# CASE STUDY-GROUND IMPROVEMENT RESULTS BY USING SETTLEMENT CLUSTER TECHNIQUE

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**Abstract -**
The monitoring of the settlement during the ground treatment process has been carried out by means of instrumentation clusters generally installed on a 100m x 100m grid in the main body of the reclamation / surcharge.

The instrumentation clusters consist of settlement markers, standpipe piezometers, inclinometers and cone penetration tests (CPT). The settlement and horizontal displacement data have been reviewed along with CPT data to monitor strength gain during construction stages.

**Index Terms** - Clusters, Settlement, Ground Improvement, CPT

## I. INTRODUCTION

### 1.1 Background

The Works include reclamation, ground improvement and shore protection of an area of 87 ha, construction of 1,000m of quay, 4 approach trestles, dredging of the maneuvering area & berth pocket and construction of infrastructure facilities for the container terminal. The ground improvement work consists of installation of prefabricated vertical drains combined with surcharging.

### 1.2 Purpose of the Document

This report presents the analysis of monitoring carried out during the ground improvement process at Section Q1, and validates the removal of the surcharge in relevant parts of this Section.

## 2. RECLAMATION AND GROUND IMPROVEMENT WORKS

### 2.1 Reclamation Areas:

The area of the reclamation and ground improvement works is broadly split into three zones for design purposes, as follows:

- Zone P1 – Rectangular area at the rear of the wharf
- Zone P2 – Triangular area behind the existing Phase
- Zone P3 – Existing reclamation area for the six lane road

### 2.2 Ground Improvement Works:

The initial level of reclamation at Section Q1 was +5.5mCD. The ground improvement solution proposed was based on ground treatment with PVDs spaced at 1.1 m centers followed by surcharging across the area up to the levels.

The design is fully described in the Reclamation Design Report. The details of the relevant area of the reclamation design are shown, which are appended to the Reclamation Design Report.

### 2.3 Settlement Monitoring:

The monitoring of the settlement during the ground treatment process has been carried out by means of instrumentation clusters generally installed on a 100m x 100m grid in the main body of the reclamation / surcharge.

The instrumentation clusters consist of settlement markers, standpipe piezometers, inclinometers and cone penetration tests (CPT). The settlement and horizontal displacement data have been reviewed along with CPT data to monitor strength gain during construction stages.

The details of the instrumentation and monitoring are shown, which are appended to the Reclamation Design Report. Figure 1 depicts the installation level of the instruments.

Eight instrument clusters comprising piezometers and settlement markers 1, 2 and 3 were installed to monitor the ground improvement process in Section Q1. The analysis aims to assess the degree of consolidation at each instrument cluster to verify if the surcharge can be removed according to the design and specification.

