

SAINT Golden conference  
Accolades Conference centre  
7-8 February 2018

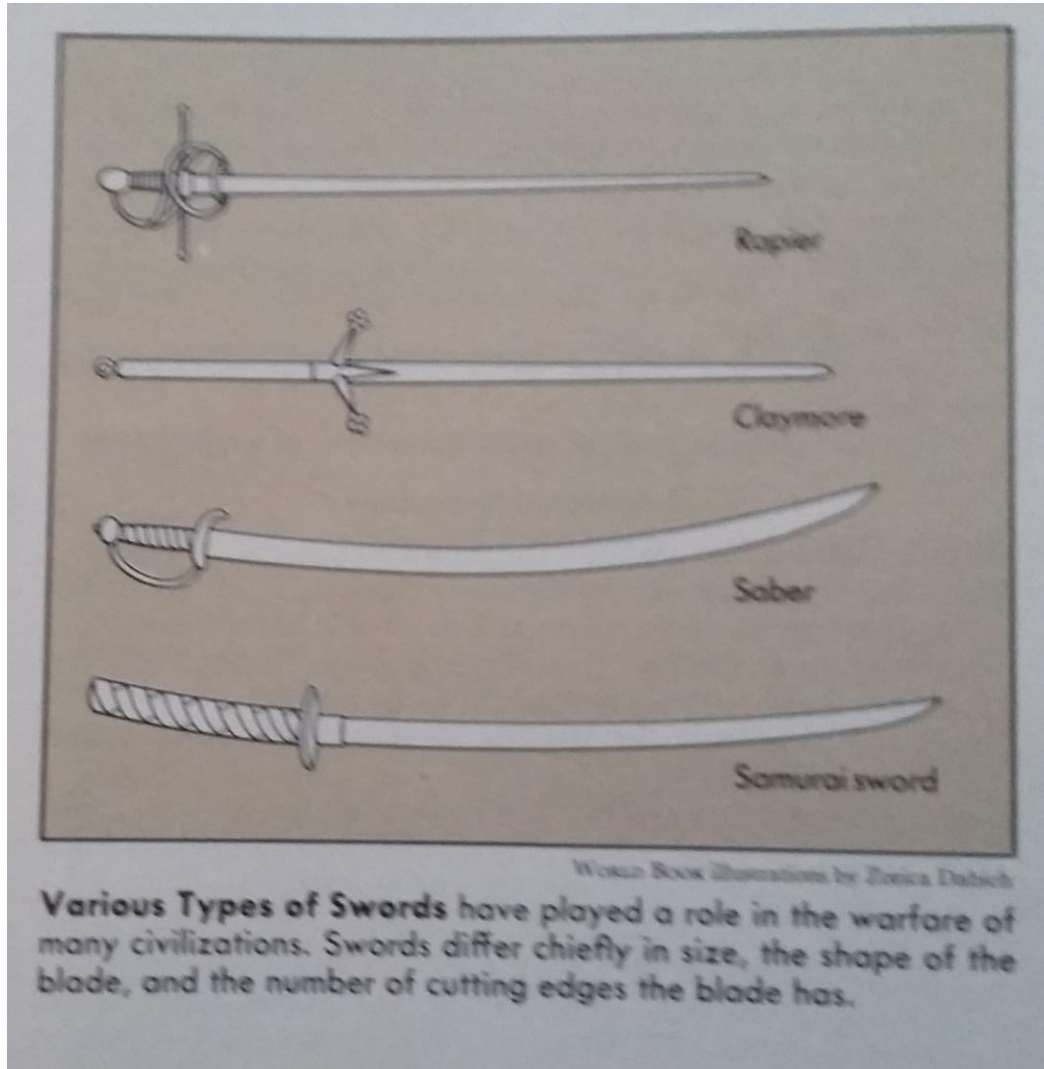
New materials introduce different NDT challenges  
relating to health and life extension projects

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## Where we came from



The bronze and iron ages show abilities in both casting and forging  
Use of heat and mechanical work



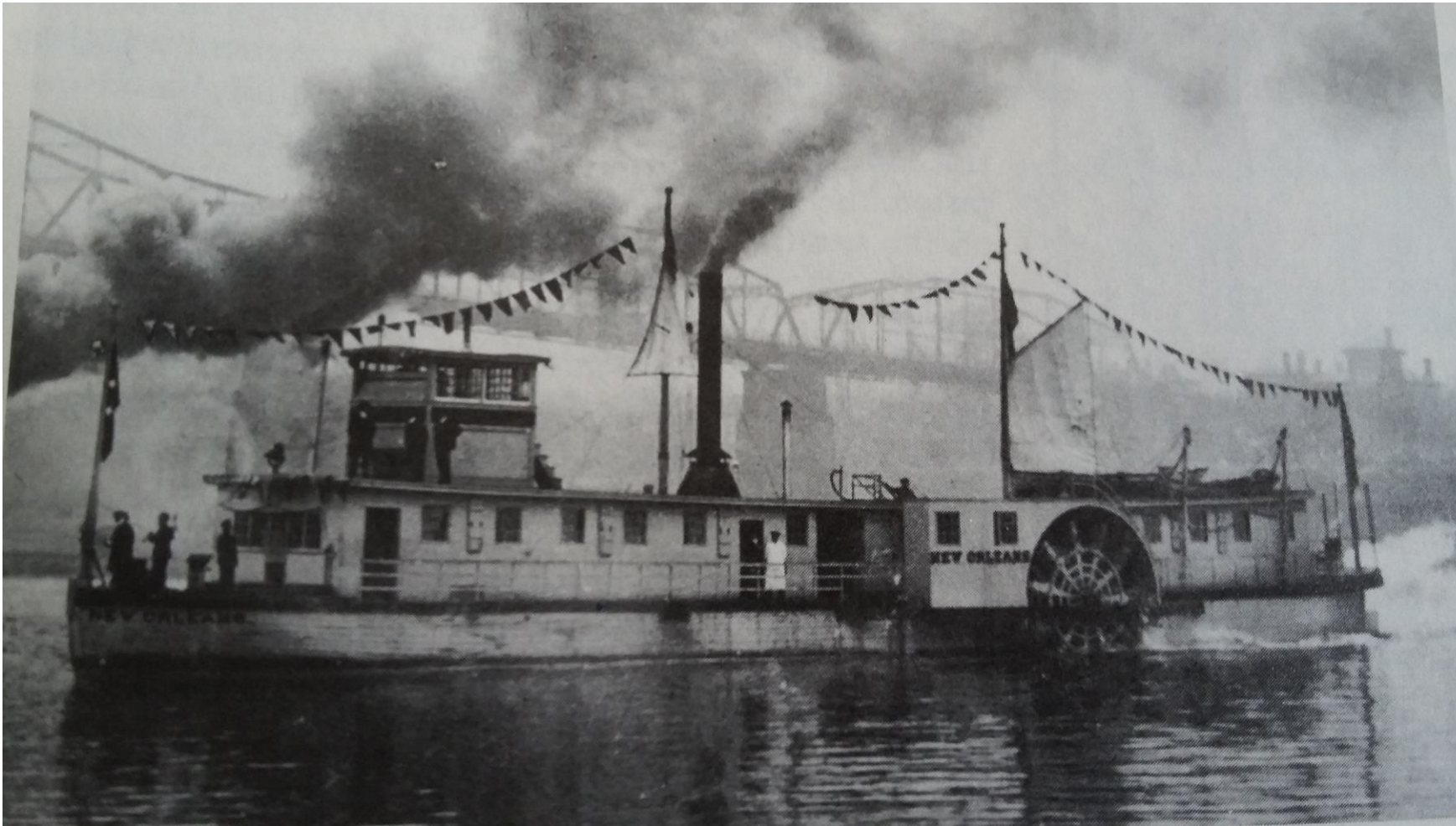
## Iron Bridge 1779

Cast iron structure  
in compression  
following timber  
construction  
design methods

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Industrial revolution  
Steam driven pumps  
Steam engines  
Steam boats

Joining by forging  
and riveting

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Sydney bridge  
joined using  
rivets

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Electrical generators developed in the 1880's

Arc welding followed in the late 1890s and early 1900's

Shielded electrodes developed in 1910's

MIG and TIG developed in the 1950's

Hot rolled steel flats and sections dependent on composition only for strength used for structures

[Research well aware of property effects of composition plus mechanical or thermal tempering (EN (emergency number) UK nomenclature)]

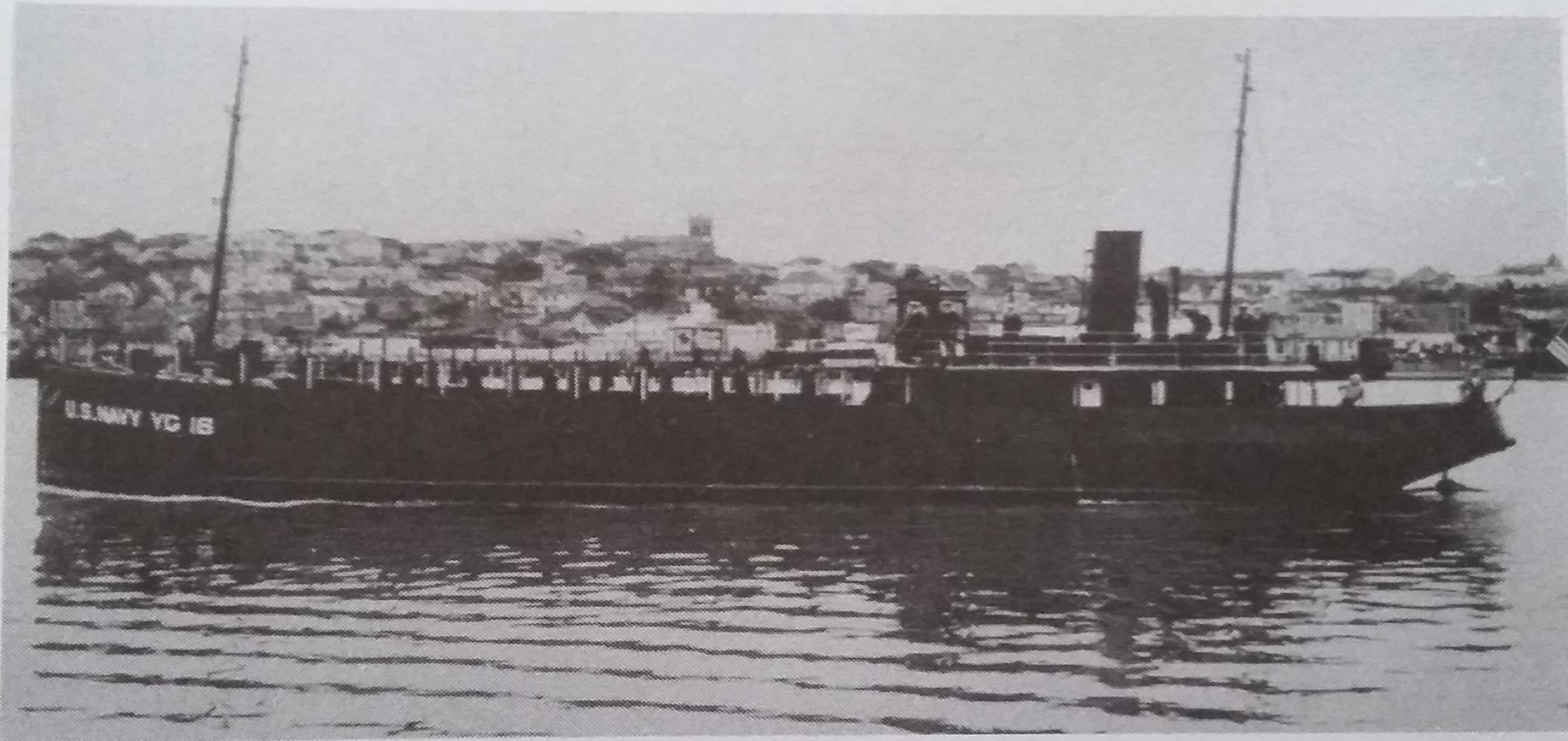
Mathematical models for structural engineering developed in late 1940's. The hypothesis of homogenous isotropic material is still used as the base for the finite element programmes used.

