Cofferdams Supported by Removable Temporary Anchors

by Tony Barley – Managing Director, Single Bore Multiple Anchor Ltd, Vice President, SBMALLC
Formerly Chairman of WG9 to CENT288 in preparation of European Standard
“Execution of Special Geotechnical Work – Ground Anchors” – EN1537


The UK’s Leading Microtunnelling, Pipejacking and Shaftsinking Journal

incorporating Tunnelling, Piling and Foundations, Sewer Renovation, Trenchless technology and Pipelines.
Cofferdams Supported by Removable Temporary Anchors

by Tony Barley – Managing Director, Single Bore Multiple Anchor Ltd, Vice President, SBMALLC
Formerly Chairman of WG9 to CENT288 in preparation of European Standard
“Execution of Special Geotechnical Work – Ground Anchors” – EN1537

Introduction:

It is difficult to establish at what precise depth and width a “pipe trench” simply supported by a designed strut system becomes a cofferdam in which temporary ground anchor support systems offer a direct economic saving by strut replacement or an indirect economic saving by provision of clear uninhibited working space.

On the new Central Station Project on Hong Kong Island, where the new airport rail link emerged from beneath Victoria Harbour, then over a 240m length of cofferdam with a 75m width, six levels of high capacity removable anchors provided a distinct economic and practical benefit to the Main Contractor, since the reinforced concrete tunnel therein was completed 4 months ahead of the adjacent strutted section (Photo 1).

Photo 1. Rapid progress can be seen within the anchor retained coffer dam whilst in the strutted section props greatly impede construction. (Anchors could not be installed in that section owing to the existence of insitu sheet piled wall). All steel anchor tendons were removed on completion as backfilling progressed.

Ground anchors have been used extensively for king post and sheet pile wall, and bored pile and diaphragm wall retention for almost three decades. However, research and development in specialist anchor technology over the last decade has made available temporary anchors with supplementary benefits: a reduction in cost per tonne of retention force provided by anchors in soils and weak rocks, in conjunction with the availability of a ground anchor system, which on completion allows the complete removal of the entire steel tensile member from the ground. This removal of steel from the ground has made the use of temporary anchors more acceptable to the owners of adjacent properties and highways since the remaining grout filled bore presents little in the way of an obstacle. Subsequent excavation into the area of anchor bores would not be obstructed, either would installation of services nor the execution of piling for new building foundation. This paper has been prepared with the intention of complementing the excellent “Sheet Piling and Shoring”, presented by Paul Hayward in the February 1999 issue of NATM. (Ref. 1).

Ground Anchor Capacities and Costs Per Ton retained:

The working capacities of temporary anchors founded in medium strength soils have been generally in the 300 to 600 kN range until the development of a new concept of anchor technology available from 1990. There were situations where use of special techniques, such as
underreaming or post-grouting could nominally enhance these capacities. However, the simple idea of installing a multiple of unit anchors in a single anchor borehole, with each unit anchor founded at a different depth in that bore has allowed the capacity of a simple straight-shafted anchor bore in the ground to be more than doubled. It has long been accepted that when a steel anchor bar or a multiple of anchor strands is grouted over a 10m fixed length in the borehole the entire load is initially resisted at the top of the 10m length and the distal end no load is applied. 

As the load is increased, the bond stress at the proximal (top) end becomes excessive and debonding occurs, which leads to a transfer of load further down the fixed length. It is only when pull-out failure is approached that the distal end is loaded. Thus, in a normal long fixed anchor the load transfer mechanism is very inefficient in mobilising the grout bond to the soil and in utilising the strength of the soil (Ref. 2). The same loading conditions occurs in weak rock and it is generally a consequence of the steel anchor tendons being more elastic than the grouted ground. The phenomenon is know throughout the industry as “progressive debonding” (Ref. 3) However, if, say four prestressing strands are specially grout bonded, each over a different 2.5m length, that makes up the 10m overall fixed length, and each one is plastic sheathed to prevent bond over the Non-bonded length, then the load transfer mechanism allows much more efficient use of ground strength. Over such a short bond length, the progressive debonding effect is very small or negligible, and if each strand (a “unit anchor”) is loaded simultaneously to the same load then the elimination of the progressive debonding effect allows the pull-out capacity of the 10m grouted fixed length to be doubled (Fig. 1). The test on the capacity of two identical vertical anchor bores in London Clay (1988) one with a normal tendon and the other with a multiple of unit anchors demonstrated ultimate anchor capacities of 470 kN and 980 kN respectively (Ref. 4). Furthermore, the multiple anchor system allows efficient utilisation of bond capacity and ground strength using total fixed (grouted) lengths as much as 25 metres, whilst BS.8081 (Code of Practice for Ground Anchorages) recommended that the capacity of a normal anchor does not increase adequately to justify use of fixed lengths greater than 8 to 10 metres.