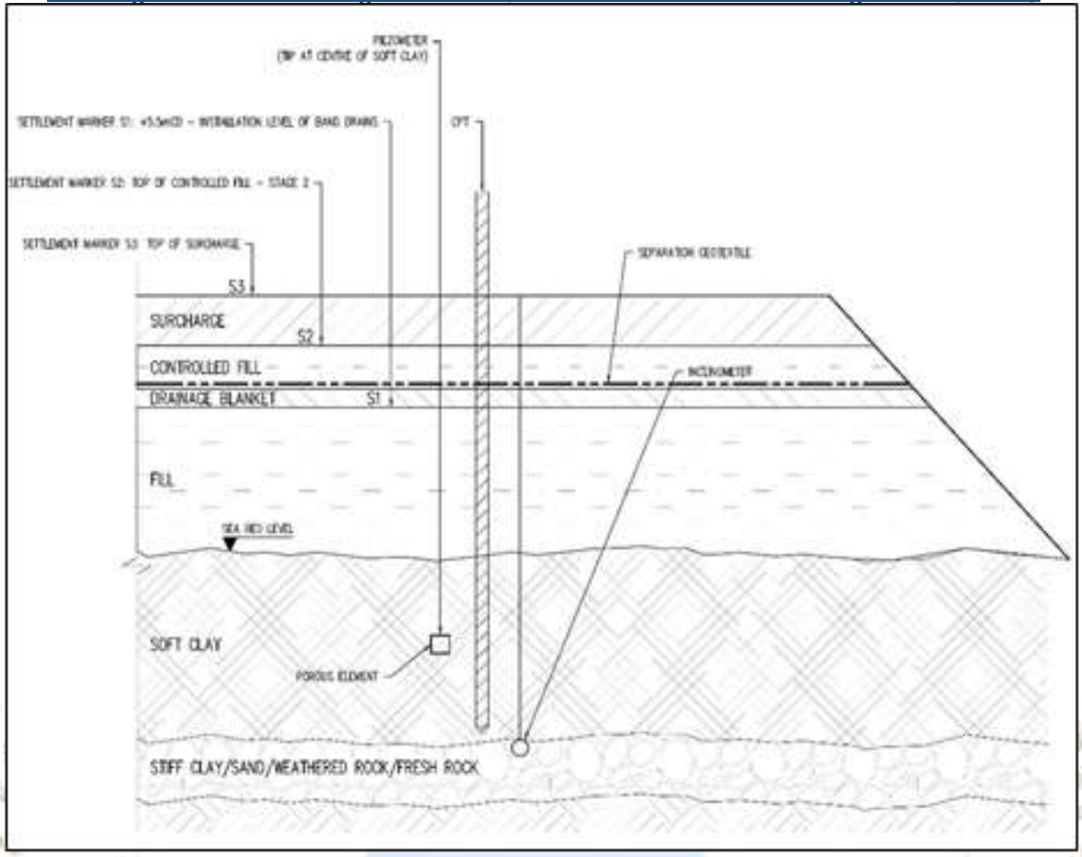

**Fig.1 Instrument Clusters Installation Levels**

**Table 1: Details Of Instrument Clusters At Section Q1**

| | | | | | |
|---|---|---|---|---|---|
| A1 | 2094778.194 | 282427.182 | +5.5 | +11.5 | 20/08/2022 |
| B1 | 2094694.780 | 282444.778 | +5.5 | +10.9 | 21/08/2022 |
| B18 | 2094624.390 | 282522.935 | +5.5 | +10.0 | 30.08/2022 |
| B19 | 2094554.712 | 282600.324 | +5.5 | +10.0 | 01/08/2022 |
| C1 | 2094732.067 | 282478.561 | +5.5 | +10.9 | 21/08/2022 |
| C2 | 2094661.475 | 282556.599 | +5.5 | +10.0 | 30/08/2022 |
| C3 | 2094591.753 | 282633.849 | +5.5 | +10.0 | 01/09/2022 |
| C4 | 2094525.010 | 282708.071 | +5.5 | +10.0 | 02/09/2022 |

