ESIA13 – 13th International Conference on Engineering Structural Assessment

19-20 May 2015
Manchester, UK

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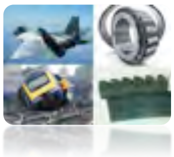

The FESI Bulletin

The magazine of the UK **Forum for Engineering Structural Integrity**
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EMAS PUBLISHING

FESI's publishing arm and source of specialised structural integrity information for engineers

ASSERTING FAILURE PROBABILITY ASSOCIATED WITH DEGRADATION OF CONCRETE STRUCTURES
Břetislav Teplý, Dita Vořechovská

"We are proud to be associated with FESI"
Alan Chung, Penspen

RELIABILITY OF DAMAGED STRUCTURES
Dan M. Frangopol, Duygu Saydam

Report on FESI's SHORT CRACKS CPD Workshop
Mahmoud Mostafavi

Professor Mike Fitzpatrick:
Leading change at the university-industry interface

Engineering Structural Integrity is **Engineering for a safer world >**

Following a contact from the Lloyd's Register Foundation, Directors of FESI met with representatives of that organisation to explore areas of common interest related to engineering structural integrity. Certainly the topics of structural integrity and systems performance are priority activities for the Foundation. I would recommend you read their Strategy 2014-2020, which can be found online at **www.lrfoundation.org.uk**. An introduction to the Lloyd's Register Foundation appears on page 10 together with an overview of the strategy document.

However, these discussions have made me reflect on the progress that has been made on the understanding of this multidisciplinary topic over the past twenty years. It was in 1992 that a conference was held in the UK with the title Structural Integrity Assessment. The published proceedings still make interesting reading, but more important are the messages in the preface prepared by Professor Peter Stanley (Department of Engineering, University of Manchester),

> "The assessment of structural integrity is a vitally important consideration in many fields of engineering, which has an influence on the full range of professional activities from conception, design and analysis, through operation, to residual life evaluation and possible life extension. In devising satisfactory procedures for this purpose there is a clear need for interaction and information exchange across this broad spectrum of activities. … (the conference) is designed to meet this need by providing a forum for the exchange of expertise and knowledge amongst engineers from a wide range of professional backgrounds and disciplines."

The conference led to the series now entitled **Engineering Structural Integrity Assessment** and the next, **ESIA13**, will be held on **19 and 20 May 2015** in Manchester. Over the intervening period FESI was established and we have seen a progressive increase in both the understanding and need for this cross-discipline topic which is so important to the engineering community and society at large. The FESI membership now includes representatives from a wide range of major engineering industries, the supply chain, business and academia in the UK. In addition, there are increasing links being developed with China via Professor Su Jun Wu (Beihang University, Beijing) and Professor Shan Tung Tu (East China University, Shanghai). Both are representatives in the Chinese Structural Integrity Committee chaired by Professor Tu.

The key to the work of FESI is communication of best practices across the various industry, business and academic sectors. To achieve this we continue to have a lively programme of workshops, and details of our biannual ESIA conference can be found on page 2 of this issue of The FESI Bulletin. I would encourage you to put these dates in your diaries for 2014 and 2015. Your participation is fundamental to their success.

Finally, I hope that you will find this issue of The FESI Bulletin both instructive and informative. Remember if you wish to publish a contribution to the future issues please contact either me, Peter Flewitt, at Peter.Flewitt@bristol.ac.uk; or Elisabeth Le May at elisabeth.lemay@fesi.org.uk

Peter Flewitt
Editor-in-Chief

INSIDE THIS ISSUE

Cover image courtesy of Coventry University

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UK FORUM FOR ENGINEERING STRUCTURAL INTEGRITY

Call for Papers

ESIA13

13th International Conference on Engineering Structural Integrity Assessment

19 and 20 May 2015, Manchester, UK

The thirteenth biennial **International Conference on Engineering Structural Integrity Assessment** will be held at the Manchester Conference Centre in Manchester, in the centre of one of the most technologically historic and exciting cities in the United Kingdom, with has one of the largest universities.

This prestigious and long-running conference will bring together delegates from around the world to discuss how to characterise, predict and analyse the Engineering Structural Integrity (ESI) of plant, components and structures together with buildings and the infrastructure. ESI is the science and practice of increasing engineering safety and reliability. We will be considering how economic challenges can be safely accommodated in both new design and in the operation of existing plant.

Oral and poster presentations will allow sufficient time for follow-up discussions, friendly debate and relaxed participation.

MAIN TOPICS

These relate to the assurance of structural integrity in relation to Safety Cases and operational reliability across industry. The areas to be covered will include:

ESI methodology developments – Materials modelling and testing for applications, including through-life property changes – *Non-Destructive inspection technology* developments – Condition monitoring of structures and components – *Design and assessment codes and standards* – Durability assessment of component damage – *Operational experience including case studies* – Risk-based inspection and maintenance – *Plant life extension methodologies* – *Issues relating to decommissioning, disposal and long term waste storage*

KEYNOTE PAPERS

Each day will be introduced by a series of keynote presentations from internationally recognised authorities, drawn from the industry, business and academic communities.

SCOPE

We invite papers from industry, regulators, academia, technology support and supply chain organisations, relating to:

Power Generation – *Renewable Energy* – Defence systems – *Aerospace* – Transport (Rail, Automotive) – *Process plant* – Oil and Gas – *Civil Engineering* – Medical devices

YOUNG PRESENTERS AWARD

The Conference Organisers are keen for postgraduates and early career workers to submit papers. To encourage this, FESI presents the Young Presenter Award and a prize for the best paper and presentation, and for the best poster.

CALL FOR PAPERS

1. Abstracts (up to 300 words) should indicate the theme and topic area to which it is appropriate and contain the presentation title, the author's name(s) and affiliation(s), five key words, an illustration and table, and the full contact details of the corresponding author.
2. The conference language is English.
3. Papers are accepted on the understanding that an author will present the paper at the Conference in English.

EXHIBITION AND POSTER DISPLAY

All the delegates will be keen to see new and innovative equipment, software and research that could assist them in their work situation. Use this opportunity to exhibit and demonstrate your latest products and developments. Posters can be used to communicate recent research in both industry and academia.

SPONSORSHIP

Put your company's or organisation's name in front of all the delegates by sponsoring a Conference Event:

- the main Conference itself,
- Conference Reception,
- Conference Dinner,
- Conference fliers.

For further information please contact Brian Daniels on the Conference Organising Committee at **brian.daniels@amec.com**

VENUE

The Conference will be held at Manchester Conference Centre close to the centre of Manchester in the United Kingdom.

DATES TO NOTE

- Abstracts must be submitted – **21 November 2014**
- Authors will be notified of acceptance – **5 December 2014** (with guidelines)
- Submission of Full Paper for review – **1 March 2015. All papers received at that date will be included in the conference proceedings of ESIA13**

CONFERENCE SECRETARIAT DETAILS

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Professor Mike Fitzpatrick

New Post as Executive Dean for Coventry University's Faculty of Engineering and Computing

Professor Michael Fitzpatrick CEng CSci FIMMM, active and respected member of the FESI Council and acknowledged as an outstanding academic leader and researcher, has been in post as Executive Dean for Coventry University's Faculty of Engineering and Computing since 1 May 2014. He is also the Lloyd's Register Foundation Chair in Materials Fabrication and Engineering.

Mike Fitzpatrick represented The Open University's engineering structural integrity (ESI) interests to FESI – and vice versa – in his former capacity as Head of the Department of Engineering and Innovation at the OU.

LEADING CHANGE IN THE UNIVERSITY-INDUSTRY INTERFACE

Professor Mike Fitzpatrick is passionate about turning the traditionally reactive relationship between a university engineering department and industry on its head. He intends to ensure that his Faculty is proactive in meeting industry's needs and solving their problems, rather than simply selling a service – an innovative approach he describes as bringing "the university [to] the factory floor".

Mike's professional experience, both as an engineer and in working for the OU for 19 years, has reinforced his view that real, relevant and timely collaborations between university departments and industry will deliver 360-degree value. Industry will benefit from an active partnership that will assist their practical evolution and productivity; university staff will deliver relevant teaching to students; students will learn to develop flexible skills grounded in the real world; and research outputs will be impactful.

HIGH QUALITY, HIGH VALUE

Not content with paying lip service to a university-industry alliance, he perceives that relevant research and development outputs are critical to the way forward for Coventry University's Faculty of Engineering and Computing, its staff and students. High quality outputs, therefore, are key to Mike's agenda.

> New undergraduate and postgraduate programmes in advanced engineering and management will result in a **new generation of highly skilled, commercially aware engineers**, who are equipped to support and lead the UK's lucrative manufacturing sector in a globally competitive market.

The students voted three of the Faculty's departments 90% or higher for teaching quality in 2014's National Student Survey. The university featured in the QS World University Rankings 2013/14, representing the world's top 4% of higher education institutions. It is ranked 27 in the Guardian League Table and 42 in The Times and Sunday Times League Table, and has been awarded the title of Modern University of The Year for both 2014 and 2015, the only University to have won the award twice in succession. Subject range, research, academic reputation and employability are key factors in the University's global league standing. Mike, known to be a highly supportive academic advisor, is working with a discerning and demanding student body, which patently shares his values of quality, relevance, and transferability. He praised the talented team of teaching staff in their support for students and their research outcomes.

Coventry University's Engineering and Computing Building

CUTTING EDGE FACILITIES FOR ACADEMICS AND BUSINESSES

Mike Fitzpatrick is joining the university when Coventry's innovative Engineering and Computing Building is just two years old. Arup Associates designed the building as a teaching tool, and envisaged that the £55m environment itself would be part of the students' learning experience.

The building, rated BREEAM 'excellent", both underpins the university's – and Mike's – experiential learning approach, and fosters team and partnership working between the students. As a demonstrator for sustainable construction, the building lends itself to being interrogated by students seeking to understand engineering practices and methodologies. It is, moreover, an organic illustration of the relationship between ESI, architecture and the built environment.

For industry and, especially, small and medium sized enterprises (SMEs), this facility is the key to accessing the innovative engineering technologies and specialisms required for their business competitiveness. Advanced laboratories, prototyping and production test facilities, CAD, 3D visualisation, digital simulation and stress and fatigue analysis are available to businesses, and preclude the need for SMEs to have these costly facilities in-house. The value of this resource as perceived by the UK's businesses is confirmed in the last audited figures, 2009/10, which showed that 37% of SMEs working with a university chose to work with Coventry.

The building's value and potential as both an effective tool and a powerful resource will continue to be harnessed and realised under Mike's leadership, and driven by a collaborative approach which promotes achievement between the partners.

ENGINEERING EXCELLENCE AT THE COAL FACE

The new Institute for Advanced Manufacturing and Engineering, a £32m joint project between Coventry University and the multinational logistics, supply chain and manufacturing Unipart Group, is set to break the mould for university-industry relationships, an exemplar which Mike is sure other universities will wish to follow.

Illustration of the Unipart site

Located at Unipart's Coventry manufacturing site, the Institute's new building will become an international centre of excellence for engineering and manufacturing through activity-led learning, with students spending time in the Institute which is contiguous with the shop floor at the Unipart facility, and at the Engineering and Computing building. Designed, ultimately, to boost the economy, the new undergraduate and postgraduate programmes in advanced engineering and management will result in a new generation of highly skilled, commercially aware engineers, who are equipped to support and lead the UK's lucrative manufacturing sector in a globally competitive market.

Carol Burke, Unipart Manufacturing Group's Managing Director, said:

> "Unipart Manufacturing enjoys a close working relationship with Coventry University as we share many of the same passions … This exciting project gives us the opportunity to support Coventry University in the development of new and innovative ways to train the engineers of the future, giving them real, industry-relevant projects and experience in a live manufacturing environment."

Mike Fitzpatrick corroborated, saying:

> "That's something that's very close to my heart. I very much believe that engineering teaching and research should be focussed on the current and future needs of our industrial base, and not just what the University can do with its existing capability. Investment in new facilities and new ways of working is one of my key objectives at Coventry."

