Improved modelling and communication of urban risks: Case studies from the United Kingdom and South-East Asia

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ABSTRACT

This paper uses recent studies to demonstrate how modern developments, including remote sensing, 3-D modelling and responsive surveys, have enabled scientists to better understand urban geological environments and geohazards and communicate them to the public. These developments are discussed here and illustrated with three diverse examples from the UK and SE Asia.

Keywords: geohazards, urban, landslides, shrink/swell, London, Bath, Hong Kong

1 INTRODUCTION

Knill (2003), Culshaw (2005), Marker (2005) and many others have for some time, presented the hypothesis that engineering geology is moving towards a point of synthesis where practitioners must move beyond the traditional boundaries of our profession, and embrace techniques and attitudes of computer modellers, mathematical modellers, economists, politicians and others. Several recent developments provide key milestones in this synthesis that demonstrate how the profession is following the predicted trend:

- Accurate Digital Elevation Models (DEM) derived from remote sensing information at national, regional and local scales
- Improved instrumentation, including new, easier to use GPS and laser surveying equipment for field measurement, smaller, lighter, cheaper field instrumentation and data logging equipment.
- Availability and access to digital geological information, geotechnical databases and attributed models
- Improved communication of geohazard information to client and public, particularly through digital and online media.

Each of these fields have undergone important developments within the last 10 years that have opened up new capabilities for the geoscientist in the study and communication of geohazards. This paper illustrates some of these developments.

2 3-D MODEL OF SHRINKAGE IN LONDON

The ability to store and retrieve information in a structured digital format, and the availability of data in a digital format has radically change the way that information can be made available to the public. The BGS National Geotechnical Database for England, Scotland and Wales contains data derived from commercial site investigation reports as well as data generated by BGS research projects.

The ORACLE based system, which replaces thousands of box-files and archive reports currently holds information on 61 000 boreholes, and 280 000 samples. An example of how the information can be used in demonstrated by the development of a high resolution 3-D subsurface model that has been used to improve our understanding of the mechanisms of ground subsidence due to clay shrinkage in and around the megacity of London. The London Clay Formation is particularly susceptible to shrink/swell behaviour. This has resulted in a long history of foundation subsidence damage within Greater London and elsewhere on the outcrop. Damage has typically incurred costs of around €600 million per year. Detailed statistical and spatial analyses of data across the London clay outcrop has revealed signs of a significant spatial trend in the volume change potential (VCP) of the formation, with an overall increase from west to east Burnett & Fookes (1974), but also showing subtle trends with depth.

A model was constructed of the London Clay Formation using 12 000 records of plasticity data within the formation. This was analysed to model the 3D distribution of the modified plasticity index as described by BRE (1993) to estimate the 3D Volume Change Potential (VCP) across the region (Figure 1). At a regional level, the data have enabled the rapid generation of a model (analyses took 24 hours) of high density geotechnical data for the capital. The result is a much improved model of the shrink/swell hazard at surface, proving a regional trend of reducing hazard towards the west of the region. The model has also enabled detailed analysis of the impact of overburden and formation thickness on the effective hazard at surface (Jones, 2007). The results have helped in the assessment of insurance risk, and the quality of information provided to householders from the insurance industry. The high resolution model has also been made available to developers and has been utilised in subsurface modelling for a proposed and infrastructure corridor (Figure 2). In this case, the availability of such a model meant that several routes could be considered even at conceptual stage, without the burden of a geologist or geotechnical engineer having to plot cross sections using conventional techniques.

The 3D model has also provided a further, unforeseen benefit. Planners and politicians, keen to develop the area around London in advance of the 2012 Olympics have been presented with the model. For some of these non-specialists, a simple, graphical representation of ground conditions, rather than a geological cross section, provided the first real insight to the importance of subsurface data for long term planning. Convincing non-specialists of this importance has proven to be far easier when a direct pattern can be seen between 'hazardous ground' and the 3D location of existing and projected sub-surface infrastructure (tunnels, piles, basements, pipes etc). From a research point of view, the model also provided valuable information on where there was little confidence in existing data. This has increased efficiency of expensive data collection and testing programmes to areas where uncertainty was greatest and information was most required (Figure 3)

