Victoria Memorial Museum Building Rehabilitation Project

The Victoria Memorial Museum Building (VMMB), which now houses the Canadian Museum of Nature, is one of the most significant heritage structures in Ottawa. Constructed between 1905 and 1910, the four-storey stone masonry structure was the first purpose-built museum building in Canada. The VMMB is designated a Classified (the highest level) federal heritage building and a Canadian National Historic Site.

In early 2000, the Canadian Museum of Nature initiated a major renovation which included an upgrade to all building systems. Halsall Associates was retained as structural engineers to remediate distress caused by settlement, seismically retrofit the existing building, and help create the new Queens Lantern.

The combination of the building's heavy stone masonry structure, its site conditions and its heritage designation made the VMMB Rehabilitation Project a structural challenge – and the opportunity of a lifetime.

VMMB is a heavy, stone-masonry structure which bears on a 30m deep deposit of silty marine clay. Since construction, the exterior walls have undergone significant settlement of more than 500mm. The ground floor has undergone significant differential settlements due to the additional interior supports. Extensive cracking in the masonry walls due to ongoing settlements has also occurred.

The original construction included a front entrance tower which was intended to reflect Parliament Hill's Peace Tower. However, shortly after construction, the original tower started to lean over and was partially demolished due to major foundation failure. When the original tower pulled away from the existing structure, wall cracks up to 300mm wide occurred.

The innovative and cost effective solution to the settlement issues was to recognize that the ongoing settlements are now at a manageable level (a rate of approximately 0.5mm/year) and that this historic building could be preserved rather than replaced. New level floors were constructed with lightweight construction replacing existing toppings. To lighten the load on the foundations, the building's mass was reduced as much as possible through the removal of redundant finishes. New foundations were constructed where required and tied to the existing structure to mitigate future differential movements. Major cracks in the masonry were reconstructed using materials compatible with the heritage fabric of the building.

When the VMMB was designed in the early 1900s, seismic loads were not considered. Today, Ottawa is known to be an area of moderate seismic risk, and this is reflected in current building codes.

Halsall's analysis concluded that the lateral load resisting system of the VMMB, consisting primarily of the unreinforced stone masonry walls, was inadequate to resist design level seismic forces. The seismic upgrade was required not only to provide minimum Code standards for life-safety, but also to protect the heritage building structure from major damage and provide a measure of protection to the museum contents.

Due to the heritage status of the building, the sensitive geotechnical site conditions and the importance of the museum collection, extensive detailed analysis was carried out to determine

Victoria Memorial Museum Building Rehabilitation Project (cont'd)

the site-specific seismic loads to be used in the retrofit design. While the design was being carried out in 2002, the proposed provisions of the 2005 National Building Code of Canada (NBCC) were referenced in recognition of the significant changes to the Code's seismic provisions. Due to the importance of the VMM and its contents, and the uncertainty of the potential magnifying effects of the underlying soft soil conditions on the seismic forces, a site-specific spectral analysis was carried out and included in the design using Dynamic analysis.

The innovative seismic retrofit strategy involved building a new steel endoskeleton truss frame all around the building against the inside of the exterior stone masonry walls. The seismic truss and the size of the steel sections were configured to maximize the stiffness of the frame so that the differential stiffness between the stone masonry walls and the steel frame was minimized.

Removing the interior terracotta walls offset the additional mass created by the new seismic frames. Seismic forces resisted by the steel frame are distributed to the soil by casting a new concrete foundation wall and footing against the inside face of the existing foundation wall. The seismic foundation wall was designed to evenly distribute the point load reactions from the seismic frame columns to the supporting soils without creating new settlement issues.

The existing floor structures consist of a system of steel beams and terracotta flat arches. Due to their heritage value, the arches were not removed; however, new lightweight concrete toppings were added to the floors to replace the original heavier toppings. The lightweight toppings also served to create new diaphragms capable of tying in the existing masonry walls and distributing the seismic loads to the new steel frames.

By taking an integrated design approach, we were able to utilize the space created by the seismic skeleton to provide a dynamic buffer zone, which protects the exterior stone masonry from the controlled high humidity required by the gallery spaces. We also integrated the ventilation system in the lantern using the new structural columns as part of the ductwork.