A major market, the motor industry gradually adopted wrought steels from the 30's and 40's



## FUSION WELDING as a means of joining

- Welding is an enabling technology that yields permanent joints.
- A small number of standard flat and shaped sections can be formed and joined to serve a multitude of end user requirements.
- As forces can be aligned, thinner sections can be used.
- Stronger modern materials are more reliably manufactured. Consequently lighter structures are designed. Welds have become more highly stressed. Concerns previously masked by scale have emerged.
- Welding was initially anticipated only to meet structural imperatives.
- The 21<sup>st</sup> C has introduced other demands from welded fabrication.



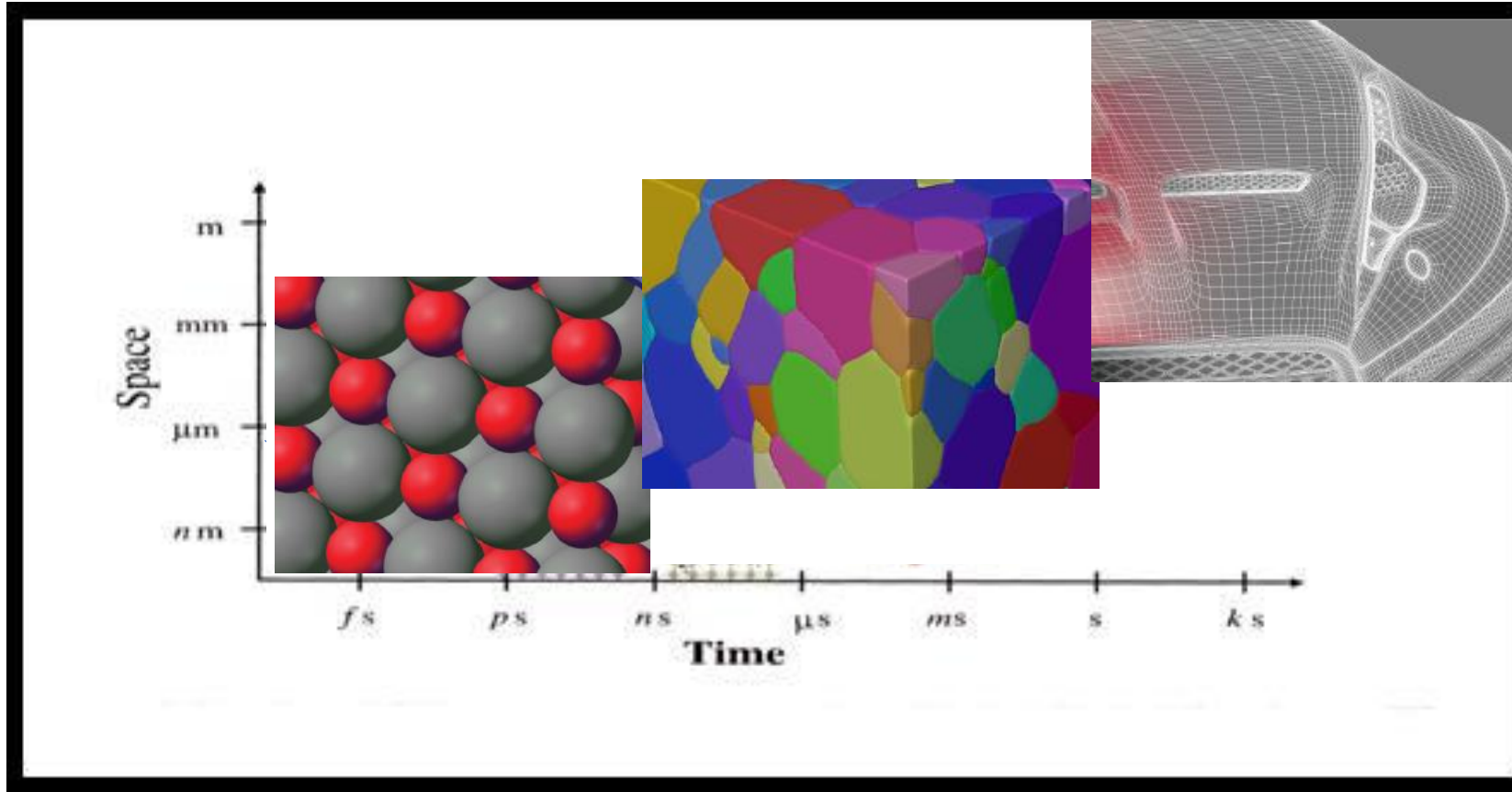
**Fig. 1-6.** An all-welded naval vessel that won a major award in a design competition in 1932.

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## Assessment of the discrete-continuous material interface between disciplines

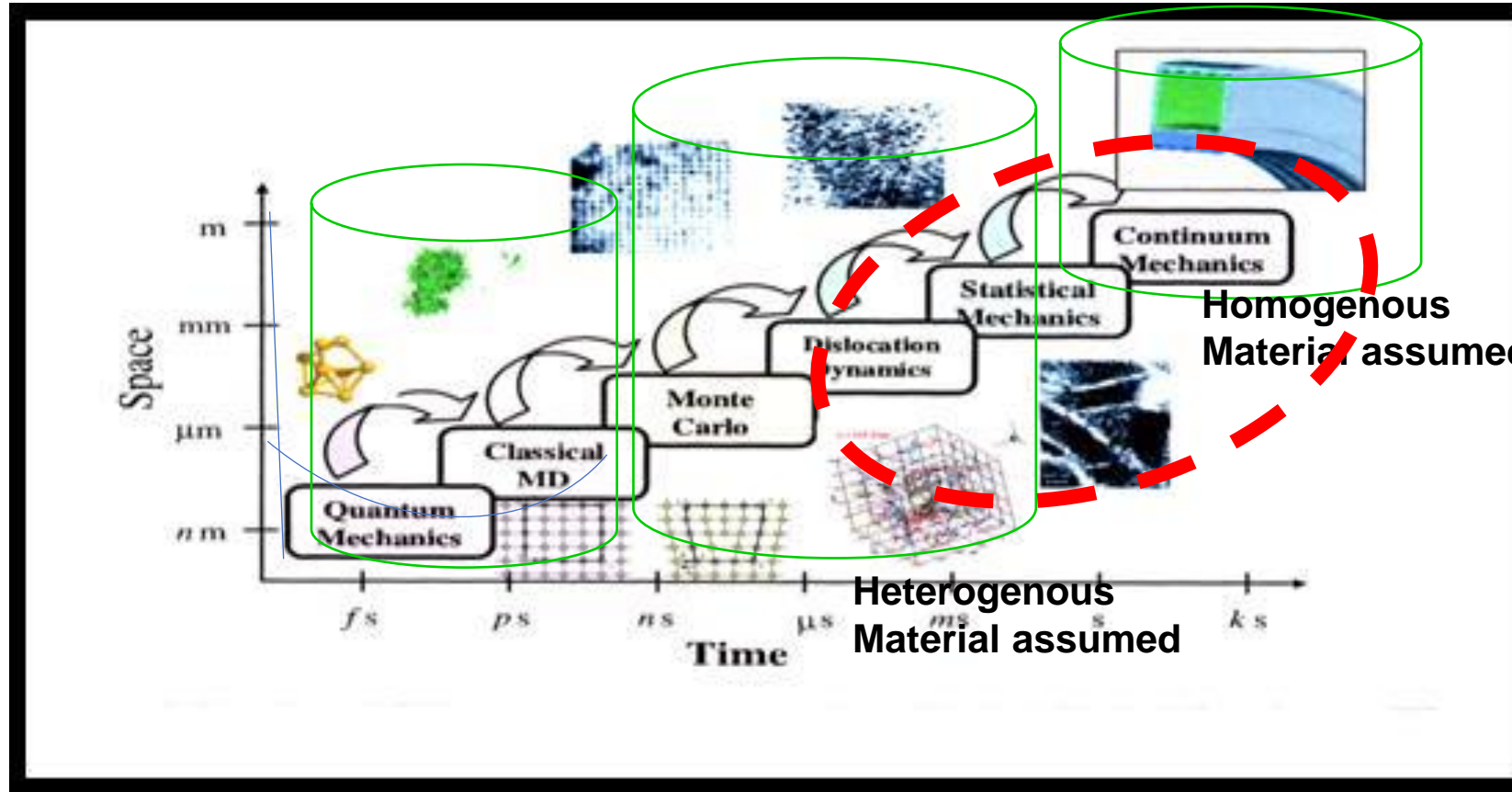


The time space relationship between  
physics, metallurgy and structural engineers

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# Assessment of the discrete-continuous material interface between disciplines