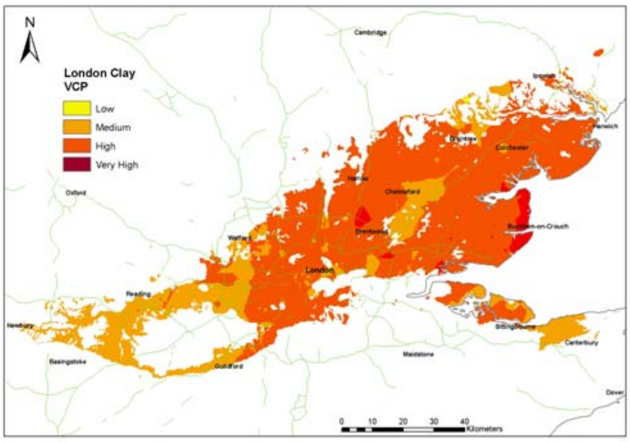

Figure 1 Spatial interpolation of VCP for the London Clay Formation in and around London

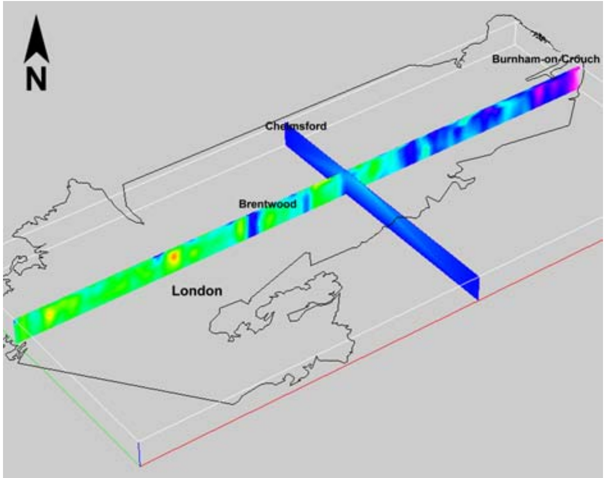

Figure 2 3-D fence model for London Clay Formation VCP

Figure 3 Sampling and testing for shrink/swell to 'ground truth' VCP assessments

3 ELEVATION MODEL OF COMPLEX, DEGRADED LANDSLIDES AND CAMBERING IN BATH

The published (but soon to be replaced BGS geological map for Bath at 1:50 000 scale merges areas of known landslide and cambering under the blanket-term 'foundered strata' (Figure 4). This was a result of very complex, very degraded topography that makes interpretation of ground features very difficult from ground investigation or air-photo interpretation. Whilst this was considered expedient at the time of the original geological mapping in the 1960's, it was difficult for the lay-person to interpret and did not easily permit interpretation of geohazards. The attribution was also incompatible with adjoining areas of similar slope terrain as depicted on adjoining published geology maps. The situation became more problematic when BGS geological map sheets were merged and incorporated into a national geohazard assessment – GeoSure layer, that uses the attributes from 1:50 000 maps as a basis for assessing slope instability susceptibility. In the area in and around Bath, the 'foundered strata' classification resulted in a high hazard rating that was ubiquitous to the entire area.

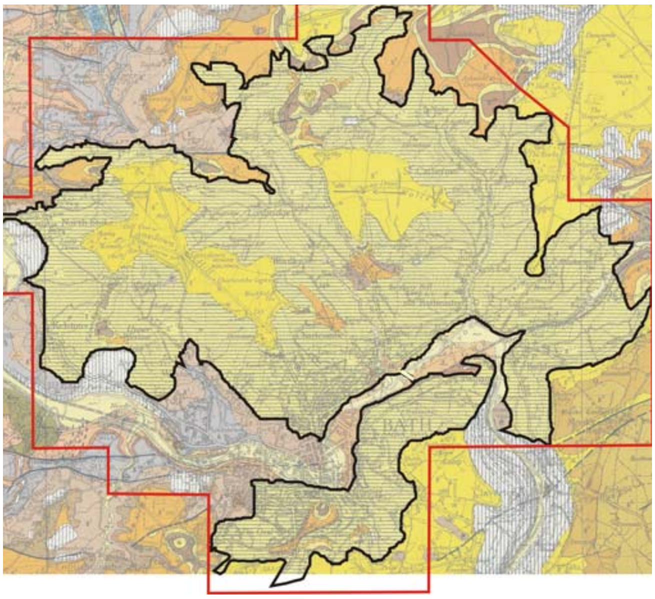

Figure 4 Area of 'foundered strata' on published BGS Bath 1:50,000 geology sheet (horizontally hachured 'green' area within black line).

