The FESI Bulletin

What is Quasi-Brittle Fracture and How to Model its Fracture Behaviour

An Intelligent Customer for NDE

Safety Assurance in China

Volume 4 Issue 4

Contents

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Editorial

As the incoming Editor of the FESI Bulletin: International Magazine on Engineering Structural Integrity, I am delighted to welcome you to this issue and to provide a brief update on how FESI intends to develop and use the FESI Bulletin for the benefit of you, our members.

The FESI Bulletin exists first and foremost to be a key vehicle for communication with FESI's members. Our vision for the FESI Bulletin is to provide a useful and timely resource which will give practical - and leading edge - intelligence on all matters related to engineering structural integrity (ESI). The publication will continue to combine significant technical papers with comments on current developments in structural integrity linked to health and safety issues, reviews of new publications and FESI seminars, information on future seminars and conferences organised by FESI and other structural integrity bodies and, finally, our links with other relevant organisations.

We believe that the FESI Bulletin also fulfils a number of very significant ancillary roles: for instance, it provides FESI with a means of outreach to the constituents of the wider engineering community and their own stakeholders and partners; it can increase recognition of ESI and the work of FESI at national and international level; and it can be used as a tool to influence those who are not yet aware of the critical role played by ESI in so many industries and walks of life. We therefore encourage you to pass the FESI Bulletin to anyone and everyone who is not yet "converted" to ESI but may find the publication to be of value and interest.

We have revised our publication strategy so that you will receive copies in the first and third quarter of each year. We would very much like to hear from you on how the FESI Bulletin meets your needs; we aim to respond positively to helpful and constructive ideas, views and comments, so please feed back to us. Moreover, if you have any articles or other written contributions, the FESI Bulletin's Associate Editor, Elisabeth Le May, would be pleased to receive these. Please e-mail in the first instance to the Chief Executive of FESI, Poul Gosney, at poul.gosney@fesi.org.uk. Please note, however, that as is usually the case, the Editor's decisions are final.

I would like to take this opportunity to introduce you to the work of FESI's Publications and Communications Sub-Committee, the members of which are listed below, and explain our link with EMAS Publishing.

EMAS Publishing is a wholly owned subsidiary of FESI, and operates as an organisation where the profits are transferred to the main FESI Group. In this way it provides essential funds to support the operation and activities of FESI. Indeed, this allows activities to be undertaken which extend beyond those that would be affordable based solely on income from membership (both corporate and individual members).

The work of the Sub-Committee is divided into several areas and we are in the process of revising our Business Plan to have a clear and positive plan in each area: books (through EMAS Publishing), conference proceedings, continuing professional development (CPD) monographs, and the FESI Bulletin (I became Editor of the FESI Bulletin when I succeeded Dr Brian Tomkins as chairman of the Sub-Committee during 2009. Dr Tomkins continues his valued contribution to FESI as a Sub-Committee member).

I am happy to report here that the Sub-Committee has experienced several recent successes in pursuit of its remit; for example, with regard to the activities of EMAS, John Draper's book 'Modern Metal Fatigue Analysis' was published in 2008 and has proved to be very popular, attracting much attention both in the UK and the USA. We aim to launch a new book by Kim Wallin entitled 'Fracture Toughness of Structural Metals estimation and application' in October 2010. By the end of the year a further publication, 'Strength and Fracture Criteria', by Antonas Zilurkas, will be available.

We are currently preparing several CPD monographs on the varied disciplines that make up structural integrity which will be launched alongside an appropriate seminar/workshop, e.g. Understanding and Implementing Codes, Understanding Structural Integrity's Role in Nuclear New Build, Understanding Monitoring and Inspection and their Roles in Structural Integrity Assessment.

Details of EMAS publications and FESI workshop registration forms will be available through the FESI Bulletin or online at FESI's website, www.fesi.org.uk.

We trust that you will enjoy this issue of the FESI Bulletin. We look forward to hearing from you, FESI's members, to help us shape the FESI Bulletin to meet your ESI needs for the future.

Peter Flewitt

Publications and Communications Sub-Committee

Professor Peter Flewitt, FREng (Chairman)
Dr. Brian Tomkins, FREng
Professor Andrew Sherry
Dr. Iain Le May
Dr. Alan Turnbull
Dr. Keith Newton
Mr. Poul Gosney
Ms. Elisabeth Le May (Associate Editor)

What is FESI?

Since 1994, a UK group of interested industry parties has organised a successful series of biennial international conferences, held on the subject of ESI, seeking to examine the status of the technology and its effectiveness in application. Now an associated programme of teaching seminars, using senior expert academic staff, propagates good practice and awareness in areas such as risk based tools and methods, and the quantification of failure. This collective experience has been brought together under the UK Forum for Engineering Structural Integrity (FESI).

The aim of FESI is to facilitate the effective development and implementation of ESI technology across industry sectors. We believe that this will be achieved through the following means:

- Teaching seminars on developments in ESI technology and its application.
- Topical discussion seminars on interdisciplinary and/or cross industry sector issues in ESI.
- Specific industry discussions/meetings/seminars on ESI, on request.
- International Conferences on Engineering Structural Integrity Assessment concerned with the dissemination of ESI technology and its application across industry sectors.
- Liaison with other bodies involved in significant ESI R&D and applications programmes.
- Collaborating with other groups with ESI interests.

Through these activities, FESI seeks to encourage technology transfer across industry sectors and the development of technologies which will support the safe and cost-effective design and operation of major engineering plant, structures and components. Its activities will cover a range of industries including aerospace, petrochemical, oil and gas, power generation, automotive, transport and construction. Technology integration includes inspection, monitoring, diagnosis, analysis, materials, IT and assessment methods.

Who's Who on the FESI Council

Dr Brian Tomkins FREng is Chairman of FESI and a consultant and an expert in engineering plant integrity and safety.

Professor Peter Flewitt FREng is Consultant Professor within Magnox North Ltd. He has worked on a range of structural integrity topics in the power generation industry amd undertakes research into fracture and locked-in stresses at Bristol University.

Professor Ferri Aliabadi holds the Chair of Aerostructures and is the Head of Aerostruture Section at Imperial College, London. His particular expertise is in the areas of computational structural mechanics, fracture mechanics and fatigue, materials modelling, and boundary and finite element methods.

Philip Heyes is Head of the Engineering Control Group at the Health and Safety Laboratory.

Dr Phil Horrocks is Principal Integrity Engineer in the Process Integrity Department of Centrica Energy Upstream's East Irish Sea asset.

Peter Roscoe is the General Manager of ESR Technology's Asset Integrity Group.

Dr Iain Le May is President of Metallurgical Consulting Services Ltd., Canada. He is a renowned expert witness in Canada and USA in the areas of materials and materials science, and the analysis of failures.

Dr Keith Newton is Director of RCNDE, the UK Research Centre in NDE based at Imperial College London.

Dr Henryk Pisarski is Technology Manager - Fracture in the Structural Integrity Technology Group at TWI, Cambridge, UK, concerned with the application of fracture mechanics testing and flaw assessment procedures (Engineering Critical Assessments) to welds.

John Sharples is responsible for a team of fracture mechanics specialists working on various research and development projects including the R6 Development Programme within Serco Assurance's Structural Integrity Assessments Department.

Professor Andrew Sherry is the Director of the Dalton Nuclear Centre at the University of Manchester.

Professor David Smith is Head of the Solid Mechanics Research Group in Bristol University's Department of Mechanical Engineering with particular interests in fracture of materials and locked-in stresses in engineering components. He is also a non-Executive Director of VEQTER Ltd.

Dr Alan Turnbull is a Senior Consulting Engineer at the National Physical Laboratory, specialising in corrosion and fatigue.

Keith Wright is the Structural Integrity Strategy Owner for the Naval Nuclear Research & Technology work. Keith has recently become an ASME committee member of the Design Analysis and Fatigue Strength subgroups.

Prof Su Jun Wu is Professor in the School of Metallurgy and Materials Science at Beihang University and a Council member of the Materials Society affiliated to the Chinese Mechanical Engineering Society.

Professor John Yates FIMechE, CE holds the EDF Chair in Modelling and Simulation in the School of Mechanical, Aero and Civil Engineering at Manchester University. He is Editor in Chief of the Blackwell Science International Journal - Fatigue and Fracture of Engineering Structures and Materials.

Andrew Holt is an Inspector of Nuclear Installations working for the Nuclear Installations Inspectorate of the Health and Safety Executive.

Are You an Intelligent Customer for NDE

Bernard McGrath

NDE is often viewed as a grudge purchase: something which can only cause problems. However, although NDE techniques are not 100% reliable, they are the only way of knowing the actual current state of plant. NDE is the primary recovery mechanism for errors in design (& analysis), construction and operational activities and so it is important then when it is applied, it is applied correctly and its capability is known and understood. This paper discusses issues relating the application of NDE which need to be addressed by any plant owner / Client wishing to be an intelligent customer of NDE services

INTRODUCTION

Structural Integrity is one of the more academic engineering disciplines: complex models are generated using FE meshes; residual stresses need to be estimated and considered; stress intensity factors need to be applied; material properties understood and bounded; the output is a practical recommendation on what to do next with the particular component.

Unfortunately, the input to the engineering assessment process derives from what may probably be considered as the least academic of engineering disciplines Non-Destructive Examination (NDE). NDE has been considered a black art in the past and a number of inappropriate assumptions have been perpetuated about its application:

- No defects found means that there are no defects at all. When an NDE report states that no defects were found it doesn't mean that the component is defect free. It just states that no defects of the type and size that the inspection technique would be able to find were observed.
- A defect measured at 5 mm is actually a defect at 5 mm. NDE is able to provide a measure of a defect size but like all measurement techniques is subject to errors. When a defect size is reported an estimate of the errors inherent in the measurement should also be provided.
- There is misplaced confidence in the ability to establish defect growth or non growth. As with a single measurement of defect size, the comparison of defect sizing between two subsequent inspections often ignores the errors inherent in the sizing techniques. When these are considered it may be that the difference in the two measured defect sizes has to be relatively large before confidence can be placed in the indication of defect growth.
- There is a greater confidence in any hard copy results. Radiography has always been a popular NDE technique because the output of the inspection is a radiograph which people can see. With the current graphing and desktop publishing abilities of PCs a colourful, polished report can easily be produced. However, the quality of the report can only be as good as the ability of the technique to detect and size the defects of concern irrespective of how data is presented.
- Inspection to a code or a standard is always appropriate and gives a respectability to the results which is not always justified. When it comes to safety related activities companies are keen to follow industry practice. One way of doing this is to follow a national or international standard. In many instances this may be appropriate but in some circumstances it may not be: the standard may offer alternatives for parameter values and the wrong selection can be made; an inspection to the standard may not be suitable to the particular geometry or material or defects.