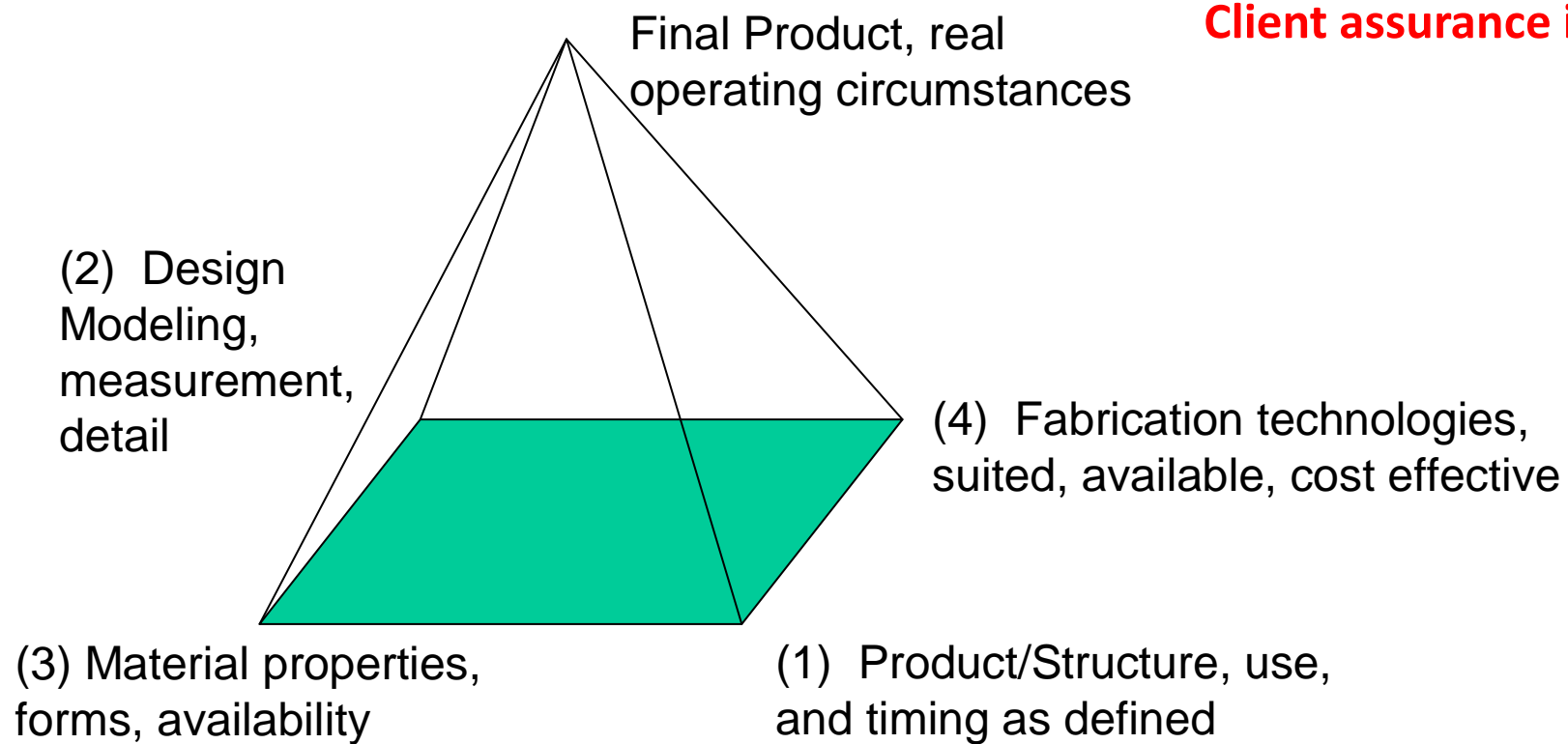
The relationship between structural engineers and  
physical metallurgists

Silo training and interpretation

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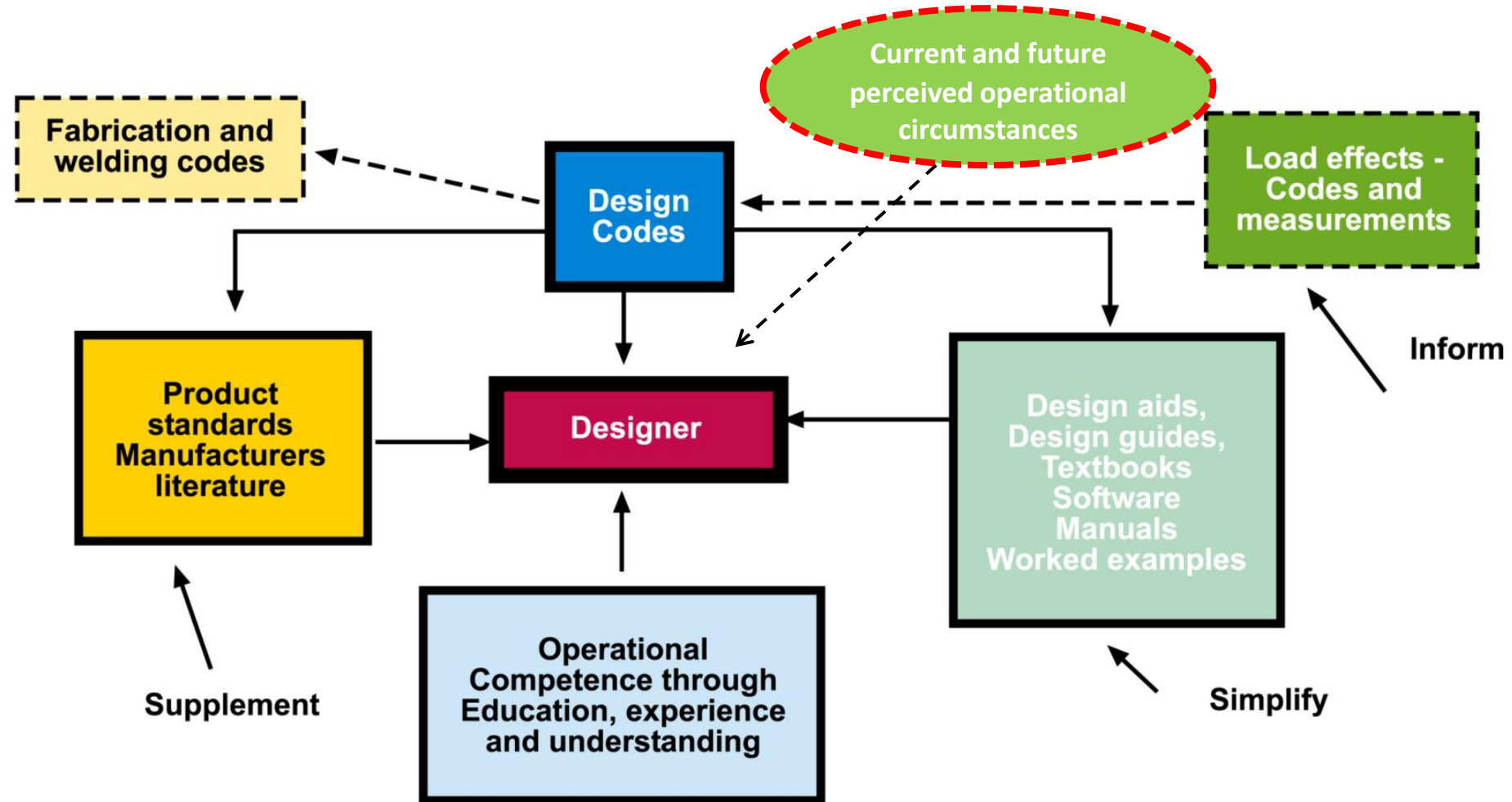
# The product platform



**Client assurance is the NDT intent**



## the design decision process



The relationship between the code/standard, the designer and support systems

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## Structural design

Homogenous isotropic structural model assumes no change of structural strength or toughness (ductility) of the weld.

Most often filler (nugget strength chosen is well above base material  
e.g. 70xx electrodes (490MPa))

However as we move from hot rolled steels which rely on composition only to the newer steels that combine composition and post composition thermal or mechanical tempering the question arises as to whether this still holds.

## Weldability of steels - composition

**Carbon Equivalent \***  
(Structural Steel)

**Strength increases with  
increasing CE**

**Grade Categories**

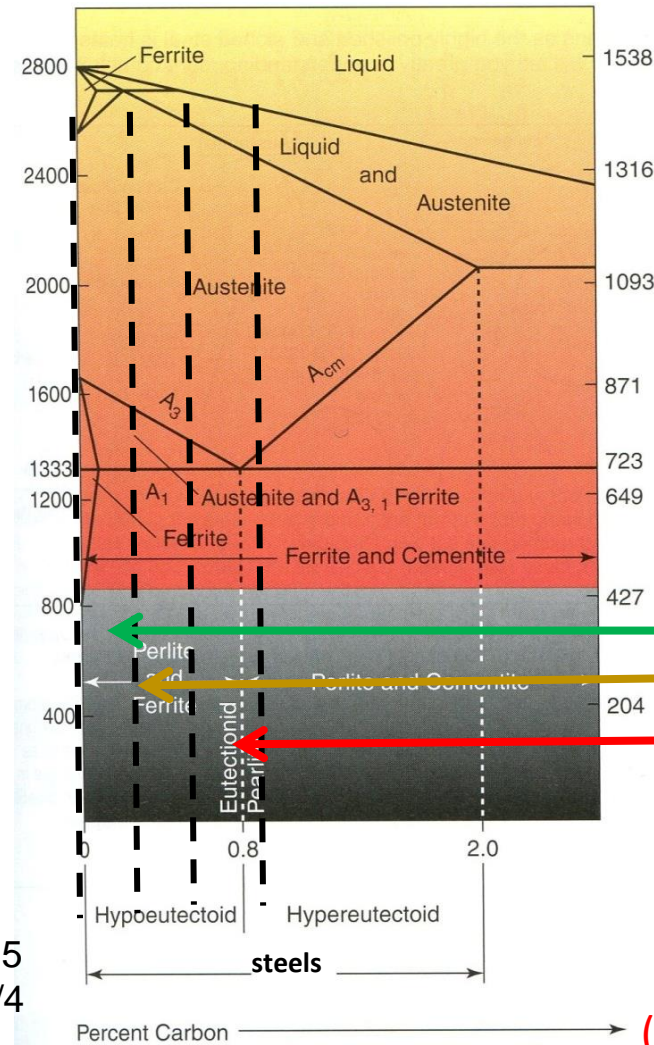
**0,0% < CE < 0,30%**

**0,3% < CE < 0,6%**

**0,6% < CE < 1,0%**

\*Carbon equivalent example

$$CE = \% \text{ Carbon} + \% \text{ Mn} / 6 + \% \text{ Ni} / 15 + \% \text{ Cr} / 5 + \% \text{ Cu} / 13 + \% \text{ Mo} / 4$$