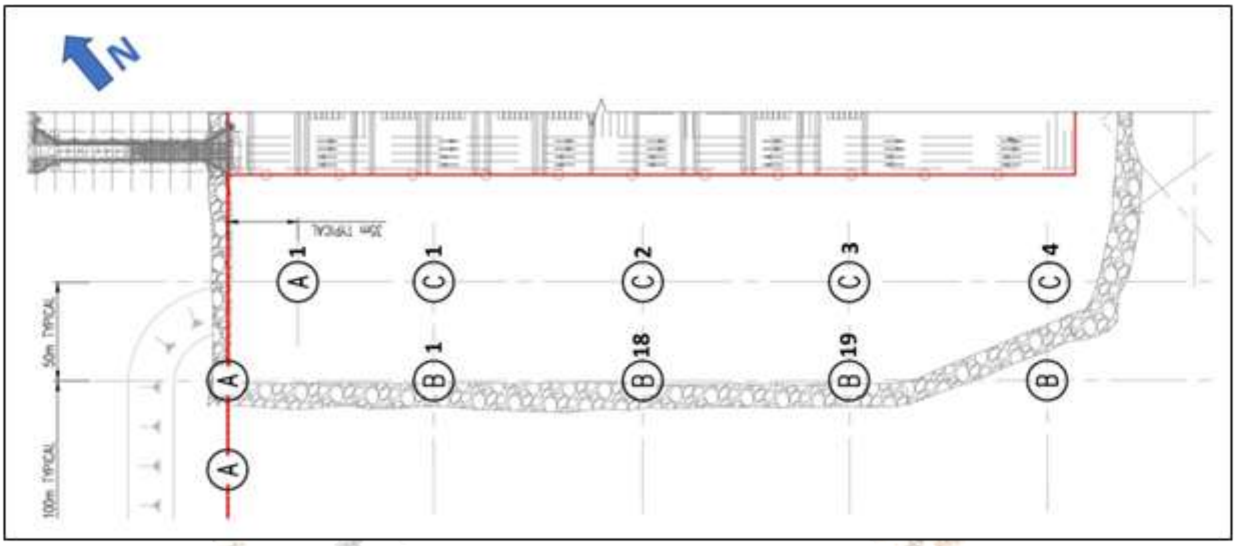

Fig.2 Location of Instrument Clusters At Section Q1

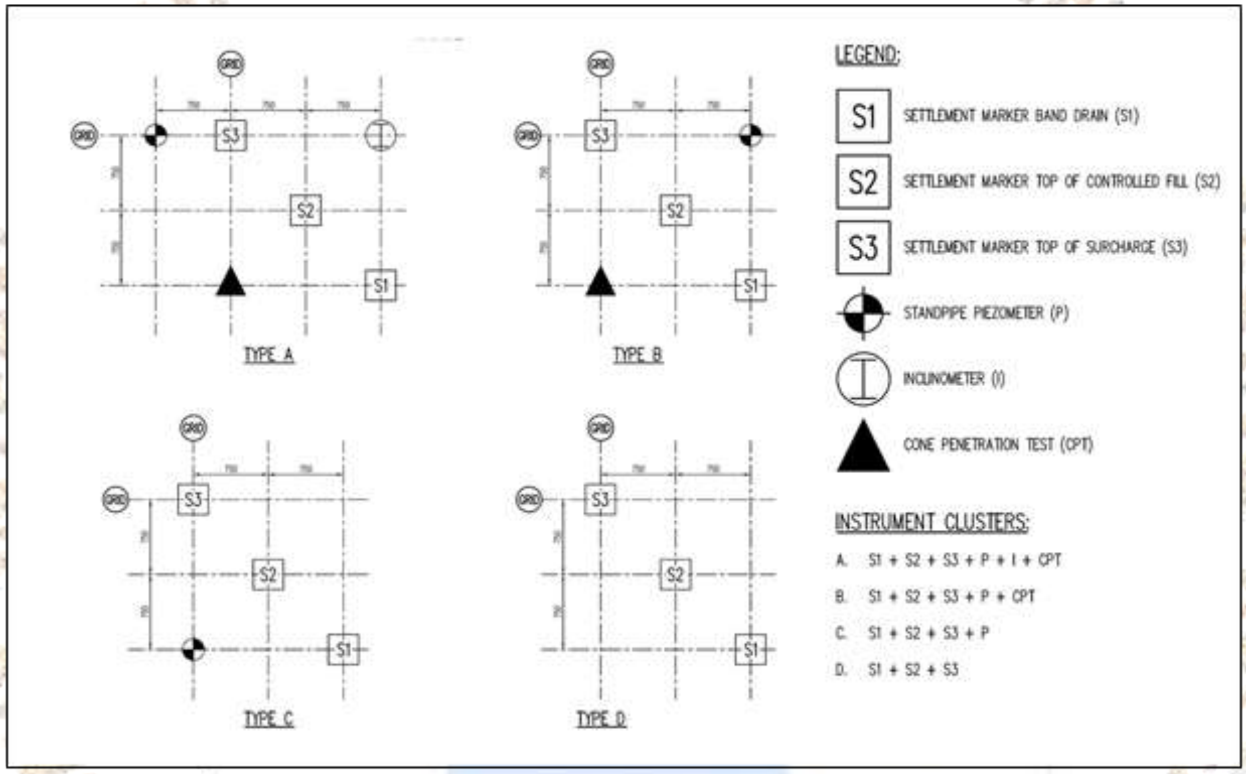

Fig.3 Instrumentation Details At Each Cluster Type

2.4 Design Requirements

There are limitations on the reclamation settlement performance which provide the basis for the ground improvement design. The residual settlement is defined as commencing at the time of handover of a portion of the site to the Employer, and the maximum permitted residual settlement is defined.

**Table 2: Residual Settlement Requirements in Design Criteria**

| Maximum Permissible Residual Settlement (mm) | | |
|---|---|---|
| After 2 Years | After 5 Years | After 20 years |
| 100 | 150 | 300 |

## II. METHODOLOGY FOR VALIDATION OF PREDICTED SETTLEMENTS

The analysis to predict the ultimate primary consolidation settlement from measured settlement data is carried out using Asoaka's observational procedure 1978, in which early settlement data can be used to predict ultimate primary consolidation settlement and the in-situ coefficient of consolidation. The basis of the method is that the one dimensional consolidation settlements $\delta 0$, $\delta 1$, $\delta 2$, etc. at time intervals 0, $\Delta t$, $2\Delta t$, etc. can be expressed as first order approximation as below:

$$\delta n = \beta 0 + \beta 1 \bullet \delta n\text{-}1$$

The above expression represents a straight line in a $\delta n\text{-}1$ vs $\delta n$ graph known as the Asoaka plot. Where $\beta 0$ is the intercept and $\beta 1$ is the slope of the line. When ultimate primary consolidation is reached $\delta n = \delta n\text{-}1 = \delta ult$ and therefore:

$$\delta ult = \beta 0 / (1- \beta 1)$$

The in-situ coefficient of consolidation for vertical drainage, cv can then be determined from below equation proposed by Magnon and Deroy (1980):

$$\ln \beta 1 \ / \Delta t = -\pi 2 \bullet cv / 4 \bullet H2$$

and the in-situ coefficient of consolidation for radial drainage, ch can be determined from the equation below:

$$\ln \beta 1 \ / \Delta t = -8 \bullet ch / \mu \bullet D2$$

Analysis of Monitoring Data:

