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Sustainability, Durability and Repair for Concrete Ports and Harbours: Insights from FIB Model Code 2020

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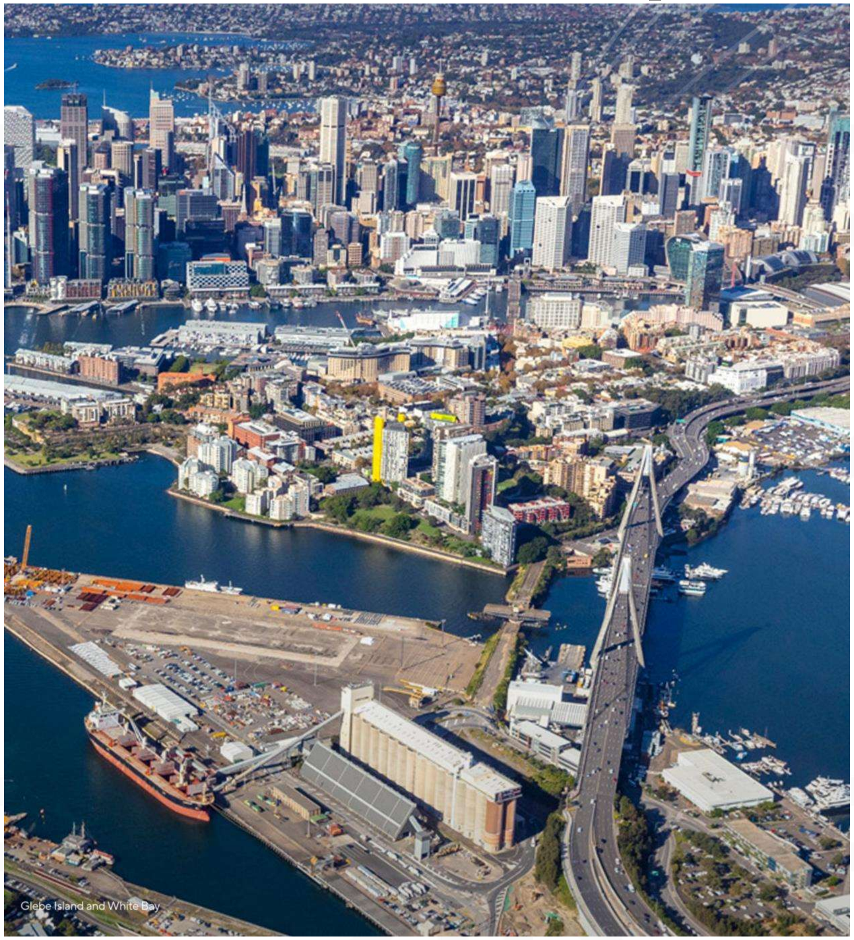
Sustainabity - “Meeting the needs of the present without compromising the ability of future generations to meet their own needs.” Brundtland Report

Sustainability, Durability, Construction & Repair

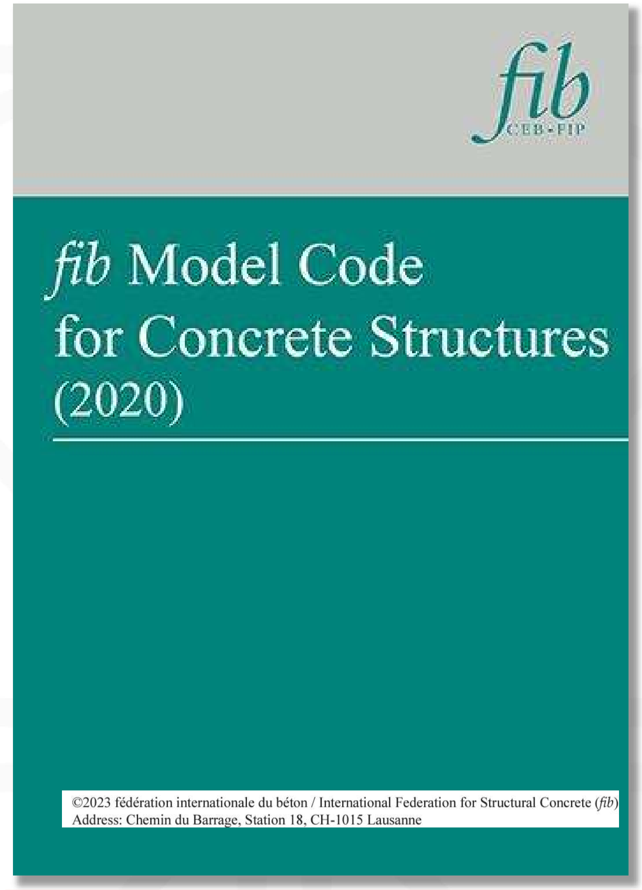
- ➢ **Port sustainability in construction**
- ➢ **Design**
  - **Code Issues**
  - **Reliability based durability design**
    - Modelling design life based on exposure and performance
      - Reduced cement, reduced section, longer life
  - **Life Cycle Cost Analysis**
  - **Safety**
- ➢ **Construction**
  - **Concrete as a special process**
- ➢ **Repair Processes**
  - **Processes for effective repair specifications**
  - **Using risk assessment to detail repairs**
  - **Understanding Materials**



The total asset value of ports in Australia is substantial ($50-100 billion). They have a critical role in trade and are an integral part of the supply chain. They are vital assets to Australia's economy.

