Ground modifications using mass soil mixing technique in geotechnical engineering

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ABSTRACT: Mass Soil Mixing (MSM) is a specialized ground improvement technique to improve soft fine-grained soils and mud deposits, including dredged material. By mechanically blending a dry or wet cement binder with the soil, mass soil mixing can also be used to neutralize and contain contaminated soils as in-situ or ex-situ treatment. The method improves mechanical characteristics of soils to stabilize and control settlement of soft soils beneath road and rail embankments, residential developments and warehouses and to create working platforms for construction equipment. MSM can also be used to strengthen soils before excavation and to stabilize excavation bases. The method can be used over water or on land.

This paper presents case study of MSM for 4.5m deep pump station excavation works within soft estuarine clays and very loose sands with high water table. The ground treatment was required down to of 6.5m depth and sufficient width to ensure stability during excavation for the pump stations. The required MSM shear strength of 250kPa (minimum) was determined by finite element modelling in Plaxis program.

This paper presents the design methodology, laboratory testing, construction works and post treatment verification of mass soil mixing works for excavation works and ground improvement.

1 MASS SOIL MIXING (MSM)

The mass soil mixing stabilization is a ground treatment technique that improves strength characteristics of weak soils such as soft soils or loose sands by mechanically blending a dry or wet cementitious binder with soils. The treatment method has been used extensively in the ground improvement for the foundation of rail and road embankments and structures such as buildings and tanks (Terzaghi, S. 2004, Topolnicki, M 2015). It is also used to create retaining, groundwater cutoff walls and in situ treatment of buried contaminants also known as in situ soil solidification (ISS).

The typical objectives of the treatment are to reduce settlements and/or improve the stability of the treated ground. Soil can be mixed entirely over the whole problematic zone or in a panel configuration with replacement ratio between 30% and 50%.

Mass soil mixing requires specialized mixing tool, which is fixed to an excavator arm. The tool comprises of two "propellers" which rotate under high speed and binder injecting from a nozzle in the center and directly "mixed" with the in-situ soils, resulting in a stabilized material with enhanced shear strength, reduced compressibility and permeability characteristics.

Figure 1 shows a typical mixing tool and Figure 2 shows a MSM set up.

Figure 1. Mixing tool of MSM

Figure 2. MSM rig and setup

The binder used is generally Ordinary Portland Cement (OPC) or cement blends including Ground Granulated Blast Furnace Slag (GGBFS). The cementitious binder is also used with chemical reagents for hazardous waste treatment, sludge stabilization/solidification and in situ chemical reduction. Binder is delivered in dry form or readily mixed grout. Mixing is executed with mixing tool moving vertically and/or horizontally within the soil mass. This method is typically used to shallow depths 3.5m to 5m with maximum treatment depth up to 7m.

While the treatment method is generally used to stabilize soil for foundation support, there is an increase in the usage of this method for retention, forming a mass gravity block. In particular, for sandy soils condition with high groundwater table, the mixed soil block with low permeability provides most appropriate solution for retention and minimizing ingress of water into the excavation zone.

Typical soil mix treatment parameters are as follow:

- Ultimate Compressive Strength (UCS): 0.1MPa to 0.5Mpa
- Shear Strength, Cu: 50kPa to 250kPa
- Permeability: 1 x 10-7m/s

2 MIXING FOR THE TREATMENT PITS/STATIONS OF CBPP

2.1 *Project description*

Upgrading of the existing facilities have been proposed for the Cleveland Bay Purification Plant (CBPP) in Townsville, Queensland. The CBPP is a membrane Bioreactor sewerage treatment plant situated approximately 5km southwest of Townsville.

The upgrade comprises of addition of three treatment pits/stations within the matrix of the existing facilities.

These additions are:

- Return Flow Splitter (RFSP) – approximate dimension in plan 8.7m x 10.4m x 4.5m deep
- Recycle Pump Station 1 (RPS1) – approximate dimension in plan 6.75m x 14.15m x 4.0m deep
- Recycle Pump Station 2 (RPS2) – approximate dimension in plan 6.75m x 14.15m x 4.0m deep

Figure 3 shows the locations of these proposed additions, and their relative positions with respect to the existing functioning facilities.

The construction of these treatment pits/station involves excavation up to 4.5m deep. The MSM has been proposed as the main ground improvement to form gravity retention masses to allow the safe excavation and subsequent construction of these facilities.

