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Designing a Test Blasting Program for an Underground Building on Parliament Hill

MARÍA INÉS SUBERCASEAUX, GERRY PERNICA, and MARCUS V. VAN BERS

The need for a service building in Canada's Parliamentary Precinct, requiring removal of rock adjacent to existing structures, prompted the development of a program to characterize the dynamic response of Parliament Hill to blasting.

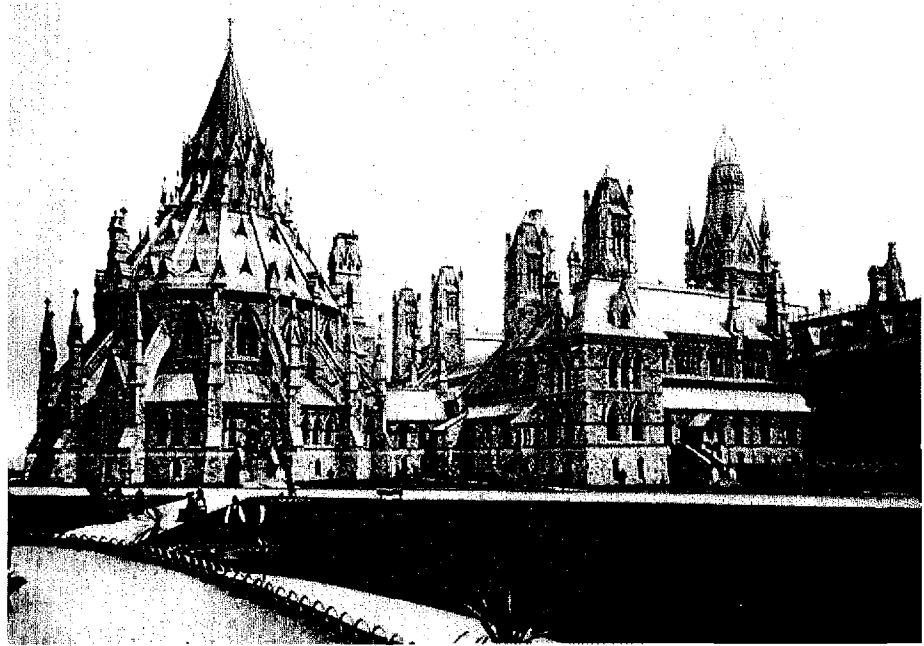


Fig. 2. A nineteenth-century view of the existing library (left) and the old Centre Block building, which was destroyed by fire in February 1916. Courtesy of National Archives of Canada.

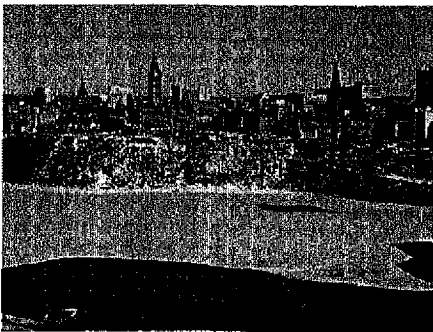


Fig. 1. Overview of Parliament Hill from Hull, Quebec. Openings in the cliffs are ventilation shafts from the new CBUS building. Photograph by Jean-Pierre Jérôme.

Introduction

The Parliament Buildings of Canada sit on Parliament Hill in Ottawa. An escarpment that overlooks the Ottawa River, the hill is located in the downtown core of the city just to the west of the northern terminus of the 150-km-long Rideau Canal (Fig. 1). When Ottawa was designated the capital of the United Canadas in 1858, the hill was purchased from the ordnance department for the site of the Parliament Buildings. The buildings were constructed from 1859 to 1868 and called East Block, Centre Block, the Parliamentary Library, and West Block. The existing Centre Block, which contains both chambers of Parliament (House of Com-

mons and Senate), was constructed between 1916 and 1927. It replaced the original structure, which was destroyed by fire in February 1916. The Parliamentary Library, which adjoins the Centre Block, was saved by the iron doors that still separate the two buildings (Fig. 2).

