GROUND IMPROVEMENT, CONSTRUCTION AND MONITORING OF CHALLENGING UNDERGROUND EXCAVATIONS BENEATH THE SENSITIVE HERITAGE LIBRARY OF PARLIAMENT BUILDING, OTTAWA

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ABSTRACT
The engineering and construction of an almost 10 metre deep, 20 metre diameter basement excavation, along with ancillary underpinning, tunnels, shafts, and raises to provide new underground space in the limestone bedrock forming the foundations of the Library of Parliament in Ottawa, Canada, without damage to the existing heritage building or disruption to the proceedings of Parliament has required innovative application of novel excavation techniques, detailed design of complex excavation geometries and implementation of stringent control procedures to ensure that the required quality of excavations is achieved. Excavation design, ground improvement and heavy pre-reinforcement as well as extensive monitoring arrays of instrumentation, together with detailed supervision of the excavation works have been key to ensuring minimal disturbance to the existing building. The excavation works have now been successfully completed without structural damage to the sensitive heritage structure.

RÉSUMÉ
Ce projet consiste en la construction d'une excavation souterraine d'une profondeur de presque 10 mètres, d'un diamètre de 20 mètres, avec reprise en sous-œuvre, tunnels et puits d'accès dans le roc en calcaire. Le projet a pour but de fournir des espaces souterrains additionnels directement sous les fondations de la Bibliothèque du Parlement à Ottawa, Canada, le tout sans endommager ce trésor du patrimoine national ou encore d'entraîner l'interruption des travaux du Parlement. L'ingénierie et la technologie requise pour mener ce projet à terme ont exigées l'application de technique d'excavation innovatrice, la conception détaillée de géométries complexes d'excavation et l'exécution de procédures rigoureuses de contrôle, incluent une suivi détaillée des travaux, afin d'assurer que la qualité exigée des travaux soit effectivement réalisée. La construction a été complétée avec succès sans générer de dommages structuraux à cet édifice du patrimoine architectural canadien.

1. BACKGROUND

The Library of Parliament in Ottawa is the only remaining part of the original Centre Block and is the most prestigious structure on Parliament Hill. Completed in 1876, the building was acclaimed both in Canada and abroad for its beauty and grandeur (ref. Figure 1). A need for renovation of the building and its heating and ventilation systems plus a requirement for improved collection space, compounded by the need for computers, photocopiers and other equipment necessary for a modern library, have led to a comprehensive rehabilitation and conservation plan. Renovations are required right from the weathervane on the pinnacle of the roof, down to the HVAC system in the sub-basement.

In addition to renewing and improving the Library, significant additional space has been deemed essential for added services for the Library collections. New, visible, above-ground expansion of the Library building was unacceptable, since any new structure would impose on and affect existing aesthetics and the national heritage environment of Parliament Hill.

Figure 1: 1860's Gothic Chapter House design Library dominates skyline north of the Parliament Buildings.

As shown on Figure 2, the conceptual model for the new underground space required:

(i) a 10 m deep basement, within the inner ring foundation walls,

(ii) three new (stair and elevator) shafts,
(iii) a link tunnel between the new Library and the adjacent service building,
(iv) a 2 m lowering of part of the floor between the inner and outer foundation walls, and
(v) six inclined, bored, ventilation raises.

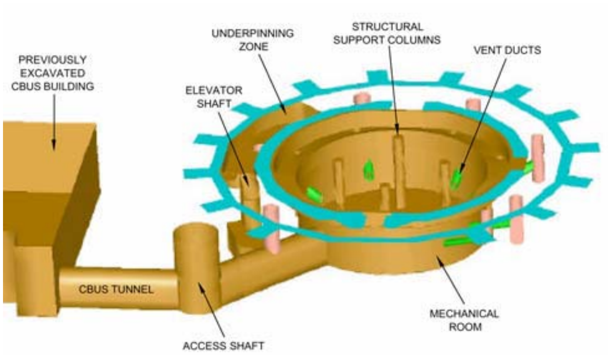

Figure 2: New sub-surface excavations in relation to existing heavily loaded foundations (shown in blue).

