EXISTING STRUCTURES

CONSERVATION AND REMEDIAL WORK

Agnieszka Bigaj-van Vliet

CONTENT

- ***Longevity of concrete structures***
- ***Conservation of concrete structures***
  - *Conservation process*
  - *Conservation strategies*
  - *Inspection, testing and monitoring*
  - *Interventions*
- ***MC2020 - advancing the through-life management and care of concrete structures***
  - *Questions & discussion*

LONGEVITY OF STRUCTURES

We adapt and reuse since centuries

Pantheon, Rome, Italy

- *built circa 126 BC*
- *still remains in service*
- *originally a Roman temple*
- *now a working church*

LONGEVITY OF STRUCTURES

We reuse and adapt since centuries

Cathedral van Córdoba, Spain

- *erected as of Christian Visigoth temple*
- *in 784 the Great Mosque constructed making use of Visigoth temple columns and other elements*
- *in 13th century the Roman Catholic Church is build in the middle of the mosque, with 400 out of 12000 collumns being removed.*

LONGEVITY OF STRUCTURES

Moerdijk bridge, Netherlands

- *built 1936*
- *demolished 1976/78*
- *10 segments for reuse*

Keizersveer bridge, Netherlands

- *6 segments reused*

Spijkenisser bridge, Netherlands

- *4 segments*

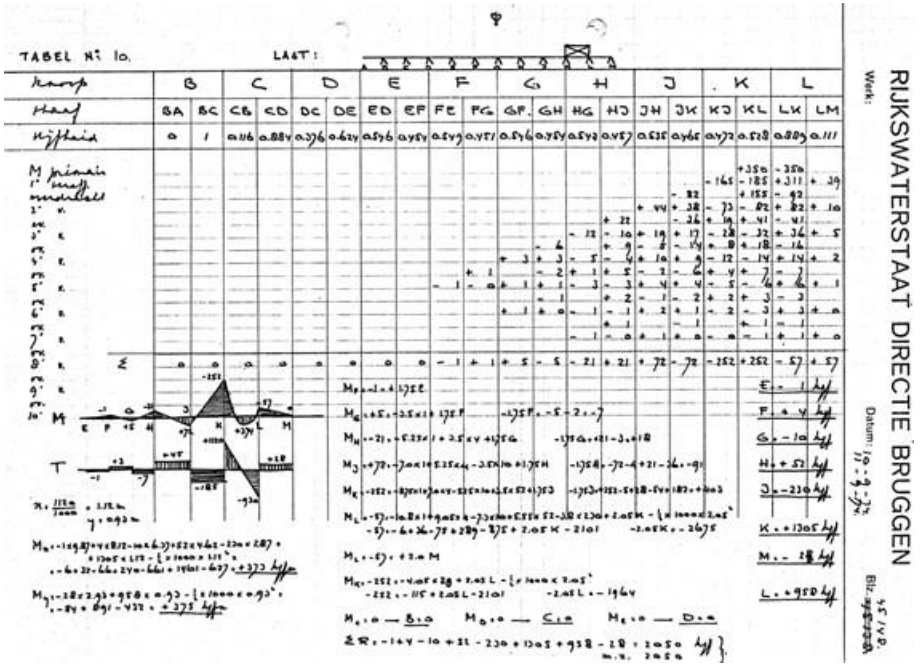
HOW TO DEAL WITH LONGEVITY OF STRUCTURES

Enginering considerations:

- *- original design*
- *- knowlede and experience with similar structures*
- *- assesment of current capacity*
- *- risks*
- *-…*

Effort Keizersveer bridge

- *Re-design in 1974 in totaal 63 pp.*
- *Ongoing re-design: 322 pp. … and still in progress*



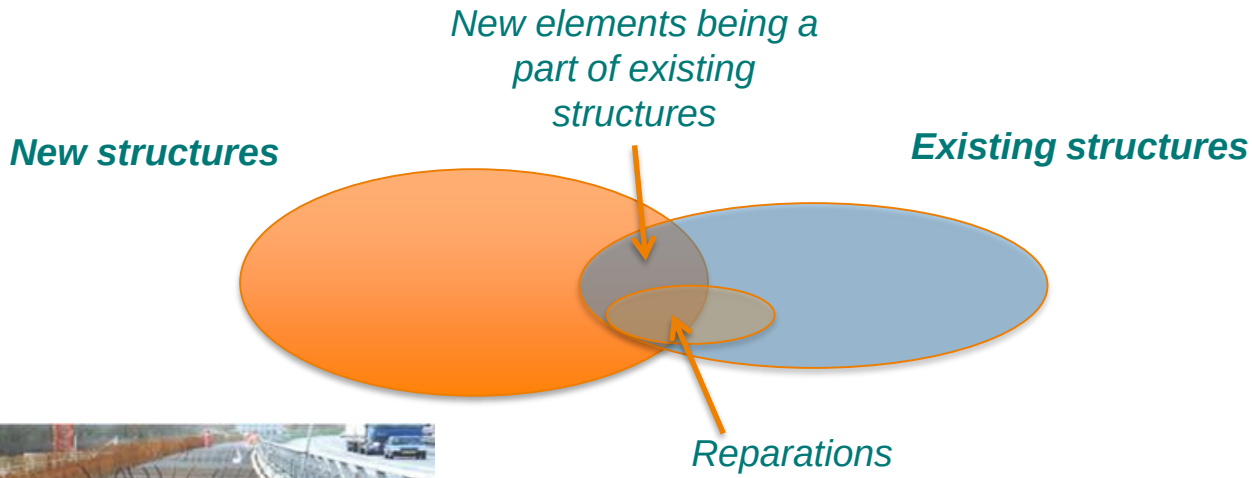
CORRENT STANDARDISATION IN EUROPE

- ***New structures:*** *Eurocode (EN 1990 – EN1999)*
- ***Existing structures:*** *update Eurocodes in progress, various national suplementary regulations*

