Institution: The University of Sheffield

Unit of Assessment: 14 - Civil and Construction Engineering

a. Context

Civil and Structural Engineering (CSE) has critical mass activity in the core fields of *Ground, Water* and *Structures*. Our vision is to undertake fundamental engineering research which stimulates innovation across all areas of our research base, applying this for significant societal, economic, practice and environmental benefit. Our impact activities focus on improving infrastructure design, construction and operation processes, by driving policy, establishing and enhancing best practice, providing specialist services and developing innovative techniques, tools and products. They align with the national and European strategic themes of *Sustainable Development*, *Infrastructure*, and *Smart Cities*, reaching a broad spectrum of beneficiaries. We adopt both strategically planned and agile approaches for delivering impact.

Our research has mitigated economic and safety risks, reduced environmental impact, informed new public policy, provided high-level professional training, enabled best sustainable use of ageing infrastructure and contributed to the development of standards and guidance. Our work on natural attenuation of pollutants alone saved more that £200M in the UK and £Billions worldwide. Much of our research is driven by the needs of end users and beneficiaries, with whom we maintain close working relationships, via project partnerships, sponsored positions, contract research, consulting, and commercialisation activities.

b. Approach to impact

Maximising impact is an integral part of our research approach. Impact is encouraged and monitored by the Departmental Director of Research and Innovation (DDRI) and our Departmental Commercialisation Champion (DCC). Our philosophy enables us to deliver long-term impact to a broad spectrum of beneficiaries in the UK and internationally, through collaborative research projects, secondments, partnerships and provision of advice and services. Beneficiaries since 2008 include: **Consultants**: AECOM, Arup, Atkins, Buro Happold, Expedition Engineering, Flint & Neill, Halcrow, Hyder, Laing, Mott MacDonald, Ramboll, Scot Wilson, URS, WSP. **Contractors:** Amey, Balfour Beatty, Costain, Interserve, Jacobs, Laing O'Rourke, Morgan Sindall, Morrison, Vinci, Tarmac. **Agencies:** City of London Surveyor, DEFRA, DSTL, Environment Agency, QinetiQ. **Utilities and Infrastructure owners/operators:** Land Transport Authority (Singapore), Network Rail, Railcorp (Australia), Premier League football clubs, SNCF, Tamar Bridge, most UK and several overseas water companies. **Special facility operators and users**: Atomic Weapons Establishment, CSE Servlec, Diamond Light Source, EDF Energy Nuclear Generation, Fugro, Hyundai, Seagate, Subsea 7. **Our Spin-outs:** Construction Innovation, Conteque, Full-Scale Dynamics, Twincon, LimitState, Vulcan, SEAMS Ltd.

Strategically planned impact activities include:

- **Collaborations and Partnerships** are a key mechanism by which we deliver impact, and are exemplified by long-standing collaborations with a diverse range of stakeholders (also mentioned in REF5). Four examples are given here to illustrate the reach, significance and diversity of our approach. Firstly, our partnership with Network Rail led to the establishment of the Rail Innovation and Technology Centre (RITC), one of four partner centres in the UK. The partnership helped accelerate the development of software now developed by *LimitState* (see case study), widely used in the rail and other industries for rapid evaluation of key safety parameters relating to infrastructure, something that is critical in extending the lifetime of our national assets. Similarly, our partnership with DSTL and QinetiQ has enabled an improved understanding of the dynamics of shallow-buried explosives to be obtained, resulting in standardised test procedures and contributing to the ongoing protection of our armed forces in conflict zones. Our agility in responding to industrial challenges has resulted in KTPs. For example, with our partner Anglian Water we developed and implemented artificial intelligence based pump control in sewer systems, to enhance operational efficiency and reduce environmental impact. Our research with Huada Genomics has led to the development biosensors for Shenzhen seawater toxicity detection. Also, a biosensor developed in partnership with Tata Steel is routinely used to detect and monitor polycyclic aromatic hydrocarbons (PAHs) and toxicity in wastewater.
- **Codes, standards and guidance/best practice documents** are targeted by CSE to enable industry uptake of our research. Examples include developing performance standards (BSI),