2. GEOLOGICAL CONDITIONS

The Parliament Hill promontory, upon which the Library is founded, consists of Palaeozoic age limestone with intercalated shales. These rocks, which form part of the Trenton Group of the Ordovician age Ottawa Formation, based on site borehole data, have been locally divided by stratigraphic elevation into three sub-units. An upper nodular limestone, a transitional shaly limestone zone, and a basal nodular limestone. In this case the unit of most interest has been the upper nodular limestone, as this generally comprises the full 10 m depth of the new basement excavations. This unit consists of slightly to moderately weathered, strong, thinly to thickly bedded limestone, with some intercalated shales.

3. DESIGN CONSIDERATIONS

Substantial technical risk was involved in undertaking excavations close to and/or under the rings of heavily loaded, settlement sensitive, masonry walls. The level of technical risk associated with developing the required rock excavations beneath the Library is unparalleled in Canada, and comparable only with other world class heritage rehabilitation projects, such as the underpinning of the mediaeval towers of York Minster or the recent remediation of the Leaning Tower of Pisa.

The challenge for the design team was to tackle the geotechnical risks of creating this required space underground, directly beneath Canada's foremost heritage building in a cost effective manner, while still maintaining the integrity of the building and also respecting its heritage nature and aesthetic setting on Parliament Hill. To achieve these aims innovative rock engineering design solutions were developed to preserve and improve the strength and integrity of the existing variably fissured, bedded sedimentary limestone bedrock, to allow the creation of the necessary underground space and also support the rock mass and building fabric. Of paramount importance to minimization of risk and for ensuring stability, was developing a staged bedrock excavation sequence, as shown on Figure 3. This allowed safe rock removal adjacent to and directly below the heavily loaded building foundations.

To achieve the required excavation controls, stringent design requirements were set such that (i) rockmass excavation would be by mechanical methods only, (ii) vibrations would be maintained below critical threshold peak particle vibration (PPV) and frequency limits, (iii) close perimeter line drilling would be used and (iv) an elaborate array of pre-support and rock reinforcement, plus grouting of prominent fissures would be specified. Control of the rock excavation sequencing and near real-time monitoring of the movements of both the rock and the

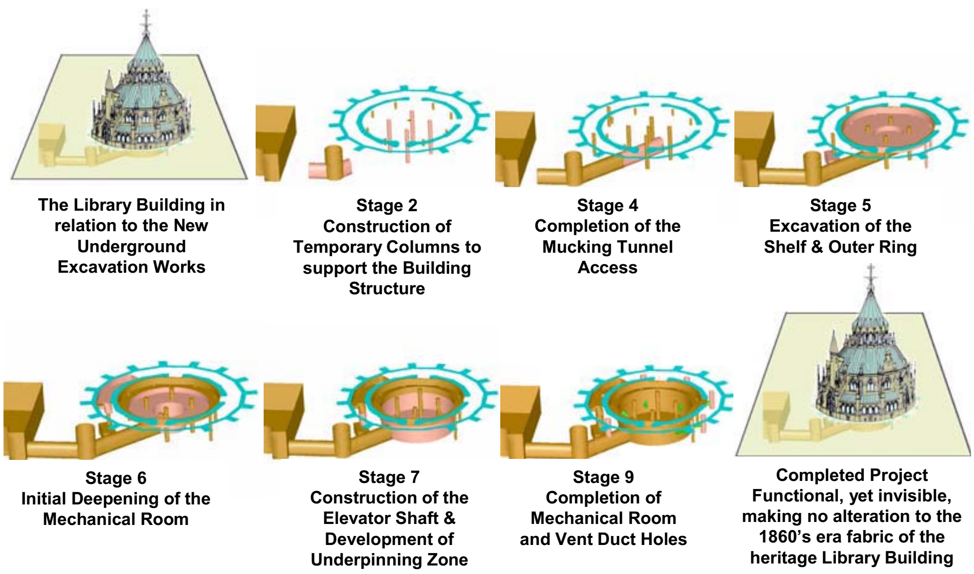

Figure 3: Selected stages of the prescribed staged excavation works.

foundation zones was also seen as critical to being able to ensure building stability. Accordingly, high precision arrays of instrumentation were specified to allow the behaviour of the masonry and the rockmass to be continually assessed.

In order to avoid disruption to Parliament, all noisy work, including: drilling, hoe-ramming and rock bolting, were specified to be completed at night, while less noisy activities, such as grouting, and mucking and loading of trucks was permitted during daytime. Occasionally, it was necessary to interrupt construction due to extended Parliamentary sittings, receptions for visiting Heads of State, and for the summer Sound and Light Show.

