The Interfacing of FEA with Pressure Vessel Design Codes

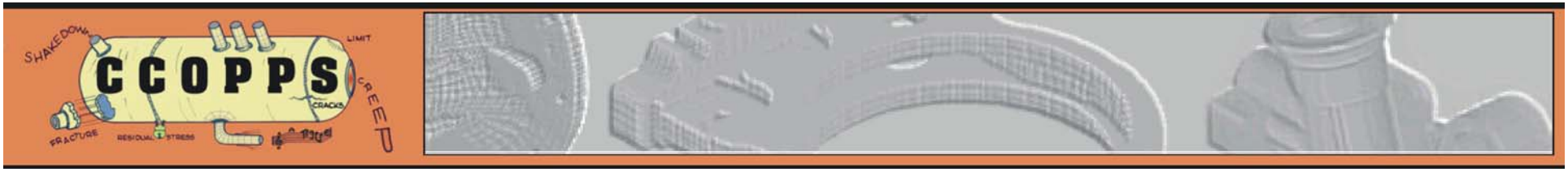
CCOPPS Webinar

Wednesday 16th January 2008

15:00 – 16:00 GMT

Jim Wood and Donald Mackenzie

University of Strathclyde



Agenda

- **Introduction and Relevant CCOPPS Activity**

  Jim Wood

- **The Use of Finite Element Analysis in Design by Analysis**

