SIX ROWS OF HIGH CAPACITY REMOVABLE ANCHORS SUPPORT DEEP SOIL MIX COFFERDAM

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Six rows of high capacity removable anchors support deep soil mix cofferdam

Six rangees de tirants demontables fortement precontraints soutiennent un caisson realise par le procede soilmix

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ABSTRACT: The use of high capacity soil anchors in lieu of internal props to support the cofferdam walls allowed rapid bottom-up construction of new rail tunnels with unimpeded progress. Innovative techniques in the use of a 38m deep soil mix wall and 2000 kN working capacity fully removable anchors were utilised.

RESUME: L’utilisation de tirants fortement precontraints a la place de butons pour etayer les parois du caisson a permis la realisation rapide de bas en haut de tunnels de chemin de fer sans encombre. Des techniques innovates pour la realisation due voile Soilmix d’une precontrainte de 2000 kn ont ete utilisees.

1. INTRODUCTION

The construction of Hong Kong’s new Chek Lap Kok Airport demanded the installation of a new 34km airport railway link. The majority of the new Hong Kong Islands terminus is located on reclaimed land and one of its temporary works elements involved a ground support system for a cut and cover section close to where the tunnels emerge from below Victoria Harbour.

The temporary work cofferdam was constructed using soil mix wall techniques and the retention system incorporated up to six rows of 1400 to 2000kN working load anchors, the steel tendons of which were removed on completion.

2. THE SOIL MIX WALL (SMW)

The soil mix wall was constructed using a triple shaft auger machine, which effectively drilled, mixed and grouted simultaneously three overlapping 850mm diameter shafts of soil to depths of up to 38m. Extensive preliminary trials were carried out to ensure that a minimum soil mix strength of 0.005N/mm² was attained throughout the soil structure of the wall, albeit soil mix sample strength of 0.4 to 6.4N/mm² at 28 days were the general range achieved during the works.

On withdrawal of the triple shaft auger system, three interconnected universal beams at 600mm centres (594 x 305 x 17kg/m) were lowered vertically into the soil mix to depths of between 277 and 30m. These members were designed to carry the full wall loading whilst the soil mix effected local soil retention and formed a water seal to the full 38m depth.

A refined system of programming and control to ensure efficient overlapping of adjacent triple shaft wall sections had been evolved by the specialist SMW contractor throughout his 20 year usage of the system.

3. THE WALING SYSTEM

Initially it was suggested that he use of a pair of steel beams at each waling level would be economic and practical. However, owing to the predicted encounter of a 18m head of water on drill penetration of the wall for the construction of the lower row anchors, it was considered prudent to provide a waling in which a safeguard water sealing system could be rapidly installed if so required.

Thus, at all levels a reinforced concrete waling incorporating preplaced steel anchor guide ducts was constructed. Prior to shuttering work, the front face of the universal beams was exposed such that both the vertical and horizontal components of anchor forces would be transferred from the
walings directly into the steel members in the soil mix wall.

4. EVALUATION OF WALING LOAD REQUIREMENTS

The cofferdam consisted of two halves; the south wall and the north wall which was further subdivided into sections depending on physical requirements (see Figures 1 and 2).

- Excavation depth varied from –15m PD to –13m PD, and required a maximum of 6 waling levels down to a minimum of 4 levels.
- An ambient ground water level of +2m PD.
- Dewatering levels – 18m PD, -15M PD in the West and East areas respectively.
- Anchor inclinations affected by adjacent structure foundations, dredge levels and access restrictions.
- The presence of an existing 25 storey building some 45 metres from the South wall.

The analyses of the anchored soil mix wall with due consideration of the above and the known ground conditions was undertaken using the program “WALLAP”. Waling loads ranging from 500kN/m on the top row to 1500kN/m in the lower rows were evaluated.