In the past in the Netherlands

Now in the Netherlands

NEED FOR STANDARDISATION FOR LONGEVITY



Old and new structures belong together

NEED FOR STANDARDISATION FOR LONGEVITY

Formulations must be consistent and based on one sound concept

NEED FOR STANDARDISATION FOR LONGEVITY

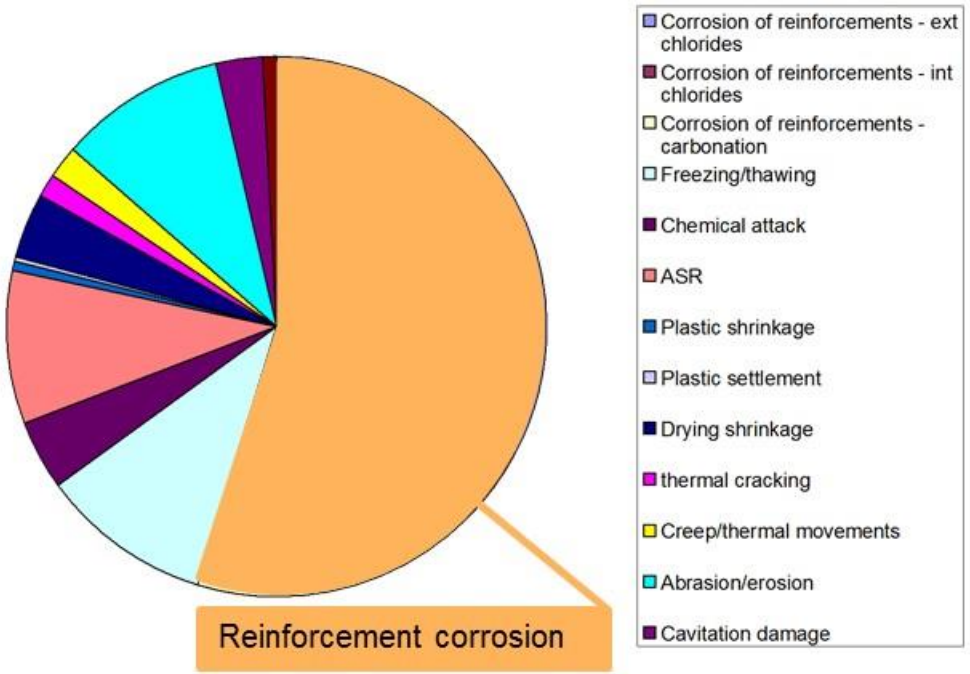
- ***Existing structures:***
  - *Cost-optimisation of required perfomance and service life*
    - *Requirements for existing structures differ from requirements for new structures*
    - *Increasing problems due to of aging, (growing) loads and exposure*
  - *Applying current standards may lead to (unnecessary) disapproval*
    - *Current standards not cover on old materials and construction methods*
    - *Detailing requirements different from old materials / application mode*
  - *Knowledge of old standards not always present*
    - *Large spread in advice*
    - *Incorrect interpretation of design data*
  - *Additional information is available (inspections, measurements)*

NEED FOR STANDARDISATION FOR LONGEVITY

- ***Existing structures:***
  - *Give more attention to through-life management & care aspects*
  - *Take full advantage of information that can be acquired by testing and monitoring of existing structures*
  - *Consideration of material degradation and / or insufficient or deficient detailing of the provided material and behaviour models,*
  - *Better models for deterioration processes – especially propagation stage*
  - *Structural models for deterioration / damage effects*
  - *Employ improved models and model parameters for existing structures and effects of (phased) interventions / works*

MODEL CODE FOR CONCRETE STRUCTURES

- ***Deterioration processes affecting concrete***
  - ***Deterioration of the concrete:***
    - *Physical deterioration and damag*
    - *Chemical deterioration processes*
    - *Biological deterioration processe*
  - ***Deterioration of the reinforcement:***
    - *Corrosion of reinforcement*



MODEL CODE FOR CONCRETE STRUCTURES

Deterioration processes affecting concrete

Reinforcement corrosion (chloride induced)

MODEL CODE FOR CONCRETE STRUCTURES

Deterioration processes affecting concrete

Reinforcement corrosion (carbonation induced)