The field settlement data relevant to settlement marker 1 (S1) is plotted against time in Figure 6 based on monitoring data from the site up to 11 April 2023. It is noted that the observed settlements at the S1 markers include the settlement in clay and murrum compression in the reclamation layer up to +5.5mCD.

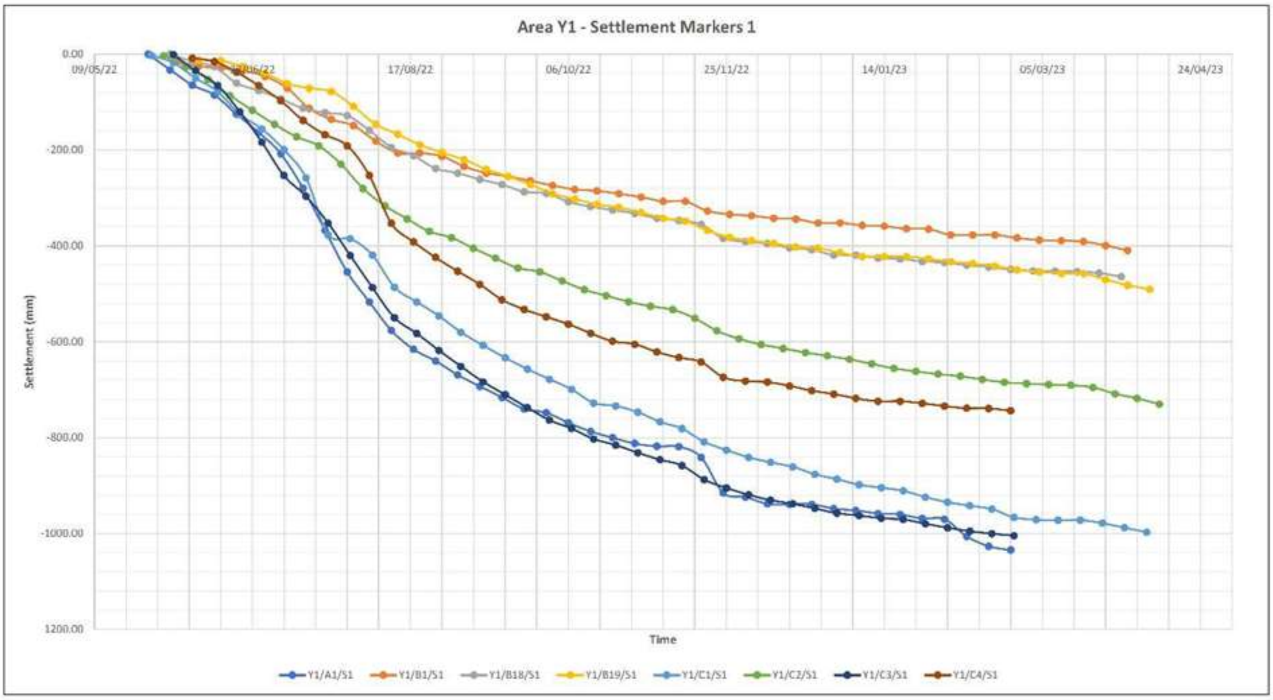

**Fig.4 Settlement At Instrument Clusters In Section Q1**

The pore pressure at approximately mid-depth of the soft clay layer was monitored during the surcharge period on site using standpipe piezometers. The measured readings regrettably did not correlate with the loading applied and therefore the piezometer readings were dismissed in the analysis.

Although the magnitude of pore pressure variation recorded in the piezometers could not be validated for the applied loading, the recorded pore pressure readings suggest that the excess pore pressures generally started to dissipate after the full application of the surcharge load. For completeness, the piezometer readings recorded during the surcharge period at instrumentation cluster shown in fig 7. And also appendix C.

