The Use of Removable Ground Anchors in Deep Basement Excavation in Hong Kong

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ABSTRACT

Deep excavation is a critical aspect of construction projects that involve building foundations, tunnels, basements, or other below-grade structures. Ground anchors are a load transfer system designed to transfer the forces applied to it to a competent stratum, commonly used to support temporary excavation support system for deep basement excavation. By using ground anchors, the need for installing temporary struts can be eliminated and so congestion in basement construction can be significantly reduced. Ground anchors are also very suitable for sites on which flying/corner struts system are difficult to be installed. For ground anchors used in private development projects in Hong Kong, the temporary perimeter piles wall are usually constructed along the lot boundaries and so unavoidably the temporary anchors are required to be installed beyond the lot boundaries and encroached upon government land. In the past, the ground anchors were unavoidable to be left-in-place below ground upon completion of basement construction. Advancements in the ground anchor technology include the development of a load distributive compression type removable anchor which offers a complete solution where anchorage systems can be easily removed once they become redundant. The use of removable ground anchors has been gaining popularity gradually because they are not required to be left-in-place below ground. This paper presents the technology behind and shares the experience of using a proprietary product of load distributive compression removable anchors in a deep basement excavation project in urban area of Hong Kong. Apart from that, the details and experience of using another type of single bore multiple anchors, which are also load distributive compression removable anchors, used in previous deep basement projects are shared. This paper presents the technology behind and shares the experience of using a proprietary product of load distributive compression removable anchors in a deep basement excavation project in urban area of Hong Kong. Apart from that, the details and experience of using another type of single bore multiple anchors (SBMAs) which are also load distributive compression removable anchors used in previous deep basement projects are shared.

1. INTRODUCTION

Ground anchors are active structural reinforcements that optimise safety and ground stability, for both temporary and permanent structures. Anchors are often used in temporary retaining walls to stabilise excavation during the construction phase, or they can even be used as a permanent solution for retaining walls – especially when building in unstable or sloping ground. The anchor ensures that the ground remains stable and allows for deep, wide excavations. It is often temporary, because the long-term stability of the ground is maintained by the structure built in the excavation (car parks, basements, etc.).

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In Hong Kong, installation of temporary ground anchors in government land outside the private lot boundaries were not common as part of the excavation and lateral support (ELS) works for basement construction in the past. Government departments including Lands Department and Highways Department have the view that ground anchors, whether permanent or temporary, are not desirable and applications for permission to install ground anchors must fully justify the need for their use as against alternative methods available. Temporary anchors, although not permanently sterilising land, are similarly undesirable and in particular can give rise to problems when detensioned.

For temporary ground anchors, in the past, after destressing operation by removing the anchor head and wedges through flame cutting of the strands, they were unavoidable to be left-in and this would sterilize the government land. Rows of temporary anchor tendons left in place can inhibit future construction especially in densely-populated urban areas. The use of removable ground anchors has been developed overseas since the mid 1970s. In Hong Kong, the use of removable ground anchors has been gaining popularity gradually because they are not required to be left-in-place below ground. Load distributive compression removable anchors is a type of removable ground anchors commonly-used in Hong Kong nowadays. In this paper, the load transfer mechanism and removal procedure of 2 types of removable ground anchors, namely, SW-RCD (Samwoo - Removable, Compressive and load Distributive) and SBMA (Single Bore Multiple Anchor) are introduced. Also, the experience of using these 2 types of ground anchors in recent projects is shared.

