Knowing the cause of concrete deterioration and finding the right repair solution

Ir Dr HW Pang

18 April 2012

Outline

1. Resources available
2. Investigation methodology
3. Finding the causes
4. Finding the solution

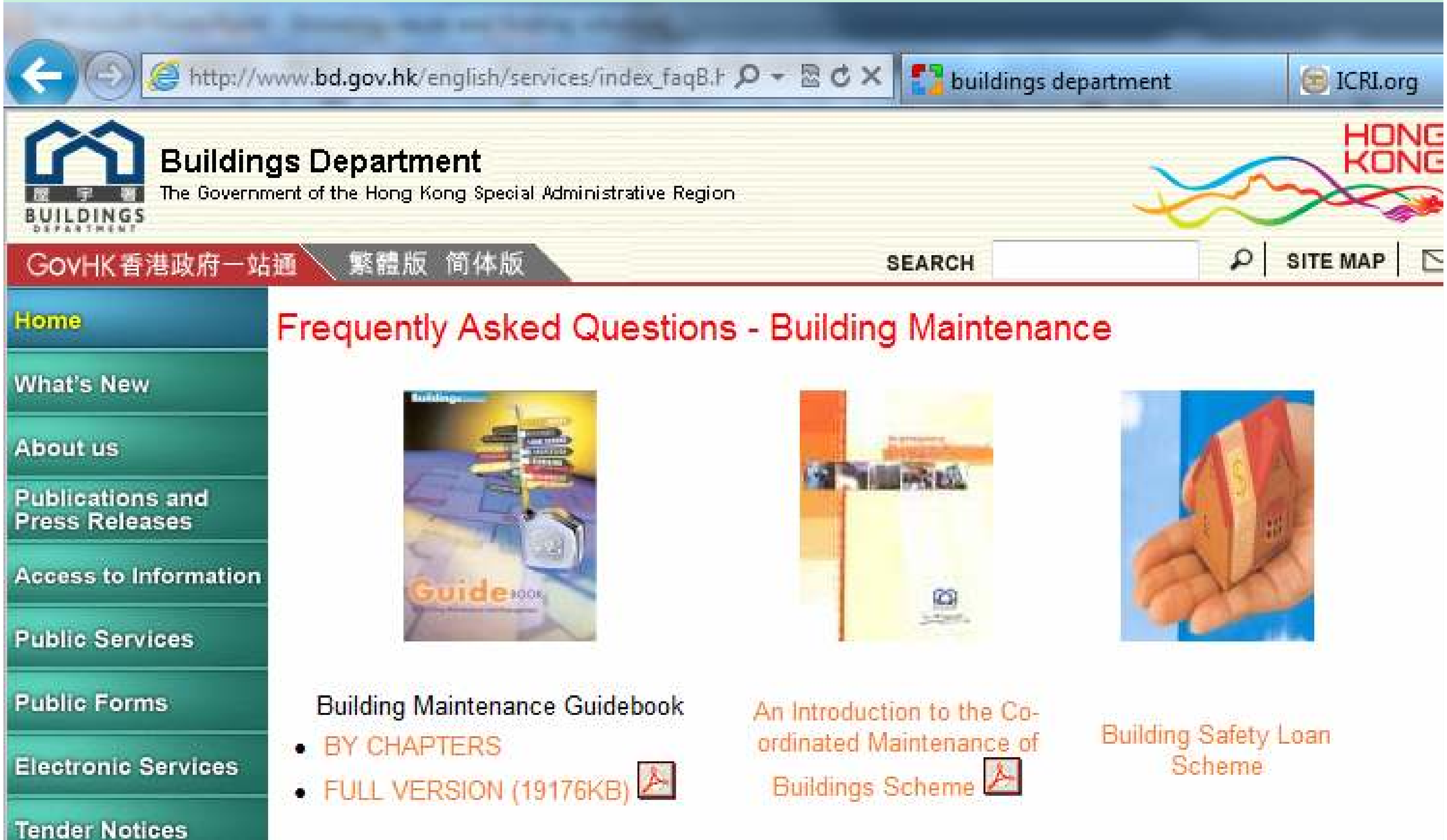
Resources at your finger-tips

HKIE

BD

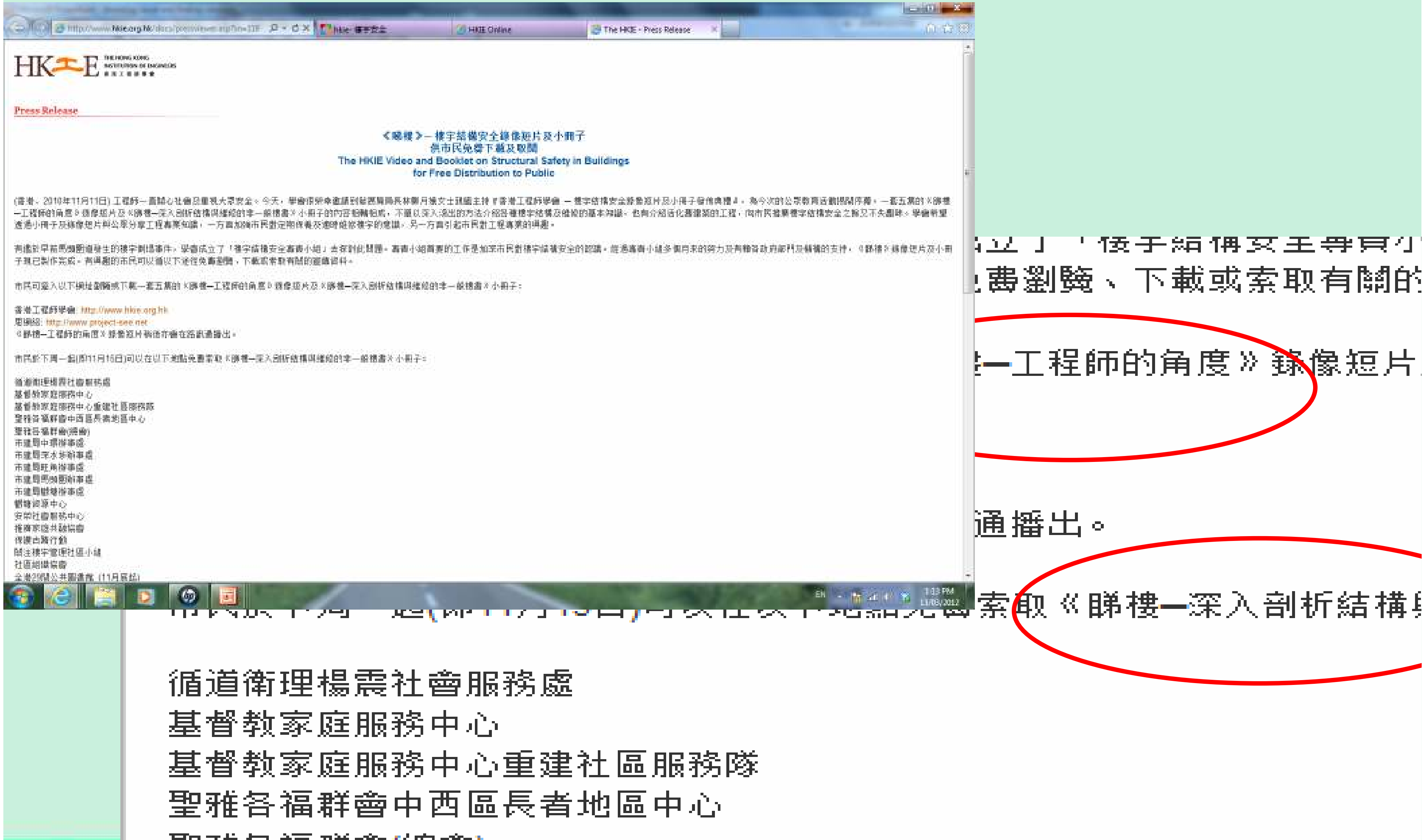
Search the web: eg,ICRI

Buildings Department



Knowing the cause of concrete deterioration in buildings and finding the right repair solution

Hong Kong Institution of Engineers



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RDS/awardsprogram.asp | icri | ICRI.org

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2000
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1997

ICRI PROJECT AWARDS PROGRAM

ICRI conducts an awards program each year to honor and recognize outstanding projects in the concrete repair industry. Entries are received from around the world, and the winning projects are honored each year at the annual ICRI Awards Dinner and Reception at each ICRI Fall Convention.

2012 PROJECT AWARDS

Rules and Entry Forms for the 2012 ICRI Project Awards are now available!
Click on the link below.

ICRI 2012 Project Awards Forms

The 2012 Project Awards Banquet will take place at the ICRI 2012 Fall Convention at the Rancho Las Palmas Resort and Spa in Rancho Mirage, CA, on Thursday, November 8, 2012.

Photos and descriptions of the 2011 Project Award winners have been posted!

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ICRI PROJECT AWARDS

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ICRI 2011 PROJECT AWARD WINNERS

2011 PROJECT OF THE YEAR

The Royal Floridian Resort is a seven-story vacation resort that is a major economic driver in the small coastal town of Ormond Beach, FL. Originally built in 1973, the building had received several alterations over the years, but the progressive deterioration caused by the harsh saltwater environment had never been addressed...

Get details >

Award of Excellence
> Bellaire Tower — The Jewel of Russian Hill
High-Rise — Sika Corporation

Award of Excellence
> St. Charles Municipal Center River Wall and Plaza Restoration
Historic — Wiss, Janney, Elstner Associaties, Inc.