5. THE GROUND ANCHOR SYSTEM

5.1 Introduction

The very high waling load requirement in the cofferdam demanded the utilisation of the highest anchor loads attainable in soils, if an anchor solution was to be feasible and economically attractive. Furthermore, the tight time constraints demanded the completion of the entire anchor works, the waling systems and the excavation within a 33 week period. The overriding factor, however, was the works specification: “In the event of the use of temporary anchors for the wall support, then the entire steel tendons installed in each anchor must be fully removed from the grouted anchor bore after use”. This removal of steel (contamination) from the ground after use would then allow the safe, unobstructed installation of piles and services into the ground outwith the cofferdam walls after the contract completion. The further development and utilisation of “air space” around and above the station area could then proceed without foundation problems.

5.2 Proposals

The development of the Keller Single Bore Multiple Anchor System (Ref. 1 and 2) over a seven year period in the UK, prior to these works allowed the design proposals for the use of over 500 high capacity soil anchors to be evolved. On the North side, the middle and upper rows of anchors were founded in the compacted marine sand fill, whilst lower rows of anchors passed through the softer underlying alluvium and penetrated into the dense to very dense silt of the completely decomposed granites (“CDG”) (Fig. 2). On the South side only the two upper rows could utilise the marine sand fill in the fixed length. Some of the middle and lower level anchors penetrated through the existing granite sea walls and foundations, through soft alluvium and into the CDG.

The Single Bore Multiple Anchor System (SBMA) consists of a multiple of unit anchors, each unit containing its own tendon and stressed with its own jack and bonded to the ground over its own fixed length in the anchor bore. This system allows each unit to utilise the grout to ground bond strength over a multiple of unit fixed lengths which may total over 20m in one anchor borehole. Each unit anchor fixed length design is based on the insitu ground strength or ultimate bond strength available at that particular depth. This allowed some units in a bore to be founded in sand in the upper part of the bore and some in CDG in the lower bore. Furthermore, the bond lengths of unit anchor founded deep in the CDG were shorter than those founded at a shallower depth in a weaker material. In addition, this anchor system can fully accommodate the counter of weak zones, which may lead to failure of one or two unit anchors. The remaining unit anchors are designed to safety accept an overload, if so required.
The initial design selected an anchor working load of 1400kN, utilizing six unit anchors in each anchor bore and providing a factor of safety of 2.0 against failure at the grout/ground interface. However, owing to the novelty of founding anchors in both marine sandfill and CDG and the proposal to utilise such very high loads in soil anchors, a complete trial anchor programme involving the four trial SBM anchors was required, prior to commencement of production works (Ref. 3).

In conjunction with the development of the SBM anchor system, the use of a special looped sheathed strand system had been researched and advanced for use as multiple units within a single bore (Ref. 4). For each unit the “loop” of strand complete with load bearing saddle and other refinements, transfers load in shear and compression into the unit length of grouted bore, and then, on completion of usage, to be destressed, and if fully withdrawn from the grouted bore.

5.3 Trial Anchors

Anchor trials were installed in two stages: the initial stage demonstrated that working loads of 1400kN or more could be safely utilised in both founding materials, and that the steel strand could be fully withdrawn from the bores. Loads between...
2000 and 2800kN were obtained but in the majority of instances the unit anchors could not be failed (Ref. 3). As installation of the two upper rows of 1400kN working load anchors progressed, a further seven trial production anchors were installed and their performance substantiated the safe use of 2000kN working load anchors below row 2. These anchors achieved loads between 2500 and 3300kN without any units failing and all demonstrate extremely satisfactory load hold behaviour (extremely low creep characteristics).

The capacities of individual unit anchors and load per metre of fixed length achieved in various strata are summarised in Tables 1 and 2.

Consistent with anchor practice and other single bore multiple anchor work relating anchor capacities to anchor fixed length, the results confirmed that use of short fixed anchor lengths (2.0 to 4.0m) is very efficient and allows mobilisation of higher bond capacity per metre length of borehole than use of longer fixed lengths, (5.0 to 8.0m).

The degree of this efficiency (“efficiency factor”) has been evaluated from trial results by Barley (Ref.2) and from published data by Woods (Ref.5).

