Life Extension Engineering of Marine Structures

From fatigue prediction to engineering remaining fatigue capacity



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SD2722 – Marine Structures · 5 October 2026

2 × 45 min

The question for today

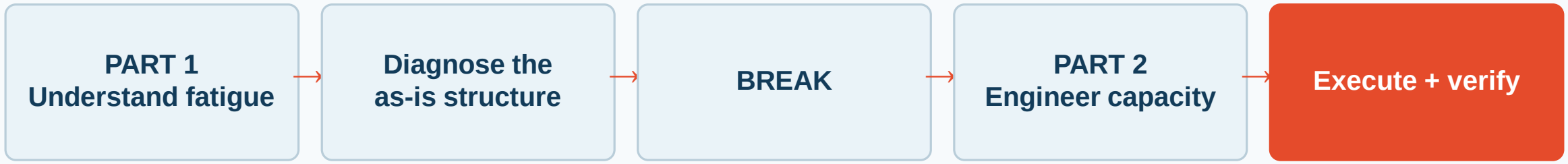
A marine structure does not know the number written in its design life.

How do we move from predicting fatigue damage to actively engineering the remaining fatigue capacity of an existing structure?

Assessment tells us where we stand. • Inspection tells us what is there. • Intervention changes what happens next.

The lecture map

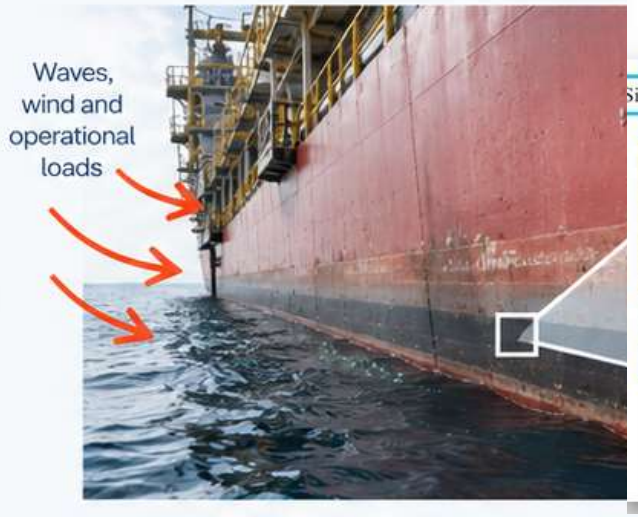
Two connected 45-minute blocks



Science → evidence → engineering decision → intervention → assurance

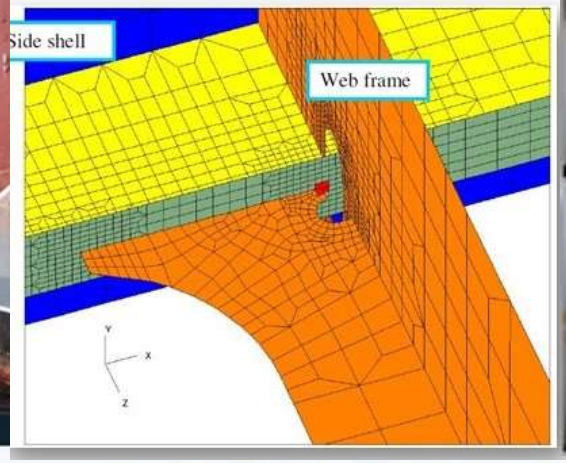
Why fatigue governs marine structures

- **Cyclic wave, wind, machinery and operational loading** generate time-varying global and local structural response.
- **Welded details introduce local stress concentration and residual stresses,** making them critical for fatigue.
- **Fatigue strength of welded joints is often governed more by the detail than by the base-material yield strength.**
- **Long service lives turn small local weaknesses into structural-integrity decisions.**



Global structural response
Hull-girder bending and global defformations

Fatigue hot-spot indicated by Finite Element Model corresponds well with coat failure on site



Local structural response
Hotspot stresses at welded details



Detail behaviour
Weld toe under cyclic loading

Global scale
(whole structure)