Development of a better understanding of the mechanisms involved in slope stability in this area have only been possible since the development of new DEM's) derived from both aerial and terrestrial remote-sensing. These have been used to analyse landforms at a range of scales between 1:50 000 and 1:500. By identifying local catchments, anomalous changes in slope and the relationships between features in adjoining valleys, it was possible to identify a number of predominantly shallow mass movement systems and hazards.

A pilot study identified critical features in the identification of different aspects of known slopes, that could be applied to a wider study of the surrounding area. Landslide features in the area are very degraded, usually occupying two zones on the slope related to a sequence of two oolitic limestones which are separated by a sand/mudstone, and overly clay strata (Figure 5). Fossil rotational landslides formed in the lower slopes tend to be larger and more deep-seated than those in the upper (Figure 6).In many cases, landforms are obscured by man-made structures, though in some cases the 18th C builders of Bath city recognised the instability and left the areas as parks (a pattern that adds to the difficulty of interpreting without remote sensing data). Nevertheless, experience in the area has shown that fossil landslides, often on slopes as shallow as 8^{o}, exist in a state of marginal stability and may be mobilised by periods of protracted or intense rainfall, or by man-made activity.

The upper slopes are widely affected by cambering of the limestone plateau, on underlying weak sands and mudrocks, This has led to the development of many 'gull caves' that may pose a significant hazard (Figure 5), (Self & Boycott, 1999). Cambering in the UK is a fossil feature under current climatic conditions. It is found in several areas of the UK but is surprisingly little studied (Parks, 1991). Frequently the features associated with it, for example 'draping' and 'gulls', are obscured by infill (e.g. head) and may less commonly be bridged by uncambered caprock as in some parts of Bath (Self & Boycott, 1999). These have occasionally been exposed unexpectedly during engineering activities.

Surface models based upon aerial and terrestrial LiDAR (Light Distance And Ranging) methods were used to analyse known features on several well investigated and well understood slopes. Resolution of DEMs of between 5 m for overall coverage (NextMap) and 0.2 m for detail (terrestrial LiDAR) has been available to the project. The former is adequate for large-scale, deep-seated landslides whereas the latter is required for shallow features, for example mudflows.

The information gathered from the pilot study was used to 'train' the analyses of airborne data, guiding the interpretation of the research team. It was felt that the complexity of degraded landforms, altered in many cases by development did not lend itself to automated analyses. The full study, showed that, after familiarisation with the pilot data, even very subtle slope features could be identified and classified by experienced operatives. The conceptual ground model shown in Figure 5 could be identified din many locations, and the spatial extents identified on stereoscopic aerial photographs (Figure 6).

The result was a new geological map of the area that no longer uses the term 'foundering'. The new slope stability map of the area, built almost entirely from remotely sensed data, has effectively resolved the complex problem of the 'foundered strata' in the area around Bath (Hobbs and Jenkins, 2008). The technique is now being used elsewhere in the UK where 'foundering' is used inappropriately, for instance in the South Wales coalfield. The model has been input to the national geohazard model to better represent hazards in this area.

As with 3D subsurface models, the application of elevation modelling to this problem provides a useful mechanism to communicate the nature and extent of slope instability in the area. By combining the relatively simple cross-sectional diagram with a surface model of the area non-specialists it is far easier to explain the complexities of large-scale mass-movement processes that occurred thousands of years ago. In a simple example, residents and planners in the Bailbrook district of Bath can now refer to a simple aerial photograph that shows the limits of the landslide. This is combined (in a GIS environment or printed report) with a diagram to show, in simple, colourful form, the type of landform that exists beneath some properties. In this case it is important that the simple diagrams are used in conjunction with supplementary information to assure residents that the landslide is ancient and will remain stable unless very significant alterations take place to the slope profile or drainage (Figures 5 and 6).

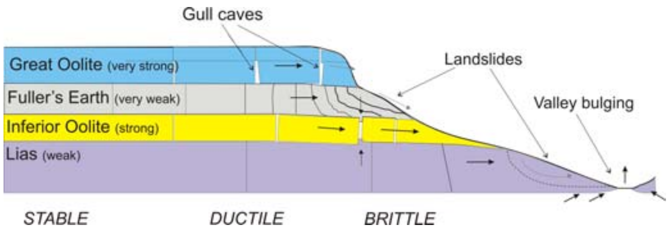

Figure 5 Conceptual model for cambering, valley bulging and landsliding at Bath (adapted from Poulsom, 1996)

