Embankment Construction Over Reclaimed Land
Using Pre-Fabricated Vertical Drains

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ABSTRACT

Prefabricated vertical drains (PVD or band drains) and stage construction technique was employed successfully for a new railway embankment constructed across the Ennore creek in Chennai, Tamil Nadu where the consolidation of the very soft underlying marine clay was accelerated to complete the embankment construction economically and within the shortest time possible. The ground improvement was carried out to reduce the post construction settlement of the railway embankment as well as to increase the shear strength of the underlying soft clay in order to safely support the newly constructed embankment and thus avoid any shear failure in the very soft underlying clay during embankment construction and operation of the rail tracks.

1. LAND RECLAMATION

Additional land had to be created from the creek by reclamation in order to construct the newly proposed railway lines. The area reclaimed was approximately 45m wide and about 1000m long. Earth fill embankment had to be constructed over the land thus reclaimed to a height of 4.0m before the additional railway lines could be constructed. Please see Figure 1.

![Fig. 1: Typical Cross Section](image)

The creek bed level at the area of the reclamation was less than 1.0m below the lowest tide level. To avoid erosion of the fill material due to currents and wave action from the creek, a suitable bund wall using timber piling and sand bags was first built along the outer periphery of the filling area to contain the embankment filling. Please see Figure 2 After the construction of the peripheral bund in stages of approx 200m in length, the top very soft clay approx 1.0m in thickness was excavated and removed as it was in very soft fluid condition incapable to safely support any soil filling. After the 200m long cell was securely bunded and top soft clay layer was excavated and removed, sand was spread evenly within the cell so that the area within the cell was raised to approx 1.0m above the highest water level to create a suitable work platform from which machinery could operate.

![Fig. 2: Land Reclamation and Bund](image)

2. SUBSOIL CONDITION

Soil investigation carried out within the reclamation area showed very soft marine clay from the creek bed level to depths varying from 10m to max. 15m. Underneath the very soft clay existed stiff clay up to depth of 20m where the boreholes were terminated. The very soft marine clay had very low shear strength not exceeding 20 kN/m2 classified as highly compressible CH soil. Consolidation
tests were unfortunately not performed on the soft marine clay samples. However from boreholes in nearby areas the following average properties have been considered for the very soft marine clay.

- Natural Moisture Content (NMC) = 60 -80%
- Liquid Limit (LL) = 100-120%
- Plastic Limit (PL) = 40 -45%
- Plasticity Index (PI) = 60 –75%
- Natural Moisture Content (NMC) = 90 –100%
- Cohesion (undrained), c = < 20 kPa
- Coefficient of consolidation (vertical), Cv = 1.25 m²/year
- Compression index, Cc = 1.0
- Initial voids ratio, e₀ = 0.8- 0.9

3. PREFABRICATED VERTICAL DRAINS

The design of the prefabricated vertical drain (PVD) for the project was done considering a ratio of Ch/Cv = 1.0 where, Ch is the Coeff of consolidation due to radial flow and Cv is the Coeff of consolidation due to vertical flow. A design spacing of 1.25m c/c in triangular grid was accordingly adopted in order to achieve the required minimum U=70% consolidation within a period of about 3-4 months. Pre-fabricated vertical drains were installed up to the full depth of the very soft clay at the design spacing over the entire area of embankment construction to accelerate the consolidation of the very soft marine clay under imposed load (Fig. 1).

The PVD employed for the project was Nylex Flodrain FD-4 which has the following main technical properties.

- Core structure = Double sided cusped
- Filter structure = Non-woven spun bond
- Drain width = 100mm
- Drain thickness = 4mm
- Discharge capacity @ 10 kPa = 70 x 10⁻⁶ m³/s

The PVD was installed with a drain stitcher and mandrel using constant rate of penetration. Maximum depth of installation was 17m below the reclamation level. (Fig. 3)

4. EMBANKMENT CONSTRUCTION

As the underlying very soft marine clay had low bearing capacity it was clear that the embankment construction could only be carried out in two stages. Minimum U=70% degree of consolidation was necessary to support the stage 2 of construction and the period required to achieve this was calculated to be 4-5 months. Only after this consolidation the 2nd stage of embankment construction could take place. The PVD would allow sufficient consolidation and increase in clay shear strength within that period under the first stage of embankment fill to support the increase in load due to the second stage of embankment construction. Accordingly the embankment was constructed in 2m lift maximum for each stage of construction.

