Controlling swelling in lime-stabilised sulfate-bearing soils using fly ash

Michael J McCarthy, Laszlo J Csetenyi, Anisha Sachdeva, Ravindra K Dhir, Division of Civil Engineering, University of Dundee

Lime stabilisation is an effective method of transforming non-conforming clay soils so that they are suitable for construction [1, 2]. In general, quicklime is spread over the application area, rotated in to the required depth, and then allowed to mellow prior to compaction (Figure 1).

The processes occurring between lime and clay minerals in the soil, in the presence of moisture, lead to several effects, including reduced plasticity, improved workability and enhanced engineering properties of the treated material [3, 4]. Further benefits can be achieved with the addition of fly ash or ground granulated blastfurnace slag (GGBS) by repeat-spreading and rotating before compaction (two-stage operation) [5]. Stabilisation methods, in avoiding the need for soil replacement, also offer several environmental and economic advantages [5].

Sulfate expansion and the role of fly ash in its control
Sulfate-containing clay soils are known to cause swelling with the application of lime, due to the formation of expansive compounds. Indeed, the reaction with such clays, in part, generates calcium-aluminium-sulfurhydrates (eg ettringite) in wet conditions, which can exhibit up to a 2.5-fold expansion and can lead to the disruption of supported structures [6, 7]. Previous work with fly ash indicates that the material gives enhanced performance to concrete and grout with respect to sulfate-related damage [8, 9].

Given its siliceous chemistry, fly ash may also be expected to combine with lime and thus limit the processes leading to swelling in stabilised soils, which has been found with the use of GGBS in the application [10, 11].

Preliminary tests
Laboratory tests were carried out to examine the potential of fly ash to limit swelling. Artificial soil samples with a 4:1 sand/montmorillonite ratio and 2% added sulfate (in the form of gypsum), were combined with 6% hydrated lime and 3%, 6%, 9% and 12% fly ash or 3%, 6% and 9% GGBS. Cylindrical specimens (40mm diameter x 40mm length) with a 4:1 solids/moisture ratio were compacted under a fixed load and immersed in water at room temperature until their linear expansion (monitored daily) levelled off.

Most changes occurred within 10-11 days with fly ash and 5-6 days with GGBS. The results showed that fly ash-treated soil gave similarly reduced expansion to that with GGBS, compared to the lime-stabilised artificial soil control (Figure 2) and, in general, greater levels of these materials increased this effect.

Experimental programme
Given the encouraging results from the preliminary tests, a research programme was formulated to examine the performance of relevant UK clay soils with a typical quicklime and a range of UK fly ashes (see Table 1). Various mix combinations and other construction-related issues, including the effect of mellowing period (0, 1 and 3 days), have been considered.

The performance of the stabilised soils has been assessed primarily by their volumetric swelling capacity and unconfined compressive strength. Additional tests have been carried out on a selective range of best-performing combinations to examine other relevant properties, including tensile strength, permeability and frost heave. The programme of work is summarised in Figure 3.

Initial swelling results
Specimens were prepared in accordance with BS EN 13286-53 [14] with a composition of 6% Ca(OH)2, and 9% fly ash (10% retention on a 45µm sieve, 6% loss-on-ignition). The range of clays considered for this comparison...
After one day of fog room storage, the specimens were immersed in a water bath at room temperature to determine their linear expansion. The results at seven and 14 days are shown in Figure 4.

Depending on mineralogy and sulfate levels in the clay, the observed expansions varied. The general trend was an increase in swelling with sulfate level, with Oxford and Kimmeridge clays giving greater expansions than those of London or Lias. In addition, swelling of stabilised Oxford clay continued after seven days.

An important observation was that the addition of fly ash to the mixes consistently reduced swelling. An example of the effect of fly ash (53.9% retention on a 45µm sieve, 11.2% loss-on-ignition), applied at different levels to one of the clays with 3% CaO and adjusted for OMC, tested using the BS EN13286-49 [15] volumetric swelling method is shown in Figure 5. As indicated, relatively high levels of fly ash – between 12% and 18% – were required to reduce volumetric swelling to the generally accepted <5%.

The benefits of fly ash have also been noted from the visual condition of specimens after seven days (Figure 6). For other clays and fly ashes, different quantities may be
necessary to reduce swelling to acceptable levels and this is being examined.

Given that the pozzolanic reactivity of fly ash is influenced by temperature, work has also been carried out under non-standard temperatures (~10°C, to more closely reflect UK field conditions) and generally showed similar trends for swelling to those noted above.

The mechanisms involved, therefore, appear to be mainly physical and tests replacing fly ash with inert filler material of similar particle size distribution are in progress to investigate this.

Concluding remarks
The following points have been noted from the research to date:

Swelling potential of clays appears to depend on both mineralogy and sulfate content;

- The effectiveness of fly ash in reducing swelling is also influenced by clay type;
- Fly ash reduces swelling of lime-stabilised clay soils, with increasing levels and coarser materials producing better results.
- Investigation of the full array of clay, lime and fly ash combinations will be reported in due course.

Acknowledgement
Funding from EPSRC (EP/PS01989-1) and the Dorothy Hodgkin Postgraduate Awards scheme as well as financial and technical support received from industrial partners, including Aggregate Industries UK, British Lime Association, Castle Cement, Hargreaves (GB), Highways Agency, and the UK Quality Ash Association is gratefully acknowledged.

References