Deep Excavation in Hong Kong – Cantilever Bored Pile Wall Design Using CIRIA Report No. C580

Excavation profonde à Hong Kong - Conception de mur cantilever à pieux forés suivant le rapport CIRIA n° C580

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ABSTRACT: The design of cantilever retaining walls in Hong Kong is mainly carried out in accordance with Geoguide 1 (Second Edition) where a simplified model is adopted for the determination of the embedment depth of the pile. Following publication of CIRIA Report No. C580 (Embedded Retaining Walls – Guidance for Economic Design) several Hong Kong projects have adopted the design approach for temporary deep excavation works. This paper describes the first local application to a permanent cantilever wall approved by the Government of the Hong Kong Special Administrative Region, Geotechnical Engineering Office.
This paper compares the design approach of a large diameter bored pile cantilever wall for a large site formation development in Hong Kong using the traditional simplified model approach and the rational, safe and economic approach described in CIRIA C580. Detailed monitoring of the wall performance during construction is also described as a review of the C580 approach.

RÉSUMÉ: La conception des murs de soutènement cantilever à Hong Kong est principalement réalisée en conformité avec GeoGuide 1 (deuxième édition), où un modèle simplifié est adopté pour la détermination de la profondeur d'ancrage de la pile. Après la publication du rapport CIRIA C580 No. (incorporés Murs de soutènement - Lignes directrices pour la conception économique) plusieurs Hong Kong projets ont adopté l'approche de conception pour des travaux d'excavation temporaires profondes. Cet article décrit la première application locale d'un mur en porte à faux permanent approuvé par le Gouvernement de la RAS de Hong Kong, Bureau administratif du génie géotechnique.
Cet article compare la démarche de conception d'un diamètre foré grand mur en porte à faux poils pour un développement formation grand site de Hong Kong utilisant la méthode simplifiée modèle traditionnel et le rationnel, sûre et économique décrit dans CIRIA C580. Un suivi détaillé de la performance du mur en cours de construction est aussi décrit comme un examen de l'approche C580.

KEYWORDS: C580, Geoguide 1, cantilever retaining wall, case study, and cost saving.

1 INTRODUCTION

In Hong Kong, the CIRIA Report C580 – Embedded Retaining Walls – Guidelines for Economic Design (Gaba et al. 2003) has been critically reviewed by the Hong Kong industry and academic research community since it's publication in 2003 and has been widely used in the design of temporary works for excavations and lateral support (ELS), (Sze et al 2005).

The authors have adopted the design approach of CIRIA Report C580 for the design of a permanent cantilever large diameter bored pile wall for the support of sloping ground and retaining around 20 m level difference for the construction of a new road in front of the wall. This is the first recorded Hong Kong project adopting the C580 design approach for a permanent application.

Analyses using the two design methods, Geoguide 1 (Second Edition) and CIRIA Report No. C580, for cantilever bored pile wall are discussed in this paper and the performance of the permanent cantilever wall during excavation is also presented.

2 SITE DESCRIPTION AND GROUND CONDITIONS

2.1 *The Site*

The Site is located at the north-eastern part of Kwun Tong, Kowloon, Hong Kong, see Figure 1. This Project comprises site formation works for a Public Housing development forming about 20 hectors of useable land on a sloping site. For the formation of the development platforms, retaining walls and slopes are required to create level platforms with significant level difference between platforms. Reinforced earth walls, reinforced concrete retaining walls as well as cut and fill slopes are proposed for retaining the level difference.

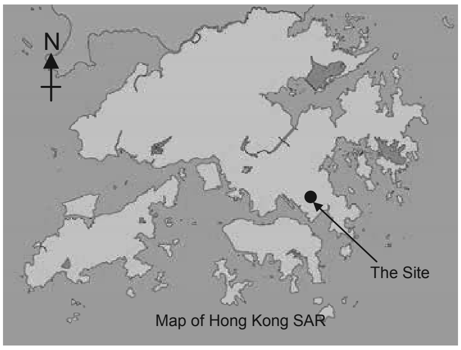

Figure 1. Site Location

The proposed works include construction of a new road as one of the principal vehicle accesses to the proposed development. The level difference between the proposed new road and an existing road and service reservoir varies from about 10m to 20m while the available horizontal clearance is approximately only 11m and 5m respectively. Different schemes were explored in the design stage including reinforced earth wall, reinforced concrete wall and steep cut slope with soil nails. These were found not feasible due to the extremely onerous space constraint. Therefore, a 3.0m diameter bored pile wall was eventually adopted. The proposed bored pile wall is approximately 110m long with 33 nos. of bored piles. The plan view of the proposed cantilever bored pile wall is illustrated in Figure 2 and the typical geological section is shown in Figure 3.