MODEL CODE FOR CONCRETE STRUCTURES

Deterioration processes affecting concrete

Freeze-thaw damage & reinforcement corrosion

MODEL CODE FOR CONCRETE STRUCTURES

Deterioration processes affecting concrete

Alcali silica reaction in concrete

MODEL CODE FOR CONCRETE STRUCTURES

Deterioration processes affecting concrete

Accidental damage: Fire

MODEL CODE FOR CONCRETE STRUCTURES

- *Overload affecting concrete*

Seismic excitations

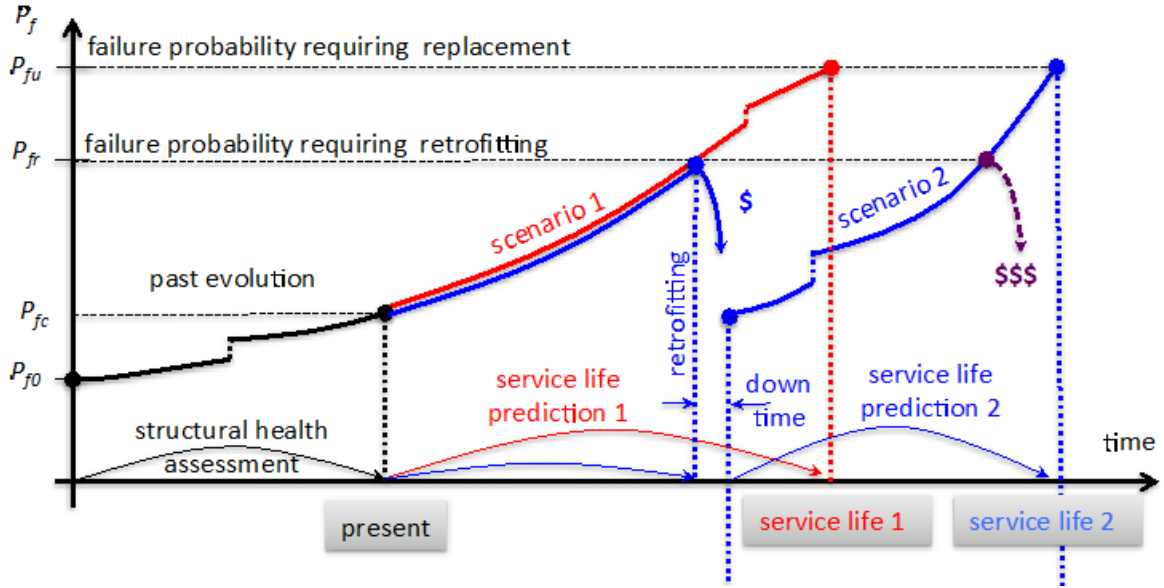
MODEL CODE FOR CONCRETE STRUCTURES

- ***Overload affecting concrete***

Snow overload, vehicle collision

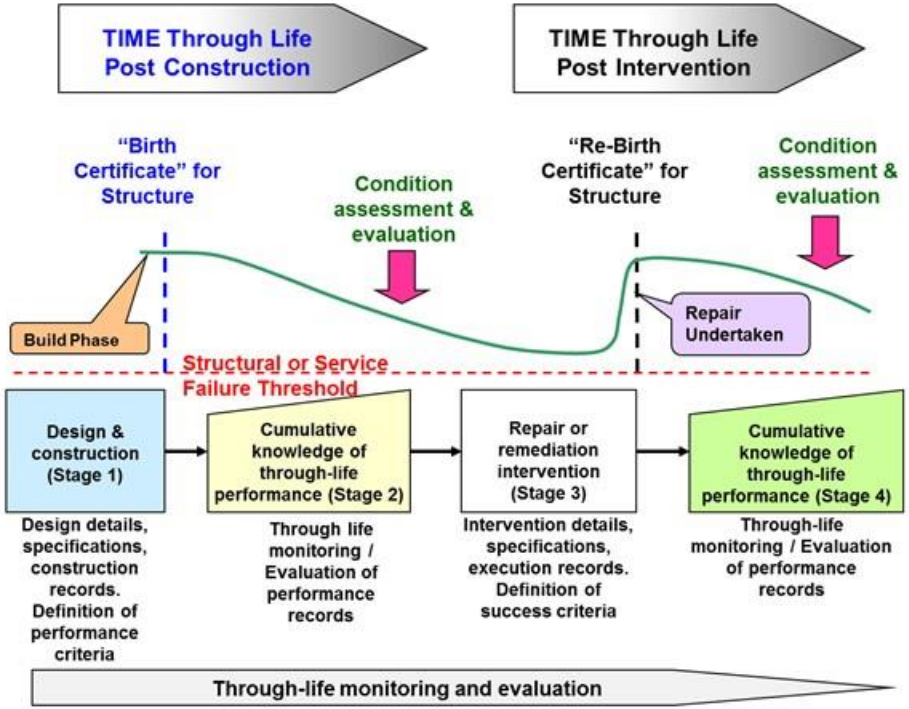
MODEL CODE FOR CONCRETE STRUCTURES

- ***Service life verification and prediction***
  - to achieve the intended design service-life of structure
  - to facilitate an extension of life / change of use of structure
  - to minimise through-life cost and environmental impacts