The new "Queens Lantern" was envisioned as a lightweight replacement of the original failed tower. It was to provide a new iconic entrance and facilitate new circulation within the museum through the introduction of the stunning steel butterfly stairs. The innovative structural solution to creating the glass box above the original tower foundations was to suspend the new construction from a new cantilevered roof structure which, in turn, was supported by new columns and elevator cores extending down to a new raft foundation at the sub-basement level. The load on the soil was balanced by sub-excavating a storey of soil from beneath the basement floor in this area.

The reuse of an existing building is one of the foundations of sustainability and was one of our primary goals for this project from the outset. Through innovative and heritage-sensitive structural engineering, Halsall Associates contributed to the renewal of one of Canada's most important heritage buildings. The Heritage "Castle" in Ottawa was returned to the community as a revitalized home for the Canadian Museum of Nature, hosting record attendance – the number of annual visitors to the museum has more than doubled since reopening – and garnering accolades and attention from the general public and the media.

Victoria Memorial Museum Building

Submitted by Halsall Associates
May 8, 2012

Halsall

Victoria Memorial Museum Building

NEW APPLICATION OF EXISTING TECHNIQUES/ORIGINALITY/INNOVATION

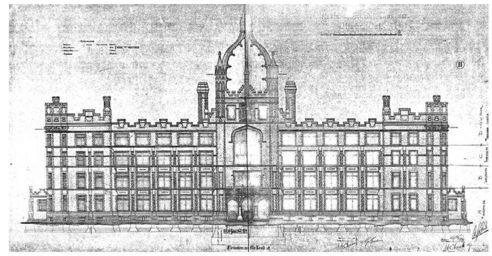
Introduction

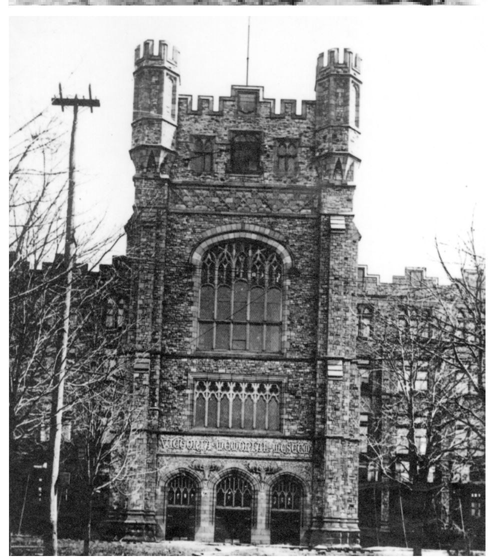
The Victoria Memorial Museum Building (VMMB) was Canada's first purpose-built national museum. Constructed between 1905 and 1910, it is a symbol of Canada's aspirations to be understood as a nation that excelled in learning, the sciences and art. The VMMB was in the past home to the collections of the National Gallery of Canada, the Canadian Museum of Civilization and, today, the Canadian Museum of Nature. From 1916 to 1919, following a fire in Canada's Parliament, it even served as a temporary home for the Canadian Houses of Parliament.

The VMMB was designed by the Dominion Chief Architect, David Ewart. Locally known as "the Castle," it is a four-storey Beaux-Arts composition in neogothic "clothing." Its imposing exterior has been variously characterized as Tudor Gothic, Scottish Baronial and, by Ewart himself, Free Gothic. The VMMB has been designated a Classified (the highest level) federal heritage building and a Canadian National Historic Site.

In early 2000, Halsall Associates was selected to participate in a major renovation of the VMMB. Halsall's role as structural engineers included remedying complex settlement issues, providing a seismic retrofit to bring the building up to the standards of the National Building Code of Canada (NBCC), and helping design the Queen's Lantern, a new glass tower to replace the original masonry tower that had been removed in 1915 due to structural instability.

The structural challenges were considerable and required an array of innovative and complex techniques. Each of the three components of Halsall's work on this project are discussed below.





The structural challenges were considerable and required an array of innovative and complex techniques.