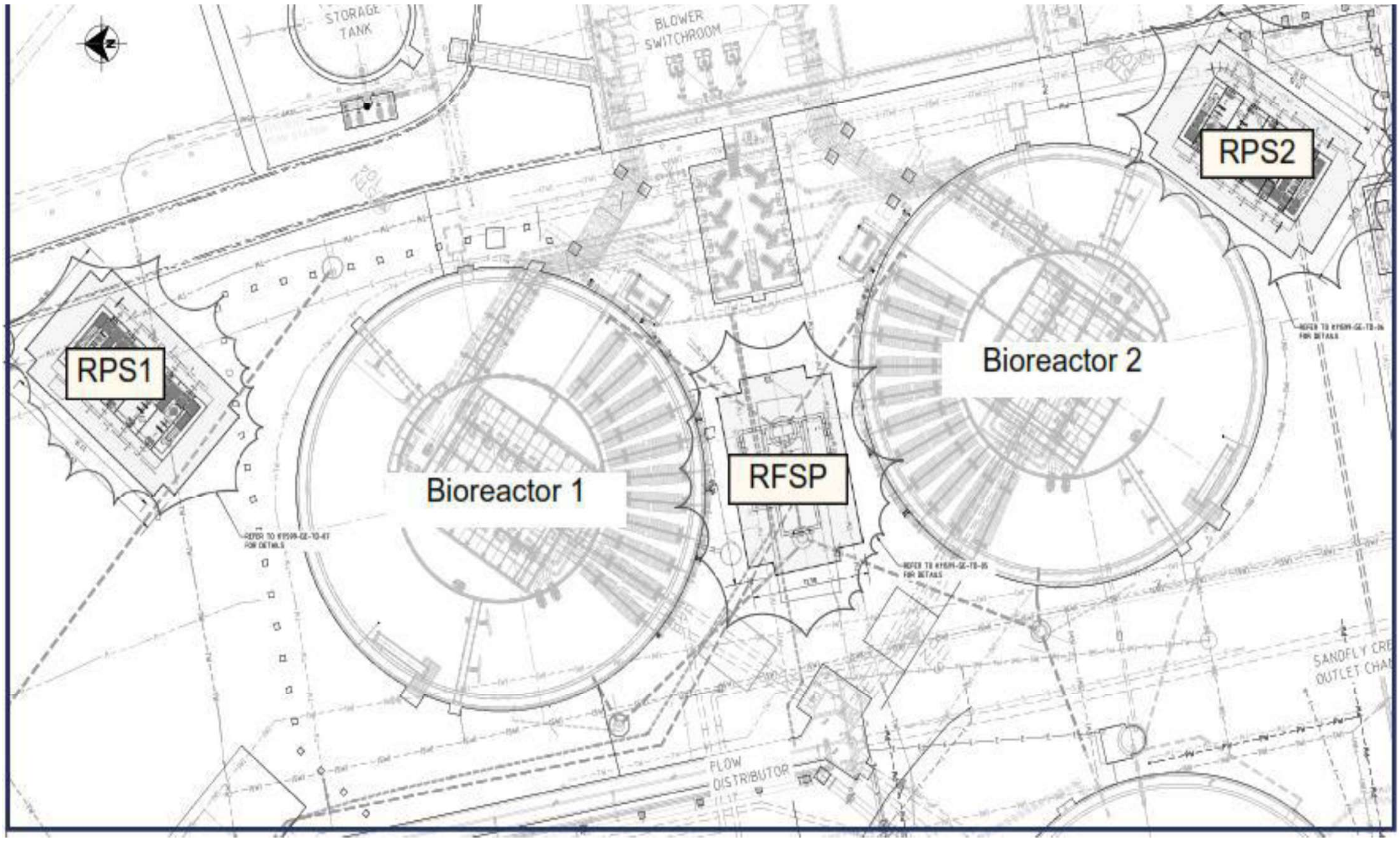


Figure 3. Locations of proposed treatment pits.

In areas where existing facilities are too close to the proposed excavation, soldier CFA piles are incorporated within MSM block to provide the required retention capability.

Conventional sheet piling works were rejected by project team as it would generate ground vibrations beyond allowable limits to existing in ground infrastructure.

2.2 *Design requirements*

Design requirements have been established based on discussions with the client and their engineers considering the temporary nature of the works.