INVESTING IN RESEARCH

Coventry University is investing heavily in its new research strategy, planning to spend over £150 million on staff and infrastructure. The strategy is being driven by Professor Kevin Warwick, the world-leading cybernetics researcher, who has joined Coventry as Deputy Vice-Chancellor for Research. Mike is working on establishing new Faculty Research Centres, with a structural integrity theme within the new Centre for Manufacturing and Materials Engineering, that is integrated with the Institute for Advanced Manufacturing and Engineering. Two new professorial posts have been recruited already, including Professor Xiang Zhang, who joins from Cranfield in January 2015. Other Faculty Research Centres include the Centre for Low-Impact Buildings, and a cross-Faculty Centre in Transportation and Mobility in conjunction with the Coventry School of Art and Design.

GLOBAL HUMANITARIAN ENGINEERING

Mike knows that not all engineering projects are created equal. Differences in engineering practices around the world, differing financial and other resources, skills levels, and cultural and social issues all mean that innovation in project delivery is key to a successful outcome. Mike is, therefore, very pleased that the Faculty will contribute, under his leadership as Executive Dean, to Humanitarian Engineering & Computing on a global scale through UNITWIN. This UNESCO initiative encourages inter-university cooperation, information sharing and collaboration by 'twinning' universities of the global North and the global South. Working with partners Massey University, New Zealand, Arusha University, Tanzania, and Malta University, Coventry's Faculty of Engineering and Computing will help to translate ideas arising through the network into reality and appropriate engineering and IT training and practices.

CAREER IN BRIEF

Mike last 19 years were spent on staff at The Open University, latterly as head of the Department of Engineering and Innovation. He is the Lloyd's Register Foundation Chair in Materials Fabrication and Engineering: the Lloyd's Register Foundation is a charitable foundation helping to protect life and property by supporting engineering-related education, public engagement and the application of research.

Mike's research interests are in the areas of nuclear structural materials; residual stress analysis using neutron and X-ray diffraction and other, destructive techniques; and materials for improved fatigue resistance of aerospace structures. Amongst his many activities he leads the EPSRC PROMINENT consortium, a £1.8m grant researching the performance of metallic materials for applications in nuclear power plant.

A particular area of interest has been the analysis of welds and joints, and the effects of residual stresses in welded structures; to this end he worked with TWI on the development of the joint OU/TWI Foundation Degree in Materials Fabrication and Engineering, and with the National Skills Academy for Nuclear on the development of their Certificate in Nuclear Professionalism.

Mike was Chair of T173 Engineering the Future, the OU's flagship first-year engineering course that ran from 2001 to 2012. Some extracts from the course texts are presented in online format on the OU's OpenLearn site.

Mike previously contributed to other courses including T207 *Mechanics, Materials, Design*, and T357 *Structural Integrity: Designing against failure.*

Coventry University's Engineering and Computing Building

MOST RECENT PUBLICATIONS

B. Ahmad, M. E. Fitzpatrick, 'Residual Stresses in Ultrasonically Peened Fillet Welded Joints', *Advanced Materials Research*: 2014: 996:755-760.

A. K. Syed, M. E. Fitzpatrick, J. E. Moffatt, 'Evolution of residual stress during fatigue crack growth in an aluminium specimen with a bonded crack retarder'. *Composite Structures*: 2014: 117:12-16.

J. A. de Oliveira, M. E. Fitzpatrick, J. Kowal, 'Residual stress measurements on a metal matrix composite using the contour method with brittle fracture', *Advanced Materials Research*: 2014: 996:349-354.

Zhang, Hongtao; Gorley, Michael J.; Chong, Kok Boon; Fitzpatrick, Michael E.; Roberts, Steve G. and Grant, Patrick S. (2014). **An in situ powder neutron diffraction study of nano-precipitate formation during processing of oxide-dispersion-strengthened ferritic steels**. Journal of Alloys and Compounds, 582 pp. 769–773.

Toparli, M. B.; Fitzpatrick, M. E. and Gungor, S. (2013). **Improvement of the contour method for measurement of near-surface residual stresses from laser peening.** Experimental Mechanics, 53(9), pp. 1705–1718.

Burca, G.; Kockelmann, W.; James, J. A. and Fitzpatrick, M. E. (2013). **Modelling of an imaging beamline at the ISIS pulsed neutron source.** Journal of Instrumentation, 8(10).

Bacon, D.H.; Edwards, L.; Moffatt, J. E. and Fitzpatrick, M. E. (2013). **Fatigue and fracture of a 316 stainless steel metal matrix composite reinforced with 25% titanium diboride.** International Journal of Fatigue, 48 pp. 39–47.

Moffatt, J. E.; Fitzpatrick, M. E. and Edwards, L. (2013). **Effect of frequency on high-temperature fatigue crack growth in a silicon carbide reinforced silicon nitride composite.** International Journal of Fatigue, 47 pp. 319–329.

Haigh, R.D.; Hutchings, M. T.; James, J. A.; Ganguly, S.; Mizuno, R.; Ogawa, K.; Okido, S.; Paradowska, A.M. and Fitzpatrick, M. E. (2013). **Neutron diffraction residual stress measurements on girth-welded 304 stainless steel pipes with weld metal deposited up to half and full pipe wall thickness**. International Journal of Pressure Vessels and Piping, 101 pp. 1–11.

Rao, Ashwin; Bouchard, P. John; Northover, Shirley M. and Fitzpatrick, Michael E. (2012). **Anelasticity in austenitic stainless steel**. Acta Materialia, 60(19), pp. 6851–6861.

Dorman, M.; Toparli, M. B.; Smyth, N.; Cini, A.; Fitzpatrick, M. E. and Irving, P. E. (2012). **Effect of laser shock peening on residual stress and fatigue life of clad 2024 aluminium sheet containing scribe defects.** Materials Science and Engineering: A, 548 pp. 142–151.

Paradowska, Anna M.; Tremsin, Anton; Kelleher, Joe F.; Zhang, Shu Yen; Paddea, Sanjooram; Burca, Genoveva; James, Jon A.; Ahmed, Rehan; Faisal, Nadimul H.; Grazzi, Francesco; Festa, Giulia; Andreani, Carla; Civita, Francesco; Bouchard, Peter J.; Kockelman, Winfried and Fitzpatrick, Michael E. (2012). **Modern and historical engineering concerns investigated by neutron diffraction on ENGIN-X.** Journal of Solid Mechanics and Materials Engineering, 6(6), pp. 408–418.

Elisabeth Le May

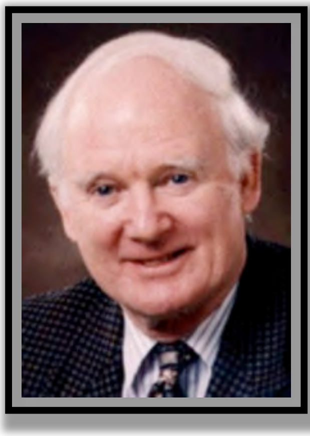
FESI's members, Council, directors, and volunteers congratulate Professor Michael Fitzpatrick on his very exciting new appointment, and thank him for his work to date with the FESI Council.

We look forward to further discussions on ESI matters, to learning from his work at Coventry University and the Institute of Engineering and Manufacturing, and to benefitting from his exceptional experience and expertise.

Mike, we wish you every possible success.

Brian Leonard EYRE

CBE, FRS, FREng



The death of Professor Brian Eyre, Senior Visiting Fellow, University of Oxford, has been announced by the University's Department of Materials.

Professor Eyre, an eminent British Materials Scientist, was a well known figure in FESI circles, having most recently given the Introductory Lecture at TAGSI/FESI Symposium, The Structural Integrity of Nuclear Power Plant: learning from history and looking to the future, held in March 2013 to mark the twenty-fifth anniversary of the formation of TAGSI (The Advisory Group on Structural Integrity of Nuclear Power Plant). This group followed the Marshall Committee convened to address structural integrity issues, raised by Sir Alan Cottrell in 1974, related to PWR power plants. TAGSI, under the Chairmanship of Professor John Knott, OBE, FRS, FREng, is an advisory body comprised of industrial and academic experts, and provides independent advice and peer review to the UK nuclear industry's structural integrity issues.

Dr Eyre's important contributions to nuclear technology, and his association with a number of the major organisations in the nuclear power generation industry, made it fitting that he should open the symposium, and in doing so choose to reflect on 'How it all Began', for the benefit of the audience.

Brian Eyre's distinguished career encompassed working for the Central Electricity Generating Board (CEGB) from 1959; he joined the UK Atomic Energy Authority (UKAEA) in 1962, and served in various posts including, from 1990-94, CEO. When UKAEA was itself restructured, he served as CEO of AEA Technology plc.

He was Professor of Materials Science in the University of Liverpool, Visiting Professor at Liverpool University, UCL, and the University of Oxford, and, from 2002, Senior Visiting Fellow in Oxford's Department of Materials. He was Fellow of the Royal Academy of Engineering (1992) and the Royal Society (2001). In 2009 he was elected as a Foreign Member of the United States National Academy of Engineering, for furthering understanding of neutron irradiation-induced damage in materials, and for developing technologies and policies for the UK nuclear industry.

Professor Eyre authored over 150 scientific papers, and he served in various capacities on a number of Boards and Councils, including the Foundation for Science and Technology (1994-2001), the Particle Physics and Astronomy Research Council (1996-2000), Council of the Central Research Laboratories (1998-2001), the Royal Academy of Engineering (1996-1999), and the Institute of Materials (1996-2000). He was Chairman of the Hampshire Neurological Alliance, which worked to ensure a better quality of life for individuals in the Alliance area affected by a neurological condition, and their families and carers.

FESI extends deepest sympathy to Brian Eyre's family, friends and colleagues.

Elisabeth Le May

News & Announcements

NEWS

Please send news about your organisation's ESI activities to elisabeth.lemay@fesi.org.uk

FESI Welcomes New Corporate Members

Sellafield Ltd

Sellafield Ltd is the Site Licence Company (SLC) responsible for safely delivering decommissioning of the UK's nuclear legacy as well as fuel recycling and the management of low, high and intermediate level nuclear waste activities on behalf of the Nuclear Decommissioning Authority (NDA). Nuclear fuel has been reprocessed at the Sellafield site for over 50 years.

Sellafield Ltd's site at Sellafield in West Cumbria is the largest nuclear site in Europe, measuring 6 square kilometres. With over 1,000 nuclear facilities on site, it has the most diverse portfolio of any nuclear site in the world.

Almost half the UK's nuclear workforce is based at Sellafield, and the more than 10,000 employees at Sellafield Ltd mean it has the largest concentration of nuclear expertise in Europe. Engineering, design and functional support capability are provided by employees based at the Risley office, near Warrington. Under the ownership of Nuclear Management Partners (NMP), a consortium comprising URS (USA), AMEC (Britain) and AREVA (France), Sellafield Ltd is safely delivering nuclear decommissioning, waste management and commercial operations. The company's aim is to achieve the NDA's vision to become the site and workforce of choice for potential new missions.

PENSPEN™

Penspen provides engineering, project management, asset management and integrity services to the oil and gas industry worldwide. Penspen is a member of the Dar Group, Penspen is able to draw upon the resources, expertise and experience of an international network of professional service firms, with over

13,000 staff in over 100 countries, dedicated to the engineering design and project management of major infrastructure projects. Alan Chung, Principal Engineer, Pressure & Storage Systems at Penspen, introduces Penspen and explains why Penspen chose to become a corporate member of FESI (page 11).

The University of Sheffield is a research university in Sheffield, South Yorkshire, England, and a member of the Russell Group of research-intensive universities.

The Times Higher Education Student Experience Survey 2014 ranked the University of Sheffield 1st for student experience, social life, university facilities and accommodation, among other categories, and named it 'University of the Year' in 2011's Times Higher Education awards. In 2012 the university had some 17000 undergraduate and 9000 postgraduate students.

Hermann Hauser with Dr Bernd Baufeld from the University of Sheffield's Nuclear AMRC

The university's internationally-recognised research institutes and centres – often interdisciplinary, with external collaboration and funding – have been created to address global challenges facing society, today and in the future. The £200 million network of Catapult Centres (2010) was designed to close the gap between universities and industry, and to rapidly translate research into productivity. The most advanced of these centres across the UK focus on High-Value Manufacturing, with the University of Sheffield home to two of the UK's seven centres - the Advanced Manufacturing Research Centre (AMRC) and the Nuclear AMRC. The university's AMRC with Boeing is a world-class centre for advanced machining and materials research for aerospace and other high-value manufacturing sectors.

A report, published on 5 November 2014 for the Department of Business, Industry and Skills, highlights the success of the University of Sheffield's two AMRCs, and recommends how this success can be extended to other fields and industries. The report's author, entrepreneur Hermann Hauser, calls for greater public investment to establish 30 CATAPULT centres across the UK by 2030.