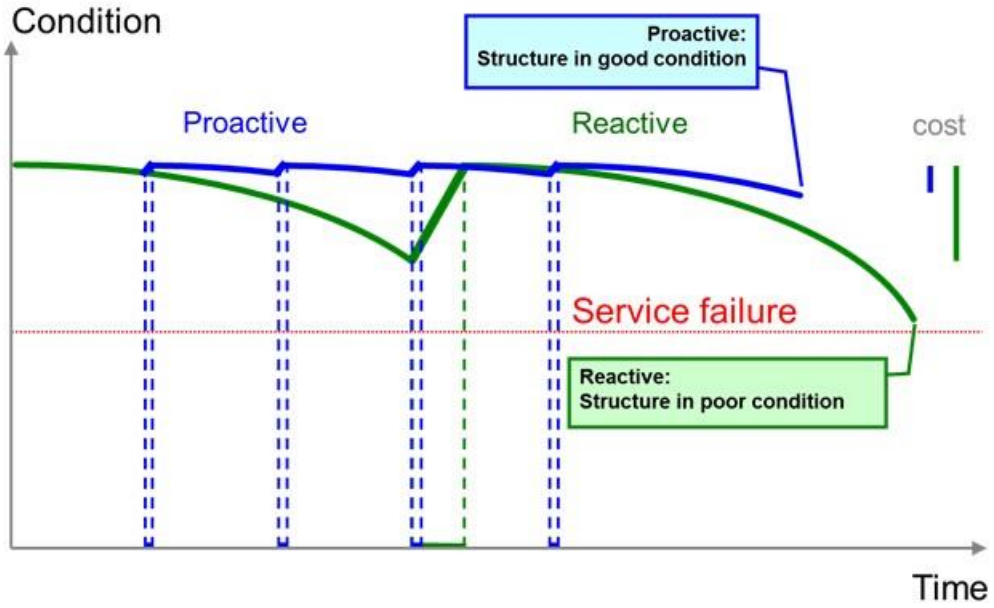
MODEL CODE FOR CONCRETE STRUCTURES

- ***Through-life management of structu***
  - stage 1: Design and construction of asset
  - stage 2: Post- construction service life phase
  - stage 3: Steps leading to an intervention
  - stage 4: Post-intervention service life phase