3.1 Excavation Layout and Design

The key governing criteria for being able to carry out the required works were (i) that post-completion of construction, no visible signs of the new works would be evident and (ii) that the 1860's heritage character of the building would be preserved. Not only did this demand innovative excavation procedures, but moreover all aspects of the underground excavation had to be invisible once the necessary mechanical and electrical upgrades to the HVAC systems had been installed. As the building was already in place, little flexibility was available for modifying the overall excavation layouts, so close attention was paid to defining (i) optimum excavation sequencing, and (ii) timing of pre-support installation.

In order to achieve the design objective of maximizing available space beneath the building and yet still maintaining existing heritage building architecture, excavation geometries became extremely complex. Severely restricted rock cover added to the complexity of achieving the design requirements. Construction difficulty was further compounded by the severely limited access and headroom available to start the excavation sequences. Further, lowering the floor between the inner and outer ring walls without compromising the stability of the Library necessitated that the foundations be underpinned while providing full structural support to the inner masonry ring wall of the building.

Particular attention was directed toward areas of complex excavation geometry or where rock excavation was required in close proximity to load bearing walls. For these areas, the building foundation and the rockmass structure were carefully examined using various analytical and two and three dimensional numerical modelling methods to:

i) optimize the geometry of the excavations,
ii) formulate appropriate rock support layouts, and
iii) develop staged excavation sequencing approaches.

A combination of numerical modelling approaches was utilized to provide insight into possible rockmass behaviour under the proposed excavation conditions. Based on the modelling, discrete areas of rockmass overstress or building impact were identified, either for more concentrated rock reinforcement, or for rearrangement of excavation layouts to mitigate any identified stability problems. Areas identified as being of specific concern requiring additional support were the abutment zones to the intersection of the Link Tunnel with the Main Mechanical Room, and also its intersection with other discrete excavations, such as the Elevator Shaft (ref. Figure 2). In these areas the rockmass could not only lose confinement due to stress interaction effects, but also, because of increased degrees of freedom created by re-entrant excavation geometries, wedges or blocks might be free to slide or rotate on pre-existing discontinuities and/or along newly created tensile fractures. For rockmass zones where the potential was predicted for general de-stressing extending into the crowns or sidewalls of the excavations, patterned reinforcement layouts were developed to keep total movements below levels that might affect the overlying masonry structure. Based on the modelling, concentric excavation sequences were specified to ensure uniform response of the rockmass to the main mechanical room excavation. For a more detailed account of the rockmass reinforcement design and excavation sequencing refer to Carter *et al*. (2004).

4. CONSTRUCTION IMPLEMENTATION

4.1 Specification Requirements

In order to ensure the design intent of minimizing disturbance to the foundation rock mass beneath the masonry walls, stringent specifications were written regarding rock excavation methodology, wall control, sequencing, and foundation improvement requirements. Detailed drawings were also provided in the Contract Documents outlining precise layouts of pre-support dowelling and subsequent pattern bolting. Blasting methods were not permitted, not just because of the complex excavation geometries required or the proximity of the new excavations to the existing foundations, but mainly because previous vibration monitoring experience gained from the Centre Block Underground Service (CBUS) building work indicated that blasting vibration levels could not be adequately controlled when closer than 11 m away from the fragile Library masonry structure (Carter *et al*., 2000). The specifications for the excavation were then prepared, such that, prior to implementation, the submission and approval of "Method Statements" was necessary for all aspects of the excavation works. Provision was made however, for adjustments to be made to the sequencing, if monitoring so dictated.

5. EXCAVATION ASPECTS

5.1 Excavation Methods

Because the pre-existing shape, limited access and heritage nature of the Library, constrained the use of typical large scale civil engineering equipment, Golder decided that mining approaches, usually used for ventilation and ore pass construction, would work better, and thus arranged design requirements to suggest their use for the challenging and complex duct work requirements. Hard rock mining equipment and excavation methods were then successfully applied to this urban civil engineering project. This included raise boring for the six inclined ventilation ducts.