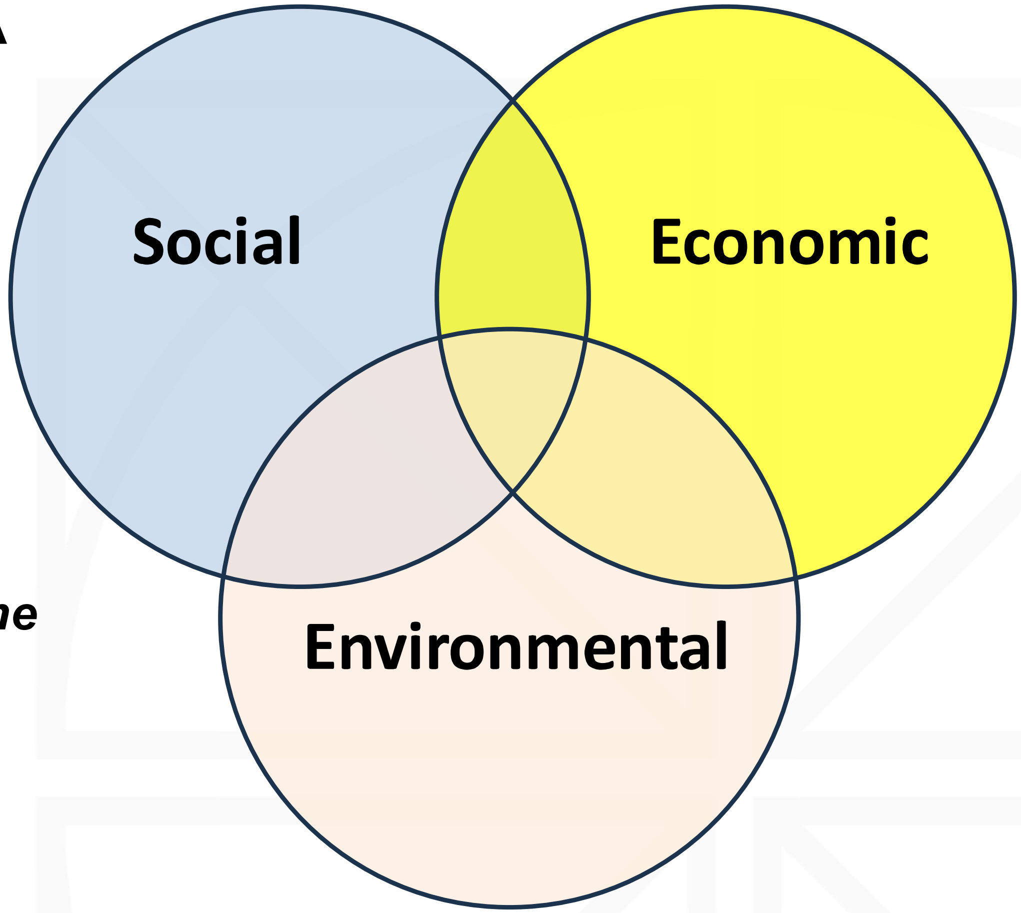
fib Model Code 2020

- *fib* - international structural concrete association
- MC2020 Compiled by fib's 9 Commissions
  - their task groups and working parties
  - i.e. hundreds of worldwide experts
- Goes beyond fib MC 2010, ISO codes, and Eurocodes
- Two new features for codes
  - Based throughout on sustainability
  - Includes new and existing concrete structures



3 Pillars of Sustainability & Construction

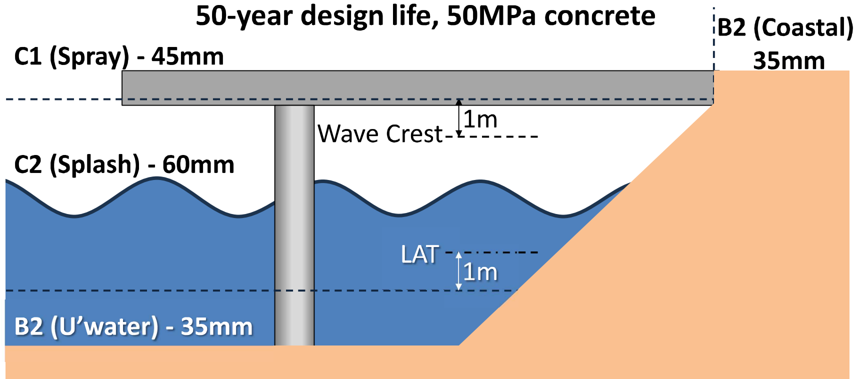
- **Design for all 3 pillars. LCCA**
  - **Economic: *$ Cost.***
    - Construction, maintenance,…
    - Operations, public
    - Disposal …refurbishment or reuse
  - **Social:** ***well-being of people***
    - Safer construction and operation
    - Local environment - noise, air, pollution, aesthetics, amenity
  - **Environment:** ***preserve and protect the natural environment.***
    - Reduced greenhouse gases
    - Better use of materials
    - Promoting circular economy



Sustainable waterborne transportation – "the long-term maintenance of environmental, economic and social well-being." Towards a Sustainable Waterborne Transportation Industry, 2011

AS Code Deemed to Satisfy Issues?