However, although NDE techniques are not 100% reliable, they are the only way of knowing the actual current state of plant. NDE is the primary recovery mechanism for errors in design (& analysis), construction and operational activities.

So how do we get the best out of the NDE in order to ensure that our structural integrity efforts are based on good data? The answer lies in not treating NDE as being any different to any other purchase of a product or a service. Even though NDE is considered by some to be a QA activity and applying QA on a QA activity seems to be a step too far, it is just as important, if not more so, to subject NDE to an appropriate level of QA rigor as would be applied to other engineering activities.

PURCHASING an INSPECTION

Everyone over the past few years will have ordered a new computer. When you did you will not have requested just “a computer”. Even though you may be a non-IT person and may a limited amount about PCs, you would have had to specify the general requirements such as the size of RAM, the size of the hard disc, the inputs, the size of the display, whether it is to be a laptop or a desktop.

However, when it comes to purchasing NDE services, standard QA practice seems to go out of the window and often the specification of requirements is expressed in a simple phrase: “perform ultrasonic inspection of weld”. If we do not produce a specification of requirements then how can we then check that what has been delivered is what we wanted?

ISO9001:2000 [1] under Section 7.4.1 states that “the organisation shall ensure that purchased product conforms to specified purchase requirements”. So all inspections, whether purchased externally or provided internally, should start with a specification of what the NDE is required to find and with what confidence. The application of risked based inspection (RBI) has improved this situation in recent years because the output from the RBI process identifies the damage mechanism and the regions where they are likely to occur and provides the basis of an inspection specification.

However, whilst specifying what to look for is important, the NDE vendor also needs to know a lot more information regarding the component geometry and material and the access available. Is it necessary to just detect defects or is it required to size them as well? What information needs to be reported? The recent PANI 3 project [2], sponsored by the UK's Health & Safety Executive (HSE), asked NDE Vendors what constituted the biggest risk to the quality of an inspection. The answer was the lack of sufficient information from the Client was identified as causing:

- Unrealistic expectations on what the inspection would achieve
- Time delays in undertaking the inspection whilst adjustments were made to account for the actual situation encountered
- Arrival at site with the wrong equipment
- The wrong personnel being assigned to the job
- Detrimental impact on personnel when they discover that the job is totally different to that which they had been led to believe

Luckily, following the first PANI project the HSE instigated the production of a number of guidance documents aimed at assisting the buyer of NDE Services [3]. The first three documents provide information on manual ultrasonics, surface techniques (magnetic particle and dye penetrant) and radiography respectively. A fourth document describes how to address ultrasonic sizing errors in Engineering Critical Assessment (ECA).

SPECIAL PROCESS

The reason why it can be difficult to purchase the inspection that is required is because NDE is a **Special Process**. A special process is a QA term which denotes a process where the resulting output cannot be verified by subsequent measurement or monitoring. This includes any processes where deficiencies become apparent only after the product is in use or the service has been delivered. A good example of a Special Process is the sterilisation of medical instruments. It is not possible to see just by looking whether the instruments have been sterilised. Confidence is provided by evidence that shows that the particular process of washing and heating the instruments over a defined time period will kill all the necessary bacteria and viruses. Likewise with NDE, confidence in the inspection to deliver the required output can only be obtained by validation (in QA terms) which is referred to as qualification or performance demonstration in the NDE community.

The official definition of qualification as defined by the European Network for Inspection Qualification (ENIQ) is: "The systematic assessment of an NDE system, by all those methods that are needed to provide reliable confirmation, to ensure it is capable of achieving the required performance under real inspection conditions." ENIQ have produced guidelines on how to undertake inspection qualification [4]. There is a perception that inspection qualification is only relevant to the nuclear industry and is always going to expensive. However, Hardie & Baborovsky [5] describe the benefits that can be gained by pragmatic application of the principles of Inspection Qualification to routine manual ultrasonics and where the approach is adapted accordingly. They present an example which demonstrated that such an approach can lead to unexpected shortcomings in standard ultrasonic techniques being revealed, enabling the procedure to be strengthened prior to use.

The treatment of NDE as a Special Process has been accepted in a number of key industries but the application of qualification still remains inconsistent.

NDE CAPABILITY

Even if the NDE ProceSs is not subjected to qualification the purchaser of the NDE should have some understanding of the capabilities of the technique or techniques being applied. Only then can the Client make meaningful decisions based on the results of the inspection. KnowinG the capability could also avoid time and money in applying inspections which may detect defects much smaller than those that it is necessary to find. An assessment of capability can be obtained from evidence which supports the use of the technique and thE equipment and shows that the personnel are sufficiently qualified and experienced to apply the technique correctly. A basic test for any inspection is to find defects in a test piece. If the positions of the defects are known to the operator then this is referred to as an open trial and is used to show the ability of the technique to generate a detectable signal from the defects. If the operator does not know if the test piece contains defects or where any of the defects are then this is referred to as a blind trial test piece. A blind trial tests whether the operator can apply the procedure and detect defects of interest.

As well as collating deterministic evidence to support the capability of an inspection, an alternative approach is to quote a probability of detection or POD. This is generally shown as a curve with probability up the Y-axis and some measure of the defect such as defect length or through wall dimension on the x-axis. The downside of this is that the ability to detect a defect is not just dependent on either the length or the through wall extent: a lot of other factors have an influence. Rummel [6] gives a number of examples of how NDE process variables (such as variation in light intensity during the viewing of dye penetrant inspection) can significantly alter the POD curve.

Another pitfall with PODs is that the term is applied irrespective of how the value has been determined. In Section V, Article 14 of the ASME Boiler Code, two alternatives are offered for calculating PODs. One is referred to as intermediate rigour and the other as high rigour. The former uses a minimum of 10 flaws or grading units whilst the latter is statistics based and aims to give 90% Confidence in 90% POD. However both are referred to as PODs.

NDE PROCEDURE and REPORT

As a purchaser of NDE services, what is it that you are actually buying? At first glance it may appear that you are purchasing an inspection report. However, the results of an inspection are only of use if they are interpreted in the light of knowledge about how they were obtained. It is the NDE process which is purchased. The process is defined by the inspection procedure and, as it is a special process, the procedure should be supported by some evidence showing that the procedure, equipment and personnel meet the inspection specification. The output of the process is the inspection report.

Both the procedure and report are key documents but they can vary considerably in quality. There is no standard template for either document. The Client should review the procedure to ensure that it provides the operator with the required information. The procedure will carry review and approval signatures but what do these signatures actually mean? What has been reviewed? What is approved?

Other factors to consider for the application of the procedure are: Is the demarcation of responsibilities between the Client and the Vendor clearly stated and understood? What supervision and management support is given to the operators?

The inspection report should describe what was actually done. It should reference the procedure and provide sufficient details for the inspection just quoting a standard may not be enough to allow a repeat inspection to be performed. The report should provide information on uncertainties in the diction and or sizing measurements. Any restrictions to test should be explicitly stated even if the are obvious. Sometimes 100% coverage is quoted and actually means 100% coverage of the available surface despite the fact that a significant proportion of the weld may not be inspectable due to a branch or fitting on the pipe. It is assumed that the Client will know about the presence of the branch or fitting and its impact on the inspection. When the report gives a value or graph of POD is it clearly stated what this actually means and how it was derived? Finally, is the report providing real data or artifice?

CONCLUSIONS

To get the necessary benefit from the application of NDE there has to be an intelligent customer. Guidance is available to help in achieving this status. It is important to apply standard QA practice and to start by specifying the requirements for the inspection. The Client should ensure that sufficient information is provided to the NDE vendor and that contractual roles and responsibilities are clearly defined. An understanding of the capability of the inspection procedure is required along with any uncertainties associated with the results. If in doubt ask the NDE vendor. Ensure that the report gives the necessary data in sufficient detail and keep records: procedure, capability & report.

Reference list

(1) "Quality management systems Requirements", BS EN ISO 9001:2000

(2) PANI 3 Report available at http://www.hse.gov.uk/research/rrhtm/rr617.htm

(3) HSE Guidance documents available at:
http://www.hse.gov.uk/comah/sragtech/ndt1.pdf - Manual Ultrasonics
http://www.hse.gov.uk/comah/sragtech/ndt2.pdf - Magnetic Particle & Dye Penetrant
http://www.hse.gov.uk/comah/sragtech/ndt3.pdf - Radiographic Inspection in Industry
http://www.hse.gov.uk/comah/sragtech/ndt4.pdf - UT Errors & Defect Assessment

(4) ENIQ documents can be found at: http://safelife.jrc.ec.europa.eu/eniq/publications/complete.php

(5) Hardie F. E. & Baborovsky V. M., "The benefits of a pragmatic approach to ENIQ for routine ultrasonic inspection", Insight 2002, vol. 44, no9, pp. 554-556

(6) Rummel, W. D. " Probability of Detection as a Quantitative Measure of Non-Destructive Testing End to End Process Capabilities", Materials Evaluation, January 1998

(7) Section V, "Nondestructive Examination" ASME Boiler & Pressure Vessel Code, 2007, ASME

Bernard McGrath is the Team Leader of the Inspection Validation Centre, SERCO TCS. He has worked closely with the HSE through the IVC based in Warrington.

This paper was orginally presented at ESIA10, the 10th International Conference on Engineering Structural Integrity - Engineering Structural Integrity Assessment: present goals - future challenges in May 2009. The full proceedings are available from EMAS Publishing.

