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Advancements in Removable Ground Anchor Technology in NZ – Removable, Compressive and load Distributive Type Anchor (SW-RCD Anchor)

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ABSTRACT

Inner city developments generally include deep basements that require perimeter retention to facilitate the excavation. Ground anchors are readily selected as part of the retention system due to their ability to be stressed and prevent structural movement.

Ground anchors comprise steel components and often the adjoining landowner or city municipalities object to obstructions left in the ground beyond completion of project for fear they will conflict with future developments.

Systems which allow removal of the steel tendon from the ground have been available for over 40years and include the removal of the unbonded lengths albeit the steel still remains in the fixed length, as well as the traditional loop system where plastic coated strands are looped around a fixed end anchorage at the base of the anchor bore to facilitate future removal.

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 are required to be removed once they become redundant. The entire steel strand can be quickly and easily removed or reengaged with limited site access.

This paper presents the technology behind the SW-RCD anchor along with project examples from both New Zealand and international applications.

1 INTRODUCTION

Ground anchors are effectively restraining devices used in many different types of structures including retaining walls, dams, wharves, bridge abutments and foundations for buildings. Ground anchors are stressed (active anchorage) to prevent structural movement and they typically transfer their load over a fixed length. These are commonly referred to as tension anchors and are suited for strong rock conditions. For anchors founded in soil or weak rock, load distributive compressive (and tension) anchors are used as they rely on the succession of small successive bond lengths rather than one unique longer bond length.