- **Issues**
  - Limited options

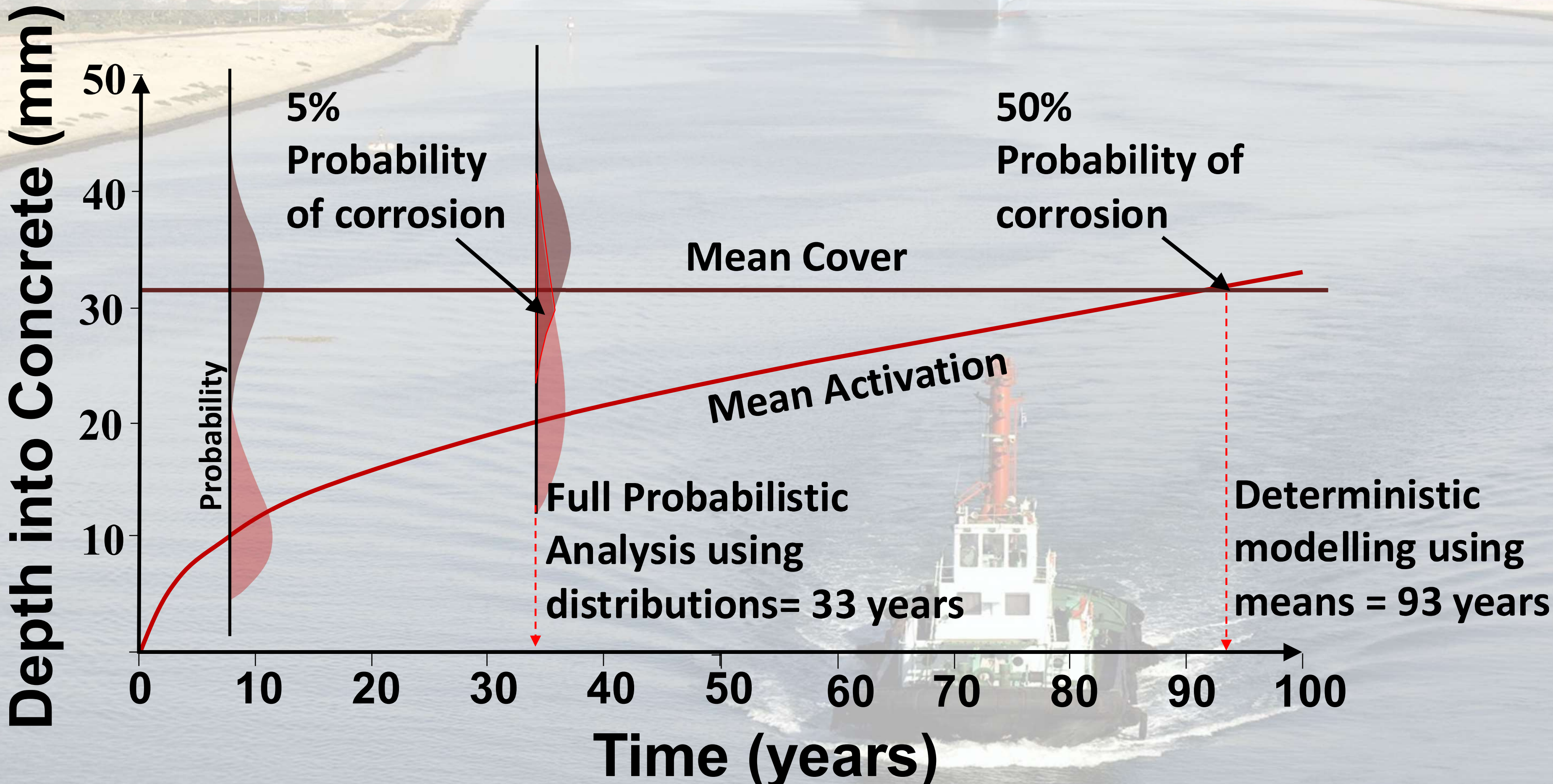


  - No reliability, or durability performance
  - May not provide a durable structure
- **Stifles innovation**
  - No modelling
  - No method to trade performance and cover

What is Reliability

- **Reliability - a measure of likelihood of failure.**
  - **Cannot design for no failure**
    - Failure (e.g. corrosion) occurs due to many mechanisms
      - e.g. Mechanism = chloride ingress rate, variables = chloride diffusivity, surface chloride level
      - Variables have a distribution.
    - Hence life modelling has to be based on probabilistic analysis (e.g. Monte Carlo).
  - **Design based on calculated reliability < target reliability**
- **Target reliability based on failure consequence**
  - **SLS (e.g. corrosion) likelihood of failure 5-10% PoF**
  - **ULS (e.g. collapse) very low likelihood of failure**
  - **Set by the parties involved**
- **Reliability depends on performance**

