The Future of Geotechnical and Structural Engineering Research

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ABSTRACT

The objective of this study was to evaluate the effects of fly ash amendment on compression behavior of mine tailings. The study included one synthetic mine tailings and two types of fly ash. A synthetic fine-grained mine tailings was created as a combination of silica powder and kaolin clay. The two fly ashes used classified as off-specification, but had sufficient calcium oxide (CaO) content (12 % and 17 %) to promote pozzolanic activity. Tailings-fly ash compression specimens were prepared at solids content of 60 and 70 % (water content = 67 and 43 %, respectively), water-to-fly ash ratios of 2.5 and 5, and were cured for 0.1 d (2 h), 7 d, and 28 d. Bi-linear compression curves on semi-log plots were observed in most of the fly ash amended tailings specimens. The break in slope on the compression curve was identified as the breaking stress, whereupon cementitious bonds are broken and there is a subsequent increase in the magnitude of compression for a given applied vertical stress. In general, higher fly ash content, lower water-to-fly ash ratio, longer curing time, and/or increase in CaO content of fly ash resulted in improved mechanical performance of tailings-fly ash mixtures. Improved mechanical performance coincided with a higher breaking stress, lower compression index, and reduced total settlement.

Keywords
Interbeddings of weak and strong rock slope Strength reduction method Failure criterion Failure mode Stability

Introduction

In 2009, the UK Engineering and Physical Science Research Council published a review (EPSRC, 2009) of academic research into geotechnical and structural engineering (G&SE). This was part of EPS'Cげゲ ongoing theme of shaping capability of and building capacity in the UK academic base. The review reached the conclusion that the ranking of UK research in this area was world class and was worldleading in a number of niche areas, especially numerical modelling, fire engineering, vibration engineering, geotechnical engineering and earthquake engineering, but it was incremental not transformational, relatively short term in vision, predominantly industry-led and with little interaction with other disciplines. The construction industry, the prime recipient of this research and, therefore the sector with the most to gain, is not as engaged in publically funded research as other sectors. This may be due to the fact that all new construction, particularly buildings, are prototypes so industry does not have time and resources to refine the design, unlike other areas of engineering and manufacturing; the inability to create/ maintain some form of competitive advantage in a project led industry where project teams are assembled from many companies; manufacturing is typically technology intensive, construction is service-based and inherently labour intensive; most research on innovation has been focused on large enterprises neglecting the SME sector which dominate construction; and SMEs tend to be more focused on survival and solving immediate project-related problems rather than invest in research. It should also be noted that indicators of research may not be so prevalent in the construction sector as other sectors; for example, the lack of patents will under estimate the innovation activity within the sector. This is unlikely to change because of the fragmented nature of the industry and the reliance on clients to invest in construction; that is, construction industry is often perceived as providing a service. Therefore, privately funded construction is particularly susceptible to economic cycles; publically funded construction is more sensitive to political cycles; and managing national infrastructure assets (e.g. water, rail, and road) is affected by the five year control periods used in the UK. Given the scale of construction projects, particularly infrastructure projects, which can involve significant public funding, the lack of national strategic planning also makes it difficult for the industry to plan and invest. The introduction of the National Infrastructure Plan in the UK has provided an indication of future requirements though it is still susceptible to political will. The most visible aspect of this is the current skills shortage that has resulted from the increasing volume of construction. There are some exceptions. For example, research into high speed railways is underway as the Government has highlighted its intention to develop such networks; that is long term planning facilitates investment in research.

There are a number of barriers to implementing G&SE research when compared to other disciplinary areas which have higher short term impact.

• The output of research in this area has a clear route to transfer knowledge through codes and standards, but the pace of change is slow.

• Public safety is a critical factor because of the scale and life span of projects.

• The industry is risk averse, which makes it difficult to implement research outcomes

• Research tends to be incremental rather than transformational, which means that it is difficult to demonstrate benefit of research in the short term.

However, the challenges of urbanisation, resource scarcity and security, climate change and population growth are placing greater demands on the urban environment, giving rise to the need to realise the benefits of research. Figure 1 shows that the construction industry uses some 50% of all the ｣ラヴﾉSげゲ resources (Minerals Education Coalition, 2015), and it has been suggested that the construction industry can influence 47% of the required reduction in CO_2 by 2050 (BIS, 2010) に it therefore impacts greatly on all aspects of society. This implies the industry has the opportunity to make a significant contribution to enhance the resilience and sustainability of society.