A sand drainage blanket approx 300mm thick was placed on top of the installed band drains to allow free drainage of expelled pore water from the band drain prior to construction of the first stage embankment construction. A non-woven geotextile filter fabric was provided over the sand drainage blanket to prevent any contamination of the sand drainage blanket with the earth fill during embankment construction (Fig. 1).

The earth fill embankment was constructed in layers not exceeding 200mm in thickness and each layer was compacted to 95% MDD.

5. GEOTECHNICAL INSTRUMENTATION

To monitor the progress of clay consolidation and ground settlement, geotechnical instruments consisting of platform type settlement gauges and Casagrande type open standpipe piezometers were installed. The settlement gauges were installed 0.5m below the reclamation fill level and the piezometers at about mid-depth of the marine clay layer.

Unfortunately the instruments were disturbed at a number of occasions during embankment construction and several had to be re-installed. The piezometer outlet pipes were broken soon after completion of the first stage of embankment construction and they could not be monitored since. Therefore the incomplete pore pressure dissipation data has not been included in this paper. It was possible to obtain settlement data for a longer period till the completion of the second stage embankment construction. Soon after completion of the second stage construction these were also totally damaged by vandals and the observations could not continue further. We have presented the available settlement data and its analysis in this paper.

6. ANALYSIS OF SETTLEMENT DATA

The settlement / time plot for selected gauges is shown in Figure 4. SG-14 represents the gauge at the deepest marine clay layer at the extreme end of the embankment, SG- 9 at...
about the middle of the embankment length and SG-1 close to landward end.

![Graph](image)

**Fig. 4:** Settlement Record

Theoretical settlement/time relationship based on vertical drainage only (without band drains) and with combined radial and vertical drainage (with band drains) are presented in Figure 5 for comparison. The plot clearly demonstrates the importance of PVD in reducing consolidation period for such projects. It may be noted that the required degree of consolidation (U=70%) was actually obtained within less than 2 months instead of 4-5 months as had been calculated at the design stage. It may also be noted that allowing only vertical drainage (without PVD) it would have taken several years to achieve this. Thus it may be clearly seen that by taking advantage of the faster radial flow and shorter drainage paths in the case of PVD reduces consolidation period considerably when compared with slower vertical flow and longer drainage path without PVD.

![Graph](image)

**Fig. 5:** Degree of Consolidation Vs Time

Barron (1948) had proposed the following consolidation – time relationship for radial drainage (Eq. 1).

\[
U_r = 1 - e^{-8T_r/F(n)}
\]  

(1)

Where,

- \(U_r\) = Degree of Consolidation
- \(T_r\) = Time factor for radial drainage = Cr x t/D^2,

where

- \(C_r\) = Coeff of consolidation due to radial flow
- \(t\) = Period for consolidation

D = Drain spacing

\[
F(n) = \left\{n^2 \ln \left(n / (n^2 -1)\right) - (3n^2 -1) / 4n^2\right\}
\]  

where

n = D/d and d= effective drain diameter

Barron (1948) had proposed the following consolidation – time relationship for radial drainage (Eq. 1). The theoretical relationship for \(Ch/Cv=1\) which was used for the initial design as well as \(Ch/Cv=3\) have been shown in the figure. It may be noted that the observed settlement/time relationship for the project closely follows the theoretical curve for \(Ch/Cv = 3\). Radhakrishnan (2006) had earlier reported observations based on an 8m high embankment constructed over soft clay and the results of both studies are comparable.

7. CONCLUSIONS

The construction of a 4m high railway embankment on land reclaimed by filling over very soft clay 10-15m deep was achieved satisfactorily within a short period of time by installing prefabricated vertical drains and adopting a two stage construction procedure for the embankment. Due to the urgency for the completion of the new railway line, embankment construction had to proceed immediately after land reclamation and had to be completed within the shortest period possible. Without ground improvement it was not possible to achieve this as the clay deposits were deep and in very soft and compressible condition.

Comparison of theoretical and observed field data showed that prediction of consolidation-time relationship...
based on established procedure is valid. For this site the Ch/Cv relationship was observed to be at least 3. Asaoka construction procedure for predicting the total settlement was found to be useful in determining the degree of consolidation achieved in the field.

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REFERENCES