Award of Excellence
> The Restoration of the Baha'i House of Worship
Longevity — The Armbruster Company

Award of Excellence

Engineers should understand

The building structure

Defects, degradation and symptoms

The durability factors

Survey, test and repair methods

Investigation Methodology

Information search

↓

Visual inspection

↓

Testing

↓

Assessment
- Aggressive action identification
- Deterioration rates
- Structural adequacy

↓

Developing repair solution

Visual inspection

Measurement

Moisture Survey

Taking Photo

Tapping Test

Open-ups, measurements and tests

1. Steel bar size and spacing
2. Concrete cover
3. Carbonation depth

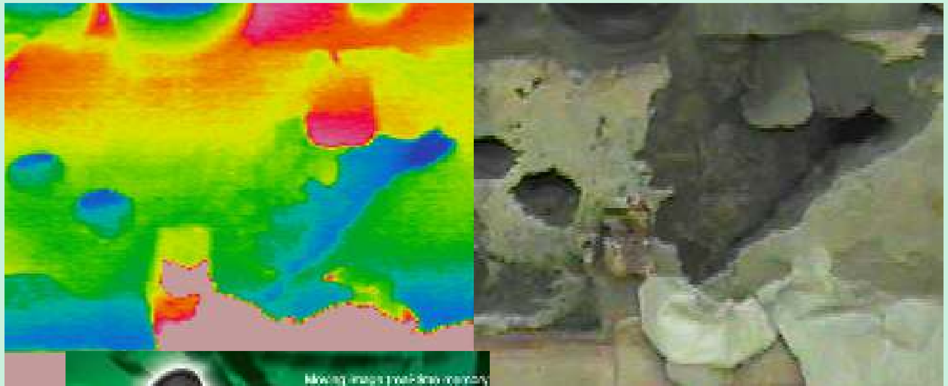
Core compression test

Chloride Content Test

1. Chloride content
2. Chloride profile

Hole drilling to extract concrete powder for chloride diagnosis

Other Tests, such as….



Infra-red Camera

Use of Florescence Solution for Seepage Detection

Re-bar Corrosion Rate measurement

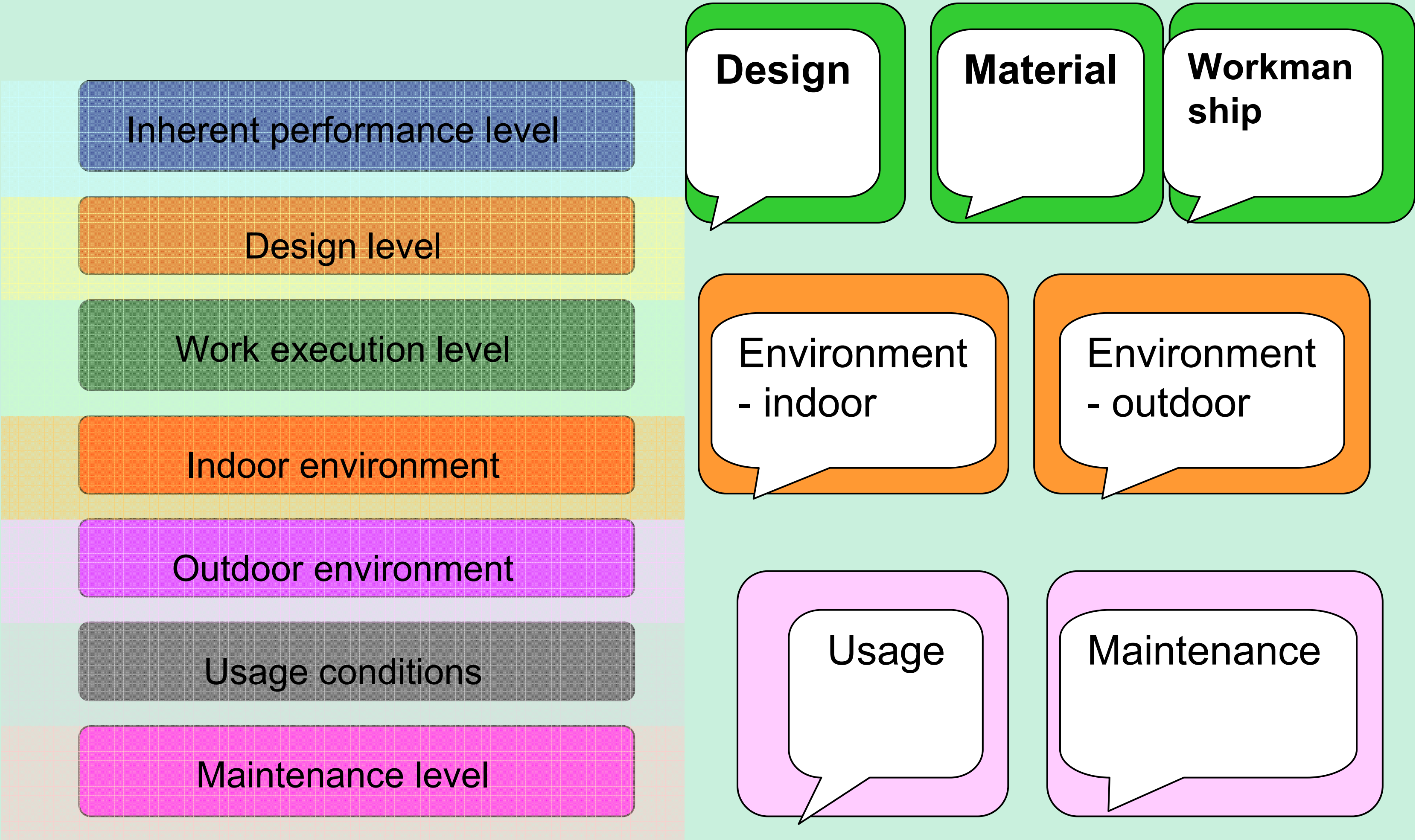
Finding the root causes – frameworks

ISO 15686

EN1504

CSIP

Factor Method for Service Life Planning (ISO 15686-8:2008) : Concepts



Multitude of Causes (1)
Material, Design and Workmanship

Piping
Through
Slab

Porous
infill to
Squad
Type
Toilet

Undesirable
Drain
Design

Inadequate
fall gradient

Multitude of Causes (1)
Material, Design and Workmanship

- Earlier design weak in durability
  - Lower concrete strength
  - Small cover to re-bars
  - Toilet-bathroom layout design
  - Little waterproofing
- Sea water for flushing toilet

