Institution: Cardiff University, School of Engineering
Unit of Assessment: UoA 15
Title of case study: Acoustic Emission Monitoring - Transforming the Inspection of Bridges Worldwide

1. Summary of the Impact

Cardiff University's research in acoustic emission monitoring and refined data analysis has been applied to large, complex structures and has subsequently transformed the inspection processes of concrete and steel bridges. This has been commercialised by Mistras Group Ltd. to provide a safer, more reliable and progressive means of bridge monitoring, enabling the company to acquire a global reputation and increase its turnover to £7.5M per year - £5M relating to Cardiff research. Cardiff's innovations have had major international impacts (in UK, Europe, India and USA) through:

- Significant economic gain;
- Enhanced industrial practice;
- World-wide dissemination to engineering professionals;
- Prevention of serious safety risks to society;
- Markedly reduced CO_2 emissions and reduced negative effects on regional economies.

2. Underpinning Research

Development of the Research

Cardiff's research in acoustic emission (AE) originated in 1993 in a project funded by SERC (Science and Engineering Research Council). The main outcomes were published in papers dating back to 1998 [3.1]-[3.3], which established the empirical evidence on which the AE monitoring technique was based. There were three major research insights which underpin the resulting impact: (i) the methodology for global and local monitoring, which enabled the techniques to be used reliably on large structures [3.1], (ii) the generation of empirical evidence for characterisation of fault types (in the PhD theses by Carter and Pullin), and (iii) the improvements in data analysis, particularly source location accuracy [3.2].

At the time it was thought that large structures could not be fully monitored by AE due to prohibitive sensor requirements. Cardiff's research challenged this by proposing that coverage of large structures could be achieved using so-called global and local arrays in specific combinations. It also provided key information regarding the propagation of stress waves arising from various faults in slender plate-like structures. Furthermore, it established the importance of accurate detection of the arrival of individual AE events in order to improve location accuracy. This knowledge led to the development of commercial AE monitoring systems by Mistras Group Ltd. (formerly Physical Acoustics Ltd.) [3.4].

The current technology resulted from extensive laboratory and field research carried out by Cardiff's AE group between 1993 and 2002, funded by SERC, two Knowledge Transfer Partnership (KTP) awards and a number of industrial contracts to validate the technique on bridges between 2000 and 2005 [3.5]. It uses passive high frequency sensors, placed externally on the surface of the structure under test, to detect energy released from growing defects, up to many metres away. The method monitors 100% of the structure, even the internal details and

inaccessible areas. Benign flaws (that do not propagate) are not detected; however, active flaws are located, enabling defects to be identified early, monitored, and managed, allowing prioritisation of repairs. The method is used as a strategic planning tool in conjunction with risk based inspection to manage assets, to provide information that enables extension of life and reduction of road closures, which subsequently result in reduced whole-life costs.

Key Research Staff Involved

The key research staff at the outset were Professor Karen Holford (providing the expertise in AE) and Dr Aled Davies (in bridge structures), then both lecturers. The key research findings resulted from the PhD studies of Damian Carter, supervised by Holford, and Rhys Pullin, supervised by Holford and Davies. Further refinement of the technique was achieved through the MPhil studies of Jon Watson (also supervised by Holford and Davies). In 2005 the technique was licensed to Physical Acoustics Ltd. for use in steel bridges. Davies left the University in 2006. Refinement of the technique and application to other structures continued, particularly through the MPhil of Tim Bradshaw and additional PhD students (supervised by Holford and Professor Bob Lark, then a lecturer). The technique continues to be extended, improved and tested in other fields, e.g. in the aerospace industry, including projects with Messier Dowty, Airbus and Boeing.

3. References to the Research

3.1 **Carter, D.C.** and **Holford, K.M**. (1998) Strategic considerations for the AE monitoring of bridges - a discussion and case study, *INSIGHT - the Journal of the British Institute of NDT*, Vol. 40 No. 2, pp. 112-116, ISSN 1354-2575

3.2 **Holford, K.M.** and **Carter, D.C.** (1999) Acoustic Emission Source Location, *Key Engineering Materials*, Vol. 167-168, pp. 162-171, ISSN 1013-9826

3.3 **Pullin, R.** and **Holford, K.M.** (1999) Damage Assessment in Steel Bridges, *Key Engineering Materials*, Vol. 167-168, pp. 335-342, ISSN 1013-9826

3.4 **Watson, J.R.,** Cole, P.T., **Holford, K.M.** and **Davies. A.W**. (2001) Damage Assessment Using Acoustic Emission, *Key Engineering Materials*, Vol. 204-205, pp.309-318, ISBN0-87849-879-0, 10.4028/www.scientific.net/KEM.204-205.309

3.5 **Holford, K.M**., **Davies, A.W**., **Pullin, R** and **Carter, D.C.** (2001) Damage Location in Steel Bridges by Acoustic Emission, *Journal of Intelligent Material Systems and Structures*, Vol. 12, pp. 567-576, ISSN 1045-389X, 10.1177/10453890122145311

Funding Information:

SERC GRJ10433 (1993-1996) **Davies A.W.** and **Holford K.M**. £50k: Health Monitoring of Steel Bridges (graded alpha3).

4. Details of the Impact

Links Between Impact and Research:

The AE knowledge and technique, established entirely through Cardiff's research, was transmitted to Mistras Group Ltd. (MGL) through two KTPs (1998 and 2000, Jon Watson and Tim Bradshaw, who are now full time employees at MGL). These provided a mechanism to embed the research and its findings in the company. They also enabled its commercial development and subsequent impact, through close collaboration and the final placement and employment of the KTP associates by MGL. Moreover, both parties have actively ensured the continued impact of the work via engagement with industry.

