The performance of Single Bore Multiple Anchor trials installed in mixed Moscow soils

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Abstract

An understanding of the concept of progressive debonding and the use of this knowledge in the design efficient fixed anchor lengths has permitted the achievement of anchor capacities more than double those previously achieved in Moscow soils. The paper briefly describes the background to the well-established Single Bore Multiple Anchor (SBMA) technology and its applicability to the ground conditions encountered on a major construction site in Moscow, Russia. A series of field trials involving the use of end-of-casing grouting in sands, post-grouting in clays and conventional tremie grouting will also be described. The test programme adequately demonstrated the effectiveness of the SBMA technology in soils and created viable precedent for the type of loading that can be reasonably achieved under similar ground conditions and using the ground anchor construction techniques described.

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. This topic has been extensively researched and reported on in the past (Barley, 1995).

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 anchor soil 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 principle of the single bore multiple anchor.
Figure 1 a) Progressive debonding along a normal anchor fixed length b) Single Bore Multiple Anchor ensures simultaneous loading of a number of short unit fixed lengths in a single borehole

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.

**The Kuntsevo Shopping Centre – background**

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 Class A office buildings and a larger retail area was planned (Figure 2).

![Figure 2 Architect impression of the new Kuntsevo Shopping Centre](image)

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, an ordinary temporary ground anchor with a fixed length of 8m, can only satisfy a maximum test load of 60 tons, which in turn will allow a working load of around 400kN. This shortfall in design load prompted the use of alternative technology and hence the implementation of the SBMA.

**Ground conditions at Kuntsevo**

The ground conditions encountered at the trial anchor locations comprised mixed soils of mainly silt interspersed with sand and clay lenses/pockets.

The natural ground elevation varies between 170.00 to 174.00m above sea level. 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. This sandy stratum is underlaid by impermeable upper jurassic clay deposits, in which the diaphragm wall is socketed. The groundwater elevation varies between 164.72 and 167.10m, with two additional artesian aquifer complexes located in the fluvio-glacial and lower cretaceous sands.

**Trial SBMAs - design, fabrication and construction**

The SBMAs were designed in accordance with procedures documented in Ostermeyer and Barley (2003) which incorporates an efficiency factor to account of the non-linear distribution of bond stress that exists in the grouted tendon.

The tendons were fabricated on site ensuring that dimensions and preparation of materials were carried out in accordance with recognised standards.

The borehole was installed through a steel-reinforced concrete stressing block (2.0m x 2.0m x 0.5m deep). 145mm diameter Auger drilling with end-of-casing air flush was performed using a diesel/hydraulic rig (C8). A 180mm o.d. and 160mm i.d. steel casing was advanced to the full depth of hole. The complete tendon comprising the three unit anchors [Top (A), Middle (B), Bottom (C)], the primary grouting pipe, and the post grouting pipe (tube à manchette) were assembled in the field and installed through the casing. The drill casing was then withdrawn as the borehole was grouted via the primary grout pipe.

**The trial anchor programme**

The trial anchor programme comprised three phases, the first of which (carried out in test
location 2) is the subject of this paper. The objective of each phase was to assess the performance of the SBMAs using different grouting techniques in different locations of the site. At each location the following trials were carried out:

- **Post-grouting trial (No. 6 – test location 2)**
- 29m long 3No. unit SBMA, inclined at 15° to vertical, end-of-casing grouting (No. 7 – test location 2)
- 25m long, 3No. unit SBMA, inclined at 15° to vertical, Post-grouted (No. 8 – test location 2)
- 15m long 3No. unit SBMA, inclined at 15° to vertical, Post-grouted (No. 9 – test location 2)
- 25m long, 3No. unit SBMA, vertical, conventional tremie grouting (No. 10 – test location 2)

**Post-grouting trials**

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.

Prior to the commencement of the post-grouting trials series of small preliminary trials were undertaken to ensure that the equipment and materials were performing as intended. These comprised laying lengths of TAM pipe on the surface, inflating the double packer unit inside and injecting water through the system. On observing satisfactory behaviour, a full length TAM pipe with riser pipes was grouted into the trial hole and placed eccentrically to simulate its position when installed alongside the anchor tendon.

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 20litres per port and 10bar, 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.

**End-of-casing grouting**

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 10-20bars and has proven effective in creating enhancement of bond capacity by a factor of 2 (Ostermeyer abd Barley, 2003).
Tremie grouting

Conventional tremie grouting was also employed to compare the behaviour of the test anchor incorporating other grouting techniques.

Testing

The jack arrangement for a three-unit SBMA includes three hydraulic rams that are synchronized by coupling to the same hydraulic powerpack, so that the same load is applied simultaneously to each unit anchor. The jacking arrangement is shown in Figure 3. A primary gauge and a reference gauge were calibrated with one of the jacks. The ram extensions were recorded using a vernier calliper for each cyclic loading stage and again during creep testing. Measurements were corrected for reaction pad movement measured by dial gauges mounted on an independent reference beam.

Figure 3 Typical stressing arrangement for trial SBMAs at Kuntsevo, Moscow
Testing of SBMAs

All stressing procedures have been carried out in accordance with “Design of Arrangement & Installation of Ground Anchors VSN 506-88” issued by USSR Ministry of Assembly and Special Constructions on 1989.

Based on previous anchoring knowledge in similar materials ultimate bond stresses 175kPa were assumed in the design of the modified suitability test anchors. The term modified is used here since the trial anchor tendons were identical to the proposed production anchors but installed vertically and sub-vertically as opposed to sub-horizontally, as they are in production.

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 4 which shows the seven loading cycles generated for trial anchor No.8. Each unit anchor achieved over 417kN without creep providing a total of over 1250kN. It is noteworthy that throughout all the trials the maximum test load was limited to 80% of the characteristic strength of the tendon.

Similar anchor performance was generally observed in all the trials and showed that the type of grouting employed did not affect the load holding capacity achieved. One notable exception occurred in trial anchor No 7. This test anchor was 29m long and was constructed using end-of-casing grouting. At the end of the final load cycle the top unit generated a permanent displacement which was about 15mm more than the other units. The grouting records for end-of-casing showed a reduced grout take across the top unit. In addition, it is commonly observed that the uppermost unit tends to be more vulnerable since ground strength usually increases with depth.

Summary, conclusion and closing remarks

The concept behind SBMA technology has been summarised and typical test results from the first phase of anchor trials carried out on a major construction site in Moscow are presented. The results, whilst preliminary, clearly demonstrate the load holding capacity that can be achieved when implementing SBMA technology.

The paper briefly describes the fundamentals of Single Bore Multiple Anchor technology incorporating a variety of grouting techniques. 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 4 Test data from one of the preliminary trial SBMAs
SBMA technology is well established throughout the world and its application has been diverse in providing support for slopes, diaphragm walls and other retaining structures.

The use of effective design can in many circumstances generate substantial economic benefits and an example of this was highlighted in the SBMA project undertaken for the A2 motorway in Austria. This is one of an increasing number of schemes where our redesign deploying **specialist techniques**, not included in the original specification, reduced overall programme time and costs. SBMA Ltd designed a solution with half the number of anchors and twice the design load.

![Figure 5: SBMA slope stabilisation for the A2 Motorway in Austria](image)

**References**