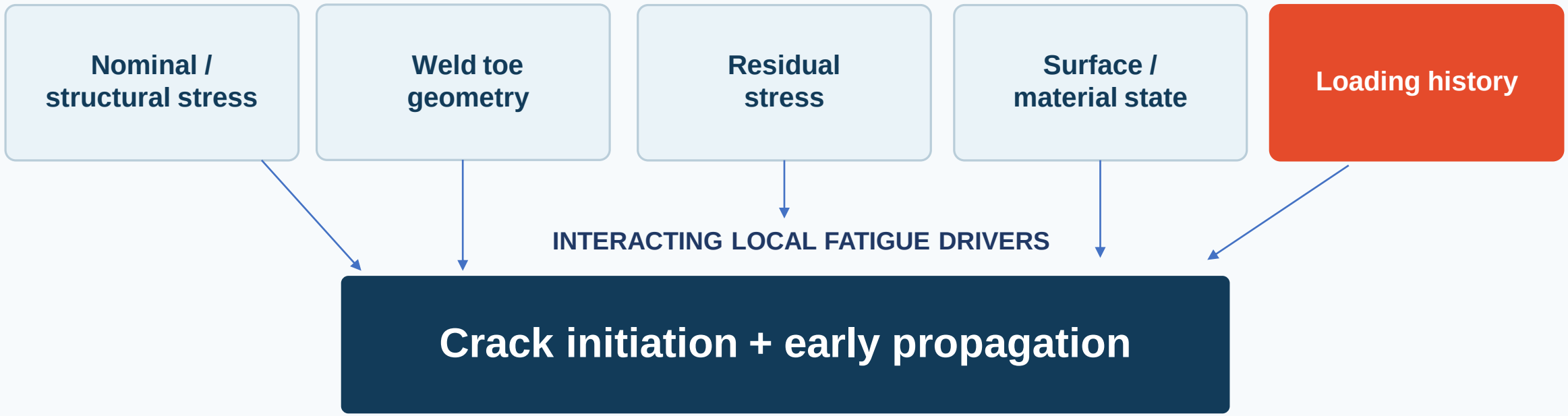
Local scale
(structural detail)

Material / detail scale
(weld toe)

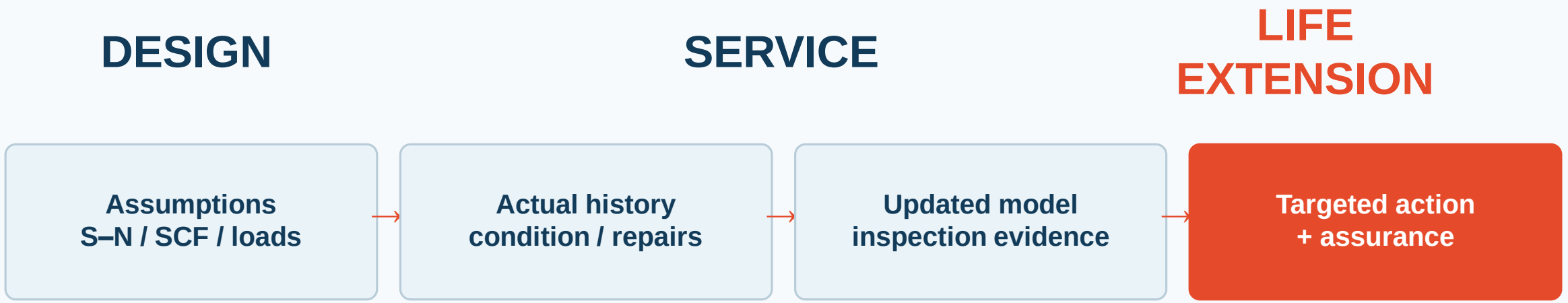
The problem is local.
The consequence can be global.

What controls fatigue initiation at a weld toe?

Think of a coupled local system—not a single parameter.



Design fatigue life ≠ physical expiry date



The engineering question changes from “What was it designed for?” to “What capacity does it have now—and what can we safely change?”

Stochastic fatigue analysis — environmental loading and pressure response

From stochastic environmental conditions to time-varying pressure on the structure.



VIDEO: example pressure-response field

ENVIRONMENTAL LOADING → PRESSURE RESPONSE

- **Time-varying environment**
  Waves, wind and current create stochastic loading conditions.
- **Hydrodynamic pressure field**
  Environmental loading is converted to a time-varying pressure distribution on the structure.
- **Basis for structural response**
  The pressure field excites global hull response, which leads to deformations and cyclic stresses in the structure.