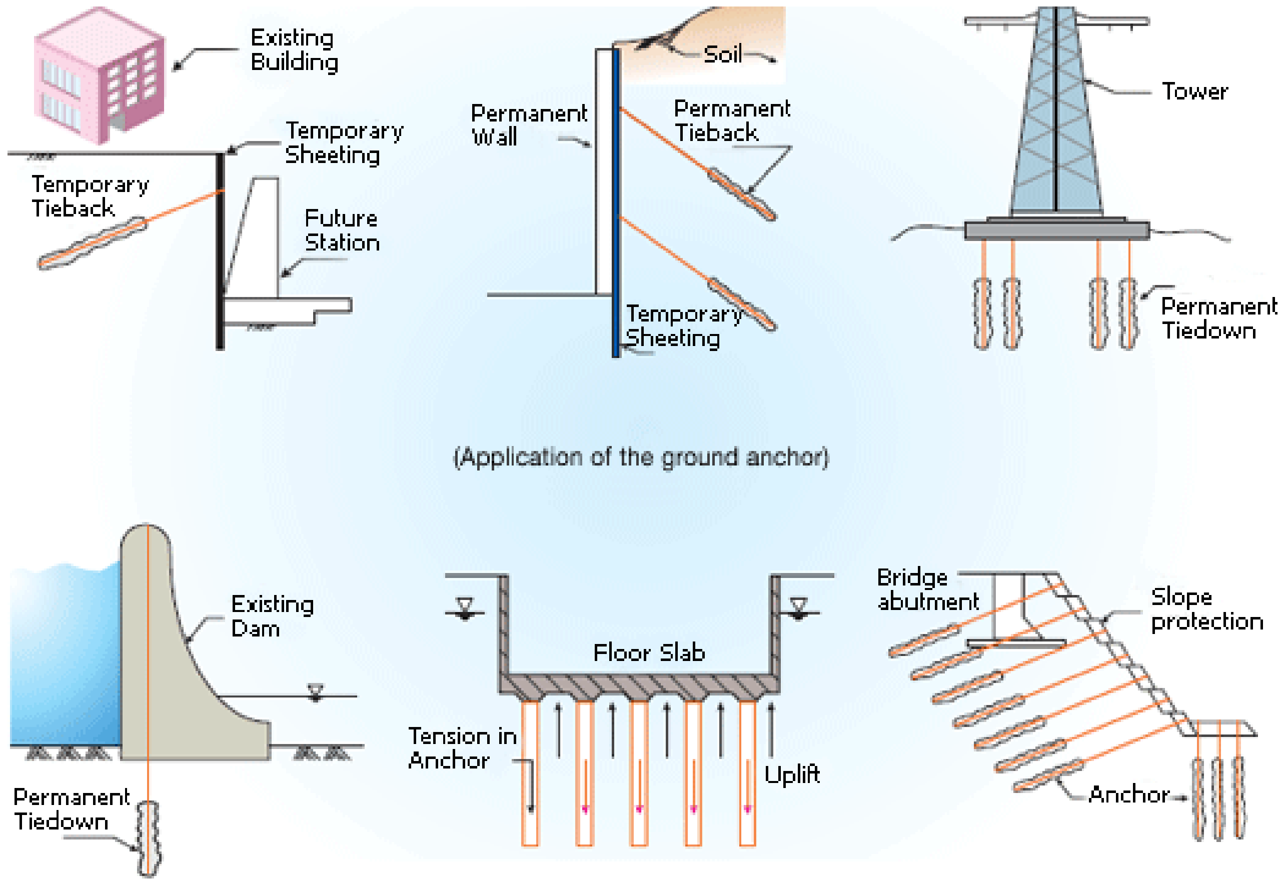

Figure 1: Ground Anchor Applications

2 CLASSIFICATION OF GROUND ANCHORS

Ground anchors are classified according to their service life, purpose, installation procedures and method of load transfer from the anchor to the ground. An anchor with a service life greater than 24 months is generally considered permanent. Permanent anchors shall always have some type of corrosion protection system based on the service life of the structure, the known aggressivity of the environment and corrosive properties of the soil and consequences of tendon failure.

Also, anchors can be classified into frictional type anchors that are supported by the friction of the grout and the ground, ground pressure type anchors that acquire anchoring force with the passive resistance of the ground using ground pressure boards or piles, and complex type anchors that are a combination of the above two types.

Frictional type anchors can further be classified into tensile type anchors and compressive type anchors based on the load application method to the grout. Lastly, compressive type anchors can be classified into load concentrative type anchors and load distributive type anchors depending on the distribution of the load.

2.1 Load Concentrative Tension Type Anchor

When stress is applied to a tension type anchor, load transfer occurs to bond length through adhesion of steel strand and grout. Due to load concentration, the parts of a tension type anchor attached with steel strand and grout become unzipped and this leads to crack and load reduction. In addition, a tension type anchor has the weakness of progressive debonding and time-dependent load reduction (creep) occurrence when friction of the load concentration zone exceeds the extreme skin friction of the target ground.

As shown by (Figure. 2), tension at the earlier phase displays the state as of ①. Then, as the parts attached with steel strand and grout become unzipped, it changes into the state as of ②. The relatively concentrated skin friction of anchor becomes higher than the allowed value between ground and grout body to progress into the state as of ③. Accordingly, load reduction takes place.

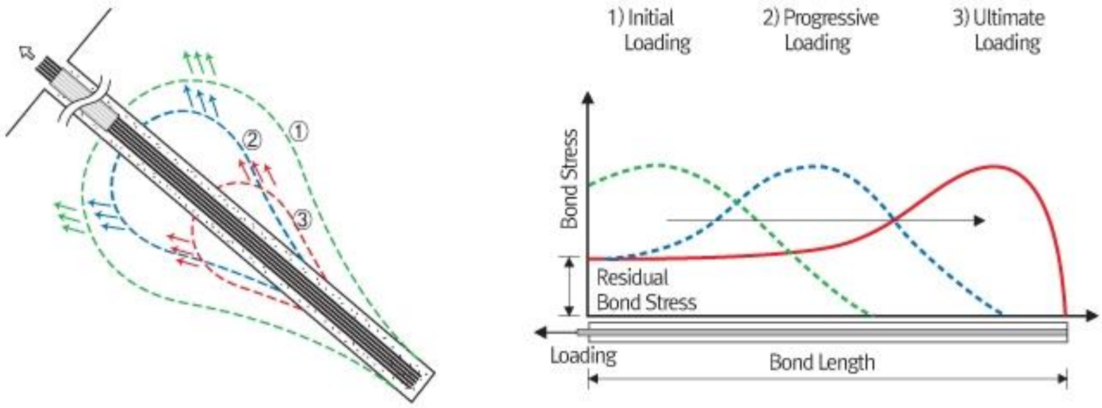

Figure 2: Load Change Diagram and Load Distribution Graph

2.2 Load Concentrative Compression Type Anchor

Compression type anchors consist of an unbonded polyethylene (PE)-coated steel strand which transfers the jacking force / load directly to a structural element located at the distal end of the anchor. Unlike the tension type anchors, the grout body for compression type anchors is loaded in compression which is capable of securing much higher loads. However, due to the concentrative design of these anchors, the use of high-strength grout is frequently required to secure the jacking forces at the distal end. Also, it is often difficult to secure concentrative anchorage force in weak soils.

Similar to the tension type anchors, compression type anchors are subject to the occurrence of progressive debonding and time-dependent load reduction (creep) as displayed in state ① as shown in (Figure 3). In this case the friction required to secure the concentrated load exceeds that of the skin friction for that zone. This effect causes grout debonding and loss of soil confinement pressure resulting in load reduction as displayed in states ② and ③.