Understanding Variables as Distributions



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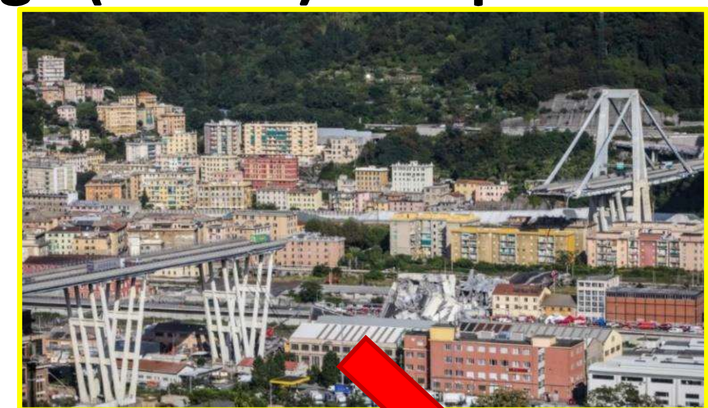
You cannot make correct decisions if you have the wrong information.
Napolean didn't attempt a Suez Canal as experts said the Red Sea was 10m higher than the Mediterranean

Design against Catastrophic Failure - ULS

In 2018 the 1967 Morandi Bridge (Genoa) collapsed due to corrosion of a stay cable.

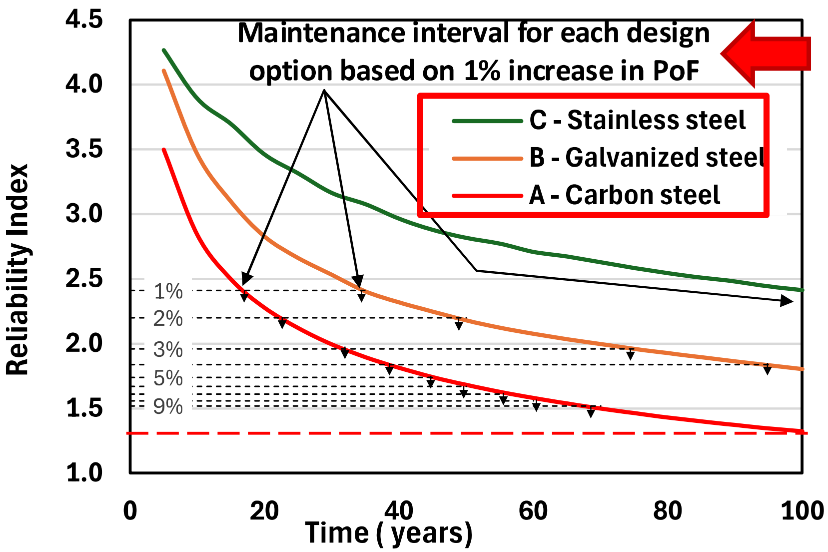


1. **DtS requirements inadequate**
2. **FPA not suitable for ULS**
3. **Design to avoid ULS failure**
4. **What is and how to achieve required redundancy?**
5. **Care with prestressed elements**

43 died. The replacement bridge has robots for cleaning and inspection.

LCCA – Major NSW Marine Structure

Case 1: Code requirement + B80			
St dev = 6 mm for cover		FA Mix	
Drcm,0	$5.0*10^{-12}$ m^2/s, COV= 0.2		
Cover	75 mm	75 mm	75 mm
	β		
Time (years)	A - Carbon steel	B - Galvanized	C - Stainless steel
20	2.28	2.83	3.46
40	1.81	2.32	2.96
60	1.58	2.08	2.71
80	1.43	1.93	2.54
100	1.32	1.80	2.41



Concrete Construction Cost

Reinforcement	Const. cost	Cost $/100m²
Carbon steel	$ 24,500,000	$ 539,678
HDG	$ 27,500,000	$ 605,761
S/S	$ 40,300,000	$ 887,715

Structure

Item	Amt.	Unit
Concrete vol	1900	m³
Soffit/deck areas	4540	m²
`Repair areas	45	Nº

Concrete Repair Cost/Repair Cycle for each Element

Item	Soffit Cost	Deck Cost	Unit
Repair area	1	1	m²/100m²
Repair cost/m²	$ 10,000	$ 5,000	$/m²
Repair Cost	$ 10,000	$ 5,000	$/rep.

On Costs / Repair Cycle for all Elements

Item	Soffit Cost	Deck Cost	Unit
Access	$ 120,000	$ 20,000	$/rep.
Management	$ 40,000	$ 5,000	$/rep.
Operational	$ 50,000	$ 10,000	$/rep.
Public	$ 20,000	$ 10,000	$/rep.
Safety	$ 2,000	$ 200	$/rep.
Environment	$ 10,000	$ 200	$/rep.

Inspection and Testing

Item	Soffit Cost	Deck Cost	Unit
Annual	$-	$5,000	$/insp.
20yrs or 1st repair	$150,000	$40,000	$/insp.