Professor Edwin 'Ted' Smith

Professor Edwin (Ted) Smith passed away peacefully on Sunday 4 July following a short illness. Ted was a major influence at the University of Manchester since 1968 when he joined as Professor of Metallurgy following seven years at the Central Electricity Generating Board. His vision, combined with that of his counterpart at UMIST, Prof. Ken Entwistle, led to the creation of a joint Metallurgy Department in the 1970s. He was Dean of Science (1983-85), Pro-Vice-Chancellor (1985-88), and thereafter Emeritus Professor and Consultant. He was elected as a Fellow of the Royal Society in March 1996 for his pioneering work on brittle fracture. He was particularly proud of his work on delayed hydride cracking undertaken in collaboration with Dr. Doug Scarth of Kinetrics, Canada, over the last 20 years.

From FESI's inception in 1994, Ted provided unwavering support in providing papers, attending numerous FESI events and also by encouraging his students both past and present to attend.

He was a marathon runner and had a great love of all sports. He was a major influence on friends and colleagues in both academia and industry and will be greatly missed by all.

Call for Papers
ESIA11- Engineering Structural Integrity Assessment: from plant and structure design, maintenance to disposal
24 - 25 May 2011, Manchester, UK

Background
This is the eleventh in the series of FESI international conferences on the topic of Engineering Structural Integrity Assessment. The Conferences are a major forum for dissemination and discussion amongst industrial, academic and regulatory bodies in this field. All aspects of this multi-disciplinary subject are addressed including the status of assessment technologies and methodologies in relation to design, operation and disposal of plant, structures and components.

The continuing need for industry sectors to provide economic advantages to both its investors and customers, has shown that there is a need for greater investment. New plant, components and systems must be able to provide increased output at reduced cost - safely and sustainability. Alternatively, there is often an economic argument to extend the life of components and systems. Running parallel is the requirement for clean disposal of out-of-commission plant and components. This latter topic is an increasingly important issue in view of the potential environmental impact.

Theme
This FESI Conference will be based around the theme of "**Engineering Structural Integrity Assessment: from plant and structures design to disposal**". The aim is to show how outputs from recent research and development can lead to improved integrity of structures and components in the area of design and new build, enhance their longevity and develop a greater understanding of the issues surrounding decommissioning and long term storage.

It will:

- consider all major industry and business sectors, including energy, transport, process and civil structures.
- address through the development and deployment of condition evaluation and assessment tools; integration into methodologies and their application to the current situation and future planning, both deterministically and probabilistically based; operational challenges of life cycle management for newly designed plant,
- consider case histories demonstrating the applicability to specific plant problems to the improved life management of existing and new structures and components and their disposal (**papers here will be particularly welcome**),
- examine current needs in terms of sustainable management concepts, strategies and methodologies, regulatory requirements, economic benefits and societal impact,
- address research and development directed to improving inspection and monitoring techniques, basic understanding of mechanisms and analytical procedures that will be used subsequently to enhance assessment methodologies and strategies.

Dates to Note
- Abstracts must be submitted by **24 October 2010**. The abstract should be 200-300 words plus key words, 1 table and picture and references
- Authors will be notified of acceptance by 1 November 2010 (with full paper format guidelines)
- Submission of the Full Paper for review by 15 February 2011. All papers received at that date will be included in the printed conference proceedings of ESIA11 to be included in the Conference pack

Full details go on our website:
Www.fesi.org.uk/esia11

or contact Poul Gosney at:
poul.gosney@fesi.org.uk

FESI Seminar Report

Understanding Structural Integrity Issues in Various Industry Sectors

11 November 2009 - Health & Safety Laboratory, Harpur Hill, Buxton

Programme

Welcome and Introduction
P Heyes, HSL (Host)
I Le May, Metallurgical Consulting Services Ltd (Chairman)

Aerospace - Developments in Airframe Structural Integrity
J Moon, QINETIQ

Automotive - Advanced Techniques for Design of Roadside Barriers for Crash Scenarios
O Tomlin, MIRA

Gas - Written Schemes of Examination derived from an RBI approach
P. Jackson, ABB

Medical Devices - Improving the Mechanical Reliability of Ceramic Components by Design
R Morrell, NPL

Nuclear Power - Structural Integrity Challenges in the Nuclear Industry
P Budden, British Energy

Offshore Inspection - Accuracy and Integrity Assessment of Corroded Offshore Pipes
A Smith, DNV

Power Generation Overview of UK Conventional Power Plant Integrity Issues
A Morris, E.ON-Engineering

Rail - Transport of DE-LIGHT: The Design and Prototyping of a Lightweight
J Carruthers, NewRail

Open Forum Discussion led by Dr I Le May

FESI Workshop delegates were greeted by Mr Phil Heyes and Dr Iain Le May, as host and Chairman respectively. Mr Eddie Morland, Chief Executive, Health & Safety Laboratory (HSL), welcomed everyone to the HSL's Buxton facility and spoke of the relevance of engineering structural integrity (ESI) to the HSL's remit which includes investigating the many serious occupational and industrial incidents which occur every week throughout the year, some as an outcome of ESI failures. He commended the day's programme and the large number industry sectors represented at the Workshop, and underlined the links between these and the work of the HSL.

Open Discussion

Chairman: Dr Iain Le May
Panel: Prof Ian Howard (University of Sheffield), Dr Keith Newton (RCNDE), Prof Andy Morris (E.ON Engineering), Dr Joe Carruthers (Newrail)

After the Programme outlined above, Dr Iain Le May thanked the speakers for their interesting and informative presentations, and introduced the Workshop's open discussion element by reiterating the day's themes, namely the:

-Need to communicate the best practice for techniques and methodologies in engineering structural integrity in different industries, business and academic communities;

-Need to identify best practice in engineering structural integrity in various industries;

-Identification of latest developments in structural integrity methodology in different industries;

-How can latest developments in best practice be transferred to other industries?

There followed a lively discussion, various strands of which appear below:

Prof Andy Morris commented that it is encouraging that young engineers enter the industry from higher education institutions and bring with them their learning, skills and competences, which may in turn support industry best practice. However, there exist many issues in the industry around staff recruitment and retention which subsequently erode the benefits of this influx. There are also issues in the industry concerning inspection practices, with many structures being designed in such a way that they are un-inspectable. It was clear that the majority of those present agreed with Prof Morris's views, in particular with regard to designing for inspection and inspection practice.

Dr Norman Swindells commented that there is a need to conserve technical data on products throughout their life-cycles, and a mechanism by which such data can be exchanged, shared and conserved to support the implementation of best practice is necessary. His company has developed a new International Standard, ISO 10303-235, to represent the results of the measurement of data values for any property measured by any process, which also extends the application of product data technology into the areas of materials engineering and materials testing. Dr Le May commented that there is a need for high quality data to underpin ESI.

Dr Qingming Li raised the matter of uncertainties in materials properties, especially where there are areas of dynamic properties. Numerical modelling becomes more important and feasible in the assessment of structural integrity; the most uncertain factors in numerical modelling are the material models and parameters and the ways to determine them, especially when the material responses is beyond elastic response and is in less familiar environments, for instance plastic deformation, failure, at high strain-rates, at high/low temperatures, and so on. Dr Li described that in his research field of material and structural responses at high strain-rates, there exist misinterpretations of material testing results, which, however, have been widely employed through the use of commercial software. He went on to say that although numerical modelling is always verified and validated by other methods (for instance, experiments), their robustness must be checked very carefully (for example, there are some non-physical parameters in numerical models, which can be adjusted to fit limited experimental results) to ensure the reliability of numerical predictions.

Prof David Smith pointed out that there is a need to define the terminology associated with proof loading so the process can be better understood. He raised the question of whether or not the ESI community might be ignoring proof loading because it is too costly, and commented that he found the notion of using numerical simulation unsatisfactory as materials properties may be uncertain.

Dr Joe Carruthers offered that, further to his experiences on the project to design a crashworthy rail vehicle driver's cab, there is a need for separate crash scenarios to illustrate proof loading, and Dr Brian Tomkins raised the question of testing sensitivities. It was also pointed out that where proof loading concerned composite cylinders for certain fluids, the cost of testing must allow for cleaning and this raises the cost considerably above conventional testing; therefore conventional testing may be preferred for this reason. However, in any event, several simulations would be required. A further issue discussed by delegates was the desirability or otherwise of certification by simulation.

Prof Ian Howard opened discussion around the need to understand components and manufacturing processes. Prof Howard went on to say that looking for defects using NDT is not always viable, and in proof testing you need to examine a population of, for instance, welds, not a single weld.

Prof John Yates raised the issue of variability in geometry because of manufacturing processes and sensitivities; an issue which needs to be taken into account is, therefore, the empirical nature of simulations.

Prof Robert Akid stated that the old adage, “garbage in, garbage out”, unfortunately but frequently applies to testing, a view which was endorsed by other delegates. Dr Le May commented that when computers are involved, the user must beware as it is all too possible to put “garbage in”, but get “gospel” out; this perpetuates many inaccuracies.

Further issues raised were the need to accelerate time-dependent processes to understand the nature of the damage, and the impact on materials properties in service.

Mr Alexander Amadioha offered that, with regard to materials manufacturing, there are certain limitations on the general understanding of such processes, and these can become embedded in testing scenarios; however, it is not possible to always test real materials in service. Dr Le May said that, generally speaking, failures may occur because people do not understand manufacturing processes and how these impact on materials properties. Dr Swindells pointed out that a property represented as a number needs to be set in the context of the conditions in which it was derived so that people can make a human judgement. Dr Keith Newton said it would be desirable to bring NDT closer to SI, and recommended that there should be a scoping study to see if this could happen at an early stage.

The issues of designing for inspection and the un-inspectable nature of many designs provoked much discussion and comment from Workshop delegates concerning difficulties with regard to inspection, the serious incidents which arise when structures fail because defects have not been detected, and the need for inspection procedures to be incorporated into products at the early design stage. Mr Phil Heyes spoke of the HSE's ergonomic approach to NDE and NDT; Dr Leon Lobo raised the matter of the need to design for inspection in the composites industry; Dr Alan Smith underlined the need to design for inspection.