2 LOAD DISTRIBUTIVE COMPRESSION REMOVABLE ANCHORS

In the conventional type of anchors for which the pre-stressing strands cannot be removed, they are of load concentrative type. Low efficiency of load transfer in conventional anchors is due in part to non-uniform load distribution along the bond length. However, it is fully acknowledged by researchers who have investigated grout/ground load transfer that the distribution of load transfer along the fixed anchor is non-uniform due to general incompatibility between elastic moduli of the anchor tendon, anchor grout and the ground. In the vast majority of conventional anchors, after initial stressing, the bond stress is concentrated over the proximal end of the fixed anchor, while the distal end of the fixed length remains unstressed. As the prestressing load is increased, the ultimate bond stress at the proximal end of the fixed length along either (or both) the steel/grout interface or the grout/ground interface is exceeded. Figure 1 depicts this load transfer phenomenon, referred to as “progressive debonding”. The area under the bond stress distribution line in red represents the ultimate load in the anchor. It can be seen that the load does not increase uniformly with increasing length, causing progressive debonding which can lead to the anchor becoming over-stressed, resulting in failure of the anchor.

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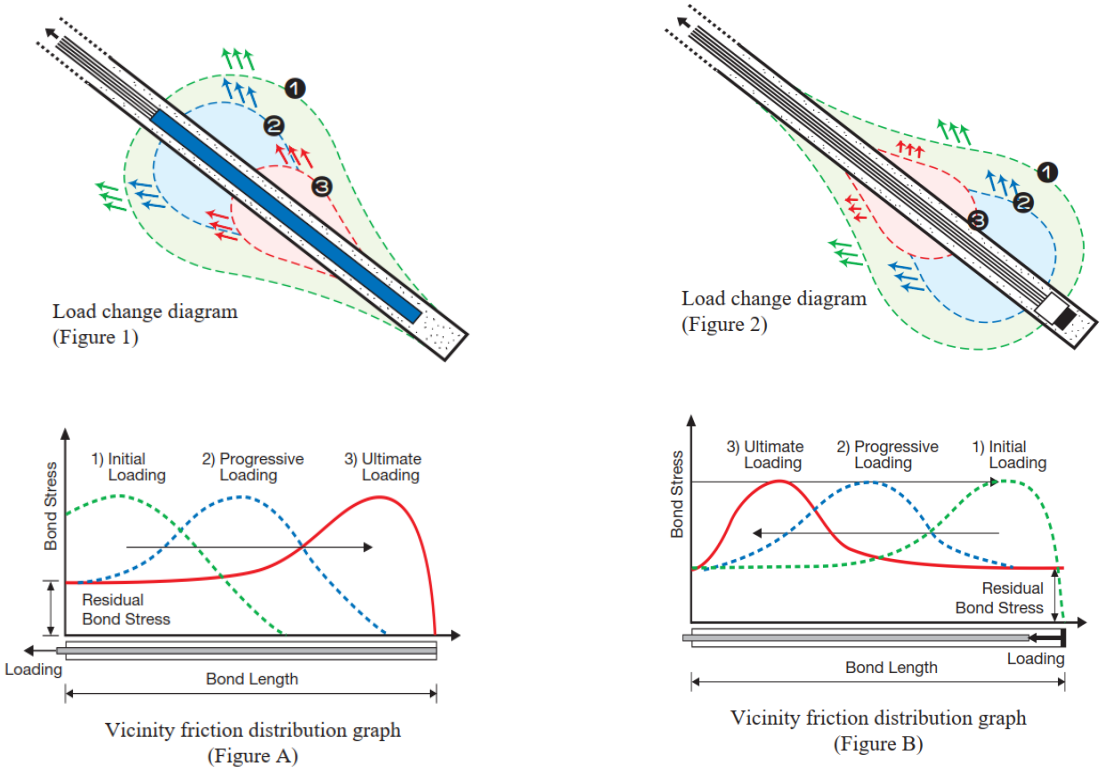

Load Concentrative Tension Type Anchor *Load Concentrative Compression Type Anchor*

Figure 1: Load Distribution of Conventional Anchors (SAMWOO)

To eliminate the problem of progressive debonding, load distributive compression type anchors, which can uniformly distribute the anchor load to the grout body and soil/rock along the theoretical length of the bond zone, are gaining its popularity. The load transfer mechanism of load distributive compression type anchors is illustrated in Figure 2.