The design life for the MSM treatment is termed short term or temporary, to allow for the excavation and construction of the pits/stations only.

Life load surcharge of up to 20kPa is to be allowed on the retention side in the analyses.

Retaining wall movement was limited to 50mm, however included possible over excavation of 0.5m.

A minimum factor of safety of 1.5 is required in design for the stability of the ground retention and against ground heave of bottom of excavation.

2.3 *Ground conditions*

At the CBPP site, a geotechnical investigation report by Coffey Geotechnics was available detailing the results of five boreholes, five trial pits and eleven cone penetration tests (CPT). The results show that the sub-soil conditions at the site consist of:

- Approximately 2.5m thick uncontrolled fill;
- Recent Alluvium comprising loose to medium dense alluvial sand and silty sand with inter-bedded layers of soft clay;
- Approximately 1m to 1.5m of firm clay;
- Older Alluvium comprising very stiff to hard clay and dense to very dense sand; gravelly sand and clayey sand.

The Groundwater table is at approximately 2m below the existing ground level.

The CPT results shows that the uncontrolled fill comprises predominantly sand with high tip resistance with localised areas of loose materials. As this fill extends below the water table, and with the excavation depth reaching up to 5m, the MSM block is to provide retention for safe excavation and also to reduce seepage flow into the excavation during construction.

2.4 *Treatment parameters and considerations*

The design of the retention system was based on providing a mass gravity structure of sufficient width by mixing the insitu soils with binder.

The computer program Plaxis, (a finite element method) software, was used to determine the required MSM block parameters and to simulate the performance of the treated ground throughout the excavation process.

The Plaxis 2-D 2017 version was used in the analysis adopting the following soil models and parameters.

Table 1. Soil models and parameters

Material	Model	(kN/m^3)	E (Mpa)	S_u (kPa)	’ (deg)
Fill*	MC***	18	5	-	28
Recent alluvium*	MC***	18	30	-	30
Firm clay**	MC***	16	5	25	-
Older alluvium**	MC***	18	30	150	-

* Drained ** Undrained *** Mohr-Coulomb

The analysis carried out show that the resultant MSM treatment parameters required to satisfy design requirements were:

- Target Unconfined Compression Strength, UCS = 500kPa
- Estimated undrained shear strength, S_u = UCS/2 = 250kPa (Filz et al. 2015)

The proposed treatment pits/stations are situated in an area with existing underground services and with two bioreactors in close proximity. Therefore where the required width of the block was not achievable, 600mm diameter piles were installed using the CFA method to provide the necessary retention. These piles were installed within 1.5m from the perimeter of the MSM-treated area.

Figure 4 shows the proposed treatment plan view at the RFSP, and Figure 5 shows the cross-sections of the RFSP treatment pit, with details of the treatment configurations. Where width of treatment was not available for stability due to presence of existing structurers, in this case the bioreactor tanks, retention piles were incorporated.

Treatment at the RPS1 and RPS2 follows similar concepts.