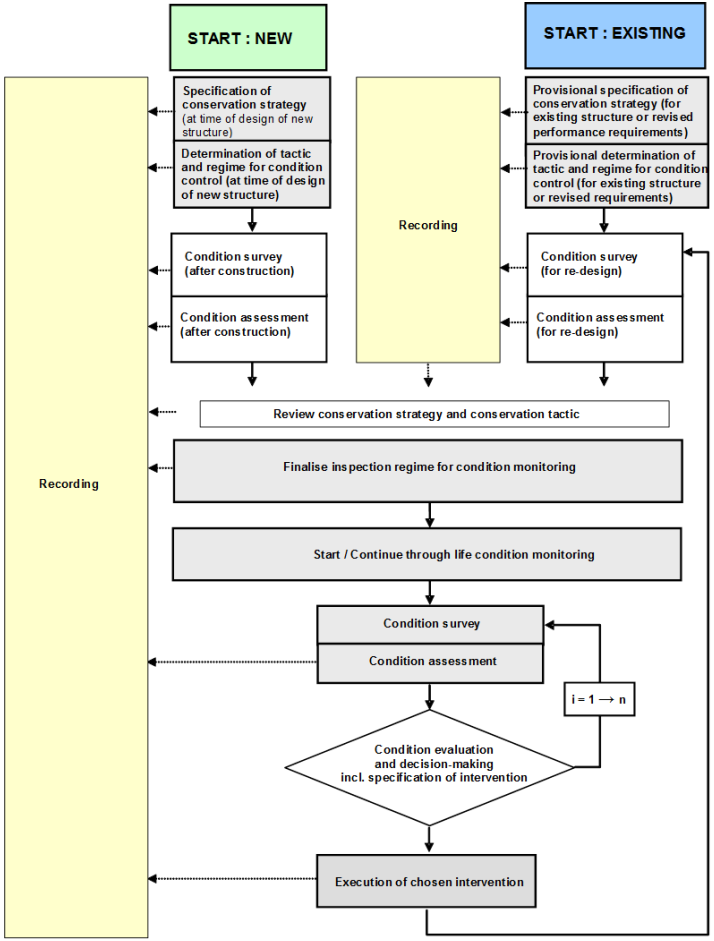


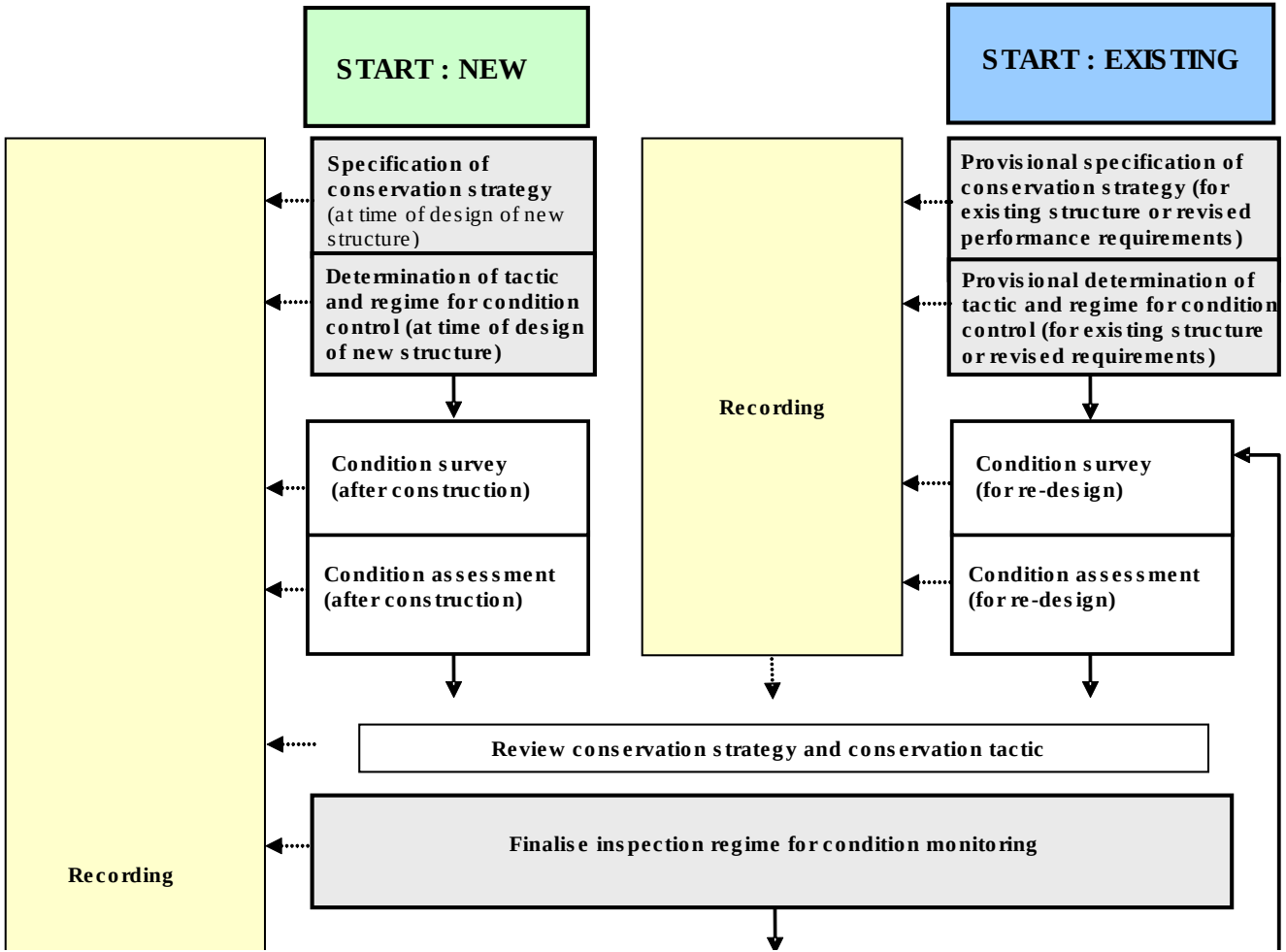
MODEL CODE FOR CONCRETE STRUCTURES

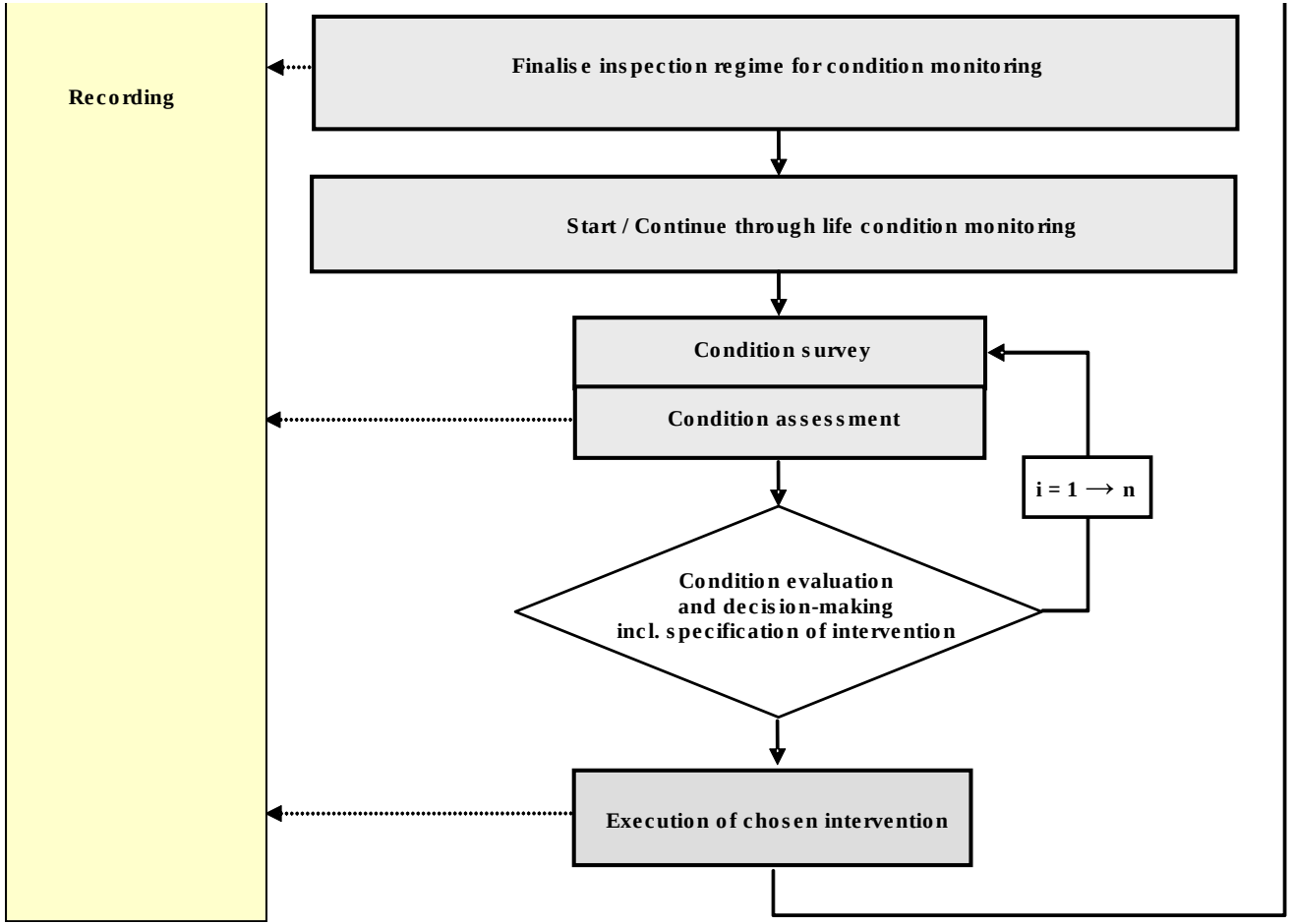
- ***Proactive & reactive approaches to through-life care of structures***