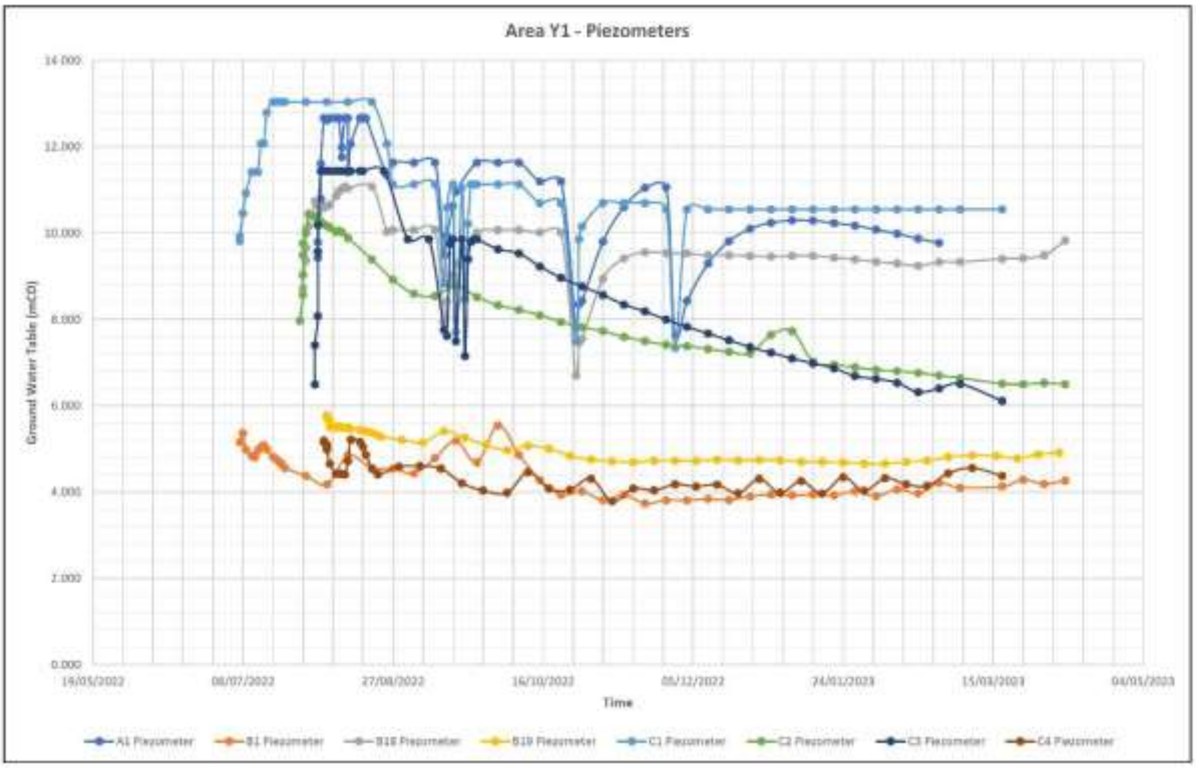

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**Fig.5 Ground Water Level At Instrument Clusters Of Area Q1**

The analysis to predict the ultimate primary consolidation settlement from measured settlement data is carried out using Asoaka's observational procedure 1978, in which early settlement data can be used to predict ultimate primary consolidation settlement and the in-situ coefficient of consolidation. The monitoring data of each instrument cluster is analysed separately. The analysis is based on the data from settlement markers 1.

The ultimate primary settlements predicted by the Asaoka method and the measured settlements under surcharge loading are summarized in Table 5 below for all Instrument Clusters at Section Q1.

## III. RESIDUAL SETTLEMENTS UNDER OPERATIONAL LOADS

The residual settlements under operational loads at Section Y1 include primary consolidation and secondary consolidation or creep of different layers of the ground, and have been calculated based on the real degrees of consolidation, practical dates and actual geotechnical profiles at each instrument cluster.

Based on the degrees of consolidation at each instrument cluster location as noted in Table 5 the over consolidation stress is calculated at each location of improved ground. The final stress increase in the long term is calculated considering required fill to reach the finished level of the platform and operational load. As the over consolidation stress is higher than the final stress, all of the primary settlement has occurred and the residual settlement will consist only of secondary and creep settlements in the improved soft ground and the fill respectively.