Coventry University is a public research university with more than 27,000 students (2013). Its main campus is in the city of Coventry, England, and a second campus has operated in London since 2010. The university comprises four faculties, including the Faculty of Engineering and Computing, and one school, and manages a number of commercial subsidiaries that provide business services to local and national organisations.

Please see page 3 for further information on FESI Council Member Professor Michael Fitzpatrick's new post as executive dean of **Coventry University's Faculty of Engineering and Computing,** and his role in the new £32m **Institute for Advanced Manufacturing and Engineering,** a joint project between the university and the Unipart Group.

FESI looks forward to working with these leading organisations, and is delighted to welcome their representatives to the FESI Council.

RCNDE to undertake strategic NDE research

RCNDE – UK Research Centre in Nondestructive Evaluation, a FESI corporate member, will undertake research to investigate new and better methods of NDE to improve the safety and longevity of critical UK infrastructure and to support and enable high-value manufacturing across important UK industry sectors.

The funding was announced by the Secretary of State for Industry, the Right Honourable Vince Cable MP, and will comprise a £5.4 million grant over six years from EPSRC (Engineering and Physical Sciences Research Council). This will be matched by an equivalent £5.4 million in cash and in-kind contributions from industrial partners of the NDE Research Association (NDEvR) through its own Strategic Partnership with EPSRC.

21st century industry faces ever more challenging requirements to achieve greater integrity and safety performance, and adopt new materials and designs. Novel NDE technologies are often crucial to making this possible. NDE involves the use of sensor and imaging technologies to assess the condition of components and structures in many situations, from manufacture and throughout their service lives. Non-destructive testing (NDT) is an important and growing industry involving R&D, sensor and instrumentation supply chains, and a service-provision sector. NDT delivers high impact in terms of safety, asset value maximization and competitive benefits for client industries such as aerospace, power generation and transport. Making the most of available benefits in the future requires planning now to allow effective navigation through the landscape of change which lies ahead. NDT is crucial for the development of new manufacturing methods and engineering materials, for assuring the integrity of much of the UK infrastructure and for asset life management.

The impact that Non-Destructive Testing (NDT) has had on the UK's priority technology areas and High Value Manufacturing competencies is outlined in a new cross-sectoral report, **A Landscape for the Future of NDT in the UK Economy**. Dr Keith Wright, Director RCNDE, and a member of the FESI Council, commends the report, saying that it is significant in highlighting

> " … the importance of linking NDE to structural integrity."

A Landscape for the Future of NDT in the UK Economy is a Knowledge Transfer Network publication from Innovate UK Network, downloadable at **https://connect.innovateuk.org**. The publication is free if you are a member of the Materials Community.

RCNDE is a consortium led by Imperial College London and involving the universities of Bristol, Manchester, Nottingham, Strathclyde and Warwick. It will involve more than 40 companies across major industry sectors including aerospace, nuclear, and oil and gas, developing tools and techniques to detect defects and extend the life and prevent failure of critical UK infrastructure such as pipelines, power stations and aircraft.

Dr Keith Wright, RCNDE's director, is a frequent contributor to The FESI Bulletin. His article **RCNDE: Annual Research Review** appears in Vol.7 No.1, and **NDE Research and Structural Integrity** appears in Vol.5 No. 1.

HORIZON NUCLEAR POWER

UK energy company and FESI corporate member **Horizon Nuclear Power**, wholly owned by Hitachi, Ltd, is developing a new generation of nuclear power stations to help meet the UK's need for safe, affordable, low carbon energy.

The mission is to build a new, leading, UK nuclear utility company, successfully developing, constructing and operating the UK Advanced Boiling Water Reactor (UK ABWR) at Wylfa on Anglesey and Oldbury-on-Severn in South Gloucestershire.

Hitachi-GE is the chosen technology provider. It is the leading the UK ABWR through the GDA process.

Horizon Nuclear Power is developing a new generation of nuclear power stations and plans to provide at least 5,400MW of new power station capacity to the UK, enough to power around 10 million homes.

Up to 1,000 permanent jobs are expected to be created at each of the sites at Wylfa (left) and Oldbury (above), with a construction workforce of around 4,000 workers for the majority of the time, potentially reaching 8,500 workers during peak periods. Horizon anticipates that this investment will boost the country's low carbon power supplies and help develop local skills and new prospects for British suppliers.

http://www.horizonnuclearpower.com

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40 MORE STUDENTS FOR NDE DOCTORATES

The Centre for Doctoral Training in Nondestructive Evaluation (NDE) promises young engineers some exciting opportunities for collaborative industry-university research. New funding for the Industrial Doctorate Centre (IDC) has made it possible for a further 4 intakes of ten students per year, for the four years from 2015 to 2018.

The IDC, sponsored by EPSRC, is part of RCNDE – UK Research Centre in Nondestructive Evaluation Research, and is administered from the Department of Mechanical Engineering, Imperial College London. The IDC has students registered at Imperial College London, Strathclyde, Bristol, Nottingham and Warwick Universities.

The four-year doctorate (EngD) combines advanced knowledge and professional development training modules with company-based research. The research may comprise a single project or a series of linked projects relating to advanced NDE technology. Projects are co-ordinated by the IDC, but supervised by any of the partner universities listed above.

Industrial partners in the EngD include large companies such as Airbus, NNL, BAE Systems, BP, EDF, E-ON, GKN, Network Rail, RWE npower, Rolls-Royce, Serco, Shell, QinetiQ, Doosan Babcock and Renishaw. There are also a similar number of smaller companies involved. Successful candidates work closely with their chosen sponsor, normally carrying out the majority of their project work at that company.

The EngD degree is aimed at both new graduates and those who have already worked in industry. Projects are available in the many areas of advanced NDE research pursued by the participating industrial companies. Research Engineers should normally have a good honours degree in engineering or physical science.

For more information, please contact the Administrator, Nina Hancock:
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Penspen: "proud to be associated with FESI."

Alan Chung, Principal Engineer, Pressure & Storage Systems

Having recently joined FESI, we would like to give you a bit of background about Penspen, our interests, and why we are excited about being actively involved in FESI.

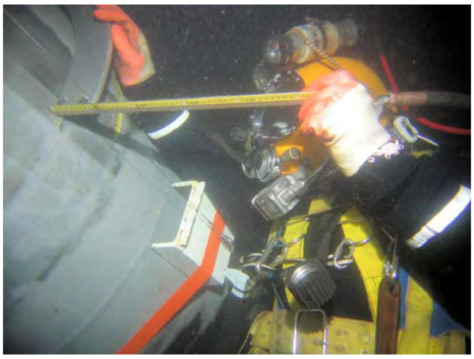
Membership of FESI also coincides with our 60th anniversary, which sees Penspen bringing all of our existing sub-companies, including Greystar Europe, Greystar Corporation, and Andrew Palmer and Associates, under the Penspen name.

Currently, we have a team of over 1,000 engineers with major offices in London, Aberdeen, Newcastle, Houston, Abu Dhabi and Bangkok.

For those unfamiliar with Penspen, our heritage is pipeline and processing systems and, as a group, we are involved in the design, commissioning, maintenance and repair, management and asset integrity of major oil and gas assets around the world.

Penspen also own and operate Manchester Jetline, which supplies aviation fuel to Manchester Airport.

Penspen is part of the Dar Al Handasah group of companies, one of the largest engineering consultancies in the world.



Inspection of anchor damage to subsea pipeline

Like most others, our industry is faced with engineering challenges associated with aging equipment and ever-higher productivity demands. However, unique to oil and gas is the needs for our engineers to have an in-depth technical understanding of a huge variety of environments. Whether it's anchor damage of subsea pipelines, settlement issues of large storage tanks or creep affected steam reformer tubes, each problem requires engineers with the appropriate knowledge and skills to resolve these challenges.

Penspen have been involved in asset integrity for many years and we are proud of our reputation within the oil and gas industry for solving technically challenging problems. We are the principal authors of the key industry document, **The Pipeline Defect Assessment Manual** (PDAM), which provides detailed guidance on the assessment of pipeline defects such as corrosion, cracking, gouges and dents, and is considered to define industry 'best practice'.

We continuously strive to develop our knowledge which has involved us in the development of novel inspection techniques, such as the use of canines to identify traces of jet fuel from leaking underground pipelines.

We also have strong links with academia and run post-graduation accredited qualifications in conjunction with the University of Newcastle, Northumbria and Tabasco (Mexico).

Processing facilities

Penspen are proud to be associated with FESI as we believe that our vision of shaping the delivery of tomorrow's energy, particularly through the provision of technical excellence, aligns closely with FESI's aim of disseminating and exchanging 'best practice' engineering structural technologies and knowledge across industries.

We are looking forward to making a positive contribution to the forum and hope to share our experiences developed over the many years of working with our clients to solve asset management and integrity issues, whilst learning from others from different industries.

For more details please contact me at
a.chung@penspen.com
or go to our website: **www.penspen.com**

The Lloyd's Register Foundation
– Meeting Today's Challenges

Professor Peter Flewitt describes in his Editorial on page 1 of this issue of The FESI Bulletin the meeting between FESI's directors and representatives of the Lloyd's Register Foundation, and indicates that there are areas of interest common to both organisations.

Professor Mike Fitzpatrick, a member of the FESI Council, is the Lloyd's Register Foundation Chair in Materials Fabrication and Engineering. His new post as executive dean of Coventry University's Faculty of Engineering and Computing is described in an article starting on page 3.

Background and introduction

The Lloyd's Register Foundation, a new charity set up in 2012, became fully operational in 2013.

Its **mission** is to protect life and property and to advance transport and engineering education and research.

The Foundation's **vision** is to be known worldwide as a leading supporter of engineering-related research, training and education, that makes a real difference in improving the safety of the critical infrastructure on which modern society relies. In support of this, they promote scientific excellence and act as a catalyst, working with others to achieve maximum impact.

They draw on a long and distinguished history dating back to 1760 through their trading arm, Lloyd's Register Group Limited, with its tradition of public benefit.

The Lloyd's Register Foundation's Strategy 2014-2020

Societies and communities around the world face major challenges linked to issues such as climate change, population growth, energy security, and food and water availability. Technology is advancing rapidly to tackle these challenges in hand with education and training to ensure the availability of the necessary skilled people.

> Working on this strategy, we have taken time to identify areas where we can make the best possible contribution to help tackle society's challenges of the future.
>
> Thomas Thune Andersen
> Chairman of the Lloyd's Register Foundation

The critical infrastructure on which modern society relies is, however, under increasing pressure to satisfy growing demand while innovating safely and protecting lives and the environment.

Strategic themes

The Foundation's strategy sets out four over-arching strategic themes related to the infrastructure above; these are formulated to support the achievement of their key objectives:

1. Promoting safety and public understanding of risk
2. Advancement of skills and education
3. Supporting excellent scientific research
4. Accelerating the application of research

These four strategic themes are mapped against specific objectives, funding priorities, and the target sectors. Each of the four strategic themes is examined in detail.

Monitoring

The impact and outcome of the four strategic themes will be monitored against key performance indicators.

The Lloyd's Register Foundation is developing a process for monitoring and tracking the outcomes arising from their support, in order to be able to demonstrate that their grants represent value for money, are achieving their charitable objectives, and are delivering benefit to wider society. Information captured from the monitoring process will, in addition, serve as an important evidence base to inform future strategy.

Research funding priorities

The Foundation's four strategic themes are supported by the following four Research funding priorities:

1. Structural integrity and systems performance
2. Resilience engineering
3. Human and social factors
4. Emergent technologies

The strategy document details the challenges identified under these four priorities; it further indicates the types of research in which they are interested and believe will assist them in meeting the objectives of the strategic themes.

Funding for the future

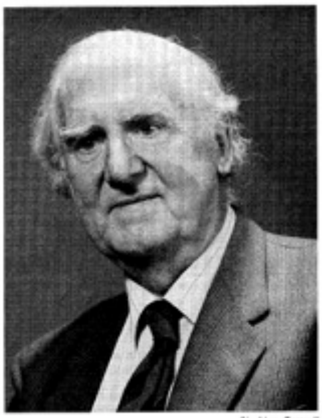
The Foundation's most direct means of achieving their mission is through awarding grants to research and education organisations.

