A multi-functional approach to slope stabilisation

SUPPORT Trials in the UK have confirmed that electrokinetic geosynthetics can be used to stabilise embankment and cutting slopes, addressing underlying causes such as weak soils and poor drainage as well as providing physical reinforcement.

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Over the past few years, a growing number of high-profile collapses of embankments or cutting slopes have disrupted rail operations in different parts of the UK. As with many railways, the network includes hundreds of kilometres of cutting or embankment where the earthworks involve slopes cut in or constructed using clay-rich soil. Railway performance is closely linked to the condition of these soil slopes, which deteriorate through a range of processes including deep or shallow slip failures.

Slope failures can be triggered by a variety of factors including weakening of the soil, changes in pore water pressures, slope geometry, hydrology and groundwater, or even seasonal climatic variations. Changes to rainfall patterns as a result of climate change may well exacerbate stability problems in the coming years.

When maintaining embankment or cutting slopes, the primary objective is to identify potential weakness and return the earthworks to full stability before any failure occurs. If a collapse has already occurred, the ideal solution would be to stabilise the failed material and thus reduce the need to import large quantities of new material during the repair process.

As most failures are caused by a reduction in strength or poor drainage, the best remedial method would be to reduce pore water pressures and provide additional drainage, thus increasing the shear strength of the material forming the slope. One way to achieve this is a multi-component treatment system using electrokinetic geosynthetics.

Electrokinetic geosynthetics

Conventional geosynthetics are now widely used in the construction and maintenance of new transport infrastructure. Typical applications include reinforcement, separation, filtration and drainage. However, in these applications the materials play a passive role; for example geosynthetic reinforcement provides tensile resistance, but only after an initial strain has occurred. Or the drains provide a passage for water but do not cause the water to flow towards the drain.

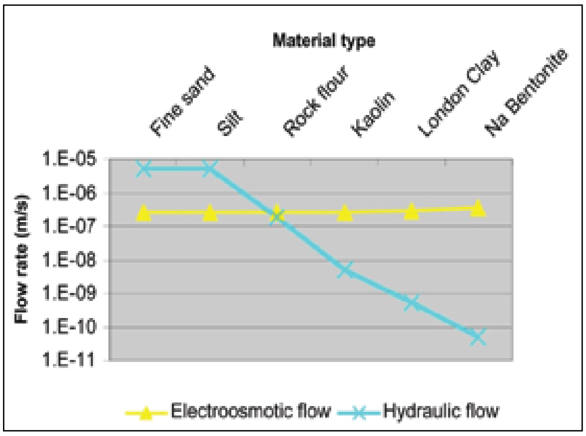
The scope of geosynthetic applications can be extended if the materials can provide an active role, initiating chemical or physical change to the matrix in which they are installed as well as providing the established passive functions. This can be achieved by combining electrokinetic phenomena with the traditional geosynthetic techniques.

EKG works by harnessing electro-osmosis, the water flow that occurs in response to an imposed voltage gradient. In fine-grained soils electro-osmosis can achieve flow rates up to four orders of magnitude greater than hydraulic flow (Fig 1). EKG also provides a means to control the physical, chemical and electrical boundary conditions.

Some pioneering work on the use of electro-osmosis in civil engineering was undertaken by Leo Casagrande in 1939, but despite the potential advantages, the lack of control over boundary conditions held back implementation for many years.

Fig 2 shows the active processes in a section of clay-rich soil during electrokinetic treatment. An applied voltage gradient creates an electro-osmotic flow from the anode to the cathode. By draining the cathode

Fig 1. Comparison of electro-osmotic and hydraulic flow rates under typical gradients.



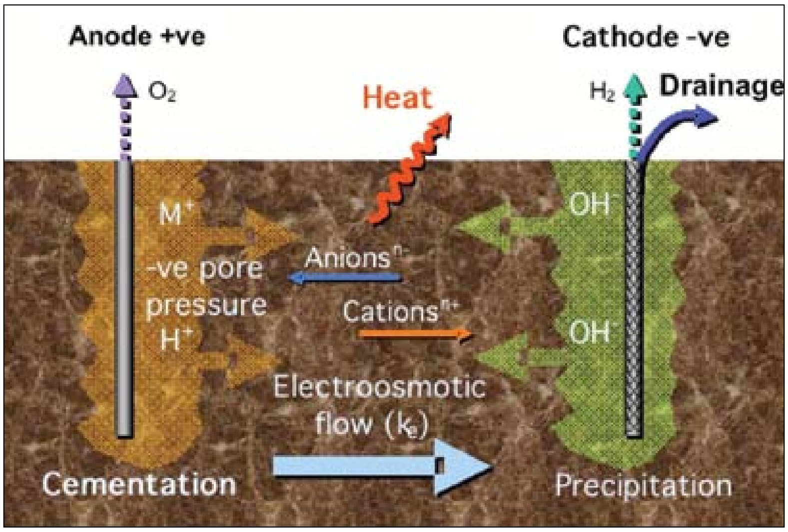


Fig 2. Summary of the relevant processes during electrokinetic ground treatment.

and preventing water ingress at the anode, this creates a major reduction in pore water pressure. The result is the consolidation of soft, weak materials, an improvement in strength and a reduction in the shrink/swell characteristics.