Dr Le May drew the animated discussion to a close as the time allowed had been over-run, saying that inspectability and design for inspection are clearly recognised but vexed issues within the industry, and are therefore priorities for ESI and FESI. He suggested that a future FESI Workshop could usefully focus solely on this important area which is so critical to health and safety generally and to the work of the HSL. He thanked all delegates for their contributions.

Mr Poul Gosney, Chief Executive, FESI, reminded all delegates to take up their entitlement to FESI membership.

Statistical Analysis of the Development of Safety Assurance in China

Qun Peng Zhong, **Su Jun Wu**, Zheng Zhang, Yi Liang You, Luowei Cao

Introduction

Many fatal accidents have occurred in the world during the last hundred years, leading to enormous financial and human losses. Such accidents essentially fall into broad classifications which may include, for instance, nuclear leaks, spacecraft catastrophes, aviation disasters, and fracture accidents in civil projects. Listed below are some typical examples for each of the classifications, drawn both from within China and from elsewhere:

Nuclear leaks: Chernobyl (1986, Former USSR), Three Mile Island (1979, USA)

Toxic gas leaks: Bhopal (1984, India), Liquid nitrogen steel cylinders explosion (1979, Wenzhou, China)

Spacecraft catastrophes: "Challenger" (1983, USA), "Columbia" (2003, USA)

Aviation disasters: CRJ-200 type NO. B3072 airplane disaster (2004, Baotou, China), Early-warning airplane disaster (2006, Anhui, China)

Fracture catastrophes in civil projects: Qinling power plant disaster (1988, China), Collapse at De Gaulle airport (2004, France), fatal fire accident at Beijing East Chemical plant (1997, China), fatal accident at Three Gorges project (2000, China)

Safety assurance (occupational and/or operational safety) has three basic characteristics[1]: absolute necessity (or unavoidable catastrophe), time-dependence (as an outcome of the economic, social, political, technological, industrial and cultural conditions prevailing at the time) and a multi-disciplinary system (there was more than one contributing factor). Absolute necessity implies a safety problem that cannot be prevented under any conditions. Different historical periods have different technological contexts so that the sorts and degree of accident are time-dependent; for example, figures given by the International Civil Aviation Organization (ICAO) show that in 2005 the number of aviation disasters involving more than seven seats was 42, leading to 944 deaths, whereas in 2004 the numbers were 18 and 510[2] respectively. The causal reasons for the safety problem are various and include materials problems, environmental effects, and human factors. These areas may be further broken down into factors that involve material science, mechanics, corrosion science, systems engineering, management science, inspection engineering, and so on; in other words, a 'multi-disciplinary problem'. In order to try to reduce the number of disparate inputs involved in occupational safety assurance, a structural integrity assessment has been explored, and related to integrity assessment, life prediction, and probability safety assessment of different types of structures and equipment.

The history of occupational Safety in China

Fig.1 demonstrates the five broad historical periods that have been identified from over the last fifty years; these have been related to safety performance, policy shifts, and the corresponding socio-economic conditions[3]. Fig. 1 illustrates three significant troughs (or 'good stages') and three major peaks in the numbers of fatalities. The first period runs from 1949 to 1957 (note that few data were recorded during the period 1949 to 1954). This period corresponds to the first trough, or 'good stage', on the fatalities axis. Following the first trough, the number of fatalities increases rapidly to the high figure which forms the first fatalities peak in the second period (1958 to 1965), caused by a lack of effective management. In the third period (1966 to 1979) there are two high fatalities peaks following a short-lived trough. Although the fatalities curve of the fourth period (1980 to 1992) is smooth, the average number of fatalities is higher than it was previously. This is attributable to the rapid development of both technology and the economy: many ambitious projects were initiated and many new kinds of equipment were introduced from foreign countries. The fifth period, from 1993 to the present, although still evolving, demonstrates two peaks. The first peak, occurring around 1993, is due to the conflict between high-growth economic development and a lack of corresponding safety assurance legislation. The overall number of fatalities in the fifth period shows a downward trend.

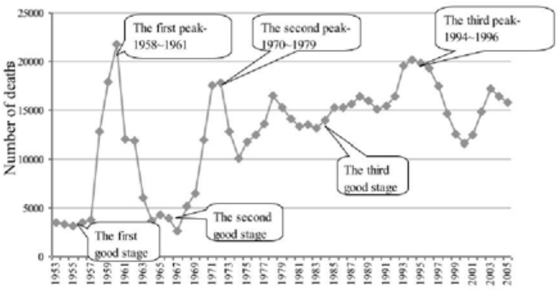

Fig.1 The death number in industrial and mining enterprises

The curve illustrated in Fig.1 clearly shows the three major peaks and three major troughs in the number of fatalities. The Great Leap Forward occurred between 1958 to 1961, the Cultural Revolution and Post-Cultural Revolution took place from 1970 to 1979, and the Chinese economy was transformed from a planned economy to a market economy between 1994 to 1996. Thus, it can be seen that the three peaks were all policy related. However, the

Fig.2 The change of the death number per 100,000

three troughs were all economy related. A low GDP (gross domestic product) and social and economic stability led to the first trough from 1953 to 1957; the second trough from 1963 to 1968 was post-Great Leap and due to a low GDP, while the period of social and economic stability following the Cultural

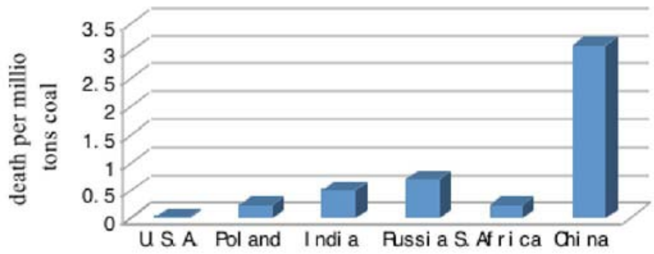

Fig.3 Comparison of death per million tons coal in different countries

Revolution gave rise to the third trough of 1980 to 1992.

Taking coal mine fatalities as an example, Fig.2 shows that from 1981 to 2005 deaths in China per 100,000 tons of coal produced decreased steadily from 8 per 100,000 to 3 per 100,000. Although coal

Fig.4 Change of the death number per 100,000 people in industrial and mining enterprises accident, 1953-2005

mine disasters occur frequently in China, occupational safety in mines is improving gradually year on year. Safety assurance development in

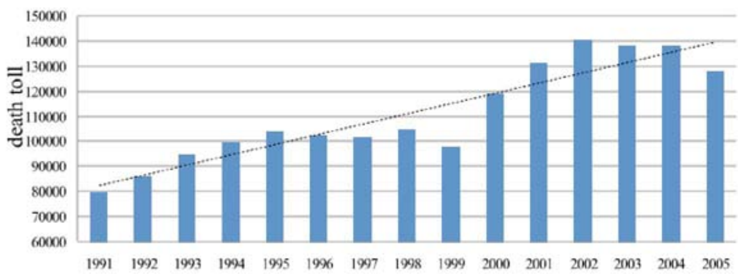

Fig.5 The death number in various accidents in China, 1991-2005

China

Current state and future trends

Fig.3 demonstrates the number of fatalities per million tons of coal produced, for different countries. In Fig.3 we see that the fatalities ratio in such accidents is generally higher in China than in other countries.

Fig. 4 shows changes in the fatalities per 100,000 workers in industrial and mining accidents from 1953 to 2005; the number of fatalities decreases incrementally.

Linear regression using sixteen years' worth of data shows that the number of fatalities grows steadily, corresponding to the equation $y=81318.2+3422x$, in which the correlation coefficient is 0.8920, as shown in Fig.5.

The current situation with respect to occupational safety in China is closely related to the establishment of a system of occupational safety laws, the strengthening of the national safety supervision system, and the improvement of workplace emergency management.

At present, the problem is divided into four main areas of concern: (1) The number of fatalities, financial losses, and loss of public assets, are significant when compared to other types of data. Data show that in 2005 the overall number of fatalities caused in industrial accidents declined 7.1% compared to 2004. Nevertheless, the total number of fatalities still climbed to 127,089. (2) Fig.6 shows that the frequency of fatal accidents and the number of associated fatalities are showing an upward trend [4]. (3) In China the upward trend of cases involving occupational hazards has increased since 1998, as shown in Fig.7. In 2000, the number of people in China impacted by occupational hazards, regardless of their evaluation as a cumulative total number or number of fatalities or as new cases, and so on, was ranked first in the world. Similarly, the number of fatalities in China in road traffic accidents and in coal mine accidents also rank first in the world. (4) Occupational safety in medium and small-size enterprises (SMEs) is the 'weak link'. Fig.8 demonstrates the main data.

However, the improvement of supervisory and management systems is under way. In 2002 the Safety Production Law was passed in China, greatly strengthening the supervision and management of occupational safety, especially in larger projects. The following year, the State Council Safety Production Committee came into being. In the early months of 2005, the State Administration of Work Safety was upgraded to a higher administrative level. Subsequently, in 2006, the National Workplace Emergency Management Center was set up. The establishment of these organizations and their enactment of legislation has greatly improved standards of occupational safety.