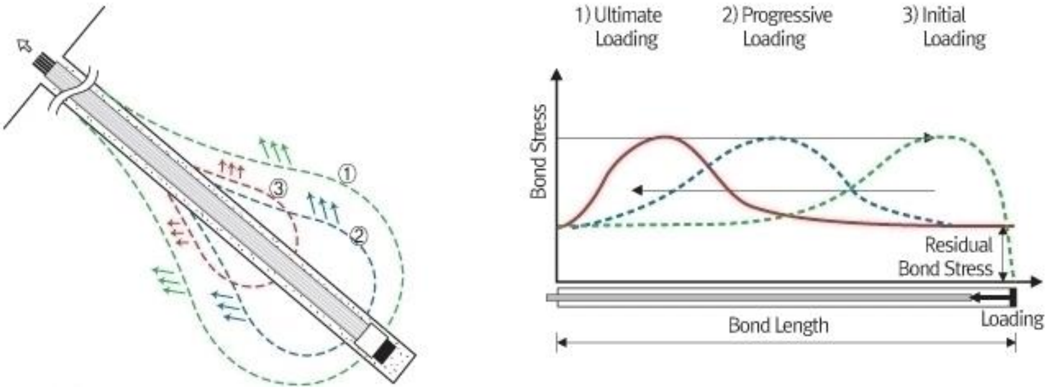

Figure 3: Load Change Diagram and Load Distribution Graph

2.3 Load Distributive Tension / Compression Type Anchor

As outlined above, high stresses from tension and conventional compression type anchors transfer concentrated loads to the soil and grout body which can become overstressed resulting in failure. Therefore, load distributive compression type anchors have been developed and are being used, which uniformly distribute the anchor load to the grout body and soil along the theoretical length of the bond zone. In addition, the grout strength requirements are reduced as well as applied eccentricity.

As a result, high loads can be achieved even in normal soil condition. Recently, load distributive tension type anchors have been developed which are capable of securing stable loads in even relatively weak soils such as clay and silts. The use of multiple short bond lengths reduces the effect of progressive debonding encountered in long conventional anchors. These anchors do not require high strength grout and have low eccentricity as well.

The use of load distributive anchors results in a more uniform distribution of the anchor force to the soil as illustrated in Figure 4 below. Therefore, load reduction and creep are minimized, enabling the anchor to maintain initial design load.

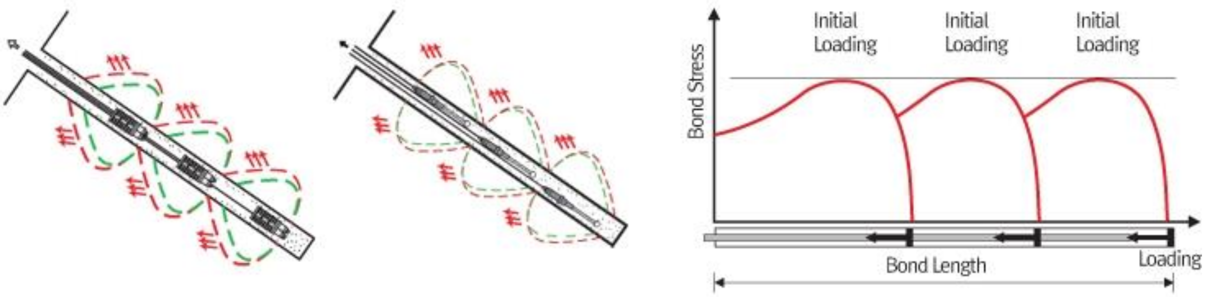

Figure 4: Load Change Diagram(s) and Load Distribution Graph

3 REMOVABLE ANCHOR SYSTEMS

Anchor technology has advanced significantly over the last 40 years and this has resulted in fully removable anchor systems that can be designed to accommodate some of the constraints imposed by urban construction. There are two basic types of removable anchor systems available. The first allows for partial removal of the steel tendon over the free length only of the anchor. The second allows for full removal of the steel tendon over the entire length of the anchor.

3.1 Partial Free Length Removal

The concept of removing the steel tendon over the free length has been commonplace for many years and for threaded bar tendons, involves unscrewing the unbonded section of bar from the bonded section, or, for strand tendons, providing a weakened connection at the junction of the unbonded / bonded lengths and shown in Figures 5 and 6 respectively.