  Donald Mackenzie & Jim Wood

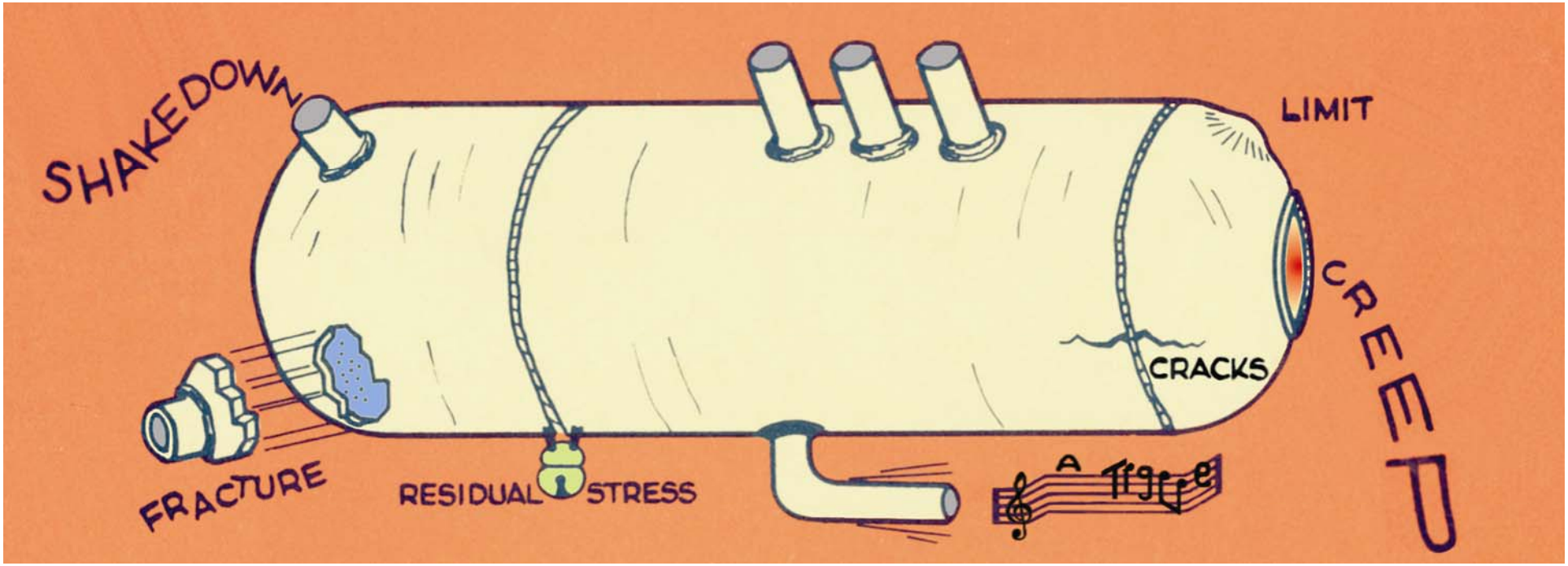
- **Q&A Session**

  Donald Mackenzie & Jim Wood

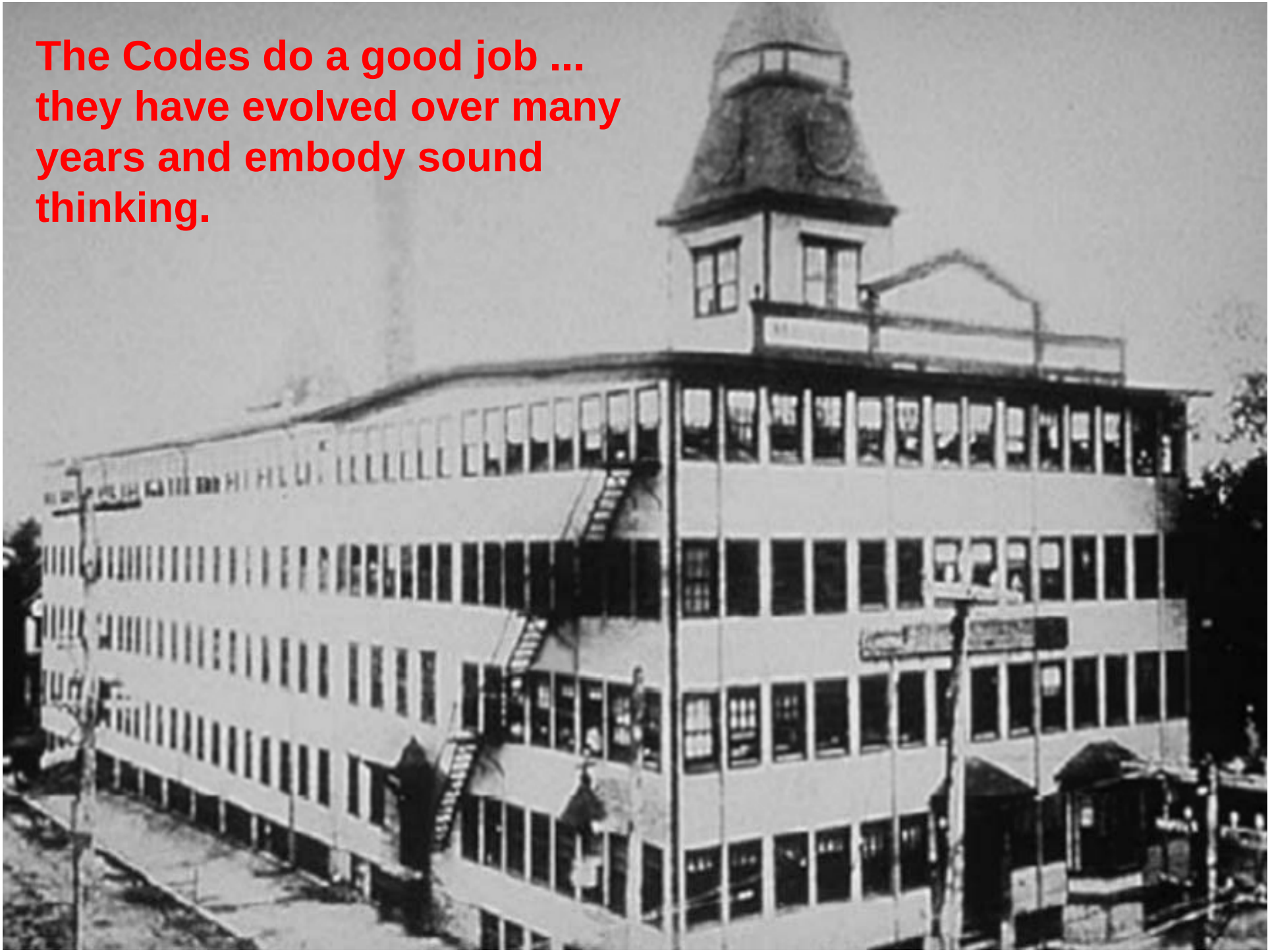
- **Closing Remarks**

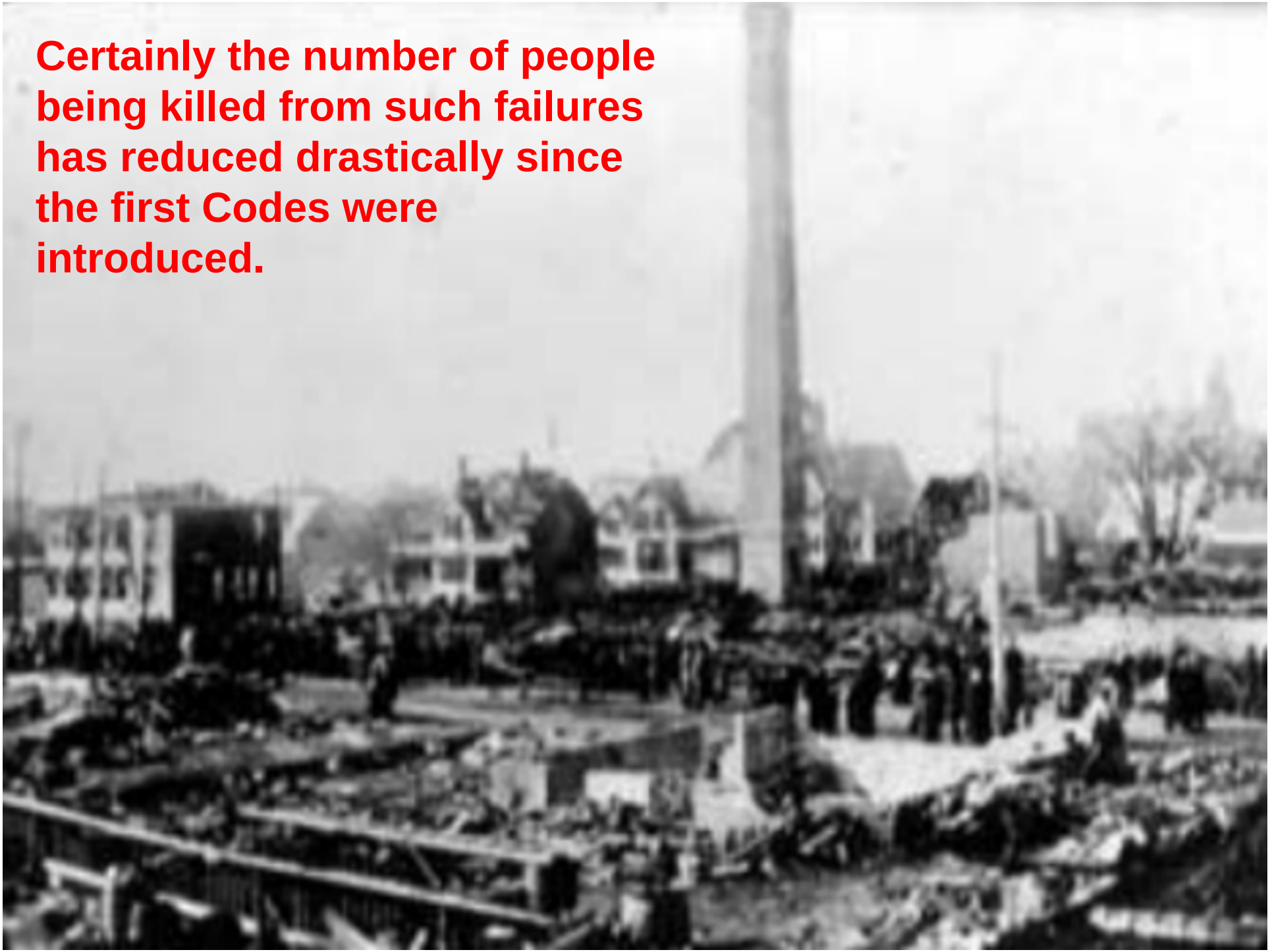
  Jim Wood

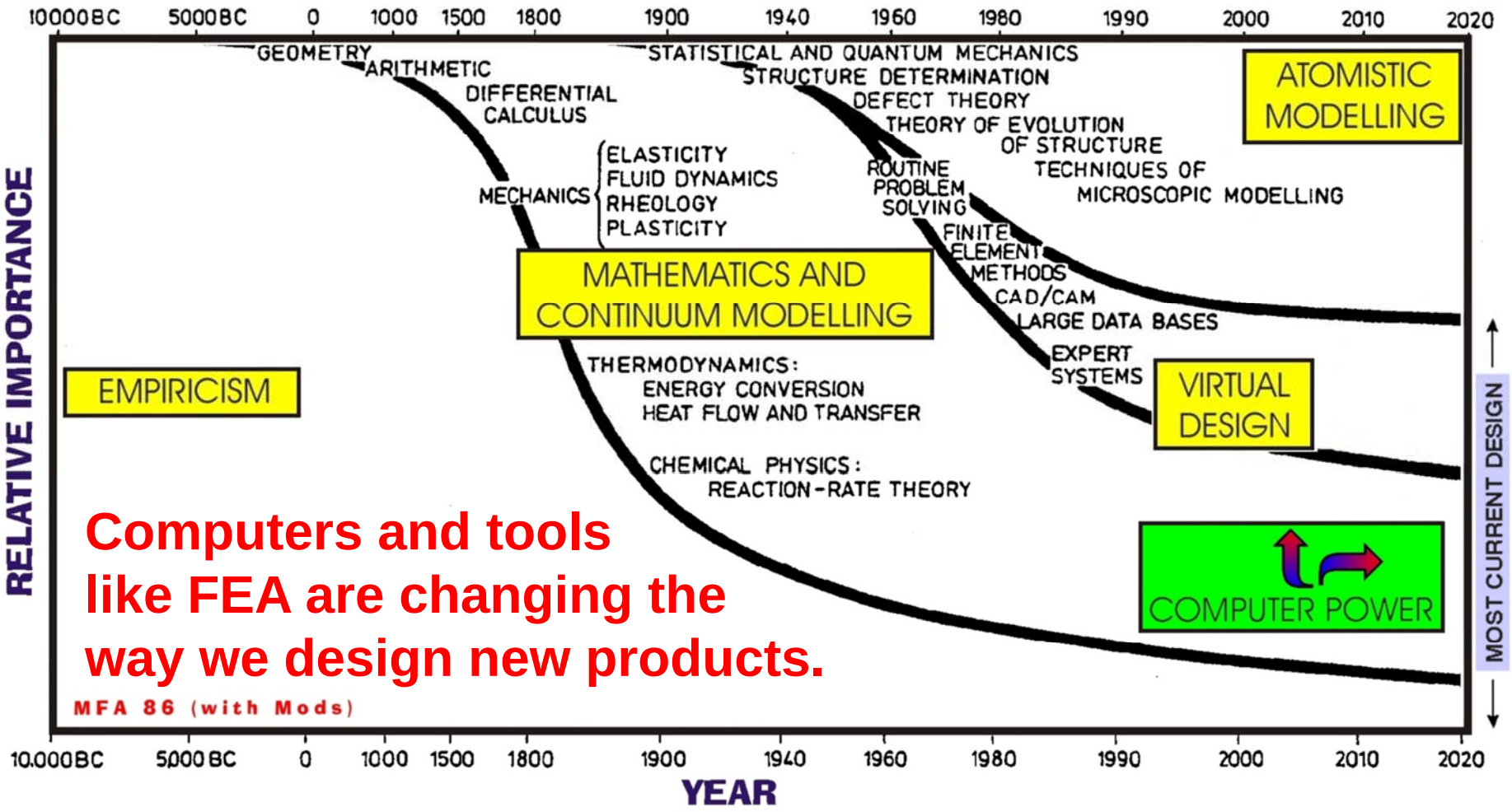
The ways in which pressure vessels fail has not changed!