Safety assurance and economic development statistics in some developed countries

Research shows that stages of safety assurance can be identified in and linked with the degree of a nation's economic development. Fig.9 exhibits the

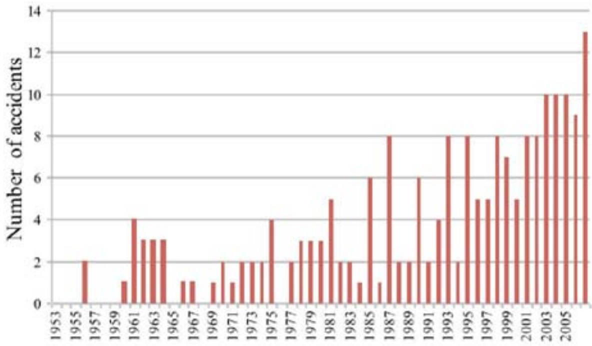

Fig.6 The number of industrial and mining enterprises accidents, 1953-2005

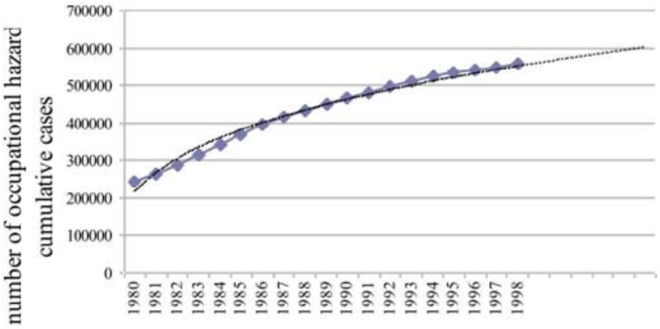

Fig.7 The trend of the number of occupational hazards in China

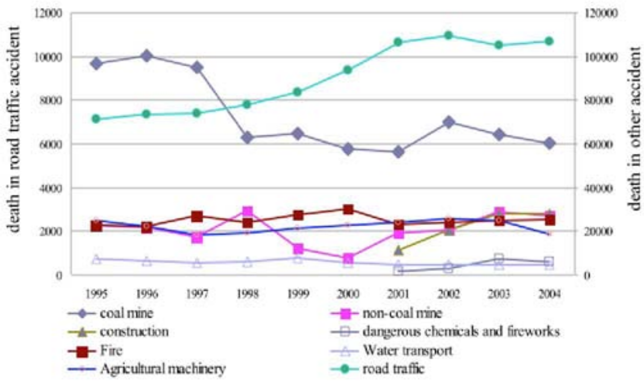

Fig. 8 The trend of death number in various types coal mine disaster in

Fig. 9 Death number change in industry accidents in UK, coal mine accidents in

stages of safety assurance which can be applied to developed countries. Studies indicate that the number of industrial or occupational accidents in any developed country is experienced in four stages: the 'accident-prone' or rapidly accelerating stage (stage I), the high-count, fluctuation stage (stage II), the rapidly declining stage (stage III) and the steadily declining stage (stage IV). Fig.10 shows the relationship between the number of industrial fatalities and the level of economic development. An asymmetric parabolic curve is assumed, which also can be divided into four stages: stage I is the primary economic development stage, with GDP per capita at about 1,000-3,000 dollars; at this stage, industries develop rapidly and occupational accidents happen frequently. Stage II is the medium economic development stage, with GDP per capita at about 10,000 dollars; at this stage, occupational accidents climb to a peak and are gradually controlled. Stage III is the advanced economic development stage, with GDP per capita at about 10,000-20,000 dollars; at this stage, safety production accidents decline rapidly. Stage IV is the post-industrialization stage, with GDP per capita at more than 20,000 dollars; at this stage, occupational accidents decline steadily and the number of fatalities is at a low level. Statistical data from the World Congress on Safety and Health at Work in Brazil in 1999 showed that the total number of accidents across the world was 250 million; however, the number of work-related accidents was 1.1 million (with one quarter killed in occupational hazard incidents), which was more than that of any other type of accident[3].

The characteristic stages cited above reveal the relationship between a country's level of economic development and its industrial safety record. In other words, the level of industrial safety in a country is also indicative of its level of economic development, and this is a common phenomenon.

Assuming that GDP per capita can be used as the indicator of economic development, and using an analysis of occupational health and safety statistics from over 70-plus years, a strong correlation between GDP per capita and the development of occupational health and safety regulations/standards is proposed (Fig.11). Further study indicates that the closer it is to the present time, the shorter the time-span of Stage 1; this is demonstrated in Table 1.

Fig.12 seems to indicate that China is still at Stage II. However, based on the relationship between the number of annual fatalities and GDP per capita, China should be at late Stage 1 by now.

Table 1

	UK	USA	Japan
Stage 1 time-span	1880-1950	1900-1960	1948-1974
Experience time (year)	70	60	26

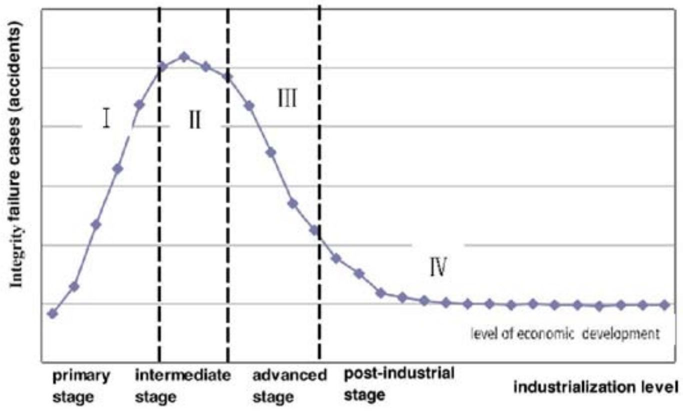

Fig.10 The relationship between safety production and the industrialization level

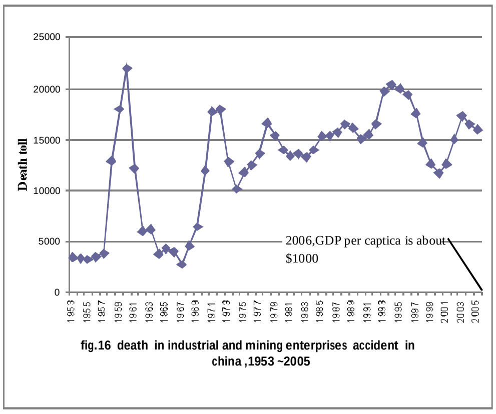

Fig.11 Trends of occupational death and GDP per capita in Japan, 1917-2002

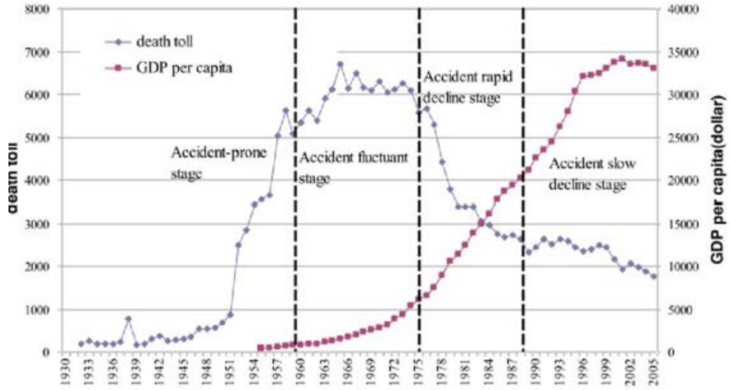

Fig.12 Death in industrial and mining enterprises accidents in China, 1953-2005

This implies that China faces the most severe safety issues at this stage.

Main factors influencing occupational health and safety

A country's occupational health and safety record is closely related to its level of economic development. According to the standard offered by the World Bank, and through analysis of 14 social and economic indicators from 27 countries with different degrees of development in four main areas, four main social and economic factors that affect safety are proposed. These are, namely, the level of economic development, industry structure, science and technology level, and education level.

(1) Economic development

Fig.12 shows the number of industrial and mining accidents in China between 1953 and 2005. However, GDP per capita in China reached 1,000 dollars in 2006. If we define 1,000 dollars as the start of the Stage 1, China is now just at the beginning of this stage. As shown in Table 1, the time-span of Stage 1 in China will be shorter than that of Japan. However, no research data indicates that how long Stage 1 will last.

Gerd Albracht finds that a direct correlation exists between a nation's economic, or global, competitiveness and its occupational health and safety record. The UK, the USA, Japan and Germany have higher levels of economic competitiveness than many countries, and their occupational health and safety record is similarly better than that of other countries. Fig.13 shows that China is ranked higher in terms of occupational health and safety and its economic competitiveness than Indonesia, and is ranked close to in Russia in these areas.

(2) Industry structure

Industry structure optimization distinctly decreases the accident fatalities rate: when tertiary industry yields more than 50% percent of GDP, the fatalities rate per 100,000 people declines markedly. In 2000, activity in the three industry sectors was proportionately 3.2:27.7:69.1 in developed countries, where greater involvement in the tertiary sector conferred significant advantage and the fatalities rate was 5.4 per 100,000 people. In China in 2005, the industry sectors were proportionately at about 12.5:47.3:40.2, with secondary industry yielding almost one half of GDP. As a result, the fatalities rate was estimated at 10 to 12 per 100,000 people, or 2 to 3 times than that of developed countries.

(3) Science and technology level

Science and technology has a great effect on occupational health and safety. A comparison of scientific research and development (R&D) showed that in developed countries this always

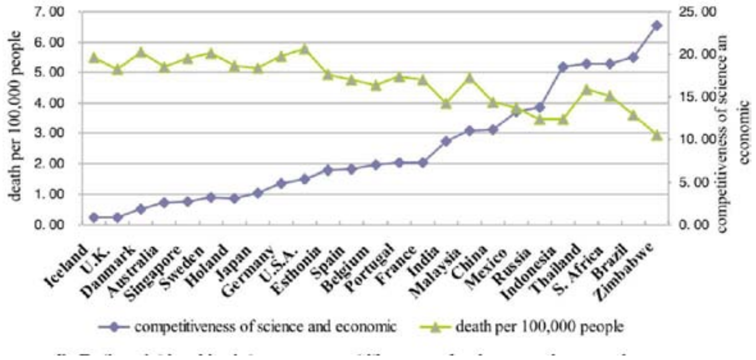

Fig.13 Relationship between economy competitive power and safety production level

exceeds 3% of GDP, whereas in China it was only 1.3% of GDP in 2005.

