A stable sector

GeoDrilling International talked to industry experts about slope stabilisation methods that employ drilling, the materials used for these installations and where the sector is heading

A drape mesh in a quarry
Photo: DSI

Slope stabilisation is often required for civil engineering projects when working on slopes, cuttings, embankments or excavations. With major infrastructure projects taking place all over the world, including many in the calendar for the UK, this market sector should continue to grow steadily in coming years.

The stabilisation solutions available to engineers include reinforced soil systems, sheet piling, soil nails, rock bolts, micropiles and ground anchors.

All methods have their advantages and disadvantages, and engineers need to take into account factors such as water cut-off, right-of-way issues, ground conditions, whether they are temporary or permanent constructs, and countless others.

"For example, it may not be possible to get a right-of-way to install anchors, so the only option might be a micropile retaining wall. If a wall is below the water table, then some type of a cut-off wall will be required. The solutions are as many in number as the problems encountered on every job," says Joe Patterson, vice-president of TEI Rock Drills.

"There are many different sizes of bars and strands, and they each require a different combination of drill rigs and tooling"

According to Dywidag-Systems International (DSI), drilled systems are by their nature more discreet than sheet piling, which typically requires heavy plant and larger working areas, and reinforced soil systems, which require a full excavation, often needing temporary support, followed by placing an imported grade fill.

The most common slope stabilisation methods used by a drilling contractor such as Albion Drilling Group (ADG) include soil nailing, rock bolting and anchoring with facings such as rock netting.

"The facing used is dependent on the steepness of the slope, with sprayed concrete, rigid mesh and stone facing as rigid solutions for steeper slopes. The main advantage of using soil nailing rather than say piling or earth solutions is usually cost and speed of installation," says Andreas Ramsauer, Albion's business development director.

Cliff stabilisation using soil nails and facing mesh at Dawlish, UK

MATERIALS AND METHODS

There are many types of equipment and materials used for soil stabilisation, but the two main construction materials for all earth-retention methods are steel and cement, explains Tom Bird of Williams Form Engineering.

The steel can be solid bars, galvanised bars, solid bars with double corrosion protection, hollow bars, strand or cable. In the US, the hollow bars and solid bars each have their own ASTM and FHWA specifications that must be met for use on projects. The cement is grout and shotcrete.

Patterson adds: "When installing permanent anchors, casing is required to drill each hole and the contractor must have different sizes of casing available for the differing capacities of the anchors. Drainage board is required to wick away water in most retaining walls.

"To summarise, there are many different sizes of bars and strands, and they each require a different combination of drill rigs and tooling. A contractor specialising in earth retention needs to have a wide variety of equipment and materials at hand."

Soil nails are solid high-tensile bars suitable for treating unstable natural soil slopes. They are usually installed centrally into pre-drilled holes and grouted into place using a separate grout line.

Barry Cunningham, project manager at Hiway GeoTechnical, explains: "The slope and installed soil nails then have concrete applied, otherwise known as shotcrete, or alternatively a flexible reinforcing mesh may be held against the soil face beneath the head plates to provide additional stability and slip resistance on the slope."

There are alternative products that can be used instead of or along with mesh that will provide extra erosion control if needed.

"The choice of soil nail depends on the ground conditions. Where the ground can be open-holed, i.e. the borehole remains open once the auger or drill string is removed, a solid GEWI-Steel threadbar can be installed and grouted via a tremie pipe. Typical ground conditions for open-holing

include well consolidated ground or cohesive soils such as clays. In loose or collapsing soils, i.e. granular soils or mixed fills, borehole collapse is likely to occur, either requiring a temporary casing, which is expensive, or a self-drilled hollow bar system," says DSI's representative.

"Self-drilled systems such as the DYWI Drill Hollow Bar enable the soil nail to be drilled into loose or collapsing soils without a casing. It combines the drilling, grouting and placement of the reinforcement in a single pass, offering increased rates of installation over drilled and placed systems. "

Slope protection mesh works in conjunction with the soil nails and bearing plates, to provide restraint to the slope face. The function of the mesh is to retain superficial instabilities between the bearing plates. As the slope re-vegetates, a root matrix is typically established, which assists with retention of the face. Slope protection meshes have developed significantly over the last 10 years from the standard Hex mesh to sophisticated chainlink meshes such as Deltax and Greenax.

Cunningham continues: "Rock bolts, as the name suggests, are used for stabilising rock excavations such as tunnels or rock cuts. They work by transferring loads from the unstable exterior to the confined and much stronger interior of the rock mass."