Their approach is to be inclusive, acting as a catalyst and working with partners and others with similar aims to ourselves, focusing our funding in the areas of supporting excellent research, education and training, accelerating the application of research, and public engagement.

> Through our grant making we aim to connect science, safety and society by supporting research of the highest quality and promoting skills and education.
>
> Professor Richard Clegg
> Managing Director of the Lloyd's Register Foundation

Lloyd's Register Foundation are pleased to consider new applications for funding. For more information, and to download the Lloyd's Register Foundation's Strategy 2014-2020, go to **http://www.lrfoundation.org.uk**

Elisabeth Le May



Sir Alan Cottrell

Sir Alan Cottrell: Bio-Verses

John Knott

Although it is now some two-and-a-half years since Sir Alan's death in February 2012, I kept feeling that I had not done full justice to his memory, because I had composed nothing *in verse.* I had written the article "Sir Alan Cottrell: Fracture and Structural Integrity" for the Spring 2013 edition of The FESI Bulletin, and this has subsequently appeared in the Proceedings of the Joint FESI/TAGSI Symposium 9-10 April 2013 "Structural Integrity of Nuclear Power Plant" edited by myself and Brian Tomkins, EMAS 2013, p307-318, and, *via* ICF connections, in "Strength, Fracture and Complexity" Vol. 8 (2013/2014) pp 71-79. The Proceedings of the FESI/TAGSI meeting were dedicated to the memory of Sir Alan, remembering also Ted Smith and David Lidbury. Professor Ray Smallman and I wrote the Royal Society Biographical Memoir for Sir Alan 2013, Volume 59, 2013, pp 93-124. (Note also the memoir of another 'megastar', Sir Hugh Ford, by Gordon Williams in the same volume pp. 145-156). I also contributed an article to a special issue of the Philosophical Magazine, dedicated to Sir Alan. (2013, Vol. 93, pp. 3835-3862). Entitled "Structural Integrity of Nuclear Reactor Pressure Vessels" it traces, with technical detail, the history of the Sizewell "B" PWR and the very strong influence that Sir Alan exerted in ensuring the safety of the RPV.

Despite all these efforts, something was missing: I wanted verses, and a tune to go with them! But it would have to be splendid in form, reflecting Sir Alan's stature: "bestriding the World like a Colossus". From my knowledge of what resonates when sung *en masse* (gained from personal experiences in Churchill College bar in the 1970s and 1980s), I finally decided on "Cwm Rhondda" ("Guide me, oh thou Great Redeemer ...."). The imagery is that of massed choirs of Welsh miners, (with metallurgists amongst them), singing their hearts out to give a final, mighty tribute to Sir Alan. Borrowing from "bio-diversity" and, noting that these are biographical verses, I think that the word "bio-verses" is appropriate. The verses, of course, give only a few highlights: for more details, see the Memoir.

Sir Alan Cottrell: Bio-Verses

(to "Cwm Rhondda")

How we mourn Sir Alan Cottrell;
Prime exemplar of our trade.
We are weak, but he was mighty:
We all cowered in his shade.
　　Alan Howard, how you towered,
　　We all cowered in your shade (*in your shade*)
　　We all cowered in your shade.

Started his career at Birmingham;
Taught us all there was to know.
All about metallic structures,
Dislocations, Plastic Flow.
Explanations, Revelations,
Dislocations, Plastic Flow (Plastic Flow)
Dislocations, Plastic Flow.

Then he makes his way to Harwell;
Magnox fuel, he keeps upright.
Windscale "2": knows what to do;
Graphite does not catch alight.
Wigner-Seitz he sets to rights, and
Graphite does not catch alight! (catch alight!)
Graphite does not catch alight!

In '58, he's off to Cambridge:
Cracks in solids to address.
Worked with Bilby and with Swinden:
Crack-tip yield and fracture stress.
With yield excess, the stress is less;
Read it all in BCS (and R6, boyo!)
Read it all in BCS

Via MOD, he goes to Government
And becomes Heath's CSA
Rothschild, Victor – contradictor;
Cottrell has to fight to have his say.
Serves the nation: much frustration;
Victor-y was never child's-play. (child's play)
Victory was never child's play.

Then a plea from Jesus College:
"To be our Master, would you deign?
Master, Jesus: it would please us"
Signed "All at Jesus, Jesus Lane".
"St. Rhadegund [1], not moribund:
We'd like some women back again! (back again!)
We'd like some women back again!"

Girls' admissions; old traditions,
Swept aside by AHC.
With wit and knowledge, runs his College;
Then elected as VC
Cambridge VC: finds quite easy,
And gives Geoffrey PhD. (PhD)
And gives Geoffrey PhD.

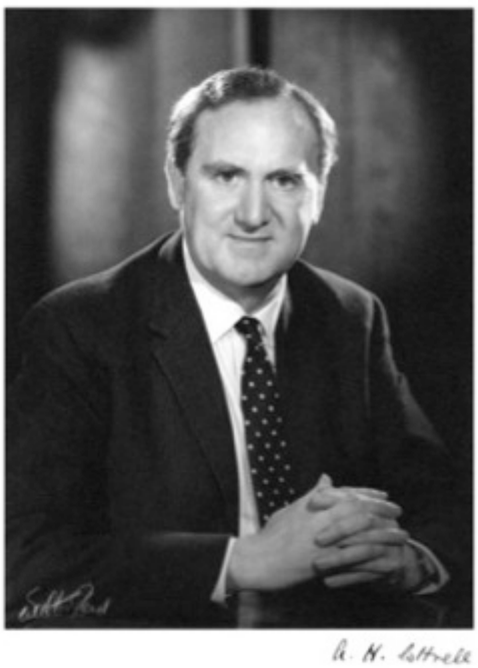
Then new science: "Embedded atoms"
Books and papers emanate.
He receives the Copley medal;
Only given to the great.
Among our clique, where-e'er you seek

Cottrell's Copley medal is unique (it's unique)
Cottrell's Copley Medal is unique

Nuclear fission: Cottrell's mission –
Safety, Sizewell RPV
To tackle snags, he works with TAGSI
And he chairs the MAC
IVC vets NDT, but
Cottrell chairs the MAC (MAC)
Cottrell chairs the MAC.

Works with Rolls-Royce: keeps their engines
Flying safely through the air.
Shafts, blades, discs: assess the risks;
Treble-check with utmost care.
Risks explored by Cottrell's Board:
Ensuring chance of failure very rare (close to zero)
Ensuring chance of failure very rare

How we mourn Sir Alan Cottrell:
Prime exemplar of our trade.
We are weak, but he was mighty –
Now the final act is played.
Alan Howard, how you towered!
May your memory never fade! (never fade!)
May your memory never fade!



Reference [1]. Jesus College was founded in 1496 by John Alcock, Bishop of Ely on the site of a priory, dedicated to St. Rhadegund, which had become "dilapidated and wasted, due to the improvidence of the nuns".

The Jesus coat-of-arms, from 1575, has three cocks on the shield and a cock for the crest, in allusion to its founder.

Women students were admitted in 1976.

www.emas.co.uk

EMAS Publishing – source of specialised ESI information

EMAS Publishing is a small bespoke publishing house wholly owned by FESI – The UK Forum for Engineering Integrity. Its remit is in the publication of resources on the subject of engineering structural integrity (ESI), on topics ranging from fatigue and failure analysis to aluminium alloys to welding.

Through EMAS, FESI also publishes the proceedings from its biennial international conference Engineering Structural Integrity Analysis (ESIA).

To this end, it services the mission of FESI in disseminating the latest advances in ESI; promoting the exchange of ESI knowledge between interested parties; and in encouraging best practice in ESI. It also provides an important revenue stream to support the operations of FESI.

Recent publications from EMAS Publishing are:

- *Structural Integrity of Nuclear Power Plant: Proceedings from the TAGSI/FESI Symposium* edited by Brian Tomkins and John Knott;
- *Beijing's Bird's Nest Stadium – A Superior Welded Structure* by Sujun Wu *et al.*;
- *The Proceedings from ESIA12*.

Our bestsellers include:

- *Fracture Toughness of Engineering Materials* by Kim Wallin;
- *Modern Metal Fatigue Analysis* by John Draper;
- *Shot Peening: Techniques and Applications* by KJ Marsh.

The latest advancements in the field of ESI provide opportunities for authors. EMAS Publishing is equipped to assist their efforts and bring their book to publication, which would include a royalties scheme.

To see EMAS Publishing's current catalogue, please go to **www.emas.co.uk**

Benjamin Gosney
Editor
EMAS Publishing

ESIS UPDATE

NEXT EVENTS – TECHNICAL COMMITTEES

- **TC4 Meeting**, Les Diablerets, Switzerland. May 27-29, 2015
- **TC4 Meeting**, Les Diablerets, Switzerland. September 30-October 2, 2015

For more information about these meetings, contact the TC4 committee secretary, Dr. Bamber Blackman.

NEXT EVENTS – CONFERENCES

- **15th International ASTM/ESIS Symposium on Fatigue and Fracture Mechanics** (40th ASTM National Symposium on Fatigue and Fracture Mechanics), Anaheim, CA, USA. May 20-22, 2015
- **IGFXXIII National Meeting - 1st International Edition**, Favignana (TP), Italy. June 22-24, 2015
- **IGFXXIII National Meeting - 1st International Edition**
- **CP2015 - The 5th International Conference on Crack Paths**, Ferrara, Italy. September 16-18, 2015:
- **ECF21, 21st European Conference on Fracture**, Catania, Italy. June 20-24, 2016

ESIS EXECUTIVE COMMITTEE – Announced October 2014

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ASSERTING FAILURE PROBABILITY ASSOCIATED WITH DEGRADATION OF CONCRETE STRUCTURES

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Abstract

With regard to performance-based design, together with sustainability and environmentally friendly policies, the probability of failure is an important indicator in design or assessment of concrete structures. The present contribution deals with three areas: the assessment of time-dependent reliability level, life cycle costing, and the quantification of risk; all are covered with regard to concrete structures. Attention is focused on steel corrosion as it is one of the most usual deterioration mechanisms attacking reinforced concrete structures.

Keywords: degradation, life cycle costing, reinforced concrete structures, durability limit states

Introduction

In the context of performance-based approaches, time is the decisive parameter and the durability issues connected with time and the consequences for reliability are pronounced. The reliability aspect is significant in service life, inspection and maintenance planning, decisions about making repairs and life cycle costing. Thus, both durability and reliability rank amongst the most decisive structural performance characteristics. This is also reflected e.g. in recent standardization activities ([1] and [2]). Both these documents advocate probabilistic approaches and the utilization of mathematical models, and in this way the enhancement of the assessment of structures for durability – i.e. a time-dependent limit state approach.

The ability to make a reliable comparison of the life-cycle costs for different construction, technological and material scenarios brings the necessary clarity to the decision-making process. Therefore, the most important topics are e.g. the probabilistic vulnerability assessment of civil infrastructure systems, life cycle costing (LCC), life cycle assessment (LCA) and life cycle management (LCM). Generally, cost-benefit issues are considered ([3] and [4]) together with sustainability and environmentally friendly policies. With regard to these areas, it is evident the probability of failure may be utilised for different purposes; in the present contribution three areas are dealt with:
(i) the assessment of time-dependant reliability level;
(ii) the LCC issue, and
(iii) the quantification of risk.
The goal of this paper is to briefly describe these items with regard to concrete structures and to show some applications. The text may serve for the purpose of instructing students and/or for the dissemination of this part of probability theory and its utilization by practicing engineers.

Concrete Structures

Reliability and Durability

The term 'target reliability level' refers to an acceptable failure probability corresponding to a specified reference period. The well known general definition of structural reliability is introduced e.g. in [5] and [2]. The verification of a structure with respect to its reliability, i.e. to a particular limit state (LS), is carried out via estimation of the probability of the occurrence of failure in a specified reference period. In other words, the aim of reliability analysis is the estimation of unreliability using a probability measure called the theoretical failure probability P_f, defined as:

$$P_f = P(R \leq S) < P_d \quad (1)$$

S is the effect of an action and R is the resistance; both are random variables (or, in a more general sense, random fields). P_d is the design (acceptable, target) probability value; Eq. (1) expresses the general limit condition for both the ultimate and serviceability limit states (ULS and SLS). The index of reliability β is alternatively utilized instead of P_f in practice; the target value then becomes β_d. The formula for the transformation reads:

$$\beta = -\Phi^{-1}(P_f) \quad (2)$$

where $\Phi(.)$ is the standard normal probability distribution function. Generally, both S and R may change in the course of time and hence P_f and β are time dependent. This should be stressed especially in the context of limit states associated with durability ([1] and [2]). Thus, for the reliability assessment of newly designed as well as existing structures the full probabilistic safety format has to be *employed.* The considerable uncertainties associated with e.g. parameters governing deterioration processes highlight the need for the use of this approach.