1333°F/723°C

**Ease of welding**

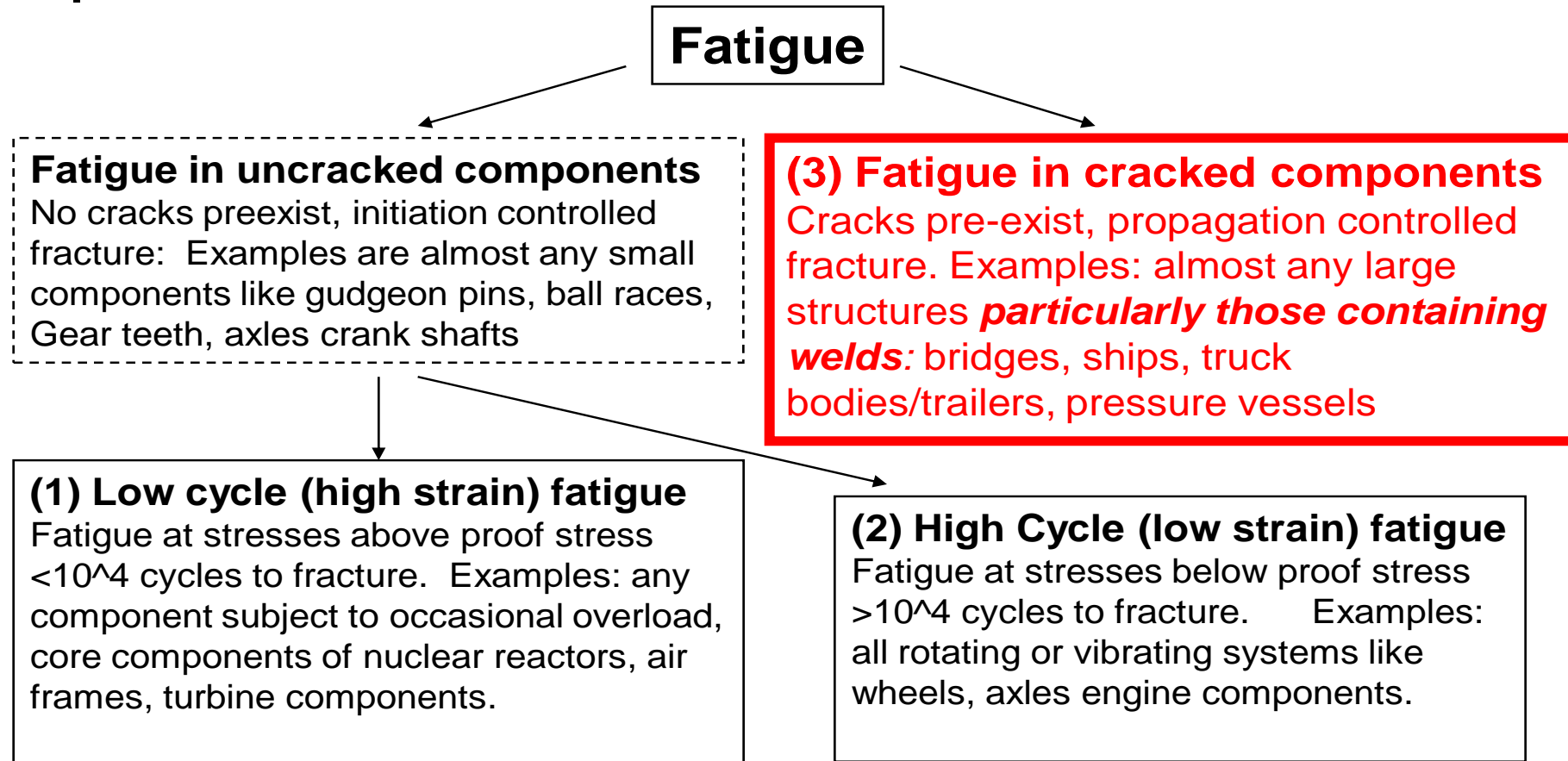
**Excellent weldability**

**Good weldability**

**Poor weldability**



Three classes of dynamic loading leading to fatigue failure exist:



## *Structural considerations*

*Number of repeats and consequence of failure*

### Consequence of failure

Low

High

Number of  
Repeats

Low

Simple, standard  
mathematical  
model  
approaches

More attention to load effects.  
Quality assurance checks on  
fabrication and joints **NDT**

High

Detailed design to  
production  
methods **NDT**

Most sophisticated with high  
level of detail plus laboratory  
tests and prototyping **NDT**  
E.g. welded safety sensitive  
applications

## Standards

Nomenclature	SAE/AISI- steel grade nomenclature composition based
	EN (1) - steel grade nomenclature composition based
	EN (2) - performance (yield) based

Design	AWS D1.1 - Method based
	EN - performance based

As the standards philosophy is different, combining standards is not recommended  
There is a complexity when standards interface as approaches are different



# What has changed in steel mechanical properties over the last 20 years?

The motor industry has always been a very significant steel market. By the late 1980s Californian environmental legislation was forcing change on the motor industry by placing a premium on fuel efficiency, placing a premium on vehicle mass. This led to a motor industry move towards aluminium (five fold increase per vehicle since 1975 to present). The steel industry responded by developing new, stronger, steels.

Steels are strengthened through two means, composition and tempering, the latter including mechanical breakdown of grains and thermal treatment.

From a structural engineering point of view, new stronger steels were introduced.

These included the commonly used S235, S275 and S355 grades, the S designating steel, the numbers minimum yield strengths. As the composition of all grades are near identical, it is clear that tempering determines the difference in performance.

The question we seek to assess is the impact of welding on the materials

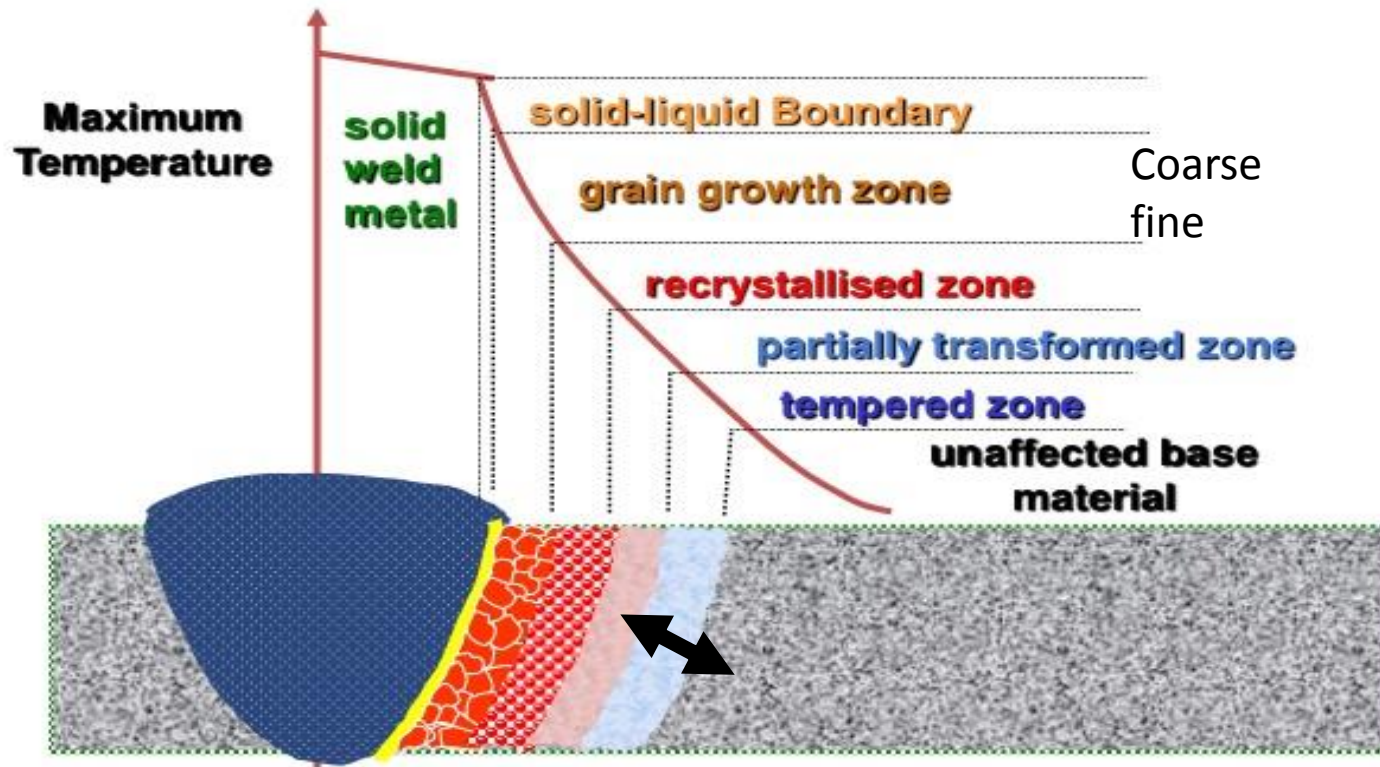
**The limits of chemical composition as a guide to structural performance in common structural steels has limits. Metallurgical and Mechanical treatment is used to modify microstructure by reducing grain size (not cold rolling).**

Note alloy overlaps compared to yield strength. There is a need to design to reduce on site welding whether in an on site workshop or not because of the impact of welding on increased mechanical treatment used for the higher grade steels.

Grade	C%	Mn%	P%	S%	Si%	CE <sub>E</sub>
<b>S235</b>	0.22 max	1.60 max	0.05 max	0.05 max	0.05 max	<b>0.49</b>
<b>S275</b>	0.25 max	1.60 max	0.04 max	0.05 max	0.05 max	<b>0.52</b>
<b>S355</b>	0.23 max	1.60 max	0.05 max	0.05 max	0.05 max	<b>0.50</b>

$$CE = \% \text{ Carbon} + \% \text{Mn}/6 + \% \text{Ni}/15 + \% \text{Cr}/5 + \% \text{Cu}/13 + \% \text{Mo}/4)$$

## Heat Affected Zone (HAZ) <sup>2.5</sup>



For structural engineering steels post weld heat treatment is not required.

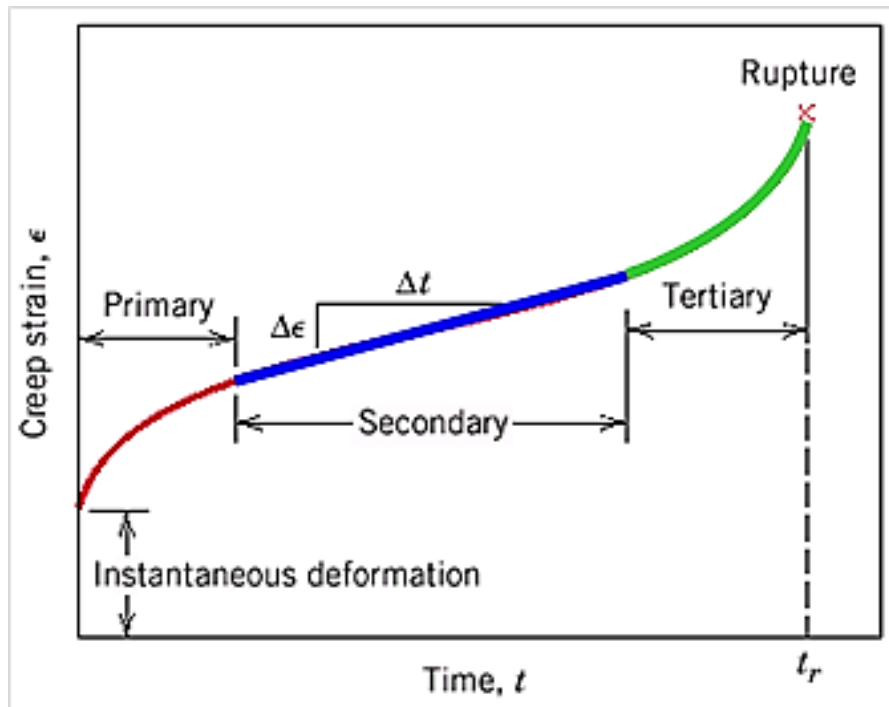
But what happens in the mushy zone at temperatures above the  $723^{\circ}\text{C}$  transformation temperature. Can we guarantee structural performance assuming homogenous isotropic properties?