Stochastic fatigue analysis — global deformation and structural response

From time-varying loading to vessel deformation and cyclic structural response

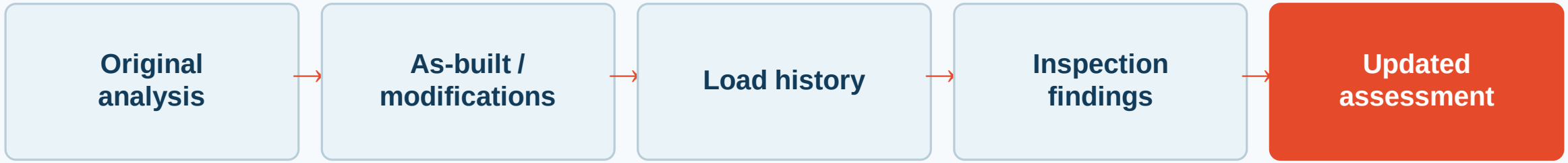


VIDEO: example VBM deformation response

WHY THIS MATTERS FOR FATIGUE

- Environmental loading produces time-varying global hull response
- Vertical bending deformation illustrates how the structure responds globally
- Global response is transformed into stress histories at fatigue-critical details
- Stress ranges and cycle counts then become input to fatigue-damage and remaining-capacity assessment

Remaining life is an evidence problem



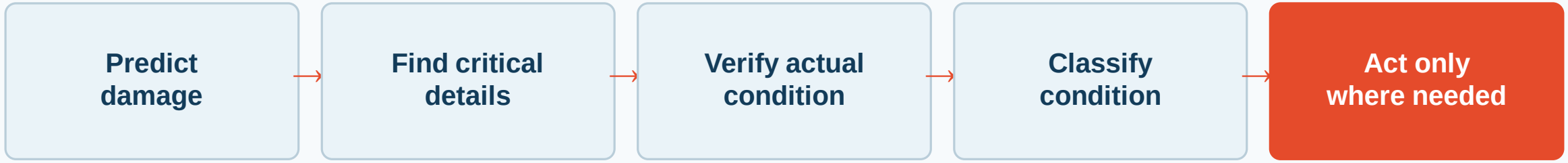
A model without condition evidence can be precise and still answer the wrong question.

Inspection is not a checkbox—it changes the engineering decision

- Visual / geometry confirmation: is the assumed detail actually there?
- MPI / surface methods: is a crack already detectable?
- UT / advanced NDT when depth or subsurface extent matters
- Inspection quality and probability of detection influence confidence
- The objective is targeted evidence at fatigue-critical details—not maximum inspection everywhere



From design philosophy to condition-based life extension



The inspection scope and intervention scope should be consequences of engineering—not independent campaigns.

From fatigue research and UIT development to life-extension engineering

SCIENTIFIC & ENGINEERING JOURNEY

1980s–90s
KTH + SSAB
Fatigue of welded high-strength steels

1998–2002
Kværner Oil & Gas / Navaltec
Applied research + offshore structural engineering

2000s
UIT moves from research to offshore intervention

2010s
Class-accepted offshore life-extension applications

Today
Life-extension engineering analysis + inspection + targeted intervention

THE WIDER INDUSTRIAL CONTEXT

~2010s
Circular economy gains international momentum

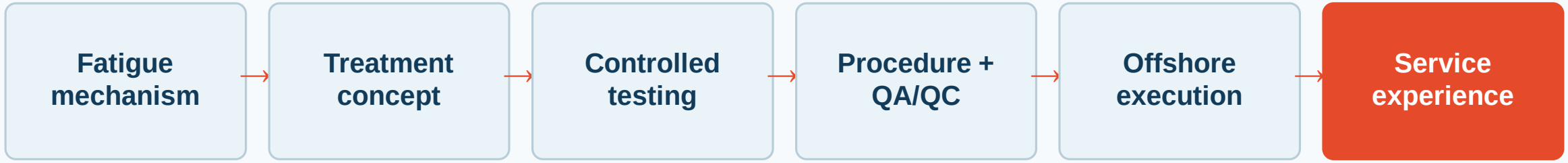
2015–2020s
Sustainability + circularity become strategic priorities

Today
Life extension connects integrity + economics + resources + sustainability

The specialty has widened: from understanding fatigue → to engineering safe additional service life → to preserving valuable structural capacity in productive use.