Durability and its reliability implications need to be addressed during the design process due to their pronounced economic and sustainability impacts; the agreement or decision of the client should be a fundamental part of that process. This is not yet a view commonly held by engineers, even though these ideas are clearly expressed in Section 3 of [2]:

> *"Specifying performance requirements and the associated constraints of service life and reliability creates an initial bridge between the needs of the stakeholders and the design or the assessment. ... The specified (design) service life or the residual service life are related to the required service life as given by the stakeholders and to other implications of the service criteria agreement e.g. with regard to structural analysis, maintenance and quality management".*

Focusing on concrete structures and their durability performance, limit states can also be alternatively expressed by means of the service life format as:

$$P_f = P(t_S \le t_D) \le P_D \quad (3)$$

where t_D is the design life; the service life t_S can be determined as the sum of two service life predictors (periods):

$$t_S = t_i + t_p \quad (4)$$

In Eq. (4), t_i is the time at which the initiation of reinforcement corrosion takes place and t_p is the part of the service life after corrosion initiation – the propagation period. Frequently, the initiation period only serves as the decisive limit state. The direct consequence of passing this limit state is that possible future measures needed to repair the structure become more expensive.

Durability Limit States

Concerning reinforcement *corrosion* as one of the main stressors, appropriate limit states (i) – (vii) may be distinguished:

a) For limit states associated with the initiation period – the principal factors causing depassivation of reinforcement in concrete are carbonation, and chloride ingress.

Then:

(i) The variables in Eq. (1) for the case of concrete carbonation may be interpreted as follows: R is concrete cover thickness and S is the actual (modelled) depth of carbonation at time t_D.

(ii) In the case of chloride ingress, it is the critical concentration of Cl- which leads to steel depassivation, and S is the actual concentration of Cl- in contact with the reinforcement in the concrete at time t_D.

b) For limit states associated with the propagation period – the volume expansion of rust products develops tensile stresses in the surrounding concrete, leading to concrete cracking (mainly affecting the concrete cover). In such cases, the following LS can be recognised:

(iii) R in Eq. (1) represents the critical tensile stress that initiates a crack in concrete at the interface with a reinforcing bar. S is the actual tensile stress in concrete at design service life t_D;

(iv) Alternatively, R is the critical crack width at the concrete surface and S is the crack width at the concrete surface generated by reinforcement corrosion at time t_D.

(v) When the progress of corrosion and consequently the opening of cracks continue, a network of cracks is propagated that possibly reaches the surface of the concrete cover. Together with cracks arising due to mechanical loading [6], a crack network may form and lead to the separation of concrete elements. Such delamination is a complex effect depending on e.g. the diameters of reinforcing bars, their location, concrete quality, coarse aggregate size, cover, the type and amount of loading, and the configuration of the structure. The limit state condition may contain for example the actual distance between cracks and the tolerated distance or the actual area of the reinforcement that is naked and the allowed one.

(vi) Given a decrease in the effective reinforcement cross-section due to corrosion and excessive deformation, loss of bearing capacity and finally the collapse of the member/structure in question may occur. In this situation, R is the actual (modelled) reinforcement cross-sectional area at time t_D and S is the minimum acceptable reinforcement cross-sectional area with regard to either an SLS or a ULS.

(vii) Finally, some changes will occur in the characteristics of the bond between steel and concrete due to corrosion. This may lead either to an excessive deflection of the structure or to a loss of structural strength. The former appears to be a more critical effect [7]. The bond may be modelled by using the time function of bond stress against to slip affected by the degree of reinforcement corrosion. The limit state condition may be defined using the actual bond between the steel and concrete and the minimum required bond.

LS (i) and (ii) are commonly regarded as belonging to the SLS category; the remaining LS listed above are either SLS or ULS depending on the impact on the structure's performance. Being random quantities, the relevant values of variables S and R used in Eq. (1) have to be assessed through the utilization of a suitable degradation model or by field or laboratory investigations. In the former case, effective probabilistic software tools should be utilized.

Example

It appears that predictive probabilistic models are needed to estimate how resistance, loads and safety levels will change over time. The software package FReeT-D (a specialized module of FReeT software at www.freet.cz) can be used efficiently. Models for carbonation, chloride ingress, reinforcement corrosion, sulphide, acid and frost attacks are provided. Some applications are described e.g. in [8].

A parametric study based on the following limit state condition has been extracted from [9] and is described below:

$$P_f(t_D) = P\{w_{cr} - w_a(t_D) \leq 0\} \leq P_D \quad (5)$$

where w_{cr} is the limit value of a crack width equal to 0.3 mm – one of the essential limits for the serviceability assessment of corrosion-affected RC structures recommended in CEN [10]. The actual corrosion-induced crack width wa over time is computed according to an analytical model implemented in FReeT-D and adopted from [11]. In this example, time t_D represents the propagation period only; to perform a service life prediction, the appropriate initiation period must be added.

All input information is listed in Table 1. Note that the adopted concrete is approximately of class C35/40, which is relevant e.g. to exposition class XD3 according to [10].

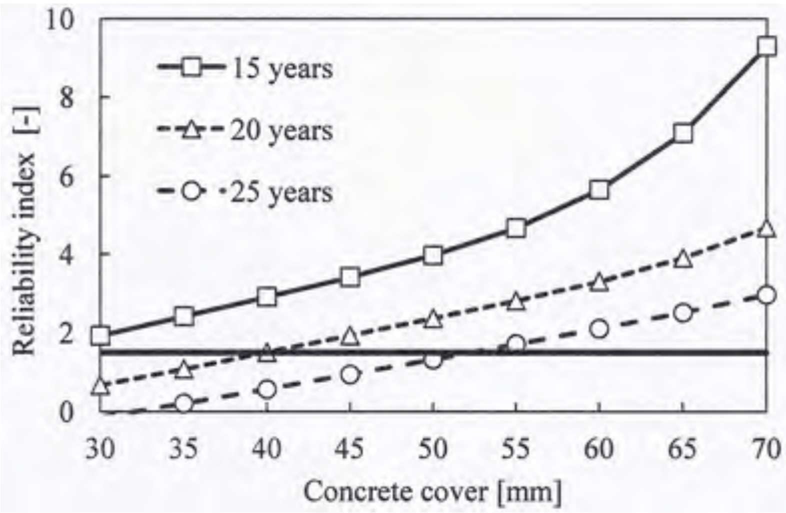

Fig. 1: Reliability index β after 15, 20 and 25 years of steel corrosion development (Eq. 5).

Fig. 1 shows the reliability index β vs. concrete cover for three different propagation time values; the limit value of β = 1.5 prescribed typically for SLS is also shown in the figure. It appears that e.g. for t_D = 25 years the cover should be greater than 50 mm to satisfy the serviceability requirements; for t_D = 15 years, 30 mm of cover would be satisfactory.

Life Cycle Costing

It should be noted that reliability level, limit state definition, target service life and cost-saving results are mutually related – some elements of whole life costs and benefits are service life dependent. These are especially:
(a) operating costs,
(b) maintenance costs, and
(c) repair and/or degraded element replacement costs (including any possible loss due to the discontinuation of operations).

Table. 1: Input parameters for crack width analysis

Input Parameter	Unit	Distribution	Mean/COV
Initial bar diameter	mm	Normal	20/0.02
Porous zone thickness	mm	Deterministic	0.0125
Concrete cover	mm	Deterministic	30-70
Time of exposure	years	Deterministic	15, 20, 25
Current density	µA/cm2	Normal	1.5/0.2
Specific gravity of rust	kg/m3	Normal	3600/0.02
Specific gravity of steel	kg/m3	Normal	7850/0.01
Ratio of steel to rust molecular weight	-	Deterministic	0.57
Tensile strength of concrete	MPa	Lognormal (2 par)	3.3/0.12
Modulus of elasticity of concrete	GPa	Lognormal (2 par)	27/0.08
Poisson ratio of concrete	-	Deterministic	0.18
Creep coefficient	-	Deterministic	2
Material constant	-	Deterministic	1
Uncertainty factor of model	-	Lognormal (2 par)	1/0.15

Typically, the effects listed in (c) can appear *with a certain probability* associated with the relevant limit state, i.e. with the probability of failure. This should be taken into account when making decisions about the optimization of costs and benefits. When doing this and when assessing some design variants, the parts of the costs in question are 'weighted' by the probability:

$$C_{i,w} = P_f C_i \qquad (6)$$

In the case of concrete structures, P_f is analyzed for the relevant limit state – see section on "Durability Limit States". The level of reliability in the context of durability should be left to the client's decision together with the definition of a target service life, creating in this way a necessary background for the making of critical decisions (e.g. financial optimisation) – see e.g. [2], [12] and [13].

Quantified Risk Utilization

Probabilistic risk and hazard assessment are increasingly being used in decision making for a wide range of applications. In certain situations, the evaluation of hazard scenarios and the associated risk analysis are based on structural lifetime considerations. In its *quantified form,* the risk R is defined as

$$R = P_f C \qquad (7)$$

with P_f standing for probability of failure (accident, limit state) and C for the consequences associated with the negative event in question. The value of quantified risk may be effectively utilized in risk management policies while, e.g.:
(a) Comparing the risk of analyzed LS appearance for several material or construction variants.
(b) Allocating R – contractual risk transfer as a form of risk management involves the
allocation or distribution of the risks inherent to a construction project between or among contracting parties.
(c) Making decisions or assessing construction or material variants with regard to costs, schedules, quality or other factors.

In practice, the quantified form of the risk R is used only seldom; the authors believe the above activities can be enhanced in this respect. Again, FReET can be used; in case (a), P_f is analyzed for a relevant limit state of concrete structures – see the list in Section Durability Limit States.

Conclusions

The role of probability values in different areas of structural engineering is described. Firstly, for safety management, i.e. for the assessment of time-dependent reliability level in the form of the probability of failure (which is an obvious and well known role). Secondly, in life cycle management, i.e. for life cycle costing purposes – the making of critical decisions considering financial optimisation. Finally, in risk management, i.e. for the quantification of risk. In the last two cases the demand of probability measure is not common, although it can have positive effects.

Acknowledgement

Financial support from a Brno University of Technology specific university research project, registered under the number FAST-S-13-2017, is gratefully acknowledged.

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RELIABILITY OF DAMAGED STRUCTURES

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Abstract

Safety evaluation of damaged structures is crucial for informed decision making after sudden local damage. Prediction of structural performance involves uncertainties due to the randomness in the loads, material properties, the deterioration processes, and the imperfections in our engineering models. This paper presents a general probabilistic methodology to evaluate performance of damaged structures. A scenario-based approach to evaluate the residual performance of structures suffering sudden local damage is implemented with emphasis on bridges and ships. Time effects due to deterioration are accounted for. The methodology uses finite element method, Latin Hypercube Sampling, and first-order reliability method. Computational procedures for residual capacity and reliability evaluation of damaged bridges and ships are provided. Several performance indicators for damaged bridges and ships are qualitatively illustrated.

Introduction

Structural systems are subjected to deterioration in strength and performance due to the mechanical and environmental stressors (e.g. corrosion, fatigue). The reliability of these systems is highly affected by their deteriorations. The resistance of a structure to an extreme event reduces in time due to the deterioration process. The tolerance to sudden local damage should be considered together with the effect of progressive deterioration in the lifetime management of structures and infrastructures. Several researchers focused on the field of damage tolerant structures and they referred damage tolerance with various related measures. These measures include collapse resistance [7], vulnerability and damage tolerance [18], robustness [3], [5], [12], [19], and redundancy [8], [10], [11].