Occupational safety is markedly improved with the progress in science and technology. Research in the USA indicated that new technologies have a significant effect on the improvement of safety in coal mines. Firstly, the wide-spread adoption of information-based and automatic supervision technology systems strengthens strategic awareness of the need to plan the exploitation of coal, and increases the prediction rate for invisible or concealed hazards. Secondly, the mechanization and automatization of mining improves work efficiency and reduces the number of workers in the mine shaft (thus, should an accident occur, the number of fatalities will be reduced). Fig.14 shows the relationship between the level of mining mechanization and the number of fatalities per million tons coal produced in China since 1980. The improvement of mining mechanization steadily decreased the number of fatalities per million tons coal, especially from 1980 to 1991.

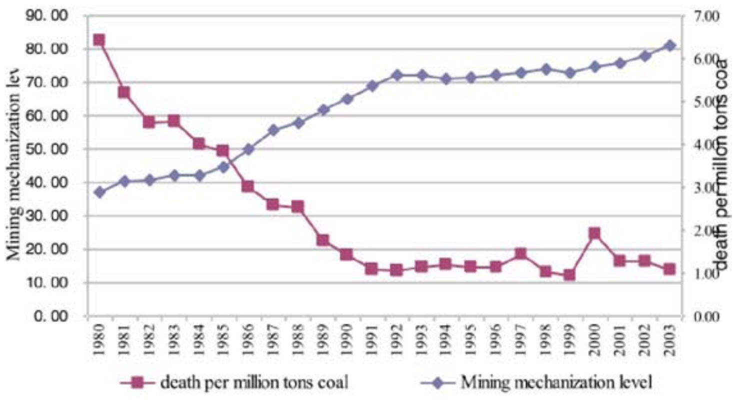

Fig.14 Trends of mining mechanization level and the death per million tons

(4) Education level

A general international indicator of educational attainment is the gross high school enrollment rate, including intermediate-level vocational education. Education has a great influence on standards of safety. For example, the gross high school enrollment rate in the UK is 156%, in Australia 160%, and in USA 95%; all these countries have a good occupational safety record. A further, more powerful, example of this premise is that although the economies of Poland, Czech and Hungary are still developing, these countries' gross high school enrollment rate is equivalent to that of developed countries, and their occupational health and safety record is also close to that of developed counties. In China, however, the gross high school enrollment rate in 2005 was only 52%. Research shows that mining disasters related to human error account for more than 90% of the total, and that fatal accidents are 100% attributable to human factors. Furthermore, 53.77% of mining accidents in China are attributable to violation of operational regulation and 99% of those who died in mining accidents were illiterate or had no background of high school education. The percentage of directors of small coal mines with a background of education equal to or higher than high school is only 4.3%, while in medium and large coal mines the figure is 34%. Therefore, the level of educational attainment is one of the main factors affecting occupational health and safety.

Different historical ages have produced different kinds of safety cultures, and these have a close relationship with educational attainment levels. Different eras exhibit different theories of and characteristics in their safety cultures. As shown in Table 2, China's safety culture has evolved through several stages.

Table 2 Evolution of safety culture

Historical Era	Theory	Characteristics
Ancient safety culture	Fatalism	Passively endured type
Early modern safety culture	Empiricism	Feeding back (de-briefing)
Modern safety culture	System theory	Combined and systemic type
Developing safety culture	Essence theory	Predictive type

The relationship between occupational safety and structural integrity

In order to ensure structural strength, fracture ductility, life and safety reliability, a more scientific and integrated quality assurance system, as well as standards, criteria, and methods (methodologies?) applicable to projects, should be established; this would assist in the systematic, stringent and scientific management of product design, manufacture, installation, operation, inspection and evaluation, repair, safety assessment, and so on. The notion of structural integrity (SI) is also associated with this purpose. SI is the influence measurement of safety and reliability for products containing flaws. SI assessment or assessment based on fitness-for-service is a quantitative assessment for products containing flaws and gives a conclusion whether it can be used or not [5].

Occupational safety is closely related to human factors (levels of educational attainment), materials factors (science and technology R&D), design factors (science and technology, economic development) and so on. As mentioned above, different countries have different levels of socio-economic development, investment in science and technology R&D, industry sector structure and educational attainment, leading to different outcomes in operational health and safety. Different countries therefore focus on different areas; for example, developed countries focus more on operational and safety assessment of the product or components because they have previously carried out sufficient research into the selection of materials or products design. In some developing countries, however, insufficient research, or incomplete systematic study of the basic materials selected for products, is apparent and greater emphasis should therefore be placed on these areas. The analysis of occupational health and safety statistics can generate meaningful guidance for countries when they require information about structural integrity research in their counties; this may be known as the Regional Character of Structural Integrity Assessment (RCSIA) study.

At present, four standards are used in projects: products design standard, construction standard or quality control standard, safety supervision standard in operations (for example, Technological Supervisory Procedures for the Safety of Pressure Vessels), standard based on Fitness-for-purpose or Fitness-for-service (FFS). The last standard is based on multi-disciplinary knowledge, including fracture mechanics, elastoplastic mechanics, materials science, reliability engineering, systems engineering, risk engineering, and so on, and this standard combines safety reliability and economy of structure, leading to optimization of economy benefits.

Developed countries have completed the first three of these standards, and further scientific and systematic FSS-based standard/s is/are under development. For example, Structural Integrity Assessment Procedure for European industry (SINTAP), a project part-funded by the European Union, commenced in 1996 with the aim of developing a unified procedure for carrying out fitness-for-purpose assessments[6]. However, in developing countries, where the process of industrialization is not complete, the standards for product design, quality control, and safety supervision in operation, are currently still under development; here there is insufficient financial support and scientific and technological ability or know-how to carry out the required systematic research, to say nothing of the application of such standards once they have been developed. The study and application of the SINTAP Structural Integrity Assessment standard is a complicated issue related to economic development, science and technology R&D, industry structure, education attainment level, which can be concluded from the statistical analysis of safety performance. This underlines the need for the RCSIA study.

Conclusions

Periods of dramatic policy change, economic reform, and social development were found to correlate with occupational safety outcomes, and five discrete historical time-periods were examined in order to better understand the development of occupational safety in China. Since 2000, occupational health and safety legislation has been enacted in China, and various relevant organizations have been established.

Current safety production and trends have been analyzed and the findings are shown in chart format. In conclusion, four main problem areas in occupational health and safety have been demonstrated in this paper, revealing the difficulties experienced in implementing occupational safety management in China.

The development of occupational health and safety has characteristics that are found to be common between nations; a country's occupational health and safety record also reflects its economic development. Simple statistical analysis indicated that the time-span of stage 1 of the incidence of accidents becomes shorter the closer it is to the present. If 1000 dollars is used to indicate the primary industrialization stage, corresponding to stage 1 of the accidents incidence graph, China will reach medium-stage industrialization before 2032. Furthermore, the actual time will be in advance of our prediction.

The main factors that affect occupational safety have been discussed in this paper. Economic development, industry structure, science and technology level and educational attainment levels were found to have great influence on a country's occupational safety record. Finally, the relationship between safety production statistical analysis and structural integrity assessment study has been discussed. Different countries have different socio-economic, science and technology, industry structure and education attainment levels, which lead to different outcomes in safety assurance. There is much evidence from the SINTAP project to show that different countries, at different stages of socio-economic development, should focus on one or two discrete areas of the study. Finally, taking forward the Regional Character of Structural Integrity Assessment (RCSIA) study is recommended.

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Book Reviews

Strength and Fracture Criteria

By Prof Antanas Ziliukas

This book, authored by Professor Ziliukus, entitled "Strength and Fracture Criteria" will be a very useful guide for students, researchers, academics and practicing engineers in the field of structural integrity. Recognising the fact that engineering structures and components in many cases nowadays need to be able to retain a satisfactorily level of structural integrity with greater emphasis placed on decreased weight and cost and increased load severity and capacity, the book brings together the various theories that form the basis of the simple and more advanced structural integrity based methodologies. The following aspects are described in the various chapters of the publication:

- Strength and yield criteria for complex staining
- Classification and comparison of strength criteria
- Demonstration of need for a universal strength criterion and required parameters for strength evaluation
- Proposed evaluation of new strength criterion
- Brittle fracture criteria
- Fracture criteria for plastic straining and crack growth
- Local fracture criteria
- Evaluation of fracture in semi-brittle and semi-plastic materials
- Fast fracture and crack tip constraint
- Dynamic resistance to crack growth
- Two-parameter fracture criteria
- Crack growth rates under varying complex loads

In summary, this book presents a comprehensive review of strength and fracture criteria. Furthermore, it proposes new criteria which are validated experimentally. It is anticipated that these criteria may be used more widely in both research and practical application environments for such aspects as designing new materials and technologies for structural applications.

About the Author

Dr. Habil. Antanas Ziliukas is professor of Fracture mechanics at Kaunas University of Technology. In 1992-2006 he was a head of Department of Solid Mechanics. From 2000 he has been the director of Strength and Fracture Mechanics Centre. In 1994-2003 he was a member of Lithuanian Science Council. In 1996-2006, he held the position of member expert of Lithuanian Science Academy.

He has taken part in international projects related to the design of hydrogen aircraft engines and safety systems for nuclear power plants.

Professor Ziliukas gives lectures on materials mechanics, theory of elasticity and plasticity, fracture mechanics, theory of reliability to students at all levels.

Modern Metal Fatigue Analysis

by Professor John Draper

There have been major advances in methods of fatigue life estimation over the past 30 years. Allowable stresses can now be estimated to an accuracy of a few percent. Much of this knowledge is available in research papers but is not readily available to designers. Modern Metal Fatigue Analysis by Professor John Draper is intended to bridge the gap between research and design by providing a concise introduction to modern methods of fatigue analysis as well as the more traditional methods.

The content was developed by the author as course notes for training courses presented in Europe, North America and Asia to engineers who need to apply fatigue knowledge in engineering design, fatigue testing and failure investigation. The material will also be of value to academics and undergraduates on mechanical engineering courses.

The book assumes no prior knowledge of metal fatigue. It introduces the concepts of strain-based fatigue analysis and the more traditional S-N curve methods. Modern theories of multiaxial fatigue are described, together with their application to strain gauge measurements and fatigue analysis of finite element models. There are chapters on statistical analysis, crack propagation, and fatigue of welded steel joints. The final chapters discuss the merits and disadvantages of different types of fatigue tests, and aspects of practical fatigue analysis. Throughout the book the emphasis is on practical application.