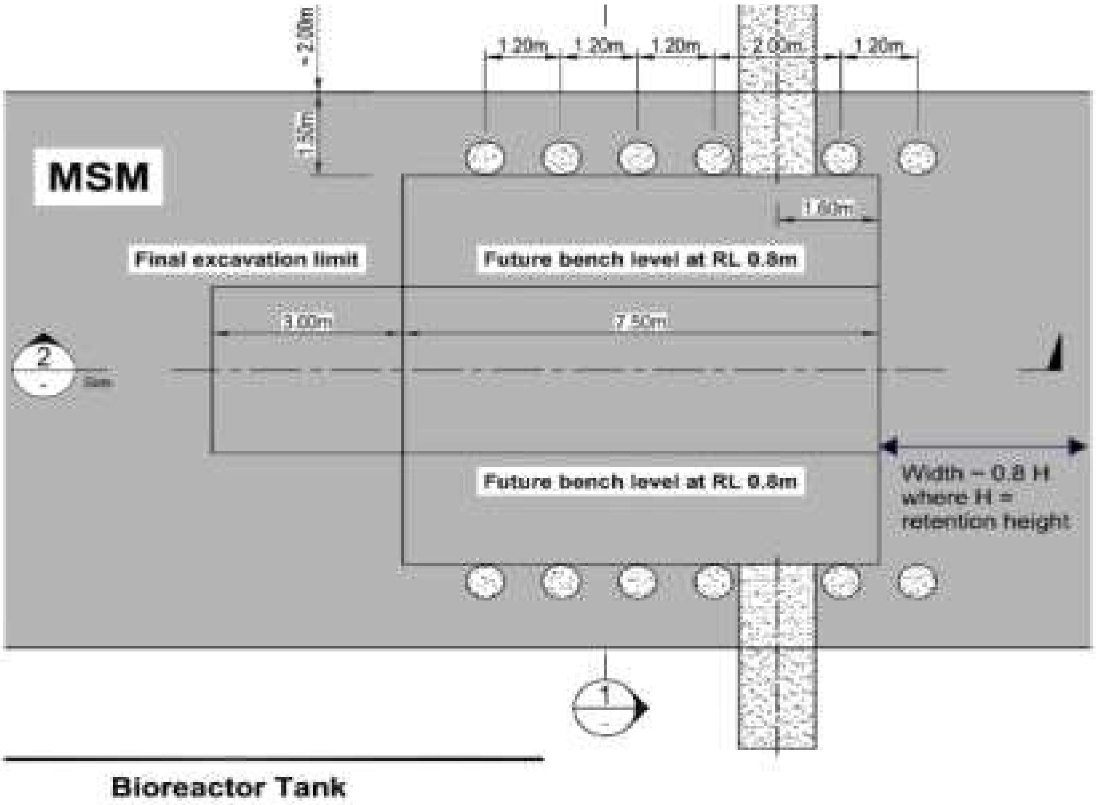
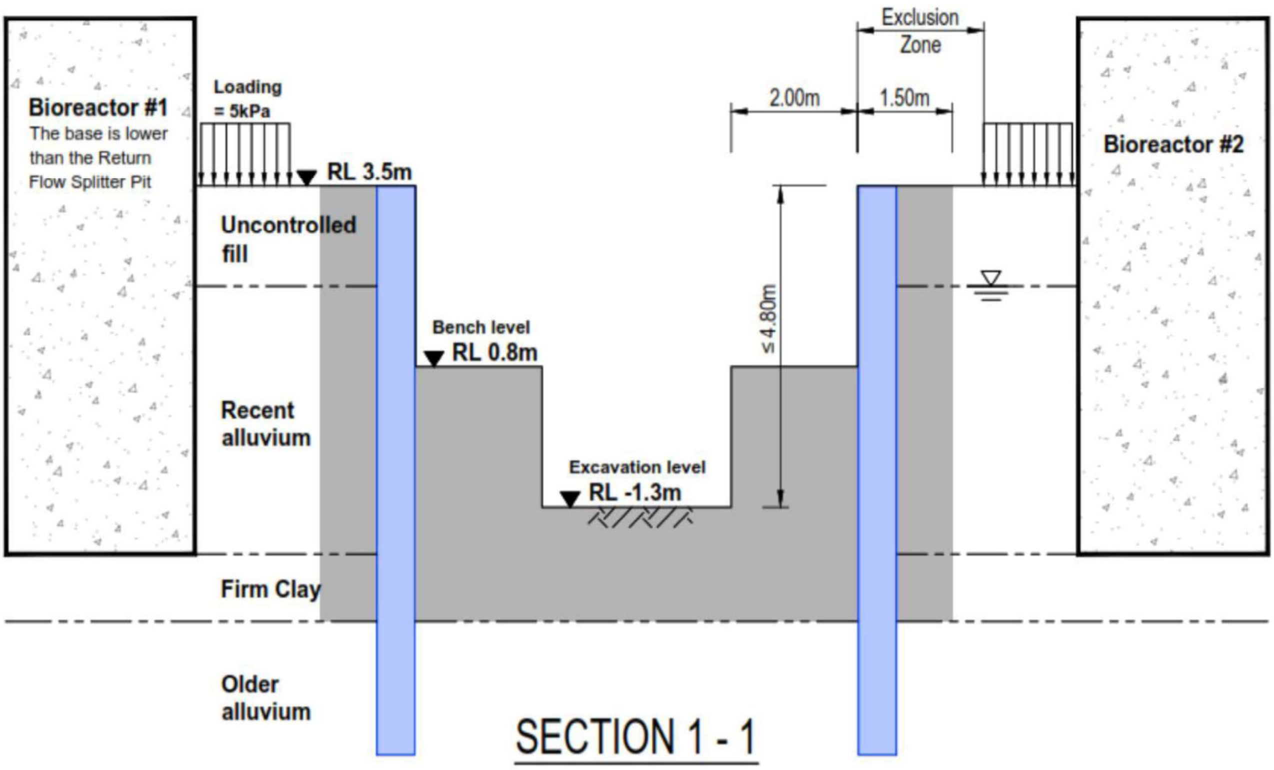
