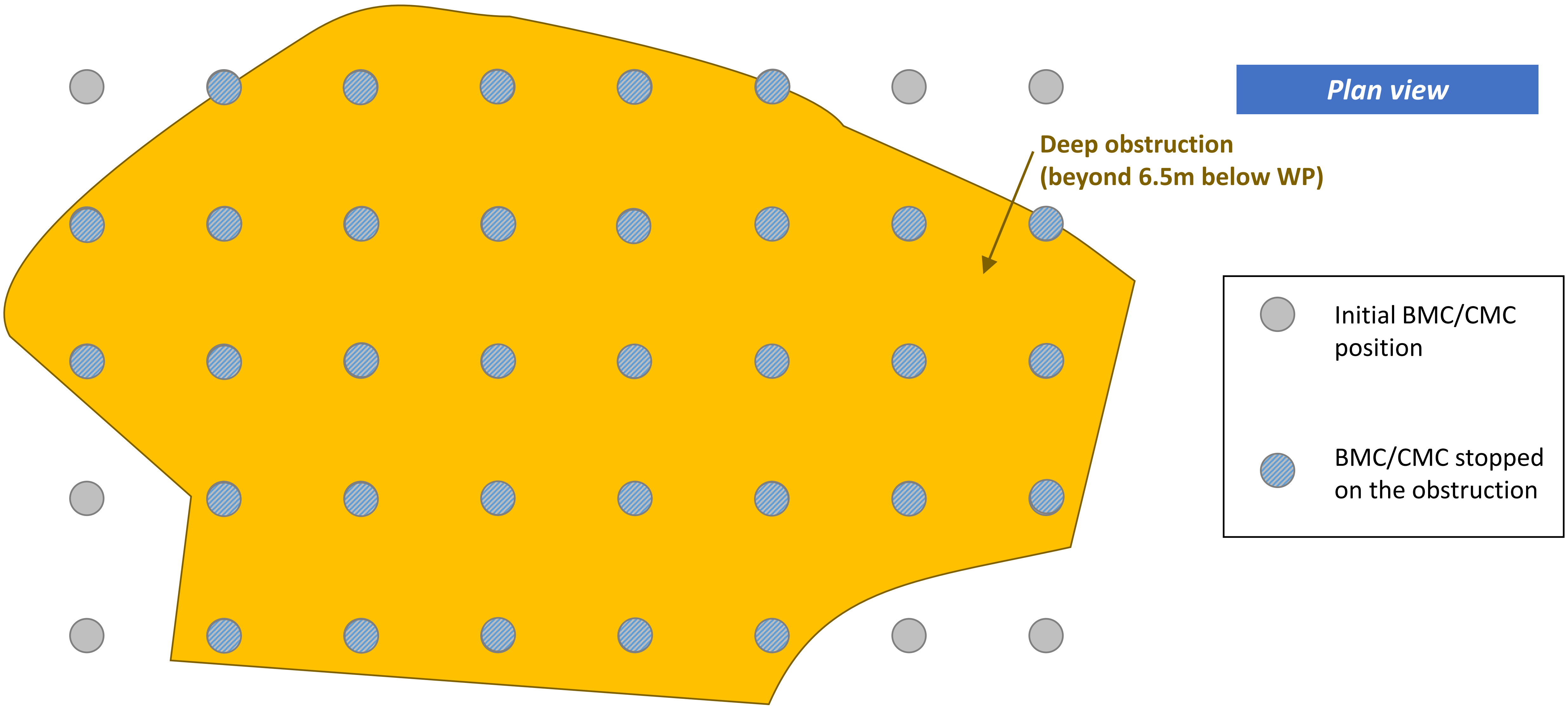

Plan view
600
600
600
Obstruction between 3 and 6.5m below WPL
= Initial BMC/CMC position
= Additional BMC/CMC
= BMC/CMC stopped on the obstruction

V29949 – Silvertown – Olympus Project

Obstruction methodology v.2



Obstructions beyond 6.5m below WPL → *BMC/CMC stopped on the obstruction (see page 6)*


Plan view
Deep obstruction
(beyond 6.5m below WP)
Initial BMC/CMC position
BMC/CMC stopped on the obstruction