*Creep As operating conditions change to higher temperature and pressures higher performing creep resistant steels are required.*

Creep resistant steels involve composition coupled to thermo-mechanical treatment.

But components such as vessels and pipes need to be joined. Post weld thermal treatment is required. What happens to the microstructure?



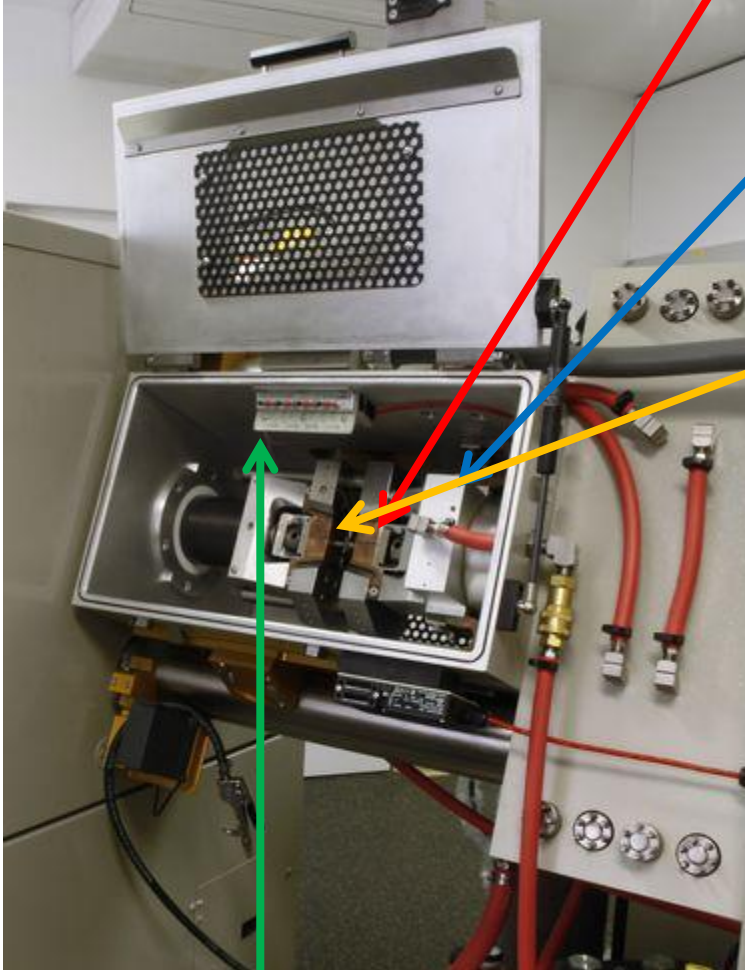
The Gleeble research tool allows precise thermal control and can grow microstructure by slowing the cooling time.

## **Effective and efficient welded connections.**

The research tool – the Gleeble

- A Gleeble 3500 was installed at Wits in late 2014 and fully commissioned by early 2015
- The Gleeble is a physical thermo-mechanical application device linked to simulation programs. It is capable of reliably repeating a wide range of experiments in a number of possible atmospheres.
- The Gleeble output compares real results with expected outcomes through simulations and extends these simulations into other areas.
- This provides a data base of results to compare with single event physical experiments.

## The heart of the Gleeble



Thermo couple connections

Heating - direct resistance  
- up to 10,000°C/second  
- can hold steady-state equilibrium temperatures.

Cooling - High thermal conductivity grips  
- quench air or water  
- controlled cooling rates in excess of 10,000°C/second at the specimen surface.

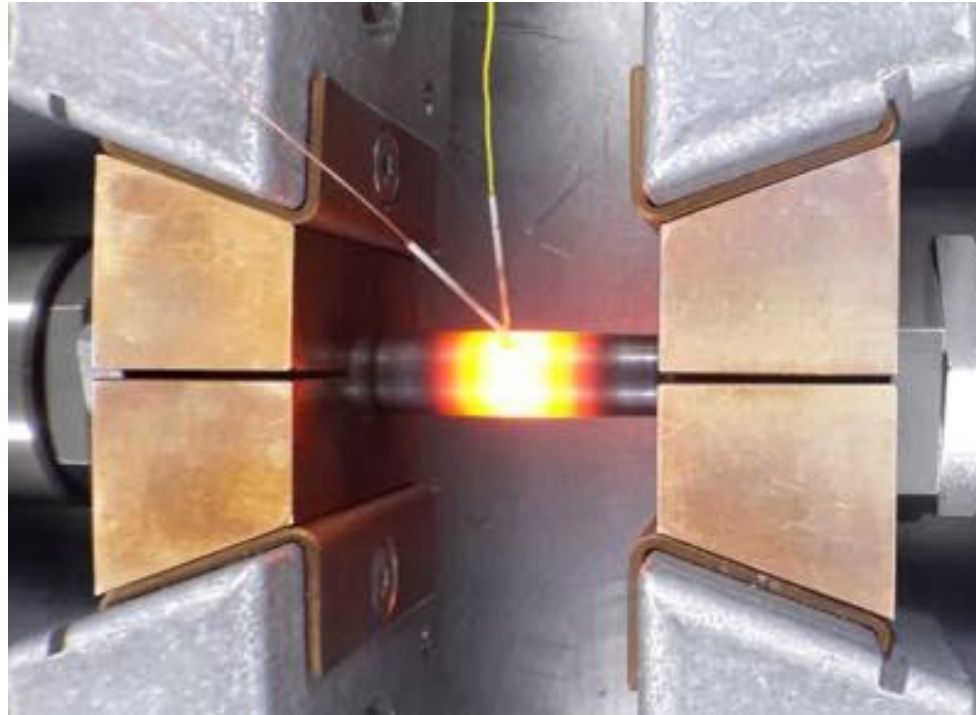
Axial force - fully integrated hydraulic servo system  
- up to 10 tons static force tension or compression.

Displacement rates up to 1000 mm/sec

Non-contact laser extensometry provides feedback to insure accurate execution and repeatability .

**Effective and efficient welded connections.**

**B) Simulation of the discrete-continuous material interface of whole welded structures to facilitate design**



*Direct resistance heating provides rapid and precise temperature control – source DSI*

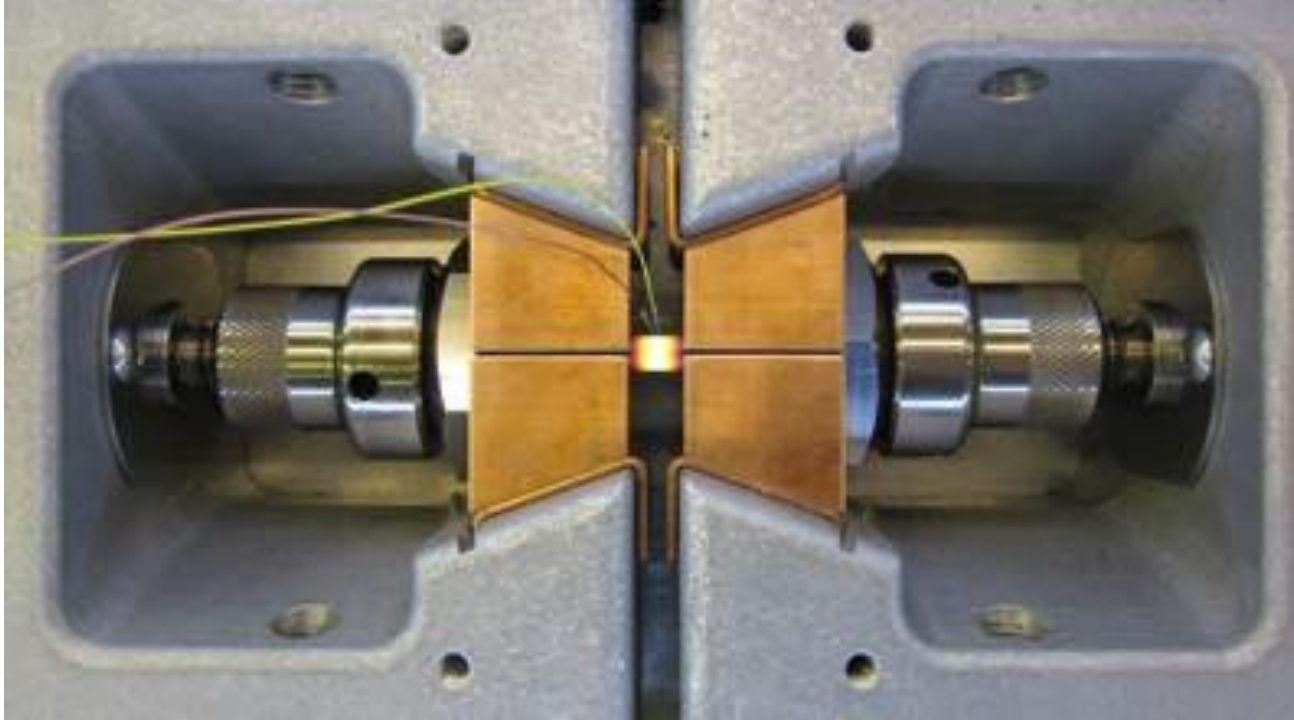
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**Effective and efficient welded connections.**

**B) Simulation of the discrete-continuous material interface of whole welded structures to facilitate design**



*Water-cooled jaws plus quenching contribute to very fast cooling rates (source DSI)*

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## The heart of the Gleeble *The chamber*



**Sealed chamber** The sample is isolated from the external atmosphere.

Vacuum – mechanical and diffusion pumps

High vacuum down to  $2 \times 10^{-5}$  Torr

Potential for - inert gasses

- *active gasses*
- *varied relative humidity*
- *normal atmospheres*
- *normal and acid rain impacts*
- *industrial environments ( $\text{SO}_2$ )*
- *marine environment (Cl)*

The Thermo mechanical section of the Gleeble is connected to simulation software through which:

- actual physical results can be compared with theory
- Results can be extended to develop stress strain relationships suited to FEA's

The 21<sup>st</sup> Century has introduced the challenges of:

- Globalisation
- The triple bottom line of planet, people, prosperity (e.g. International SHE)
- The finite limits of engineering material availability
- The finite limits of energy sources
- The finite limits of water

Globalisation has encouraged international standards generally drawn up from developed countries lead.

From a systems control point of view input (method) specifications are preferred to output (performance) specifications - But RSA has chosen the EN route.

