Conservation of Historic Concrete Buildings Case Study
Structural and Material Appraisal of the Central Market

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Central Market
Time of Constructions

- Original Building was completed in 1939
- Several Addition & Alteration Works carried out throughout its operation life
  - 1950’s
  - 1970’s
  - 1990’s

Roof A&A in 1950’s
Roof A&A in 1970’s
Various A&A in 1990’s
Framing Plans

- Framing Plans of the existing building
  (The building is approximately 40m wide X 100m long X 20m tall)
View of the 1st Floor Central Corridor
Structural Features of Central Market

Haunch Beam

Transfer Beam (At Roof Floor)

Twin Beams
Structural Features of Central Market

- External Fins
- Non-structural concrete benches, tanks and partitions
- Column Head
- Grand Staircase
- Non-structural concrete shelves
- Non-structural concrete benches, tanks and partitions
Structural Form & Loads Path of Central Market

- Portal Frame system resist Lateral Wind Load
- Slab, Beam, Column system resist Gravity Load
- All loading will transfer to Foundation

Gravity Load

Lateral Load (Half Building Shown)
Back – Analysis

- **Design Live Load**

  - **Retail/Market (30’s)** – 5.4 kPa
  - **M & E (90’s)** – 7.5 kPa
  - **Inaccessible Roof (90’s)** – 2 kPa
  - **Stair/Landing (30’s)** – 5.7 kPa
  - **Domestic (30’s)** – 3.3 kPa
  - **Staircase (90’s)** – 3.5 kPa

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**1/F Loading Key Plan**
## Back – Analysis

<table>
<thead>
<tr>
<th>Wind Effect</th>
<th>Checking</th>
</tr>
</thead>
<tbody>
<tr>
<td>L.C.C. By-laws 1915</td>
<td>OK with 33% Enhancement</td>
</tr>
<tr>
<td>HK Building Regulation 1956</td>
<td>Not OK</td>
</tr>
<tr>
<td>HK Code of Practice on Wind Effect 1983</td>
<td>Not OK</td>
</tr>
<tr>
<td>HK Code of Practice on Wind Effect 2004</td>
<td>Not OK</td>
</tr>
</tbody>
</table>
Reinforcement Deduced from Open-up Inspection and Back Calculation

Reinforcement in Primary Beam

Reinforcement in Slabs

Reinforcement in Secondary Beam

Reinforcement in Columns
Foundation

- Lack of information on existing foundation
- Approximate dimension of pilecaps is retrieved from Site Investigation
- An article extracted from “The Hong Kong Builders” has reported Cast in-situ Vibro Piles foundation system is used
Foundation – Vibro Pile

**Fig. 8.26. Stages in forming a Vibro Pile**

(a) Driving pile tube.
(b) Concreting pile shaft.
(c) Ramming concrete with pile tube.
Non-Compliance with Current Codes and Standards

- **Fire Resistant Period of Structural Elements (CoP of FRC 1996)**
  - 2 Hours of FRP for every elements is required for “Place of Assembly” which exceeding 7000m³ but not exceeding 28000m³

- **Wind Load (CoP on Wind Effects 2004)**

  ![Wind Load Diagram]

  **HK Wind Code 2004**
  - 2.23 kPa
  - 2.01 kPa
  - 1.82 kPa

  **LCC By-laws 1915**
  - 0.98 kPa
Significance of Central Market

<table>
<thead>
<tr>
<th>Central Market</th>
<th>Other Historical Building</th>
</tr>
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<tbody>
<tr>
<td>Skeleton Frame Action</td>
<td>Brick wall as stability element, Steel joists, concrete, timber or steel floor</td>
</tr>
<tr>
<td>Composite action</td>
<td>Discontinuous joints between different material</td>
</tr>
<tr>
<td>Same material for the whole building</td>
<td></td>
</tr>
<tr>
<td>Materials are installed in-situ</td>
<td>Pre-fabricated steel joists</td>
</tr>
<tr>
<td>(e.g. Reinforcement and Concrete)</td>
<td></td>
</tr>
</tbody>
</table>
Famous Historic Concrete Buildings

Roman Pantheon – the largest unreinforced solid concrete dome

Boston City Hall 1968 – both pre-cast and poured in place concrete
Central Market 1930’s

Mei Ho House 1950’s
Significance of Central Market Concrete Materials

1. Monolithic – Flexible
2. Truly Composite
3. In-Situ
Concerns on Historical Concrete Buildings

Materials Appraisals Concerns

- Durability
  - Could be chemical
  - Could be physical

Performance depends on Environmental Exposure and maintenance
Causes of Concrete Deterioration

