**Institution: University of the West of Scotland**

**Unit of Assessment: 15 – General Engineering**

**Title of case study: Development and Testing of Self Compacting Concrete**

**1. Summary of the impact** (indicative maximum 100 words)

The Advanced Concrete and Masonry Centre (ACMC) at UWS was among the pioneers in development of practical self-compacting concrete (SCC) in Europe. As a lead partner, the group contributed to two large EU projects on SCC, which underpinned the European standards on SCC test methods.

The group's research has contributed to the steadily increasing use of SCC in general construction, which has brought many benefits, such as enhanced durability, improved productivity, reduced overall cost, improved working environment and sustainability. Given the massive quantities of concrete being used (>14 billion tonnes/year globally), the increased use of SCC has had important economic, societal and environmental impacts.

**2. Underpinning research** (indicative maximum 500 words)

The research on underwater concrete mixes undertaken by Professor Bartos and Dr Zhu in the early 1990s achieved similar characteristics to that of the original proprietary Japanese SCC mix (first demonstrated at the University of Tokyo in 1988, but with very little information in the public domain). During 1997 to 2000, the ACMC group (with Professor Bartos as the Director) was a lead partner for the first EU funded research project on SCC – 'Rational Production and Improved Working Environment through using Self-compacting Concrete' (1997-2000) [G1], led by industry. In this R&D project, where various SCC mixes were developed and their properties studied in comparison with those of conventional concrete mixes, the ACMC group was responsible for studying properties of various hardened SCCs. The research on SCC published in leading international journals included: Uniformity of in-situ properties [3.1], Durability/Permeation property [3.2], Bond to reinforcement and interfacial properties [3.3], and these papers were among the first published in the field which provided essential information on the performance of various hardened SCCs.

Due to its success and the benefits realised, the SCC project was one of the ten finalists considered for the EU Descartes Prize in 2002. However, the absence of suitable test methods to identify its key fresh properties hindered the increased use of SCC because it was difficult to validate mix designs except by full-scale trials (feasible in special projects only) and confidence in the material was therefore undermined. To overcome such a critical obstacle and to facilitate the adoption of SCC technology in general construction, ACMC led the second EU research project – Testing-SCC (2001-2004, 12 partners) [G2]. 15 test methods (and/or combinations) were evaluated both in the laboratory and on site. The project culminated in a systematic and rigorous pan-European inter-laboratory 'round-robin' evaluation, in which 23 major companies, research institutes and universities from 12 countries participated. Results of selected test methods on repeatability and reproducibility, and their sensitivity to detect meaningful changes in the key characteristics of a wide range of SCC 'test' and commercial mixes during construction were obtained and published [3.6], which formed the basis for the new European standards for SCC [5.1 - 5.5].

In addition, there is often a requirement for increased powder content in SCC mixes, which is usually met by the use of more cement. However, an increase in cement content leads to a significant rise in material cost, and has negative impact on the environment and some concrete properties (e.g. increased thermal stress and shrinkage). Significant research was thus carried out at UWS to study the use of low cost and waste 'dusts' (e.g. fly ash, limestone/chalk powders and quarry fines) in practical SCC mixes [3.4 - 3.5, G3 - G5]. These studies facilitate the inclusion of such 'dusts' in SCC mixes, which leads to more competitive SCCs in practice and also brings additional environmental benefits.

Key Researchers of ACMC:

Prof Peter JM Bartos, Director of ACMC, retired and became an Emeritus Professor in 11/2004.
Mr John Gibbs, Deputy Director of ACMC, left in 04/2005.
Dr Wenzhong Zhu, Lecturer.
Dr Mohammed Sonebi, Lecturer, left in 03/2004.