Financials

Item	Rate	Comment
Inflation	3.0%	Long term inflation rate
IRR	7.0%	Long term rate

Reinforcement	Concrete		Quality	NPV $m
Carbon	Ternary	B80	Good	565
HDG	Ternary	B80	Good	608
Stainless	Ternary	B80	Good	891
Carbon	Fly ash	B80	Good	567
HDG	Fly ash	B80	Good	609
Stainless	Fly ash	B80	Good	891

Sustainable cost solution depends on operational and public costs

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Leveraging data and advanced analytics in design and maintenance planning enhances the sustainability and durability of port infrastructure, leading to smarter and more efficient operations."

Tauranga Harbour Link

Advanced Mix Design

SCC – avoids poor compaction

V.Low Sorptivity – $0.036 mm/m^{0.5}$

V.Low Chloride diffusivity $1.37 \times 10^{-12}\ m^3/sec.$

Very high resistivity – 45.6 k Ohm.cm

High Level Quality Control

High-performance bar spacers located to BS 7973 ensure 2mm tolerance

Well-tied reinforcement maintains 2mm tolerance

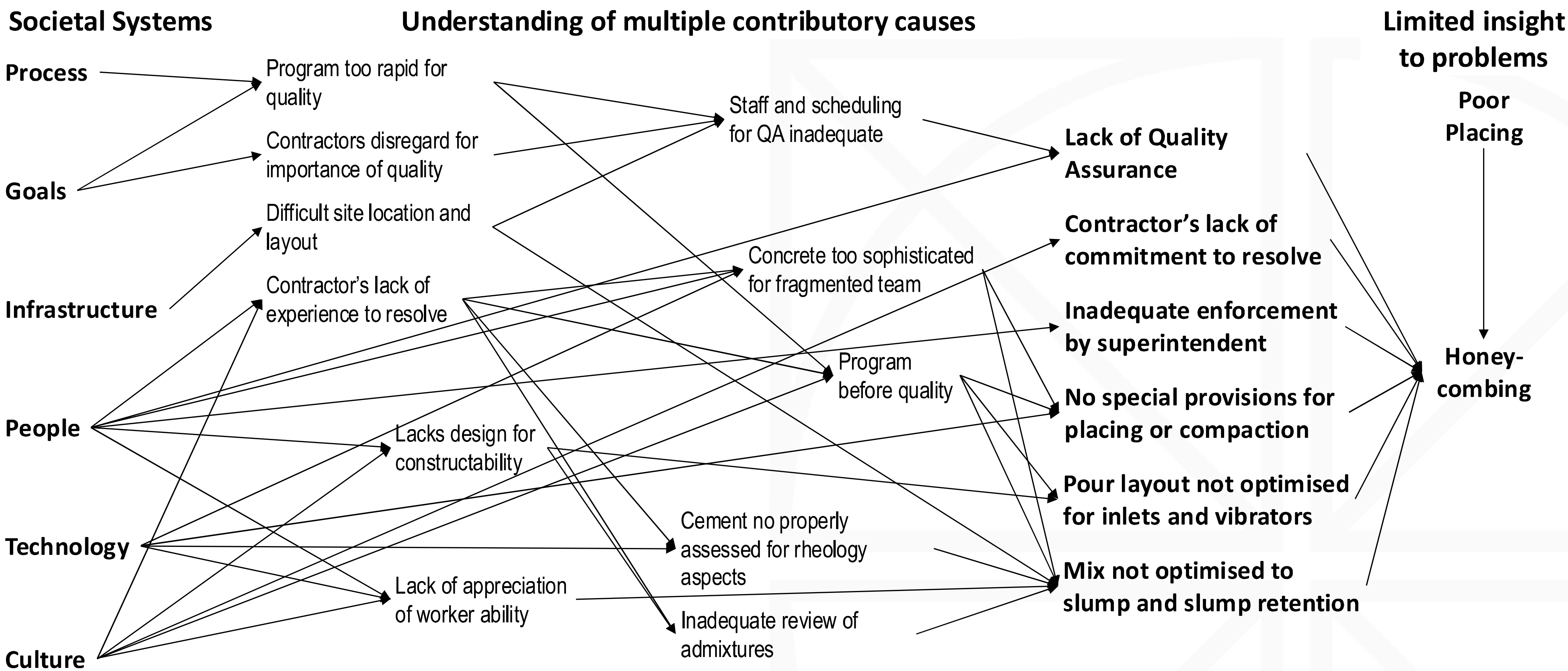
Lighter beams
Longer spans
Fewer piers
Smaller cranes
Less concrete
Less prestress

Construction as a Special Process

- Construct to avoid defects
- Issues
  - Cause
  - Hidden Defects
  - Program
  - Construction Cost
  - Structural
  - Repair Durability

Concrete Compaction Failure Analysis

It is not Just Poor Placing!



