Sustaining reinforced concrete buildings in public rental housing estates

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Presentation outline

- Setting the issue into context
- Describing what we do
- Illustrating by an example
A historical perspective

- 2500 BC - major concrete users
- 1200 BC - iron age began
- Around 3000 years later... Steel reinforced concrete
Reinforced concrete is quite ‘new’

- 1854: WB Wilkinson of England erected a 2-story RC servants cottage
- 1902: RC buildings up to 6 stories high
- 1903: Ingalls Building, Ohio - the first RC high-rise building (16 stories), still there!
Codes are quite new

- 1948 CP114, CP110, BS8110, EN206
- 1992 BS EN 1504 (10 parts) ‘products and systems for protection and repairs of concrete structures’

Problem is quite serious...
“If indirect costs are included, the annual cost of steel corrosion to the US economy, conservatively estimated at US$552 billion, some estimates indicate the range to 30% of this total is related to corrosion in concrete structures.”

Concrete International, Dec 2004
“There are approximately 583,000 bridges in the US…Approximately 15% of these bridges are structurally deficient because of corroded steel and steel reinforcement.”

Source: FWHA
Corrosion of the reinforcing steel in concrete structures such as motorway bridges, buildings and marine installations is costing the UK an estimated 550m GBP per year.

BRE website March 2007
‘...majority of significant deterioration of existing bridges (in Japan) built before the 1984 guidelines occurred within 15 years of construction.’

Mar/Apr 2006 PCI Journal
Our story....
Mark I blocks after the Shek Kip Mei fire at 1953
Redevelopment programmes

- 70's – cleared 250 resettlement blocks
- 80's – extended to another 26 blocks
- 1988 - Comprehensive Redevelopment Programme (CRP) targeting at 566 blocks (completion 2008/09)
Long Term Housing strategy 1998

- No large scale redevelopment programme
  the CRP.

- Clearance to be considered only if
  - Building is structurally unsafe, or
  - Beyond economical repairs

(2005 – comprehensive structural investigation programme; initially 10 estates, extended to another 32 estates in a 10 year programme)
Methodology for Investigation

Reference documents:
- Appraisal of existing structures by IStructE and CSTR No.11 of the Concrete Society
- BRE Digest 444
- UK Highways Agency BD44/95, BD51/95, BD44/95 and BA44/96
Methodology for Investigation

Develop our own methodology taking into account of our particular circumstances.
Methodology for Investigation

- Aim – not just a snap-shot, but what needs to be done to best sustain the buildings for at least 15 years.
- We have computerized repair history for over 10 years.
- Deterioration inside flats (especially toilet) is often more significant than common areas.
- Presence of sitting tenants.
Methodology Framework

- Information Searching
- Visual Survey
- Testing
- Structural Assessment
- Develop Solution
# Maintenance Record in last 10 years

Example: for XX Estate, toilet

<table>
<thead>
<tr>
<th>Estate</th>
<th>Block</th>
<th>Total No. of Flats (A)</th>
<th>No. of Toilet Spalling Cases (B)</th>
<th>No. of Toilet Seepage Cases (C)</th>
<th>No. of Toilet Spalling &amp; Seepage Cases (B)+(C)</th>
<th>No. of Toilet Spalling &amp; Seepage Cases per 100 Flats</th>
<th>No. of Toilet with Repair more than once</th>
<th>No. of Toilet Repaired at Toilet</th>
<th>No. of Toilet with Spalling &amp; Seepage Cases</th>
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<tbody>
<tr>
<td>A</td>
<td>A</td>
<td>753</td>
<td>185</td>
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<td>603</td>
<td>78</td>
<td>481</td>
<td>199</td>
<td>176</td>
</tr>
</tbody>
</table>
Visual Survey

- Where, how (serious), why?
- Provide information for planning testing work
- Limitations
  - Representativeness
    - In flat, at least : 5%
    - Common area : all
Key Tests

- Open up and reinforcement survey
- Concrete core compression test
- Chloride content
- Carbonation front measurement
- Moisture meter measurement
Opening-ups

- Steel bar size and spacing
- Concrete cover
- Carbonation depth
Steel Bar Measurement

Based on BD38/93

Cross sectional area of Steel Bar is the minimum:

\[
\frac{\pi}{4} \times Y_{\text{min}} \times X_{\text{min}}
\]

\[
\frac{\pi}{4} \times Y_{\text{min}} \times X_{\text{min}}
\]
Chloride Content Test

Average chloride content and profile

Hole drilling to extract concrete powder for chloride diagnosis.
Moisture Meter Measurement

- Calibration against actual moisture content in concrete
- Regular grids and profile
Structural Assessment

- Statistical approach in strength assessment
- Global vs local considerations
Develop Repair Solution

- BS EN 1504 - first comprehensive concrete repair standard
- Guides on product performance
- Principles and repair methods for concrete defects and reinforcement corrosion
Develop Repair Solution

- Varying extent of defects
- Tailored solutions
Comprehensive Structural Investigation on Toilets at Wo Lok Estate
Desk Study

- Reports
- Design
- Repair Records
Desk Study
(Information Collected)

a) Toilet improvement was carried out during 1995 to 1997

b) For the past 10 years, about half of toilets received seepage or concrete repair, about 1/3 of which were repaired more than once

c) Toilets were converted from squatting type to sitting type
Desk Study

Squatting Type Toilet

Concrete filling

In-filled cement/sand

Sitting Type Toilet
Visual Survey

Soil Pipe

Flushing Pipe

Floor drain
Visual Survey

Taking Photo

Moisture Survey

Tapping Test
Visual Conditions of Toilet Ceiling

- Fair
- Moderate
- Poor
Moisture Condition of Toilet Slabs

Dry

Locally Wet

Wet
Visual Survey
(Dinning Room adjoining Toilet)
Testing and Measurement
Testing and Measurement
Testing and Measurement

Core Compression Test

Steel Bar Measurement

Carbonation Test

Laboratory Test
Corrosion of Rebars

- Pitting Corrosion
- General Corrosion
- Pitting Corrosion
Cause of Defects

Reinforced concrete wall

In-filled sand

Rebar

Non-structural R.C. wall

TOILET

DINNING ROOM
Structural and Durability Assessment Findings

a) Structurally adequate

b) Reinforcement bars are vulnerable to deterioration
Repair Solution
Toilet Improvement

- In-filled cement/sand
- Wall Finishes
- High Performance concrete
- Closed-end Pipes
- Slab Thickness Increased
- In-filled cement/sand
Patch Accelerated Corrosion

Patch Accelerated Corrosion

Repaired Area
Installation of Sacrificial Anodes
Installation of Sacrificial Anodes

Sacrificial Anodes

End of presentation. Thank you.