Anchor Advances

Report on BGA Meeting on advances in ground anchor technology, held at the Institution of Civil Engineers on 13 November 2002, by Peter Jewell, KBR

The main presentation was by Tony Barley, director of Single Point Multiple Anchor and Geoserve Global. He began with an update on the codes of practice for ground anchors (EN1537: 2000 and BS8081) and soil nailing (pr EN1537: 2999 and BS8081) and soil nailing. (pr EN 144490-draft) and clarified the differences between an anchored wall and a soil nailed face.

Ground anchors are essentially founded in the resistant zone (outside any potential failure plan) and retain the active zone by prestressing the wall, while soil nails tie the resistant zone to an active zone by full length bonded elements. A hybrid system that both nails and pre-stresses – “the anchor nail” is now available.

Barley highlighted the differences between corrosion protection recommendations for anchors and soil nails, but said the intent of longevity and the requirement of preliminary and on site testing was the same for both systems.

He said most anchor design formulae are relatively simple and indicate that anchor load capacity is proportional to fixed length. However, a host of researchers investigating the load distribution along a fixed anchor had concluded that at initial load the bond stress is concentrated at the proximal end of an anchor and as load increases this load concentration progressing along the fixed length.

Barley summarised work by three researchers who have modified the formulae to accommodate the progressive debonding phenomenon in anchor design. He described his own extensive investigations carried out over a decade at Keller Ground Engineering’s testing facilities.

Based on this work, he introduced an “efficiency factor” that provides a simple supplement to existing design formulae. He quantified this using a best fit curve applied to results obtained from investigating the range of ultimate bond stresses from different fixed length in the same stratum (Figure 1).

Barley’s load distribution, now in simple empirical terms, compared favourably with shapes of the Ostermayer curves presented two decades ago.

The principals of the investigatory work highlighted the efficiency of short anchors (9m to 4m) in mobilising ground strength and the inefficiency of long fixed lengths (8m to 10m). It was this simple understanding that led to the development of the single bore multiple anchor (SBMA) system in 1990. This comprises multiple unit anchors in a single anchor borehole, each unit having a short fixed length at staggered locations (Figure 2).

Both pull-out tests and use of the new design formulae approach, confirm that four unit anchors each with a 2.5m fixed length, provide typically twice the capacity of a single 10m fixed length anchor. The number of unit anchors may be increased to as many as seven, and summation of the unit fixed lengths may reach about 20m.

A SBMA test anchor founded in soil recently attained 5,0000kN capacity with a fixed length of only 14m. Barley reminded the audience that in the early days of anchoring, achieving 500kN in soil was a considerable accomplishment.

Another advance in anchor development is the totally removable anchor, where the entire prestressing strand can be withdrawn from both the free length and the fixed length. Use of temporary anchors which leave tendons in the ground has been unacceptable. Total removal is frequently specified. This prevents problems during construction of adjacent deep basements, tunnels or utility installation.

Contracts in London, Manchester, Edinburgh, Leeds, Kent, Berlin, Graz, Hong Kong, Singapore and Los Angeles
have already employed totally removable
anchors.

In one case, the system allowed up to six rows of 2,000kN temporary anchors up to 50m long – about 100km of strand – to be removed from anchor bores.

It is now possible to install permanent anchors below low water level (typically for increasing wall toe fixity) from a simple dry cofferdam. The “Limpet Dam” developed by John Martin Construction, complete with a drill mast and lighting may be set up to install and stress anchor in 15 minutes. This means divers no longer have to carry out this work – or short pile inspection and repairs – in extremely difficult conditions.

Barley emphasised the need for corrosion protection and testing to avoid failures. Examples given included an enormous 60m high anchored face and a deep quay wall. He concluded:

- Anchor designs can now accommodate the true phenomenon of progressive debonding
- Anchor systems have advanced enormously to allow ultimate loads in soils up to 5,000kN and working loads of 1,000kN to 2,500kN;
- Anchors can now be founded economically in weaker soils;
- Anchors for permanent usage are fully protected against corrosion by isolation from the environment;
- Anchors can be installed below low water level;

Anchors in Chalk

Devon Mothersille, director of Geoserve Global, discussed chalk anchors – exhumation, load transfer mechanisms and design guidelines.

He briefly described a ground anchor test programme at the site of a deep basement for the Castle Mall development in Norwich, UK. He explained that one benefit of the rigorous construction and testing requirements for ground anchors is that analysis can be carried out on the field data.

However, observations during exhumation of a tested anchor after its service life is finished are of even more value as they allow correlation with the ground conditions, construction technique, grout penetration and design. Results from the Norwich site have been used to present a novel approach to the design of fixed anchors installed in fissured chalk.

Temporary support for the contiguous bored pile perimeter wall, used to support the 18m deep excavation at Castle mall, compressed 1,120 SBMA ground anchors. Most of these were founded in the fissured chalk, typically grades IV to VI.

Mothersille made the distinction between the exhumed section of free anchor length, which is grouted with no application of grout pressure, and the exhumed section of the fixed anchor, which is grouted under pressure.

For the free anchor length, the key feature was an exhumed grout body with a relatively smooth profile showing on a print of the borehole profile on its surface. This is because without pressure the grout does not intrude into the surrounding ground.

In contrast, in the fixed anchor length, it was apparent that the pressurised grout had been forced out into voids and solution features in the rock mass, which accounted for the bulbous, irregularly shaped profile of the exhumed grout body.