Through-life management process




START : NEW
START : EXISTING
Specification of conservation strategy (at time of design of new structure)
Determination of tactic and regime for condition control (at time of design of new structure)
Provisional specification of conservation strategy (for existing structure or revised performance requirements)
Provisional determination of tactic and regime for condition control (for existing structure or revised requirements)
Recording
Condition survey (after construction)
Condition assessment (after construction)
Condition survey (for re-design)
Condition assessment (for re-design)
Review conservation strategy and conservation tactic
Finalise inspection regime for condition monitoring
Recording


Recording
Finalise inspection regime for condition monitoring
Start / Continue through life condition monitoring
Condition survey
Condition assessment
i = 1 ⟶ n
Condition evaluation
and decision-making
incl. specification of intervention
Execution of chosen intervention

MODEL CODE FOR CONCRETE STRUCTURES

- ***Conservation strategies***

- ***Strategy A: Structures which are to be managed by planned condition control activities***
  - *Structures where deterioration would be technically unacceptable or must not be seen.*
  - *Monumental, important or sensitive buildings & structures.*
- ***Strategy B: Structures or parts thereof which are managed by reactive activities.***
  - *Structures where remedial measures can be taken after deterioration becomes visible.*
  - *Buildings and other common structures.*
- ***Strategy C: Structures or parts thereof for which condition control is not practical.***
  - *Structures where it would be difficult economically and / or technically for preventative or remedial measures to be taken, such as foundations.*

MODEL CODE FOR CONCRETE STRUCTURES

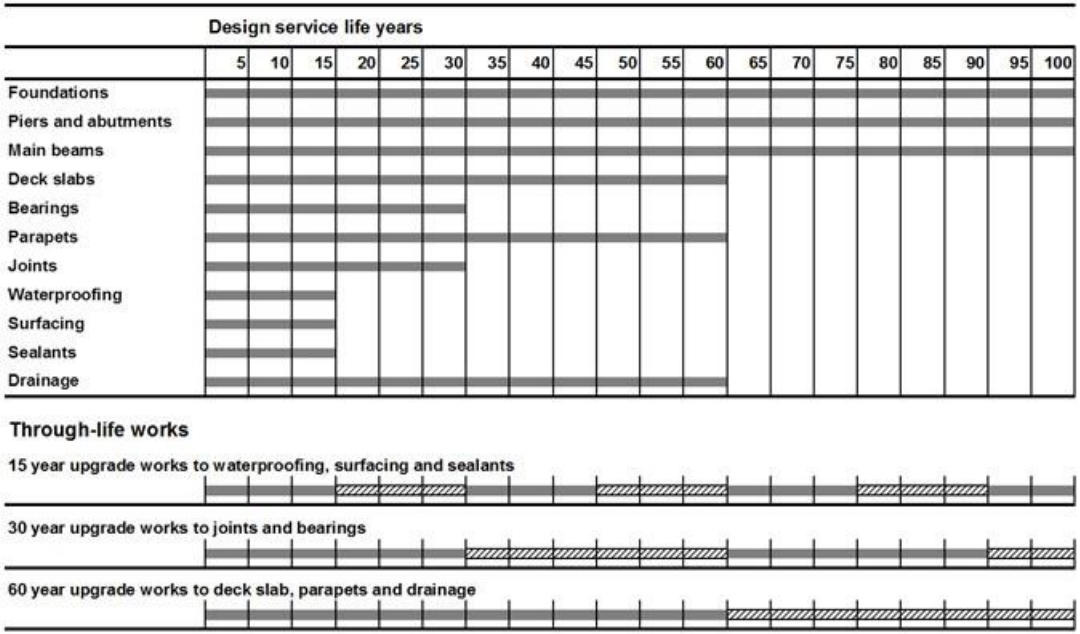
- *Inspection, testing and monitoring regimes for different classes of condition control*