In order to comply with the stringent specifications regarding wall control, vibration limitations and utilization of only mechanical excavation methods, the Contractor experimented with a variety of excavation techniques. To test these various approaches the Contractor undertook a number of off-site and on-site excavation trials, aimed at assessing induced vibration levels for various degrees of achievable rock fragmentation. Seven different non-explosive excavation methodologies (including hoe rams, two different types of non-explosive cartridge detonation products, two forms of hydraulic rock splitters, controlled foam injection methods, and chemical expansive agents) were trialled before the Contractor decided on his most efficient methodologies consistent with adherence to the stringent vibration control and overbreak and rock mass damage criteria incorporated in the contract documents. As shown on Figure 4, the Mechanical Room mass excavation accounts for the majority of the excavated volume, with most of the bulk excavation works (shaft sinking, tunnelling and basement excavation) carried out using hydraulic piston-type rock splitters in conjunction with various sized hoe-rams.

5.1.1 Hoe-Rams

Hoe-rams ranging up to 66 kW power output (as shown in Figure 5) were used in combination with other rock fragmentation methods. The upper zone of weathered rock to 6 m depth (the max reach of the excavator) of the Access Shaft was excavated using this equipment. However because of access difficulties and necessity of maintaining vibration limitations, most of the breaking within the mechanical room and tunnels, once the rock had been split, was also undertaken using hoe-ramming, but using smaller machines.

5.1.2 Non-Explosive Pyrotechnics

Following a series of trials, a segment of the main Assess Shaft was excavated using a non-explosive pyrotechnic cartridge at 20 and 40 g charge weights. This provided adequate, but often unpredictable fragmentation. Only single shots could be fired without exceeding the PPV criteria. This compromised loading multiple holes and sequentially firing the propellants since initation lead-wires were often severed and miss-fires were common. The final perimeter generated using this propellant approach however, was reasonable and typically gave a very smooth final profile (analogous to a post-shear blast), since production and line drill holes, using a jackleg drill, were usually done on a relatively ‘tight’ spacing, to ensure good fragmentation and to minimize peak particle velocity initiation. In total, only about 100 m3 of the overall required excavation works were excavated by this methodology.

Figure 5: 66 kW Hoe Ram as used to excavate the upper portion of the Access Shaft (left). 25 kW Hoe Ram working in the Mechanical Room (right).

5.1.3 Controlled Foam Injection

Controlled Foam Injection (CFI) is a novel technique for fracturing rock and concrete, where foam is injected under high pressure into a pre-bored hole to initiate rock breakage (Young and Graham, 1999). Peak particle velocities generated during rock fragmentation by this method were low (less than 5 mm/s at about 5 m), however relatively low rates of advance were achieved in trials during early tunnel excavation. Furthermore, based on downhole video footage obtained from observation holes drilled 250 mm from the final tunnel profile, in spite of the closely spaced line drilling, it was evident that pressurised foam could ‘escape’ and potentially damage the rock mass beyond the tunnel design line. Although deemed a promising development in non-explosive

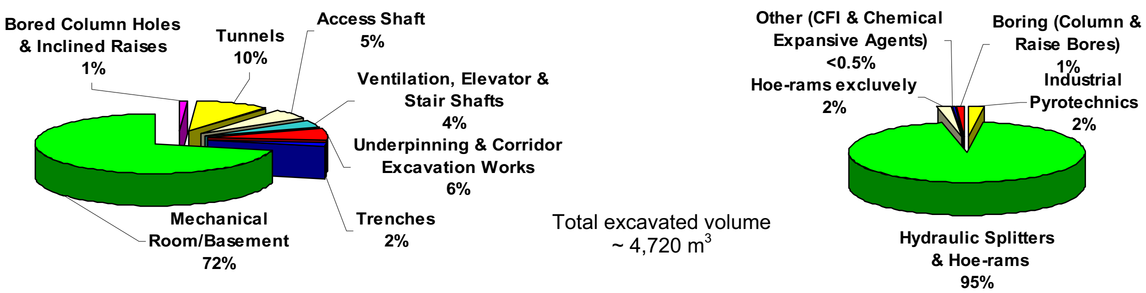

Figure 4: Summary of excavation volumes for different aspects of the works (left) and various excavation methods (right).

excavation technology, the Contractor elected to utilize alternative more productive excavation techniques. The tunnel digging machine (TDM) mounted CFI apparatus was only used for less than 20 m^3 of tunnelling advance.

5.1.4 Chemical Expansive Agents

Limited trials with an expansive chemical agent were undertaken, primarily with the objective of using this product in areas of difficult access. Due to the low productivity of this method in the competent limestone, the technique was only used in experimental trials.

