A REVIEW OF FINITE ELEMENT DURABILITY AND LIFE EXTENSION TECHNOLOGY ADDRESSED IN THE FENET PROJECT

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SUMMARY

An overview of Finite Element technology issues related to Durability and Life Extension (DLE) is presented. A series of 12 workshops on DLE technology were held within the FENET European Thematic Network from 2001 to 2005. This paper summarises the main issues raised in these workshops in several industrial sectors and identifies the current difficulties and limitations in FE technology and the need for future developments.

1: INTRODUCTION

The FENET network [1] has addressed three main FE technology themes; Durability and Life Extension, Product and System Optimisation, and Multi-Physics. This paper focuses on the technology issues related to Durability and life Extension (DLE) which include structural integrity, fracture, damage, plasticity, creep, fatigue, residual stresses, welds, life assessment and life extension. Other more generic technology issues such as contact mechanics and design by analysis were also covered in the DLE workshops. These issues are major concerns in many industries including aerospace, automotive, power generation, building, transport and offshore engineering.

Although FE technology and software have reached maturity in many DLE areas, there are still many technological challenges and difficulties faced by industrial users. The FENET DLE workshops have been attended by many delegates from industry, universities and research organisations, and have provided a forum for discussion and identification of the current difficulties experienced by FE users and the need for future advances of FE technology. Table 1 presents a list of all the DLE workshops held within the FENET project. This paper presents an overview of the main DLE technology issues raised by FENET participants.

Table 1: List of FENET Workshops on Durability and Life Extension (2001-2005)

Workshop	Title	Date	Location
DLE Workshop 1	Industrial views on durability and life extension issues	13 November 2001	Wiesbaden, Germany
DLE Workshop 2	Finite Element simulation of contact problems	27-28 February 2002	Copenhagen, Denmark
DLE Workshop 3	FE issues related to structural integrity-fracture, fatigue, and creep	13-14 June 2002	Zurich, Switzerland
DLE Workshop 4	Finite Element simulation of fracture and crack growth	11-12 September 2002	Trieste, Italy
DLE Workshop 5	Finite Element simulation of welds and joints	27-28 February 2003	Barcelona, Spain
DLE Workshop 6	Modelling fatigue of metals	9-10 October 2003	Noordwijk, Netherlands
DLE Workshop 7	Finite Element issues related to creep and viscoelasticity	25-26 March 2004	Majorca, Spain
DLE Workshop 8	Advanced FE contact benchmarks-1 (problem definition)	25 March 2004	Majorca, Spain
DLE Workshop 9	Finite Element modelling of damage	7-8 October 2004	Glasgow, UK
DLE Workshop 10	Advanced FE contact benchmarks- 2 (users feedback)	7 October 2004	Glasgow, UK
DLE Workshop 11	The use of FEA in design codes of practice	24 February 2005	Budapest, Hungary
DLE Workshop 12	Advanced FE contact benchmarks- 3 (solutions)	25 February 2005	Budapest, Hungary

2: INDUSTRIAL VIEWS ON DURABILITY AND LIFE EXTENSION ISSUES

FE technology issues relevant to a number of industrial sectors were discussed the First FENET Annual Workshop (13-14 November 2001, Wiesbaden). The main DLE topics raised in this workshop are summarised in Table 2.

Table 2: Durability and Life Extension Issues Relevant to Industry

Industry Sector	**Topics relevant to Durability and Life Extension**
Aerospace	Damage assessment, damage tolerance Crack growth Residual strength Linking FE and Boundary Element Methods Probabilistic analysis
Land Transport	Fracture, crack growth Adaptive meshing Residual strength Characterization of composites
Bio-Medical	Wear modeling for prostheses Modelling bone fracture Interface modeling for implants biomaterials
Civil Construction	Reinforced concrete deterioration Residual life prediction Durability of constructions
Consumer Goods	Abuse loads Impact analysis Life estimation
Marine & Offshore	Fatigue Stochastic loading damage Delamination, composites
Power & Pressure Systems	Residual stresses Crack growth High temperature and damage assessment Use of probabilistic fracture analysis Extreme loads
Process & Manufacturing	Extending product life through process optimization Durability and wear of tools Obtaining and applying failure criteria Effect of manufacturing defects on life
Generic issues	Terminology/glossary Contact mechanics Fracture and fatigue of rubber and plastics Cracks in welds Adaptive meshing in fracture and contact problems Case studies on durability and life extension