Condition control strategy: Class of condition control	Inspection, testing and monitoring regime (Associated Condition Control Level)
Proactive conservation measures: Category A structures or structural elements	Planned periodic inspection and systematic monitoring of parameters relevant to the design, especially the deterioration processes that are critical for the verification of the limit states associated to durability. Condition Control Level: CCL3
Reactive conservation measures: Category B structures or structural elements	Planned periodic inspection (i.e. visual inspection by qualified staff). No systematic testing or monitoring. Condition Control Level: CCL2
	Ad-hoc inspection and testing / investigation. No systematic inspection, testing or monitoring. Condition Control Level: CCL1
No conservation measures: Category C structures or structural elements	No direct inspection, testing or monitoring. Condition Control Level: CCL0

MODEL CODE FOR CONCRETE STRUCTURES

Through-life work plan

A design service life performance plan for elements of a bridge

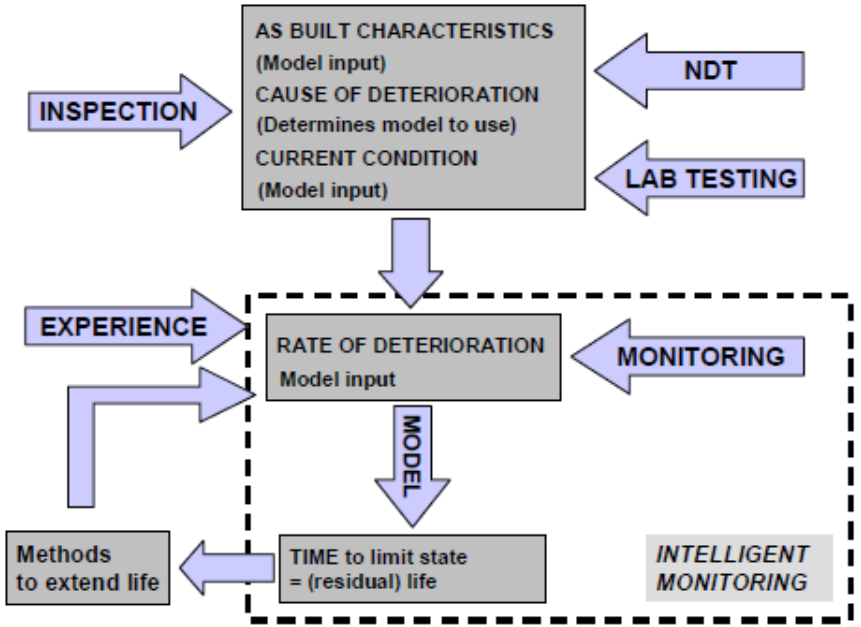


(example BRE)

MONITORING IN MANAGEMENT OF STRUCTURES

What remains to be done?

- Locations for surveys, testing and monitoring activities
- Condition survey and monitoring activities
- Tools and techniques for surveys and monitoring
- Gathering data for condition control purposes
- General flow of condition survey process
- Automated monitoring of concrete structures
- Automated monitoring and updating of service life prediction



MONITORING IN MANAGEMENT OF STRUCTURES

Element	Property or behaviour			
	Structural change	Reinforcing bar corrosion	Moisture & Temp	Chemistry
Reinforced concrete / prestressed concrete section	Section strength			
	Deflection			
	Vibration			
Joints & cracks	Displacement			
Concrete	Concrete stress	Concrete resistivity	Temperature	Total chloride
	Concrete strain	Cl threshold level	Moisture state	Free chloride
	Cracking	See chemistry column ref: chlorides, pH and nitrite		pH
	Young's modulus			Sulfate, nitrite
				Alkali silica gel

Feasibility of automated monitoring	Possible	Debatable	Not currently possible

MONITORING IN MANAGEMENT OF STRUCTURES

Element	Property or behaviour			
	Structural change	Reinforcing bar corrosion	Moisture & Temp	Chemistry
Reinforcing bar or prestressing steel tendon	Reinforcing bar stress	Half-cell potential	Temperature	
	Reinforcing bar strain	Galvanic current		
	Prestressing wire breaks	Polarisation resistance		
		Cumulative corrosion		
		Electrochemical noise		
External environment	Earthquake	Soil stray currents	Soil / water temp, pressure	Water pH, Cl, SO_4
			Air temp, RH, rainfall	Air composition