5.3 Production anchors installation

Production anchors were installed using six Casagrande C6 drilling rigs, each advancing 152mm casing and 101mm rods up to anchor depths of 60m, using controlled water flush drilling techniques, (Photo 1). Special precautionary measures and safeguards were evolved to reduce and control ingress of water into the cofferdam as a consequence of the external groundwater head present. This head equated to 18m when drilling the wall for the bottom row anchors. Furthermore, the presence of the 25 storey Harbour Building just 2m beyond the extremity of the anchor works, demanded further measures of tight control in order to prevent heave or settlement.

After tendon installation, end of casing grouting methods applied pressures ranging from 5 to 15 bars during casing withdrawal over the fixed length. On extraction of casing from the bore, a special extended anchorhead cap was temporarily fitted to allow controlled application of grout pressure through the waling to the back of the wall. This countered any nominal soil loss and subsequent restricted or eliminated water inflow whilst the anchors were in use. These were particularly sensitive operations, balanced such that the pressures did not jeopardise the stability of the wall.

5.4 Production anchor testing

Each anchor containing six or seven unit anchors was loaded simultaneously with six or seven 600kN capacity, hydraulically synchronised hollow ram jacks to a test load on a multiple of units of either 1750 or 2500kN. After a satisfactory load cycle and load hold monitoring period, each anchor was locked off at 80% of the designated working load. Each seven unit anchor was required to satisfy 21 basic test requirements prior to its acceptance into the works. Out of the 3010 production unit anchors installed, only 23 units failed, and in only two instances did this necessitate the re-drilling of an anchor. In all other cases, the designed “fall-back” system accommodated the unit failures encountered in occasional zones of weak ground.

5.5 Wall movement and monitored anchor loads.

As an essential safeguard, a monitor system was put in place to assess both wall movement and load change in the anchors in three vertical panels.

The change in load within the anchors from the designated 80% working capacity initially applied was not in excess of 5%. This would indicate that the overall design approach was conservative since the full anchor working load was not mobilised to retain the wall. Furthermore, the inward wall movement did not exceed 50% of the predicted 70mm, which had been established from the wall analysis programme. Such occurrence is not uncommon, based on past experience with prestressed anchored walls. Associated with the use of modern analytic methods originated for propped walls is a preference for the application of prestress of a relatively low percentage of anchor working capacity (50 to 70%) as compared to historic anchor practice of application of 110% working capacity. This generally stems from the computed analysis of staged excavation, which indicates that fully prestressed anchors may become overloaded as excavation may become overloaded as excavation proceeds. Such predictions of potential anchor overload, or alternatively of large values of wall movement when only a percentage of prestress is applied, may be attributed to calculations relating to soil structure interaction in which inappropriate values of soil modulus are applied.
Table 1: Single Bore Multiple Anchor Capacities in Compacted Marine Sandfill (SPT 14 to 59)

<table>
<thead>
<tr>
<th>Ref</th>
<th>Unit Fixed Lengths m</th>
<th>Unit Load kN</th>
<th>Overburden Depth m</th>
<th>No Units Failed</th>
<th>Maximum Anchor Load Kn</th>
</tr>
</thead>
<tbody>
<tr>
<td>TA1</td>
<td>2.5 to 4.0</td>
<td>337F; 6 x 384</td>
<td>11.0 to 23.3</td>
<td>1</td>
<td>2641</td>
</tr>
<tr>
<td>TA2</td>
<td>2.0 to 2.5</td>
<td>325F; 6 x 407</td>
<td>10.0 to 19.8</td>
<td>1</td>
<td>2767</td>
</tr>
<tr>
<td>TA ‘G’</td>
<td>2.0 to 5.0</td>
<td>7 x 430</td>
<td>5.0 to 8.7</td>
<td>0</td>
<td>3010</td>
</tr>
<tr>
<td>TA ‘J’</td>
<td>2.0 to 5.0</td>
<td>122F; 402; 5 x 430</td>
<td>22.5 to 37.0</td>
<td>2</td>
<td>2674</td>
</tr>
<tr>
<td>TA ‘K’</td>
<td>3.0 to 5.0</td>
<td>424F; 403F; 460F; 4 x 460</td>
<td>9.4 to 20.0</td>
<td>3</td>
<td>3127</td>
</tr>
<tr>
<td>TA ‘N’</td>
<td>3.0</td>
<td>430F; 417F; 4 x 430</td>
<td>4.4 to 7.0</td>
<td>2</td>
<td>2567</td>
</tr>
<tr>
<td>TA ‘E’</td>
<td>2.0</td>
<td>7 x 384F</td>
<td>8.0 to 10.0</td>
<td>7</td>
<td>2463</td>
</tr>
</tbody>
</table>