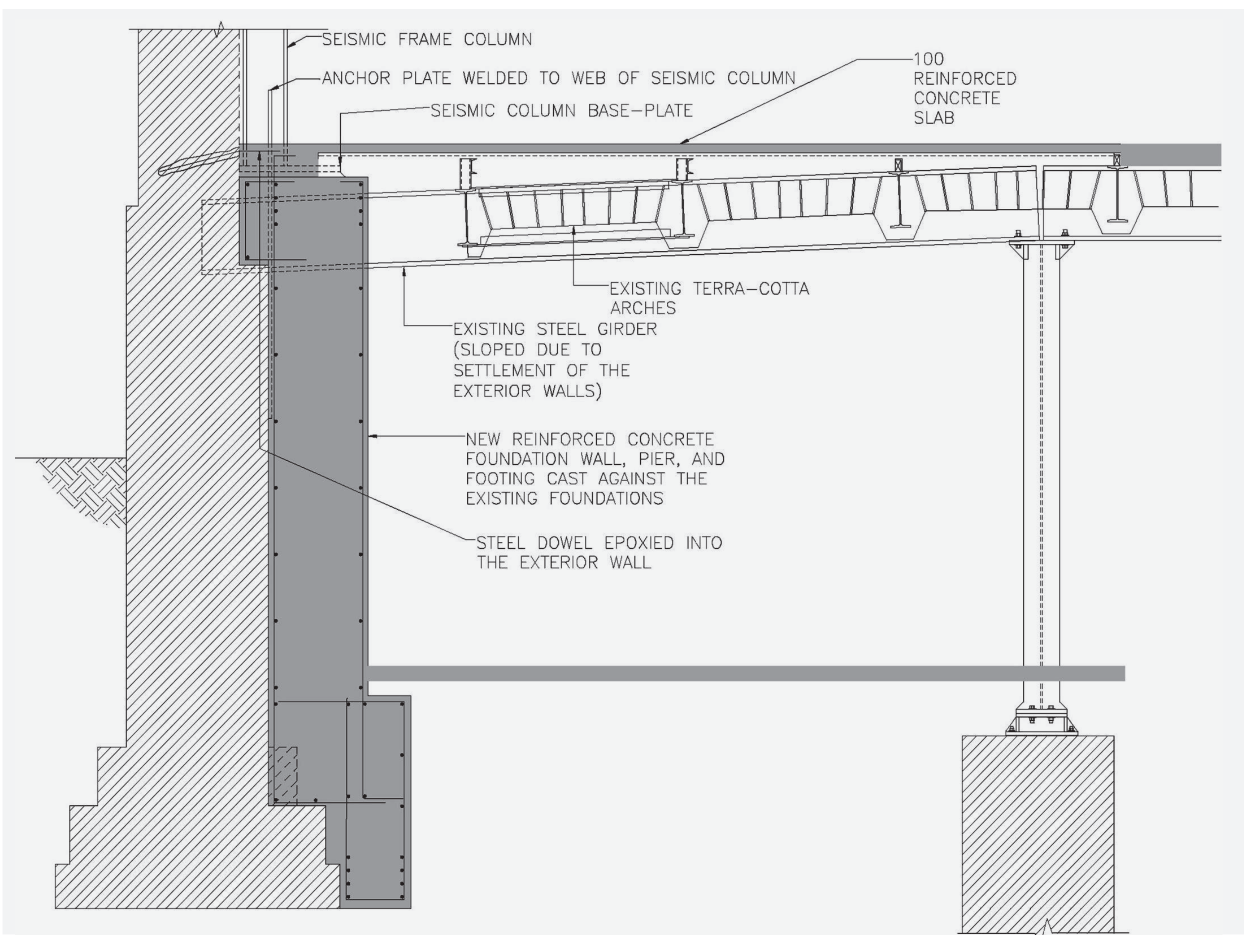
Settlement Remediation

The VMMB is a heavy, stone-masonry structure resting on a 30-metre-deep deposit of Leda clay, a silty marine material. Since construction, the exterior walls have settled more than 500 mm into the underlying deposit of Leda clay, causing extensive cracking. When the original entrance tower failed, pulling away from the main building, cracks up to 300 mm wide occurred. In addition, the ground floor underwent significant differential settlements with corresponding distress.

Following a detailed analysis, we recognized that the ongoing settlements had reached a manageable level (approximately 0.5 mm/year) and that we could preserve, rather than replace, the existing building and with it, an important part of Canada's heritage.