LIFE-EXTENSION ENGINEERING
where structural integrity, asset economics, resource efficiency and circularity meet

Case-history logic: laboratory → qualification → offshore



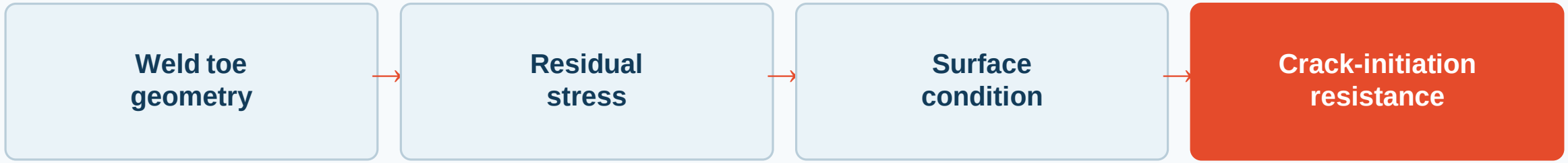
A life-extension method becomes engineering only when the complete chain is controlled.

10 MINUTE BREAK

Part 2: Can we engineer the remaining fatigue capacity?

Think about one question:
If fatigue is governed locally at the weld toe, what variables would you try to change?

Part 2 — Change the local fatigue system



UIT / HFMI acts locally where fatigue is initiated.

UIT / HFMI — what physically changes?