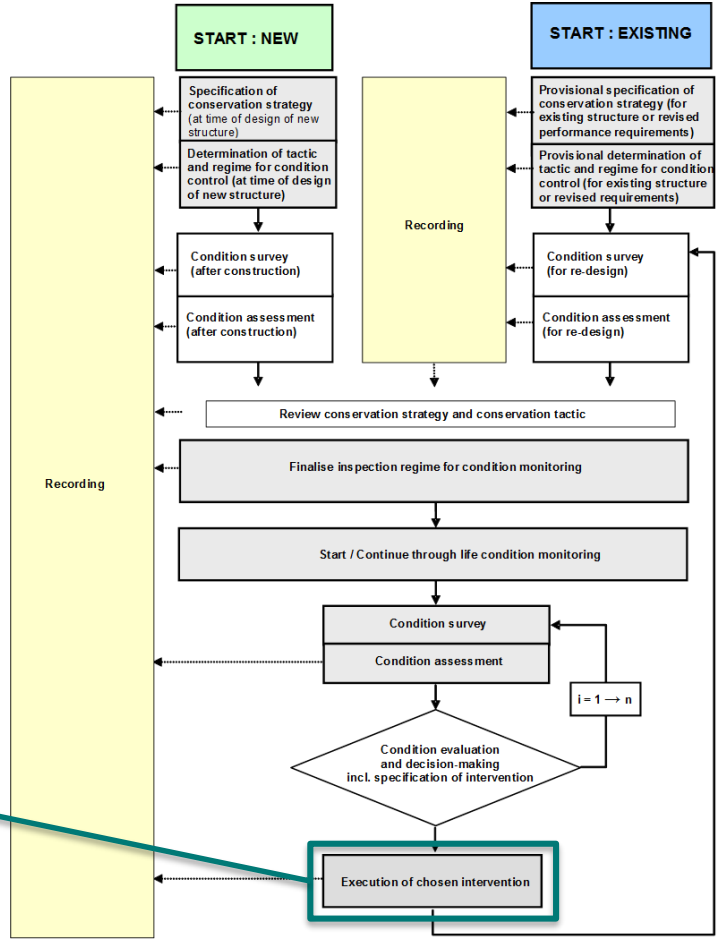
Feasibility of automated monitoring	Possible	Debatable	Not currently possible

MONITORING IN MANAGEMENT OF STRUCTURES

Installation of corrosion rate monitoring probes

Future: using many wireless sensors / MEMS creating BIG DATA

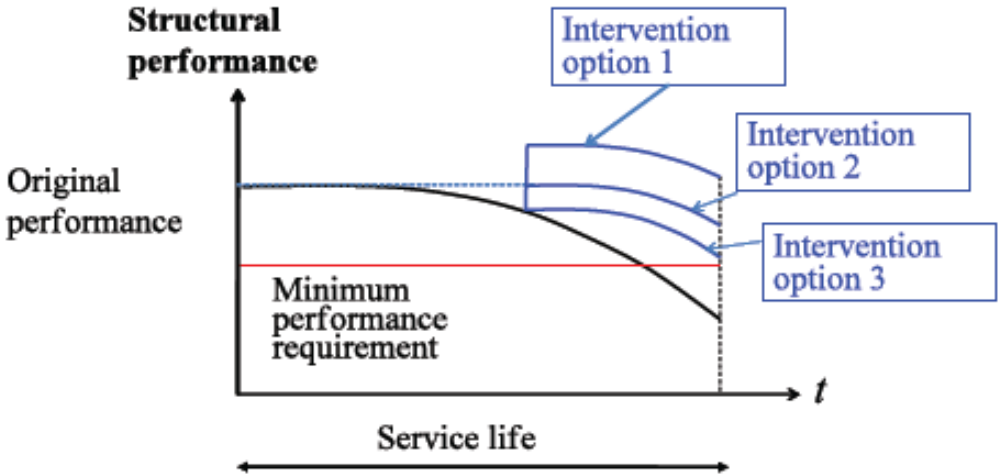
Through-life management process



Interventions

INTERVENTIONS IN MANAGEMENT OF STRUCTURES

- Intervention includes measures for prevention, remediation, repair and strengthening.
- The target improved performance after intervention can be higher than, equal to, or lower than the original design performance level.



Note:
Option 1 is to upgrade the performance and to lessen the deterioration rate.
Option 2 is to restore the performance and to lessen the deterioration rate.
Option 3 is to lessen the deterioration rate only.

INTERVENTIONS IN MANAGEMENT OF STRUCTURES

Considerations:

- Information required for design/execution of intervention and method for collecting information (damage existing in structure to be intervened is one of information)
- Materials for intervention are different to conventional materials used in existing concrete structures.
- Each intervention method usually requires a specific execution technique, such as the pre-treatment of the substrate concrete surface
- Maintenance and re-intervention of structures after intervention (including assessment of performance of structures after intervention):
    - proper maintenance after the intervention is needed, including monitoring
    - re-intervention may be necessary as a planned or as unplanned activity.
    - necessary information on maintenance and re-intervention needs to be provided.

INTERVENTIONS IN MANAGEMENT OF STRUCTURES

Structural interventions (examples)

External bonding
(CFRP sheet)

Bracing
(steel frame & pipe)

External cable
(FRP cable)

Jacketing
(reinforced concrete)

Overlaying
(spraying cement-based material)

INTERVENTIONS IN MANAGEMENT OF STRUCTURES

Non-structural interventions (examples)

Crack injection (injecting resin)

Prevention of concrete peel off (external bonding of FRP sheet)

Surface protection (coating resin)

Prevention of reinforcement corrosion (kathodic protection)

THANK YOU FOR YOUR ATTENTION