Base Isolation Seismic Upgrade of a Heritage Building at Lord Strathcona Elementary School

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• Client / Owner: [VSB logo] Vancouver School Board

• Prime Consultant: The Colborne Architectural Group
Summary

• Heritage 1897 three-storey, load-bearing brick and stone building

• First base isolated building in Canada, new or existing, completed late 2016

• Analysis/design followed provisions for seismically isolated new buildings, first introduced in National Building Code of Canada (NBCC), 2015 edition - 3D NLTH only method accepted *
Vancouver Schools Prototype
Typical Building

- **Beam Beyond**
- **column Beyond**
- **4” Tile**
- **Plaster**
  - **3” Hollow Tile**
  - **Pitch**
  - **6” Hollow Tile**
- **Isolation Plane**
- **Isolator**
- **Slider**
- **12’ +**
- **No Work**
- **All Work Here**
- **12’ +**
- **4” Brick**

**Timber Framed Roof**
$26 M Renewal and Seismic Upgrade
Original Structure
Upgrade Schemes Studied

Conventional
- several schemes
- collapse prevention performance per MEEd performance-based Seismic Retrofit Guidelines

Base Isolation
- Estimated costs of conventional and BI essentially equal *
- Base isolation scheme selected for superior post-earthquake performance and heritage preservation
Earthquake Ground Motions

- Site class C, 2% in 50 year, $\text{Sa}(0.2) = 0.84\text{g}$
- Record selection and scaling per guidelines in Commentary 2015 NBCC *
- Similar magnitude-distance as this site, site class C or D
- For scaling in appropriate period band

<table>
<thead>
<tr>
<th>Source</th>
<th>Magnitude</th>
<th>$R_{rup}$</th>
<th>Period Band</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crustal (5)</td>
<td>M6.3 to M7.3</td>
<td>5 to 50km</td>
<td>0.2 to 1.5s</td>
</tr>
<tr>
<td>Intraslab (5)</td>
<td>M6.5 to M7.5</td>
<td>50 to 120km</td>
<td>0.2 to 1.5s</td>
</tr>
<tr>
<td>Subduction (11)</td>
<td>M8.2 to M9.2</td>
<td>80 to 250km</td>
<td>1 to 4s</td>
</tr>
</tbody>
</table>
Earthquake Ground Motions

- Scaled to be at or above UHS in applicable period range
- All three components ultimately scaled by same value
Analysis

- Full 3D NLTH analysis, design and tendering carried out for 2 systems
  - Lead Rubber Bearing (LRB) combined with sliders
  - Triple friction pendulum system

- LRB/slider system selected (cost, schedule)

- Final design configuration, number of LRBs versus sliders, size of each isolator, determined based on numerous iterations
30 isolators

- lead-rubber bearing (12)
- pot slider bearing (18)
Analysis

- Variability in isolators: lower and upper bound property modification factor methodology per AASHTO “Guide Specification for Seismic Isolation Design”

- Effects of ageing, temperature, rate of loading, cyclic loading, manufacturing variability
Analysis

- 3D NLTH analysis: SAP2000
  - every wall modeled
  - both stiff and soft substructure/soil
  - upper and lower bound isolator properties
  - four unique models for each of three suites of records
  - 12 sets of analyses and results extraction
Analysis

• For each suite, per NBCC 2015 the *mean-plus-one standard deviation* was calculated for:
  - interstorey drift
  - base shear
  - superstructure demand at selected critical points
  - isolation system deformation

• Stability check of bearings under extreme loading conditions
  - Need time-coincident maximum displacement and axial load data
Isolator Testing

- Prototype testing of 2 full scale isolators

- Production isolators installed in building - all tested
Isolator Test Results and Further Analysis

• LRB properties from prototype tests; results within tolerance
• Slider properties (coefficients of friction) per vendor data - waived proposed prototype tests, at vendors request/risk

• LRB isolators production tests; some aspects outside tolerance limits
  - As-tested properties used in re-analysis; performance acceptable

• Sliders; some aspects outside tolerance limits
  - As-tested properties used in re-analysis; performance acceptable