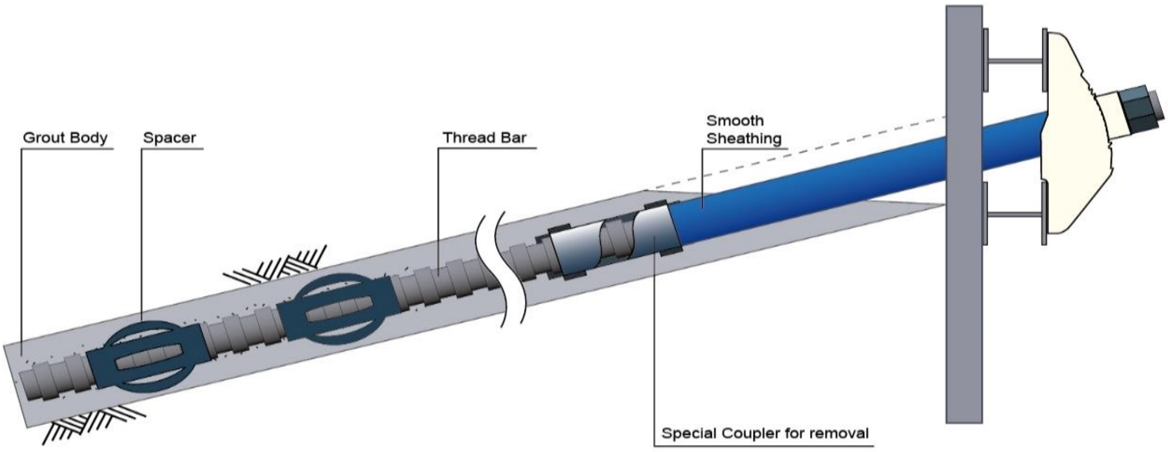

Figure 5: Removable Bar Tendon – free length only

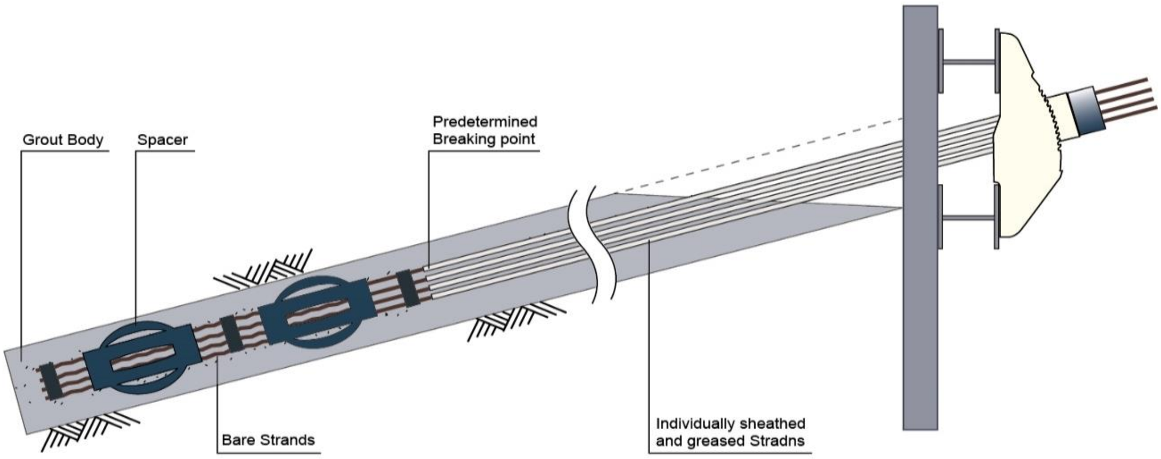

Figure 6: Removable Strand Tendon – free length only

This is a simple concept, however, in practice it has been proven to be very difficult to implement with limited levels of success, and as a result, free lengths of removable anchors on numerous projects have generally remained in place.

3.2 Full Length Removal

Removal of both the unbonded and bonded length of a steel anchor has historically been difficult to achieve as it is practically impossible to over-stress an anchor to yield the grout to ground bond. The use of detonation cord to shatter the grout while an effective method, is no longer practical due to more stringent safety regulations and negative environmental impacts.

For bar anchors, recent innovations involving sonic drilling have meant that it is possible to completely remove hollow-bar self-drilling anchors using the sonic frequency to shatter the grout column, however, the size of the equipment needed generally precludes this technique on the small footprint of inner urban sites.

For strand anchors, an early innovation involved the use of looped greased and sheathed strand around a distal saddle. Both ends of the strand are terminated at the anchor head and loaded simultaneously. Load was transferred from the loop to a saddle which in turn transferred the load to the grout and ground – effectively a load distributive compression type anchor. During removal, one end of the strand is loaded and the strand pulls around the saddle and extracted from the ground. Due to the complete isolation of the bond between the steel strand and grout, the entire length of strand was able to able removed, and although this system was generally successful, heavy equipment was required to remove the strand on site. Additionally, damage to the sheathing at the saddle bend was common and this had an impact on the removal success rate. The loop system also reduces the strand properties in the bend section resulting in limited working loads and therefore more anchors are required to achieve the same capacity as other anchoring systems.

