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Removable strand anchors, state of the art

Tirants d'ancrage par câbles démontables, état de l'art

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ABSTRACT: Ground anchors are devices widely used in urban constructions. The use of tiebacks on temporary support of deep excavations provides a technical solution advantageous for construction sequence and schedule saving. However, the concern of municipalities to keep the subsoil of large cities unobstructed to future underground projects leads to restrictions on using conventional anchors. Therefore, the anchors that enable the strands to be removed from the neighbouring ground at the end of its service life are proposed as the most appropriate and sustainable alternative. The reliability of the system and efficiency of the tendons removal have placed these devices in many urban constructions around the world. In this paper, removable strand anchor systems are presented and explained, followed by a comparison between them that shall prove useful to engineers in order to assess the pros and cons of current commercial removable strand anchors.

RÉSUMÉ: Les ancrages dans le sol sont des dispositifs largement utilisés dans les constructions urbaines. L'utilisation d'ancrages pour le soutènement temporaire de fouilles profondes constitue une solution technique avantageuse pour le déroulement de la construction et l'économie du temps. Toutefois, la préoccupation des communes de garder le sous-sol des grandes villes libre pour de futurs projets souterrains mène à limiter l'utilisation d'ancrages conventionnels. Par conséquent, les ancrages par câbles permettant de retirer les tirants du sol voisin à la fin de leur durée de vie sont proposés comme l'alternative la plus appropriée et la plus durable. La fiabilité du système et l'efficacité de l'enlèvement des tirants sont liées à l'emploi de ces dispositifs dans de nombreuses constructions urbaines à travers le monde. Dans cet article, les systèmes de tirants d'ancrage par câbles démontables sont présentés et expliqués, suivi d'une comparaison entre eux qui s'avérera utile aux ingénieurs afin d'évaluer les avantages et les inconvénients des ancrages démontables commerciaux actuels.

KEYWORDS: ground anchors; urban construction; deep excavation; temporary tiebacks; sustainability.

1 INTRODUCTION

Ground anchors are devices widely used in civil engineering. In urban environments, one of its main applications is the construction of tied-back retaining walls as the supporting system of deep excavations pits. According to the usual building system, the lateral resistance provided by the tieback anchors is only necessary during the construction phase, since once the excavation has been completed, the bracing is provided by floor slabs. The steel strands of these temporary tiebacks are then abandoned in the surrounding ground.

Nowadays, global metropolises are increasingly demanding the use of underground space as part of the urban, environmental, social and economic development of modern societies. Progressively more, the use of the subsoil of these cities is subject to further restrictions on the installation of ground anchors because the abandoned steel strands can conflict with future underground constructions or deep foundations, such as tunnels, diaphragm walls or piles. Thus, the current trend of local authorities is to limit the use of temporary tiebacks below the streets or utilities, and to apply fines for steel elements not removed. Therefore, the solution in these situations shall be to install anchors whose steel strands can be removed from the ground at the end of the construction phase.

Since the 70s, through a great research and industry support, scientists and engineers have developed the technology required to bring removable anchors into the market. The reliability of the system and efficiency of the tendons removal has increased significantly in the last decade, to the extent that several removable anchor systems are now commercially available and are being placed in urban constructions around the world.

In this paper, the typology of strand anchors according to its method of load transfer and load distribution is firstly described. Then, the main commercial systems of removable strand anchors are presented, summarizing the particularities and extraction technology of each one. Finally, a comparison of its main features is done, highlighting the pros and cons of current commercial removable strand anchors.

2 ANCHOR TYPES

Main components of ground anchors are bonded length (grout body) and unbonded length (free length). The internal behaviour of a ground anchor is ruled by the way the grouted body is loaded, either in tension or compression, so as by the distribution of the bond stress along the bonded length of the anchor.

The features of every anchor type bring out the main differences between the technology used in conventional anchors and modern ones, both available nowadays in the market.

2.1 *Tension type anchor*

This type of anchor corresponds to conventional anchors and its the most common on temporary tiebacks used nowadays. These devices are prestressed with a hydraulic jack in the extreme of the unbonded length, sheathed by a HDPE tube. The tension force at the bonded length is transferred into the ground through adhesion of steel strands, cement grout and soil. The entire grout body is thereupon loaded in tension.