"John Draper's book Modern Metal Fatigue Analysis provides a highly readable and comprehensive introduction to the study of fatigue behaviour of metals and alloys for students, a description of the details of fatigue assessment methods for the design engineer, and includes a level of detail that expert practitioners will find useful. With clear figures, a clarity of description, and many practical examples, the book outlines the material response to simple and complex cyclic loading.

Professor Draper has succeeded in providing a comprehensive, readable and clear scientific textbook on fatigue and fatigue assessment that materials science and engineering students, design engineers and structural integrity practitioners will find extremely useful."

About the Author

John Draper worked as a fatigue design specialist in the aircraft industry, then as a project manager in British Rail R&D Division for fatigue research projects, and failure investigation projects using service strain measurement. He formed Safe Technology Limited in 1987 to develop fatigue analysis software from strain gauges and FE models, and provide fatigue related consultancy services. He has supervised SMART award projects and teaching company schemes in fatigue. He acts as a consultant across the industry sector. He is a regularly invited presenter at conferences in the UK, Europe, Asia and the USA. He is an Honorary Visiting Professor to Sheffield Hallam University.

What is Quasi-Brittle Fracture and How to Model its Fracture Behaviour

Bhushan Karihaloo

There are many materials of great engineering significance, e.g. concrete, that are regarded as brittle which are to be used only under compression. Yet when attempts were made as far back as the 1950s to apply classical brittle fracture theories of Griffith and Irwin to concrete, these proved unsuccessful in the sense that the onset of fracture could not be quantified uniquely by the critical stress intensity factor or the critical energy release rate (i.e. fracture toughness). It was however observed that the behaviour of hardened cement paste with its fine microstructure was close to the predictions of linear elastic fracture mechanics (LEFM), but the behaviour deviated the more from the LEFM predictions the coarser, or the more heterogeneous, the microstructure of concrete became.

We now understand fully the reasons for the lack of success of LEFM as far as concrete is concerned (Karihaloo, 1995). These stem from the role of defects such as micro-cracks in the response of all cement-based materials that are traditionally regarded as being brittle, but in reality exhibit a far more sophisticated response. They are moderately strain hardening prior to the attainment of their ultimate tensile capacity, reminiscent of the response of high strength metallic materials. However, unlike the latter, they are characterised by an increase in deformation with decreasing tension carrying capacity past the ultimate strength. Such a response is called tension softening. The materials that exhibit moderate strain hardening prior to the attainment of ultimate tensile strength and tension softening thereafter may be called quasi-brittle. The softening is due to many fracture processes, such as localised micro-cracking, bridging by coarser aggregates, crack branching, etc. Included in the class of quasi-brittle materials are concrete, rocks, coarse-grained ceramics. However, we shall concentrate only on concrete in this talk.

The primary reason for the observed deviation of the behaviour of concrete from the LEFM prediction is the formation of an extensive fracture process zone (FPZ) ahead of a pre-existing notch/crack in which the material progressively softens due to the above-mentioned fracture processes. Therefore a fracture theory capable of describing the behaviour of concrete must include in it a description of the material softening taking place in the FPZ. Such a theory will necessarily be a non-linear one, but we must distinguish it from non-linear fracture theories applicable to ductile materials such as metals because in the latter the FPZ is very small and surrounded by a large non-linear plastic zone, whereas in a quasi-brittle material the FPZ practically occupies the entire large zone of non-linear deformation. In contrast, the non-linear zone is practically absent in brittle materials.

The first non-linear theory of fracture for concrete was proposed by Hillerborg et al. (1976). It includes the tension softening FPZ through a fictitious crack ahead of a pre-existing crack. The length of the fictitious crack is dictated by the microstructure of concrete; the coarser the microstructure the longer the fictitious crack. The term “fictitious” is used to underline the fact that this portion of the crack Cannot be continuous with full separation of its faces. Indeed the latter are acted upon by certainclosing stresses such that the stress intensity factor vanishes at the tip of the extended crack. The closing stresses are not constant in the FPZ, as in Dugdale-BCS model of planar plastic zones ahead of a crack, but they increase from nothing at the tip of the pre-existing traction-free crack to the full uniaxial tensile strength of the material at the tip of the fictitious crack. The distribution of the closing stresses, $\sigma(w)$, along the fictitious crack depends on the opening of its faces, w. The fictitious crack model (FCM) for concrete also differs from Barenblatt's cohesive crack model, in that the size of the FPZ may not be small in comparison with the size of the traction-free pre-existing crack. Unlike LEFM, the description of the fracture of concrete requires two additional material parameters, namely the tension softening relationship $\sigma(w)$ in the FPZ and the area under the tension softening curve, namely the specific fracture energy G_F.

As the FPZ is not continuous (hence the notion of a fictitious crack) and as it does not necessarily develop in a narrow discrete region in line with the continuous traction-free crack, it has been argued by Bazant (1976) that the tension softening relation $\sigma(w)$ can equally well be approximated by a strain softening relation $\sigma(\varepsilon)$, i.e. a decreasing stress with increasing inelastic strain. This strain is of course related to the inelastic deformation w and the specific fracture energy G_F through a certain gauge length h. It was assumed that the FPZ is spread over a band of thickness h, hence the name of this model as the crack band model (CBM) or the smeared crack model to distinguish it from the discrete crack approach implied in the FCM.

The complete failure process of a concrete structure can therefore be modelled by the FCM or CBM once the two additional material parameters G_F and $\sigma(w)$ of the concrete mix are known. However, as the tension softening region (i.e. the fictitious crack) is generally discontinuous, any attempt at the precise determination of $\sigma(w)$ would seem to be doomed to failure from the outset. This has not prevented researchers from attempting to establish it directly from measurements using uniaxial tension tests. Such tests can be performed in a very limited number of laboratories in the world. By far the majority of the attempts have been directed at inferring the $\sigma(w)$ relationship from the measured specific fracture energy G_F, supplemented by other physical information. For example, it is observed that the part of the softening diagram immediately after the peak load is controlled by micro-cracking and is very steep, whereas the tail part of the diagram which is controlled by frictional processes such as bridging by coarser aggregates is shallow. Thus a bilinear approximation of what is essentially a continuous relation is quite adequate. We mention *en passant* that the tension softening relation can be established from rigorous micromechanical principles relating the microstructure of a concrete mix to its macroscopic response (Karihaloo, 1995).The determination of the specific fracture energy has been a subject of intense debate among researchers because it has been found to vary with the size and shape of the test specimen and with the test method. It has been confirmed recently by Abdalla & Karihaloo (2003) and Karihaloo et al. (2003) that the specific fracture energy of concrete measured on laboratory specimens is dependent on the shape and size of the specimen because the local energy in the fracture process zone decreases as the crack approaches the back face of the specimen, as suggested earlier by Hu & Wittmann (2000). It was also observed that size-independent specific fracture energy of concrete could be obtained by testing three point bend (TPB) or wedge splitting (WS) specimens of just one size. However, it is necessary that half the number of specimens contains a very shallow, while the other half contains a deep starter notch. This observation was based on limited numbers of TPB and WS specimens made from normal and high strength concretes. Specific fracture energy data of concretes published in the literature (26 available data sets) were then re-evaluated and confirmed this observation. Thus the determination of the true specific fracture energy of concrete has become a simple and straightforward task requiring few specimens of the same size and shape. Abdalla & Karihaloo (2004) also proposed a method based on the concept of a nonlinear hinge (Ulfkjaer et al. 1995) for constructing a bilinear approximation of the tension softening relation consistent with this true specific fracture energy. The parameters of this bilinear approximation are inferred in an inverse manner from the load-displacement diagrams registered in TPB or the load-crack mouth opening diagrams registered in WS tests.

Structures made of quasi-brittle materials exhibit size and scale effects. The apparent strength would appear to decrease as the size of the structure increases. Also, structures made of the same material exhibit a transition from ductile to brittle response as the size increases. Leicester (1973) seems to have been the first to identify two fundamental causes of size effect in structures made from quasi-brittle materials, such as concrete, namely the material heterogeneity (i.e. statistical size effect) and the occurrence of discontinuities in the flow of stress, such as at cracks and notches (i.e. deterministic fracture mechanical size effect). In quasi-brittle materials, any crack or notch tips are blunted by the formation of a process zone ahead of them. In this process zone the stresses are redistributed and energy dissipated which is thus not available for crack propagation. The size of this fracture process zone (FPZ) can be commensurate with that of most structural elements (*W*). Only in very large structures can this size be regarded as small in comparison with the characteristic dimensions. The redistribution of stresses and dissipation of energy in the FPZ was not accounted for by Leicester. That was done by Bazant (1984) who derived the following formula for geometrically similar structures

$$(\sigma_N)_u = \frac{A_2}{(1+W/B_2)^{\frac{1}{2}}}$$

where A_2 and B_2 are positive coefficients. The above formula reduces to the linear elastic fracture mechanics as *W* when the size of the FPZ is very small in comparison with *W*. In fact the formula can be established by Taylor's expansion from this asymptotic limit (Karihaloo, 1995). Since its appearance in the literature in 1984, it has been re-derived from energy considerations and asymptotic matching techniques (see, e.g. Bazant, 1997). The positive coefficients A_2 and B_2 are related to the specific fracture energy G_f and the FPZ size c_f measured on a very large specimen (*W* with *a*/*W* = fixed), as well as the non-dimensional geometry factor g() and its first derivative g(). The geometry factor g() depends on the notch to depth ratio = *a*/*W* and is different for different test specimen shapes. However, it transpires that both G_f and c_f cannot be regarded as material properties because they vary with , *W* and the shape of the test specimen. Thus, it is not clear how much of the size effect in the strength of a quasi-brittle structure predicted by this formula is a result of the intrinsic size effect in the G_f itself? In other words, if the specific fracture energy of a quasi-brittle material that did not depend on the shape and size of the test specimen could be independently determined, would a structure made of such a material still exhibit a strong size effect in strength? This question was recently answered in the affirmative by Karihaloo et al. (2006) who showed that

$$\frac{(\sigma_N)_u}{f_t} = D_1(\alpha)\left(1+\frac{W/l_{ch}}{D_2(\alpha)}\right)^{-\frac{1}{2}} + \frac{D_1(\alpha)}{2D_2(\alpha)}\frac{W}{l_{ch}}\left(1+\frac{W/l_{ch}}{D_4(\alpha)}\right)^{-1}$$

Here, the coefficients $D_1(\alpha)$, $D_2(\alpha)$ and $D_4(\alpha)$ are obtained by nonlinear regression of the test results on notched specimens of any shape and D_3 is related to the other coefficients via

$$D_3 = \frac{D_1 D_4}{2D_2}$$

The concrete mix characteristic length l_{ch} is a derived material parameter related to its stiffness *E*, tensile strength f_t and specific fracture energy G_F via $l_{ch} = E\,G_F/(f_t)^2$.