Two research networks were formed: Future Infrastructure Forum led by Cambridge University (FIF, 2010) and LimesNET led by the University of Bath (LimesNET, 2010) to develop a vision for the future of research into geotechnical and structural engineering. The Institution of Civil Engineers took this forward involving delegates from universities, contractors and consultants from the industry, client organisations, research organisations and government. This paper is a summary of the recommended areas of research developed from these activities, placing them in context of global challenges, national strategic planning, sustainable economic growth and the vision of the future of civil engineering.

2. Background

Geotechnical and Structural Engineering ; account for approximately 4% of the total expenditure on Engineering and Physical Science research. It is characterised by individual Responsive Mode grants, though there are some more strategic grants (large multidisciplinary grants; e.g. those led by Powrie, 2010; Mair, 2011; Rogers, 2013; Collins, 2013; and Dawson, 2013). Associated themes include energy, water, transport and environmental engineering which, collectively, define the economic infrastructure of an urban environment (Table 1).

2009 also saw the publication of the UK Council for Science and Technology report on the National Infrastructure for the 21st century (UKCST, 2009) and in 2010 the UK Infrastructure Planning Commission report (IPC, 2010), both of which highlighted the need for a high quality national infrastructure to support economic growth and social well-being. Much of the existing national economic infrastructure began over one hundred years ago (Table 1) creating a substantial asset. Maintaining this asset has presented a number of challenges in terms of renewing around a patch work of adjacent assets in tight time scales. Meeting these challenges in a commercially economic manner has meant that output of construction on existing assets has focused on keeping the asset running, without considering the longer term strategy. It has also given rise to sub-system specialists who have progressed in their careers without broader systems

knowledge. It has been adapted to cope with changes in technology, regulations, environment and demand. Over the last fifty years, there has been a shift from a series of unconnected networks to an interconnected system. The economic infrastructure is primarily owned and operated by the private sector embedded within a regulatory framework

Importantly, the infrastructure is ageing; resilience is reducing; it is susceptible to the effects of climate change; and there is increasing demand. The cost of replacing ageing infrastructure, the need to decarbonise existing infrastructure by adapting its use and to create new, carbon neutral infrastructure that is adaptable and more resilient have placed the industry in a position that it has never experienced before. This is at a time when the construction industry is embracing the benefits of the digital world.

Investment in economic infrastructure is a global challenge (OCED, 2007). For example, OCED suggests that air passenger traffic could double over the next 15 years, air freight triple in 20 years and port handling quadruple by 2030. This in turn suggests that by 2030, US$53T of investment is needed; this is about 2.5% of the global GDP. This would rise to 3.5% of GDP if energy investment is included

The OCED is a better quality of life using long-term solutions that will benefit everyone. The UK construction sector encompasses economic and social infrastructure, accounts for about 8% GDP employing 3 million people and is worth over £100B per year (BIS, 2008). Importantly, it uses about 300 million tonnes of material per year, or about 6 tonnes per person, while construction, operation and maintenance of the infrastructure account for The construction industry makes a significant contribution to the five guiding principles of sustainable development (UKEFR, 2005),

The Future of Civil Engineering Construction is a transformational process. It produces an outcome that transforms peoplesげ lives; therefore the views of the users, operators and owners are important. Historically, construction has had an output focus, relying on experience, regulation and guidelines to create something that had value. The evolution of design for construction is similar to that for research. It has been an incremental process starting with an empirical approach based on observation of actual behaviour. Gradually, a more scientific approach developed as testing of materials and elements became possible. This led, at the beginning of the 20th century, to the development of standards and regulations which, over time, have been updated to recognise practice and research findings. Towards the end of the 20th century, numerical modelling became a reality and, more recently, the ability to monitor performance of buildings a possibility. This is now leading to the realisation of the concept of the built environment as a system

This aligns with the concept of convergence which is a cross-, inter- and multi-disciplinary systems approach informed by social science research and underpinned by the natural and physical sciences It requires a different approach to research, and this has been both encouraged andmanifestly advanced by the UK Research Councils, and EPSRC in particular via its pioneeringSustainable Urban Environments programme. There are now programmes of research that areexploring the far future needs of cities and their citizens, and the research is having impact inTransport Catapults. Thus, there is a hierarchy of research (Figure 2) addressing the challenges atdifferent scales. A challenge for the research community is to demonstrate the impact of theirresearch outside of the pockets of excellence where this is happening, and specifically in theconstruction industry rather than the organisations and structures within which the communityworks.