(From the front of a Strathclyde training course leaflet from 1973.)

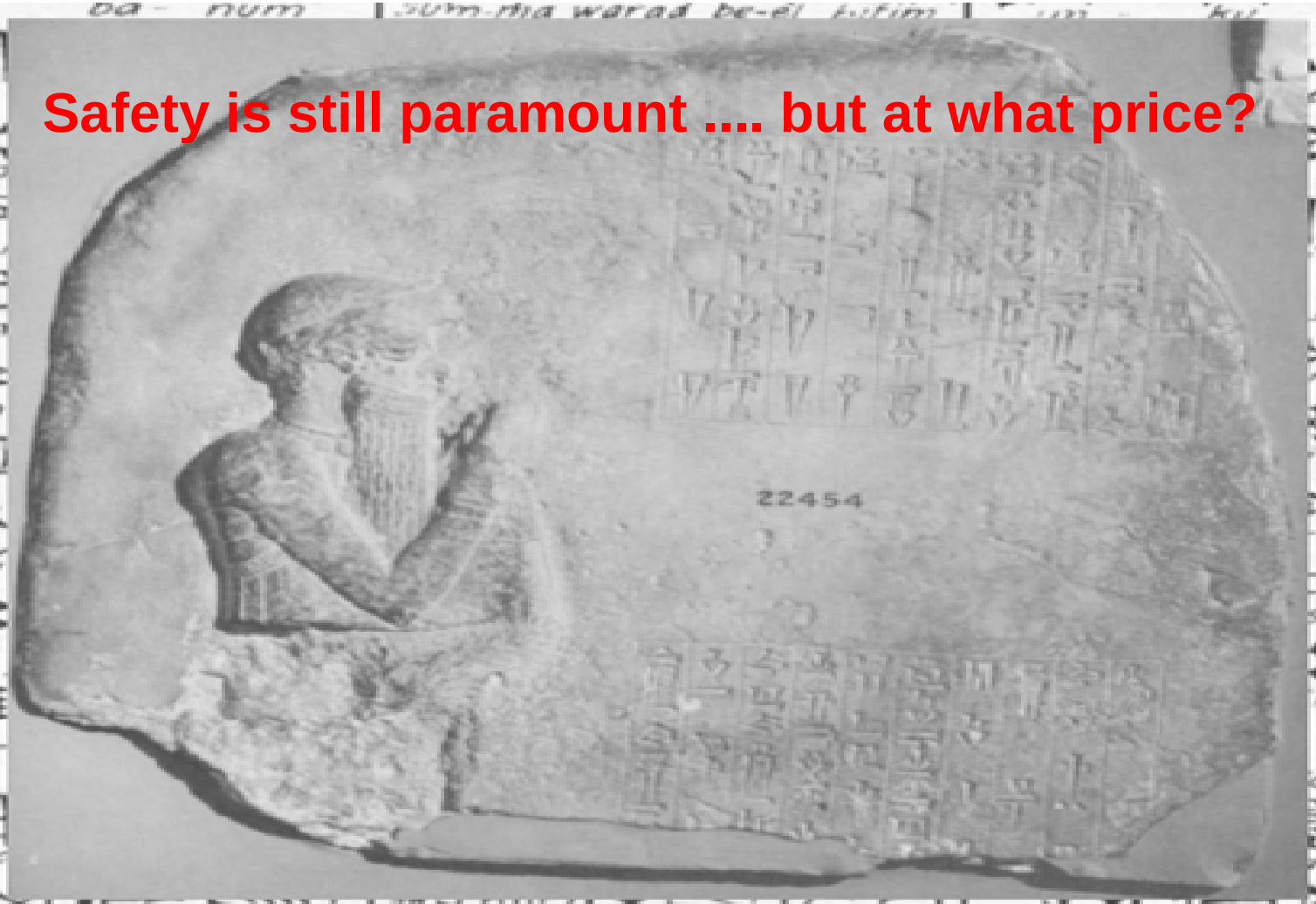

The Codes do a good job ...
they have evolved over many
years and embody sound
thinking.


Certainly the number of people being killed from such failures has reduced drastically since the first Codes were introduced.



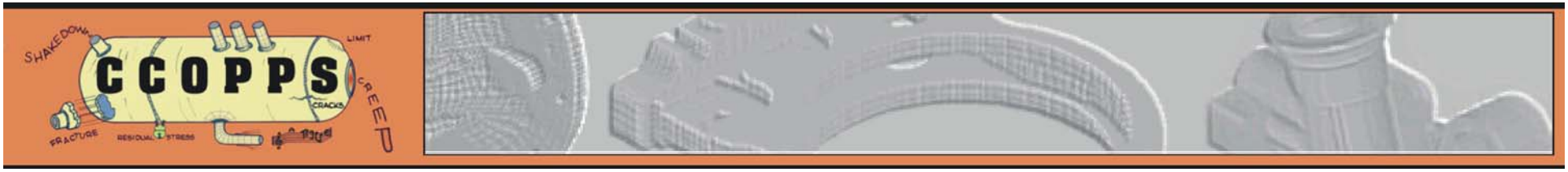
Computers and tools like FEA are changing the way we design new products.

Safety is still paramount .... but at what price?



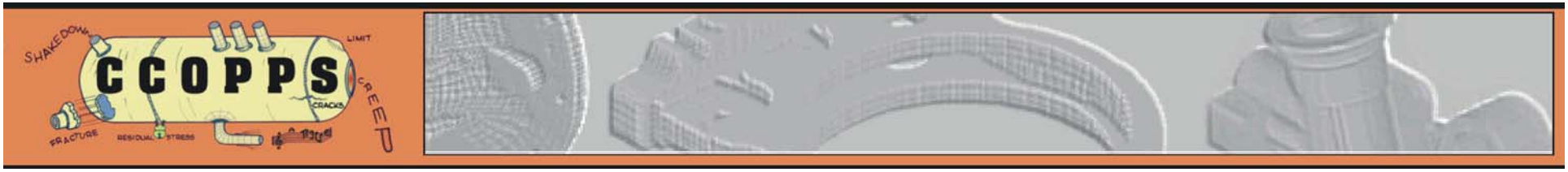
FROM THE
CODE OF LAWS
OF
HAMMURABI (2200BC)
KING OF BABYLONIA

A. If a builder build a house for a man and do not make its construction firm and the house which he has built collapse and cause the death of the owner of the house – that builder shall be put to death



The CCOPPS Project ... 1

- **Industry Needs Survey**
  - ***Preliminary report launched today***
  - ***Available for download from http://www.ccopps.eu/***
  - ***Findings relevant to this webinar:***
    - ***FEA use is increasing as is complexity of models***
    - ***DBA probably still to reach its full potential***
    - ***Interfacing with codes of practice seen as issue***
    - ***Happy with facilities in commercial codes in general (exception is weld modelling and assessment + automation of the analysis process)***
    - ***Non-European Codes are used often by most respondents.***