The progressive failure process of a structure made of a quasi-brittle material or a particulate composite under loading can be simulated by lattice models (see, e.g. Burt & Dougill, 1977) used for solving classical problems of elasticity. Bazant et al. (1990) and Schlangen & van Mier (1992) extended lattice models to concrete; the former used truss elements, while the latter adopted Euler-Bernoulli beam elements. The lattice model at the mesolevel projects directly the material multi-phase structure on to the lattice. It is a relatively simple and powerful technique to identify micro-cracking, crack branching, crack tortuosity and bridging, thus allowing the fracture process to be followed until complete rupture. However, these models have produced unreasonably brittle post-peak response of plain and reinforced concrete beams. A recent improvement by Karihaloo et al. (2003) who allowed for the non-linear behaviour of the matrix (i.e. cement mortar) and/or the interface between the matrix and hard phase (i.e. coarse aggregate) produced the expected ductile response.

Lattice models are however useful only for small structures. For medium and large size structures one has to resort to finite element analysis. Both the FCM and the BCM have been implemented in almost all commercially available finite element codes. In particular, Karihaloo and his co-workers have recently shown how to analyse cracked concrete structures very accurately using rather coarse meshes by combining FCM with the extended finite element methodology (XFEM) (Xiao et al. 2007).

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Forthcoming FESI Events

Structural integrity of welded structures - what we have learnt and what we need

Chairman:	Prof Andrew Sherry, Manchester University
Date:	3 November 2010
Venue:	TWI Conference Centre, TWI Ltd, Granta Park, Great Abington, Cambridge

Purpose
Engineering structural integrity (ESI) is a key element across industry sectors in the safe maintenance and economic management of components and structures over their lifecycle: from design and build, through operation to retirement. Welding provides an essential role in the fabrication of components and structures and the integrity of welded joints is critical to safe and economic operation. However, it is almost inevitable that the welding process will incorporate imperfections or flaws into the weld. The satisfactory operation of welded structures shows that in the vast majority of cases their presence does not have significant impact on safety. Indeed, fitness-for-service concepts, often based on fracture mechanics methods, have been developed and refined in order confirm that the component can be safely operated or enable rational sentencing of unacceptable flaws for repair. However, for many welded structures where fatigue loading is significant, often local geometry within the component is more important to integrity than the presence of small flaws.

The purpose of this seminar is to show how structural integrity concepts have been applied to welded components for a wide range of industrial applications and how these are being developed to meet increasingly stringent demands on perceived safety and challenging operating conditions. The seminar will address:

- The requirements of high integrity nuclear components for electricity generation.
- Integrity requirements for welded structural components used the Oil and Gas sector and including pipelines.
- Development of fracture mechanics assessment methods to address challenging operating conditions.

Who Should Attend
This seminar will be of interest to engineers of all disciplines, regulators and policy makers, managers from across the industry sector, technology suppliers and academia. Down load the Registration Form on-line at www.fesi.org.uk

Programme

09:00	Registration and Coffee
09:45	**Introduction** Andrew Sherry [Manchester University]
10:00	**Using Computational Methods to Assess Welded Structures: The Current State of the Art and Future Directions** Ted Anderson [Quest Integrity Group, LLC]
10:30	**Measurement and Modelling of Welding Residual Stresses for Integrity Assessment** David Smith [University of Bristol]
11:00	**Current Status and Future Direction of Integrity Assurance in DNV Codes** Alan Smith [DNV]
11:30	**New developments in BS7910 Assessments Procedures** Isabel Hadley [TWI Ltd], John Sharples [Serco]
12:00	**Nuclear Component Integrity - Where Next after 50 Years of Progress?** John Wintle TWI
12:30	Lunch
13:30	**Integrity of Pipelines - the Longest Welded Structures in the World** Bob Andrews [BMT-Fleet Technology]
14:00	**Strain Based Assessment for Girth Welds in Pipelines Subjected to Plastic Straining** Mohamad Cheaitani [TWI Ltd]
14:30	**Achieving High Integrity Pipeline Girth Welds for Offshore Pipelay** Alan Denney [Saipem UK]
15:00	Refreshments
15:00	**Having Confidence in NDT Results for Welded Structures - the Basis for Safe and Reliable Operation of Plant** Russ Booler [Serco]
15:30	Open Discussion
16:30	Finish

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Further Forthcoming Events From FESI

Modelling Fracture in Quasi-Brittle Materials: Achieving Consistency between Different Length Scales

Date: March 3rd 2011
Venue: Staff House Conference Room, The University of Manchester, Manchester

Purpose
All major industry sectors are faced with the safe maintenance and economic management of the lifetime of their plant/structures; from design and build, through operation to retirement and decommissioning. In the recent past we have seen quite dramatic failures. With the increasing development of off-shore wind farms, deep oil drilling and the proposed new build of nuclear power plant, understanding the fracture behaviour of concrete, mortars, cement, aggregates and graphites comes to the fore.

This meeting will bring together researchers from diverse backgrounds who have expertise in modelling fracture in quasi-brittle materials at different length scales. The objective of the workshop is to develop interdisciplinary links for improving understanding of quasi-brittle materials and the tools used to assess their fracture behaviour.

A series of presentations will be given by invited speakers to discuss the challenges for modelling fracture behaviour, at different length scales in quasi-brittle materials.

Who Should Attend
This Continuous Professional Development Technical Meeting will be of interest to engineers of all disciplines, regulators and policy makers, managers from across the industry sector, technology suppliers and academia concerned with the application of this technology in the inspection, management, regulation and insurance of major assets.

Programme

Morning - Present Goals

- Consistancy - An Overview on Current Position
- Current Issues for Concrete, Cement and Mortar
- Current Issues for Porous Ceramics
- Current Issues for Geological Materials
- Current Issues for Graphite

Afternoon - Future Challenges:

A: For Research - Prof J Marrow(TBC)
B: For Industry - Power Generation/Construction/O&G

Plenary discussion - Prof P Flewitt

Further Events for 2011

Understanding the Challenge of Structural Integrity Monitoring [April 2011]
A co FESI/SIMoNET Meeting

ESIA11 - Engineering Structural Integrity Assessment: from plant design, maintenance to disposal" [24 - 25 May 2011], Manchester UK
FESI's Biennial Conference

Internal Fatigue Caused by Rolling Contact - Issues for Wind and Marine Turbines[June 2011]
A FESI CPD Seminar/workshop supported by the Dalton Institute and ESR Technology

Structural Integrity and Materials Modelling: to what Extent are Experimental Programmes still Required [November 2011]
A FESI CPD Seminar/workshop supported by Serco and University of Manchester

2012/2013

Structural Integrity of Wind Turbines - Current Issues, Future Challenges

Improved Management of Structural Integrity Issues for [Radioactive] Waste Storage Facilities

Decommissioning Issues for Structural Integrity

Integrity of Electronic Materials/Components

Cold Work Repair Schemes for Pressure Systems

Application of Structural Integrity to Medical Devices

Inspection Techniques: Capabilities and Applications

Risk Based Inspection and Maintenance

Partial Safety Factors

Proof Testing and Structural Integrity

Forthcoming Worldwide Events

Conferences/Seminars

Carbon Capture and Storage: How is it working and what next?
I Mech E, London, 13-14 October 2010
Further details at: **www.imeche.org/s1515**

VHCF-5, 5th International Conference on Very High Cycle Fatigue
Berlin, Germany, 28 June - 1 July 2011
Further details at: **http://www.vhcf5.de**

International Symposium on Fatigue Design & Material defects
NTNU, Trondheim,23-25 May 2011
Further details at:
Http://www.ntnu.no/videre/konferanse/Fatigue Defects2011/

3rd Symposium on Structural Durability SOSID 2011
Darmastadt, Germany, May 26-27 2011
Further details at: **http://www.sosdid.de/**

19th European Conference on FractureFracture Mechanics Against Catastrophic Failures (ECF19)
Kazan, Russia, August 20-24, 2012
Further details at: **http://www.ecf19.ru/**

The 4th International Conference on Crack Paths (CP 2012)
Italy, 19 - 21 September, 2012
Further details from:
Conference Chairmen:
Professor Andrea Carpinteri (andrea.carpinteri@unipr.it)
Professor Les P. Pook (les.pook@tesco.net)

13th International Conference on Fracture (ICF13)
Beijing, China, May 26-31, 2013
Further details at: **www.icf13.org/**

The 10th International Conference on Multiaxial Fatigue and Fracture (ICMFF10)
Kyoto (Japan), 3 - 6 June, 2013
Further details from:
Conference Chairman: **Professor Masao Sakane (sakane@tea.ocn.ne.jp)**

Courses Information

HOIS NII Seminar: Non-intrusive inspection in the oil and gas industry
Aberdeen Marriott Hotel, Aberdeen, 11 November 2010
Further details:
http://www.esrtechnology.com/page_view2.asp?InfoID=650

ATEX for Offshore Operations 2010 : What have we learnt so far
Aberdeen, 23 November 2010
Further details:
www.imeche.org/events/s1483

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