Creep settlement in the Fill and secondary compression in the clays takes place continuously over a long period and is estimated according to a logarithmic relation with time as follows:

$$S_c = C_\alpha H \log\left(\frac{T_2}{T_1}\right)$$

Where:

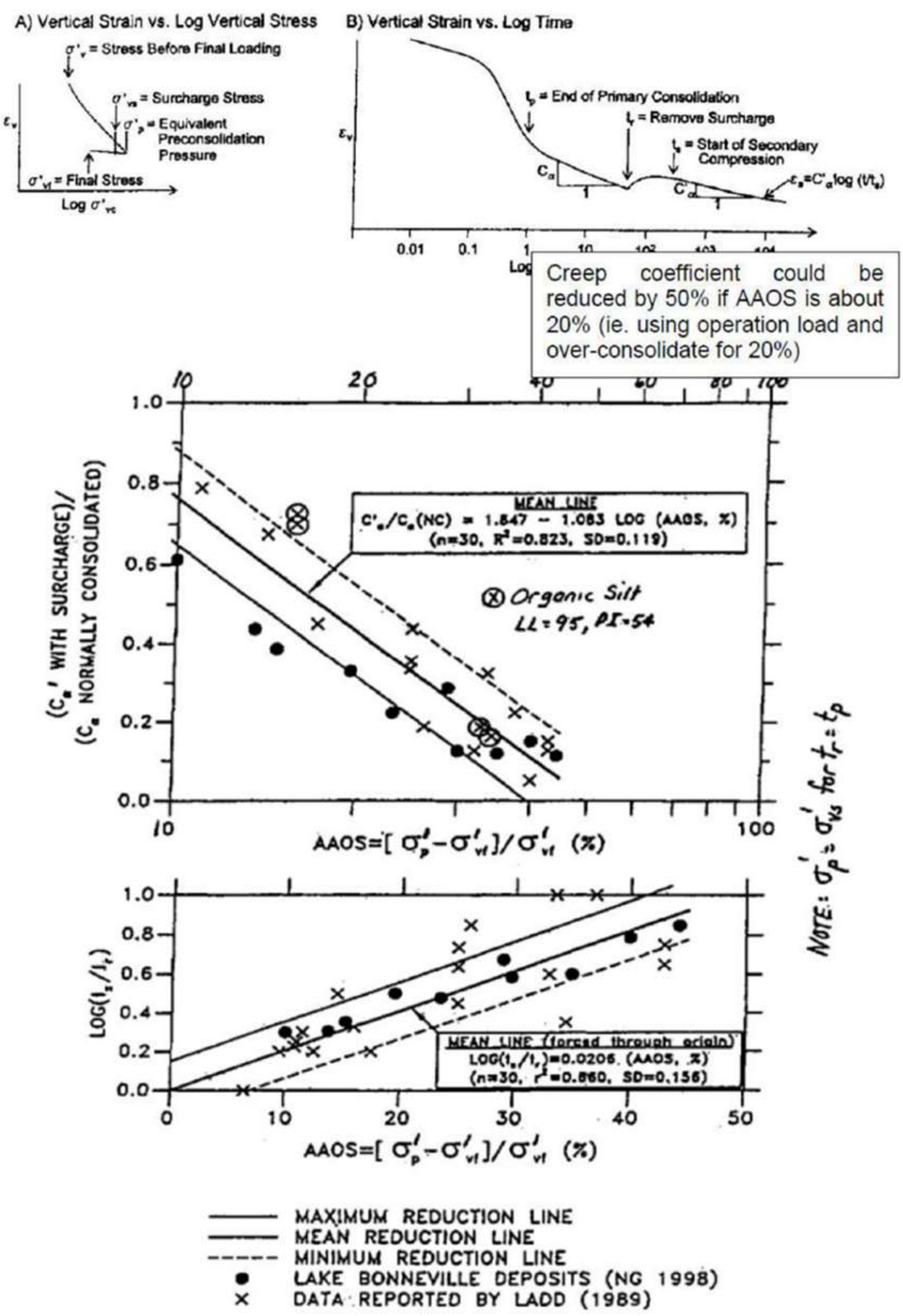
Sc is the secondary/creep settlement of the soil
Cα is the logarithmic creep compression rate
H is the thickness of the layer
T1 is the time of commencement of creep settlement
T2 is the elapsed time after fill placement to the time of interest

Recent publications indicate that the creep settlement of soft clay is reduced by higher surcharge and thus increased over-consolidation ratio. It is suggested that the higher Adjusted Amount of Surcharge (AAOS) ratio would reduce the ratio between creep coefficient of over-consolidated (OC) clay, C'α, and normally consolidated (NC) clay, Cα (Figure 8). This principle has been applied to many projects over the world and presented in different publications such as in the US (Lambrechts el al., 2004) and Australia (Lai et al., 2015)

Settlement analysis is based on the nearest borehole profiles of geotechnical investigations before reclamation and confirmatory boreholes or cone penetration tests after surcharging of the ground.

The calculations are based on the following assumptions:

- the finished formation level is +7mCD.
- The mean sea level is +2.5mCD.
- The bulk density of fill is 17kN/m3.
- A single drainage condition is assumed for the PVDs since the Basalt is assumed to have a low permeability.
- There are three layers of soil for the settlement calculations including Murrum Fill, soft clay and stiff clay.
- Gravelly sand/weathered Basalt below the stiff clay are competent strata and provide a rigid boundary in the consolidation analysis with the settlement of Nil.