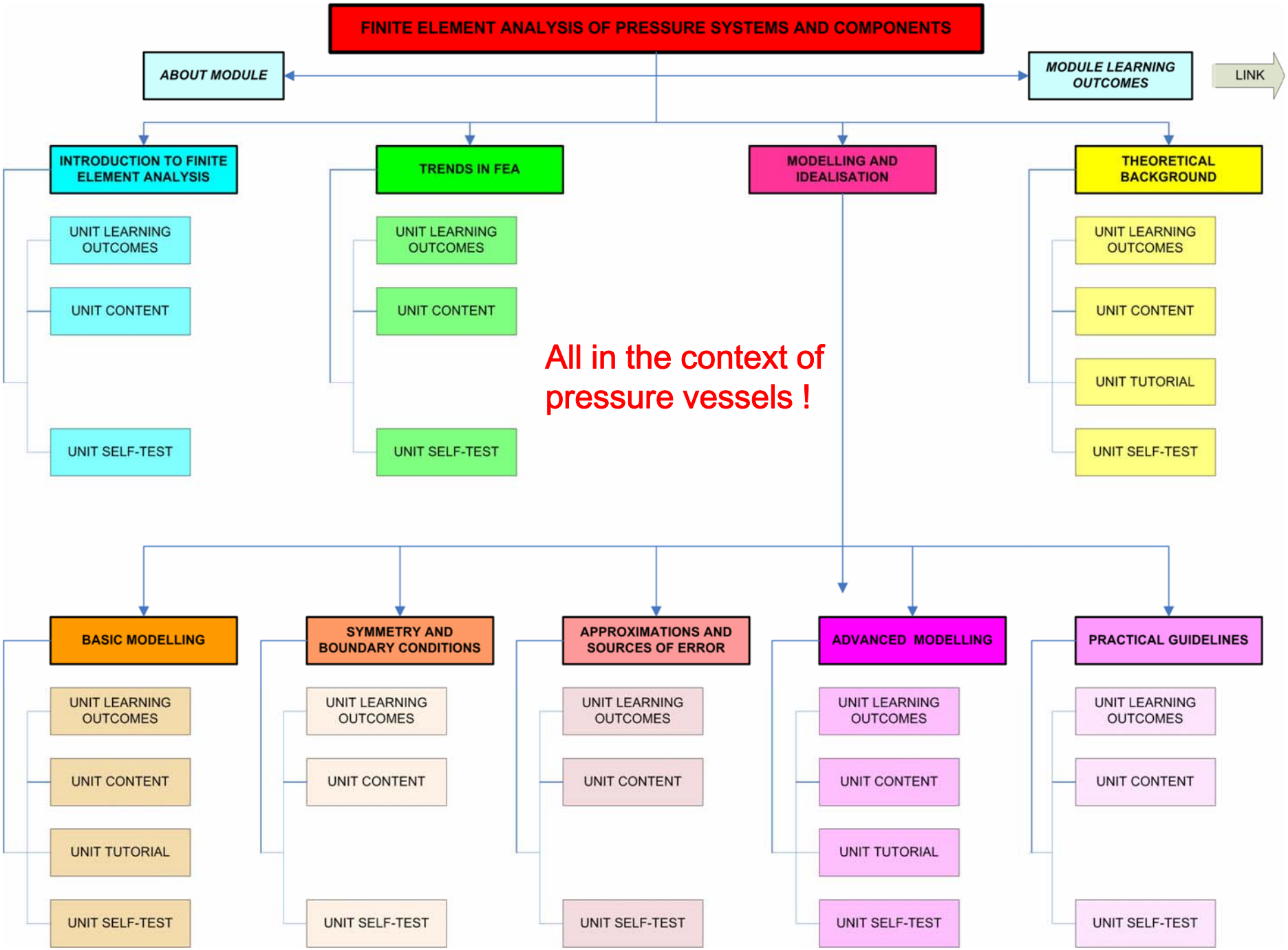
The CCOPPS Project ... 2

- **Educational Base**
  - ***Provides statements of competence in the following 16 topic areas relating to the use of FEA for the analysis of pressure components:***

Beams, Membranes, Plates and Shells
Code of Practice Philosophy and Application
Composite Materials and Pressure Components
Flaw Assessment in Pressure Components
Mechanics, Elasticity and Strength of Materials
Nonlinear Geometric Effects
Pressure System Components and Fabrication
Buckling and Instability
Creep and Time-Dependency
Pressure Vessel Materials
Fatigue
Dynamics and Vibration
Plasticity and Shakedown
Thermo-Mechanical Behaviour

Finite Element Analysis of Pressure Systems and Components
Design by Analysis

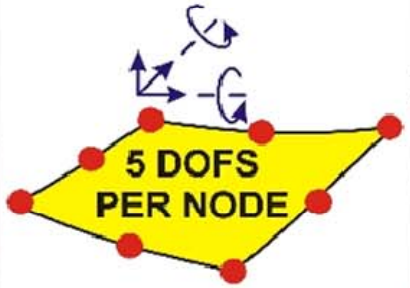
Category & Code Number	STATEMENT OF LEARNING OUTCOME (click for Threshold and Comprehensive performance interpretations)	Standard or Advanced and EQF Level	Resource Reference	Achieved (Minimum or Comprehensive)		Attested By
				Informally	*Formally*	
Knowledge						
FEAkn1	List the various steps in the analysis/simulation process.	S,6	FEAref1			
FEAkn8	List the requirements for an axisymmetric analysis to be valid.	S,6				
Comprehension						
FEAco2	Discuss checks that may be used post-solution to check for the presence of inaccuracy.	S,6				
FEAco35	Discuss the terms *Validation* and *Verification* and highlight their importance.	S,6				
FEAco40	Discuss the challenges of modelling a *flanged connection*.	S,7				
Application						
FEAap1	Employ an analysis system for the determination of stresses and strains in small displacement, linear elastic problems.	S,6				
FEAap3	Illustrate the approximate nature of finite element analysis, through examples chosen from the pressure system and component field.	S,7				
FEAap13	Use through-thickness *stress linearization* facilities where appropriate.	S,7				
Analysis						
FEAan2	Compare the results from small displacement, linear elastic analyses with allowable values and comment on findings.	S,6				
Synthesis						
FEAsy2	Plan an analysis, specifying necessary resources and timescale.	A,7				
Evaluation						
FEAev1	Select appropriate idealisation(s) for components / structures, which are consistent with the objectives of the analyses.	A,7				


FINITE ELEMENT ANALYSIS OF PRESSURE SYSTEMS AND COMPONENTS
ABOUT MODULE
MODULE LEARNING OUTCOMES
LINK
INTRODUCTION TO FINITE ELEMENT ANALYSIS
UNIT LEARNING OUTCOMES
UNIT CONTENT
UNIT SELF-TEST
TRENDS IN FEA
UNIT LEARNING OUTCOMES
UNIT CONTENT
UNIT SELF-TEST
MODELLING AND IDEALISATION
THEORETICAL BACKGROUND
UNIT LEARNING OUTCOMES
UNIT CONTENT
UNIT TUTORIAL
UNIT SELF-TEST
All in the context of pressure vessels !
BASIC MODELLING
UNIT LEARNING OUTCOMES
UNIT CONTENT
UNIT TUTORIAL
UNIT SELF-TEST
SYMMETRY AND BOUNDARY CONDITIONS
UNIT LEARNING OUTCOMES
UNIT CONTENT
UNIT SELF-TEST
APPROXIMATIONS AND SOURCES OF ERROR
UNIT LEARNING OUTCOMES
UNIT CONTENT
UNIT SELF-TEST
ADVANCED MODELLING
UNIT LEARNING OUTCOMES
UNIT CONTENT
UNIT TUTORIAL
UNIT SELF-TEST
PRACTICAL GUIDELINES
UNIT LEARNING OUTCOMES
UNIT CONTENT
UNIT SELF-TEST

Which is the best element to determine the gross geometrical stress concentration caused by the support legs on the spherical vessel?