design guidance (for CIRIA, SCI, IStructE, fib, ACI), best practice guidance (ASCE, DfT) and technical bulletins for end-users. Exemplars of effective delivery of diverse impact by this route include: a predictive approach for the length of pollution plumes which was adopted in the Environment Agency guidance on risk assessment of groundwater pollution and a contaminant industry handbook for Shell. We have been leading the development of design guidelines for FRP concrete reinforcement (fib), and helped shape guidelines on dynamic performance and the effects of human induced vibrations on structures (IStructE, SCI, ASCE). We edited the Steel Designers Manual and contributed to Eurocode3: Structural Fire Design.

- **We engage with Professional Bodies, Interest and Trade Associations** to ensure active dissemination, for example by organising and/or delivering presentations at professional meetings, e.g. "Advances in geotechnical limit analysis" (ICE), or dissemination events such as the UK Water Industry Forum, SWIG (sensors for water interest group) or trade association meetings, e.g. Reuse of tyre wire (European Tyre Recyclers Association).
- **Short courses for industry** have directly engaged and transferred knowledge to industry. Our suite of taught MSc courses is specifically designed using a block structure, to facilitate attendance of industry delegates. Our CPD on contaminant hydrogeology has informed industry, directly linking knowledge transfer to our Natural Attenuation impact case study. Other examples include: “Development of web-based CPD material showing the interaction between Eurocodes and national regulations, conditions and practice” (across the EU), “Design and assessment of structures for vibration” (S. Africa) and “Blast and Ballistic Effects on Structures” (Singapore).

Flexibly managed Exploitation/Commercialisation Impact activities:

Due to the unpredictable nature of exploitable research, IP development and consultancy needs, we have developed an agile approach managed by our DCC who advises on IP protection, commercialisation and non-academic routes to impact. All new academic staff and researchers are mentored and encouraged to develop IP and to exploit their research. Impact is rewarded in the promotions process. The DCC works with the University’s Research and Innovation Services (R&IS) and commercialisation company, Fusion IP, to encourage and coordinate IP and know-how exploitation. The University has a well-established Commercial Assessment System (CAS). University staff are required to disclose potentially exploitable research through a CAS form. For promising IP, a Commercial Business Development Manager is allocated to help with IP protection and exploitation. Our flexibly managed impact activities include:

- **Consulting and Contract testing** activities are encouraged and directed to enhance impact. Total consultancy income since 2008 is £900k (excluding spin-outs). These activities are co-ordinated via our Research Centres, such as the Kroto Research Institute, the Centre for Cement and Concrete, and our spin-outs. Following successful consultancy work with Arup on the London Millennium Bridge retrofit, our academics were invited to join the IStructE Working Group on the Dynamic Performance and Design of Stadia Structures, which led to safety validation projects for several Premier League football clubs and the Olympic Velodrome (see impact case study). Our experts consulted on the Thames Tideway and Couters Creek projects, designing and overseeing the operation of a bespoke full-scale testing facility for sewerage septicity issues. We developed and tested new products (e.g. Lenton Steel Fortress Punching Shear Reinforcement). *Blastech* (est. 2003), operating out of our blast & impact laboratory at Harpur Hill, developed bespoke methodologies for the assessment of the performance of structural and personnel protection systems to blast & ballistic attack. Follow-on work, in collaboration with DSTL and QinetiQ, has focused on experimental investigations using our unique multi-axial compression rig (MAC^2ET) to develop constitutive models for use in numerical simulations of soil response under the intense pressure of an explosion. The MAC^2ET facility has also enabled us to guide industry on the design and manufacture of concrete encasement systems for nuclear power stations, demonstrating the national importance of our research-led interventions and solutions. Our unique hydraulic and soil testing facilities have increased UK uptake of green roofs by providing certification testing to ensure contaminant free material, resulting in enhanced urban biodiversity.
- **Commercial Software** developed in the Department is used by industry and for consultancy. Examples include our award-winning commercial “Vulcan” fire analysis and design software, which is used by consulting structural engineers to specify fire protection for buildings with more certainty, leading to economic benefits and safer structures (applied to the London Olympic Stadium and the Yale Management School). Further examples are the RING and GEO structural

and geotechnical analysis software, the latter exploiting our Discontinuity Layout Optimisation patent. Support for commercial development originated in the RCUK Business Planning Competition in 2000, enhanced by Director sabbaticals and secondments (supported by CSE, KTA and EPSRC Advanced Research Fellowship). A key beneficiary is the offshore industry, where productivity gains in multi-$bn operations are considerable (see impact case study).

