Klohn Crippen Berger

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Strata Plan BCS1172 – Brava
c/o Baywest Management
#300- 1770 Burrard Street
Vancouver, BC V6J 3G7

Ms. Monica Dare, Strata Manager

Dear Ms. Dare:

**Review of Remediation Proposals for Parking Level P5 - The Brava**

This letter summarizes my review of information and proposals regarding proposed remediation to treat loose soil beneath the parking level P5 foundation of The Brava Tower, 1199 Seymour Street.

I have reviewed various documents, listed at the end of this report, and have had discussions with Mr. Matt Kokan of GeoPacific Consultants Ltd. (GeoPacific), the geotechnical engineer responsible for the foundation design; with Messrs. Roger Woodhead and Paolo Gazzarrini of SNC-Lavalin Inc. (SNC-Lavalin), representing Canada Line, which tunnels pass beneath the tower; and with Mr. John Bryson of John Bryson & Partners (Bryson), the structural engineer responsible for the tower design. My understanding of the existing conditions and proposals for remediation follows from those reviews, discussions and exchanges.

## History

The Brava Tower was completed in about 2005. The tower is supported on two core structure foundations and several spread footings beneath columns. The foundation material was anticipated to be sandstone bedrock, but upon excavation was found to be very dense sand. The allowable bearing pressure was revised from an initial value of 40 kips per square foot (ksf, note Imperial units are used on drawings) to 25 ksf, then to 15 ksf for most spread footings. I understand from GeoPacific that the bearing pressures were chosen to limit settlement of the foundations to small values; a typical design value would be 25 mm, with differential settlement between adjacent footings being smaller. Settlement, rather than bearing capacity, is the usual controlling design aspect for foundations on granular soil.

I understand from Bryson that the design earthquake was the "475 year" earthquake (earthquake causing an acceleration with an annual probability of exceedance of 0.002), as required by the 1998 BC Building Code and 1999 Vancouver Building Bylaw.

The outbound or north tunnel of the Canada Line was excavated beneath the building in about January 2007. "Increased tonnage" (mass of soil or rock greater than the theoretical mass as the tunnel boring machine advanced 1.4 m, the length of the precast concrete lining segments) was recorded at two locations; the first beneath Seymour Street, adjacent to the building; and the second beneath the building. I do not know the actual volumes of excavation.

In April 2007, a large void, as deep as about 3 m to 6 m below the underside of the P5 floor (documented estimates vary), was discovered beneath parking level P5, the lowest parking level of the building. The void occurred in the vicinity of a sump which had apparently been functioning in January 2007. Various documents state that approximately 65 $m^3$ and 114 $m^3$ of concrete were placed to fill the void within a few days of its discovery. I understand that about 65 $m^3$ was placed initially and 114 $m^3$ was ultimately placed to completely fill the void.

Following the void filling, Golder Associates performed a ground penetrating radar survey beneath the P5 floor over the area where concrete had been placed, in April 2007. They identified various anomalies beneath the floor.

Subsequently, GeoPacific performed probe drilling beneath the basement in May and June 2007, to as deep as 13.4 m below the P5 floor. For reference, the top of the tunnel is approximately 15 m below the floor. Measurements of the soil density or "condition" (such as with standard penetration tests, SPTs, or cone penetration tests, CPTs) were not made. GeoPacific pushed and drilled a hollow-core anchor with a small drill on a chain drive to sound the soil and determine the location of relatively dense soil where the drill met "refusal" (unable to advance the anchor further). In two of the probe holes, the anchor was advanced as deep as 13.4 m under only the force of the chain drive, indicating relatively loose soil. However, the extent and density of the loose soil have not been thoroughly assessed.

Bryson performed a careful examination of the building following discovery of the void. He detected no cracking or distortions that would indicate distress of the building. This is despite one or more of the column foundations being completely unsupported due to the void.

Survey monitoring data taken on the P5 floor over the tunnel from December 2006 to May 2008 indicate that the area of the void settled a maximum of about 6 mm.

GeoPacific supervised drilling in September 2007, with SPTs to assess the density or condition of the soil, from the P5 level over the route of the inbound or south tunnel. Dense soil was encountered within 1 m to 2 m beneath the concrete slab. I understand that the inbound tunnel was excavated in late 2007, without incident.

## Summary of Existing Condition

It appears that the existing condition with respect to the void incident can be summarized as follows.

The settlements recorded from December 2006 to May 2008 indicate that the building has settled very little in the area where the void was discovered. It therefore appears that the building has not experienced distress due to the presence of the void. There is no obvious distress evident in the building.

Relatively loose soil of unknown (both laterally and depth) extent exists beneath the floor and concrete infill. It extends to at least a depth of about 13 m in some locations. The condition (density) of this soil is unknown.

Despite the satisfactory performance of the existing foundations, remediation of the loosened ground is required to ensure adequate long term static and seismic performance of the building. The design criteria for remediation should be agreed to by all parties, prior to selecting an appropriate remedial method.