At the beginning of the ground anchor stressing, the load is transferred to the top of the bonded length, and as the stress continues, the load is progressively transferred to its lower part.

Thus, the load transfer mechanism is not through a uniform stress distribution. This results from the incompatible elastic properties of tendon, grout and soil, causing the phenomenon known as progressive debonding (Barley, 1997).

The representation of the progressive debonding at steel-grout or grout-soil interface is shown in Figure 1. This phenomenon means that the bonded length is not able to mobilise the maximum resistance of the soil along its entire length. Meanwhile, in the remaining bonded length only a residual bond stress develops. This results in an inefficient use of the available in-situ soil strength.

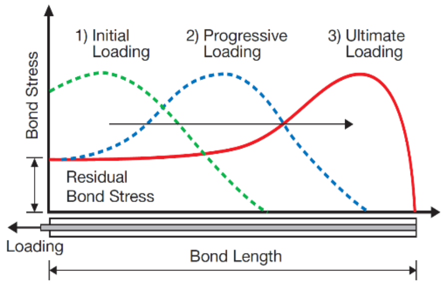

Figure 1. Load distribution graph in tension type anchor (Samwoo Anchor Technology, 2014).

2.2 *Compression type anchor*

This type of anchor consists of a non-adherent steel cable covered with polyethylene (PE) along its entire length, which transfers the axial stress generated by the tensioning jack directly to a structural element located at the distal end of the anchor (Figure 2). Unlike conventional anchors, the grout body is loaded in compression, avoiding the formation of classic tensile cracks, which are a consequence of the brittle behaviour of the cement grout, thus increasing its durability. Compression anchors also afford better corrosion protection because the steel strands within the ground are isolated from the environment by plastic sheath.

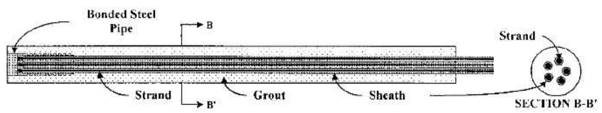

Figure 2. Compression type anchor (Kim, 2003).

When a compression anchor is loaded, the highest bond stress develops near the lower end of the bonded length, in contrast to tension anchors. As a result, the section of soil that is activated is larger than in a conventional anchor. During loading, if the load continues to increase to a high value, the friction required to maintain the concentrated load exceeds the adhesion between the grout and the soil in that area, resulting in loss of adhesion of the grout body and loss of soil confining pressure. The maximum bond stress then shifts from the distal zone to the proximal zone of the bonded length, while residual bond stress develops in the remaining bonded length (Figure 3).

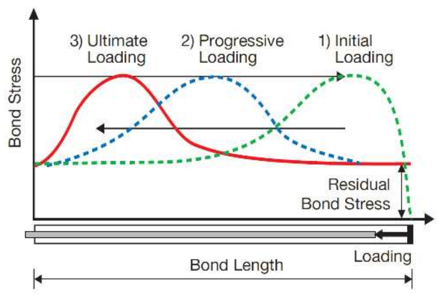

Figure 3. Load distribution graph in compression type anchor (Samwoo Anchor Technology, 2014).

2.3 *Load distributive type anchor*

High stresses in tension and compression anchors transfer concentrated loads to the bonded length and the ground, thus generating very non-uniform stress distributions along the entire grout body. This can lead to anchor failure due to the phenomenon of progressive debonding. The maximum bond stress is concentrated in a short length of the grout body while the rest of the bonded length only develops residual bond stress. This results in an inefficient use of the surrounding soil resistance.

As a solution to this problem, a system was developed that can simultaneously transfer the load to several bonded lengths, thus avoiding progressive debonding. In this way, the ground resistance can be mobilised more efficiently and the anchorage capacity can be increased considerably. This system is the fundamental principle of load distributive anchors (Figure 4). These devices consist of a number of unit anchors or anchor bodies arranged in series. Each unit anchor consists of its own individual tendon with its own unbonded and bonded length. The bonded length can be loaded in tension or compression depending on the type of anchor unit.

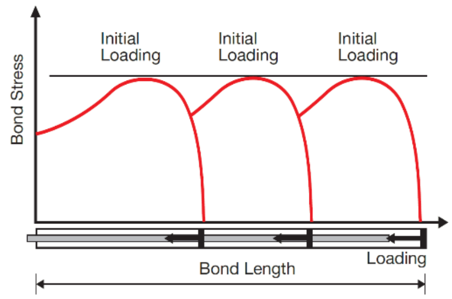

Figure 4. Load distribution graph in load distributive compression type anchor (Samwoo Anchor Technology, 2014).