The evaluation of performance of damaged structural systems is an important research field not only for civil infrastructure but also marine infrastructure. Wang *et al.* [25] proposed an analytical expression for assessing the residual strength of hull girders with damage and provided simple equations correlating residual strength with damage extent. Hussein & Guedes Soares [15] studied the residual strength and reliability of double hull tankers for different damage scenarios. Saydam & Frangopol [24] provided a probabilistic framework for performance assessment of ship hulls under sudden damage accounting for different operational conditions. The information on the residual strength of a damaged hull structure can be very helpful for making decisions on how to proceed with the damaged ships after accidents. The decision making process could be enhanced greatly when the information regarding the reliability of damaged ship hulls after grounding and collision is available. It is necessary to establish methods for reliability assessment of damaged ships for different operational conditions. For instance, the reliability information for different ship speeds, heading angles and sea states could provide guidance to avoid the ultimate failure of the damaged hull structures. In addition, the aging effects should be integrated in this approach.

The aim of this paper is to present a general probabilistic methodology to evaluate the performance of damaged structures. Time effects due to deterioration are accounted for. A scenario-based approach to evaluate the residual performance of structures suffering sudden local damage is implemented with emphasis on bridges and ships. The methodology uses finite element (FE) method, Latin Hypercube Sampling, and first-order reliability method. Computational procedures for residual capacity and reliability evaluation of damaged bridges and ships are provided. Definitions of several performance indicators for damaged structures are presented. These indicators are qualitatively illustrated for bridges and ships.

General methodology

The methodology for assessing the performance of damaged structures considering aging effects is illustrated in Fig. 1. The first step of the methodology is identifying the failure mode to investigate. The next steps can be basically categorized in two parts. These are the computations for the resistance and the load effects. The random variables associated with the resistance must be identified. The load capacity of the structure associated with the failure mode under consideration should be computed accounting for uncertainties. For bridges, the variation of the live load over time is required in order to perform time-dependent reliability analysis. A live load model based on the variation of the number of trucks passing the bridge over time and interpretation of this data by using extreme value statistics can be used. For ships, one component of the load effects is due to the still water. Still water load effects can be evaluated based on expressions given in codes or hydrostatic analysis. Another component of the load effects is due to waves. Wave-induced load effects depend on the operational conditions (e.g., ship speed, heading, sea state). In order to compute the loads for different operational conditions, hydrodynamic analyses of the ship should be performed. The limit state equation including the resistance and the load effects can be established at this stage. First-order reliability method (FORM) or second-order reliability method (SORM) can be used to obtain the instantaneous probability of failure and/or reliability index associated with a sudden damage scenario (and an operational condition for ships). In order to obtain the variation of the reliability in time the procedure should be repeated at different time steps with time-variant values of resistance and load effects. For ships, the procedure should be repeated for different operational conditions to obtain the reliability index with respect to speed, heading and sea state.

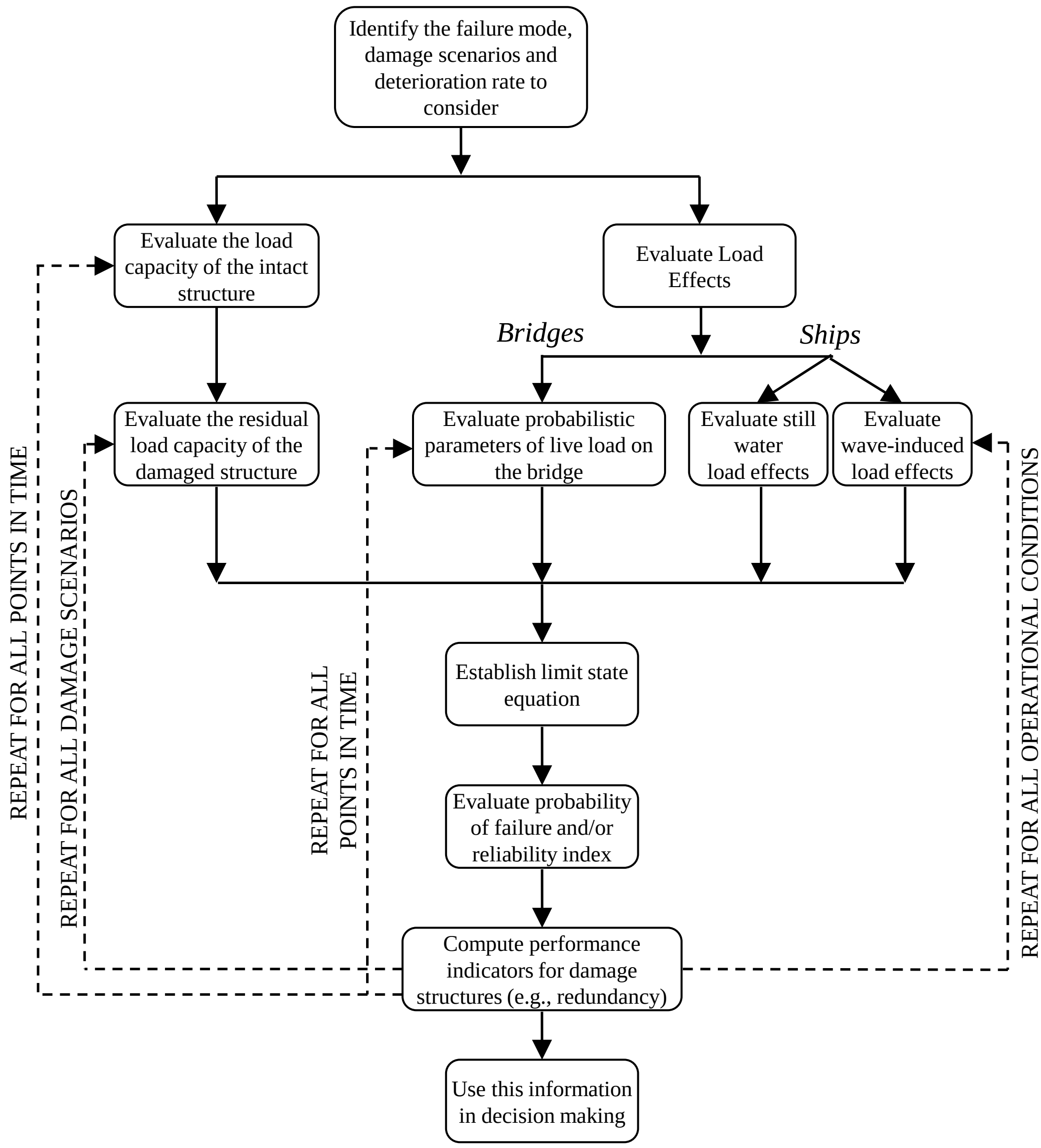

Fig. 1: The general methodology for performance assessment of damaged structures

Probabilistic evaluation of structural performance

Probabilistic evaluation of bridge performance

The bridge system reliability can be evaluated based on appropriate assumptions regarding the interaction of individual components, such as series, parallel and combined system assumptions [6], [13]. In this method, the reliability of a bridge structural system is evaluated by considering the system failure as series-parallel combination of the component failures. First, the random variables and their statistical parameters for component reliability analysis should be determined. The limit states for different possible failure modes of the components can be included in the system model. The derivation of a limit state equation for a bridge girder varies considerably depending on whether the girder is simply supported or continuous [2]. Flexural or shear capacity for girders and the slab can be calculated using the formulas given in AASHTO LRFD Bridge Design Specification [1]. One major assumption in this model is that the system failure is considered to occur when either slab fails or any two adjacent girders fail.

Another approach for reliability assessment of bridges makes use of FE method. An appropriate statistical distribution for the desired output of FE analysis (e.g., stress, displacement, bending moment) can be obtained by repeating the analysis for a large number of samples of the random variables associated with the structure. However, for complex structures, the time required to repeat FE analysis many times may be too large. In such cases, Response Surface Method can be used to approximate the relation between the desired output of FE analysis and random variables by performing analyses for only a significantly less number of samples.

Load carrying capacity of a bridge superstructure can be expressed in terms of a load factor, LF, when the structure reaches its ultimate capacity or very large vertical displacements causing low levels of safety. Load factor, LF, indicates the ratio of the maximum load carried by the bridge to the total weight of AASHTO HS-20 vehicle, when the applied load has the pattern of HS-20 vehicle loading. The failure of the bridge superstructure can be defined by the inequality

$$g = LF - LL < 0 \qquad (1)$$

with

LL = the live load effect in terms of the multiples of the AASHTO HS-20 vehicle weight,

g = the performance function.

The material and geometric nonlinearities can be included in the FE model for better accuracy in idealizing the reality. The details of such a procedure can be found in [12], [23].

Probabilistic evaluation of ship performance

The maximum value of the vertical bending moment is the most important load effect in the analysis and design of ship structures [14]. The ultimate flexural capacity of the hull can be evaluated based on FE analysis, incremental curvature method [16] and progressive collapse method [14]. Okasha & Frangopol [21] proposed an efficient deterministic method for computation of the ship hull strength based on optimization. The ship hull cross-section is discretized into elements, each composed of a longitudinal stiffener and its attached plate. Stresses in the hull section are determined using the constitutive models of these elements. The constitutive models take into account the various possible failure modes of stiffened panels. Initial imperfections are also taken into account. For a given curvature, the bending moment of the section is determined in a way similar to that of the incremental curvature method. However, instead of finding the ultimate strength by incrementing the curvature, the ultimate strength is found by an optimization search algorithm. The curvature is treated as a design variable and the objective is to find the curvature that maximizes the bending moment. In order to find the moment capacity of the hull in a probabilistic manner, the sample space associated with the random variables should be created using a sampling method. Latin Hypercube Sampling is a technique allowing the reduction of the number of necessary samples to reach a certain level of confidence [20]. By combining these two steps, a probability distribution for the maximum moment capacity of the ship hull section can be obtained.

Reliability assessment of ships under different operational conditions requires probabilistic characterization of the loads. The hull is subjected to still water bending moment and wave-induced bending moment. The minimum still water ending moment to be considered in sagging and hogging for seagoing operations can be computed according to IACS common rules [16], in terms of the ship block coefficient, the ship length, the ship breadth, and a wave coefficient. The internal forces within a hull structure due to sea waves can be evaluated based on linear response theory. In this theory, the wave spectrum for a wide range of wave configurations can be obtained through the linear superposition of single waves. Wave-induced vertical bending moments vary for different ship operation conditions. The operational conditions are represented by a set of parameters including ship speed, heading, and sea state. The response of ship structures due to natural sea waves depends on hydrodynamics. In general, hydrodynamic analysis is highly complex and time consuming. Hydrodynamic analysis of ship structures can be performed using strip method [17]. Strip method introduces some simplifications such that the ship hull is divided into prismatic segments. The interaction between the adjacent segments is ignored and the hydrodynamic forces due to harmonic waves are evaluated within the individual segments. The hydrodynamic forces within the segments are integrated to obtain the global load effects. The time-variant limit state equation associated with the flexural failure of amidship for different operational conditions in sagging and hogging, respectively, is expressed as

$$g_{SS,U,H}(t) = x_R \cdot MC(t) - x_{sw} \cdot M_{sw} - x_w \cdot M_{w,SS,U,H} = 0 \qquad (2)$$

with

$MC(t)$ = time-variant vertical bending moment capacity of the midsection of the ship in sagging or hogging;
M_{sw} = still water bending moments amidship in sagging or hogging;
$M_{w,SS,U,H}$ = wave-induced bending moment amidship reflecting the effects of different operational conditions;
x_R, x_{sw}, x_w = the random model uncertainties associated with the resistance, still water bending moment, and wave-induced bending moment, respectively.

Performance indicators for damaged structures

Redundancy

A measure of redundancy, in the context of availability of warning before system failure, was proposed by Frangopol & Curley [8] as

$$RI_1 \frac{P_{f(dmg)} - P_{f(sys)}}{P_{f(sys)}} \qquad (3)$$

with

$P_{f(dmg)}$ = probability of damage occurrence to the system,
$P_{f(sys)}$ = probability of system failure.

A measure of redundancy, as the availability of alternative load path after sudden local damage, was proposed by Frangopol & Curley [8] as

$$RI_2 = \frac{\beta_{INTACT}}{\beta_{INTACT} - \beta_{DAMAGED}} \qquad (4)$$

with

β_{INTACT} = reliability index of the intact system,

$\beta_{DAMAGED}$ = reliability index of the damaged system.

Redundancy is a system performance measure. The load modifiers that accounts for bridge system redundancy in *AASHTO LRFD Bridge Design Specifications* [1] are based on the redundancy definition in Frangopol & Nakib [9]. Application of redundancy concept to deteriorating bridge structures can be found in Okasha & Frangopol [22], Ghosn *et al*. [12], and Saydam and Frangopol [23]. In Fig. 2, the effect of a sudden damage is illustrated on the lifetime reliability index profile qualitatively.