Impacts During the REF Period:

Direct Economic Gain - Through commercially exploiting the techniques developed and refined by Cardiff University (under a know-how licence, 2005-2015), MGL's turnover in the UK has soared from £300k in 2005, £608k in 2008, to £2.5M in 2012. In the current financial year the company has recorded a turnover of £7.5M – £5M relating to Cardiff University's research. MGL is now the market leader in using AE for structural testing. It claims over 85% of the global market share in AE sensors and equipment sales. Its AE techniques are exported to subsidiary companies in Northern Europe, the Middle East and Asia. The current value of the company worldwide (after the integration of Cardiff's innovations) is $531M [5.1]. Referring to the immediate and lasting impact of the research, Phil Cole (the Group Executive Vice President, International, of MGL) stated that '*as a result of the KTP, Physical Acoustics Ltd. is now the market leader in the application of acoustic emission technology to civil engineering structures. The KTP proved invaluable for my company.*' [5.2]

MGL's major contracts have included the M4 Thames Bray Bridge, M5 J1 and J2 box girders, M6 J6-J9 box girders, M6 J21 Thelwall Viaduct, M8 Whitecart Viaduct, M53 Bidston Moss, M50 Queenhill Viaduct and M60 Irwell Bridge. Furthermore, Cardiff's research has allowed parallel developments of other applications with large commercial contractors on both Severn (£550k) and Humber (£900k) Suspension Bridges, A4 Hammersmith Flyover (£2.4M), Royal Navy Trident submarine dock, M4 elevated section, A38(M) Aston Expressway and North Sea oil platforms. MGL is now regarded worldwide as a major structural monitoring contractor which has aided corporate positioning, allowing bids for major new build projects such as the Izmit Bay Suspension Bridge in Turkey (worth £1M), Qatar to Bahrain Causeway (£20M) and the proposed Messina Suspension Bridge between Italy and Sicily (£10M). Examples of the international contracts the company has secured to date are the San Francisco Oakland Bay Bridge (£3.4M), the Anthony Wayne Suspension Bridge (£1M), and the Manhattan and Ben Franklin Suspension Bridges [5.1].

Figure 1. **Oakland Bay Bridge, San Francisco, USA**

The research and expertise gained from Cardiff have enabled MGL to expand into new areas. Recently MGL has successfully applied the techniques to the monitoring of cables and wind turbines (both on and off shore). Jon Watson, Project Manager at MGL, stated that *'the techniques*

developed through the research have been used on concrete and steel bridges in the UK and have significantly developed the UK branch of Mistras and helped to gain business abroad and add value to the parent company overall…Moreover, the techniques have been applied to other fields…which would arguably not have been possible without the original research'. [5.1]

Environmental and Economic Savings - Cardiff's research enables bridges that previously had to be manually inspected to be promptly, accurately and safely monitored using AE techniques. It acts as an early warning system to prevent major structural repair. Subsequently it mitigates lengthy road closures, traffic congestion, CO_2 emissions, and delays to individuals and emergency services (and the negative effects thus caused to regional economies). Government statistics estimate that traffic delays costs the local economy £8B/year while the International Road Transport Union states that traffic congestion can increase CO_2 emissions by 300% [5.3],[5.4]. Examples of major and lengthy road closures that have occurred through the need to perform expensive structural repairs are the Hammersmith Flyover in London (closed at Christmas 2011 and not fully reopened until May 2012, as part of work costing £10M), the Sutton Ford Bridge in Essex (closed for 6 weeks, in August 2012, in a £2.9M rebuild) and the Lovell Park Road Bridge in Leeds (closed for 9 months until March 2013, costing £25M). Cardiff's AE techniques act as a preventative to this and are applicable on an international basis [5.5].

Industrial benefits - Cardiff's research has had a major impact on industrial practises and standards. Cardiff University jointly composed the Highways Agency "Advice Notes on the Non-Destructive Testing of Highway Structures – 3.6 Acoustic Emission", which is used by engineers throughout the UK [5.6]. Moreover, as mentioned above, the techniques have been adopted by contractors performing AE tests UK-wide and internationally as a product of MGL transmitting the know-how it has gained to its subsidiary companies in Northern Europe, the Middle East and Asia. The AE techniques have been disseminated to industry professionals through seminars organised by the BSSM, the Institute of Physics and MGL. Furthermore, staff from Cardiff University and MGL are members of relevant industrial advisory groups that work with organisations such as London Underground, Network Rail, the Highways Agency and Sellafield Ltd. [5.7].

5. Sources to Corroborate the Impact

All documents and website pages saved as PDFs October 2013 and available from the HEI

5.1 Project Manager, Mistras Group Ltd. *Corroborates the use of the research by MGL and the resulting impact for the company.*

5.2 Group Executive Vice President, International Mistras Group Ltd. *Corroborates the impact of Cardiff's research on MGL*.

5.3 IMechE_Intelligent_Transport_Intelligent_Society.sflb.pdf. *Corroborates the cost of road disruptions to the economy. Available from Cardiff University upon request.*

5.4 http://www.iru.org/en_policy_co2_response_flowingtraffic *Corroborates the increase in CO_2 emissions as a result of traffic congestion.*

5.5 http://www.echo-news.co.uk/news/local_news/rayleigh/9842324.Roadworks_to_repair_bridge_at_Sutton_Road/. *Provides an example of a bridge closure due to the need for structural repairs*.

5.6 http://www.dft.gov.uk/ha/standards/dmrb/vol3/section1/ba8606.pdf *The Highways Agency Advice Notes composed as a consequence of the research.*

5.7 http://www.bssm.org/default.asp?p=6&event=163 This is an e*xample of an event where the research was disseminated. The audience included industry members.*