The rebuilt Centre Block was designed to respect the stylistic character of the original High Gothic Revival building. The rebuilt structure is, however, an original building, whose plan, structural design, and architectural decoration belong to the twentieth century. The conceptual clarity of the building plan has its roots in the École des Beaux-Arts in Paris. In the Centre Block the architects combined Gothic

Revival and Beaux-Arts classicism into a single modern building and created 45 specially designed rooms, each with unique architectural features and craftsmanship.

The Senate occupies the east half of the building and the House of Commons the west half. The two sectors are separated by primary public areas, the Hall of Honour and Confederation Hall, both situated on the central axis. These areas lead to the Parliamentary Library, also located on the central axis at the north end of the building. Centre Block has been designated a National Historic Site and Classified, the highest designation under the Federal Heritage Review policy.

After nearly eighty years, space and services within Centre Block became inadequate for an expanded Parliament. In the late 1980s, a Centre Block Underground Services (CBUS) facility was proposed to mitigate pressure on service space within the building. Construction of this two-story building at the rear of Centre Block required the removal of

about 25,000 m³ of horizontally bedded limestone rock, some situated within 3m of the Centre Block foundation wall. The volume of rock required that blasting be used, since only a ten-week period during the Parliament's summer recess was allotted for the entire excavation.

In early 1996 the Parliamentary Precinct Directorate (PPD) of Public Works and Government Service Canada (PWGSC) asked the Heritage Conservation Program (HCP), an architectural and engineering conservation group within PWGSC, to participate in a test blast program with Golder VME Ltd. (GVME), a member of the CBUS consultant team, and the National Research Council Canada (NRC), a government research and development organization, to characterize the dynamic response of Parliament Hill to blasting. The program was designed to obtain this vital information whilst protecting Parliament Hill from the effects of the test blasts.

Objectives and Initial Considerations

Controlled blasting was considered the only practical method to remove the majority of the estimated 25,000 m³ of bedrock from the CBUS site due to the very restrictive ten-week excavation window (July-August) permitted by the Speaker of the House of Commons. A test blast program was initiated to establish safe blasting criteria and procedures for the excavation of CBUS during the summer of 1997; to evaluate the response of all heritage structures on Parliament Hill affected by the CBUS blasts; and to determine attenuation characteristics of blast-induced ground vibrations on Parliament Hill. The program was conducted during August 1996.

The following preliminary steps were undertaken to implement the test blast program while respecting the heritage designation of Parliament Hill. These included

- a literature survey to retrieve information (experience and standards) on blasting adjacent to heritage structures
- discussions with architectural and engineering consultants to ascertain the extent, depth, and location of the excavation
- a survey of the buildings with the maintenance and operational staff to establish the overall state and condition of building components and acceptable procedures for monitoring both the interior and exterior of the buildings
- review of historical and modern documents on the structural and architectural makeup of the various buildings on Parliament Hill and on the condition of the escarpment
- tour of the Parliamentary Library and Centre Block with a House of Commons curator to examine the most historically, politically, and architecturally sensitive areas within the Library and along the perimeter of the Centre Block adjacent to the CBUS site.