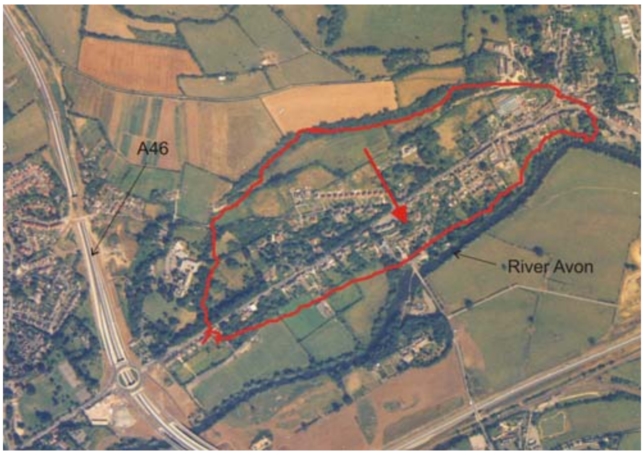

Figure 6 The Bailbrook landslide, Bath

4 COMMUNICATION OF URBAN LANDSLIDE RISK IN HONG KONG

The slope-related geohazards in Hong Kong provide a sharp contrast to those in the UK in terms of their considerably heightened scale, density and safety implications. The land mass of the Hong Kong Special Administrative Region is approximately 1100 sq km of which natural slopes account for approximately 60%. The rapid expansion of the population post 2nd World War from about 2 million in the 1950's to about 7 million today has resulted in the implementation of large scale civil and residential projects from the 1960's onwards. As much of the land mass is at a steep gradient, the construction of building platforms has resulted in the formation of many man made slopes (often not properly engineered pre-1977). More recently encroachment into the steep natural terrain has occurred as most of the relatively horizontal available land stock has already been developed. Hong Kong is therefore in a unique position of being a highly advanced society with modern infrastructure and facilities but also, due to the steep rugged igneous terrain and sub-tropical climate, exposed to high levels of landslide risk from both man-made and natural slopes. A recent example of the meta-stable nature of Hong Kong slopes occurred on 7 June 2008 when an average of 300 mm of rain fell over Hong Kong in 12 hours triggering 89 landslides, killing two people and causing significant economic loss (South China Morning Post, 2008). This being despite the Hong Kong Government spending on average €90M per year on upgrading 250 sub-standard man made slopes per year since 2000 (Chan, 2007). The consequence of potential loss of life coupled with the general public's low level of landslide risk tolerance (Malone, 1998) has lead to a sophisticated scientific and community based approach to communicating landslide risk to the general public.

The Geotechnical Control Office, now the Geotechnical Engineering Office (GEO) was formed in 1977 on the recommendation of an Independent Review Panel on Fill Slopes appointed by the Hong Kong Government after the fatal fill slope collapse at the Sau Mau Ping Housing Estate in 1976. GEO's mandate was to "provide continuity throughout the whole process of investigation, design, construction, monitoring and maintenance of slopes in Hong Kong" (Hong Kong Government, 1977). The GEO is now part of the Civil Engineering and Development Dept. (CEDD) of the Hong Kong SAR Government.

The communication of landslide hazard and risk to the public is through the Hong Kong Slope Safety System, which is continually being developed, upgraded and maintained by the GEO. This is considered the most sophisticated slope safety system in the world and, as described by Malone (1998) has two key aims: to reduce the landslide risk and to address public attitudes to landslide risk. It is the communication and urban community aspect of the Slope Safety System which will be described further.

Malone (1998) subdivides the education and information role of the Slope Safety System into five components, each of which is designed to contribute to the reduction of landslide risk and also to address public attitudes as follows:

1. Maintenance campaign – reduces the hazard
2. Personal precautions campaign – reduces vulnerability and addresses public attitude
3. Awareness programme - reduces hazard, vulnerability and addresses public attitude
4. Information services - reduces hazard, vulnerability and addresses public attitude
5. Landslip warning and emergency services - reduces hazard, vulnerability and addresses public attitude

An excellent account of the community based approach to landslide risk reduction which has been successfully adopted by the GEO, implemented through the Slope Safety System, is given by Massey, Mak and Yim (2001). This approach is used as a tool to advise the community on issues of slope safety, and in particular, to reinforce the communities' responsibility for reducing the landslide hazard and therefore the risk, for slopes that they are responsible for maintaining. The main tools discussed in this paper are summarised in Table 1.

