Geotechnical engineering collaboration between clients, consultants, contractors and universities: A European perspective

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ABSTRACT: There are many initiatives currently providing funding for collaboration between universities and construction companies working in the geotechnical sector in Europe. Arup is currently managing or taking part in numerous initiatives in the geotechnical sector alongside UK and other European and international universities. The funding for these collaborative research projects comes from various sources.

The initial part of this paper describes some of these research initiatives and describes the drivers for these studies and the funding arrangements in place. The input and feedback received from the EC framework projects; Scout, RuFUS, Topic and GeoTechNet will also be discussed. A UK funded ground source heat project and the benefits of collaborative EngD research projects will also be described. Examples are identified from current and past experience where collaboration has provided opportunities for commercial organisations, educational institutions and Arup.

The paper concludes by identifying some generic areas where collaboration has been highly successful and where opportunities appear to lie in the future.

1 INTRODUCTION

Arup is a global firm of designers, engineers, planners and business consultants providing a diverse range of professional services to clients around the world. The firm has over 9000 staff working in 86 offices in more than 37 countries. Geotechnical engineering is an essential element to many projects that Arup works on. Arup has approximately 400 geotechnical staff working in many of these offices. Collectively this geotechnical staff resource is referred to as Arup Geotechnics.

Collaborations on research projects with other companies and educational institutions have offered significant opportunities in recent years. For Arup, the collaborative work has provided the opportunity for knowledge to be shared and for an important contribution to be made to development in engineering practice.

The work also offers staff from different levels of seniority in companies and research institutions to develop a range of new skills. The nature of the research often allows the development of skills in new technologies that enable companies and research organisations to bid and compete for work in new markets.

The paper provides several examples of collaborative research projects carried out in recent years by geotechnical staff in Arup.

2 RECENT ARUP PROJECTS INVOLVING COLLABORATION

2.1 EC framework projects

European Community (EC) framework projects have provided opportunities for engineering research institutions and commercial companies to collaborate in research initiatives aligned with EC funding objectives. The award of 5th Framework Project (FP) EC research funding started in 1998. More recently awards have been made for 6^{th} and 7^{th} Framework projects.

The EC funding objective or goal is to, 'support the transformation of the European industry towards a more knowledge-based and added value industry. The funding aims to provide improvements in competitiveness and in sustainability'. It encourages both end users and stake holders to participate in these long term objectives. It also provides an opportunity for harmonisation of geotechnical processes across Europe, and networking with different countries.

2.1.1 RuFUS (ReUse of Foundations for Urban Sites)

The redevelopment and reconstruction of urban areas is fundamental to the economic sustainability of cities, their environs and the EC.

The project aimed to provide ways to overcome the technical and non-technical constraints to the reuse of foundations for sustainable development.

The project team was led by Building Research Establishment UK Ltd (BRE). Arup were one of eight companies that partnered in this collaborative research programme. Funding was provided from a 50% contribution from the EC following submission of an FP5 proposal.

For the past 50 years, civil engineers have been filling the ground under our towns and cities with, among other things, bored concrete piles. In London Clay in particular, such piles are a quick, quiet and cost-effective method of supporting ever-taller buildings and structures. When the building reaches the end of its life and the site needs to be redeveloped, the easiest solution (but one that is clearly not sustainable) is to fill up the space in between with more piles. The engineering industry possesses the machinery and expertise to remove old pile foundations from the ground, but unlike shallower footings, the cost of removal of deep foundations is high. It can also cause unwanted soil disturbance, affecting the capacity of new foundations. Therefore, this is only done in the most extreme circumstances.

Commercial buildings in major European financial cities have on average a working life of about 25 years and in regional centres about 40 years. Underground development of services and infrastructure in urban centres already confines the location of building foundations. Over several generations of buildings the ground becomes congested to the point where no space is left for the new foundations, therefore stifling new development and inhibiting economic sustainability. Consequently it is essential that redevelopment attempts to use existing building foundations to reduce the environmental impact of the reconstruction.

Arup carried out research in the following areas for the RuFUS project:

- Materials (non destructive testing for integrity, durability and geometry);
- Foundation performance and improvement (unload-reload, failure, improvement techniques);
- Future proofing foundations (foundations documentation systems);
- Economics and risk (decision model); and
- Exploitation and dissemination.