The use of load distributive devices generates a uniform distribution of bond stress along the bonded length through its anchor units. This distribution enables the ultimate grout/ground bond capacity to be mobilised more efficiently; the grout strength requirements are reduced and the phenomenon of progressive debonding is avoided. Therefore, the probability of system failure is minimised, enabling the anchor to maintain its initial design load. Finally, higher working capacities can be achieved.

3 REMOVABLE ANCHOR SYSTEMS

A removable anchor is a temporary device which enables the tendon to be removed from the ground at the end of its service life.

Within the urban restrictions prohibiting the abandonment of steel strands, it is generally accepted that cement grout remains in the ground, as it behaves in a similar way to soil during mechanical excavation. Plastic elements such as sheaths, pipes or other accessories of short length do not hinder excavation works, as well as fibreglass parts.

Removable anchors systems vary depending on the extent to which the steel parts may remain in the ground. This depends on the technology used and influences the production costs and the reliability of the system.

Since the beginning of their development, many removable systems have been proposed and tested. However, few of them have been successfully implemented in the market with satisfactory results and guaranteed system reliability. A structured summary of currently available systems is shown in Table 1.

Table 1. Types of removable anchors systems.

Type	*Anchor system*	*Extraction grade*
Tension	Anchor with breaking points	Partially removable by overstress
	Anchors with explosives or expanding material	Fully removable by destruction of bonded length
	Sliding wedge anchor	
Load distributive compression	SBMA	Fully removable by mechanisms
	SW-RCD anchor	
Compression	DYWIDAG QuickEx	

3.1 *Anchor with breaking points*

It is a partially removable tension anchor, enabling the strands to be removed only in their free length, while the bonded length remains in the ground. This may be acceptable in situations where the grout body is buried deeply and far from the potential conflictive area to future construction works.

The extraction mechanism consists of stressing the strands until rupture occurs at the predetermined breaking point. Once all the strands have been individually broken at these points, they can be completely removed by winch, excavator or vehicle.

To ensure that the steel strands fail at the end of the unbonded length, predetermined breaking points are created during the manufacturing process at the transition between the free length and the grout body (Figure 5). These points are generated by two methods: a) inductive heat procedure, reducing the resistance of the steel by applying heat locally; b) mechanical process, reducing the steel section area.

It is a robust anchor in terms of handling on site, as it does not require special treatment during installation. However, its main disadvantage is the reduction in the load capacity due to the reduced strength of the steel at the breaking points, as well as the time-consuming process of extracting the strands.

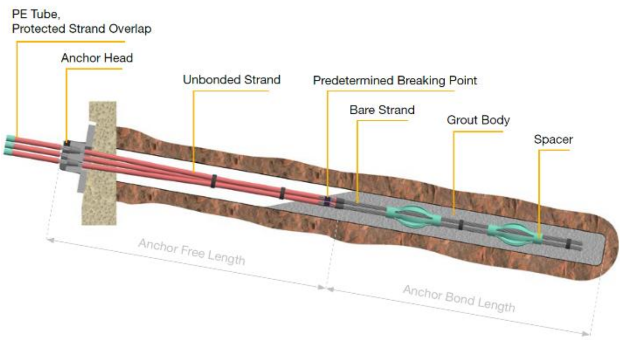

Figure 5. Anchor with breaking points (DYWIDAG-Systems International, 2016).

3.2 *Anchors with explosives or expanding material*

This anchor system has the conventional behaviour of a tension anchor. In this case, the tendon is completely extracted from the ground. The bond between the cement grout and the steel strands is broken by detonating an explosive charge along the grout body or by introducing an expandable material inside it. Once the grout body has been destroyed and unbonded from the strands, these are removed.

A hollow polyethylene tube, sealed at both ends, is installed in the centre of the strands (Figure 6). At the end of its service life of the anchor, the tube is opened and a detonating cord is inserted. At the moment of explosion, the anchor may be prestressed or unstressed. In the first case, the anchor may be suddenly ejected from the borehole. In the second case, the anchor is firstly unstressed and then the strands are removed by hydraulic jack or winch. Extraction operation is slow due to the limited stroke length of the jack.

