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Seismic Upgrade of the Canadian Parliament Building: Part 3 – Testing Program

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ABSTRACT

Centre Block was constructed in 1916 using materials and techniques considered state-of-the art at the time. This included a combination of unreinforced masonry, steel framing, reinforced concrete, plain concrete, and hollow terracotta tiles. As a precursor to the building's seismic upgrade design, an extensive testing program was completed to investigate the structural properties of its unique materials. The program included in-situ tests, laboratory tests of extracted specimens, ambient vibration tests and cyclic testing of hollow terracotta tile floor subassemblies. This paper provides an overview of the tests and a summary of the results.

Keywords: seismic, material testing, unreinforced masonry, terracotta

INTRODUCTION

Centre Block, Canada's heritage designated federal Parliament building, was constructed in 1916 after fire destroyed an earlier building of the same name that occupied the site. It was reconstructed using materials and techniques considered state-of-the art at the time (see Figure 1). These included mass concrete basement walls, a reinforced concrete ground floor slab, load bearing unreinforced masonry constructed with a high cement content mortar, structural steel framing and hollow terracotta tile floor assemblies. After a century of service, Centre Block is currently undergoing a major renovation to prepare it for its next 100 years. Part of its renovation includes a seismic upgrade.

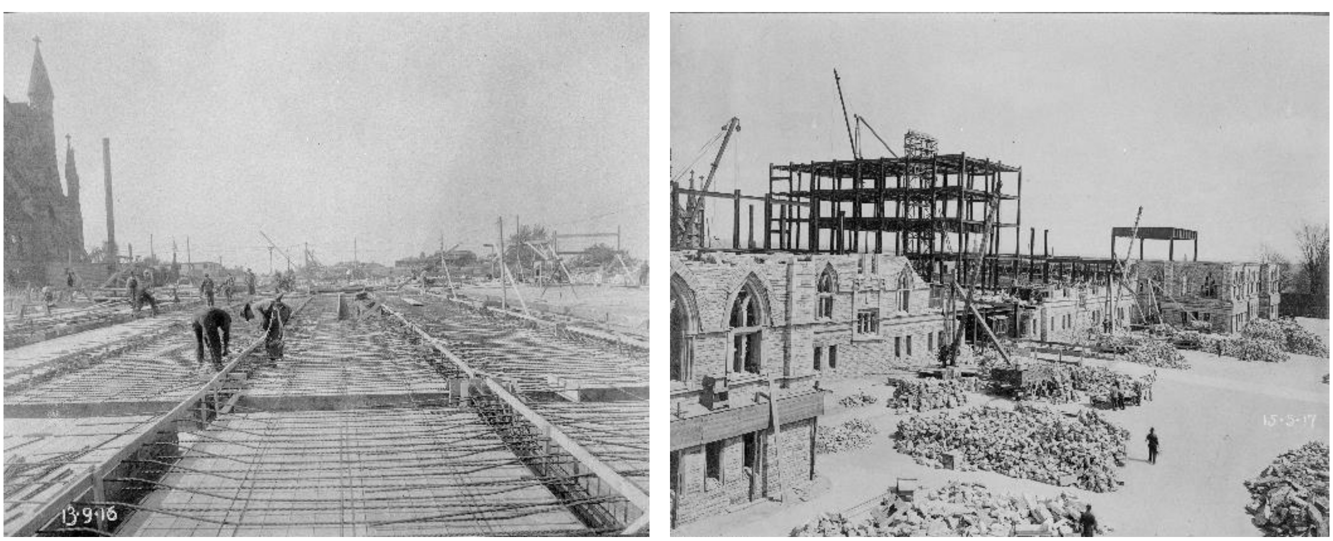

Figure 1: Construction of Centre Block's reinforced L1 slab (left) and load bearing URM walls and steel framing (right)

An extensive testing program has been undertaken to inform Centre Block's seismic upgrade design. This has included strength testing of its various materials, using both in-situ test protocols and laboratory tests of extracted specimens. In addition, ambient vibration testing of the overall structure was performed to provide a verification of the project analytical model, as well cyclic lateral load testing of its hollow terracotta tile floor diaphragms. An overview of the testing initiatives is provided in the following sections.