Selection of blast sites. Two sites, each about 80m², were selected within the

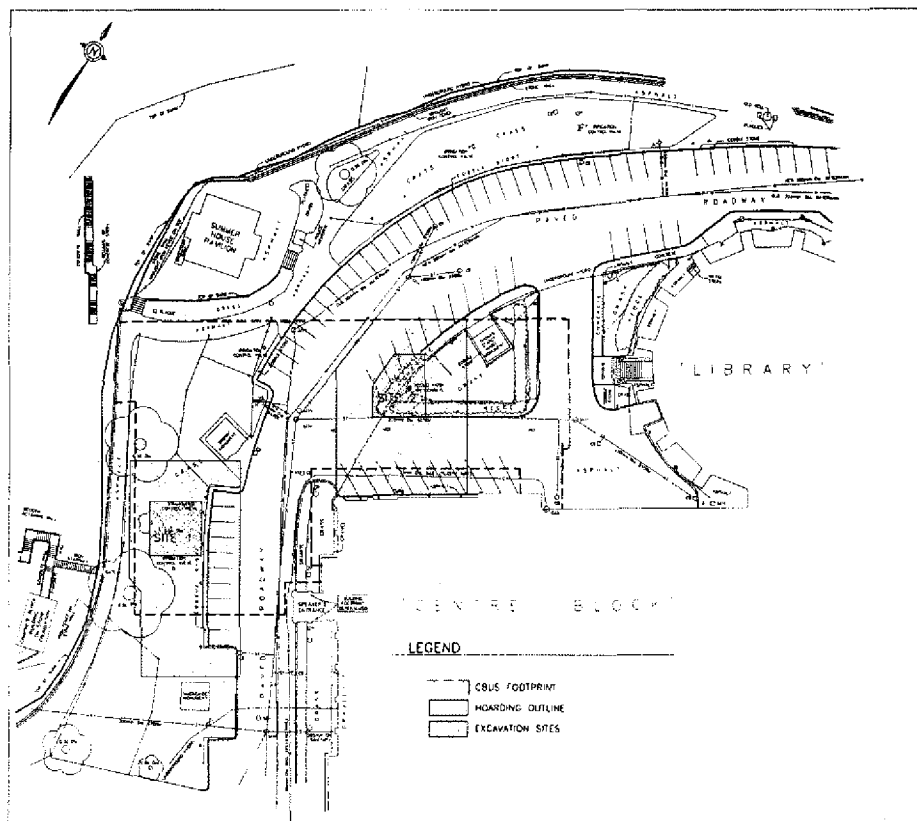


Fig. 3. Plan showing CBUS test-blast locations. Courtesy of Golder VME Limited.

CBUS footprint for the test blasts. Site locations were chosen so that the response to blasting of portions of Parliament Hill adjacent to the excavation could be suitably captured and characterized (Fig. 3). In addition, each site was positioned within the footprint to ensure that pedestrian paths along the perimeter of the escarpment were not obstructed, access to the House of Commons loading dock on the north side of the Centre Block was maintained, and emergency vehicles had access to the Centre Block building. All statues were removed to sites outside the areas hoarded for the tests, and underground services sustained only minimal disruptions. Existing tunnels running from the rear of the Centre Block to the escarpment were outside the test areas.

Pre-blast surveys. Two condition surveys were conducted prior to the test blasts. The first, a detailed examination of the Centre Block and Parliamentary Library, was performed by GVME. Pre-blast condition of the two buildings was established by photographing and videotaping interior corridors, stairwells, rooms, offices, chambers along the perimeter of the buildings nearest the blast sites, and exterior masonry walls and window frames overlooking the sites. Walls, floors, ceilings and windows cracks, and other defects were noted and recorded. Areas susceptible to movement, which would require monitoring during the test blasts, were identified. At the conclusion of the blasts the survey was repeated, and the pre- and post-blast conditions were compared.

On the second survey an archeologist examined the thin layer of soil (about 1-m thick) overlaying the bedrock at the two blast sites and the condition of a small air-intake tunnel just to the east of the CBUS footprint, which connected the Centre Block and Library to the face of the escarpment. The survey indicated that the foundation of a nineteenth-century military barracks had been located near the blast site, directly behind the Centre Block. The masonry tunnel was in relatively good condition, although its opening to both the Library and Centre Block had been bricked over.

Monitoring Program

The monitoring program was designed to minimize the likelihood of blast-induced building damage during the test blast program, to characterize the response of the ground, buildings, and building components and contents on Parliament Hill to technically feasible levels of blasting, and to establish safe blasting levels (velocity criteria) for buildings on Parliament Hill during the excavation of bedrock for CBUS.