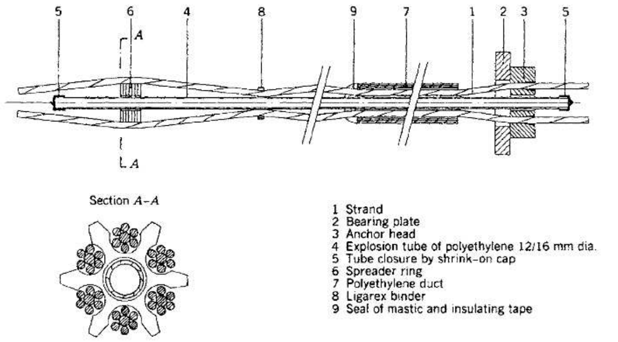

Figure 6. Anchor with explosives (Rey, 1978, from Xanthakos, 1991)

The main advantage of this method is the efficacy in recovering the tendon. However, the use of explosives requires a blasting specialist and corresponding permits, which increases the cost. Furthermore, its use in urban environments is limited by the vibrations produced and its proximity to buildings or utilities, as the effects of the explosive or expandable material cannot be accurately predicted. Therefore, this system is not used any longer.

3.3 *Sliding wedge anchor*

It is a tension anchor fully removable by destruction of the grout body by a wedge-shaped element under tensile overstressing. It has been used mainly in Japan.

This system requires the installation of an additional strand with a wedge-shaped element fitted at its distal part which is tapered in the direction of tendon extraction (Figure 7). The additional strand is located in the centre of the other strands and is sheathed along the entire length of the anchor, thus isolating the steel from the cement grout. This grout may contain filler materials, such as polystyrene foam, in order to generate small voids or air bubbles inside the grout body.

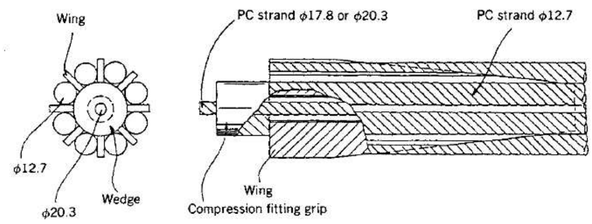

Figure 7. Sliding wedge anchor (Yamada, 1978, from Xanthakos, 1991).

The extraction procedure consists of pulling the central strand by hydraulic jack, which causes the attached sliding wedge to exert a force on the grout by disintegrating it, thereby detaching the strands from the grout. The grout fails before the steel strands. Once the bonded length has been destroyed, the strands are pulled out individually with jack and then manually. The whole operation is a very time-consuming task and is therefore rarely used today.

3.4 *SBMA (Single Bore Multiple Anchor)*

This is a load distributive compression anchor, which combines a tendon recovery method with the concept of load distribution along the entire bonded length through the use of several anchor units. Several tendons are inserted in the same borehole. Each of these tendons have different free lengths, thus the bonded lengths are arranged in series. The set of a tendon, with its own free length and grout body, is called an anchor unit. The units are individually tensioned by a set of hydraulically synchronised jacks which ensure that the load applied to the different units is always the same. The grout bodies are loaded in compression.

The total anchor load is the sum of the loads applied individually to all anchor units. According to this design concept, there is no theoretical limitation on the total bonded length (the sum of all anchor units' bonded lengths), but the habitually used effectively is between 10 and 25 m. Furthermore, the load transfer mechanism avoids progressive debonding; so, in a homogeneous soil, the maximum ground strength can be mobilised uniformly and simultaneously along the entire bonded length of each anchor unit (Figure 8).

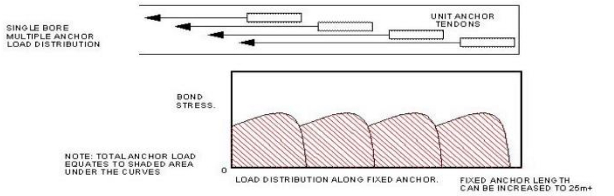

Figure 8. Load distribution of a Single Bore Multiple Anchor (Barley and Windsor, 2000).