Closer examination of the exhumed fixed anchor length revealed that pressure grouting increased the diameter of the grout body, typically between 30mm and 200mm, with visible evidence of grout penetrating fissures in the rock mass. Such features formed the basis of a new approach to considering the load transfer mechanism within the fixed anchor.

Mothersille said the mechanism of load transfer within the fixed anchor length was complex. Using a schematic of the fixed tendon length grouted through fissured chalk (Figure 3), he described:

- Mechanism 1, which represented failure by shearing at the grout/chalk interface.
- Mechanism 2, which represented failure by shearing across the grouted fissure.
- Mechanism 3, which represented shearing within the chalk rock mass itself.

He said that design practice would establish the capacity of the anchor by applying a bond stress over the surface area of the fixed anchor bore, assuming it to be a smooth cylinder. The study at Castle Mall sought to extend this approach by considering the contributing effects of the grouted fissures and efficiency factor theory described by Barley.

In considering how to use this in design, Mothersille explained that the fixed anchor design comprises two elements. Initially the bond stress at the grout/chalk interface is effectively applied to the non fissured area of the
borehole. Added to this is the shearing resistance offered by the fissured area of the borehole to give overall anchor capacity.

Using an example from the Castle Mall study, he showed that the non-fissured area and the fissured area represented 95% and 5% of the total borehole area respectively. Tests showed grout strength could be an order of magnitude greater than the interfacial bond stress. So despite the relatively small proportion of the total area apportioned to grouted fissures, their contribution to overall anchor capacity was significant.

Mothersille concluded that the visual examination and dimensional analysis of exhumed grout bodies allowed the proposal of a failure mechanism comprising shaft resistance and shear of grouted fissures. Further details will be found in the forthcoming technical paper.

**Anchors in weak mudstone**

Rohan Weerasinghe, another director of Geoserve Global, described a small part of a field research programme with Bradford University to investigate the behaviour of full-scale anchors in the weak to moderately weak mudstones of the Coal Measure Series. The primary object was to understand how anchors fail in weak argillaceous rocks.

He presented a typical test anchor arrangement illustrating the instrumentation system used in the field (Figure 4). He described the use of strain gauges on seven-wire strands for measuring the load distribution along the tendon, both in the free and fixed tendon lengths.

An unusual feature of the instrumentation was the use of dummy strands at the top and bottom of the fixed anchor length. These are unstressed with a nut welded on the end and are used to respond to any movement of the fixed anchor which is then measured with dial gauges at the anchor head.

The anchors were installed to a depth of 10m with a 130mm diameter, 3m long fixed anchor. Comparison was made between a conventional straight-shafted anchor and a rock under-reamed anchor. Test results indicated that the ultimate capacity of the under-reamed anchor was 45% higher.

Results from the load and bond distribution and fixed anchor displacement were illustrated (Figure 5) showing clearly that an initial displacement of the top of the fixed anchor occurred as the load transferred into it. At this early stage, no displacement of the distal end was witnessed. This differential movement between top and bottom of the fixed anchor resulted in cracking of the fixed anchor grout. Weerasinghe said this observation reinforced the need for adequate corrosion protection.

The point of maximum bond stress was clearly seen to progress along the fixed anchor and associated with this was movement of the bottom of the fixed anchor – relative displacement between top and bottom ranged between 2mm and 11mm. Up to 60mm full body movement occurred up to the point of failure.

The maximum grout-strand bond did not exceed 1,400kN/m² were generally used and that expanded cavities would not be expected to form if pressures were kept to less than 20% above overburden.

Greenwood then asked Devon Mothersille how the extent of fissures was assessed when pricing for jobs and how to satisfy the factor of safety in the code of practice.

Mothersille explained his work amounted only to a design philosophy at present, and that ideas now needed to be developed to be of benefit to the industry.

Andrew Lord of Arup Geotechnics offered an analogous observation, in the form of exhumed CFA piles at a site underlain by chalk. Open fissures in the natural ground were typically wider than 3mm but had become much tighter next
to the piles. Cement grout penetrated the chalk blocks, thereby enhancing the capacity of the piled ground as a whole.

Lord took issue with Myles’ position that soil nails and ground anchors behaved very differently. He cited pull-out tests undertaken on the North Downs Channel Tunnel Rail Link site, which suggested there was not a great different in bond strengths in chalk. Clearly the mode of construction of the anchors is critical to their performance, particularly the orientation (whether horizontal, vertical or inclined) which can dramatically affect the amount of debris left in the hole.

Barley agreed that the manner of installation was highly relevant to obtaining the actual capacity. In addition, he warned against using excessive grouting pressures leading to water/cement separation and caking of the grouted annulus.

In response to a question from Chris Sullivan of Fibreforce, Barley explained that he had not had any personal experience of the use of carbon fibre in the ground anchors, but anticipated that carbon fibre anchors would perform better than GRP anchors, for example, on account of their expected low elasticity.

Consultant George Hallowes pointed out that Lugeon tests were much used in the past, and perhaps could be a useful indicator of the extent of fissuring.

Convenor (and author of this report) Peter Jewell concluded that there was a clear message that design approaches more in keeping with actual behaviour of ground anchors can readily demonstrate why recorded capacities are often much higher than those predicted from the over-simplistic traditional design method.