Instrumentation. A comprehensive monitoring network was designed, assembled, and installed by GVME and NRC, comprising about 135 velocity and accelerometer sensors attached at 55 locations on the grounds and buildings (Fig. 4). Sensors were mounted on the Parliamentary Library and Centre and West Blocks, in a pedestrian tunnel connecting West and Centre Blocks, on the promontory slope, and on entrances to several air-intake tunnels just below the top of the escarpment. Twenty-four subsurface sensors were grouted into the bedrock at eight locations between the two blast sites and the Centre Block and Library. Twenty-seven cracks, identified during the pre-blast survey and considered representative of the crack set, were monitored for differential movement using pins, tape, and glass telltales.

Sensor layout. Because the supply of sensors and recording channels was limited, a survey of rooms and offices in the Parliamentary Library and Centre and West Blocks was undertaken to select the most appropriate interior locations for the sensors. Several factors were reviewed:

- engineering considerations: the need to characterize building and component responses by determining the extent, amplitude, and frequency content of blast-induced vibrations
- heritage considerations: the need to protect architectural, cultural, historical, and political elements of building fabric and the grounds or objects housed within the buildings or on the grounds
- political considerations: the need to be mindful that the program falls



Fig. 4. Sensors installed on the sidewalk near the Centre Block building assessed the effects of blasting on the ground. Photograph by Maria Inés Subercaseaux.

under the watchful gaze of senior politicians and their staff who work on Parliament Hill.

Building locations. About one-hundred sensors, attached at fifty locations, were selected in the Parliamentary Library and Centre and West Blocks to assess the effects of the blasts on buildings and to assist in the design of the rock-removal program by establishing safe parameters for blasting. About half the sensors monitored the overall vertical and horizontal motions of the buildings, and half monitored the response of vibration-sensitive building components and components supporting significant heritage objects. For example, to monitor building response, sensors were installed on the basement floor slab and foundation wall of the Centre Block; to monitor objects, sensors were mounted on the masonry wall of the House Chamber just below the large, two-story stained-glass windows (Fig. 5). Most sensors in each building were placed along the perimeter, either adjacent to or nearest the CBUS footprint.

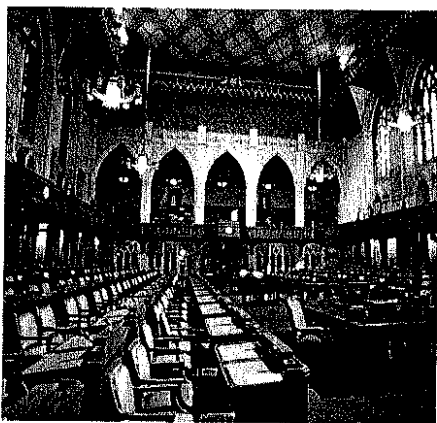


Fig. 5. The interior of the House of Commons, Centre Block, Parliament Hill, 1998. During the test blasting, stained-glass windows and decorative elements had to be monitored by NRC and Golder VMC for blast impact. Photograph by Jean-Pierre Jerome.

Several monitoring/recording stations were set up in the three buildings to minimize the length of cables connecting sensors to data-acquisition systems. Because the buildings were operational, cables were attached to walls and ceilings away from pedestrian traffic and normal maintenance activities. Vinyl tape, which would not mark painted or stone surfaces, held the cables in place.

Ground locations. Sensors were mounted at several locations on the promontory slope to gauge the response of the escarpment to the test blasts. The concern focused on the stability of the slope, especially the top thin layer of soil. Past soil slides had left areas void of green vegetation.

Twenty-four subsurface sensors were also grouted into the bedrock at eight locations between the two blast sites and the Centre Block and Library to determine the attenuation rate for blast-induced vibrations within the bedrock.

Attachment of building sensors. Sensors attached to finished interior (walls and floors) and exterior (stone masonry) surfaces were firmly connected to objects, so as to measure their responses accurately. But strong mechanical devices or adhesives that would permanently damage, disfigure, or stain

surfaces could not be used. Sensors were either taped or glued to the interior surfaces using two-sided tape or non-staining glues, (these products were pre-tested in the laboratory). Sensors placed on exterior masonry surfaces were attached by screws placed into the mortar joints.