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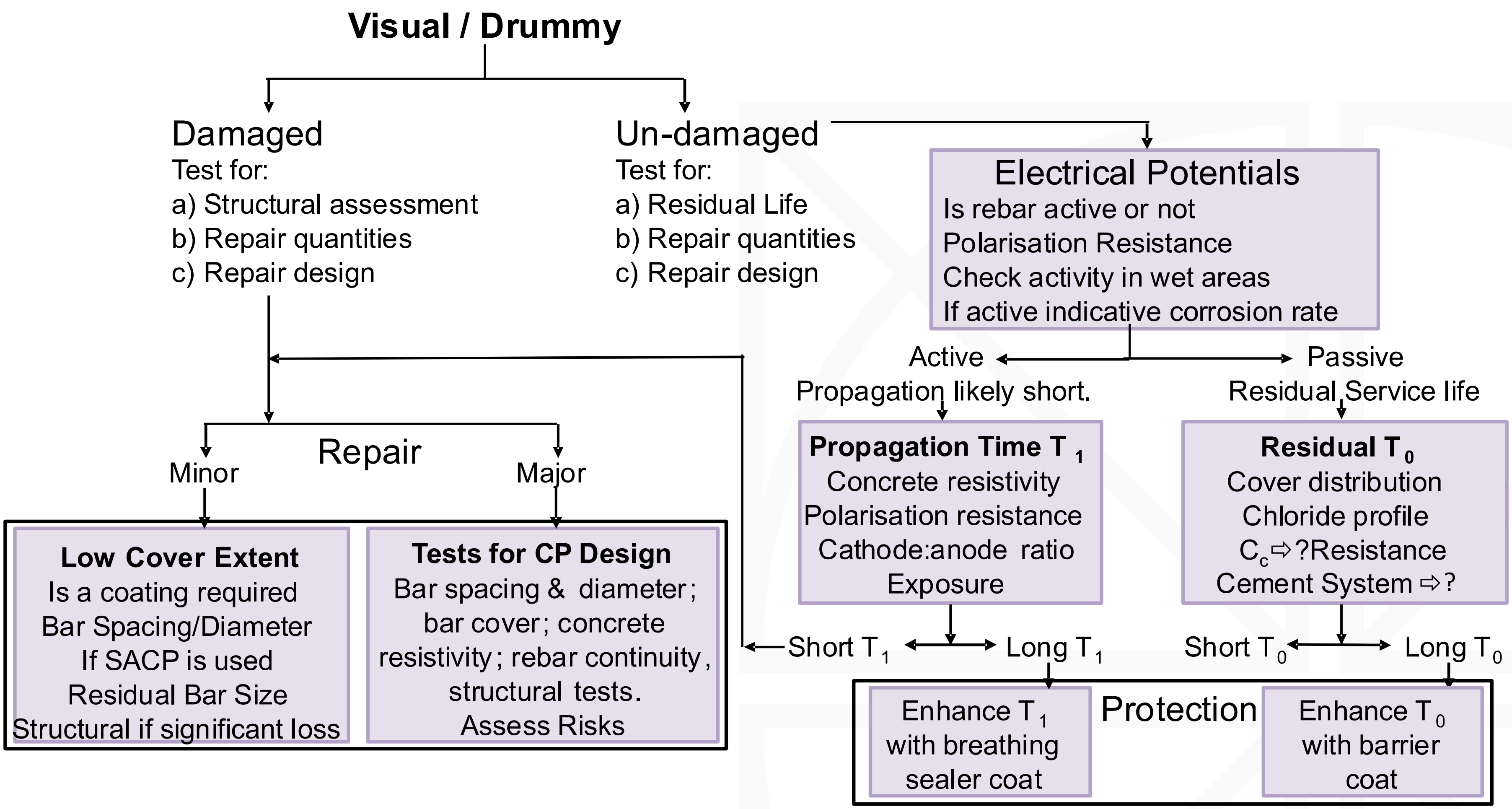
Specifications need to recognize that concrete is a special process and need tinclude clauses that will ensure appropriate consideration is given to ensure adequate quality at each step.

Inspection and Repair Process



Survey results can be misleading if the tests and process used are not well designed and implemented. May lead to incorrect repairs and/or wrong estimate of areas for repair.