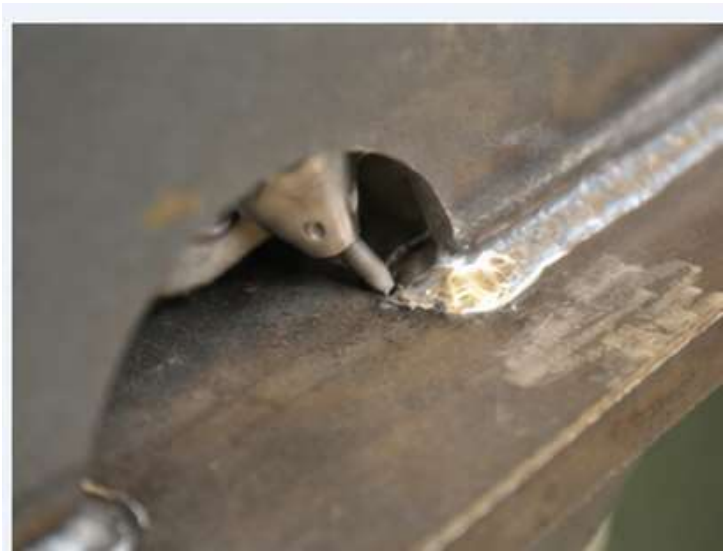
1 AS-WELDED WELD TOE



As-welded condition

→

2 UIT MECHANICAL IMPACT



UIT treatment at the weld toe

→

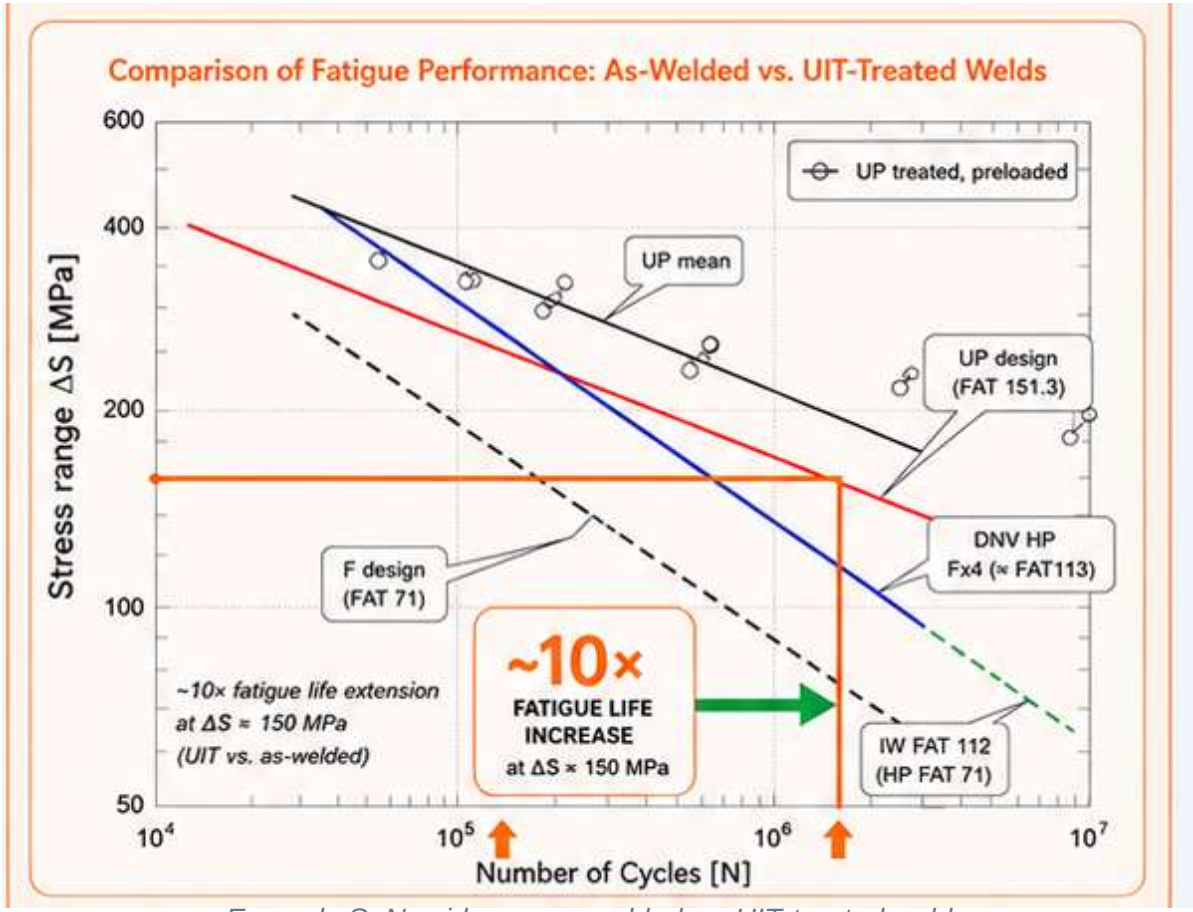
3 PHYSICAL EFFECTS

Geometry	Smooth / reshape toe transition
Residual stress	Introduce beneficial compression
Near-surface layer	Plastic deformation + hardening

RESULT → delayed crack initiation at the weld toe and increased fatigue resistance

UIT changes the fatigue resistance — not by magic, but by mechanics

The improvement is real, but its magnitude depends on the detail, loading and treatment qualification.



Example S–N evidence: as-welded vs. UIT-treated welds

WHAT CONTROLS THE IMPROVEMENT?

Weld detail & failure mode — UIT is most effective when fatigue initiation is weld-toe controlled.

Stress state — Stress range, mean stress / R-ratio and residual-stress relaxation matter.

Material & geometry — Strength, thickness and local weld-toe geometry influence the achievable benefit.

Treatment quality — Coverage, indentation geometry, equipment and operator control determine repeatability.

Prior fatigue history — Existing cracking or consumed fatigue life changes the engineering decision.

Qualification — Use the applicable design recommendation and project-specific acceptance basis.

Key message: do not apply a generic “improvement factor” without engineering justification.

Preventive treatment and remedial treatment are not the same decision

NO DETECTABLE CRACK INDICATION

Best-defined application window

Treat the fatigue-sensitive weld toe while inspection finds no crack indication.

Objective: delay initiation / increase fatigue resistance.