Blast Methodology

Ten controlled blasts were detonated at each blast site between August 12 and 23, 1996. Each blast involved detonating between 10 and 15 50-mm diameter holes in lifts (depth of blast) of 1.0 to 2.0m. Each blast consisted of a series of smaller blasts, produced by the action of delay detonators attached to each of the holes. Non-electric millisecond detonators were used because of the presence of radio towers, wireless radios, and cellular phones and to minimize charge weights (amount of explosive material) per delay. Various timing delays were tried to determine the influence of delay time on the vibrational response of adjacent structures. Cartridge explosive products were also used to avoid inaccuracies in the accounting of explosive material within each blast delay (Fig. 6).

Each blast was covered with a minimum of three layers of rubber-tire blasting mats to contain the blast and suppress any potential flyrock. A thin geosynthetic filter fabric was also placed over the mats to contain any small rock fragments that may have been trapped within the rubber mats from previous blasts. Just prior to each blast, the immediate area around the hoarded site was cleared of all pedestrian traffic, and a sequence of warning whistles was sounded.

Data Collection and Analysis

Sensor signals were collected and stored on multi-channel, computer-based data acquisition and analysis systems. About thirty seconds of data, commencing about three seconds prior to the start of each test blast, were collected. Recorded signals were analyzed and displayed immediately after each blast to obtain the response levels at all building locations; to modify, if necessary, previously developed blast parameters; and to set more appropriate data-collection parameters. Vibration data and masonry crack measurements were reviewed after each blast to evaluate the impact on all struc-

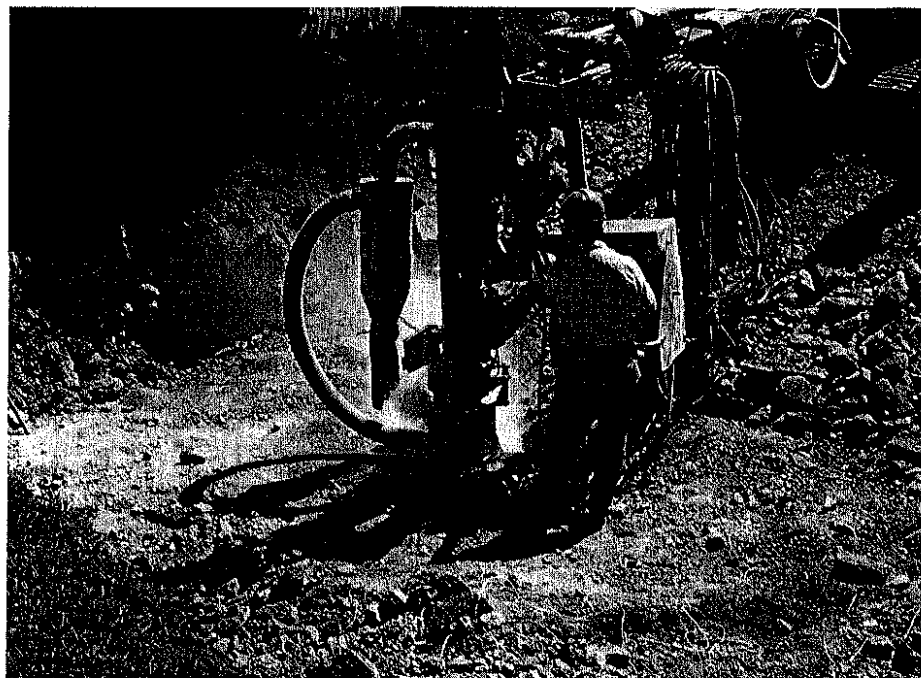


Fig. 6. Blasting areas outlined in Fig. 3 had to be marked on the ground. Grass was removed, boundaries delineated, and the sites were prepared for the installation of cartridge explosives. Photograph by Maria Inés Subercaseaux.

tures and structural components. While this constant review limited the number of blasts to two per day, it was considered integral to the testing program.