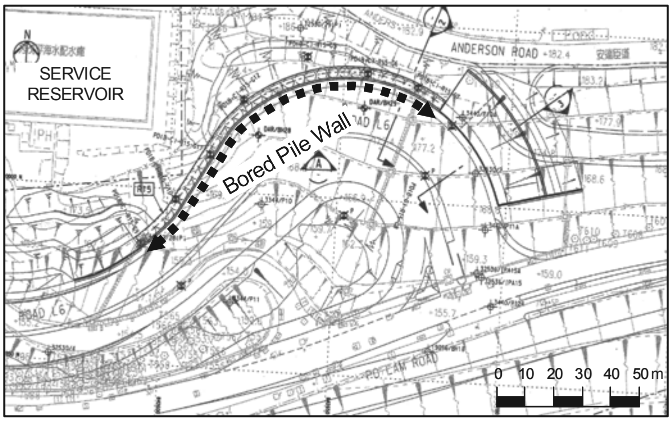

Figure 2. Layout of the bored pile wall with adjacent constraints

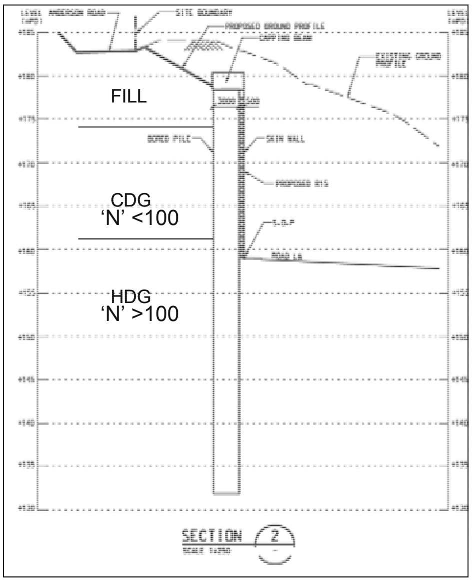

Figure 3. Geological section

2.2 Geological Conditions

The soil stratigraphy of the site comprises Fill and weathered granite. The fill was generally present within the Site with maximum thickness of fill up to 8m below existing ground level. The fill comprises loose to medium dense, gravely silty sand or sandy clayey silt, with some rock and concrete fragments and occasional domestic waste. The SPT 'N' values ranged from 5 to 15 indicating a loose state. Completely to highly decomposed granite is present beneath the superficial deposits. The granites are commonly fine to medium grained greyish pink to pinkish grey in colour in fresh state and the granite is weathered to varying depths. The thickness of completely decomposed granite (CDG) weathering Grade V ranges from 5 m to 10 m with SPT-N values from 15 to 100. Highly decomposed granites (HDG) of weathering Grade IV occurs with SPT 'N' value larger than 100. The maximum depth to moderately to slightly decomposed granites (M/SDG) encountered ranges from 15m to 40m below existing ground level. The uniaxial compressive strength of the M/SDG ranging from 40 to 135mPa. A geological section along the proposed cantilever bored pile wall is presented in Figure 4.

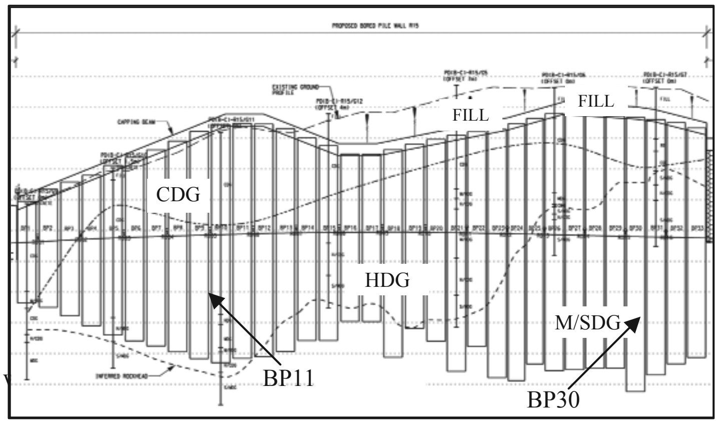

Figure 4. Geological long section

2.3 Geotechnical Design Parameters

The engineering properties of soils and rocks have been assessed using the field and laboratory test data. A total of 105 nos. consolidated undraineing judgment with reference to the 'best fit', 'lower bound' and average values. The adopted design parameters are listed in Table 1.