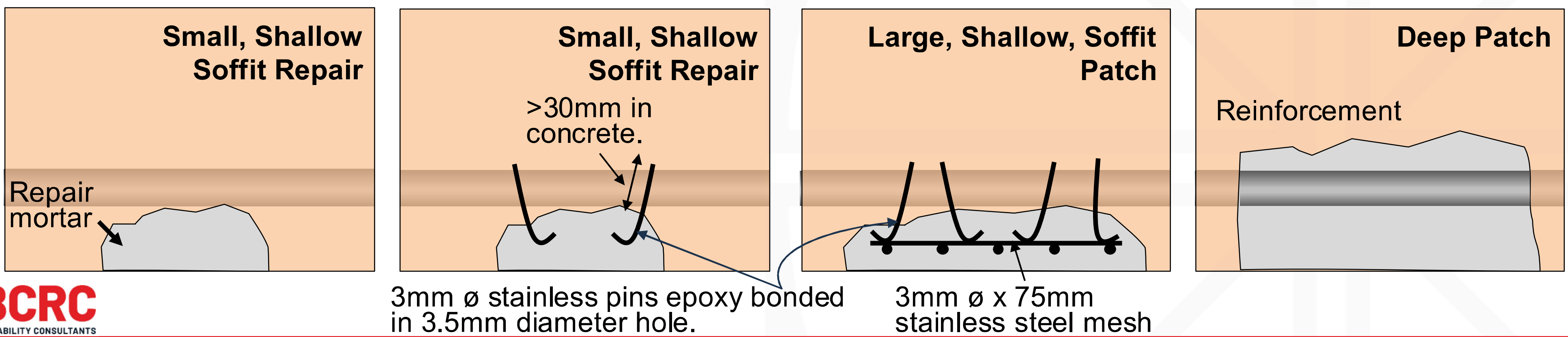
Risk Assessment Matrix

Likelihood	Consequence				
	Negligible	**Low**	**Moderate**	**Very High**	**Extreme**
Almost Certain	Moderate	High	Extreme	Extreme	Extreme
Likely	Low	Moderate	High	Extreme	Extreme
Possible	Very Low	Low	Moderate	High	Extreme
Unlikely	Negligible	Very Low	Low	Moderate	High
Rare	Negligible	Negligible	Very Low	Low	Moderate

'Managing Climate Change Uncertainties' 2022 highlights why non-structural and structural interventions should be assessed. … monitoring to inform decision-making … methods that recognise and accommodate uncertainty.

Risk Analysis - e.g. Patch Repair

Patch Repair Type	Performance Features	Risk Analysis		
		Likelihood	Consequence	Risk
Shallow, small, good prep.	Good bond strength.	Rare	Low	Neg.
Shallow, small, poor prep.	Low bond strength.	Possible	Low	Very Low
Shallow, large, no anchors.	Mortar's poor expansion restraint.	Walls: Possible	Walls: Mod	Moderate
		Soffit: Likely	Soffit: V.High	Extreme
Shallow, large with anchors.	Eliminates the issue of bond.	Walls: Rare	Walls: Mod.	Very Low
		Soffit: Rare	Soffit: V.High	Low
Moderate depth, no rebar.	Well matched/placed.	Unlikely	Low	Low
	Not well matched or placed.	Possible	Low	Very Low
Deep repairs, include rebar.	Rebar anchors & distributes strain.	Rare	Negligible	Negligible



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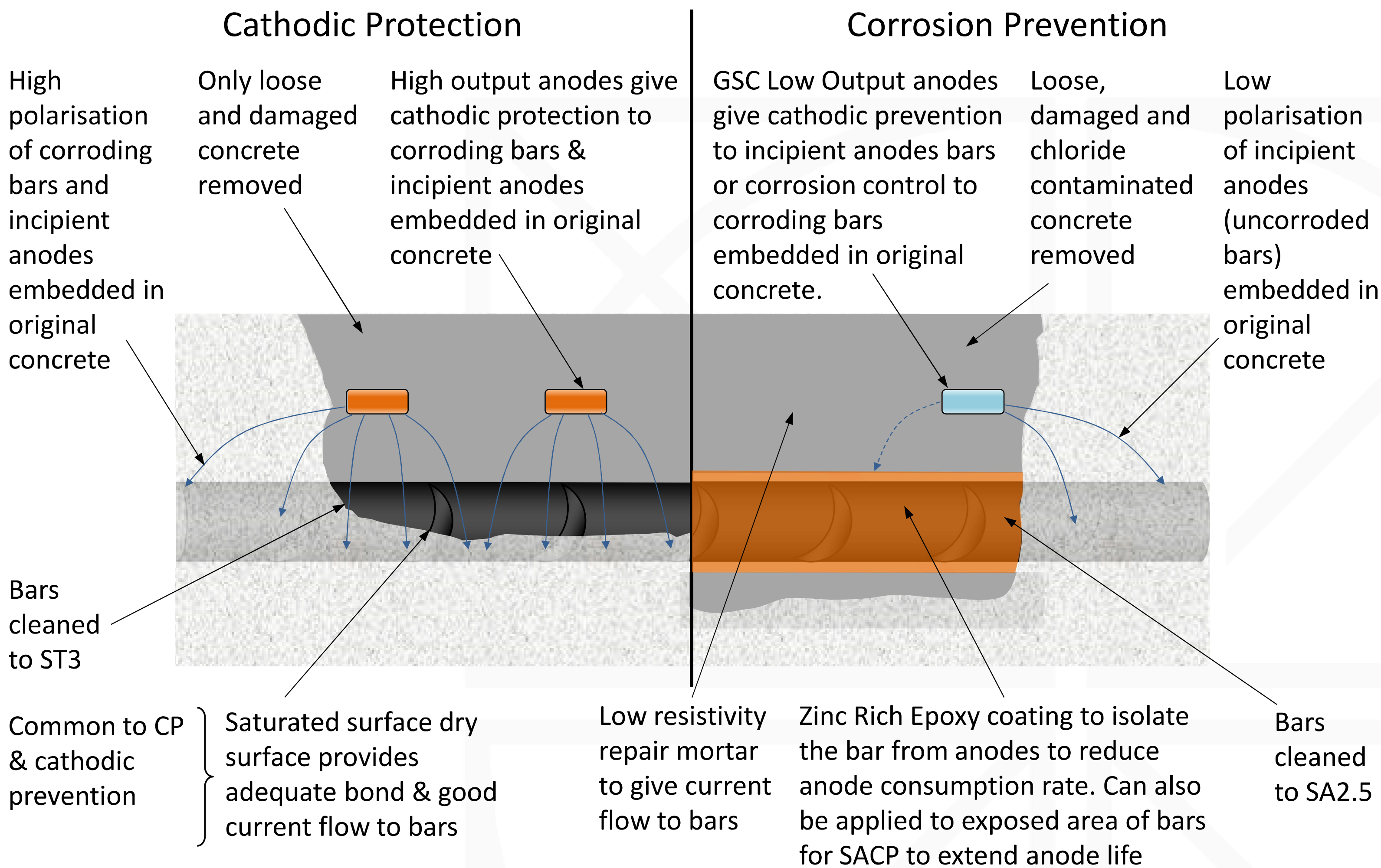
Understanding Materials Properties