5.1.5 Hydraulic Splitters

Although labour intensive, the majority of the rock excavation work was undertaken using hydraulic rock splitters. In some parts of the works, in areas of difficult access and areas of complicated excavation geometry, conventional feather and wedge splitters with splitting forces ranging from 220 to 385 tonnes were used in 44.5 mm (1 ¾”) diameter holes. For the majority of the rock excavation works, rock breaking was performed using piston-type hydraulic rock splitters, each with four 85 mm (3 ⅓”) diameter splitter cylinders, giving a total rock splitting force of 1050 tonnes per splitter. Production holes (89 mm, 3 ½” diameter) were drilled by jumbo and crawler drill rigs. During two 10 hr shifts per day, typically between about 7.5 and 14.5 m^3 of tunnelling mode excavation was achieved for the top heading (horseshoe geometry 3m high and 3.5 m wide including production and line drilling). Where holes were able to be pre-drilled (independent of the excavation cycle) – such as for the basement excavation, higher production rates of about 80 m^3 per day could be achieved. Over the nineteen month excavation works about 4,720 m^3 of *in situ* rock was excavated, at a rate of nearly 250 m^3 per month. Actual monthly excavation rates are summarized on Figure 6.

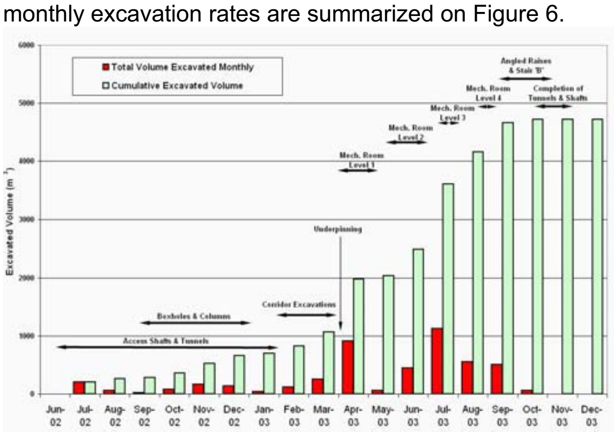

Figure 6: Excavation works progress and monthly excavation volumes.

5.1.6 Raise Bores

In order to achieve the complex design arrangement geometry for the access staircases and for the required duct work, six angled raises and seven vertical shafts were excavated. The angled raises were bored and the vertical shafts, which ranged in diameter from 1.5 m to 1.8 m, were split using piston hydraulic splitters and hand held chippers. Where accessible mini-excavators were used to muck the broken material from the shafts, however in most instances mucking was carried out by hand using buckets on ropes. For the six inclined (+35°) shafts, use was made of an RB-40 raise bore machine (as shown on Figure 7). Four bores of 1.22 m diameter and two of 0.66 m were required. To ensure intersection with the vertical shafts, and compatibility with the pre-manufactured steel vent liners, the borings had to be completed to very stringent tolerances. These large diameter bores were successfully completed with only 0.4 to 1.5 % deviation over the bore length.

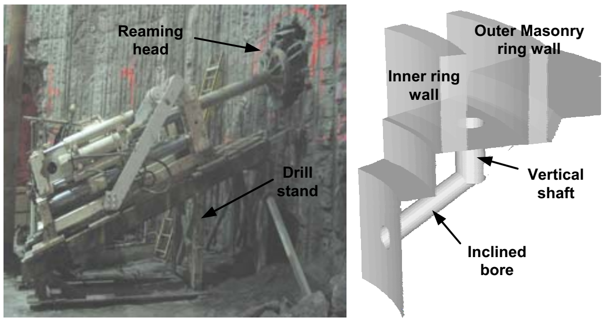

Figure 7: RB-40 Raise bore, and schematic showing vertical shaft and inclined bore.

5.2 Line & Production Hole Drilling

To mitigate overbreak and rock mass damage beyond the design lines, the Contractor predrilled (or saw cut) all final excavation surfaces. This was usually achieved by drilling 89 mm (3 ½”) diameter holes leaving 75 mm (3”) wide intervening webs. In some instances where difficult access or poor ground conditions dictated, either interlocking cored holes were drilled or rock saw cuts were made in lieu of percussion-drilled perimeter holes.