Figure 7: Looped Strand Anchor

3.3 SW-RCD Anchor

The SW-RCD anchor is a load distributive compression type removable anchor that offers a complete solution where anchorage systems are required to be removed once they become redundant.

As the anchors are loaded as illustrated in Figure 8 below, the grout body is subject to compressive or tensile stresses. In the case of compression type anchors with applied compressive stress, the diameter of the grout body expands as a function of Poisson's ratio. As a result, frictional resistance between the grout body and soil increases. Also, the additional confining soil pressure due to the expansion of the grout body will increase the ultimate compressive strength of the grout. This is known as the confining pressure effect and is an advantage of compression type anchors.

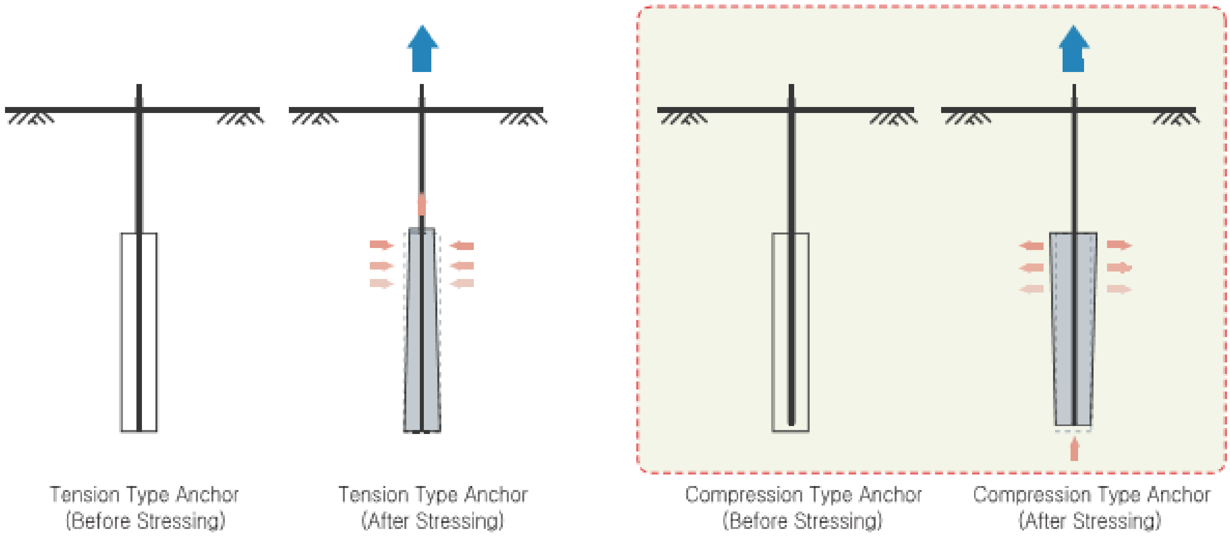

Figure 8: Tension versus Compression

The anchors are manufactured in a semi-automated standardised facility with state of the art equipment resulting in stringent quality control. Anchors are fully assembled and packaged in coils for transportation.

The SW-RCD anchor components include steel strand within a polyethylene sheath terminated within a corrosion resistant aluminium anchor body located within the bond zone of the anchor. Allowing the steel strand to penetrate through the inside of the aluminium anchor body, and, be secured to the end of the anchor body, results in distribution of the jacking force along the length of the anchor body which maximizes the effective cross-sectional area of the grout body.

Single, double, triple, quadruple and sextuple anchor bodies are available, and this allows for anchors comprising up to 24-strands. The maximum number of strands for each anchor body combination / hole diameter is set out below:

- Single anchor body combination: maximum 7No strands (1+1+1+1+1+1+1) 150mm
- Double anchor body combination: maximum 6No strands (2+2+2) 150mm
- Single / double anchor body combination: maximum 7No strands (2+2+2+1) 150mm
- Triple anchor body combination: maximum 9No strands (3+3+3) 175mm
- Quadruple anchor body combination: maximum 12No strands (4+4+4) 185mm
- Sextuple anchor body combination: maximum 24No strands (6+6+6+6) 240mm

Tendon configurations utilising 12.7mm, 15.2mm and 15.7mm strands are common which provides for a maximum ultimate tensile strength of 6,696kN. The various anchor body configurations can be seen in Figure 9. The drill hole needs to be grouted over the entire length.