The conclusion from the research was presented in a best practice handbook (BRE, 2006a). A conference hosted by BRE was also held in October 2006, where papers written from the research were published in conference proceedings (BRE, 2006b).

2.1.2 European Geotechnical Network for Research and Development (GeoTechNet)

The objective of GeoTechNet comprises 'harvesting' and harmonising geotechnical knowledge across Europe into one centralised system. 50% of the project was funded by the EC following a successful application for FP5 funding. The overall client for the research work was the Centre for Civil Engineering Research & Codes (CUR, Gouda). CUR, Gouda based in The Netherlands was the network coordinator and carried the overall responsibility for the accomplishment of the network.

GeoTechNet has about 40 members from 17 European countries. It is proposed to extend the network with more (corresponding) members and to have contacts with other national and international geotechnical networks.

Arup acted as a partner in this research providing geotechnical input on several key work packages (WPs). The WP's produced final reports with recommendations which have been published on the GeoTechNet website (2005a, b & c). The work carried out on three of these packages is briefly described in this paper:

1. WP2: Recommendations for the convergence of the Eurocode 7 approach & National Annexes within Europe

The working group reviewed Eurocode 7 (EC7) Part 1 – Design. In particular the three alternative Design Approaches (DAs) and the National Annexes (NAs) that each Member State will produce to indicate how the Eurocode is implemented in that State. A collection of design case studies was prepared to illustrate the different results that the three DAs produce. An example of one of the design case studies considered is given in Figure 2.1. It is hoped that these will assist the eventual elimination of the alternatives and any other differences in national approach indicated in NAs that are not essential because of local climatic or other unique natural phenomena. Recommendations have been made as part of the research that may help this. The work has been carried out by working parties, others involved in EC7 and contacts in the geotechnical societies of the nations not directly engaged in EC7 development activities, including the eastern European countries that are candidates to join the European Union. The working party also sought to encourage geotechnical engineers in Europe to apply EC7-Part 1 in their designs of foundations and other geotechnical structures and to stimulate local training programmes through National Societies of the International Society for Soil Mechanics and Foundatin Engineering (ISSMGE), universities and other relevant organisations.

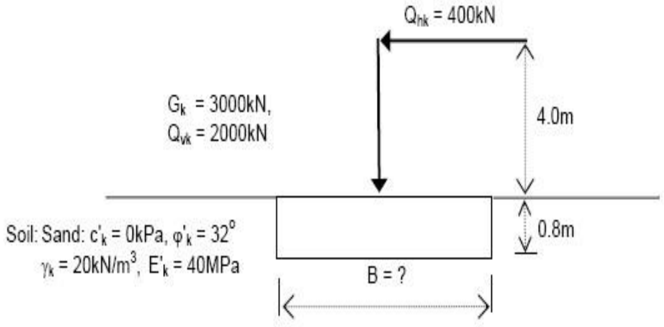

Figure 2.1: GeoTechNet, WP2, example problem comparing design codes

2. WP3: Design tools: Finite element methods and Observational Method Processes

The general objective of this working group comprised stimulating and accelerating the proper use of innovative and more cost-effective design methods.

In particular Finite Element Methods (FEM) and Observational Method (OM) processes were studied. Knowledge related to these methods was gathered and disseminated (soil models, soil input parameters, importance of the modelling factors for proper use of FEM etc.). This was supported by consultable databases addressing numerical programs and measurement techniques. Comparisons were made between various FEM models (FLAC, PLAXIS etc), the common pitfalls in using FEM were described, and these culminated in a final report.

Arup and the Belgian Building Research Institute (BBRI) carried out studies on the use of FEM & OM according to the semi-probalistic safety approach of EC7 (characteristic values, design values, partial safety factors, see Figure 2.2). The use of OM in Europe was carefully considered by collecting six case studies of its application so that the proper use of the OM could be applied to engineering projects to provide benefits to clients in terms of cost and programme savings.

From these studies, the WP aimed to improve the confidence in geotechnical design and reduce the risk of accidents related to geotechnical work. Through demonstration of this the WP has stimulated the application of these innovative methods.