The floor construction generally consists of steel beams and girders supporting terra-cotta flat arches. We constructed new level floors using lightweight toppings on top of the

Drawing of new foundation with steel beams, and lightweight steel level floor.



terra-cotta arches. Where the original ground floor structure was significantly deformed, we designed a light weight steel substructure above the original deformed structure.

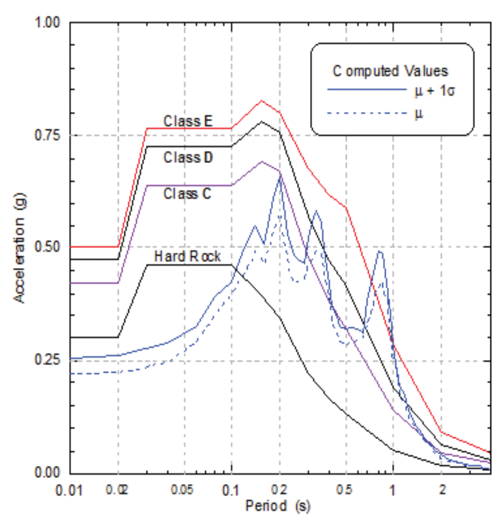
The original floors, consisting of hardwood over a mortar bed, had to be removed due to asbestos contamination. We replaced them with new, reinforced concrete toppings, creating floor diaphragms to tie the building together. The diaphragms redistribute seismic loads and tie the original stone masonry back to the structure.

To reduce the mass of the building and lighten the load on the foundations, we removed all redundant finishes. Where we added new concrete, we used structural-quality lightweight concrete throughout the project. Where we found it necessary to construct new foundations, we tied them to the existing structure to mitigate future differential movements. Finally, to restore major cracks in the masonry, we selected materials compatible with the heritage fabric of the building.

Seismic Retrofit

At the time of the VMMB's construction, building design did not take account of seismic loads. Ottawa is now known to be in an area of moderate seismic risk. Halsall's analysis of the original structure of the VMMB determined that the lateral load resisting system consisting primarily of unreinforced stone masonry was insufficient to resist design-level seismic forces. We concluded that a seismic upgrade was necessary not only to meet NBCC standards for life-safety, but also to protect the historic museum building and its important contents.

Due to the VMMB's heritage status, sensitive geotechnical site conditions, and the importance of the museum's collections, we conducted extensive, detailed analysis to determine the site-specific seismic loads to be used in the retrofit design. We performed a spectral analysis of the site and incorporated dynamic modelling based on a site-specific response spectrum into our design. Recognizing the importance of this heritage building and the value of the museum collection, the design team planned an upgrade of the seismic resistance to 150% of the code, exceeding the minimum life safety requirements. Although we carried out the work in 2002, we referenced the seismic provisions of the 2005 NBCC in anticipation of significant planned changes.