- **Patents/licensing** Six patent applications originated from CSE leading to 38 patents granted or pending since RAE08. Patents actively being exploited by our spin-outs include: the novel Erico LSF punching shear reinforcement (*Conteque*), Discontinuity Layout Optimisation (*LimitState*) and Tyre wire in Concrete (*Twincon*). IP on tyre wire in concrete was developed by a string of ten research projects with industrial collaboration. Spin-out *Twincon* (est. 2009) secured an agreement with Twintec Int. to buy all initial production of fibres, up to 10k tonnes per annum.
- **Spinouts** are specifically used as vehicles to maximise engagement with industry and stakeholders, to maximise uptake of research expertise and findings, and to support further research. Our approach to spinouts is that of initial incubation leading to on-going self-sufficiency (e.g. *SEAMS*). For example, *Blastech* has been involved in a six nation EU FP7 project on the development of a blast-resistant container for use in mitigating the effects of explosions in luggage holds of aircraft. A subsequent product patent application was lodged in 2012. *Twincon* is involved in three major research grants, developing equipment and applications for its fibres. **Since 2008 the combined turnover of CSE new companies is £4,234,379.** On the May 2013 payroll the equivalent of **19 full time employees** were remunerated through these companies.

c. Strategy and plans

We see ourselves in a position of strength and our strategic and agile activities deliver both societal and economic impacts across all areas of our research. Our strategy going forward is to maintain our agile approach and develop further our impact delivering resources through a phased modernisation and expansion of our laboratory facilities. In addition, we aim to strengthen and develop new strategic partnerships, target marketing, and accelerate commercialisation of our IP.

Following on from the establishment of a new centrifuge facility, we have plans for a new concrete technology suite, and modernisation and extension of our Heavy Structures Laboratory, internally funded by the Faculty. We have appointed a Departmental Business Development Manager (BDM) who will act as a champion for impact. The BDM will be supported by our DDRI, our DCC and the Faculty of Engineering Research and Innovation Hub (FERIH), and will aim to develop new strategic partnerships with key stakeholders (e.g. Costain). We will use the Faculty's Engineering Gateway to market our resources and expertise and to proactively identify new industrial partners. Impact activities and case studies will be formally reported in our Annual Research Report. We will also continue to formally assess impact activities in the staff annual review, which directly informs promotion and/or exceptional contribution awards. We will run impact seminars highlighting and celebrating industry uptake, develop best practice guides, and publicise impact case studies in collaboration with the University's Media Centre.

d. Relationship to case studies

Reflecting the variety of our impact delivery modes, the case studies describe different vehicles and types of impact: The *Structures* and *Structures/Ground* case studies demonstrate an agile approach to exploitation/commercialisation, whilst our *Ground* and *Water* case studies convey strategic engagement with industry, utility companies and national agencies.

1. '***Rapid analysis and design software for engineers*'** is an example of fundamental research generating patented IP and applications with stakeholders such as oil service companies. Spinout Limit State was formed to market and support the research-driven software.
2. '***Managing full scale dynamic performance of civil infrastructure*'** illustrates how addressing industry needs led to international design guidance and the volume and quality of high level consulting activities enabled the creation of a highly successful spinout company.
3. **'Changing policy and practice for contaminated land and groundwater'** describes major economic and environmental impact based on fundamental research and the creation and application of national policy.
4. **'Management of discolouration in drinking water distribution systems'** shows how our engagement with the water industry resulted in multiple research projects, creating knowledge, tools and techniques widely adopted in the industry, resulting in significant economic impact.