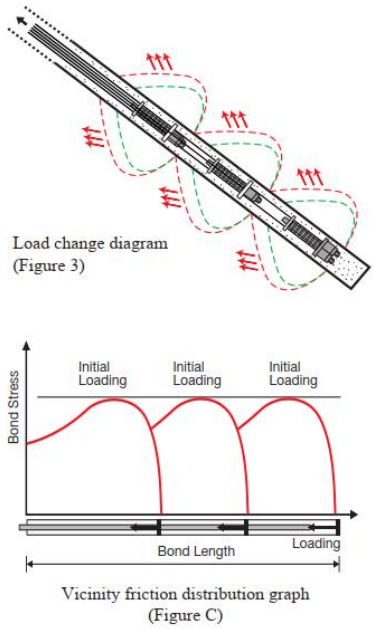

Figure 2: Load Transfer of Load Distributive Compression Type Anchors (SAMWOO)

In Hong Kong, at least 2 types of load distributive compression type anchors had been used so far. One is SBMA anchors and the other is SW-RCD anchors, both are removable ground anchors.

3 SBMA Anchor System

The SBMA system (see Figure 3) involves the installation of multiple units of anchors into a single borehole and the fixed length of each unit anchor being staggered within the borehole length to mobilize its own capacity independent of other unit anchors. Each unit anchor has its own individual tendon and its own unit fixed length in the borehole, and is loaded by its own unit stressing jack. The loading of all the unit anchors is carried out simultaneously by multiple hydraulically synchronized jacks which ensure that the loads in all unit anchors are always identical. The strands are contained in the strand tubes, each tube bends around a metal/aluminum saddle connected to a short steel reinforcement/GFRP stabilizing bar. This multiple SBMA anchors system is also called "U-loop" anchors system.

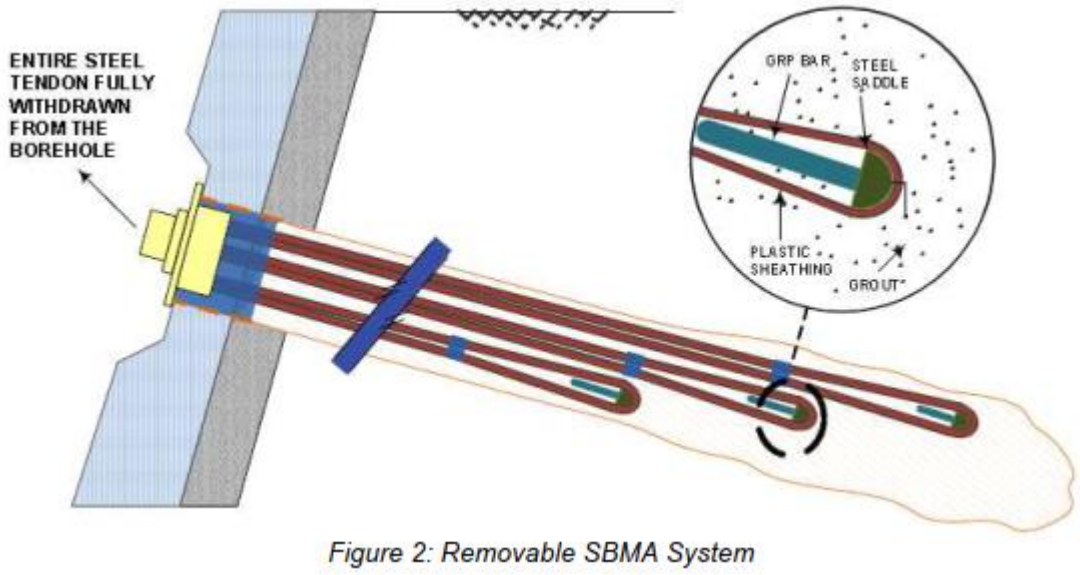

Figure 2: Removable SBMA System

Figure 3: Typical Detail of SBMA Anchors (M. R. Sentry (2012))

The general procedure for destressing and removing the prestressing strands of SBMA anchors by means of a U-loop system is illustrated in Figure 4.