☐

THIN SHELL



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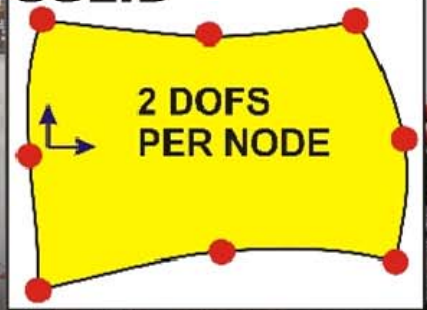
AXISYMMETRIC SOLID



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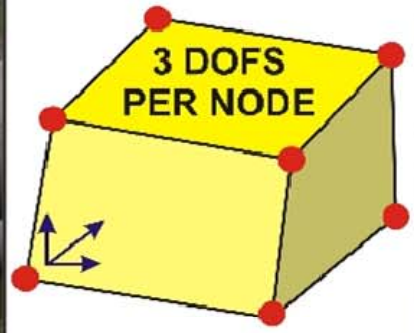
3D SOLID



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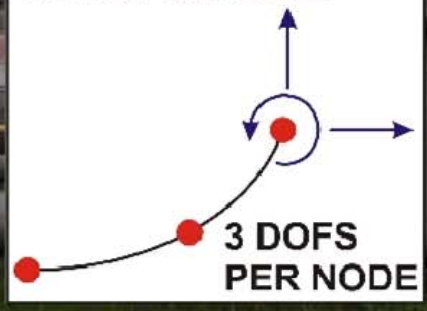
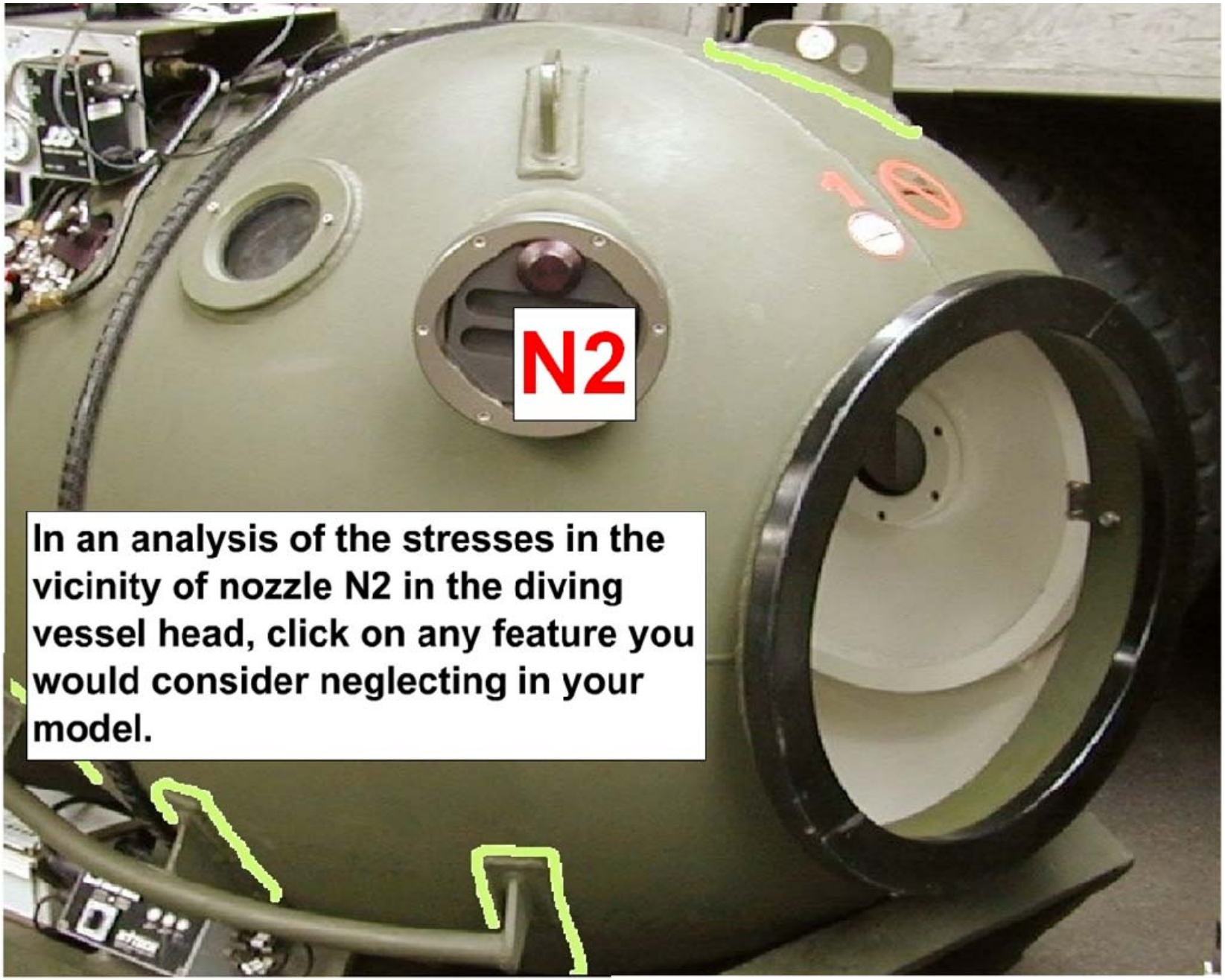
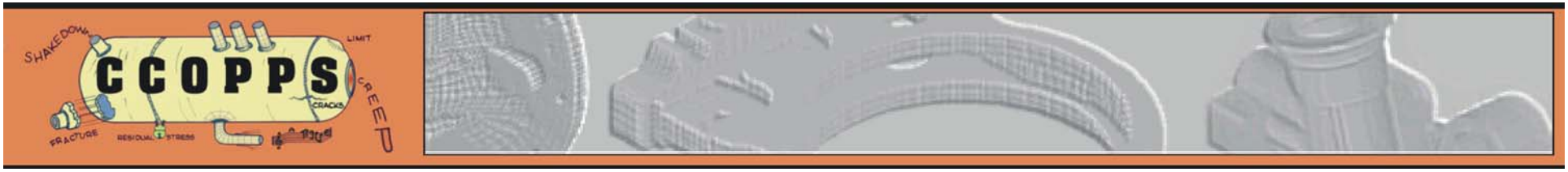
AXISYMMETRIC THIN SHELL



Check Answer | Explanation | Click on a Checkbox.

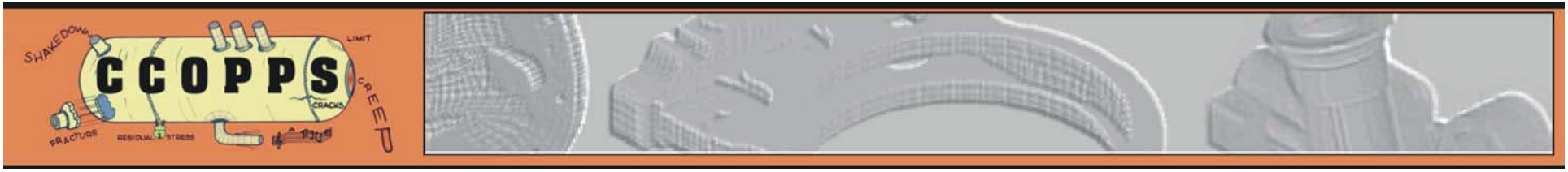


Check Answer | Reset | Explanation | Click the Check Answer | 26 / 26



The CCOPPS Project ... 4

- ***We are looking for organisations to test the Educational Base and Work-based Learning Modules. If interested contact me at j.wood@strath.ac.uk***



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Design by Analysis

- In recent years there has been a significant move towards more routine DBA in pressure vessel design
- EN 13445:2002
  - Annex B.1 *(Direct Route)*
    - "Design by analysis provides rules for the design of any component under any action. It may be used … as an alternative to design by formulas … as a compliment to design-by-formulas …"
  - Annex C.1 *(Elastic Analysis & Stress Categorisation*)
    - "…may be used … as an alternative to design by formulas … as a compliment to design-by-formulas …."