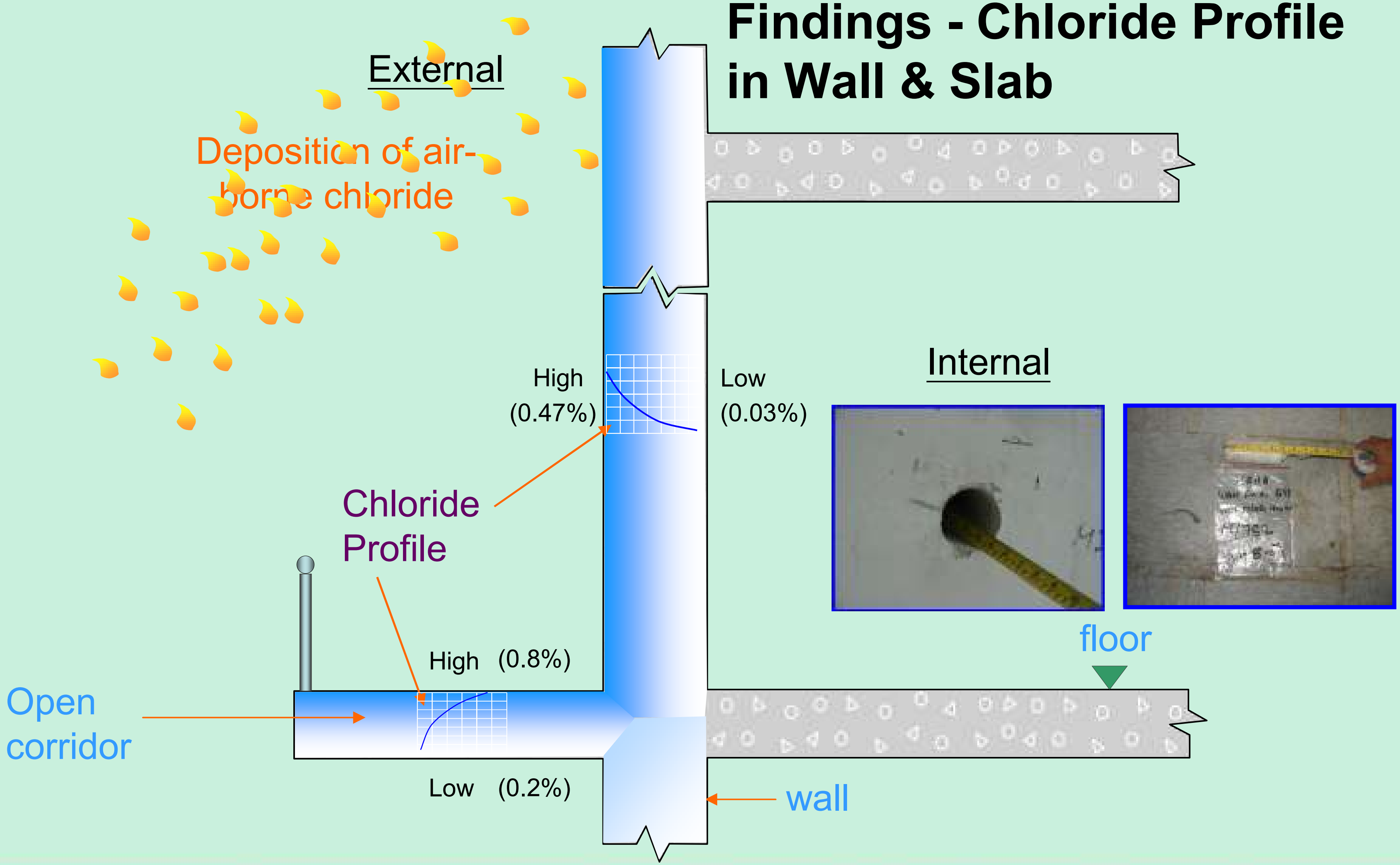
Multitude of Causes (2) Environment

Overflow of Salt Water

Wet and Dry External Areas

Air-borne chloride near the sea

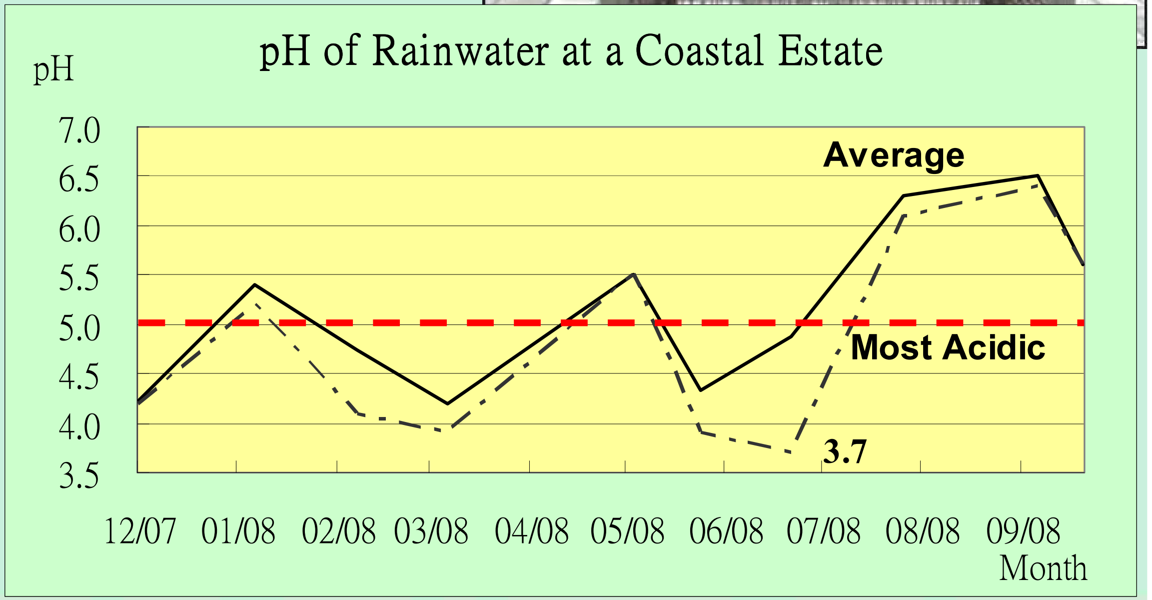
Findings - Chloride Profile in Wall & Slab



Acid Rain

Findings

- Acid rain test – pH as low as 3.7 recorded
  - Reference from Hong Kong Environmental Protection Department - acid rain if pH < 5.0
  - pH value of vinegar – 2.4 to 3.4



Multitude of Causes (3)
Usage and Maintenance

- Low level of tenants' care
- Low maintenability

Congest
Piping

Difficult
Repair
Area

Finding the right repair solutions – frameworks

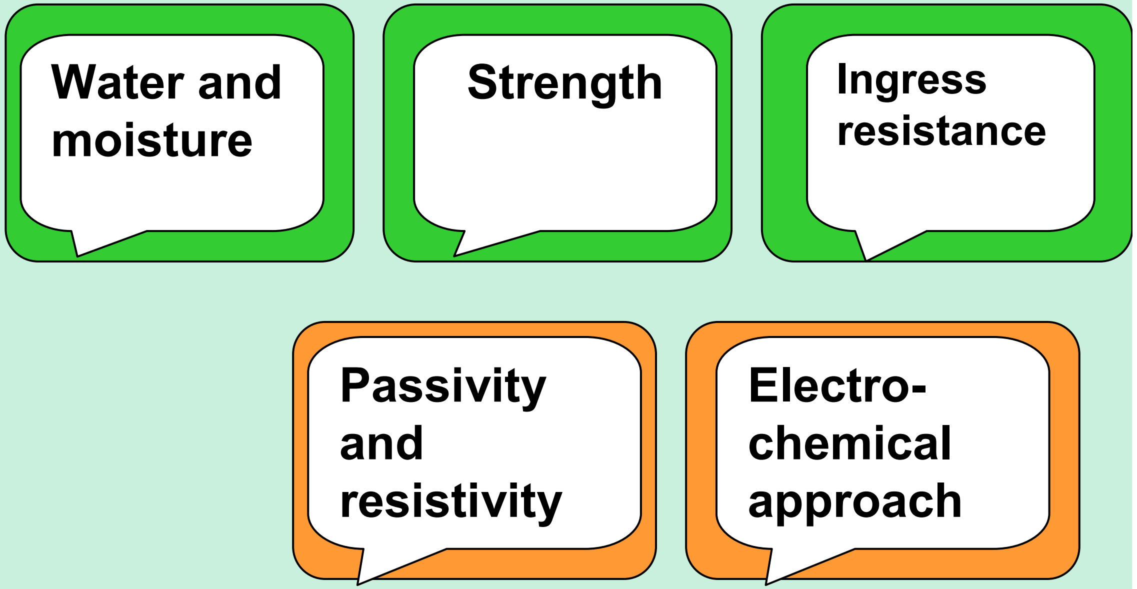
ISO 15686

EN1504

CSIP

Principles of Repair according to EN1504

- Ingress Protection
- Moisture Control
- Restoration
- Strengthening
- Physical Resistance
- Chemical Resistance
- Restoring Passivity
- Increasing Resistivity
- Cathodic Control
- Cathodic Protection
- Anodic Control



Additional Principles based on CSIP Experience

Increasing Maintainability

Improving Micro-environment

Omitting Vulnerable Elements

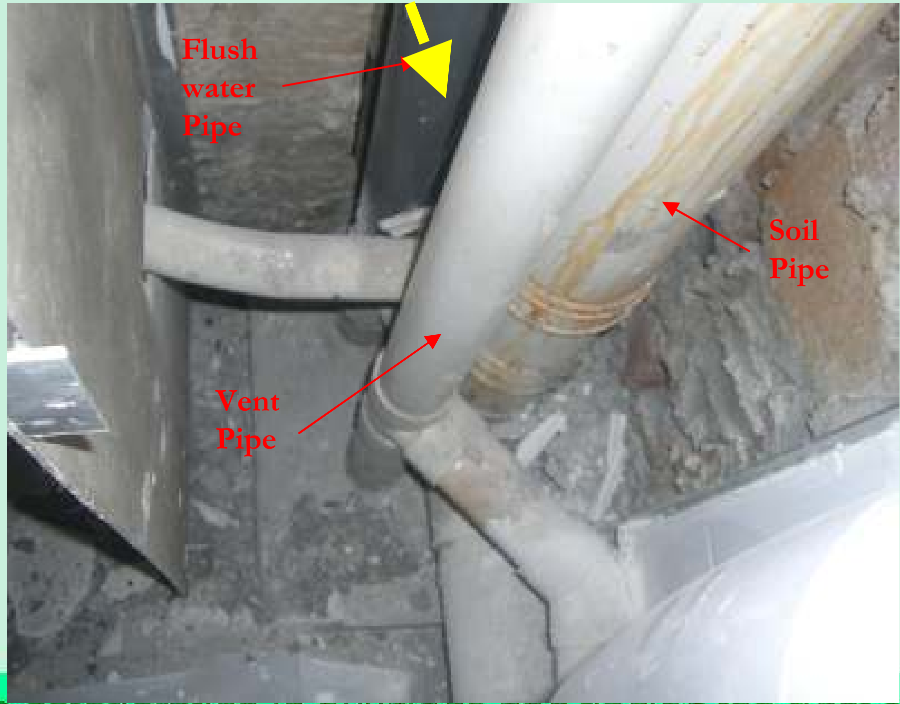
Replacing Vulnerable Elements

Increasing Maintainability

Improving Micro-environment

Omitting Vulnerable Elements

Replacing Vulnerable Elements



Inspection panel required

Increasing Maintainability

Improving Micro-environment

Omitting Vulnerable Elements

Replacing Vulnerable Elements

Solution: remove enclosure

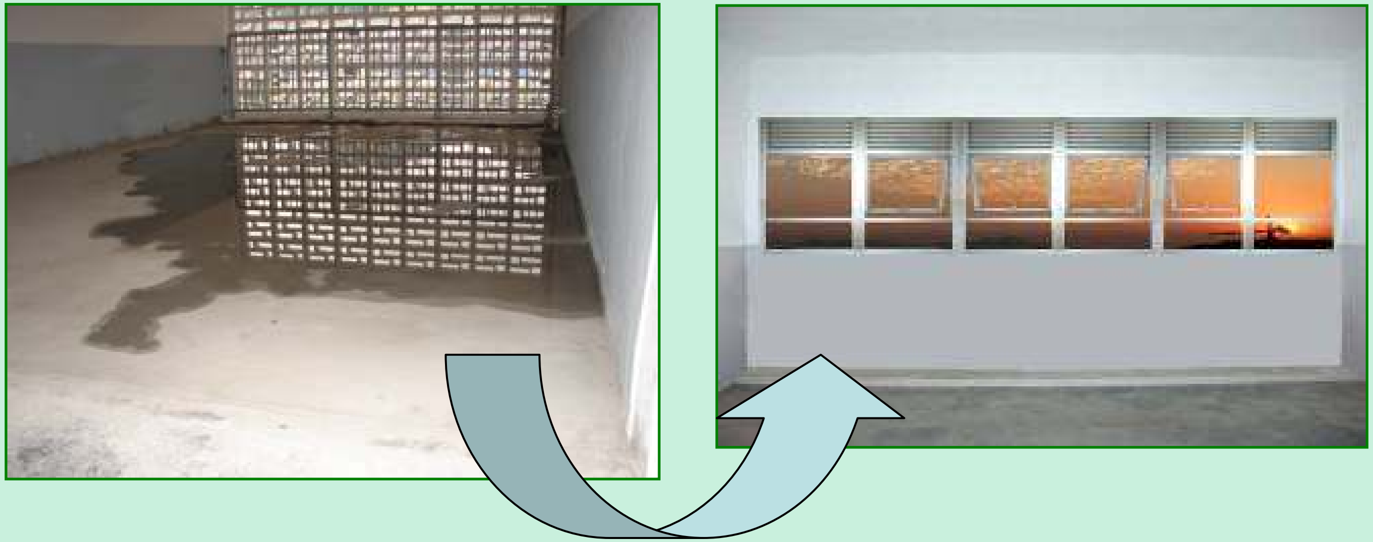
Increasing Maintainability

Improving Micro-environment

Omitting Vulnerable Elements

Replacing Vulnerable Elements

Converting grille facade walls to solid walls with windows



Increasing Maintainability

Improving Micro-environment

Omitting Vulnerable Elements

Replacing Vulnerable Elements

Solution: lay screed with adequate fall

Increasing Maintainability

Improving Micro-environment

Omitting Vulnerable Elements

Replacing Vulnerable Elements

Porous Plinth Material

- Increasing Maintainability
- **Improving Micro-environment**
- Omitting Vulnerable Elements
- Replacing Vulnerable Elements