Vulnerability

A probabilistic measure of vulnerability was proposed by Lind [18], defined as the ratio of the failure probability of the damaged system to the failure probability of the undamaged system

$$V = \frac{P(r_d, Q)}{P(r_0, Q)} \qquad (5)$$

with

r_d, r_0 = particular damaged state and pristine system state, respectively,
Q = prospective loading,
$P(r_d, Q)$ = probability of failure of the system in the damaged state,
$P(r_0, Q)$ = probability of failure of the system in the pristine state,
V = vulnerability of the system in state r_d for prospective loading Q.

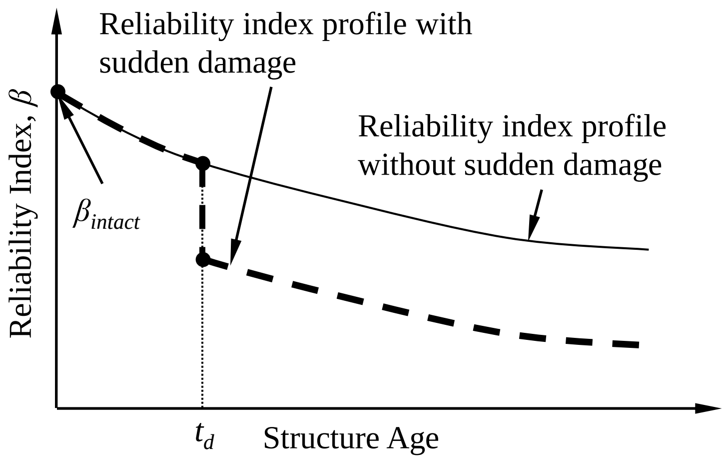

Fig. 2: Qualitative lifetime reliability profile

Risk

A common formulation of risk in engineering involves the multiplication of probability of occurrence of an event by the consequences of this event. Direct risk is associated with the damage occurrence itself while indirect risk is associated with the system failure as a result of the damage. Direct and indirect risks can be formulated as [3]:

$$R_{DIR} = \int_x \int_y C_{DIR} f_{D|E}(y|x) f_E(x) dydx \quad (6)$$

$$R_{Indir} = \int_x \int_y C_{Indir} P(F|D=y) f_{D|E}(y|x) f_E(x) dydx \quad (7)$$

with

C_{Dir} and C_{Indir} = direct and indirect consequences, respectively,

x and y = random variables in the event tree, respectively,

$f_X(x)$ and $f_Y(y)$ = probability density functions of random variables x and y, respectively,

E, D and F = hazard occurrence, damage occurrence, and system failure, respectively.

Robustness

A reliability-based measure of robustness associated with a certain damage scenario is formulated as [24]

$$ROI_1 = \frac{\beta_i}{\beta_0} \quad (8)$$

with

β_i = reliability index associated with the damaged hull for scenario i,

β_0 = reliability indices associated with the intact hull.

The reliability and robustness indices for a ship considering different operational conditions are illustrated qualitatively in polar plots in Fig. 3(a) and (b), respectively.

Baker *et al*. [3] stated that a robust system the one where the indirect risks do not contribute significantly to the total system risk, and proposed a robustness index defined as follows:

$$ROI_2 = \frac{R_{Dir}}{R_{Dir} + R_{Indir}} \quad (9)$$

with

R_{Dir} = direct risk,

R_{Indir} = indirect risk.

This index varies between 0 and 1.0 with larger values representing a larger robustness. Robustness is a system performance indicator. Additional robustness indicators and applications to bridge structures are indicated in Ghosn *et al*. [12], Biondini & Frangopol [4], and Saydam & Frangopol [23].

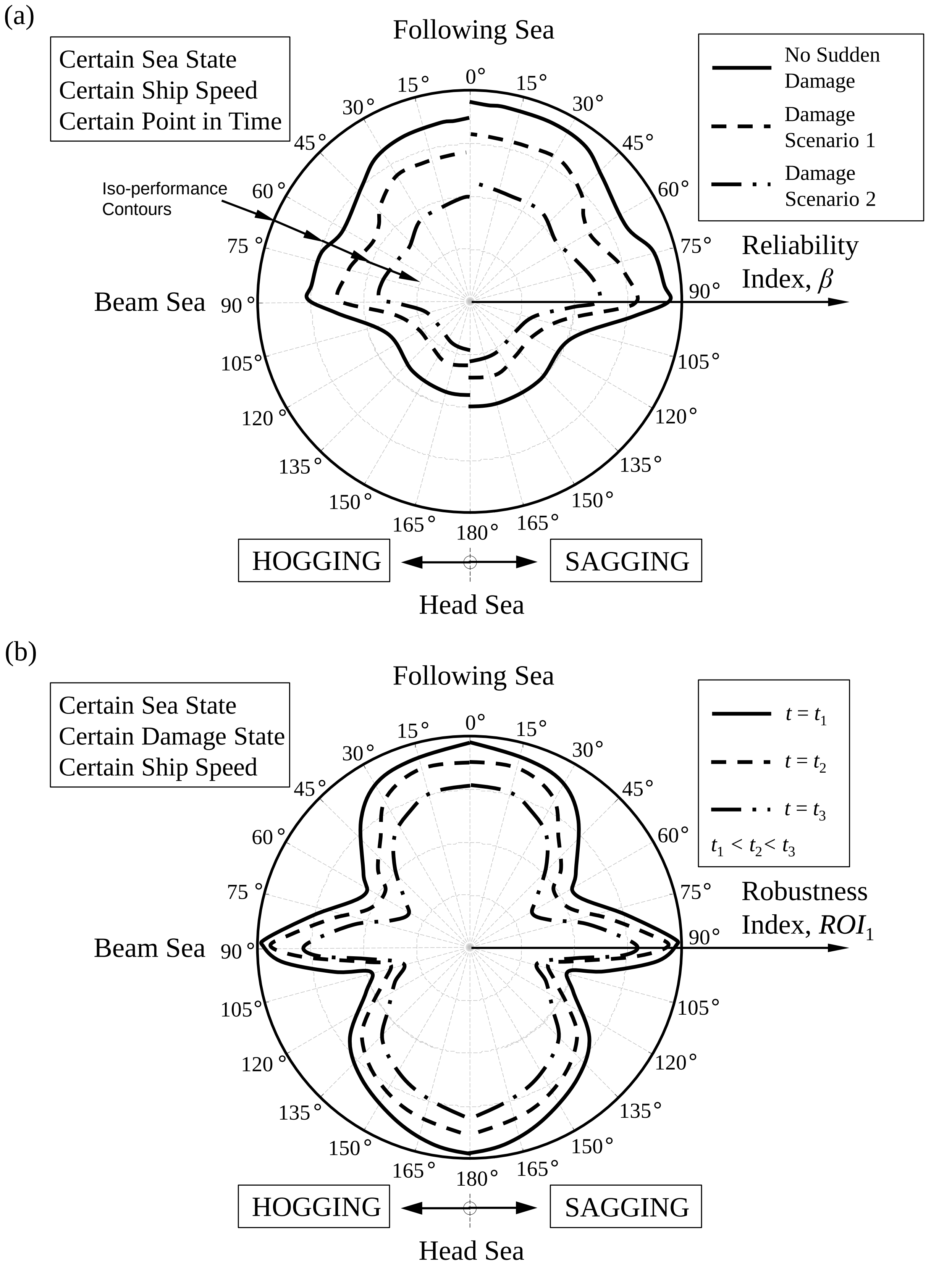

Fig. 3: Qualitative polar representation of ship performance for: (a) reliability index, and (b) robustness index

Conclusions

In this paper, a probabilistic methodology to evaluate performance of damaged structures considering time effects is presented. Emphasis is given on bridges and ships. The residual performance of structures suffering sudden local damage is evaluated based on damage scenarios. The methodology uses FE method, Latin Hypercube Sampling, and first-order reliability method depending on the application type. Computational procedures for residual capacity and reliability evaluation of damaged bridges and ships are provided. Several performance indicators for damaged structures are presented and illustrated qualitatively for lifetime of bridges and ships.

The presented framework can be used in optimization of the design and maintenance of structural systems. Further research on this topic should include a methodology for combining the effects of different scenarios in a risk-based approach.

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Short Cracks – do they matter?

Chairman: Dr Brian Tomkins, FREng
Venue: Nightingale Hall at "The Pavilion", Moor Lane, Derby
Date: 22nd May 2014.

Background

A previous, well-subscribed FESI CPD workshop considered the changes made to the Nuclear Fatigue Design Curves for stainless steels in a PWR wetted environment. This follow-on workshop introduced the current need for an improved understanding of short cracks versus a pragmatic view of engineering significance to consider whether or not short cracks really matter, and also provided an overview of developments in short crack behaviour and understanding from related industries.

REPORT

The workshop was held at Rolls-Royce, Derby on 22 May 2014, and was well attended by an audience from different sectors of the engineering community. Mr Keith Wright welcomed everybody to Rolls-Royce and then Dr Brian Tomkins, the chairman of FESI, explained the role of FESI by emphasising the importance of disseminating SI information and that the role of continuing professional development (CPD) in FESI workshops enables this to happen. He gave a short overview of the workshop and reminded the attendees that a similar workshop had been hosted by Rolls-Royce in 2011, and that this present workshop allowed the topic to be explored further.

Dr Tomkins proposed two sets of questions:

1. What are the consequences of our increased ability to identify more localised damage in components by advanced NDE techniques? If we can find much shorter cracks, does it mean we have to change our strategy to do something about them? Do we need a methodology to deal with them?

2. It was thought that small damage was a minor problem in the past but now we understand better the relation between short cracks and component failure. Does it mean that we now have to change our strategies of assessing the integrity of structures for discrete damage mechanisms to combined damage mechanisms (e.g. simultaneous fatigue and corrosion)?

Dr Tomkins encouraged the audience to express their opinions so the discussion session at the end of the workshop would be richer and more inclusive.

Following Dr Tomkins' introduction, Mr Keith Wright (Rolls-Royce's Chief Stress Engineer – Submarines) gave an overview of the position of the nuclear industry on the fatigue behaviour of short cracks, and also of international developments in this field since the 2011 workshop. He pointed out that the main focus in the nuclear industry is on the fatigue of austenitic stainless steels, although nickel super-alloys are also gaining more application and more attention. This was a point also raised by the next speaker, Dr David Tice of AMEC Clean Energy, who presented some recent research work on the evaluation of the early stages of cracking. Both speakers pointed out the significant difference of life assessments which can result from using various standards and concluded that:

1. There is no widely accepted definition for "short cracks" although the comparison between the grain size and the crack size can be beneficial in establishing a unified definition;

2. There is no clear role of stress gradient in assessing the life of components that have short cracks;

3. The nuclear industry needs ideas from other industries.

Following the theme of nuclear materials, Dr David Tanner from the University of Bristol and EDF Energy presented different methods and issues on total life assessment of different components such as pipes. He suggested that Buckingham-π theorem should be used to correct for dimensions if standard methods, such as R5, are to be used for assessing the impact of short cracks on the life assessment of engineering-size components.

The approach of the first three presentations, **Nuclear Industry, International Developments**, Keith Wright, Rolls-Royce; **Evaluation of Early Stages of Cracking**, David Tice, AMEC Clean Energy; and **Total Life Assessment – methods and issues**, David Tanner, University of Bristol, describing applied engineering in the nuclear industry, created an interesting contrast with the next two presentations: **Short Cracks and Life**

Prediction in Aerospace, Professor Phil Irving, Cranfield University, and **Short Cracks in Turbines,** Professor Philippa Reed, University of Southampton, which focused more on the microstructural aspects of short cracks in the aerospace and steam turbine industries. They showed the interaction of the microstructures with short cracks using tools such as X-ray diffraction and tomography, detailed finite element analysis and electron backscattering diffraction.

Finally, Dr Alan Turnbull, NPL, gave a talk entitled **Environmentally Assisted Small Crack Growth**, which focused on the corrosion aspects of short cracks. Aligned with the two speakers before him, he explained the effects of the recent advances in optical techniques, in particular digital image correlation, that are making observations of crack shapes in a controlled experiment routine.

After the presentations, Dr Brian Tomkins chaired a discussion session steered by a panel comprised of the speakers. He started the session by posing the question:

Where is the place of short cracks in different industries covered during the workshop?