3: FE SIMULATION OF CONTACT PROBLEMS

Contact analysis has been identified as an important area of development of FE technology. The second FENET DLE workshop was focussed on the FE simulation of contact problems (27-28 February 2002, Copenhagen). The following issues were discussed:

- FE contact benchmarks
- Difficulties experienced by FE users in modelling contact problems

- Current limitations of commercial FE software
- Desirable contact features not currently being offered by FE software
- The need for further research in FE contact analysis

The workshop identified several current challenges in FE modelling of industrial contact problems, including the following:

- Loaded rigid surfaces
- Identification of unknown or unexpected contact regions
- Automation of contact analysis
- Re-meshing during contact analysis
- Visualisation of contact elements
- Informative post-processing diagnostic display
- Improved contact performance of quadratic elements
- Better friction models
- Experimental verification of FE contact solutions
- Coupled thermo-mechanical contact
- Heat conduction across interfaces
- Cemented joints
- Thin lubricating films

The contact workshop has stimulated many discussions regarding the need for advanced contact benchmarks and case studies. NAFEMS has published a number of documents on contact analysis [2, 3], including a benchmark report on two-dimensional contact problems [4]. It was acknowledged that although the current published NAFEMS benchmarks were limited in scope, they were important as the first step in establishing contact benchmarks.

It was agreed that there is a need for developing more complex contact benchmarks, through the FENET network. A series of FENET workshops, chaired by Prof. A.A. Becker, were launched to devise new advanced contact benchmarks. An invitation was issued to all FENET members to suggest new potential contact benchmarks, and a new FENET Contact Working Group was formed to discuss the merits of the benchmarks.

In the first of the contact benchmarks workshops (25 March 2004, Majorca), the requirements for advanced contact benchmarks were discussed and a list of new advanced contact benchmarks was proposed. The merits and disadvantages of each of the candidate contact benchmarks were evaluated, and it was agreed to concentrate on only 5 contact benchmarks, as follows:

- 2D Contact of cylindrical roller
- 3D Punch with rounded edges
- 3D Sheet metal forming
- 3D Loaded pin
- 3D Steel roller on a rubber base

The selected contact benchmarks were chosen to exhibit the following features:

- 3D contact

- Frictional stick-slip in contact area
- 2D/3D Linear vs. quadratic elements
- Shell contact
- Large strain contact
- Metal forming
- Mesh dependency
- Compression of rubber
- Rolling contact

It was recognized that the dimensions and the material properties will play an important role in highlighting the relevant features of the contact benchmarks. Therefore, further FE analyses were performed to establish the geometric parameters, material constants, values of the applied loads and the coefficient of friction. The task of running the benchmarks was assigned to Dr. A. Konter [3]

Two further workshops on the FENET contact benchmarks were held to discuss comments and solutions received from various FENET members (7 October 2004, Glasgow) and to discuss the final FE solutions (25 February 2005, Budapest). A formal technical report on the advanced contact benchmarks will be issued to all FENET members in July 2005, and will be subsequently released as a NAFEMS document.

4: FE TECHNOLOGY ISSUES RELATED TO STRUCTURAL INTEGRITY

The third DLE workshop was held to identify further workshop topics on the theme of structural integrity (13-14 June 2002, Zurich). The workshop addressed the difficulties experienced by FE users in structural integrity analysis, current limitations of commercial FE software and desirable features that are not currently being offered by FE software.
The discussions during this workshop identified a number of technology issues related to structural integrity that require further development. Consequently, a series of DLE workshops was launched to cover these issues. The following is a list of the main topics raised in the DLE workshops.

4.1 Fracture and Crack Growth

A workshop was held to discuss FE simulation of fracture and crack growth (11-12 September 2002, Trieste). The main objectives of this workshop were to identify the current state of the art and the limitations of current FE methods and tools in the simulation of fracture and crack growth.

The following topics were discussed:

- Modelling crack closure
- 3D crack models
- 2D and 3D crack propagation laws
- Interaction of two or more cracks
- Crack propagation and re-meshing in commercial FE packages

The main conclusions of the workshop were that FE elastic analysis of 2D and 3D cracks and numerical procedures for non-linear fracture mechanics were well established.

However, re-meshing techniques and numerical simulations of crack initiation, propagation and merging were not widely used and would require the development of new tools to be incorporated in commercial FE software.