• All reviewed by independent external reviewer * (J Johnson, Reaveley Engineers)
Force displacement properties of LRBs – As-Tested and Aged Properties

Peak movement
230mm

System Stiffness
(Aged Properties)

System Stiffness
(As Tested Properties)

0% 50 100 150 200
Lateral Displacement (mm)

Lateral Force
(% of W)

0 50 100 150 200
Lateral Force
(% of W)

.15W Target Maximum Demand

1/50 Wind

2%
Simplified Construction Sequence

• original structure
Simplified Construction Sequence

- demolish SOG
- excavate and pour portions of new foundation
Simplified Construction Sequence

• install shoring for upper floor and attic
• tolerance 4mm
• (also new timber shear walls in attic; not shown for clarity)
Simplified Construction Sequence

- remove some brick walls (transverse direction, not shown)
- new shotcrete walls at perimeter
Simplified Construction Sequence

- demolish main floor, main interior brick walls and remaining foundations
- (also install some shoring diagonal bracing; not shown for clarity)
Shoring supporting upper two levels of brick walls and timber floors
Simplified Construction Sequence

- complete new foundation
Simplified Construction Sequence

- pour new concrete floor
- connections for upstand beams to exterior wall, pour upstand beams
embedded plates at isolator locations in new main floor
Upstand Beam

- A ‘triple’ redundant design to ensure load transfer with less than 1/16” movement: mechanical wedge design; and two sets of epoxy anchors (one to stone, one to brick)
Simplified Construction Sequence

- install new timber beams and new columns
- Remove upper shoring
- install some isolators
- new interior columns (8) in basement
Lead Core Rubber Bearings
Lead Core Rubber Bearing
Simplified Construction Sequence

- new pilasters (22)
- install remaining isolators/sliders
Sliders

8.219" Nominal
Slider Isolator
Simplified Construction Sequence

- partial cut of perimeter wall
Sawcutting 24” wall

custom 4 ft. dia.
Simplified Construction Sequence

• jack all isolators to transfer all building load to isolators
Jacking and Load Transfer

- ‘Flat jacks’ or ‘plate jacks’ – 18” diameter, 1” thick
- First pressurized using fluid; 4 at a time
- Then re-balanced loads and deformations at each location
- 9 set up locations, 22 increments of loading, 22 surveys, 22 visual inspections
- Site engineer checked
  - load and deflection criteria
  - no visual damage to exterior heritage façade
  - before next increment of loading

- Epoxy transfusion, one at a time, 1 ½ days total for all 30

- Maximum vertical movement was 1/8”, max flat jack load was 210 tons
new concrete floor

flat jack

flat jack initially pressurized with water, then transfused with epoxy for permanent strength

only 1/8” expansion required to transfer load
Force-Deflection summary after the load transfer was complete
Completed Structure

Modified Structure

- New concrete upstand for load transfer
- New concrete slab/beam
- New isolator
- Sawcut stone to create new isolation plane
- New anchors
- New shotcrete around perimeter
- Complete cut of perimeter wall

Isolators
Completed isolation plane insulated/caulked, to ‘blend’ with original construction
Fire protection flexible joint

location of new isolation plane (dotted) 250 mm movement

portion of wall ‘hung’ from floor above

mechanical, electrical services designed to accommodate large movement

new partition walls ‘cantilevered’ from floor to isolation plane
load bearing central wall completely demolished

new isolation plane (dotted for illustration) barely visible

fire rated enclosures for isolators
Isolation plane shown by dashed line

Thank you!
Upcoming Base Isolation Canadian Projects?

Vancouver City Hall

Centre Block - Ottawa
Summary

• NLTH analysis required to meet NBCC requirements for base isolation
• Custom combination of bearings and sliders specific and applicable for this ‘light’ building
• Flat jacking very effective for critical load transfer of 2200 tons of building onto isolators
• Above-grade isolation plane is cost effective
• Local contractors have all the skills and capabilities for such projects *
• Floors above the isolation plane can be occupied, while work and jacking proceeds below
• Enhanced post-earthquake (resilience) and heritage preservation is practical for archaic, heritage buildings using this technology