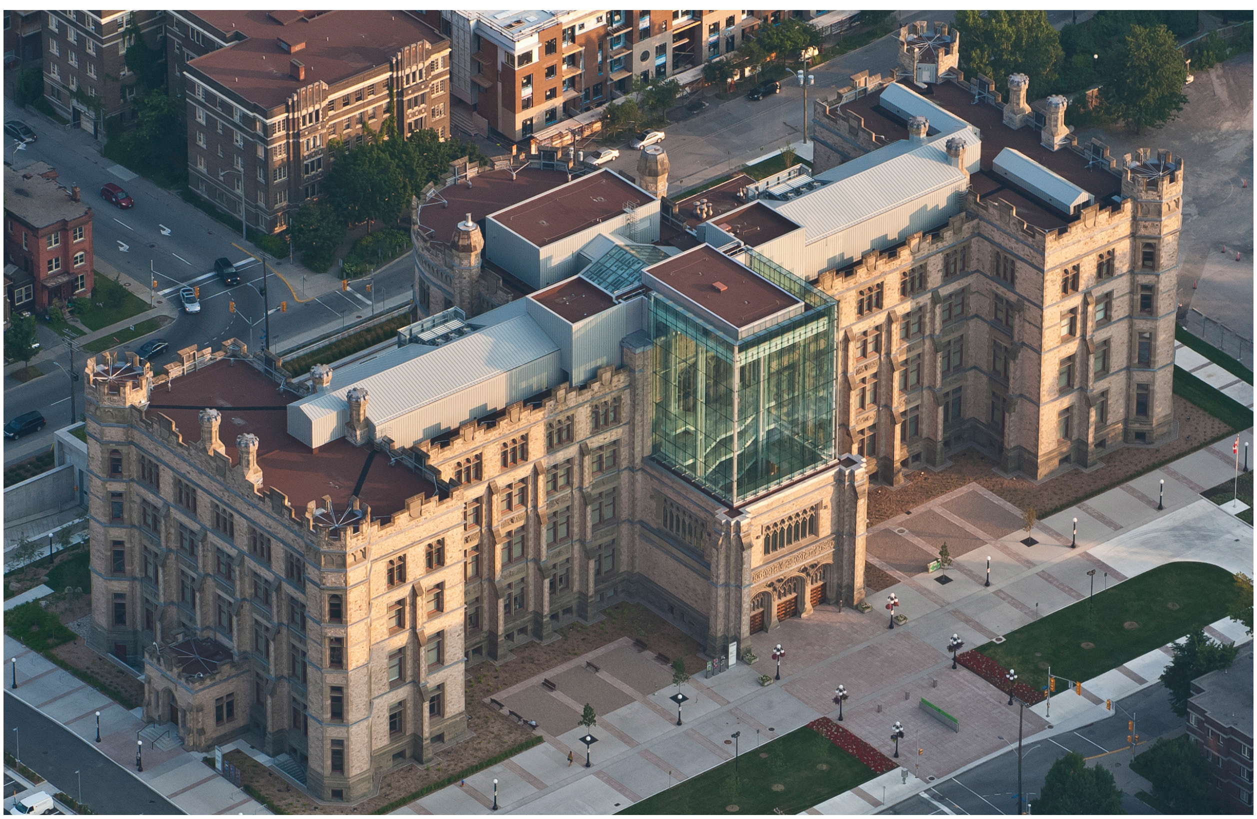
Top to bottom: 300mm cracks; ground floor differential settlements; Spectral analysis of the site

Our final retrofit strategy incorporated numerous innovations. First, we built a seismic endoskeleton consisting of a steel truss frame that extends around the entire building against the inside of the exterior stone masonry walls. We configured the truss and set the size of the steel sections to maximize stiffness, minimizing the differential stiffness between the skeleton and the stone masonry walls. While the skeleton added to the building's mass, we were able to offset this by removing terra-cotta walls from the building's interior.

Detail Aerial view of parapet restraints.

Secondly, to distribute the forces absorbed by the seismic skeleton to the soil, we constructed a new concrete foundation wall and footing against the inside face of the existing foundation wall. We designed the new wall to evenly distribute the point load reactions from the seismic skeleton's columns to the supporting soils without creating new settlement issues.

Finally, the museum's original floor structure consisted of a system of steel beams and terracotta flat arches. We retained the arches due to their heritage value. However, by installing new, lightweight concrete floor toppings, we



were able to create diaphragms that tie in the existing masonry walls and distribute seismic loads to the new steel skeleton.

During the early stages of the construction process we were able to verify the structural capacity of the unreinforced flat arch floor construction by load test. However, during demolition of ceiling finishes in the renewal process, it became apparent that the terra-cotta masonry floor structure could pose a risk from falling pieces of mortar and tile.

To mitigate this risk we designed a wire mesh catcher system suspended from the steel beams below the terra-cotta. As in any museum, there is a need for suspending building systems as well as artifacts. To eliminate the need to install anchors into the terra-cotta soffit, we designed a structural grid specifically for suspending artifacts throughout the gallery spaces.

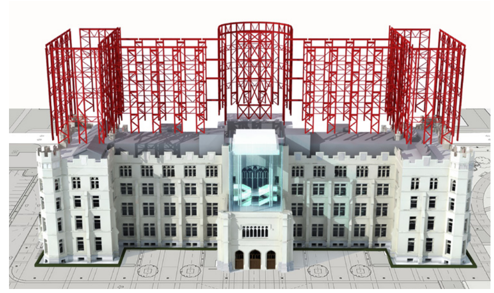
The VMMB features high stone masonry parapets and other projecting elements above the roof. We identified these as a particular seismic risk and designed a discrete steel back up bracing system to ensure that in the event of an earthquake the parapets would not tumble down.