Test Blast Protocol

A test blast protocol was developed for the buildings nearest the blast sites to minimize the likelihood of any blast-induced damage going unnoticed. The protocol was modified following the second blast at Site 2 to take into account the responses measured in the masonry pinnacles (freestanding vertical cantilevers) of the Parliamentary Library facing the blast site. The following actions comprised the protocol:

- visual inspection of building components and areas adjacent to the blast site following the first blast at each site, each blast producing vibration levels of concern within the buildings, and each day of blasting
- monitoring of existing cracks in the masonry walls of a stairwell at the northwest corner of the Centre Block
- review of blast-induced vibrations and crack measurements after each test blast
- re-evaluation and, if necessary, adjustment of blast parameters previously developed for the next blast.

The following actions were added to the protocol for blasts at Site 2.

- monitoring of existing cracks in the exterior masonry walls and pinnacles of the Library
- up close visual inspection (using a crane) of the exterior masonry walls and pinnacles of the Library facing the blast site.

Results

A summary of the maximum velocities induced by the test blasts in the Centre Block and Parliamentary Library is given in Table 1, using a few locations, in various portions of the two buildings, which were most affected by the blasts. West Block responses are not given since velocities at monitored locations were less than 1 mm/s and therefore posed no

Table 1. Summary of Maximum Velocities Induced by the Test Blasts in Centre Block and Parliamentary Library

BUILDING	LOCATION	DIRECTION	VELOCITY mm/s
LIBRARY	Top of Pinnacle	Horizontal	27.5
	Mid-Height of Pinnacle	Horizontal	6.9
	Base of Pinnacle	Horizontal	7.9
	Top of Chimney	Horizontal	6.0
	Ring Truss Supporting Dome Lantern	Vertical	6.9
CENTRE BLOCK	2nd Story, Floor, North-West Sector	Vertical	6.1
	3rd Story, Floor, NW Sector	Vertical	3.7
	3rd Story, Floor, SW Sector	Vertical	1.8
	4th Story, Floor, SW Sector	Vertical	1.0
	6th Story, Floor, NW Sector	Vertical	0.9