The community based approach is supplemented by the GEO's own programme of stabilising and 'greening' Government owned man-made slopes. This programme reinforces the Hong Kong Governments commitment to reducing the risk of economic and human loss through landslide events throughout the community. The upgrading programme of man-made slopes is now almost complete and the GEO is now focussing on the risk associated with natural terrain landslide hazards. In 2008, GEO has implemented a programme to investigate and mitigate (through consultants) the hazard posed by natural terrain landslides in Hong Kong. It is envisaged that the GEO will now develop equally effective methods of translating the risk to the population from natural landslides as has been and continues to be for mad-made slopes.

The issue of slope safety and the participation of the community will still be a continually evolving theme in Hong Kong as maintenance plays a highly important role in ensuring that man-made slopes are not allowed to degrade to a point where they become a significant risk to those that may be affected by their collapse.

Hong Kong has several advantages which enable the GEO to successfully implement the Slope Safety System. It is a compact administrative region, has a well educated population with a keen sense of community and has the financial resources to fund the system. Lager, more densely populated administrative regions may find it difficult to replicate the Hong Kong Slope Safety System but it should be held-up as a gold standard for all to aim for.

Table 1. Community based approach to landslide risk reduction (based on Massey *et al* 2001)

Public Education
Public Education Programme • TV & Radio campaign, printed materials, exhibitions, seminars, advertising, media promotion
Partnership with Media through: • Media tours to GEO, briefing journalists at landslide sites, regular press releases, technical, legal and administrative briefings to key reporters, media training to all GEO professional staff
Slope Safety Training through: • Maintenance guides for the professional and layman, lectures on slope safety to slope owners and professional bodies, courses in slope maintenance, technical training video and information kit on slope maintenance for owners
School Education through: • Student visits to GEO, school slope safety project competitions, school seminars on slope safety, school geography syllabus includes topics on landslides and slope safety, school teaching kit on slope safety

Public Information
• Telephone Helpline: Enquiry helpline for general information on slope safety
• Web-based GIS-based Slope Information System Technical information on all 54,000 man-made slopes accessible by the public via the Internet and CEDD Library. Bilingual Website with location maps, technical data, photographs, slope safety messages, slope stabilisation advice, news on slope safety issues
• Maintenance Responsibility Compilation of a register of maintenance responsibility for all man made slopes by the Lands Dept. aided by GEO and known as the Systematic Identification of Maintenance Responsibility of Slopes in the Territory (SIMAR). Web based maintenance responsibility data base open to the public through the Lands Dept. Website.

Community Outreach and Partnership
• Partnership with the Community through: Information on slope safety for interested parties, discussions with legislators, partnership with the Red Cross to provide safety advice for families in shanty towns, information also disseminated by Home Affairs Dept., Information Services Dept., Education Dept.
• Community Advisory Service assists private owners to discharge their slope safety duties by: Seminars on slope safety, 'meet-the-public' service giving general advice, outreach services for owners legally required to upgrade an unstable slope, meetings with owners corporations and Mutual Aid Committees on slope maintenance
• Quasi-legislative Means – to enhance public awareness of their responsibility for slope safety by: Inclusion of slopes and retaining walls in the definition of Common Parts to be kept in good repair by owners, developers required to include Slope Maintenance Manuals in Deeds of properties, publication in the Gazette a Code of Practice on building management maintenance which stipulates a slope maintenance standard, solicitors required to include a slope maintenance clause into the Deeds, safety screening of 300 slopes per year by GEO to assess stability – orders can be issued by Government for sub-standard slopes to be investigated and upgraded if required

5) CONCLUSIONS:

This paper forms one of a series of papers published to provide 'milestones' against which the hypotheses of Knill (2003) and others can be judged. The paper demonstrates that recent developments in technology have enabled improved understanding of engineering geology phenomena in built up areas where conventional investigation may be unsuitable or may provide an incomplete answer. The paper illustrates how engineering geology is moving towards a point of synthesis where practitioners move beyond the traditional boundaries of the profession. Crucially, the techniques described also provide an improved means by which scientists and engineers can communicate those phenomena and the understanding of their implications to non-specialist audiences. The development of 3D models and the improved access to remote sensing data are proving to be valuable tools in communicating engineering geology in the UK.

We compare this approach to a case study from Hong Kong. In this instance, the problem is far greater (in terms of people affected and the severity of hazard). The nature of the landslide problem in Hong means that geological investigation and information is far more engrained in the everyday lives of citizens.

Although these studies have great scientific value, without effective communication they have arguably limited value to wider society. The key to successful reduction in risk from geological processes is the effective communication of hazards and risks and their implications to society, and incentives for decision makers to act upon information presented. It is also important that some aspects of hazards and risks are re-assessed periodically, and in some cases monitoring programmes are required.

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