**3. References to the research** (indicative maximum of six references)


3.1 Zhu, W, Gibbs, JC and Bartos, PJM, 'Uniformity of in-situ properties of self-compacting concrete in full-scale structural elements', *Cement and Concrete Composites*, 2001, 23 (1), pp.57-64.
3.2 Zhu, W and Bartos, PJM, 'Permeation properties of self-compacting concrete', *Cement and Concrete Research*, 33 (6), 2003, pp.921-926.
3.3 Zhu, W, Sonebi, M and Bartos, PJM, 'Bond strength and its interfacial transition zone with reinforcement in self compacting concrete', *Materials and Structures*, 37(271), 2004, pp.442-448.
3.4 Zhu, W and Gibbs, JC, 'Use of different limestone and chalk powders in self-compacting concrete', *Cement and Concrete Research*, 35 (8) 2005, pp.1457-1462.
3.5 Sonebi, M, "Medium strength self-compacting concrete containing fly ash: modelling using factorial experimental plans", *Cement and Concrete Research*, 34 (7) 2004, pp. 1199-1208.
3.6 Zhu, W, Gibbs, JC, et al., 'Measurement of properties of fresh self-compacting concrete', Final technical report of European Testing-SCC project (G6RD-CT-2001-00580), 2005, 66pp, available online at http://www2.cege.ucl.ac.uk/research/concrete/Testing-SCC/Final%20project%20report.pdf .


Evidence of the Quality: According to the Google Citation report at 10/10/2013, the 5 peer-reviewed journal papers 3.1 - 3.5 have been cited 369 times. Paper 3.4 was on the top of the most downloaded articles list for that journal for two consecutive periods (Jul.-Dec. 2005).

**Relevant grants and contracts:**

G1. 1997-2000, ~ €3M, EU, "Rational Production and Improved Working Environment through Using Self-Compacting Concrete", Brite EuRam project BR-PR-CT96-0366, NCC AB, Sweden (co-ordinator), GTM Construction, Betongindustri AB, LCPC, University of Paisley (now UWS), CBI Sweden, Lulea Technical University, NV Bekeart, Sika Spain.
G2. 2001-2004, ~ €936k, EU FP5 GRD2-2000-30024 "Measurement of Properties of Fresh Self-Compacting Concrete (Testing – SCC)", University of Paisley (now UWS) as the co-ordinator, with eleven European partners from Sweden, France, Belgium, Germany, Netherlands, Denmark, Iceland and UK.
G3. 2001, £7k, to J Gibbs, from Omya UK, "Use of Limestone and Chalk Powders in Self-Compacting Concrete".
G4. 2002-2003, £59k, to Dr M Sonebi, from EPSRC, "Optimization of mix-design for medium strength self-compacting concrete".
G5. 2008, £5k, to Dr W Zhu, from Scottish Government KTTBE project (SEEKIT programme), "Self compacting concrete for use in an existing precast concrete plant – a feasibility study".

**4. Details of the impact** (indicative maximum 750 words) 800 words

Concrete is the most widely consumed material in the world after water. The need to fully compact fresh concrete to remove the entrapped air and produce a dense homogeneous mass with the required strength, durability and finish has long been recognised. Compaction by vibration, however, is slow, noisy, dangerous and often difficult to carry out and supervise. Due to its high filling ability, passing ability and resistance to segregation, SCC flows freely into the pre-formed moulds/formwork and achieves full compaction under its own weight, thus eliminating the need for mechanical vibration. This saves time, improves quality of the hardened concrete, reduces labour needs, cuts energy demands, facilitates automation, and particularly, removes the health/safety risks associated with vibration (e.g. deafness, "white fingers", and noise-led stress). As a result, SCC is widely considered as the most significant innovation in concrete construction for the last 50 years.

Research carried out at UWS has made several important contributions to the development and increased use of SCC. The study on hardened properties of different SCCs (G1, 3.1 – 3.3) provided essential performance data for using SCCs, which led to more confidence in the industry in using such materials. The work on SCC test methods by UWS and the partners of the EU Testing-SCC project (G2, 3.7) has resulted in new European standards for testing this concrete [5.1 - 5.5], and thus removed a critical obstacle for the widespread adoption of SCC technology in general construction. Research results and findings of the ACMC researchers and from the EU projects were widely disseminated, through invited lectures/presentations in international conferences and to industrial companies in Europe, USA, Mid East, China and New Zealand, etc. UWS researchers also achieved impact through their leadership and participation in various national and multi-national interest groups/technical committees. For example, Professor Bartos chaired the SCC Working Party of the UK Concrete Society (with Mr Gibbs as the Secretary), which together with the Building Research Establishment, produced a comprehensive review report on SCC [5.7] in addition to other related documents. Through working with RILEM technical committee TC – 205 DSC "Durability of Self-Compacting Concrete" (by Drs Zhu and Sonebi), ACMC made a significant contribution to the RILEM State-of-the-Art reports on 'Durability of Self-Compacting Concrete' [5.8]. Through active links with industry and CEN, the results and findings were also used by the European industry to produce the widely-accepted 'Guidelines for SCC: Specification, Production and Use' in 2002 and 2005 [5.6], and in the new European standards for testing SCC. In a letter of support provided by ERMCO (the industry organisation representing most concrete producers in Europe), it stated that UWS has been one of the principal actors in SCC development, and UWS's role in the above development has been pivotal [5.10].

