RECENT APPLICATIONS OF THE SINGLE BORE MULTIPLE ANCHOR SYSTEM

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Abstract

The use of ground anchors to provide support to geotechnical structures has a history spanning over eight decades. Throughout this period one of the main challenges facing engineers has centred around generating enhanced anchor capacity in weak ground (i.e. soils and weak rocks). The Single Bore Multiple Anchor (SBMA) system directly addresses this challenge and is arguably one of the most significant developments within the ground anchoring industry of recent years. Research and development and successful applications on a world-wide basis has established a viable technology that can effectively double the capacity of conventional anchors in soils and weak rocks with supplementary benefits; the reduction in cost per kN of retention force.

The paper describes three recent applications of the SBMA system taken from projects where ground conditions were challenging. The three case histories have been selected to cover the full range of ground anchor applications, namely permanent anchors incorporating double corrosion protection to recognised codes of practice, temporary anchors with a specified service life of less that two years in non aggressive ground, and fully removable anchors which permit full removal of steel tendons from the ground at the end of the designed service life.
Introduction

An anchor tendon with a 8m fixed length in soil or rock, will, at test load, need to extend some 25mm at the proximal end of the fixed length before any load will be transferred to the distal end of the tendon. It is unusual for the elastic behaviour of the grouted soil around the anchor tendon to be compatible with the elasticity of the tendon and allow a uniform distribution of load along the fixed length. Thus, it is widely acknowledged that, in the majority of circumstances, debonding at the tendon/grout or the grout/ground interface must occur as anchor load increases and prior to any load being transferred to the distal end of the fixed length. This phenomenon is commonly known as progressive debonding and is associated with grossly non-uniform distribution of bond stress along the fixed length at all stages of loading. Load transfer in grouted bonded tendons and progressive debonding is a subject area that has been extensively researched and reported on in the past (e.g. Barley, 1995, Mothersille et al, 2008).

Progressive debonding generally results in a highly inefficient use of the in situ ground strength; in the load condition where the ground strength deep in the fixed length is being utilised, the ground strength above has been exceeded and only a residual strength is available there at the ground/grout interface (Figure 1). However, a system that can transfer the load simultaneously to a number of short lengths in the fixed anchor bore without the occurrence of progressive debonding, will mobilise the in-situ ground strength efficiently and result in a considerable increase in anchor capacity. This is the founding principle of the single bore multiple anchor system.

Figure 1: Principles of the SBMA System (a) progressive debonding effect on anchors; (b) SBMA system

The SBMA system

The system involves the installation of a multiple of unit anchors into a single borehole. Each unit anchor has its own individual tendon, its own unit fixed length of borehole, and is loaded with its own unit stressing jack. The loading of all the unit anchors is carried out simultaneously by a multiple of hydraulically synchronised jacks which ensures that the load in all unit anchors is always identical.
In a situation where the load transfer mechanism from tendon to grout eliminates progressive debonding, or where the unit fixed lengths are short enough to be unaffected by the progressive debonding, then in a homogenous stratum the maximum ground strength can be mobilised (by bond) uniformly and simultaneously over the entire fixed length. Furthermore, with such a system there is no theoretical limit to the total overall fixed length utilised whilst in normal anchors little or no increase in load capacity is expected with fixed lengths greater than 8 to 10m.

In the case of non-homogenous soil conditions in the fixed length, each unit fixed length can be designed for the appropriate condition. If the soil is weaker in the upper fixed length, then the proximal unit anchors will have longer unit fixed lengths than those at greater depth such that when equal load is applied to each unit anchor, each one is mobilising the same percentage of the ultimate grout/ground bond capacity or such that each failure occurs simultaneously. Albeit, if the unit anchors are founded in soil conditions with different creep characteristics, the unit fixed lengths would be designed such that each unit anchor design complies with the appropriate creep criterion in the working condition.

The SBMA system can also be designed for the encounter of soil with strength reducing with depth or with strength varying throughout the fixed length, or even for the encounter of very weak bands of soil at irregular depths. In the latter case the number of unit anchors is designed to allow for a potential failure of one or two unit anchors whilst the remaining intact unit anchors will still sustain the total anchor working load with an appropriate factor of safety.