Creep coefficient could be reduced by 50% if AAOS is about 20% (ie. using operation load and over-consolidate for 20%)

**Fig.6 Ground Water Level At Instrument Clusters**

The predicted residual settlements meet the ground improvement design criteria of limiting the residual settlement to 100mm, 150mm and 300mm over a two year, five year and 30 year period after hand over respectively. Based on this assessment, the surcharge at areas associated with all instrument clusters at Section Y1, shown in Figure 10 can be removed.

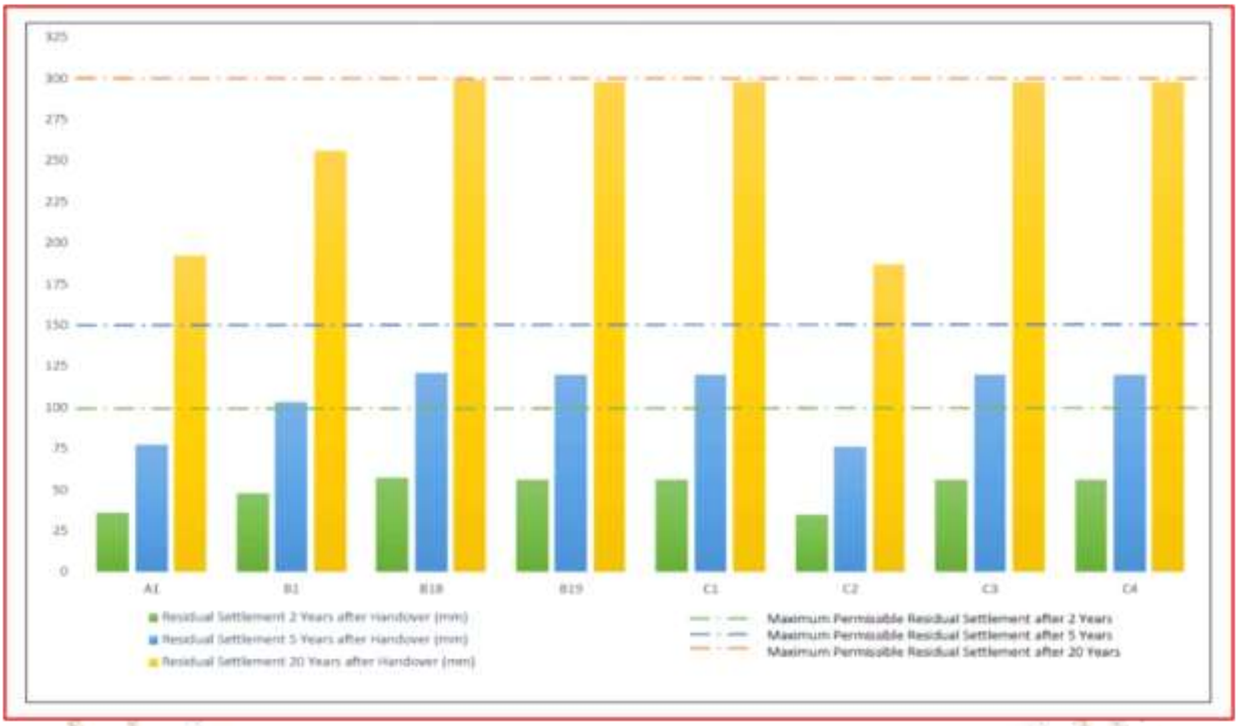


**Fig.6 Residual Settlements At Each Instrument Cluster At Section**

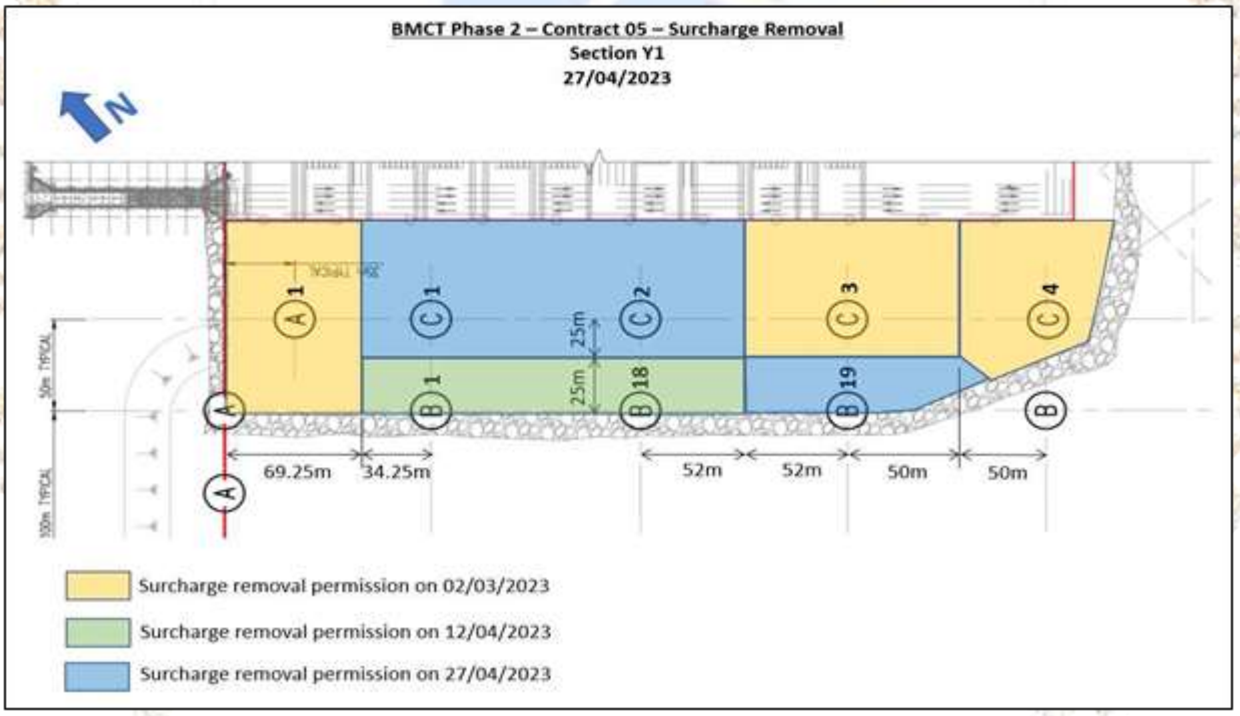


**Fig.6 : Instrument Clusters Allowed For Surcharge Removal**

### 3.4 Differential Settlements

Differential settlement calculations are undertaken from the residual settlement calculations 20 years after handover. The calculation is made by considering two adjacent boreholes and the proposed orientation of a container and calculating the difference in residual settlement divided by the distance between the two boreholes.

The results show predicted differential settlement is small and within the limits of the specification.

This report presents the analysis of monitoring carried out during the ground improvement process at Section Q1, and validates the removal of the surcharge in relevant parts of this Section .