Plinth jacketing

Increasing Maintainability

Improving Micro-environment

Omitting Vulnerable Elements

Replacing Vulnerable Elements

Loose bedding under floor tiles promotes undesirable aquaduct effect

Protection Against Water Ingress

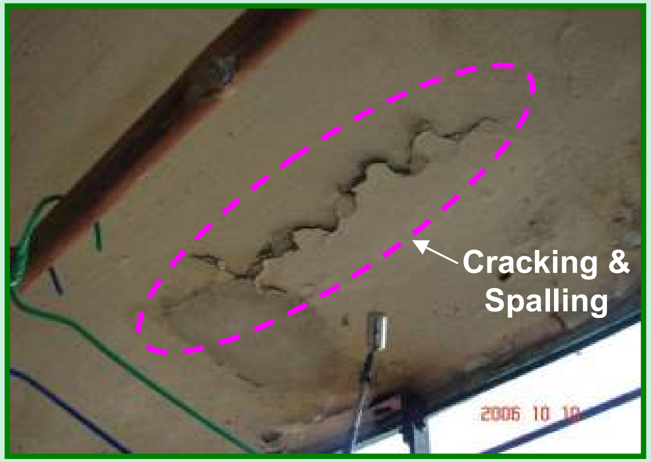
Increasing Maintainability

Improving Micro-environment

Omitting Vulnerable Elements

Replacing Vulnerable Elements

Past



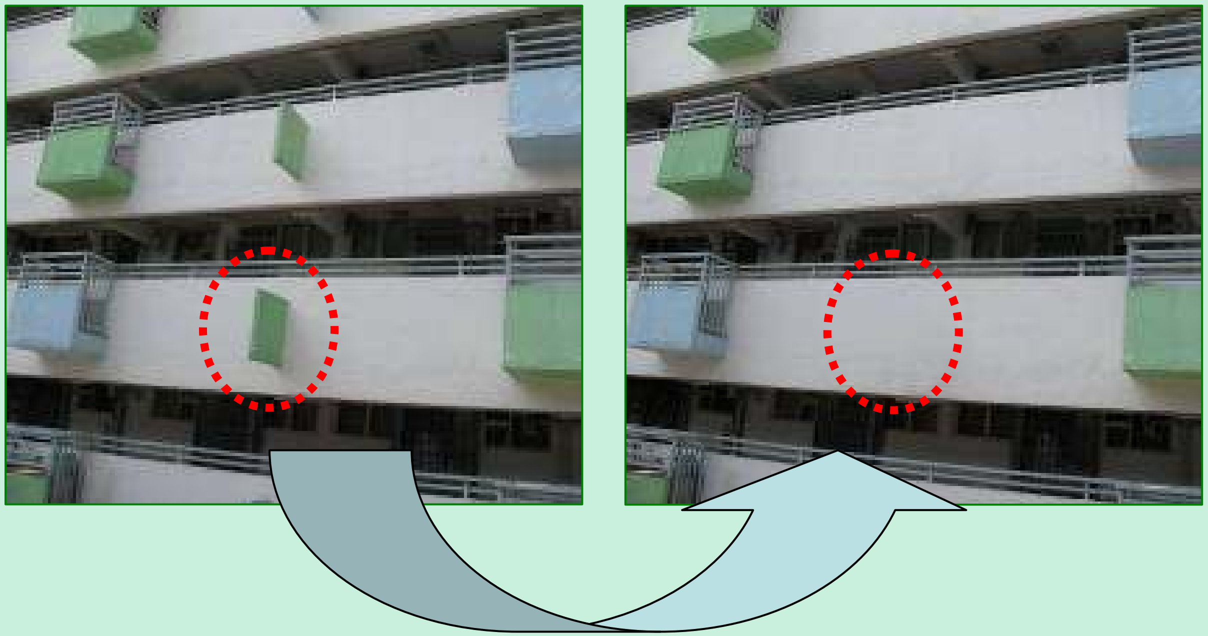
Now

Increasing Maintainability

Improving Micro-environment

Omitting Vulnerable Elements

Replacing Vulnerable Elements

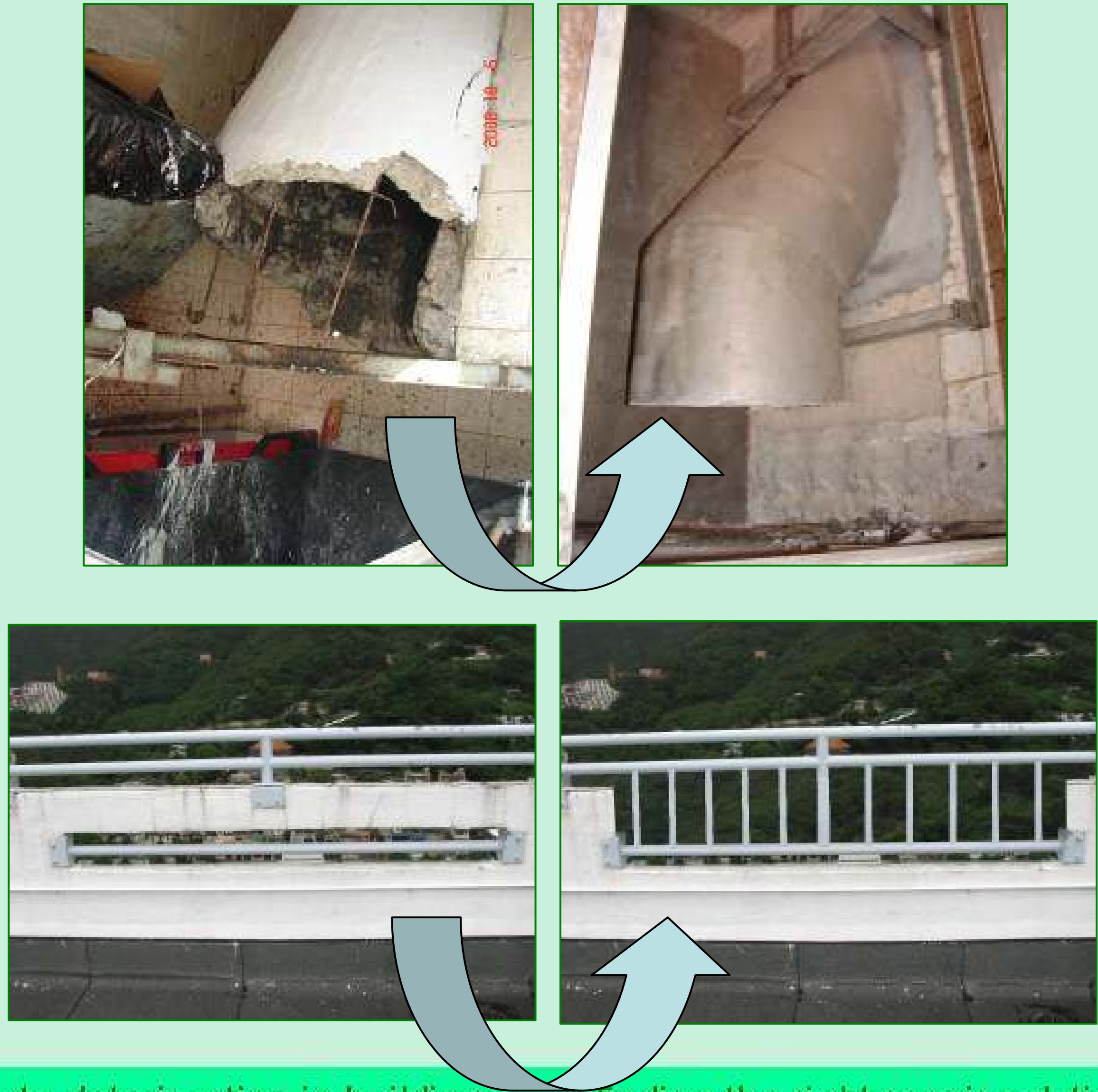


Increasing Maintainability

Improving Micro-environment

Omitting Vulnerable Elements

Replacing Vulnerable Elements



Concrete Repair Strategy – People Orientated Approach

Shortest Time

Nuisance Minimized

Inconvenience Minimized

Working Environment Improved

Welcomed by Tenants

High Performance Concrete Work in a day
(open to tenants at night)

Shortest Time

Nuisance Minimized

Inconvenience Minimized

Working Environment Improved

Welcomed by Tenants

Environmental Friendly Concrete Removal Method: Hydro-Scarification

Shortest Time

Nuisance Minimized

Inconvenience Minimized

Working Environment Improved

Welcomed by Tenants

Noise Absorbent Curtains at working areas to reduce noise and dust

Dust Screen Protection in Tenant's Flat

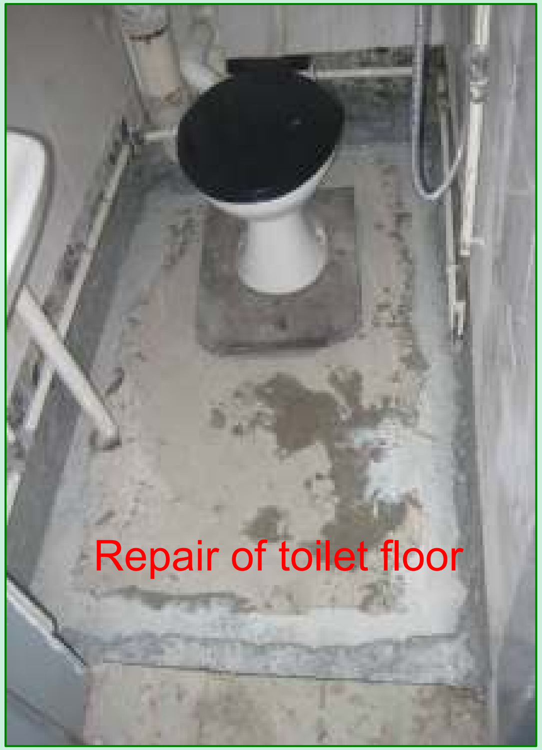
Shortest Time

Nuisance Minimized

Inconvenience Minimized

Working Environment Improved

Welcomed by Tenants



Temporary toilet installed in tenant's flat after day 1 work

Completion of Toilet Improvement (day 2)