**Permanent anchors at Hunter River, Newcastle Australia**

Ground anchors have seen widespread use in the support of waterside structures (Mothersille and Barley, 2007) since in many cases they offer economic advantages over gravity based structures. Specialist anchor contractor Menard Bachy Pty Ltd (Australia) constructed some 285No SBMAs as part of the support system associated with the Inshore Sheet Piling Works for the Hunter River Remediation Project.

The project site was located on the South Arm of the Hunter River approximately 5km north west from Newcastle. The works were located on the southern bank of the South Arm of the Hunter River to the north of Industrial Drive and Selwyn St. (Figure 2).

![Figure 2: Plan View of Project Location](image)
The geotechnical structure comprised sheet pile walls utilising SBMAs as the primary support elements. The geotechnical profile along the wall length was relatively uniform comprising four soil types: fill, silty clay, sand and clay in succession. Initial design parameters for the ultimate bond capacity of the ground/grout interface were estimated from the geotechnical parameters based on previous experience. In the Alluvial deposits comprising silty clay, 350kPa was adopted and 500kPa was adopted in the sand layers based on the effective use of end-of-casing grouting techniques.

Design working loads ranged from 521 to 874 kN and the number of unit in each SBMA varied between 3 and 4 with fixed anchors of 9 and 12m and over lengths of 29 and 32m. The boreholes were 185mm diameter and the nature of the ground required that they were fully cased during the drilling process.

**Corrosion protection**

The prestressing strand was delivered with a factory applied hot extruded double polypropylene sheath. Within this sheath the strand is grease impregnated to allow free movement of the strand during stressing. Over the unit bond length the individual strand sheaths are removed and the strand wires (7 No.) unravelled and fully degreased. The strand wires are rewound and noded at intervals along the king wire prior to being cast into a high quality cement grout contained within two concentric corrugated high density polythene ducts to form the fixed length encapsulation (Figure 3). Encapsulation grout consisted of a neat water/cement mix using Ordinary Portland Cement in a w/c ratio of 0.45. Typical strength development indicated that such mixes attained > 40N/mm² within 28 days.

**Stressing**

Each unit anchor (comprising 2 strands) had its own stressing ram (600 kN capacity) seated on a chair above the head plate. All rams were loaded simultaneously to the same load by the use of a single hydraulic power pack coupled to the ram via a manifold. Anchors were cyclically loaded in accordance with the Acceptance and Suitability Tests in accordance with BS 8081 (Figure 4).

![Figure 3](left) Double corrosion protection applied to two strand unit anchor tendons within the SBMA system

![Figure 4](right) Hydraulically synchronised stressing system applied to SBMAs supporting sheet pile walls at Hunter River.
Extensive dredging planned to be carried out in front of the wall, required that the sheet pile wall was designed to deflect during its service life and as a consequence it was anticipated that the anchors would acquire proportionate load increases during their designed service life. The nature of the SBMA system is that the whole anchor tendon is comprised of individual tendon elements which form unit anchors with different free lengths. Each unit can be stressed, tested and locked off individually. As the displacement load relationship between the head of the anchor and the bond zone is proportional to the free length, each unit require a different lock off load to account for the uniform head displacement anticipated during the service life. Following lock-off, the loads in the anchors were monitored using the 24No load cells on a monthly basis and satisfactory performance was confirmed.

**The Kuntsevo Shopping Centre**

Originally built in 1997, the Kuntsevo Shopping Centre was one of the first western-style hypermarket and shopping centres in Moscow. Due to growing market demand, the available retail space had become inadequate and the decision was made by the owners to completely demolish the building and rebuild it. In its place, a modern mixed complex comprising of office buildings and a larger retail area was planned. The geotechnical challenge was to ensure the safe and viable construction of the five-level basement floors, which required a 25m deep excavation within a heavily urbanised location. For this reason a diaphragm wall of 45m total depth was designed together with 6-levels of temporary ground anchors provided for structural support.