## IV. CONCLUSIONS

The Section Q1 ground improvement design was validated using the Asaoka analysis of the settlement monitoring data at each instrument cluster. The residual settlements at each instrument cluster were calculated based on the achieved degrees of consolidation, observed ground profiles in pre and post ground investigations, actual dates of surcharging, and practical date of handing over the area to the Employer. The predicted residual settlements 2, 5 and 20 years after handover were checked against design criteria. The differential settlements calculations were also performed to validate the design criteria

## V. REFERENCES

[1] Hausmann, M (1990), Engineering principles of Ground modification, McGraw-Hill Publications

[2] Binquet,J.& Lee, K.L. (1975), Bearing capacity test on reinforced earth slabs, Journal of Geotechnical Engineering Division, ASCE, 101(12), 1241-1255.

[3] Guido, V.A., Chang, D.K. & Sweeney, M.A. (1986), Comparison of geogrid and geotextile reinforced earth slabs, Canadian Geotechnical Journal (23), 435-440. 304 | Page

[4] Liu, J. (2003), Compensation grouting to reduce settlement of buildings during an adjacent deep excavation, Proc. 3rd Int. Conf..on Grouting and Ground Treatment, Geotechnical Special Publication120, ASCE, New Orleans, Louisiana, 2: 837-844.

[5] Van Impe, W. F. (1989), Soil improvement techniques and their Evolution, Taylor & Francis.

[6] Charlie, W.A., Jacobs, P.J., & Doehring, D.O. (1992), Blasting induced liquefaction of an alluvial sand deposit Geotechnical Testing Journal, ASTM, 15(1): 14-23.

[7] Bo, M.W., Chu, J., Low, B.K. & Choa, V. (2003), Soil Improvement Prefabricated Vertical Drain Technique, Thomson Learning.

[8] Mitchell, J.K., & Katti R.K. (1981), Soil Improvement‖ - State of the Art Report. 10th ICSMFE, Stockholm, 4: 509-565. AUTHOR DETAILS K.kiran, pursuing M.Tech from