- **Different anodes for cathodic protection and corrosion prevention**
  - **Polarisation capacity**
  - **Anode consumption rate**
  - **Anode zinc mass**



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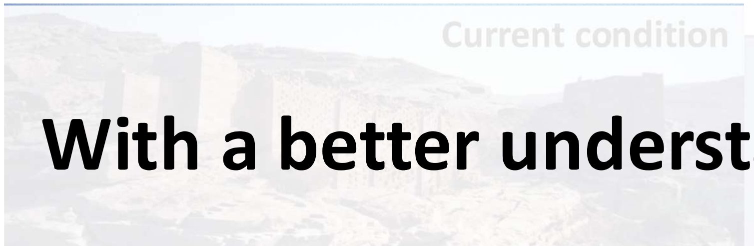
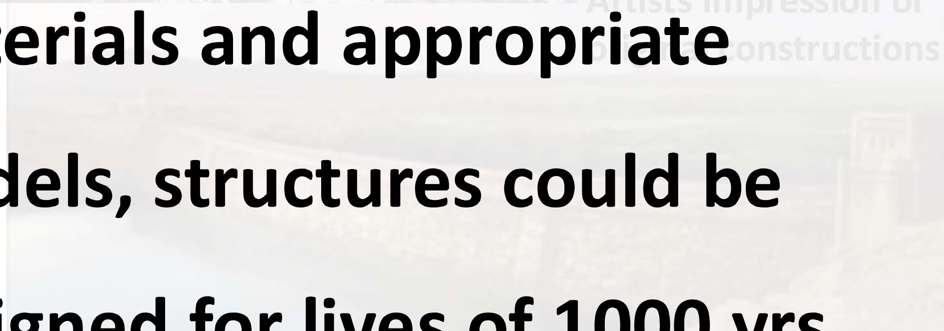
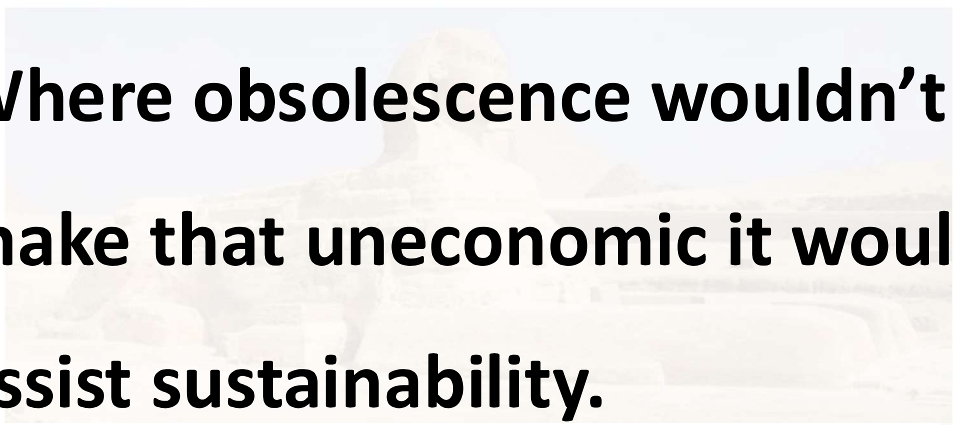
Conclusions

- fib MC 2020 has detailed coverage of sustainability
  - Details life time approaches for new and existing structures
  - Code writers and specifiers should draw from MC2020
- DtS is not the most sustainable durability design
  - Establish target reliability based on consequence of failure
  - Do FPA modelling and LCCA (3 Pillars) to select optimum design
- Specify greater testing – Know the materials
  - Performance, properties, rheology
  - Applies through design, construction, long term, repair materials
- Use risk assessment to verify repair approach







With a better understanding of materials and appropriate models, structures could be designed for lives of 1000 yrs. Where obsolescence wouldn't make that uneconomic it would assist sustainability.

Design Life

Dam of Ma'rib

1700BC -Constructed 580m long, 4m high rock soil fill
500BC – raised to 7m high
114BC – Raised to 14m. Irrigated 100km^2
570AD -Damn overtopped and left unrepaired
Service life around 2300 years.

Great Sphinx of Gixa

2500BC - Constructed 20m x 19m x 73m cut from bedrock
1400BC – Excavated & restored with limestone block
664BC & 100AD - Cleared again
Service life around 4500 years….so far.
Low maintenance but could have been better!

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