4.2 Fatigue of Metals

A FENET workshop was held to discuss fatigue of metals (Noordwijk, 10 October 2003). The following topics were discussed:

- Crack path prediction
- Rate dependent low cycle fatigue modelling
- Modelling fatigue of welds
- Application of non linear fracture mechanics for failure assessment
- Integration of FE and fatigue analysis codes

The main conclusions of the workshop were that more reliable material data for fatigue analysis and FE tools were needed for modelling fatigue of welds and bolted Joints, and there was a need for experimentally validated benchmarks covering multi-axial fatigue problems and fatigue crack growth.

4.3 Creep and Viscoelastcity

A workshop was held to discuss FE analysis of creep and viscoelasticity (25-26 March 2004, Majorca, Spain). The following topics were discussed:

- Modelling viscoelastic polymer-bonded materials
- Creep stress relaxation and healing effects
- Modelling superplastic forming and high temperature manufacturing processes
- Difficulties in generating creep material properties
- Modelling creep of welds
- Creep continuum damage mechanics
- Benchmarks for creep damage modelling
- Creep-fatigue interaction

The main conclusions of the workshop were that reliable creep material properties were difficult to obtain, particularly in welds and around Heat-Affected Zones, and creep continuum damage was not easily incorporated in commercial FE codes. In the power generation industry, the effects of ageing/degradation of the material were difficult to measure.

4.4 Welds and Joints

A workshop was held to discuss FE analysis of welds and joints (27-28 February 2003, Barcelona). The Following topics were discussed:

- Use of general-purpose and specialist FE software in simulating welds
- Analysis of structural integrity of pipeline welds
- Creep and damage in welds and weld repairs
- Analysis of joints and welding processes

The main conclusion of the workshop was that there are many difficulties and challenges

in modelling weld processes and analysing weld behaviour. FE models of large 3D welded structures required very fine meshes and can be impractical for structures containing welds. Residual stresses were difficult to calculate and difficult to implement in FE analysis. General-purpose FE codes were capable of analysing heat transfer and thermal stresses caused by the weld process, but required specialist subroutines and user interaction to simulate the welding process. Specialist FE weld simulation software incorporated built-in complex phase transformation data which enabled users to simulate the welding process.
A state of the art review of weld simulation using FE methods has been completed [5] covering thermal, mechanical, phase transformation and residual stresses resulting from the weld process.

4.5 Damage

A workshop was launched to discuss FE modelling of damage (7-8 October 2004, Glasgow). The Following topics were discussed:

- Modelling interacting cracks
- Fatigue damage
- Continuum damage mechanics
- Damage of composite structures

The main conclusions of the workshop were that a range of different damage models can be incorporated in FE software and several validated tools for implementing damage are available, at least at the research level. Interaction of several fatigue cracks can be modelled to predict the remaining life of a component and creep continuum damage models can be incorporated in commercial FE software to predict creep rupture time.

4.6 Design By Analysis

A workshop was held jointly with the FENET Education and Dissemination Group on the use of FE analysis in design codes of practice (24 February 2005, Budapest). The objectives of the workshops were to review the state of the art of Design by Analysis in different industries, and to identify common problems of FE analysis validation and acceptance in Design Codes of Practice. The workshop addressed the following topics:

- The status of FE analysis in design codes in different industries
- Conflicts between design code requirements and FE analysis results
- Problems encountered in validating FE analysis
- Changes to design codes required to accommodate FE analysis

There were several contributions from different industry sectors such as automotive, marine, transport, civil and pressure vessel analysis. The main conclusions were that the drive for the development of Design by Analysis in different sectors is economic, i.e. reducing the costs of development, improving safety and reducing the insurance cost of products. Different industry sectors implement different levels of acceptance of Design by Analysis in the codes of practice.

5: CONCLUDING REMARKS

FE technology is widely used in many industry sectors to analyse structures and components to assess their structural integrity and predict their failure lives. Within the FENET project, 12 workshops on Durability and Life Extension were launched to provide a forum for the FE community to discuss the state of the art of FE technology and to address the need for further developments.

The DLE workshops covered many analysis disciplines, namely contact mechanics, fracture, welds, creep, fatigue, damage and design by analysis. A number of challenges were identified such as the need for better FE models for analysing stick/slip contact zones, better implementation of damage models in commercial FE software, incorporating residual stresses and more robust tools for modelling crack growth and crack interaction.
A series of workshops were held to devise new advanced contact benchmarks and have resulted in a set of advanced 3D contact benchmarks that can be used to verify FE solutions and to provide educational material in highlighting to new users the type of problems that may be encountered in modelling complex contact problems.

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