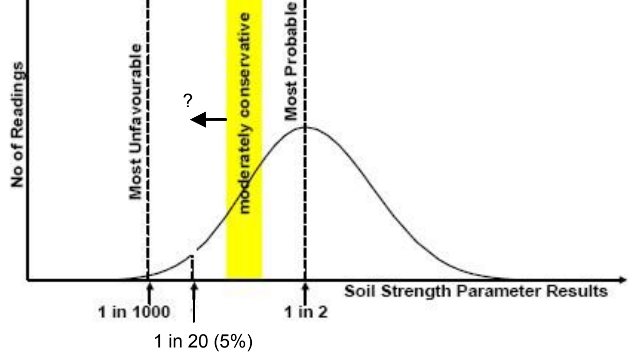

Figure 2.2: Defining soil strength. CIRIA 185 (1998), considers Characteristic (or Moderately Conservative) to correspond to 5% likelihood of movement predictions being exceeded

3. WP 6: Determination of socio-economic impact of natural disasters

The objective of this WP was to review data from natural disasters across Europe, which may result from sudden events such as earthquakes, landslides and floods, resulting in ground collapse or geotechnical engineering problems. The study aimed to quantify the social and economic impact of these events. The WP contributed to the determination of priorities for future investment and provided recommendations for mitigating the cost caused by natural disasters.

Arup used in-house skills and data on landslides, earthquakes and flooding to carry out work for this WP, culminating in a published report informing the EC of future policy for identifying countries most at risk. The recommendations from the report proposed tightening of hazard assessment processes and providing guidelines for managing the risk at both regional and local country level. Priorities for future research in hazard assessment were also identified.

2.1.3 Sustainable Construction of Underground Transport Infrastructures (SCOUT)

The primary objective of the SCOUT project is to develop a new concept for the sustainable construction of cut and cover tunnels in urban areas. The research aims to optimise the safety and cost of construction and eliminate or drastically reduce nuisances to the urban environment associated with construction projects. These nuisances include noise, dust, and the large size of construction equipment causing long-term traffic disruption.

This three-year EC funded project fits in with the development of the Trans-European Transport Network (TEN). The project is funded by the EC under the FP6 'Sustainable Surface Transport' programme. The project is led by Soletanche Bachy. Arup is one of nine participants.

In many instances tunnels are the best option for the integration of new transport infrastructure into existing systems in crowded urban contexts or in greenfield developments. These tunnels avoid surface congestion and noise impact, and in many projects are the only possible option to build the intermodal connections linking underground stations to airports, parking lots and pedestrian access. However, their construction can be costly and disruptive. There are generally two methods of constructing these tunnels (bored or cut and cover). The cut and cover method is generally considered a cost effective method to build shallower tunnels to depths of about 20m.

The aim of the project was to cut up to 15% of the total cost of new construction through the development of new horizontal diaphragm walling equipment, the wider implementation of the Observational Method and a new design approach for the retaining and tunnel structure that includes the use of composite materials. Arup partnered in the development of the design approach.

The particular skills Arup bought to the project included:

- Numerical modelling skills, which helped understand and model the diaphragm wall construction process and back up analysis of the physical modelling work.
- An understanding of design codes for pile foundations both in Europe and worldwide. Arup staff have been involved with the development of EC7.
- Involvement in the publication of the guidance on the use and management of the Observational Method in ground engineering.
- Case history experience of the construction challenges associated with retaining walls and adjacent structures. This includes the interpretation of instrumentation results from automated monitoring systems.

The research work on this project is currently being concluded.

2.1.4 Technically Optimised Piling Concept (TOPIC)

TOPIC was a four year project funded by the EC FP5 funding programme. The project team was co-ordinated by Soletanche Bachy and comprised seven European organisations, including Arup who acted as overall Technical Advisor.

Concern for the environment means that traditional construction practices are being refined to reduce waste, pollution and use of resources while remaining cost-effective. The research led to the invention of a new displacement screw pile tool and highlighted the need for a European Standard for screw piles.

The project allowed development of a new method of pile installation that would be acceptable in urban environments, a real-time quality control system for the complete piling process and new concrete mix designs with improved working stresses. The development was supported by an extensive research programme using numerical and physical modelling to simulate the pile construction process, ending with a full scale field test.

The results of this research has led to a better understanding of the drilling processes which impact on pile capacity and the work also resulted in important studies being carried out comparing continuous flight auger (CFA) piles and displacement pile behaviour. The new displacement pile tool is currently being used in France.