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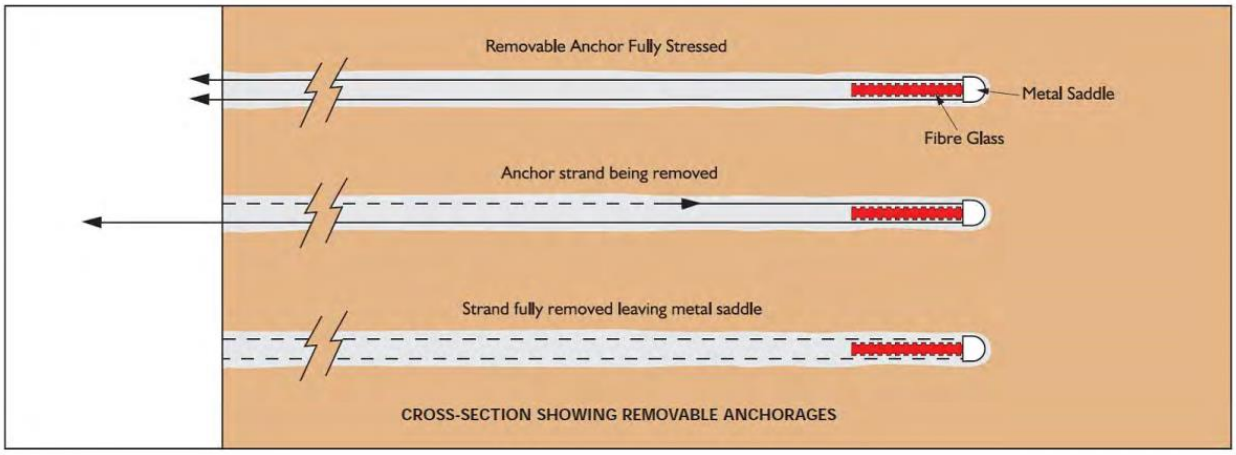

Figure 4: Removal of Strands of SBMA Anchors

SBMA anchors with capacity of 2000 kN were firstly used in Hong Kong for excavation of MTRC Central Station (see Plate 1).

Photograph 3. 200-tonne working capacity multiple anchors at Central Station in Hong Kong.

Plate 1: SBMA Anchors used in MTRC Central Station

4 SW-RCD Anchors

In SW-RCD removable anchors, the prestressing strands are contained in Polyethylene PE sheath (black colour) and the sheath is connected to an aluminum anchor body, see detail in Figure 5.

Classification	• Removable Anchor (SW-RCD Anchor) 
Material	Corrosion-resistant aluminum anchor body
Manufacturing Method	Aluminum die-casting technique
Anchor Body Structure	• Steel strand built-in structure protects PE sheath and steel strand. • Precision combined method and structure created by die-casting technique prevent grout infiltration.
Performance	• Due to decrease in grout debonding, removal performance increases. • Due to high precision and steel strand built-in technique, removal performance increases.

Figure 5: Aluminum Anchor Body of SW-RCD Anchors (SAMWOO)

Typical anchor bodies for multiple strands are shown in Figure 6. The greater is the number of PE sheaths, the larger is the anchor capacity. As shown in Figure 7, a typical section showing SW-RCD anchor bodies in different locations of a drilled hole is illustrated.

Figure 6: Aluminum Anchor Body of SW-RCD Anchors with Different Nos. of Strands (SAMWOO)

Figure 7: SW-RCD Anchor Bodies at Different Locations along the Anchor Length (SAMWOO)

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The removal principle of SW-RCD anchors is illustrated in Figure 8. The strands are first destressed by flame cutting to separate them from the waler. After removing the waler, by rotating the steel strands in clockwise direction, the wedges are released. The strands can then be removed manually to separate them from the wedges.