When site conditions require the anchor to be fully removable, the SBMA applies a particular design, inspired by the concept of retrieving a climbing rope in a rappel. The strands are looped towards the distal end of each anchor unit, greased and sheathed along their entire length, and its two ends come out of the borehole. The load is transferred in the loop area to a U-shaped metal device, where the strands are bent through 180° (Figure 9). This device transmits the force exerted by the hydraulic jack to the cement grout and then mobilises the ground strength. This configuration is identical for each anchor unit, the only thing that varies is the free length and, depending on the design, the bonded length. Each anchor unit is loaded simultaneously by a jack with a multi-ram stressing arrangement.

a) b)

Figure 9. a) U-shaped device in loop area of a Single Bore Multiple Anchor (www.sbmasystems.com); b) Color coded unit anchor tendons in SBMA installed (theanchormanblog.wordpress.com)

Once the anchor function has been completed, each strand loop is unstressed. Then, the strands are pulled about one metre by jack. As the strands are fully greased and sheathed along its entire length, they slip around the U-shaped device at the distal end of each anchor unit. Then, the remaining length can be pulled out by winching.

Based on the results of field investigations, SBMA system is capable of supporting working loads in the range of 800 to 2000 kN, which is two to three times that of conventional anchor systems installed using the same construction techniques albeit with longer overall fixed lengths (Barley et al, 2003). The use of 6 anchor units can provide a capacity in excess of 2400 kN.

Its main disadvantage is that the strands extraction process is time-consuming because it has to be done mechanically due to the narrow radius of curvature of the U-shaped device.

3.5 *SW-RCD anchor*

It is a load distributive compression type removable anchor. Thus, the system transfers the load to several bonded lengths in series within the same borehole, which are loaded in compression. It was developed in South Korea by the company Samwoo and was first commercialised in 2001.

SW-RCD anchors consist of several prefabricated aluminium bodies arranged in series within a single borehole. The steel strands are fully sheathed in high-density polyethylene (HDPE) and are individually connected to each anchor body. For the anchor installation, it is necessary to stress all strands with the same load. As the free lengths vary depending on the number of installed anchor bodies, anchor stressing is done by specific hydraulic jack (SW-Smart Jack) that uniformly distributes the stressing force to individual strands of each anchor body.

The total bonded length and the surrounding soil are loaded uniformly in compression and the phenomenon of progressive debonding is avoided by distributing the compressive load through several bonded lengths (Figure 10). According to the manufacturer, maximum design load of 3300 kN can be achieved using a combination of 6 anchor bodies with 4 steel strands each (15.7mm dia.).

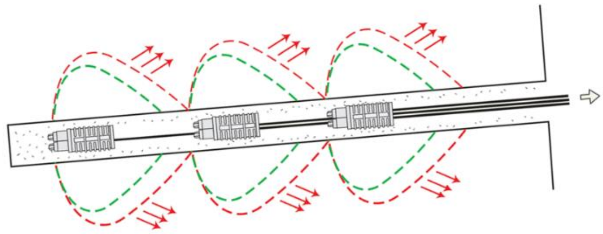

Figure 10. Schematic diagram of SW-RCD Anchor with 3 anchor bodies (Samwoo Anchor Technology, 2014).

This system enables the manual removal of steel strands during decommissioning of the temporary support system. The mechanism consists of a wedge retention system located in every anchor body. The strand tip inside the anchor body is secured in place by a wedge that can be loosened from the surface at the end of the anchor's service life (Figure 11).

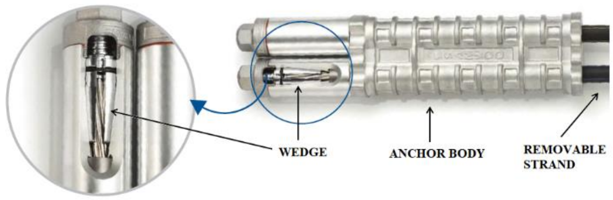

Figure 11. Wedge retention system in a double anchor body (Modified from Samwoo Anchor Technology, 2014).

The removal procedure begins by cutting the strands with a torch or a disc and separating it from the waler system. When the anchor is unstressed, the wedge fixed into the anchor body moves towards its distal end. The strand is then rotated clockwise with a hand tool. The rotation of the steel strand disengages the wedge inside the anchor body, and releases the strand, allowing for easy removal by pulling it out manually. The entire steel strand is easily withdrawn through the HDPE sheath leaving the small aluminium anchor body in the ground. The steps for a typical removal procedure are shown in Figure 12.