Table 1. Summary of adopted soil parameters

Soil Stratum	*Density* *(kN/m^3)*	*Cohesion, c'* *(kPa)*	*Fictional Angle,* *(degree)*	*E value* *(MPa)*
FILL	19	0	35	10
CDG	19	7	38	20
HDG	19	7	38	40

2.4 Groundwater levels

Piezometers and standpipes have been installed over the Site to provide groundwater information during construction. Generally, groundwater levels tend to be at or near the rockhead level and typically rise by up to about 3m after rainfall. The groundwater level is assumed to be +166 mPD on the retained side and at the excavation level (approximately +159 mPD) at the excavated side.

3 DESIGN OF CANTILEVER BORED PILE WALL

3.1 Design considerations

The results of analyses using the two design methods, Geoguide 1 (Second Edition) using a simplified model and CIRIA Report No. C580, for cantilever bored pile wall are presented. These calculations assume that the entire embedded portion of the cantilever bored pile wall is in soil. The effect of the capping beam is ignored in the analysis and the long term creep effect is to be controlled by the post construction of a 500mm thick skin wall.

3.2 Traditional Approach (Geoguide 1)

The traditional approach of the design of a cantilever bored pile wall was carried out in accordance with the recommendation given in Section 11.2.3 and Figure 50(c) of Geoguide 1 (Second Edition) where a simplified model was adopted for the determination of the embedment depth of the pile, (Pang et al 2005).

3.3 *C580 Approach*

In the CIRIA C580 design approach, the embedment depth is determined by achieving equilibrium in a soil-structure interaction analysis using a pseudo-finite element program FREW (Oasys 2007).

In the C580 design, partial factors as suggested in "Notes on Design of excavation and Lateral Support works Using the Limited State Partial Factor Method" (BD 2005) were adopted instead to reflect the application of limit state design.

The cantilever bored pile wall is subjected to the unbalanced loading of slopping ground and hydrostatic pressure. In both calculations, the pile heads deflections are controlled to be within 1% of the excavation depth.

4 DESIGN COMPARISION

Two sections are reviewed in this paper: BP11, which is the closest pile to the existing service reservoir, with retained height of 18.0 m and BP30, with retained height (deepest excavation) of 19.4 m.

The results of the deflection and internal structural force for both of the sections are presented in Figures 5 and 6 respectively.