Rock bolts are bonded within the borehole by either grout or resin. According to DSI, the standard grout is OPC, typically mixed at 0.45w/c ratio, with a cure time of approximately seven days. Where faster curing times are required, either a thixotropic grout can be used, which has a high early strength after 24 hours, or resin cartridges, which have an even quicker setting time. Where resin cartridges are employed, the standard procedure is to power-spin the bolt through the cartridges, mixing the resin as the bolt is installed.

Ground anchors, in turn, are suited to strong rock conditions and heavier loads; they can effectively restrain retaining walls, dams, wharves, bridge abutments and foundations for buildings.

"Ground-anchored structures such as retaining walls or gabions use steel bar or strand anchors, double corrosion-protected with plastic sheaths for long-life critical structures, reinforced concrete walls or sheet piles," say BAM Ritchies' David Gibson and Owen Francis.

Slope stabilisation methods

BAM Ritchies lists the common techniques and their benefits:

- Soil nailing – flexible solution, relatively cheap, adaptable, can be greened, does not require heavy plant;
- Ground-anchored structures such as retaining walls or gabions – active support, good where space is limited, design life of up to 120 years;
- King post walls – only requires access to toe, does not need lateral space possibly infringing third-party land;
- Contiguous piled walls – high strength, low maintenance;
- Other piled walls – high strength, low maintenance; and
- Combinations of the above such as anchored piled (including sheet-piled) walls.

A Williams 76mm hollow bar with 133mm bit

Ground anchors feature a free length, which can be pre-stressed to provide active restraint against service loadings. They are often heavily loaded and can be installed in depths up to 30m and more.

DSI expounds: "Drilling systems for all of the above installations vary in accordance with the application. For soil nailing, where there is a large quantity of soil nails at different heights on the face, excavator-mounted drill booms are the most efficient drilling system. The excavator is highly versatile with a reach over a large area of the soil-nailed face.

"On deeper cuttings, long- ►

M23 Gatwick Spur

The Balfour Beatty Mott Macdonald JV awarded BAM Ritchies with the geotechnical works at the abutment of M23 Gatwick Spur located between Junction 9 and 9a in the UK. The purpose of the works was to stabilise the south face of the embankment with soil nails and erosion matting. The project's client was the Highways Agency.

BAM Ritchies installed 850 5m-long, 150mm-diameter R32-250 bar soil nails, and subsequently placed 1,500m² of Greenax slope protection mesh.

Soil-nail installation works were carried out by two drilling rigs positioned at the toe of the embankment. The rigs consisted of long-reach excavators (Cat 330) fitted with in-house fabricated lightweight drilling masts assisted with a Colmono 4/10 grout plant providing grout flush. Using long-reach excavators eliminated the need to backfill a trench adjacent to the works. This offered savings to the client's budget and meant that the busy stretch of M23 motorway was kept free of road works.

Following initial soil-nail installation, five random nails underwent successful acceptance stress testing.

The Greenax mesh was laid on soil-nailed embankment and secured with galvanised 250x250x8mm head plates.

Upper: emergency stabilisation works at Hooley railway cutting, UK
Lower: traditional soldier pile and lagging earth retention

reach excavators are often employed, as they are able to position the drill boom to each different nail position with ease, with little disruption to rail lines at the base of the cutting."

According to DSI, rock-bolt drilling systems are often dictated by access, with winch-anchored A-frame drill rigs used on steeper rock faces. Rope-access drilling with A-frame or Dachs-frame rigs offers drilling access in extreme conditions such as cliff faces or steep slopes. Both rotary percussive and down-the-hole-hammer (DTH) drilling can be employed, depending on the borehole diameter and the hardness of the rock. In harder rock DTH will always be the most efficient.

Ground anchors require more powerful drilling equipment as the boreholes are deeper and larger in diameter, compared with soil nails or rock bolts, so torque demands and pull-back loads are greater, requiring the power of a crawler-mounted drill rig.

SITE REQUIREMENTS

Every slope or site that requires stabilisation is different and numerous factors need to be considered, including purpose, design, life, durability, ground conditions, access (for both construction and maintenance), restrictions, health and safety, environment, ecology, third parties, traffic, services, costs, budgets, working time, weather, climate change, location, vegetation, drainage; the list goes on.

"Detailed geotechnical evaluations help to identify critical stability conditions and potential sliding mechanisms unique to each site. This enables our geotechnical team to provide solutions for both emergency repairs and long-term solutions," says Cunningham.

Naturally, every project has its own set of criteria that will determine the design, materials and installation methods that need to be used. "In some cases, multiple methods need to be employed in order to achieve the best solution," confirms Allen Cadden of Schnabel Engineering.