AFTER CRACK INDICATION

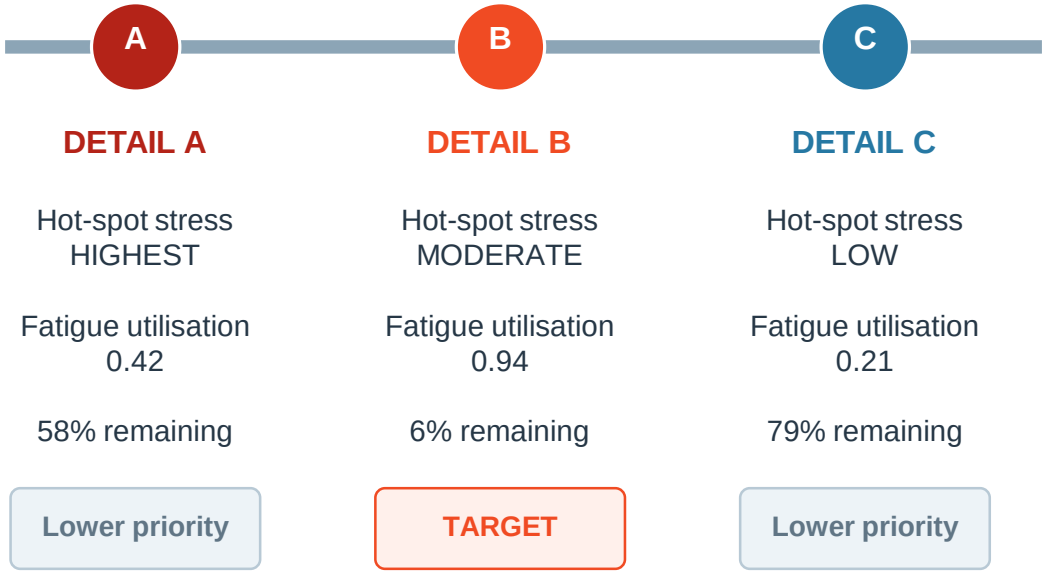
Different engineering problem

Crack size, depth, removal/repair, NDT capability and acceptance criteria become decisive.

Do not treat “UIT” as a substitute for defect assessment.

Fatigue capacity is not consumed uniformly

A stress concentration identifies a fatigue-sensitive location — not how much fatigue capacity remains.



THE ENGINEERING POINT

- **Highest stress ≠ highest fatigue utilisation**

  Local stress level alone does not define remaining fatigue capacity.

- **Service history matters**

  Stress range, spectrum, cycles, S–N behaviour and accumulated damage determine utilisation.

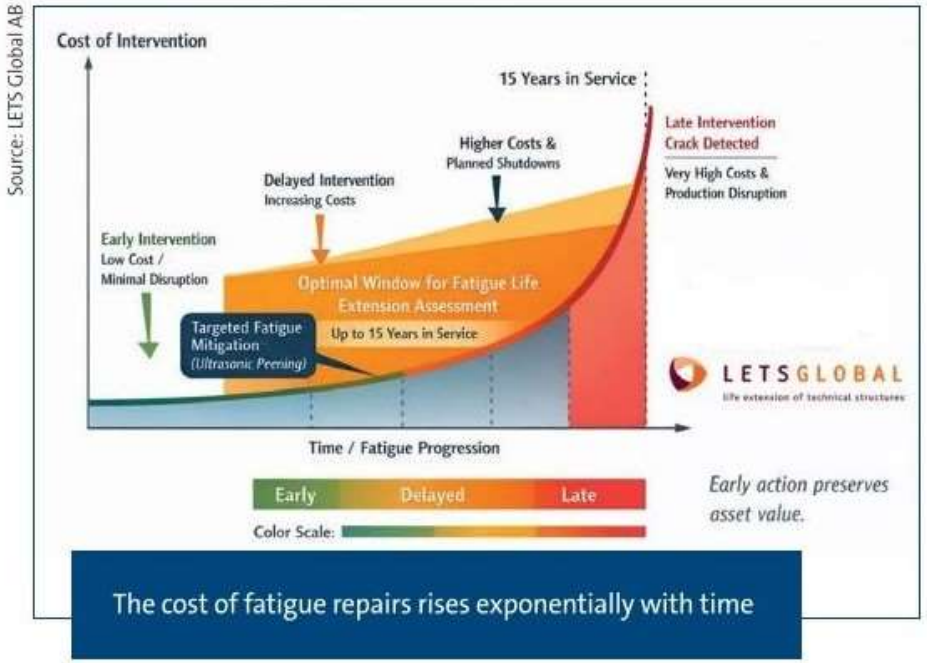
- **Target the governing detail**

  Increase fatigue capacity where it is closest to being exhausted — not simply where stress is highest.

**Treat where fatigue capacity is being exhausted —
not simply where stress is highest.**

Mid-life intervention — act before fatigue becomes a repair problem

The value of intervention is not only technical — timing determines cost, disruption and the remaining engineering options.