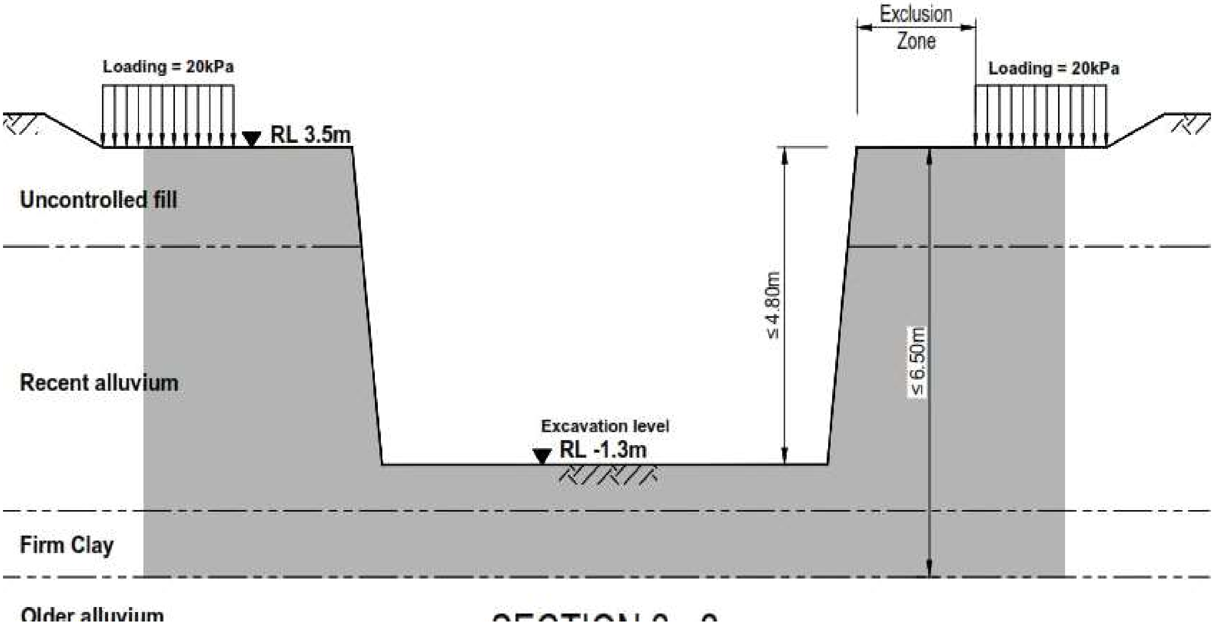