2.2 Other External collaborations

2.2.1 Development of ground storage heat energy

Between 2003 and 2005, Arup led a two year multi-disciplinary research project investigating the use of ground storage of building heat energy in the UK. This project was funded by the Department of Trade and Industry's (DTI) 'Partners in Innovation' research scheme. Partners in Innovation (PII) is a collaborative scheme that provided up to half the costs of research for innovation projects within the construction sector. It is open to all UK companies, industry bodies, institutions, research and technology organisations and universities.

The DTI ran PII as an annual competition. All projects supported under PII are expected to contribute to the economic, social and environmental policy aims at the heart of the DTI Construction Sector Unit's agenda for Construction Research and Innovation.

The PII project was carried out by five partner organisations (Arup, Skanska Cementation Foundations, Environment Agency, University of Birmingham and University of Newcastle). During the project significant contribution was also provided by organisations on a steering group and technical support from Atelier Ten and WJ Groundwater Engineering.

Ground source heat pumps work by utilising the constant temperature of the ground or groundwater beneath a building (typically 10°C to 14°C in the UK) to provide cooling in the summer and/or heating in the winter. The systems typically use a third of the energy consumed by traditional heating and cooling systems, resulting in 50% less CO^2 being produced, in line with the UK government target to reduce carbon dioxide emissions by 20% by 2010 (DEFRA, 2001). In economic terms, ground storage systems have similar capital costs to conventional heating and cooling systems, but have lower running costs over the system's lifetime. They are less intrusive than conventional systems and take up less space.

The findings of the project have been disseminated via an overview report (Arup, 2005) and a series of presentations. The report investigated appropriate conditions for application in the UK and analysed detailed cost savings for a number of specific systems. The regulatory framework that the systems will be assessed against was also considered. Following feedback from guests attending the presentations, the project overview report has been updated to include further sources of information. Figure 2.3 illustrates the configuration of the geothermal pipes attached to a CFA pile cage as part of a trial carried out during the project. Figure 2.4 provides a schematic showing the operation of a ground source heat pump.

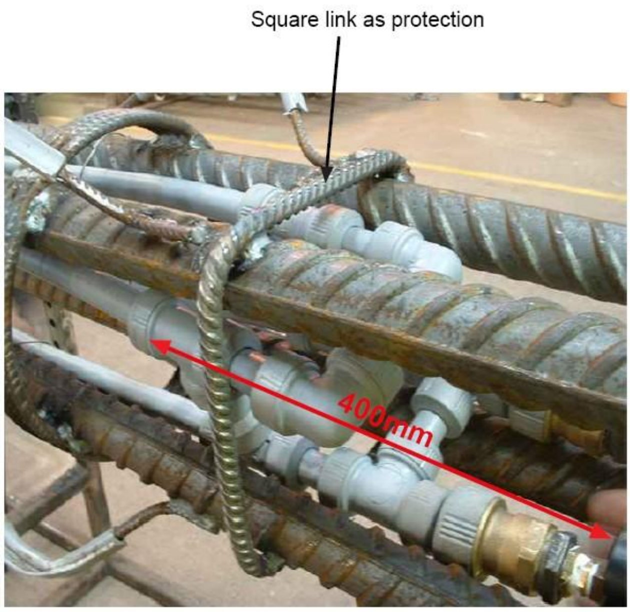

Figure 2.3 CFA pile cage and geothermal pipe, from Arup (2005)

2.2.2 *EngD collaborations*

EngD's were introduced in the UK by the Engineering and Physical Sciences Research Council (EPSRC) in 1992. EngD programmes were set up in response to a belief held in industry and supported by Government that the traditional PhD research degree did not adequately prepare researchers for careers in industry. Since this time approximately 15 EngD centres have been set up at UK universities.

The format of EngD courses comprises of approximately 1 year of taught engineering and management courses offered from the collaborating university and approximately 3 years of research carried out alongside the collaborating company. Funding of the student is provided from a 50% contribution from the company and 50% from the EPSRC.

The parent company can benefit from these collaborations in a number of ways. For a relatively modest investment the research carried out by the student over the course of 3 years can be targeted towards improving a companies technical knowledge in a given area. The parent company assigns a mentor to channel this research work. In Arup, EngD students are researching applications of Geographical information systems (GiS) and reviewing basement construction and monitoring. These are areas that Arup already has a strong presence, however, the EngD students can be used to carry out research to further improve these skills.