The unique feature of the anchor design was the high magnitude of the design load up to 600kN, which in turn required a testing load of 900kN. Based on previous knowledge on similar ground conditions in Moscow, a conventional temporary ground anchor with a fixed length of 8m, can only satisfy a maximum test load of 60 tons, permitting a working load of around 400kN. This shortfall in design load prompted the use of alternative technology and hence the implementation of the SBMA system.

The ground conditions encountered at the trial anchor locations comprised mixed soils of mainly silt interspersed with sand and clay lenses/pockets. The fixed anchor zones associated with the first four levels are located in mixed soils comprising clay with interbedded with sand, glacial sandy silt with lenses of gravel and fluvio-glacial deposits of water-saturated fine to average sands. In the lower two levels, the fixed anchor zones are founded in lower cretaceous deposits of up to 20m thick water bearing sands with clay pockets.

Boreholes were installed through a steel-reinforced concrete stressing block (2.0m x 2.0m x 0.5m deep). Drilling was completed using 145mm diameter Auger with end-of-casing air flush was performed using a diesel/hydraulic rig. The nature of the ground conditions necessitated that a 180mm OD and 160mm ID steel casing was advanced to the full depth of hole. The complete tendon comprising the three unit anchors, the primary grouting pipe, and, when required, the post grouting pipe (tube à manchette) were assembled in the field and installed through the casing so that as the drill casing was withdrawn the borehole was grouted via the primary grout pipe.

**The trial anchor programme**

The trial anchor programme comprised three phases, the objective of each phase was to assess the performance of the SBMAs using different grouting techniques in different locations of the site.

In order to gain an understanding of the ground response to post-grouting a trial was designed with the objective of establishing a range of break-out pressures for the tube à manchette (TAM) valves, refusal pressures, volume of grout take and flow rates. Such parameters are a necessary prerequisite to establishing an effective post-grouting regime in the production anchors. The 50mm TAM had ports at 300mm intervals and was pressured rated to 100bar. The grout was delivered to each port through a double inflatable packer placed at the corresponding sleeve location. The post-grouting trial comprised two post-grouting episodes which were carried out within 24 hours of primary grouting, water was applied to each port at pressures of 20 to 30 bar to
fracture the valve grout. Neat cement grout was then injected at a target volume and pressure of 20 litres per port and 10 bar, respectively. After the refusal criteria for each port were obtained, the double packer was advanced to the next sleeve in the post-grouting sequence. The secondary sleeve grouting followed the primary sleeve grouting by 24 hours.

When sandy soils or substantially non-cohesive stratum was encountered, end-of-casing grouting techniques were employed. This technique involves the application of grout through the end of the casing at pressures of typically 10-20 bars and has proven effective in creating enhancement of bond capacity by a factor of 2 (Ostermeyer and Barley, 2003). Conventional tremie grouting was also employed to compare the behaviour of the test anchor incorporating other grouting techniques.

The stressing jack arrangement for a three-unit SBMA includes three hydraulic rams that are synchronized, through a manifold, to the same hydraulic power pack, so that the same load is applied simultaneously to each unit anchor. The jacking arrangement is shown in Figure 5. All anchors were stressed after a minimum of 7 days of setting time had been given to the grout with a w/c of 0.45.

Typical test data associated with this work are presented in Figure 6 which shows the seven loading cycles generated for unit anchor in test anchor No.8. Each unit anchor achieved over 417 kN without creep providing a total of over 1250 kN. It is noteworthy that throughout all the trials the maximum test load was limited to 80% of the characteristic strength of the tendon. The preliminary results from this programme are presented by Mothersille et al. 2011.

The results, clearly demonstrated the load holding capacity that can be achieved when implementing SBMA technology. In all cases the trial anchors exceeded the proposed load requirements for the project. No load loss due to creep was encountered within a normal time period at maximum test loads limited by 80% of the characteristic strength of the tendon. The creep criteria stipulated in the Russian standard was satisfied and the excellent anchor performance is considered due to the beneficial effects of the constructional and operational features of each unit SBMA.

