25 Years from Carsington.

June 1984 and the Carsington Reservoir upstream dam wall failed. Fortunately the reservoir was not yet complete and filled with water otherwise this article might have been a little more sombre. The wall was 37m wide and some 500m or so long and it was progressively slipping but why?

As the dam wall was exerting pressure upon the underlying strata (it was founded upon 'yellow clay') a natural process of settlement would have occurred especially as the site was underlain by the soft Edale Shale Group (Aitkenhead, 2001). The succession includes interbedded sandstones and siltstones with subordinate ironstones and impure limestones, a bed of chert like siltstone, associated volcanic laminae and marine bands (containing bivalves and goniatites) (Potts *et al*, 1990; Aitkenhead, 2001). Surficial mudstones were particularly weathered to a pale brown clay that had been mobilised by solifluction to produce a head deposit of approximately 1m thick ('yellow clay') (Potts *et al*, 1990). This clay was also used as the core (Aitkenhead, 2001).

The yellow clay was left in place beneath the embankment primarily due to the fact that it was not identified in the site investigation reports as a plastic head deposit (Aitkenhead, 2001). The clay was shown to have weak clay minerals associated incorporated in its matrix. The valley in the region has been highly weathered by Devensian periglacial conditions (Potts *et al*, 1990; Aitkenhead, 2001). Moreover the shaly mudstones contained a significant amount of pyrite. The subsequent oxidation of the sulphide to sulphate and an expansive reaction with limestones produced gypsum and carbon dioxide (Aitkenhead, 2001).

Production of crystalline gypsum is perhaps the most significant of the mechanisms giving rise to 'classic' heave within pyritic shales. Basically, oxidation of pyrites (iron sulphide) in the presence of moisture, produces sulphuric acid which, in turn, reacts with a source of calcium (calcite within shale, naturally occurring limestone for example), producing calcium sulphate solution that crystallises out, ultimately, as gypsum. The corresponding volume increase arising from formation of crystalline gypsum within the laminar structure of shales exerts a considerable expansive force with the corresponding effects of heave and movement as the layers of shale are literally driven apart. Other factors resulting in volume increase due to oxidation of pyrites include the conversion of pyrite to ferric sulphate (calculated increase in the region of 170%) and production of jarosite - hydrous iron potassium sulphate, a typical weathering product of pyrite and a basic indicator of pyritic oxidation (calculated increase of around 115%). The action of acid/acidic conditions on carbonate strata produces carbon dioxide; at Carsington, the conditions and pre-requisites for pyrItic heave and liberation of CO_2 were in existence but the implications and potential consequences not sufficiently identified prior to construction. In practice, the rate of gas production and levels were so high that this, sadly, led to the death of 4 people by asphyxiation within an inspection chamber.

All in all the initial site investigation and embankment design proved to be inadequate and the geology, physical stresses from oversized embankment angles and the geochemistry of the area resulted in the failure of a significant structure, of which the consequences could have been significantly greater. Before rebuilding the dam the head deposit was removed, as were the reactive limestone layers (Aitkenhead, 2001). The final cost of the dam added several tens of millions of pounds to the final cost, not to mention the time delay.

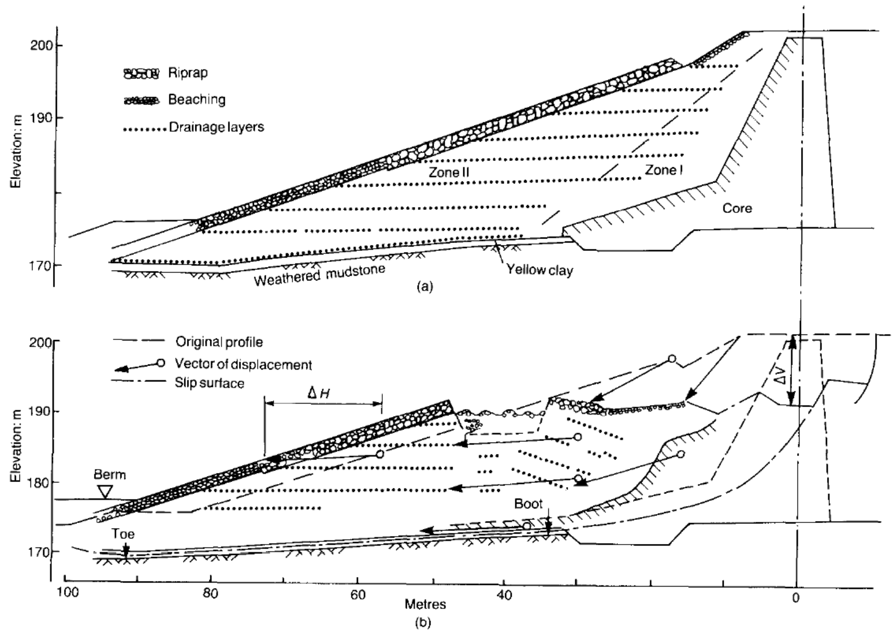

Figure 1. a) pre failure b) post failure sketches from Skempton and Coats (1985)

This underlies the need for meticulous site and material investigation and how this may prevent consequences with regard to time delays and financial restrictions. More importantly it highlights the fact that lives are put at significant risk if site investigations and conceptual models are not developed and fully understood.

The design of the final build was changed and the boot core was replaced with a wedge core and the angles of Zone I and II slopes were reduced so as to reduce the stresses imparted upon the core. Furthermore the underlying head stratum was removed (Aitkenhead, 2001).

This unfortunate case is also an example of a number of weathering processes and expansive reactions combining to force a geotechnical failure which fortunately did not result in a major catastrophe.

So 25 years on I enjoy a walk around the man-made lake but such a project that still has a small black cloud over it – even on the sunniest of days we must remember how an inadequate investigation or design can significantly affect people's lives, not to mention their families.

Reference material and further reading:

Aitkenhead, N. (2001) *Carsington and Harboro'* Journal of the East Midlands Geological Society Nottingham: Norman Printing

Potts, D.M., Dounias, G.T. and Vaughan, P.R. (1990) *Finite Element Analysis of Progressive Failure of Carsington Embankment*. Geotechnique 40 No 1 pp79-101

Skempton A.W. and Coats, D.J. (1985) *Carsington Dam Failure* Failures in Earthworks pp203-220 London: Institute of Civil Engineers