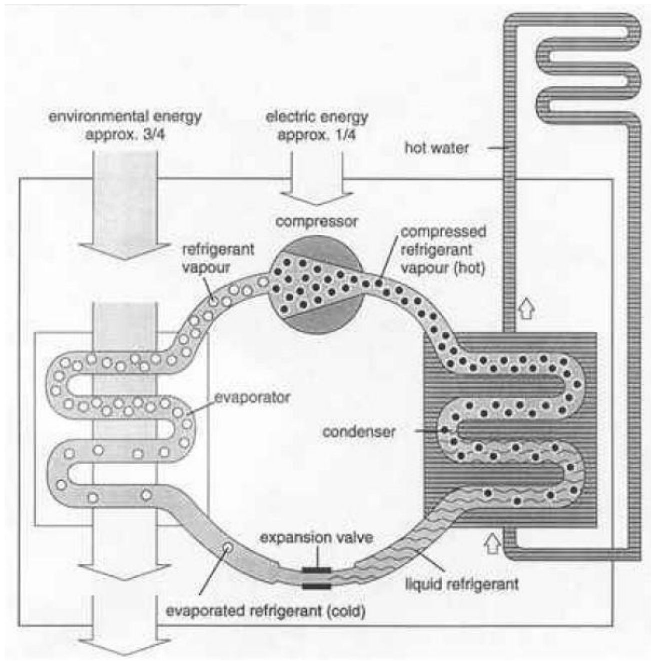

Figure 2.4 Ground source heat pump schematic, from Arup (2005)

3. OBSERVATIONS OF SUCCESSFUL APPLICATION

The recent projects carried out by geotechnical staff in Arup provide an overview of recent collaborations. By reviewing results of` these projects, several common themes are evident with respect to the benefits that can be achieved:

- It allows engineers to understand the `needs of the stakeholders as they are often involved in these collaborative projects

- Research improves the technical design skills of the collaborating companies. Given the nature of the projects, this is often in innovative techniques where the market is relatively undeveloped. For consulting engineers and contracting companies, improving technical skills is often vital for continued financial success of the business.

- The collaboration between companies provides useful networking opportunities with important clients. The networking often leads to the collaborating companies winning new commissions both related and unrelated to the core research work.

- Work carried out on the research projects has been invaluable for delivering solutions to clients needs. One example could be the numerous recent commissions carried out by Arup to appraise the applicability of ground source heat systems in proposed building projects.

- The winning of innovative research work provides opportunities for recruitment and improves staff retention. The varied and interesting nature of work allows development of staff and provides new business opportunities from within the collaborating organisation.

- Research work is often initiated by collaborative organisations from internal research funding. This initial research may lead to successful applications for external funding. The acquiring of external funding sources allows the cost contribution by the collaborating organisation to be offset, thus reducing overhead costs.

- The collaborative work often exposes the parent company to new markets where their presence isn't as strong as in their home market. This is particularly relevant to EC funded projects.

- It allows emerging Eastern European economies to understand current practices in Western Europe and to allow them to strengthen codes and standards.

The degree of benefit that the collaborating organisation see will vary based on these factors listed. In addition the following must be appraised:

- Ensuring that the development of the collaborating companies business needs is closely matched with the research carried out.

- Ensuring the role played by the organisation in any collaboration is in keeping with the required objectives. The cost benefit of participation should be reviewed in this respect. For instance, the lead company in the collaboration will carry out a significant amount of project management in ensuring timely submission of deliverables. In carrying out this role, technical skills may not be as easily acquired.

4. CONCLUSIONS AND OPPORTUNITIES FOR THE FUTURE

From the observations made in the previous section it is evident from a consulting engineers perspective that continued and selectively chosen investment in research and development is required to yield the optimum benefit. The investment in research must be aligned to the overall objectives of business development.

The expansion of the EU into Eastern Europe in particular presents new opportunities for collaborative research projects. Companies and research organisations based in both Eastern and Western Europe will have a significant opportunity to expose themselves to new markets.

The collaborative projects described in this paper has provided varied and interesting work for staff in different areas of engineering research. The varied nature of the work allows staff to improve technical skills. Research projects also provide an opportunity for construction companies to collaborative with research institutions and raise their profile to potential employees. In particular, programmes such as the EngD qualification provide recruitment opportunities for students and engineering companies.

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