Triple bottom line reporting places more emphasis on health. Internationally and locally health legislation has been progressively tightened.

Based on standards, administration has become the driver rather than the facilitator. Check lists supersede applied engineering skills; Inspectors have replaced supervisors.

Consequently, quality tends not to be built in but inspected out.



# NDT DEMANDS FOR PROCESS PLANTS



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## Health related process plants

- Process plants with an operational life of decades typically include (thin wall) pipes linking treatment tanks, heat exchangers or distillation columns. Standard plates and pipes are formed, then welded together into systems that meet prevailing or future perceived operating environments.
- Biofilm formation on inside surfaces encourages both bacteria growth and Microbial Induced Corrosion (MIC).
- A particular group of process plants, pharmaceutical, dairy, food, beverage and brewing, are subject to health legislation.
- International and local health legislation is increasingly demanding lower and lower bacterial (and spore) counts (alive or dead) in the end product. Pasteurisation is no longer acceptable.
- Hygienic fabrication and operation are required to guarantee pharmaceutical and food safety.
- For hygienic fabrication, whilst good design standards exist, major gaps are found in the lack of practical guidelines, education and, pertinent to South Africa, skill training and development together with appropriate supervision
- Maintenance of existing plants decades old needs to comply with current health legislation

*Note: In terms of health legislation sterilize, disinfect, sanitize, and clean represent decreasing ranks.*

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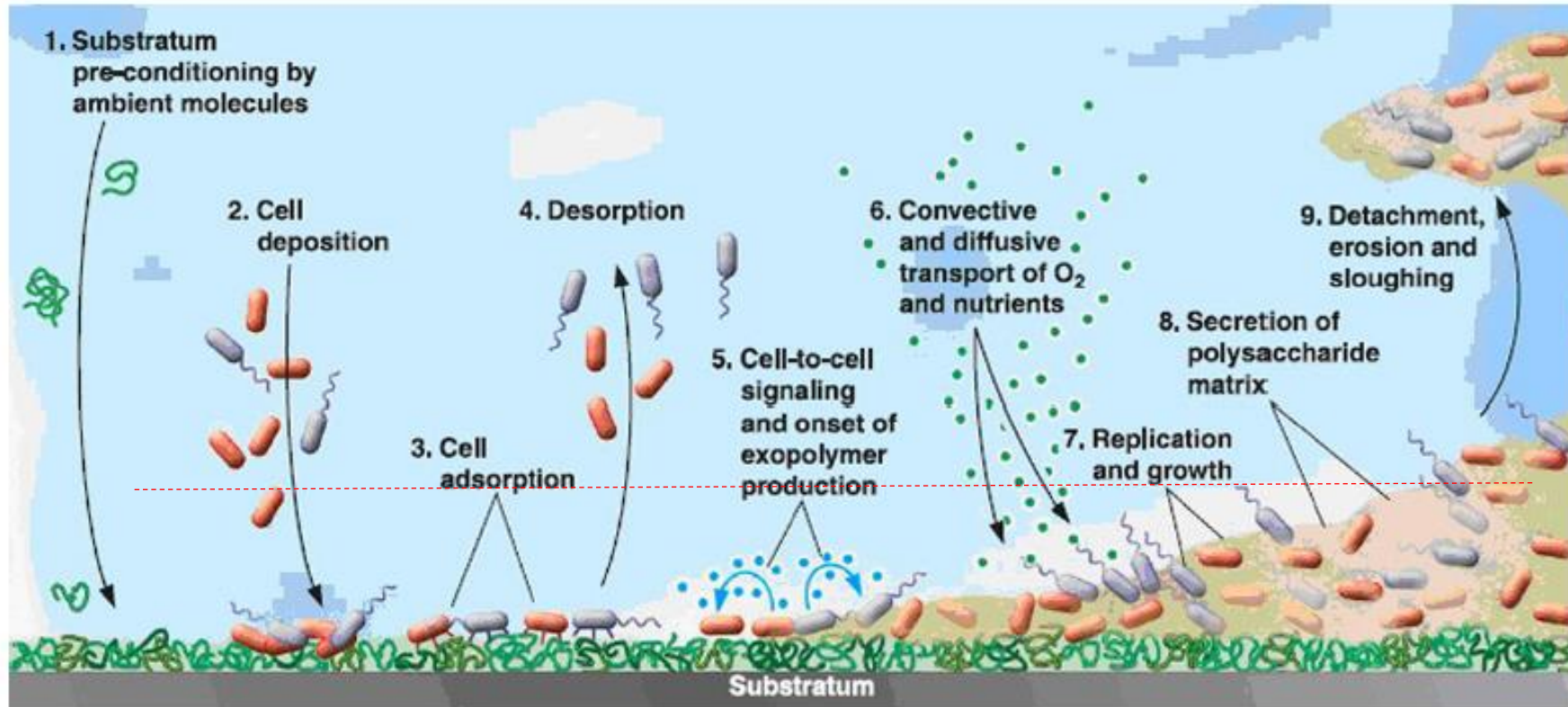
# Effective and efficient welded connections

- Hygiene requirements, potentially more demanding to achieve than structural integrity, are an addition to engineering fabrication/operational requirements.
- Welding is a source of surface roughness
- Welded area a very small part total area of installation
- Good design standards exist for hygienic fabrication
- Major gaps are found in the lack of practical guidelines
- *Realistically, hygienic welded fabrication, particularly with on-site welding, is more challenging, more costly.*
- *Heat exchanger tubes are faced with similar problems but related to MIC*
- *The NDT question is whether we are looking deeply enough into non structural performance issues such as health and corrosion*

# Effective and efficient welded connections

*(Biofilm formation- not limited to health related sectors)*

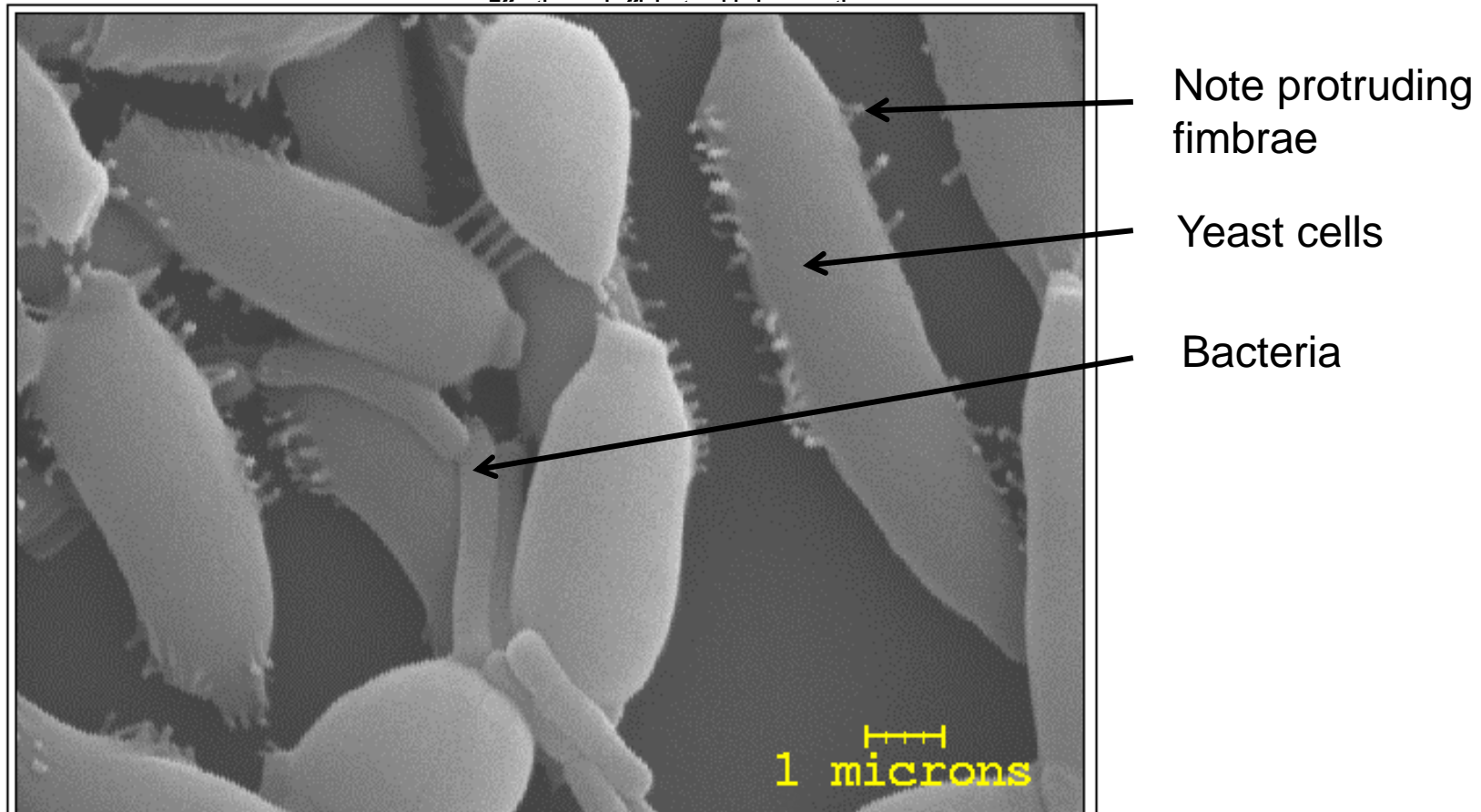
- **Depth  $\delta$  increases with increased surface roughness, increased temperatures, and lower flow speeds**



Source: A review of current and emergent biofilm control strategies  
Manuel Simoes, Lucia C. Simoes, Maria J. Vieira  
LWT - Food Science and Technology 43 (2010) 573–583  
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# Effective and efficient welded connections



*Scanning electron micrograph of a biofilm on the inner surface of a dispensing line.*