As a result of the above developments (led by UWS researchers) and contributions made by many others, the application of SCC in general construction has been steadily increasing in many European countries, e.g. SCC has achieved around 30% of the total concrete market share in Denmark, around 10-15% in Sweden and the Netherlands, and many precast concrete manufacturers now use 100% SCC. In fact, Europe is the world leader in this innovative construction technique (SCC is used more widely in Europe than in Japan and USA). It has been predicted that SCC is likely to replace most of the conventional concrete in the future [5.9 – 5.10].

These authoritative reviews/reports, guidelines and standards, though produced in Europe, have also had a global impact, as they formed the basis for Reviews/Guidelines/Specification/Test methods for SCC which were adopted by many other countries. The research, particularly the work associated with testing SCC standards, prevented each country or company adopting different test methods, and thus facilitated increased confidence in the materials and a more rapid acceptance of SCC in general construction. With the application of SCC in general construction, the construction industry has benefited from improved productivity and reduced overall costs (due to faster production process, lower labour & equipment demand and less repaired work). The superior level of finish and durability achieved through the use of SCC benefits the users and owners of the structure/building. The elimination of vibrating equipment improves the environment on and near construction and precast sites where concrete is being placed, reducing the exposure of workers and the public to noise and vibration. Furthermore, UWS's research on using low cost and waste 'dusts' in practical SCC mixes [G3, G4, 3.4, 3.5] has also impacted on the increasing use of industrial by-products/wastes in SCCs, and contributes to a vital drive for better environment and sustainability.

Considering the scale of construction industry (e.g. representing 11% of GDP and 7% of workers in Europe) and the massive quantities of concrete being used (>2 tonnes/person/year), the increased use of SCC has had and will continue to have a major economical, societal and environmental impact.

**5. Sources to corroborate the impact** (indicative maximum of 10 references)

The claims presented here can be validated through the published papers/reports referenced above, and through the review papers/reports, guidelines and European standards listed below.

5.1 BS EN 12350-8: 2010, Testing fresh concrete - Part 8: Self-compacting concrete – Slump-flow test
5.2 BS EN 12350-9: 2010, Testing fresh concrete - Part 9: Self-compacting concrete – V-funnel test
5.3 BS EN 12350-10: 2010, Testing fresh concrete - Part 10: Self-compacting concrete – L box test
5.4 BS EN 12350-11: 2010, Testing fresh concrete - Part 11: Self-compacting concrete – Sieve segregation test
5.5 BS EN 12350-12: 2010, Testing fresh concrete - Part 12: Self-compacting concrete – J-ring test
5.6 BIBM, CEMBUREAU, ERMCO, EFCA and EFNARC, 2005, The European Guidelines for Self-Compacting Concrete: Specification, Production and Use, 68pp, available at: http://www.europeanconcrete.eu/images/stories/publications/en_guidelines.pdf?phpMyAdmin=16bbb563ca43adfed14bd78eb7d8cd8a .
5.7 Concrete Society/Building Research Establishment (BRE) (2005), Self-compacting Concrete: a Review, Report of a Joint Working Group. The Concrete Society and BRE, Camberley, Surrey, UK, Technical Report No. 62.
5.8 State-of-the-Art Report of RILEM Committee TC – 205 DSC “Durability of Self-Compacting Concrete”, RILEM Report 38, RILEM Publications, Paris, Sept. 2007, 185 pp. ISBN- 978-2-35158-048-6.
5.9 De Schutter, G, Bartos, PJM, Demone, P and Gibbs, J, Self Compacting Concrete, 288pp, Whittles Publishing (2 April 2008), ISBN-10: 1904445306, ISBN-13: 978-1904445302.
5.10 European Ready-Mixed Concrete Organisation (**ERMCO**), Statement of support for the University of the West of Scotland’s submission for REF 2014, November 2013. **Available on request.**