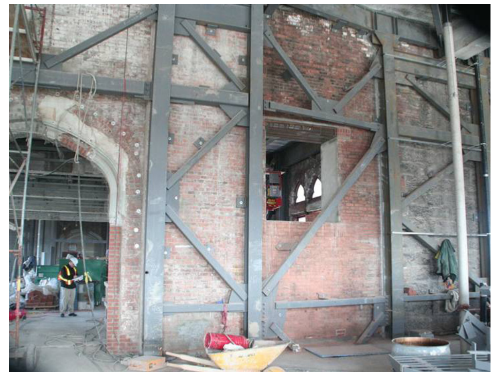
The Queens' Lantern

Named in honour of the current Queen of Canada, Elizabeth II, and her forbear, Victoria, the new Queens' Lantern entrance structure was envisioned to function as the visual signature of the museum and its renewal and to improve the circulation of visitors through the museum. The real structural challenge was that the lantern also had to be lightweight. To meet these criteria, the architects designed a striking glass box -- the lantern -- suspended above the foundations of the original tower.

The structural design included a new, cantilevered roof structure from which the glass lantern is suspended. The steel roof structure is in turn supported on new columns and elevator cores which extend down to a new raft foundation at the sub-basement level.

Recognizing that the original tower foundations had failed, we needed to carefully balance the load on the underlying soil. To achieve this we sub-excavated a storey of soil from beneath the basement floor within the lantern footprint.





Top to bottom: Drawing of seismic endoskeleton; details of seismic endoskeleton; wire mesh catcher system; gallery with suspended artifact.

Installation of the cantilevered roof structure

Inside the lantern, a dramatic new “butterfly” staircase provides visibly improved visitor access to the museum’s upper storeys.

By taking an integrated design approach, we were able to utilize the space created by the seismic skeleton to provide a dynamic buffer zone, which protects the exterior stone masonry from the controlled high humidity required by the gallery spaces. We also integrated the ventilation system in the lantern using the new structural columns as part of the duct work.

In recognition of Halsall’s innovative work on this project as a whole, the firm was invited to share our experience at two technical conferences: “Determination of Design Loads for the Seismic Retrofit of the Victoria Memorial Museum,” 1st Canadian Conference on Effective Design of Structures, McMaster University, (2005) and, “Seismic Retrofit of the Victoria Memorial Museum,” 100th Anniversary Earthquake Conference, San Francisco, California, USA, (2006).

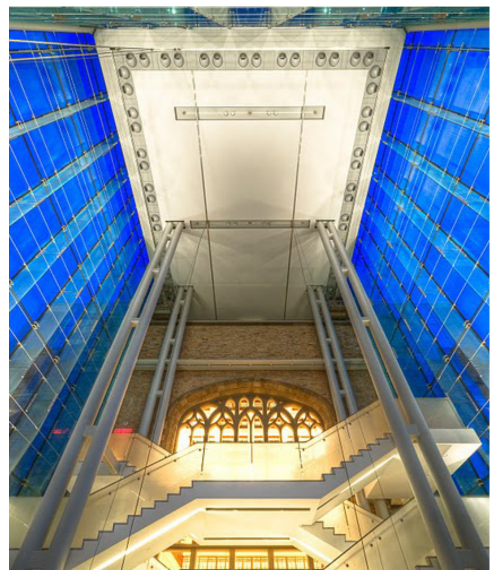
COMPLEXITY

As described above, this project involved a complex set of problems which stemmed from the type of building – a heavy, stone masonry structure – and the site conditions, that is, that the VMMB was built on a 30m deep deposit of silty, marine clay. The combination of these factors had created massive settlement issues which had led to differential settlement in the floors and cracks in both the floors and walls.

The building also required a seismic upgrade, not only for life-safety reasons, but to protect the historic building itself and its important collections. But the solution for the seismic retrofit had to innovative to take account of the building and its site.

Finally, the Queen’s Lantern had to be designed so it would not add undue load and stress.

All of these challenges were compounded by the fact that the VMMB is a heritage-designated building, and any upgrades had to be sensitive to the building’s heritage fabric.



Exterior and interior views of Queen’s lantern

Top to bottom: Halsall boardroom table using surplus steel beam; mammal gallery.