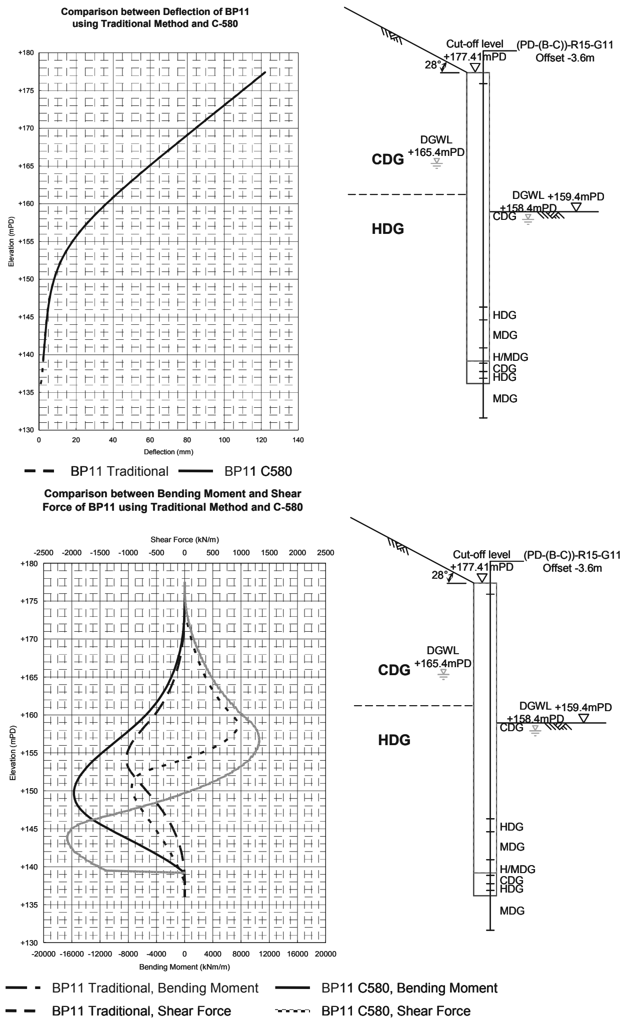

Figure 5. Calculated deflection, bending moment and shear force along cantilever bored pile wall (BP11)

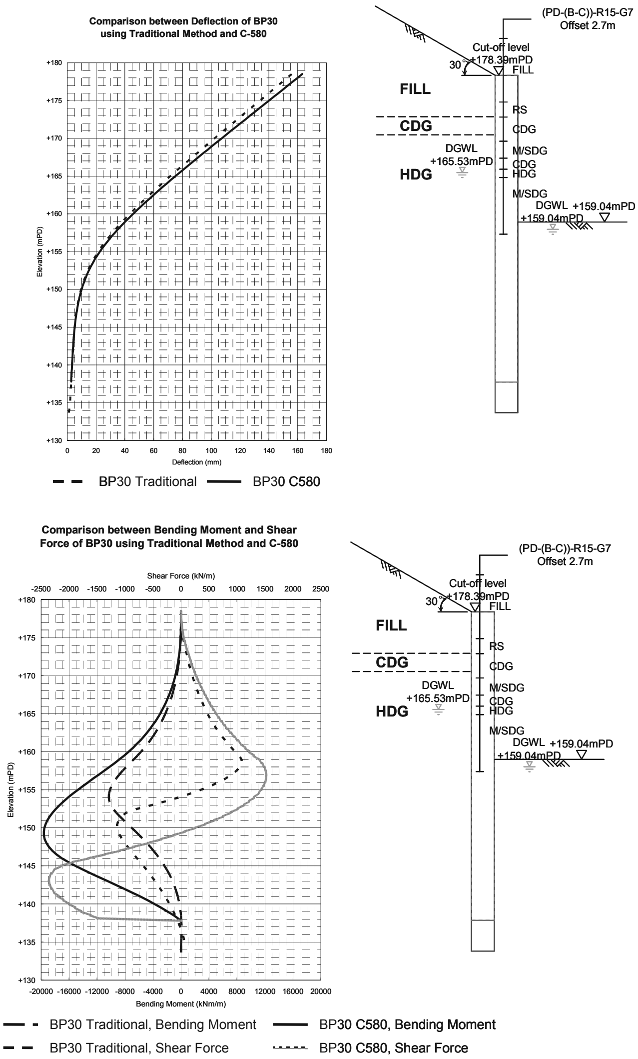

Figure 6. Calculated deflection, bending moment and shear force along cantilever bored pile wall (BP30)

The wall deflection, bending moment, and shear force of the two methods calculated using FREW at the final stage of the excavation were compared and summarized in Tables 2 and 3.

Table 2. Comparison of forces in wall and deflection (BP11*)

	Embed-ment (m)	*Bending Moment (kN-m/m)*	*Shear Force (kN/m)*	*Deflection (mm)*
Traditional Approach (Geoguide 1)	23.21	8,267	1,041	146.7
C580	20.20	15,710	2,108	146.7
% Change	- 13%	+ 90%	+ 102%	No Change

* BP11 is the closest pile to the existing service reservoir with retaining height of 18.0m

Table 3. Comparison of forces in wall and deflection (BP30#)

	Embed-ment (m)	*Bending Moment (kN-m/m)*	*Shear Force (kN/m)*	*Deflection (mm)*
Traditional Approach (Geoguide 1)	25.26	10,320	1,269	184.8
C580	21.24	19,610	2,403	193.9
% Change	- 16%	+ 90%	+ 89%	+ 5%

BP30 is a pile with the highest retaining height of 19.4m

Based on the table above, there is an average decrease of 3m embedment by using C580 approach which is about 14% reduction to the original proposed embedment. However, the advantage of the reduction of embedment by using C580 results in a substantial increase in structural forces. Thus, it would require an increase of structural capacity by increasing the steel ratio in these cases.