<table>
<thead>
<tr>
<th>Category</th>
<th>Causes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental Influences</td>
<td>• Carbon dioxide&lt;br&gt;• Acidic gases</td>
</tr>
<tr>
<td>Inferior Materials</td>
<td>• Too high cement content&lt;br&gt;• Poor aggregate selection</td>
</tr>
<tr>
<td>Poor Workmanship</td>
<td>• Poor mixing</td>
</tr>
<tr>
<td>Inadequate Materials Selection</td>
<td>• Inadequate design for creep&lt;br&gt;• Incorrect concrete grade for purpose</td>
</tr>
<tr>
<td>Inadequate Maintenance</td>
<td>• Lack of inspection and effective repair</td>
</tr>
</tbody>
</table>
Visual Survey - Extent of Defects

Ground Floor

First Floor
Examples of Materials Testing Assessment

Test Plan – Test Location at First Floor
Examples of Test Locations

Detailed Sampling Area

Random Sampling Area
Material Testing – Chemical

- Carbonation affects pH value of concrete and reduces corrosion protection
- Chlorides causes pitting and corrosion of reinforcement bars
Material Testing – Physical

- Strength of concrete used in structures
- To verify the design strength of material
- Rebound Hammer test relates to the surface hardness of concrete
- Open up inspection allows reinforcement content & arrangement retrieved for structural back analysis
- Condition of reinforcement assessed
Material Test Results – 1

Strength Assessment

<table>
<thead>
<tr>
<th>Material Strength</th>
<th>Average Tested Strength of Material</th>
<th>Design Strength based on LCC By-laws 1915</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete Strength</td>
<td>17.8 MPa</td>
<td>15.5 MPa</td>
</tr>
<tr>
<td>Reinforcement Strength</td>
<td>139.7 N/mm²</td>
<td>110 N/mm²</td>
</tr>
</tbody>
</table>

1. The estimated strength from tests conforms with assumptions made on material used in the original Central Market
2. The deduced design strength of materials are used in structural back analysis
Material Test Results – 2

Durability Assessment

<table>
<thead>
<tr>
<th>Test Carried Out</th>
<th>Average Test Result</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Beam</td>
</tr>
<tr>
<td>Concrete Cover Meter</td>
<td>23 mm</td>
</tr>
<tr>
<td>Depth of Carbonation</td>
<td>43 mm</td>
</tr>
</tbody>
</table>

- Beam and Slab have carbonation depth greater than their nominal covers
- Protection provided by concrete to reinforcement has been lost
- Risk of reinforcement corrosion
Material Test Results – 3
Predication of Life Cycle of Concrete based on Carbonation Depth

Concrete Service Life Prediction Based on the Results of Carbonation Depth

Graph showing the predicted service life of concrete elements (Beam, Slab, Column) based on the carbonation depth over a period of years. The graph indicates the current carbonation depth and predicts the depth over time.
Material Test Results – 4

Durability Assessment

- **Chloride Content**
  - 11 out of 80 tested samples were found high level of chloride content
  - High level of chloride content samples are taken from defective areas

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![Interpretation of Chloride Profile in respect to Concrete Depth (Example)](image1)

**Chloride Profile** in respect to Concrete Depth (Example)

Threshold Concentration for Corrosion (0.03%)

- **Rebar 1**: Chloride concentration: 0.12% (Corroding) at average rebar depth of 40 mm.
- **Rebar 2**: Chloride concentration: 0.03% (Threshold: Start Corrosion) at average rebar depth of 62 mm.
- **Rebar 3**: Chloride concentration: 0.001% (No Corrosion) at the average depth of 80 mm.

**Post-Tensioned Duct**: Chloride concentration is negligible at the average depth of 95 mm.
Material Test Results – 5

Durability Assessment

- Concrete Open Up Inspection
  - Exposed reinforcement bars are of mild corrosion status
  - The cause of corrosion is possibly due to lost of protection from carbonated concrete
Possible Repair Approach

- All proposed approach is based on assumption the building will have regular maintenance in the future operation.

<table>
<thead>
<tr>
<th>Elements</th>
<th>Possible Repair Approach</th>
<th>Applicable for</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Nominal cover</td>
</tr>
<tr>
<td>Beam/Slab</td>
<td>Patch Repair *</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Partial Re-casting / Re-construction</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Re-alkalization</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Repair Method – 1
Conventional Patch Repair

Remove Surface
Deterioration and Replace
with new Concrete

Example of patch repair
Recasting

- The contaminated part of the concrete will be removed
- Replace or recondition any corroded reinforcement
- Recast it with the same or even better grade concrete to restore its structural strength
- Also improve any FRP performance as required
Repair Method - 3
Concrete Re-alkalization

Basic Theory
Electrochemical re-alkalization is non-destructive to halt and prevent corrosion in carbonated concrete. The process raises the pH of the carbonated concrete through electro-osmosis. When an electric field is applied, alkali (hydroxyl) ions migrate from the electrolyte into the concrete, raising its pH to the original levels. The passivating layer of the rebars is thus re-established to protect them from corrosion.
Summary

- A good way of preserving RC buildings as opposed to objects is to keep them in use.

- By understanding the mechanisms of decay and deterioration, we can increase conservation skills for prolonging the life of RC buildings for future generations. However, future maintenance and repair will be an inevitable part of the process.
THANK YOU