Code Guidance on using FEA 1

- **ASME VIII Div2 2007**
  - **Foreword**

    "*The Committee recognizes that tools and techniques used for design and analysis change as technology progresses and expects engineers to use good judgement in the application of these tools*... "

  - ***… The Code neither requires nor prohibits the use of computers* ... However, designers and engineers *using computer programs for design or analysis are cautioned that they are* responsible *for all technical assumptions inherent in the programs they use and they are* responsible *for the application of these programs to their design*."**

Code Guidance on FEA 2

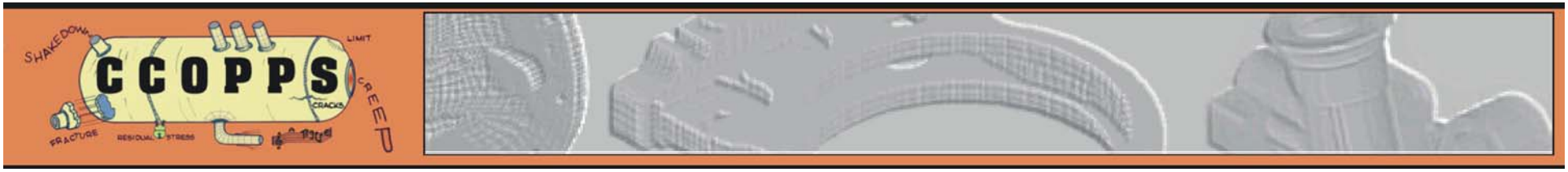
- **ASME VIII Div2 2007**
  - **5.1.2.3** ***Recommendations on a stress analysis method, modeling of a component, and validation of analysis results are not provided. While these aspects of the design process are important and shall be considered in the analysis, a detailed treatment of the subject is not provided because of the variability in approaches and design processes. However, an accurate stress analysis including validation of all results shall be provided as part of the design.***

Code Guidance on FEA 3

- **ASME VIII Div 2 Section 5.2.3 *Limit-Load Analysis Method***
  - **Inelastic FEA is cited as an example method**
  - **No guidance is given on non-linear solution parameters, such as convergence criteria.**
    - **Limit load is defined as the point when solution fails to converge**
- **The analysis model is required to incorporate global geometry, boundary conditions and applied loads.**
  - **Small details such as small holes and fillets need not be included.**

Code Guidance on FEA 4

- ***ASME VIII Div 2 Section 5.2.4 Elastic-Plastic Stress Analysis Method***
  - **Inelastic FEA is cited as an example method**
  - **No detailed guidance on performing elastic plastic analysis is given**
    - **Plastic load is defined as the point when solution fails to converge**
- **The analysis model is required to incorporate global geometry, boundary conditions and applied loads.**
  - **refinement of the model around areas of stress and strain concentration is specified, implying that small geometry details such as small holes and fillets should be included.**



Code Guidance on FEA 5

- **Annex 5E provides design methods for tubesheets and Figure 5.E.2 provides details of the 'Finite Element Analysis Boundary Condition' for a 'smeared' 2D idealisation.**
  - **Also discusses the requirements for a 3D solid 'numerical analysis' as opposed to an axisymmetric solid 'numerical analysis'.**
- **Annex 5A provides 18 pages of guidance on linearization of stress results for stress classification, including:**
  - **Selection of classification lines**
  - **Appropriate use of shell and continuum elements and retreival of structural stress at weld toes**
  - **FE modelling techniques for welds**
  - **Mesh guidelines in relation to structural stresses**

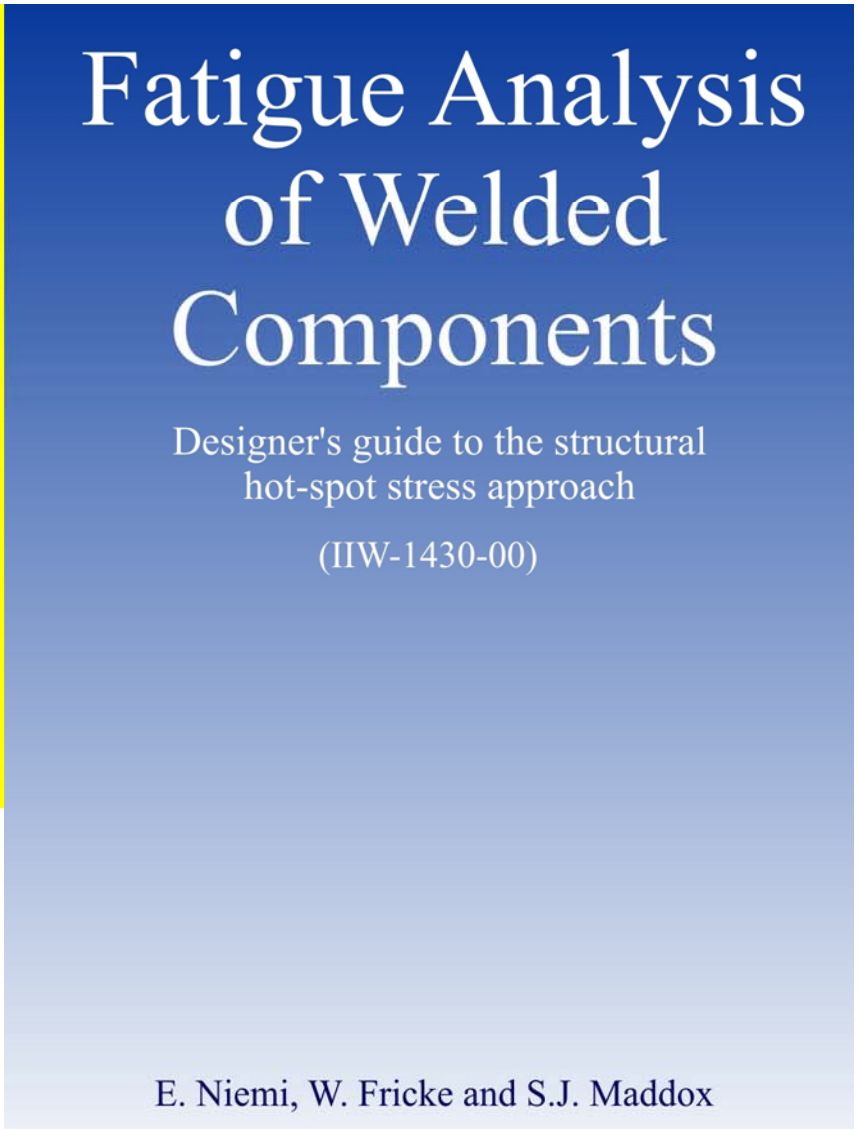
Code Guidance on FEA 6

- **En13445:2002**
  - **C.4.5.2 Part 3** ***The choice of the method used for determining stresses is under the responsibility of the manufacturer. This method may be numerical … [and] adequate to ensure a good representation of the calculated stresses … use of tested and recognised practices is recommended.***
  - **18.6.1 Part 3** ***provides brief guidance on FE mesh requirements for structural stress at weld toes.***
  - **Annex D.4.1 Part 6 (Assessment of fatigue)** ***states that these rules apply to DBF and DBA (using FEA) components***
  - **E.4 Part 6** ***states that DBA calculations must include details of the finite element type used and discusses the requirement for an FEA mesh sensitivity review and equilibrium check.***