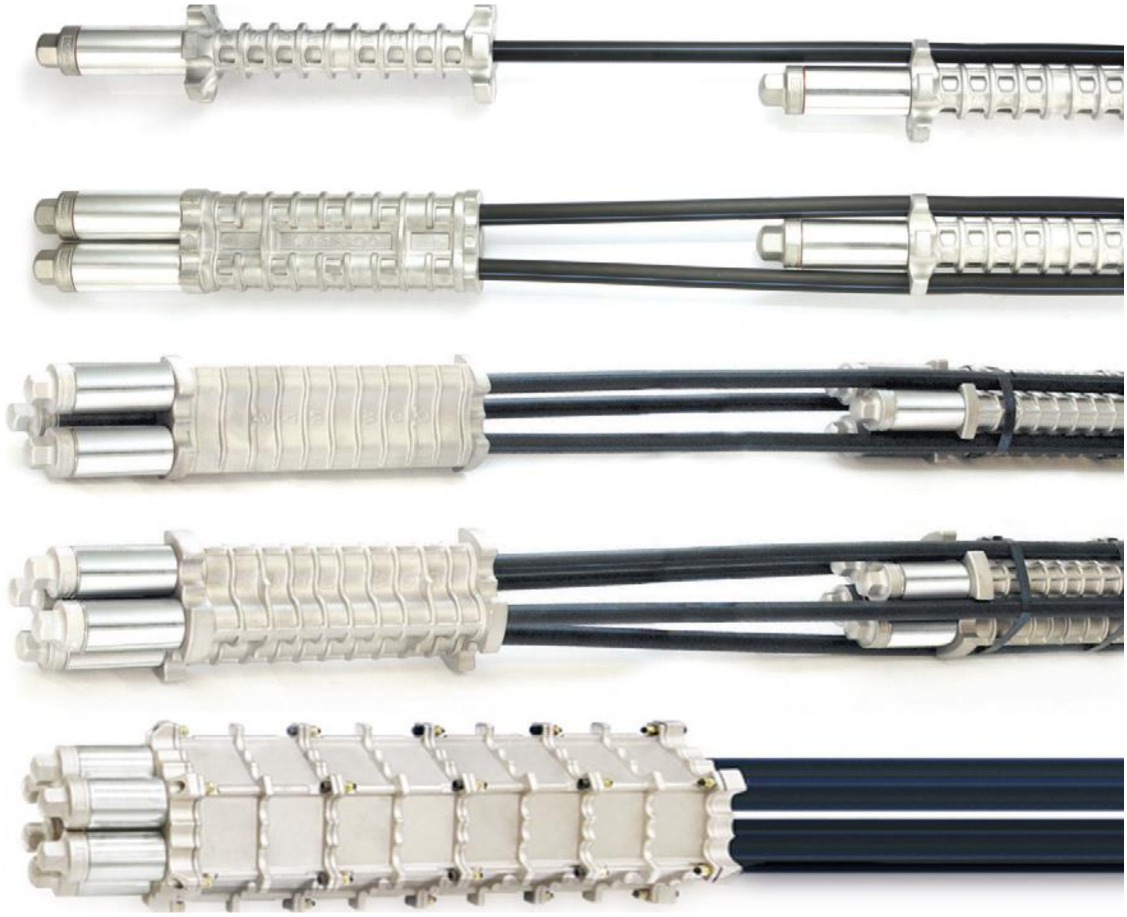

Figure 9: SW-RCD Anchor Body Configurations

For multiple anchor bodies, the distribution of the anchor bodies within the bond length is generally obtained by evenly distributing them over the bond length. However, the ground conditions have an impact on the selection of anchor body type and a minimum 1.7m distance between anchor bodies is recommended in weak rock.

A minimum 5m bonded length should also be adopted.

If the ground for the targeted bond zone is weak (N<20), multiple single anchor body configurations are preferred to facilitate higher load distribution – this is the concept of single bore multiple anchors. The quadruple anchor body is the largest that should be applied in weak rock.

The sextuple anchor body is designed solely for strong rock conditions.

The load distributive type anchor has the significant advantage of being able to achieve greater anchoring forces whilst avoiding load concentration to grout due to the equal distribution of load within the bonded length in comparison to the load concentrative type anchor.

There are two effective methods for stressing load distributive type anchor, which are elongation control method and load control method.

1. Elongation control

This method compensates for the elongation difference with pre-stressing after calculating the elongation difference of each anchor body in consideration of the relation of difference in length to load according to the spacing between the anchor bodies. A conventional centre hole jack is required (not a mono strand jack). The strand(s) in the lowest anchor body is loaded to the calculated extension and the process repeated for all anchor bodies prior to stressing the anchor to the required load.

