An introduction to earthworks in Europe

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Earthworks encompasses a range of engineering activities that goes well beyond the conventional digging out of soil and rock and movement of the material to another part of a site. Although these activities may be amongst the most fundamental of civil engineering construction activities, and take place whenever and wherever a development takes place, earthworks also include embankment dams, foundations (especially those for linear infrastructure) such as capping layers for road construction, structural fill for retaining walls, and for reinforced and anchored soil and earth. Conventional cut and fill operations are often somewhat disparagingly known in the UK as 'muckshift', the processes of excavation to form temporary and permanent cuttings and trenches, controlled placement of material for structural backfill, creation of embankments including earth and rockfill dams, and preparation of foundations for all forms of structure is a highly skilled geotechnical design practice. To undertake this work safely and economically requires an evaluation of the engineering geology of the site where the works are to take place, accurate descriptions of the nature and properties of the materials involved, detailed material specifications, assessment of earthwork quantities, settlement calculations for structures and foundations, analysis of short and long term slope and foundation stability, and the design of appropriate construction practices. The methods for excavating materials must be determined, the short and long term stability of excavations must be evaluated, and the suitability of any materials to be used in construction needs to be established. During any fill placement monitoring is necessary to ensure the materials meet specification and which may define pre-determined methods. It is also necessary to ensure that post-compaction properties meet performance specification, rates and amounts of settlement fall within expected limits, and that the foundations and side slopes of all structures meet design requirements.

Once construction is finished the long term behaviour of excavations (i.e. cuttings) and structures (embankments, backfill, reinforced earth, etc.) requires inspection and, in some instances, monitoring for signs of distress to ensure remedial measures can be designed and implemented should failures occur. Given that the largest embankment in the world is presently the Nurek Dam in Tajikistan at over 300 m in height and 730 m long holding back over 10 km^3 of water (Stephens 1976; Ghasimi 1994), the critical importance of safe design, construction and long term monitoring is readily apparent. However, large scale earthworks do fail and examples of embankment dam failures are to be found in many countries, including the USA. (e.g. Hebgen Dam in Montana in 1959; Sherard 1959) and the UK (e.g. Carsington Dam in Derbyshire in 1984; Skempton & Vaughan 1993). Similarly a study of the M1 motorway earthworks in Bedfordshire in England identified a considerable acceleration in the rate of failure of cuttings and embankments on the heavily overconsolidated Gault Clay after a period of about 15 years (Andrews 1990; Perry 1995). Indeed, in England assessing the probability of failure is seen as part of the maintenance of highway earthworks as geotechnical assets (Highways Agency 2003, 2008).

There are many large earth and rockfill embankment dams; however, a substantial proportion of earthworks around the world are either associated with the construction of transport infrastructure or loose tipped waste (non-engineered fill). At the 2nd International Seminar on Earthworks in Europe that took place in the London in 2009, the main focus of the meeting was the design and construction of cuttings and engineered fill for transport infrastructure. This is reflected in the papers compiled for this present volume as outlined below.

Earthworks associated with transport infrastructure are essentially linear in nature, comprising cuttings and embankments, and are either built from the arisings from adjacent cuttings or, in certain circumstances, specially imported materials. Soil and rock from cuttings are used directly on site (reused), used after treatment (recycled) or transported off-site as waste (potentially a costly process) for either recovery or disposal. This activity has occurred since prehistoric times when the first earthworks were built as defensive ditches and ramparts around settlements, drainage

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ditches and the first roadways. Such pre-historic activities are found throughout the world, such the Pre-Columbian earthworks discovered in western Amazonia (Pärssinen, *et al.* 2009), with canals being dated to 4000 BC in Iran and earth dams at 3200 BC in Jordan (McFarlan 1989). With the industrial revolution there was a need for cuttings to remain stable in the long term and for embankments to carry the heavy loads associated firstly with waterways, then railways, and, in the 20th century, highways. These long linear combinations of cuttings and embankments are structures that require a far more sophisticated approach to design and construction (e.g. see Ekins *et al.* 1993; Perry 1995; Vaughan *et al.* 2004) and form a substantial component of the construction, associated construction duration, and cost of modern transport infrastructure. The papers in this volume provide an insight into the development of modern earthworks construction practice, mainly in the context of highways. These studies build upon previous notable conferences and symposia on the subject that in the UK include Clays Fills (Institution of Civil Engineers 1979), Failures in Earthworks (Institution of Civil Engineers 1985), Compaction Technology (Institution of Civil Engineers 1988) and Engineered Fills (Clarke *et al.* 1993).