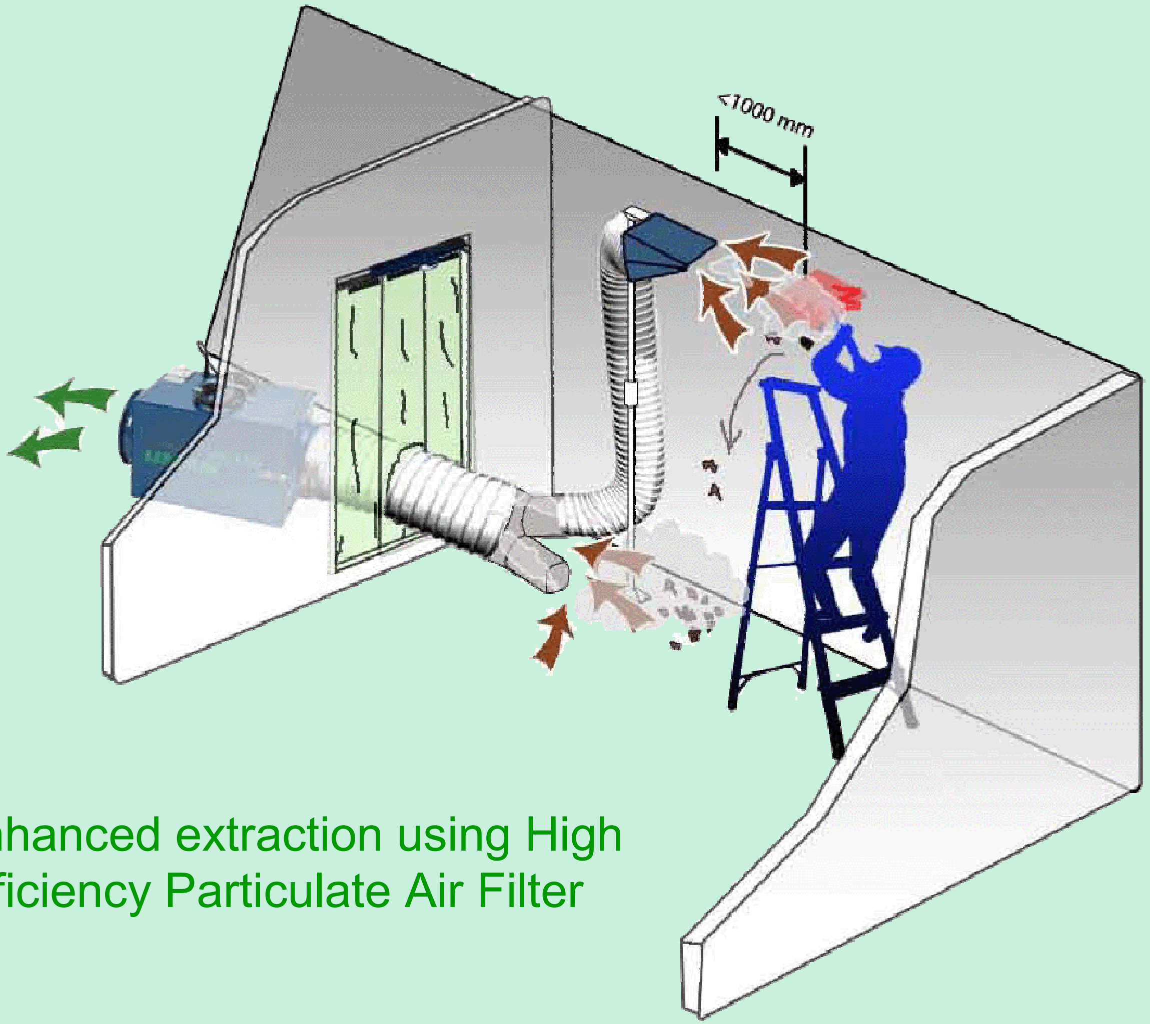
Shortest Time

Nuisance Minimized

Inconvenience Minimized

Working Environment Improved

Welcomed by Tenants



Enhanced extraction using High Efficiency Particulate Air Filter

Shortest Time

Nuisance Minimized

Inconvenience Minimized

Working Environment Improved

Welcomed by Tenants

Consultation with Tenants & Council Members

Partnering Workshops with Tenants

References

(1) PANG, H.W., CHAN, C.O. and AU, Bosco L.K.
"Sustaining reinforced Concrete Buildings in Public Rental Housing Estates"
Proceedings of the Hong Kong Standing Committee on Concrete Technology Annual Seminar, 18 Feb 2008

(2) PANG, H.W. and CHAN, C.O.
"The Comprehensive Structural Investigation of Hong Kong's aging public Rental Buildings"
Proceedings of the 17th Congress of IABSE, Chicago USA, 17-19 September 2008

(3) PANG, H.W., and AU, Bosco, L.K.
"Sustaining public rental housing with environmental friendly repair solutions"
Proceedings of the Hong Kong Institution of Engineers Materials Division, Materials Science and Technology in Engineering Conference- the Industrial Application of Environmentally Friendly Materials Technology, Hong Kong, 3-4 December 2009.

(4) PANG, H.W, CHAN C.O. and AU, Bosco, L.K.
"Solution – Based Approach in Structural Defect Assessment and Repair of Public Rental Buildings"
Proceedings of the Hong Kong Concrete Institute Seminar on Concrete Damage Assessments- Concrete Repair, and Concrete Mix Technology, Hong Kong, 5 Feb 2010.

(5) PANG, H.W., CHAN, C.O. and AU, Bosco, L.K.
"The Three Enables of Building Sustainability – Building Pathology, Performance Monitoring and Estate Improvement"
Proceedings of the HKIE/IStructE Joint Structural Division Annual Seminar – Structural Engineering for Sustainable Development, Hong Kong, 15 June 2010.

(6) PANG, H.W., AU, Bosco L.K.
"Advances in the Practice of Concrete Repairs – the Hong Kong Housing Authority Experience."
Proceedings of the MaSTEC 2011 cum HKCI Annual Seminar on Construction Materials in the Next Decade: Innovation and Sustainability, Hong Kong: 1 Dec 2011.

Thank you for your attention

How long can a reinforced concrete building serve us?

Ir Dr HW Pang

18 April 2012

Outline

1. From a historical perspective
2. Concepts and questions on service life
3. A model of prediction of residual service life

A brief history of….

Knap of Howar
A stone house in Scotland

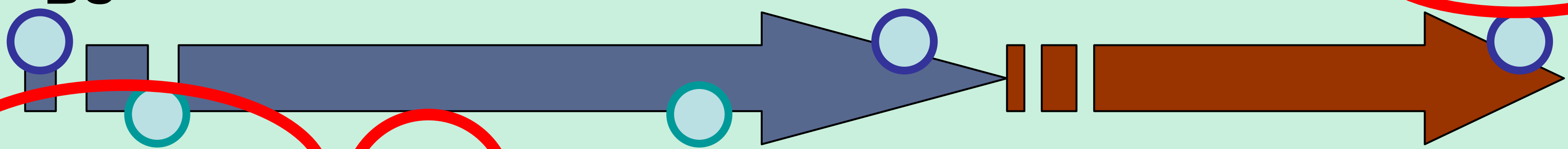
3500-3100 BC

The Maison Carree of France

432-447 BC

Ingalls Building, Ohio, US - the first **reinforced concrete** high-rise building (16 storeys)