In addition, the soil around the anodes becomes cemented due to electro-chemical changes, which can be enhanced or controlled by selecting the structure and composition of the anode material. The use of conditioning fluids promotes cation exchange reactions, and further cementation reactions take place throughout the soil mass in a process known as 'modification'.

The effects of modification, cementation and precipitation will cause a reduction in the plasticity and an increase in cohesion of the soil. The bond strength between the anode and the soil is increased significantly, which is beneficial as the anodes are left in place as permanent soil nails following the electrokinetic treatment. In this way EKG acts as a multi-component system, both improving the strength of the soil and providing key components of conventional slope treatments such as reinforcement with soil nails and installing horizontal drains. Modification is particularly applicable to highly-plastic clays, but it is not a requirement for EKG slope stabilisation.

EKG treatment is based around a cellular array of electrodes which can be manipulated to accommodate obstacles such as trees. Combined with small and nimble installation, this means that the preservation of trees and topsoil can be maximised and the local environmental impact minimised.

Practical implementation

The use of EKG to strengthen and repair embankments and cuttings offers technical, economic, environmental and operational benefits, which were demonstrated in a recent pilot project with Network Rail on a section of London Clay embankment at Greenford, to the northwest of the capital.

Built in the middle of the 19th century, this 9 m high embankment had a history of gradual slope movement. A 22 m long section was treated with EKG, having been fitted with an inclinometer to monitor the slope movement before, during and after active treatment.

The electrodes were installed using a small slope-climbing drilling rig, which required minimal effort to gain access to the site and caused little disturbance. The electrodes were installed over a two week period, and the active treatment then ran for six weeks. Installation and connection required only two people to be on the embankment at any given time, and no-one was needed on site during the active treatment.

Data collected during the project showed an increase in the soil strength, the development of strong bonds with the EKG reinforcement, significant volumes of water forced out of the slope and the cessation of slope movement. Track-level measurements showed that there was no track deformation caused by the EKG treatment.

Costs and benefits

An analysis comparing the costs of slope stabilisation using EKG against the lowest-cost alternative of gabion baskets and slope reduction indicated potential savings of 26%. This was based on comparing cost data for a 40 m long section of embankment which was repaired by slope slackening with an extrapolation of the 22 m long EKG trial section.

Much of the cost saving comes from the major reductions in labour and avoidance of the need to move large quantities of earthworks or structural materials — particularly primary aggregates. Both of these aspects involve

Installation of the electrodes was undertaken with a slope-climbing drilling rig which posed minimal access problems.

Once the electrodes had been installed, the electro-kinetic remediation process took place over six weeks with no staff on site.

complex problems of site access, such as providing welfare facilities for large numbers of workers, and physical access for large items of plant as well as storage areas for materials being brought to the site. By contrast, EKG is relatively 'light touch' in terms of its small plant, requiring minimal vegetation clearance and reducing the need for material movements.

Similarly, the comparison found that the carbon footprint of EKG was little more than half of that for conventional treatment. Total emissions in terms of CO_2 equivalent for the EKG method were calculated at 19·4 tonnes, arising mainly from the fuel for the generator used to power the DC supply and the materials used in the electrodes and wiring. For the purpose of these calculations, the wiring was conservatively assumed to be used for just the one project.

By contrast, the total CO_2 footprint for conventional treatment was calculated to be 35·8 tonnes, arising mainly from the fill materials, construction plant and steel for the gabion baskets. The increased labour, including transport and welfare facilities accounted for a further increase in carbon emissions. We estimate that the 47% saving could be raised to 54% by increasing the efficiency of the generator.

From our initial trial, we believe that EKG treatment provides an effective multi-functional method for slope stabilisation at reduced cost, thanks to the lower labour required and associated reduction in health and safety risks. The small equipment simplifies access to the site, allowing rapid deployment when necessary. Treatment can proceed whilst the railway remains in full operation, as happened during the trial. And following the treatment the filtration and drainage functions used during EKG will provide better long-term drainage of the slope in the passive mode.

EKG has now been selected as the preferred design for remediation of four embankments and one cutting on both road and rail networks.

For more information about the technology and applications visit **www.electrokinetic.co.uk**