## Design Criteria for Remediation

Remediation should ensure adequate ongoing performance and should limit deformation of the foundations during the design earthquake event.

Regarding static performance, the large concrete void infill has likely resulted in a redistribution of footing loads to relatively firm ground beneath the concrete infill; however, its long term performance has not been ascertained. Remediation should ensure there is intimate contact between the infill concrete and footings for both the core and columns that were undermined by the void. This will prevent movement due to any future loads larger than those experienced to date, or due to long-term creep or readjustment in stresses.

Remediation should ensure that foundation displacements during the design earthquake event are very small and tolerable by the structure. The foundation soil should not liquefy (a phenomenon by which loose, saturated soil behaves as a fluid with extremely low strength) during the earthquake. In the absence of liquefaction, settlement of the relatively loose soil due to earthquake shaking should be negligible.

Remediation of the loose soil must not transfer additional load onto the existing tunnels.

## Proposed Remediation Schemes

Since the investigation, both GeoPacific and SNC Lavalin have proposed schemes to remediate the loose foundation soil. These are briefly described below, along with my comments on the proposals. My understanding is from sketches and from discussions with the parties; specific aspects and details may not be exactly as described.

GeoPacific Proposal

GeoPacific proposes to jet grout the foundation. Design sketches show, in plan, overlapping jet grouted columns within the area of the April 2007 void. The columns are arranged to extend beneath several footings, including the core footing, in the vicinity of the void. The treated plan area is in the order of 70 $m^2$ (750 $ft^2$). The typical section shows the columns extending to a depth of "approx. 40' varies" (12 m; all dimensions on GeoPacific's sketches are in Imperial units) with the bottom of the columns a minimum 10 ft from (above) the tunnel. A four foot diameter jet grouted column is specified.

The extent (number and depth) of the jet grout columns would be determined during the treatment by assessing the ease of penetration of the jet grout rod. I understand that GeoPacific wants to create a relatively stiff, strong medium in order to approach or exceed the (assumed) properties of the in situ dense soil. In my opinion, the strength and stiffness of the jet grout columns will greatly exceed the strength of the original soil foundation, as it is difficult to closely control properties of the final grout mix.

GeoPacific noted that the loose / dense soil contact is irregular, so the jet grout treated zone would be carried on dense soil at its periphery. Imposed loads from above would not be carried to depth directly over the tunnel, but would "arch" to the dense soil. However, GeoPacific did not provide documentation which confirms the arching. The comment regarding arching could equally apply to SNC Lavalin's proposed scheme, described below.

SNC-Lavalin Proposal

SNC-Lavalin proposes to "stitch" the foundation together using "micro-piles" (hollow rods) that are advanced using grout as the drilling medium. The grout would be relatively stiff, and would be injected under pressure (at least 100 bars) as the rods are advanced, to densify the surrounding soil. The rods would be spaced in the order of 50 to 60 cm and would be left in place to provide a permanent pile. The text accompanying an illustrative sketch indicates that "a rectilinear structure (would be) created, with inclined holes below the footing in the area of loose soil." I understand that SNC-Lavalin has not used this foundation treatment, and they did not know where this approach had been used

previously. The scheme appears to be a hybrid of compaction grouting and mini-pile installation, both of which, separately, are common foundation treatments.

The sketch (section) illustrating the proposed remediation shows the treatment to be terminated at a depth of 6.1 m below the underside of the footings. Deeper holes (mini-piles?) are shown to a depth of 12.2 m (varies; minimum 3 m from tunnel) and labeled "some of these holes to be used to check soil strength." However, it is not clear that if loose soil is encountered at depth it will be treated by pressure grouting. Both vertical and inclined anchors are shown. There is no basis given for the 3 m clearance between the deepest check holes and the top of the tunnel.

SNC-Lavalin indicates, in the text description, that their proposed method is faster than jet grouting and that smaller equipment, causing fewer logistical problems, would be required.

I understand that "soil stitching" is not a standard or well-developed procedure. Some development/testing would likely be required (away from the tower footings) to optimize the procedure, before it could be applied to the tower foundation. Following treatment, the foundation would comprise a series of relatively very stiff columns (piles or rod in grout) between less stiff, compacted (by virtue of the grout pressure) soil. Given the large contrast in stiffnesses from steel rod to grout to dense soil to, possibly, untreated or less dense soil, the performance of the "system" is not readily apparent. In my opinion, this would require a specific analysis to demonstrate its adequacy; in particular, the seismic case would require analysis to demonstrate adequate performance. In addition, since the treatment is shown to be generally to a depth of only 6.1 m, the performance of the composite treated zone / untreated deeper soil would have to be demonstrated by analysis.