The critical importance of the safe construction of earthworks is recognized globally by a series of important publications (e.g. U.S. Bureau of Reclamation 1974; Geotechnical Engineering Office 1984; Canadian Geotechnical Society 1985; Horner 1988; Geotechnical Control Office 1990; Halcrow 1994; Trenter 2001). In the UK this importance was demonstrated by the production of the Code of Practice for Earthworks CP2003 in 1959 (BSI 1959). This was revised in 1981 as BS6031 (BSI 1981) and then again in 2009 (BSI 2009) when it was incorporated in Eurocode 7 (BSI 1997; Simpson & Driscoll 1998). The history and development of BS6031 is reviewed by **Lamont** whilst **Harris** assesses the design of stable earthworks according to the requirements of Eurocode 7. Design and construction practice for major highways in the UK is controlled by the *Design Manual for Roads and Bridges* (DMRB 1994; see also Department for Transport 2012). Advice Note HA70/94 established that highway embankments can be built according to a method specification (defined material placed and compacted in a standard way) or an end-product specification (testing of the completed embankment to ensure it meets design requirements). **Perry** examines the management and contractual risk associated with these construction methods and goes on to evaluate the long term risk of cutting and embankment failures in the context of asset management. The concept of asset management for the English Highways Agency is a theme also discussed by **Power *et al.*** who recognize that a key tool in the process is use of the Geotechnical Data Management System (Highways Agency 2003, 2008). Both of these papers build upon the earlier work reported by the Construction Industry Research and Information Association (Perry *et al.* 2003*a*, *b*) and the research undertaken by the Transport Research Laboratory (e.g. Perry 1989). Because their network was established in the 60s and 70s another facet of the UK Highways Agency concern has been the potential for deep-seated delayed failure of cuttings, as experienced on the London Underground (Skempton 1964, 1996), and this work is presented by **Parry**.

Most countries have their own national codes of practice, such as the Australian Standard AS3798 (1990). In Spain, design work is carried out according to the Technical Regulation for the Construction of Roads, Motorways and Masonry Bridges (PG3 2002) as discussed by **Dapena & Parilla**. In the Czech Republic there are a range of well-defined standards based on Eurocodes and this includes the newly revised system CSN 73 6133 '*Design and Execution of Earthworks on Highways*' which has recently been introduced and is described by **Herle**. There are also learned societies that promote co-operation and exchange of knowledge with respect to earthworks design and **Gomes Correia *et al.*** present the work of the Technical Committee TC3 'Geotechnics of Pavements' which is part of the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE). They highlight progress towards the performance specification of earthworks and the development of design, specification and construction techniques for tyre bales (Winter *et al.* 2006).

Whilst codes of practice and technical committees can provide the general standards of work required for safe and economic earthworks construction, the use of particular materials, some associated with certain regions, may need a more localized study. **Rutty & Johnston** discuss the situation in Ireland where the material used as engineered fill is derived primarily from glacial soils and some excavated rock and they note the widespread use of the Moisture Condition Value as a control (Parsons & Boden 1979; Parsons 1992; Matheson & Winter 1997; Winter 2004). **Petkovšek & Majes** report on the situation in Slovenia where over 500 km of motorways have been constructed since 1994 over bedrock of stiff clays and argillaceous sedimentary rock. Because of the decrease in suction following construction that led to wetting and softening of the embankments, for much of this work use has been made of Proctor compaction diagrams complemented with the corresponding soil water characteristic curve. In the Irish and Slovenian examples the materials used in construction of the embankments were derived from arisings from cuttings. However, some situations require the use of completely different materials for the engineered fill and **Hodgson *et al.*** present a case study of the use of tyre bales as a lightweight fill for a road improvement scheme near Bedford in the UK, which draws upon the methods developed by Winter *et al.* (2006). More conventional alternative fill materials that have been widely used are the waste material from heavy industries, including mining. This is the situation in the Czech Republic and **Kresta** describes the use of colliery spoil, fly ash and blast furnace slag for fill.

Despite careful design and construction, cuttings and embankments do still fail; indeed one could argue that any engineer who has not had an earthworks failure is likely to have been over-conservative in his/her design and cost the client money (Stephens, pers. comm. 1984). At the Earthworks Seminar this issue was addressed by three papers, each looking at a different facet of failure. **Macdonald *et al.*** examined the well-established practice of installing deep counterfort drains into cut slopes to reduce pore water pressures and act as a reinforcing agent. They recognized that Hutchinson (1977) still represents the standard empirical technique for the design of such drains but point out that there is little published data on drain performance. **Lamont-Black *et al.*** reviewed a completely different technique for stabilizing an old Victorian railway embankment built out of London Clay, namely the use of electrokinetic geosynthetics and electrokinetic soil nails. The reported success of the technique suggests that this is a method that warrants further research. The third paper in this sequence, by **Macdonald *et al.***, looked at how seasonal effective stress changes can result in the progressive failure of clay embankments and how this correlates with soil moisture deficit values. The paper goes onto to discuss how rainfall and temperature forecasts may be used as a predictor of changes in the soil moisture deficit.

Another theme that emerged from the Earthworks Seminar was the need to take account of environmental issues, including climate change. The effects of climate change on the stability of embankment slopes was addressed by **Toll *et al.*** who describe the building and monitoring of a full-scale trial embankment. **O'Riordan & Phear** take an overview of the environmental impact and look at the reuse of excavated tunnel spoil, using ground treatment to minimize earthwork impact and combining performance-based design with carbon footprint and cost analyses. The issue of carbon footprint and energy emissions as a measure of the environmental impact and how this could assist in engineering design selection is addressed in the paper by **Pantelidou *et al.*** which brings the book to its conclusion.

The 'Earthworks in Europe' seminars have been established to discuss and promote the technical progress and understanding of recent developments and issues in the design and construction of earthworks in European countries. This volume of papers derived from the 2nd international seminar held in the UK represents an important part of the dissemination of good practice.

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