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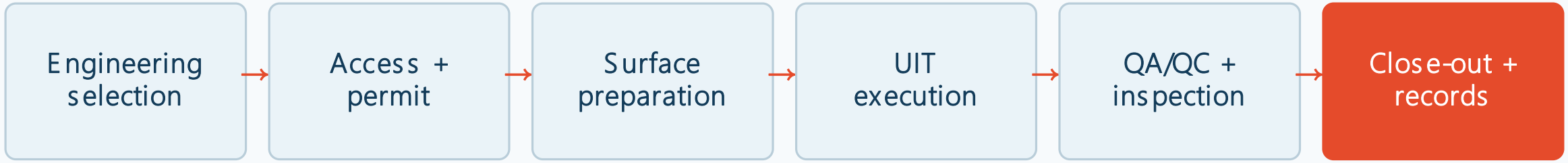
ENGINEERING MESSAGE Identify the governing detail and intervene while fatigue mitigation remains possible — before cracking drives repair, shutdown and production consequences.

Offshore execution is part of the engineering



A treatment factor on paper is worthless if the offshore process cannot reproduce the qualified condition.

Case history — FPSO Triton: engineering becomes offshore execution

A real application of the workflow: identify → qualify → execute → verify → continue service



Reality check: engineering translated into offshore execution

FROM ANALYSIS TO REALITY

1 Identify what governs

Fatigue assessment focuses the intervention on the welded details that control remaining life.

2 Verify the actual condition

Inspection confirms whether the detail is suitable for treatment — calculation alone is not enough.

3 Engineer and execute the intervention

Qualified procedure, controlled UIT parameters and offshore QA/QC turn the assessment into a physical change at the weld toe.

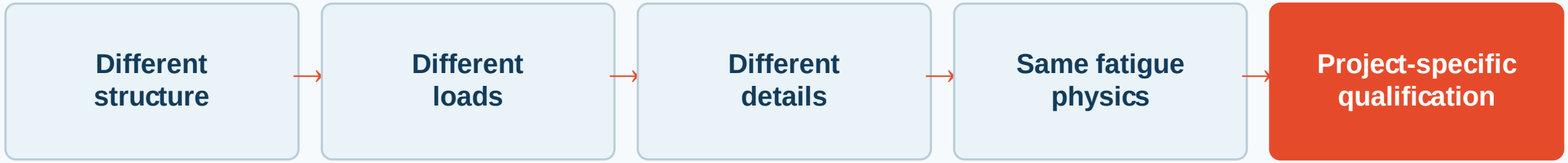
4 Preserve the evidence

Traceability and follow-up connect the intervention to continued safe service and future life-extension decisions.

The value is not the treatment alone — it is the complete engineering chain.

Case history — TLP Neptune and offshore transferability

The method is portable. The engineering justification is not.



Do not copy a treatment scope from one asset to another. Transfer the methodology, then re-establish the evidence.

Case history — offshore wind / meteo mast

Different asset. Different loading and details. Same underlying fatigue physics.



UIT execution on the meteo mast

Fatigue improvement applied directly to the governing welded detail offshore.



Offshore wind / meteo mast

A different structural system and loading environment.

SAME CORE PROBLEM

Fatigue-critical welded details

Identify → verify condition → increase capacity where required

The application changes. The engineering methodology remains: find what governs, establish the evidence, and intervene where fatigue capacity matters.

Pioneering Class Acceptance — Lloyd's Register, 2010

- **3 December 2010:** Lloyd's Register approval of the LETS Global Life Extension process using ultrasonic peening.
- **Class-recognised fatigue improvement:** under the LR FDA Level 1 procedure.
- **Controlled process:** LETS equipment, trained operators and documented application.
- **Project-specific acceptance:** supported by engineering justification and QA/QC.

From fatigue-improvement technique → to a qualified life-extension engineering process.



Certificate No: MNDE/REP/0060/01

LETS GLOBAL BV NETHERLANDS
Post bus 50531,
3007 JA,
Rotterdam,
The Netherlands

has been granted Approval in accordance with the requirements of Lloyd's Register for the application of the following process:

LETS GLOBAL® LIFE EXTENSION

for fatigue improvement by ultrasonic peening compliant with Lloyd's Register FDA Level 1 procedure

Approval to use the process for a particular application will be subject to review on a case by case basis and demonstrate compliance with the requirements of Lloyd's Register.