Figure 4: Plan view at RFSP.



(a)



(b)

Figure 5: (a) Cross-section 1-1 and (b) Cross-section 2-2 at RFSP.

2.5 *Pretreatment laboratory trial mixes*

Prior to the commencement of mixing on site, representative soil samples were collected for laboratory trial mixes and UCS tested to determine the optimum cement content to achieve the required UCS specified. Samples were tested at 3, 7, 14 and 28 days to establish a trend of strength gain over time, and so that estimation of strength at 56 days could be made.

Figure 6 shows the results of UCS testing carried out on trial mix samples with different cement content and water cement ratios.

The factor is the ratio between the laboratory tested samples to the insitu test results and could range between 1.1 to 1.5 for wet mixing. Based on Keller's experience, a factor of 1.2 was adopted.

The results of the above trial mixes were used to assist the designers in determining the possible mixing parameters (cement content and water-cement ratio) to achieve the target UCS.

Based on the trial results, a cement content of 160 kg/m^3 was used in the treatment of the pits. Note that minor adjustment of this cement content was carried out during the operation phase depending on the soil encountered on site.

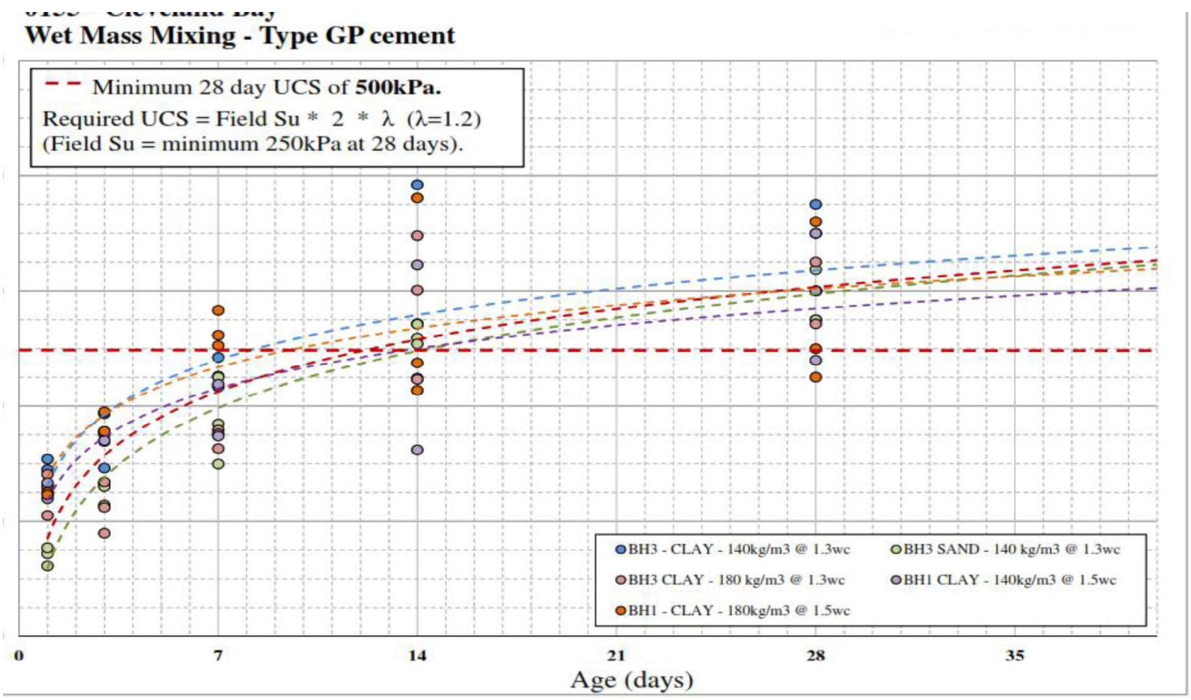


Figure 6. Laboratory trial mixes.

2.6 *Site execution*

The treatment work was carried out under extremely challenging site conditions, with the presence of the functioning bioreactors and numerous existing services running through the footprint of the proposed pits/stations. Site coordination and cooperation with the civil contractor in identifying, removing or relocating these services while ensuring unhindered treatment operation has allowed the work to be carried out meeting the tight construction schedule of the project. It is to be noted that the existing facilities were kept functioning, except those destined for decommissioned, throughout the treatment process.

Figure 7 shows a typical mixing rig in operation at the footprint of RFSP.

Figure 7. MSM in operation.

2.7 *Quality control during execution*

Fully automated monitoring system has been equipped in all installation rig to assist the operator in ensuring the correct amount of binder was used over the depth of treatment to conform to requirement of design.