2. Load control

This method compensates for the load difference with pre-stressing step-by-step after calculating the load difference for each anchor body by the spacing between anchor bodies when the strands are stressed simultaneously. A conventional centre hole jack is required (not a mono strand jack). The strand(s) in the lowest anchor body is tensioned to the calculated load and the process repeated for all anchor bodies prior to stressing the anchor to the required load.

To facilitate the successful removal of the strands, a 900mm strand tail beyond the anchor head needs to be maintained during the working life of the anchor. Interaction with structural building elements needs to take this into account.

The removal process is generally done by hand and the entire steel strand can be quickly and easily removed or reengaged with limited site access. A force needs to be transmitted down each strand to disengage the wedge retaining clip and then simply rotate the strand to release the wedges which are fixed in the end of the anchor body and the entire steel strand is withdrawn through the PE sheath leaving the small aluminium anchor body within the grouted drill hole.

Figure 10 depicts the SW-RCD removal mechanism.

The following link provides a video of the strand removal process https://youtu.be/wut8LVNsuNY

In some instances, particularly for longer anchors, where difficulties are experienced in disengaging the lower wedge, it is possible to transmit a larger force down each strand using a mono-strand jack with partial wedge engagement – this facilitates the slip of the strand within the jack wedge grip at a predetermined load and upon release, the strand impacts the lower wedge.

Additionally, for problematic strands, a hydraulic rotator can be connected to the strand to simultaneously provide a rotational and pulling force to assist in extracting the strand. The ability to use small equipment is a real advantage.