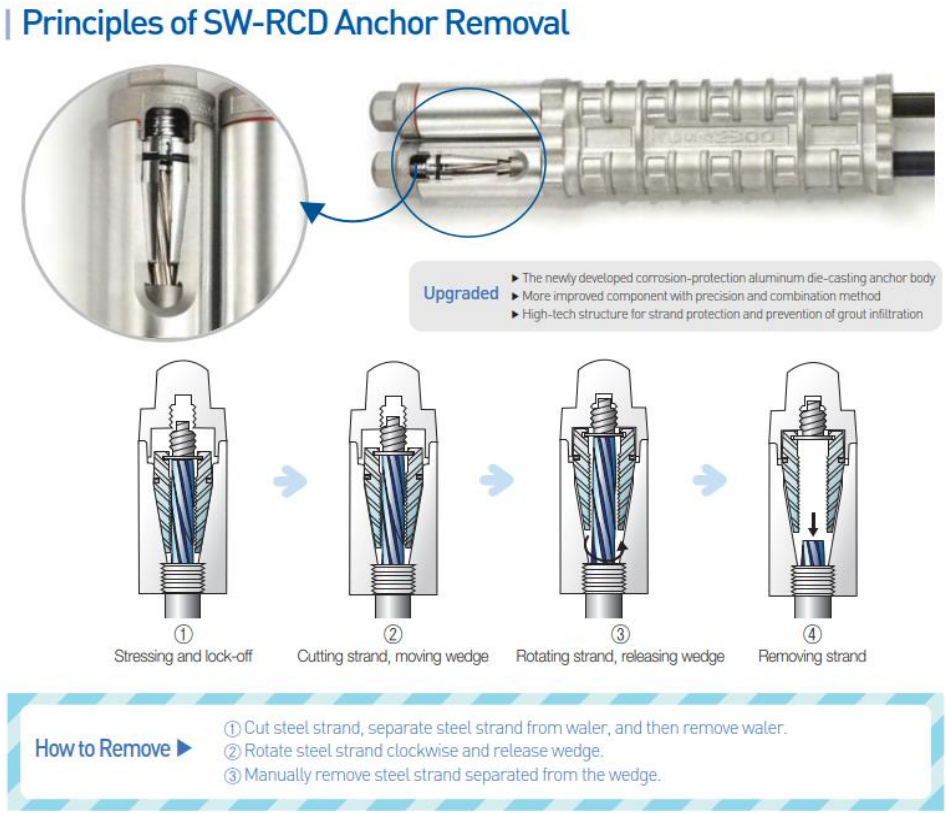

Figure 8: Principles of Removing SW-RCD Anchors (SAMWOO)

The following link provides a video of the strand removal process:

https://www.youtube.com/watch?v=wut8LVNsuNY

5 PROJECT EXPERIENCE SHARING IN USING SBMA AND SW-RCD ANCHORS

5.1 Project A (Using SMBA Anchors)

A large natural terrain on government land is located at the back of the project site. Bulk excavation (maximum depth was about 20 m) along the toe line of the natural terrain was carried out for construction of a semi-basement structure supported by bored piles foundations. The temporary ground anchors were unavoidably required to be installed below government land and Lands Department had imposed a condition that the anchors should be removed upon completion of the building. So removable ground anchors were the only option for implementing the basement excavation works.

The first author adopted 6 layers of SBMA anchors to provide lateral support system to the temporary soldier piles (303x305x223 kg/m UC at 1 m c/c) given that conventional flying/raking struts were not feasible to be installed. The length of anchors varied from 15 m to 29 m and inclined at 30 degrees from the horizontal. Each anchor consisted of 12 strands with 15.7-mm diameter super grade low relaxation wires (with capacity of

1,750 kN). The anchors were designed to be bonded in Grade III rock. FLAC analysis was adopted for the ELS analysis. The close-up views of U-loop saddle and fabricated anchors units used are shown in Plates 2 and 3 respectively.