ENVIRONMENTAL IMPACT

The reuse of an existing building is a foundation of sustainability and was one of the primary goals for this project from the outset. Our settlement analysis, which showed that the settlement was occurring at a manageable rate of 0.5 mm/year, gave the design team confidence that this important historic building could indeed be successfully preserved and restored, rather than replaced.

In close collaboration with the museum and design team, we were able to meet environmental goals on numerous other levels. Wherever possible, we ensured that steel members removed from the museum during the renovations were reused to frame new floor openings for building services. We reused the original hardwood floor as a floor finish in parts of the museum. And, with the cooperation of the project team, Halsall salvaged a surplus steel beam to create a feature conference table in our offices which are adjacent to the VMMB.

SOCIAL AND ECONOMIC BENEFITS

Our innovative approach to stabilizing the foundations of the VMMB generated substantial gains in both financial and cultural value. Instead of adding costly new reinforcement piles, we managed stresses on the underlying soil by reducing the weight of the building and selectively constructing new foundations. By doing so, we also preserved as much of the original historic fabric of the building as possible, allowing one of Canada's most significant heritage buildings to be enjoyed for years to come.

Although our work was not formally finished until May 2011, the renewed museum opened to the public on May 22, 2010. The iconic lantern was dedicated by Queen Elizabeth II during her visit to Canada on June 30, 2010.

Through innovative and sensitive structural engineering Halsall Associates has contributed to the renewal of one of Canada's most important heritage buildings and to the revitalization of the Canadian Museum of Nature. The new building has solidified the museum's economic viability: annual attendance numbers have more than doubled, going from around 200,000 before renovation to over 500,000 after the building reopened.

The VMMB has received awards from numerous organizations including the Ontario Association of Architects (Recognition of Excellence) 2011, City of Ottawa Urban Design Award 2011, Ottawa General Contractors Association and the Consulting Engineers of Ontario 2012 Award of Excellence.

The renovated building has also received extensive and effusive media coverage, including feature interviews on CBC Radio and feature articles in Canadian Architect magazine, Canadian Geographic, McLean's magazine, Accolades magazine, and in major dailies such as the Ottawa Citizen. The project was also the subject of a documentary film, *A Modern Castle*, which aired on the History Channel.

MEETING AND EXCEEDING THE OWNER/CLIENT'S NEEDS

A fundamental goal for the project was to preserve an important part of Canada's heritage. To meet this requirement, the project was subject to review by the Federal Heritage Review Board (FHBRO). By working with FHBRO and the project team, Halsall was part of the solution. At the end of the project's design stage, Barry Padolsky (Principal Architect with PKG) advised us that "The presentations by Halsall to FHBRO were a significant contribution to gaining FHBRO approval."

This project had many stakeholders, each of whom had different goals for its success. To ensure that our proposed solutions were technically valid, Halsall participated in several structural charrettes where we tested the concepts not only with the project team but with experts from Public Works and Government Services, as well as representatives from the construction industry and academia.

The ultimate structural solutions developed for the VMMB provide cost-effective strategies from the ground up. Resolving the foundation settlement issues without adding new deep foundations such as piles throughout the building provided significant cost savings and permitted the original structure to be adapted and reused again resulting in economy, as well as preserving part of Canada's Heritage. The final construction cost was completed within the project budget.

Top to bottom: Museum interior

The new building has solidified the museum's economic viability: annual attendance numbers have more than doubled, going from around 200,000 before renovation to over 500,000 after the building reopened.

One of the Museum of Nature's primary goals was that the project be completed on time and that the museum remain open to the public during the renovation. Ensuring that the museum remain opened required significant work on the part of all team members to plan and execute a phased renovation approach. Halsall was a key participant in this process, from planning how the structural work could be phased to designing temporary facilities and dedicating the necessary resources to ensure that unforeseen conditions that occurred as the project progressed could be resolved in a timely manner. The result was that the museum was able to remain open throughout the construction with only minor closures.

Once the date for the Grand reopening was set and the timing for the dedication by Queen Elizabeth II was confirmed, the schedule could not be changed. The VMMB was ready for the festivities.

A measure of the client's satisfaction with Halsall's work on this project is that the Museum continues to seek our advice and participation in the planning and implementation of ongoing exhibits in the Galleries whenever structural questions arise.

Opening Day