5 COST SAVING

Although, the bending moment and shear force of the cantilever bored pile wall increased 90% in average as shown in Tables 2 and 3 above, the increase of the steel reinforcement percentage is only from 1.32% to 1.78% mainly due to the use of 3 m diameter bored pile with high bending capacity. The cost comparison using the two appraches is presented in Table 4.

Table 4. Summary of cost difference

	Average pile length (m)	*Steel percentage (%)*	*Total cost per pile (million HK$)*
Traditional Approach (Geoguide 1)	43.0	1.32	3.03
C580	39.5	1.78	2.74
% Change	- 3.5	+ 0.46	- 0.29 (Saving of 10%)

The increase of the construction cost of the bored piles is not directly proportional to the increase of pile depth. Normally, it is an exponential increase with depth. Thus, the reduction of a pile embedment results in a saving in the overall construction cost. From the table above, there is about 10 % of overall cost saving on the cantilever bored pile retaining wall system when using C580 approach. This represents an amount of HK$ 9.6 million saving on this project.

Besides the cost saving, there is also a non-quantified saving by using C580 approach such as the reduction of construction risk for deeper pile, (Sze et al 2005).

6 PEFORMANCE AND MONITORING

A 2.0 m deep capping beam was installed onto the pile heads before excavation and deformation markers were provided for the measurement of the wall top movement by land surveying methods. The excavation commenced in December 2011 and was completed by stages in June 2012, The condition of the cantilever wall during the excavation stage in January 2012 is shown in Figure 7.

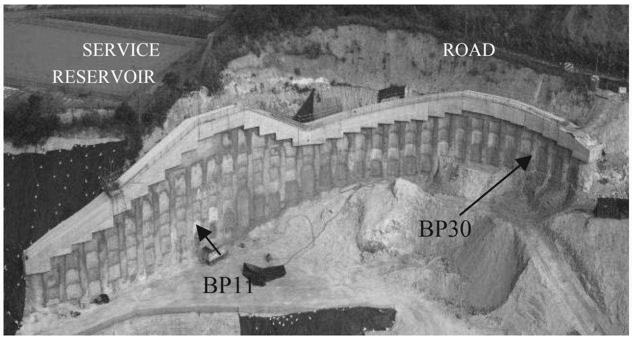

Figure 7: Excavation of the cantilever bored pile wall (January 2012)

The monitoring results of the wall top movement by land survey is compared with the design predictions are shown in the Table below. It is concluded that the use of C580 is a safe approach for the design of a permanent cantilever bored pile wall.

Table 5. Comparison of predicted and actual wall deflection

	Traditional Approach (Predicted)	*C580 (Predicted)*	*Actual lateral movement*
BP11	146.7 mm	146.7 mm	21 mm
BP30	184.9 mm	193.9 mm	20 mm

The actual movement from monitoring results maybe less than predicted due to:

1. the beneficial effect from the capping beam is not accounted for in the design
2. the slopping ground on the retaining side was significantly reduced in height due to the formation of a temporary piling platform and hence loading was reduced
3. local variations in the bedrock weathering profile was not accounted for in the design

A comprehensive and continuous monitoring of the wall movement was conducted throughout the construction period comprising the followings will be discussed in future:

1. Piezometers provided behind the wall to monitor the groundwater conditions.
2. Inclinometers and B-OTDR (Brillouin Optical Time Domain Reflectometer) optical fibres were installed into ducts reserved in the piles to monitor the behaviour of the cantilever bored pile wall.

7 CONCLUSIONS

The use of C580 design approach together with partial factors as suggested in “Notes on Design of Excavation and Lateral Support Works Using the Limit State Partial Factor Method” (BD 2005) is a safe and economic design for a cantilever bored pile wall. In general, there is a cost saving by using C580 design in comparison with the traditional design approach as described in Geoguide 1 (Second Edition)

However, the pile deflection profile and the long term effect (i.e creep effect) of a cantilever bored pile wall system using C580 design approach should be further reviewed.

8 ACKNOWLEDGEMENTS

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