Research into the behaviour and capacity of single Bore Multiple Anchors in a variety of lengths has allowed the quantification of an efficiency factor which relates the efficiency of the anchor in mobilising peak value of grout bond to the soil, to the actual fixed length (L) chosen. In mathematical terms, the efficiency factory approximates to $1.6L - 0.57$

But what this means to the industry is that the number of anchors installed to retain a cofferdam wall can now be half the number required a decade ago and as a consequence the cost of retaining the wall with ground anchors is reduced as is the period of anchor installation.
Removable Ground Anchors:

Asking an adjacent landowner of the city site if you can drill under his plot leads to a number of questions. Probably the two most important are: what is the purpose of the anchors and what is left in the ground when you’ve finished? Well, the purpose is clear in that temporary use of the adjacent owners’ ground and its strength stops the cofferdam wall falling in. But, if you are proposing to leave steel bars or pre-stressing strand cross-crossed under his property ad infinitum, then he may understandably be very reluctant to authorise this permanent ground contamination. For instance, if in the future a deep excavation for his own new basement is required, the presence of the steel component will influence the works, as it would if he elected to install piles or other services. However, if the ground disturbance was reduced to solely a grouted borehole then the remaining bores would be of little concern. Systems which allow removal of the steel tendon from the free lengths (unbonded) have been available for more than a decade, albeit the steel still remains in the fixed length. However, part of the development of the high capacity multiple anchor system has involved the utilisation of totally unbonded strand loops within the bore. A plastic coated strand of 12, 15 or 18mm diameter is pre-bent as its midpoint to internal diameter as little as 60mm. This loop, complete with a “saddle” placed with the loop is installed to the base of the anchor bore. A second looped strand is installed to a depth 3 or 4m from the base of the bore and third, fourth and fifth etc., at the progressive distances from the base. The bore is then grouted. The pair of strand ends from each loop pass through a hollow ram jack at the anchor head and are locked off with a collet to allow the strand to be loaded. Other strand heads passing through their own hollow ram jack are loaded simultaneously (Photo 2) and since all the jacks are coupled to the same hydraulic power pack, the “unit” anchor loads are always equal.

On completion of the usage of the anchors, each strand loop is destressed, the collets removed and the entire length of each unbonded loop of strand totally removed from the bore by jacking or more favourably by winching from a remote fixed point. On the HK contract, over 100 km of strand were removed from the ground (Ref. 5). The system has been successfully used in the UK (Photo 3), HK and Austria.

Photo 2. Each hollow ram jack loads the ends of each strand loop (unit anchor) and being driven by a common hydraulic power pack ensure identical load application.

Although the system is intended for temporary usage and performance is expected for less than 2 years, there are instances when works are delayed (Photo 3A) due to financial difficulties or change of intent. The looped strand system incorporates for the entire length of the tendons an inbuilt corrosion protection system in the form of grease coating and plastic sleeving. It is then inexpensive to extend the degree of corrosion protection to the anchor head components and provide an anchor appropriate for an extended lifespan.

An alternative simple but low capacity (circa 50kN working load) removable anchor system is also readily available at the other end of the spectrum. This is in the form of an auger type system in which 95% of the auger flights are not present around the auger stem. The remainder of the flight ensure that it can be “augered” into the ground and then provides a number of inclined end plates at staggered depth. These provide resistance to pull out. This system is easily back-screwed to allow removal and required no grout unless the empty bore utilised grouting on completion.

**Cofferdam Walls:**

Until the 1980’s, sheet piling and king post wall systems were the most commonly used temporary walling systems. King post may show an advantage where ground conditions are more easily penetrated by predrilling when compared with pile driving, and may be more economical when left insitu as back shutter. When cofferdam depth requirements increase bored pile and diaphragm walls are due for consideration, although if they are not to be incorporated in the structure as permanent works, they may not be cost effective. It is possible to increase the pile spacing and be more economic but only when the ground is partially self-

supporting or supplementary ground support is provided.