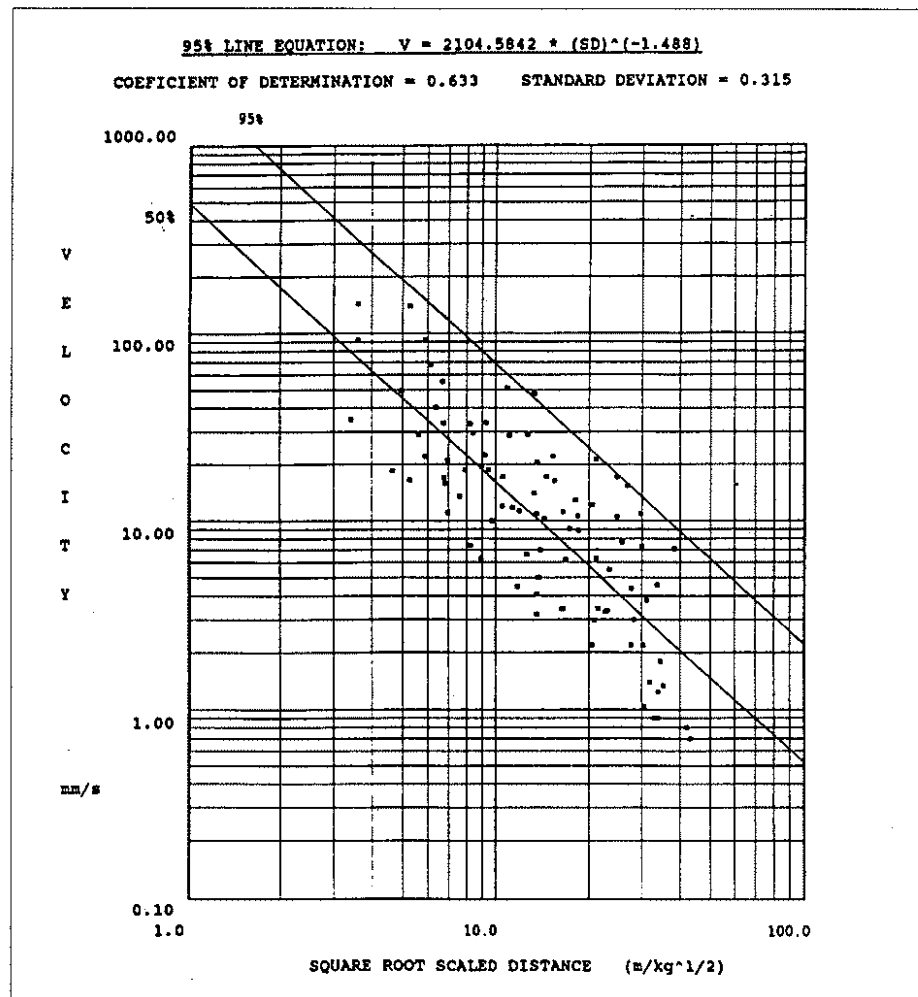


Fig. 7. Ground vibration attenuation characteristics. Courtesy of VME Limited.

threat to the fabric of that structure. Blast-induced velocities in the Centre Block and Library indicated that the pinnacles, vertical cantilevers on the exterior of the Library, underwent the largest motions (up to 28 mm/s) to the test blasts. These sensitive masonry elements were, therefore, chosen to limit the size and closeness of blasts to the Library during the planned excavation for CBUS. The largest responses within the Centre Block were recorded in its northwest corner, the portion of the building nearest the two blast sites. Responses within the Centre Block decreased rapidly with distance from the top of the foundation wall closest to the blast site. To limit blast-induced effects on the building, the foundation wall was selected as the Centre Block element that would, in conjunction with the pinnacles, govern the design of blasts in the CBUS footprint. Finally, because blast-induced responses for the Centre Block and Library contained primarily high-frequency components, vibration criteria for these buildings could be set at economically feasible levels for blasting.

Delay intervals. While a 25 ms delay was used for all ten blasts at Site 1, different intervals were tried at Site 2 to speed up the blast (shorter duration), as well as to slow it down. Increasing the duration of the blast by increasing the delay between groups of holes did not appear to have any noticeable beneficial effect on the vibration intensities or frequencies recorded in the adjacent structures. It was evident, however, that a minimum delay interval of 25 ms should be incorporated into the blasting operations for CBUS due to the scatter in delay times that was recorded between successive detonations by the array of subsurface sensors.

Crack monitoring. Lateral and diagonal displacements measured across selected cracks, typically less than 0.1 mm wide, were no greater than those measured between control points, indicating that movements across cracks were comparable to those occurring elsewhere in the masonry. Nevertheless, cracks did show evidence of both opening and closing

Table 2. Recommended Vibration Criteria for Blasting for Buildings Adjacent to the CBUS Excavation

FREQUENCY RANGE, Hz	VIBRATION LIMITS [†] mm/s	
	Centre Block	Library of Parliament
< 10	5	3
10 to 40	5 to 40	3 to 17.5
> 40	40	17.5

[†] Vibration limits (peak particle velocity) for the two heritage structures are specified for the bedrock directly in front of the foundation wall.

during the blasting program. Measurements taken during a three-day period prior to the commencement of blasting also showed similar amounts of movement. However, no attempt was made to determine the effect of environmental conditions (namely, temperature and humidity) on measured crack displacements either prior to or during the test blast program.

Ground attenuation. A scaled-distance relationship, which describes the rate at which ground vibration levels at the CBUS site decay with increasing distance from a blast, was established from the monitored subsurface responses (Fig. 7). The regression line, which was obtained from the set of bedrock responses, was expressed as $PPV = 2104(SD)^{-1.488}$, where PPV = peak particle velocity (mm/s), SD = scaled distance ($d/W^{0.5}$), d = distance in meters from blast, W = charge weight (weight in kg of explosive material per delay).

Recommendations for CBUS Excavation

Vibration criteria. Table 2 shows vibration criteria recommended for the Centre Block and Parliamentary Library, based on the ground attenuation characteristics and the response of the structures during the test blast program.