MATERIAL TESTING

A key first step in Centre Block's seismic upgrade design has been the investigation and testing of its unique material properties. Material properties play an important role in defining both a building's seismic demand and its seismic capacity. An increased knowledge of material properties allows for less conservatism in material property assumptions, potentially reducing required strengthening work.

The following material properties were investigated:

- Clay brick unit compression strength - see Figure 2
- Mortar compression strength - see Figure 3
- Sandstone unit compression strength
- Brick prism (5 course assembly) compression strength (ASTM C1314 protocol) - see Figure 4
- Sandstone prism (3 course assembly) compression (ASTM C1314 protocol) - see Figure 5
- Brick masonry coefficient of friction (ASTM C1531 protocol)
- Stone masonry coefficient of friction (ASTM C1531 protocol)
- Mortar flexural bond strength (ASTM C1072 bond wrench test) – see Figure 6
- In-situ brick masonry stiffness (ASTM C1197 protocol)
- In-situ stone masonry stiffness (ASTM C1197 protocol) - Figure 7
- Concrete compressive strength
- Structural steel tensile strength
- Reinforcing steel tensile strength

Figure 2: Brick unit compression test

Figure 3: Mortar sample compression test

Figure 4: Brick prism compression test

Figure 5: Stone prism compression test

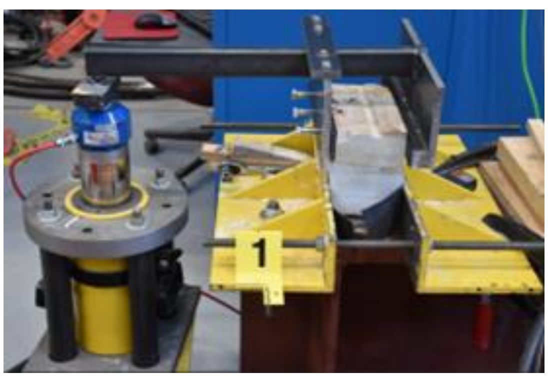

Figure 6: Mortar flexural bond test

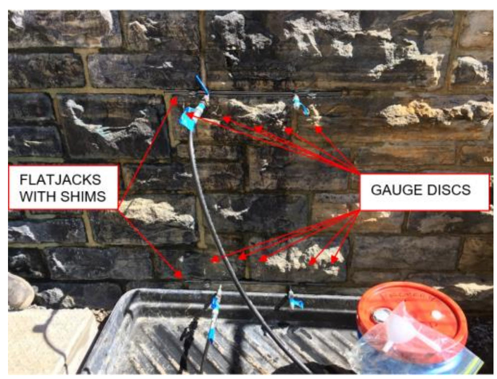

Figure 7: ASTM C1197 test

A summary of the material testing results is presented in Table 1 below:

Table 1: Average material test results

Clay brick compression strength	f'_m = 37.4 MPa	
Mortar compression strength	f'_m = 52.9 MPa	
Sandstone compressive strength	f'_m = 114.0 MPa	
Clay brick masonry	f'_m = 10.3 MPa	E = 5 800 MPa

Sandstone masonry	f'_m = 25.6 MPa	E = 13 300 MPa
Clay brick masonry coefficient of friction	1.0	
Sandstone masonry coefficient of friction	1.0	
Mortar flexural bond strength	f_t =1.0 MPa	
Centre Block basement wall concrete compression strength	f'_c = 16.9 MPa	
Peace Tower pier concrete compression strength	f'_c = 33.7 MPa	
Structural steel yield strength	f_y = 276 MPa	
Twisted reinforcing steel yield strength	f_y = 528 MPa	

AMBIENT VIBRATION TESTING

In 2017, Public Services Procurement Canada (PSPC) engaged Sensequake to perform ambient vibration testing (AVT) of Centre Block. The testing purpose was to empirically identify the dynamic characteristics of Centre Block and the Peace Tower, allowing for a validation/calibration of the project's analytical model. A comparison of the vibration periods determined by Sensequake's AVT to the vibration periods determined from the project analytical model is provided in Table 2 and Table 3 below. An excellent agreement between the empirical AVT results for Centre Block and the project analytical model was observed. For the Peace Tower, an increased allowance for stiffness reduction due to cracking was deemed appropriate.