![Photo 3a. “Temporary” support of some cofferdams requires to be extended.](image)

The use of soil mix walling method has almost a twenty year history in Japan, albeit their usage has only come to fruition outside Japan over the last decade. The use of the H bream reinforced soil mix wall system in HK, installed to a depth of 30m and retaining a 20m excavation depth and just 40m from a 25 storey building, required absolute confidence in the system (Ref. 6).

In lieu of a structural support system retained by anchors (or struts), the use of soil nail reinforced shotcrete walling method may be considered. This has a twenty year history of use in France and Germany, whilst in the UK confidence in the system has only been generated in the last decade (Photo 4).

![Photo 4. Soil nailed face](image)
It should be noted that the soil nail system provides passive reinforcement in the soil which demands wall and soil movement to mobilise the soil nail resistance. This aspect may be the controlling factor in the potential use of the support system in normally sensitive urban areas. Furthermore, experience in design and expertise in applications of the entire system is imperative if local or overall soil failure is to be eliminated.

**Waling Systems and Anchor Load Distribution:**

In king post systems (“Berlin Wall”) the posts themselves may be directly retained by ground anchors. In this situation, the use of a pair of spaced channels as the king post is a practical solution with the maximum vertical spacing of the anchors being controlled by the bending capacity of the posts. Horizontal spacing of the posts generally varies between 2 and 3m depending on the cladding system used between the posts. In the case of the king posts being of I beam section then front walings are generally required to transfer load from the inclined anchors to the posts. When anchors are located at mid-span, the waling is subject to high bending and thus it is more appropriate to locate the anchors adjacent to the posts and place the major axis of the waling perpendicular to the anchor inclination (Photo 5). This system requires supporting gussets be welded to the face of each king post.

When sheet piles are retained by anchors, the inclined waling system, generally in the form of twin channels, is also most appropriate (Photo 6). The locating of inclined gussets (which may be fabricated from taper sections cut from a I beam) on each pile front face, serves a multiple purpose; in correcting the inclination of the anchor and waling; in providing a packer to correct for any out of alignment of the sheet piles; in resisting the vertical component of the anchor force. It is generally preferable to position the anchors through a front pile face such that the vertical component of force can be taken direct to that pile via that pile gusset.

When channel pairs are utilised as waling but placed perpendicular to the sheet pile then the gap between them must be adequate to allow passage of the inclined anchor and each channel must bear directly on the sheet pile face, or any gaps must be filled with packer plates. The geometry demands the use of long tapered gussets between anchor head plate and the waling, and a wide supporting bracket beneath the waling to resist the vertical component of anchor force (Photo 7). If the bracket is not wide and strong enough to support the outer face of the channel waling then the pair of channels must be internally spaced and reinforced to act as composite section,
otherwise the pair of channels will deform in sway. This has not been an uncommon occurrence during anchor stressing!

Whichever waling system is utilised, the maximum horizontal spacing of the anchors is controlled by the bending capacity of the waling and the maximum vertical spacing by the bending capacity of the sheet pile section.

An alternative system that allows greater horizontal spacing of anchors is the use of a reinforced concrete waling which is also self-correcting for misalignment of the pile line and by the construction of an inclined anchorhead recess or upstand adjusts for the inclination of the anchor (Photo 8). It may be necessary to weld brackets to the pile face to enhance the transfer of vertical component of anchor force from the waling to the pile.

Bored pile and soil mix walls generally favour the use of reinforced concrete walings. However, when anchor spacing is restricted to alternative pile gaps, lightly reinforced concrete blocks doweled to the pile, can be cast to transfer the anchor load direct to the adjacent piles, and the concrete block in the non-anchor gap prevents lateral pile movement and stiffens the pile wall system (Photo 9).

The reinforced concrete walings complete with cast-in steel guide ducts and the steel anchor bearing plates, when used in Hong Kong, also ensured the provision of the essential supplementary safeguards. Drill penetration of the soil mix wall encountered ground water at pressure up to 18m head. A refined control system was designed to withstand water and soil ingress due to this pressure during drilling, but in the event of similar difficulties, inundation could have been stemmed by immediate installation of an expanding packer within the preplaced waling duct. Furthermore, on completion of anchor installation, pressure grouting via a sealed temporary anchor cap, itself bolted to the waling plate was carried out to ensure that no consequential voids remained.
immediately behind the wall. The relatively heavy reinforced waling systems allowed the spacing of 2000 kN working load anchors at up to 3.0 m centres. The vertical spacing of the waling was determined from the bending capacity of the vertical universal beams installed as structural members within the soil mix.