1903



cementitious materials
3000BC

Iron age began
1300-1200BC

Roman concrete

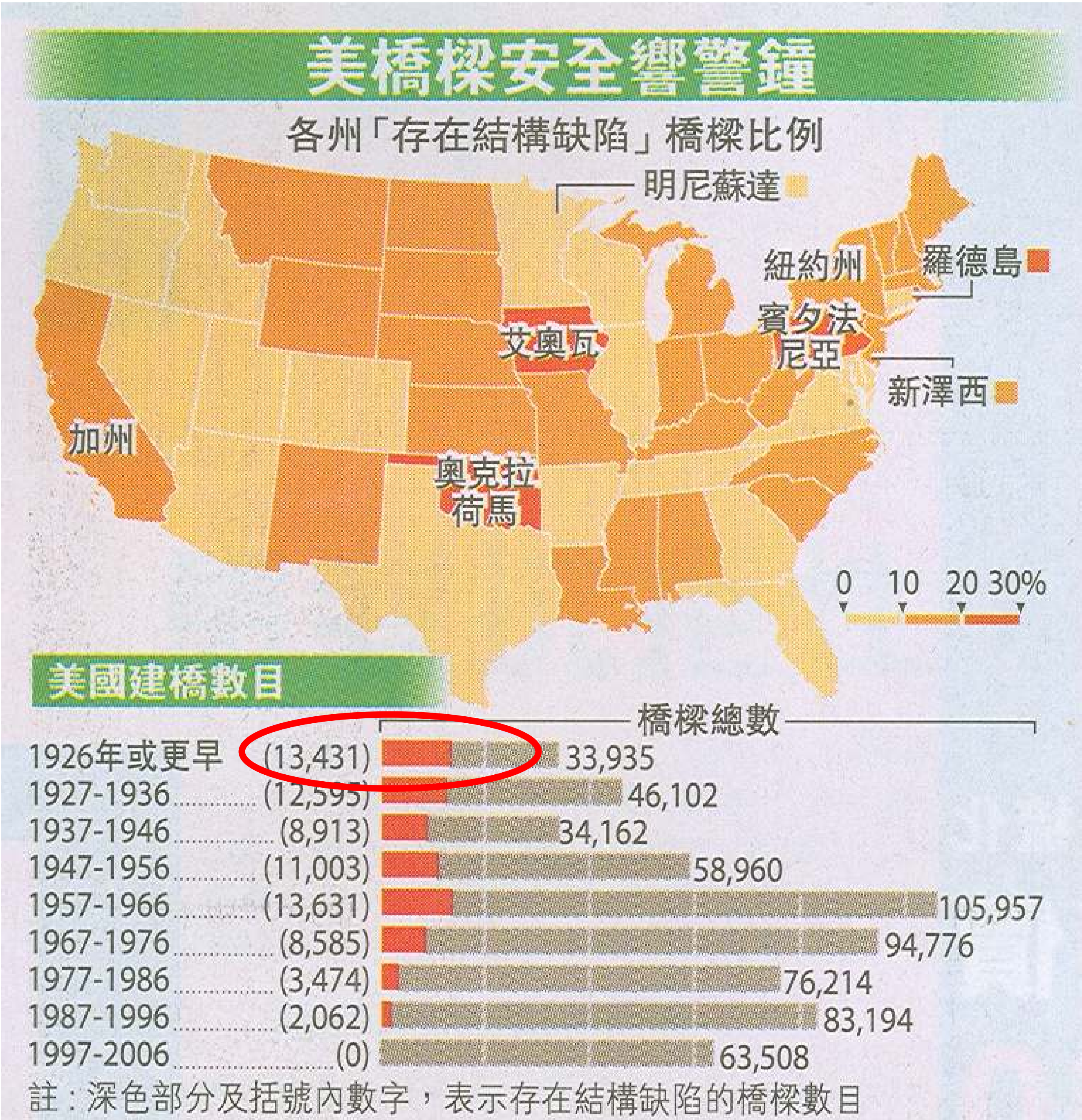
2012

Knap of Howar
A stone house
in Scotland

3500-3100 BC

The Maison Carree of France – the only completely preserved temple of the ancient world

432-447 BC



US bridge collapse
August 2007

How about buildings?

Engineers learned from experience and produced better designs…

(Fib 2006): Service life relates to

- •A number (of years)
- •A limit state
- •A probability
- •A Degradation model

Published examples (1)

New city development project at Tjuvholmen, Oslo, Norway (2005)

1. Design life - 150 years
2. SLS – initiation of corrosion due to chlorides
3. Not more than 10% probability of corrosion initiation at 150 years
4. Verification by measurement of chloride diffusivity and concrete cover (results based on 28-day control 1-4%; insitu data 0.7%)

Source: Concrete International, September 2010

Published examples (2)

Design of Busan-Geoje Fixed Link, South Korea

1. Design for 100 years
2. SLS – initiation of corrosion
3. 90% probability, reliability index 1.3

Source: Proceedings of the International Conference on Concrete Repairs, Rehabilitation and Retrofitting 2006

Published examples (3)

Appraisal of 2 relatively new concrete structures (7-8 years old) in Norwegian harbours

1. Monte Carlo Simulation of variables (concrete covers, chloride diffusion coefficients)
2. SLS – initiation of corrosion
3. 90% probability, reliability index 1.3

Source: Proceedings of the 4th International Conference on Concrete under Severe Conditions of Environment and Loading, Seoul, Korea, 2004

Published examples (4)

Design of Sitra Bridges, Bahrain

1. Design for 120 years
2. SLS – initiation of corrosion due to chlorides or carbonation
3. 90% probability of no corrosion initiation, reliability index 1.3
4. Degradation model, DuraCrete (2000)

Source: Concrete International, September 2010

Concept of limit state and reliability

Limit States

Service life has to be associated with a defined limit state : serviceability (SLS) or ultimate (ULS).

Reliability

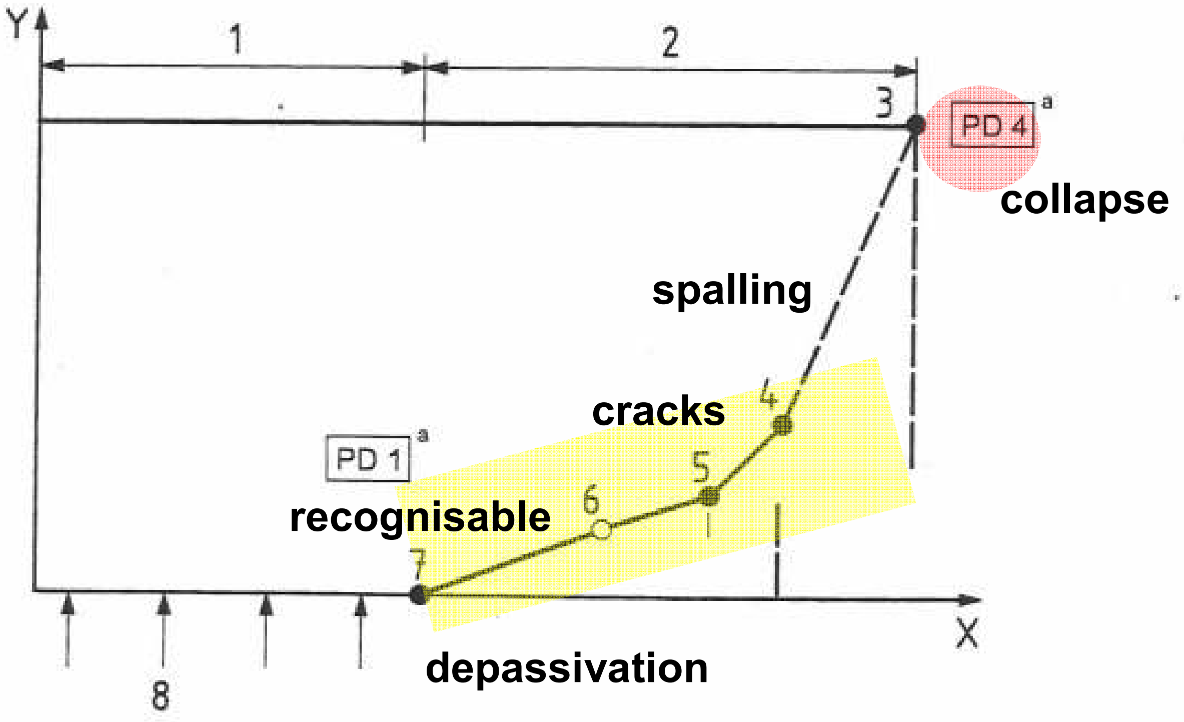
There are world-recognized levels of reliability for SLS and ULS

References:

1. **ISO 15686 (Buildings and constructed assets- service life planning) various parts 2000+**
2. **Fib Model Code for service life design 2006**
3. **Fib Model Code 2010**

Limit States

Reliability



Key

Y level of deterioration

X time of exposure, years

1 initiation period

2 propagation period

3 collapse of the structure through bond failure or reduction of the cross section of the load bearing reinforcement

4 spalling of the concrete cover

5 formation of cracks

6 deterioration recognizable through non-destructive measuring methods

7 depassivation of the reinforcement

8 condition can be comprehended by monitoring

[a] Performance degrees (PD) are defined in 5.3.4.2.2.

Figure B.1 — Levels of deterioration of concrete as related to performance degrees and limit states[43]

ISO 15686 (Buildings and constructed assets- service life planning)- Part 7- 2006 (Performance evaluation)

Appropriate limit states:

Limit States

Reliability

1. Depassivation of rebars
2. Cracking due to rebar corrosion
3. Spalling of concrete cover
4. Collapse due to loss of rebar steel area

(SLS represents all limit states except that associated with collapse or other similar forms of structural failure)

Fib Model Code for service life design 2006

Limit States

Reliability

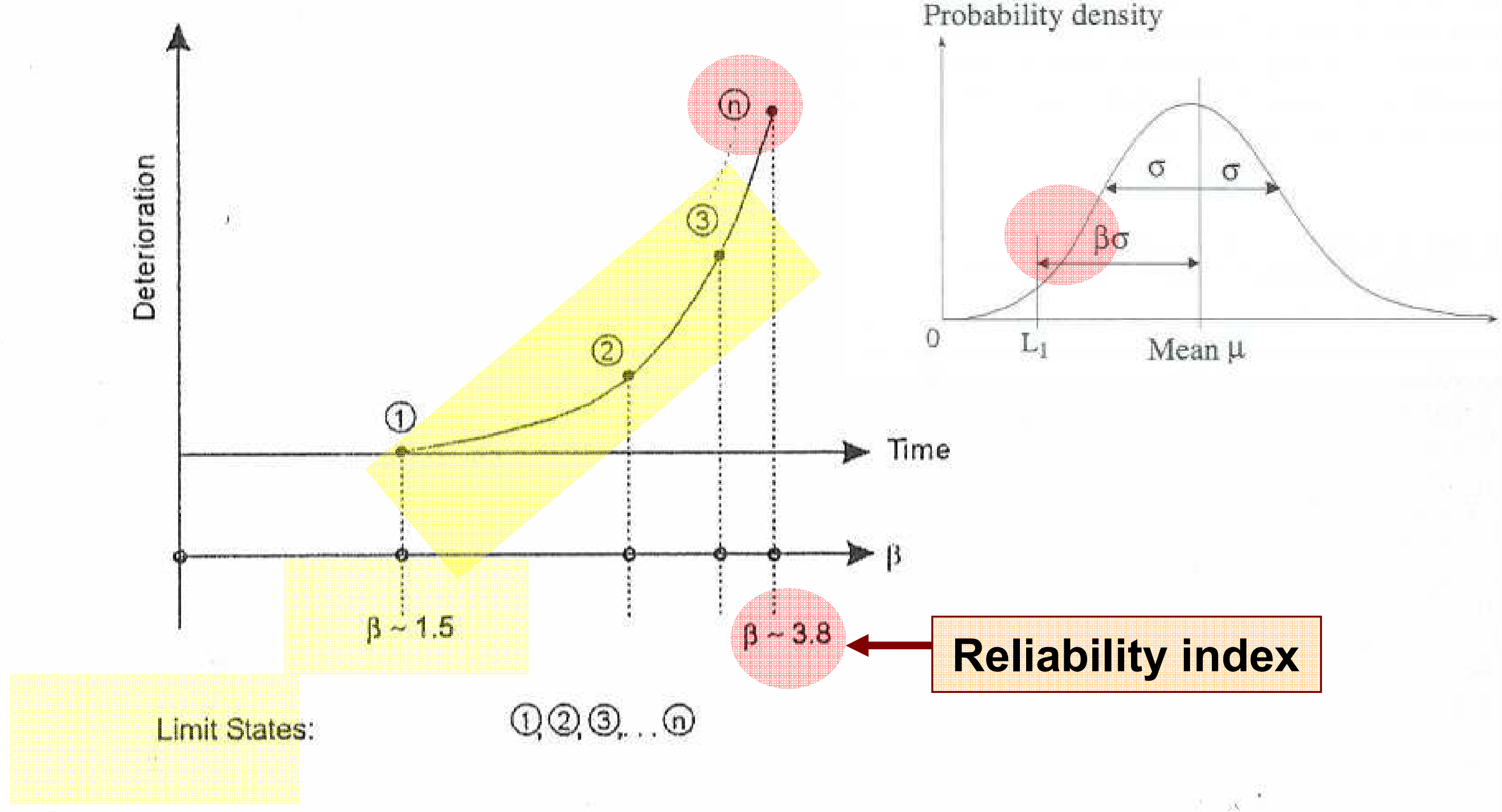


Figure R1.1-1: Deterioration process of reinforcement corrosion and definition of limit states for basic scheme of the service life design