As expected, the most cost-efficient option is often chosen. Bob Slyh, president and owner of Northwest Soil Stabilization, comments: "Hollow-bar soil nails (HBSN) and shotcrete are the least expensive by 60% over soldier pile and tie-backs. And HBSN are quick to install and require less equipment and labour than cased tie-backs. But HBSN are not used for permanent anchors and they are not accepted for use by all engineering firms."

Whatever the installation method, corrosion protection is an important part of the slope stabilisation solution. "Soil nails and rock bolts are classified as lightly loaded passive installations, therefore a lower level of corrosion protection is typically applied, such as sacrificial corrosion allowance with supplementary galvanising," DSI explains.

"For tension piles, it is important to define the level of load, with sacrificial corrosion allowance typically suitable for lightly loaded tension piles. Heavier-loaded tension piles by their nature carry greater risk, therefore clients are more inclined to specify double corrosion protection. Ground anchors are pre-stressed installations, often heavily loaded, which are required by both British and European Standards to have double corrosion protection."

A long-reach excavator for drilling in cuttings
Photo: DSI

FUTURE

Looking at the future development of slope stabilisation, sonic drilling emerges as one possible installation method; as the sonic market continues to mature and expand into more common use around the world, the method will continue to grow in popularity.

Cadden thinks that better skills in modelling ground-improvement elements with soil conditions will also contribute to improvements in construction methods for soil stabilisation. And new software modelling and better ground sensors will help to improve people's knowledge of soil stabilisation overall.

Furthermore, different takes on grout injection during and after drilling continue to bring new products to the market, including high-pressure nozzles for hollow bars, larger grout plants and grout additives.

"But the one thing that everyone has agreed on is the increased use of hollow bars for soil nails and micropiles. The ease and quickness of installation has made this the preferred method for speed and cost. As more studies and tests are performed with hollow bars, the engineering community will have the information they need to increase the use of this simple method," says Patterson.

According to Gibson and Francis, electrokinetic methods ►

"The one thing everyone has agreed on is the increased use of hollow bars for soil nails and micropiles"

Rocks Road

Heavy rain and erosion resulted in major slope failure near the coast line above Rocks Road in Nelson, New Zealand, disrupting the flow of traffic in and out of the main centre and posing a potential safety threat to the houses above and the public below.

Hiway Geotechnical was provided with an engineered design that included the use of rock bolts ranging from 8m to 12m and drainage holes up to 20m. This was then covered by high-tensile galvanised steel mesh, which was carefully moulded by the contractors to fit the contour of the slope. This was then shotcreted to provide additional erosion protection.

Work was carried over a 3-month period on multiple sites. Due to access restrictions, work was carried out via rope access, cranes, hiabs and elevated work platforms. It was also necessary to work night shifts to minimise the disruption to the public and to ensure that the work was completed as per the schedule.

Photo: DSI

Centre: soil nails used for a railway-widening project

Right: drill mast fitted onto a long-reach excavator installing soil nails on a slope stabilisation project in Donside, Scotland

have been trialled and can be advantageous in the right ground conditions. Willow sticks have also been tested but have not found widespread use, while research is under way into other forms of vegetation-stabilised slopes.

Development of existing methods and materials will naturally carry on, and the use of building information modelling in the design, installation, monitoring and maintenance processes will continue to advance. Overall, better developed and improved standards will promote more cost-effective designs and installations.

West Substation

A project currently being undertaken by ADG is the St Helier West substation in Jersey, UK, where a temporary excavation up to 18m deep and formed at 60° to the horizontal is being supported by soil nails between 7m and 8m long with rock netting on the face.

This is a top-down excavation and undertaken in lifts to minimise the risk of short-term instability. As soon as the face is exposed, ADG installs the soil nails and covers the face with a geotextile and netting.

The excavation is into an area of steep sloping ground, thus making a piling solution difficult due to access for the piling machinery and also the cost involved.

Soil nailing was chosen by the client as the best solution on this particular site. In addition, the permanent works will comprise a Reinforced Earth Company segmental wall that will be tied back to the soil nails. So not only do the soil nails act as temporary works, they form part of the permanent structure.

The ground conditions comprise ash fill to a former quarry, with the natural soil on the former quarry flanks consisting of clayey sandy silt and weathered andesite bedrock lower in the slope. ADG is using a combination of R32 and R38 hollow-bar soil nails galvanised, being drilled in with a rotary-percussive drill TEI mast and a 13t excavator. The project is proceeding as planned.