Table 2: Single Bore Multiple Anchor Capacities in Dense to Very Dense Silt (Completely Decomposed Granite)

<table>
<thead>
<tr>
<th>Ref</th>
<th>Unit Fixed Lengths m</th>
<th>Unit Load kN</th>
<th>Overburden Depth m</th>
<th>No Units Failed</th>
<th>Maximum Anchor Load Kn</th>
</tr>
</thead>
<tbody>
<tr>
<td>TA3</td>
<td>2.0 to 2.5</td>
<td>163F; 2 x 302F; 4 x 314</td>
<td>21.5 to 34.0</td>
<td>3</td>
<td>2023</td>
</tr>
<tr>
<td>TA4</td>
<td>1.5 to 3.5</td>
<td>157F; 116F; 337F; 4 x 407</td>
<td>15.5 to 28.0</td>
<td>3</td>
<td>1831</td>
</tr>
<tr>
<td>TA ‘F’</td>
<td>3.0 to 5.0</td>
<td>431F; 6 x 487</td>
<td>21.5 to 34.5</td>
<td>1</td>
<td>3353</td>
</tr>
<tr>
<td>TA ‘M’</td>
<td>3.0 to 5.0</td>
<td>7 x 473</td>
<td>22.5 to 37.0</td>
<td>0</td>
<td>3311</td>
</tr>
<tr>
<td>TA ‘P’</td>
<td>3.5 to 5.0</td>
<td>3 x 375F; 5 x 375</td>
<td>18.0 to 30.5</td>
<td>2</td>
<td>2250</td>
</tr>
</tbody>
</table>

F = unit anchor failure, other units did not fail
The application of prestress into the soil mass, the application of load against the wall, all executed at different stages of excavation, apply a range of loading conditions to the soil mass and hence alter the stress level in the soil well before excavation reaches final level. It is acknowledged that soil modulus is not only stress and strain dependant but also varies with stress history. However, modelling of the stress paths followed by the soil as a result of construction activities, is not generally undertaken in routine calculations and hence it is essential that a balance between the prior art and the analytical evaluation is adopted.

5.6 Tendon withdrawal

After excavation was completed and whilst the four reinforced concrete rail tunnel structures were built upwards, backfilling was carried out gradually, making the anchors obsolete. Each unit anchor was unloaded in turn using a monojack and after removal of all barrels and wedges, one end of the looped strand was jacked out for approximately a metre. The strand end was then connected to a crane and the full strand loop length, up to 120m, was winched from the bore. The withdrawn strands were cut and removed from the site. General backfilling, anchor destressing and tendon removal progressed until finally surface level was attained.

6. SUMMARY

These temporary works operations on a fast track programme effectively utilised two relatively novel systems despite the encounter of constructional difficulties:

- the soil mix wall provided an efficient cut-off trench and a high quality retaining wall
- the soil anchors provided probably the highest working capacities ever used in anchors founded in fine sands and dense silts
- the wall movement that occurred during excavation did not exceed 50% of the predicted value of 70mm
- the ability to remove the steel tendons from the free and fixed anchor length after use, indicated a further advancement in ground anchor technology

7. ACKNOWLEDGEMENTS

Client
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Main Contractor
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Temporary works designer
- Robert Benaim & Assoc. (Asia) Ltd.

REFERENCES