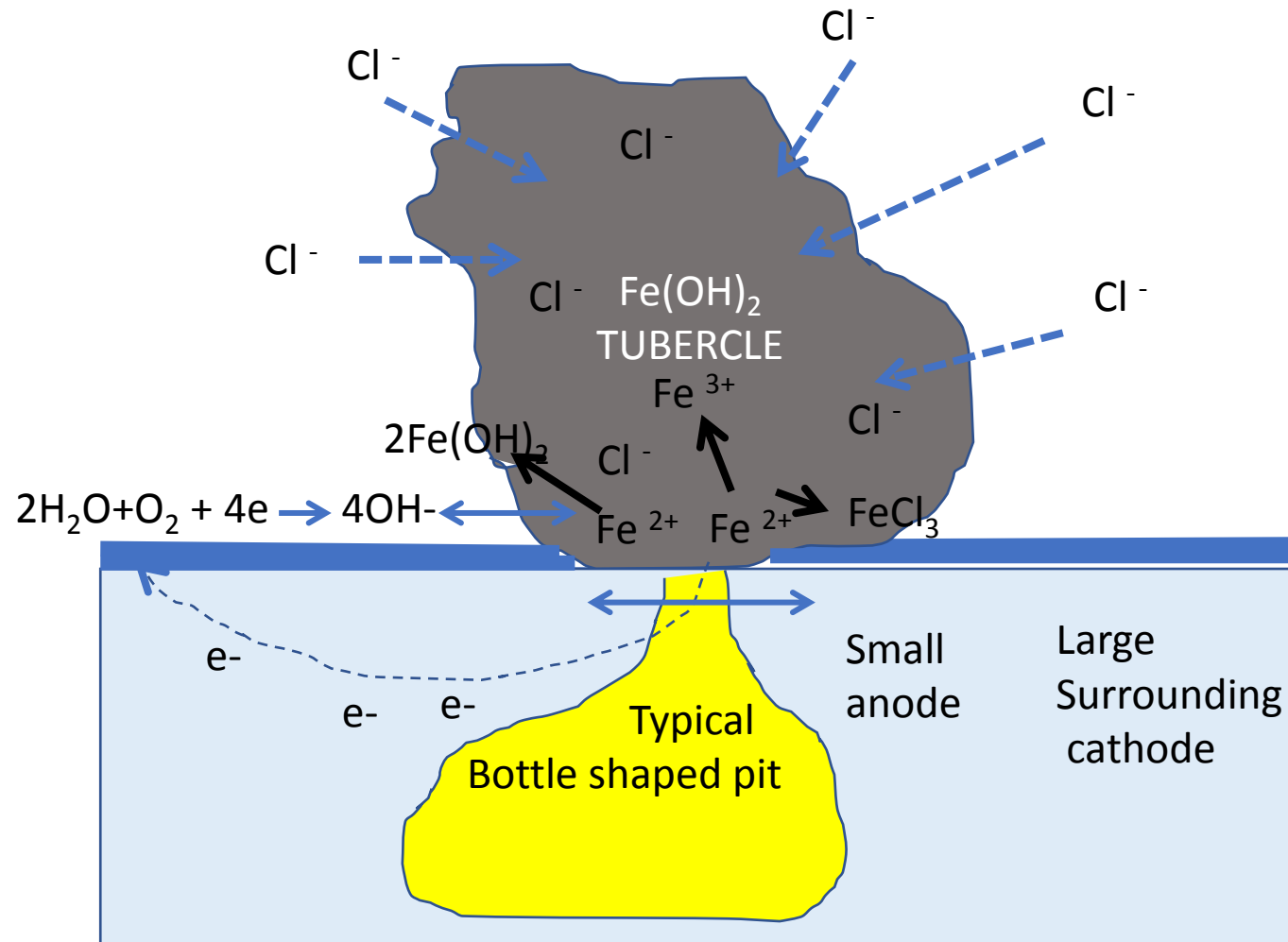
Source Erna Storgårds Process hygiene control in beer  
production and dispensing VVT publication 410 2000

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# Biofilm build up on product contact surfaces- MIC



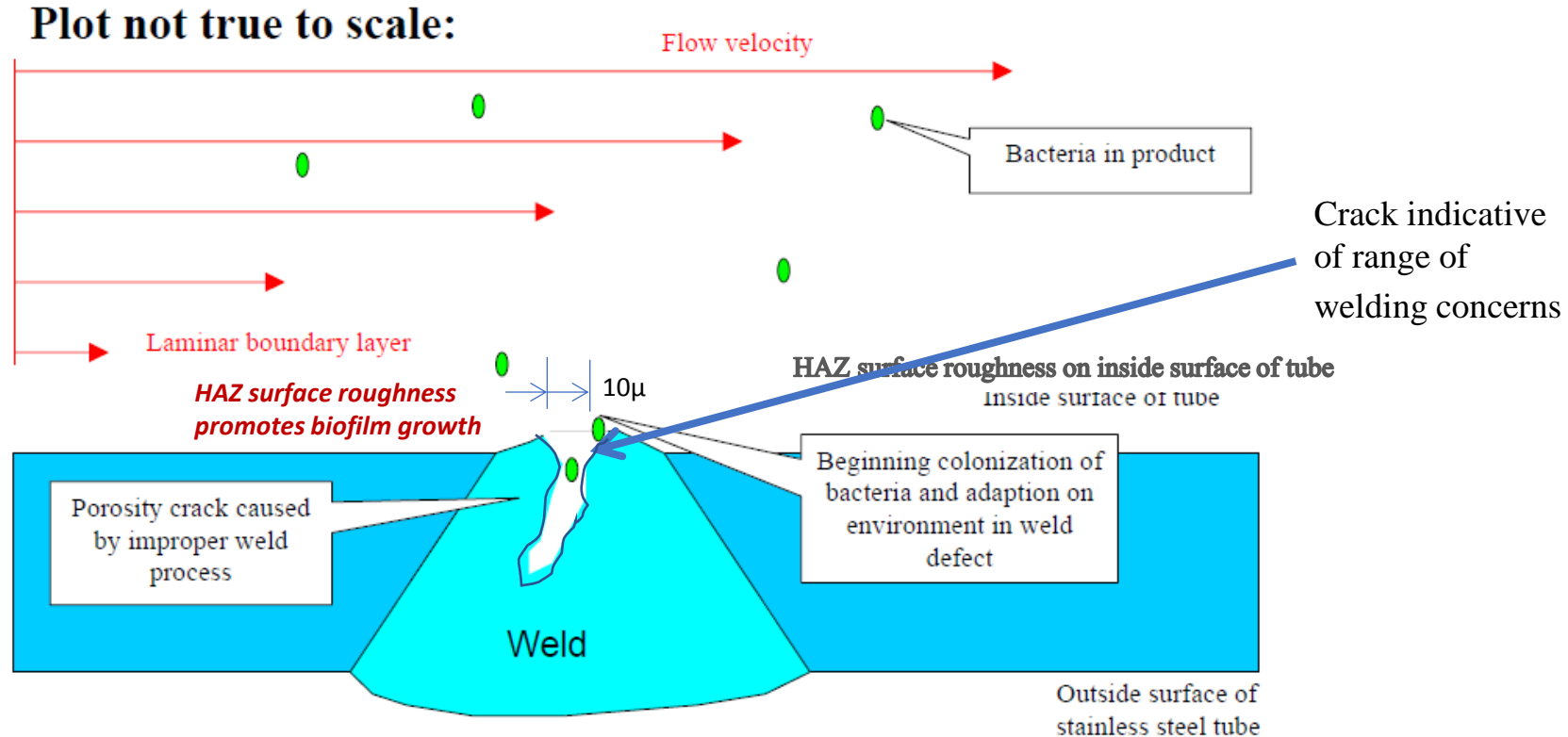
Also affects heat  
exchanger tubes

## Microbial Induced Corrosion – tubercle and pit

Welding is particularly prone to MIC as welds include micro cracks

### 3) Weld imperfection effects on health – product flow

- Porosity
- Cracks



#### Progressive Microbial impacts of imperfections

Based on source- Presentation Knuth Lorenzen,  
European Hygienic Engineering & Design Group, October 2007

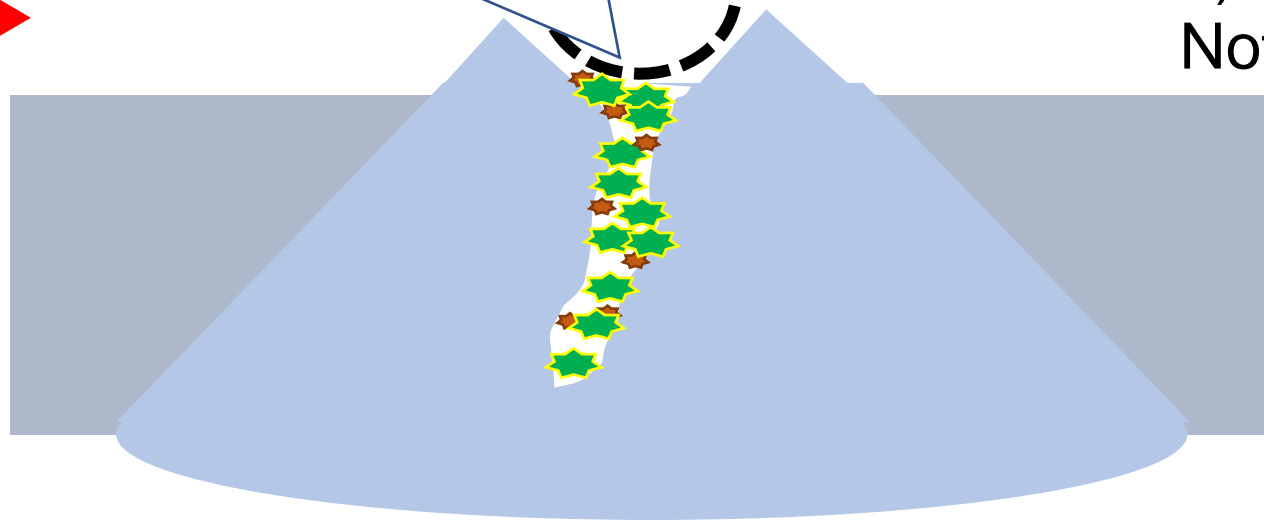
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Flow and flow rate of cleaning and disinfection fluids



Cleaning and disinfection fluids will only affect the biofilm on the outside lip of the crack



CIP chemical concentration, time and temperature effects;  
1) Polish  
2) Etch  
3) Mill  
Note Dilution over distance

## Limited effect of clean in Place (CIP) processes

*Based on source- Presentation Knuth Lorenzen,  
European Hygienic Engineering & Design Group, October 2007*

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# Pipe manufacturing and fabrication

## Manufacturing - measurement deviations result from:

- Rolling operation – rolling tolerances relate to the difficulty of keeping the sheet either a precise thickness or perfectly flat (In addition, rolls are not set flat but bulge slightly at the centre.)
- Sheet anneal or stretch
- Slitting operation – width differences resulting from setting or tool wear
- Pipe forming operation – alignment, gap, welding effects and spring back
- Possible effects on pipe ends from cutting to length operation
- Possible transport effects related to welding stress relief and packaging.

**The net result is pipes and tubes are neither circular nor of even wall thickness.**

In the case of thin wall pipes related to hygienic fabrication the impacts can be significant in terms of increased CIP operations.

Manufacturing effects may be overcome by using pipe end forming methods

Also, the potential move from 316L Stainless steel towards stronger Duplex grades, e.g. 2304, could lead to even thinner pipe walls.

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Configuration	Random orientation >80% Overlap	Aligned major axis >80% Overlap	Random orientation >80% Overlap	Aligned major axis >80% Overlap
Material and wall thickness	316L Current thickness	316L Current thickness	2304 Half thickness	2304 Half thickness
Pipe to pipe	%	%	%	%
s-s low tolerance M1 (1)	17	47	1	12
s-s high tolerance M2 (2)	100	100	79	82
s-s M1 to M2 (3)	33	39	4	6
Pipe to bend (elbow)				
s-b low tolerance M1 (4)	22	59	2	16
s-b high tolerance M2 (5)	58	85	6	26

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# **Strategy of sweating the assets - Life extension**

This implies working existing assets either beyond design life or under different operating conditions.