Fib Model Code for Service Life Design (2006)

Limit States

Reliability

Table 3.3-6: Suggested range of target reliability indices β for existing structures, related to the specified reference periods.

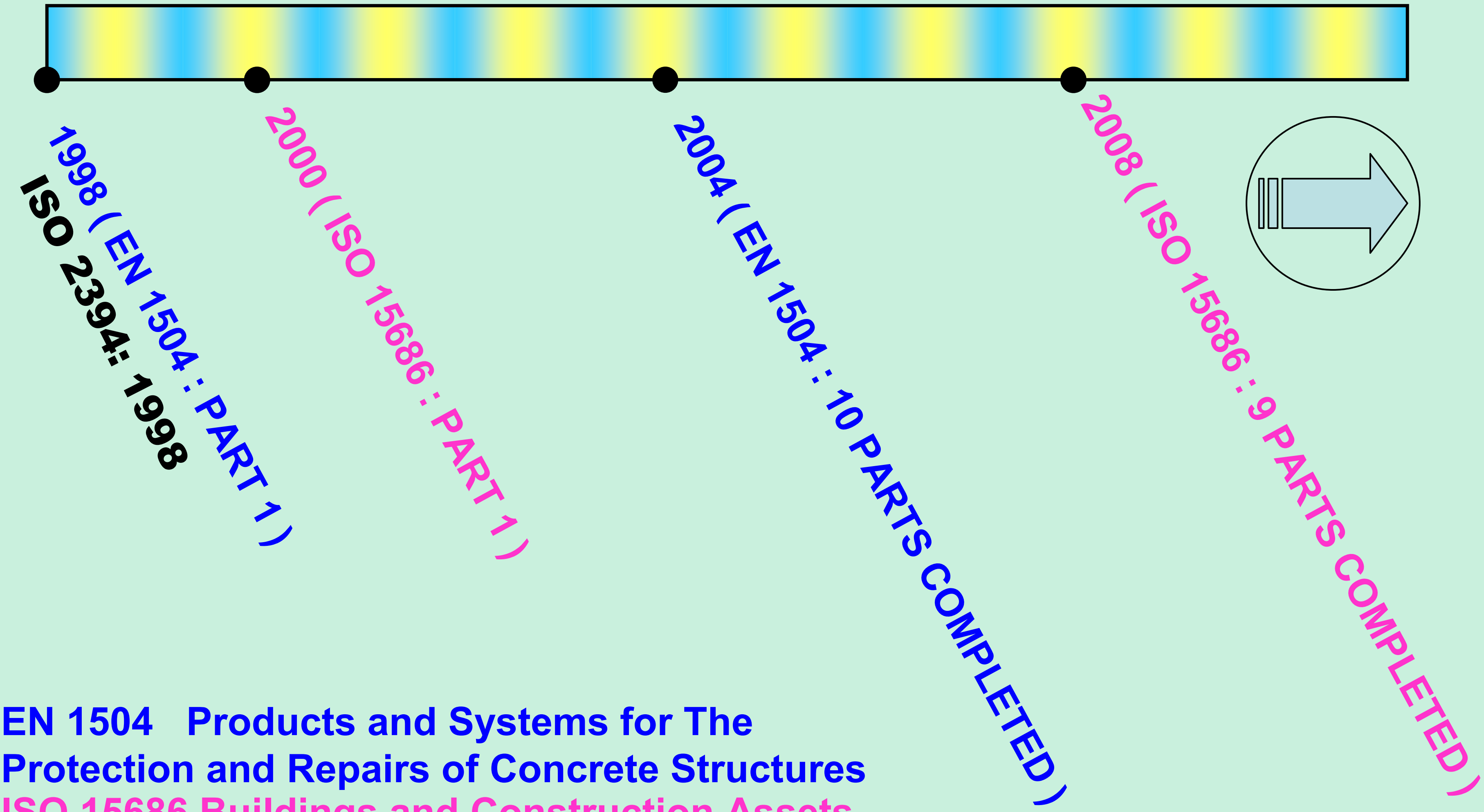
Limit states	Target reliability index β	Reference period
Serviceability	1.5	Residual Service Life
Ultimate	in the range of 3.1 - 3.8*	50 years

Fib Model Code 2010

Is there life after corrosion starts?…

Questions: will service life ends even if

- **Some elements have no corrosion**
- **Spalling repairs can easily be done**
- **There is spare structural capacity**



EN 1504 Products and Systems for The Protection and Repairs of Concrete Structures

ISO 15686 Buildings and Construction Assets – Service Life Planning

ISO 2394: 1998 General principles on reliability of structures

Reversible limit state

Table E.1 — Relationship between β and P_f

P_f	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}
β	1,3	2,3	3,1	3,7	4,2	4,7	5,2

Table E.2 gives an example of calibration life time target β-values, depending on the consequences of failure and the relative cost of safe design.

Table E.2 — Target β-values (life-time, examples)

Relative costs of safety measures	Consequences of failure			
	small	some	moderate	great
High	0	A 1,5	2,3	B 3,1
Moderate	1,3	2,3	3,1	C 3,8
Low	2,3	3,1	3,8	4,3

Some suggestions are:

A: for serviceability limit states, use $\beta = 0$ for reversible and $\beta = 1,5$ for irreversible limit states.

B: for fatigue limit states, use $\beta = 2,3$ to $\beta = 3,1$, depending on the possibility of inspection.

C: for ultimate limit states design, use the safety classes $\beta = 3,1$, $3,8$ and $4,3$.