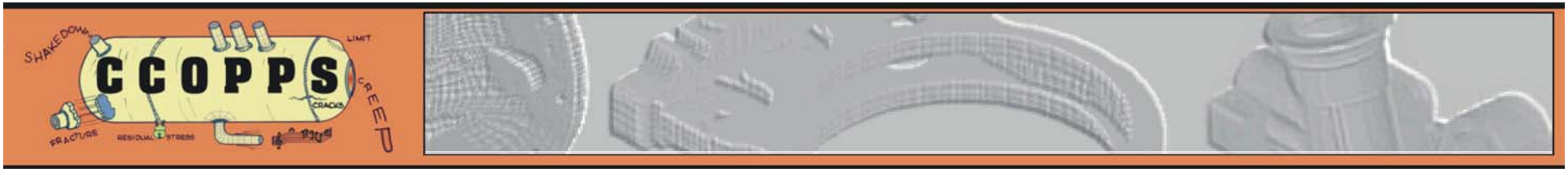
Code Guidance on FEA 7

- In Annex A Part 1, while discussing the use of the standard, there is a recognition that FEA will usually be used in practice when calculating stresses for DBA and fatigue.
- B.2.17 and B.7.6 mentions that FE shell or beam elements may give structural strain directly and recommends use of quadratic surface extrapolation for the hot-spot for models using brick elements.
- D.6.1 part 6, indicates that 3D FEA may be used to justify a lower value for SCF than 3 for cases of detail not covered in tables.
- 5.2.4.3 Part 5 (Inspection and testing) outlines the documentation requirements for analysis carried out using FEA.

What is the status of various guidance documents such as ....

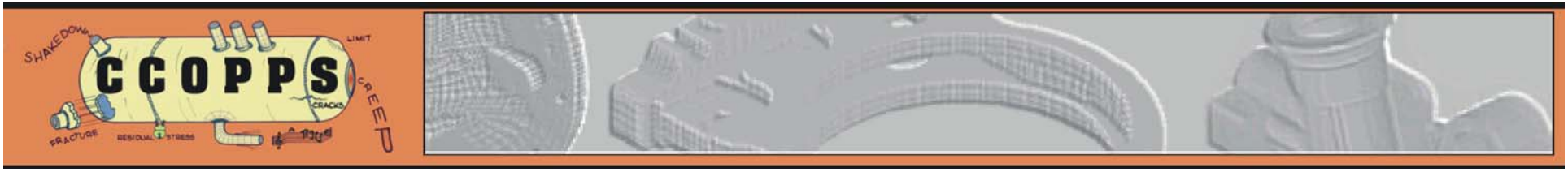


Should standard bodies be producing such documents or at least approving as embodying "tested and recognised practice"?



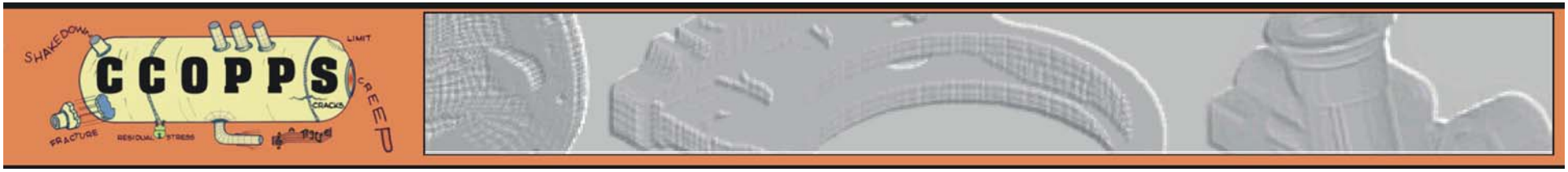
Guidance documents have been produced to cover analytical solutions ..... so why not for FEA?

- **Explanatory supplement to BS 5500: 1988 'Specification for unfired fusion welded pressure vessels', section three 'Design'; Part 1. Domed ends (heads)**
- **Explanatory supplement to BS 5500: 1988 'Specification for unfired fusion welded pressure vessels', section three 'Design'; Part 2. Openings and branch connections**
- **Explanatory supplement to BS 5500: 1988 'Specification for unfired fusion welded pressure vessels', section three 'Design'; Part 3. Vessels under external pressure**
- **Explanatory supplement to BS 5500: 1988 'Specification for unfired fusion welded pressure vessels', section three 'Design'; Part 4. Heat exchanger tubesheets**



Commercial Finite Element Systems

- Wide range elements and analysis types
- Macro facilities to generate meshes automatically for range of common components
- Robust quality, assured systems
- Stress linearisation
- Fatigue pre and post processors
- Modelling and assessment welds?
- Stress categorisation
- Expert systems
- Can they do more?



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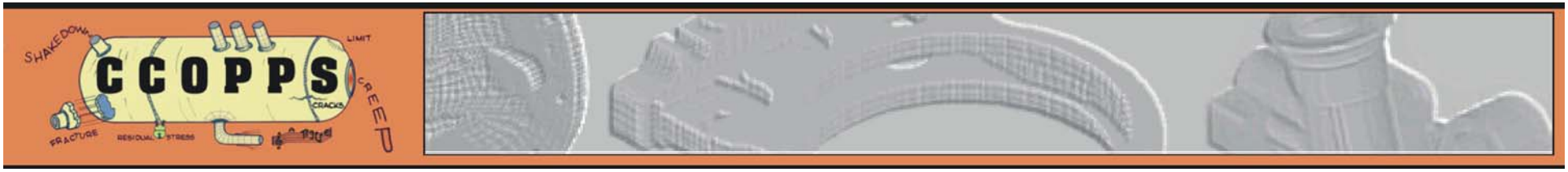
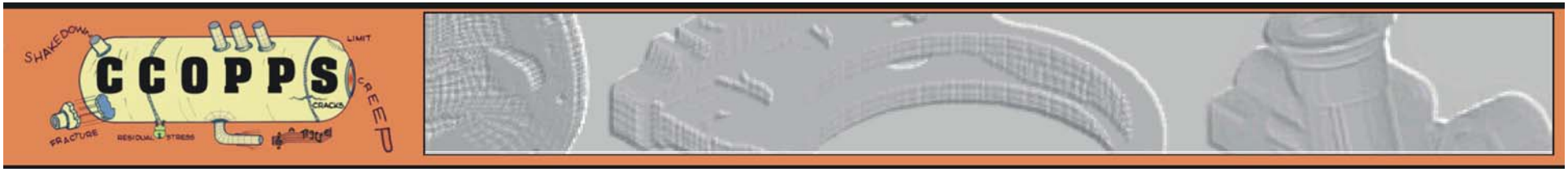


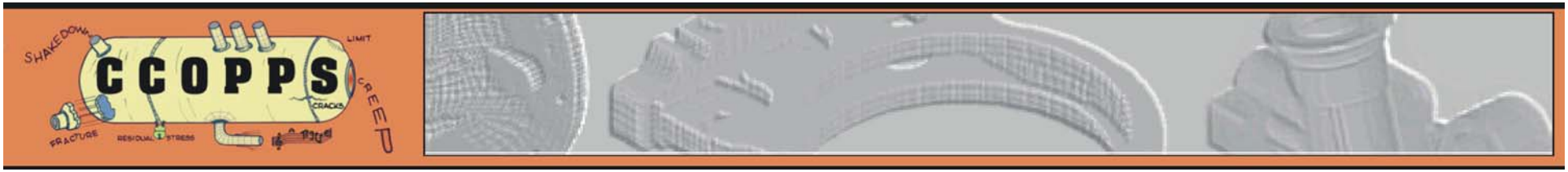
Should Codes of Practice remain independent of analysis method or should they provide better guidance and support for the use of FEA in the design and assessment of vessels and components?