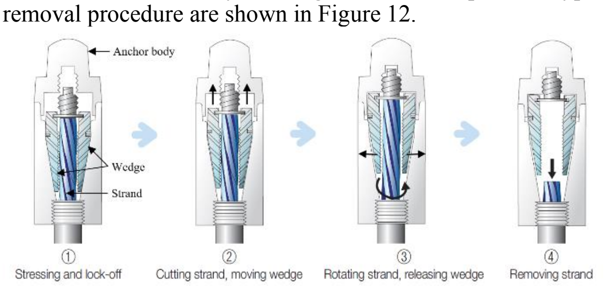

Figure 12. SW-RCD Anchor removal process (Modified from Samwoo Anchor Technology, 2014).

3.6 *DYWIDAG QuickEx*

This system combines the geotechnical characteristics of a compression type anchor with a simple method of steel strands extraction. It has been developed and patented by DYWIDAG-Systems International and was first commercialised in 2014.

The steel strands are enveloped by a high-density polyethylene (HDPE) tube along its entire length and are fixed at the distal end of the anchor into a footbox with extruded left-hand thread grips. A steel cone is placed on top of the extruded grip to facilitate future strands extraction, but also to enable the HDPE individual tube to slide over the cable and thread into the footbox, forming a sealed connection that prevents the ingress of cement grout.

The anchor load is initially transferred to the footbox through an internal thread system where the extruded thread grip is connected, functioning like a typical compression anchor. Then, the load is transferred from the footbox via the compression body's rib-shaped surface to the cement grout and into the surrounding soil. The main parts of this type of anchor are shown in Figure 13.

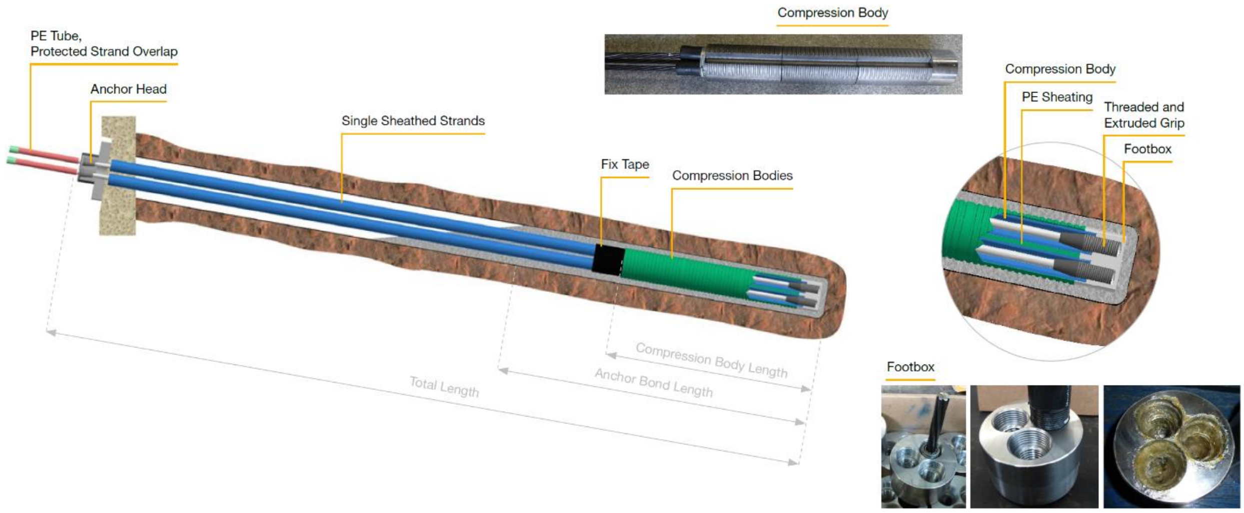

Figure 13. Set-up of DYWIDAG QuickEx anchor (Combined from DYWIDAG-Systems International, 2016 and Wörle, 2014).

All strands have the same free length as they are all connected at the distal part of the anchor. Therefore, prestressing can be done using a conventional multi-strand hydraulic jack.

Once the service life of the anchor is over, the strands can be easily removed from the ground. The first step is to unstress the strands using a multi-strand jack. Then, the unlocked wedges are removed by hand or a magnetic tool. Strands are rotated using a hand drill and a socket spanner. This rotation causes the threaded extruded grip to loosen from footbox. Once the extruded grip is completely unscrewed, the strands can be removed manually by pulling them out (Figure 14).