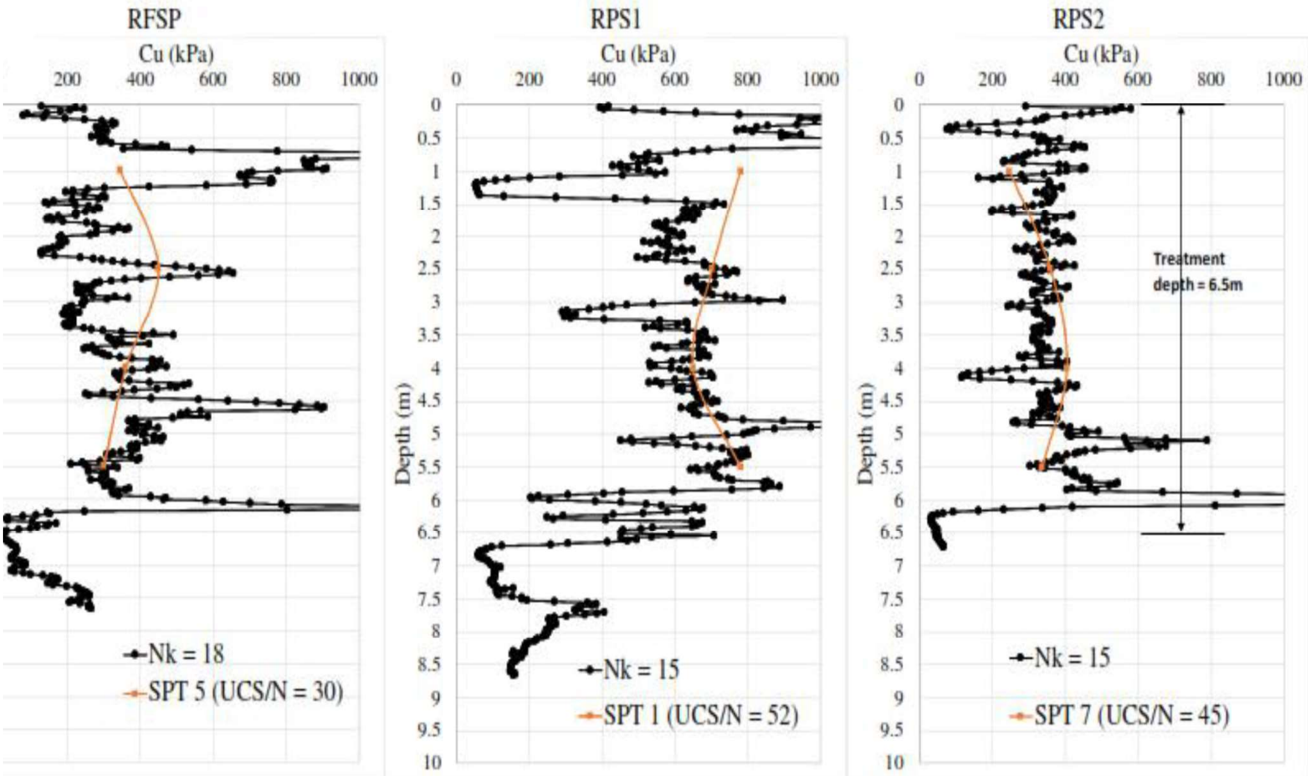
During production, verification of the treated soil was carried out using the following testing:

- Retrieve mixed samples for laboratory UCS testing – 1 set of 4 samples (7, 10, 14 and 21 days) per 200m^3 of mixed soil
- Insitu CPT test – 1 set of 8 test per pit for 7, 10 and 14 days
- Insitu borehole SPT test – used as additional as and when required or when early termination of CPT was encountered

The UCS results were then correlated with the CPT and SPT data to determine the appropriate factor to be used in the subsequent determination of resultant shear strength from the insitu testing.

The correlated results of insitu testing are presented in Figure 8. The resultant cone factor Nk for CPT, where Cu = Qc/Nk, is between 15 and 18. The EuroSoilStab and SGF Report have recommended a value of 10. The ratio between UCS and SPT blow-count, N is between 30 and 50, from which Cu is calculated as resultant UCS / 2.

It is to be noted that inherent variability of tested results are to be expected and conclusion was arrived at after considering a substantial number of testing at each pit/station.



Figures 8. Results of the post compaction RFSP, RPS1 and RPS2.

2.8 *Completed excavation*

Figure 9 the excavation and construction of the RFSP. Excavation was carried out with the assistance of a rock-breaker.

Figures 9. Excavation at RFSP

Figure 10 shows the construction of the RFSP pit carrying out in an area with sandy soil and groundwater table about 3m above the final excavation level.

Figures 10. Construction of RFSP

The excavation at RFSP up to 5m deep was able to be completed without any signs of instability and only minor seepage of water was detected. Similar results were observed at RPS1 and 2.

3 CONCLUSIONS

The traditionally use of MSM treatment technique to strengthen subsoils conditions to support foundations has now been extended to its use in providing retention for excavation and environmental in situ solidification.

The resultant treated block makes this method most suitable in areas with sandy soils where excavation is to be carried out below the high groundwater table or very soft soils that would require significant internal bracing to retaining wall structure which in turn would congest/affect excavation working space. The impermeable nature of the treated block resulted in considerable time and cost saving when excavation can be carried out in the dry without the need for de-watering and treatment of contaminated groundwater.

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