For the nuclear industry, the ASME approach is to use the available materials S-N curves and apply reduction factors on stress and life to account for various possible effects, including environment. However, this does not separate the mixed effect of environment and fatigue processes; for example, corrosion will have a different effect on the initiation and the propagation of short cracks and hence on the lifetime at high and low stresses. Therefore, regardless of how difficult it is to change established approaches, there seems to be a need for more realistic approaches to fatigue assessment in the presence of an aqueous environment.

It was noted that despite enthusiasm for a more realistic approach, there are still a significant number of influential parameters, e.g. in corrosion there are many factors that can change the behaviour of a short crack, such as pH and the presence of oxygen. It is difficult to include these where the mechanisms are not fully understood. A solution might be to use a probabilistic approach as opposed to current deterministic approach. In addition, one of the characteristics in short crack regimes is scatter. For example, the variation of microstructure was shown by the workshop's presenters to be important, yet it cannot be taken into account for a real engineering component. However, probabilistic approaches are based on assuming certain distributions for the influence of each factor. Thus, use of probabilistic approaches becomes difficult, where one factor can become dominant and fundamentally change the distributions of the other parameters. Therefore, more research is required to understand the physics behind each factor governing the growth of short cracks, which will help determine the weight of each contribution on the overall growth mechanisms; this knowledge is essential to tune the probabilistic approaches.

Research is largely carried out in laboratories and this needs careful attention when converting it to engineering component applications. For the laboratory work to be representative of plant behaviour, many conditions should be considered carefully. For example, the material variability can be significant. One solution is to test specimens extracted from the plant to ensure the validity of the material used in laboratory work. Another example is the mechanism for short cracks propagation, which is usually in mode II. However, a crack that is considered "short" in an engineering component is not necessarily short enough to have significant mode II propagation. Another laboratory testing parameter is the load multi-axiality, which usually exists in the plant components and is frequently ignored in laboratory work.

The question of "How big is a short crack?" remained unanswered during these discussions, but it was recognised that the length-scale is important. The discussion did, however, explore possible answers to three questions:

1. Is it the lower limit of continuum mechanics applicability?
2. Is it when its length is same order as the grain size, or less?
3. How does it depend on the loading condition? For example, a crack propagating under thermal transience or in material surface residual stress field (e.g. from peening).

Mr Keith Wright closed the session by concluding that short cracks do matter, although we do not have a definition for them. We need to learn about them, but we can still take the conservative approach in practice and over-design in order to be operating safely.

Mahmoud Mostafavi
November 2014

FESI's CPD Events 2015

The **What's On** Listing

A selection of the many conferences, seminars, workshops and opportunities for Continuous Professional Development (CPD). Email details of your organisation's ESI event to fesi@fesi.org.uk

- FESI's members receive a discount on all events organised or co-sponsored by FESI, together with a certificate that counts against CPD targets.
- FESI Members receive IMechE member rates for all jointly organised FESI/IMechE events.

Key: TBA = to be announced   TBC = to be confirmed

Event	Date	Location	Contact
2014			
Light Aircraft Design – Methods and Tools 2014	17 November	London, UK	www.Imeche.org
The 12th Ian Hewerdine Memorial Lecture – Safety in the Skies	17 November	Cardiff, UK	www.Imeche.org
Shale Gas – The Facts about Fracking	18 November	Birmingham, UK	www.Imeche.org
Engineering Integrity Society's Basic Fatigue Course	19 November	Coventry, UK	info@e-i-s.org.uk 01572 811315
Career Opportunities in Mechanical Process Engineering	19 November	Manchester, UK	www.Imeche.org
Advanced Aerospace Manufacturing: Automation	19 November	Blackburn, UK	www.Imeche.org
Gears 2014 Technical Awareness Seminar	20 November	Newcastle, UK	http://bga.org.uk/gears2014
The Use of Virtual Verification in Engineering Today's Aston Martin	20 November	Birmingham, UK	www.Imeche.org
How the Alliance Handles Innovation: Railway Engineering Lecture	21 November	Leeds, UK	www.Imeche.org
Whitechapel Bell Foundry Tour	22 November	London, UK	www.Imeche.org
Grand Tour of the Royal Albert Hall	22 November	London, UK	www.Imeche.org
Tunnel Ventilation for HS2	24 November	London, UK	www.Imeche.org
nCode Product Training: Practical Fatigue Theory	24-25 November	Darley Dale, UK	http://www.ncode.com/en/training/training-calendar/registration
Engineering the Future of Medicine	25 November	Cambridge, UK	www.Imeche.org
Modern Manufacturing Revolution – 3D Printing	25 November	Manchester, UK	www.Imeche.org
British Motorsport: Engineering the Future	26 November	Nottingham, UK	www.Imeche.org
nCode Product Training: FE-based Fatigue Analysis with nCode Design Life	26-27 November	Rotherham, UK	http://www.ncode.com/en/training/training-calendar/registration
ACAM 8 – 8th Australian Congress on Applied Mechanics	26 November	Melbourne, Australia	http://www.convention2014.org.au
Caterham Car Factory Tour	28 November	Dartford, UK	www.Imeche.org
Concorde – A Real-life Time Machine	2 December	Colchester, UK	www.Imeche.org
Digital Snooping and Data Security	3 December	Leeds, UK	www.Imeche.org
nCode Product Training: Interactive Data processing with nCode GlyphWorks	3-4 December	Rotherham, UK	http://www.ncode.com/en/training/training-calendar/registration
Improving the Safety Performance of the Railway	4 December	Derby, UK	www.Imeche.org
Manchester Metrolink M5000 Tram – Five Years in Service	9 December	Manchester, UK	www.Imeche.org
Replica Trevithick Locomotive	10 December	Glasgow, UK	www.Imeche.org
Bird Strike and Airframe Design	10 December	Hull, UK	www.Imeche.org
FEA of Railway Crossings	16 December	Edinburgh, UK	www.Imeche.org
2015			
The Sabre Engine	6 January	Shrewsbury, UK	www.Imeche.org
Flush and Forget – the Story of Sewage Treatment	7 January	Barrow-in-Furness, UK	www.Imeche.org
The Class 374 Eurostar	13 January	Manchester, UK	www.Imeche.org
Solway Energy Gateway Project Update	15 January	Cumbria, UK	www.Imeche.org
Talyllyn Railway – 21st Century Engineering on a 150 Year Old Railway	19 January	Cambridge, UK	www.Imeche.org
Offshore Floating Structures Design	19-21 January	Glasgow, UK	www.asranet.co.uk
An Unreliable History and the Development of Stainless Steel	20 January	Leeds, UK	www.Imeche.org
Small Modular Reactors	21 January	Lancaster, UK	www.Imeche.org

Engineering for Fun – Inspiring the Next Generation	21 January	Gloucester, UK	www.Imeche.org
Design of Pipelines and Risers	26-28 January	Glasgow, UK	www.asranet.co.uk
Gas, Renewables and Realism	3 February	Shrewsbury, UK	www.Imeche.org
Structural Integrity Analysis (Fatigue and Fracture)	16-18 February	Glasgow, UK	www.asranet.co.uk
Unmanned Air Systems in the MoD	17 February	TBC	www.Imeche.org
Corrosion 2015	15-19 March	Dallas, TX, USA	http://events.nace.org
Through-life Monitoring and 3D Modelling of Ageing Structural Systems	TBA	TBA	www.fesi.org.uk
Engineering Integrity Society's Instrumentation, Analysis and Testing Exhibition	17 March	Silverstone, UK	info@e-i-s.org.uk 01572 811315
ICM 12 – 12th International Conference on Mechanical Behaviour of Materials	10-14 May	Karlsruhe, Germany	www.icm12.com
5th International Conference on Laser Peening and Related Phenomena	10-15 May	Cincinnati, OH, USA	http://ceas.uc.edu/lspcenter/lspconference.html
ESIA13 – FESI's 13th International Conference on Engineering Structural Integrity Assessment	19-20 May	Manchester, UK	www.fesi.org.uk
15th International ASTM/ESIS Symposium on Fatigue and Fracture Mechanics	20-22 May	Anaheim, CA, USA	www.astm.org/E08ASTM-ESISMay2015
PSFVIP 10 – 10th Pacific Symposium on Flow Visualization and Image Processing	15-18 June	Naples, Italy	www.psfvip10.unina.it
ICEAF IV – 4th International Conference of Engineering Against Failure	24-26 June	Skiathos, Greece	http://ltsm.mead.upatras.gr/lab/lang_en/conference/
ICDM2 – The Second International Conference on Damage Mechanics	8-11 July	Troyes, France	http://icdm2.utt.fr
ICSMA-17 – 17th International Conference on the Strength of Materials	9-14 August	Brno, Czech Republic	http://www.icsma17.org
SMiRT23 – FESI Workshop on Corrosion Fatigue	10-14 August	Manchester, UK	www.fesi.org.uk
SMiRT 23 – 23rd Conference on Structural Mechanics in Reactor Technology International	10-14 August	Manchester, UK	www.smirt23.org
CP 2015 – 5th International Conference on Crack Paths	16-18 September	Ferrara, Italy	www.structuralintegrity.eu
Working on Linking Defect Tolerance and Inspection	TBA	TBA	www.fesi.org.uk
R6 Development – Update Seminar	TBA	TBA	www.fesi.org.uk
2016			
ECF21 – 21st European Conference on Fracture	20-24 June	Catania, Italy	www.structuralintegrity.eu

Membership pays – join FESI today!

JOIN

Joining FESI as an Individual Member brings a range of rewards and benefits.

As an Individual Member you will receive:

- A **certificate of attendance** for events, that counts towards **CPD** targets
- Automatic **membership of ESIS**, the European Society for Structural Integrity, for one calendar year
- **10% discount** on all events organised or co-sponsored by FESI
- **20% discount** on all EMAS Publishing publications, when ordered directly through FESI **at emas@fesi.org.uk**
- **Discount rates** for events held by affiliated organisations
- Regular **updates** on ESI-related events and conferences
- **The FESI Bulletin** delivered direct to your Inbox
- A link to see the work of **ESIS's Technical Committees**
- **Networking opportunities** with leaders and colleagues in the field of ESI
- **Networking** opportunities with **prospective employers,** for students, post-graduates and recent graduates

All this and more from just £40 per calendar year

FOR FULL DETAILS VISIT **www.fesi.org.uk**
NETWORK AT **www.linkedin.com/company/fesi---uk-forum-for-engineering-structural-integrity**

ASRANet

A spin-out company of the Universities of Glasgow and Strathclyde

ASRANet, exists to provide expertise to the **marine** and **structural engineering industries** through courses, conferences and consultancy services.

A sample of **COURSES** January to March 2015

- **Offshore Floating Structures Design** – 19 January
- **Foundation Design of Offshore Wind Turbine Structures** – 22 January
- **Ships at Sea** – 4 February
- **Structural Integrity Analysis (Fatigue and Fracture)** – 16 February
- **Structural Response under Fire and Blast** – 23 February
- **Risk Analysis and Structural Reliability** – 16 March
- **Subsea Structures and Installations** – 23 March

A sample of **CONFERENCES** 2015

- **Decommissioning of Offshore and Subsea Structures** – 22 June
- **Floating Structures for Deepwater Operations** – 5 October
- **Lightweight Design of Marine Structures** – 9 November

To find out more about our full range of COURSES and CONFERENCES, see asranet.co.uk

5TH INTERNATIONAL CONFERENCE ON LASER PEENING & RELATED PHENOMENA

MAY 10-15, 2015
CINCINNATI, OHIO

The **International Conference on Laser Peening and Related Phenomena** returns to its origins in the USA for the fifth conference in the series from **May 10-15, 2015** in the vibrant and scenic Ohio river valley city of **Cincinnati**.

University of Cincinnati West Campus

The conference will be held on the attractive campus of the University of Cincinnati in the Tangeman University Center, providing a range of amenities for delegates and their partners.

This conference, with its workshop-style approach of a single session and an emphasis on discussion and networking, will be enhanced in 2015 with a focus on industrial problems and applications.

There will be a new, dedicated section of the conference for industrial application of laser peening, alongside the basic phenomena of materials response and the development of laser systems for the future. The conference will have a satellite workshop on the modeling of laser peening using finite element techniques, in recognition of the intensive efforts in this area to optimize the application of laser peening to an increasing range of industrial materials and components.

http://ceas.uc.edu/lspcenter/lspconference.html