![Figure 5](image1.png)  ![Figure 6](image2.png)

Figure 5 (left) Trial anchor testing at Kuntsevo Shopping centre Moscow
Figure 6 (right) Typical stressing data for a unit anchor
Removable SBMA test case – Australia

The concept of the SBMA removable anchor system has been described previously (Barley et al. 2008) and has seen increased successful usage throughout the world. Until recently the system had not been applied in Australia and this brief case history describes the work of specialist anchor contractor Geotech Pty Ltd in pioneering the first application.

A series of test removable SBMA anchors were installed as temporary supports for deep excavation piles, in slightly weathered Basalt, in the North Western suburbs of Melbourne. The purpose of these test anchors was essentially to assess the performance of removable anchor system and verify removability of the strand tendon from within the borehole. The removable test anchors were installed adjacent to conventional anchors for comparison purposes. The design working of load the anchors was 200kN with and overall length of 12m.

Boreholes were drilled using the same technique for all anchors involved in this test case. Anchors were installed and grouted using a w/c ratio of 0.45 and the grout was mixed in a high shear colloidal grout mixer to ensure full strength of the mix was achieved. Based on the classical SBMA removable tendon looped system (Barley et al. 2008), Figure 7 shows the fabrication the saddle unit, location of the anchors and installation of the removable anchors.

![Figure 7: Test case for SBMA removable anchors (left) Fabrication; (middle) location; (right) installation](image)

The removable anchors were stressed using the multi-strand stressing system to ensure uniformity of the applied load to each side of the looped tendon. In accordance with Australian standards each anchor was acceptance tested to 1.5 times the design working load (DWL) and the creep monitored for a period of 30 minutes. The anchors were maintained in service for 9 months after which they were required to be decommissioned. Upon decommissioning of the temporary and removal anchors, lift-off tests were carried out on each anchor to verify anchor performance (Table 1). The results indicate that the removable anchors perform as effectively as conventional temporary anchors when exposed under the same working conditions. A 2% load loss was recorded after 9 months of service.

<table>
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<th>Table 1: Lift-Off Performance Test</th>
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<td>Lift-off Load (kN)</td>
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<td>Lift-off Load (kN)</td>
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<td>% of DWL</td>
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Each removable anchor was then distressed without damaging the strand. Once distressed, the tendons were removed by a combination of hydraulic jacking (initial stages - Figure 8) and electronic winching mobile plant (Figure 9).

![Figure 8: Hydraulic jacking of removable tendon (note extension of ram in second photo)](image)

![Figure 9: Removal of tendon using winch](image)

During the removal of the tendon, it was observed that the force required to mobilise the tendon varied between 80-90kN. Once initiated, an applied force of between 30-40kN was required to extract the tendon from the hole. Once the tendon was clear from the saddle an applied force of the order of 50kN was required to extract the tendon. The reason for this increase is due to the strand coiling effect as a result of being pulled through the saddle at the anchors distal end.

In order to minimise a whipping/springing effect of the tendon as it exited the borehole, the tendon was progressively extracted in two to three meter sections at a time and the extracted section cut with a grinder. This method ensured safety of plant operator and surrounding work environment. The lengths of extension can be adjusted to suit on site space availability and recycling constraints.
CONCLUSION

The SBMA system is well established on a world-wide basis and continues to offer a viable alternative to specialist contractors who wish to exploit greater anchoring loads in weaker ground. The paper has presented the basic principles of progressive debonding which has been corroborated by many researchers over the last 25 years. Recognition of these principles forms the basis of the SBMA design and the reason behind its proven success in the field.

The paper also presented the key features in recent projects where fully corrosion protected permanent SBMAs, temporary SBMAs and removable SBMAs have been employed. The supported structures varied from sheet and contiguous pile walls constructed in Australia to a deep 6 level deep diaphragm wall constructed in Moscow, Russia. It should be noted that the use of SBMA technology is limited to the support of deep excavations and offers tremendous potential to slope stability projects where substantially economic saving can be exploited by implementing a system that can effectively double the loads offered by conventional anchors installed in soils and weak rocks.

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References