Line and product hole drilling was carried out using two wagon drills, while two Furakawa (HCR9-ES) crawler rigs and a Tamrock Jumbo (H107) were used for tunnelling and for the underpinning. For each round of excavation advance within the LOP and CBUS Link Tunnels, more than 60 perimeter line drilled holes were utilized to create the tunnel periphery, these holes were drilled such that intervening rock webs no greater than 75 mm were left between the line drill holes. Perimeter and production drill hole ‘rounds’ were typically advanced no more than 1.8 m (6’) long, since this corresponded with the typical rate of advance that could be achieved during two to three excavation shifts. Also this helped keep the unavoidable ‘look-out’ over-break volume to a minimum.

The Specifications stipulated that line drilling for the Mechanical Room and other vertical excavations (shafts, sumps and trenches) required single pass full depth drilling to ensure a straight ‘flush’ final wall profile. Line and production hole drill depth, for the various Excavation Levels in the Mechanical Room, was controlled using a laser level set at a specific elevation. The details of the production and line drilling carried out for the Mechanical Room excavation works are presented in Table 1. The line drilling arrangement typically resulted in a scalloped final wall profile, depending on line drilling accuracy and hole deviation. Where the final excavation profile did not conform to the specified excavation tolerances, the walls were cut back to the design line at the contractor's expense. Where access permitted, this chipping was easily done using mini hoe-rams.

Table 1: Mechanical Room Line and Production Hole Summary.

		Shelf Excavation (Level 1)	**Remaining Excavation (Levels 2 to 4)**	**Total**
Volume (m^3)		765	2,492	**3,257**
Line Drilling	No. Line Drill Holes	363	406	
	Drilled Length (m)	535	2,834	**3,369**
Prod. Drilling	No. Prod. Holes	2,018	2,164	
	Drilled Length (m)	2,974	15,105	**18,079**
		Grand Total Drilled (m)		**21,448**

Figure 8: Final excavation profiles showing tight line drilling and good wall control for the Mechanical Room wall, Stair 'B' Tunnel (left) and LOP Tunnel (right).

6. FOUNDATION IMPROVEMENT

6.1 Grouting and Stitching

As previous experience during the CBUS excavation works (Carter *et al*., 1999) had shown that in some areas of the upper zone of the rock mass, open or clay-infilled fractures existed, and initial concept investigation stage drilling inside the accessible areas of the Library had also suggested that similar zones of poor quality rock existed at similar elevations, the Contract Specifications contained provisions for grouting joints and bedding, and reinforcing any intersected adverse discontinuities with either cement grouted dowels or tensioned elements.

Rock mass conditions, as exposed after demolition of the basement and corridor floor slabs, confirmed that some areas of the Library foundation rock mass were sufficiently fractured as to warrant "grouting and stitching". Since detailed mapping of the exposed rock surfaces showed that almost all of the intersected joints were near vertical, the primary and secondary groutholes were angled at 45° down through the intersected joints and through intervening sub-horizontal bedding planes. For ease of layout of the primary holes and for split-spacing the secondaries and also to facilitate uniform reinforcement installation lengths, grout holes were drilled either 5 or 10 m long, with water acceptance tests performed on 5 m lengths. A highly portable Craelius Dramex 232 drill rig was used for all grout hole drilling and a Concrete 'high-shear' mixer with Moyno pump was used for the grouting. The majority of the grout holes were drilled using a 70 mm diameter bull-nose bit, however some holes were cored (NX sized, 75 mm diameter). The grouting and stitching programme, included over 300 m of grout hole drilling and required injection of nearly 5,400 litres of grout.

This programme comprised three stages:

Stage 1: Water Acceptance Testing & Fracture Flushing to determine whether open or infilled voids were present at depth and connected to surface.

Stage 2: Two Stage Consolidation Grouting to fill identified voids and fissures, with initial grouting undertaken using a thick 1:1 w/c ratio mix aimed at filling the larger voids, followed by a progressively thickened mix sequence from 3:1 to 0.5:1 by weight to infill smaller fractures and bedding planes. These thickened sequence mixes were each pumped to reach a pressure-defined or volume-defined GIN style "closure" criteria.

Stage 3: Stitching with reinforcement elements, by inserting dowels into the primary and also into any key secondary grout holes to place shear steel across the major fractures. Overall consolidation grout take values are summarised below:

Table 2: Summary Consolidation Grout Takes for Primary and Secondary Holes.