Table 2: Centre Block natural periods of vibration

Mode no.	Mode type	AVT measured period	Analytical period from computational model
1	1st lateral in NS direction	0.29 sec	0.32 sec
2	1st lateral in EW direction	0.26 sec	0.25 sec

Table 3: Peace Tower natural periods of vibration

Mode no.	Mode type	AVT measured period	Analytical period from computational model	
			(pre-calibration)	(post-calibration)
1	1st lateral in EW direction	0.91 sec	0.83 sec	0.91 sec
2	1st lateral in NS direction	0.83 sec	0.75 sec	0.83 sec
3	1st torsion	0.48 sec	0.39 sec	0.43 sec
4	2nd lateral in EW direction	0.29 sec	0.24 sec	0.26 sec
5	2nd lateral in NS direction	0.25 sec	0.22 sec	0.24 sec
6	3rd lateral in EW direction	0.19 sec	0.17 sec	0.18 sec
7	3rd lateral in NS direction	0.17 sec	0.14 sec	0.16 sec

FLOOR DIAPHRAGM SUBASSEMBLAGE TESTING

One of Centre Block's critical structural components that requires seismic upgrading is its hollow terracotta tile floor diaphragms. These floors are vulnerable to damage when subjected to in-plane (horizontal) deformations due to their brittleness. Additionally, these floors rely on historic steel-to-steel connections, which typically have inadequate capacity to resist seismically induced axial force in combination with a vertical gravity shear force. As a result, an earthquake could jeopardize their ability to support vertical loads. A testing program, conducted at the National Research Council Canada Structures laboratory in Ottawa, was developed to determine an appropriate upgrade strategy.

Cyclic lateral load testing was conducted on replica specimens of Centre Block's hollow terracotta floor assemblies to establish their existing performance as a structural diaphragm (see Figure 8). The same tests were repeated on strengthened assemblies. Two strengthening options were tested: 1) strengthening with a thin ultra-high-performance concrete (UHPC) topping and 2) strengthening with in-plane steel cross-bracing installed beneath the floor.

The tests demonstrated that both upgrade options are viable and provide substantial performance improvement. However, the UHPC topping upgrade option is able to provide a larger strength and stiffness enhancement relative to the upgrade option using steel cross bracing. Furthermore, the UHPC option requires less physical space to implement and is simpler to construct. Consequently, it has been selected as the preferred diaphragm upgrade option for Centre Block's rehabilitation.

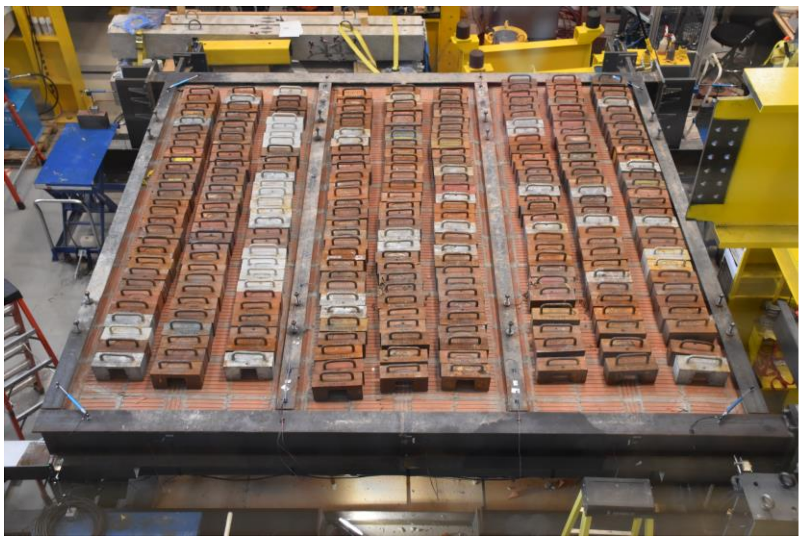

Figure 8: Hollow terracotta floor tile diaphragm reversed cyclic lateral load testing

SUMMARY

The Centre Block Rehabilitation is a project of national importance, and one of the largest heritage building renovations ever undertaken in Canada. As such it provides a unique opportunity to investigate early 20th century materials and construction methods. A significant quantity of material testing has been performed as a precursor to Centre Block's seismic upgrade design, providing a useful database of material properties. The hollow terracotta floor tile diaphragm testing has also contributed to the existing body of knowledge regarding the seismic performance of this historic floor assembly.

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