Older assets operated for decades are of older materials and older design

In Johannesburg one example is the practice of increasing water pressure beyond design pressure to facilitate service delivery to an increasing population.

Clearly failures are to be expected – the weakest link will break first

## **What is the weakest link – when will it break – how can life be extended?**

Currently one problem that is emerging is delamination on pressure and thermal vessels and pipes. Others have been noted in welds.

Roll refurbishment that seeks to add wear resistant layers risks delamination if not properly assessed

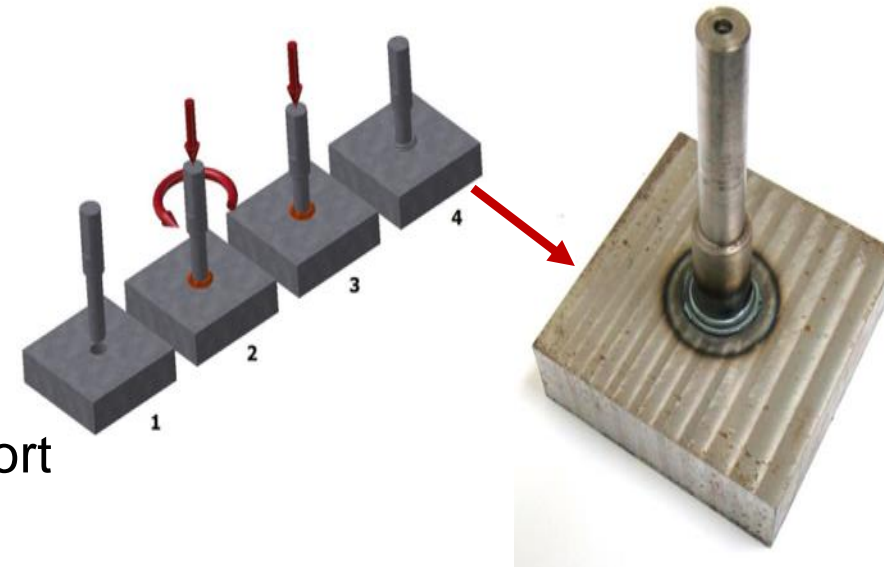
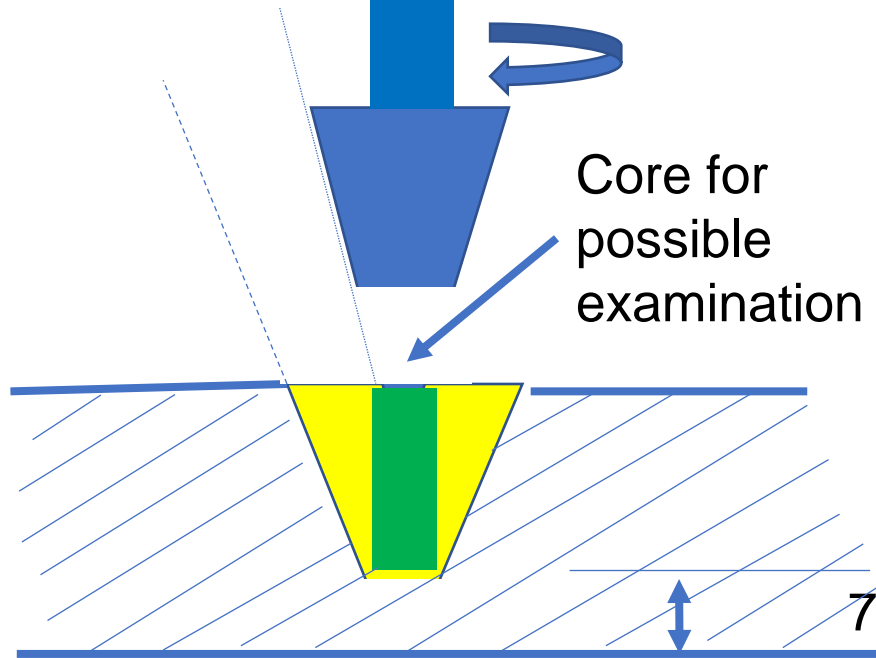
Whilst clients want to extend life, industrial research using NDT tools seen appropriate.

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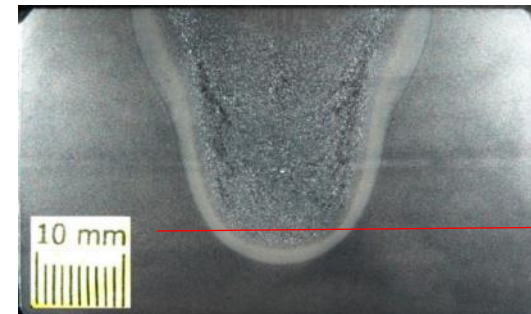
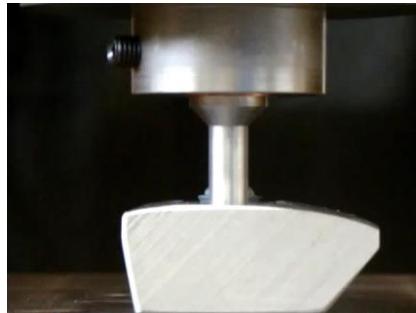


## ***One repair tool - Friction Hydro Pillar Process (FHPP):***

- FHPP was invented by The Welding Institute (TWI) in the early 1990's
- It is a solid state friction welding technique with inherent advantages over conventional arc welding; i.e. reduced heat input, small HAZ, reduced distortion, highly repeatable process
- The technique involves axially rotating a consumable tool, under an applied load, co-axially in a circular cavity, continuously generating and depositing plasticized layers of material
- A parallel sided hole-tool or a tapered hole-tool arrangement can be employed
- Pinning or stitch welding can be achieved



Example of application with narrow support



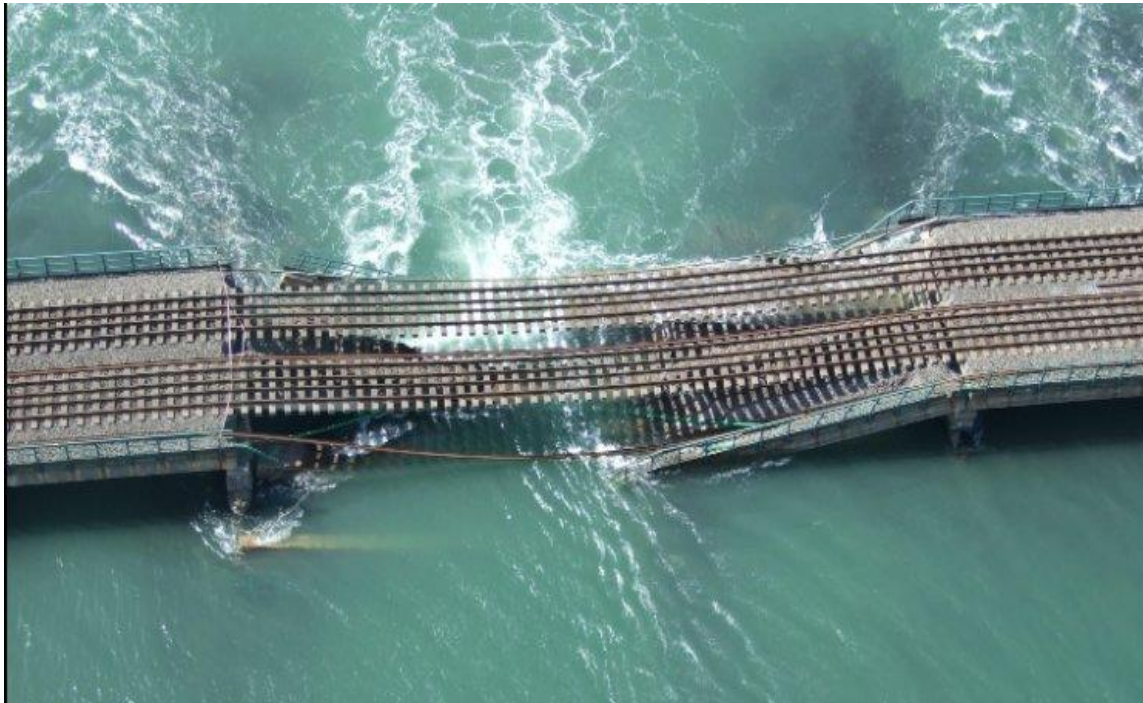
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Initially constructed in 1844, modified in 1860 and later the Malahide Viaduct just north of Dublin, Ireland, was 176 m long, had 11 post-tensioned concrete beams spans mounted on 10 masonry piles supported on a stone weir. The stone weir was required as the structure was susceptible to scour due to the tidal flow in the estuary. The stone weir required regular maintenance. For more than 150 years the weir structure had been susceptible to scour and had a maintenance regime to control the risk. Stone discharges occurred in 1976 and 1996.

It was 6:22 pm on the 21st of August 2009 and a passenger train was crossing the Malahide Viaduct when the driver noticed a portion of the viaduct beginning to collapse. The cause was found to be scour.



But, how could it be scour? What about the historic knowledge of the scour risk and the maintenance regime? Did they simply forget? The answer is ... yes. As an *organisation* they forgot. This is called Corporate Memory Loss.

Corporate Memory is “knowledge and information from the company’s past which can be accessed and used for present and future company activities” (Railway Accident Investigation Unit, 2010).

When considering life extension Corporate Memory may well be an issue worth investigating. Look beyond the obvious.



# What has all this to do with NDT?

Operating circumstances have changed – eg water sources

New NDT approaches and tools are required

On the health side more use can be made of borescopes linked by optical fibre to a camera and/or PC

More important is the need increase levels of communication beyond simply pass/ fail to assess what works from the point of view of assisting clients, manufacturers and fabricators. Then an informed cost/benefit analysis can be completed

On life extension projects, investigate beyond the obvious.

The FHPP process opens the opportunities to systematically examine microstructure and to pin laminations to extend working life.

# Conclusions

- The past 120 years have seen considerable changes in materials and joining methods
- Many existing structures are in excess of 40 – 50 years old and were designed differently
- The purpose of NDT is to provide client assurance that the structure will meet expectations
- This is different to ensuring that standards have been complied with.
- Materials have changed; standards have changed
- Health legislation has introduced a new challenge
- Operating circumstances have changed particularly regarding water
- Ultrasound can be used to kill bacteria
- Life extension of older plants introduced new challenges
- Consider the effects of corporate memory loss when considering life extension
- NDT approaches and techniques require continuous review and adaptation to changing operating circumstances

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New materials introduce different NDT challenges relating  
to health and life extension projects

Thank you      Questions

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