Plate 2: Saddle at the end of U-loop System

Plate 3: Fabricated Anchor Units

Close-up and bird's-eye views of the completed ELS works are shown in Plates 4 and 5 respectively.


Fig. 8 Ground anchor system can provide clear site for subsequent construction works

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Plate 4: 6 layers of SBMA anchors

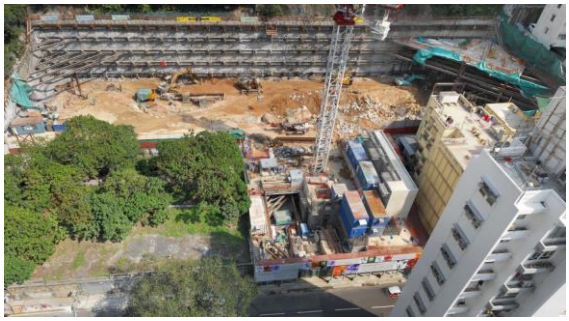

Plate 5: Bird's-eye View of the Completed ELS Works

5.2 Project B (Using SW-RCD Anchors)

The project site was located in urban area. Deep excavation with depth of 48 m was carried out for construction of a semi-basement structure. A public road, which is a single 2-lane carriageway is located on the crest platform at the top of the excavation. The vertical elements of the ELS system comprised 610-mm dia. pipe piles (inserted with 305 x 305 x 223 kg/m UC) at 1.8 m c/c. Similar to the site condition of Project A, conventional flying/raking/corner struts were not feasible to be installed. The temporary ground anchors were unavoidably required to be installed below the public road, and Highways Department and Lands Department had imposed a condition that the anchors should be removed upon completion of the building. So removable ground anchors were an economic option for implementing the basement excavation works and the two authors proposed to adopt 12 layers of SW-RCD anchors (302 nos., 22 strands in each anchor with capacity of 3,260 kN). The strand diameter was 15.7 mm complying with BS-5896 Super Grade and Low Relaxation.

Due to the constraint of the adjacent lot boundary (i.e. private lots are located adjoining the public road),

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the anchors with lengths varying from 14 m to 33.5 m were designed to be inclined at 45-degrees to the horizontal and bonded in Grade III rock (see the PLAXIS model in Figure 9). The actual site monitoring readings of ground settlement and pile wall deflection were smaller than those as predicted by PLAXIS. General view of the completed ELS works is shown in Plate 6.

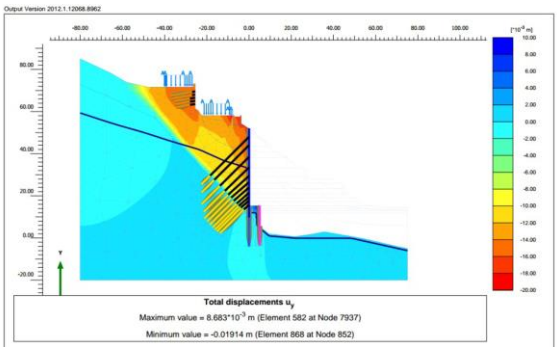

Figure 9: PLAXIS Model for ELS Analysis

Plate 6: General View of Completed ELS Works

Close-up view showing anchor body before inserting into the drilled hole and jacking of the anchors in progress are shown in Plates 7 and 8 respectively.

Plate 7: Anchor Body before inserting into Drillhole

Plate 8: Jacking of Anchors in Progress

Plate 9 shows rotation of the strands in clockwise direction for releasing the wedges.

Plate 9: Removal of strands in Progress

6 CONCLUSION

Two successful projects of using soldier/pipe piles laterally supported by removable ground anchors to facilitate deep basement excavation are presented in this paper.

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"SAMWOO ANCHOR TECHNOLOGY"