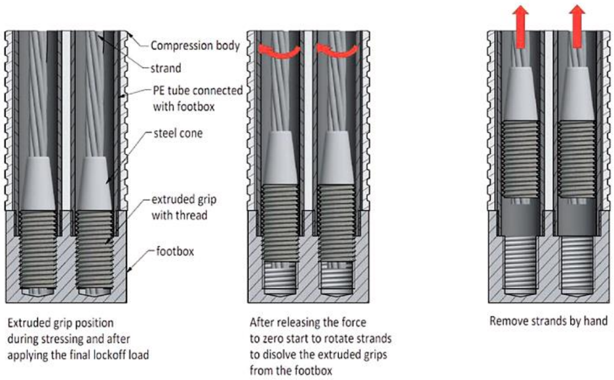

Figure 14. Anchor removal mechanism of DYWIDAG QuickEx (Wörle and Dedic, 2016).

The principal four steps of steel strands removal previously described are shown in pictures of Figure 15.

Figure 15. Anchor removal steps of DYWIDAG QuickEx: a) De-tensioning strands with light jack; b) Wedge removal with magnetized tool; c) Rotating strand with hand drill; d) Extracting strand by hand (Bogdan and Wörle, 2018).

According to technical data, the system can be manufactured up to 7 strands capacity, which can achieve a maximum design resistance of 1500 kN (15.7 mm diameter 1860 High Grade Steel).

The main advantages of this system are the easily removing of strands manually and the use of conventional stressing equipment. The possibility to remove the strands without machinery in construction sites with often restricted space shall save time and resources to the contractor.

4 CONCLUSIONS

This paper highlights the relevance of removable strand anchors in the future development of large cities. The use of these devices provides a technical solution to restrictions imposed by municipalities on the abandonment of steel strands in the subsoil of adjacent properties. Therefore, the advantages of using temporary tiebacks over horizontal struts in deep excavations are maintained and furthermore, they do not hamper future underground works.

Aiming to contextualise the virtues of different removable anchors, the internal behaviour of existing types of ground anchors has been described, identifying the particularities of each one. Conventional tension type anchors are prone to progressive debonding, which results in an inefficient use of the surrounding ground strength. Anchors whose grout body is loaded in compression have major protection against corrosion and activate a larger section of soil, so are less prone to progressive debonding. Load distributive type anchors have a uniform distribution of bond stress along their total bonded length, so that ground strength is used more efficiently and progressive debonding is avoided.

Several systems of removable anchors are currently on the market, each one with different technology and characteristics. The most efficient ones combine the geotechnical qualities of compression anchors with various methods of steel strands extraction.

In regard to their internal behaviour, SBMA temporary anchors and SW-RCD anchors apply the concept of load distribution by arranging several short bonded lengths in series. This enables them to ensure a high anchor capacity. By cons, both systems require the use of special hydraulic jacks for stressing operations. On the other hand, QuickEx anchors transfer the concentrated load to a structural element at the distal end of the anchor. This anchor system has the advantage of being installed and loaded by conventional equipment.

In terms of strands recovery mechanisms, the most outdated systems use obsolete technologies that remove the steel strands by overstressing or destroying the grout body. The most modern systems allow the steel strands to be fully removed using mechanisms. The reliability of these systems and the strands recovery success are backed up by the results obtained in international projects where they have been used. Finally, Table 2 summarises the main characteristics, as well as the pros and cons of principal current commercial systems.

Table 2. Summary of main removable anchor systems.

Anchor system	*Load transfer*	*Anchor capacity (kN)*	*Pros*	*Cons*
SBMA	Distributed load	800 – 2400	Efficient use of the surrounding soil resistance.	Time-consuming and mechanical strands extraction. Anchor loading requires jack with a multi-ram stressing arrangement.
SW-RCD anchor	Distributed load	400 – 3300	Quick and manual strands extraction. Efficient use of the surrounding soil resistance.	Anchor loading requires specific hydraulic jack (SW-Smart Jack).
DYWIDAG QuickEx	Concentrated load	200 – 1500	Quick and manual strands extraction. Anchor installation and loading with conventional equipment.	Lower anchor capacity.

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