Basic modelling – e.g. boundary conditions and decay lengths.
Challenging detail – e.g. bolts, seals and welds, local loads, nozzles, supports, tubesheets etc
Advanced analysis – e.g. post-buckling, gross plasticity, shakedown, creep



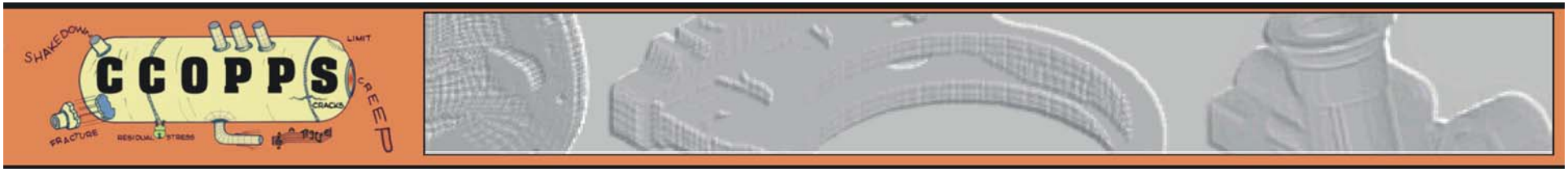
Can or should Codes procedures and philosophy be modified to make them more amenable to the facilities in modern FEA systems?

- ***Is it necessary – where are problems? What are the drivers?***
- ***What are the safety concerns if any?***



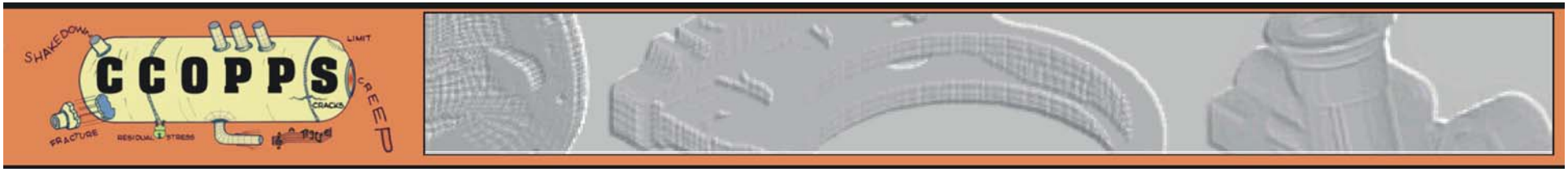
Does DBA by FEA pose more of a validation challenge than other DBA methods?

Education
Legal
Quality assurance.



What role do commercial FE Systems have in improving the interface between Codes of Practice and analysis?

Models that embody industry best practice?
Ease of use in modelling and assessment?
Adaptive meshing based on Code related parameters?
Assist with identifying the need for buckling and large displacement?



Do Codes of Practice inhibit the use of FEA for optimisation, non-deterministic studies and advanced methods in general?

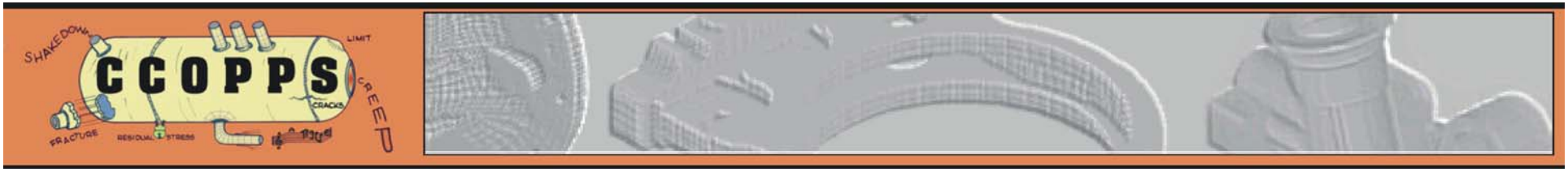
Studies have shown that such analyses are not as widely used in industry as one might expect – why is this and if they do have a role in PV design, where and how?

It has long been argued that Codes of Practice inhibit creativity ...

Isambard Kingdom Brunel christened the committee set up to develop the first code of practice for bridge building, as the committee to prevent further innovations in bridge design!

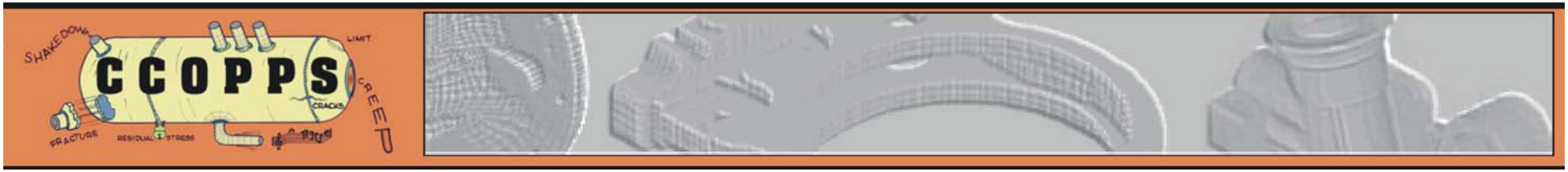
William John McQuorn Rankine who's study in 1842 of the derailment of a French train led to the first assertion of the importance of stress concentration in rail axles, expressed similar sentiments when he wrote ... the kind of legislation to which an Institution of Engineers should turn it's attention, is that concerning public safety. If an laws of the kind be provided, they should be such as shall not check the enterprise of engineers – nor waste time, nor involve any greater restraint or inconvenience than is absolutely necessary.

The Foreword to ASME VIII Div2 2007 points out however that: The rules ... are not to be interpreted as limiting in any way the manufacturer's freedom to choose any method of design or any form of construction that conforms to the Code rules.

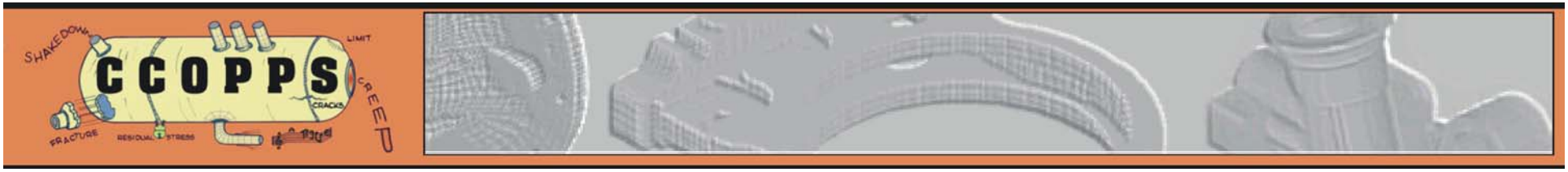


Other drivers and issues

- ***Although industry access to FEA is probably easier than ever, the number of FEA proficient engineers may be falling.***
  - ***The CCOPPS survey showed 45% of respondents spent less than 20% of their time on analysis***
  - ***FEA is not seen as a stand alone skill***
  - ***Do casual users have the required level of understanding of the FEM?***



Questions and comments please?



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Address for Discussion Forum: http://ccopps.8.forumer.com/

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