Where an application of LETS Global® Life Extension is agreed, the ultrasonic peening equipment used must be LETS Global's own equipment and the operator must have followed the training requirements of LETS Global BV and be authorised for the application of the process.

This Certificate is issued to the above company and their official representatives and is valid until the date given below.

Valid until: 2 December 2013
Date of issue: 3 December 2010

J Przydatek
Principal Surveyor to Lloyd's Register EMEA
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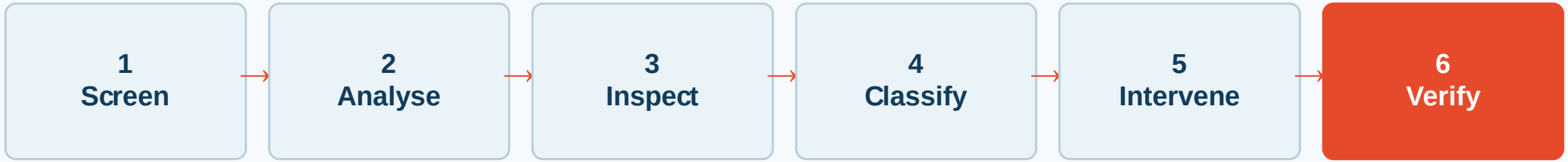
Pioneering project acceptance

A modern life-extension workflow



Not every low calculated fatigue life requires treatment.
Not every apparently sound weld should be left untreated.

The value is in combining analytical risk with physical condition.

The engineer's decision matrix

INSPECTION → ACTUAL CONDITION

FATIGUE ASSESSMENT	NO CRACK / INDICATION	CRACK / INDICATION
ADEQUATE CALCULATED CAPACITY	**CONTINUE / MONITOR** Calculation and observed condition are consistent. Maintain inspection evidence and reassess as service history develops.	**INVESTIGATE** A crack indication conflicts with the predicted adequate capacity. Revisit loads, detail modelling, fabrication condition and inspection evidence.
LOW / MARGINAL CALCULATED CAPACITY	**PREVENTIVE INTERVENTION WINDOW** Calculated fatigue margin is low, but no crack indication is detected within the inspection capability. Verify condition and consider targeted UIT before crack propagation governs.	**CHARACTERISE THE DEFECT** Establish crack size and significance first. Then decide between FFS, repair, replacement or a qualified treatment strategy.



KEY LIFE-EXTENSION WINDOW

Analysis predicts. Inspection verifies. Engineering decides.

The strongest preventive opportunity is often before a fatigue-critical detail becomes a crack-repair problem.

Three questions every life-extension engineer should ask

Life extension combines prediction, condition evidence and a justified engineering intervention.

01 CHALLENGE THE PREDICTION

How well does the calculated fatigue life represent the actual condition of the critical detail?

- Fatigue analysis predicts expected performance; it does not measure actual remaining life.
- Service history, local condition and modelling uncertainty determine where the detail stands today.

02 VERIFY WITH REALITY

What does inspection tell us that the fatigue model cannot?

- Inspection provides evidence of the actual condition within the capability of the selected method.
- Use that evidence to confirm assumptions, resolve discrepancies and focus further analysis where it adds value.

03 ENGINEER THE LIFE EXTENSION

Where and how can we increase fatigue capacity to achieve the required additional service life?

- Identify the governing details and verify that they are suitable for intervention.
- Quantify the required improvement and implement a qualified treatment with controlled QA/QC.

Analysis predicts. Inspection establishes condition. Engineering creates the life-extension solution.

Five principles to take with you

1. **Fatigue is local**
2. **Design life is not an expiry date**
3. **Inspection is engineering evidence**
4. **Intervention must target the governing fatigue mechanism**
5. **Execution + QA/QC complete the engineering process**

Life Extension Engineering

is the discipline of turning uncertainty into evidence —
and acting on that evidence to enhance fatigue capacity
precisely where needed to preserve structural integrity.

Preserving structural integrity also preserves asset value, resources and productive capacity..

Questions & discussion

Luis Lopez Martinez · LETS Global AB