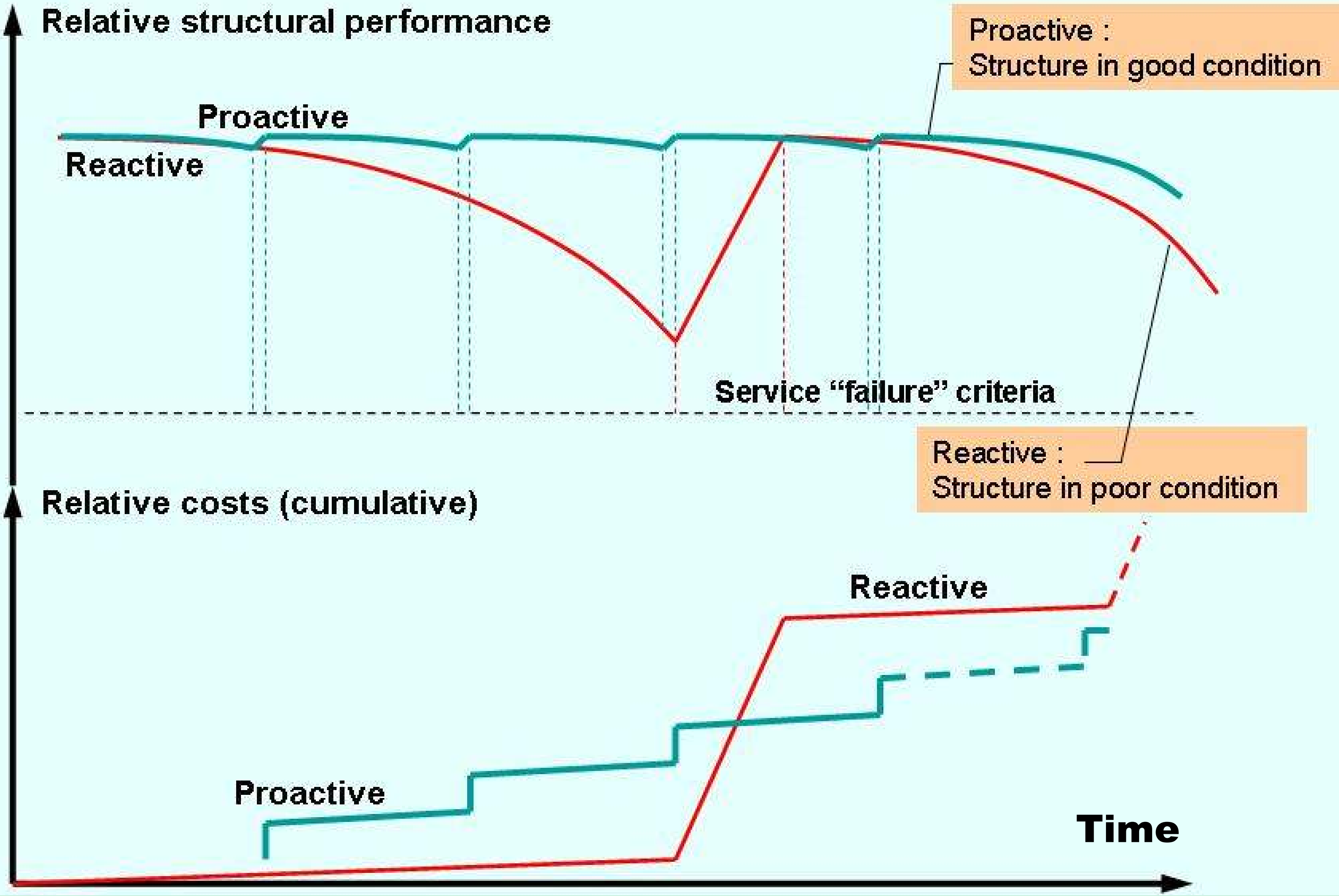
Reversible Limit State

ISO 2394: 1998

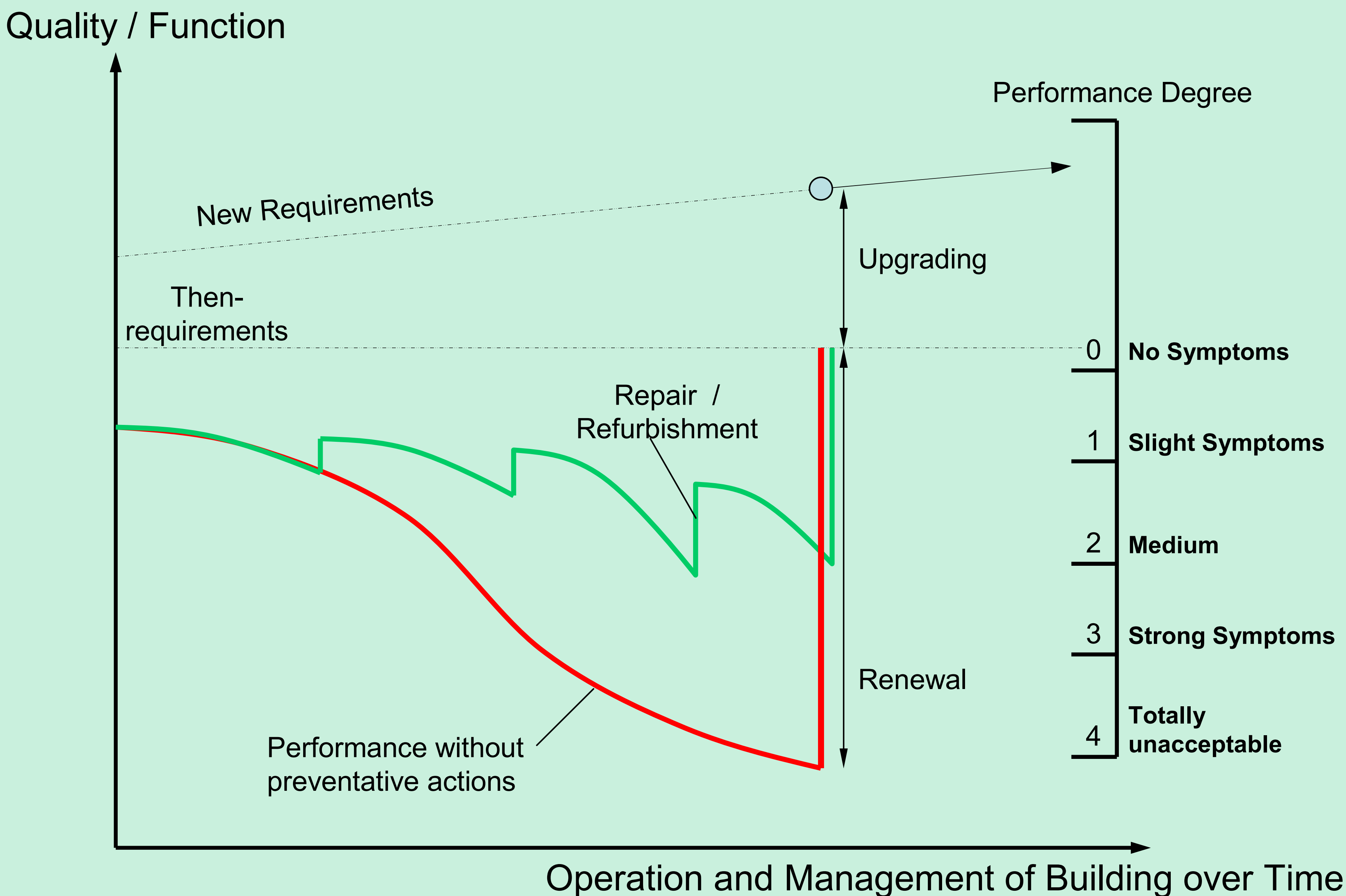
Reversible Limit State

It is perfectly acceptable to replace a ceiling light bulb,… but not every day!

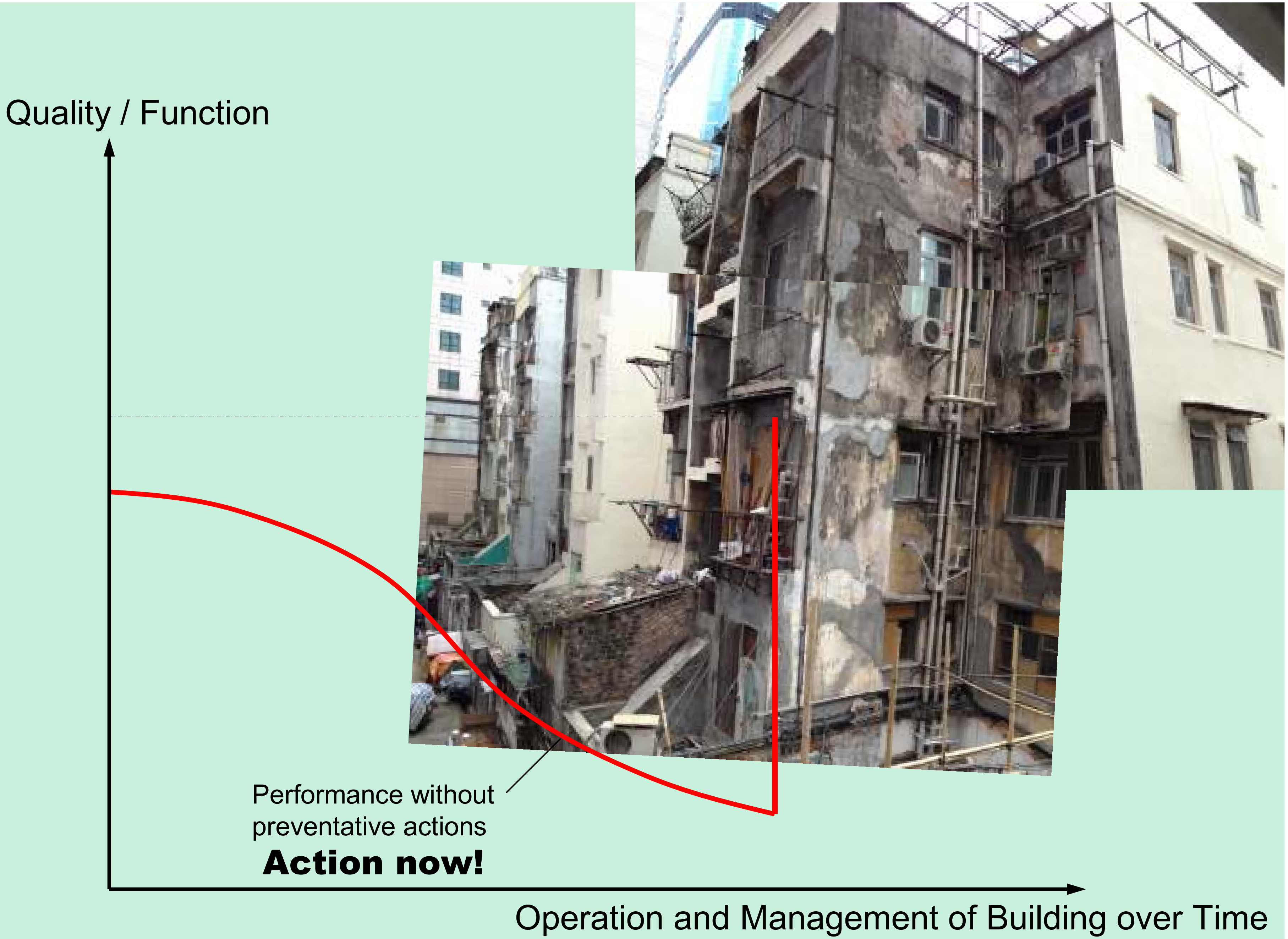
Approaches to the Management and Maintenance of Structures



Adapted from CSTR 69:2009 Repair of Concrete Structure with ref to BS EN 1504



Adapted from ISO 15686-7:2006


Quality / Function
Performance without preventative actions
Action now!
Operation and Management of Building over Time

Residual Service Life

Need for service life model for aged buildings with corrosion in propagation stage

1. Slabs and walls deteriorate differently
2. Large variability of corrosion rates
3. Difficulties in verifying the reliability of the existing structure
4. Contribution of structured inspections and maintenances
5. Slab spalling repairs: a normal maintenance task, not end of life

A new methodology - principles

Slab corrosion

- Reversible serviceability limit state (RSLS)
- Repair cost as acceptability of the RSLS

Wall corrosion

- Ultimate limit state
  - Appraisal based on measured corrosion rates and its variability
  - Structural sensitivity analysis

References

(1) PANG, H.W., CHAN, C.O. and CHAN, W.B.
"Durability Assessment at Advanced Age of Public Rental Buildings in Hong Kong"
Proceedings of the 12th International Conference on Durability of Building Materials and Components XII DBMC, Porto, Portugal, 12-15 April 2011. pp 1693-1700.

(2) PANG, H.W., CHAN, C.O. and CHAN, W.B.
"Prediction of Residual Service Life and Through-life Maintenance Costs for Hong Kong Public Rental Housing Estates"
Proceedings of the 5th Cross Strait Conference on Structural and Geotechnical Engineering, Hong Kong, 13-15 July 2011.

(3) PANG, H.W. , AU, Bosco, L.K and CHAN, W.B.
"Classification of Environmental Exposure of Building Elements by Tests"
Proceedings of the RILEM International Conference on Advances in Construction Materials through Science and Engineering, Hong Kong, 5-7 September 2011.

Thank you for your attention