		Short Holes (5 m)		**Long Holes (10 m)**	
		Prim.	Sec.	Prim.	Sec.
No. of Holes		21	4	12	6
Cum. Grout Take (litres)	Ave.	131	80	164	59
	Std.Dev.	155	98	136	51
	Max.	614	224	404	158
	Min.	4	10	29	23
Total (litres)		Prim.	4719	Sec.	674

For grouting and stitching operations typically an initial mix (water:cement:silica:superplasticizer ~ 1:1:0.1:0.0075 by weight) was used, and the water content systematically reduced from 1 to 0.75 during grouting. Open permeable fractures to surface were sealed using a specified grout mix design comprising (1:1:0.05 ~ water:cement:bentonite) to fill the fissures. Mechanical and inflatable packers were used to maintain seals on each grout hole during water acceptance tests, flushing and subsequent grouting. In order to not only evaluate rock mass permeability and grout acceptance, but also to ensure no adverse hydrofracture/hydrojacking behaviour of the rock mass, all the water testing and grouting was carried out using electronic state-of-the-art monitoring (flow and pressure). The monitoring equipment comprised; Magmaster magnetic flowmeters, Bristol Babcock pressure transducers and a Honywell DPR 100 data logger. Typically, it was found that the rockmass was of low to moderate permeability with Lugeon values ranging from 0 to 20, however a small number of test holes were very permeable with values >>100, while other holes which crossed joints with significant clay infillings showed low initial takes, but after multi-stage flushing took significant grout quantities. As is evident from Table 2, these variations in jointing and bedding plane characteristics are also apparent in the grout take records. Fractures open to surface were lanced and flushed with a combination of compressed air and water jetting. Fissure injection cementitious grout mixes typically included 5% bentonite.

6.2 Underpinning

In order to achieve architectural space requirements in the building it was required that extra space be created in the corridor annulus between the existing masonry supporting walls of the Library. This necessitated that the inner ring masonry wall be underpinned to a depth of 2 m below the existing foundations over a radial length of more than 20 m (ref Figure 10).

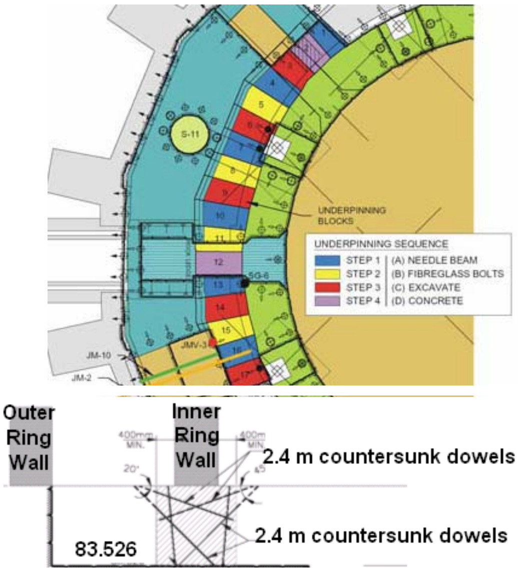

Figure 10: Underpinning block extraction sequence and fiberglass support arrangements.

At the design stage, concern was felt that the integrity of the upper zone of the rock mass could be problematic and therefore would need careful evaluation during construction to ensure the safe underpinning of the building structure. Initial design assessments suggested that foundation loadings from the 1.2 m wide masonry wall would be in the order of 740 kPa, and would increase to a maximum of 985 kPa on the remnant rock pillars temporarily created during the underpinning process.

While the need to heavily pre-support the load bearing outer and inner ring walls at this location had been identified at the concept design stage, only the outer ring pre-support could realistically be laid out on the Contract Drawings, as design of the temporary pre-support of the rock rib pillar below the inner wall could only be designed once the Contractor's preferred approach to the underpinning was known and only implemented after actual rock conditions could be examined during construction. As shown on Figures 10 and 11, the underpinning was carried out by sequenced excavation of seventeen 1.2 m wide by about 2 m high blocks, with care taken to remove the weaker zones of the rock mass early in the sequence, thereby leaving the stronger zones as remnant supporting pillars.

The underpinning was completed without any significant effects being observed by the instrumentation. This was achieved through adequate rib pillar pre-support using fibreglass reinforcement elements, careful excavation, attention to line drilling, optimization of excavation sequence and timely dry packing of cured concrete underpinning blocks. Only localised, relatively small responses of the order of 2-4mm were noted.

Figure 11: Completed inner ring wall underpinning.