Key Issues

The EPSRC-supported Future Infrastructure Forum held five two-day workshops involving representatives from academia, industry, and client, including government. The forum started with a review of research currently taking place. As expected, it included materials, instrumentation, design, processes, modelling and civil engineering as a system. Given the context in which the challenge was set, it suggests that the research activity was addressing many of the emerging issues, but not necessarily in a structured or collaborative manner. The link between research projects and the issues was not clear in all cases, and the research outcomes were not necessarily impacting on the industry. The focus of the research community, which has become increasingly scientific, was not necessarily aligned with that of industry, which is more commercial. It was recognised that establishing a strong research base in geotechnical and structural engineering is important to provide underpinning knowledge for industry, as well as maintaining an academic base necessary to deliver the next generation of engineers.

Paradigm Shift in Design

Design is supported by guidelines and experience, restricted by codes and enhanced by analysis. It is continually evolving but the pace of technological change, the environexpectations means that the current codified approach to design may be increasing the risk to the built environment as the pace of change accelerates. The built environment is continually being maintained, updated and adapted. This will accelerate to minimise environmental impact. Codified design is current practice, but scenario modelling, risk-based design and design for flexibility (adaptive design) are emerging because current codes may no longer be relevant. Examples of the limitation of current codes are those used prior to 2010 in New Zealand. Following the Christchurch earthquake, buildings are being reassessed, and strengthened if necessary, using more stringent criteria. Dealing with local and medium catastrophes is introducing the concept of designing for resilience.

Construction Processes

Quality control and workmanship are key risks to any construction. Factors can be applied in design to compensate for these risks, but increasingly complex structures will require improvements in assembly to overcome human error. Offsite manufacturing, 3D printing and robots have developed to an extent where application in the construction industry is feasible. This is primarily driven by commercial investment, skills shortages, reduced transport costs and concerns over health and safety. However, it does offer an opportunity to undertake research into the expected enhancement in the improvements to the structures. Optimisation becomes feasible. For example, producing beams shaped to optimise material use leading to material reduction is now feasible provided the building performance is fully understood. Construction is a manufacturing process in which most projects are prototypes, even though they are assembled from elements that have been optimised both in design and manufacture because of their repeatability. Offsite manufacture has the potential to improve quality, reduce times for construction and improve safety because it is possible to implement optimised, manufacturing processes. These processes, together with lean construction, could be applied to on site construction.

Building Performance

A building is a system, therefore to truly capitalise on its components it should be considered as a whole に the structure, the fabric, the utilities as well as the function. This is currently subdivided such that components of a building are often considered in isolation. For example, the foundation provides a stable base upon which to build a structure, yet the foundation and structure interact. The distribution of loads within a structure, the response of the structure to movement of the foundations and the impact of the load on the foundations are not fully understood. Therefore, greater use of instrumentation to monitor actual performance, leading to a database which can be interrogated for future projects, should lead to improvements in design. This will be facilitated by Building Information Modelling (BIM) though an understanding of the risks associated with this has

Smart Buildings

The impact of the digital world in the built environment is increasingly being recognised as an opportunity to fully realise the capacity and capability of the environment, to improve its operation, to minimise interventions, to focus interventions and to improve future design. The cost and design of sensors is such that it is now possible to install them during construction, thus providing greater insight into how the built environment performs environment, and makes greater use of the intrinsic properties of the materials and elements that create the environment to be more resilient and multi functional. Further, through observation and which is continuously being updated through maintenance and adaption. The built environment can last several generations and is fundamentally important for the health, wealth and well-being of society. Therefore, in addition to its capital value, it also has cultural and economic value. In order to realise the true value of the built environment it is necessary to appreciate current capacity and capability, and establish the remaining life at that capacity and capability. Extending the capacity and capability is feasible through maintenance and adaption. Changes in regulations, use, technology and the environment require a reassessment of capacity and capability if the value of the existing built environment is going to be fully realised. Building performance is inextricably linked to asset management which aims to extend the life of the asset, intervene before failure occurs and realise the full value of the asset. Therefore, performance monitoring extends to predicting lifetime performance and capacity remaining at the end of life for re-use.

Conclusions

The ESPRC review of geotechnical and structural engineering occurred at the same time as the political recognition of the value of economic infrastructure. The commercial realisation of instrumentation, data capture and interpretation and modelling are occurring at the same time as the impact of the grand challenges of climate change, resource security and scarcity, a growing population combined with a changing demographic, and growing urbanisation are impacting on the built environment.

This is the background to a partnership created with the support of EPSRC to identify the research that geotechnical and structural engineering academic community needs to address. A series of workshops involving delegates from consultants, contractors, clients, research organisations and universities led to ten themes:- hazards, understanding material behaviour, paradigm shift in design, construction processes, building performance, smart buildings, asset management, intervention, decarbonisation and adaption.

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Doi: 10.4103/0971-3026.95396