## Alternative Treatment Method

In my opinion, compaction grouting is an alternative methodology which could be appropriate for remediation of the foundations. In this method, a nearly soil-like grout is injected under high pressure from a drill rod, causing compaction of the nearby soil. The rod is withdrawn as the soil is treated from bottom to top of the column. Compaction grouting can create a treated soil mass that is dense; is not rigid; is sufficient to carry a significant load; and is more than adequate to prevent liquefaction and significant seismic settlement of the treated soil.

uring discussions with SNC-Lavalin, they expressed concern over the amount of water that would be used during the drilling of the compaction grout rods. Depending on the ground, the water flow rate is up to the order of 30 gallons per minute. Although this rate might be sufficient to displace loose soil, any void created during drilling would be filled as the rod is withdrawn, and any soil which sloughs into the void created by washing out the soil would be densified by the compaction grouting process.

Compaction grouting has been used in relatively low head-room settings for remediation of structure foundations. The procedure would involve drilling and grouting on a large grid spacing; repeating at intermediate points; and grouting just below the footings (or at the void infill / soil contact) to ensure intimate contact between the footings and soil.

Since compaction grouting uses relatively small equipment, a trial compaction grouting program could be readily carried out in advance of final remediation design to check the procedure, grout mix and performance.

## Summary of Remediation Methods

In my opinion, either of the methodologies for foundation remediation proposed by GeoPacific and by SNC-Lavalin could provide adequate treatment to ensure long-term performance, including seismic performance. Jet grouting, proposed by GeoPacific, will likely provide a treatment that is much stronger and stiffer than required. The soil stitching concept proposed by SNC-Lavalin will require analysis to demonstrate the performance of the overall system (including soil between columns and untreated soil beneath the treated zone). For both proposals, the typical treatment depth appears to be arbitrary.

Compaction grouting is an alternative treatment which, in my opinion, could provide an adequate foundation.

## Recommendations

The extent and condition of the relatively loose soil are unknown. I recommend that investigations be performed over (and beyond, if necessary) the area of the void, including SPTs and/or CPTs to document the soil density. This will permit the remedial design to address the specific conditions beneath Brava Tower.

I recommend the preparation of a design basis memorandum for remediation, agreed to by all parties.

I recommend that GeoPacific and SNC-Lavalin evaluate their respective proposals with respect to the documented requirements in the design basis memorandum. Compaction grouting could also be evaluated.

## Closure

I trust this letter adequately summarizes the current conditions, my comments and opinions on proposed remediation schemes, and recommendations to move forward to final treatment of the Brava Tower foundation. If you have any comments or questions please contact the undersigned.

Yours truly,

**KLOHN CRIPPEN BERGER LTD.**

Garry W. Stevenson, P.Eng., P.Geo.
Principal

GWS/hb

List of documents reviewed:

Drawings for Proposed Residential Towers and New Media Center, Davie and S(e)ymour Street by John Bryson & Partners, October 2004: S-1, General Notes & Typical Details; and S-5, Level P5 / Foundation Plan, both "Final Design Plans, October 28.

Drawings for Proposed Residential Towers and New Media Center, Davie and S(e)ymour Street by SRC Engineering Consultants, March 2003: P2.0, Plumbing, Foundation Plan; and P2.1, Plumbing, Level P5 Parking Plan; both Issued for Building Permit, March 31.

Letter, April 14, 2007, GeoPacific to Baywest: Geotechnical Engineering Review of Under Slab Void at the Brava South Tower, 1199 Seymour Street, Vancouver, BC.

Letter, May 11, 2007, Golder to SNC Lavalin, Geophysical Investigation: Brava Tower.

Letter, May 17, 2007, John Bryson & Partners to Brava Strata Council c/o Baywest: Loss of Soil Under Footings, Brava, 1199 Seymour Street, Vancouver, BC.

Letter, May 18, 2007, Golder to SNC Lavalin, Geophysical Investigation: Canada Line Tunnel.

Logs by GeoPacific of drill holes TH-1 to TH-7 drilled beneath Brava Tower from May 28 to June 7, 2007.

Letter, September 17, 2007, Canada Line to InTransitBC, Brava Towers – Opinion as to the cause of the Void.

Letter, October 23, 2007, GeoPacific to Baywest: Geotechnical Engineering Review of Sub-slab Conditions at Canada Line South Tunnel Alignment, Adjacent to Brava South Tower, 1199 Seymour Street, Vancouver, BC.

Letter, January 25, 2008, SNC-Lavalin to Baywest: Brava Towers – Ground Improvement Above Canada Line Tunnel.

Memo, May 13, 2008, Jacques Whitford AXYS to BCS 1172 c/o Baywest, Brava Towers, Independent Geotechnical Engineering Review.

Incident report, Brava Towers, 1199 Seymour Street, Vancouver, undated, provided by R. Woodhead of SNC Lavalin on September 4, 2008.

Email from P. Gazzarrini on behalf of SNC-Lavalin, September 30, 2008, Settlement records for "Building No. 24: 1199 Seymour Street", Outbound Survey Points from 18-Dec-06 to 8-May-08; Inbo.