Although the vibrations recorded during the test blast program typically

exhibited high-frequency characteristics at both ground and building locations, prudence dictated establishing frequency-dependent vibration criteria due to the possibility of producing substantial and potentially more damaging lower-frequency responses (<20 Hz) at some locations in both buildings. Velocity limits for all other structures, and underground services and tunnels were set at 50 mm/s.

Blast parameters and procedures.

Using the established ground attenuation characteristics and building vibration criteria, minimum blast to building distances were calculated for the excavation of the CBUS site adjacent to the Centre Block and Library. A charge weight of 0.5 kg/delay was assumed, based on the minimum weight required to remove a 1.0-m lift (thickness of rock) during the test blast program. The minimum distances determined the amount of bedrock along the perimeter of the two buildings that needed to be removed by methods other than blasting, such as hoe ramming. Calculations also indicated that about half of the CBUS site could be removed in 2.0-m lifts.

The scaled-distance equation was also used in 1997 by the CBUS blasting contractor to calculate acceptable charge weights for various blast distances to the two buildings from within the CBUS footprint. Three zones, using different blast depths and charge weights, were ultimately established by the contractor. It was further recommended that:

- blasts should be designed using a minimum delay interval of 25 ms
- blast hole diameters should be limited to 64 mm
- only cartridge explosives and non-electric initiators should be used
- hydraulic drills equipped with operating dust collectors and noise suppressors should be used
- a minimum of three layers of blasting mats should be placed over each blast area

- blasting mats should be covered with a filter fabric similar to that used during the test blast program
- the perimeter of the excavation should be line drilled and wall-control blasting techniques, such as buffer blasting, smooth-wall blasting, or cushion blasting, should be employed in perimeter locations.

Blasting contractor. The blasting contractor should submit, for approval, a complete blasting plan describing proposed blast methodology. This should include details on patterns, hole diameter, explosive products, initiation systems, size of blasts, and matting details. The blasting contractor should be pre-approved at the tendering stage. The contractor should include details of

prior experience in similar sensitive environments and provide references.

Conclusion

Blasting parameters and procedures were re-evaluated at the conclusion of the test blast program and refined blasting parameters were developed. The final excavation plan was designed by the blasting contractor using these parameters and procedures and executed during the summer of 1997. Monitoring indicated that vibration limits, established for the excavation, were exceeded by only one of the 279 blasts that were needed to remove the 25,000 m³ of rock from the CBUS footprint. The excavation was completed in just under eight weeks. The work was finished two weeks before the September 15, 1997

deadline, safely, within budget, and with no apparent damage to the historic fabric of Parliament Hill. The test blast program cost less than 10% of the cost of the excavation and proved to be a useful means by which to achieve a safe and practical blasting operation, safeguard the heritage features of Parliament Hill, and minimize the impact to politicians, staff, and visitors.

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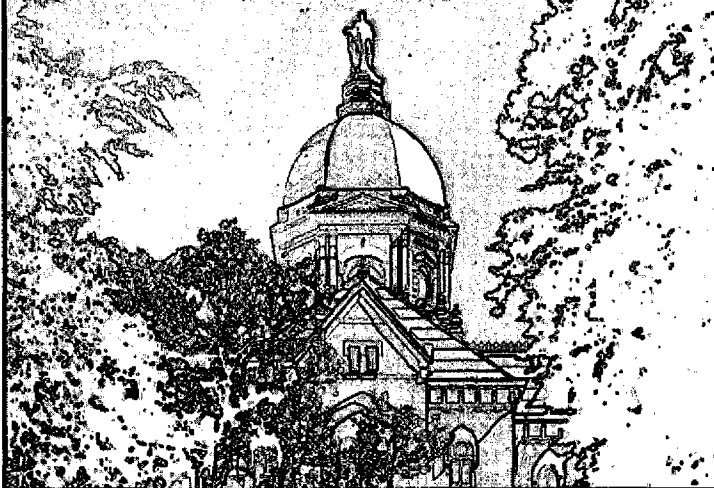
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