Diaphragm walls generally incorporate horizontal reinforcement at the level of the anchors to provide an inbuilt waling/load distribution system.

Generally anchor spacing is controlled by panel width, but if the anchor capacities and most economic distribution of anchors is known in advance of the works, then the choice of panel width may be appropriately adjusted. Anchor heads and anchor guide ducts are best predesigned and incorporated in the reinforcement cage. Polystyrene taper blocks can be used to ensure provision of an inclined bearing surface for an anchor bearing plate within the wall itself. At this location, the plates can be designed in rectangular shape to reduce depths of penetration into the wall. Alternatively, the diaphragm wall reinforcement can be exposed and a reinforced concrete plinth or blister cast against the face.

**Anchor Prestressing:**

The lock-in of the full designed working load, plus a 10% overload to allow for nominal load loss has been practised successfully for approximately 30 years. It is consistent with the recommendation of BS. 8081 and has only led to problems in areas of new sheet pile quay walls where backfill between old and new walls has not been fully compacted. In those instances, load application has been adjusted to minimise rearward movement of the piles.

However, associated with the use of modern analytic methods introduced for the design of propped walls there is a preference for the application of prestress in the mid-range of the designated anchor working capacity (50 to 70%). This generally stems from the computed analysis of the staged excavation which indicates that fully prestressed anchors may become overloaded as excavation proceeds. Such prediction of 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.

The application of prestress into the soil mass and the application of load against the wall with both applied to each row of anchors at different stages of excavation induce a range of loading conditions into the soil mass and hence alters the stress level in the soil well before excavation reaches the final level. It is acknowledged that soil modulus is not only stress and strain dependant, but also varies with stress history. However, modelling of stress paths followed by soil, due to these construction activities are not generally undertaken in routine calculation and hence it is essential that a balance between the prior art and the analytic evaluation is adopted. Generally, application of higher prestress to the anchors is more favourable than potential understress since the latter load conditions some undesirable wall movement into the excavation is inevitable.

**Potential Shortfalls to be Avoided:**

The optimum inclination of ground anchors generally lie in the 20 to 35° range to ensure the encounter of soil of adequate strength within the fixed anchor. Although the intent of the anchor usage is for provision of horizontal restraint, when several rows of anchors are installed the summation of the vertical component of force can be considerably. There must be adequate toe-in of the structure to ensure
that this force component does not cause downward movement.

Photo 10. Shet pile excavation below the pile toe resulted in downward movement of the cofferam wall.

Photo 10 illustrates the effect of these vertical forces in an unusual situation where excavation proceeded below the toe of the pile. In such a situation, the provision of a ground beam is essential. The toe failure illustration (Photo 11) stemmed not from the downward anchor force but from inadequate toe depth to prevent overall rotation, fortunately this occurred after the structure was completed.

Photo 11. Toe failure resulted in classic rotation of the anchored sheet pile wall and the reinforced soil.

The construction of a king post wall requires continual control and quality performance in fitting of this soil retention panels, backfilling, compacting or concreting behind, if necessary. Photo 12 illustrates; unacceptable management of construction techniques; an appalling choice and poor fabrication of a waling system; considerable attempts at remedial measures; which all resulted in excessive street settlement and extensive service damages. Design, risk assessment, quality control, experience, compliance with Codes of Practice and HSE requirement are essential. None can be overlooked.

Summary:

The use of ground anchors to retain well-designed cofferdam walls has thirty years of proven success, only with the occasional blemish. The Code of Practice for ground anchorages demands the testing of each individual anchor to 1.25 or 1.50 times the designated working load (1.33 is the new “Eurocode”) prior to lock-off, to ensure that the performance of every anchor is demonstrated prior to acceptance in the works.

The introduction of a new anchor system with more than double the working capacity (800 to 2000kN) of normal anchors in soils and weak rocks, has provided a supplementary economic benefit in the use of the anchor systems; an advantage beyond that of the provision of open inhibited working space for construction within the cofferdam.

High load and low load capacity anchor systems now exist which allow the total removal of the steel tendon from the anchor bore and from the ground. This removal after temporary provision of safe support of the cofferdam makes the use of anchors more “environmentally friendly” and more acceptable to adjacent property owners.

Photo 12. Just plain bad practice
Information:

See www.theanchorman.com
www.sbmasytems.com

Contact tony.barley@sbmasytems.com

References:

Ref 1: Hayward, P. 1999 “Sheet Piling and Shoring” NATM February 1999