7. INSTRUMENTATION

Due to the fragile nature of the Library's masonry walls and the scale of the required excavation works, it was deemed crucial to assess in real time whether there would be any impact of the excavation works on the building structure or on it's rock foundations. Consequently, instrumentation was laid out to monitor displacements of the rockmass (dilation, tilt, settlement, shear), and of the masonry ring walls (deflection, tilt, settlement), as well as potential groundwater level changes. Monitoring was achieved through state-of-the-art geotechnical instrumentation including:

1) 8 No. Borehole Extensometers (MPBX)
2) 14 No. Convergence points
3) 8 No. Electrical Inclination Sensor (EIS)
4) 2 No. Electrical in-place inclinometers
5) 16 No. Vibrating wire joint meters
6) 8 No. Steel survey pins
7) 2 No. Vibrating wire piezometers
8) 6 No. Flexible sonic probe extensometers
9) 8 No. Vibrating wire strain gauges
10) 4 No. Tell-take crack meters
11) 2 No. Precise Survey Markers

The overall monitoring program included management, analysis and near real-time reporting for all critical parts of the building and rockmass. As is evident from the typical summary data and location plots for horizontal joint meter JM-2, as shown on Figure 12, both building and rockmass response to excavation has been small (typically <4 mm), generally localized to the immediate vicinity of the major excavation works. As expected, the most significant instrument responses have been associated with the excavation of the Mechanical Room. Although the readings have been corrected for thermal affects, changes in the ambient temperature due to seasonal and diurnal effects and/or artificial heating within the Library are clearly evident in the plots.

As with most instrumentation programmes, the dilemma of adequate instrument protection from damage and inadvertent bumping (despite best efforts to protect the instruments) has proven challenging. Initially when instruments were bumped and/or damaged, this resulted in work stoppages until the cause of the spurious readings was ascertained or replacement instruments were installed and stable readings again obtained in the case of irreparably damaged instruments. These problems diminished with increased instrumentation protection and greater education of the Contractor's staff.

8. CONCLUSIONS

The excavation of the main Mechanical Room has been successfully completed with only minor movements developing on specific bedding plains and joint structures. Movement magnitudes have been similar to those anticipated during the design stage with discrete movement focused only on specific geologic structural features. Excavation control using closely spaced perimeter line drilling with mechanical splitting of the rock mass has achieved excellent excavation profile wall quality, while minimizing vibration impact on the heritage building structure. All excavation works right up to the edge of major foundations have been undertaken within the building with peak particle velocities less than 17.5 mm/sec. as required by the initial design evaluation. The protection of the building's heritage status and the guaranteed operation of essential building systems has been achieved, thereby preserving this heritage treasure as a national trust for future generations.

This project is the first, and in many ways one of the most challenging, in the Long Term Vision and Plan for renovating the entire Parliamentary Precinct. The objective is to renovate the Main Library Building to create a sustainable facility for at least another 50 years, to serve not only as a functioning library but also as a significant tourist destination. The successfully completed rock excavation works now provide the much needed space for the services necessary to fulfil this aim, thereby providing a renewed and sustainable resource for future parliamentary use.

9. ACKNOWLEDGEMENTS

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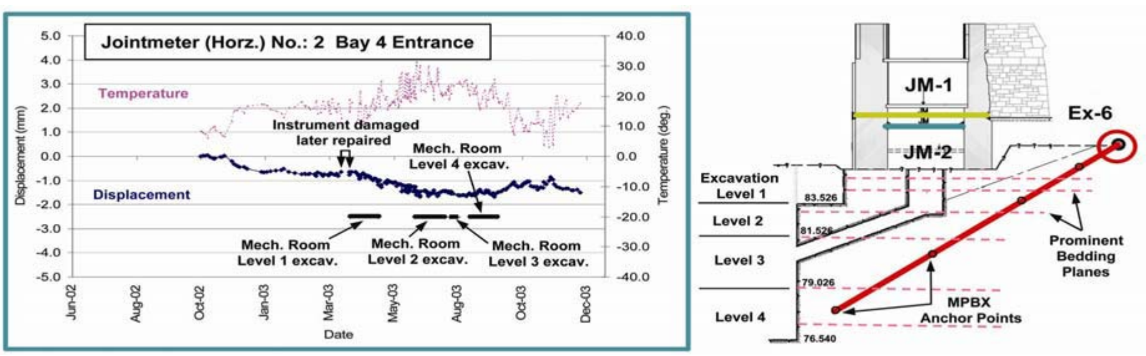

Figure 12: JM-2 location and summary data plot.