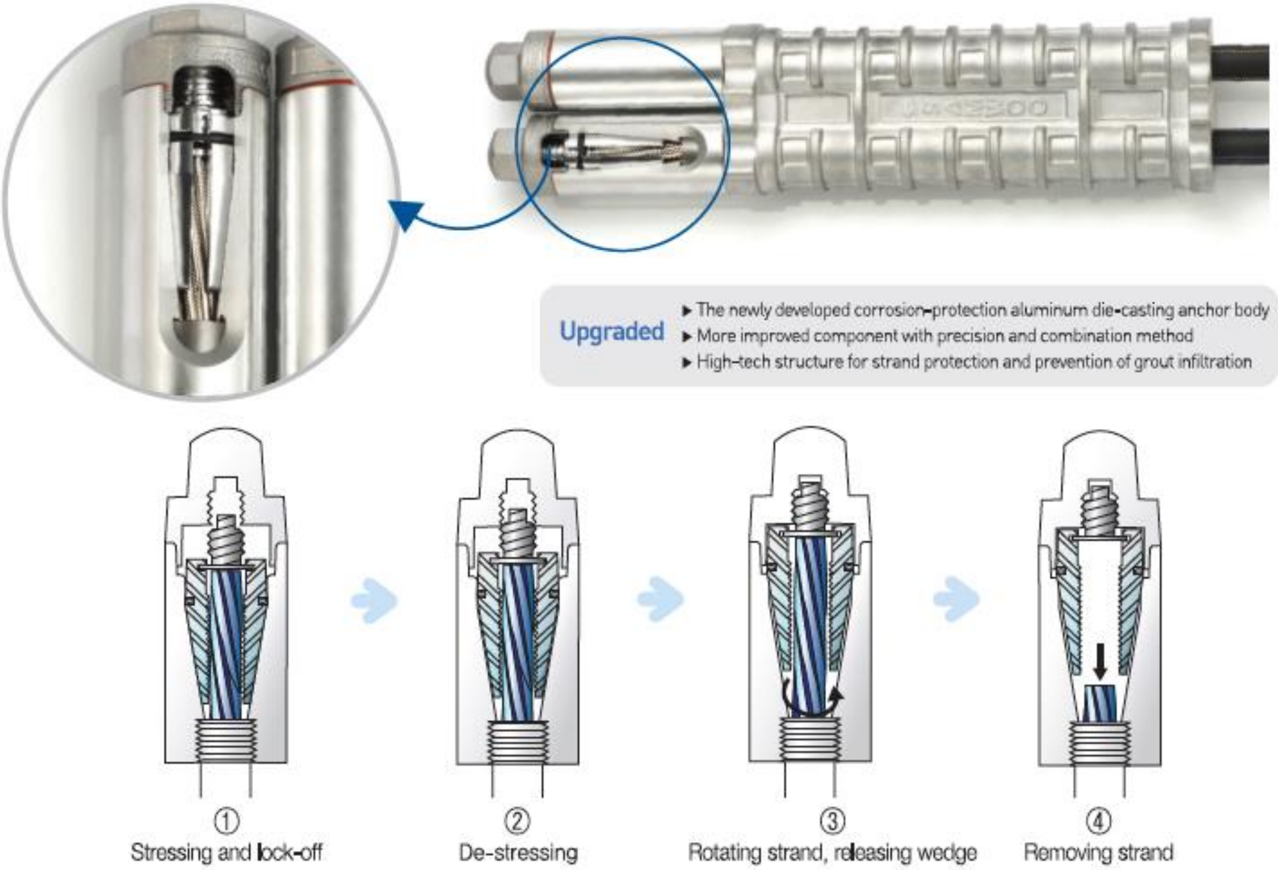

Figure 10: SW-RCD Removal Mechanism

4 PROJECT EXAMPLES

Since the initial development in 2000, the SW-RCD anchors have been utilised in over 2000 projects around the world including job sites in South Korea, Vietnam, Mayalysia, Singapore, Hong Kong, China, Myanmar, Europe, North America, Brazil, Qatar, Oman, Dubai, Turkey, Australia and New Zealand.

In New Zealand, the SW-RCD anchors were introduced in 2011 and specific construction statistics are summarised below:

- 450 individual anchors
- 12km of completed anchors
- 75km of strand

All projects completed in New Zealand have been fully scrutinised with site specific performance and proof testing undertaken and without exception the SW-RCD anchors have met the requirements of the project specifications. Site testing has included cyclic load testing up to 1,540kN and creep monitoring with the results being consistent with conventional temporary tension type strand anchors.

Selected project examples from New Zealand are presented in Table 1.

Figure 11: New Zealand International Convention Centre

Table 1: Project Examples – New Zealand

Project	Year	No of Anchors	No of Strands	Length
Remuera Rd	2011	48	2-9	25-30m
Fonterra	2014	28	5-7	35m
Building A	2014	20	12	35m
74 Sales	2014	13	3	23m
96 St Georges Bay	2015	13	3-5	18m
46 Sales	2015	7	5	17m
Building 5A Wynyard	2015	31	9	33m
Union St	2016	35	7	20-30m
Alma St	2016	66	5-8	24-30m
NZICC	2017	51	7	20-30m
Ramada Victoria	2017	59	3-5	17-25m
Waiparuru Hall	2017	47	3-11	24-30m
155 Fanshawe	2018	8	5	31.5m
Wakefield St	2019	9	3-5	13.5-19.5

Key international construction statistics are summarised below:

- Circa. 850,000 individual anchors
- 25,000km of completed anchors
- 130,000km of strand

International project examples are presented in Table 2.

Table 2: Project Examples – International

Project	Year	No of Anchors	No of Strands	Length
South Korea	2000-20	826,465	2-10	13-38m
Singapore	2002-20	2,048	4-21	30-43.5m
Europe	2009-20	1,709	2-9	11-48m
Vietnam	2009-20	7,028	4-5	13.5-35m
Malaysia	2009-20	4,682	3-7	15.5-33m
North America	2009-20	321	3-9	16-22.5m
Woolworths Brisbane	2012	25	4	16m
Sao Paulo Brazil	2012	200	4	18m
Dubai	2013-2016	480	4-7	20.5-27.5m
Oman	2014	139	4-8	22.5m
Qatar Doha Metro	2014-17	3,028	3-8	13-30.5m
XinRong China	2016-17	642	4-5	28.5m
Turkey	2017	88	5	24m
Melbourne	2017	30	2	15m
Hopewell Hong Kong	2016-18	302	22	33m
Burj Tower Qatar	2017	768	5-8	26m
Myanmar	2017-18	260	4-6	19.5m
Caringbah Australia	2018	24	4	17m
Melbourne Metro	2019	372	10-13	17.5m
George St Sydney	2019	25	3-5	18m
Tai Wo Ping Hong Kong	2019-20	240	20-24	47m

5 SUMMARY

High load and low load capacity removable anchors now exist which allow for the total removal of the steel strand tendon from the ground.

The grout body for compression type anchors is loaded in compression which is capable of securing much higher loads.

The removal process is simple and does not require heavy machinery or equipment – generally removal is possible by hand.

SW-RCD anchors are a cost-effective solution where the use of conventional tieback anchors are forbidden or discarded due to logistical and or practical site constraints. When compared to normal temporary strand anchors, the SW-RCD anchors are in the order 1.3 times the cost.

The SW-RCD anchor is manufactured in a semi-automated standardised facility with state-of-the-art equipment resulting in stringent quality control. Anchors are fully assembled and packaged in coils for transportation. The SW-RCD anchor is an internationally patented product with the design based on compression type, load distribution theory.

The successful removal of multiple-strand anchors allows for future developments to proceed unencumbered.

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